SOUTH AFRICAN PEATLANDS: ECOHYDROLOGICAL CHARACTERISTICS AND SOCIO-ECONOMIC VALUE

Report to the

Water Research Commission

By

P-L Grundling[1,3,6], AT Grundling[2,7], L Pretorius[1,6], J Mulders[4] and S Mitchell[5]

1 – WetResT

2 – ARC-ISCW

3 – DEA, NRM, Working for Wetlands

4 – Prime Africa Consultants

5 – Bufo Technology

6 – UFS-CEM

7 – UNISA-ABEERU

WRC Report No. 2346/1/17

ISBN 978-1-4312-0892-0

June 2017

Obtainable from

Water Research Commission

Private Bag X03

Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Investigation of Peatland Characteristics and Processes as well as Understanding of their Contribution to the South African Wetland Ecological Infrastructure* (WRC Project No. K5/2346)

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

It is globally accepted that ecosystems, as natural features in the landscape, provide environmental, social and economic benefits to associated communities. The value of ecosystems in providing these ecosystem services is becoming increasingly evident. There is a growing recognition of the importance of the services delivered by freshwater ecosystems to human well-being. Ecosystem services are quantifiable benefits people receive from ecosystems. Wetlands are highly productive ecosystems. Due to their ecological complexity, wetlands provide a variety of goods and services of value to society. These services can be described as services of nature, directly enjoyed, consumed, or used to yield human well-being.

Wetlands in South Africa are defined by the National Water Act, Act 36 of 1998, as a key component of the water resources of South Africa. Wetlands have been shown to contribute to the livelihood of rural communities by providing valuable grazing land, cultivation areas, building materials and medicinal goods. In addition to these services, wetlands provide a host of other services, which are often indirectly used by society and are therefore undervalued in economic markets. These services include among others flood attenuation, water purification and the provision of fresh water.

Different wetland types provide ecosystem services based on their hydrogeomorphic characteristics. Peatlands are one such wetland ecosystem. Peatlands represent a third of wetlands worldwide, which contribute a range of ecosystem services. The most pronounced services are biodiversity conservation, water quality and climate regulation. The addition of peat to a wetland allows these wetlands to have additional ecosystem services. The unique properties of peat allow for a variation in the dynamics of the ecosystem services provided, making peatlands major contributors to wetlands' increased capacity for climate, water quality and quantity regulation, biodiversity conservation and waste assimilation.

Peatlands cover approximately 3% of the earth's surface. The global carbon stored in peat is estimated to be about 500 billion tonnes, which is approximately 30% of the world's soil carbon. Furthermore, peat stores 10% of the world's fresh water. Although peatlands are not common in South Africa where less than 10% of the wetlands are peatlands, some peatlands are unique. The Mfabeni Mire, for example, is 45 000 years old and is one of the oldest active peat-accumulating wetlands in the world.

Much of South Africa is semi-arid to arid with a highly variable rainfall, thus making water use efficiency critically important. Rivers draining approximately 70.5% of South Africa's total area are shared with neighbouring states, and these water resources are under enormous pressure in South Africa. The destruction of peatlands causes a visible and immediate degradation in the integrity of the aquatic ecosystems downstream of peatlands. This affects rivers and associated ecosystem health. Impacts such as draining and erosion of peatlands change the hydrology of the system. The rewetting of these systems will mitigate environmental change at a local level and climate change at a regional level in accordance with the REDD+[1] regulations supporting the objectives of, and South African commitments to, the Climate Change and Ramsar Conventions.

In South Africa, there is less knowledge about peatlands than other less sensitive and less strategic ecosystems such as forests. Thus, policy formulation and management decisions are not always grounded on a good knowledge base and may inadvertently lead to further destruction of these important ecosystems. Therefore, the first step in effective peatland conservation is to have accurate scientific baseline information to draft effective management guidelines and to define the socio-economic value of these ecosystems to society. Through this research project, eight case study peatlands in the different peat ecoregions have been characterised, classified and mapped to compile

---

[1] Reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, plus the enhancement of forest carbon stocks in developing counties

an inventory and determine their conservation status. The socio-economic value of peatlands in South Africa was established using these scientific baseline values.

The project will not only support the current wetland inventory of the South African National Biodiversity Institute (SANBI), the Department of Environmental Affairs' obligations towards the Ramsar Convention and the wetland rehabilitation initiatives of Working for Wetlands, but will also contribute to future wetland research in South Africa. The contribution in understanding peatland systems will benefit the southern African wetland community at large, for example, The National Freshwater Inventory Geodatabase and Preliminary Guide for the Determination of Buffer Zones for Rivers, Wetlands and Estuaries. Determining the socio-economic value of wetlands, such as peatlands, based on scientific research contributes to the credibility of conservation protocols in a regulatory environment where the value of ecosystems is forever competing in a losing battle with infrastructure and social development initiatives.

Therefore, the aim of this study was to evaluate the characteristics of peatlands and related processes and their contribution to South African wetland ecosystem services. The specific objectives of this project, which were all achieved, were:

1. To improve the existing peatland ecoregion model to identify potential peatland areas based on new recordings (recordings made since the ecoregion model was developed).
2. To upgrade the existing peatland database, collect data of new recordings generated in the past 15 years as well as future related research on South African peatlands.
3. To investigate the processes and factors driving peat distribution and accumulation in South African wetlands based on selected case studies.
4. To investigate the potential of South African peatlands as a carbon sequestration mitigation mechanism.
5. To demonstrate the socio-economic value of peatlands in South Africa, based on the concepts of ecological infrastructure and ecosystem services delivered (including carbon sequestration, other regulating services, provisioning services and cultural services).
6. To recommend further research needs.

The existing peatland ecoregion model was improved by using expert knowledge in the modelling process such as providing the boundary conditions (upper and lower limits) for each parameter, resulting in a series of key indicator layers. These parameters were combined in a model that identified areas where all criteria were met. Several variations on the key indicators of the selected parameters were processed while trying to identify the best-fit model. The output of the model was a geographical information system (GIS) coverage depicting potential peatland ecoregion distributions for South Africa. This GIS map depicts areas where peatlands might possibly occur considering several spatial parameters. An accuracy assessment was done using existing spatial peat points of known peatland occurrence (such as the 635 known peatland points in the updated South African Peatland Database). The greatest accuracy (87%) was attained when both models were combined.

New knowledge was generated through a process based on expert knowledge. The same criteria as used in the 2001 model were used. The 2001 and the 2016 models were combined to provide the most accurate representation of peatland distribution. The possibility of using terrain units as an indication of where wetlands might occur was investigated. It was found that 54% occurred in Unit 3: Midslope, and 38% occurred in Unit 4: Foot slope.

The upgrade of the existing peatland database was designed to be compatible with the SANBI National Wetland Inventory. A request for new peatland data was posted through the South African Wetland Society. This yielded 990 additional data points that have been incorporated into the South African Hydrogeology Database, of which the peatland database forms part. Of the 990 points, 116 qualified as peatlands and were added to the South African Peatland Database (of the 116 points, 106 still need to be verified infield). The updated database now contains 635 peat points: 164 (25.83%) occur in Ramsar sites; 222 (34.96%) in formally protected areas; 2 (0.31%) in informally protected areas; and the rest on private and communal land.

The database, which is compatible with the SANBI Wetland Database, is hosted and maintained at the Agricultural Research Council – Institute for Soil, Climate and Water. This updated peatland database has added significant value to two current projects, namely, The National Freshwater Inventory Geodatabase and the Preliminary Guide for the Determination of Buffer Zones for Rivers, Wetlands and Estuaries.

The processes and factors driving peat distribution and accumulation in South African wetlands were studied at eight selected peatlands. These peatlands represent different geology and climate regions and land use associated with them to illustrate the various processes and factors driving peat distribution and accumulation. A three-tiered approach to the sites was followed. Tier 1 consisted of the study site with the most information, and Tier 3 of the study sites with the least information.

- Tier 1:
    - Vazi North Peatland.
- Tier 2:
    - Lakenvlei Peatland.
    - Matlabas Mire.
    - Kromme Peatland.
    - Malahlapanga Wetland.
- Tier 3:
    - Colbyn Valley Peatland.
    - Gerhard Minnebron Wetland.
    - Vankervelsvlei Peatland.

Isotopic and dating results are discussed in detail for Vazi North Peatland (Section 4.3.1) and the Matlabas Mire (Section 4.4.2). Two general sections on flow paths and peat formation and accumulation rates in peatlands discuss the combined results of all the case studies.

The baseline data collected for all sites included:

- Geological controls.
- Hydrological controls.
- Extent of peat body and collective amount of carbon in each peatland.
- Biodiversity information (such as WET-Ecoservices and ecological importance and sensitivity).
- Land use.

Research findings confirmed that peatlands in South Africa are mostly groundwater-dependent ecosystems that occur in the wetter eastern and southern parts of South Africa. Isotope analysis and water flow measurements results support the fact that groundwater is the main driver. The isotope signatures of the peatlands in both the interior and coastal regions strongly suggest that the source for the sustained base flow is groundwater discharging in the wetlands; therefore, reiterating the importance of conserving groundwater recharge areas for peatland protection.

The potential of South African peatlands as a carbon sequestration mitigation mechanism was investigated by studying the ^{14}C ages of peatlands in South Africa. Peat accumulation during the past 50 000 years indicates variable conditions favouring peat formation in the Late Pleistocene and Holocene with a significant gap from 35 000 to 15 000 years BP. This gap is most likely linked to the colder and drier conditions of the last glacial maximum.

The most favourable period for peat accumulation in South Africa was the Middle Holocene. There is, however, a gap of approximately 20 000 years in the onset of peat formation between the Pleistocene and the Holocene. Accumulation rates were found to vary between 0.5 mm/yr and 2 mm/yr. The accumulation rate in the Matlabas Wetland in the Marakele National Park is estimated at 4 mm/yr. This high rate is ascribed to the ingress of sediment into the peatland.

An ecosystem services approach was applied to demonstrate the socio-economic value of peatlands in South Africa. The study did not aim to put a total value on peatlands, but rather to demonstrate a range of possible peatland values at the hand of several models and case studies.

The ecosystem services identified as the most important peatland services were carbon sequestration, water purification, knowledge and education, peat as a commodity, hydrological regulation, tourism, recreation and spirituality. The carbon sequestration of peatlands was evaluated by estimating the annual carbon accumulation rates. The storage ability was evaluated by estimating the current levels of carbon stocks in peatlands. Both estimations were done by acquiring specific physical data pertaining to various peatlands across the country, thus building on the scientific analysis conducted through this project. Where there were data gaps, peatland experts were consulted and ranges were determined. In this way, data required was inferred across regions to ultimately demonstrate the value of peatlands across South Africa.

In terms of their carbon storage ability, the stock was estimated to range between 4.2 million tonnes and 431.5 million tonnes. Estimates of the accumulation rates ranged between approximately 2 500 and 45 000 tonnes of carbon per year. Although compared to global figures the climate regulation ability is not remarkable, South African peatlands do play a substantial role in storing and sequestering atmospheric carbon.

The value of carbon stocks present in peatlands displayed a proxy worth an average of R13 billion, possibly being worth as much as R191.8 billion. The annual sequestration value of peatlands was estimated to be between approximately R5.6 million with a possible maximum of R19.8 million a year.

Based on these results, the scope for payments for ecosystem services schemes based on the carbon accumulation services alone is relatively low compared to the growing biomass carbon storage schemes such as the Spekboom Project in the Eastern Cape. However, the ecological infrastructure value of peatlands increases by more than an order of magnitude when the additional ecosystem services are added.

The water quality (water purification and waste assimilation) service provided by peatlands demonstrates a very significant value. An estimate based on the Klip River Peatland south of the Witwatersrand indicates that the water purification value from an ecological infrastructure perspective could be as much as R179 billion. This does not include any other South African peatlands. Thus, the waste assimilation service value will almost certainly be larger than R179 billion, making this service potentially more valuable than the carbon sequestration service for peatlands.

Compared to global abundance, peatlands are an extremely scarce ecosystem type in South Africa with only 1% of total wetland area being peatlands. The regionally distinctive characteristics and local variation of floral composition of South African peatlands influence the substitutability value of these systems. This value is further enhanced by the knowledge service potential present in peat, which is largely unequalled by any other terrestrial source of paleo-environmental data. Substitutability in economics is the degree to which one goods or service is substitutable for another goods or service. In the case of very scarce resources, substitutability is limited; in extreme cases, this would negate the determination of an economic value. A landmark case was the St Lucia heavy minerals environmental impact assessment completed in 1996, which determined that Lake St Lucia was so unique that mining-related risks could not be allowed. The same case cannot be made for all peatlands, as there are many across the country; however, on a case-by-case basis, there may be peatland systems that are so unique that a case for a zero degree of substitutability could be made. The irreplaceability value should be handled with caution when valuating peatlands economically, but this value should not be ignored when making management decisions as the value is highly significant.

Significant cropping within some of South Africa's peatlands has been seen; however, at the time of the study, insufficient data did not allow for the value provided by this service to be demonstrated. The commodity price of peat stocks and peat accumulation (i.e. the value of peat as an economic good for use as a compost or similar use) was estimated as being as much as R6 billion and R0.6 million per year respectively. These values are relatively low when compared to the cumulative economic values indicated by other services. This finding is highly significant as it indicates that the gain of revenue through peat harvesting is miniscule when compared to the loss of revenue due to replacing services lost through peatland degradation.

The quantification and valuation of the hydrological regulation and cultural services including tourism, recreation and spiritualism were not possible due to limited data. This is not to say that the services do not exist. The ability for peat to provide additional hydrological regulation and cultural services needs further quantitative investigations to logically include or exclude them as services enhanced by the presence of peat.

This study has therefore demonstrated the value of services provided by South Africa's peatlands. Peatlands are more valuable due to the presence of peat stocks within them. Based on the services evaluated and the available data, the value of the cumulative services provided by South African peatlands was estimated to be as high as R174 billion, expressed as an ecological infrastructure value. This means that for every R1 of carbon storage value, approximately another R12 can be added for other ecosystem services. This value equates to approximately R5.7 million per hectare.

This is a substantial value that must be considered when making decisions regarding peatland management in South Africa to conserve and sustain the peat and peat-forming conditions within them. South Africa's peatlands are already at risk through various land use practices. These include alterations of water courses and water tables, encroachment of infrastructure, urban and industrial effluent, extraction (peat mining) and agricultural land transformation. These activities degrade peatlands resulting in the exposure and subsequent loss of peat and peat-forming conditions.

The high economic value displayed has illustrated the importance of peatlands in the socio-economic landscape of South Africa. In addition, there is also a major intrinsic value attached to the irreplaceability of these features that cannot be ignored. The loss or degradation of peatlands would reduce natural benefits significantly. This investigation has highlighted the importance of the protection, sustainable use and maintenance of these natural features.

Recommendations for future research include the following:

1. Calculate the peatland change on a catchment scale. The depiction of percentage decrease or increase in peatland area between the old 2001 and new 2014 model should be investigated as a follow-up project.
2. Several peat points have been identified that still need to be verified. This needs to be done to confirm these points.
3. Knowledge gaps identified during this project are:
    a. The microbiology (for example, bacterial and fungal guilds) of peatlands.
    b. The identification, description and barcoding of phyla (nematodes, spiders, mites and insects) in peatlands.

4. Knowledge generated through this project should guide the conservation of peatlands and build research capacity in the South African wetland/conservation community. For example, assisting in developing recommendations for listing peatlands as a national threatened ecosystem and contribute to future wetland research in South Africa
5. The quantitative valuation ecosystem services provided by peatlands:
    - The investigation into the socio-economic value of peatlands only provided a qualitative snapshot into the value of these natural features. This is what was possible given the limited availability of appropriate data needed to indicate a more accurate and specific quantitative value. Thus, there must be further investigations to quantify services provided using valuation techniques as a framework for the approach. These investigations should focus specifically on obtaining national data on the water quantity and quality regulation, the extent of cropping within peatlands and the cultural services provided by peatlands.
    - The full spectrum of ecosystem services provided by peatlands can then be valued quantitatively as opposed to qualitatively, thus allowing for an improved overall understanding of the total value displayed by peatlands, as well as other wetland types, in South Africa. A key way forward from the results described above will be towards informed decision-making processes involving the use and development of environmental and water resources.
    - Understanding the value of ecosystem services, described in socio-economic terms, will result in internalising all environmental risks, thus informing the feasibility of a proposed activity. A comparison of the (typical) direct socio-economic consequences of an activity with the socio-economic implications, into perpetuity, arising from impacted ecosystem services will empower sustainable policy development and decision-making.
6. The peatland ecoregional model may be further verified using data for the wetlands mapped for Mpumalanga and the Free State. However, as not all wetlands are peatlands, this would have entailed work that was beyond the scope of this project.

ACKNOWLEDGEMENTS

- The Water Research Commission for financially supporting this research (Project No. WRC K5/2346) and for providing the Reference Committee with research and administration guidance.
- The ERA Foundation and University of Groningen for in-kind contributions and financial support.
- Sanparks for permission to work in the Kruger National Park and the Marakele National Park, as well as for providing logistical support.
- PG Bison and the Department of Agriculture, Forestry and Fisheries, as well as the Tembe Tribal Authority for permission to work in Vankervelsvlei and Vazi respectively.

Contributions towards the peatland database was received from:

- Nelson Mandela Metropolitan University.
- Department of Agriculture.
- Western Cape Government.
- KwaZulu-Natal Agriculture and Environmental Affairs.
- Free State – Department of Economic Development, Tourism and Environmental Affairs.
- Sanparks.
- Cape Nature.
- Consultants:
  - Ecotone Freshwater Consultants.
  - DH Environmental Consulting and Director (Africa): International Environmental Management Services (Ltd).
  - Wetland Consulting Services.
  - Imperata.
  - Wet-Earth.
  - Wet-Rest.

REFERENCE COMMITTEE

Committee:

Mr B. Madikizela	Water Research Commission (Chair)
Mr H. Marais	Mpumalanga Tourism and Parks Authority
Dr W. Roets	Department of Water and Sanitation
Dr D. Kotze	University of KwaZulu-Natal
Dr D.M. Schael	Nelson Mandela Metropolitan University
Ms N. Mbona	South African National Biodiversity Institute
Mr C. Cowden	Ground Truth cc
Ms J. Jay	Department of Water and Sanitation Planning
Dr C.J. Kleynhans	Department of Water and Sanitation Resource Quality
Dr H.L. Malan	Freshwater Research Centre

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ARC-ISCW	Agricultural Research Council Institute for Soil, Climate and Water
ASPT	Average Score per Taxon
ETS	Emission Trading Schemes
GEF	Global Environmental Facility
GHG	Greenhouse Gas
GIS	Geographical Information System
IMCG	International Mire Conservation Group
KNP	Kruger National Park
MCP	Maputaland Coastal Plain
MNP	Marakele National Park
NFEPA	National Freshwater Ecosystem Priority Areas
PCA	Principal Component Analysis
PES	Payments for Ecoservices
SAMFA	South African Mushroom Farmers Association
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SRTM	Shuttle Radar Topography Mission
STAP	Scientific and Technical Advisory Panel
TEEB	The Economics of Ecosystems and Biodiversity
WRC	Water Research Commission

Page left blank intentionally

1 INTRODUCTION

P.-L. Grundling, A.T. Grundling and S. Mitchell

1.1 Introduction

Worldwide, peatlands cover approximately 3% of the earth’s surface and hold approximately 30% of the world’s soil carbon (Joosten et al., 2012). Among the ecosystem services that peatlands deliver are water storage (10% of global fresh water), regulation and filtration, biodiversity conservation, and carbon sequestration and storage (30% of global terrestrial carbon). The use of peatlands for *inter alia* agriculture, peat mining and forestry has resulted in about 15% of the world’s peatlands being drained, leaving them vulnerable to destruction through burning for instance. This loss is effectively irreversible, with peat fires contributing about 25% of the emissions from entire land use. This makes peatland conservation a low-hanging fruit for climate change mitigation (Joosten et al., 2012), as was indicated under the REDD+[2] agreement during the Durban Climate Convention.

Much of South Africa is semi-arid to arid with highly variable rainfall, making water use efficiency critically important. Rivers draining approximately 70.5% of South Africa's total area are shared with neighbouring states, and these water resources are under enormous pressure in South Africa (Ashton et al., 2008). The ecosystem service of water regulation provided by peatlands serves to recharge groundwater, maintains low flows during dry periods and mitigates floods. Marneweck et al. (2001) found that most peatlands in South Africa occur in the eastern and southern coastal areas and the north-central part of the country, with 11 peatland ecoregions covering the gradient from moist (annual precipitation >1 500 mm) to arid (<100 mm) climate. The peatland ecoregion survey of Marneweck et al. (2001) has drawn the attention of subsequent fieldworkers to the occurrence of additional peatlands not located during this work.

1.2 Background

The first peatland ecoregion survey was driven by the Council for Geoscience, the National Department of Agriculture, and the Inventory and Mapping of Peatlands in Southern Africa initiative through the International Mire Conservation Group (IMCG). It was not possible to verify all identified peatlands during this survey. However, the peatland ecoregion report (Marneweck et al., 2001) arising from this study has raised awareness of the importance of peatlands. Since its publication, other studies have not only located additional peatlands but have also drawn attention to the importance of these ecosystems in maintaining biodiversity. It has also become apparent that other fields of natural science (such as paleoecology) have peatland databases that could be incorporated into a single national peatland database for South Africa.

Less is known about peatlands than other less sensitive and less strategic ecosystems, thus policy formulation and management decisions are not always grounded on a good knowledge base and may inadvertently lead to further destruction of these important ecosystems. The first step in effective peatland conservation is having accurate information. Through this current research, eight case study peatlands in the different peat ecoregions have been characterised, classified and mapped to compile an inventory with their status. Impacts will include hydrological, geomorphological and vegetation features that are typically used to assess wetland health.

The project will not only support the current wetland inventory of the South African National Biodiversity Institute (SANBI), the wetland rehabilitation initiatives of Working for Wetlands and the obligations of the Department of Environmental Affairs towards the Ramsar Convention, but also contribute to future

---

[2] Reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, plus the enhancement of forest carbon stocks in developing counties

wetland research in South Africa. The contribution in understanding peatland systems will benefit the southern African wetland community including The National Freshwater Inventory Geodatabase and the Preliminary Guide for the Determination of Buffer Zones for Rivers, Wetlands and Estuaries.

1.3 Study Area

The project will focus on two levels: Level 1 is the study area of South Africa to produce a national scale product, and Level 2 will focus on local peatland case studies (Figure 50, Appendix 5).

1.4 Objectives

- To improve the existing peatland ecoregion model to identify potential peatland areas based on new recordings (recordings made since the ecoregion model was developed).
- To upgrade the existing peatland database and collect data of new recordings generated in the past 15 years as well as future related research on South African peatlands.
- To investigate the processes and factors driving peat distribution and accumulation in South African wetlands based on selected case studies.
- To investigate the potential of South African peatlands as a carbon sequestration mitigation mechanism.
- To demonstrate the socio-economic value of peatlands in South Africa based on the concepts of ecological infrastructure and ecosystem services delivered (including carbon sequestration, other regulating services, provisioning services and cultural services).
- To recommend further research needs.

1.5 Overview of Peatlands

Although peatlands are not common in South Africa, some are unique. The Mfabeni Mire, for example, at *ca.* 45 000 BP (Grundling et al., 1998; Grundling, 2014), is one of the oldest active peat-accumulating wetlands in the world. In South Africa, peatlands are under threat from many sources. Peatlands provide productive agricultural land that is specifically targeted in rural areas where surrounding soils often have marginal soil fertility (such as the sandy soils on the Maputaland Coastal Plain). Peatlands are consequently targeted for clearing and draining where they play an important role in food security (Grobler, 2009).

Peat is mined for fuel and mushroom cultivation, although mushroom cultivation has now largely ceased in South Africa. Peatlands are also under threat from poorly managed grazing, excessive groundwater abstraction and infestation by alien invasive biota. These threats expose peatlands to the danger of desiccation that can cause peat to burn, causing irreversible damage. Although each of these activities provides short-term gain, the benefits lost in the long term to society and the natural economy through the contribution of the ecological infrastructure far outweigh this (Grundling & Grobler, 2005). Threats are projected to increase in the future due to global (climate and demographic) change and anthropogenic landscape transformations, specifically hydrological modifications to flow patterns, the availability of water for ecosystems, and water quality.

Peatlands provide products such as water, building materials and medicinal plants directly to society, particularly in rural areas where people rely on the stream of ecosystem services delivered by peatlands. Improved conservation of peatlands will enable the formulation of effective policy and management decisions, ensuring that the ongoing stream of benefits will be available for future generations in a sustainable manner. Furthermore, improved conservation of peatlands will also ensure the ongoing stream of benefits that the economy derives from these ecosystems. The study of peatlands as natural archives could serve as indicators of environmental change over time and how we should adapt with future change.

The ecosystem services delivered by peatlands will contribute towards maintaining the health of the population through flow regulation, flood attenuation, filtering of water, specifically in the case of impurities from mining and agriculture, as well as the sequestration and holding of carbon (30% of the global terrestrial carbon – far more than in all forests or in the atmosphere), contributing to the global carbon reduction initiative.

There are a variety of peatland habitat types in southern Africa – from tropical coastal valley bottom systems to alpine seeps. However, scientific research into peatlands has been limited compared to other aquatic ecosystems such as alluvial rivers and dams. Peatlands not only contribute to the diversity of habitats available (from dense swamp forests to sparsely vegetated heaths), but also play a key role in maintaining other associated habitats through their surface flow (10% of the world's fresh water is in peatlands) and filtering of water (Rydin & Jeglum, 2006). In addition, there are many secondary benefits to these contributions, such as downstream erosion control by means of the peatland's flood attenuation capacity.

The destruction of peatlands causes a visible and immediate degradation in the integrity of the aquatic ecosystems downstream of the peatland. This affects the river and associated ecosystem health. Impacts such as draining and erosion of peatlands change the hydrology of the system. The rewetting of these systems will mitigate environmental change at a local level, and climate change at a regional level in accordance with the REDD+ regulations supporting the objectives of, and South African commitments to, the Climate Change and Ramsar Conventions.

The project provides an opportunity for assessing characteristic peatland plant species, including threatened and protected species, that can be expected to occur in peatland systems. It will also provide better understanding of the biodiversity importance of peat systems from a floristic approach.

2 SOUTH AFRICAN PEATLAND DATABASE

A.T. Grundling, E.C. van den Berg and C. Dekker (ARC-ISCW)

2.1 Introduction

This chapter addresses the second objective of the project to:

1. Update the existing peatland database (Marneweck et al., 2001) by collecting data of new recordings generated in the past 15 years.
2. Use the updates to assess the past and new models accurately (Refer to Section 3.3.1: Accuracy Assessment).
3. Identify future related research on South African peatlands.

2.2 Background

Peatlands accumulate and store dead organic matter from wetland vegetation under almost permanent water-saturated conditions and low oxygen content, thus making them a valuable resource for soil carbon and fresh water (Figure 1). Peatlands serve as water regulators to recharge groundwater, maintain base flows during dry periods and mitigate floods. However, not all wetlands are peatlands; peatlands are not common in South Africa.

Figure 1: Photo from the Rietvlei Nature Reserve indicating the dark colour of accumulated organic matter and high-water table found in peatlands (Soil Survey Staff, 2006)

2.3 Methodology

There were 519 records in the 2001 South African Peatland Database. After consultation and feedback from wetland specialists and soil scientists specialising in hydropedology, it was decided to use the following criteria to include additional sites in a hydropedology database of which the peat database forms part:

- Peat: at least >30% organic material (dry mass) with depth at least 300 mm. If only 15% to 29% carbon, then profile depth should be at least 300 mm.
- Champagne: 9.1-14.49% organic carbon and an average of 10% organic carbon over a depth of 200 mm.
- High organic soil: if only 2-9.49% carbon, then profile depth should be at least 100 mm.

The wetland and soil science community was requested to contribute towards the South African Peatland Database. A literature review was conducted to find new peatland recordings in literature for the past 15 years. A requirement for the South African Peatland Database was that it should be compatible with SANBI's National Wetland Inventory. The South African Peatland Database is part of the hydropedology database that is housed and maintained at the Agricultural Research Council Institute for Soil, Climate and Water (ARC-ISCW) (Figure 31, Appendix 3). Appendix 2 lists the important attributes to be recorded per site. Contributions were made using the South African Peatland Database recording spreadsheet and Google Map™ placemarks of possible peatland sites. Follow-up meetings with stakeholders took place on 11 March 2015 in Bredasdorp to identify areas.

2.4 Results

Figure 32 (Appendix 3) indicates the spatial distribution of the 1509 records, 635 points of which are peat sites in the hydropedology database of which the South African Peatland Database forms part. To date, 116 additional points have been added to the South African Peatland Database, of which 106 points need to be verified infield (unconfirmed points). Only 40 peat sites include detailed profile information. Nine peatlands in KwaZulu-Natal have ^{14}C ages recorded at various depths. The ages vary from 130 years BP to ±45 000 years BP (Grundling et al., 1998). From the 79 literature records, 13 additional peat sites were included in the database. Additional sites to the hydropedology database include 29 Champagne sites and 439 high organic soil sites. Other contributions include 300 sites with organic soils (0-1.49% carbon).

2.5 Conclusion and Recommendations

By comparing the known peat sites with the National Freshwater Ecosystem Priority Areas (NFEPA) wetlands layer, Ramsar sites and formal protected areas, it was indicated that 480 peat points fell in NFEPA wetland polygons and could be classified as peatlands, 164 peat points fell in Ramsar sites and 222 peat points in formal protected areas. Only four Ramsar sites contained peat points, namely, Verloren Vallei Nature Reserve, Kosi Bay System, St Lucia System and uKhahlamba-Drakensberg Park (Figure 32) (Appendix 3). Although many points were acquired (990), 519 were already part of the 2001 peatland database. Some of the points are part of the same wetland/peatland system and can be only a few meters apart. Although 116 verified additional peatland sites were added, 106 still need to be verified. This study showed that to verify and add additional peatland points, a proper peatland inventory is necessary for South Africa. It was clear that e-mail correspondence was not effective enough.

3 PEATLAND ECOREGION MODEL

A.T. Grundling, E.C. van den Berg and C. Dekker (ARC-ISCW)

3.1 Introduction

This chapter addresses the objective of the project to improve the existing peatland ecoregion model (Marneweck et al., 2001) based on updated input layers since 2001. The 2001 peatland ecoregion map and peatland database (Marneweck et al., 2001) were used as the baseline for the investigation to identify possible areas where peatlands could occur in South Africa. Figure 33 (Appendix 3) depicts the ecoregions of South Africa (IWQS, 1998) that serves as a basis (Level 1) to display the peatland ecoregion model results. The primary objectives were to use the updated peatland database (Chapter 2) in the accuracy assessment of the 2016 model and produce best available digital maps of peatland ecoregions in South Africa.

3.2 Background

Wetland Consulting Services (Pty) Ltd (Marneweck et al., 2001) led the first peatland ecoregion model project to define and classify the peatland ecoregions of South Africa. A peatland ecoregion model was developed using a geographical information system (GIS) and available electronic data at a national scale, which is between 1:750 000 and 1:250 000 scale. This is acceptable to produce a national scale product at 1:1 000 000 scale. The peatland ecoregion model by Marneweck et al. (2001) is depicted in Figure 34 (original map) (Appendix 3), and Figure 35 (original map with different legend colours) (Appendix 3).

3.3 Methodology

The study area focuses on South Africa to produce a national scale product at a 1:1 000 000 scale. Expert knowledge was used in the modelling process, namely, providing the boundary conditions (upper and lower limits) for each parameter, resulting in a series of key indicator layers. The key indicators or conditions (within each parameter) ideal for peatland occurrence are listed in Table 1.

These parameters were combined in a model that identified areas where all criteria were met. Several variations on the key indicators of the selected parameters were processed while trying to identify the best-fit model. The output of the model was a GIS coverage, depicting potential peatland ecoregion distributions for South Africa.

The model was run using the criteria list favouring peatland occurrence (Grundling & Marneweck, 1999; Marneweck et al., 2001). The dataset types for the 2016 peatland ecoregion mapping were similar to those identified for the 2001 mapping exercise, but the latest spatial datasets were acquired and applied. These datasets include the precipitation layer at 1 km resolution (Malherbe, 2014) and slope information generated from the 90 m Shuttle Radar Topography Mission (SRTM) (Weepener et al., 2011). Table 1 shows the datasets with their thresholds that would most likely create the most accurate peatland probability map for South Africa.

Table 1: Peatland ecoregion defining parameters, key indicators and special data sources

Name of Layer	Source	Scale and Key Indicator	Reference
Precipitation: spatial rainfall data grid at 1 km resolution per month, average monthly (mm)	ARC-ISCW	≥500 mm	Malherbe, 2014
Geology (dolomite)	Council for Geoscience	Dolomite, conglomerate, arenite, quartzite, dolerites, mudstone, other sedimentary lithologies	CGS, 2014
Slope	SRTM digital elevation model	≤12%	Weepener et al., 2011
Mean annual groundwater recharge	Recharge mean	≥5 mm	Vegter, 1995
Groundwater component of river base flow	Base flow	≥10 mm	Vegter, 1995
Depth to groundwater level and springs	Depth to groundwater level; springs	Water level ≤20 m combined with polygons that overlap or intersect with either thermal or cold springs	Vegter, 1995; DWA, 2014

The spatial software ArcGIS™ 10.1 was used to produce the models, spatial products and maps. The 2001 coverage was produced as a vector file (older spatial version), while the 2016 generated product was in a shapefile format (copied on CD). The new 2016 product was buffered by 5 km, the same as the 2001 product. The flow diagram given in Figure 36 (Appendix 3) was constructed using the Model Builder function in ArcGIS™ 10.1. This model can be changed easily to include different parameter thresholds and new parameters or processes.

Figure 37 (Appendix 3) includes the location of springs in the model, buffered by a 5 km radius. The Eastern Uplands ecoregion of the 2016 model results did not confirm known peat occurrences. Therefore, the area was reduced to account for overprediction, as per expert opinion (Figure 38B). The product (Figure 39, Appendix 3) is a combination of the 2001 (Figure 38A) and 2016 peatland ecoregion model results (Figure 38B). The final 2016 peatland ecoregion model spatial product (Figure 39) will be supplied as a shapefile on CD. The larger scale map is included in Figure 40 (Appendix 3).

3.3.1 Accuracy assessment

Accuracy assessment was done by calculating the percentage known peatland points (635) in the peatland database that do occur in the predicted peatland ecoregion areas (Figure 40, Appendix 3).

3.4 Results

The peatland ecoregion combined 2016 model was created by a visual combination, namely, overlapping the 2001 and 2016 peatland ecoregion model results to produce the distribution of peatland ecoregions in South Africa (Figure 40, Appendix 3). Of the 635 known peatland points in the peatland database, 554 points were in the peatland ecoregions combined 2016 model, constituting an accuracy of 87.24% (Figure 31, Appendix 3). The model improved by 10.86% from the 2001 to 2016 peatland ecoregion combined model. Table 2 indicates the number and percentage known peatland points located within each of the 16 peatland ecoregions. The Natal Coastal Plain peatland ecoregion is the highest (63%) followed by the Central Highlands peatland ecoregion (15%).

Table 2: Number and percentage known peatland points located within each of the final 2016 combined peatland Ecoregions

Legend	Ecoregion	Count	Percentage
🟩	Bushveld Basin	2	0.4
🟫	Cape Folded Mountains	8	1.5
🟨	Central Highlands	82	15.1
🟦	Eastern Coastal Belt	8	1.5
🟫	Eastern Uplands	1	0.2
🟪	Ghaap Plateau	0	0.0
🟪	Great Escarpment Mountains	31	5.7
🟥	Great Karoo	0	0.0
🟧	Highveld	38	7.0
🟩	Limpopo Plain	1	0.2
🟩	Lowveld	20	3.7
🟨	Nama Karoo	0	0.0
🟦	Natal Coastal Plain	343	63.1
🟥	Southern Coastal Belt	20	3.7
⬛	Southern Kalahari	0	0.0
🟥	Western Coastal Belt	0	0.0
	Total Points on Model	**554**	**100**

3.5 Discussion and Conclusion

The terrain unit spatial raster dataset for KwaZulu-Natal (Weepener et al., 2011) was used with the known peatland points in KwaZulu-Natal to investigate if terrain units could be an indication of where possible peatlands could occur. Although most of the peatland points were located within terrain Unit 3: Midslope (54%) and Unit 4: Foot slope (38%) in the KwaZulu-Natal Province, peatlands are not restricted to these terrain units only. Therefore, the location of peatlands in terms of terrain units seems to be site-specific.

The peatland ecoregion combined 2016 model was proven to have better accuracy results (10.86%) and the aim to spatially display the distribution of peat ecoregions in South Africa was achieved. Figure 41 to Figure 49 in Appendix 3 give close-ups of the nine provinces.

4 PEATLAND CASE STUDIES: PROCESSES AND FACTORS DRIVING PEAT DISTRIBUTION AND ACCUMULATION

Compiled by L. Pretorius, with contributions from:

P.-L. Grundling	*Department of Environmental Affairs,* WetResT*, UFS-CEM*
L. Pretorius	*Centre for Wetland Research and Training (WetResT), UFS-CEM*
A. Linström	*Wet-Earth Eco-Specs Consulting*
N. Job	*University of the Free State*
S. Elshehawi	*University of Groningen, the Netherlands*
Prof. A. Grootjans	*University of Groningen, the Netherlands*
M. Gabriel	*Hümboldt University of Berlin, Germany*
S. Bukhosini	*University of Zululand*
A. Bootsma	*University of South Africa*
L. Delport	*University of Pretoria*
S. Mandiola	*University of Groningen, the Netherlands*
S. Khoza	*University of South Africa*
M. van der Walt	*University of Pretoria*
B. Mabuza	*University of the Free State*
P. Rossouw	*Rossouw and Associates Soil and Water Science (Pty) Ltd*
D. van Wyk	*University of the Free State*

4.1 Introduction

Peatlands are maintained by hydrological processes and their position in the landscape determines their character and response to change (Mitsch & Gosselink, 1993). Most peatlands occur in temperate climates where precipitation exceeds evapotranspiration, although a significant proportion does occur in subtropical climates with a water deficit. Less than 5% of the world's peatlands occur in Africa (Lappalainen, 1996).

Southern Africa is a semi-arid region with an average rainfall of 497 mm/yr, which is well below the world average of 860 mm/yr (DWAF, 1986). Wetlands are characterised by strong seasonal water table variations and streamflow patterns reflecting the variability in precipitation and evapotranspiration. Wetlands in South Africa are therefore mostly seasonal and temporarily wet and the occurrence of peatlands in this semi-arid land must therefore be a function of a more complex interaction of hydrological factors than just precipitation.

Previous studies on regions such as the Maputaland Coastal Plain (MCP) on the eastern seaboard in the KwaZulu-Natal Province indicate that peatlands are often groundwater-dependant (Grundling, 2014). In addition, geological controls and geomorphological setting usually play a significant role in groundwater supply to peatlands. It is important to determine the nature and importance of surface-groundwater interactions within landscapes where rainfall is seasonal and there is high inter-annual variability, as the dependency of these systems on groundwater leaves them vulnerable to catchment changes and groundwater exploitation. Inadequate knowledge of these processes and their linkages compromise our ability to make sound management decisions in the conservation of wetlands in semi-arid regions.

The aim of this chapter is to:

- Highlight the variety of peatlands in South Africa.
- Establish the main characteristics of South African peatlands.
- Investigate the processes responsible for peat accumulation.

This is done based on eight selected case study sites:

- Vazi North Peatland.
- Lakenvlei Peatland.
- Matlabas Mire.
- Kromme Peatland.
- Malahlapanga Wetland.
- Colbyn Valley.
- Gerhard Minnebron Wetland.
- Vankervelsvlei Peatland.

A three-tiered approach to the sites was followed, where Tier 1 consisted of the study site with the most information (Vazi North Peatland), and Tier 3 of the study sites with the least information (Colbyn Valley, Gerhard Minnebron and Vankervelsvlei). Isotope data was collected for all sites. There are age models for many of the sites as well. However, isotopic and dating results were only discussed in detail in the sections on the Vazi North Peatland and the Matlabas Mire. Two general sections on flow paths (Section 4.6) and peat formation and accumulation rates (Section 4.7) in peatlands discuss the combined results of all the case studies.

For each case study site, there is a summary table of the peatland attributes. These are attached for quick reference in Appendix 4. Land use is discussed in Appendix 6. Management recommendations for each wetland are attached in Appendix 7.

4.2 Methods

The location of the eight case study sites is indicated in Figure 2. The sites were selected to represent different peatland types in various parts of the country, ranging from temperate to subtropical coastal areas, the Lowveld and Highveld on the plateau to the cooler mountains in the interior. The hydrogeomorphic setting, geology, climatic conditions, predominant land use such as conservation, agriculture, forestry, urbanisation and rural communal land; exceptional features, and literature available at the sites were also considered during the selection process (Table 3).

The baseline data which was collected for all sites included:

- Geological controls.
- Hydrological controls.
- Extent of peat body and collective amount of carbon in each peatland.
- Biodiversity information (such as WET-Ecoservices and ecological importance and sensitivity).
- Land use.

Datasets such as the biodiversity information and peat volume estimations were collected for the sake of Chapter 4. Data was collected for all the sites through literature reviews, fieldwork, and consultation with other specialists.

Table 3: The main characteristics considered during site selection

Site	**1. Vazi**	**2. Lakenvlei**	**3. Matlabas**	**4. Kromme**	**5. Malahlapanga**	**6. Colbyn**	**7. Gerhard Minnebron**	**8. Vankervelsvlei**
Location	27°10’36.50”S 32°43’4.05”E	25°33’43.90’’S 30°06’03.10’’E	24°27’40.36”S 27°36’9.59”E	3°52’36.62”S 24°3’7.86”E	22°53’20.0”S 31°02’25.8”E	5°44’18.17”S 28°15’26.12”E	26°28’48.00”S 27°8’60.00”E	34°1’50.09”S 22°51’14.22”E
Closest town	Manguzi/ Mbazwane	Belfast	Marakele National Park	Kareedouw/ Joubertina	Kruger National Park	Pretoria	Potchefstroom	Sedgefield
Setting	Coastal	Inland	Inland	Coastal	Inland	Inland	Inland	Coastal
Primary land use	Forestry	Agriculture	Conservation	Agriculture	Conservation	Urban infrastructure	Agriculture	Conservation
Secondary land use	Communal	Tourism	Tourism	Water supply	Tourism	Education	Mining	Forestry
Exceptional features	Deep peat	High biodiversity	High altitude/steep slopes	Palmiet vegetation	Hot spring mire	Urban peatland	Karst	*Sphagnum* vegetation, deep peat

The colours are used to enable rapid identification of the various land use sectors, e.g. red = forestry; yellow = communal/urban; green = conservation; etc.

Figure 2: The location of case study sites

This study describes the peat profiles by detailing the various horizons as identified by areas of change in decomposition and organic or mineral content, colour, texture, and using the Von Post Humification Scale. The Von Post Humification Scale ranges from H1 (completely undecomposed peat that releases clear water when squeezed and plant remains easily identifiable) to H10 (completely decomposed peat with no discernible plant structure, and when squeezed, all the peat escapes between the fingers).

The carbon content was determined (or in some cases, gained from previous studies) using either the Loss on Ignition Method or the Walkley-Black Method (depending on the sources of data). Using this information, the peat and carbon volume of the peatlands were determined. The volume of peat was determined using constant values to represent the ratio of the peat basin. Peat samples were collected using a Russian peat auger for radiocarbon age dating.

In some of the case studies (Vazi, Colbyn and Matlabas), hydrological networks were set in place. At these points, PVC piezometers were installed to measure the hydraulic head – one within the peat layer, and one within the mineral soil. PVC wells were also installed to measure water levels. The hydraulic heads, water table and temperature profile transects were corrected for the elevation.

The water samples for chemical analysis were collected from the piezometers in 100 ml PVC[3] bottles. The water samples for isotopic analysis were collected in 30 ml and 100 ml dark PVC bottles and filled to the brim. Water samples were analysed for HCO_3, Cl, NO_3, SO_4, Ca, Na, Mg, K, SiO_2, Fe, and pH. Natural isotopes ^{18}O and ^{2}H were analysed at the Centre for Water Resources Research, University of KwaZulu-Natal. The isotopic composition of water samples was plotted in Microsoft Excel™ versus the global meteoric water line and a rainwater sample.

During the vegetation analysis, the area was traversed on foot and all species or indications of plants observed were recorded during the site visit. Floral surveys were conducted within the disturbed wetland area and natural reference wetland habitat in the immediate area. In some of the case studies (Vazi, Lakenvlei, Gerhard Minnebron), species were also classified according to their hydric status. In the other case studies, only the dominant species was identified. Unknown species were taken to herbaria for identification.

The WET-Ecoservices toolkit was applied to determine the general ecoservices for each of the peatlands (Kotze et al., 2009).

---

[3] Polyvinyl chloride

4.3 Tier 1: Vazi

4.3.1 Vazi North

Study area location

Vazi North is located 20 km to the south of the town Manguzi and 23 km north-west of the town Mseleni in north-eastern KwaZulu-Natal (more commonly known as Maputaland) (Figure 3). Vazi North is situated within the northern portion of the Manzengwenya State Plantation. This has led to a reduction in the water table resulting in extensive peat fires in Vazi Pan. The geology in the Vazi area seems to be dominated by the Kosi Bay and Isipingo formations from the mid-Late Pleistocene (Botha & Porat, 2007). The Kosi Bay formation and Mvelabusha quarry were examined (Elshehawi, 2015). The Mvelabusha quarry comprise sandy silts and is enriched in ferricrete, which has probably enhanced the presence of a perched groundwater table (Botha & Porat, 2007).

In Figure 3, the picture on the left shows the location of Vazi Pan. The picture on the right is an enlarged view of the Vazi peatland complex, where the blue polygon indicates Vazi Pan, and the yellow polygon indicates Vazi North (the focus of this study).

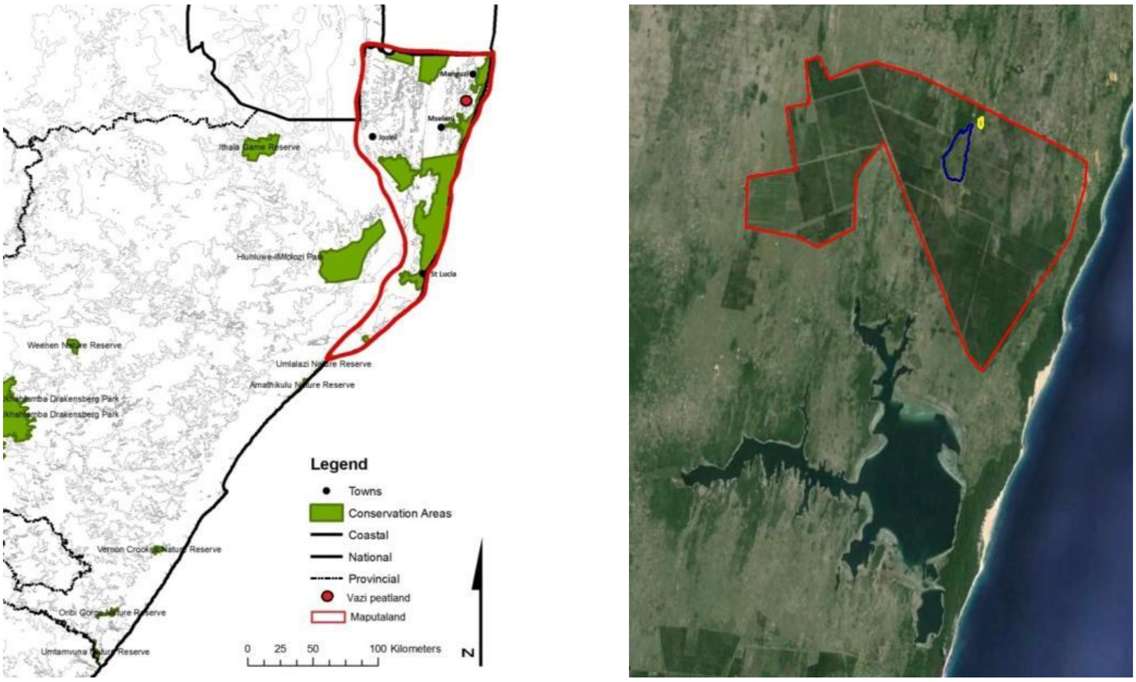


Figure 3: Location of the Vazi Peatland complex

Wetland characteristics

Peat extent, carbon volume, age and accumulation rate

In the two transects crossing Vazi North, 24 profiles were described. Samples were collected from two profiles in each of the transects by Mr Marvin Gabriel and Ms Camelia Toader from the Hümboldt Universität zu Berlin, Germany (Gabriel, Undated; Toader, Undated). The write-up of their dissertations is still in progress. The peat and carbon volume were determined.

The deepest core is 7.60 m. However, informal coring on other occasions has reported depths of more than 8 m (Rosskopf, pers.comm., 2014). Vazi North is characterised by a top layer of approximately 20 cm of amorphous peat. This layer is earthified and aggregated, which is indicative of a high degree of degradation taking place. This is followed by an uneven layer of root-peat. The water table can generally be found at this depth. Root-peat is characterised by an undecomposed organic layer where many roots and fibrous plant material are still visible. This is indicative of a saturated peatland with extensive vegetation growth at the surface. A thick layer of a mixture of root-peat and gyttja is underneath the root-peat. The layer does not have the characteristics to classify as a pure form of either peat or gyttja. This is an expected transition to the even deeper gyttja layer. The gyttja layer, which constitutes most of the peat body, is indicative of limnic conditions. The edges of the peat body are characterised by amorphous peat, sand- or root-peat-gyttja, and sand gyttja.

A previous estimation of peat volume for Vazi North was 111 000 m^3 using a peat thickness of 3.40 and a basin factor of ¾ (Grundling, 2002). An updated peat volume estimation of 355 182 m^3, which is more than three times the original estimation, can be given with the additional information from this study. The total carbon is estimated to be 20 182 tonnes. The estimated average peat-accumulation rate was determined to be 1.15 mm/yr.

One peat core was taken for carbon dating. Peat samples were analysed at the Centre for Isotope Studies in the University of Groningen (Elshehawi, 2015). Vazi North dates at 8490 years BP at a depth of 7.58 m (Table 4). The top 0.47 m has already been aged at 1665 years BP. It can therefore be assumed that an estimated 1200 years' worth of carbon has already been lost through degradation (Figure 4). The shaded area in Figure 4 indicates the period for which accumulated carbon has been lost through degradation.

Table 4: Age of different depths within the Vazi Peatland (Elshehawi, 2015)

Elevation (m a.s.l.)	***Cal BP (yr)***	***σ (%)***	**δ^{13}C‰**	***Thickness (m)***	**Accumulation rate (mm/yr)**
53.32	1665	68.2	−16.65	0.47	0.69
52.85	2350	56.5	**−20.72**	0.34	0.63
52.51	2892	68.2	**−24.14**	0.54	**1.75**
51.97	3200	57.5	**−26.17**	0.32	**1.51**
51.65	3412	68.2	**−23.57**	3.02	1.25
48.63	5830	68.2	−19.83	2.89	1.09
45.74	8490	68.2	−17.76	–	–

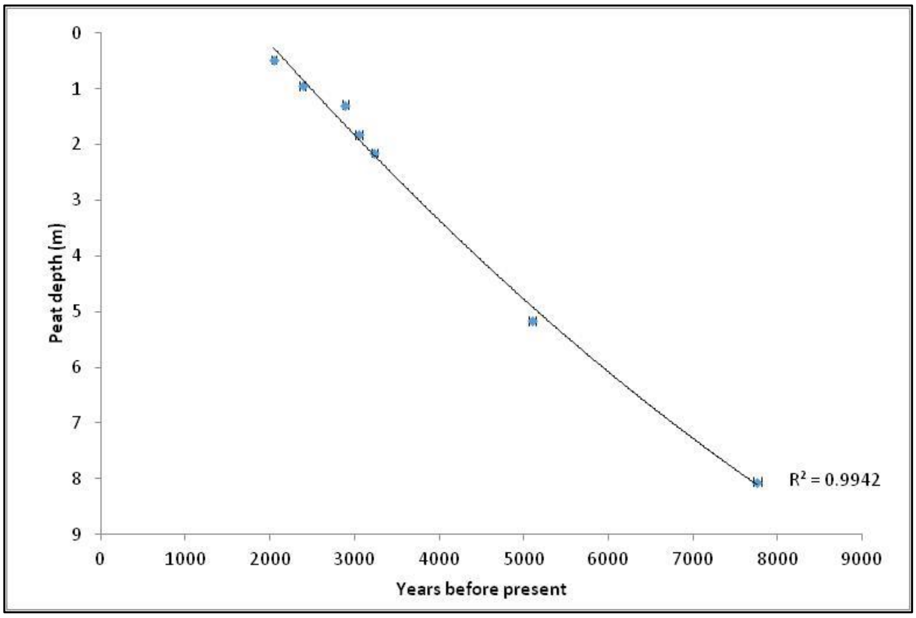


Figure 4: Age of Vazi North

Peatland hydrology

A hydrological network consisting of 16 measuring points was installed as part of the Water Research Commission (WRC) project and student projects (Figure 5). PVC piezometers were installed to measure the hydraulic head – one within the peat layer, and one within the mineral soil. PVC wells were also installed to measure water levels. The water samples for chemical analysis were collected from the piezometers in 100 ml PVC bottles. Water samples were analysed for HCO_3, Cl, NO_3, SO_4, Ca, Na, Mg, K, SiO_2, Fe, and pH at the ARC-ISCW. Natural isotopes ^{18}O and ^{2}H were analysed at the Centre for Water Resources Research, University of KwaZulu-Natal.

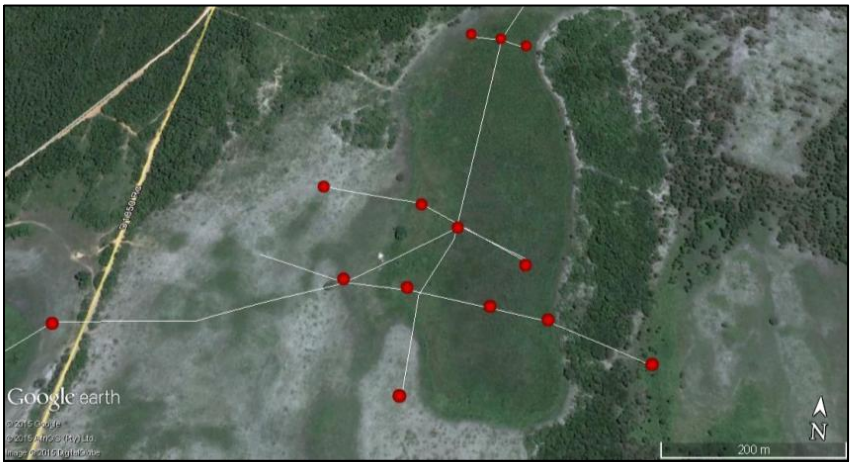


Figure 5: The hydrological network in Vazi North

The following section is taken from the MSc thesis of Elshehawi (2015), which was based on the baseline water monitoring and surveying data collected during this WRC project. Figure 6 indicates the topography of Vazi North with the water table.

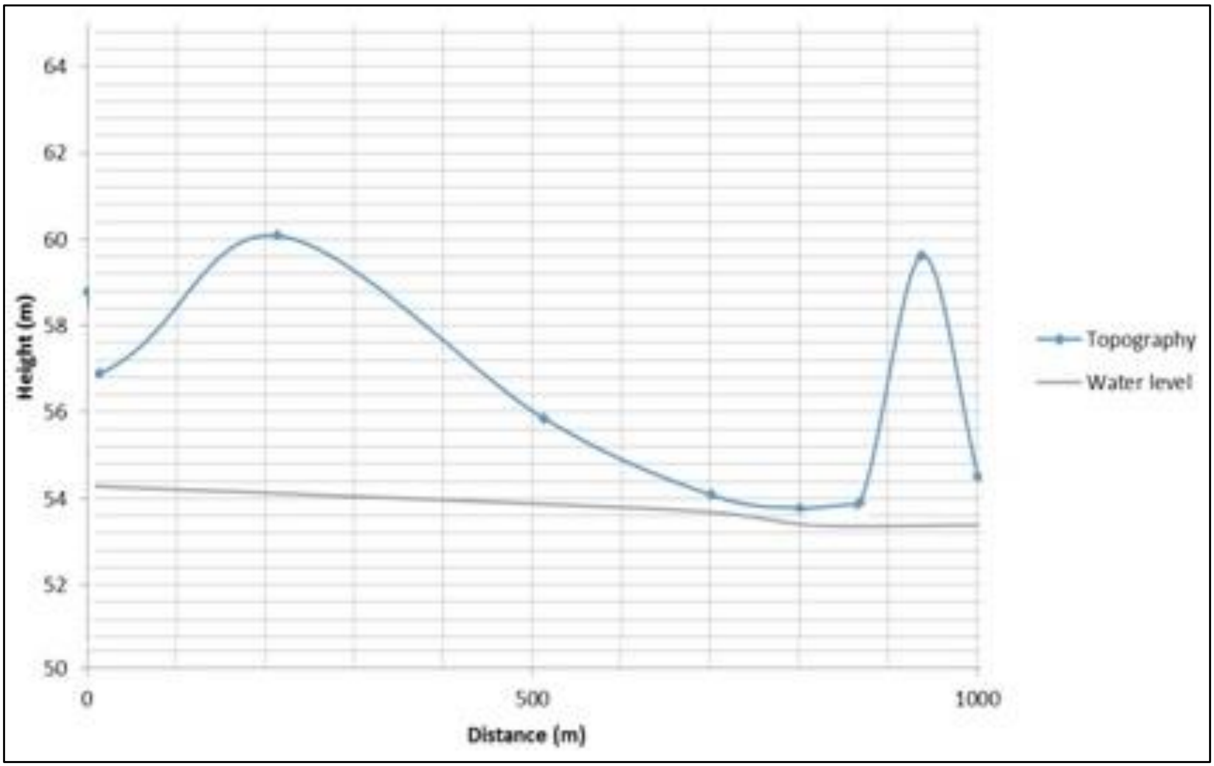


Figure 6: The topography and water level (adapted from Elshehawi, 2015)

Figure 7 indicates the hydraulic pressure profiles. The hydraulic pressures in the mineral soil show the flow to be following the regional pattern (west–east flow). When comparing the peat hydraulic pressures with the mineral soil hydraulic pressures, a discharge of groundwater on the western flank of Vazi, and a recharge from the peat to the groundwater in the eastern flank are visible. There is a through-flow in the peat from valley flanks into the centre, as shown in the peat layer hydraulic pressures. P(d) indicates the deep piezometer, and P(sh) indicates the shallow piezometer.

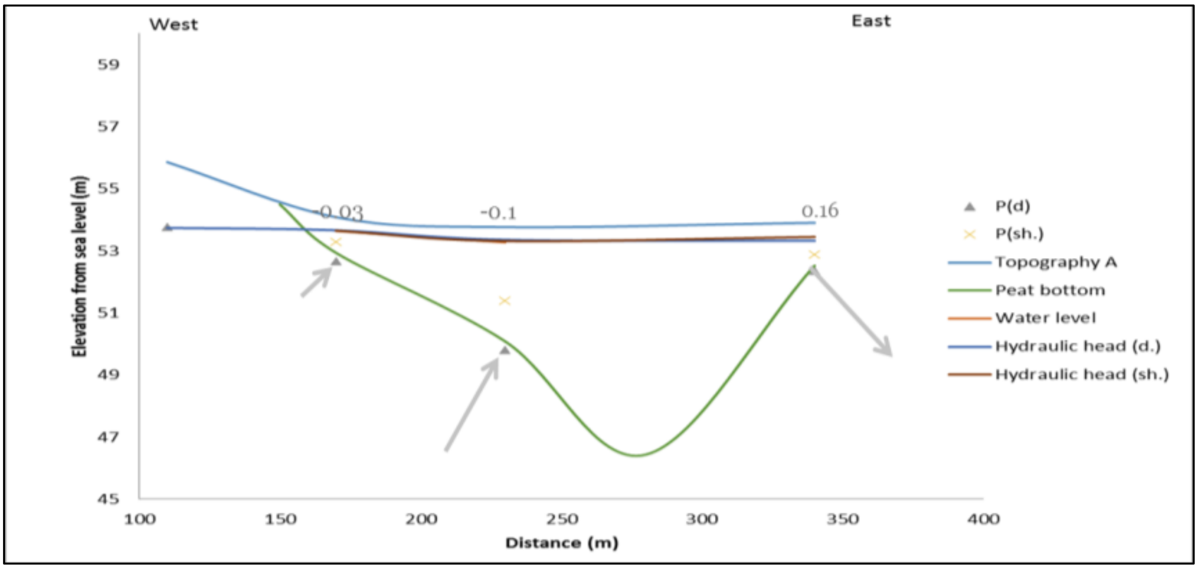


Figure 7: Hydraulic pressures and their corresponding vertical flow directions (Elshehawi, 2015)

Temperature profiles

The results of the temperature profiles are shown in Figure 8. The temperature gradient decreases from west to east. The numbers indicate the surface temperature, which hardly changes from west to east. On the other hand, there is a slope in the temperatures at a depth of 20-200 cm deep (Elshehawi, 2015).

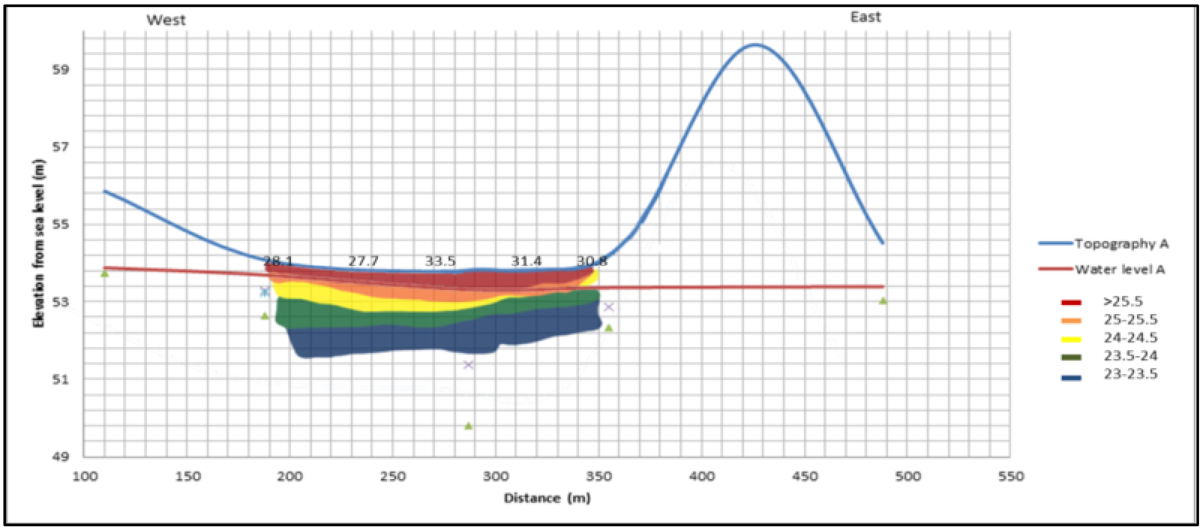


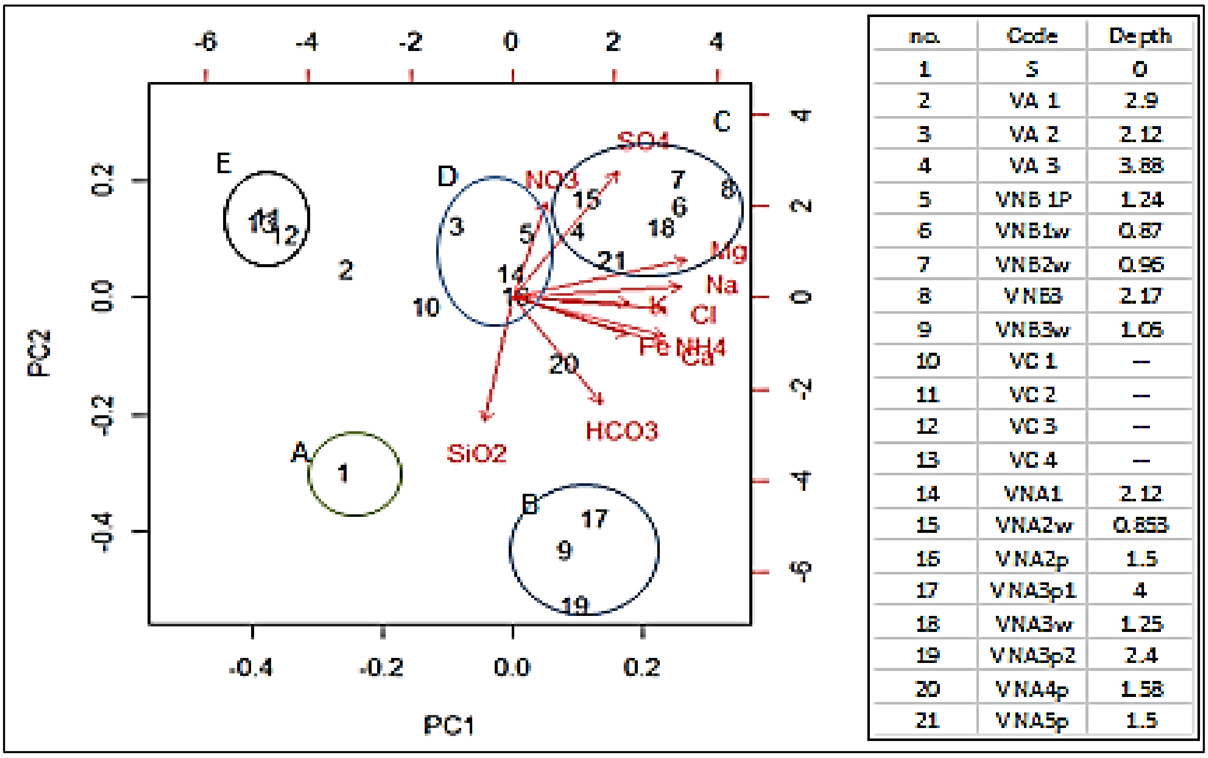
Figure 8: Temperature profile in Vazi North

Macro ionic composition and stable isotopes

Figure 9 shows the principal component analysis (PCA) of the water chemical compositions. The samples are classified according to their correlation from the PCA. There are five main groups:

- Group A is the Siyadla river sample.
- Group B is the water sample from the west of Vazi North, which shows purely anaerobic groundwater exfiltration.
- Group C is the water types affected by evaporation within the peat, and contains the most number of samples.
- Group D is the water samples on the western side of Vazi North showing more aerobic signature as the iron and SO_4 are no longer evident.
- Group E is the water samples from the community wells and surroundings of Vazi Pan with low evaporation patterns (except for Sample No. 3 which is more shifted).

In Figure 9, VA = Vazi Pan; VN (A or B) = Vazi North (transects); VC = community deep wells; S = Siyadla river sample.



no.	Code	Depth
1	S	0
2	VA 1	2.9
3	VA 2	2.12
4	VA 3	3.88
5	VNB 1P	1.24
6	VNB1w	0.87
7	VNB2w	0.96
8	VNB3	2.17
9	VNB3w	1.05
10	VC 1	–
11	VC 2	–
12	VC 3	–
13	VC 4	–
14	VNA1	2.12
15	VNA2w	0.853
16	VNA2p	1.5
17	VNA3p1	4
18	VNA3w	1.25
19	VNA3p2	2.4
20	VNA4p	1.58
21	VNA5p	1.5

Figure 9: PCA of the chemical composition data from Vazi (Elshehawi, 2015)

The chloride and sulphates concentrations and the oxygen were used to indicate the flow patterns indicated by the evaporation and oxidation processes respectively. All illustrate flow directions indicative of an exfiltration of groundwater in the western portion of Vazi Pan, with a subsequent through-flow of water through the peat in the eastern direction. The results of the stable isotopes of hydrogen and oxygen show that almost all indicators are subjected to evaporation processes.

Biodiversity and ecological assessment

The MCP lies in what is considered as the Maputaland Centre, one of Africa's most important biodiversity hotspots and centres of endemism (Van Wyk & Smith, 2001). The Maputaland Centre of endemism is located at the southern end of the African tropics, where many plant (and animal) species reach the southernmost limit of their range (Van Wyk & Smith, 2001). Many of the sedge species recorded on the MCP are tropical of origin, and therefore restricted to the area (Baartman, 1997). Three types of peatland vegetation are recognised in Maputaland, namely, reed-sedge fen (55%), grass-sedge fen (15%), and swamp forest vegetation (30%). The main peat formers are thought to be *Cyperus papyrus, Phragmites australis, Ficus trichopoda,* and *Syzygium cordatum* (Baartman, 1997). (Grundling et al., 1998) report the following species composition from 1996 and 1997: one fern species, six grasses, five sedge species, 12 herbaceous species, ten tree and shrub species, one parasitic species, and one weedy species. Plant species encountered included:

Thelypteris interrupta, Pinus elliottii, Andropogon eucomis, Digitaria didactyla, Eragrostis inamoena, Leersia hexandra, Panicum aequinerve, Cladium mariscus, Cyperus fastigiatus, Cyperus prolifer, Pycreus nitidus, Scleria poiformis, Hyphaene coriacea, Commelina diffusa, Protasparagus setaceus, Smilax anceps, Ficus natalensis, Ficus trichopoda, Ficus verruculosa, Polygonum plebeium, Cissampelos torulosa, Capparis fascicularis, Abrus precatorius, Albizia adianthifolia, Grewia flavescens, Peddiea africana, Syzygium cordatum, Centella asiatica, Strychnos spinosa, Carissa bispinosa, Cuscuta campestris, Ipomoea sp*., Solanum sisymbriifolium, Halleria lucida, Pentodon pentandrus, Richardia brasiliensis, Spermacoce natalensis, Lobelia flaccida,* and *Conyza* sp*.*

Grundling et al. (1998) report that peat-forming flora tends to be mono-specific. There is little uniformity between peatlands, and each exhibits its own character. This statement is contradicted by the study of Pretorius et al. (2014) that found that different wetland types on the MCP have very indicative wetland vegetation (the study did however not only focus on peatlands). In 1998, species composition in the northern section of Vazi North represented mixed bushveld (Baartman, 1997) invaded by exotic pines. This has been shown to be a result of desiccation by the surrounding pine forests, where the peatland has been dried out to such an extent that ‘dryland’ communities can now be supported.

Vegetation data was collected in April 2015. Only the dominant species were identified. Unknown species were taken to the KwaZulu-Natal Herbarium for identification. Vazi North is defined as a grass-sedge peatland. It is very heterogeneous, with no single dominant plant species. Figure 10 broadly illustrates the vegetation communities. The ensuing list names the dominant plant species in each community.

There are distinct seasonal zones on the edges of Vazi North where plant species more indicative of seasonal wetness are dominant. In the northern section of Vazi North (Community 16), *Cyperus procerus* forms a dominant stand. The rest of the peatland is a very heterogeneous mixture of species. Many of the communities are vague, and do not have dominant and/or diagnostic species. Species that have been found dominant in other interdunal peatlands on the MCP, namely, *Cladium mariscus,* and *Phragmites australis* (Pretorius et al. 2014), were found in Vazi North, but only in small, insignificant clusters. However, some of the dominant-edge species, namely, *Leersia hexandra* and *Cynodon dactylon*, were consistent with what was found in the study of Pretorius (2011). Community 5 is a cluster of invasive species that is found repeatedly throughout Vazi North.

The dominant species of the various communities are (Figure 10):

1. *Cynodon dactylon*; 2. *Dactyloctenium giganteum*, *Cyperus natalensis*; 3. *Eriosema preptum*, *Cynodon dactylon*; 4. *Leersia hexandra*, *Hydrocotyle bonariensis*, *Pycreus polystachyos*; 5. *Rubus cuneifolius*, *Solanum mauritianum*; 6. *Panicum repens*, *Cladium mariscus*; 7, 8, 9. *Cynodon dactylon*, *Cyperus procerus*, *Hydrocotyle bonariensis*, *Pycreus polystachyos*, *Cyperus sphaerospermus*; 10. *Panicum repens*, *Cyperus sphaerospermus*; 11. *Stenotaphrum secundatum*, *Cyperus sphaerospermus*; 12. *Panicum repens*, *Typha capensis*, *Stenotaphrum secundatum*; 13. *Cynodon dactylon*, *Leersia hexandra*; 14 *Leersia hexandra*; 15. *Cyperus procerus*.

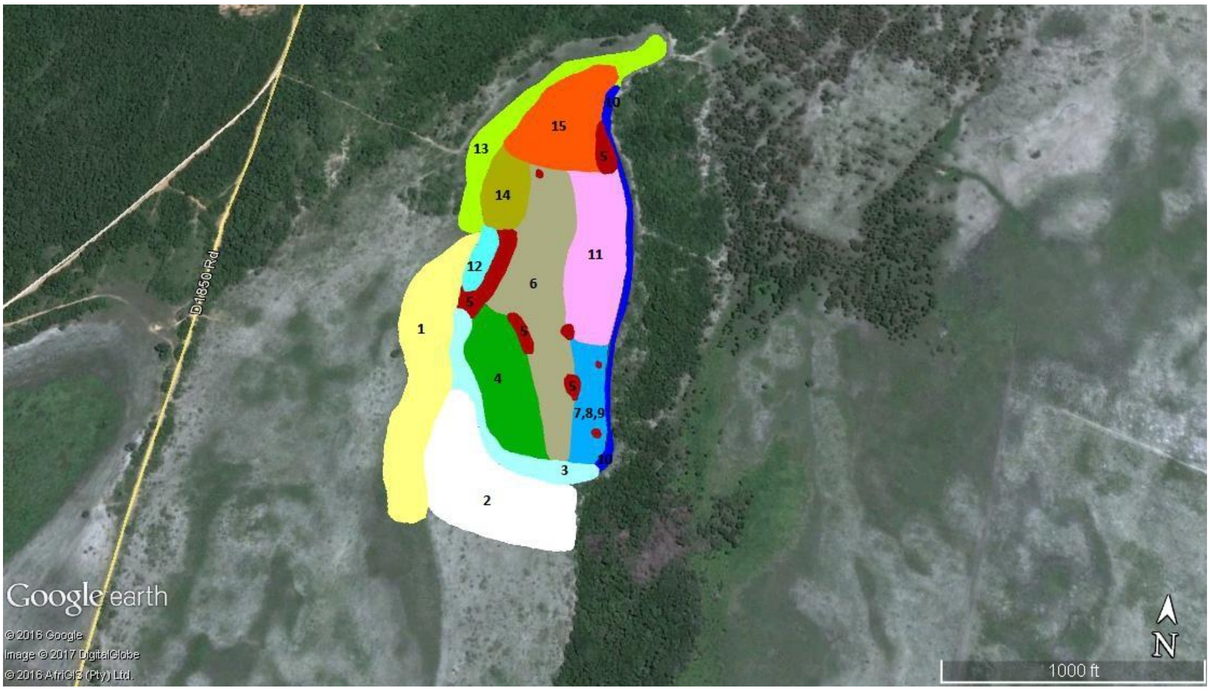


Figure 10: The broad vegetation communities on Vazi North

Other species encountered in these communities in lesser abundances are:

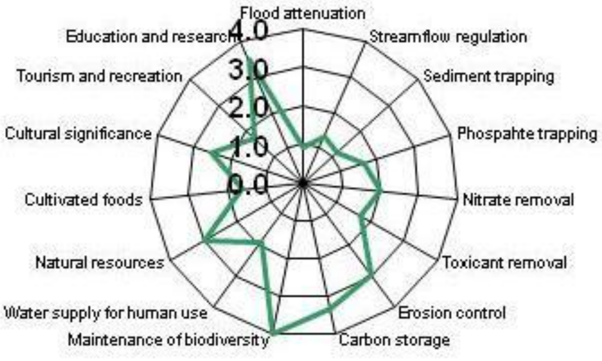
Centella asiatica, Helichrysum kraussii, Eucalyptus sp., *Pteridium aquilinum, Eragrostis heteromera, Asclepias physocarpa, Fuirena umbellata, Schoenoplectus* sp., *Lantana camara, Ficus trichopoda, Cuscuta campestris, Ipomoea* sp., *Rhynchospora holoschoenoides, Syzygium cordatum, Conyza ulmifolia, Symphyotrichum squamatum, Cyperus prolifer, Phragmites australis,* and *Persicaria attenuata.*

Five services scored ‘High’, with very high scores (

Table 5). As Vazi Pan is located within a state plantation, the cultural significance thereof did not score very high. Erosion control scored very high due to the low slope, the high vegetation cover and the lack of erosion in the wetland. However, as a depression wetland, the ability of Vazi to curb erosion is not effective as eroded sediment would be deposited in Vazi itself. There is no downstream water source where eroded sediment can be deposited. There were no wetland functions that scored ‘Low’. Once again, many services (such as streamflow regulation, sediment trapping and flood attenuation) scored relatively low values because Vazi is not linked to a stream channel or downstream water resources. The threats to the system (defined as activities or events with a potential detrimental impact on the ecosystem services supplied) scored a 4, which is very high. ‘Future opportunities’ scored 2, which is very low.

Direct human benefits scored ‘Very High’ (3.0 – Class A), mostly because of the current education and research taking place on Vazi, as well as the cultural heritage for the community and the water use for cattle. The ecological importance and sensitivity scored ‘High’ (2.8 – Class B) due to the rarity and protection status of peatlands. No red data species or populations of unique species were encountered in Vazi, although it must be emphasised that the peatland has not been visited by a biodiversity specialist yet. The hydro-functional importance of Vazi was only ‘Moderate’ (1.5 – Class C) due to the same reasons as is given in the ecoservices analysis.

Table 5: Results and discussion of the ecosystem services provided by the Vazi North Peatland

	Function	Score	Significance
 	Maintenance of biodiversity	**4.0**	**High**
	Education and research	**3.5**	
	Carbon storage	**3.3**	
	Natural resources	**3.0**	
	Erosion control	**3.0**	**Moderately High**
	Cultural significance	**2.5**	
	Nitrate removal	2.0	Intermediate
	Water supply for human use	1.9	
	Toxicant removal	1.7	
	Tourism and recreation	1.7	
	Phosphate trapping	1.6	
	Cultivated foods	1.6	
	Streamflow regulation	1.3	
	Sediment trapping	1.2	Moderately Low
	Flood attenuation	0.9	

Land use

The catchment is dominated by pine plantations, both planted and by self-propagation. Other uses include cattle grazing, and use of the peatlands in the catchment for water. Some locals use areas in the catchment for gardens and plant collection. These practices are, however, limited.

Discussion and conclusion

According to Hobday and Orme (1979), peatlands on the MCP form within valleys of a paleo-dune landscape and are the result of a shallow water table. Most of the peat deposits on the MCP originates from the Holocene period, and is controlled by the underlying coastal dune topography of the Late Pleistocene age, and high rainfall (Grundling et al., 1998). This results in elongated peat bodies being deposited in north–south trending interdune valleys. These peatlands are sustained by the groundwater supply when the water table is high, and perched aquifers in the surrounding sand dunes are also a source of water for the peatlands.

This seems consistent with what was found during the investigation of Vazi North. Vazi North is located at a lower elevation than Vazi Pan. Vazi North itself slopes in a west to east direction, as well as in a slight south to north direction. The peat formation process probably commenced due to the combined effect of the deeply incised valley position and impermeable Kosi Bay and Isipingo formations, where the high-water table resulted in permanent inundation. The thick organic gyttja horizon at the bottom indicates that the valley was permanently inundated for 5078 years. Organic gyttja started about 2000 years after the pan first started forming. At approximately 3200 years BP, vegetation started colonising the open water. Through the terrestrialisation process (Heathwaite et al., 1993), the gyttja-filled basin, a limnic system, was now suitable for the start of peat accumulation.

The current estimation of peat-accumulation rate for Vazi North is 1.15 mm/yr. Smuts (1997) indicated that the peat-accumulation rate for reed-sedge peats in southern Africa is 100 mm/yr. Thamm et al. (1996) as well as Mazus and Grundling (1995) established accumulation rates of 0.26-18.5 mm/yr. The average accumulation rate of 1.06 mm/year in Maputaland during the past 7000 years as reported by Thamm et al. (1996) is supported by Grundling (2002). The total peat volume of Vazi North is estimated to be 355 182 m^3, three times more than what was previously thought. The total carbon is estimated to be 20 182 tonnes.

Two distinct peat age trends are present in the peatlands of the MCP: peatlands originating from the Late Pleistocene age (Mfabeni and Mhlanga, located in the southern area of the coastal plain); and peatlands younger than 7 000 years from the Holocene age (Grundling et al., 2015a). The formation of Vazi North therefore commenced in the Holocene period, very close to the Pleistocene-Holocene boundary, and is somewhat older than the other peatlands on the MCP. Vazi North is much older than its larger counterpart Vazi Pan, which was dated at 2370 years BP at its deepest peat layer of 4.05 m (Grundling & Blackmore, 1998). According to the carbon dating results, it can be assumed that an estimated 1700 years' worth of carbon has already been lost because of degradation.

The top 20 cm of amorphous, earthified and aggregated peat at the surface of Vazi North is indicative of a high degree of degradation that is taking place. This is most probably a result of a drop in the water table due to both the drought and surrounding plantations, which cause the peat to mineralise and oxidize, as well as compress and therefore become denser. There is no evidence of fire inside Vazi North, although an ash layer was found only on the western edge of Vazi North where the organic layer (not peat) is no longer saturated at all.

According to Elshehawi (2015), the water level data shows a steady drop of the water table over the course of the measurement period, especially in the eastern portion of Vazi North. The water composition, temperature, and hydrological monitoring data all indicate that that water flows from the west to the east. Vazi North is driven by groundwater discharge at the south-western edge of Vazi North, with a through-flow and recharge to the mineral soil in the eastern and northern edges of the peatland. The presence of the peat horizon slows the water movement and subsequently increases the evaporation patterns towards the eastern portion of the peatland. The study by Elshehawi (2015) hypothesises a hydraulic connectivity between Vazi North and Vazi Pan, where Vazi Pan sustains Vazi North hydrologically. Vazi Pan is located on the catchment divide, but Vazi North feeds the Siyadla river catchment to the north rather than the Sibaya catchment to the south.

The vegetation shows a shift both historically with a change from C3 to C4 type plants; as well as recently towards more dry conditions, where the desiccated peat is creating a stressed environment favourable for alien and invasive species to move in. The higher salinisation in the eastern portion of Vazi North is indicative of increased evaporation due to the water table drop. The vegetation has changed somewhat from the study done by Baartman (1997), which is indicative of a drier Vazi North than in 1998. The desiccation of the peat results in more favourable conditions to a larger range of species than before, and species usually encountered in terrestrial areas can now move into the peatland. The heterogeneous nature of the peatland could also be indicative of disturbance.

Much of the data collected indicates environmental stress during the last 2000 years, which has significantly escalated since the establishment of the Manzengwenya plantation. Despite the threats to the system, Vazi North is still relatively intact and functioning. Vazi North has significant potential and with a proper management plan supported by both the tribal authorities as well as the Manzengwenya plantation management, Vazi's ecoservices could be better conserved and utilised at the same time.

4.4 Tier 2: Lakenvlei, Matlabas, Kromme and Malahlapanga

4.4.1 Lakenvlei Peatland

Study area location

Lakenvlei is situated in Belfast, Mpumalanga (Figure 11). The Lakenvlei study area covers several farms, namely, Welgevonden 128 JT, Moeilykheid 129 JT, Hartebeestefontein 130 JT, Zwartkoppies 316 JT, Middelpunt 320 JT, Avontuur 319 JT, Elandskloof 321 JT, Elandsfontein 322 JT, Lakenvlei 355 JT and Groenvlei 353 JT. The picture on the right is an enlarged view of the Lakenvlei Peatland. Peat occurs in the permanent zones of the main Lakenvlei valley bottom wetland.

Figure 11: Location of Lakenvlei Peatland (orange polygon)

Wetland characteristics

Geology

The geology of the Lakenvlei Peatland comprises quartzitic, cross-bedded sandstone of the Vryheid Formation in the south-west, hornfels with layers of silt and sandstone of the Vermont Formation in the south and Lakenvlei Formation quartzites in the west. Various north-west–south-east striking faults and north–south-oriented diabase dykes transect the area, with diabase sills occurring in the north.

Peat extent

The Lakenvlei Peatland comprises various basins and tributaries containing peat. The lower valley bottom basin contains 2 m thick peat in places, and the upper wetland basin contains 2.6 m of peat in places. The artesian springs, which occur mainly in the tributaries, have typical peat depths of less than 0.5 m with some containing 1.5-2 m of peat. The peat is a reed-sedge peat, fibrous at the surface grading into fine-grained peat towards the bottom. Dark organic rich clay with thin layers of sand and grey to orange mottled clay towards the bottom underlies the peat. The peatland basins cover of 252 ha, which covers 63% of the total main wetland basin area of 401 ha. These basins contain a significant amount of peat, which is estimated at 1 934 193 m^3.

Biodiversity and ecological assessment

According to Mucina and Rutherford (2006), the Lakenvlei Peatland is situated in the Lydenburg Montane Grassland vegetation type. According to Myburgh (in Burgoyne et al., 2000), wetlands in the Lakenvlei area are poor in plant species, but the different wetlands are floristically and ecologically quite distinct. Bloem (in Burgoyne et al., 2000) similarly recognises a large variety of wetland communities, each with unique species composition but with low plant species richness. The wetland vegetation in the study area is dominated by sedge species that are often indicative of moist soils.

The dominant plant types are sedge and grasses such as *Phragmites australis*, *Pycreus nitidus*, *Schoenoplectus brachyceras*, *Isolepis costata*, *Juncus oxycarpus*, *Carex acutiformis*, *Cristaerenea cognata*, *Eleocharis palustris*, *Euphorbia dregeana*, *Leersia hexandra*, *Harpochloa* sp., and *Berula erecta*. The stability of the water level in the peatlands may be a major determinant of the occurrence of wetland vegetation that underlies much of the variation observed between the broad categories of wetland plant preferences observed during the study. The presence of carnivorous plants in two of these wetlands is indicative of the low nutrient status of this habitat.

The presence of threatened, endangered or sensitive flora/fauna species was confirmed. Birds such as the wattled crane, grey crowned crane, blue crane, white-winged flufftail, grass owl, corncrake, African marsh harrier, bald ibis, Baillon's crake and Denham's bustard were observed.

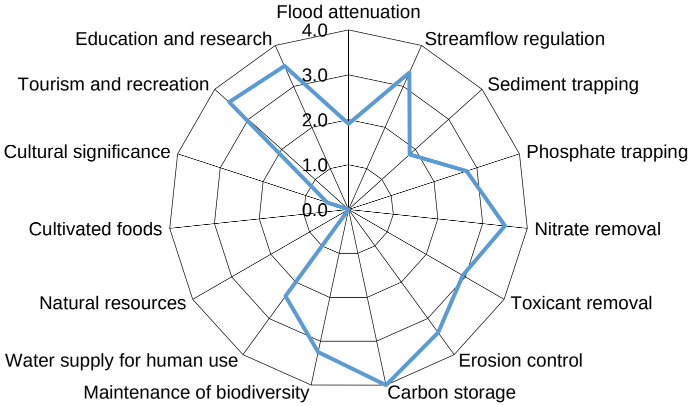
Other species, or signs of other species, such as the freshwater burrowing crab (*Potamonautes flavusjo* – a newly described species, with the Lakenvlei Peatland as one of its latest new localities in the Mpumalanga Highveld), the water mongoose (*Atilax paludinosus*), Cape clawless otter (*Aonyx capensis*), the swamp musk shrew (*Crocidura mariquensis*), and various frog species such as the Karoo toad (*Bufo gariepensis*), common river frog (*Amietia angolensis*) and long-toed Kassina (*Hemidactylus wealii*) were observed.

Due to good vegetation cover and peat content, this wetland contributes significantly towards carbon storage (Table 6). The following services can be expected from this wetland:

- Water quality enhancement through streamflow regulation.
- Phosphate and nitrate removal.
- Erosion control.
- Education and research take place in the area.
- Tourism and recreation are very popular in the area, mostly related to fishing and bird watching.
- The local community does not depend much on this wetland, although they do use it for grazing and water.

This peatland scored a 'Very High' (4.1 – Class A) present ecological state, indicating that the wetland is close to its approximated natural condition. There are some impacts, such as dams, burning regime, grazing and limited drainage channels. The ecological importance and sensitivity of this wetland are considered to be 'Very High' (4 – Class A), which means the peatland is ecologically important and sensitive on a national and even on an international level. There is good vegetation cover that provides various habitats for wetland-dependent species (Figure 12).

Table 6: Results and discussion of the ecosystem services provided by the Lakenvlei Peatland



Function	Score	Significance
Carbon storage	4,0	High
Tourism and recreation	**3,6**	
Nitrate removal	**3,5**	
Education and research	**3,5**	
Erosion control	**3,4**	
Streamflow regulation	**3,3**	
Maintenance of biodiversity	**3,3**	Moderately High
Toxicant removal	2,9	
Phosphate trapping	2,8	
Water supply for human use	2,4	
Flood attenuation	1,9	Intermediate
Sediment trapping	1,8	
Cultural significance	0,5	Low
Natural resources	0,0	Non-existent
Cultivated foods	0,0	

Peat wetland with open water and good vegetation cover

Figure 12: Visuals of blue cranes in the study area

The hydro-functional importance is ‘Very High’ (3.9), which means that this wetland plays a significant role in moderating the quantity and quality of water in wetlands and rivers downstream. The wetland’s size, the good vegetation cover and the spreading out of water all contribute to the wetland’s ability to attenuate and regulate stream flow. The direct human benefits score is ‘Moderate’ (2), indicating that the wetland does contribute in terms of water use, grazing, tourism, research and education, etc.

Land use

The study area is used in agriculture in the form of cultivation (maize), cattle farming, sheep farming, trout fishing, mining in the form of exploration (or potential mining), and tourist-related activities (birding, trout lodges, horse riding). Alien invasive species in the form of *Eucalyptus* species, wattle species and poplar species occur in clumps (mainly managed as woodlots) and affect the area. Indirect impacts include farm management roads, dams in and adjacent to wetlands, trout industrial footprint (dams, roads, housing, etc.), possible wrong burning regime to accommodate maximum grazing potential, mining in the form of diamonds and coal, and increased acid rain and sulphur emissions from power stations in the area. There are a coal mining facility, pottery works, diamond prospecting works and farmland that has been fertilised in the past within the Lakenvlei area. The area is currently used for grazing purposes.

Lakenvlei is affected by various impacts within the catchment ranging from past and current mining and exploration activities, agriculture, plantations and infrastructure. Mining and related infrastructure pose the most severe threat to the Lakenvlei wetlands with physical destruction, groundwater flow disruption and pollution being the most likely impacts. Other impacts are:

- Dams and related fish farming within many of the main wetland and various of the smaller systems.
- Roads through wetlands and streams.
- Coal mining on the watershed of the catchment.
- Diamond exploration in and adjacent to a small wetland.
- Cultivation on the edges and within wetlands.
- Overgrazing and trampling; especially within the smaller hillslope seeps and springs.
- Plantations within or on the edge of the smaller wetland systems.

Peat fires occur sporadically in smaller peatland systems due to either localised draining, plantations or flow interruption by roads.

4.4.2 Matlabas Mire

Study area location

The Marakele National Park (MNP), which is situated in the Limpopo Province, South Africa, is dominated by the Waterberg Mountains in the south-eastern part of the park with undulating to flat plains characterising the north-west (Figure 13). Matlabas is indicated with a square on the left figure, and a bird's eye view of the wetland on the right (with the blue polygon indicating wetland and the green polygon indicating the peat body).

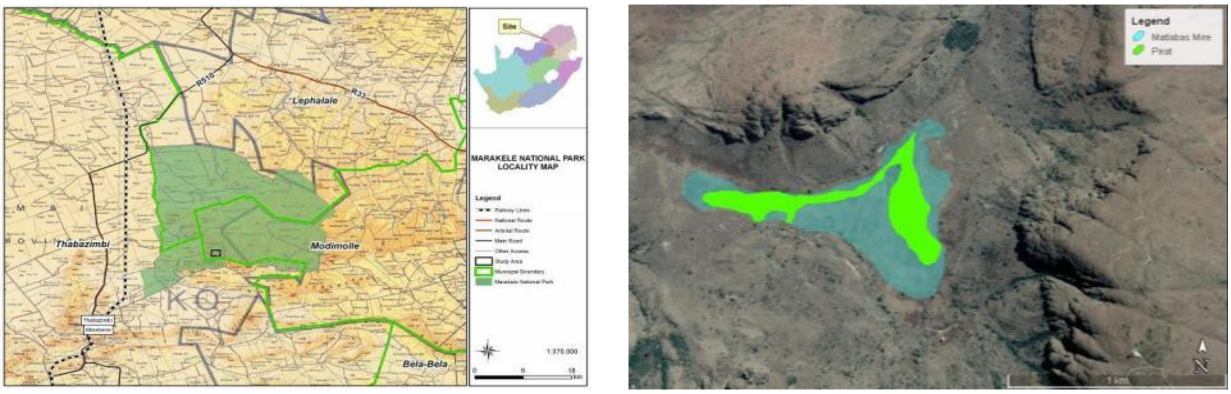


Figure 13: Location of the MNP

Wetland characteristics

Geology

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). 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). The wetlands in the MNP occur mainly in the intermediate to higher lying areas (1000 to 2200 m a.s.l) that receive higher rainfall than 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). Wetlands mainly occur in valleys arranged in a prominent kite-like pattern because of diabase dykes intruding along faults/fractures striking west-northwest–east-south-east and north-east–south-west into Waterberg Group sandstones. 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 into different wetland types including channelled and unchanneled valley bottom and hillslope seepage wetlands (Grundling et al., 2013). The differences between the western and eastern sides of the mire are a result of geological processes, for example, the presence of a geological fault (Bootsma, 2015).

Peat extent

The peatland is 14 ha in extent (22% of the larger wetland extent of 64 ha), with an average peat thickness of 1 m (in the 6 ha western part, the peat is maximum 3 m deep) and 1.5 m (peat maximum 4 m thick) in the eastern part (8 ha). The inferred peat volume for the system is 150 000 m^3. The peat is mostly a grass-sedge peat, mostly fibrous only, at the surface finer grained peat in profile with courser layers in some domes. Sand and gravel occur in layers in the eastern basin and at the bottom of domes where spring water enters these domes. This wetland plays a significant role in biodiversity and baseflow maintenance of baseflow as it is located at source of the Matlabas River feeding into the Limpopo, which flows through the larger Mapungubwe and Limpopo Transfrontier conservation areas.

Considering the layers of sand and clay in the soil profiles, it is possible to hypothesise that sand/clay sporadically washed into the mire may cover vegetation that is not able to decompose aerobically but rather forms peat. The events washing sand and clay into the mire are also expected to be associated with increased water inflow facilitating anaerobic decomposition of sedges and therefore peat formation. This is supported by preliminary data that indicates a very fast rate of peat formation in the Matlabas Mire compared to other peatlands in southern Africa (Elshehawi, 2015).

The radiocarbon dates show that the Matlabas Mire development took place during the Late Pleistocene to Holocene period (11 160 Cal BP). Projecting these ages on topographical and hydrological maps shows that groundwater is most likely supplied to the mire from the higher hill slopes (Bootsma, 2015). There are periods of stronger surface water flow, indicated by the presence of sand intercalations within the stratigraphy of the peat. These intercalations are present particularly in the lower sections of the profile. The valley flanks worked as flooding plains while the lower part was probably a channelled valley. The infilling of the valley centre with clay and organic material very slowly allowed peat accumulation. The valley flanks (south and west) started to accumulate peat 5000 years later than the centre of the valley (Elshehawi, 2015).

Hydrology

The Matlabas Mire is within the Matlabas River headwaters, which is a key component of the MNP. The mire occurs in a valley with steep slopes within a rugged mountainous area. It can be described as a valley bottom hillslope seepage wetland complex. The western wetland has a slope of 4% and the eastern part has a slope of 5%.

A hydrological pilot study identified prominent discharge zones that, together with the occurrence of peatlands and artesian springs, bear convincing evidence of geological/geomorphological control and sustained groundwater input. The valley of the Matlabas Mire is bordered by steep talus slopes where unsorted rock boulders and coarse fragments form highly permeable valley slopes acting as effective recharge areas for groundwater flow towards the wetland. Groundwater flow into the wetland system can be further related to the dynamics between interflow (lateral movement of water in the unsaturated zone of the mire), surface water, and base flow (water from deeper layers). Artesian springs appear to feed various peat domes.

Stable isotopes

According to Elshehawi (2015), the isotopic concentrations show almost no evaporation of the rainwater. The concentrations of the macro ions in the water samples are very low, therefore implying that the eastern part of the mire is mainly fed by relatively recently infiltrated groundwater from the near hill slopes and by rain water, which follows the topography closely. To the northern part, the water goes in a through-flow pattern in the peat layer, hence showing more evaporation. The water samples from the western section show no evaporation. A possible interpretation could be a recharge of the water flows from the surface water and the hillslopes groundwater into the peat. This through-flow in the peat layer is slower than surface or groundwater due to the lower hydraulic conductivity of peat. Therefore, the water is slowed down where it is closer to the surface and subjected to more evaporation patterns.

Land use

The Matlabas Mire is in MNP where land use is predominantly conservation and tourism. This land use is relevant to the catchment of the mire and to the mire itself. The wetland was found to be under stress (for example, erosion and desiccated peat) from past land use practices including overgrazing and possibly road construction. Degradation of MNP and other Waterberg wetlands is of concern as these headwater systems are important water discharge areas ensuring sustained flow to ecosystems downstream.

4.4.3 Kromme Peatland

Study area location

The headwaters of the Kromme River are located on the Krugersland farm in the Eastern Cape Province. Figure 14 shows Kromme (top picture) with an enlarged view (bottom picture) where the blue polygon indicates the boundaries of the wetland system. The section of peatland investigated for this study is in the upper mid-catchment, between 350 m a.s.l and 300 m a.s.l, with an average slope of 0.6%. It is the uppermost area of what once was an extensive series of peat basins. Most of the remaining downstream peatlands are now under cultivation or have been lost to erosion. The peat basin under investigation is approximately 2% of the catchment. The catchment is narrow and steep, bordered in the north by the Suuranys mountain range, reaching 1050 m a.s.l., and the Tsitsikamma Mountain range, reaching 1500 m a.s.l., in the south (Haigh et al., 2002; Rebelo *in* Blignaut, 2012).

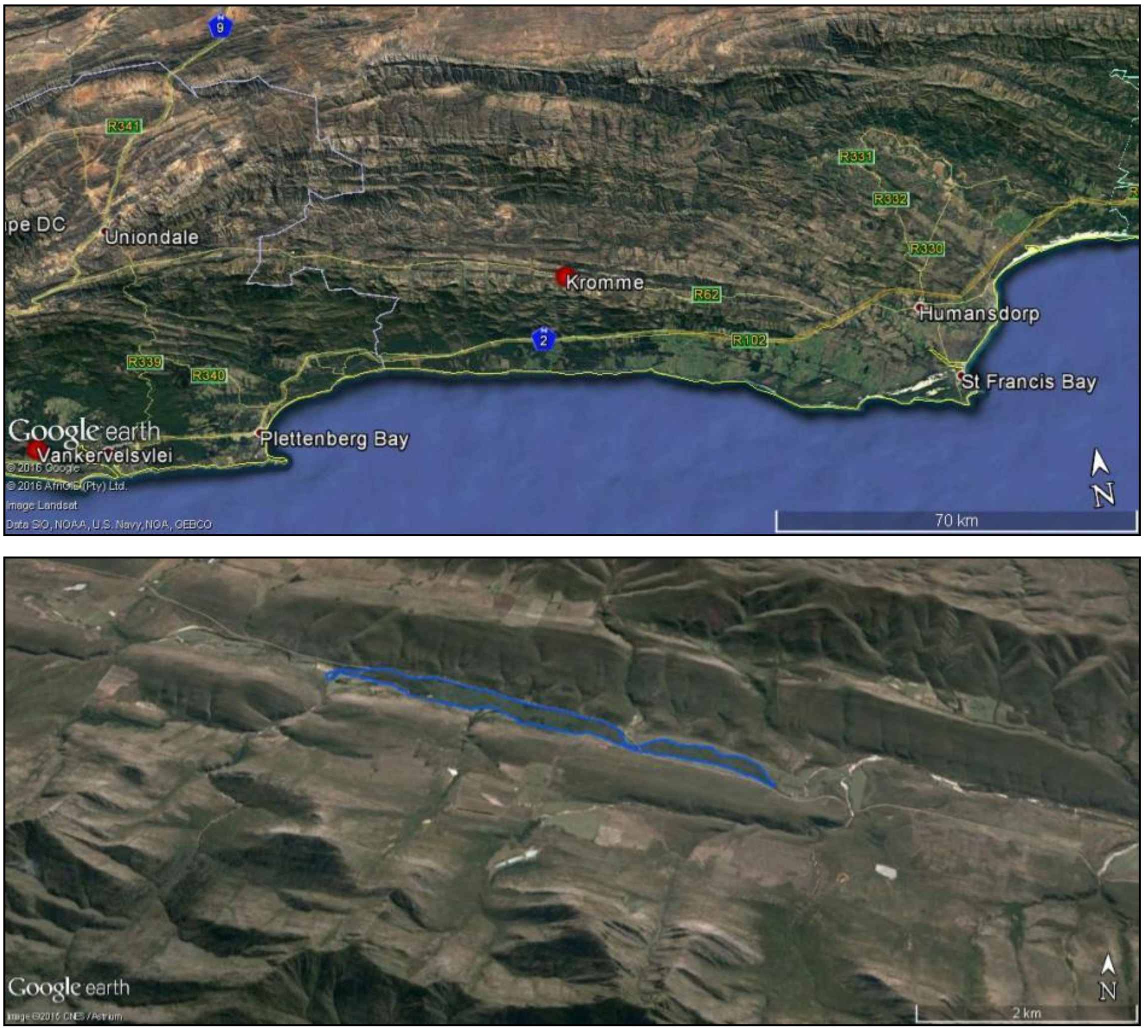


Figure 14: Location of Kromme

Wetland characteristics

Geology

The peatland is underlain by the folded and fractured quartzite lithologies of the Cape Supergroup. Multiple alluvial fans are a feature of the Kromme River valley floor at the distal ends of tributaries entering the Kromme. These fan-shaped deposits stretch into the palmiet wetlands, restricting them to narrow sections against the opposite valley wall and separating what would have been one long continuous wetland into a series of basins.

Peat extent

The peatland investigated forms part of the much larger Kromme wetland complex. This basin is 126 ha with an average peat thickness of 3 m (peat maximum 4.8 m thick) in the north-western part. The full extent of peat within the Kromme River is estimated to have once covered an area of approximately 547 ha (Haigh et al., 2002; Job & Ellery, 2013). Historically, the peatlands were a series of large peat basins, constricted into narrow strips wherever extensive alluvial fans impinged into the valley. The Krugersland peat basin is approximately 90 ha. The inferred peat volume for the system is 3 780 000 m^3. The estimated average carbon accumulation rates were determined to be 0.26 mm/yr. The peat comprises sandy medium-fine to fibrous palmiet-sedge peat; fibrous to fine-grained in texture; sometimes a bit clayey, or less frequently with charcoal or thin ash horizons (Haigh et al., 2002) (Table 7). A sample within 1.4 m of the peat surface revealed a recent age of approximately 50 years ago, while a sample at 3.6 m was dated at 910 years BP; a third sample at 10.6 m revealed an age of 1050 years BP.

Table 7: Description of Kromme peat core

Depth (cm)	Description
0-30	Palmiet plant fibres
30-60	Sand
60-65	Peat
65-100	Organic clay
100-115	Silty fibrous peat
115-125	Water
125-150	Silty peat
150-180	Water
180-200	Peat
200-220	Silty peat
220-250	Organic silty sand
250-300	Silty peat
300-390	Peat

Hydrology

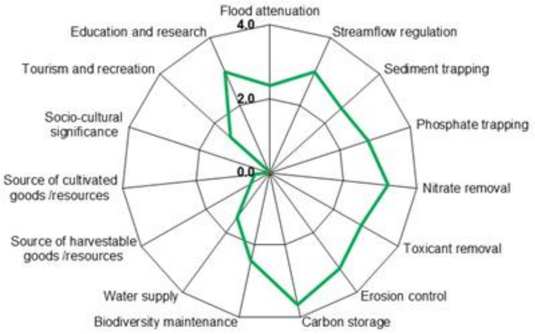
The distribution of peat and the extent of the wetland appeared have been investigated in a similar wetland within the Goukou River. It was found to be controlled by the palmiet plant whose clonal nature and robust root, rhizome and stem system allowed it to grow from channel banks and islands into fast-flowing river channels, slowing river flows and ultimately blocking the channel (Sieben, 2012; Job & Ellery, 2014). Promoting diffuse flows within the dense stands of palmiet creates conditions conducive to water retention and peat accumulation. By growing across the full width of the valley floor, the plant constricts the stream, thus trapping sediment and slowing flows such that the fluvial environment is changed from a fast-flowing stream to one with a slow diffuse flow. These processes create conditions conducive to organic sediment forming, accumulating to form a deep peat basin. The sustained input of water from the folded and fractured quartzite lithologies of the Cape Supergroup making up the Langeberg Mountains, which provide the bulk of the water supply to the wetland, is also important in promoting permanent flooding in the wetland (Job & Ellery, 2014).

Palmiet peat is endemic to South Africa. The value is also in the size of the Kromme Peatland complex and the significant volume of peat. Its role in flood mitigation and baseflow maintenance upstream of the Churchill and Mpofu dams is considerable.

Biodiversity and ecological assessment

According to Mucina and Rutherford (2006), the study area is located within the Tsitsikamma Sandstone Fynbos vegetation type where shrubs are the dominant type of vegetation. Characteristic vegetation includes *Prionium serratum, Cliffortia ferruginea, Cliffortia strobilifera, Psoralea affinis* and *Carpha glomerata.* Other plants include *Thelypteris* sp., *Pteridium aquilinum, Cyperus textilis* and *Fuirena hirsuta*. Due to good vegetation cover, permanent wetland zones supporting diffuse water flows and the presence of deep peat, the following services can be inferred from this wetland (Table 8): carbon storage, flood attenuation, sediment trapping and biodiversity maintenance, and to a lesser extent, water quality enhancement through streamflow regulation, phosphate and nitrate removal, and erosion control. The remaining habitat has added significance given the high cumulative impact to which palmiet wetlands have already been subjected. Although the wetland is on private land, multiple historical studies as well as ongoing research have been conducted on the wetland and it is an important reference site. Prevalent invasive species include *Acacia mearnsii* and *Rubus cuneifolius*, *Juncus lomatophyllus, J. capensis, Phragmites australis, Pennisetum macrourum, Chrysanthemoides monilifera* and *Persicaria lapathifolia*.

Table 8: Ecosystem services provided by the Kromme Peatland



Function	Score	Significance
Carbon storage	3.7	High
Erosion control	3.2	
Education and research	**3**	Moderately High
Streamflow regulation	**3**	
Toxicant removal	2.9	Intermediate
Nitrate removal	2.8	
Sediment trapping	2.8	
Phosphate trapping	2.6	
Flood attenuation	2.4	
Maintenance of biodiversity	2.4	
Water supply for human use	1.5	Moderately Low
Tourism and recreation	1.4	
Natural resources	0.6	
Cultivated foods	0.4	
Cultural significance	0.3	Low

The ecological importance and sensitivity of this wetland is ‘High’ (3 – Class B), mostly as it is one of the last remaining fragments of a highly threatened wetland type in the region. It is thus expected to be ecologically important on a local, national and even international level. There is good vegetation cover that provides habitat for wetland-dependent species. Species use of the wetland is undocumented but is expected to be important for any species found to be present as no similar habitat occurs in the vicinity. The permanent water regime appears to be relatively stable, allowing the wetland to be relatively resilient.

The hydro-functional importance is ‘High’ (2.6 – Class B), which means that this deep peat basin plays a vital role in moderating the quantity and quality of water in wetlands and rivers downstream. The wetland’s size, good vegetation cover and diffuse flows all contribute to the wetland’s ability to attenuate and regulate stream flow. The Kromme River can be a high-energy system with low flows for much of the year interspersed with occasional extreme peak flows. The wetlands play a significant hydrological buffering role in the Kromme system as they absorb initial flooding; with the robust palmiet vegetation being particularly well-adapted to break the force of water flow. The dense vegetation and high organic soils also act as natural water filters by trapping sediments and pollutants, thus improving water quality and reducing high sediment loads from entering downstream dams.

The direct human benefits score is ‘Moderate to Low’ (0.7 – Class D), indicating that the wetland does not contribute in terms of water use, grazing, tourism, but is important to research and education.

Land use

Prevailing land use within the valley floor is a mix of irrigated and dryland agriculture, including crops, orchards and pasture supporting dairy and meat production, while the mountain slopes are largely natural vegetation. The Kromme peat basin has been severely affected and degraded by inappropriate land use activities and road development, especially in the last 60 years (Haigh et al., 2002). Orchards and grazing were the most common forms of land use until 1930. In 1931, a particularly large flood destroyed many orchards along the river banks, causing severe erosion. After this, many farmers turned to pasture, dairy and meat production (Blignaut, 2012). After the 1931 floods, black wattle (*Acacia mearnsii*) appeared for the first time along the stretch of the Kromme River and good rainfall years ensured their establishment. After orchards were again swept away in a flood in 1965, farmers raised the banks of the river to contain future floods. This caused significant channel erosion (Blignaut, 2012). By 1986, more than 50% of the valley floor had been converted to agriculture. Black wattle formed dense stands on the flood plains (Blignaut, 2012).

Peatland use and impacts within the catchment include agriculture, alien plant invasions, draining, dams, fences, grazing, head-cut and donga erosion, peat fires, roads and water abstraction (Haigh et al., 2002). The Krugersland peat basin is among the last large intact areas of wetland along the Kromme River.

4.4.4 Malahlapanga Peatland

Study area location

Malahlapanga is located with the Kruger National Park (KNP). As can be seen in Figure 15, the park is in the Lowveld region of South Africa. The map on the left indicates the Transfrontier Park between South Africa and Mozambique with the position of the Malahlapanga Peatland indicated in red. The map on the right is an enlarged view of the Malahlapanga Peatland and its catchment.

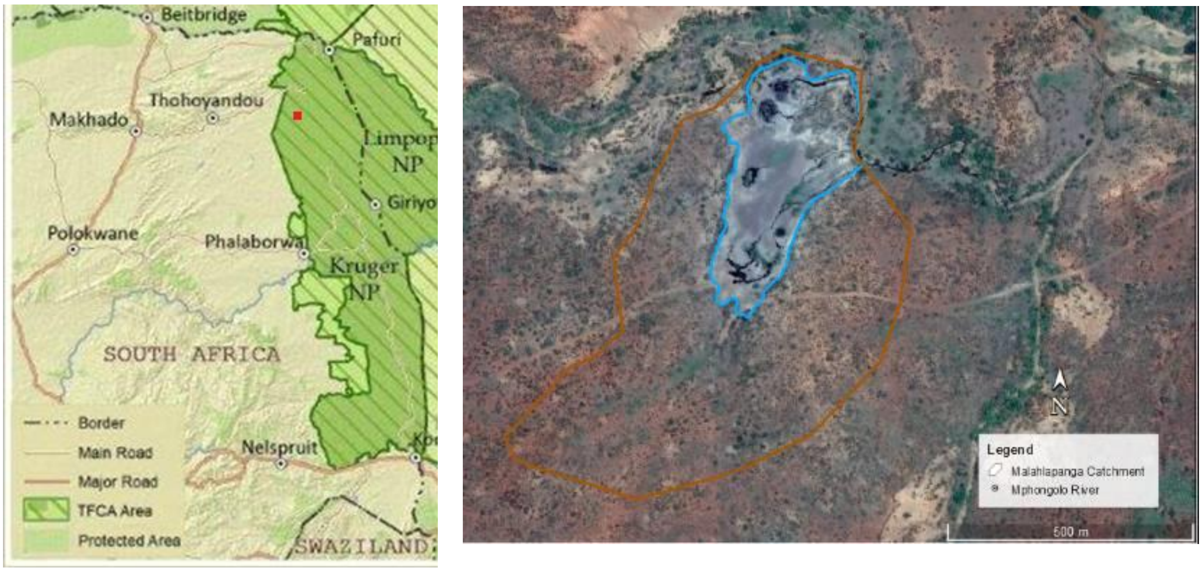


Figure 15: Transfrontier Park

Wetland characteristics

The Malahlapanga spring mire is in a small tributary close to the confluence with the Mphongolo River. The Malahlapanga Wetland has a catchment of 42 ha and falls entirely in the Shangoni Section of the KNP (Figure 15). The KNP has several larger rivers rising in the interior and are susceptible to land use impacts in catchments outside the park. Wetlands and rivers such as the Malahlapanga springs and associated stream rising within conservation areas are of importance as areas of internal water supply. This applies even more so at a time where management is closing artificial waterholes to promote a more ecosystem-oriented approach.

Geology

The underlying geological formations are undifferentiated metamorphic rock and amphibolite from the Swaziland system. Malahlapanga is underlain by the Goudplaats Gneiss. A major fault zone with the Dzundwini and Nyunyani Faults striking from east to west occurs about 10 km north of the spring. This fault zone dips to the north away from the spring. However, an offshoot from the southern Nyunyani Fault strikes roughly north to south in line with Malahlapanga but stops 2 km short of it. Two parallel lineaments determined by remote sensing follow the same orientation as the fault, intersecting an east to west striking diabase dyke at Malahlapanga.

Peat extent

The Malahlapanga Wetland is about 9 ha and consists of a seepage area with a slope of less than 0.5% on the banks of the tributary of the Mphongolo River containing several thermal springs and spring mires (Figure 16). Four small (*ca*. 200-500 m^2) peat domes (cupolas) rise 1-2 m above their surroundings. Smaller seepage patches (1-10 m^2) are present between the larger mires. These are sparsely vegetated and damaged by animals such as elephant and buffalo that trample the peat to get to the water; also, possibly going after the mineral salts contained in the peat. This has resulted in erosion within the wetland. The top of the two largest cupolas are dried out and lack wetland vegetation, which was present only at the bases of these domes. Markers monitoring the height of these domes clearly indicate a lowering of the domes as water drains from the peat and peat pores collapse. Two smaller and wetter cupolas occurring between the two dried-out domes have many wetland plant species across their entire surfaces. However, the rims of the four domes were breached by trampling and subsequent erosion; therefore, resulting in the draining of these small mires (Figure 17).

The peatland component (the domes) is 0.2 ha (compared to the 15 ha of the total wetland), with an average peat thickness of 1.5 m. The inferred peat volume for the system is 2310 m^3. The peat is a reed-sedge peat, mostly fibrous only at the surface finer grained peat in profile with courser layers in some domes. Sand and gravel occur at the bottom where spring water enters the domes.

Gillson and Duffin (2010) estimated that peat formation started *ca.* 5000 years BP at Malahlapanga. This is an underestimation, since the larger cupolas are much deeper than the maximum (110 cm) profile depth reported by these authors. A conservative estimate based on peat thickness and accumulation rates from Gillson and Duffin (2010) suggests that some domes at Malahlapanga may be between 7000 and 14 000 years old.

Figure 16 is schematic overview of the Malahlapanga Wetland sites showing four peat domes (A-D) and a mineral spring (E) discharging warm groundwater from a deep aquifer.

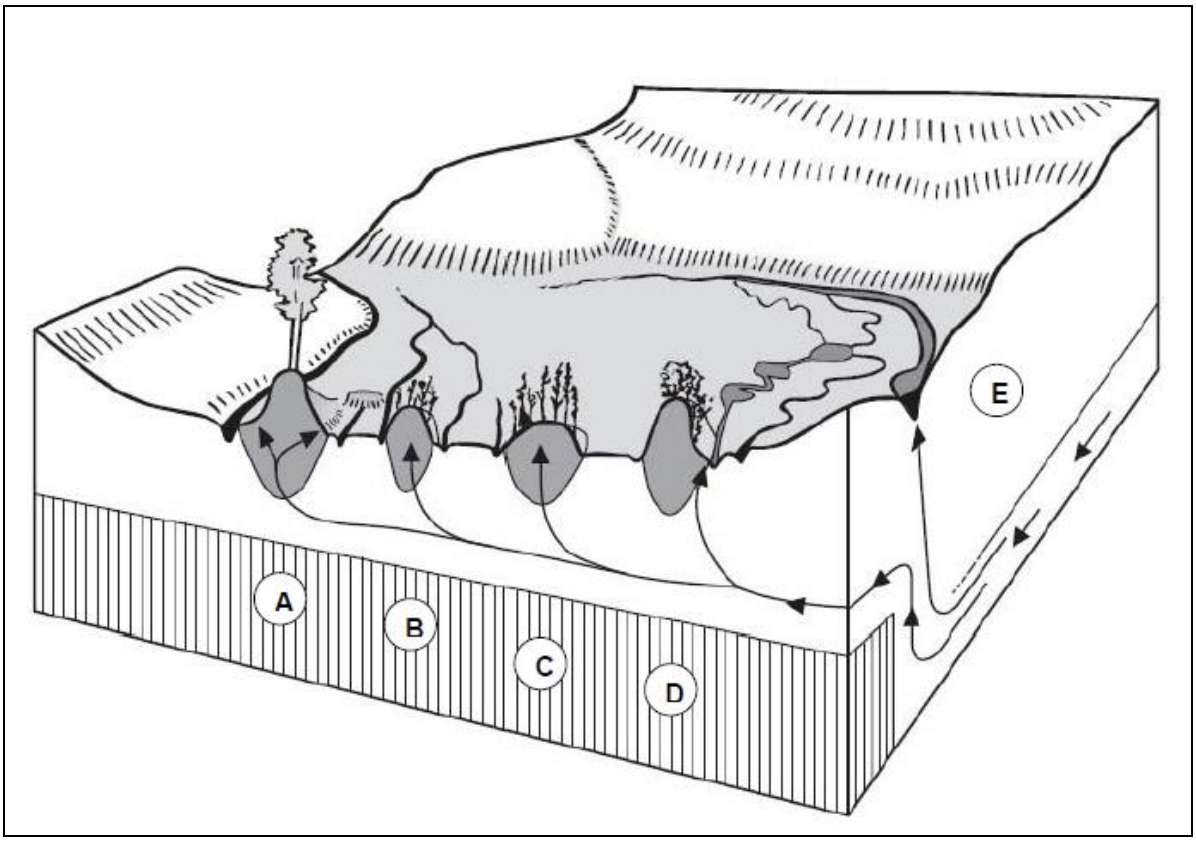


Figure 16: Schematic overview of the Malahlapanga Wetland sites (Grootjans et al., 2010)

Figure 17 shows severely eroded peat cupolas in the Malahlapanga spring mire complex with trees or shrubs on their summits (top). A smaller peat dome (bottom left) is much wetter and covered with typical wetland species. The small spring (bottom right) discharges groundwater at 37°C.

Figure 17: Severely eroded peat cupolas in the Malahlapanga spring mire complex

Land use

The wetland and the catchment area are in a formal conservation area and used for water and grazing for game, wilderness trails and research. The landscape is preferred habitat for a variety of game. The value in this system is not so much in its size but in its irreplaceability as it is only one of two documented artesian hot water spring mires described in scientific literature (Grootjans et al., 2008). KNP is the only location where these mires are officially conserved.

4.5 Tier 3: Colbyn, Gerhard Minnebron and Vankervelsvlei

4.5.1 Colbyn Peatland

Study area location

The Colbyn Valley is bordered by the Colbyn residential area in the west, the N1 highway in the east, the N4 highway and the Colbyn golf range in the south, and by quartzite ridges in the north (**Error! Reference source not found.**). It is also intersected by the Hartbees–Koedoespoort railway line. The Hartbeesspruit, originating in the suburb of Waterkloof Ridge (groundwater), flows through the valley towards the Roodeplaat dam.

Wetland characteristics

Geology

The wetland is underlain by sediments and volcanic lava of the Transvaal Group. It is in a valley comprising shales of the Silverton Formation and is bordered in the east by andesitic lavas. A quartzite ridge (Daspoort Formation) forms a key point on northern side. The Hartbeesspruit flows through a breach in this quartzite ridge. Localised backflooding of Hartbeesspruit because of restricted flow through the poort and flow seeps upstream of the poort resulted in the formation of the wetland and the accumulation of peat under the associated favourable conditions.

Figure 18: Colbyn Valley Nature Reserve (adapted from Van der Walt, 2015)

Peat extent

The wetland is approximately 15 ha and has a slope of 1.5%. The peatland is 7 ha (47% of the larger wetland), with an average peat thickness of 0.5 m (maximum 3 m thick), which has been infilled by Metrorail after erosion threatened the railway on the eastern edge of the peatland (Figure 19). It is possible that the peatland could be much bigger than the 7 ha this study indicates. The inferred peat volume for the system is 35 000 m^3. The peat is mostly a reed-sedge peat, fibrous and finer grained peat in depth with ash layers in paces (Table 9).

Figure 19: Boundaries of peat areas in Colbyn Valley (adapted from Van der Walt, 2015)

Table 9: Colbyn peat core description (adapted from Van der Walt, 2015)

Depth (cm)	Description
0-30	Organic rich soil
30-75	Grey clay
75-85	Grey clay with some organic soil
85-100	Brown and blonde fibre peat
100-120	Phragmites vegetation
120-125	Reed rhizomes
125-150	Ash layer
150-160	Definite ash layer
160-170	Fine peat
170-190	Rough peat
190-200	Course fibre
200-210	Clay and fibres
210-230	Clay and yellow fibres
230-250	Clay and limestone

Peatland hydrology

The hydraulic characteristics of the Colbyn Peatland were determined using different hydraulic parameters (gravimetric water content, specific yield, bulk density and porosity) (Van der Walt, 2015). Colbyn has a medium water retention capacity overall. The gravimetric water content decreases with increasing depth. Therefore, the deeper, older peat parts are more decomposed than the upper layers. Colbyn has a moderate to high hydraulic conductivity, and a low overall bulk density, consistent with the high sustainable yields and gravimetric water content.

Biodiversity and ecological assessment

The area falls within the Rocky Highveld zone of the Grassveld biome where sedges and grasses are the dominant vegetation types with species such as *Phragmites australis, Carex cernua* var. *austro-africana, Typha capensis, Hyparrhenia tundra, Cyperus angularis, Cynodon dactylon* and *Themeda triandra* being dominant. Seven rare bird species and the Lycaenid butterfly have been recorded on-site. The area experiences an average summer rainfall of between 650 mm and 750 mm per annum.

Land use

The catchment is 100% transformed by urbanisation and farming activities. The peatland itself is an important urban open space providing conservation tourism opportunities such as hiking, birding and environmental education, as well as research. The value in this system is not so much in its size but in its irreplaceability; within an urban area not only as a sense of place in an urbanised area but also in wetland filtration and flood attenuation.

4.5.2 Gerhard Minnebron Peatland

Study area location

The Gerhard Minnebron Wetland is situated on the farm Gerhard Minnebron 139 IQ, north-west of the town Potchefstroom, in the North West Province. The wetland occurs at an altitude of between 1400 m and 1410 m a.s.l, with a gradual slope (<0.1%) towards the south-west. The wetland falls within the Rocky Highveld zone of the Grassveld biome, with an average summer rainfall of between 600 mm and 750 mm per annum (Low & Rebelo, 1996).

Wetland characteristics

The existence of fens in karst topography has been described worldwide. It can be attributed to the dissolution of the underlying limestone causing a slumping of the land surface, thereby creating distinct basins. These basins may or may not be connected to surface water or groundwater. Wetlands that form in such depressions are commonly referred to as sinkhole wetlands. Lost streams (streams that disappear underground) and underground caverns are common in karst areas. Some sinkhole wetlands receive groundwater discharge from surrounding and/or underlying limestone deposits, such as Gerhard Minnebron. Others simply occur in basins formed by the dissolution of underlying limestone. Fens are known to develop through a directional change from open water mires, in a process where the open water is slowly displaced by the accumulation of peat in the system due to the proliferation of wetland plants dominated by reeds (Joosten & Clarke, 2000). Such directional changes may be seen in the Boskop Dam a few kilometres downstream in the Mooi River, where reeds are proliferating and slowly displacing open water. This is exacerbated by anthropogenic activities.

The Gerhard Minnebron Wetland is underlain by dolomite of the Malmani Subgroup and is fed by several dolomitic springs, which include the Gerhard Minnebron Eye. It is located on the Vaal River karst type with slightly undulating terrain morphology, and represents an area of approximately 150 ha in a small tributary of the Mooi River (Figure 20). The wetland consists of several dolomitic eyes and a valley bottom fen of approximately 150.4 ha.

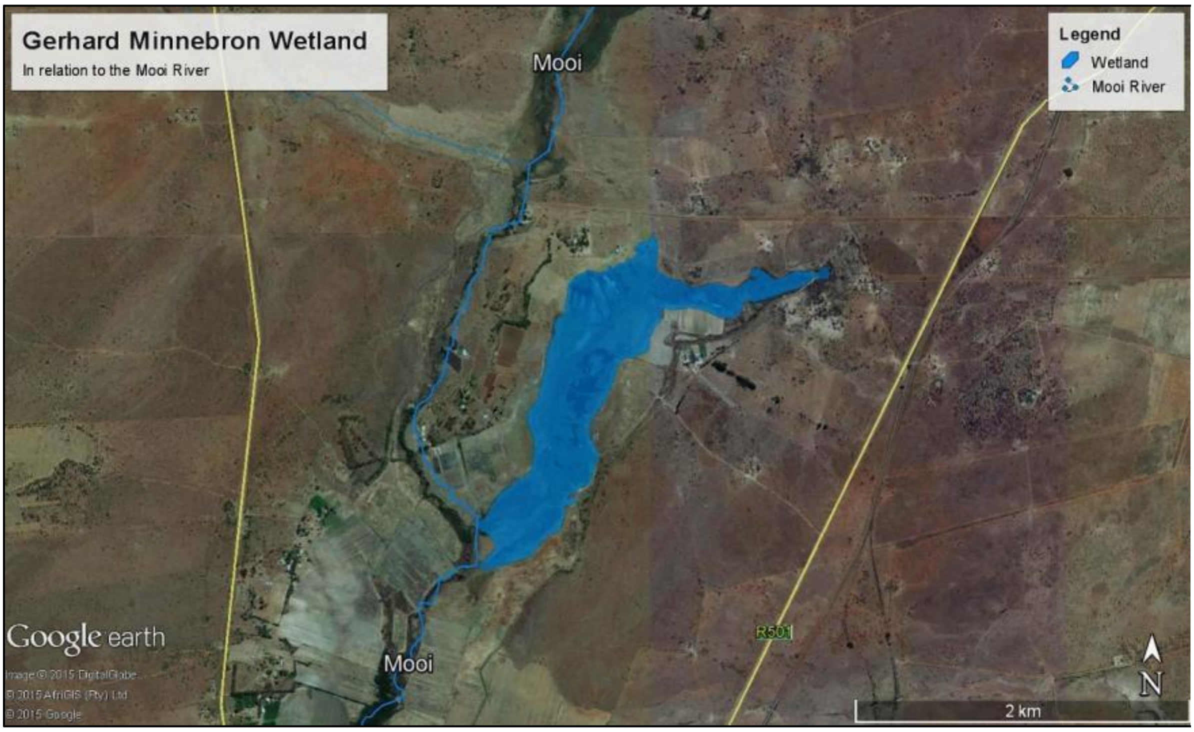


Figure 20: Position of the Gerhard Minnebron Wetland

The Gerhard Minnebron Wetland has a small catchment area of approximately 1275 ha with a gentle slope (0.5%). It is mainly fed by dolomitic springs at the head of the system and within the wetland. The main dolomitic spring occurs in the headwaters of the wetland on the remaining portion of Gerhard Minnebron 139 IQ. Ephemeral streams may contribute some runoff during rainfall events, and a stream originating close to the Mooi River can divert water from the Mooi River into the Gerhard Minnebron Wetland during high-flow events. The largely mono-specific stand of common reed *Phragmites australis* and *Carex acutiformis* indicate a mature fen. This also suggests a uniform hydrological regime, which is not subjected to any extreme hydrological disturbances that would have created a mosaic of different habitats and associated plant species. The abundance and depth of peat also support the assumption that the system has been perennially inundated for thousands of years with a stable low energy hydrological regime.

The peatland is 95 ha in extent with an average peat thickness of 2.75 m (peat maximum 5.75 m thick). The inferred peat volume for the system is 2 612 500 m^3 before peat extraction. The peat is mostly a reed-sedge peat, fibrous and finer at the bottom with ash layers in places. The value of this system is not only the substantial amount of peat it contains, but also its filtration capacity downstream of polluted groundwater discharge zones (primary uranium from the mining industry).

The chemistry of the groundwater feeding into the Gerhard Minnebron Wetland gives an indication of the geology, hydrology and biology of the aquifers and phreatic caves within the karst system supplying water to the wetland. Some of these water chemistry parameters may be indicative of pollution. Changes in the quality of the water in the Gerhard Minnebron Wetland may also give some indication of the sequestration of some chemicals via wetland functions and the release of other chemicals due to natural processes or the mining of the peat.

According to Mucina and Rutherford (2006), this wetland is located within the Carletonville dolomite grassland vegetation type with dominant plant types being sedges and grasses. Dominant plant species include *Phragmites australis, Schoenoplectus brachyceras, Juncus effusus, Carex acutiformis, Mariscus congestus, Leersia hexandra, Imperata cylindrica, Ranunculus meyeri* and *Typha capensis.*

The presence of threatened, endangered or sensitive flora/fauna species was recorded. The white-backed night heron, little bittern, Baillon's crake, and grass owl were observed, as well as springhare, Angoni vlei rat and greater cane rat.

The Gerhard Minnebron catchment is small and there are cultivation, fallow lands, diamond diggings, grazing and trampling, farm management roads, exotic vegetation, dwellings, water canal, tar road, infrastructure and footprint of previous peat mining present. Presently, the major impacts on the ecology of the wetland are related to water abstraction from the Gerhard Minnebron Eye and from peat mining activities. This has reduced the effective size of the footprint for the wetland, therefore subjecting large parts of the wetland to dehydration and desiccation that resulted in destruction by fire. Mining and dumping of peat have exacerbated the occurrence of fires in the peripheral areas of the wetland. Peat fires occur annually (Potgieter, pers. comm., 2004) and layers of ash occur in the upper portions of the peat, indicating recent desiccation.

Peat mining activities have created a system with open water and a maze of entrance roads into the wetland (Figure 57, Appendix 6). Adjacent agricultural activities, diamond diggings and mining entrance roads to the wetlands have exacerbated the proliferation of alien invasive plants spreading into the wetland especially via the access roads into the wetland.

The Gerhard Minnebron Wetland is dominated by very dense mono-specific stands of tall emergent reeds and some sedges (*Phragmites australis* and *Carex* spp.), which do not support a high species richness. The Gerhard Minnebron Wetland could support a larger abundance and diversity of species.

4.5.3 Vankervelsvlei Peatland

Study area location

Vankervelsvlei is located close to the coast approximately 8 km east of the town of Sedgefield in the Western Cape. The catchment is fairly steep with slopes varying between 11% and 33% comprising deep sandy soils. The land use is predominantly commercial plantation. Figure 21 indicates the location of Vankervelsvlei (top) with an enlarged view (bottom), where the blue polygon indicates the boundaries and the green polygon the catchment of the wetland system.

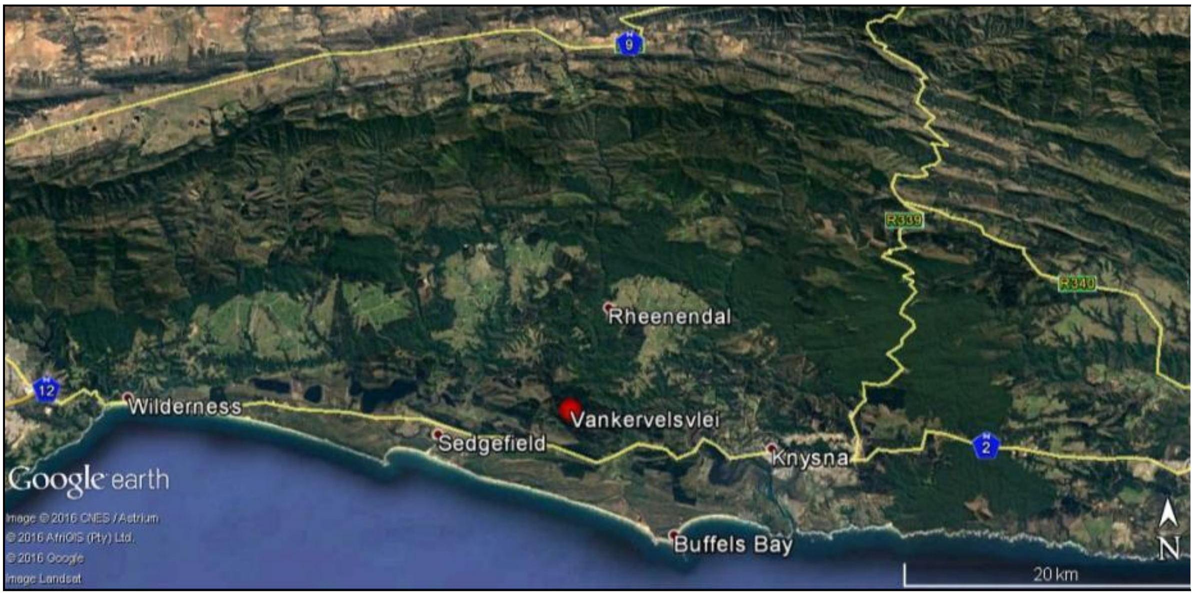


Figure 21: Location of Vankervelsvlei

Wetland characteristics

The area is underlain by rocks of the Peninsula Formation of the Table Mountain Group, but the depth of this fractured aquifer system is not known. An extensive area of quaternary aeolian sands in the form of a series of fossilised dunes characterise the catchment. Vankervelsvlei is an interdunal depression, approximately 31 ha with no discernible slope. The wetland is in the upper reaches of the catchment.

Irving (1998) proposes that Vankervelsvlei follows the model of a lake transitioning into a terrestrialising system over the past 40 000 years. Quick (2013) suggests that Vankervelsvlei originated as an open water near-coastal back barrier lake, formed at some time after the coastal dune cordon's stabilisation 300 000-400 000 years ago. It persisted as an interdunal wetland in response to solution of interstitial calcium carbonate creating an impermeable base layer (Irving & Meadows, 1997). Fine clays in the lowermost sample cores suggest a time before organic soils began to accumulate, possibly extensive drier phases where the wetland may have been covered in wetland vegetation. During subsequent wetter phases into the Holocene, the impermeable clay layer facilitated accumulation of overlying organic material in a permanently inundated lake setting, gradually transitioning to coarser peat closer to the present-day surface layers, as vegetation covers the entire lake surface.

The peatland is 22 ha in extent (70% of the larger wetland extent of 31 ha), with an average peat thickness of 7 m (peat maximum 12 m thick) in the southern part. The inferred peat volume for the system is 1 540 000 m^3. The peat is mostly a sphagnum floating mat on surface with fibrous below and finer grained peat and gyttja layers in depth. The value in this system is not so much in its size or the significant amount of peat, but in its irreplaceability as it is the thickest peat system in the country. Spanning both the Holocene and Late Pleistocene, it represents an important ecological archive.

The wetland is surrounded by mature plantations of *Pinus,* with several short windbreaks of the Australian genus *Eucalyptus* also present. The small collection of houses (Keurvlei) on the south-western edge of the wetland was populated in 1992, but by 1996 appeared derelict and deserted (Irving, 1998). The area is restricted to the public since it forms part of a commercial plantation. Entry is attained by special permission only. The peatland is largely undisturbed, except for a small area of side seepage that is entirely planted with pine trees.

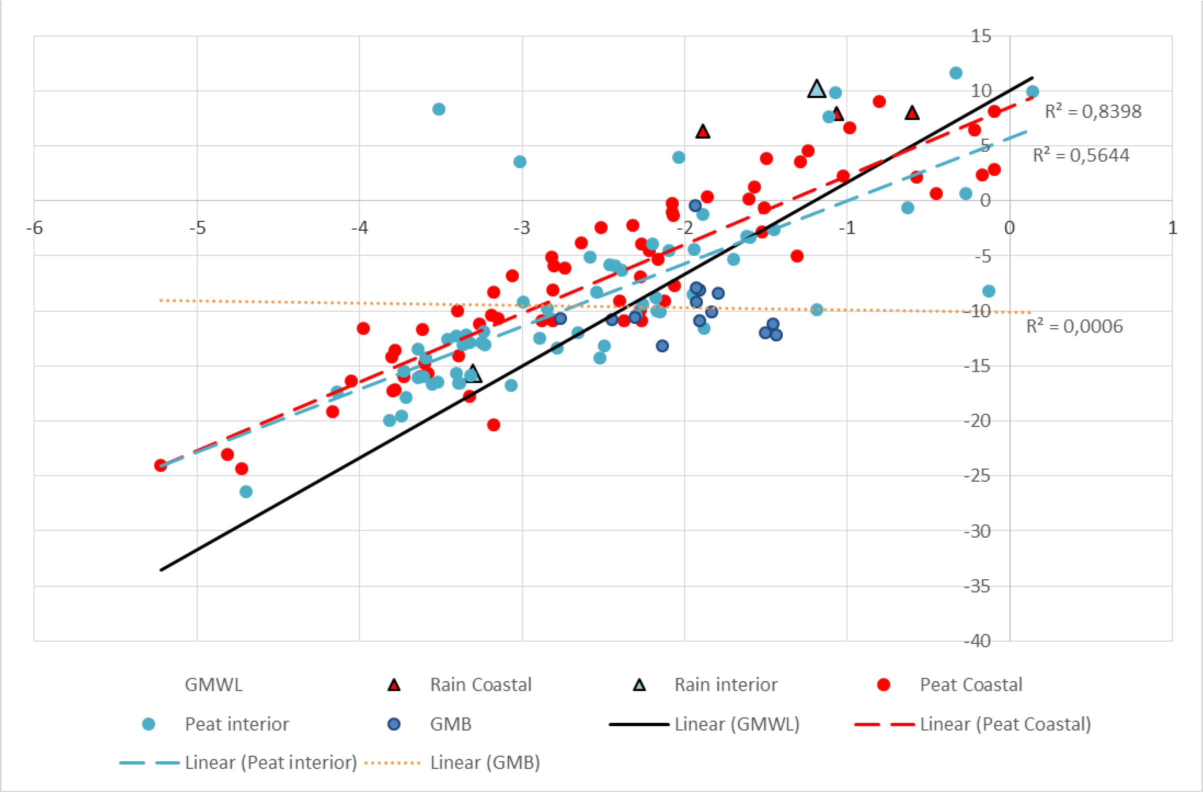
4.6 Isotope Studies: Determining Water Source and Flow Paths

Studies such as Grundling et al. (2014) of the surface and groundwater exchanges of wetlands in southern Africa indicated that in semi-arid environments, wetlands are likely to maintain internal ecosystem processes rather than regulating stream flow to downstream ecosystems. However, the links between the primary hydrological (rainfall, evapotranspiration, inflow and outflow) components are not clear from hydrological investigation. Isotopic analyses can be used to improve the interpretation and verification of the feedbacks between rainfall, evaporation, groundwater and surface flow of peatlands in South Africa. Studying the stable isotope composition of various hydrology components of a peatland provides insight into the feedbacks between rainfall, evaporation, groundwater and surface flow through the system.

4.6.1 Isotope analyses

Water samples were collected from the eight selected study sites. Piezometers were used to sample the water within the peat at various depths. Streams and pools were used to sample surface water and where possible boreholes in the catchment were accessed to sample groundwater. Rainwater sampling was restricted as fieldwork mainly took place in winter.

The isotope values show a clear grouping between coastal peatlands (red dots) and those of the interior (light-blue dots) (Figure 22). The coastal peatlands plotted higher (red line) on the diagram than the peatlands from the interior (blue line) relative to the global meteoric waterline (black line). This is most likely due to the more arid climate of the southern African interior compared to the wetter southern and eastern coastal areas. Furthermore, the peatlands of the interior plot more abandoned to the left part (blue line) of the diagram because of the cooler higher altitude inland effect on isotope fractionation. The coastal peatlands represented in the lower (left) groupings relatively to the rest represent the southern Cape peatlands within the cooler higher latitudes of southern Africa. Water from both the coastal and interior peatlands indicate a strong evaporation signature (red and blue dashed lines) indicating that evaporation could be a significant flux of water out of these ecosystems in South Africa.



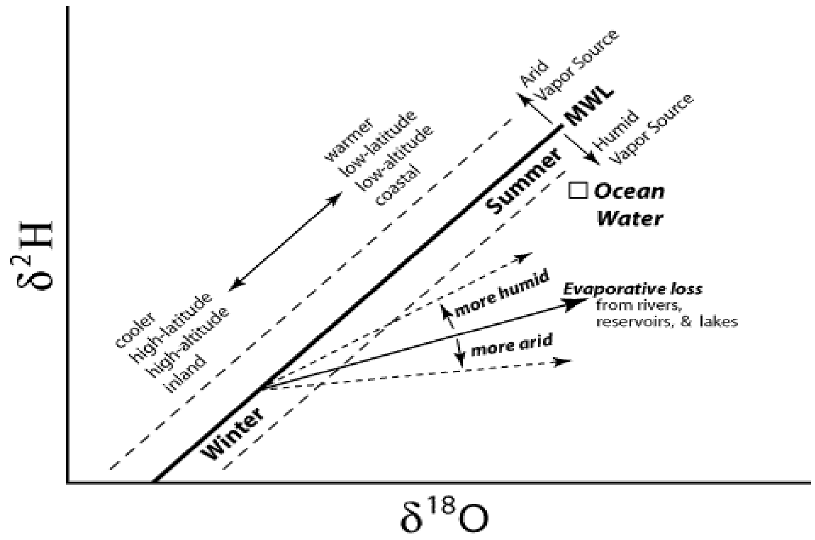


Figure 22: Isotopic signatures (δ2H and δ18O) of rainfall, streamflow, surface water and groundwater indicate a distinct grouping between water from coastal and interior peatlands

Legend: GMWL: Global Meteoric Water Line; GMB: Gerhard Minnebron

The stable isotopes supported the hydrogeological evidence and illustrated the longer term persistence of the hydrological functions of peatlands. Groundwater discharging at peatlands, shallow subsurface flows and flow across the peatland surface are all mechanisms that maintain the wetness of peatlands and therefore maintain peatland integrity. The isotope signatures of the peatlands in both the interior and coastal regions strongly suggest that the source for its sustained base flow is groundwater discharging in the wetlands; therefore, reiterating the importance of conserving groundwater recharge areas for peatland protection.

4.7 Peatland Age: Onset of Peat Formation and Accumulation Rates

Mires are actively peat-accumulating wetland systems. They have expanded globally in the Holocene, especially during the last 7000 years. South Africa has a limited number of peatlands that are mostly smaller in extent than the cooler temperate regions in the northern hemisphere. The current drought in the region and associated peat fires bear testimony to the vulnerability of these ecosystems to the variability in our climate patterns ranging from drought-induced peat fires in the tropical coastal plain to intense downpours causing erosion in the palmiet peatlands of the Cape Fold Mountains in the southern Cape. Are peatlands in these conditions sequestering carbon or have they become a source of carbon contributing to climate change? This study presents the results of ^{14}C dating analyses of various peatlands in South Africa ranging from the Late Pleistocene aged Mfabeni Mire on the Indian seaboard to the to the Early Holocene mires of the high plateau interior of South Africa. Accumulation rates within various peat profiles are compared to determine when these systems commenced and whether these systems are still accumulating peat.

4.7.1 Onset of peat accumulation

During this study, the 50 previously dated peatland sites were considered (Table 29, Appendix 5). An additional seven peatlands were dated as part of this research. Peat accumulation during the past 50 000 years indicates variable conditions favouring peat formation in the Late Pleistocene and Holocene with a significant gap from 35 000 to 15 000 years BP. This gap is most likely linked to the colder and drier conditions of the last glacial maximum. Furthermore, during this time, many southern African rivers experienced incising. Consequently, many peatlands could have been eroded during this period. The Holocene was notably a favourable period for peat accumulation, both on the coast and the interior. The period of about 5000 year BP is significant (*Figure 23*).

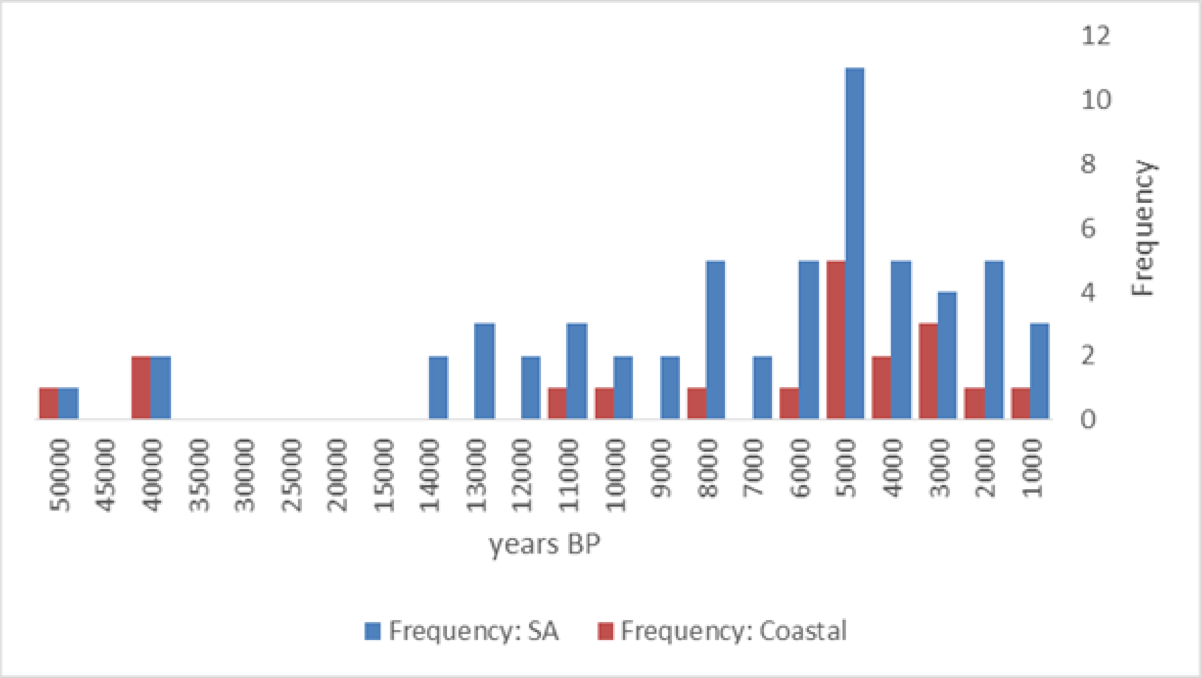


Figure 23: Peat accumulation during the past 50 000 years indicate more favourable conditions during the Middle Holocene

Plotting the dates against elevation clearly shows that coastal areas were more favourable for long-term peat accumulation (*Figure 24*). Another interesting feature is that the southern African landscape between about 200 m to 1300 m a.s.l. (Figure 25) does not favour peat accumulation. This is most likely related to the steepness of the great southern African escarpment and the associated steep drainage lines. Accumulation in the Lesotho Alpine mires (>2850 m) are evident – towering above the South African plateau (1800 m).

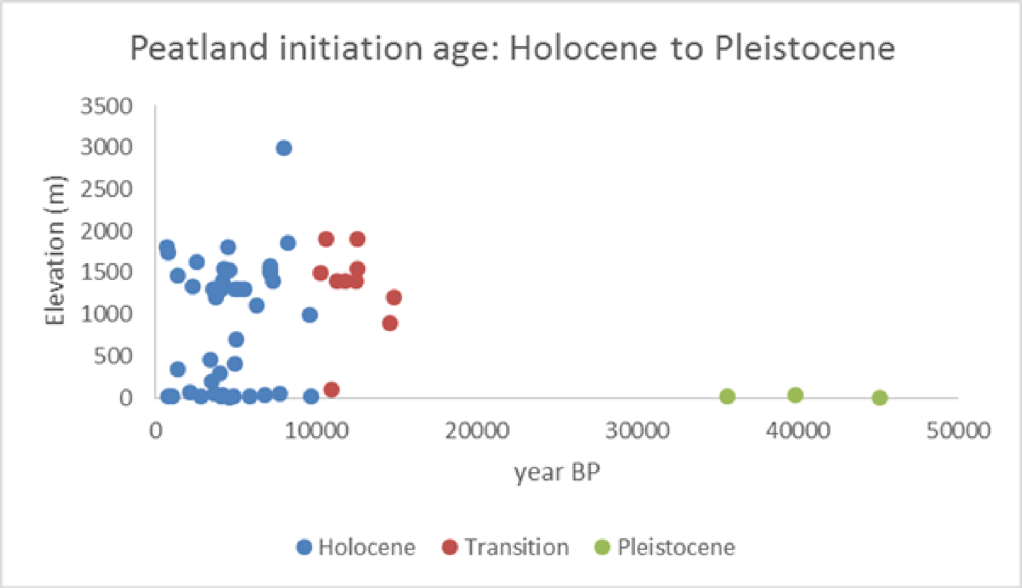


Figure 24: Peat accumulation in South Africa spanned from the Late Pleistocene to the Holocene at the coastal areas with accumulation in the interior only starting towards the Holocene.

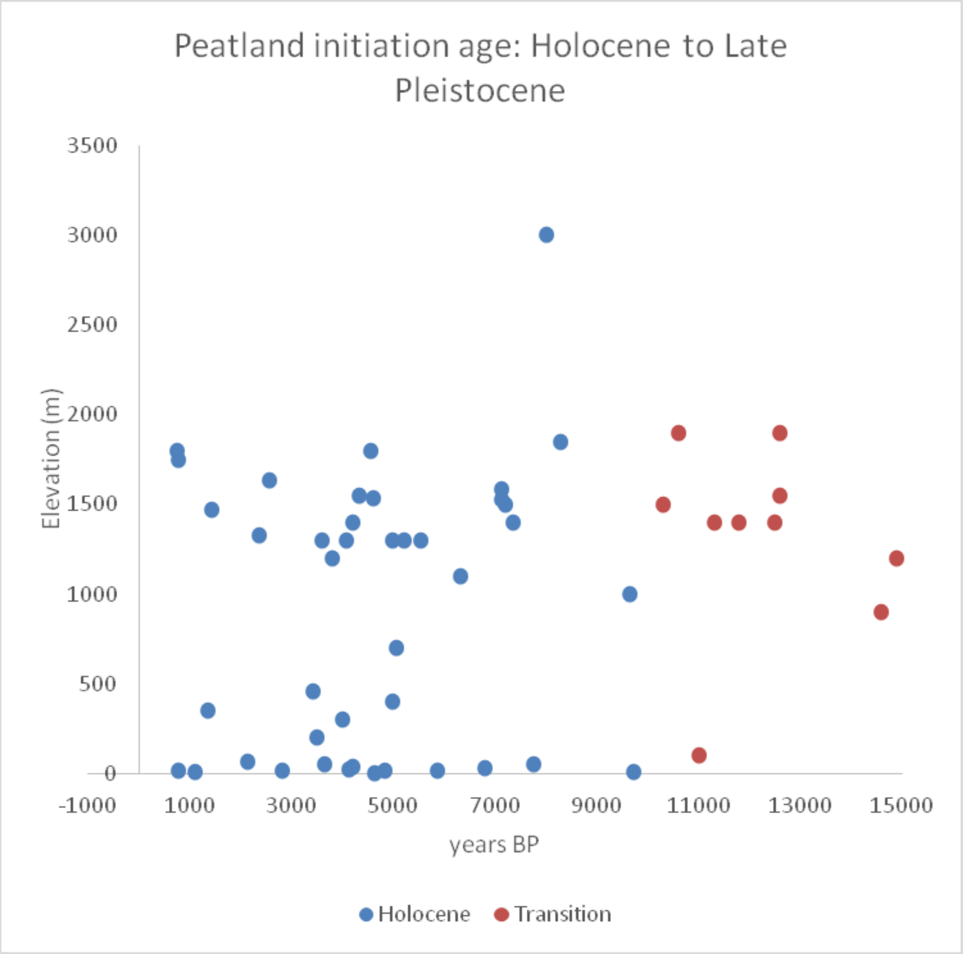


Figure 25: Peat accumulation is more common in the coastal areas and the inland plateau and mostly absent from 200 m to 1300 m a.s.l.

4.7.2 Chronology and accumulation rates

The chronological development of the investigated sites showed a difference in peat-accumulation trends. It is apparent that various peat-accumulation phases existed in southern Africa and in different settings. The Vazi and Marakele systems are two examples representing these differences. The $\delta^{13}C$ values for Vazi show that most samples consist of remnants of plants with the C3 pathway. These have average values of $\delta^{13}C = -24‰$ (O'Leary, 1981). Others represent plants with C4 or CAM ("Crassulacean Acid Metabolism") pathways from −10 to −20‰-, which indicate more severe conditions for accumulation (Hatté & Schwartz, 2003). Vazi North started accumulation almost 8500 Cal BP, with a total thickness of 8 m. This period is close to the most moisture period as derived from pollen studies (Scott, 1989; 1993). The stratigraphy alternates between gyttja, peat lenses, gyttja-peat mix and fibrous peat, later on amorphous peat.). Hence, the $\delta^{13}C$ values show an enrichment signature with slower accumulation rates and more C3 type with faster ones.

The accumulation rate (~4 mm/yr) in the Vazi Pan system between 2885 Cal BP and 2800 Cal BP is relatively high, but it matches estimations (not measured) in older studies of peat dating in Maputaland (Thamm et al., 1996). This range within the Vazi Pan contains the best-preserved peat with (H<3 according to the Von Post classification). During the same period, Vazi North accumulated a mix of peat-gyttja at its highest rate of accumulation (2.17 mm/yr). This again shows the close relationship between the accumulation rates of peat on one hand and the groundwater table height relation to the topographic position on the other hand.

The Vazi Pan has a different pattern of accumulation as appeared from the cores made while sampling. It shows sand layer at the bottom overlaid by gyttja, fibrous peat and amorphous peat respectively. A possible interpretation is the height difference of the topography in Vazi North versus the Vazi Pan. Under high-water table conditions, Vazi North allowed the accumulation of gyttja in open water bodies (Heathwaite et al., 1993). Meanwhile, the Vazi Pan started gyttja accumulation in open water at ~3650 Cal BP, giving room to peat accumulation under the water table only at the surface. Vazi North, which is located at a lower altitude, had a different pattern of accumulation at this same time, accumulating gyttja when the Vazi Pan accumulated its fibrous peat.

The radiocarbon dates show that the Matlabas Mire development took place during the Holocene. The oldest age (5120 Cal BP) is on the south-eastern part. The western section of the Matlabas Mire, which is located on a higher elevation, has almost the same age as the ones of the valley bottom (transect B). The $\delta^{13}C$ values of the deep samples at both wetland sections all show C4 plant types. Though in the vertical profile of B, the top samples show C3 plant type. The C3 plant types are similar to the ones in the temperate areas; the C4 ones representing more arid conditions (O'Leary, 1981; Scott, 2002). Therefore, the change in the $\delta^{13}C$ values could refer to more recent wetter conditions, at least in the middle of the eastern section (Hatté & Schwartz, 2003).

4.8 Conclusion

The term *mires* is defined as active peat-accumulating wetlands. A copious supply of water and anaerobic conditions for the accumulation of organic material in a stable environment are the optimum peat-forming conditions. Eight case study peatland sites were selected to represent different hydrogeomorphic settings, geology and climatic conditions as well as land use such as conservation, agriculture, forestry, urbanisation and rural communal land. Seven provinces, which excludes the Free State and Northern Cape, are represented with the case study selection. The peatland case study sites are Malahapanga, Lakenvlei, Vazi, Matlabas, Colbyn, Gerhard Minnebron, Vankervelsvlei and Kromme.

The purpose of the in-depth study of these peatland sites was to understand the processes and environmental factors driving these unique systems. The results of this chapter contribute to the existing knowledge of peatlands in South Africa. The diversity of peatlands in the country as well as the main characteristics that can be expected is established through the in-depth investigation of eight case studies. The processes responsible for peat accumulation are studied by isotope analysis, carbon dating and water flow measurements.

Although general environmental factors for peatland occurrence include mean annual precipitation that range from 500 to 1180 mm/yr, elevation between 50 m and 1900 m a.s.l. and evaporation rates as high as 2200 mm/yr, the research findings confirm that peatlands in South Africa are groundwater-dependent ecosystems that occur in the wetter eastern and southern parts of South Africa. Isotope analysis and water flow measurements results support the fact that groundwater is the main driver. Peatland condition and productivity emanate from its hydrological response, which is not dependent on rainfall or elevation, but rather on the depth to water table, and the regional and local hydrogeology (and in some cases, rainfall events).

Peat-accumulation rates for South African peatlands range from 0.5 mm/yr to 2 mm/yr, with ^{14}C ages ranging from 3000 years to 45 000 years. Extensive peat loss is evident both through the erosion of peatlands and the occurrence of peat fires. This is mainly caused by anthropological pressures on and mismanagement of these systems.

Mires provide valuable ecosystem services to an increasing population demand. Destruction of peatlands and mires threatens the water and food supply for large rural and urban populations, and results in a range of ecological and social (mostly health-related) problems. Destroyed peatlands lead to a large-scale degradation of the ecological integrity of the catchment. Baseline management recommendations for the case study sites, which can be used as a basis for the management of most peatlands in South Africa, are contained in Appendix 7.

5 THE SOCIO-ECONOMIC VALUE OF PEATLANDS IN SOUTH AFRICA

J. Mulders, J. Crafford and K. Harris (Prime Africa Consultants)

5.1 Introduction

As natural features in the landscape, ecosystems provide environmental, social and economic benefits to associated communities. The value of ecosystems in providing these ecosystem services are becoming increasingly evident. There is a growing recognition of the importance of the services delivered by freshwater ecosystems to human well-being. Peatlands are one such ecosystem, representing a third of wetlands worldwide contributing a range of ecosystem services (Parish et al., 2008). The most pronounced services being biodiversity conservation, water quality and climate regulation (Millennium Ecosystem Assessment, 2005).

Peatlands function as major stores of atmospheric carbon contributing to the regulation of climate change. The global carbon stored in peat is estimated to be in the order of 500 billion tonnes (Strack, 2008), meaning that peatlands contain over 30% of soil carbon worldwide. They can also sequestrate atmospheric carbon. Given the current extent of peatlands, the global sequestration rate is estimated at 100 million tonnes per year (Strack, 2008). This makes peatlands the most important natural ecosystem in terms of climate regulation (Joosten & Clarke, 2002; Frolking et al*.,* 2006; Parish et al., 2008). The impact of accelerated atmospheric carbon on global climate patterns has amplified the importance of the carbon sequestration and storage ability displayed by peatlands.

Additionally, peatlands have an enhanced ability to provide existing wetland ecosystem services due to the presence of peat. These include services such as the support of habitats and biodiversity (Phillips, 1990; Yule, 2008), water purification and waste assimilation (McCarthy & Venter, 2006), and a source of paleo-environmental data (Godwin, 1981).

These systems are under threat globally with land transformation in the forestry, agricultural and mining sectors already having destroyed 25% of peatlands (Parish et al., 2008). Peat is extracted commercially worldwide by various industries. The annual extraction of peat results in a loss of approximately 4 million tonnes of carbon per year (Paappanen et al*.,* 2006). The destruction of peatlands results in a loss of ecosystem services as well as a subsequent release of stored carbon into the atmosphere.

The value of the services provided by South Africa's peatlands has never been determined. It is important to firstly understand what, how and where peatland ecosystem services are supplied to be able to identify the socio-economic value provided by South African peatlands. The value of the service provided by these systems needs to be understood to ensure that they are sustainably utilised and managed.

5.1.1 Aim

The aim of this study was to demonstrate the socio-economic value of peatlands in South Africa based on the concepts of ecological infrastructure and ecosystem services delivered (including carbon sequestration, other regulating services, provisioning services and cultural services). Understanding the relationship between the socio-economic climate and the contribution by ecosystem services by route of market value linkage, allows for better decision-making that will stimulate the benefits received by peatlands rather than limit them.

Peatland ecosystem services

The unique combination of geomorphologic, hydrologic and vegetative characteristics provides for the ecological infrastructure present in a wetland allowing it to provide a range of ecosystem services. These ecosystem services are real benefits provided to people and the economy.

The Millennium Ecosystem Assessment (2005) Framework and The Economics of Ecosystems and Biodiversity (TEEB) Assessment classify ecosystem services into four broad categories, namely, supporting (denoted by the support service provided by habitats in TEEB (2013)), regulating, provisioning and cultural services. The supporting and regulating services produced by wetlands originate from the role of wetlands in the biogeochemical cycling and storage of nutrients, organic material and metals and its role as a sink or a source of these compounds depending on the wetland's state and oxygen levels. Sediments are also retained by wetlands. Normal hydrological flux within a wetland and wetland functioning, therefore, have great value in the control of water quality and erosion (Kotze et al., 2009).

5.1.2 Ecological infrastructure

The SANBI (2014) defines ecological infrastructure as a naturally functioning ecosystem that delivers valuable services, such as healthy mountain catchments, rivers, wetlands, coastal dunes and nodes, and corridors of natural habitat, to people. Together these services form a network of interconnected structural elements in the landscape. This results in ecological infrastructure being seen as an asset, which is the source of a variety of valuable services. Ecological infrastructure is the natural version of manmade infrastructure and is the platform on which services are provided. The same way a water pipe and plumbing deliver water to a home, so do streams, rivers and waterways supply water to downstream areas. It is the presence of ecological infrastructure that is crucial for the delivery of ecosystem services.

Following the common approach to asset valuation, the value of ecological infrastructure would be equal to the discounted value of all ecosystem services produced into perpetuity.

5.1.3 Risks to peatlands

Peatlands are globally under threat with current peat stocks declining by 0.02% per year (Joosten, 2012) with the agricultural, mining and forestry industries having already destroyed 25% of peatlands (Parish et al*.,* 2008). In addition to losing a valuable provider of a variety of ecosystem services, the destruction and degradation of peatlands result in a release of the carbon stored within them. Through various impacts to peatlands, they lose their natural ability to produce and maintain peat stocks.

Through extensive water extraction and draining of wetlands, peat is exposed to air, which allows the decomposition (mineralisation) process of the organic material present in peat to continue. This process releases stored carbon in the peat transforming the peatland into a source rather than a sink of atmospheric carbon. The drying of peat makes it vulnerable to burning, which further releases carbon at an increased rate. The clearing and burning of various peatlands in South-east Asia alone, may have already contributed as much as 3% of global human induced carbon emissions (Ballhorn et al., 2009). Unsustainable or the inefficient extraction of peat for the horticultural and energy industries may result in damaging peatlands, which influence their integrity as service providers. The extraction also exposes the peat to oxygen, thus further contributing to carbon emissions. Peat stocks worldwide contain approximately 500 billion tonnes of carbon, which is equivalent to 30% of all soil carbon globally (Strack, 2008). The release of this carbon through improper peatland management will result in a significant contribution to atmospheric carbon levels.

South African peatlands are under pressure from various threats. These include alterations to water courses and the water table, peat fires, peat extraction, infrastructure development, sewage, acid mine drainage, forestry and cultivation.

A reduction in the water table may cause peat to be exposed to air. This causes increased decomposition and/or increased vulnerability to burning. Because of a drop in the water table from extensive water abstraction, the Vazi Pan in KwaZulu-Natal has lost extensive amounts of its peat due to fires occurring over the past two decades (Grundling & Blackmore, 1998). Land use impacts at the Gerhard Minnebron Peatland in North West Province have caused major changes to the wetland's hydrology (Grundling et al., 2015a). The construction of dams upstream of the Schoonspruit and Rietfontein Peatlands in Gauteng has altered the hydrology of the area changing the peat surface characteristics, which has resulted in extensive burning of the peat that is present (Grundling & Marneweck, 1999).

Infrastructure development, cultivation and forestry are major threats to South African peatlands with land transformation placing pressure on the functioning and integrity of these systems. The Witfontein, Klip River and Rietvlei Peatlands in Gauteng have been affected significantly by infrastructure development, agricultural activities and urban sewage occurring within its functional buffer. Overgrazing and extensive burning regimes may have resulted in the dehydration of the Heddelspruit Peatlands (Grundling & Marneweck, 1999).

Industrial mining and associated waste have affected various South African peatlands with levels of uranium being found in peat samples within the Klip River Peatland in Gauteng (McCarthy & Venter 2006). Acid mine drainage has entered peatlands in Carletonville from associated mines and polluted the peat soils (Keepile, 2010).

The commercial extraction of peat is typically for the horticulture industry (Grundling & Grobler, 2005). There are many local examples of peat extraction for commercial purposes including the Lichtenburg, Schoonspruit, Gerhard Minnebron, Witfontein, Venterspos, Wonderfontein, Tarlton, Vlakfontein, Klip River, Elandsfontein, Rietvlei and Rietfontein Peatlands (Grundling & Marneweck, 1999).

5.1.4 Payments for ecosystem services

Payments for ecosystem services (PES) is an instrument developed for a market approach valuation of ecosystem services. The definition of PES is “a voluntary transaction in which a well-defined environmental service (or land use likely to secure that service) is being ‘bought’ by a (minimum of one) ES [ecosystem services] buyer from a (minimum of one) ES provider if and only if the provider continues to supply that service (conditionality)” (Wunder, 2005). This means that the custodians or land owners of the ecosystems responsible for providing the ecosystem services should be paid for the service provided.

This is an innovative approach to nature conservation that includes a variety of arrangements through which the beneficiaries of environmental services reward those whose lands provide these services with subsidies or market payments. Arranging payments for the benefits provided by forests, fertile soils and other natural ecosystems is a way to recognise their value and to ensure that these benefits continue well into the future.

PES is a new approach to internalising the positive environmental externalities associated with ecosystem services. It involves financial transfers from the beneficiaries of these services (those demanding them) to others who are conducting activities that generate these environmental services (those supplying them). PES schemes reward people, either with cash or in-kind benefits, to manage their land in ways that will secure environmental services. PES is one type of economic incentive for those who manage ecosystems to improve the flow of ecosystem services that they provide. Generally, these incentives are provided by all those who benefit from ecosystem services, which include local, regional, and global beneficiaries. PES is an environmental policy tool that is becoming increasingly important in developing and developed countries. These payment schemes can be designed and introduced in a context where there are already well-defined and measurable links between a certain activity (or conservation practice) and the quantity and quality of ecosystem services. They can also be introduced in a context where there is a change in conservation practice (such as land use) that will lead to a change *cum* improvement of ecosystem services.

South Africa's peatlands have a potential for a carbon-based PES scheme. For the scheme to be applicable, it is important to establish (1) an ecosystem service beneficiary who has the wherewithal as well as the ability to pay for the ecosystem services; and (2) a practical intervention that can secure the delivery of ecosystem services while achieving biodiversity conservation objectives.

Peatland carbon schemes are increasingly of interest as a carbon offset in exchange for conservation of unique peatland systems. Peatlands are unique and scarce wetland systems with significant carbon storage potential. In a bilateral agreement, a developed country with high carbon emissions may offset carbon, while a developing country may gain valuable revenue for land management and biodiversity conservation.

5.2 Valuation of Peatland Ecosystem Services

5.2.1 Background

The value of ecosystem services provided by peatlands can be expressed using several ways and methods. **Error! Not a valid bookmark self-reference.** lists common ecosystem services and corresponding techniques for valuation. The values can be expressed qualitatively (which cities benefit from which peatlands for water purification or flood control) or quantitatively (the number of people benefitting from clean water). The values can also be expressed in monetary terms (the monetary value of sequestered carbon, avoided cost of water pretreatment and supply, or avoided cost of potential flood damage) (TEEB, 2013). **Error! Not a valid bookmark self-reference.** presents the financial value of services provided by global wetlands (TEEB, 2010; De Groot et al*.,* 2012. It shows the economic benefits arising either directly or indirectly from ecosystem services provided by global wetlands to be in the range from US$86 to US$44 597 per hectare per year.

Table 10: Ecosystem service indicators – useful as quantitative measures of value of nature (TEEB, 2013)

Ecosystem Service	Ecosystem Service Indicator
Provisioning Services	
Food: Sustainably produced/harvested crops, fruit, wild berries, fungi, nuts, livestock, semi-domestic animals, game, fish and other aquatic resources etc.	Crop production from sustainable (organic) sources in tonnes and/or hectares Livestock from sustainable (organic) sources in tonnes and/or hectares Fish production from sustainable (organic) sources in tonnes live weight (e.g., proportion of fish stocks caught within safe biological limits)
Water quantity	Total freshwater resources in million m^3
Raw materials: Sustainably produced/harvested wool, skins, leather, plant fibre (cotton, straw etc.), timber, cork etc.; sustainably produced/harvested firewood, biomass etc.	Timber for construction (million m^3 from natural and/or sustainable managed forests)
Regulating Services	
Climate/climate change regulation: Carbon sequestration, maintaining and controlling temperature and precipitation	Total amount of carbon sequestered/stored = sequestration/storage capacity per hectare × total area (Gt CO_2)
Moderation of extreme events: Flood control, drought mitigation	Trends in number of damaging natural disasters Probability of incident

Ecosystem Service	Ecosystem Service Indicator
Water regulation: Regulating surface water runoff, aquifer recharge etc.	Infiltration capacity/rate of an ecosystem (e.g. amount of water/surface area) – volume through unit area/per time Soil water storage capacity in mm/m Floodplain water storage capacity in mm/m
Water purification and waste management: Decomposition/capture of nutrients and contaminants, prevention of eutrophication of water bodies etc.	Removal of nutrients by wetlands (tonnes or percentage) Water quality in aquatic ecosystems (sediment, turbidity, phosphorous, nutrients etc.)
Erosion control: Maintenance of nutrients and soil cover and preventing negative effects of erosion (e.g. impoverishing of soil, increased sedimentation of water bodies)	Soil erosion rate by land use type
Cultural and Social Services	
Landscape and amenity values: Amenity of the ecosystem, cultural diversity and identity, spiritual values, cultural heritage values etc.	Changes in the number of residents and real estate values Number of visitors to protected sites per year
Ecotourism and recreation: Hiking, camping, nature walks, jogging, skiing, canoeing, rafting, recreational fishing, diving, animal watching etc.	Amount of nature tourism Total number of educational excursions at a site
Cultural values and inspirational services: Such as education, art and research	Number of TV programmes, studies, books etc. featuring sites and the surrounding area

It is not always possible to value all services, as can be seen in Table 11. The full range of services provided by floodplains, swamps, marshes and peatlands was used for the valuation and thus would not be appropriate to use as a basis for the valuation of peatlands.

Table 11: Economic value of services provided by inland wetlands globally (floodplains, swamps/marshes and peatlands) (TEEB, 2010; De Groot et al., 2012)

Inland Vegetated Wetlands	No. of Used Estimates	Minimum Values (US$ per ha/yr)	Maximum Values (US$ per ha/yr)
Total:	**86**	**86**	**44 597**
Provisioning Services	**34**	**34**	**9 709**
Food	16	16	2 090
(Fresh) water supply	6	6	5 189
Raw materials	12	12	2 430
Genetic resources			
Medicinal resources			
Ornamental resources			
Regulating Services	**30**	**30**	**23 018**
Influence on air quality	?	?	
Climate regulation	5	5	351
Moderation of extreme events	7	7	4 430

Inland Vegetated Wetlands	**No. of Used Estimates**	**Minimum Values (US$ per ha/yr)**	**Maximum Values (US$ per ha/yr)**
Regulation of water flows	4	4	9 369
Waste treatment/water purification	9	9	4 280
Erosion prevention			
Nutrient cycling/maintenance of soil fertility	5	5	4 588
Pollination			
Biological control			
Habitat Services	**9**	**9**	**3 471**
Lifecycle maintenance (esp. nursery service)	2	2	917
Gene pool protection (conservation)	7	7	2 554
Cultural Services	**13**	**13**	**8 399**
Aesthetic information	2	2	3 906
Opportunities for recreation and tourism	9	9	3 700
Inspiration for culture, art and design	2	2	793
Spiritual experience	?	?	
Cognitive information (education and science)	?	?	

5.2.2 Valuation of South African peatland ecosystem services

There is a large gap in literature when it comes to the valuation of South African peatlands. The ecosystem service valuation process therefore takes the approach of demonstrating valuation techniques for each ecosystem services provided. Some of these techniques provide an economic valuation while others provide conceptual methodologies for valuation.

When identifying services provided by peatlands, it is important to recognise the services provided by the wetland as a whole in the absence of peat. A peatland is after all a wetland, and in addition to the peat present, can only function as a wetland if various functional components are present. These components allow a wetland to function as it should to provide ecosystem services and are the foundation on which a peatland can function. It is then important to identify the services that are enhanced as well as additional services by the wetland due to the presence of peat. Identifying the chain of causality between the peat in a peatland and ecosystem services is the key to pinpointing the services provided by peatlands.

Table 12 shows ecosystem services identified that both enhance services provided by wetlands as well as provide additional services due to the presence of peat. The focus throughout the rest of the document will be on the services outlined.

Data availability was a major limitation in this study and the scope did not allow for comprehensive field investigations. The limitations will be discussed further in Section 6.5, which outlines the scope for further research. The demonstration of value relied heavily on available appropriate literature and expert opinion. Ecosystem services specifically provided by peatlands were investigated and the value determination thereof was demonstrated.

Table 12: Peatland specific ecosystem services (MA 2005; TEEB 2013)

Service Type	Ecosystem Service (MA 2005; TEEB 2013)	Description	Valuation Method	Case Study Peatland
Provisioning Service	Products	Goods harvested and sold or used including examples such as peat, fish, grazing, fruits, grains, fuelwoods, logs or soil for agriculture	Market value	Products/ harvested peatlands
	Genetic material	Ecosystems provide for a source of genes for ornamental species, resistance to plant pathogens and the extraction of medicines	Substitutability	Global environmental facility (GEF)
Regulating Service	Hydrological regulation	The regulation of hydrological flows through groundwater recharge/ discharge, buffering extreme events such as droughts and floods through water retention	None	None
	Water purification	Retention, recovery and removal of excess nutrients and pollutants through waste assimilation and purification	Mitigation cost method	Colbyn Valley Wetland; Klip River Wetland
	Climate regulation	Regulation of greenhouse gases (storage and sequestration), temperature, precipitation, and the chemical composition of the atmosphere	Carbon market	Multiple peatlands within peatland ecoregions
Cultural Service	Tourism/ recreation	Opportunities for tourism and recreational activities	Qualitative	None
	Knowledge/ education	Opportunities for formal and informal education and training. For example, the peat archives and carbon dating	Qualitative	Wonderkrater
	Spiritual	Personal feelings and well-being, religious significance, appreciation of natural features	Qualitative	None
Supporting Service	Habitat platform	Habitats provide a support service for biodiversity, thus providing a platform for survival including food, water and shelter for a range of lifecycles	Substitutability	GEF

5.3 Carbon Sequestration

5.3.1 Background and valuation

Carbon sequestration

Atmospheric carbon is captured through the growth of plants and photosynthesis. Dead parts of plants are subjected to decomposition, which under specific conditions such as permanent water saturation (within peatlands), forms peat resulting in a positive carbon balance. Through this process, carbon is sequestrated from the atmosphere in turn contributing to climate regulation. Peatlands worldwide hold up to 450 Gt of carbon (Gorham, 1991), which is just less than half of global forest and soil carbon combined (Dixon et al., 1994). As long as conditions remain stable, carbon will remain stored. However, if the peat is burnt or exposed to aerobic conditions due possible drainage or mining of peatlands, the peat will release CO_2 back into the atmosphere, thus changing peatlands from a sink to a source of this greenhouse gas (GHG).

Climate change

Human activities have increased the amount of GHGs in the atmosphere leading to predicted global warming. Expected impacts include a rise in sea level, increased frequencies and severity of extreme weather events, loss of biodiversity and changes in agricultural productivity. The effects of climate change will have wide societal impacts such as loss of livelihoods of vulnerable communities and an increase in negative health impacts through spread of infectious diseases such as malaria.

Naturally occurring GHGs in the atmosphere include water vapour (H_2O), carbon dioxide (CO_2) and methane (CH_4). CO_2 quantities far exceed other GHG emissions. It is for this reason that GHG impact mitigation focuses on reducing CO_2 releases.

Climate change

Human activities have increased the amount of GHGs in the atmosphere leading to predicted global warming. Expected impacts include a rise in sea level, increased frequencies and severity of extreme weather events, loss of biodiversity and changes in agricultural productivity. The effects of climate change will have wide societal impacts such as loss of livelihoods of vulnerable communities and an increase in negative health impacts through spread of infectious diseases such as malaria.

Naturally occurring GHGs in the atmosphere include water vapour (H_2O), carbon dioxide (CO_2) and methane (CH_4). CO_2 quantities far exceed other GHG emissions. It is for this reason that GHG impact mitigation focuses on reducing CO_2 releases.

Carbon market

CO_2 is the most important contributor to anthropogenically accelerated climate change (IPCC, 2007). This has resulted in the need for CO_2 regulatory mechanisms at an international scale. The emissions trading market was developed through national and international attempts to create measures to deal with global climate change but more specifically limit GHG emissions. The premise is to provide an economic incentive for achieving emissions reductions through emission trading schemes (ETS), which will ultimately reduce the total amount of GHGs worldwide.

One type of ETS is carbon credit, carbon offset or certified emissions reduction. These are all units of measurement that represent the removal of one tonne of CO_2 equivalent from the atmosphere. A credit allows the holder to emit one tonne of CO_2. This allows entities who expect to exceed their emissions quota to purchase carbon credits from other entities. These credits allow for carbon emissions trading and are obtained through activities that remove carbon from the atmosphere (carbon sequestration) or reduce future carbon from being released into the atmosphere. It offsets residual emissions resulting in emissions being carbon neutral.

Carbon tax is a tax levied based on the release of carbon emissions. The tax is typically placed on hydrocarbon fuels and depends on the carbon content of the fuel. These taxes are often used as incentives to use hydrocarbon fuels more efficiently and stimulate renewable energy sources. Carbon taxes are used internationally and vary depending on the policies and objectives of various countries. For example, according to the World Bank Group (2015), international carbon tax prices range from US$130 in Sweden, US$53 in Norway, US$38 in Tokyo, US$27 in the UK, US$15 in France, US$8 in Beijing to approximately US$1 in Mexico.

In South Africa, the proposed carbon tax by the National Treasury is R120 per tonne of CO_2 and is set to increase by 10% per year. This tax is part of the country's solution to move away from a carbon-intensive economy.

5.3.2 Methodology

Overview

The valuation of the country's peatlands in terms of ecosystem services they provide was done in a phased approach. Firstly, the total peat stocks in the country was determined to understand the extent of the resource present. Secondly, the ability of peat as a feature within peatlands to provide specific ecosystem services was determined and valued. Lastly, the value provided by peatlands in South Africa was determined based on the full extent of peat present in the country.

The data required for this investigation was very specific to individual peatlands and was needed at a national scale – meaning the data requirements were extensive. Most South African peatlands had not been investigated comprehensively and much of the required data was not readily available. This meant that for many cases, the study had to be conducted on an inferred level, collecting data at the finest scale possible and applying the corresponding range at a regional scale.

The regions chosen corresponded to the data required in an attempt to reduce variation of results between peatlands within the regions. Peatland ecoregions were ideal for this purpose and were chosen as their delineation is based on characteristics that provided for a similarity in peat-forming conditions (Marneweck et al., 2001). This provided for an appropriate regional unit; especially when investigating peat specific parameters such as peat stocks and accumulation rates.

Data was collected from as many sample peatlands as possible within each ecoregion using appropriate international and local literature. This data was reviewed by peatland experts and a value range was determined and applied to corresponding ecoregions. Where there was a gap in available data, peatland experts were consulted and ranges were determined. This way, data required was inferred across regions to ultimately demonstrate the value of peatlands across South Africa.

Peatland inventory

The South African Peatland Database developed by Grundling et al. (2015a; 2015b) was used as a basis for data collection. It must be noted that the current peatland inventory is a work in progress. Various stakeholders and interested parties were requested to collect data on the distribution of peat, Champagne and high organic soils. This was not a foolproof process and much of the collected data still needs to be verified; this was especially true for the unconfirmed peatland points. It must also be noted that there were gaps in the data, of which inferences were made based on commonalities within a peatland ecoregion.

Soil types within the dataset were separated based on their carbon percentage values. As inferences were made based on data obtained, the resolution of data (especially percentage carbon) was diminished. For example, the literature may describe a specific peatland as having soils with percentage carbon ranging from 10% to 30%. This would include both Champagne (>10%, <20% carbon content) and peat (>20% carbon content) soils making it impossible to separate the two into corresponding volumes. Champagne soils were thus grouped together with peat soils in the investigation.

The remainder of the points found in the inventory were unconfirmed peat and high organic soils and confirmed high organic soils. The unconfirmed soil points were omitted from the study as they displayed major uncertainties relating to the nature of the soil present at the points and much of the data needed to determine carbon stocks at these points was unavailable. These points could realistically be included in the future upon confirmation of the points and increased availability of data relating to them. The high organic soil points were also not included in the investigation. In addition, uncertainties in the local extent of these soils and because many of these points did not fall within wetlands, an investigation of high organic soils fell outside the scope of this investigation, where the focus was specifically on peat soil.

Points classified as peat as well as points displaying a carbon content of greater than 10% were placed within their corresponding peatland ecoregion, and datasets of required values were determined.

The peatland ecoregion map was derived from modelling procedures and was based on the Level 1 ecoregions of South Africa (Kleynhans et al., 2005). Level 1 ecoregions were thus used to classify soils that did not fall into a specific peatland ecoregion. The distribution of the resulting peat soil points across South Africa can be seen in Figure 31 of Appendix 3.

Carbon stock determination

The carbon sequestration and storage ability of peatlands were calculated by determining carbon accumulation per year and carbon stocks respectively using the following formula (Henry et al., 2009; Agus et al., 2011):

$$C_{\text{stock/accumulation}} = V.\%\, C_{\text{org}}.BD$$

Where the variables include:

$C_{\text{stock/accumulation}}$ = Carbon stocks (T)/Carbon accumulation (T/yr)
V = Volume of peat stock (m^3)/Volume of peat accumulation (m^3/yr)
% C_{org} = Percentage organic carbon in peat
BD = Dry bulk density of peat (T/m^3)

Of the peat sites in the database, 516 of the peatlands were identified and investigated by Marneweck et al. (2001). Thus, a large proportion of the data needed for carbon stock determination was available. The peatland inventory contained a large proportion of data needed for many of the points investigated. As for the rest of the points, the variables needed were not necessarily all available in literature and had to be inferred based on data which was available. Experts were consulted throughout this process.

Carbon stock value determination

The carbon stock values were determined using the carbon stocks as well as their accumulation rates. These were used together with the latest carbon pricing proposed for South Africa by the National Treasury.

Limitations

One of the goals of this investigation was getting an accurate account of peat stocks found in South African peatlands. Data limitations did not allow for precise accounting. Thus, the investigation was done on an inferred level. The process was dependent on available data which could be improved, pending an increase in accessibility to more accurate and appropriate descriptive data pertaining to the country's peat stocks.

5.3.3 Results and discussion

Carbon stocks and accumulation rate

Area

Peatland area was one of the more crucial variables as it was used to determine the volume and extent of peat stocks and the volume of peat accumulation per annum. A large proportion of peatland areas was obtained from Marneweck et al. 2001. The remainder of the peat soils was calculated using available literature and desktop mapping techniques including the NFEPA wetland dataset and satellite imagery (Google Earth^{TM}).

Results showed the total national areas of confirmed peat were approximately 30 716 ha. A large proportion of this (66%) was found to be in the Natal Coastal Plain peatland ecoregion.

Depth

Many of the points found within the peatland inventory displayed depths of soils. Depth ranges were obtained from Marneweck et al. (2001) for each of the peat ecoregions. These ranges and averages were inferred for peatlands points of which no depth data could be found.

The results for depth ranged from 0.01 m to 3.59 m with an average of 1.54 m (Table 13).

Volume

The volume range of peat was calculated using the peat depth range and the cumulative areas of peatlands within each ecoregion. The volume of carbon was the product of the percentage soil organic carbon (SOC) and the volume of peat present.

The results for volume of peat in confirmed peatlands ranged from approximately 481 million tonnes to 2500 million tonnes with an average of approximately 612.6 million tonnes (Table 13, columns 8, 9 and 10).

Carbon content

Carbon stock determination was based on the percentage of SOC. Data for percentage SOC for various peatlands within the peatland ecoregions was obtained from various sources including literature and expert consultations (Smuts, 1997; McCarthy & Venter, 2006; McCarthy et al., 2010; Baker et al., 2014; Lindstrom et al., 2014; Kotze, 2015). Where applicable, percentage soil organic matter (SOM) was converted to percentage SOC by applying the Van Bemmelen Factor (Van Bemmelen, 1890):

$$\%SOC = \%\ SOM/1.724$$

Where:

%SOC = Percentage soil organic carbon
%SOM = Percentage soil organic matter

The peatland inventory contained limited data on percentage carbon. Where data was not available in literature, workshops and consultations were held with experts. During this time, data obtained from relevant literature was reviewed to ensure its appropriateness.

The total range for carbon content for confirmed peat showed the minimum of 10% and the maximum found was approximately 60% (Figure 26).

Bulk density

The bulk density of soil is degree of compaction of soil and is a measure of the dry weight per unit volume. The bulk density of a soil increases with increasing depths as it becomes more compacted under increased weight. Bulk density also has a negative relationship with the amount of organic material in the soil; with increasing SOM there is a decrease in dry bulk density (Avnimelech et al., 2001; Perie & Ouimet, 2007; Erdal, 2012; Chaudhari et al., 2013).

Bulk densities were determined using values based on work done by Grundling et al. (2015c) in the Colbyn Valley Wetland in Pretoria, South Africa. Bulk densities and percentage SOM were determined along various transects in the peatland. These values were plotted against each other and the exponential trend line with $R^2 = 0.5751$ was obtained (Figure 26). The trend line equation for increasing percentage SOM against dry bulk density was:

$$Y = 0.5986e^{-0.025(\%\ SOM)}$$

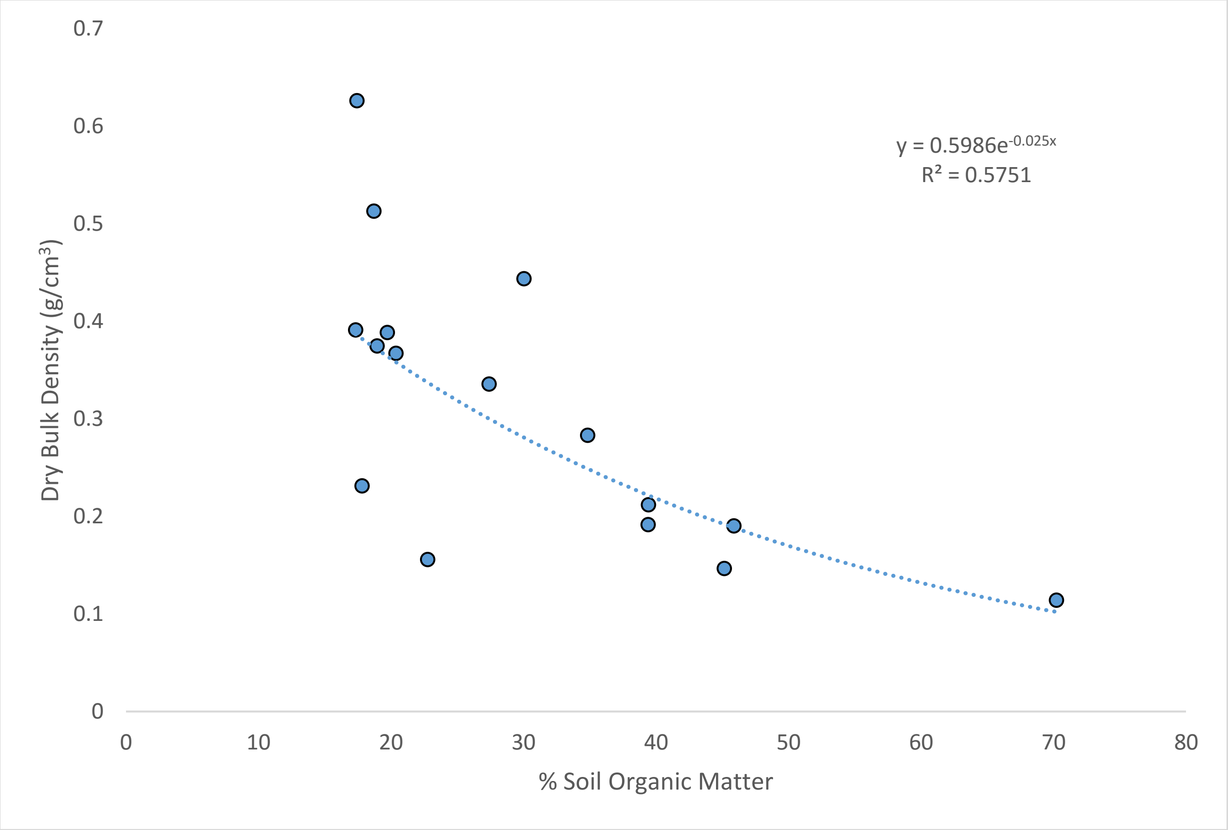


Figure 26: Percentage SOM and dry bulk density (g/cm^3) of peat in the Colbyn Valley Wetland

Figure 27 illustrates the general trend of bulk density based on increasing percentage SOM. The equation was used to infer bulk density values for corresponding percentage SOM determined for the various peatland ecoregions.

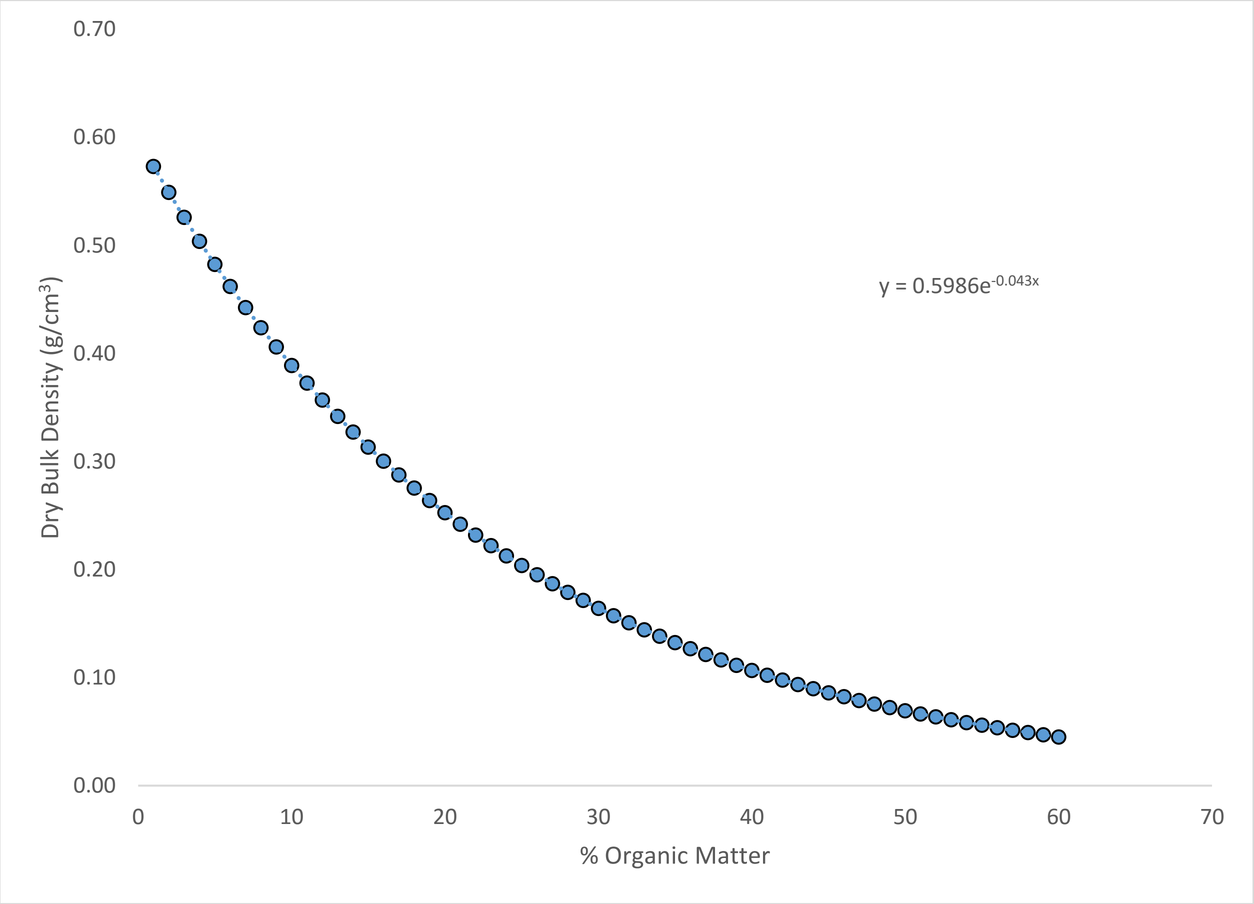


Figure 27: Percentage SOM and dry bulk density (g/cm^3) as inferred by results obtained from peat in the Colbyn Valley Wetland

Results showed bulk densities to range between what is expected of soils with SOC greater than 10% but less than 60%. The range had a low of 0.05 T/m^3 and a high of 0.39 T/m^3 (Table 13, columns 14, 15 and 16).

Table 13: Summary data for South African peat points within peatland ecoregions including physical characteristics such as extent, depth, percentage carbon, with corresponding volumes and accumulation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ecoregion	**Area**	**Depth (m)**			**% Carbon**			**Volume Peat (m^3)**			**Volume Carbon (m^3)**			**Bulk Density (T/m^3)**		
	(m^2)	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**
Bushveld Basin	27 000	0.40	0.40	0.40	10	45	34	10 800	10 800	10 800	1 080	4 860	3 672	0.09	0.39	0.14
Cape Folded Mountains	4 644 000	0.15	0.15	0.15	10	41	26	2 317 100	12 503 100	6 715 600	231 710	5 126 271	1 746 056	0.10	0.39	0.20
Central Highlands	25 643 277	0.50	4.50	1.10	10	36	22	12 942 185	114 581 561	27 933 993	1 294 229	41 249 087	6 424 686	0.13	0.39	0.23
Eastern Coastal Belt	678 000	0.40	4.00	2.57	20	60	40	271 200	2 712 000	1 742 460	54 240	1 627 200	696 984	0.05	0.25	0.11
Eastern Uplands	14 050 396	0.60	1.90	1.25	10	40	25	8 431 198	26 683 198	17 557 198	843 122	10 671 122	4 388 222	0.11	0.39	0.20
Ghaap Plateau	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Great Escarpment Mountains	9 909 227	0.01	2.00	0.66	10	32	14	7 256 987	19 169 128	12 212 438	799 225	6 112 040	2 554 598	0.15	0.39	0.27
Great Karoo	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Highveld	28 640 132	0.40	5.75	3.59	18	41	27	25 256 053	162 430 759	88 843 580	4 546 090	66 596 611	23 987 767	0.10	0.28	0.19
Limpopo Plain	110 000	1.40	2.40	1.93	10	20	15	154 000	264 000	212 300	15 400	52 800	31 845	0.25	0.39	0.31
Lowveld	10 615 024	0.30	3.50	1.43	10	20	14	3 196 687	37 089 615	18 872 166	319 669	7 416 923	2 830 325	0.25	0.39	0.32
Nama Karoo	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Natal Coastal Plain	202 300 000	2.00	10.00	2.03	12	52	32	404 600 000	2 023 000 000	410 669 000	48 552 000	1 051 960 000	131 414 080	0.06	0.36	0.15

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ecoregion	**Area**	**Depth (m)**			**% Carbon**			**Volume Peat (m³)**			**Volume Carbon (m³)**			**Bulk Density (T/m³)**		
	(m²)	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**	**Low**	**High**	**Avg.**
Southern Coastal Belt	10 543 946	0.60	10.20	1.83	24	48	35	9 575 838	97 799 838	20 879 538	2 298 201	46 943 922	7 307 838	0.08	0.21	0.13
Southern Kalahari	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Western Coastal Belt	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	**307 161 002**							**474 012 047**	**2 496 243 999**	**605 649 072**	**58 954 965**	**1 237 760 835**	**181 386 072**			

Carbon stock

Carbon stocks were determined based on the equation described in the previous section using results obtained in this section. The total carbon stock in South African peat soils falls between approximately 4.2 million tonnes and 431.5 million tonnes with an average of 29.5 million tonnes (Table 14).

Table 14: Carbon stock range (T) of peat soils within peatland ecoregions in South Africa

Peatland Ecoregion	**Carbon Stocks in Peat Soils**		
	Low	**High**	**Avg.**
	T	**T**	**T**
Bushveld Basin	93	1 891	508
Cape Folded Mountains	23 694	1 994 148	340 820
Central Highlands	164 201	16 046 122	1 427 178
Eastern Coastal Belt	2 446	411 354	74 411
Eastern Uplands	90 216	4 151 125	894 412
Ghaap Plateau	–	–	–
Great Escarpment Mountains	123 116	2 277 090	620 026
Great Karoo	–	–	–
Highveld	464 871	18 351 146	4 484 748
Limpopo Plain	3 893	20 539	9 986
Lowveld	80 948	2 885 224	887 643
Nama Karoo	–	–	–
Natal Coastal Plain	3 090 317	375 421 234	19 806 132
Southern Coastal Belt	173 803	9 988 077	967 815
Southern Kalahari	–	–	–
Western Coastal Belt	–	–	–
Total	**4 217 598**	**431 547 949**	**29 513 679**

Accumulation rate

Peat-accumulation rates are typically determined through two methods, namely, carbon dating and pollen analysis. Both rely heavily on the depth of the peat at the point of sampling. It is this reliance on depth that is risky for inferring accumulation rates for peatlands. Derived rates can be over- or underestimated depending on changes to the thickness of peat due to impacts from various events during peat formation. Siltation events, for example, may occur at various points during the peat formation process. This results in foreign layers of non-peat material within the peat profile. These layers increase the thickness of the peat and result in a false rate of accumulation resulting in an over estimation. Examples of this is the Matlabas peatland in the MNP and the Wakkerstroom Peatland (Grundling & Marneweck, 1999).

On the other hand, a reduction in the water table may cause peat to subside becoming more compact. Exposing the peat to air may reduce its thickness due to decomposition action or burning. This will result in an underestimation of the accumulation rate of peat. An example of this is at the Vazi North Peatland where due to a severe drop in the water table, approximately 50 cm of peat has been lost (Grundling et al., 2015c). The Vazi Pan has lost extensive amounts of its peat due to fires occurring over the past two decades (Grundling & Blackmore, 1998. Land use impacts over the last 50 years at the Gerhard Minnebron Peatland have caused major changes to the wetland’s hydrology. Ash layers have been found in the peat profile, which indicate either historical burning of the peat or recent subsurface fires (Grundling et al., 2015a). Examples of similar ash layers found in peat profiles are the Schoonspruit, Witfontein South (Grundling & Marneweck, 1999) and Majiji (Grundling, 2000) peatlands.

These events may have occurred throughout the formation of peatlands in the country and have more than likely been relatively specific to various peatlands. This would result in a variety of peat profiles seen between peatlands, even within common peatland ecoregions making regional inferences on peat-accumulation rates problematic.

Experts were consulted about accumulation rates for the various peat ecoregions. For the reasons stated above (for the most part), the conclusion was to use relatively general accumulation rates in the analysis. It was decided that a rate of 1 mm/yr for coastal and 0.5 mm/yr for inland peatlands would be used based on accumulates in Grundling et al. (1998) and Grundling and Marneweck (1999).

Carbon accumulation per year was determined based on the equation described earlier using results obtained in this section. The total carbon accumulation per year in South African peat soils falls between approximately 2 500 T/yr and 45 000 T/yr with an average accumulation of 12 600 T/yr (Table 15).

Table 15: Carbon accumulation rate (T/yr) of peat soils within peatland ecoregions in South Africa

Ecoregion	**Carbon Accumulation in Peat Soils**		
	Low	**High**	**Avg.**
	T/yr	**T/yr**	**T/yr**
Bushveld Basin	0.12	2.36	0.63
Cape Folded Mountains	23.74	370.34	117.84
Central Highlands	162.65	1 795.52	655.07
Eastern Coastal Belt	6.11	102.84	28.95
Eastern Uplands	75.15	1 092.53	357.86
Ghaap Plateau	–	–	–
Great Escarpment Mountains	87.06	576.18	250.35
Great Karoo	–	–	–
Highveld	263.58	1 617.86	722.86
Limpopo Plain	1.39	4.28	2.59
Lowveld	134.24	412.74	249.62
Nama Karoo	–	–	–
Natal Coastal Plain	1 545.16	37 542.12	9 756.72
Southern Coastal Belt	191.37	1 076.83	488.74
Southern Kalahari	–	–	–
Western Coastal Belt	–	–	–
Total	**2 491**	**44 594**	**12 631**

Value of carbon stocks and accumulation

Carbon stock was determined using the peat soil carbon stocks. Accumulation values were determined using the accumulation rates. A conversion factor was used to convert carbon into CO_2 equivalent. A conversion factor of 0.27 was used based on the molecular weights of carbon and oxygen being 12 and 16 respectively. The market value of the proposed carbon tax of R120/T, as promulgated by the National Treasury, was used.

Results showed existing carbon stocks to be valued between R1.8 billion and R191.8 billion, with an average of R13 billion (Table 16).

Table 16: Carbon stock value range (R) of peat soils within peatland ecoregions in South Africa

Ecoregion	**Carbon Stock Value in Peat Soils**		
	Low	**High**	**Avg.**
	R	**R**	**R**
Bushveld Basin	41 311	840 252	225 653
Cape Folded Mountains	10 530 699	886 287 928	151 475 351
Central Highlands	72 978 145	7 131 609 561	634 301 218
Eastern Coastal Belt	1 086 897	182 824 034	33 071 456
Eastern Uplands	40 095 985	1 844 944 522	397 516 539
Ghaap Plateau	–	–	–
Great Escarpment Mountains	54 718 300	1 012 040 007	275 567 333
Great Karoo	–	–	–
Highveld	206 609 553	8 156 064 765	1 993 221 307
Limpopo Plain	1 730 267	9 128 663	4 438 376
Lowveld	35 976 907	1 282 321 845	394 508 171
Nama Karoo	–	–	–
Natal Coastal Plain	1 373 474 264	166 853 881 774	8 802 725 190
Southern Coastal Belt	77 245 609	4 439 145 246	430 140 066
Southern Kalahari	–	–	–
Western Coastal Belt	–	–	–
Total	**1 874 487 936**	**191 799 088 598**	**13 117 190 661**

The value of accumulating carbon was shown to be between R1.1 million and R19.8 million, with an average value of R5.6 million (Table 17).

Table 17: Carbon accumulation value (R) of peat soils within peatland ecoregions in South Africa

Ecoregion	**Carbon Accumulation Value in Peat Soils**		
	Low	**High**	**Avg.**
	R/yr	**R/yr**	**R/yr**
Bushveld Basin	52	1 050	282
Cape Folded Mountains	10 553	164 596	52 374
Central Highlands	72 291	798 008	291 143
Eastern Coastal Belt	2 717	45 706	12 868
Eastern Uplands	33 400	485 569	159 047
Ghaap Plateau	–	–	–
Great Escarpment Mountains	38 693	256 081	111 266
Great Karoo	–	–	–
Highveld	117 147	719 047	321 273
Limpopo Plain	618	1 902	1 150
Lowveld	59 663	183 438	110 942
Nama Karoo	–	–	–
Natal Coastal Plain	686 737	16 685 388	4 336 318
Southern Coastal Belt	85 055	478 591	217 216
Southern Kalahari	–	–	–
Western Coastal Belt	–	–	–
Total	**1 106 925**	**19 819 376**	**5 613 879**

5.4 Water Purification

5.4.1 Background and valuation

Wetlands influence water quality in aquatic systems by retarding the flow, which allows for many chemical and biological processes to occur. The retention time allows suspended particles to settle, pollutants to separate and adhere to sediments, and nutrients to be used by vegetation and organisms present. Peat within a peatland assists in reducing the velocity of water and holds water allowing quality regulation processes to function. The various processes within wetlands in turn regulate suspended particles (Strecker et al., 1992), nutrients (Reddy & DeLaune, 2008), metals (Sheoran & Sheoran, 2006), organic pollutants (Hemond & Benoit, 1988) and bacteria (Rogers, 1983). Peatlands have a strong ability to, once filtered out, store and sequestrate pollutants and contaminants of incoming water sources (McCarthy & Venter, 2006).

The water purification functions of wetlands have been relatively well documented. The presence of this service in peatlands has, however, not been as thoroughly investigated. The subject of the ability for peatlands to filter polluted waste water has gained increased attention (Ringquist & Oeborn, 2000; Ringquist et al., 2001; Coggins et al., 2005; Van Roy et al., 2006). Brown et al., (2000) showed peat soil to be a very efficient filter in removing dissolved heavy metals from water. He further stated, however, that this ability relies on varying factors such as pH, load and type of competing metals in solution. The fact remains that the waste assimilation service provided by peatlands is a major advantage to passive water quality management.

Key to the valuation of the water purification service provided by peatlands is to understand the potential of a peatland to treat contaminated water. The outcome of these processes (for the most part) can be replaced using various alternative commercial processes. Understanding the baseline water quality parameters prior to and after the peatland provides insight into the number of contaminants a peatland is able to treat. This information and the costs associated with the alternative of treating the water commercially allow us to quantify the value of the water quality treatment service delivered by peatlands generally and economically.

The water purification service potential of peatlands is explained in two examples, namely, the Gerhard Minnebron Peatland in North West Province (Section 0) and the Klip River Peatland system in Gauteng (Section 0).

5.4.2 Gerhard Minnebron Peatland

The ability for the Gerhard Minnebron Peatland to regulate uranium coming from upstream mining activities was investigated by Wilde (2011). Due to mining activities upstream, there was an influx of almost 3500 g of uranium per annum (based on data between 1997 and 2008) entering the underground karst aquifers through seepage. These influxes of uranium were seen to be sporadic, most likely because of staggered precipitation events. This subsequently resulted in sporadic sixfold increases in uranium concentration in the Gerhard Minnebron Eye over the same period. The Gerhard Minnebron Eye is the main source of water to the Gerhard Minnebron Peatland, thus introducing large concentrations of uranium to the site.

The peatland was observed be a very efficient uranium removal filter for the introduced water, removing 100% of the uranium content. However, it was further seen that between events of high uranium concentrated water entering the system, there were stages where clean dolomitic water would flow through the peatland. This caused the remobilisation of almost 98% of the uranium stored, which was released into the downstream system. The remobilisation of uranium was seen to be a result of both a weak binding of uranium to the peat and high concentrations of chlorine, magnesium and hydrogen carbonate ions in dolomitic water.

In summary, the study indicates that peat is a very powerful and efficient filter for uranium. The value of this service should be acknowledged. Unfortunately, in this specific system, the combination with fresh dolomitic water nullifies the service. This would not be the case in all systems.

5.4.3 Klip River Peatland system

Overview

Since 1886, the Klip River catchment has been exposed to the economic development of the Johannesburg area, which has resulted in a highly urbanised landscape. The Klip River Peatland has been on the receiving end of many of the associated impacts. Through runoff events (or other means), the Klip River system has received contaminants such as industrial pollution due to mining and industrial activities, and waste water effluent from sewage treatment plants. It was estimated that 253 million m^3/yr of treated sewage and industrial water enter Klip River (McCarthy & Venter, 2006).

The geochemical signature of the peat confirms these historical and present influences on the system. McCarthy and Venter (2006) found that concentrations of phosphorus, copper, uranium, mercury, cadmium, nickel, cobalt, zinc and lead increased in decreasing depths of peat samples taken from the Klip River Peatland. Safi (2006) found that various heavy metal concentrations were highest in peat samples taken upstream. These observations indicate two factors, namely, 1) the removal of pollutants by various processes within the wetland; 2) an accumulation of these pollutants in the peat over time, demonstrating the sequestration ability and storage capacity of peat for such pollutants. McCarthy and Venter (2006) noted that the peat-accumulation rates were likely accelerated resulting from enhanced vegetation growth caused by increased inputs of (nutrients) phosphates and nitrates into the system.

The ability of peat in the Klip River system to filter as well as accumulate pollutants provides a valuable service in terms of water quality regulation and waste storage. The loss or degradation of the peat in this system will result in a reduced ability for the seizure and sink capacity for these pollutants. Further physical alteration of the peat could possibly trigger a release of existing historical stocks into the downstream systems (such as the Vaal Barrage).

Methodology

The value of the waste storage service provided by peatlands will be demonstrated by the work done by McCarthy and Venter (2006) at the Klip River Peatland. The valuation of this service involves quantifying contaminants stored in the peatland. The observed load could be related back to the fact that if the peatland is destroyed, it will release all contaminants into the Vaal Barrage. Depending on the concentration of contaminants released, this would cause subsequent damage to aquatic systems downstream. Impacts could include decreased health of dependent communities, destruction of the ecosystems and negative effects on soil productivity and property values. This approach would attempt to value a highly complex chain of causality introducing a large probability of inaccuracy. Due to the limitations within the scope of the study, this approach was not taken.

A more commonly used approach in environmental economic studies would be the use a proxy value as a substitute for wetland water purification. One could also calculate the cost of mitigation if the peatland system was degraded to the point where it was no longer functional and was unable to deliver the identified ecosystem service. In the case of the Klip River Peatland, a cost of mitigation approach was taken. Mitigation would involve the cleansing of the peatland by removing the contaminants stored. This would result in avoiding the release of contaminants downstream and provide a suitable proxy for the storage service provided by the peatland. There is however a gap in the literature regarding the methods specific to peat pollution removal. Literature mostly refers to general aquatic sediments typically found on riverbeds coastal floors.

Mitigation costs were obtained from Perelo (2010) who reviews the remediation of pollutants from sediments in aquatic systems. The study identifies nine cases where dredging techniques were used to remediate polluted sediments in rivers. The costs involved varied greatly and were based on the volumes of sediments remediated. The lower the volumes of sediment remediated, the higher the costs. This inferred that there was a setup cost for the treatment of sediment. The Klip River Peatland displayed comparatively high volumes of peat to be remediated; therefore, the lower echelon cost and because heavy metals were removed from the sediment, a cost of US\$250/m^3 was used as an indication for costs incurred. An exchange rate of R14.03 to the Dollar[4] was applied to get South African Rand equivalent and the appropriate economic value was calculated. The estimates of volume of peat present in the Klip River Peatland were obtained from Grundling and Marneweck (1999) and Smuts (1997). The lower estimate was estimated to be 10% of the upper estimate.

---

[4] Exchange rate on 25 November 2015

5.4.4 Results and discussion

Based on a peat stock in the Klip River Peatland ranging from 40 864 000 m^3 to 51 080 000 m^3 (Grundling & Marneweck, 1999; Smuts, 1997), the contaminant loads for various contaminants are given in Table 18.

Table 18: Contaminants with corresponding concentrations (mg/ℓ) (McCarthy & Venter, 2006), maximum and minimum total load (kg) present in the peat of the Klip River Peatland

Contaminant	Concentration (mg/ℓ)	Total Load (kg)	
		Minimum	Maximum
Cadmium (Cd)	0.4	16 173	20 217
Mercury (Hg)	0.2	7 559	9 449
Barium (Ba)	295.3	12 068 439	15 085 548
Cerium (Ce)	72.2	2 949 431	3 686 788
Cobalt (Co)	112.8	4 609 847	5 762 309
Chromium (Cr)	272.1	11 119 389	13 899 236
Copper (Cu)	103.9	4 249 398	5 311 748
Gallium (Ga)	24.4	998 997	1 248 746
Niobium (Nb)	14.7	601 126	751 407
Nickel (Ni)	412.2	16 845 297	21 056 622
Lead (Pb)	18.1	740 052	925 064
Rubidium (Rb)	75.9	3 102 692	3 878 365
Scandium (Sc)	27.6	1 129 368	1 411 710
Strontium (Sr)	43.3	1 770 593	2 213 241
Uranium (U)	6.2	255 070	318 837
Vanadium (V)	199.9	8 171 018	10 213 773
Yttrium (Y)	29.6	1 208 847	1 511 059
Zinc (Zn)	426.0	17 408 906	21 761 132
Zirconium (Zr)	232.7	9 508 718	11 885 897

Considering these volumes, the cost of remediation of these aquatic systems if lost would range from R143 billion to R179 billion. This is a considerable value, but it must be considered that the Klip River system is at the end of highly transformed urban, industrial and mining area, which has been responsible for a significantly large volume of contaminants. The loss of these peatlands would have significant impact on water quality to downstream users.

The two peatland systems discussed in this section, the Gerhard Minnebron and Klip River systems, contribute significantly to water purification within their respective catchments. The loss or degradation of these systems could result in additional contaminants finding their way into the aquatic system and subsequently to the beneficiaries of the aquatic ecosystem services. This section illustrated the potential value of peatlands contributing to water purification. It must be noted, however, that excessive assimilation of contaminants would severely affect the functioning of peatlands.

5.5 Irreplaceability

5.5.1 Background and valuation

Substitutability

Peatlands provide additional ecosystem services over and above the wetland services. The magnitude of ecosystem services provided by wetlands is thus increased due to the presence of peat. This addition of services provided is unique to these systems. Only 10% of all wetlands in the country are peatlands (Immirzi et al., 1992; Joosten & Clarke, 2002). Peatlands mostly only occur along the eastern coastline and central plateau (Marneweck et al., 2001). There is a variety of geomorphologic, hydrological, climatic and biological characteristics within these areas that provide for the conditions necessary to produce peat. This influences the type of peatland depending on the nature of conditions present. Apart from peatlands already being rare features within the South African landscape, there are characteristics that separate various peatlands, which make them distinct to their regional settings. The distinctive characteristics, relative rarity and unique blend and magnitude of services of these features influence the substitutability of these systems. Thus, they cannot be replaced easily.

Intrinsic value

Intrinsic value is the "value that an entity has in itself, for what it is, or as an end" (Sandler, 2012). This is the contrast to instrumental value, which is the value of an entity to be able to provide the means to acquire something else of value. Instrumental value is a value that can be quantified based on the market values of infrastructure or benefits received and can fluctuate based on desirability of the entity (Sandler, 2012). Instrumental value can be attributed with an economic equivalent; however, intrinsic value cannot as this value is not one which can typically be quantified.

Peatlands have instrumental value in their ability to provide services and benefits that can (generally speaking) be valued-based on market-related economic values. The peatland may be perceived as beautiful by onlookers and thus has instrumental value. However, the intrinsic value of peatlands does not arise from what market-based benefits they can provide, but rather from the value of being a unique and irreplaceable entity in the landscape.

This intrinsic value can best be illustrated through the loss of such a system. There would be a loss in potential for the system to exist and evolve as a unit.

St Lucia case study

An environmental impact assessment was conducted for the proposed mining of the eastern shores of the Lake St Lucia. Situated within the coastal dunes of northern Kwa-Zulu Natal, the area is in a biogeographic transition zone that includes a range of habitats including terrestrial, marine and freshwater habitats. It was thus regarded as very important for conservation. In a typical manner, the process involved an in-depth investigation of environmental, economic and social costs and benefits. The investigations were strongly informed by extensive public participation receiving their views, beliefs, values and preferences on the matter assessing the impacts on indirect and intrinsic concerns of the public. A review panel was chosen in consultation with interested and affected parties who would make the ultimate decision whether mining activities would go ahead.

The decision was made not to go ahead with the proposed mining operation. The decision was guided by the strong concern that the Greater St Lucia was a "special and unique place" (Kruger et al., 1997) and that the intrinsic value associated with the ecological variety was too significant to risk. Other factors included scepticism behind the estimated economic benefits and also a lack of knowledge of the ecological processes of the area resulted in scientific uncertainties concerning the impacts on ecosystems of the area. The major concern, however, was that the sense of place would be risked if the proposed mining activity was to proceed. The precautionary principle was thus applied considering the risks and uncertainty identified in the economic and environmental assessments, and together with the high intrinsic value placed on the area by the associated public. Instead of the proposed activities, the review panel proposed that the area be protected in a national park and ecotourism be developed.

The intrinsic value of the eastern shores of Lake St Lucia did not hold economic or beneficial value, but this 'perceived' value was sufficient to largely influence the ultimate decision for the proposed activities. This value was quantified (indirectly through extensive public concern and involvement) to be too great to risk or lose as a trade-off to local economic development.

Unique habitats and biodiversity

Habitat and biodiversity are very specific unique characteristics of peatlands. There is not especially high biodiversity found within the peat in peatlands specifically, although the extreme chemical and hydrological conditions found in peatlands result in specialised and significant biodiversity (Phillips, 1990; Yule, 2008). Plant species need to be resilient against generally high acidic and nutrient-deficient soils, and a constant yet fluctuating water level. This results in an area within the actual peatland that is distinct or significantly differs in biological composition to adjacent non-peat soil areas. Thus, the presence of a peatland in the landscape allows for a high structural diversity in a local context. The characteristic permanent water saturation within a peatland, together with seasonal wetted areas within surrounding wetlands and drier regions along the fringes provide for heterogeneous habitat types resulting in a high variety of faunal and floral components being able to occupy the region. Furthermore, depending on the geomorphological, hydrological, climatic and physical characteristics of peatlands, species composition may differ between peatlands (Page et al*.,* 1999) suggesting that on a regional scale, peatlands are relatively unique in their biological composition (Corner, 1978).

The unique characteristics and services provided at a regional scale and rarity at a national scale demonstrate the value of peatlands in terms of their irreplaceability. Perhaps the economic or cultural implications of losing a rare and unique ecological feature in the landscape is not very clear; however, the loss would be one which cannot be substituted for another and there is value in that. This value can better be illustrated by looking at the Guidelines for Wetland Offsets for South Africa (SANBI & DWS, 2014). These guidelines allow for the compensation required due to the loss or damage of wetland systems to be calculated. The level of compensation depends on the magnitude of impact on a system based on the size, importance and significance of the wetland being affected.

Peatlands are highly specific ecological features in the national landscape and it is for this reason that they fall outside the National Wetlands Classification System of South Africa (Ollis et al*.,* 2013). This means that they are not specifically protected nor are they explicitly included as important systems at a national level. In principle, however, the rarity of these systems in the national landscape requires that a precautionary approach be applied to the wetland offset guidelines resulting in appropriate provisions for the suitable quantification for compensation purposes. This ensures that the highest ratio for replacing land area equivalents be used (Holness; pers. comm. 2015). The value in the rarity of a system ensures that these systems be treated in an appropriate manner and are not lost without appropriate compensation. It is noted however that even with appropriate (as per guidelines) compensation, the loss or damage of a peatland cannot be replaced by non-peatland compensation activities.

System resilience

Although not specifically unique to peatlands, wetlands can provide maintenance services to associated natural systems. The regulation services provided by wetlands are not only advantageous and to the benefit of society but also benefit natural systems. It is in their level of resilience and ability to recover from disturbance that they are valuable within the natural landscape. There is an intrinsic value displayed by the natural cycles and pathways present that maintain and allow for ongoing survival of these systems.

Colbyn case study

The Colbyn wetland is a peatland found along the upper Hartbeesspruit in Pretoria East, South Africa. The peatland is fed through a range of hydrological pathways but typically through-flow from the Hartbeesspruit upstream. The urban stream flows through a variety of land use intensities of which the close association with the urban and commercial activities and transformed landscape provide for a source of contaminants into the stream. In a study done by Mulders (2015), it was found that the Colbyn Peatland played a significant role in regulating physical and chemical composition in surface water downstream, which in turn caused an increase in various indices of the macroinvertebrate community composition. This indicates an improvement in river health.

Surface water contaminants had a high variation in concentrations, accumulation and dilution due to changing temporal conditions and the presence of dams upstream of the peatland. Downstream of the peatland, however, contaminant levels were stable throughout changing conditions and contaminant concentrations. Macroinvertebrate assemblages, which are often used as indicators of ecosystem health (Azrina et al*.,* 2006; Cooper et al*.,* 2006; Arman et al*.,* 2012; Baa-Poku et al*.,* 2013; Kemp et al*.,* 2014, were seen to have a significant increase in South African Scoring System score (SASS), Average Score Per Taxon (ASPT) and Shannon Weiner Diversity from up- to downstream of the peatland. Please note that the SASS5 methodology (Dickens & Graham, 2002) was not used in the investigation, rather only the tolerance values for various taxon were used to obtain the SASS score and ASPT. Nonetheless, the results indicated that the presence of the wetland played a significant role in increasing the health of the ecosystem downstream (Mulders, 2015). Other factors such as connectivity of flow, physical stream characteristics and diversity of microhabitats also played a role. However, these factors were also seen to be positively influenced by the presence of the peatland.

The valuation of substitutability

GEF example

The valuation of the substitutability of a feature is not as straightforward as finding direct proxy values for a service provided. However, there are methods. An alternative to conventional valuation of a system could be demonstrating value through the willingness to protect or improve such a system (as shown above). For example, the size of an investment grant into the maintenance or protection of a natural system may serve as a proxy for the value of such a system.

One such investor is the GEF, a non-profit organisation developed through the World Bank. The GEF assists with the protection of the environment and promotes environmentally sustainable development. More specifically, the GEF provides additional grants that transform environmental projects with national benefits to projects with global environmental benefits. The GEF serves as the financial mechanism for the Convention on Biological Diversity, United Nations Framework Convention on Climate Change, Stockholm Convention on Persistent Organic Pollutants, UN Convention to Combat Desertification, the Minimata Convention on Mercury, and various other international funds. They have a scientific and technical advisory panel (STAP) with expertise in the main focal areas of the GEF. STAP provides expert scientific advice on all GEF policies, strategies, programmes, projects and funding interacting with other relevant scientific and technical bodies. The projects and the funding thereof are an expert-based reflection of priority areas needing attention. Thus, the methodological premise is that the attention given to specific ecological systems may be used as an indicative proxy whereby valuation can be based.

In a study done by Ginsburg et al. (2011), multiple GEF projects were investigated to determine if there were any statistical connections between various characteristics (potential drivers including area, threatened species, country, duration of project and other indicators of biodiversity) of the projects and the magnitude of the project costs. It was found that there was a strong positive correlation ($R^2 = 86\%$) between the magnitude of the project grant and the number of red data species associated with the project. This illustrated that an abundance of red data species was the most important factor (perhaps not consciously by GEF) playing a role in the financial investment by GEF. The relationship observed between red data species and investment by the GEF indicates a clear relationship with probability of loss and importance for conservation and preservation. As a species becomes more threatened and rare (indicated by the red data status of a species), it will in turn receive increased support, attention and effort (indicated by magnitude of funding). It is through the increased probability of loss of an irreplaceable rare entity that the substitutability value increases.

Peatlands are unique and rare ecosystems in themselves (regardless of the presence of red data species) and the relationship demonstrated above between financial willingness and perceived importance due to rarity illustrates a method for the valuation of peatlands.

5.5.2 Methods

The relative scarcity of peatlands versus wetlands was determined by using the updated peatland database against the NFEPA Wetland Database (SANBI, 2011). The total area of wetlands in the NFEPA Wetland Database was compared to the total area of peatlands. Through this process, the relative abundance of peatlands as wetland ecosystems was determined. The relative scarcity of peatland type was determined by comparing 1) the number and 2) the volume of peat within each peat ecoregion. This allowed for an indication of scarcity and subsequent irreplaceability of specific peatland types.

The GEF database was investigated (data mined), identifying projects focusing on peatland restoration, rehabilitation, management and protection. The total GEF investments and co-investments by associated countries and size (hectare), duration and year of acceptance were determined. This data and appropriate exchange rates were used to determine Rand equivalents for investments into peatland ecosystems. Please note, the study by Ginsburg et al. (2011) shows that funding magnitude does not correlate with the size of the area invested in. It is understood that this may not give an appropriate indication of substitutability value; however, for the purposes of demonstrating this value, these methods were used.

5.5.3 Results and discussion

The total area of NFEPA wetlands is 2 915 914 ha. The total area of peatlands is 30 716 ha. Thus, 1% of wetland area in South Africa is peatlands, which illustrates the relative scarcity of peatlands as wetland types. The relative scarcity of peatland types is illustrated in Figure 28. It shows the variability between the peat ecoregion with the highest abundance of peatlands, Natal Coastal Plain with 397 peatlands, and the peatland ecoregion with the least number of peatlands, Limpopo Plain with only one peatland. This illustrates the variation in scarcity within an already scarce wetland group between peatland types. Through this demonstration, we can see that the substitutability value would vary depending on the region where the peatland is found.

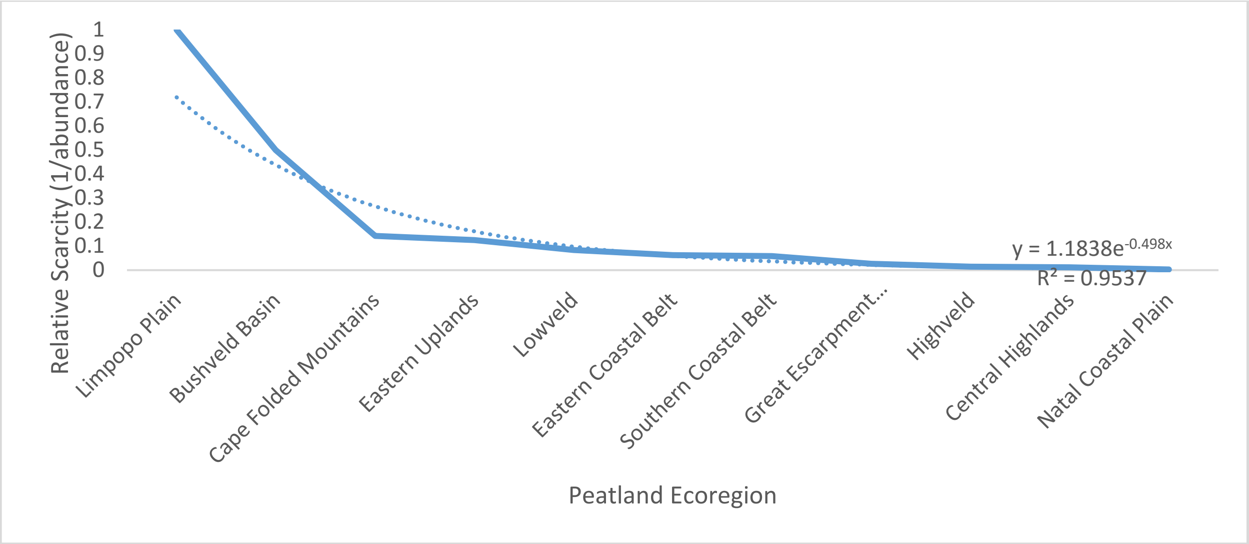


Figure 28: Relative scarcity (1/abundance) of peatland type based on the abundance of peatlands within each peatland ecoregion

Figure 29 shows the relative scarcity of peat within each ecoregion. Although there is only one peatland in the Limpopo Plain, there is a relatively larger volume of peat present than in the Bushveld Basin.

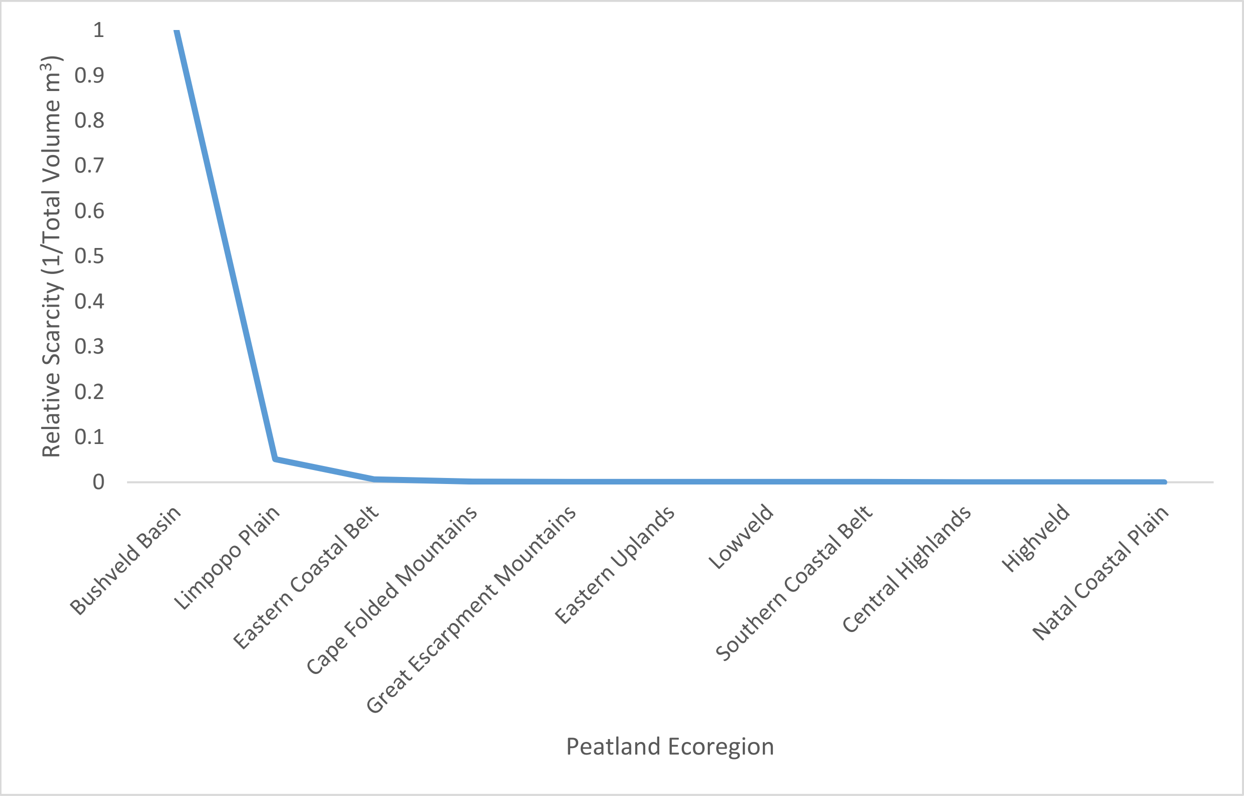


Figure 29: Relative scarcity (1/total volume m^3) of peatland type based on the total volume of peat present in peatlands within each peatland ecoregion

Of six GEF projects, only four displayed the appropriate criteria for use in this investigation (Table 19). The investment per hectare was relatively focused, ranging from R754 to R1100. This resulted in a total irreplaceability value of R274.7 billion.

Table 19: Total amounts invested (US$) by the GEF and associated countries, area of receiving site and R/ha for peatland restoration, rehabilitation, management and protection

Country	Total Investment (US$)	Year Accepted	Area (ha)	R/ha
Malaysia	13 665 000	1999	106 836	754.7
Belarus	3 283 425	2004	28 207	803.2
Belarus	400 000	2011	3 000	920.0
Thailand	16 184 400	2013	128 000	1 100.3

The relative scarcity of peat within various peatlands must be reviewed carefully to understand the irreplaceability value thereof. Although there is only one peatland in Limpopo Plain but two in the Bushveld Basin, the total peat volume found in the Limpopo Plain is larger. It is important to understand the systems we wish to value and what it is that is valuable. If it were not for the entire system, there would be no peat; however, it is the service ability of the peat being investigated. Nonetheless, there are varying degrees of irreplaceability within the peatlands of South Africa, which makes the valuation of substitutability more complex.

The irreplaceability value identified by investment willingness for peatland restoration, rehabilitation and conservation was determined to be a substantial amount. This value was calculated based on a proxy, which demonstrates a technique for the intrinsic valuation of peatlands. This value should not be seen as a direct market value, but rather as a demonstration of the magnitude of the value placed on these ecosystems.

5.6 Knowledge and Education

5.6.1 Background and valuation

Knowledge and education

Ecosystems are highly complex systems. Complex systems are defined as “a network of many components whose aggregate behaviour is both due to, and gives rise to, multiple-scale structural and dynamical patterns which are not inferable from a system description that spans only a narrow window of resolution” (Parrott & Kok, 2000). It is this complexity that makes ecological systems difficult to understand, but at the same time difficult to predict in terms of their knowledge potential. It is only through analysis and attempts at understanding them that the dynamics and associated components can become clear. This means that there are vast possibilities for these systems to contribute to gain insight; making them an invaluable asset.

Historical knowledge

Peat is a highly valuable source of historical data. Peatland paleo-ecology is a field that can provide insight into a wide range of historical events, including human records, volcanic eruptions, heavy metals and nitrogen in the atmosphere, and climate change (Brothwell, 1986; Pilcher et al., 1995; Turner & Scaife, 1995; Wagner et al., 1996; Dwyer & Mitchell, 1997; Malmer et al., 1997; Shotyk et al., 1997; Barber et al., 2000). Peat core samples have been seen to store pollen, spores, organisms and vegetation at various layers giving an indication of conditions on a temporal scale. The cumulative process whereby peat is formed allows it to hold and store these various samples on a temporal scale. This ultimately means that peat stores its own history. These stores can give an indication of specific environmental conditions at various points during the formation of the peat and are called the peat archives (Godwin, 1981).

This source of stored organic matter can be used to create a timeline of past conditions assisting in understanding climatic changes over the time of peat formation. This period can be for thousands of years, thus indicating and defining climatic conditions throughout the Quaternary Period. The Quaternary Period comprise the Pleistocene Epoch (2 588 000 years ago to 11 700 years ago) and the Holocene Epoch (11 700 years ago till present). An example of this temporal extent is the Tswaing Crater in Limpopo, South Africa, which holds peat that started forming approximately 200 000 years ago (Partridge et al., 1997). Ice core records can provide information on climatic conditions as far back as 650 000 years. However, the nature of the data does not allow for the temporal resolution obtainable by peat (for example, ice core records cannot differentiate between the Holocene and Pleistocene Epochs).

This is the major advantage that sets peat apart from other proxies for historical climate data, thus making it the most popular terrestrial proxy for paleo-climatic data (Battarbee et al*.,* 2004). Other terrestrial proxies include tree rings, speleothems, corals and marine sediments. Tree rings have a high resolution being able to provide annual climatic data; however, the timescale for this indicator is limited (Lindholm & Eronem, 2000). Speleothems allow for a source of paleo-climatic information stored in calcite precipitation in cave water. Although a valuable source of data, the accumulation rates (therefore timespans) covered can be highly variable (Battarbee et al*.,* 2004). Corals are highly reliable and are being increasingly analysed as a source of paleo-climatic data, but only for the past 100 to 200 years. Marine sediments, like peat formation, provide a reliable source of data with high temporal resolution. Studies typically look at planktonic foraminifera but also other sedimentological, biological and geochemical characteristics.

This opportunity for knowledge service provided by peat allows for the development of intellectual capacities that is compounded by the availability of a rare and unique form of information (Birks & Birks, 1980; Godwin, 1981; Barber, 1993). The nature of this information provides an indication of conditions before human influence and can thus be utilised as reference point on which the magnitude of human impact on various environmental parameters can be measured.

Wonderkrater case study

The Wonderkrater is a peatland situated in Limpopo, South Africa. It consists of an 8 m thick peat mound formed by an artesian spring occurring along a fault. The peat consists of a pollen record that extends back 35 000 years; meaning it straddles the Late Pleistocene and Holocene (McCarthy et al*.,* 2010). This provides a valuable record of climatic conditions in the area. In a study done by McCarthy et al. (2010), the peat-accumulation rates were determined to be slower during the Late Pleistocene (0.06-0.1 mm/yr) than the Holocene (0.2-0.38 mm/yr). This indicated drier conditions during the Late Pleistocene epoch. A major sedimentary layer was found in the peat profile around the transition period of the two epochs. This indicated extremely dry periods where the peat mound reduced in size. During this time, the rate of sedimentation was larger than the rate of peat accumulation, which resulted in the observed clastic sedimentation layer. Late Pleistocene faunal fossils were also found in the sediments of this period. This further confirms the extreme dry period as the peatland, which is fed by groundwater, would have been a region where fauna of the time would frequent due to the reduced water availability of the region.

The high ash content in various portions of the mound indicates exposure of the peat with oxygen, which resulted in desiccation and peat fires. This would have occurred through the combination of high and low inputs of water from the artesian spring into the mound. During periods of high flow, the mound would increase in height and width. During periods of low flow, the exposed regions would become exposed. In this way, the peat mound would have increased and decreased in size through varying climatic and flow conditions.

Currently, southern Africa displays a wide range of climatic zones. These zones range from true deserts to Mediterranean to humid subtropical conditions. Within each of these there is a full range of seasonalities. The current and past climatic conditions would have been highly variable over a relatively small geographic region. This means that peatlands at a regional scale across South Africa are valuable in their historical archives as they provide regional-specific insight into past conditions.

5.6.2 Discussion

Work on the peat archives has shown immense potential for peat to be used as a source of paleo-environmental data. The value illustrated in knowledge is one which is all in its potential. Obviously, there are also direct costs involved in the study of peat; however, this potential value is seen to be the significant contributor to its total value. There are obvious difficulties in the valuation of this potential. By understanding the past, we may understand current trends and project future changes. This allows for anticipation and the avoidance of impacts, which would have economic repercussions. Using a proxy such as this is not possible at present. It is in this potential though where the knowledge and education value of peatlands lie.

5.7 Products from Peatlands

5.7.1 Background and valuation

Wetlands have been used globally for agriculture. Floodplains allow for nutrient-rich and naturally fertilised soils arising from flooding events. Peat as a soil type has also attracted attention from cultivators internationally. Peatlands found in the coastal plains of the Netherlands have long been drained and used for crops due to their high mineral content and subsequent fertility of the peat (Borger, 1992). This did however mean the destruction of 8000 km^2 of wetlands in the region. Over the past 50 years, approximately 270 000 km^2 of peatlands in South-East Asian have been deforested for agricultural purposes (Hooijer et al., 2006). Although the intensity of agriculture in these areas increases so that much of the peatlands are deteriorated and destroyed, they provide a valuable cropping service to the regional economy.

There is evidence of this type of use in South African peatlands. Informal agriculture or rather the development of ‘gardens’ within peat soils by communities has been seen in the Manguzi area within the Natal Coastal Plain (Moreno et al., Unpublished/in progress). Within this area, there are approximately 17 peatlands. Many of these peatlands are being farmed by households in the area. Of these farming households, 65 were surveyed. Approximately 65% had one, and 35% had more than one ‘garden’ within a peatland. Most of the peatlands cropped had been done so for over 15 years. This illustrates a significant use of this resource by communities for cropping in the area. The peat soils provide for an advanced service to subsistence farmers that is not provided by adjacent or unrelated local soils.

The valuation of this service is not possible at present due to lack of data at a national scale. Nonetheless, this additional service by peatlands cannot be ignored in the valuation of South Africa’s peatlands and must be included into further investigations.

The use of peat as an extracted commodity on the other hand is another service that is provided by peatlands. Peat is extracted globally for a variety of purposes, but it is generally used as a source of fuel for heating and energy production, in horticulture as an additive to soil and as a filter in water quality management. Due to the relative scarcity and slow growth rate of peat in South Africa, it is often viewed as a non-renewable resource (although not classified this way). Peat is predominantly extracted for the horticultural industry as a soil conditioner. Peat is a valuable medium for crop growth due to its effective ability to hold water and high nutrients. It improves soil structure in sandy soils and aerates clay soils, thus improving drainage. Its chemical properties are also desired due to its pH buffering ability and cation-exchange capacity. Peat is a precursor to coal, which is formed over millions of years. It is the high organic properties of peat that make it a valuable fuel source. Rwanda is currently developing Africa's first peat-fired power stations (Bikorimana, 2014).

In South Africa, the commercial extraction of peat is mainly for the nursery and mushroom industry (Grundling & Grobler, 2005). There are many examples of peat extraction for commercial purposes in South Africa, including the Lichtenburg, Schoonspruit, Gerhard Minnebron, Witfontein, Venterspos, Wonderfontein, Tarlton, Vlakfontein, Klip River, Elandsfontein, Rietvlei and Rietfontein peatlands (Grundling & Marneweck, 1999).

Commercial peat extraction

In 2007, the South African Mushroom Farmers Association (SAMFA) stopped the use of South African reed-sedge peat in operations as it is considered a scarce resource, which has been seen as a non-renewable resource by the industry (Lazenby, 2010). Instead, 50 000 T/y *Sphagnum* peat is now imported for the industry from the Netherlands, Canada and Ireland (Booyens, 2012). SAMFA includes a large proportion of the mushroom-growing industry including companies such as Chanmar Mushrooms, Chantarelle Mushrooms, Country Mushrooms, Denny Mushrooms, Forest Fresh Mushrooms, Highveld Mushrooms, Medallion Mushrooms, Reese Mushrooms, Royal Mushrooms, Forest Mushrooms, Sylvan Africa (Pty) Ltd and Tropical Mushrooms.

This meant that it was difficult to obtain South African prices for peat harvested in the country. As an alternative, prices for reed-sedge peat were obtained from the United States Geological Survey Mineral Industry Surveys (USGS, 2012). The average cost of all reed-sedge peat sold in 2010 was approximately US$24 per metric ton.

5.7.2 Methods

The chain of causality between peatlands and the service of providing food and fibre resources is not as clear as the extraction of peat. The providing service of these products relates more to wetlands in general and is thus not seen as being directly related to peatlands. These services were therefore not included in the investigation of the value of services provided by peatlands.

The commercial value of South African peat was based on South African peat stocks and accumulation rates determined in Section 3. This value was the product of total volumes and accumulation rates and the market price for reed-sedge peat. The current value is set at approximately US$24 per tonne. The current exchange rate of R14.03 to the Dollar[5] was applied to get South African Rand equivalent and the appropriate economic value was calculated.

---

[5] Exchange rate on 25 November 2015

5.7.3 Results and discussion

The average commercial value of peat stocks is approximately R414 076 916 and can be as much as R6 054 617 724 (Table 20). The accumulation commercial value of peat per year is R177 212 and can be as much as R625 653.

Table 20: The commercial economic value of peat stocks and peat accumulation for South African Peatlands

	Commercial Value of Peat Soils		
	Low (R)	**High (R)**	**Average (R)**
Peat Stock (total)	59 172 899.94	6 054 617 724.47	414 076 916.37
Accumulation (per year)	3 381.23	625 653.82	177 212.93

The yearly commercial value of peat due to its rate of accumulation is relatively low. This is owing to the extremely slow pace at which peat forms. Because commercial utilisation and extraction are not sustainable, peat is often seen as a non-renewable resource. The commercial economic value of peat is not significant compared to other South African non-renewable resources and is not a substantial option for economic gain.

5.8 Hydrologic Regulation

5.8.1 Background

Wetlands are valuable water quantity regulators maintaining basal flows in the dry season and attenuating excess runoff in the wet season. This is done through the basic action of slowing down incoming water and preventing it from flowing out directly at the same velocity. The presence of peat in a wetland enhances this process. Saturated peat is typically 90-98% water by mass (Holden et al., 2007) acting as a sponge being able to hold significant quantities of water. South African peat has a lower water-holding capacity than peat in the northern hemisphere due to the comparatively lower peat quality (Grundling & Grobler, 2005). This allows peatlands to act as a storage for excess water in a catchment, acting as a sink, assisting with flood prevention and reducing flow velocity. Peat has been seen to store large volumes of water in the rainy season and slowly releasing it in the drier parts of the year (Price & Schlotzhauer, 1999).

There is however a train of thought that states that peatlands do not always act as sponges by storing water, maintaining base flows in the dry season and attenuating excess water in the wet season (Holden et al., 2007). Peat within a peatland may have the properties necessary to efficiently hold and release water, but it is rather the hydrogeological properties of the peatland that maintain basal flows through groundwater discharge and not the peat (Roulet, 1990). It is the height of the water table and permanent presence of water that allows for water quantity regulation in the dry season. In the wet season, peat may contribute to some storage of excess water; however, if the peat is saturated at the time of the runoff event, then no water can be stored by the peat. In terms of reducing excess runoff through infiltration, the high-water table present at peatlands allows for little spare space for excess water storage through seepage during and after high rainfall events (Holden et al., 2007). This gives peatlands a reduced ability to attenuate flood events compared to non-peatland wetlands. Peatlands have reduced ability to regulate flow in wet seasons but high ability in dry seasons, but this is not due to the wetland and the presence of peat but rather the conditions that provide for permanent saturation (such as groundwater recharge, climate, and impeded flow).

There is however evidence that shows that the presence of peat in a valley influences the quantity of water stored in the adjacent landscape (Grundling, pers. comm. 2015). The presence of peat allows water to rise above the actual water level. This rise causes a rise in stored water level in sediments adjacent to the peat formation. Furthermore, water quantities influence peat surface oscillation, whereby peat will expand and contract, influencing the relative water level.

Peat has a clear influence on water quantity within a catchment; however, the quantification thereof will require more investigations. The hydrological regulating service of peatlands could therefore not be directly valued due to limited data. Further investigation is required to logically include them in this study.

5.9 Tourism, Recreation and Spiritualism

5.9.1 Background and valuation

Tourism, recreation and spirituality

The potential for cultural services provided by wetlands is very high. The recreational potential lies in offering a variety of opportunities such as bird and wildlife viewing, water-related activities and of course the general appeasing aesthetics of the systems. The relative inaccessibility of peatlands makes them less suited to provide major recreational opportunities, but where there is appropriate infrastructure, these opportunities increase and so do visitors (Joosten & Clarke, 2002). The beauty that is supported in peatlands is seen in the aesthetic functions of peatlands. Evidence of this appreciation has been captured in art (multiple instances since 1495 Joosten & Clarke, 2002), and through the aesthetic marketing and collection of fauna and flora (Ng et al., 1994; Lee & Chai, 1996).

The direct tourism of wetland systems can provide major economic benefits to a region. For example, the Everglades, a large wetland network in eastern United States, amounts to approximately US$450 million in the entire tourism sector (UNWTO & Ramsar, 2011). In South Africa, the presence of wetland systems provides for sources of economic growth through ecotourism. This is especially true for Ramsar sites such as the iSimangaliso Wetland Park, Kosi Bay, Lake Sibaya and Langebaan Lagoon.

Worldwide, peatlands have played a major spiritual and religious role in history (Müller-Wille, 1999). Today, if anything, peatland systems continue to provide society with a source of existence functions that offer a concept of and evolutionary connection to natural and ecological systems.

In a South African context, the value provided by the presence of peat and peat-forming conditions within a peatland is not seen to be specific to providing “over and above” tourism, recreational and spiritual services compared to that of wetlands. This does not mean that when these services are provided by peatlands they are not valuable, but rather that the presence of the peat in the system does not directly contribute to the services provided. This judgement is however based on limited knowledge of the subject of peatlands providing these specific cultural services.

5.10 Discussions: Demonstrating the Value of South African Peatlands

South Africa does not have vast peatland resources when compared to peatland resources found in neighbouring African countries and even less so with countries across the globe. The average carbon stock calculated for South African peat resources consists of only 0.006% of global carbon stored in peat (Strack, 2008). This gives an indication that perhaps the comparative benefits and services received by peatlands within this country are substantially less than those received by other peatland-rich countries. This does not mean that they are not important in playing a role in providing socio-economic benefits to South Africa.

5.10.1 Climate regulation

Carbon stock results gave a relatively broad range of possible stock values. This range was due to the nature of the methodology used. The inference of values used was done in a conservative manner to ensure the general accuracy of the resulting range.

In terms of their carbon storage ability, the stock range calculated was between 4.2 million tonnes and 431.5 million tonnes of carbon. To put these figures into perspective, the amount of carbon stored is approximately equivalent to the carbon emissions released by the combustion of between 35 million and 3.6 billion barrels of crude oil (US EPA, 2013), or the average yearly GHG emissions produced by between 3.2 million and 333.8 million passenger vehicles. This calculation was based on the weighted average combined fuel economy of economy cars and the average distance travelled in the United States in 2011 (FHWA, 2013).

The carbon sequestration ability showed a relatively low level of carbon accumulation per year due to the slow accumulation rate of peat and relatively limited 30 700 ha of available peatlands in South Africa. The accumulation rates ranged between approximately 2500 and 45 000 tonnes of carbon per year. The amount of carbon accumulated per year is approximately equivalent to the carbon emissions released by the combustion of between 21 000 and 380 000 barrels of crude oil per year (US EPA, 2013), or the average yearly GHG emissions produced by between 1900 and 34 000 passenger vehicles (FHWA, 2013).

The average carbon stock of 29.5 million tonnes of carbon and average accumulation rate of 12 600 tonnes of carbon per year are likely the more accurate values as these averages were calculated based on values obtained throughout the valuation process. This ensured that accuracy was not lost during the calculation process. Although compared to global figures the climate regulation ability is not remarkable, South African peatlands do play a substantial role in storing and sequestering atmospheric carbon.

The carbon storage and sequestration service provided by peatlands displayed a relatively high market value for carbon stocks but the value for carbon accumulation ability was not as substantial. The value of carbon stocks present in peatlands displayed a proxy worth an average of R13.0 billion, possibly being worth as much as R191.8 billion. This value is an indication of the value provided by the atmospheric carbon storage capability of the country's peatlands. It is an observation of the theoretical costs avoided by preventing the destruction of peatlands. Increased risks to peatlands and ongoing destruction and degradation of peat reserves will evidently reduce the worth of carbon stocks reducing its value.

The sequestration value of peat was not as extensive, which is worth an average of approximately R5.6 million a year, with a possible maximum of R19.8 million a year. This value indicates the potential cost invested into reducing atmospheric carbon per year. Typically, organisations would benefit from reducing their carbon emissions through a subsequent reduced carbon tax. The reduction of carbon emissions, however, brings with it economic costs. The country's peatlands reduce atmospheric carbon at no cost, effectively saving the country on average R5.6 million a year in carbon taxes. This value is not high since the protection and management of the country's peatlands (for a year) would likely incur much greater economic costs.

The scope for PES schemes based on the carbon accumulation services alone is therefore relatively low, although possible. However, the value of the service provided in the storage of carbon stocks is substantial, and the value lies in the stock of peat as a stored resource and an additional feature in a wetland. The country contains an average peat stock of approximately 612.6 million m^3, which could be as high as 2.5 billion m^3. It is important to remember that not only does peat provide carbon storage and sequestration services, but it also provides further ecosystem services. These services provide additional value to the country's peatlands; meaning that the presence of peat within a peatland alone has a multiplier effect on the value of the peatland.

5.10.2 Water quality regulation

Peatlands show an ability to remove contaminants from water flowing through it. In the case of the Klip River Peatland, it was seen that almost 100 years of water purification had left behind substantial amounts of various heavy metals. This shows remnants of the waste assimilation service but does not directly highlight the service provided. It thus cannot be quantified efficiently. In the case of the Gerhard Minnebron Peatland, observations show the removal of a specific contaminant between upstream and downstream water, thus clearly indicating the presence of the service. The storage of this contaminant is however not maintained, proving only that the service is perhaps short-lived and serves to delay the eventual effects of increased pollution. The investigation has highlighted the fact that there is a major service provided by peatlands; however, in this case, further investigation is needed to accurately quantify the water quality regulation service provided by peatlands in South Africa.

The water quality service provided by peatlands displayed a much higher economic value than the carbon stock value. The mitigation cost proxy value could be as much as R179 billion. Furthermore, this value is only for the services provided by the Klip River Peatland and does not include any other South African peatlands. Limitations did not allow for an estimation of value for the whole country's peatlands as, firstly, not all peatlands perform the type of service that the Klip River Peatland does (due to its proximity to the industrial activities) and, secondly, if they do, there is no data available. This raises the question: If there is no contamination of water upstream, does a peatland still perform a waste assimilation service? The potential to perform the service is there, however, for many of South Africa's peatlands, this service is perhaps not being performed as actively as by the Klip River Peatland. Further investigations would need to be done to effectively integrate the whole country's peatlands into this type of valuation. There is however, given the state and threat level of South African wetlands, a strong possibility that there are other peatlands that perform similar services at similar levels. This means that the waste assimilation service value will almost certainly be larger than R179 billion, making this service more valuable than the carbon sequestration service for peatlands.

5.10.3 Irreplaceability value

Compared to global abundance, peatlands are an extremely scarce ecosystem type in South Africa with 1% of total wetland area being peatlands. Peatland distribution is further limited within the country due to the need for a very specific combination of geomorphologic, hydrological, climatic and biological characteristics that provide for peat-forming conditions. These characteristics vary over space making peatlands unique to their regional settings. Conditions within a peatland compared to that of the wetland and terrestrial zone provide for a high heterogeneity of conditions influencing habitat and biodiversity composition at a local scale.

The regionally distinctive characteristics and local variation of floral composition of South African peatlands influence the substitutability of these systems. A peatland in the Lowveld peatland ecoregion cannot, for example, be substituted for a peatland situated in the Central Highlands peatland ecoregion. It is in this irreplaceability that peatlands in South Africa have increased value. This value is further increased due to the relative abundance of peatlands within each peatland ecoregion. As an example, the substitutability value of the single Limpopo Plain peatland is higher than the value of a single Natal Coastal Plain peatland, which is one of 357 peatlands.

Peatlands as complex ecosystems have a vast potential to provide knowledge and insight into a system whose dynamics cannot be fully quantified. This can however be said for many complex systems and does not mean that peatlands are especially unique in this regard. It is in the peat archives found in peatlands where the knowledge value lies. Peatlands provide for a unique account of past events of which the temporal resolution and historical extent are not matched by many other terrestrial historical indicators.

The valuation of an entity due to its irreplaceability is highly conceptual and to some may seem controversial. How does one realistically place economic value on an entity due to its value outside of the economic market? The value is in the fact that it exists and has an intrinsic worth. This value is even further increased as it is a rare entity in the landscape. Peatlands in South Africa have been seen to be a rare ecosystem type nationally and have highly varying degrees of rarity on a regional scale. This means that they have a certain level of irreplaceability in the landscape. There is no denying that there is value in this of which the quantification is attempted in this report. Now, the proxy of real known investments into preservation, rehabilitation and conservation of peatlands was utilised for this purpose. Although the methodologies were not as robust as one would have preferred, this proxy served to provide an idea of the connection between the intrinsic value of peatlands and economics. A value of approximately R274 billion was determined. This value was almost double the sum of all other ecosystem services valued in this investigation and thus upon initial inspection was viewed with some trepidation. It is however important to understand that the purpose of this investigation is not to place a cost on peatlands for placing them on the market, but rather an attempt to demonstrate the connection between the value provided by these biological ecosystems and the language that is spoken through ecological applications. As an addition, the knowledge potential present in peat is largely unequalled by any other terrestrial source of paleo-environmental data. Further investigations would need to be done to efficiently include the past and potential value of knowledge provided by the peat archives. The irreplaceability value should be handled with caution in the economic valuation of peatlands, but this value should not be ignored when making management decisions as it is highly significant. The presence of peatlands in the country contributes greatly to the heterogeneity and diversity present and peatlands should thus be viewed as an irreplaceable and invaluable resource.

5.10.4 Product/harvest value of peat

The raw products providing service provided specifically by peatlands are generally cropping within peatlands themselves and the peat produced. Significant cropping within some of South Africa’s peatlands has been seen; however, at the time of the study, insufficient data did not allow for the value provided by this service to be demonstrated.

This commodity value of peat is one which stands alone aside from all other services. The reason for this is that this service cannot exist without influencing the other services, for example, if peat is harvested or removed from a peatland, there would be a loss of services enhanced by the presence of peat. There is value in peat as a commodity, but the gain value from other services outweighs the gain in the commodity service.

The commodity price of peat stocks and peat accumulation was identified as being as much as R6 billion and R0.6 million per year respectively. These values are relatively low when compared to the cumulative economic values indicated by other services. This finding is highly significant as it indicates that the gain of revenue through peat harvesting is miniscule when compared to the loss of revenue due to the replacement of services lost through peatland degradation.

5.10.5 Hydrological regulation and cultural services

It was not possible to quantify and valuate the hydrological regulation and cultural services including tourism, recreation and spiritualism in this report due to limited data. This is not to say that the services do not exist. The ability for peat to provide additional hydrological regulation services compared to that of wetlands has been questioned. However, there is a clear link to increased water provisioning under specific conditions. Further quantitative investigations will need to be done to logically include or exclude it as a service enhanced by the presence of peat. The cultural services identified have been seen to be provided by peatlands internationally. However, in a South African context, this could not be attributed to the presence of peat specifically and thus was omitted from strict valuation in this investigation. Again, further investigations incorporating in-depth cultural pricing methods would need to be undertaken to efficiently include this service in valuation.

6 DISCUSSION AND RECOMMENDATIONS

6.1 Peatland Ecoregion Model

Work done since the peatland ecoregion map of 2001 has been completed generated new knowledge on the occurrence and distribution of peatlands in South Africa. The need for an updated ecoregion map had become a necessity. The process was initiated using expert knowledge to identify key indicators with their limits using the same criteria as were used for the 2001 model. The 2016 model was combined with the 2001 model to achieve the greatest accuracy with 87.24% of the known peat points contained within the combined model. The new model improved the old 2001 model by 9.76%. The Natal Coastal Plain peat ecoregion has the highest concentration of peatlands (63%), which is followed by the Central Highlands peat ecoregion with 15% peatlands.

The possibility of using terrain units as an indication of where wetlands might occur was investigated using the KwaZulu-Natal datasets. It was found that 54% occurred in Unit 3: Midslope, and 38% occurred in Unit 4: Foot slope (see Figure 30 in Appendix 1). The location of peatlands in the terrain seems to be site-specific and, if included, this should be considered.

6.2 Peatland Database

The peatland database has been designed to be compatible with SANBI's wetland inventory and the NFEPA layer although this does not have an attribute for peatlands.

The 2001 South African Peatland Database had 519 records of which 40 sites included detailed profile information. Nine peatlands in KwaZulu-Natal have ^{14}C ages recorded at various depths with ages varying from 130 to ±45 000 years BP (Grundling et al., 1998).

A total of 116 peat points has been added to the database and an additional 106 points still need to be verified. Only 40 of the peat sites include detailed profile information. Of the 9635 peat points in the database, 480 (75.59%) are in NFEPA sites, 164 (25.83%) are within Ramsar sites, 222 (34.96%) are within formally protected areas, and two sites (0.31%) fall within informally protected areas.

The decision was taken that the percentage decrease or increase in peatland area between the old and new models would be an add-on spatial product for Phase 2 in a follow-up project.

6.3 Case Studies

Eight case study peatland sites were selected from across South Africa's peatland range to represent different hydrogeomorphic settings, geology and climatic conditions as well as land use such as conservation, agriculture, forestry, urbanisation and rural communal land. The main characteristics are described briefly in Table 3.

6.3.1 Groundwater dependence

Research into these and other peatlands confirms that peatlands in South Africa are mostly groundwater-dependant. The source of the groundwater varies, but isotope analyses and water flow measurements support the finding that ecosystems are groundwater-dependant. This underlines the importance of conserving groundwater recharge areas for peatland protection. This is particularly important in areas where the groundwater is being exploited for other uses such as irrigation.

6.3.2 Accumulation rate

The onset of peat accumulation in South African peat sites varies widely. The most favourable period was the middle Holocene. There is, however, a gap in the onset of formation of approximately 20 000 years between the Holocene and the Pleistocene.

Peat-accumulation rates vary from 0.5 mm/yr to 2 mm/yr but there are exceptions to these rates. The accumulation rate in Vazi Pan of between 2885 and 2800 years BP has been estimated at approximately 4 mm/yr. Matlabas Peatland in the MNP also has a high accumulation rate because of events washing sediment into the mire.

6.4 Socio-economic Value of Peatlands

This study has demonstrated the value of services provided by South Africa's peatlands. Peatlands are valuable due to the presence of peat stocks within them. Based on the services tested for and the available data, the value of the cumulative services provided by South African peatlands, expressed as ecological infrastructure value, was estimated to be between R174 billion (average), up to as much as R370 billion. This is an order of magnitude higher than the carbon value alone. This value equates to approximately R5.7 million per hectare.

This is a substantial value that must be considered when making decisions on peatland management in South Africa to conserve and sustain the peat and peat-forming conditions within them. South Africa's peatlands are already at risk through various land use practices. These include alterations of water courses and water tables, encroachment of infrastructure, urban and industrial effluent, extraction (peat mining) and agricultural land transformation. These activities degrade peatlands resulting in the exposure and subsequent loss of peat and peat-forming conditions.

The high economic value displayed has illustrated the importance of peatlands in the socio-economic landscape of South Africa. In addition, there is also a major intrinsic value attached to the irreplaceability of these features that cannot be ignored. The loss or degradation of peatlands would result in a major reduction of natural benefits. This investigation highlighted the importance of the protection, sustainable use and maintenance of these natural features.

6.5 Recommendations for Future Research

1. Calculate the peatland change on a catchment scale. The depiction of percentage decrease or increase in peatland area between the old 2001 and new 2014 model should be investigated as a follow-up project.
2. Several peat points have been identified that still need to be verified to confirm these points.
3. Knowledge gaps identified during this project are:
    a. The microbiology (such as bacterial and fungal guilds) of peatlands.
    b. The identification, description and barcoding of phyla (nematodes, spiders, mites and insects) in peatlands.
4. Knowledge generated through this project should guide the conservation of peatlands and build research capacity in the South African wetland/conservation community. For example, assisting in developing recommendations for listing peatlands as a national threatened ecosystem and contribute to future wetland research in South Africa.

5. The investigation into the socio-economic value of peatlands only provided a qualitative snapshot into the value of these natural features. This is what was possible given the limited availability of appropriate data needed to indicate a more accurate and specific quantitative value. Thus, as a way forward, further investigations must take place to quantify services provided using valuation techniques as a framework for the approach. These investigations should specifically focus on obtaining national data on the water quantity and quality regulation, extent of cropping within peatlands and the cultural services provided by peatlands.
    a. The full spectrum of ecosystem services provided by peatlands can then be valued quantitatively as opposed to qualitatively thus allowing for an improved overall understanding of the total value displayed by peatlands in South Africa.
    b. A key way forward from the results described above would be towards informed decision-making processes involving the use and development of environmental and water resources.
    c. Currently, the key regulatory instrument used for allocating water resources is water use licences. Although effective in identifying and quantifying both negative and positive impacts on social, economic and environmental parameters, these methods do not provide a common currency to compare impacts effectively. This is vital when looking at the sustainability of an activity as long-term costs may outweigh short-term benefits. This is especially important when looking at impacts on ecological infrastructure that result in the cumulative cost of the reduced ability to provide ecosystem services.
    d. Understanding the value of ecosystem services, described in socio-economic terms, will result in internalising all environmental risks thus informing the feasibility of a proposed activity. Comparing the (typical) direct socio-economic consequences of an activity with the socio-economic implications, into perpetuity, arising from impacted ecosystem services, will empower sustainable policy development and decision-making.
    e. The socio-economic approach to the valuation of ecosystem services used in this peatlands study has been shown to effectively describe the value of ecological infrastructure in socio-economic terms. This linkage allows for a comparative understanding of how all impacts that developments have will affect the socio-economic well-being of a catchment.
6. The peatland ecoregional model may be further verified using data for the wetlands mapped for Mpumalanga (Job, pers. comm., 2014) and the Free State (Collins, pers. comm., 2014). However, as not all wetlands are peatlands, this would have entailed work beyond the scope of this project.

LIST OF REFERENCES

Agus, F., Hairiah, K., and Mulyani, A. 2011. Measuring Carbon Stock in Peat Soils: Practical Guidelines. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program, Indonesian Centre for Agricultural Land Resources Research and Development. 60p.

Anderson, M.P., and Woessner, W.W. 1992. Applied Groundwater Modeling. San Diego, CA: Academic Press.

Arman, N.Z., Salmiati, Said, M.I., Azman, S., Azuri, S., and Safeai, M. 2012. Benthic Macroinvertebrates as an Alternative Tool for Biological Monitoring in Assessing River Water Quality. *International Proceedings of Chemical, Biological and Environmental Engineering*. 35: 52-56.

Ashton, P.J., Hardwick, D., and Breen, C. 2008. Changes in Water Availability and Demand within South Africa’s Shared River Basins as Determinants of Regional Social and Ecological Resilience. Chapter 9 in: Exploring Sustainability Science: a southern African perspective. M. Burns and A. (eds). SUNPress, Stellenbosch.

Avnimelech, Y., Ritvo, G., Meijer, L., and Kochba, M. 2001. Water Content, Organic Carbon and Dry Bulk Density in Flooded Sediments. *Aquacultural Engineering*. 25: 25-33.

Azrina, M.Z., Yap, C.K., Rahim Ismail, A., Ismail, A., and Tan, S.G. 2006. Anthropogenic Impacts on the Distribution and Biodiversity of Benthic Macroinvertebrates and Water Quality of the Langat River, Peninsular Malaysia. *Ecotoxicology and Environmental Safety*. 64: 337-347.

Baa-Poku, J., Asante, F., and Amakye, S. 2013. Impact of Urban Effluents on the Macroinvertebrates of a Creek in Accra, Ghana. *West African Journal of Applied Ecology*. 21: 97-109.

Baartman, L. 1997. Plant Species Composition on Peatlands in Maputaland, KwaZulu-Natal. Council for Geosciences Geological Survey, Pretoria.

Baker, A., Routh, J., Blaauw, M., and Roychoudhury, A.N. 2014. Geochemical Records of Palaeoenvironmental Controls on Peat-Forming Processes in the Mfabeni Peatland, KwaZulu-Natal, South Africa Since the Late Pleistocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 395: 95-106.

Ballhorn, B., Siegert, F., Mason, M., and Limin, S. 2009. Derivation of Burn Scar Depths and Estimation of Carbon Emissions of Carbon Emissions with LIDAR in Indonesian Peatlands. *Proceedings of the National Academy of Sciences*. 106: 21213-21218

Barber, K.E. 1993. Peatlands and Scientific Archives of Biodiversity. *Biodiversity and Conservation*. 2: 474-489.

Barber, K.E., Maddy, D., Rose, N., Stevenson, A.C., Stoneman, R.E., and Thompson, R. 2000. Replicated Proxy-climate Signals Over the Last 2000 Years from Two Distant UK Peat Bogs: New Evidence for Regional Palaeoclimate Teleconnections. *Quaternary Science Reviews*. 18: 471-479.

Battarbee, R.W., Gasse, F., and Stickley, C.E. 2004. Past Climate Variability through Europe and Africa. Netherlands: Springer Science & Business Media.

Bikorimana, D. 2014. Rwanda Prepares to Switch on Africa’s First Peat Fired Power Plant. KT Press. Accessed on 15 September 2015. Available: [http://www.prnewswire.com/news-releases/rwanda-prepares-to-switch-on-africas-first-peat-fired-power-plant-reports-kt-press-350348778.html].

Birks, H.J.B., and Birks, H.H. 1980. Quaternary Palaeoecology. London: Edward Arnold.

Blignaut, J. 2012. Restoring the Natural Landscape on Sustainable Rural Employment and Land Productivity through Payment for Environmental Services. Deliverable 14. Water Research Commission, Report No. K5/1803, Water Research Commission, Pretoria.

Bootsma A. 2015. Natural Mechanisms of Erosion Prevention and Stabilization in a Marakele Peatland: Implications for Conservation Management. MSc Thesis. In Progress, University of South Africa.

Booyens, Y. 2012. Mushroom Industry has Option to Stop Depleting Natural Resources. *Creamer Media's Engineering News*. Accessed on 24 November 2015. Available: [http://www.engineeringnews.co.za/print-version/mushroom-industry-has-the-option-to-stop-depleting-natural-resources-2012-08-10].

Borger, G.J. 1992. Draining-digging-dredging: The Creation of a New Landscape in the Peat Areas of the Low Countries. In: Verhoeven JTA, ed. Fens and Bogs in The Netherlands: Vegetation, History, Nutrient Dynamics and Conservation. Dordrecht: Kluwer Academic Publishers. 131-172.

Botha, G., and Porat, N. 2007. Soil Chronosequence Development in Dunes on the Southeast African Coastal Plain, Maputaland. South Africa. *Quaternary International*. 162-163: 111-132. doi:10.1016/j.quaint.2006.10.028.

Brothwell, D. 1986. The Bog Man and the Archaeology of People. London: British Museum Press, Cambridge: Harvard University Press.

Brown, P.A., Gill, S.A., and Allen, S.J. 2000. Metal Removal from Wastewater using Peat. *Water Research*. 34: 3907-3916.

Burgoyne, P.M., Bredenkamp, G.J., and Van Rooyen, N. 2000. Wetland Vegetation in the North-eastern Highveld, Mpumalanga South Africa. *Bothalia.* 30.2: 187-200.

Chaudhari, P.R., Ahire, D.V., Ahire, V.D., Chkravarty, M., and Maity, S. 2013. Soil Bulk Density as Related to Soil Texture, Organic Matter Content and Available Total Nutrients of Coimbatore Soil. *International Journal of Scientific and Research Publications*. 3: 1-8.

Coggins, A.M., Jennings, S.G., and Ebinghaus, R. 2005. Accumulation Rates of the Heavy Metals Lead, Mercury and Cadmium in Ombrotrophic Peatlands in the West of Ireland. *Atmospheric Environment*. 40: 260-278.

Collins, N. 2014. Pers. comm. (CollinsN@detea.fs.gov.za).

Cooper, S.D., Lake, P.S., Sabater, S., Melack, J.M., and Sabo, J.L. 2006. The Effects of Land Use Changes on Streams and Rivers in Mediterranean Climates. *Hydrobiologia*. 719: 383-425.

Corner, E.J.H. 1978. The Freshwater Swamp-forest of South Jahore and Singapore. Gardens Bulletin Singapore. 1: 1-26 In Posa, M.-R.C., Wijedasa, L.S., Corlett, R.T. 2011. *Biodiversity and Conservation of Tropical Peat Swamp Forests. Bioscience*. 61: 49-57.

Council for Geoscience (CGS). 2014. Geology Spatial Data Geological Map of South Africa. Council for Geoscience, Pretoria.

De Groot, R., Brander, L., Van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., Ten Brink, P., and Van Beukering, P. 2012. Global Estimates of the Value of Ecosystems and their Services in Monetary Units. *Ecosystem Services.* 1: 50-61.

Department of Water Affairs and Forestry (DWAF). 1986. Department of Water Affairs: Management of the water resources of southern Africa. Government Printers, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2005. A Practical Field Procedure for Identification and Delineation of Wetland and Riparian Areas. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2014. Springs Vector Data File. Department of Water Affairs and Forestry, Pretoria.

Dickens, C.W.S., and Graham, P.M. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *African Journal of Aquatic Science*. 27: 1-10.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C., and Wisniewski, J. 1994. Carbon Pools and Flux of Global Forest Ecosystems. *Science*. 263: 185-190

Dwyer, R., Mitchell, F.J.G. 1997. Investigation of the Environmental Impact of Remote Volcanic Activity on North Mayo Ireland During the mid-Holocene. *Holocene*. 7: 113-118.

Elshehawi, S. 2015. Ecohydrological Assessment and Peat Development of Two South African Peatlands: Understanding the Hydrological Systems of Matlabas and Vazi-North Peatlands. MSc Thesis. University of Groningen, Netherlands.

Erdal, S. 2012. Organic Carbon Organic Matter and Bulk Density Relationships in Arid Semi-Arid Soils in Southeast Antolia Region. *African Journal of Biotechnology*. 11: 1373-1377.

Ewart-Smith, J.L, Ollis, D.J., and Day, J.A. 2006. National Wetland Inventory: Development of a Wetland Classification System for South Africa. WRC Report No. KV 174/06. Water Research Commission, Pretoria.

Federal Highway Administration (FHWA). 2013. Highway Statistics 2011. Office of Highway Policy Information, Federal Highway Administration. Table VM-1.

Frolking, S., Roulet, N.T., and Fuglestvedt, J., 2006. How Northern Peatlands Influence the Earth's Radiative Budget: Sustained Methane Emission versus Sustained Carbon Sequestration. *Journal of Geophysical Research*. 111.

Gabriel, M. Undated. Genesis, Substrates and Properties Exemplified by the Region "Greater Manguzi": A Basis for Adequate Recommendations on Sustainable Farming and Restoration. Unpublished PhD Dissertation. Hümboldt Universität zu Berlin, Germany.

Gertenbach, W.P.D. 1983. Landscapes of the Kruger National Park. *Koedoe*, 26, 9–121.

Gillson, L., and Duffin, K.I. 2010. Thresholds of Potential Concern as Benchmarks in the Management of African Savannahs. *Philosophical Transactions of the Royal Society B*. 362: 309-319.

Ginsburg, A., Mitchell, S., Breen, C., and Crafford, J. 2011. Development of Effective Ways of Extracting Information from Research to Support Decision Making on Social-Ecological Systems. Water Research Commission, Report No. K5/1978, Water Research Commission, Pretoria.

Godwin, H. 1981. The Archives of the Peat Bogs. Cambridge: Cambridge University Press.

Gorham, E. 1991. Northern Peatlands: Role in the Carbon Budget and Probable Responses to Global Warming. *Ecological Applications.* 1: 182-195.

Grobler, L.E.R. 2009. A Phytosociological Study of Peat Swamp Forest in the Kosi Bay Lake System, Maputaland, South Africa. MSc Thesis. University of Pretoria.

Grootjans, A.P., Grundling, P.-L., Grundling, A. Linström, A. Engelbrecht, J., and Price, J.S. 2010. Spring Mires Fed by Hot Artesian Water in Kruger National Park, South Africa. *Mires and Peat*. 6: 1-10.

Grundling, A.T., Van den Berg, E.C., and Pretorius, M.L. 2014. Influence of Regional Environmental Factors on the Distribution, Characteristics and Functioning of Hydrogeomorphic Wetland Types on the Maputaland Coastal Plain, KwaZulu-Natal, South Africa. Water Research Commission, WRC Report No. 1923/1/13. Water Research Commission, Pretoria.

Grundling, P. 2002. The Quaternary Peat Deposits of Maputaland, Northern KwaZulu-Natal, South Africa: Categorization, Chronology, and Utilization. MSc Thesis. Rand Afrikaanse Universiteit, Johannesburg.

Grundling, P. 2007. Some Notes on Wetland and Peatland Hydrology. PhD student paper. University of Waterloo, Canada.

Grundling, P. 2014. Genesis and Hydrological Function of an African mire: Understanding the Role of Peatlands in Providing Ecosystem Services in Semi-arid Climates. PhD Dissertation, University of Waterloo, Canada.

Grundling P., Grootjans A.P., Clulow, A.D., and Price, J. S. In Press. *Peat surface oscillation on an African peatland: mitigating the impact of a changing environment.*

Grundling, P., and Blackmore, A. 1998. Peat Fire in the Vazi Pan Peatland, Manzengwenya Plantation. Report no.: 1998-0208, Council of Geoscience, Pretoria.

Grundling, P., Mazus, H., and Baartman, L., 1998. Peat Resources in Northern KwaZulu-Natal Wetlands: Maputaland. Department of Environmental Affairs and Tourism Report no. A25/13/2/7. 102.

Grundling P.-L., Baartman L., and Mazus, H. 2000. Peat Resources of KwaZulu-Natal Wetlands: Southern Maputaland and the North and South Coast (Council for Geoscience Report 2000-0132). Pretoria: Department of Environmental Affairs and Tourism.

Grundling, P.-L., and Grobler, R. 2005. Peatlands and Mires of South Africa. Stapfia 85, zugleich Kataloge der Oö', Landesmuseen Neue Serie 35: 379-396.

Grundling, P.-L., 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.-L., Linström, A., Pretorius, M. L., Bootsma, A., Job, N., Delpoort, L., Elshehawi, S., Grootjans, A., Grundling, A., and Mitchell, S. 2015a. Investigation of Peatland Characteristics and Processes as well as Understanding of their Contribution to the South African Wetland Ecological Infrastructure. Deliverable 2: Progress Report. Water Research Commission. Report No: KSA 2: K5/2346. Water Research Commission, Pretoria.

Grundling, P.-L., Linström, A., Pretorius, M. L., Bootsma, A., Job, N., Delpoort, L., Elshehawi, S., Grootjans, A., Grundling, A., and Mitchell, S. 2015b. Investigation of Peatland Characteristics and Processes as well as Understanding of their Contribution to the South African Wetland Ecological Infrastructure. Deliverable 3: Progress Report. Water Research Commission. Report No: KSA 2: K5/2346. Water Research Commission, Pretoria.

Grundling, P.-L., Linström, A., Pretorius, M. L., Bootsma, A., Job, N., Delpoort, L., Elshehawi, S., Grootjans, A., Grundling, A., and Mitchell, S. 2015c. Investigation of Peatland Characteristics and Processes as well as Understanding of their Contribution to the South African Wetland Ecological Infrastructure. Deliverable 4: Progress Report. Water Research Commission. Report No: KSA 2: K5/2346. Water Research Commission, Pretoria.

Grundling, P.-L., and Marneweck, G. 1999. Mapping, Characterisation and Monitoring of the Highveld Peatlands: Compilation of Existing Data and Evaluation of Inventory Methodology. Wetland Consulting Services (Pty) Ltd. Report to the Institute for Soil, Climate and Water (ISCW), Agricultural Research Council for the Directorate for Land and Resources Management (DLRM), Department of Agriculture, and Pretoria. WCS Report No: 28/99. Water Research Commission, Pretoria.

Grundling, P.-L., and Marneweck, G. 2000. Proposed Rehabilitation of the Railway at the Poort Section in the Colbyn Valley Wetland (Slope Failure at 8,8 km Hartbeesfontein – Koedoespoort), Preliminary Wetland Study, Wetland Consulting Services (Pty.) Ltd., Reference: COL 01/35/2000.

Grundling, P.-L. 2015. Personal Correspondence: Piet-Louis Grundling, Deputy Director: Programme Implementation, NRM wetlands Programme, DEA.

Haigh, E.A., Grundling, P.-L., and Illgner, P. M., 2002. Report on the Scoping Study on the Status of the Kromme River Peatland Complex and Recommended Mitigatory Measures. Department of Water Affairs and Forestry, Pretoria.

Hatté, C. & Schwartz, D. 2003. Reconstruction of paleoclimates by isotopic analysis: What can the fossil isotopic record tell us about the plant life of past environments? *Phytochemistry Reviews*. 2(1):163–177.

Heathwaite, A.L., Gottlich, K., Burmeister, E.G., Kaule, G., and Grospietsch, T. 1993. Mires: Definitions and Form. In A.L. Heathwaite and K. Gottlich (eds), Mires: Process, Exploitation and Conservation. John Wiley & Sons.

Hemond, H.F., and Benoit, J. 1988. Cumulative Impacts on Water Quality Functions of Wetlands. *Environmental Management*. 12: 639-653.

Henry, M., Valentini, R., and Bernoux, M. 2009. Soil Carbon Stocks in Ecoregions of Africa. *Bioscience Discussions*. 6: 797-823.

Hobday, D.K., and Orme, A.R. 1979. The Port Dunford Formation: A Major Pleistocene Barrier Lagoon Complex Along the Zululand Coast. *Transactions of the Geological Society of South Africa*. 77: 141-149.

Holden, J. 2005. Peatland Hydrology and Carbon Release: Why Small-scale Process Matter. *Philosophical Transactions of the Royal Society*. A 363, 2891-2913.

Holden, J., Chapman, P., Evans, M., Hubacek, K., Kay, P., and Warburton, J. 2007. Vulnerability of Organic Soils in England and Wales. Final Technical Report to DEFRA and the Countryside Council for Wales.

Holness, S. 2015. Personal Correspondence: Stephen Holness, Sanbi Co-Author of “South African Wetland Offset Guidelines.”

Hooijer, A., Silvius, M., and Wösten, H. 2006. Peat-CO_2, Assessment of CO_2 Emissions from Drained Peatlands in SE Asia. Delft, The Netherlands.

Immirzi, C.P., Maltby, E., and Clymo, R.S. 1992. The Global Status of Peatlands and their Role in Carbon Cycling. A Report for Friends of the Earth by the Wetland Ecosystems Research Group, University of Exeter. Report No. 11. Friends of the Earth, London, UK. In: World Energy Council. 2013. World Energy Resources: 2013 Survey. World Energy Council, London.

Intergovernmental Panel on Climate Change (IPCC). 2007. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Eggleston, S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K. (eds). IGES, Japan.

International Peat Society/International Mire Conservation Group (IPS/IMCG). IMCG. 2010. Responsible Peatland Strategy. Draft 4 (final draft for approval). IPS/IMCG Terminology Working Group.

Irving, S.J., and Meadows, M.E. 1997. Radiocarbon Chronology and Organic Matter Accumulation at Vankervelsvlei, Near Knysna, South Africa. *South African Geographic Journal*. 79: 101-105.

Irving, S.J.E. 1998. Late Quaternary Paleoenvironments at Vankervelsvlei, Near Knysna South Africa. Unpublished PhD Thesis. University of Cape Town, Cape Town.

Institute for Water Quality Studies (IWQS). 1998. Electronic Database for the Classification of Ecoregions (Level I) for South Africa Derived from Terrain and Vegetation, with some Consideration of Altitude, Rainfall, Runoff Variability, Air Temperature, Geology, Soil. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

Job, N., and Ellery, W. 2013. Halting Degradation of Southern Cape Peatlands in Agricultural Landscapes. Policy Brief Number 8. Department of Environmental Science, Rhodes University.

Job, N. 2014. Pers. comm. (NancyMJob@gmail.com).

Job, N., and Ellery, W. 2014. Policy Brief. Rhodes University, Grahamstown.

Joosten, H. 2012. The Status and Prospects of Global Peatlands. *Natur and Landschaft*. 87: 50-55.

Joosten, H., and Clarke, D. 2000. Global Guidelines for the Wise Use of Mires and Peatlands. International Mire Conservation Group.

Joosten, H., and Clarke, D. 2002. Wise Use of Mires and Peatlands, International Mire Conservation Group and International Peat Society, Jyväskylä, Finland.

Joosten, H., Tapio-Bistr’m, M-L., and Tol, S. (eds) (2012). Peatlands – guidance for climate change mitigation through conservation, rehabilitation and sustainable use (Second edition). Published by the Food and Agriculture Organization of the United Nations and Wetlands International Mitigation of Climate Change in Agriculture (MICCA) Programme.

Keepile, K. 2010. Mines Must Take ‘Prime Responsibility’ for Acid Drainage. *Mail and Guardian*. Accessed on 29 September 2015. Available: [http://mg.co.za/article/2010-09-07-mines-must-take-prime-responsibility-for-acid-drainage].

Kemp, M., De Kock, K.N., Wepner, V., Roets, W., Quinn, L., and Wolmarans, C.T. 2014. Influence of Selected Abiotic Factors on Aquatic Macroinvertebrate Assemblages in the Olifants River Catchment, Mpumalanga, South Africa. *African Journal of Aquatic Science*. 39: 141-149.

Kleynhans, C.J., Louw, M.D., and Graham, M. 2008. Module G: Ecoclassification and Ecostatus Determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical Manual). Joint Water Research Commission and Department of Water Affairs and Forestry Report. WRC Report No. TT 377/08. Pretoria.

Kleynhans, C.J., Thirion, C., and Moolman, J. 2005. A Level I River Ecoregion Classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria.

Kotze, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S., and Collins, N.B. 2009. WET-EcoServices: A Technique for Rapidly Assessing Ecosystem Services Supplied by Wetlands. WRC Report No. TT 339/08, Water Research Commission, Pretoria.

Kotze, D. 2015. A Survey of Organic Soils in the Upper Riviersonderend Catchment. Compiled for WWF, South Africa. Unpublished.

Kruger, F.J., van Wilgen, B.W., Weaver, A.V.B., and Greyling, T. 1997. Sustainable Development and the Environment: Lessons from the St Lucia Environmental Impact Assessment. *South African Journal of Science*. 93: 23-33.

Land Type Survey Staff. 1972-2006. Land Types of South Africa (Digital Map – 1: 250 000 Scale and Soil Inventory Databases). Agricultural Research Council – Institute for Soil Climate and Water, Pretoria.

Lappalainen, E. 1996. Global Peat Resources. International Peat Society, Finland

Lazenby, H. 2010. Scarce Peat Conserved. *Creamer Media's Engineering News*. Accessed on 30 November 2015. Available: [http://www.engineeringnews.co.za/article/scarce-south-african-peat-conserved-2010-08-06].

Lee, H.S., and Chai, F. 1996. Production Functions of Peat Swamp Forests in Sarawak. In: Maltby, E., Immirzi, C.P., and Safford, R.J., (eds): Tropical Lowland Peatlands of Southeast Asia. IUCN, Gland, Switzerland. 129-136.

Lindholm, M., and Eronen, M. 2000. A Reconstruction of Mid-Summer Temperatures from Ring-Widths of Scots Pine Since AD 50 in Northern Fennoscandia. *Geografiska Annaler*. 82: 527-535.

Lindstrom, A., Grundling, P., and Rossouw, P.S. 2014. A Basic Broad-scale Assessment of Lakenvlei Wetlands and its Carbon Capacity: Draft Report. International Crane Foundation/Endangered Wildlife Trust Partnership, South Africa.

Low, A.B., and Rebelo, A.G. (eds) 1996. Vegetation of South Africa, Lesotho and Swaziland. Pretoria.

Malherbe, J. 2014. Rainfall Grids. Agricultural Research Council – Institute for Soil, Climate and Water, Pretoria.

Malmer, N., Svensson, G., and Wallén, B. 1997. Mass Balance and Nitrogen Accumulation in Hummocks on a South Swedish Bog during the Late Holocene. *Ecography*. 20: 535-549.

Marneweck, G.C., Grundling, P.-L., and Grundling, A.T. 1999. An Environmental Plan for the Protection Maintenance and Wise-Use of Wetlands on the Steenkampsberg Plateau. Wetland Consulting Services (Pty) Ltd.

Marneweck, G.C., Grundling, P.-L., and Müller, J.L. 2001. Defining and Classification of Peat Wetland Eco-Regions in South Africa, Wetland Consulting Services (Pty) Ltd. Report to the Institute for Soil, Climate and Water (ISCW), Agricultural Research Council for the Directorate for Land and Resources Management (DLRM), Department of Agriculture, Pretoria.

McCarthy, T.S., and Venter, J. S. 2006. Increasing Pollution Levels on the Witwatersrand Recorded in the Peat Deposits of the Klip River Wetland. *South African Journal of Science*. 102: 27-35.

McCarthy, T.S., Ellery, W.N., Backwell, L., Marren, P., De Klerk, B., Tooth, S., Brandt, D., and Woodborne, S. 2010. The Character, Origin and Palaeoenvironmental Significance of the Wonderkrater Spring Mound, South Africa. *Journal of African Earth Science*. 58: 115-126.

Meadows, M.E. 1988. Late Quaternary peat accumulation in South Africa. *Catena*. 15(5): 459-472.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being: Synthesis. Washington: Island Press.

Mitsch, W.J., and Gosselink, J.G., 1993. Wetlands, 2nd ed. New York, NY: John Wiley.

Moreno, NG., Kollmann, J., Scott, D., and Silva, J. 2016. Socio-Economic Characteristics of Manguzi Traditional Community as a Pre-requisite for Conservation, Restoration and Wise Use of Wetlands. Technische Universitaet Muenchen (Unpublished).

Mucina, L., and Rutherford, M.C. 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South Africa National Biodiversity Institute, Pretoria.

Mulders, J.A. 2015. The Effects of Land Use Change on Benthic Macroinvertebrates in the Upper Reaches of the Apies-Pienaar Catchment. Unpublished Master's Thesis. University of Pretoria, Pretoria.

Müller-Wille, M., 1999. Opferkulte der Germanen und Slawen, Opfer- und Hortfunde in Mooren. -1. Aufl., 102 S., 109 Abb.; TheissVerlag, Stuttgart In*:* Joosten, H., and Clarke, D. 2002. Wise Use of Mires and Peatlands, International Mire Conservation Group and International Peat Society, Jyväskylä, Finland.

National Wetlands Working Group. 1997. The Canadian Wetland Classification System. 2nd ed. University of Waterloo, Waterloo, Ontario.

Ng, P.K.L., Tay, J.B., and Lim, K.K.P. 1994. Diversity and Conservation of Blackwater Fishes in Peninsular Malaysia, Particularly in the North Selangor Peat Swamp Forest. *Hydrobiologia*. 285: 203-218.

O'Leary, M.H. 1981. Carbon isotope fractionation in plants. *Phytochemistry*, 20:553-567.

Ollis, D.J., Snaddon, C.D., Job, N.M., and Mbona, N. 2013. Classification System for Wetlands and Other Aquatic Ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria.

Paappanen, T., Leinonen, A., and Hillebrand, K. 2006. Fuel Peat Industry in EU, Research Report, VTT-R-00545-06.

Page, S.E., Rieley, J.O., Shotyk, O.W., and Weiss, D. 1999. Interdependence of Peat and Vegetation in a Tropical Peat Swamp Forest. *Philosophical Transactions of the Royal Society*. 354: 1885-1897.

Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M., and Stringer, L. (eds). 2008. Assessment on Peatlands, Biodiversity and Climate Change: Main report. Kuala Lumpur: Global Environment Centre; Wageningen: Wetlands International, 179.

Parrott, L., and Kok, R. 2000. Incorporating Complexity in Ecosystem Modelling. Complexity International. 7.

Parsons, R.P. 2014. Quantifying the role of groundwater in sustaining Groenvlei, a shallow lake in the southern Cape region of South Africa. PhD thesis, Institute for Groundwater Studies, University of the Free State, Bloemfontein.

Partridge, T.C., De Menocal, P.B., Lorentz, S.A., Paikar, M.J., and Vogel, J.C. 1997. Orbital Forcing of Climate Over South Africa: a 200 000-year rainfall record from the Pretoria Saltpan. Quaternary Science Reviews. 16: 1-9.

Perelo, L.W. 2010. Review: In Situ and Bioremediation of Organic Pollutants in Aquatic Sediments. *Journal of Hazardous Materials*. 177: 8-19.

Perie, C., and Ouimet, R. 2007. Organic Carbon, Organic Matter and Bulk Density Relationships in Boreal Forest Soils. *Canadian Journal of Soil Science*.

Phillips, V.D. 1990. Peatswamp Ecology and Sustainable Development in Borneo. *Biodiversity and Conservation*. 7: 651-671.

Pilcher, J.R., Hall, V.A., and McCormac, F.G. 1995. Dates of Holocene Icelandic Volcanic Eruptions from Tephra layers in Irish Peats. *The Holocene*. 5: 103-110.

Potgieter, Renè. 2004. Pers. comm. (Portion 6 of the Farm Gerhard Minnebron, Potchefstroom).

Pretorius, M.L. 2011. A Vegetation Classification and Description of Five Wetland Systems and their Respective Zones on the Maputaland Coastal Plain. MSc Thesis. University of South Africa. Pretoria.

Pretorius, M.L., Brown, L.R., Bredenkamp, G.J., and Van Huyssteen, C.W. 2014. The Ecology and Species Richness of the Different Plant Communities within Selected Wetlands on the Maputaland Coastal Plain, South Africa. In: Oscar Grillo (Ed.), Biodiversity – The Dynamic Balance of the Planet, ISBN: 978-953-51-1315-7, InTech.

Price, J.S., and Schlotzhauer, M. 1999. Importance of Shrinking and Compression in Determining Water Storage changes in Peat: The Case of a Mined Peatland. *Hydrological Processes*. 13: 2591-2601.

Quick, L.J. 2013. Late Quaternary Paleoenvironments of the Southern Cape: Palynological Evidence from Three Coastal Wetlands. Unpublished PhD Thesis. University of Cape Town, Cape Town.

Reddy, K.R., and DeLaune, R.D. 2008. Biochemistry of Wetlands: Science and Applications. Boca Raton, FL: CRC Press, Taylor and Francis Group.

Ringquist, L., and Oeborn, I. 2000. Copper and Zinc Adsorption onto Poorly Humified Sphagnum and Carex Peat. *Water Research*. 36: 2233-2242.

Ringquist, L., Holmgren, A., and Oeborn, I. 2001. Poorly Humified Peat as an Adsorbent for Metals in Wastewater. Water Research. 36: 2394-2404.

Roets, W. 2008. Groundwater dependence of aquatic ecosystems associated with the Table Mountain Group Aquifer. PhD thesis, University of the Western Cape, Cape Town.

Rogers, F.E.J. 1983. Wetlands as Accreting Systems: Wastewater Treatment. *Journal of the Limnological Society of South Africa*. 9: 110-116.

Rosskopf, Niko. 2014. Pers.comm. (rosskopf.niko@gmail.com).

Roulet, N. 1990. The Hydrological Role of Peat-covered Wetlands. *Canadian Geographer*. 34: 82-83.

Rydin, H., and Jeglum, J.K. 2006. The Biology of Peatlands. Oxford University Press.

Safi, M. 2006. A Study of the Regional Pollution Patterns in the Upper Klip River Catchment (Lenasia area) Using Peat Profiles. B.Sc. (Hons) project, University of the Witwatersrand, Johannesburg.

Sandler, R. 2012. Intrinsic Value, Ecology, and Conservation. Nature Education Knowledge. 3:4.

Scott, L. 1989. Climatic conditions in Southern Africa since the Last Glacial Maximum, inferred from pollen analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology.* 70: 345-353.

Scott, L**.** 1993 Palynological evidence for late Quaternary warming episodes in Southern Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 101: 229-235.

Sheoran, A.S., and Sheoran, C. 2006. Heavy Metal Removal Mechanism of Acid Mine Drainage in Wetlands: A Critical Review. *Minerals Engineering.* 19: 105-116.

Shotyk, W., Norton, S.A., and Farmer, J.G. 1997. Peat Bog Archives of Atmospheric Metal Deposition. *Water, Air, and Soil Pollution*. 100: 213-413.

Sieben, E.J.J. 2012. Plant Functional Composition and Ecosystem Properties: The Case of Peatlands in South Africa. *Plant Ecology*. 213(5): 809-820.

Smuts, W.J. 1997. Characteristics of South African Peats: Potential Exploitation. PhD Dissertation. University of Pretoria.

Soil Classification Working Group. 1991. Soil Classification: A Taxonomic System for South Africa. Department of Agriculture, Pretoria.

Soil Survey Staff. 2006. Soil Profile Descriptions and Soil Analyses Data. In ARC-ISCW Soil Profile Information System. ARC-Institute for Soil, Climate and Water, Pretoria.

South African National Biodiversity Institute (SANBI). 2012. Wetland Offset Guidelines Beta Version June.

South African National Biodiversity Institute (SANBI). 2014. A Framework for Investing in Ecological Infrastructure in South Africa. South African National Biodiversity Institute, Pretoria.

South African National Biodiversity Institute (SANBI) and Department of Water and Sanitation (DWS). 2014. Wetland Offsets: A Best Practice Guideline for South Africa. South African National Biodiversity Institute and the Department of Water and Sanitation. First Edition. Pretoria. 53 pages.

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

Strecker, E.W., Kersnar, J.M., Driscoll, E.D., Horner, R.R., and Davcenport, T.E. 1992. The Use of Wetlands for Controlling Stormwater Pollution. The Terrene Institute, Washington, DC.

Thamm, A.G. Grundling, P., and Mazus, H. 1996. Holocene and Recent peat growth rates on the Zululand coastal plain. *Journal of African Earth Sciences*. 23(1): 119-124.

The Economics of Ecosystems and Biodiversity (TEEB). 2010. The Ecological and Economic Foundations.

The Economics of Ecosystems and Biodiversity (TEEB). 2013. The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels; Ramsar Secretariat, Gland.

Toader, C. Undated. Pedologic and Stratigraphic Studies of Two Degraded Peatlands in Maputaland, South Africa. Unpublished MSc Thesis. Hümboldt Universität zu Berlin, Germany.

Turner, R.C., and Scaife, R.G. (eds) 1995. Bog Bodies. New Discoveries and New Perspectives. London: British Museum Press.

United Nations World Tourism Organization (UNWTO), and Ramsar. 2011. Destination Wetlands Report: Tourism and Wetlands. Document SC43-27.

United States Environmental Protection Agency (US EPA). 2013. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. Annex 2: Methodology for estimating CO_2 emissions from fossil fuel combustion. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA. Report No 430-R-13-001.

United States Geological Survey (USGS). 2012. Mineral Industry Surveys: U.S. Peat Producers-2010. U.S. Department of the Interior, U.S. Geological Survey. Accessed on 24 November 2015. Available: [http://minerals.usgs.gov/minerals/pubs/commodity/peat/dir-2010-peat.pdf].

Van Bemmelen, J.W. 1890. Die Zusammensetzung Des Meeresschlic'ks In Den Nuen Alluvien Des Zuiderzee (Niederlande). *Die Landwirtschaftlichen Versuchs-Stationen.* 37: 239-256.

Van der Walt, M. 2015. The Spatial Extent of the Colbyn Valley Peatland and Its Peat Characteristics. Honours research project. University of Pretoria, Pretoria.

Van Roy, S., Vanbroekhoven, K., Dejonghe, W., and Diels, L. 2006. Immobilization of Heavy Metals in the Saturated Zone by Sorption and in situ Bio-precipitation Processes. *Hydrometallurgy*. 83: 195-203.

Van Staden, P.J. 2002. An Ecological Study of the Plant Communities of MNP. MSc Thesis. University of Pretoria, Pretoria.

Van Wyk, A.E., and Smith, G.F. 2001. Regions of Floristic Endemism in Southern Africa. Pretoria: Umdaus Press.

Vegter, J.R. 1995. An Explanation of a Set of National Groundwater Maps. Department of Water Affairs and Forestry, Pretoria.

Vegter, J.R. 2001. Groundwater Development on South Africa and an Introduction to the Hydrogeology of Groundwater Regions. WRC Report No. TT 134/00. Water Research Commission, Pretoria.

Wagner, F., Below, R., De Klerk, P., Dilcher, D.L., Joosten, H., Kürschner, W.M., and Visscher, H. 1996. A Natural Experiment on Plant Acclimation: Lifetime Stomatal Frequency Response of an Individual Tree to Annual Atmospheric CO_2 Increase. *Proceedings of National Academy of Science*. 93: 11705-11708.

Weepener, H.L., Van den Berg, H.M., Metz, M., and Hamandawana, H. (2011). The Development of a Hydrologically Improved Digital Elevation Model and Derived Products for South Africa Based on the SRTM DEM. WRC Report No. K5/1908. Water Research Commission, Pretoria.

Wilde, F. 2011a. Peatlands as Filters for Polluted Mine Water? A Case Study from a Uranium-Contaminated Karst System in South Africa Part I: Hydrogeological Setting and U Fluxes. *Water*. 3: 291-322.

Winter, T.C. 1999. Relation of streams, lakes, and wetlands to groundwater flow systems. *Hydrogeology Journal* 7(1): 28-45.

World Bank Group. 2015. Carbon Pricing Watch 2015. World Bank Group: Climate Change. ECOFYS. Report No 96602.

Wunder, S. 2005. Payments for Environmental Services: Some Nuts and Bolts. CIFOR, Occasional Paper No.42.

Yule, C. M. 2008. Loss of Biodiversity and Ecosystem Functioning in Indo-Malayan Peat Swamp Forests. *Biodiversity Conservation*. 19: 393-409.

APPENDIX 1: GLOSSARY

Bog: a peatland that is influenced solely by water falling directly onto it, e.g. precipitation (Ewart-Smith et al., 2006; Grundling, 2007).

Champagne soil form: contains organic carbon of 10% at 0-200 mm and is saturated for extended periods with water (Soil Classification Working Group, 1991).

Discharge: refers to groundwater that moves upwards across the water table and discharges directly to the surface or unsaturated zone.

Ecosystem service: the benefits people obtain from ecosystems such as provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits (Millennium Ecosystem Assessment, 2005).

Effective recharge: the total recharge minus losses that occur after infiltration to the groundwater.

Fens: peat-forming systems influenced by water derived from outside their immediate limits. Wetlands that commonly receive groundwater discharge (Winter, 1999).

Floodplains: these can be defined as valley bottom areas with a well-defined meandering river system characterised by alluvial transport and deposition of sediment (Ewart-Smith et al., 2006).

Geohydrology: Vegter (2001) defines geohydrology (also hydrogeology) as the field dealing with subsurface water (i.e. water in both the saturated and unsaturated zones).

Groundwater: water in the saturated zone that flows into boreholes/wells or debouches as springs (Vegter, 2001).

High Organic Soil: an organic carbon containing soil not exceeding 10% organic carbon content. Criteria used in this report: high organic soil if only 2% to 9.49% carbon.

Hydrogeomorphic: relates to a classification system; one based on the shape of the land (landform setting) and the patterns of surface and subsurface water flow (Ewart-Smith et al., 2006).

Mire: a term used to indicate living peatlands that actively accumulate peat (IPS/IMCG, 2010).

Peat: defined as a sedimentary (*in situ*) accumulated material that comprises at least 30% (dry mass) of dead organic matter (IPS/IMCG, 2010). A dark brown or black organic soil layer, composed of partly decomposed plant matter and formed under permanently saturated conditions (Ewart-Smith et al., 2006).

Peatland*s:* wetlands that have accumulated a minimum layer of 30 cm of peat (National Wetlands Working Group, 1997; Joosten & Clarke, 2002). Peatlands can be divided into fens, bogs and several swamp types (including swamp forest based on the origin of water supply).

Permanent inundated: surface water (open water) is present throughout the year (Ewart-Smith et al., 2006).

Permanent wetland: a wetland or the inner zone of a wetland that is permanently saturated (DWAF, 2005).

Recharge: the volume of infiltrated water that crosses the water table and becomes part of the groundwater flow system (Anderson & Woessner, 1992).

Runoff: surface runoff occurs when water is unable to infiltrate and when the ground surface is sloping. Surface runoff rate depends on surface slope and roughness, soil moisture content at the surface, as well as on the rates at which additional water is supplied by rainfall and extracted by infiltration or evaporation.

Saturated: as relating to wetland sediments, waterlogged, usually resulting in hydric soils that support vegetation adapted to aquatic conditions (Ewart-Smith et al., 2006).

Seasonal zone of wetness: the zone of a wetland that lies between the temporary and permanent zones and is characterised by saturation for 3-10 months of the year, within 50 cm of the surface (DWAF, 2005).

Seep: concave or convex area that is permanently or periodically saturated, usually on a slope, where the groundwater or inflow meets the surface (Ewart-Smith et al., 2006).

Spring: an outflow of groundwater at the surface (Ewart-Smith et al., 2006).

Temporarily inundated: surface water (open water) is present for less than three months of the year.

Temporary zone of wetness: wetland area characterised by saturation within 50 cm of the soil surface for less than three months of the year, e.g. the outer zone of a wetland (DWAF, 2005).

Terrain units**:** Terrain Unit 1 represents a crest, 2 a scarp, 3 a midslope, 3(1) a secondary midslope, 4 a footslope and 5 a valley bottom.

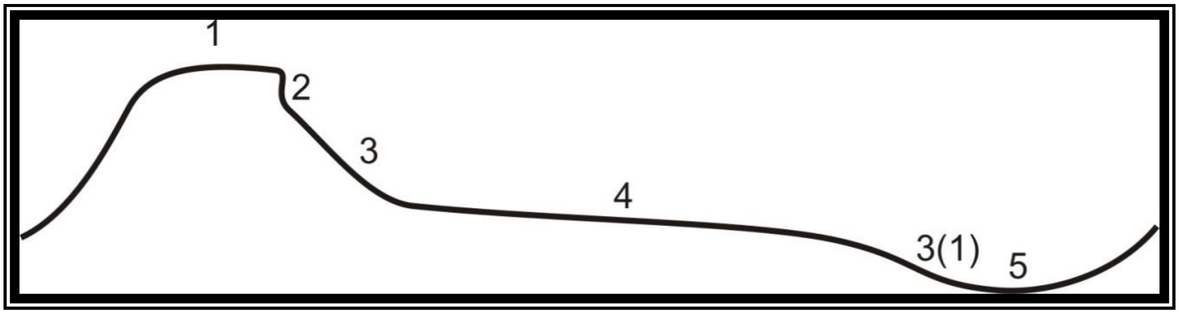


Figure 30: Terrain units

APPENDIX 2: SOUTH AFRICAN PEATLAND DATABASE – ATTRIBUTES RECORDED

*South African Hydropedology Database that includes the peatland database – on CD.

The list of important attributes per site are:

- Wetland name.
- Contact details (for example, Wetlands Consulting and ARC-ISCW).
- Acquisition date (when profile was recorded).
- X-coordinate (Decimal deg./of DD/MM/SS all WGS84).
- Y-coordinate (Decimal deg./of DD/MM/SS all WGS84).
- Peat thickness (m).
- Peat area (ha).
- Wetland type (such as seep, depression, and valley bottom).
- Vegetation cover type (dominant sp.)
- Red data species (presence).
- Land use in wetlands.
- Other impacts (such as drains and erosion).
- Land ownership.
- Comments.
- Scientific information available:
    - Peat profile description and/or photo.
    - Percentage carbon.
    - Water level.
    - pH.
    - Water quality.
    - Palynological studies (pollen).
    - Carbon dating.
    - PES (e.g. wet-health) and EIS (e.g. Kleynhans et al., 2008).

APPENDIX 3: CHAPTER 2 AND CHAPTER 3 MAPS

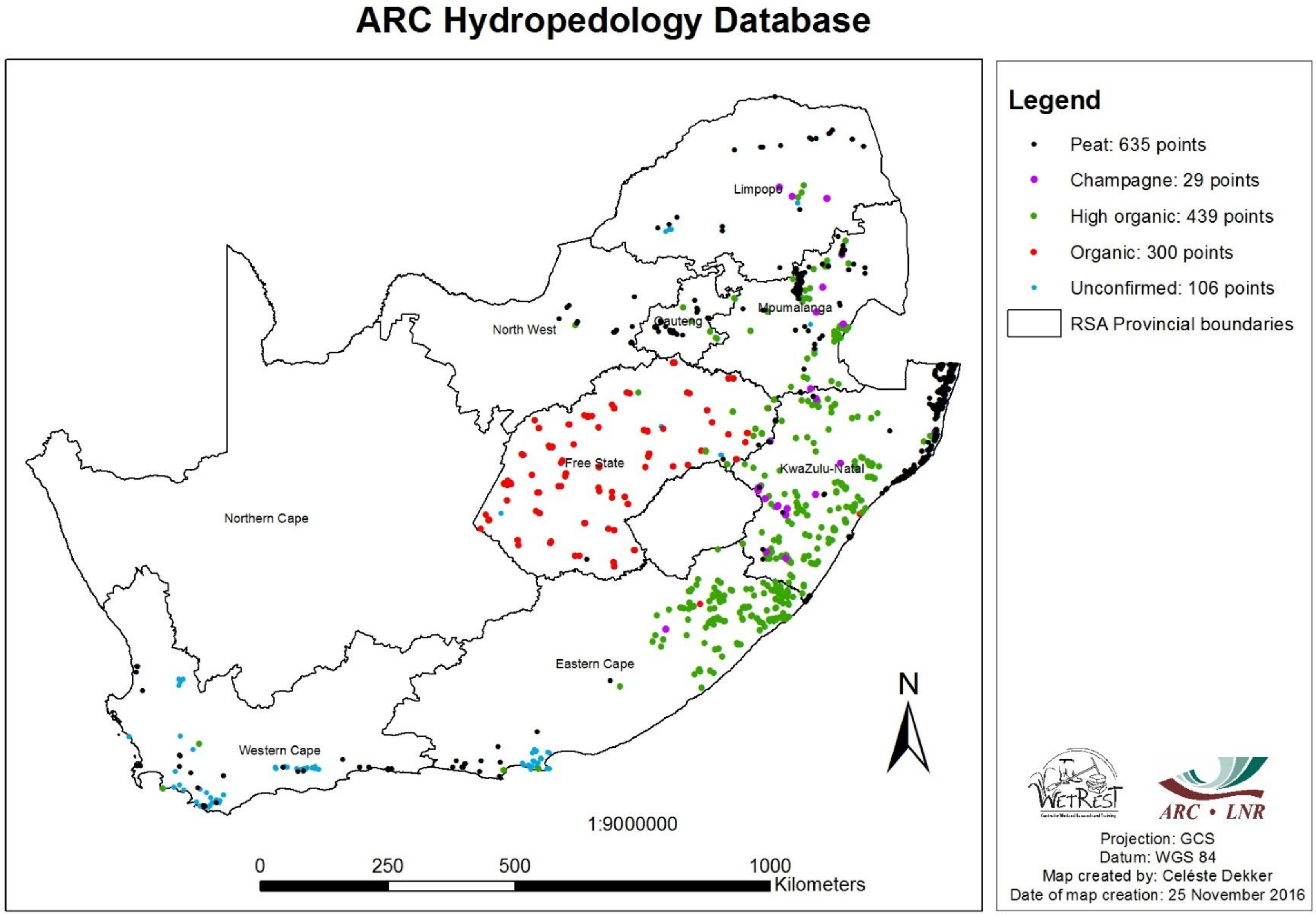
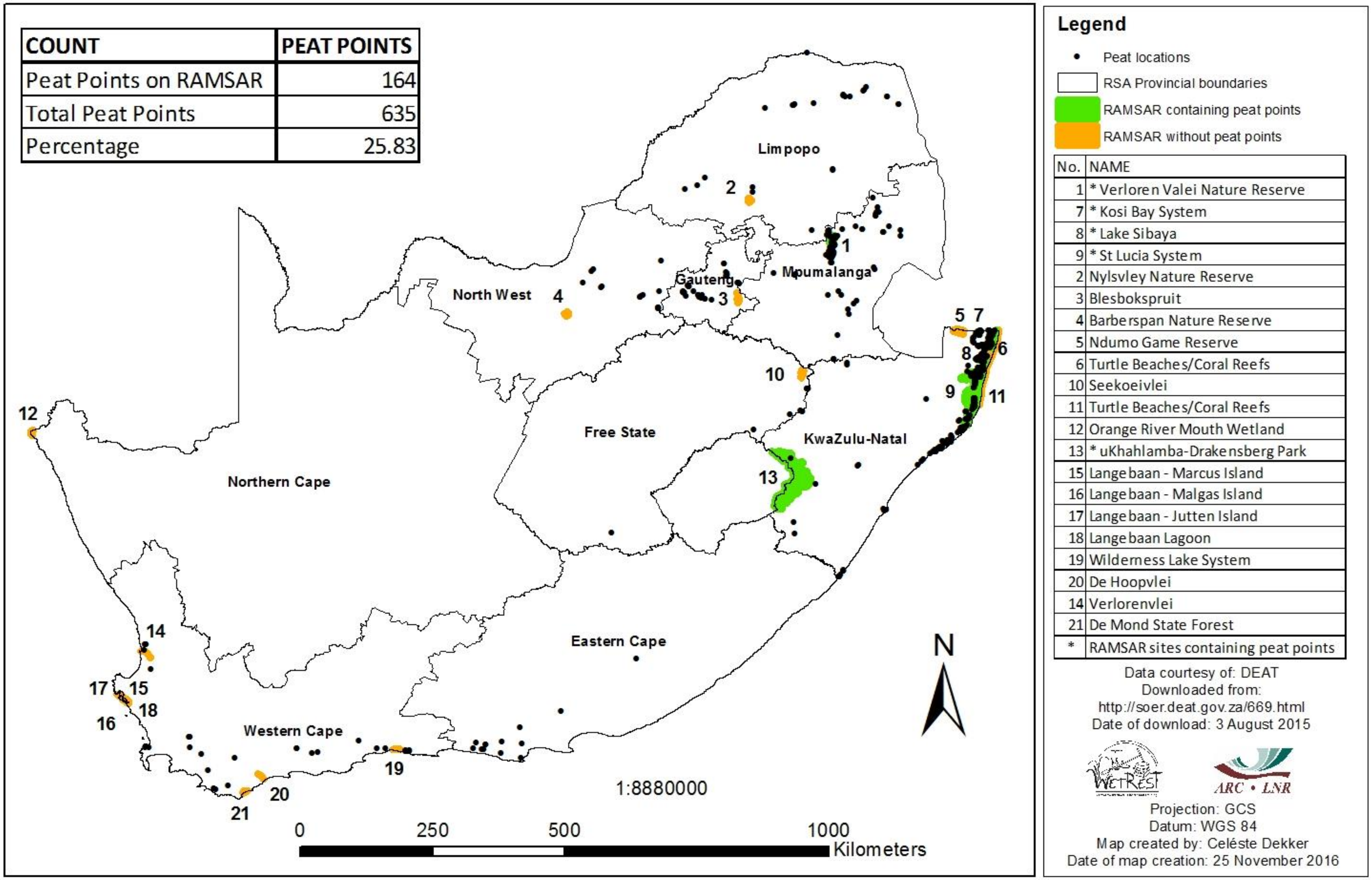


Figure 31: Spatial distribution of records in hydropedology database containing the peatland database

Peatland Eco-Region Model 2016: RAMSAR Sites



COUNT	PEAT POINTS
Peat Points on RAMSAR	164
Total Peat Points	635
Percentage	25.83

No.	NAME
1	* Verloren Valei Nature Reserve
7	* Kosi Bay System
8	* Lake Sibaya
9	* St Lucia System
2	Nylsvley Nature Reserve
3	Blesbokspruit
4	Barberspan Nature Reserve
5	Ndumo Game Reserve
6	Turtle Beaches/Coral Reefs
10	Seekoeivlei
11	Turtle Beaches/Coral Reefs
12	Orange River Mouth Wetland
13	* uKhahlamba-Drakensberg Park
15	Langebaan - Marcus Island
16	Langebaan - Malgas Island
17	Langebaan - Jutten Island
18	Langebaan Lagoon
19	Wilderness Lake System
20	De Hoopvlei
14	Verlorenvlei
21	De Mond State Forest
*	RAMSAR sites containing peat points

Data courtesy of: DEAT
Downloaded from:
http://soer.deat.gov.za/669.html
Date of download: 3 August 2015

Projection: GCS
Datum: WGS 84
Map created by: Celéste Dekker
Date of map creation: 25 November 2016

Figure 32: Location of Ramsar sites with peat points

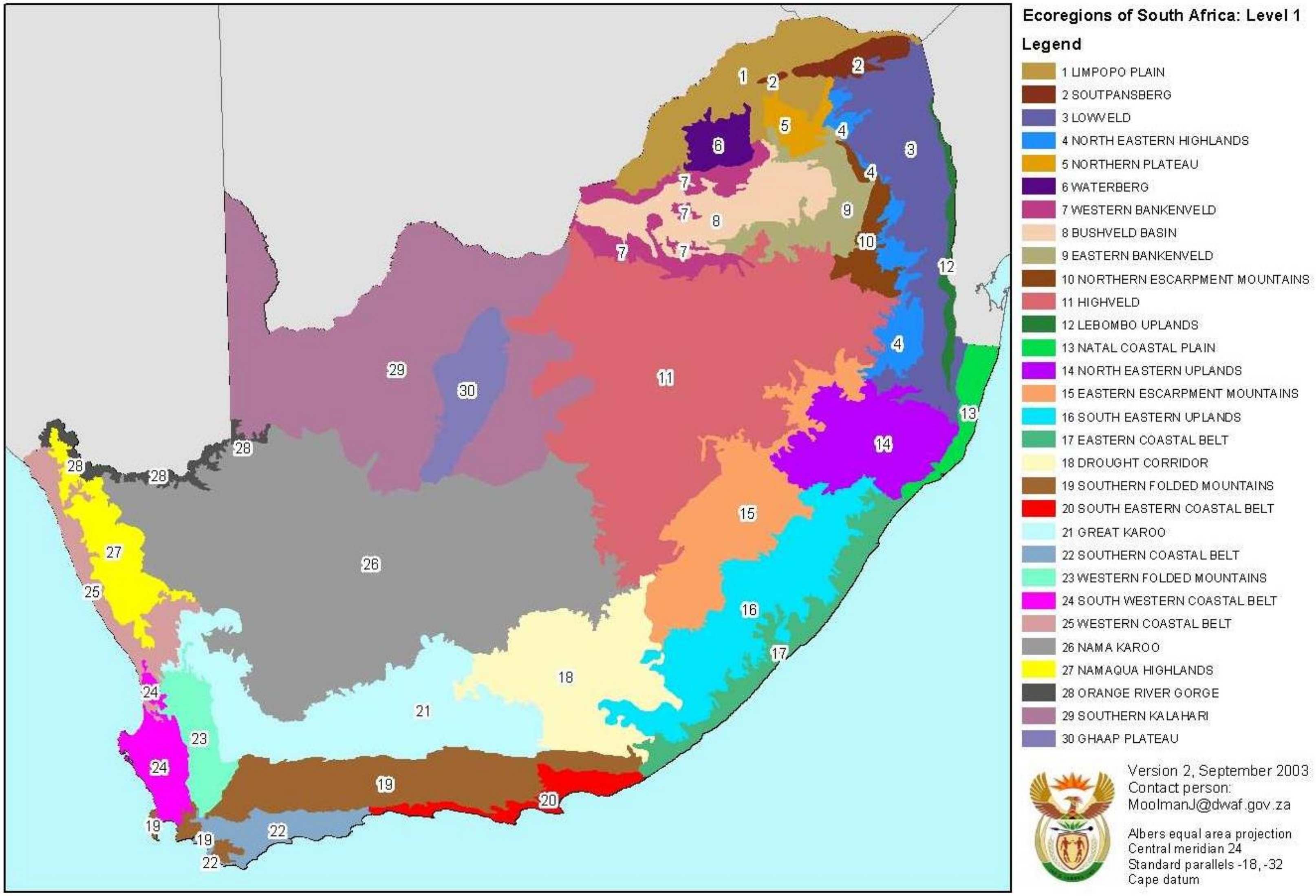


Figure 33: Level 1 ecoregions of South Africa (IWQS, 1998)

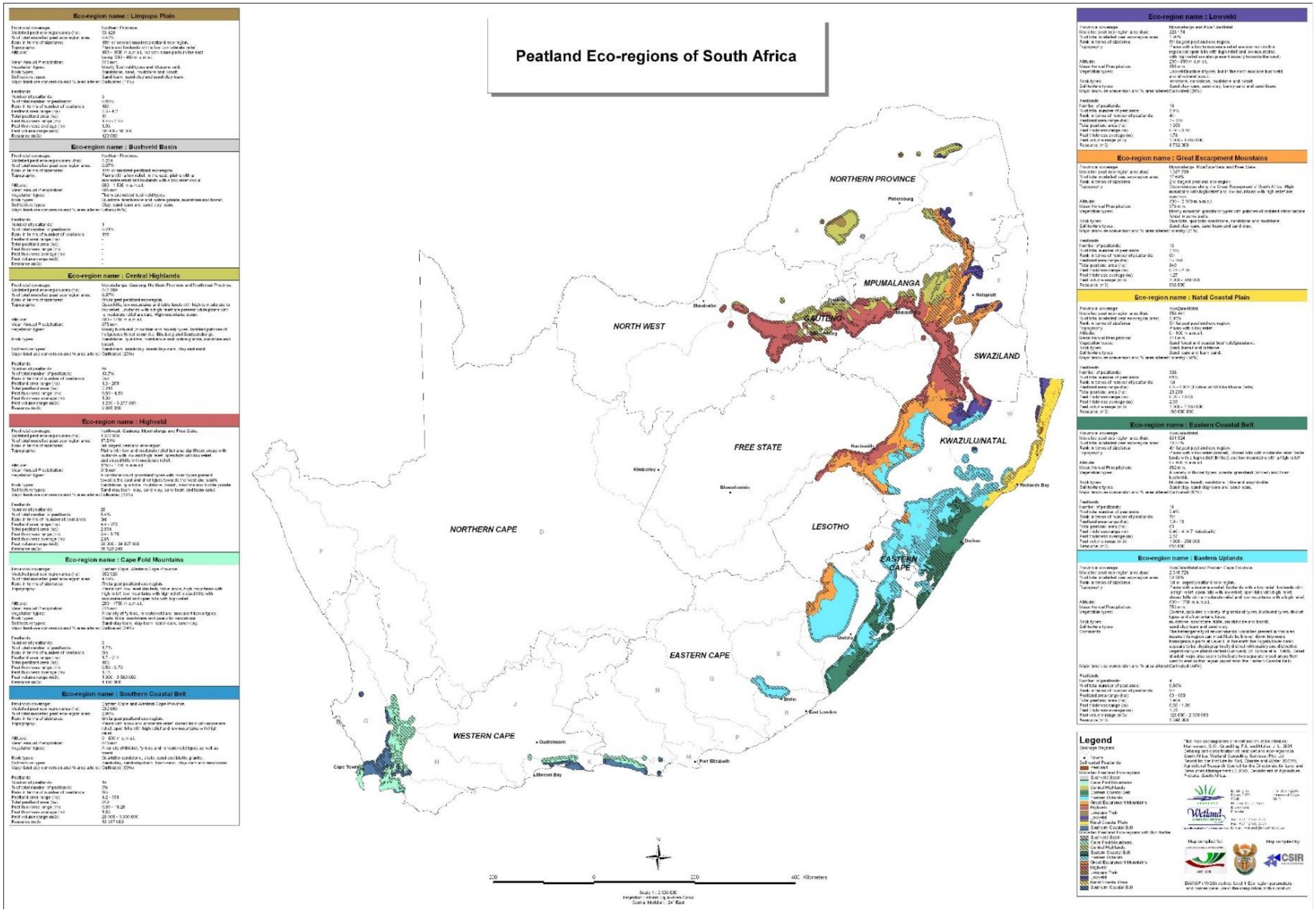


Figure 34: A depiction of the 2001 peatland ecoregion model (Marneweck et al., 2001)

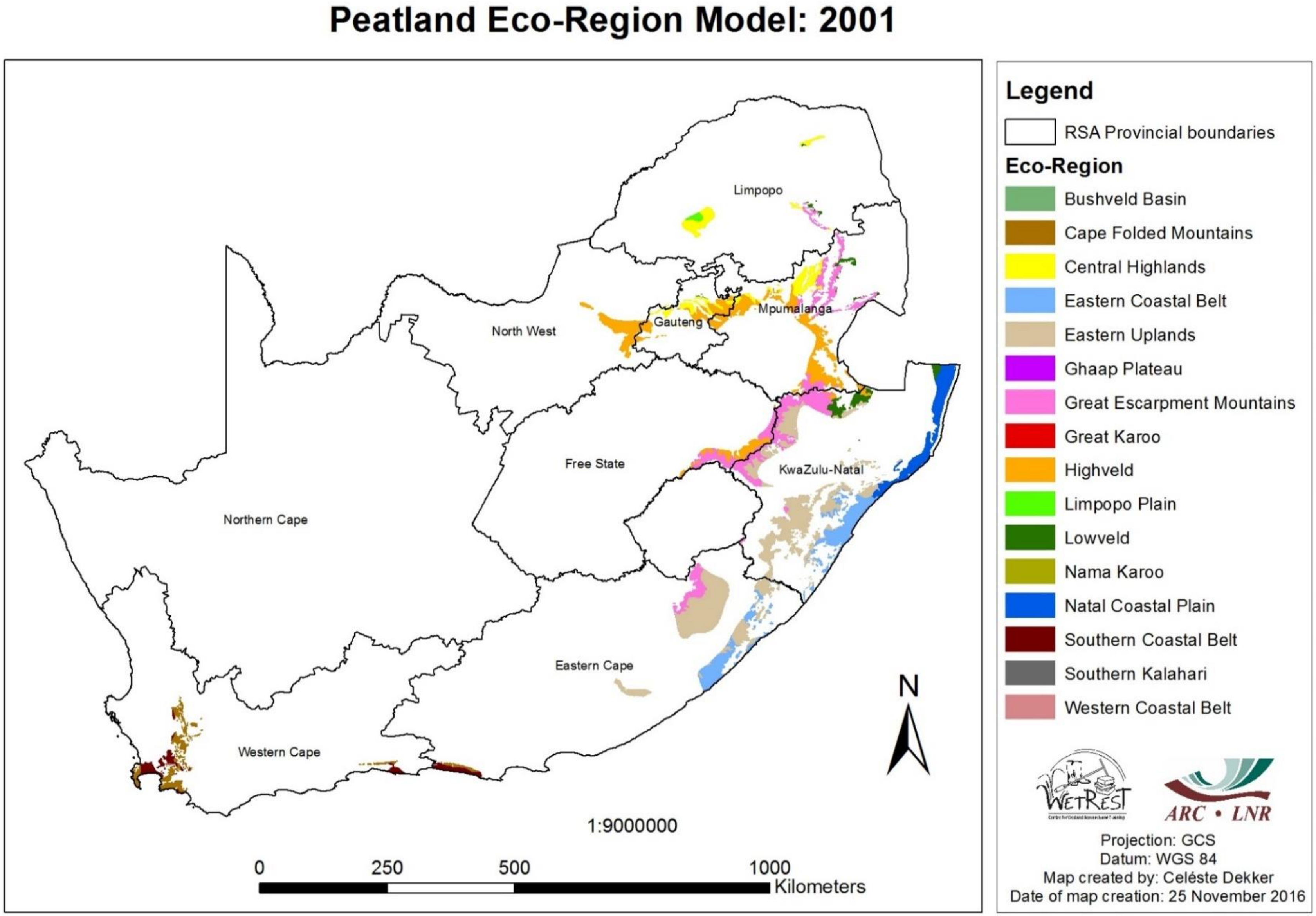


Figure 35: Peatland ecoregion map 2001 with different legend colours (based on Marneweck et al., 2001)

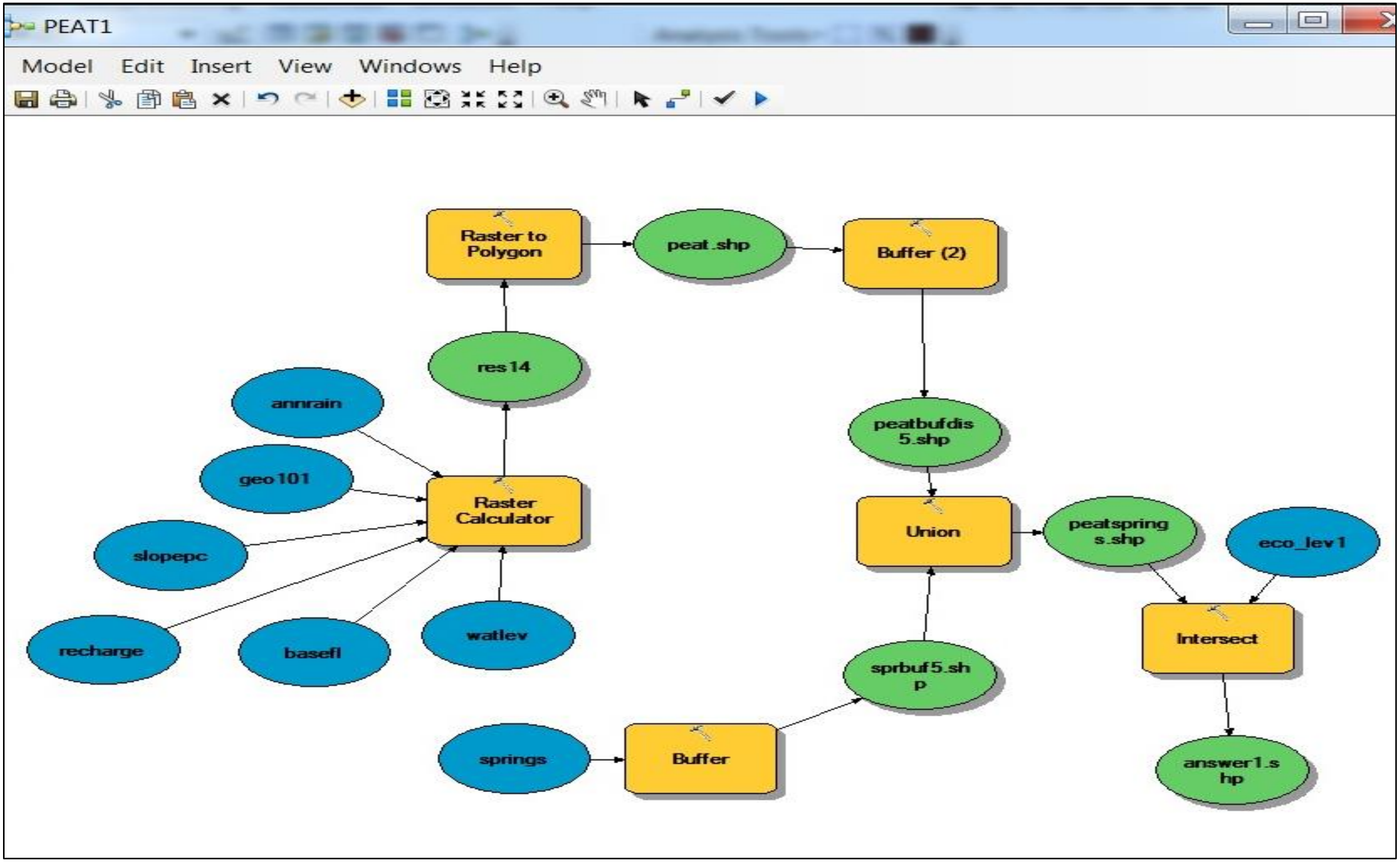


Figure 36: Flow diagram of the new peatland ecoregion model in ArcGIS 10.1™

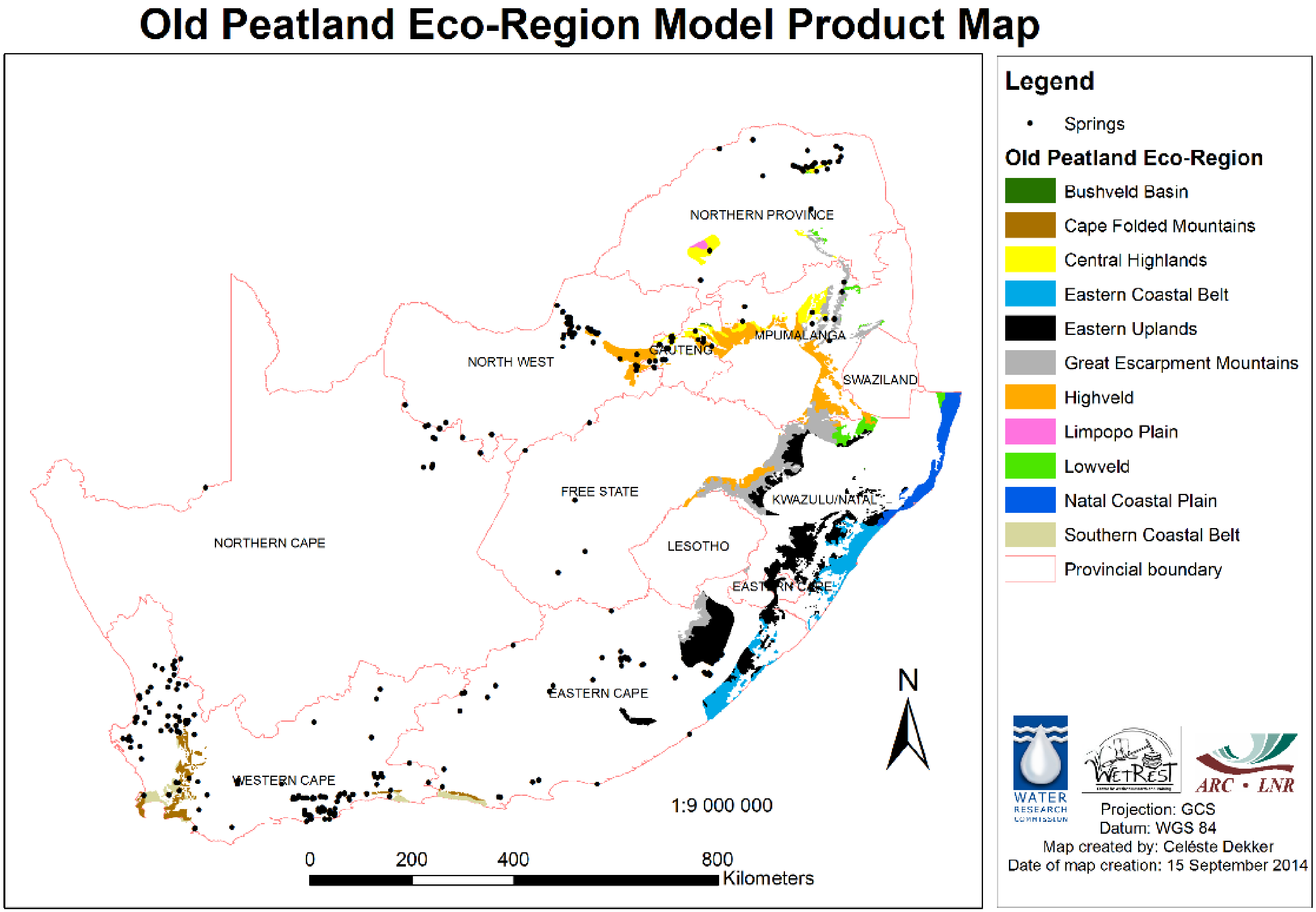


Figure 37: Old peatland ecoregion map (Marneweck et al., 2001) and positions of natural springs

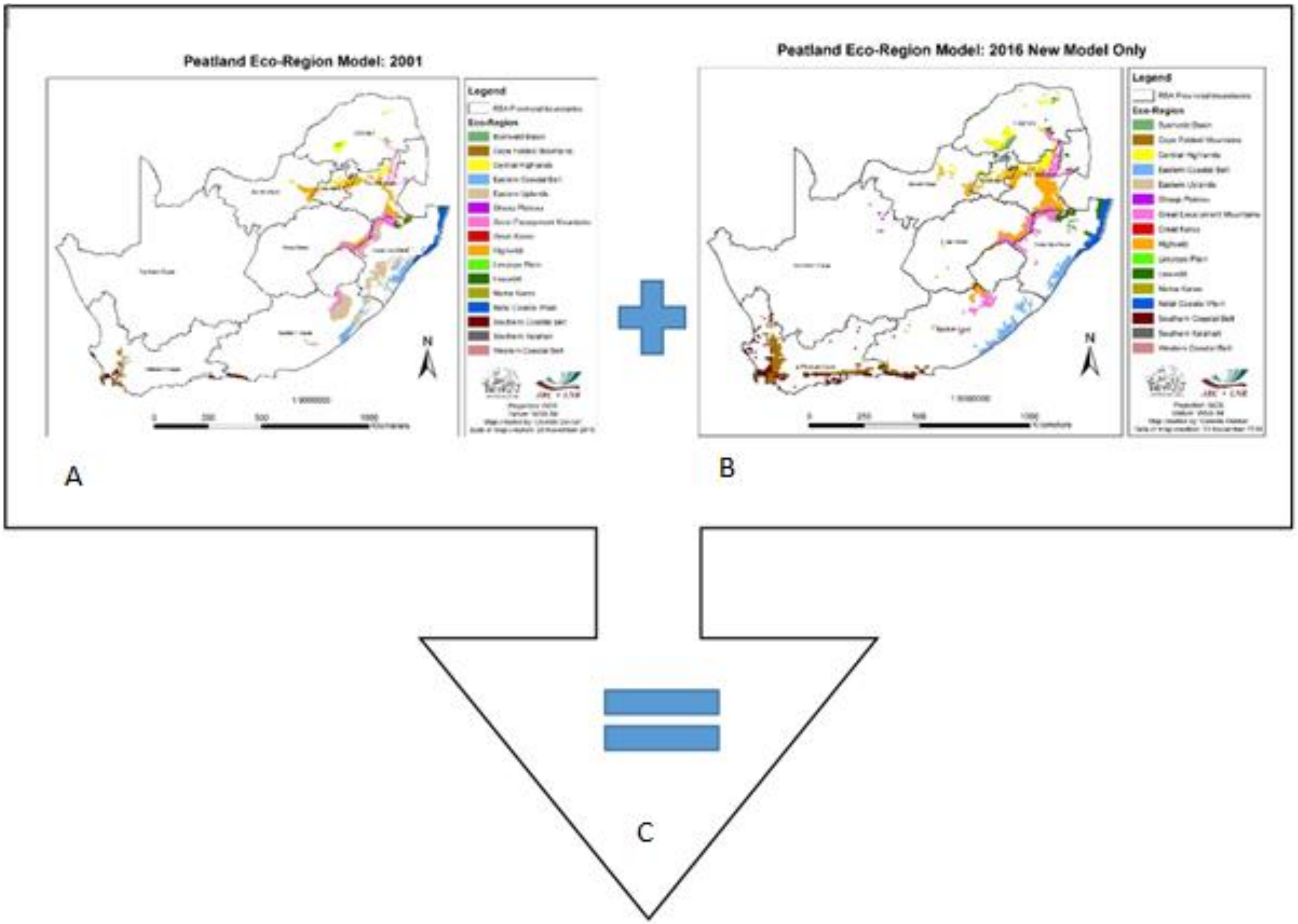


Figure 38: 2001 and 2016 ecoregion models

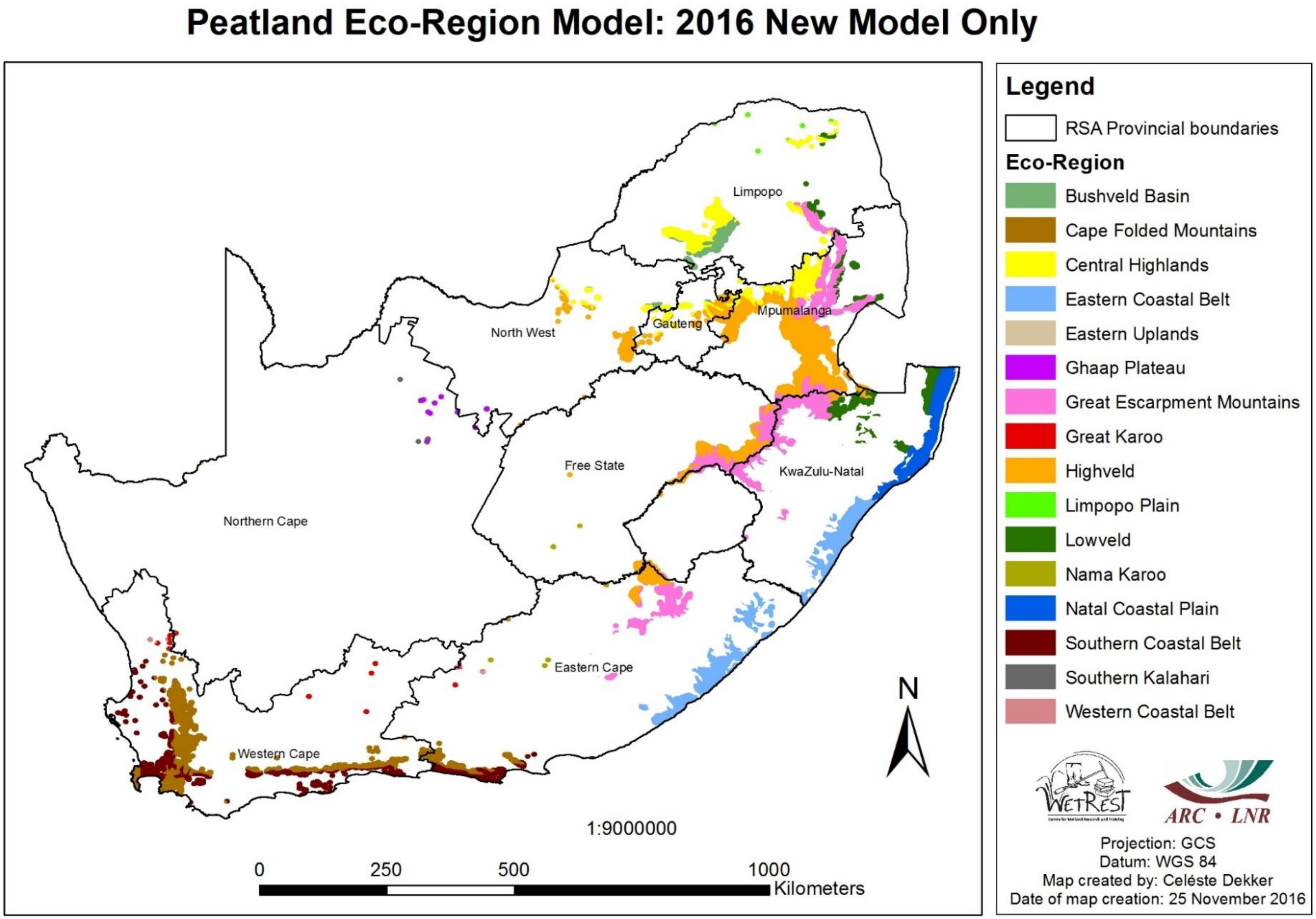
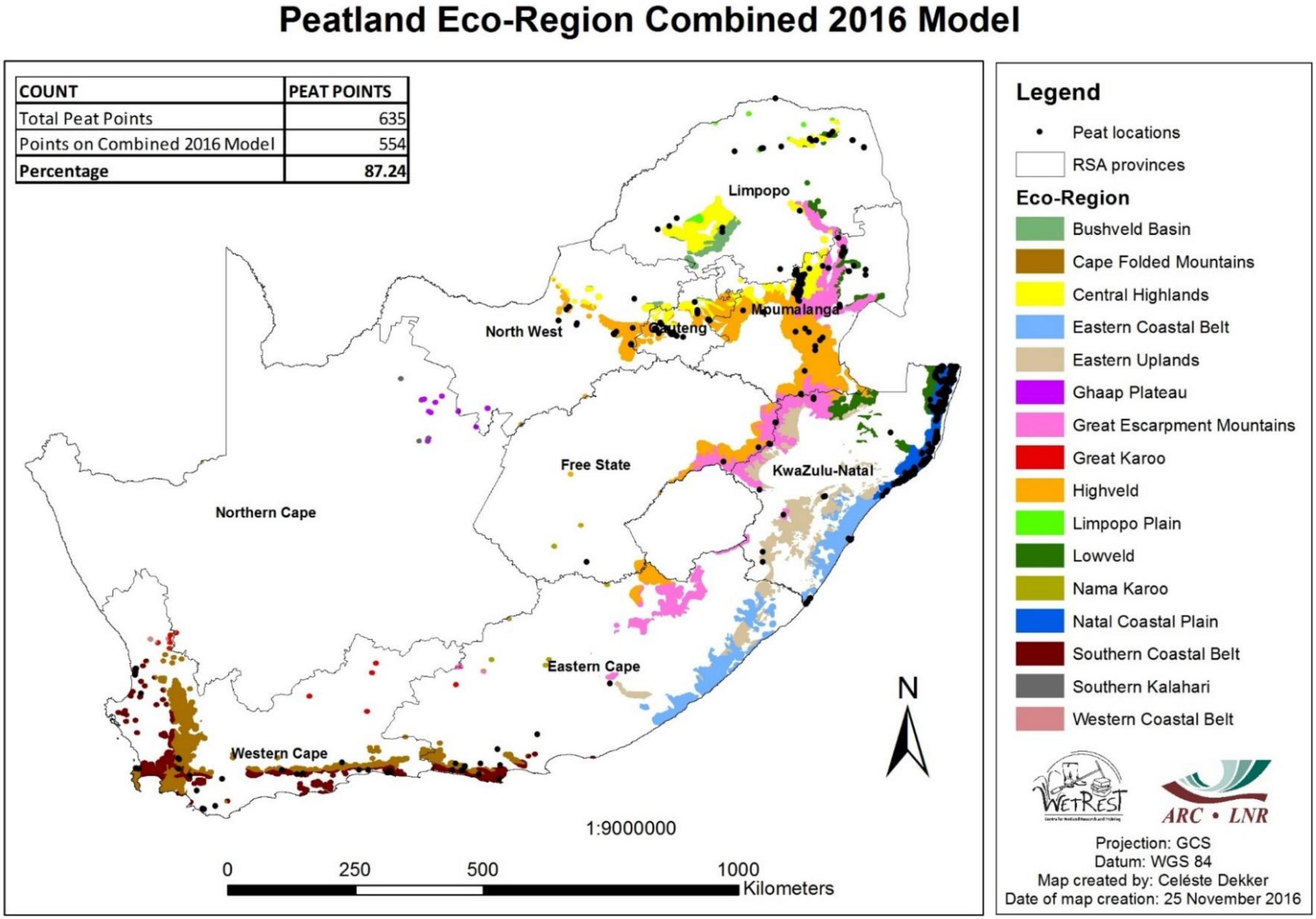


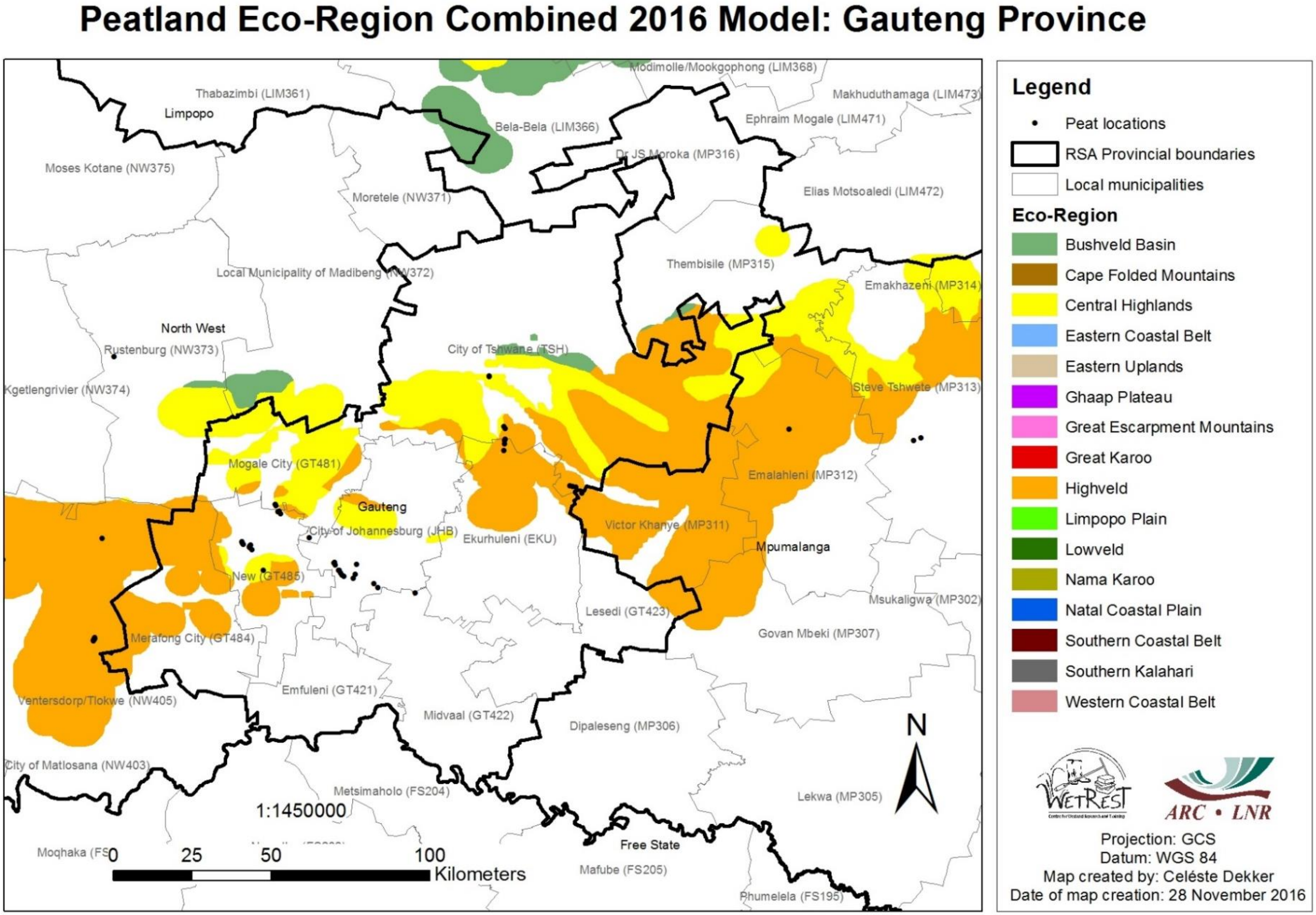
Figure 39: New 2016 peatland ecoregion map



Peatland Eco-Region Combined 2016 Model

COUNT	PEAT POINTS
Total Peat Points	635
Points on Combined 2016 Model	554
Percentage	**87.24**

Figure 40: Old and new peatland ecoregion model to produce the peatland ecoregion combined 2016 map


Peatland Eco-Region Combined 2016 Model: Gauteng Province

Projection: GCS
Datum: WGS 84
Map created by: Celéste Dekker
Date of map creation: 28 November 2016

Figure 41: Peatland ecoregion combined 2016 map, Gauteng Province close-up

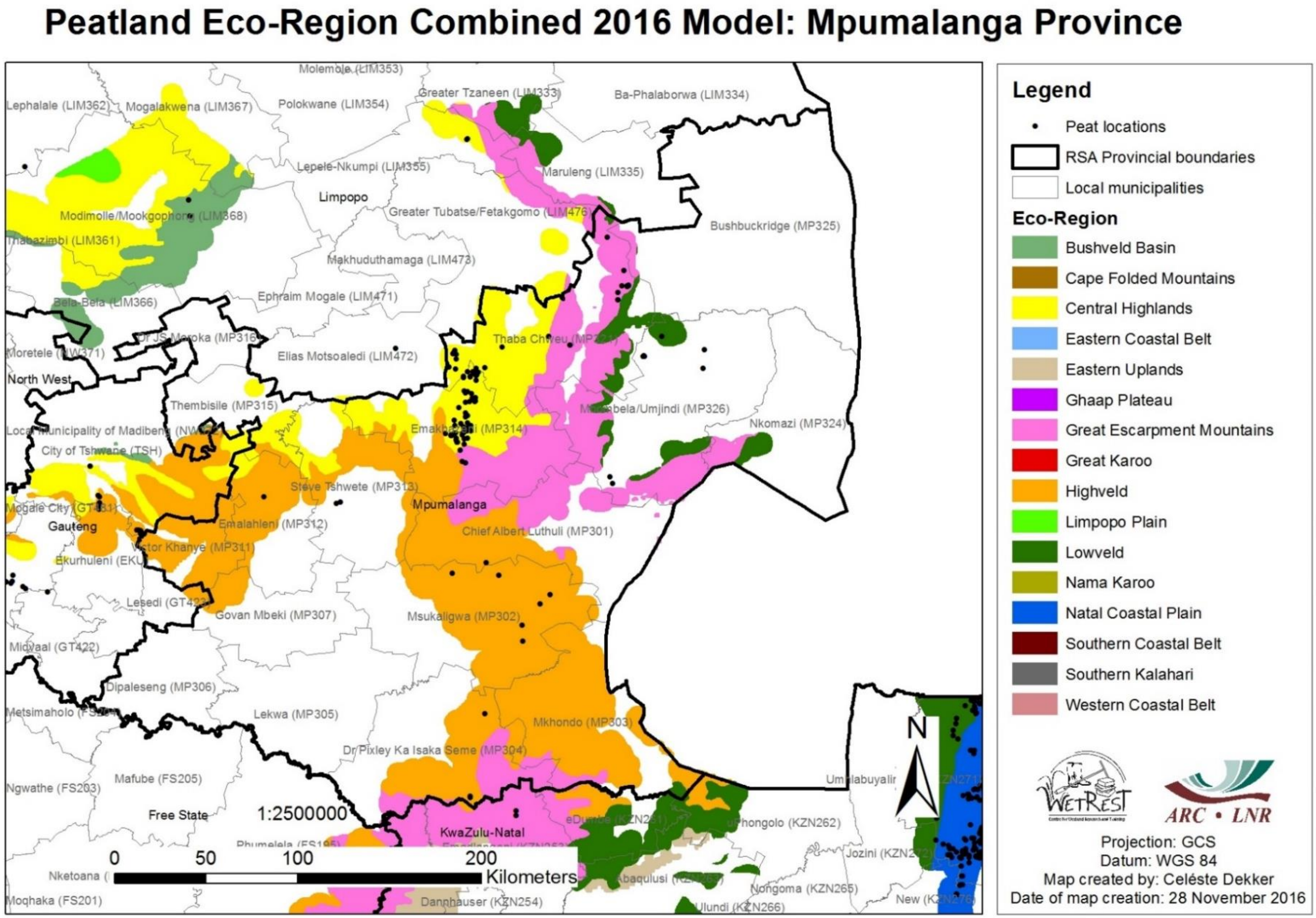
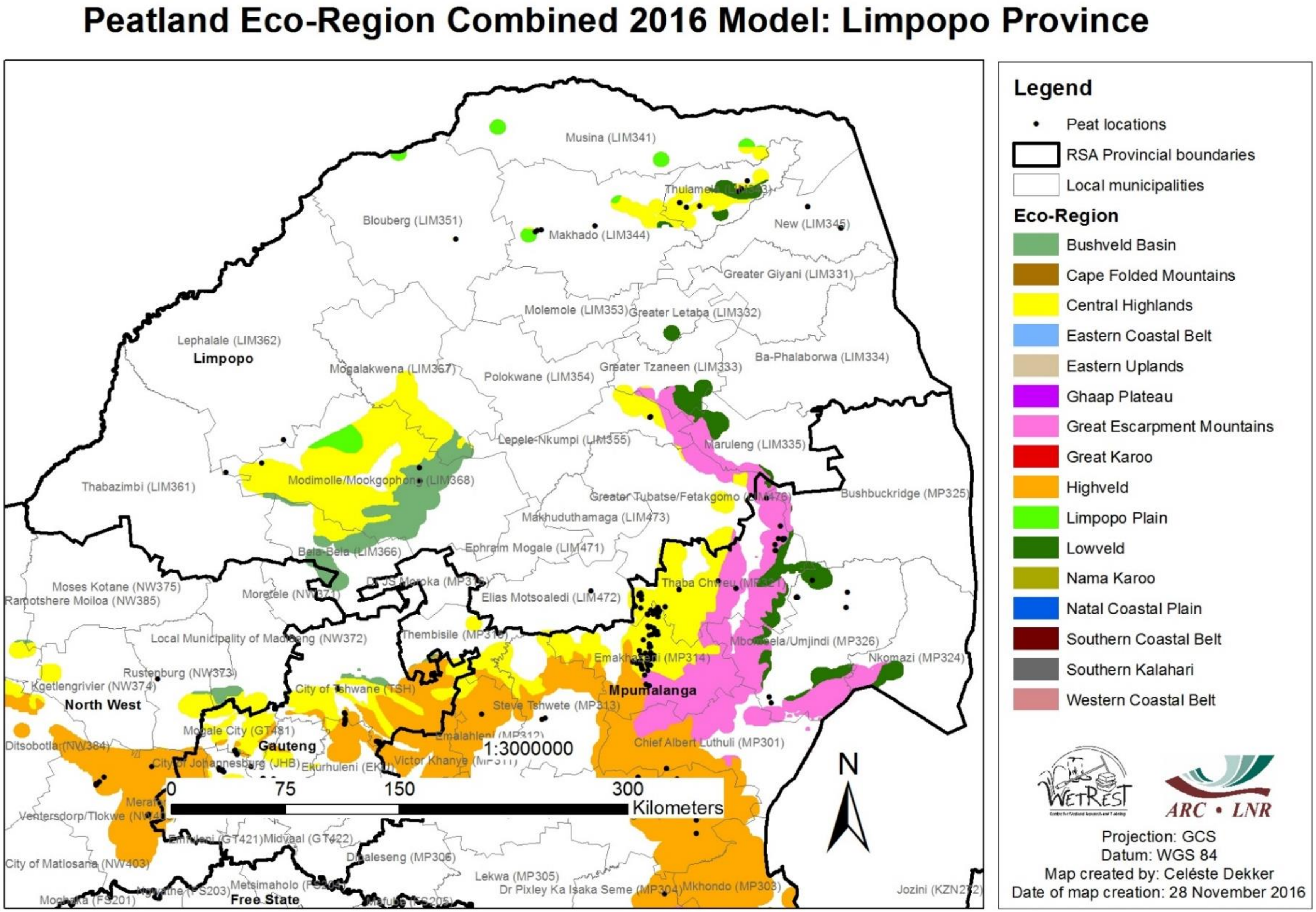


Figure 42: Peatland ecoregion combined 2016 map, Mpumalanga Province close-up



Peatland Eco-Region Combined 2016 Model: Limpopo Province

Projection: GCS
Datum: WGS 84
Map created by: Celéste Dekker
Date of map creation: 28 November 2016

Figure 43: Peatland ecoregion combined 2016 map, Limpopo Province close-up

Peatland Eco-Region Combined 2016 Model: North West Province

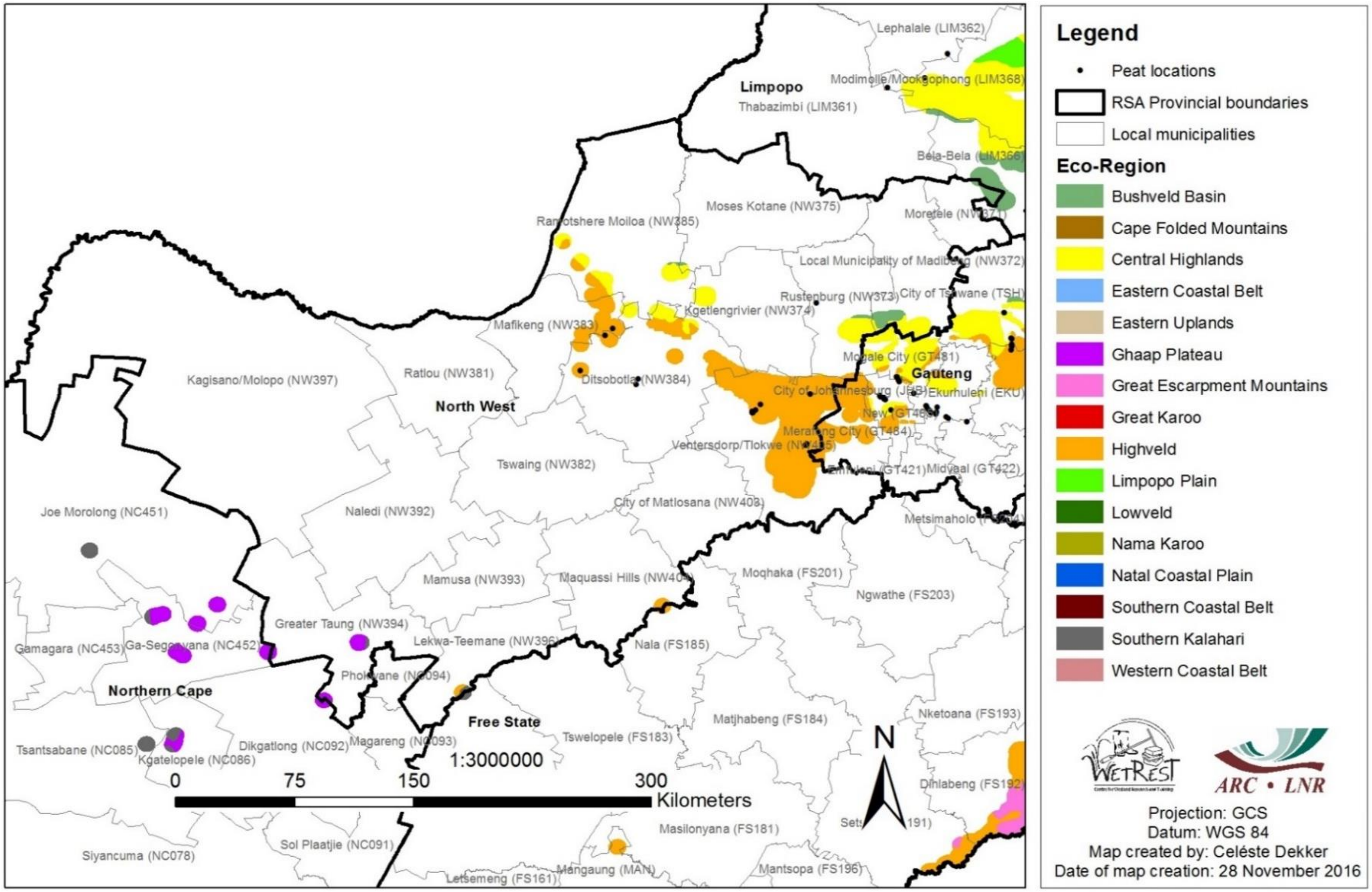


Figure 44: Peatland ecoregion combined 2016 map, North West Province close-up

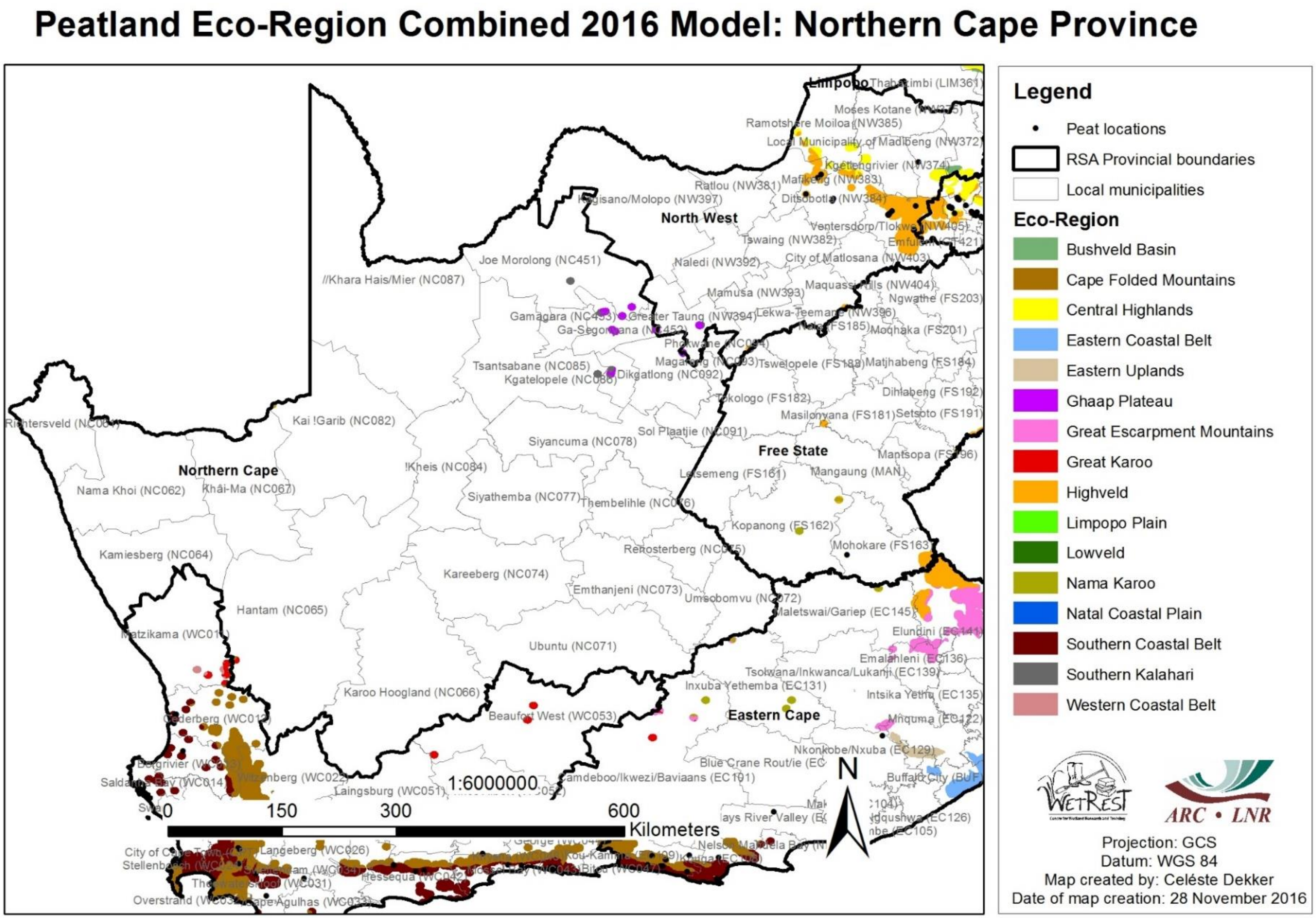


Figure 45: Peatland ecoregion combined 2016 map, Northern Cape Province close-up

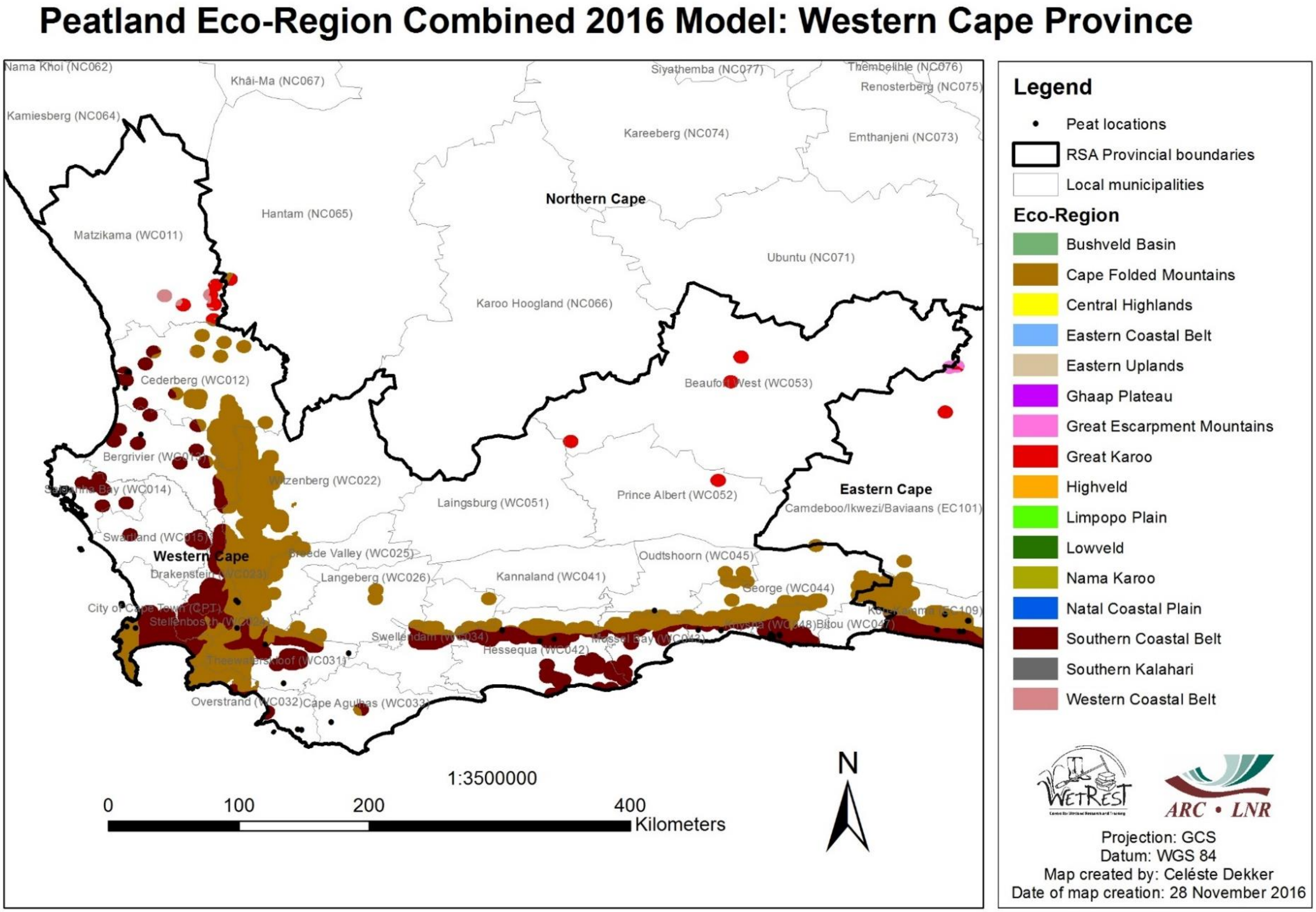


Figure 46: Peatland ecoregion combined 2016 map, Western Cape Province close-up

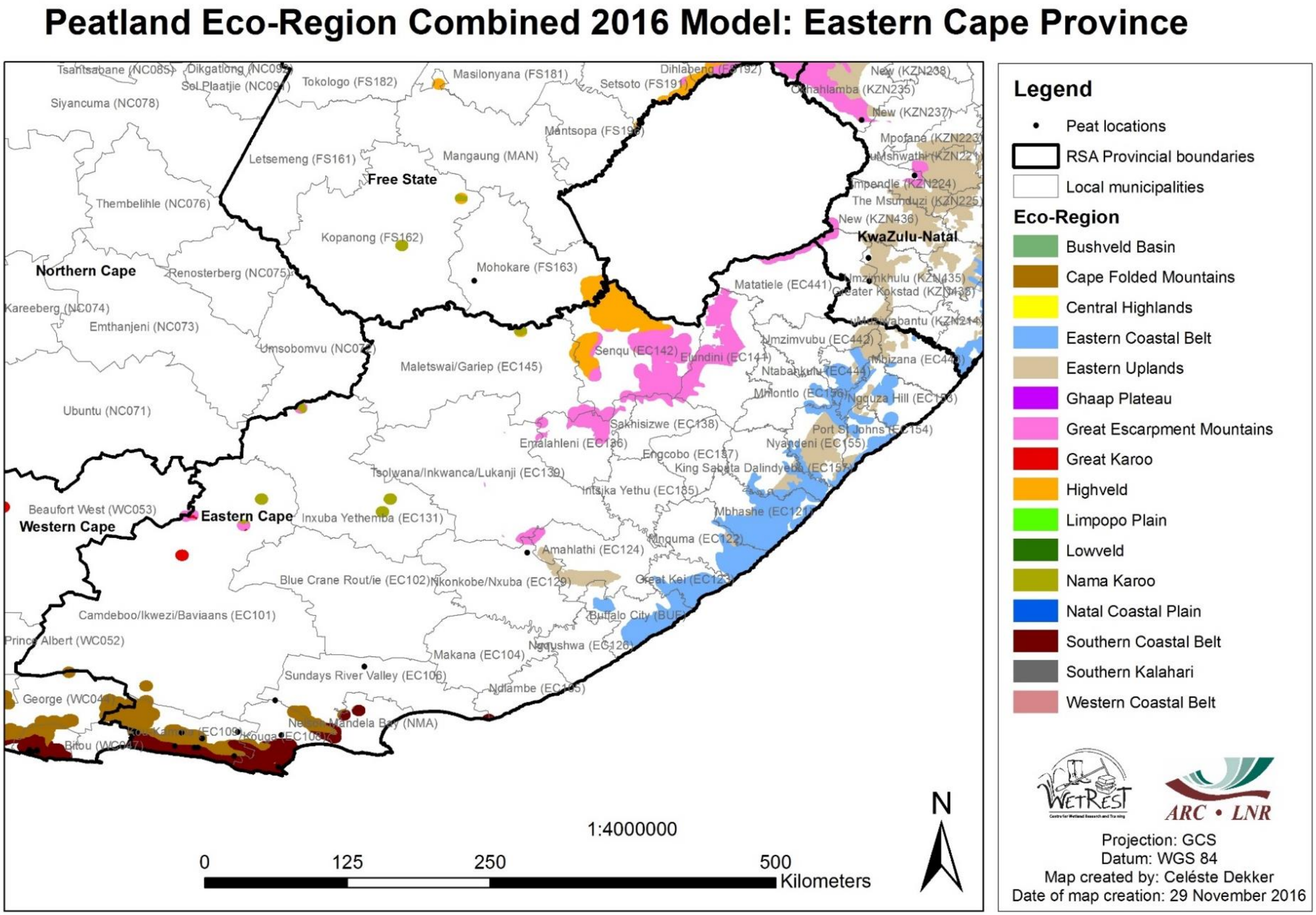


Figure 47: Peatland ecoregion combined 2016 map, Eastern Cape Province close-up

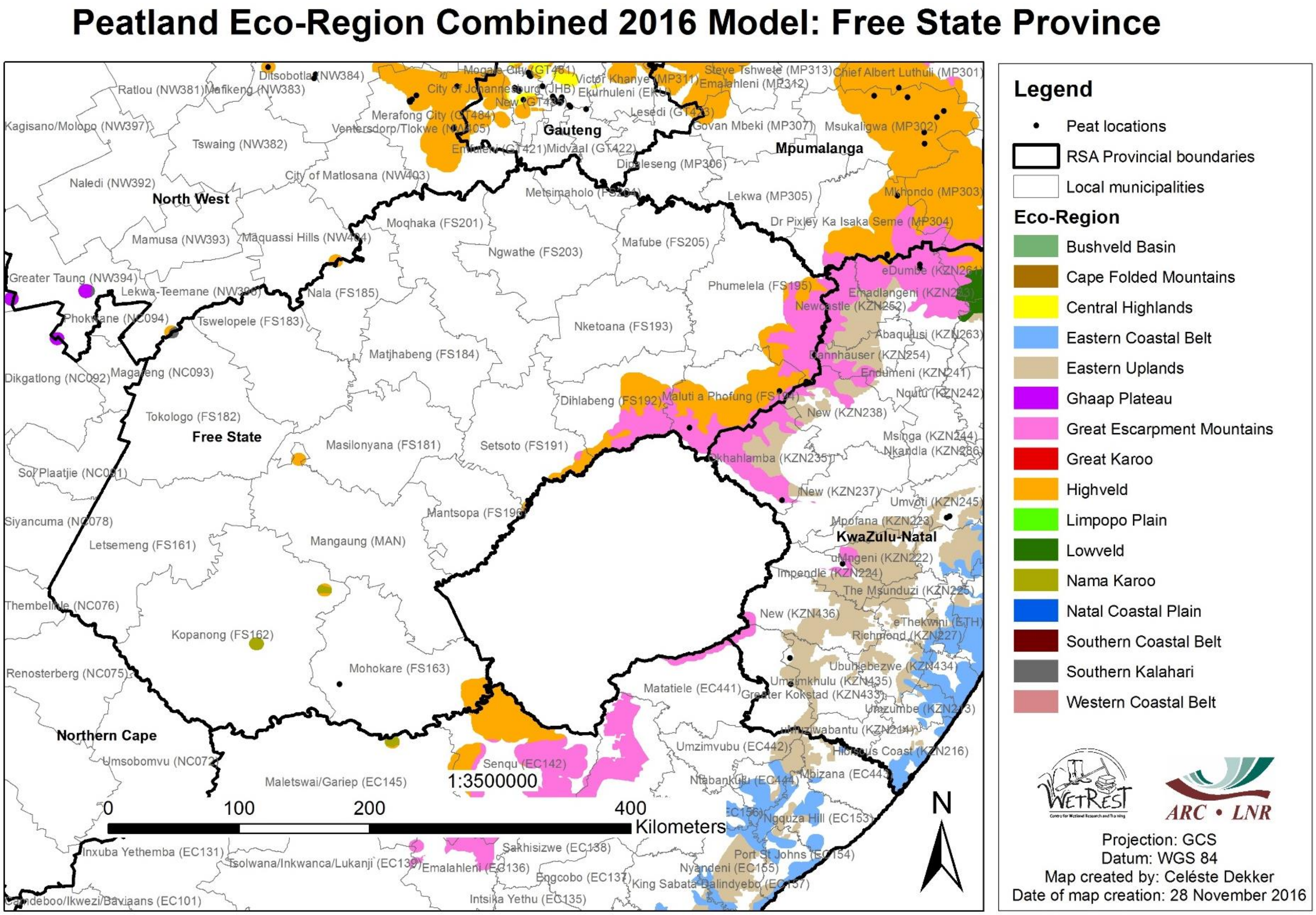


Figure 48: Peatland ecoregion combined 2016 map, Free State Province close-up

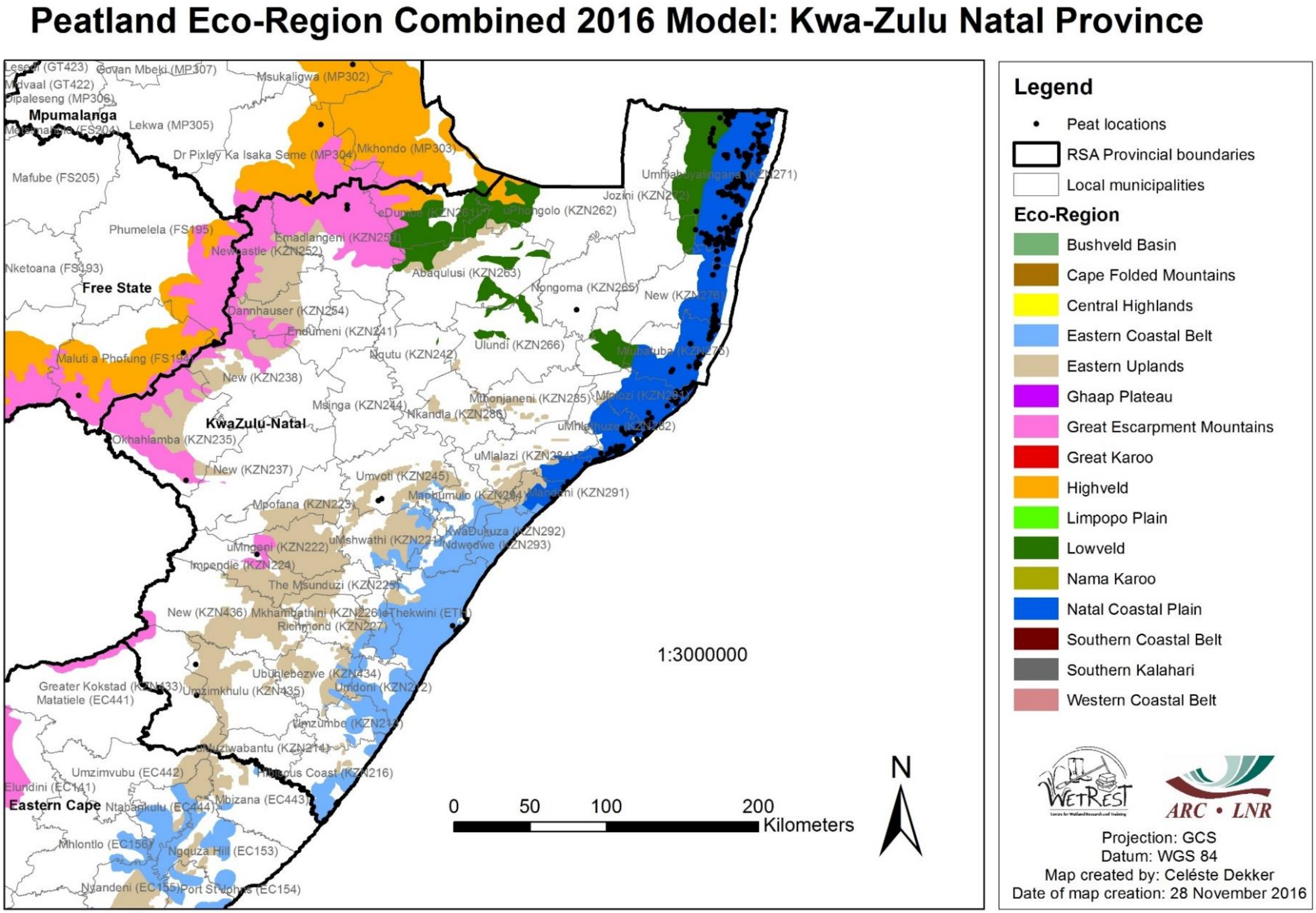


Figure 49: Peatland ecoregion combined 2016 map, Kwa-Zulu Natal Province close-up

APPENDIX 4: SUMMARY OF PEATLAND ATTRIBUTES

No. 1. Malahlapanga Wetland

Table 21: Overview information for the Malahlapanga Wetland

Location	Physical Characteristics
Province: Limpopo Closest town: Giyani Location: S22°53'13.7" E031°02'25.6" Farm: Shangoni Section: KNP Peat Ecoregion: Lowveld Quaternary Catchment: B90A-Mphongolo River System	**VEGETATION** Vegetation type: According to Gertenbach's Landscapes of the Kruger National Park (1983), the vegetation is an open tree savanna with low shrubs. Dominant trees in the landscape are: *Colophospermum mopane, Acacia nigrescens, Combretum hereroense, Dalbergia melanoxylon* and *Maytenus heterophylla.* The field layer is dense and is dominated by *Themeda triandra, Bothriochloa radicans* and *Digitaria eriantha*. Dominant plant types: Sedges/grass and *Phragmites* Dominant plant species: ***Phragmites australis, Bolboschoenus maritimus and Thelypteris confluens*** Presence of threatened, endangered or sensitive flora/fauna species: The landscape is preferred habitat for a variety of game. Large numbers of zebra, buffalo, elephants and impala are present. Sable and roan antelope, kudu and even white rhino occur in this veld when the grass increase in height. **GEOMORPHOLOGY** Landscape setting/position: Bench HGM unit: e.g.: Seep/with artesian streams Altitude min (m a.s.l.): 400 Altitude max (m a.s.l.): 469 Altitude mean (m a.s.l.):420 Slope percentage: <0.5% Aspect: North/east Catchment slope: Gentle Catchment geology: The Malahlapanga spring mire is in a small tributary close to the confluence with the Mphongolo River and is underlain by the Goudplaats Gneiss Peatland geology: Key point/origin: A major fault zone with the Dzundwini and Nyunyani Faults striking from east to west occurs about 10 km north of the spring. However, an offshoot from the southern Nyunyani Fault strikes roughly north to south in line with Malahlapanga but stops 2 km short of it. Two parallel lineaments determined by remote sensing follow the same orientation than the fault intersecting an east to west striking diabase dyke at Malahlapanga. **HYDROLOGY** Rainfall min (mm/yr): 500 mm Rainfall max (mm/yr): 600 mm Rainfall mean (mm/yr): 572 mm Dominating water source: Groundwater, surface inflow, precipitation Evapotranspiration (max/potential): Unknown Water quality data: Measured at Mfanyani-Woodlands section KNP adjacent to Shangoni section EC (mS/s): 102 Malahlapanga – very high due to animal activity in the area pH: 7.0 Na+: 21.2 Fe^{2}+: Cl-: 20.2

No. 2. Lakenvlei Peatland

Table 22: Overview information for the Lakenvlei Peatland

Location	Physical Characteristics
Province: Mpumalanga Closest town: Belfast Location: 25°33’43.90S/30°06’03.10E Farm: The study area covers several farms, namely: - Welgevonden 128 JT - Moeilykheid 129 JT - Hartebeestefontein 130 JT - Zwartkoppies 316 JT - Middelpunt 320 JT - Avontuur 319 JT - Elandskloof 321 JT - Elandsfontein 322 JT - Lakenvlei 355 JT - Groenvlei 353 JT	**VEGETATION** Vegetation type: (according to Mucina & Rutherford, 2006): Lydenburg Montane Grassland Dominant plant types: Sedge and grasses Dominant plant species: *Phragmites australis, Pycreus nitidus, Schoenoplectus brachyceras, Isolepis costata, Juncus oxycarpus, Juncus oxycarpus, Cares acutiformis, C. cognata, Eleocharis palustris, Eleocharis dregeana, Leersia hexandra, Harpochloa* sp., *Berula erecta,* etc. Presence of threatened, endangered or sensitive flora/fauna species: Yes Birds: Wattled crane, grey crowned crane, blue crane, white-winged flufftail, grass owl, corncrake, African marsh harrier, bald ibis, Baillon’s crake, Denham’s bustard, etc. Oorbietjie, burrowing crab, swamp musk shrew, common brown water snake, spotted skaapsteker, etc.
Peat Ecoregion: Eastern Highlands Quaternary Catchment: B41A (Middle Olifants Sub-Water Management Area, Olifants Water Management Area)	**GEOMORPHOLOGY** Landscape setting/position: Valley bottom HGM unit**:** Valley bottom Altitude min (m a.s.l.): 1880 Altitude max (m a.s.l.): 1907 Altitude mean (m a.s.l.): 1260-2160 m Slope percentage: 0.79 Aspect: South-west Catchment slope: 0.1% to 11.3% Catchment geology: Comprise quartzitic, cross-bedded sandstone of the Vryheid Formation in the south-west, hornfels with layers of silt and sandstone of the Vermont Formation in the south and Lakenvlei Formation quartzites in the west. Various north-west–south-east striking faults and north–south oriented diabase dykes transect the area, with diabase sills occurring in the north. Peatland geology: As above Key point/origin: Quartzite outcrop The contact between a south-western extension of the Lakenvlei quartzite and the hornfels of the Vermont Formation forms the key point of the main basin. **HYDROLOGY** Rainfall min (mm/yr): 660 mm Rainfall max (mm/yr): 1180 mm Rainfall mean (mm/yr): 858 mm Dominating water source: Groundwater Evapotranspiration (max/potential): 1840 mm Water quality data: EC (mS/s): 7.6 pH: 7.2 Na+: 3 $Fe^{2}+$: 0.941 Cl-: >5

No. 3. Vazi

Table 23: Overview information for the Vazi Peatland

Location	Physical characteristics
Province: KwaZulu-Natal Closest town: Manguzi, 20 km to the north; Mseleni, 23 km to the south-west Location: Velabusha, Manzengwenya plantation Coordinates: 27°10'41.10"S 32°43'3.15"E Farm: N/A Peat Ecoregion: Natal Coastal Plain Quaternary Catchment: W70A	**VEGETATION** Vegetation type: (according to Mucina & Rutherford, 2006): Maputaland Coastal Belt Dominant plant types: Sedge and Grasses Dominant plant species: *Cynodon dactylon, Dactyloctenium giganteum,* Unidentified sedge*, Cladium mariscus, Panicum repens, Stenotaphrum secundatum, Leersia hexandra* Presence of threatened, endangered or sensitive flora/fauna species: N/A **GEOMORPHOLOGY** Landscape setting/position: Deep interdunal depression on a sandy coastal plain HGM unit**:** Depression (interdunal) Altitude min (m a.s.l.): 73.67 Altitude max (m a.s.l.): 74.33 Altitude mean (m a.s.l.): 73.99 Slope percentage: 1.14% from west to east; 0.53% east to west; 1.33% north–south; 0.21% south–north Aspect: N/A Catchment slope: <3% Catchment geology: Kosi Bay and Isipingo formations Peatland geology: Underlying sandy silts enriched in ferricrete Key point/origin: N/A, probably impermeable finer texture sands below peat layer **HYDROLOGY** Rainfall min (mm/yr): 586 mm Rainfall max (mm/yr): 1180 mm Rainfall mean (mm/yr): 586 mm/yr currently (Grundling et al., 2014) Dominating water source: Groundwater Evapotranspiration (max/potential): 1900 mm/year (Mucina & Rutherford, 2006) Water quality data: EC (mS/s): 77.5 mS/s; pH: 5.65; NO-3: 1.18; Cl-: 166.57; SO4-2: 96.91; HCO-3: 72.17; Na+: 93.67; K+: 5.60; Ca+2: 24.87; Mg+2: 20.19.

No. 4. Matlabas Mire

Table 24: Overview information for the Matlabas Mire

Location	Physical Characteristics
Province: Limpopo Closest town: Thabazimbi Location: MNP Farm: Waiting for information Peat Ecoregion: To be confirmed Quaternary Catchment: A41A	**VEGETATION** Vegetation type: (according to Mucina & Rutherford, 2006): Waterberg-Magaliesberg Summit Sourveld Dominant plant types: Sedge, grasses and ferns Dominant plant species: *Miscanthus junceus, Kyllinga melanosperma, Thelypteris confluens, Pteridium aquilinum, Oxalis obliquifolia, Panicum dregeanum* and *Aristida canescens* Presence of threatened, endangered or sensitive flora/fauna species: Yes *Drosera collinsiae* is a sensitive species although not listed as endangered but as Least Concern. Cape griffon vultures utilise the mountains but are not directly dependant on the mire. Landscape setting/position: The valley of the Matlabas Mire is bordered by steep talus slopes where unsorted rock boulders and coarse fragments form highly permeable valley slopes acting as effective recharge areas for groundwater flow towards the wetland. These hillslope processes are likely to be a significant contributor to flow into the system. Groundwater flow into the wetland system could be further related to the dynamics between interflow, surface water, and base flow. In this context interflow refers to the lateral movement of water in the unsaturated zone of the mire and base flow refers to water from deeper layers. Artesian springs appear to feed various peat domes. HGM unit: valley bottom hillslope seepage wetland complex with seasonal and permanent wetland plant communities Altitude min (m a.s.l.): 1549.84 Altitude max (m a.s.l.): 1603.72 Altitude mean (m a.s.l.): 1593.63 Slope percentage: 4.6% to 6.3% Aspect: South and east facing Catchment slope: 39.0% Catchment geology: **GEOMORPHOLOGY** 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). 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.

Location	Physical Characteristics
	Peatland geology: The peatland occurs in a valley arranged in a prominent kite-like pattern because of diabase dykes intruding along faults/fractures striking west-northwest–east-southeast and north-east–south-west into Waterberg Group sandstones. These dykes and fault/fracture zones weathered faster than the surrounding sandstone and formed preferential flow paths for groundwater. Groundwater seeps from these paths to form a valley resulting into a channelled and unhandled valley bottom with hillslope seepage components Key point/origin: Surface and seepage from talus slopes and groundwater input from artesian springs **HYDROLOGY** Rainfall min (mm/yr): 1 mm (http://www.climatedata.eu/climate.php?loc=sfzz0024&lang=en) Rainfall max (mm/yr): 136 mm (http://www.climatedata.eu/climate.php?loc=sfzz0024&lang=en) Rainfall mean (mm/yr): 18.58 mm (http://www.climatedata.eu/climate.php?loc=sfzz0024&lang=en) Dominating water source: Groundwater Evapotranspiration (max/potential): 1840 mm Water quality data: EC (mS/s): data was not dependable but values were very low ranging from 8.9 to 273 pH: 6.04 in the dry season and 5.85 in the wet season Na+: 3.91 in the dry season and 3.66 in the wet season Fe^{2}+: 6.07 in the wet season Cl-: 1.58 in the dry season and 1.41 in the wet season

No. 5. Colbyn Valley

Table 25: Overview information for the Colbyn Valley

Location	Physical Characteristics
Province: Gauteng Closest town: Pretoria Location: Colbyn suburb next to N1/N4 east, Kilnerton Road on the west Farm: Strubenkop Peat Ecoregion: Highveld Quaternary Catchment: Crocodile West Catchment	**<u>VEGETATION</u>** Vegetation type: Rocky Highveld zone of Grassveld biome Dominant plant types: Sedge and Grasses Dominant plant species: *Phragmites australis, Carex cernua* var. *austro-africana, Typha capensis, Hyperemia tundra, Cyprus angularis, Cynodon dactylon* and *Themeda triandra* Presence of threatened, endangered or sensitive flora/fauna species: Yes Seven rare bird species, Lycaenid butterfly **<u>GEOMORPHOLOGY</u>** Landscape setting/position: The wetland is a channelled valley bottom in an urban setting between two quartzite ridges. The peatland occurs at the lowest south-eastern point of the wetland. It is permanently saturated while the wetland is seasonally flooded. Water supply is primarily from underground flow and a tributary of the Hartbeesspruit. The fringes are seepage areas primarily from underground water. HGM unit: Channelled valley bottom Altitude min (m a.s.l.): 1332 m Altitude max (m a.s.l.): 1345 m Altitude mean (m a.s.l.): 1342 m Slope percentage: 1.4% average Aspect: Catchment slope: 3.4% Catchment geology: Shale, siltstone, quartzite Peatland geology: Key point/origin: Quartzite ridge of Daspoort Formation in North **<u>HYDROLOGY</u>** Rainfall min (mm/yr): 355 mm (Mucina & Rutherford, 2006) Rainfall max (mm/yr): 1091 mm (Mucina & Rutherford, 2006) Rainfall mean (mm/yr): 732 mm (Parsons, 2014) Dominating water source Groundwater Water quality data: EC (mS/s): 466 pH: 7.3 TDS: 324 ppm

No. 6. Gerhard Minnebron Wetland

Table 26: Overview information for Gerhard Minnebron Wetland

Location	Physical Characteristics
Province: North West Closest town: Potchefstroom Location: 26°29’05S/27°08’10E Farm: Gerhard Minnebron 139 IQ Peat Ecoregion: Highveld Quaternary Catchment: C23E	**VEGETATION** Vegetation Type (according to Mucina & Rutherford, 2006): Gh 15 Carletonville dolomite grassland Dominant plant types: Sedge and grasses Dominant plant species: *Phragmites australis, Schoenoplectus brachyceras, Juncus effusus, Carex acutiformis, Mariscus congestus, Leersia hexandra, Imperata cylindrica, Ranunculus meyeri, Typha capensis,* etc. Presence of threatened, endangered or sensitive flora/fauna species: Yes White-backed night heron, little bittern, Baillon’s crake, grass owl, etc. springhare, Angoni vlei rat, greater cane rat, etc. **GEOMORPHOLOGY** Landscape setting/position: Valley bottom HGM unit: Valley bottom Altitude min (m a.s.l.): 1402 m Altitude max (m a.s.l.): 1408 m Altitude mean (m a.s.l.): 1404 m Slope percentage: 0.5 Aspect: South-west Catchment Slope percentage: 2% Catchment geology: It is underlain by dolomite of the Malmani Subgroup and is fed by a dolomitic spring, the Gerhard Minnebron Eye. It is located on the Vaal River karst type with slightly undulating terrain morphology. Peatland geology: The peatland occurs in karst topography and can be attributed to the dissolution of the underlying limestone causing a slumping of the land surface, thereby creating distinct basins, which may or may not be connected to surface water or groundwater. Key point/origin: Wetlands that form in such basins or depressions are commonly referred to as sinkhole wetlands. Lost streams (streams that disappear underground) and underground caverns are common in karst areas. Some sinkhole wetlands receive groundwater discharge from surrounding and/or underlying limestone deposits, such as Gerhard Minnebron. Others simply occur in basins formed by the dissolution of underlying limestone. **HYDROLOGY** Rainfall min (mm/yr): 600 mm Rainfall max (mm/yr): 1180 mm Rainfall mean (mm/yr): 593 mm Dominating water source: Groundwater Evapotranspiration (max/potential): 2388 mm Water quality data (average ranges for the peatland): EC (mS/s): 75-82 mS/m pH: 7.28-7.31 Na+: 14.27-17.54 mg/L Fe^{2}+: 0.941 Cl-: 29.44-35.29 mg/L

No. 7. Vankervelsvlei

Table 27: Overview information for Vankervelsvlei

Location	Physical Characteristics
Province: Western Cape Closest town: Sedgefield Location: 34º0’71”S/22º54’22”E Farm: PG Bison Peat Ecoregion: Southern Coastal Belt Quaternary Catchment: K40E	**VEGETATION** Knysna sand fynbos (Mucina & Rutherford, 2006) Dominant plant types: Sedge/grass Dominant plant species: *Phragmites australis, Juncus kraussii, Typha capensis, Cladium mariscus, Thelypteris palustris, Carex clavata, Hydrocotyle verticillata* and *Sphagnum sp.* Presence of threatened, endangered or sensitive flora/fauna species: None noted **GEOMORPHOLOGY** Landscape setting/position: interdune swale on coastal platform HGM unit: depression Altitude min (m a.s.l.): 148 Altitude max (m a.s.l.): 150 Altitude mean (m a.s.l.): 150 Slope percentage: flat Aspect: n/a Catchment slope: 11-33% Catchment geology: Peninsula formation of the Table Mountain Group Peatland geology: Stabilised aeolian dunes Key point/origin: Fossilised/hardened dunes (interdune depression) **HYDROLOGY** Rainfall min (mm/yr): 670 (Mucina & Rutherford, 2006) Rainfall max (mm/yr): 1090 (Mucina & Rutherford, 2006) Rainfall mean (mm/yr): 653 (Parsons, 2014) Dominating water source: Groundwater (supplemented by hillslope interflow and precipitation) Evapotranspiration (max/potential): Min: 1.28 mm/d; Max: 10 mm/d; 1028 mm/a (Parsons, 2014, for Groenvlei) Water quality data EC (mS/s): 72-16 (Roets, 2008) pH: 6.6-5.3 (Roets, 2008)

No. 8. Kromme

Table 28: Overview information for Kromme

Location	Physical characteristics
Province: Eastern Cape Closest town: Kareedouw; Joubertina Location: 34º0’71”S/22º54’22” Farm: Krugersland Peat Ecoregion: Cape Coastal Belt Quaternary Catchment: K90A	**<u>VEGETATION</u>** Vegetation type: Tsitsikamma Sandstone Fynbos (Mucina & Rutherford, 2006) Dominant plant types: Shrubs Dominant plant species: *Prionium serratum, Psoralea affinis, Cliffortia strobilifera* Presence of threatened, endangered or sensitive flora/fauna species: unknown **<u>GEOMORPHOLOGY</u>** Landscape setting/position: Valley floor HGM unit: unchanneled Valley bottom Altitude min (m a.s.l.): 350 Altitude max (m a.s.l.): 390 Altitude mean (m a.s.l.): 370 Slope percentage: 0.8 Aspect: South-east Catchment slope: 20-60% Catchment geology: Table Mountain Sandstone Peatland geology: Table Mountain Sandstone Key point/origin: alluvial fan, narrowing of valley due to geology, fault **<u>HYDROLOGY</u>** Rainfall min (mm/yr): 286 (Mucina & Rutherford, 2006) Rainfall max (mm/yr): 1082 (Mucina & Rutherford, 2006) Rainfall mean (mm/yr): 650 Water levels: Fluctuating Water quality data: (Average ranges for the peatland) EC (mS/s): 109-200 pH: 5.8 eH: 100 Main source of water: River, groundwater, side seepage, shallow flows through alluvial fans Other signs of groundwater discharge: Side seepage

APPENDIX 5: MAPS AND FIGURES OF CHAPTERS 4, 5 AND 6

Figure 50: Location of peatlands dated

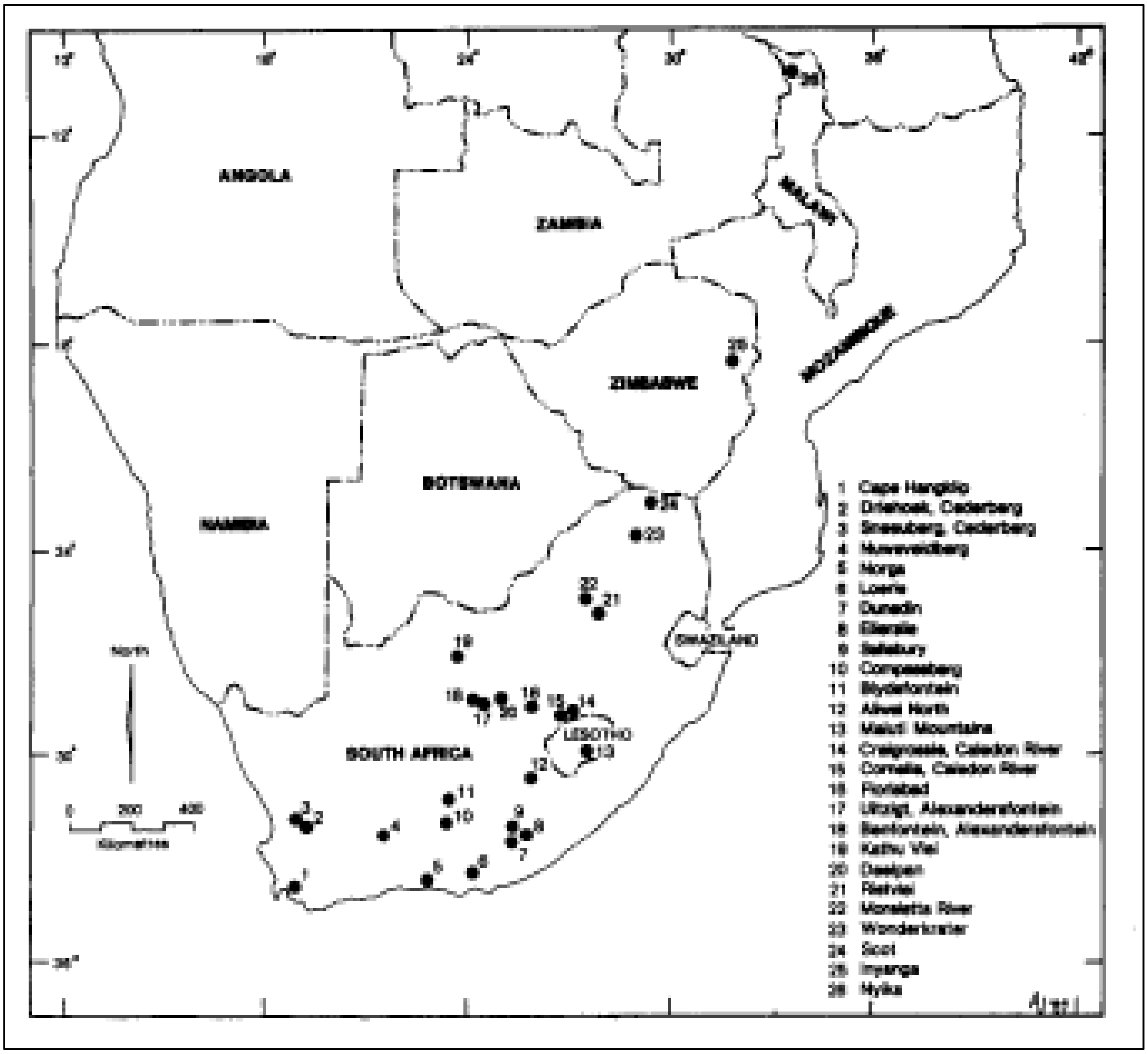


Figure 51: Late quaternary peat accumulation in South Africa (Meadows, 1988)

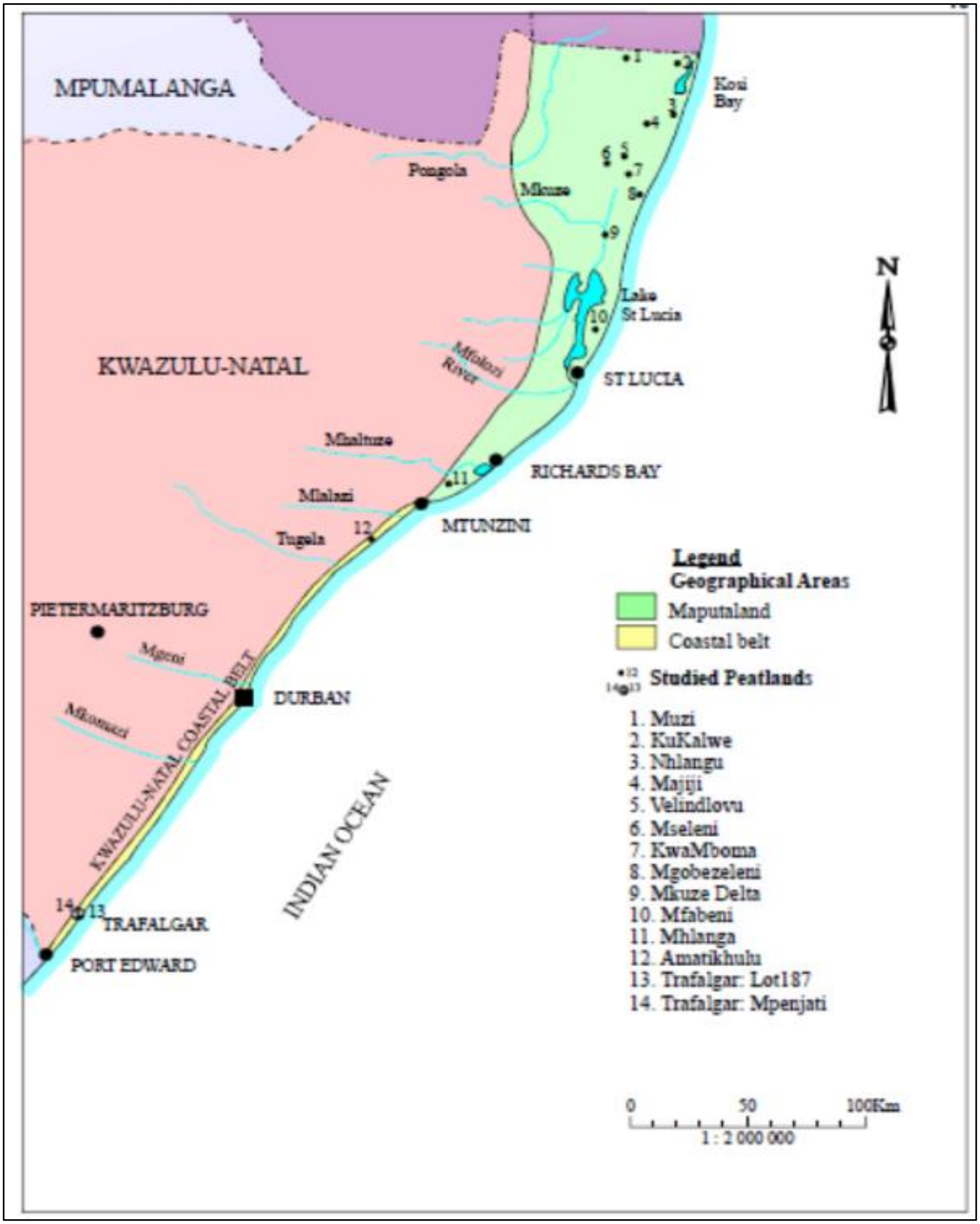


Figure 52: Peat resources (Grundling et al., 2000)

Table 29: Onset of peat accumulation – ^{14}C dates

Site No.	Site Name (and material if not peat)	Years BP: (not calibrated)
1	Cape Hangklip	11 000
2	Driehoek Cedarberg	14 600
3	Sneeuberg Cedarberg	9 640
4	Nuweveldberg	760
5	Norganica	3 500
6	Loerie	4 010
7	Dunedin Winterberg	12 500
8	Ellerslie Winterberg	4 200
9	Salisbury Winterberg	11 800
10	Compassberg	3 590
11	Blydefontein Organic Clay	5 000
12	Aliwal North Organic Clay	12 600
12	Aliwal North Peat	4 320
19	Kathu Vlei Organic Clay	7 350
13	Maluti	8 020
14	Craigrossie Clarens Organic	10 600
15	Cornelia Clarens Organic	12 600
16	Florisbad Organic	5 530
17	Uitzigt Alexandersfontein Humus	4 075
18	Benfontein Alexandersfontein Organic	14 900
20	Deelpan Organic Clay	3 800
21	Rietvlei Organic Clay	10 300
21	Rietvlei Peat	7 200
22	Moreleta Spruit	5 220
23	Wonderkrater	6 330
24	Scot	5 070
25	Schoonspruit	1 440
*26	Gerhard Minnebron	11 310
27	Witfontein North	1 050

Site No.	Site Name (and material if not peat)	Years BP: (not calibrated)
28	Witfontein North	2 580
29	Witfontein South	4 600
30	Rietspruit, Tarlton	7 120
*31	Colbyn	2 360
32	Rietvlei	7 130
*33	Lakenvlei	8 290
34	Wakkerstroom	780
35	Malahlapanga	4 980
36	Mafayeni	1 365
*37	Marakele	4 550
*38	Vankersvelvlei	6 795
39	Vankersvelvlei	39 900
*40	Kromme	3 415
*41	Vazi	3 660
*42	Vazi North	7 760
43	Mgobezeleni	1 100
44	Mseleni	770
45	Nhlanu	4 840
46	Muzi North	4 200
47	Majiji	2 140
48	Kukalwe	4 640
49	Velindlovu	2 820
50	Kwamboma	4 120
51	Mfabeni	45 100
52	Mhlanga	35 600
53	Trafalgar	5 870
54	Mpenjati	9 730

APPENDIX 6: LAND USE AND MANAGEMENT RECOMMENDATIONS

Malahlapanga Wetland

The wetland and catchment area are situated in a formal conservation area. It is used for water and grazing for game, wilderness trails and research.

Lakenvlei Peatland

Catchment

Lying within the Lakenvlei catchment is a coal mining facility, pottery works, diamond prospecting works and farmland, which has been fertilised in the past. The area is currently used for grazing purposes.

The terrestrial area has been invaded by several alien and invasive plant species that should be controlled by a management plan. These included *Acacia dealbata, Acacia mearnsii, Eucalyptus grandis* and *Pennisetum clandestinum*. Other exotic weeds such as tall khaki weed (*Tagetes minuta*) and purple top (*Verbena bonariensis*) also occur in disturbed areas.

Wetlands are not isolated features in the landscape and impacts within the catchment could be as detrimental to the health of a wetland as those in the wetland itself. Lakenvlei is affected by various impacts within the catchment ranging from past and current mining and exploration activities (coal, clay, diamonds, sand), agriculture (cultivation, grazing and poultry/piggeries), plantations and infrastructure (roads, railway, dams, tourism development and abandoned industry). Mining and related infrastructure poses the most severe threat to the Lakenvlei wetlands with physical destruction, groundwater flow disruption and pollution being the most likely. Agriculture and plantations could adversely change the runoff characteristics of the catchment with erosion, sedimentation and pollution potential hazards. Tourism and related development such as lodges and roads could result in catchment changes affecting surface flow and water quality. Fish farming could particularly have severe negative consequences on runoff (Figure 53) and water quality with dams being constructed in the catchment.

Figure 53: Overflow runoff from a trout dam

Peatland

The statuses of the Lakenvlei wetlands themselves seem to have improved during the past 15 years as many of the impacts described by Marneweck et al. (1999) and Grundling and Marneweck (1999) within the wetlands themselves have been addressed:

1. Drains and canals: all the drains and canals within the wetland have either been abandoned or blocked. Abandoned drains and canals could be better managed by effective blocking.
2. Pasture: pasture within the main wetland have been abandoned and natural wetland vegetation succession has commenced.
3. Firebreaks: firebreaks within the seep-zones of the valley bottom wetlands are generally still being maintained, but the hoeing of tracer belts results in erosion, which is having an impact (Figure 54).
4. Fences: fences are mostly not being maintained and fragmentation is therefore less of a problem.
5. Erosion: erosion has been addressed by the involvement of Working for Wetlands.

Figure 54: Hoed tracer belts as part of firebreak preparation

However, the following is still of concern in Lakenvlei, not only due to physical destruction, altered streamflow patterns, associated erosion and sedimentation, and biota migration interruption, but also due to pollution of water resources:

- Dams and related fish farming within many of the main wetland and various of the smaller systems.
- Roads through wetlands and streams.
- Coal mining on the watershed of the catchment.
- Diamond exploration in and adjacent to a small wetland.
- Cultivation on the edges and within wetlands.
- Overgrazing and trampling; especially within the smaller hillslope seeps and springs.
- Plantations within or on the edge of the smaller wetland systems.

Peat fires occur sporadically in smaller peatland systems due to either localised draining, plantations or flow interruption by roads.

Vazi

Catchment

The catchment is dominated by pine plantations, both planted and by self-propagation. Other uses include cattle grazing, and use of the peatlands in the catchment for water. Some of the local communities use areas in the catchment for gardens and plant collection. These practices are however limited. *Eucalyptus* and *Pinus* plantations are present in the area resulting in a reduction of the water table.

Peatland

Vazi Pan and surrounds provide grazing and water supply for cattle. The impacts on this peatland vary between alien and/or invasive species encroachment, and reduction of the water table by the plantations and fire.

Matlabas Mire

The Matlabas Mire is in the MNP where land use is predominantly conservation and tourism. This land use is relevant to the catchment of the mire and to the mire itself.

Colbyn Valley

Catchment

A railway runs through the wetland, dividing it into two halves. The University of Pretoria’s animal study farm is located adjacent to the wetland. Some vagrants use the area for sleeping and washing of clothes. Next to the western side of the wetland is a golf club, scout hall and bowling club. The area was previously used for farming, and some ridges and ditches are still visible. Most of the surrounding catchment is urbanised with roads, buildings and housing.

Peatland

Colbyn is an important urban open space providing conservation tourism opportunities such as hiking, biding and environmental education, as well as research.

Gerhard Minnebron Wetland

Catchment

The Gerhard Minnebron catchment is small and activities such as cultivation, fallow lands, diamond diggings, grazing and trampling, farm management roads, exotic vegetation, dwellings, water canal, tar road, infrastructure and footprint of previous peat mining are present. These activities could adversely change the runoff characteristics of the catchment through erosion, sedimentation and potential pollutant hazards. Wetlands are not isolated features in the landscape. Impacts within the catchment could be as detrimental to the health of a wetland as those in the wetland itself.

Wetland

An abstraction weir was built in 1962 just below the Gerhard Minnebron Eye and water has been abstracted via a channel for irrigation purposes (Figure 55). The Department of Water Affairs and Forestry’s (now DWS) flow records from the gauging weir at the eye suggest that most of the available water has been abstracted since 1966 and periods of no flow have been recorded for several days at the weir. Before 1957, the flow in the wetland and the abstraction from the eye were very constant as reflected in the constant total flow from the eye. This most likely represents the best reflection of what the natural flow out of the eye should be (±20 million m^3/annum). From 1957 to about 1965, there seems to have been a significant increase of flow into the wetland (±10 million m^3/annum). However, this likely reflects an increase of vegetation behind and below the gauging weir, affecting the accuracy of the measurement, rather than an actual increase of flow from the eye. This pattern is also repeated between 1971 and 1979 (±9 million m^3/annum increase for 1979) and does not reflect an actual increase in the water from the eye but rather an inflated reading at the gauging weir between the eye and the wetland.

Figure 55: Gerhard Minnebron dolomitic eye and water abstraction canal diverting a substantial proportion of the water for agriculture use

After 1965, there has been a complete inverse of the amount of flow into the wetland and the amount abstracted. There has also been a very erratic flow pattern into the wetland since 1965. Except that there may be inflated readings at the gauging weir, exacerbating the erratic flow pattern, the wetland has not developed under such low and erratic flow conditions. The reduced and erratic flow pattern since 1965 has reduced the effective size of the attainable footprint for the wetland; therefore, subjecting parts of the wetland to dehydration and desiccation (i.e. fire and oxidation).

Prior to the commencement of abstraction from the weir (before 1965), between 15 and 25 million m^3/annum flowed from the eye into the wetland, but since 1965 releases ranging between 0.5 and 5 million m^3/annum were recorded. According to the DWAF cross-sectional data at the gauging weir, the depth associated with this flow ranged between 28 cm and 24 cm in the active channel. After 1965, the reduced flow would have caused this water depth to drop significantly, ranging between 2 cm and 19 cm.

Therefore, dehydration of the fen and subsequent fires could have had a significant negative impact on the fen.

Presently, the major impacts on the ecology of the wetland are related to water abstraction from the Gerhard Minnebron Eye and from peat mining activities. The reduced and erratic flow pattern since 1965 due to the abstraction of water has reduced the effective size of the attainable footprint for the wetland, therefore subjecting large parts of the wetland to dehydration and desiccation, which resulted in destruction by fire. Mining and dumping of peat have exacerbated the occurrence of fire in the peripheral areas of the wetland. Peat fires occur annually (Potgieter, pers. comm., 2004) and layers of ash occur in the upper portions of the peat, indicating recent desiccation. However, ash layers are also evident in the profile indicating historical events and/or recent subsurface fires (Figure 56).

Figure 56: Layer of ash found several meters deep, indicating historical and/or recent subsurface fires

Peat mining activities have created a system with open water and a maze of entrance roads into the wetland (Figure 57). Adjacent agricultural activities, diamond diggings and mining entrance roads to the wetlands have exacerbated the proliferation of alien invasive plants spreading into the wetland especially via the access roads into the wetland.

The Gerhard Minnebron Wetland is presently dominated by very dense mono-specific strands of tall emergent reeds and some sedges (*Phragmites australis* and *Carex* spp.), which do not support a high species richness. The Gerhard Minnebron Wetland has developed through a directional change from much more diverse open water mires that could support a larger abundance and diversity of species, to a mono-specific reed dominated fen that supports much less diversity and abundance. This was also the opinion of the IMCG that visited the Gerhard Minnebron Wetland during 2005.

Figure 57: Conventional wet peat mining resulted in a maze of access roads and open water in the wetland

Because the open water mires in Gerhard Minnebron were directionally displaced by a reed fen, the removal of reeds would contribute towards the recreation of open water mires that can support a larger abundance and diversity of generalist species. The creation of open water has notably favoured the reestablishment of a large variety of open water plant and animal species. However, it is essential that the hydrological characteristics that favour the formation of peat in the wetland should not be compromised in the process.

A narrow but ecologically important and species-rich transitional zone occurs between the wetland and the surrounding terrestrial habitats. This zone is dominated by grass and sedges and is very susceptible to disturbance. It has largely been disturbed by access roads and dumping of peat on some areas along the perimeter of the wetland and has been transformed by invasive species as a result (Figure 58).

Figure 58: Comparison of natural marginal zone and disturbed zone with invasive exotic species

Vankervelsvlei

Catchment

The wetland is surrounded by mature plantations of *Pinus,* with several short windbreaks of the Australian genus *Eucalyptus* also present. The small collection of houses (Keurvlei) on the south-western edge of the wetland was populated in 1992, but appeared derelict and deserted by 1996 (Irving, 1998). The area is restricted to public access since it forms part of a commercial plantation. Entry is attained by special permission only.

Peatland

The wetland is largely undisturbed, except for a small area of side seepage, which is entirely planted with pine trees.

Kromme

Catchment

The Kromme peat basin has been severely affected and degraded by inappropriate land use activities and road development, especially in the last 60 years (Haigh et al., 2002). Orchards and grazing were the most common forms of land use until 1930. In 1931, a particularly large flood destroyed many orchards along the river banks, causing severe erosion. After this, many farmers turned to pasture, dairy and meat production (Blignaut, 2012). After the 1931 floods, black wattle (*Acacia mearnsii*) appeared for the first time along the stretch of the Kromme River and good rainfall years ensured their establishment. After orchards were swept away again in a 1965 flood, farmers raised the banks of the river to contain future floods. This caused significant channel erosion (Blignaut, 2012). By 1986, more than 50% of the valley floor had been converted to agriculture and black wattle had formed dense stands on the flood plains (Blignaut, 2012).

Peatland

Peatland use and impacts within the catchment include agriculture, alien plant invasions, draining, dams, fences, grazing, head-cut and donga erosion, peat fires, roads and water abstraction (Haigh et al., 2002). The Krugersland peat basin is among the last large intact area of wetland along the Kromme River.

APPENDIX 7: MANAGEMENT RECOMMENDATIONS

Malahlapanga Peatland

Rehabilitation measures (such as fences on the boundary and patrol roads) should be implemented to make the system more robust in terms of anthropological-induced and large herbivore impacts. The effects of implementation of a rehabilitation strategy and proposed interventions will increase the integrity of the system, enhancing the wetland hydrological function of the wetland and assist in maintaining not only unique biodiversity but also internal water resources. To achieve the broader rehabilitation objectives defined for the Malahlapanga Wetland, several interventions are proposed. However, it is crucial that the rims of the basins are restored to a level where the basins are inundated, peat formation processes restored, trampling limited and wet period flow.

The rehabilitation objectives are:

- Reinstate hydrological function of the system.
- Arrest current and possible future erosion.
- Secure wetland biodiversity (hots spring mires).
- Ensure road driveable throughout the year for management purposes.

Lakenvlei Peatland

Buffer zones

For Lakenvlei, it is likely that a buffer of >50 m from the edge of the temporary zone may adequately fulfil several functions and values such as promoting bank stability and affecting stream microclimate. A larger buffer may, however, be necessary to adequately cater for biotic requirements. A decrease in the buffer width from 50 m to 20 m will affect the buffer's ability to fulfil functions such as flood attenuation, general wildlife habitat, connectivity, and habitat for semi-aquatic species. This 50 m width should cater for most buffer functions as mentioned above. This buffer zone is largely based on biotic requirements and does not cater for geohydrological impacts.

Water balance

The groundwater component of the water balance for Lakenvlei should be studied to determine the dependence of the wetland on different water sources.

Wetland restoration

Rewetting of desiccated areas at Lakenvlei is a priority in terms of maintaining the carbon balance of the wetland. Closing of drains and canals as well as arresting erosion should commence as soon as possible. Trampling (as well as overgrazing) and erosion, especially in seeps, should be addressed urgently.

Catchment management

Erosion control activities in the catchment should be increased. These could include storm water control (such as water harvesting to reduce high runoff), encouragement of vegetated cover and sediment traps.

Vazi Peatland

Buffer zones

A study should be done to determine the correct buffer zone width that would protect the peatland from the detrimental effect of the plantations' water abstraction on a coastal aquifer such as the MCP. The appropriate buffer width should then be applied and be adhered to strictly.

Integrated management plan

An integrated management plan for the whole Manzengwenya plantation that considers sensitive areas, rehabilitation of peatlands, potential fire hazard areas, and possible offset actions should be developed as soon as possible before the transfer of the plantations from the State to the TMM Trust.

Both the tribal authorities as well as the plantation management should take ownership of Vazi Pan and work together to implement the management plan from the previous point.

Other

- Alien invasive species should be removed from Vazi North.
- Monitoring wells and piezometers should be monitored for a longer period to reflect the true fluctuation of the water table over seasons.
- The temperature profiles need to be measured several times more, with better monitoring of the temperatures on the edge of the peatland.

Matlabas Mire

Water balance

Sources of water that enter the mire should be investigated since preliminary data shows that groundwater pressure dynamics may be important in natural erosion stabilisation processes.

Wetland restoration

Erosion channels recorded particularly in the eastern section of the mire should be stabilised and monitored. Impacts of grazing of the mire should ideally be controlled to ensure that preferential flow paths potentially created by game do not lead to further erosion. Burning of the mire creates a further opportunity for damage by trampling. The dynamics of natural erosion stabilisation processes should be further investigated to refine management recommendations.

Other

- Mechanisms of peat accumulation should be analysed.

Colbyn Valley Peatland

The current management plan for the reserve should be updated and implemented:

- These include fences, firebreaks and the removal of alien invasive species, especially poplars growing within the peatland itself.
- It is important that current interventions such as erosion control measures be maintained.
- Rewetting of the system should be investigated and implemented where required.

- The wetland should be made accessible (both in terms of safety and access) to the public and used for education, awareness and tourism.

Gerhard Minnebron Peatland

Peat mining

- No more peat mining should be allowed in this wetland.
- Wetland rehabilitation measures should be implemented with specific goals favouring the hydrological characteristics that will benefit peat formation. It is also important that sufficient new peat-forming plant material is produced and available on a sustainable basis. The rate of recovery will depend on the availability and input of peat-forming moribund decomposed and macerated plant material into the newly created open water that can accumulate at the bottom of the newly created open water.
- However, it is essential to promote and/or re-establish diffuse flow across the wetland and avoid concentrating the flows in any one area.
- Old access points and loading bay areas must be rehabilitated.
- All disturbed marginal areas must be rehabilitated and alien invasive plants eradicated and managed. These areas should also be protected against overgrazing by livestock during the rehabilitation.
- All access roads and disturbance in the surrounding terrestrial area needs to be managed to control the influx of invasive species into the wetland.
- Further monitoring of flow patterns, water levels and damming of water by old redundant structures must take place to ensure stability of remaining vegetation and buffers. To avoid erosion, problematic increased velocities in the wetland will be addressed when and where identified.

Buffer zones

For the study area, it is likely that a buffer of >50 m from the edge of the temporary zone may adequately fulfil several functions and values such as promoting bank stability and affecting stream microclimate. A larger buffer may, however, be necessary to adequately cater for biotic requirements. A decrease in the buffer width from 50 m to 20 m will affect the buffer's ability to fulfil functions such as flood attenuation, general wildlife habitat, connectivity, and as a habitat for semi-aquatic species. This 50 m width should cater for most buffer functions as mentioned above. This buffer zone is largely based on biotic requirements and does not cater for geohydrological impacts.

Fire control

The reduced and erratic flow pattern since 1965 has reduced the effective size of the attainable footprint for the wetland, therefore subjecting parts of the wetland to dehydration and desiccation, especially by fire. Firebreaks must be created during May and June, which consist of tracer burns and mowing around the wetland.

Control of alien invasive species

The control of alien invasive plants involves eradicating adult, juvenile, seedlings and/or regenerating plants. It also involves establishing and managing alternative plant cover to prevent the reestablishment of invasive species that can establish via wind, water, and animal borne seeds or seeds already in the soil. The control method must avoid damage or disturbance to desirable plants or to the soil during control to minimise the overall long-term rehabilitation costs. Reliable results can only be achieved through careful planning. Control measures in the form of mechanical and chemical control can be implemented.

Water balance

The groundwater component of the water balance should be studied to determine the dependence of the wetland on different water sources.

Wetland restoration

Rewetting of desiccated areas is a priority in terms of maintaining the carbon balance of the wetland. Closing of drains and canals as well as arresting erosion should commence as soon as possible. Trampling (as well as overgrazing) and erosion, especially in seeps, should be addressed urgently.

Catchment management

Erosion control activities in the catchment should be increased. These could include storm water control (such as water harvesting to reduce high runoff), encouragement of vegetated cover and sediment traps.

Vankervelsvlei Peatland

This wetland has been earmarked in the 2015 CapeNature Protected Area Expansion Strategy for inclusion as a potential future Protected Area or for consideration for formal Stewardship status.

Further investigations into the groundwater component of the water balance to determine the dependency of this wetland on different water sources are warranted as this issue remains unresolved and has direct bearing on best management recommendations for conserving this important site.

Other management activities that would contribute to the improved integrity of the wetland could include drawing back of plantation trees out of the seepage area adjacent to the main depressional wetland, the removal of bramble and other non-commercial weedy species fringing the wetland, and overall implementation of a long-term maintenance plan to keep the wetland and its immediate buffer free of weedy species.

Kromme Peatland

Palmiet can be considered an “ecosystem engineer” that is integral to the formation of these deep peat basins (Seiben, 2012; Job & Ellery, 2014). Removing palmiet from these systems is likely to have negative consequences for the wetland and its functions because water storage will be reduced, erosion will increase dramatically, and the water purification function of the wetlands will be lost. Management of these wetlands, which are close to the geomorphic threshold slopes for their size, is therefore essential if they are to be preserved for the benefit of human well-being.

The Krugersland basin and remaining peat wetlands in the Kromme River have been placed under protection and they are not permitted to be transformed for agriculture.

Invasive alien tree removal is underway within the wetland. Ongoing control and removal of invasive trees will continue to be a long-term challenge.