DEVELOPMENT OF MANAGEMENT AND REHABILITATION PROTOCOLS FOR PEATLANDS IN SOUTH AFRICA: CASE STUDIES OF PEAT FIRES

Jason le Roux, Ayabonga Gangathele, Alanna Rebelo, Lesley Gibson, Rebecca Stephenson, Donovan Kotze and Althea Grundling

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DEVELOPMENT OF MANAGEMENT AND REHABILITATION PROTOCOLS FOR PEATLANDS IN SOUTH AFRICA: CASE STUDIES OF PEAT FIRES

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Peatlands are under pressure globally and are being lost at increasing rates. Land use changes to agriculture and forestry both within and around peatlands, as well as direct peat extraction, have been the greatest contributors to the degradation of peatlands. These land use changes result in the lowering of the water table of a peatland, causing desiccation and erosion, all of which expose peatlands to an increased risk of peat fires.

Peat fire occurrence is increasing across South Africa. Peat fires result in a loss of sequestered carbon to the atmosphere as organic carbon stores are combusted, thereby contributing to anthropogenic climate change. Furthermore, peat fires pose risks to respiratory health due to substantial fumes and are a safety hazard to people and animals. These risks are amplified by the prolonged subsurface nature of these fires. The location of subsurface burning may be undetectable and can pose a danger of severe burns to any organism traversing the peatland. The South African Peatland Database has recorded 635 peatland observations, with an estimated storage of about 29 million tons of carbon. The total loss of carbon due to peat fires is estimated at about 280 000 tons to date.

There are gaps in knowledge relating to peatlands in South Africa, including their full extent and location, their carbon storage, the occurrence of peat fires, and restoring functionality to burnt peatland systems. The overarching aim of this Water Research Commission funded research study (WRC Project No. 2019/2020-00098) was to develop management and rehabilitation protocols for South African peatlands affected by peat fires from the determined peat loss in selected case studies.

Specific aims of the project:

1. To estimate the potential loss of peat in three selected peatlands in South Africa by establishing the extent of peatland desiccation and the loss of peat through erosion and fire.
2. To identify ecosystem services that peatlands historically provided to the affected communities.
3. To develop a protocol for the prevention, management and rehabilitation of degraded peatlands, as well as for controlling peat fires.

Research questions that were addressed:

1. How much peat has been lost due to peat fires in the studied peatlands?
2. How do burnt peatlands function hydrologically?
3. What ecosystem services/functions have been lost to local communities due to peat fires in the studied peatlands?
4. How can peat degradation be prevented in peatlands, i.e. what management interventions are required?
5. How can burnt peatlands be rehabilitated?

Peatland case studies:

The following peatlands were selected as case studies for burnt peatlands:

- Molopo Peatland (North West Province)
- Onrus Peatland (Western Cape)
- Muzi and Vasi Peatlands (KwaZulu-Natal)

Some case studies were conducted in more detail than others.

The following wetlands were selected as case studies for preventative assessments:

- Palmietrivier Wetland and Onrus Peatland (Western Cape)

Methods:
The methods are briefly outlined for the three main report sections.

1. **Processes and factors driving peatland degradation and the socio-economic impacts of this degradation: Case studies of the Molopo, Onrus and Muzi/Vasi Peatlands (Chapter 2)**
   Catchment land use, peat/carbon loss, peatland characteristics and hydrology, stratigraphy and water levels were determined for the three peatland case studies. Additionally, a socio-economic study was done on the impact of peat fires in the case studies. Ethical clearance was obtained through the University of the Free State (UFS-HSD2020/2139/233). The project was registered and permits for sampling obtained from the North West Parks Board, Ezemvelo KwaZulu-Natal Wildlife and iSimangaliso Wetland Park.

2. **Peatland management and rehabilitation: Case studies of the Palmietrivier and Onrus Peatlands (Chapter 3)**
   This case study presents an example of how to conduct a wetland assessment for management purposes to prevent degradation, based on the stratigraphy of two palmiet wetland systems. The study includes peat profile descriptions, carbon content of profiles, landscape setting and level of degradation which were described for the peatland case studies. From the case studies, recommendations were developed to minimize any further degradation.

3. **Protocols (Chapter 4)**
   The findings from this research project, as well as the collective experience of the project team, were used to develop recommendations for controlling peat fires (section 4.1), as well as for the prevention, management and rehabilitation of degraded peatlands (4.2). These were then incorporated into a draft set of protocols for these two topics in the form of "decision tree" frameworks (4.3).

Results:
The results from the three main report sections and case studies are summarized for each of the three study aims.

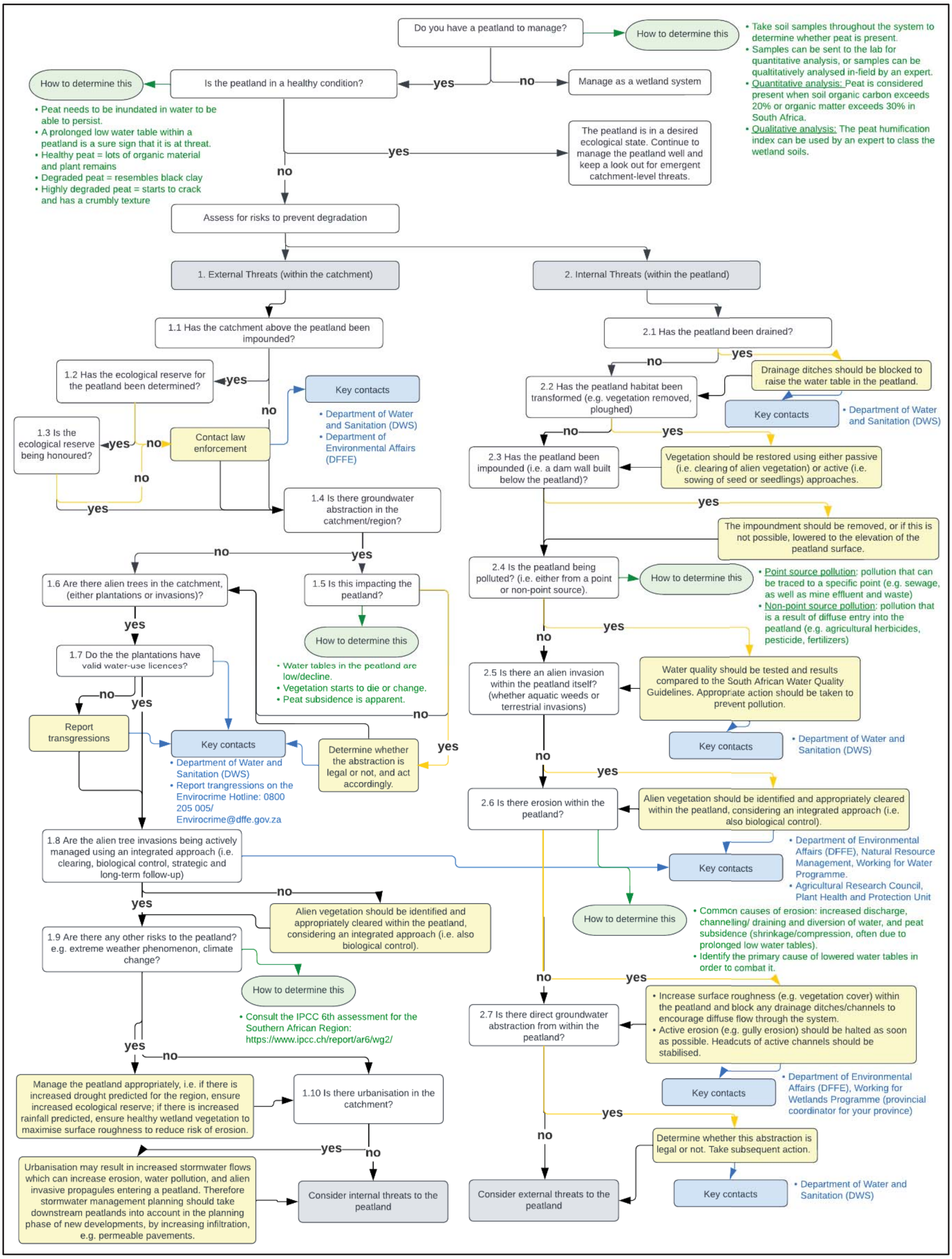
Aim 1: Peat loss determination (Chapter 2)
Peat loss was estimated at the Molopo, Onrus and Vasi Peatlands. The results indicate that a peat layer approximately 1.67 m in thickness (~344 000 m^3 of peat) over approximately 20 ha may have been lost from the Molopo Peatland due to the degradation and resultant fire. This peatland therefore had the highest peat loss of the three systems studied. The Onrus Peatland lost approximately 12 500 m^3 of peat following the peat fire in 2019, but still has a small amount of peat remaining. The Vasi Peatland is estimated to have lost 129 000 m^3 of peat and thus experienced the second highest peat loss of the case studies. This is indicative of the severe degradation of the peatland system due to the continued land use changes to the catchment, primarily linked to forestry activities.

Aim 2: Community ecosystem services of peatlands (Chapter 2)
Communities from the Molopo, Onrus and Muzi Peatlands all experienced a direct loss in ecosystem services following peat fires. Based on the assessment of the three case studies, the ecosystem services lost include "a sense of place", clean water (water storage), vegetation cover and biodiversity, as well as the amount of peat that was lost through erosion and fire, thereby losing carbon to the atmosphere and contributing to climate change. Provisioning services that were lost include the source of income generated by local communities by harvesting reeds. We also report on how the relevant authorities responded to the peat fires in each case study.

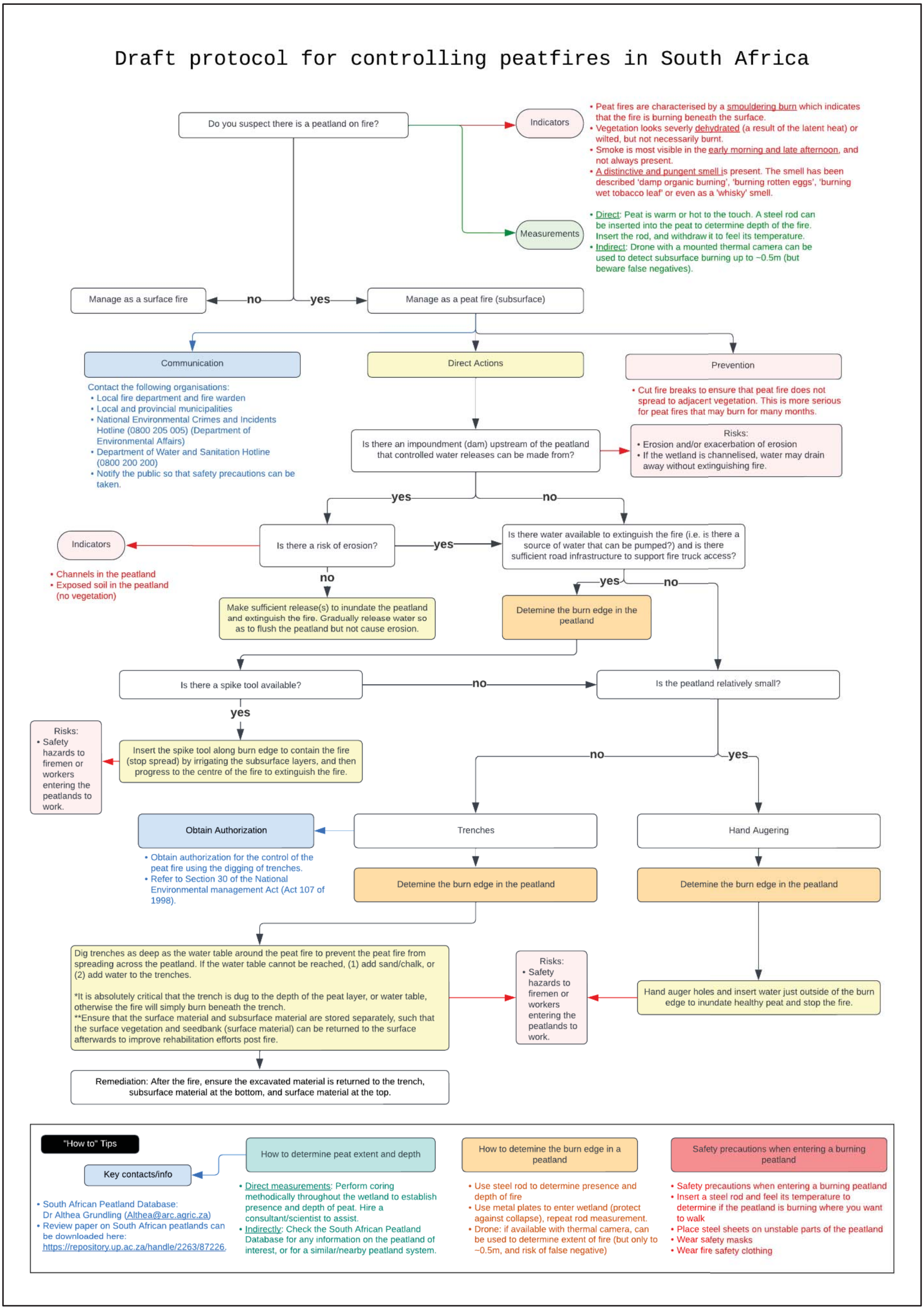
Aim 3: Management and rehabilitation protocols (Chapters 3 & 4)
Two draft frameworks, presented as “decision trees”, were developed which may be used as guidelines by regulators, managers, landowners or communities to prevent peatland degradation (Framework 1) and for controlling peat fires (Framework 2). Each step has a question which requires answering, which aids people working through the framework. These “decision trees” are presented as a foundation to build upon. We propose that the frameworks should be further workshopped with mandated authorities for refinement and finalization to support the draft South African Peat Protocol.

Recommendations:
Based on the findings of the case studies and the collective experience of the project team, the following recommendations are made:

1. A pre-emptive approach of a) identifying the most vulnerable areas and b) determining specific threats will create awareness of key management interventions with landowners, communities and other partners (e.g. governmental conservation programmes).
2. Loss of ecosystem services or functions (particularly water storage and carbon-related sequestration) should be used as a tool to raise awareness about the risks associated with the loss of peatlands.
3. Develop peat training materials for regulators (i.e. mandated authorities). Regulators were not aware that wetlands may contain peat and of the risk of peat fires. Given the danger that desiccated and burning peat poses, awareness should be raised on the threat to human and animal health. These health risks range from burning peat assessment to fire control activities. Training material should include safety precautions to follow when entering a burning peatland and specific methods to control peat fires.
4. Workshop the draft protocols (“decision trees”) developed in this project with mandated authorities, which can then be incorporated into the South African Peatland Protocol.
5. There is a need for policy to be developed around peat fires and their prevention, and this should include a regulatory tool.



Draft Framework 1: Draft protocol for the prevention, management and rehabilitation of degraded peatlands (Figure 4.4 in the report).



Draft Framework 2: Draft protocol for controlling peat fires (Figure 4.5 in the report).

Importance and policy implications:

The research findings from this study contributed towards drafting protocols for the prevention, management and rehabilitation of degraded and burnt peatlands and to support the national peatland protocol in controlling peat fires. The protocols that various institutions should follow once they suspect that a peatland has the potential to burn or has begun to burn will assist in the conservation and management of these systems. This study has also provided substantial evidence to give input to the envisaged wetland policy for management and rehabilitation.

Capacity building:

The study created various opportunities for capacity building and for future research:
Internal: One MSc student submitted his thesis at the end of 2022 while another MSc student and a PhD student aim to complete in 2023. Students won awards at the National Wetlands Indaba 2022 for Best Student Paper Presentation and Best Student Poster.
External: Various government institutions ranging from local municipalities to conservation authorities were informed and trained in aspects relating to peat fires, management and conservation.

Publications:

Grundling P-L, Grundling AT, Van Deventer H & Le Roux JP (2021). Current state, pressures and protection of South African peatlands. *Mires and Peat* 27 (26): 1-25; doi: 10.19189/MaP.2020.OMB.StA.2125

Le Roux JP, Gangathele AM, Hanekom C & Grundling AT (2021). The Muzi peatland reed cutters and their perspectives on a subsurface peat fire. *The Water Wheel* 20(1): 36-39.

Future research:

A follow-up project is proposed where the draft protocols are workshopped with key stakeholders and authorities to be refined accordingly, and particularly information on key contacts and official procedures to be added. A graphic designer could be budgeted for to develop a user-friendly final product.

Conclusion:

The Global Peatland Assessment highlighted the need for action to conserve, restore and manage peatland systems in a sustainable manner. This WRC project has shown that land use changes influence the hydrology of peatlands and can have a negative impact on the peatland, causing its degradation either by drying out, eroding or burning. The case studies presented in this report confirm that the lowered water tables, due to land use change, have negative implications for peatland functionality and the related provision of ecosystem services. A peatland's ecological reserve should therefore be determined and honoured for all historic and future developments.

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ABBREVIATIONS

ARC-NRE	Agricultural Research Council – Natural Resources and Engineering
CSIR	Council for Scientific and Industrial Research
DFFE	Department of Forestry, Fisheries and the Environment
DWS	Department of Water and Sanitation
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
INR	Institute of Natural Resources
KZN	KwaZulu-Natal
NW	North West Province
NWDARD	North West Department of Agriculture and Rural Development
NWI	National Wetlands Indaba
NWPB	North West Parks Board
SAEON	South African Environmental Observation Network
SU	Stellenbosch University
UFS	University of the Free State
WC	Western Cape
WETREST	Centre for Wetland Research and Training
WRC	Water Research Commission

1 INTRODUCTION

1.1 BACKGROUND

Peatland systems make up only 3% of the Earth's land cover (Wilkinson et al., 2021) but they are under pressure and being lost at increasing rates, and are left susceptible to burning (Grundling et al., 2019; Job & Ellery, 2013; Page & Baird, 2016). Although peatland systems make up only a small percentage of global land cover, their importance cannot be understated. They have been identified as systems which are important for hydrological, limnological, zoological, botanical and ecological functioning (Tooth & McCarthy, 2007). Land use changes to agriculture and forestry, both within and around peatlands, as well as direct peat extraction, have been the greatest contributors to the degradation of peatlands (Kirpotin et al., 2021). These land use changes result in peatland draining, desiccation and erosion, all of which expose peatlands to an increased risk of peat fires. Many European and North American countries are facing the issue of a significant portion of their peatlands being drained and therefore threatened, e.g. Germany (98%), Netherlands (95%), Denmark (93%) and Ireland (82%) (Tanneberger et al., 2017). Although most of these land use changes take place in the northern hemisphere, they have been increasing in the tropics in recent years too (Kirpotin et al., 2021). The tropics hold about 15% of global peat, with South-east Asia holding 41% of tropical peat. These areas are at threat to peat draining and fires. Here the peatland changes are due to rainfall reductions likely because of climate change (Kirpotin et al., 2021). The Global Peatland Assessment Report (UNEP, 2022) highlighted the need for action to conserve, restore and manage peatland systems in a sustainable manner.

To date, South Africa has experienced 51 peat fires across 20 peatland systems since 1988, in seven of the nine provinces, where the frequency of these subsurface fires has also been increasing (Grundling et al., 2021). Peat fires refer to a fire in a peatland that occurs within the peat body itself and is characterized by subsurface fires. They are dominated by smoldering combustion and can persist under low temperatures, high moisture content and low oxygen concentrations, and as a result can burn for long periods despite rain events (Belcher et al., 2010). In South Africa, the deepest peat fire has occurred in the Bodibe Peatland, to a depth of 7 m, which burnt intermittently between 2000 and 2009 until it reached the underlying bedrock (Grundling et al., 2000; Grundling et al., 2021).

Because of desiccation, peatlands that become vulnerable to and then become exposed to subsurface fires can supply a fraction of the ecosystem services that they were once capable of in their pristine state. The ecosystem services that peatlands can provide have been divided into three classes by a Common International Standard for Ecosystem Services (CICES) framework, namely provisionary services, regulatory services and cultural services (Haines-Young & Potschin, 2013). Provisionary services include the provision of material and energy such as drinking water, foods and timber; regulatory services include the maintenance of environmental conditions such as climate regulation through carbon storage and sequestration, and the regulation of water quality through the filtration of pollutants; and cultural services include the provision of non-material benefits such as opportunities for recreation, aesthetic experiences as well as gaining information and knowledge (Bonn et al., 2016). It is, however, important to note that the values of wetlands and the ecosystem services accessed by individuals can differ amongst communities (Mitsch & Gosselink, 2000) as people value environmental features in different ways (Choi, 2007). Restoration action should therefore bear in mind the ecosystem services that are most valued by different communities. Whilst it is known that peat fires result in a loss of peat, it is unknown whether ecosystem services are lost as a result of fire, or previous stages of degradation, as the ecological state of the selected peatlands was not measured before they burned.

Water is the principal driver behind the occurrence of a peatland, as constant water levels are required to reduce aerobic decomposition in order for peat to form (Joosten & Clarke, 2002). In order for a desiccated and burnt peatland to be rehabilitated, an understanding of the system's hydrology is required. The overarching aim of this research project was therefore to understand the hydrology of selected peatlands that have been exposed to peat fires, and the measures that can be taken to restore the hydrological functioning of these systems. The research also determined how much peat has been lost in these systems, as well as the impacts that these fires have had on respective local communities. Case studies were undertaken to identify how different peat fires were managed by various stakeholders. This allowed recommendations to be made concerning the future management of peat fires.

1.2 AIMS OF THE PROJECT

The specific aims of this research project were as follows:

1. To estimate the potential loss of peat in three selected peatlands in South Africa by establishing the extent of peatland desiccation and the loss of peat through erosion and fire.
2. To identify ecosystem services that peatlands historically provided to the affected communities.
3. To develop draft protocols for the prevention, management and rehabilitation of degraded peatlands, as well as controlling peat fires.

1.3 STRUCTURE OF THE REPORT

This report consists of five main chapters. The introduction (Chapter 1) focuses on the problem statement, specific aims of the project and its limitations. Chapter 2 focuses on the peatland case studies with regard to the processes and factors driving peatland degradation and the related socio-economic impact. Chapter 3 discusses peatland management, prevention of degradation and rehabilitation. Chapter 4 provides the discussion and recommendations with a draft set of protocols in the form of "decision tree" frameworks and Chapter 5 gives the conclusion.

1.4 PROJECT LIMITATIONS

- Covid-19 restrictions limited stakeholder engagement activities. For example, the impacts of peat fires on the communities at the Onrus Peatland, along with the management of the respective peat fires, only commenced at the end of November 2021 and was completed in 2022.
- Damage to equipment by buffalo and elephant in Tembe Elephant Park (Muzi Peatland), and the financial implications of replacing this equipment.
- Due to safety concerns, a peat loss survey could not be conducted for the Muzi Peatland. Given that Tembe Elephant Park contains dangerous game, an armed escort is required to always accompany researchers while on foot in the park. A large section of the Muzi Peatland is covered with reeds (*Phragmites australis*), thus reducing visibility in the peatland. The Tembe Elephant Park is understaffed and does not have excess personnel capable of carrying a firearm to escort the survey team for the days required to survey the peatland.
- At the Molopo Peatland, the water table was below the residual ash and patchy thin layers of remaining peat, which are underlain by bedrock. Therefore, it was not possible to determine the hydrological functioning of the system. A detailed description of the peatland's stratigraphy was also not conducted as the vast majority of the system is covered in peat ash, with sporadic areas of unburnt but highly desiccated peat.

1.5 SYNERGIES WITH OTHER STUDIES

There is strong synergy between the WRC funded projects in Maputaland. The Agricultural Research Council (ARC) is working together with the Council for Scientific and Industrial Research (CSIR) and the South African Environmental Observation Network (SAEON). The other projects include:

QUANTIFYING THE EXTENT AND RATE OF CHANGES IN WETLAND TYPES OF THE MAPUTALAND COASTAL PLAIN (MCP) WITH REMOTE SENSING
Project leader: Dr Heidi van Deventer (HvDeventer@csir.co.za)
CSIR

AIMING FOR SOCIETAL IMPACT THROUGH ENGAGED RESEARCH AND INTERDISCIPLINARY INTEGRATION IN THE MAPUTALAND COASTAL PLAIN WETLAND SYSTEM
Project leader: Ms Susan Janse van Rensburg (s.jansevanrensburg@saeon.nrf.ac.za)
SAEON: Grasslands-Forests-Wetlands Node

2 PROCESSES AND FACTORS DRIVING PEATLAND DEGRADATION AND SOCIO-ECONOMIC IMPACTS OF THIS DEGRADATION: CASE STUDIES OF THE MOLOPO, ONRUS AND MUZI/VASI PEATLANDS

2.1 INTRODUCTION

Grundling et al. (2021) reported on the current state and pressures on South Africa's peatlands and found that cumulative anthropogenic pressures have resulted in an increase in the number and temporal frequency of peat fires, with 49 peatland sites having burnt in the past 5 years, compared to 23 in the 24-year period preceding it. **Figure 2.1** indicates the location of burnt peatlands across South Africa and the Maputaland Coastal Plain, where approximately 60% of the country's peatlands are located (Grundling et al., 2021).

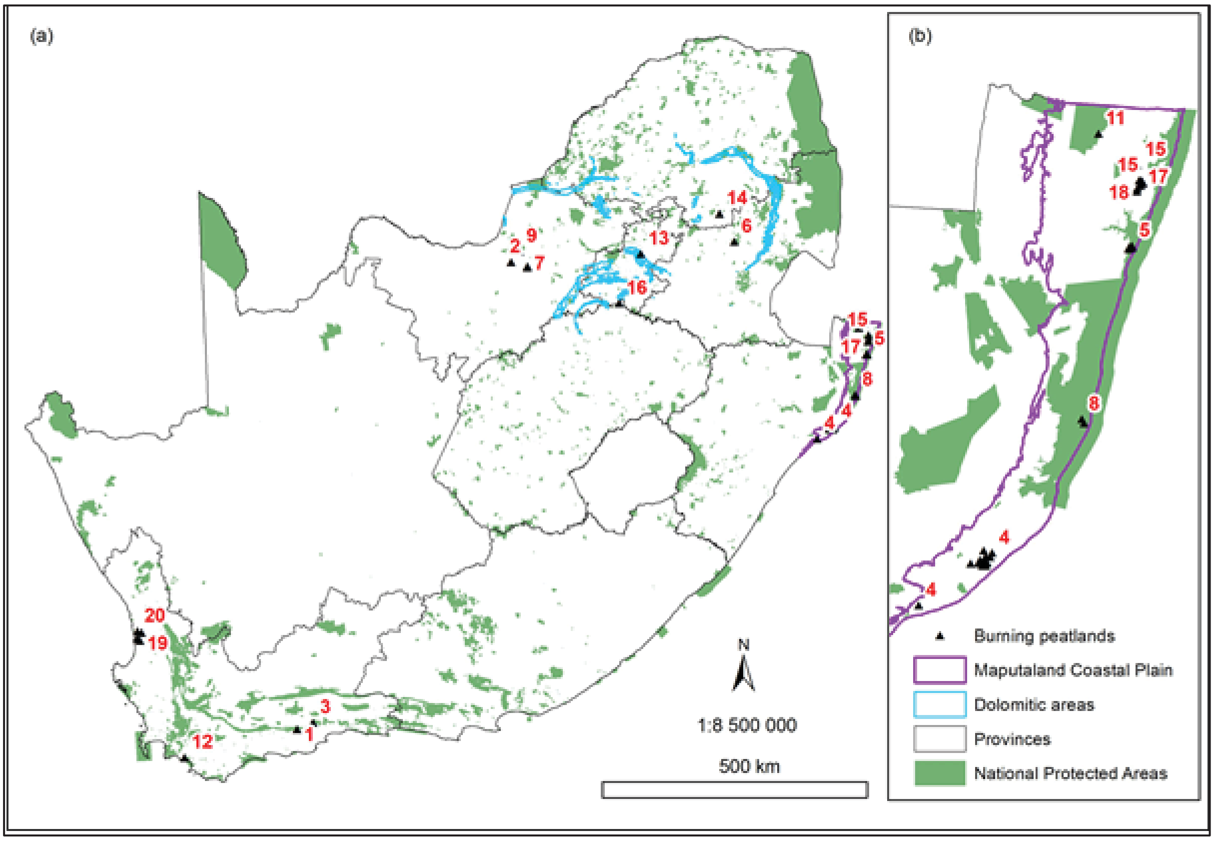


Figure 2.1 Location of burnt peatlands across South Africa and the Maputaland Coastal Plain (Grundling et al., 2021).

Peat fires can only occur when the water table of a peatland drops, as the high moisture contents of peat soils in pristine peatlands naturally prevent peat from burning (Frandsen, 1997; Turetsky et al., 2015). Furthermore, hydrology is often regarded as the most important factor controlling peatland formation, as well as functioning. This is most likely due to constant water levels being required to reduce aerobic decomposition for peat to form (Joosten & Clarke, 2002). Once a peatland is established, the peat itself begins to regulate the peatlands hydrology, which in turns influences its biodiversity, as well as the hydrology and biodiversity of surrounding areas. Without vegetation, peat cannot form. If one of these components is altered, changes in the peatland's ecosystem services, including its biodiversity, may also occur. Peatlands therefore comprise three components (i.e. water, plants and peat) that are intricately connected and equally interdependent (Joosten, 2016) (**Figure 2.2**).

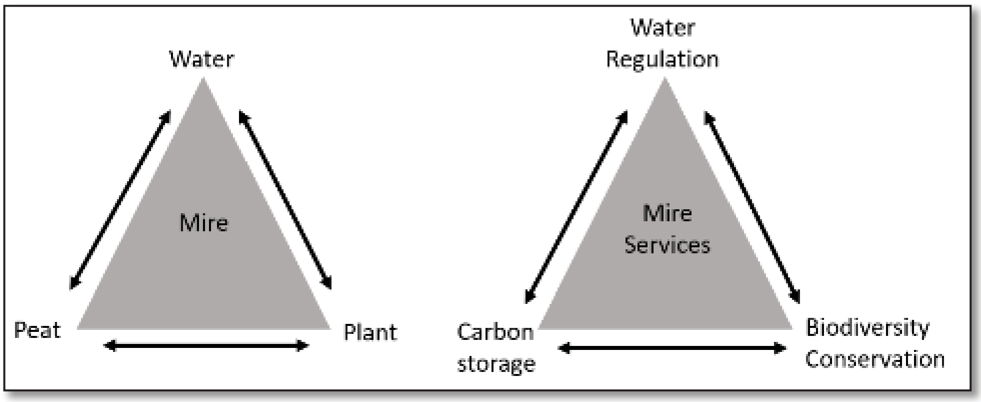


Figure 2.2 Important ecosystem relations and ecosystem services of mires (active peat forming peatlands) (Joosten, 2016).

The carbon loss attributed to peat fires in South Africa was determined by Grundling et al. (2021). Carbon loss was calculated based on the methods of Agus et al. (2011) using volumes determined by digitizing burnt extents from aerial imagery and depth of burns recorded via infield sampling. Carbon contents and bulk density values for most of the burnt peatlands were extrapolated from Mulders et al. (2017), except for Muzi North where values were taken from Grundling et al. (2010). Carbon dioxide (CO_2) that was emitted was estimated using the atomic mass of carbon in relation to CO_2. Results indicated that peat fires have resulted in an estimated loss of 280 513 tons of carbon and 1 036 822 tons of CO_2 in South Africa since 1988 (**Table 2.1**) (Grundling et al., 2021). Results also showed that of all the burning peatland systems, Vasi Peatland had the highest loss of carbon and CO_2, with an estimated 55 920 tons of carbon lost and 205 226 tons of CO_2 emitted. South Africa's *per capita* emissions stood at 9.5 tonnes of CO_2 equivalent (tCO_2e) in 2015, which is well above the emission rates in most other countries (Carbon Brief, 2018). South Africa’s burning peatlands contribute to this high emission rate.

Table 2.1 Estimated loss of peat, carbon and carbon dioxide from burnt peatlands in South Africa (modified from Grundling et al., 2021)

Name of peatland system (number of sites)	Province	Depth burnt / desiccated (m)	Extent burnt (ha)	Volume burnt (m^3)	Carbon loss (tons)	CO_2 emitted (tons)
1. Bergfontein	WC	**1.5**	3	45 000	2 340	8 588
2. Bodibe	NW	**7**	9.9	693 000	33 551	130 472
3. Kamma	WC	**2.5**	5	2 500	6 500	23 855
		2.5	2	50 000	2 600	9 542
4. KwaMbonambi (13 sites)	KZN	**0.5-1**	35.0	174 850	8 393	30 802
5. Lake Sibaya (8 sites)	KZN	**0.5**	5.6	27 750	1 332	4 888
6. Lakenvlei (2 sites)	MP	**0.5-1**	1.07	5 350	271	994
7. Lichtenburg Game Breeding Centre (LGBC) (2 sites)	NW	**1.0-2.0**	48	480 000	24 624	90 370
			13	130 000	6 669	24 475
8. Mfabeni (2 sites)	KZN	**0.5**	11.5	57 500	2 762	10 135
			77.7	388 500	18 646	68 431
9. Molopo (2 sites)	NW	**0.5-1**	50	250 000	12 825	47 068
10. Muzi North-East	KZN	**0.5**	50.6	253 000	9 453	34 694
11. Muzi North-West	KZN	**0.5**	43.1	215 500	8 052	29 551
12. Onrus	WC	**1-1.5**	9	90 000	4 680	17 176
13. Rietvlei	GT	**0.5-1**	62	310 000	14 607	53 608
14. Sehlakwane Zaaiplaats	LP	**0.5**	1	5 000	253	929
15. Siyadla (6 sites)	KZN	**0.5**	29.8	149 560	7 179	26 347
16. Vaal River tributary (race course)	FS	**0.5**	5	25 000	1 283	4 707
17. Vasi Peatland (North)	KZN	**0.5-1.5**	31.3	156 500	7 512	27 569
18. Vasi Peatland (South) (2 sites)			233	1 165 000	55 920	205 226
19. Verlorenvlei (2 sites)	WC	**0.5-1**	29	145 000	6 380	23 415
20. Wadrif-Langvlei (2 sites)	WC	**1**	95	950 000	43 225	158 636
		1	3.2	32 000	1 456	5 344
TOTAL					**280 513**	**1 036 822**

2.2 PEATLAND CASE STUDY SITES

Four peatland case study sites were selected in three provinces in South Africa for the biophysical and socio-economic investigations of this project: the Molopo Peatland (North West Province); the Onrus Peatland (Western Cape); and two study sites in the Maputaland Coastal Plain in KwaZulu-Natal, namely the Muzi Peatland, commonly referred to as Muzi Swamp, and the main basin of the Vasi Peatland complex, commonly referred to as Vasi Pan (**Figure 2.3**).

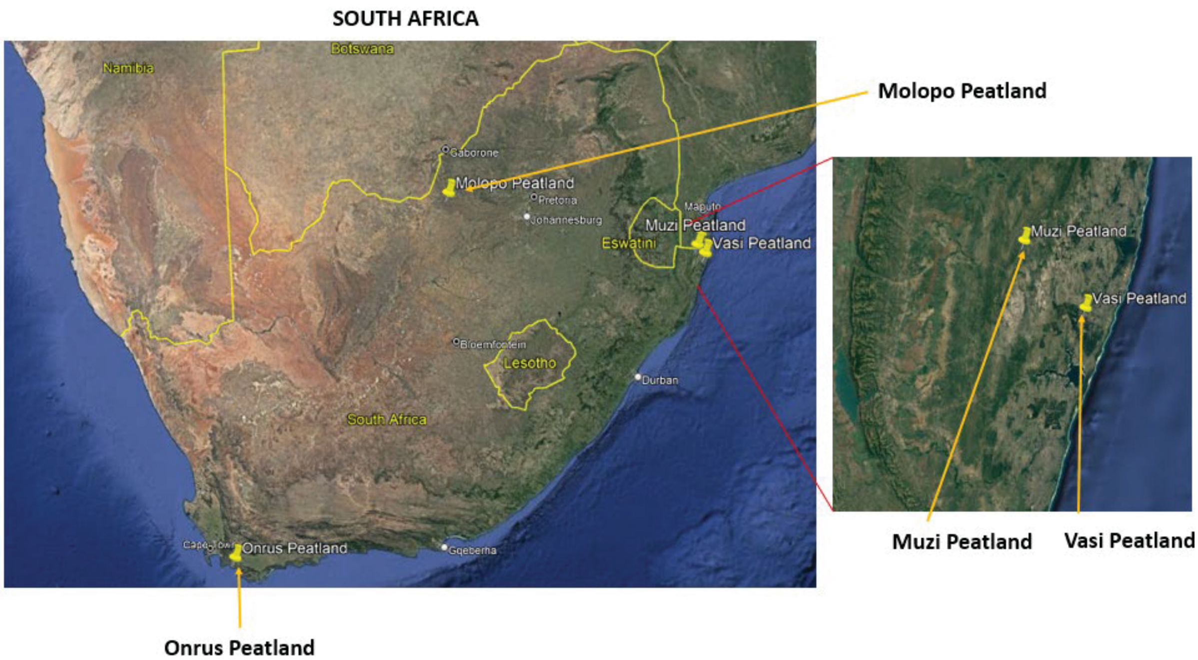


Figure 2.3 Location of the peatland case study sites in South Africa.

2.2.1 Molopo Peatland (North West Province)

The Molopo Peatland is one of the dolomitic peatland systems (karst fens) of the North West Province. Other karst fens in the province include *inter alia* the Molemani, Schoonspruit and Gerhard Minnebron Peatlands. These systems are unique in South Africa, particularly with respect to the number of endemic and endangered faunal species which they support, as well as their associated peat deposits (Grundling & Marneweck, 1999). Most of the springs and seeps feeding the peatlands originate on or near the contacts of dykes that transect the dolomite, whilst others are associated with dolomitic contacts with the Black Reef Lithological Formation, as well as contacts between the Monte Christo/Oaktree and Eccles/Lyttelton Lithological Formations (Bredenkamp, 1995). These different formations are characterized by a difference in permeability and storage capability of groundwater which influences the distribution of peatlands across the region (Grundling & Marneweck, 1999).

The Molopo Peatland is located in the headwaters of the Molopo River in the North West Province (**Figure 2.4**). It is a minerotrophic peatland fed by a dolomitic eye (spring) known as the Molopo Oog (or Eye) which is located in the Molopo Oog Private Game Reserve. The eye is situated at an altitude of 1 476 m above sea level (**Figure 2.5**). The peatland is a linear feature that extends in a north-westerly direction along the Molopo River. It is approximately 63.2 ha in size and its widest point is 320 m. The peatland is classified as an unchannelled valley bottom wetland (Ollis et al., 2013).

Approximately 730 m downstream of the Molopo Eye, upstream of where the peat fire occurred, a weir was installed to impound water for transfer to Mahikeng, the capital city of the North West Province. This local abstraction, combined with regional over-abstraction of the aquifer through borehole use, has resulted in a decline in water supply to the downstream peatland. The reduction in water has led to the desiccation of the peatland and subsequent fire events since 2016 until 2018, which started to burn the desiccated peat (**Figure 2.6**). There are currently only a few remnants of peat left in the wetland (**Figure 2.7**). The impoundment, the resultant peat fires and their ecological consequences have subsequently negatively affected the communities adjacent to the system.

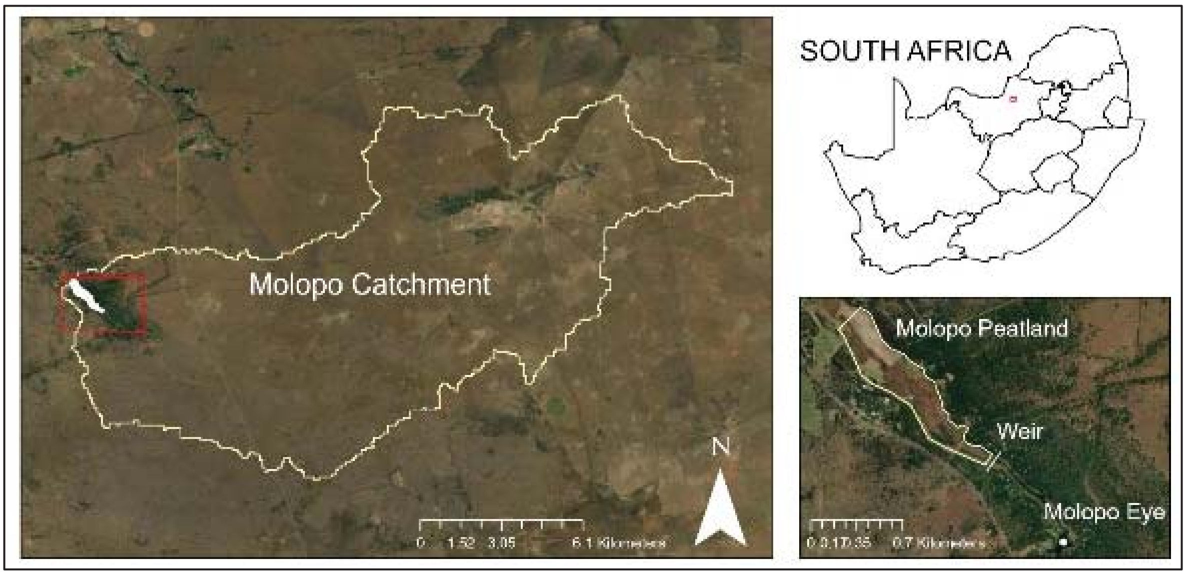


Figure 2.4 The Molopo Peatland within the Molopo Catchment, situated in the North West Province of South Africa. The peatland is identified as the white polygon within red extent indicator. The location of the Molopo Eye (spring) is shown with a point.


Figure 2.5 The Molopo Eye (the spring that feeds the Molopo Peatland system), North West Province *(Photo: Alanna Rebelo)*.

Figure 2.6 The Molopo Peatland burning in 2016 *(Photo: Piet-Louis Grundling)*, and visited again in 2018 *(Photo: Althea Grundling)*. The sign to the left of the bridge states "Deep water 1.5 m", warning people to be cautious. The sign was later covered by "Peat fire warning".

Figure 2.7 Peat remnant in the Molopo Peatland.

2.2.2 Onrus Peatland (Western Cape Province)

The Onrus Peatland is situated in the Hemel-en-Aarde valley, about 25 km outside Hermanus in the Western Cape Province of South Africa. The peatland is mostly situated on Camphill Farm, with the farm situated on the north-west and a road running on the south-east of the peatland, which is adjacent to Hamilton Russell Vineyards. The peatland, consisting mainly of endemic palmiet (*Prionium serratum*), was historically an unchannelled valley bottom. This along with the peat fire in 2018/19 has led to much peat being lost and the invasion of some alien species (**Figure 2.8**).

Hermanus falls in the Western Cape Mediterranean climate regime which experiences hot summers and cold wet winters (Western Cape Government, 2014). Hermanus receives on average 609 mm of rainfall a year, mostly in the winter months of June and July (Climate-data, 2022). The average maximum temperatures also vary through the year with January and February reaching an average of 24.7˚C and 24.9˚C respectively, and winter maximum temperatures in June and July reaching an average of 16.5˚C and 15.9˚C respectively (Climate-data, 2022).

There is a fault that runs through the Hemel-en-Aarde valley. The south-east of the fault is dominated by the Bokkeveld Group, underlain by the Rietvlei Formation, Skurweburg Formation, Goudini Formation, Cedarberg Formation, Pakhuis Formation, a dominant layer of Peninsula Formation and finally the Cape Granite Suite (Umvoto, 2020). The stratigraphy to the north-west of the fault is the same, with the Peninsula Formation being exposed in the peatland itself (Umvoto, 2020). There is severe erosion through areas of the peatland where peat has been lost and subsidence has occurred. There are two main erosion channels that run parallel to the peatland: an older erosion channel that is located along the north-west banks of the peatland, and a second, highly active channel towards the south-east. Areas upstream of the erosion channels are still in pristine condition.

Figure 2.8 Onrus Peatland (WC) – Onrus Peat fire in 2019 *(Photo: Onrus Municipality)*.

2.2.3 Muzi and Vasi Peatlands (KwaZulu-Natal Province)

The Maputaland Coastal Plain, located on the north-eastern seaboard of South Africa, is a recognized centre of endemism (Smith et al., 2008) and contains approximately 60% of the known and mapped peatlands in South Africa (Grundling & Grundling, 2019). Studies in the region have shown how peatlands have the ability to control local water tables (Grundling et al., 2013; Elshehawi et al., 2019), retain water from high rainfall events and impede rapid discharge to low-lying wetland areas (Pretorius et al., 2014; Gabriel et al., 2018), provide areas for subsistence agriculture (Grundling & Grobler, 2005), as well as contribute towards the local biodiversity and tourism value of the region (Grundling et al., 2014; Janse van Rensburg, 2019).

The incidence of peat fires on the Maputaland Coastal Plain has shown a significant increase since 2014. Grundling et al. (2021) suggest that this increasing trend in peat fires is the cumulative impact of both anthropogenic pressures and factors associated with climate variation within the past 5 years. This has resulted in many peatlands on the Maputaland Coastal Plain losing their resilience to a tipping point of collapse. The anthropogenic pressures are mostly attributed to exotic pine (*Pinus* sp.) and blue gum (*Eucalyptus* sp.) plantations, that numerous scientists have advocated to be removed from the Maputaland Coastal Plain due to their excessive water consumption, which lowers the regional water tables that the peatlands of the region are dependent on (Grundling et al., 1998; Bate et al., 2016; Elshehawi et al., 2019).

The Muzi Peatland is located within Tembe Elephant Park which spans an area of 300 km^2, is a Big 5 reserve and is the ancestral home of the Tembe people who co-own the reserve. There are no rivers running through the park, hence Muzi Peatland is the only permanent water source found within its boundaries, as the wetland pans in the park are seasonal and dependent on rainwater, making the Muzi Peatland integral to the existence of the Tembe Elephant Park (Grundling et al., 2014). Large sections of peat in the Muzi Peatland were exposed to subsurface fires on three occasions between 2013 and 2017 (**Figure 2.9**). The most recent subsurface fire was also the most severe and burnt continuously for 18 months. The peat fires mostly occurred in the eastern sections of the Muzi Peatland (**Figure 2.10**).

Figure 2.9 A 2017 aerial image of the Muzi Peatland following the last peat fire (Google Earth Pro, 2022).

Figure 2.10 The Muzi Peatland in August 2021.

The Vasi Peatland complex, located 25 km south-east of Tembe Elephant Park, is the peatland site in South Africa with the largest burnt surface area of 233 ha (Grundling et al., 2021). The peatland is surrounded by the Manzengwenya State Plantation, which was established in the 1960s (Thamm et al., 1996). It has experienced peat fires on three occasions. The first fire occurred in 1996, followed by another in 2016, and lastly a peat fire that began in September 2022 and was continuing to burn in November 2022. The Vasi Peatland exhibits large, desiccated mounds (roughly 1 m in diameter), surrounded by desiccation cracks. The west of the peatland is void of vegetation, whilst *Phragmites australis* and *Cyperus congestus* occupy the east of the peatland (**Figure 2.11**).

Figure 2.11 (Left) Bare desiccation mounds in the west of the Vasi Peatland. (Right) Vegetation occurring in the east of the Vasi Peatland *(Photos: Jason le Roux)*.

2.3 METHODOLOGY

2.3.1 Catchment Land Use

To determine whether changes have occurred in a peatland's catchment and how they may have influenced the hydrology of the study site, remote sensing in the form of land use/cover change mapping was used to identify respective long-term environmental and anthropogenic changes. Land use/cover change for different time periods between 1994 (Van den Berg et al., 2008) and 2020 (DFFE, 2020) were mapped and land use/cover change statistics calculated to quantify the degree of change.

2.3.1.1 Tier 1: Molopo Peatland (North West Province)

The Molopo Catchment area of interest that was used in the remote sensing and land use/cover change mapping is indicated in **Figure 2.12**. The catchment used is an upstream segment of quaternary catchment D41A. This portion of the catchment forms part of the feeder for the Molopo Peatland, and land use/cover in this area is most likely to impact the peatland.

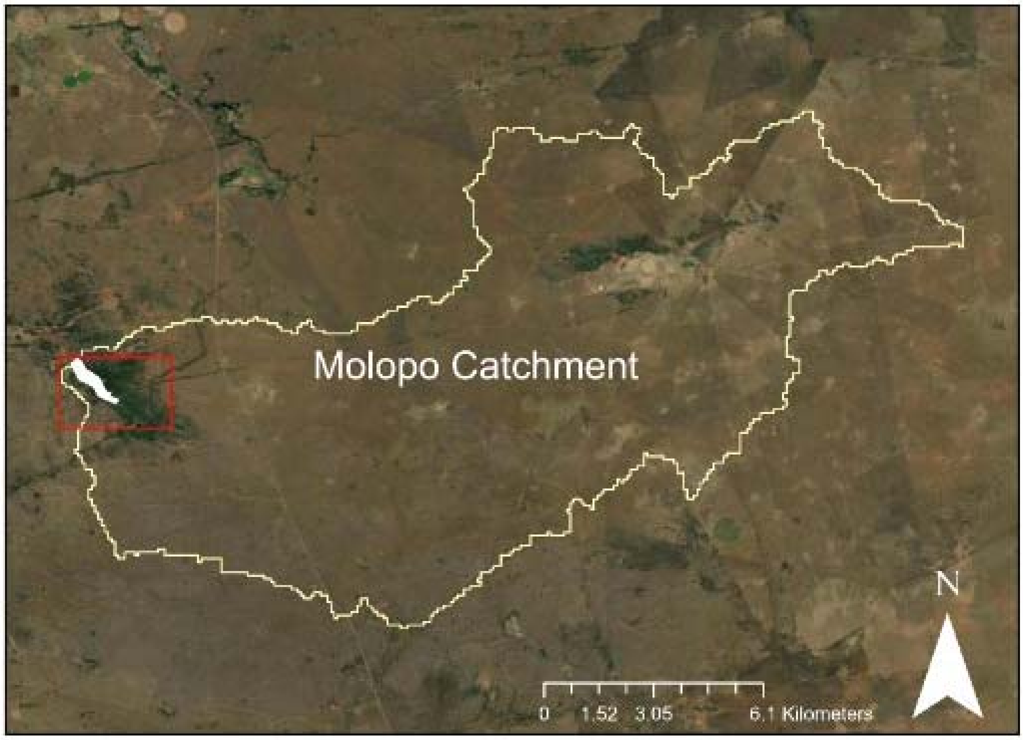


Figure 2.12 The Molopo Catchment boundary used as the area of interest to determine land use/cover change for 1994 and 2022. The Molopo Peatland is identified as the white polygon within the red rectangle.

2.3.1.2 Tier 2: Onrus Peatland (Western Cape Province)

The catchment area of interest that was used in the remote sensing and land use/cover change mapping included the catchment of the De Bos Dam and the Onrus Peatland, as well as the extent of the fire scar from the 2019 fire that consumed large areas of the Overstrand Municipality and was the source of ignition for the Onrus peat fire (**Figure 2.13**). Aerial imagery was also used to assess the land use/cover changes that have occurred in the catchment between 1976 and 2021.

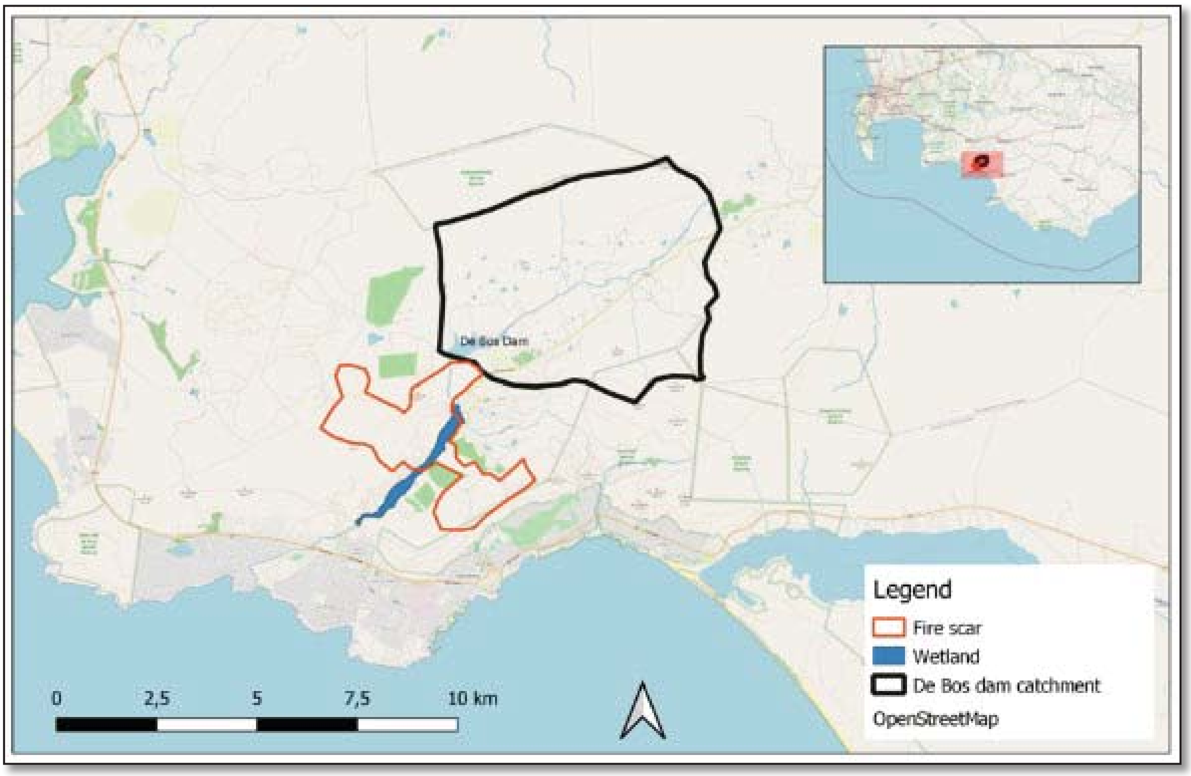


Figure 2.13 Location of the Onrus Peatland, the De Bos Dam and the fire scar from the 2019 fire.

2.3.1.3 Tier 3: Muzi and Vasi Peatlands (KwaZulu-Natal Province)

The W70A quaternary catchment boundary was used to map the land use/cover change for 1994 and 2020 (DFFE, 2020) and to calculate the land cover change statistics (**Figure 2.14**). This catchment incorporates both the Muzi and Vasi Peatland systems.

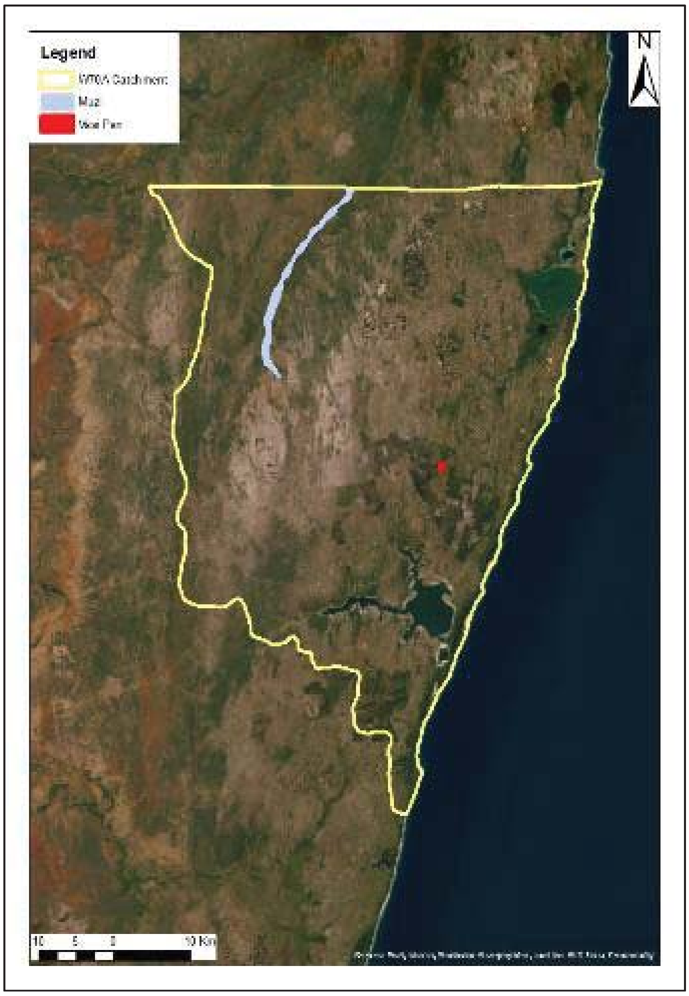


Figure 2.14 The W70A quaternary catchment boundary with the Muzi Peatland in purple and the Vasi Peatland in red.

2.3.2 Peat / Carbon loss

A dumpy level was used to measure the peat lost due to fire and erosion in the respective peatlands. A handheld GPS was used to capture the coordinates of survey points, where the elevation of each point was recorded using a measuring staff and thereafter correlated to the relative height of the dumpy station. In order to correlate the survey points to sea level, a GPS point was taken at the eye level of the dumpy station. The first and last point in each transect which had evidence of peat (i.e. presence of peat ash or degraded peat) at notable elevation changes aligned with the edge of the respective watercourse, was assumed to be the previous peat edge before the onset of degradation (**Figure 2.15**). Other indicators such as the bottom of fences were also used. An inspection profile of the soil/peat was also performed at the survey points using a soil or Russian peat auger.

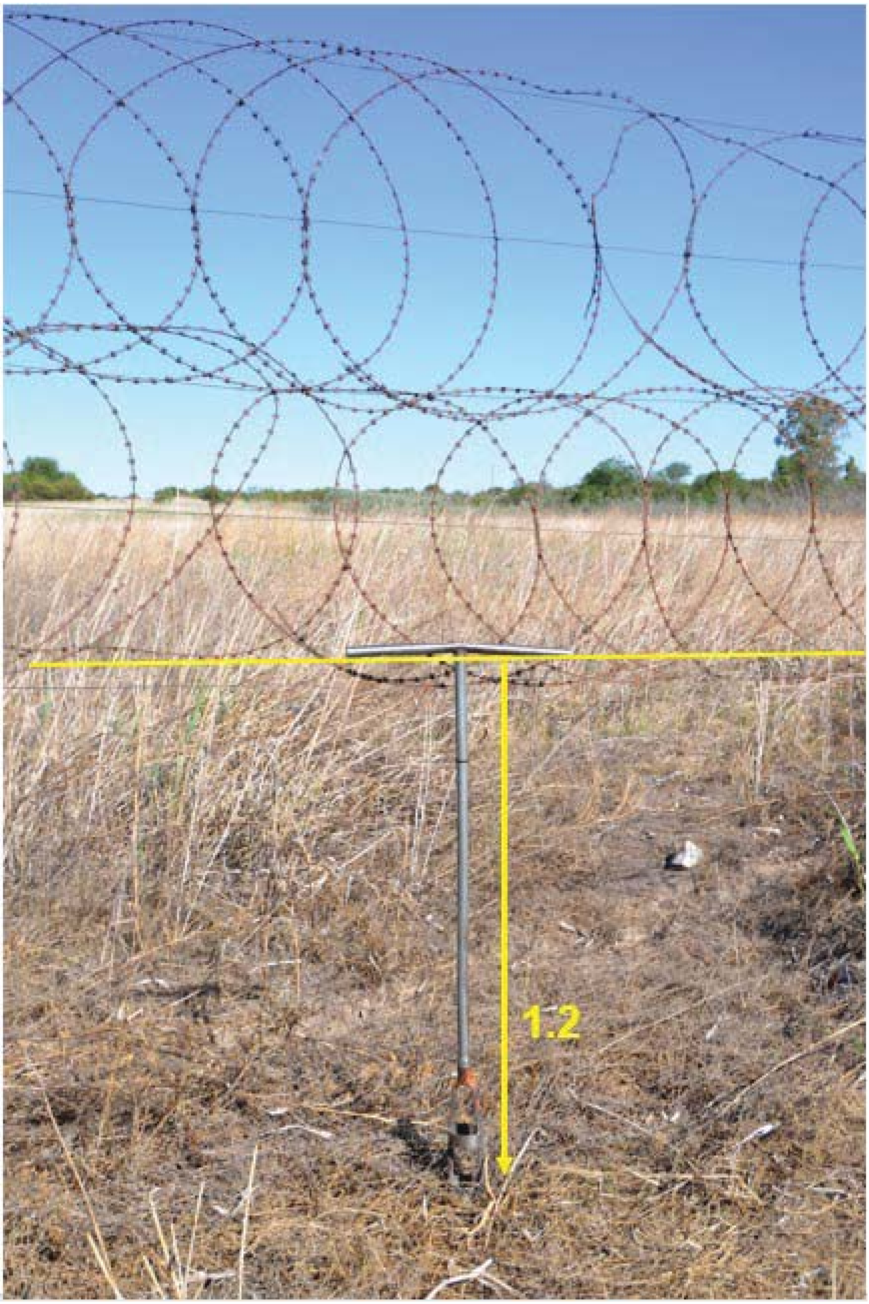


Figure 2.15 A soil auger indicating the 1.2 m of peat loss using the bottom of the fence line as an indicator of the former level of the peatland surface.

Following processing of the elevation data, coordinates of every sample point were imported into ArcGIS and projected to the Transverse Mercator projection best aligned with the location of the respective peatland. A historical and present DEM was created per site using the Nearest Neighbour interpolation method to obtain a smooth surface from the collected data. Thereafter the Raster Calculator Tool was used to subtract the differences in elevation between the historical and present peatlands, which resulted in the amount of peat lost due to degradational processes.

2.3.2.1 Tier 1: Molopo Peatland (North West Province)

The peat loss survey was undertaken in August 2022. The peatland section in the Molopo Private Park where the survey was carried out is approximately 990 m in length and 200 m wide. Changes in surface elevation were measured every 20 m along six transects approximately 200 m apart running across the peatland (**Figure 2.16**). Determining the elevation of the peatland proved challenging as it was inundated at the time of the survey (the water table having been below the peatland surface for the previous 2 years).

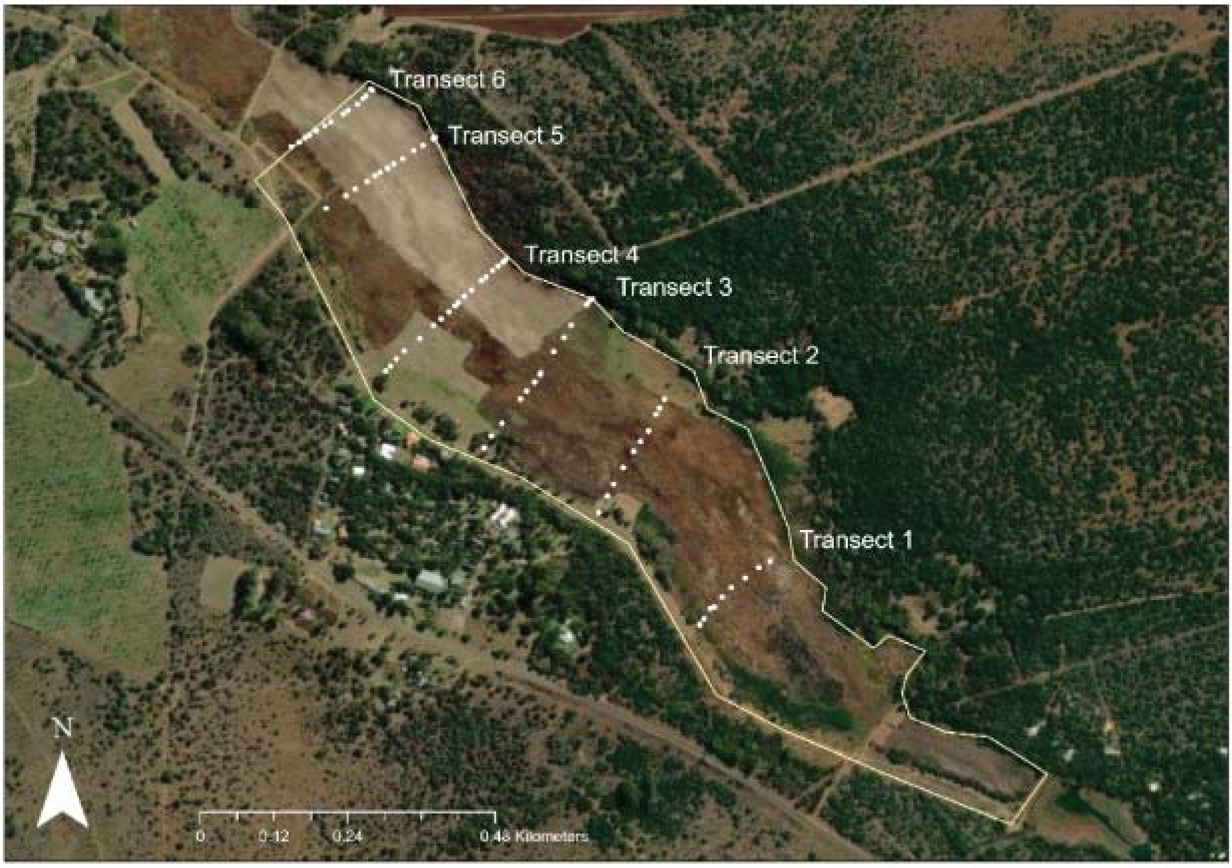


Figure 2.16 Surface elevation sampling transects in the Molopo Peatland, North West Province.

2.3.2.2 Tier 2: Onrus Peatland (Western Cape Province)

The peat loss survey was conducted in February 2022. Elevation sample points were taken at every notable change in slope. Nine main transects were established and are displayed in **Figure 2.17**. In addition to the main transect points, due to the erosion present on site and the related changes in elevation, sample points were also taken along the channel banks and at the base of the channels.

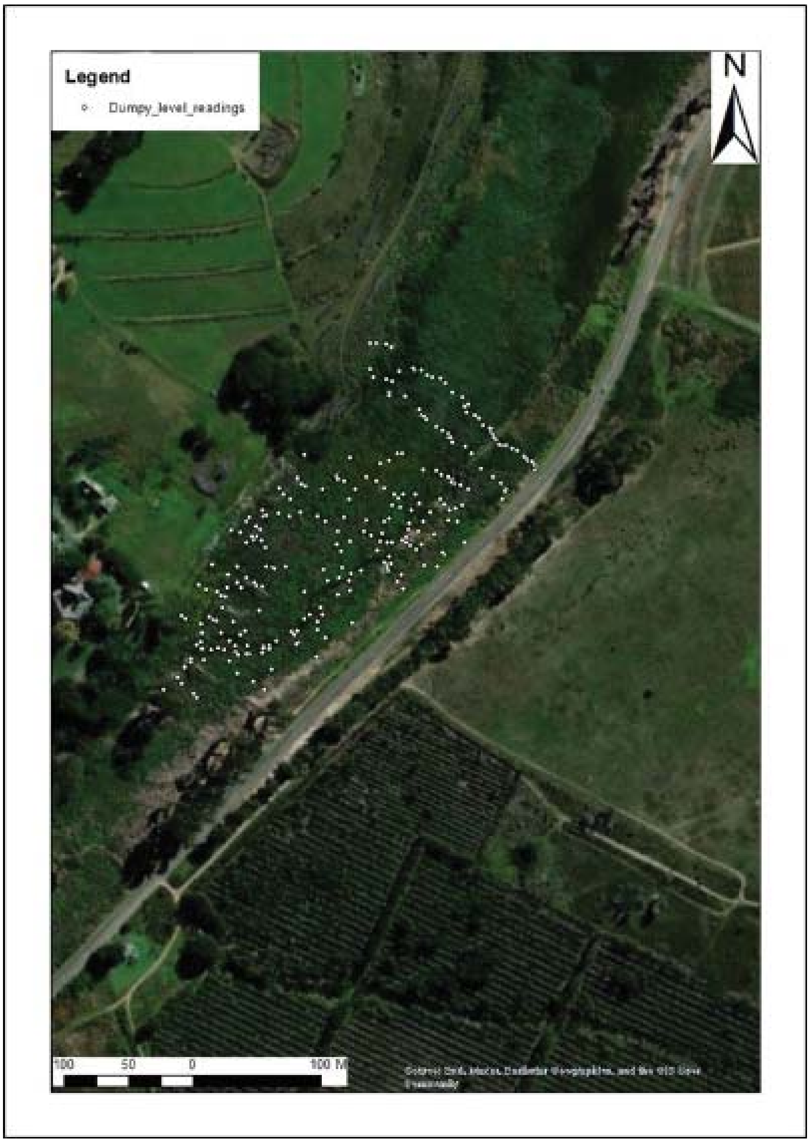


Figure 2.17 Surface elevation survey points along the Onrus Peatland, Western Cape.

2.3.2.3 Tier 3: Muzi and Vasi Peatlands (KwaZulu-Natal Province)

The peat loss survey was conducted in October 2022. Due to the crack and mound topography of the site, elevation readings of the mound's surface layer would not result in an accurate determination of the current elevation of the peatland due to the depth (up to 1 m) and width (up to 0.3 m) of the desiccation cracks. Therefore, the peatland was divided into relatively homogenous units with similar depth and width of desiccation cracks (n=7). These homogeneous units are referred to as 'crack size units'. In each crack size unit, 3 x 1 m^2 random plots were established, where the average size of the desiccation cracks was manually measured. Eleven elevation transects were surveyed with the staff being placed on top of the mounds, and the crack size unit recorded (**Figure 2.18**). The staff reading on each mound was then adjusted by subtracting the average size of the respective crack size unit. Examples of the different crack size units are displayed in **Figure 2.19**.

Figure 2.18 Surface elevation sampling points in the Vasi Peatland, KwaZulu-Natal.


Figure 2.19 Examples of two different crack size units used to determine the amount of peat lost in the Vasi Peatland.

A peat loss survey was not undertaken for the Muzi Peatland for reasons explained in the limitations of this study in Chapter 1.

2.3.3 Peatland Characteristics and Hydrology (Transects) / Stratigraphy and Water Levels

2.3.3.1 Tier 1: Molopo Peatland (North West Province)

2.3.3.1.1 Peat characteristic / Stratigraphy of the Molopo Peatland

A description of the stratigraphy and hydrology was not conducted for the Molopo Peatland. For the vast majority of this research study duration, the water table in the Molopo Peatland was below the base of the peatland, in the underlying bedrock. To attain some form of understanding of how the peatland functions, Topodrive was used to model the hydrological flow across the peatland from south to north. Topodrive is a two-dimensional computer model designed to simulate topography-driven groundwater flow in the case of the Molopo Peatland. The model is based on an assumed hydrological connectivity value estimated on the basis of the flow medium (i.e. peat ash, earthified peat, sand and gravel, and rock). The result is a theoretical flow diagram showing conceptual flow paths through the different strata across the peatland.

2.3.3.1.2 Gauge analysis of the Molopo Peatland

The gauge for the Molopo River at Rietvallei (gauge D4H013) is located about 10 km east of Mahikeng and about 10 km west of the Molopo Eye and downstream peatland.

2.3.3.2 Tier 2: Onrus Peatland (Western Cape Province)

To analyse the hydrology and peat characteristics, three transects were established with four or five sites selected along each transect for hydrological investigations and peat descriptions. Transect 1 was located in the pristine part of the peatland upstream of the head cut erosion, Transect 2 was located at the edge of the head cut erosion, and Transect 3 was downstream of the head cut erosion in the most degraded part of the peatland (**Figure 2.20**).

Figure 2.20 Onrus Peatland study area showing transects and sites.

2.3.3.2.1 Peat characteristic / Stratigraphy of the Onrus Peatland

Peat descriptions were made at the following sites: A1, A2, A3, A4, B1, B2, B3, C1, C2, C3. The remaining sites displayed in **Figure 2.20** were in mineral soil. A Russian peat auger was used for sampling where peat was analysed and classified according to the Von Post humification scale (Von Post, 1922). Photographs were taken and appropriately catalogued for future reference.

2.3.3.2.2 Water levels of the Onrus Peatland

Water levels were measured using piezometers and wells. At each site, a hydrological nest (water monitoring station) was installed consisting of piezometers of different heights and a well. The heights at which the piezometers were placed were determined by targeting dominant layers of peat according to the humification of the peat and its botanical origin. Once the appropriate depths were identified, a Russian peat auger was used to create holes in which the piezometers and wells were placed.

The piezometers and wells were constructed using 50 mm diameter PVC pipes. To make the piezometers, incisions were made every 1 cm along the length of the first 20 cm of the pipe, whilst incisions were made along the entire length of the pipe for the wells. Incisions were roughly the width of the pipe and were wrapped in a geotextile membrane which was firmly secured with duct tape and cable ties. A PVC cap was placed at the end with the incisions at the base of the pipe. The piezometers and wells were labelled accordingly with a permanent marker, for example, 'A1P0 3m'. Data was collected weekly from the beginning of January 2022 to the end of September 2022 using the Survey123 mobile application.

2.3.3.3 Tier 3: Muzi and Vasi Peatlands (KwaZulu-Natal Province)

As both the Muzi and Vasi Peatlands exhibit degradational gradients, one detailed hydrological transect was established across each peatland. Nine monitoring sites / hydrological nests were established in Muzi Peatland (**Figure 2.21**), whilst eight were established in Vasi Peatland (**Figure 2.22**). At each site, piezometers and wells were installed and detailed descriptions made of the stratigraphy. The wells were used to measure the water levels across the peatlands while the piezometers were used to measure piezometric pressure and collect water samples for chemistry and isotope analysis. At the Muzi Peatland, dry season water samples were collected in September 2021, before the rain season had begun, and again in April 2022. Water samples were collected in the Vasi Peatland in March and July 2022, before and after the heavy rainfall experienced in the KwaZulu-Natal Province in April 2022. Precipitation data was obtained from a weather station located inside Tembe Elephant Park.

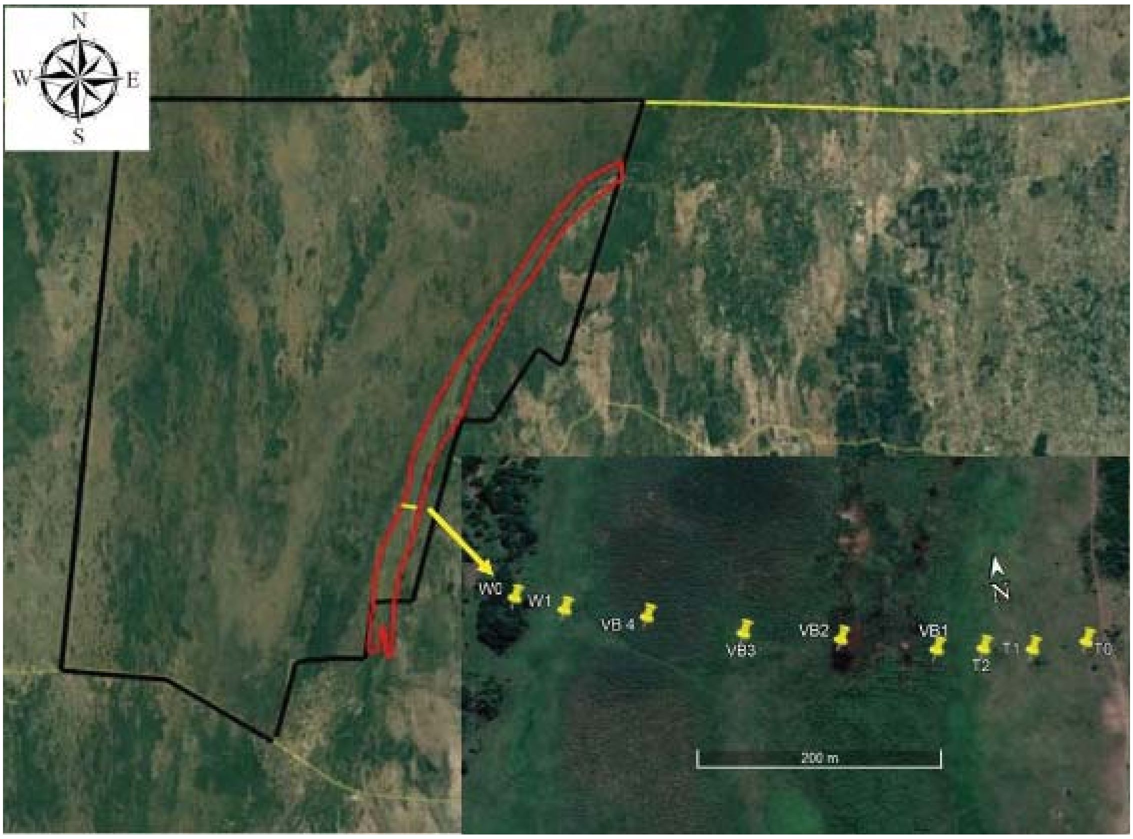


Figure 2.21 Locations of hydrological monitoring sites in the Muzi Peatland (red polygon), located within Tembe Elephant Park (black).

Figure 2.22 Locations of the hydrological monitoring sites in the main basin of the Vasi Peatland complex.

2.3.4 Socio-economic Impact of Peat Fire

2.3.4.1 Tier 1: Molopo Peatland (North West Province)

Ethical clearance was obtained through the University of the Free State to conduct interviews with the residents of Molopo Private Park (**Figure 2.23**). Due to Covid-19, a questionnaire was sent out by e-mail to 59 residents of the Molopo community living in the Molopo Private Park on the 24th of May 2021. The aim of this questionnaire was to determine the effects that the Molopo peat fire had on the community. Specifically, the questionnaire aimed to understand (i) how the physical appearance of the peatland influenced the community's lives prior to the fire, (ii) how the community was affected by the fire event, (iii) how the lives of the community have changed since the fire, and (iv) their views on rehabilitation and restoration of the system and potential perceived benefits thereof. Of the 59 residents invited to take part in the survey, 17 responded (i.e. a 29% response rate). An in-person interview with one of the residents was also conducted in October 2021.

Figure 2.23 Molopo Private Park adjacent to the burnt Molopo Peatland *(Drone photo provided by Molopo Private Park)*.

2.3.4.2 Tier 2: Onrus Peatland (Western Cape Province)

The ARC held a peatland training course and stakeholder workshop in December 2021, where various stakeholders, including landowners, local farmers and residents, NGOs, municipality staff and the Deputy Fire Chief shared their experiences on how they were affected by the peat fire. The training course aided in contextualizing what peatlands are, how they form and their importance in providing ecosystem services. The knowledge shared helped the stakeholders to understand the subsurface fire that burned for months, whereby they were provided with an opportunity to ask questions and share their perspectives regarding peatland management for the Molopo Peatland.

2.3.4.3 Tier 3: Muzi Peatland (KwaZulu-Natal Province)

One of the conditions in the proclamation agreement of Tembe Elephant Park is access by local communities to harvest natural resources on a sustainable basis. To ensure sustainable harvesting, a Resource Utilisation Operational Management Plan (Hanekom et al., 2008) was established in 2008 by Ezemvelo KwaZulu-Natal Wildlife. The aim of this document was to re-enforce and formalize the management actions relating to resource use within Tembe Elephant Park which have been in place since the proclamation of the protected area in 1983. Harvesting is currently limited to 6 months a year (1 April - 30 September) from Monday to Friday during daylight hours.

To understand the role that reed harvesting has on the lives of local reed cutters and how the peat fires affected them, reed cutters were interviewed on the 8th and 9th of September 2020 at the KwaMsomi gate, which is the most active of four control access gates they use. Reed cutters are restricted to 35 people per day at KwaMsomi and must carry their harvested resources out of the park on the same day, to allow for monitoring of each day's harvest. The reed cutters were divided into five groups ranging between 3-5 people as they were not comfortable to be interviewed alone. The group was composed entirely of women aged between 28 and 61 (averaging around 50 years old) from five wards around KwaMsomi.

2.4 RESULTS

2.4.1 Catchment Land Use

2.4.1.1 Tier 1: Molopo Peatland (North West Province)

The Molopo Catchment is situated entirely within the Grassland Biome, but adjacent to the southern boundary of the Savanna Biome. The major land use in the catchment is commercial game farming on the grasslands (**Figure 2.24** and **Figure 2.25**). There is also some crop farming and fallow fields. Mining was previously common in the catchment. Ecotourism is important for the region, with the Molopo Private Park as an example due to its desirable properties, namely the aesthetic value and open water for recreational activities. Residences near the peatland were of high commercial value at the time of purchase when the peatland was in a more pristine condition. The Molopo Peatland itself was composed mainly of *Phragmites australis* reed beds, which supported high biodiversity, including many bird species.

Land use/cover comparison from 1994 to 2022 shows that the city of Mahikeng (and surrounds) grew by 121.41 km^2 over 26 years, hence the increasing need for water, which is threatening the peatland systems (**Figure 2.25**). The expansion in the Mahikeng area also brought about changes in land use to accommodate the people living there. This is evident by the increase in the built-up area and cultivated land with a decrease in the area of wetlands (**Figure 2.26**).

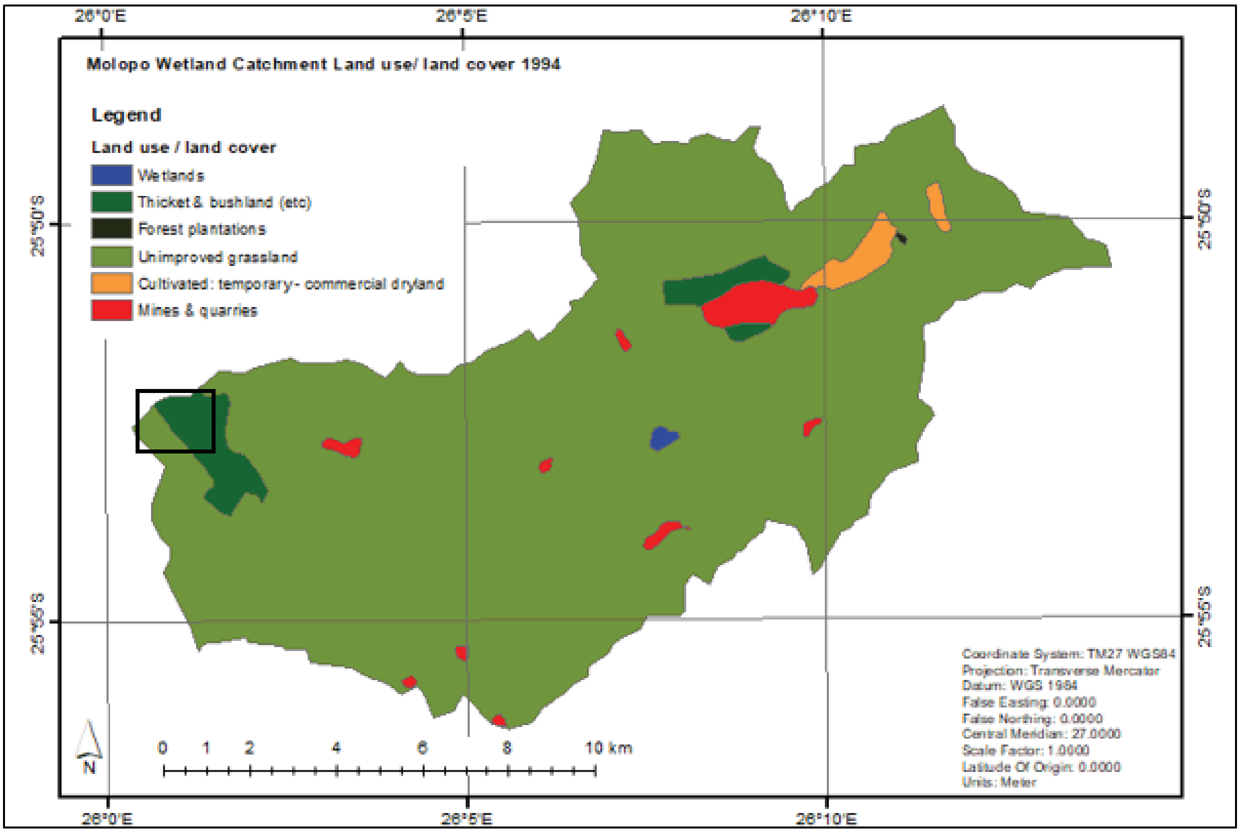


Figure 2.24 Land use/cover within the Molopo Catchment in 1994. The location of the Molopo Peatland is indicated in a black rectangle.

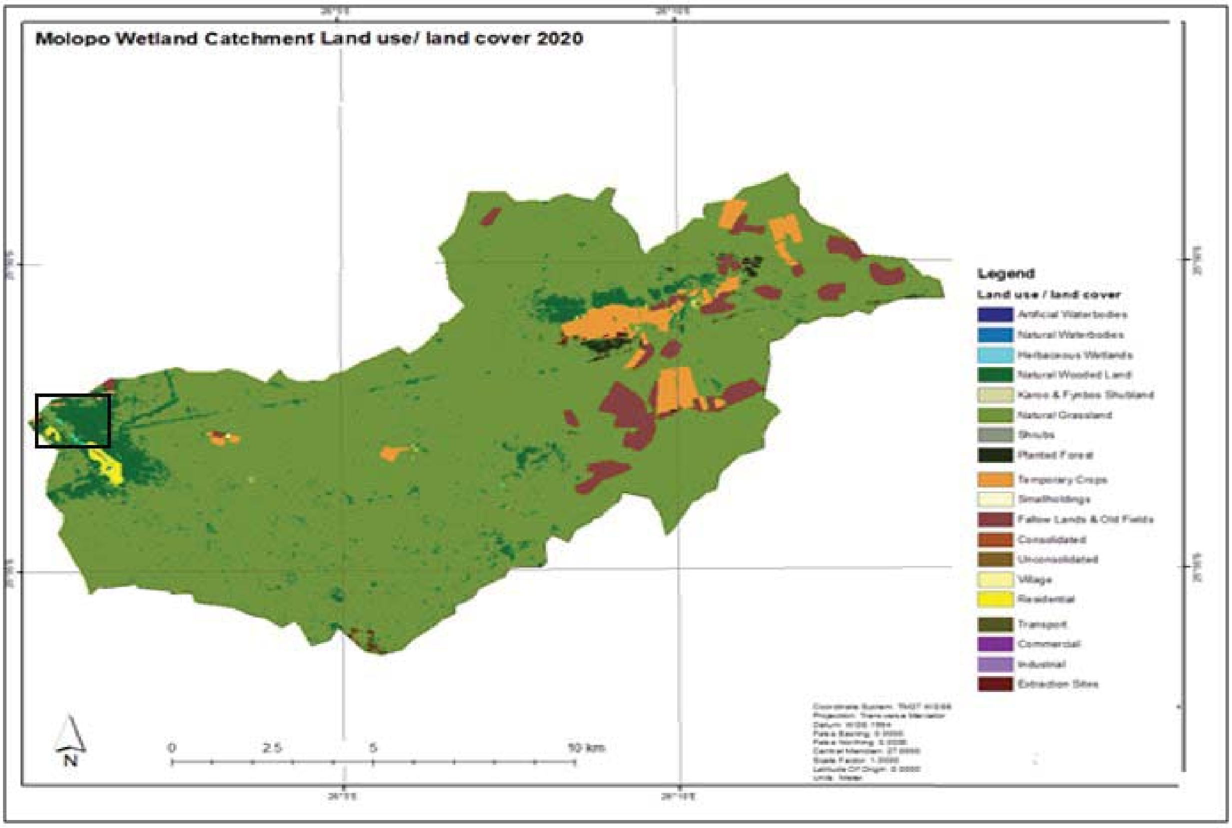


Figure 2.25 Land use/cover within the Molopo Catchment in 2020 showing the major changes from 1994. The location of the Molopo Peatland is indicated in a black rectangle.

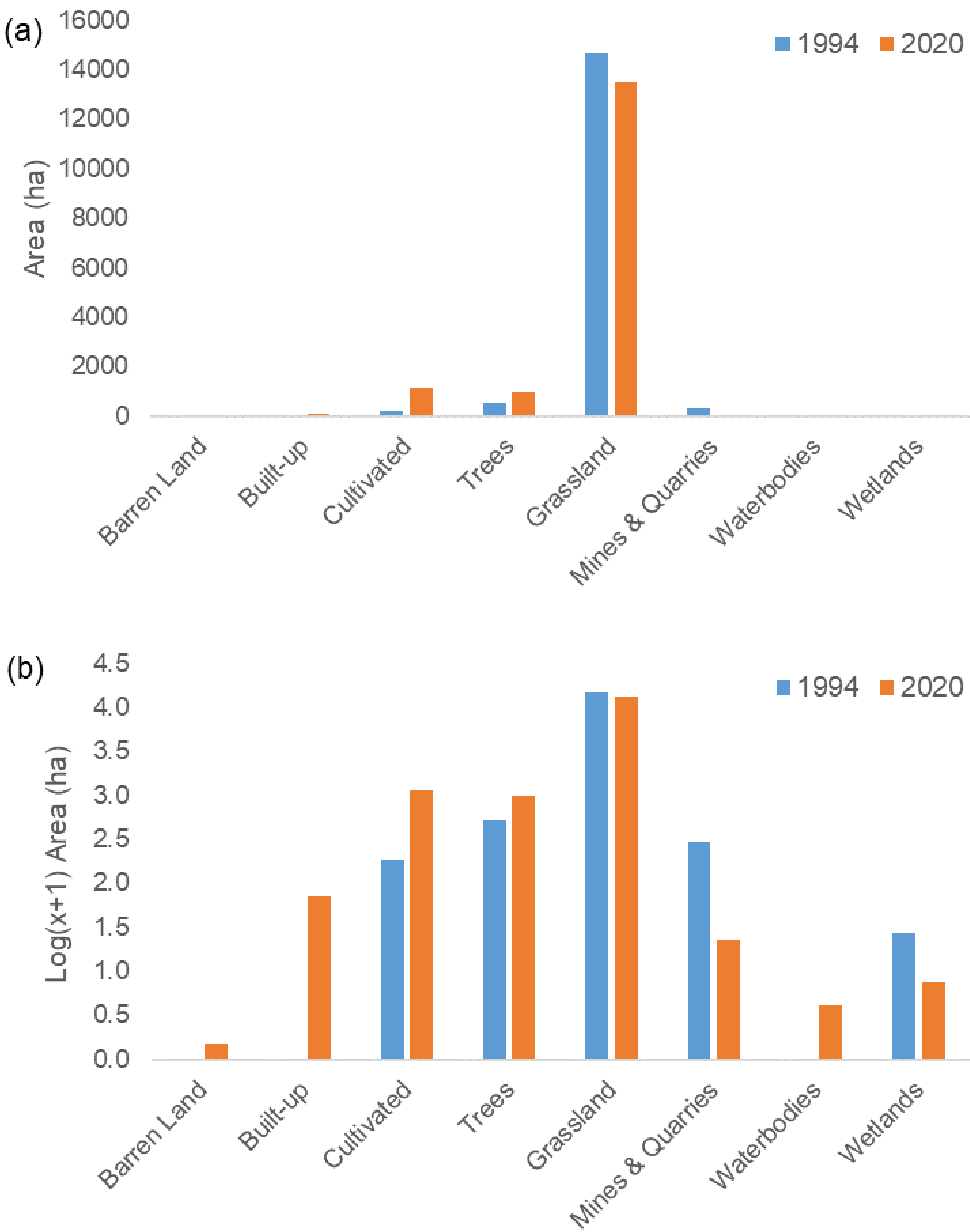


Figure 2.26 Change in land use/cover within the Molopo Catchment between 1994 and 2020 (a) in ha, and (b) expressed on a log scale to emphasize changes of land use or land cover with smaller areas within the catchment.

2.4.1.2 Tier 2: Onrus Peatland (Western Cape Province)

Land use changes include an increase in farming activities, as well as the building of De Bos Dam (upstream of the peatland) in the 1970s which has likely resulted in irregular water inputs into the peatland that is needed to maintain saturated conditions. This has resulted in sediment loss and geomorphological changes due to natural and accelerated erosional processes (Grundling et al., 2019). Along with the peat fire in 2019/20, this has led to much peat being lost and the invasion of some alien species.

Land cover classification using 1994 and 2020 imagery resulted in a disparity in the number of classes between the two years. The 1994 classification had 7 classes, whilst 2020 had 32 classes, resulting in a problematic direct comparison. There are, however, conclusions that can be drawn from these results, with the aid of aerial photography. Land cover classes (**Figure 2.27**, **Figure 2.28** and **Figure 2.29**) and aerial photography (**Figure 2.30**) show an increase in water bodies from 1994 to 2021. This is attributed to the intensification of agriculture in the catchment which links to an increase in groundwater abstraction for irrigation. The land in the catchment of the Onrus Peatland is clearly fragmented which has been shown to accelerate degradation (Gajendra et al., 2005).

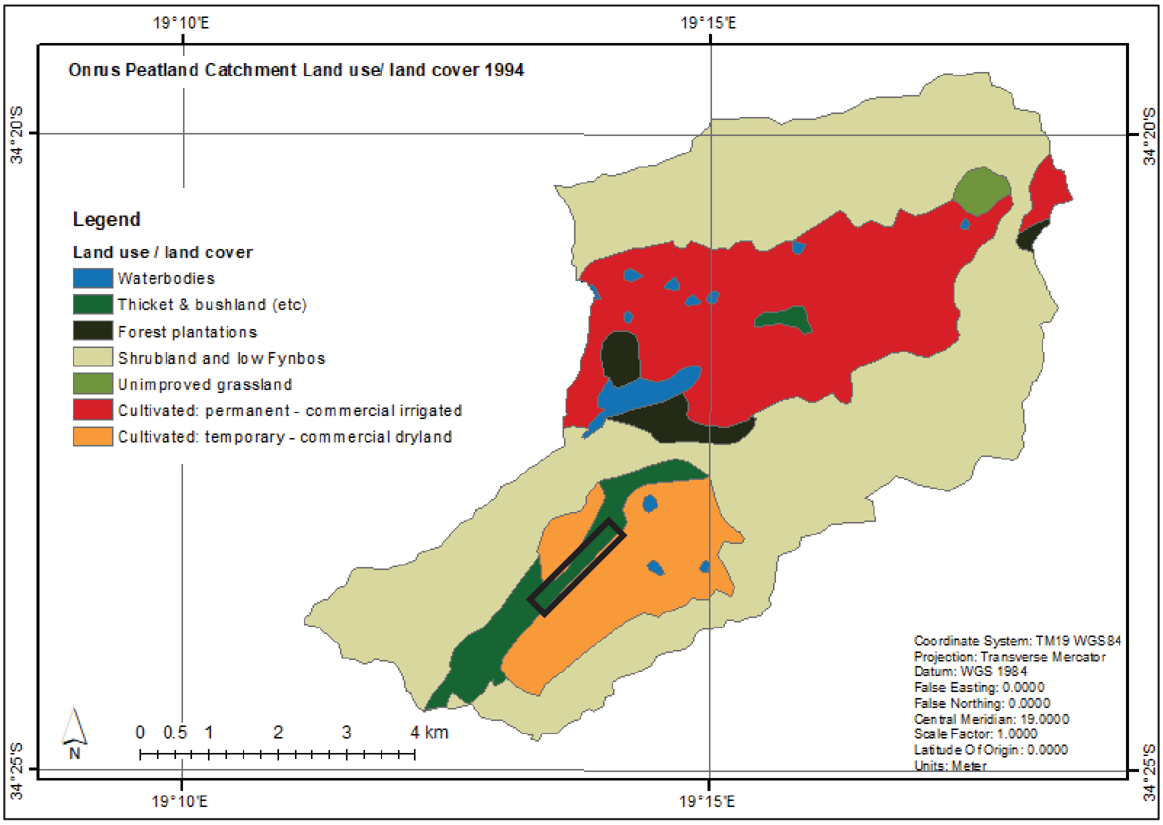


Figure 2.27 Land use/cover within the Onrus Peatland Catchment in 1994. The location of the Onrus Peatland is indicated in a black rectangle.

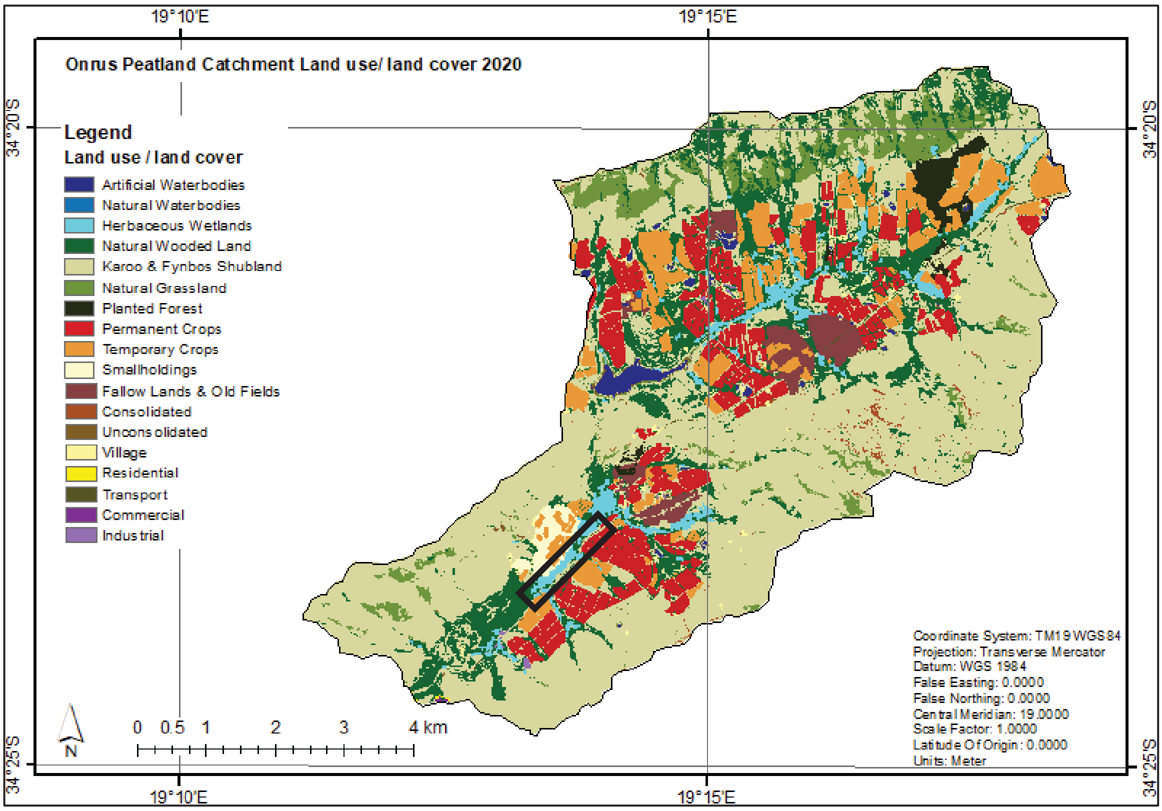


Figure 2.28 Land use/cover within the Onrus Peatland Catchment in 2020. The location of the Onrus Peatland is indicated in a black rectangle.

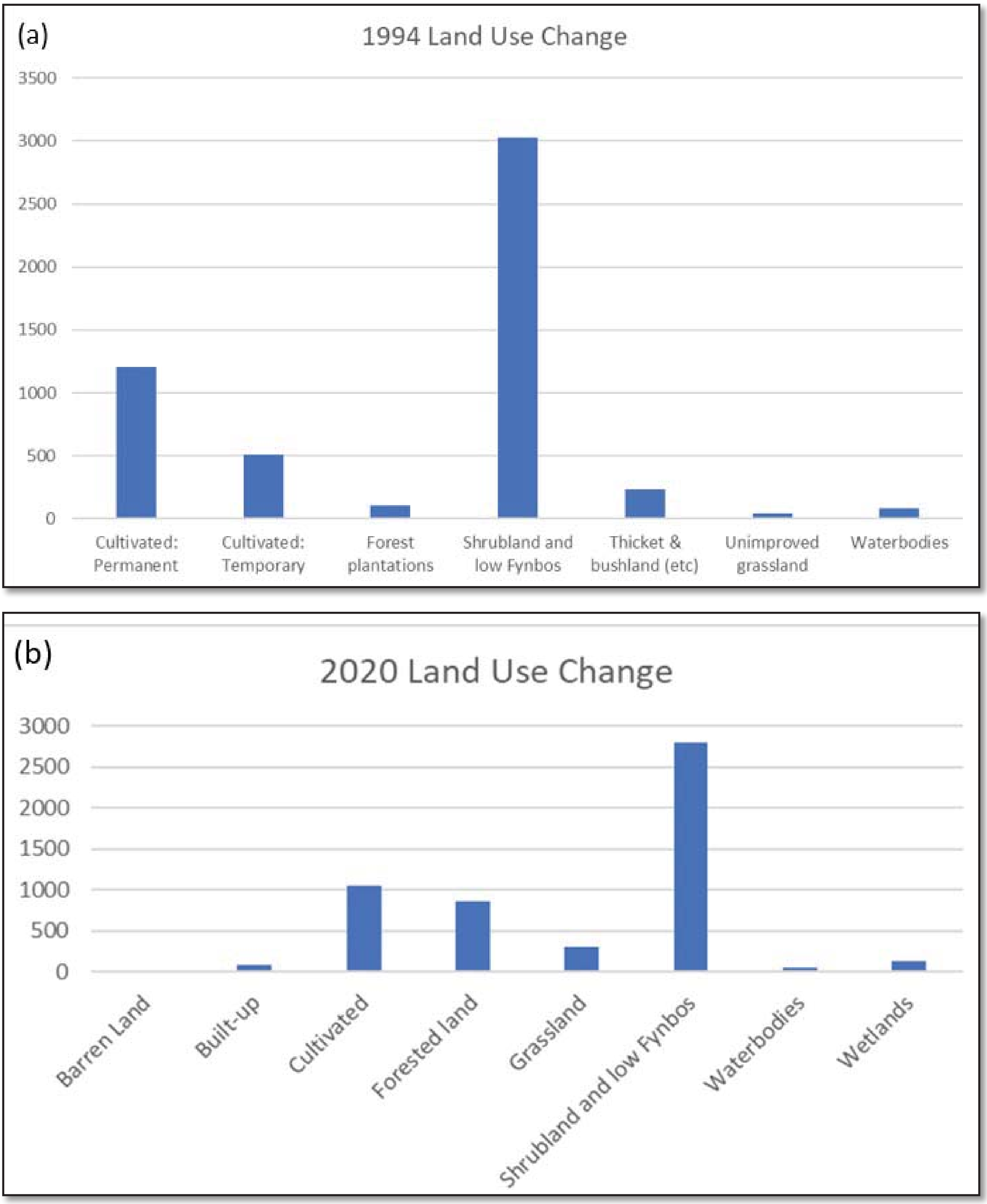


Figure 2.29 Land use/cover classes in the Onrus Catchment for the years (a) 1994 and (b) 2020 showing that shrubland, cultivated and forested land are now the main land use classes.

Figure 2.30 A compilation of aerial images from the years 1976 and 2021 showing the main changes in land cover over the past 45 years.

2.4.1.3 Tier 3: Muzi and Vasi Peatlands (KwaZulu-Natal Province)

Land use/cover comparison from 1994 to 2022 shows a decrease in wetland extent and cultivated area and an increase in the area of barren land and grassland (**Figure 2.31**).

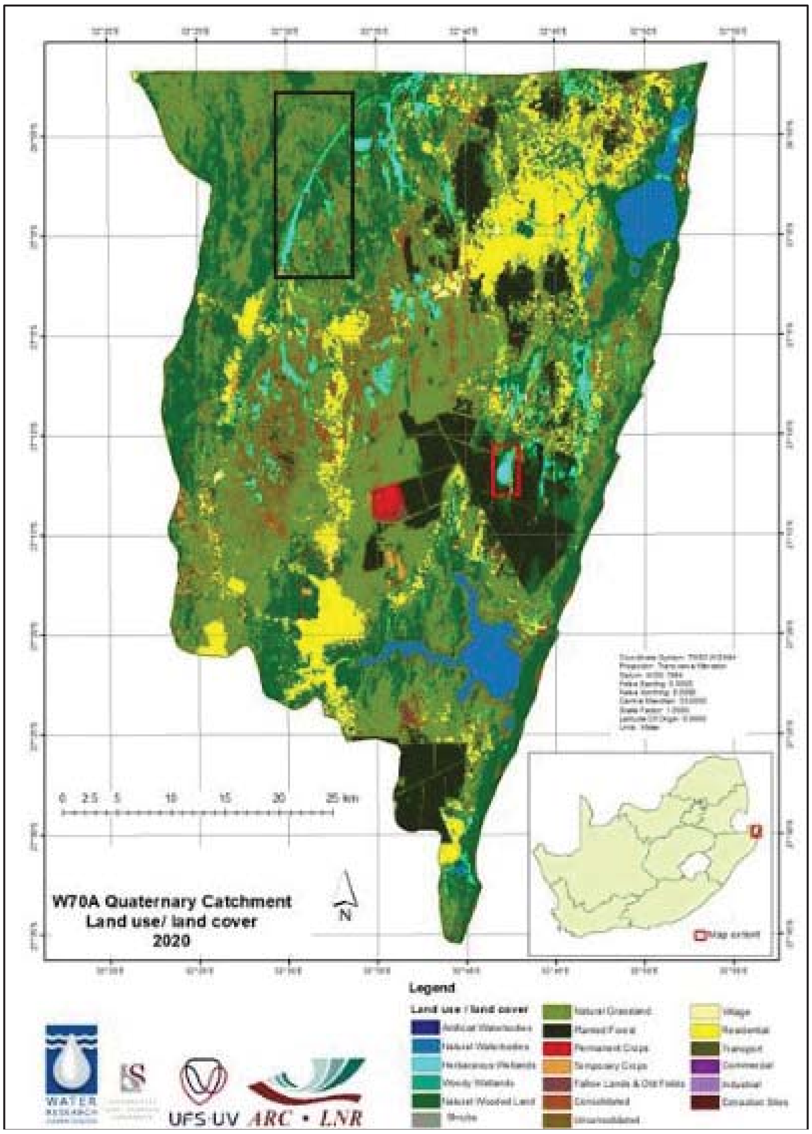


Figure 2.31 Land use/cover of the W70A quaternary catchment that includes the Muzi and Vasi Peatlands, indicated with a black and red rectangle, respectively, in 2020.

In 1994 the majority of land use/cover was forest and woodland as well as a large amount of thicket coverage (**Figure 2.32(a)**). This has, however, decreased since and now grasslands account for the vast majority of the land cover. This would have an impact on the hydrology and sedimentology of the catchment and the functioning of the peatland system. The most notable change is the significant decrease in wetlands since 1994. This clearly shows that the peatland systems are in significant decline and are under great threat. What was once wetland systems may have dried out, resulting in them being classified as grasslands or barren land. In 1994 there were no significant built-up areas but in 2020 there were over 5 000 ha of built-up areas (**Figure 2.32(b)**). This indicates an increase in human settlements and the associated strain on natural resources such as wetlands.

Degradation was present as early as 1994, showing that this system has been under pressure since then, which has subsequently increased. All these land use changes will have contributed to this increased pressure on the peatlands.

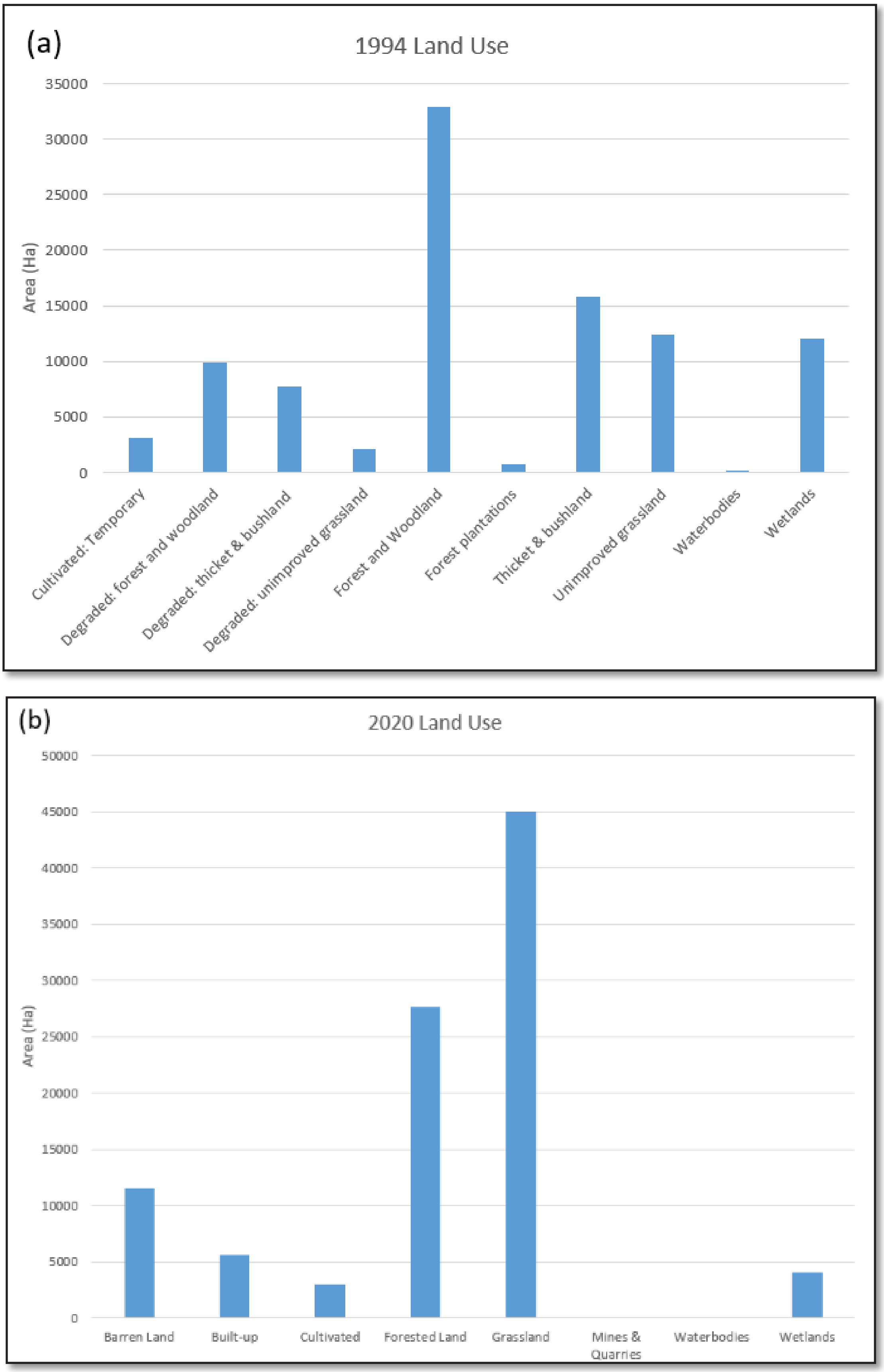


Figure 2.32 Land use/cover classes in catchment W07 for the years (a) 1994 and (b) 2020.

2.4.2 Peat / Carbon Loss

2.4.2.1 Tier 1: Molopo Peatland (North West Province)

The results of the survey show the current surface curvature of the valley bottom wetland (**Figure 2.16**) which was used to provide a map estimating the surface elevation of the Molopo Peatland (**Figure 2.33**). Approximately 1.5 m of peat has been lost from the first transect (**Figure 2.16**), based on evidence from past fence levels and the presence of peat ash. An estimated 2.5 m of peat was lost from the second transect, assuming that the peat was evenly distributed across the transect. Transects 3 and 4 covered the lowest lying sections of the peatland. This is also located near to the platform that was previously used to launch boats and canoes and may have undergone a certain degree of disturbance when the platform was erected. Although the launching platform is no longer there, some residents of the private park still use this point to launch their canoes (**Figure 2.34**).

Transects 3 and 4 have a lower surface elevation than the two downstream transects (**Figure 2.16**). This implies that there may have been excavation between transects 3 and 4 to accommodate some recreational activities. There is also a possibility that the substrate of the wetland has a depression along these two transects, which may have instigated the accumulation of peat in the first place. Approximately 1.5-2 m of peat may have been lost in this depression either through excavation or degradation. An estimated 1.3 m of peat was lost in Transect 5 while 1.2 m may have been lost from Transect 6. An estimated 277 588.79 m^3 of peat may have been lost in this portion of the peatland through peat desiccation, compaction and subsequent fires (**Figure 2.35**).

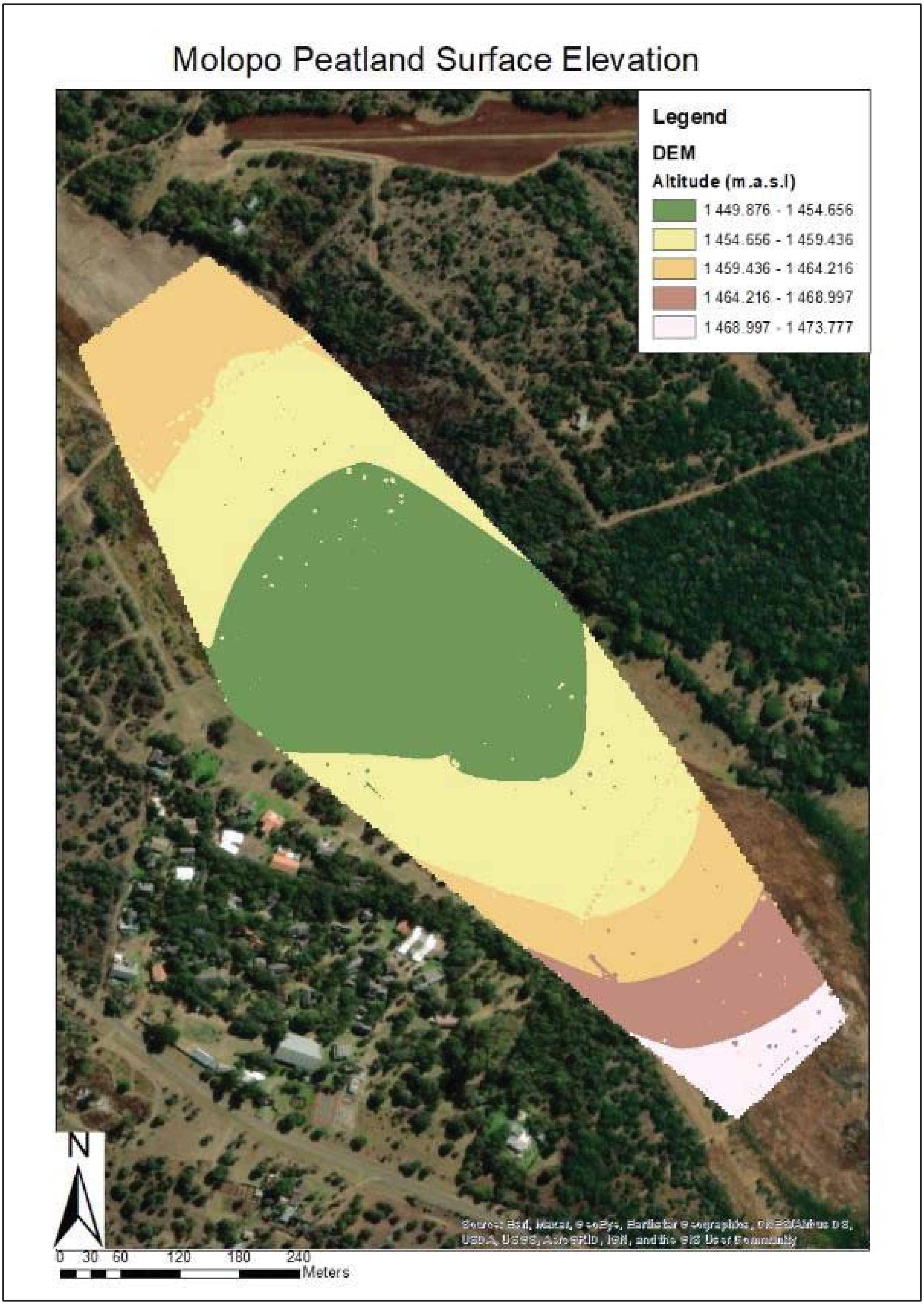


Figure 2.33 A map estimating the surface elevation of the Molopo Peatland, North West Province.

Figure 2.34 A resident of Molopo Private Park canoeing along the Molopo Peatland, assisting the peat loss survey team member (Photo taken on 4 August 2022).

Figure 2.35 A map estimating the peat loss of the Molopo Peatland, North West Province.

The surveyed transects had a relatively uniform soil description. The mid-slope soil profiles had topsoil dominated by organic enriched sand ranging between 6-15 cm in thickness. A light brown layer of sand underlies the topsoil, extending 5-10 cm down the profile. At a depth of 20-25 cm there was a sand and gravel layer that extended down to approximately 70 cm below the surface. The gravel pebbles get progressively larger while the sand content decreases down the profile towards the bedrock. This gravel layer offered a lot of resistance to auguring and hence marked the bottom of the profile for the purpose of this survey.

The valley bottom slope unit exhibited a different profile from the mid-slope, which was homogeneous across all transects. The top 8-28 cm of the valley bottom are composed of peat ash. This peat ash layer is on top of a layer of partially burnt earthified peat with charcoal fragments, approximately 5-7 cm thick. At approximately 35 cm is a highly oxidized peat layer extending another 30 cm to +/-60 cm in depth. This peat layer sits on top of an organic enriched sand layer with very little clay content, extending a further 20-30 cm down the profile. The bedrock is found approximately 90 cm below the wetland surface.

The results indicate that a peat layer on average 1.67 m in thickness has been lost from this peatland through degradation (**Figure 2.35**). Based on markers of antecedent surface levels (e.g. the bottom of the fence), it is estimated that 344 437.5 m^3 of peat have been lost through fire. The Molopo Peatland is degraded to such an extent that only a 32 cm depth of peat, on average, remains in the system, with many places being void of peat. The peat that remains is highly humified and oxidized due to the prolonged drying over the years since the water table was lowered. This level of desiccation has caused the peatland to lose many of its ecosystem services. The loss in ecosystem services is not only limited to and experienced by residents of the Molopo Private Park but its impacts extend further downstream along the Molopo River. Recent rainfall events have led to renewed surface flow in the peatland and has revived the recreational activities in the park. This brings the residents hope that the Molopo Peatland can be rehabilitated.

2.4.2.2 Tier 2: Onrus Peatland (Western Cape Province)

The results obtained from the dumpy survey were used to draw a map of the surface elevation of the Onrus Peatland. The Nearest Neighbour (NN) interpolation method was applied to the data to obtain a smooth surface from the collected data. The outcome is a current surface model for the Onrus Peatland (**Figure 2.36**). The previous surface level was modelled using previous surface level indicators and applying the NN interpolation once more to create a smooth surface (**Figure 2.37**). The peat loss was then estimated using the Raster Calculator function in ArcMap 10.4 to subtract the current surface level from the modelled previous surface.

Figure 2.36 A map estimating the current surface elevation of the Onrus Peatland, Western Cape.

The field survey points that showed evidence of peat presence in the past were used to create an estimated previous surface level which was used to determine the difference between the old and current surface levels to show the estimated volume of peat lost in the surveyed portion of the peatland. The difference (modelled peat loss) is shown in **Figure 2.37**. Negative values should not be assumed to represent an area of deposition, but rather due to extrapolation in a small number of cases. These should be assumed to be zero and did not influence the results.

Figure 2.37 A map estimating the peat loss (in metres) of the Onrus Peatland, Western Cape.

Based on the field survey results, as well as indicators of previous surface levels, it is estimated that a volume of 12 571.45 m^3 of peat has been lost through peat degradation and fire. Some sections of the peatland remain intact and pristine while other areas have experienced head cuts and gully erosion which contribute to peat degradation and loss.

2.4.2.3 Tier 3: Vasi Peatland (KwaZulu-Natal Province)

The results obtained from the dumpy survey were used to draw a map of the surface elevation of the Vasi Peatland. The NN interpolation method was applied to the data to obtain a smooth surface from the collected data. The outcome is a current surface model for the pan shown in **Figure 2.38**. The previous surface level was modelled using previous surface level indicators and applying the NN interpolation once more to create a smooth surface. The peat loss was then estimated using the Raster Calculator function in ArcMap 10.4 to subtract the current surface level from the modelled previous surface.

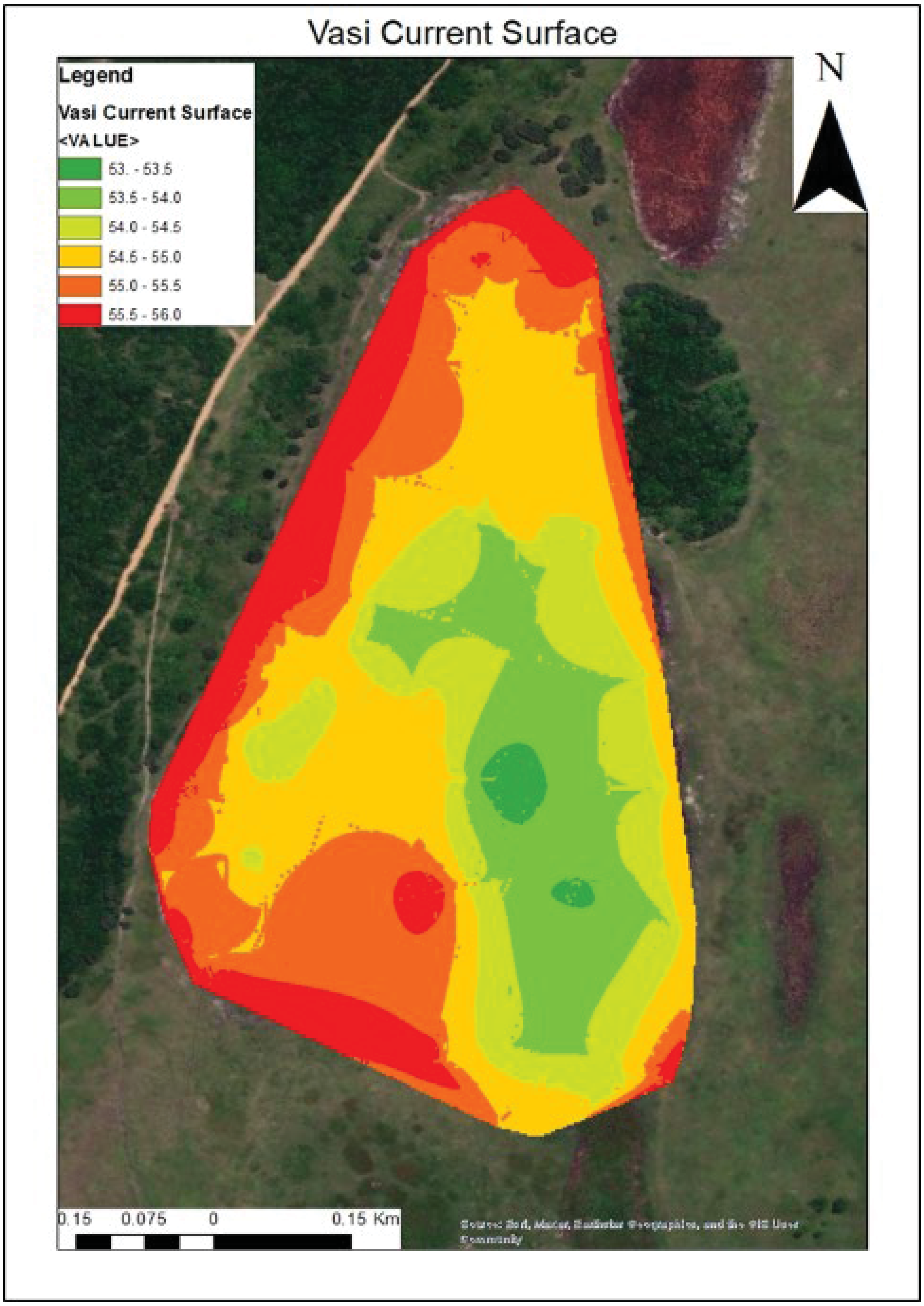


Figure 2.38 A map estimating the current surface elevation of the Vasi Peatland, KwaZulu-Natal.

The field survey points that showed evidence of peat presence in the past were used to create an estimated previous surface level which was used to determine the difference between the old and current surface level to show the estimated volume of peat lost in the surveyed portion of the peatland. The difference (modelled peat loss) is shown in **Figure 2.39**.

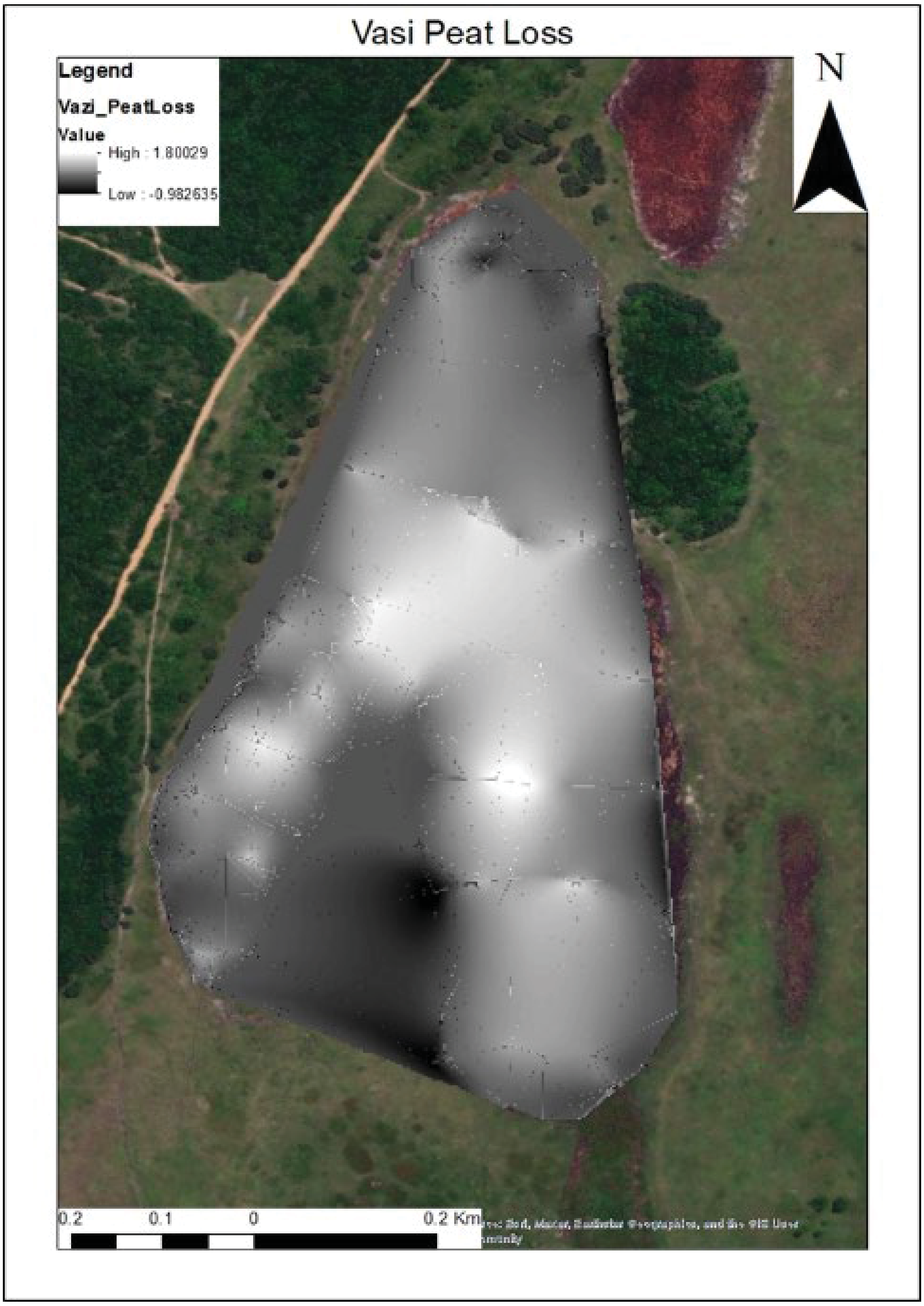


Figure 2.39 A map estimating the peat loss of the Vasi Peatland, KwaZulu-Natal.

Based on markers of antecedent surface levels, it is estimated that a total of 129 094.97 m^3 of peat, on average, has been lost through peat desiccation and fire. The peat that remains is highly humified and oxidized due to prolonged drying over the years. This level of desiccation has caused the peatland to lose many of its ecosystem services.

2.4.3 Peatland Characteristics and Hydrology (Transects) / Stratigraphy and Water Levels

2.4.3.1 Tier 1: Molopo Peatland (North West Province)

2.4.3.1.1 Peat characteristic / Stratigraphy of the Molopo Peatland

A theoretical cross-section of a flow diagram demonstrates that water is more likely to flow from east to west on the surface, following the topography of the system. **Figure 2.40** is a conceptual flow diagram which models the estimated flow paths along the peatland following the gradient of the geomorphological template. The surface flow in the system is from east to west following the micro-topography of the system with the main flow in a north-westerly direction towards Botswana. The subsurface flow is more likely to be dominant in the sand and gravel layer due to its texture which promotes water flow. The middle portion of the peatland does not have peat ash present which is likely to be the result of high velocity flow washing away the ash, causing the flow to accumulate on the earthified peat layer. Some flow accumulates on top of the hard rock on the sand-gravel matrix, causing this layer to have the most dominant flow layer.

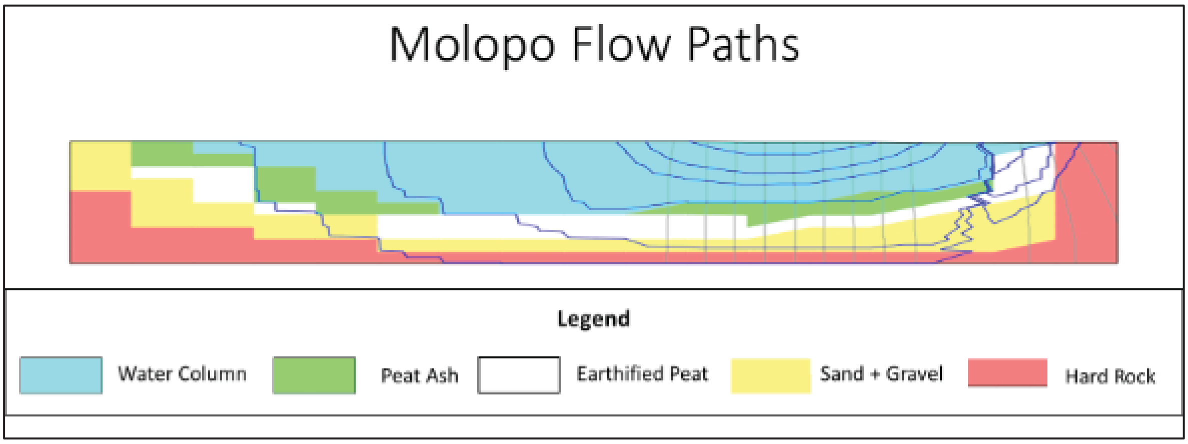


Figure 2.40 A theoretical flow path diagram for the different soil types in the Molopo Peatland, going from west (left) to east (right).

2.4.3.1.2 Gauge analysis of the Molopo Peatland

The mean annual available surface water volume recorded at the Molopo Catchment gauge is approximately 7.6 million cubic meters (Mm^3), with very high annual variation ranging from a minimum of 0.7 Mm^3 to a maximum of 47.7 Mm^3. This variation may be due to the catchment's characteristics or to abstraction and water use above the gauging weir, but can nevertheless be used as a rough indicator of times of water surplus and stress. Peaks in surface water availability at the gauging weir shift between winter and summer (January in 2002 - summer, April in 2000, 2006 and 2011 - autumn, and July in 2010 - winter). There also appears to be a change in the pattern and magnitude of available surface water between 1973 and 1995 (22 years) where there seems to be a very wet period followed by a long drought, or a time of low water use followed by a time of high water use. The data are patchy, particularly from 2017 onward, due to a large number of missing data records, which precludes a detailed analysis. However, there appears to be a general decreasing trend in available surface water at this gauging weir over time (**Figure 2.41**).

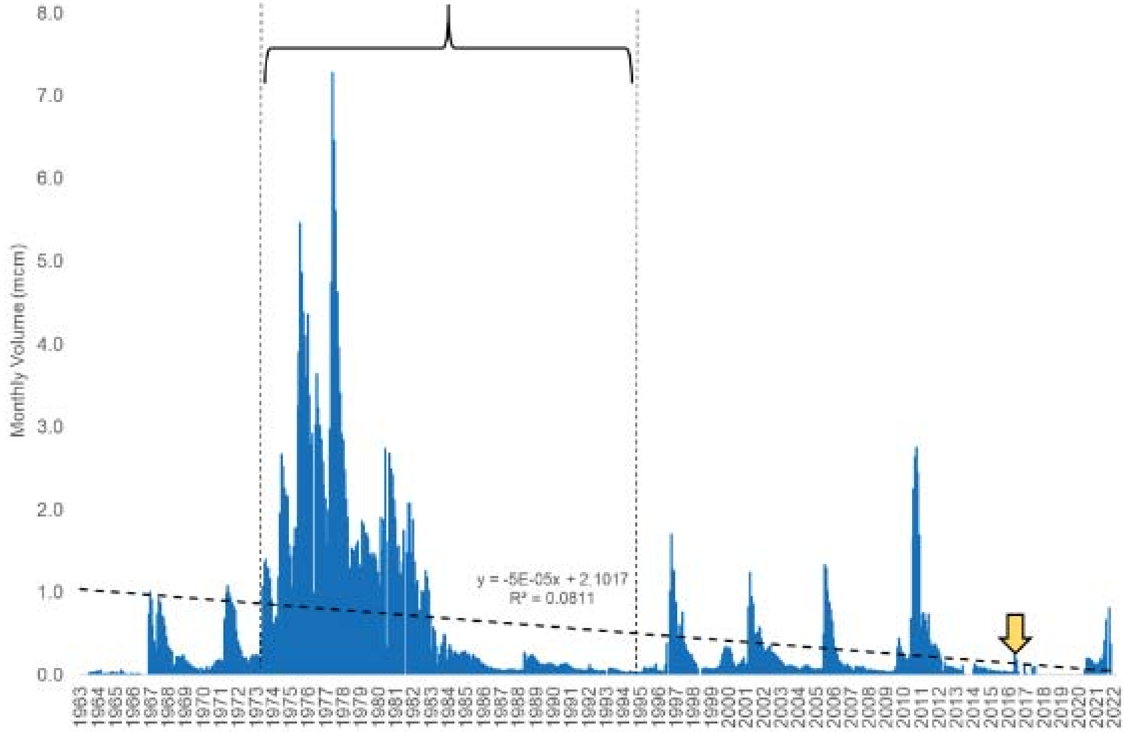


Figure 2.41 The long-term monthly flow volumes for the Molopo River at Rietvallei (gauge D4H013; -25.85639, 25.86561), North West Province, South Africa. The yellow arrow indicates the approximate period of the peat fire, from 8 May 2016 to 9 January 2018, which coincides roughly with the installation of the weir above the peatland and abstraction of water for the town of Mahikeng. Data from 2017 onward are patchy, with many missing records.

In contrast, the available surface water recorded at the Molopo Eye (gauge D4H014) seems to be relatively stable over time (**Figure 2.42**), with peaks in monthly volumes that coincide with those of the gauge downstream (**Figure 2.41**). While the monthly surface water volumes of both gauges do not seem to indicate any major stress before or during the period from 8 May 2016 to 9 January 2018 (the time of the Molopo peat fire), nearby groundwater records indicate stress exactly during this period, with groundwater use dropping to below 100 000 m^3 per month (**Figure 2.43**; DWS, 2022). In contrast, the Grootfontein wellfield continued to sustain high groundwater use over this period (**Figure 2.43**). These data may be evidence of local groundwater abstraction draining the peatland system, especially during dry periods, exposing the peatland to increased risk of desiccation and fire. It is recommended that data be acquired from the recently installed weir and abstraction point (Talma & Vogel, 2001), just above the Molopo Peatland, for further analysis and to confirm whether there was pressure from both groundwater and surface water sources, or just the former (**Figure 2.16**).

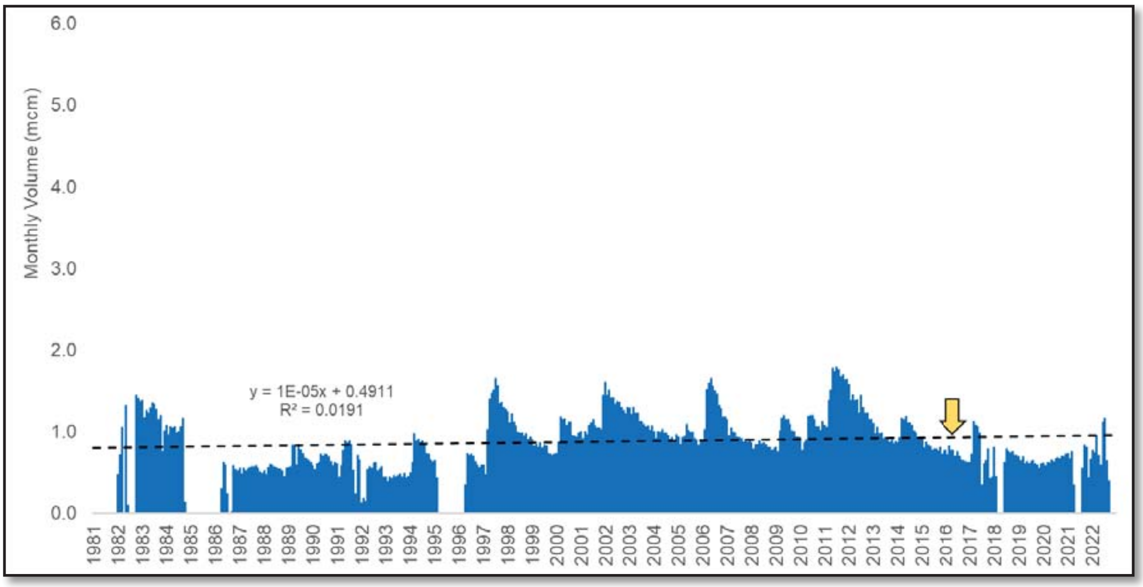


Figure 2.42 The long-term monthly flow volumes for the Molopo Eye (gauge D4H014), North West Province, South Africa. The yellow arrow indicates the approximate period of the peat fire. For the location of the Molopo Eye, please refer to **Figure 2.4**.

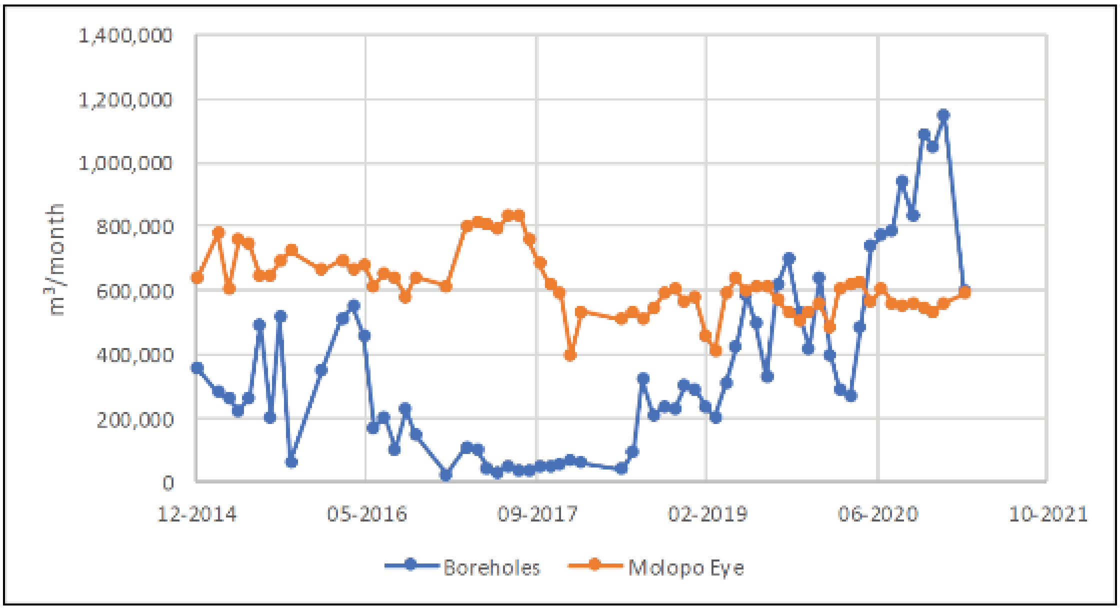


Figure 2.43 Groundwater use from Molopo Eye and Grootfontein wellfield (DWS, 2022).

2.4.3.2 Tier 2: Onrus Peatland (Western Cape Province)

2.4.3.2.1 Stratigraphy and water levels of the Onrus Peatland (Western Cape Province)

Transect A

Water levels along transect A (near the pristine part of the peatland) were mostly stable and near the surface, especially A5, A4 and A3. Water table fluctuations were the largest at site A1, which is characterized by peat ash and organic enriched clay (**Figure 2.44**). This can be attributed to the eastern hillslope being dependent on seasonal water flows, or the reduced ability of peat ash to maintain high water tables, thereby making the eastern parts of the peatland more susceptible to desiccation. The lowering of the water table at site A4 is due to the channel that runs along the north-west of the peatland. The low piezometric pressures in the deepest piezometer at site A2 indicate a downward flow of groundwater. A similar trend is observed at site A3, but with a higher piezometric pressure. This indicates a south-eastward flowing trend of groundwater below the peatland. Consistent water tables at site A5 indicate a sustained flow of groundwater in the west of the peatland. The stratigraphy at site A1, which is located near the tar road, with peat underlying clay, indicates that this area of the peatland was modified when the road was constructed, with clay material being placed on top of the peat.

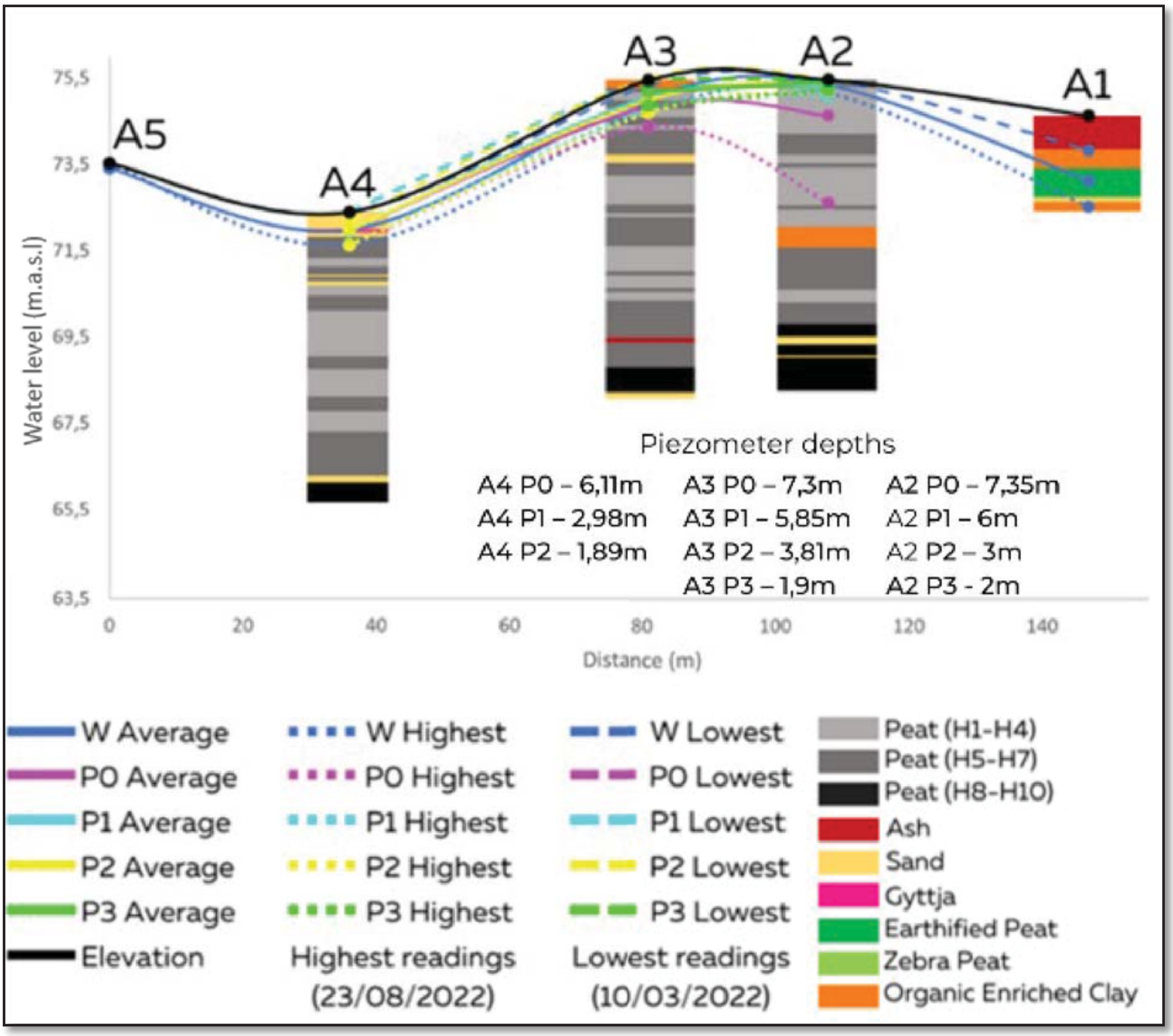


Figure 2.44 Water levels and peat profiles of transect A.

Transect B

Water levels along transect B are consistently below the surface. The peat present at sites B1 and B2 contains ash and shows signs of earthification near the top of the profiles. Site B1, which was located outside of the peatland, had the lowest water levels for the transect, as well as large water table fluctuations (**Figure 2.45**).

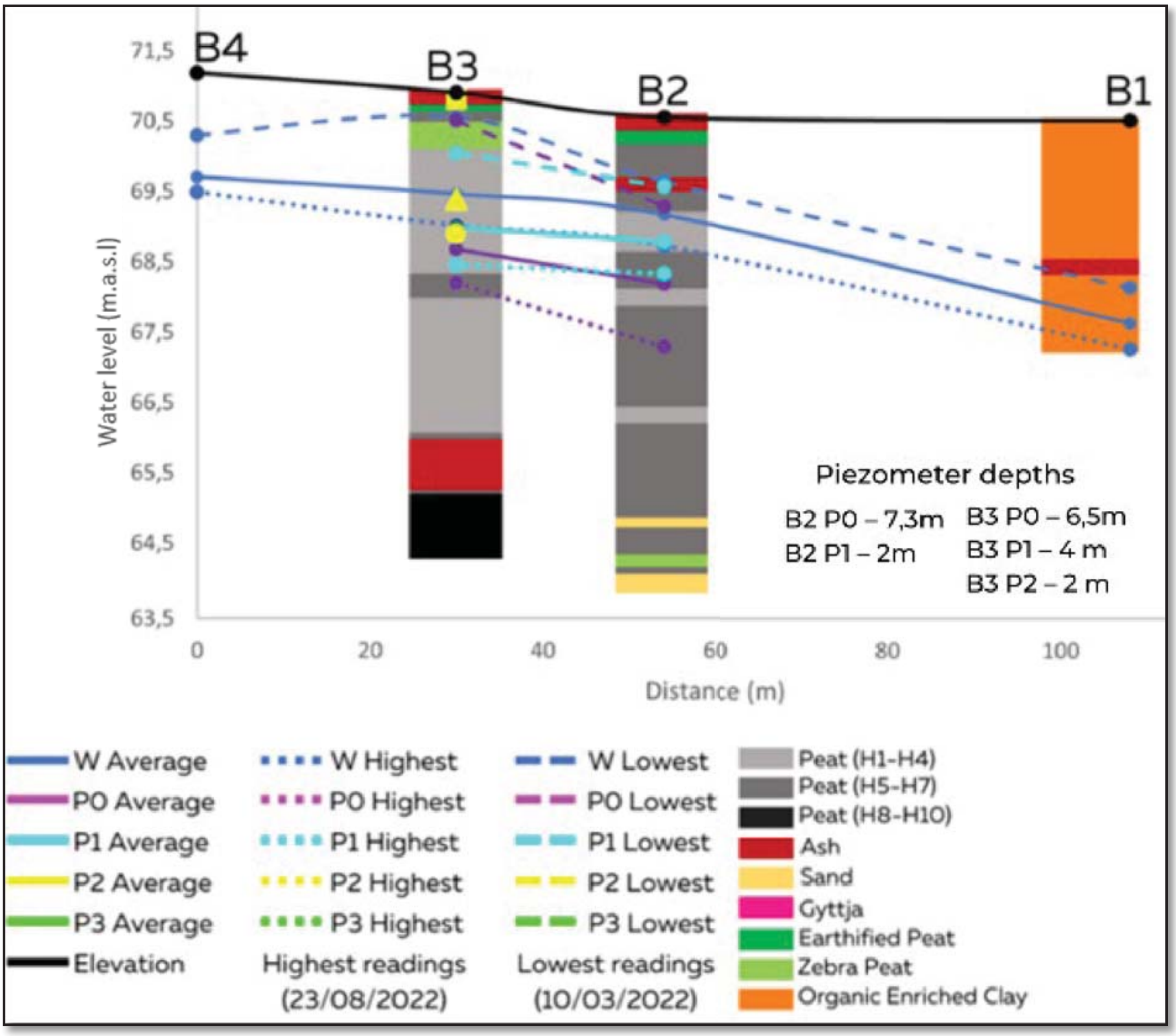


Figure 2.45 Water levels and peat profiles of transect B.

Transect C

Water levels are consistently below the surface and show a large water table drawdown at site C2 which is in a gully. Sites C3 and C2 contain deep layers of peat ash, while C1, located in the adjacent mineral hillslope, also exhibits large water table drawdowns and fluctuations (**Figure 2.46**).

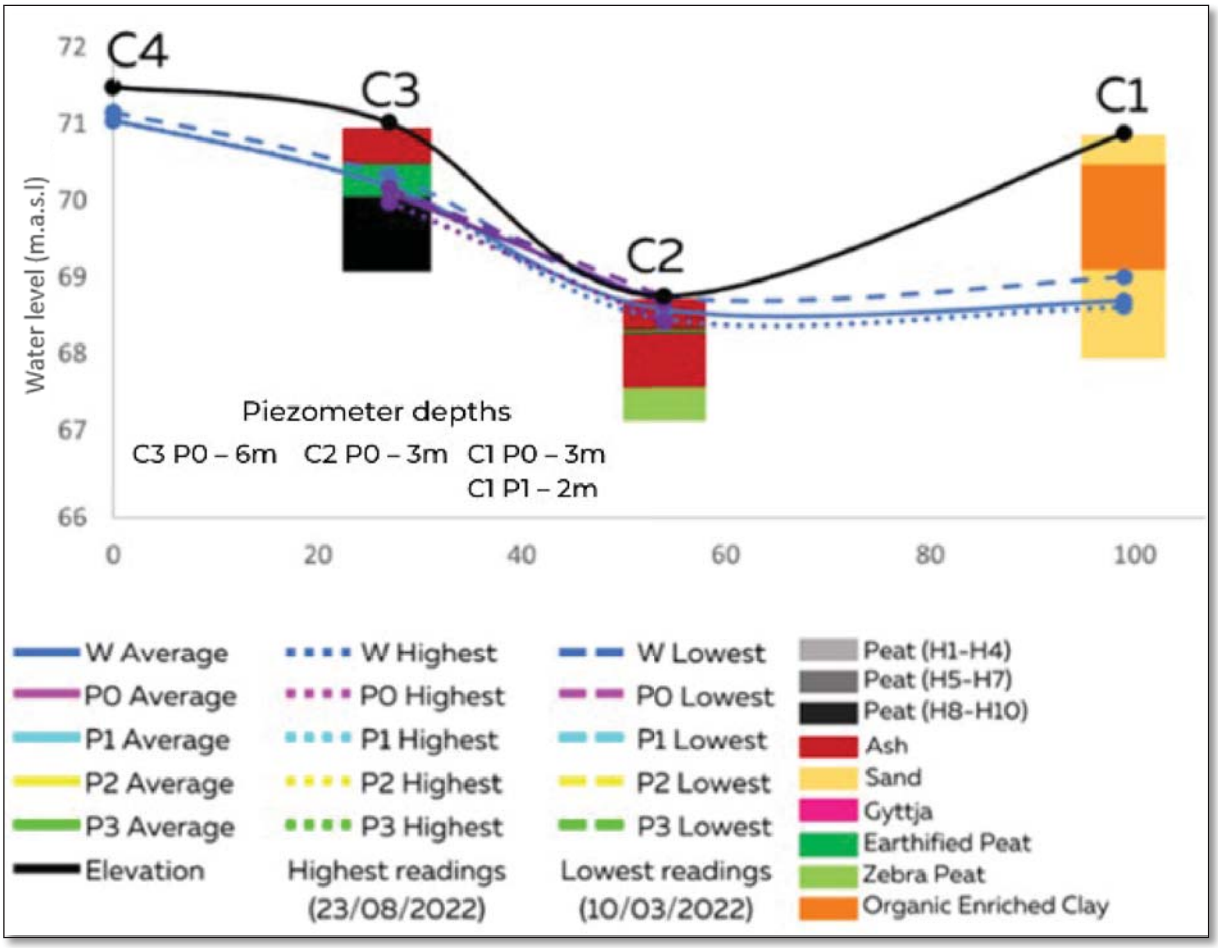


Figure 2.46 Water levels and peat profiles of transect C.

2.4.3.2.2 Discussion on peat characteristics and hydrology of the Onrus Peatland (Western Cape Province)

Transect A is located in the pristine section of the peatland. Relatively high and stable water levels in the peat, especially sites A4 and A3, indicate that this area of the peatland maintains near constant saturation, which is required for peat to form, and prevent degradation. Palmiet is the dominant form of vegetation around sites A4 and A3 which aids in protecting the peat from erosion and regulates the flow of water through the peatland. At site A1, which is in earthified peat and mineral soil, the water levels are noticeably lower and show greater fluctuations. The only peat present at this site is earthified, which furthermore indicates periods of low water tables. The ash located on top of the transect indicates that this part of the peatland was exposed to peat fires. Besides a thin layer of ash at A1, no other ash was found along the other sites of the transect, indicating that this area of the peatland has largely been protected from drying and therefore from fires. The greater fluctuations in the east of the peatland may indicate that the peat there has lost its ability to retain high water levels.

Transect B, which is located near the head cut erosion, exhibits water levels that are consistently below surface level. Sites B2 and B3 are in peat, whilst sites B1 and B4 are in the adjacent mineral slopes. At the lowest reading at B2 P0, water levels had dropped to 4 m below the surface and were on average 3 m below the surface. Give the proximity of B2 P0 to the gully, this may indicate a cone of depression because of water table drawdown attributed to the gully. The low water levels have likely caused the drying of areas around B3 and B2, which also contained earthified peat. The ash present at these sites confirms that the lowered water tables resulted in the peat drying to an extent that it became vulnerable to ignition. No peat was found at B1 as this site lies near the roadside and is outside of the peatland. This transect is dominated by bracken fern and other invasive vegetation and there is no palmiet present. The low water tables confirm the effects that the gully is having on lowering the water table in the wetland.

Transect C is located along the most degraded portion of the peatland where large amounts of peat have been lost to subsistence, fire and erosion. Water levels are consistently below the surface of the peatland. Water levels at site C2, which is in an erosion gully, show a significant water table drawdown. The relatively thick layers of ash and earthified peat at sites C3 and C2 indicate that the low water levels resulted in the drying and subsequent burning of the peat. At site C1, located in mineral soil (organic enriched clay) and underlying sand, the persistent low water tables can indicate eastward flowing groundwater.

Around eroded areas of the peatland (Transects B and C), water levels were consistently below the surface. This can be attributed to the presence of the active headcut and gully erosion within the peatland. At these sites, the presence of peat ash indicates that the peat fires occurred at greater depths in areas with lower water tables. This is confirmed by the high water tables in Transect A which is upstream of the active erosion in the peatland, apart from site A4 which is located near the western side drainage line. Furthermore, the peat identified in Transect A exhibits less signs of humification, which is attributed to higher and more constant water tables.

The piezometric pressure in the deep piezometers (P0) is consistently lower than the other piezometers across all monitoring sites, with P1 (middle piezometer) also being lower than P2 (highest piezometer). This is an indication of groundwater recharge taking place in the wetland. It shows that there is very little groundwater input in the Onrus Peatland and that the wetland is dependent on the inflow from the upstream dam and adjacent hillslopes. As such, changes that occur within the catchment have a direct influence on the hydrology of the Onrus Peatland.

2.4.3.3 Tier 3: Muzi and Vasi Peatlands (KwaZulu-Natal Province)

2.4.3.3.1 Stratigraphy of the Muzi Peatland (KwaZulu-Natal Province)

The stratigraphy of Muzi Peatland is displayed in **Figure 2.47**. The gyttja present in the eastern sides of the peatland indicate that peatland development began with an open water body. This was followed by a calcium carbonate layer, which originates when groundwater, rich in calcium and bicarbonate, is exposed to the surface under warm temperatures (Grootjans et al., 2005). Following this period, a sandy alluvium horizon was encountered indicating higher flows of water, which was followed by a longer period of calcium carbonate development that also occurred in the west of the peatland. Whilst the west was still accumulating calcium carbonate, swamp forest species developed in the east followed by organic gyttja in the west. A highly humified (Von Post class 9) peat layer is present throughout the upper 2 m of the peatland with Von Post class 6 peat present in the east. The upper layers of the peatland contain earthified peat, ranging from 60 cm in the west to 30 cm in the east, indicating high levels of degradation (Gabriel et al., 2018). The peat fire mainly occurred in the central east of the peatland to a depth of 55 cm, with thin burn lines present towards the eastern edges. In the eastern parts of the peatland where the fire occurred, peat burnt in a non-uniform manner where burn depth and degrees of burning varied as both ash and char were identified. Furthermore, it should be noted that in places, lower layers of the peatland experienced subsurface fires whilst the upper layer showed no signs of burning.

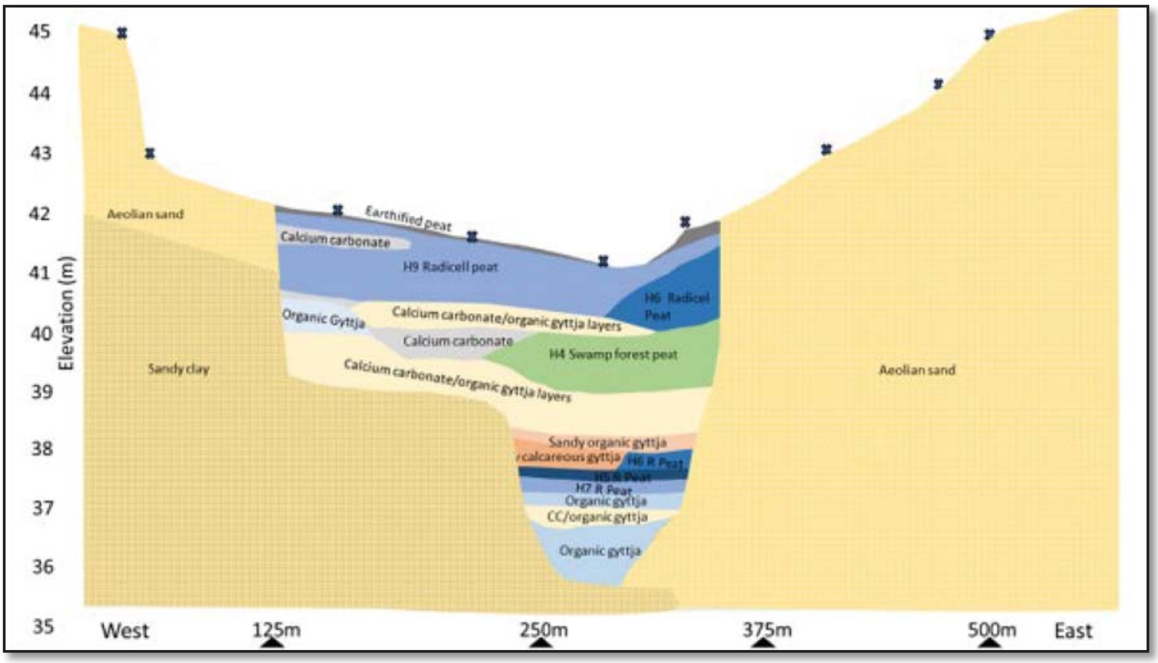


Figure 2.47 Stratigraphy of Muzi Peatland.

2.4.3.3.2 Water levels of the Muzi Peatland (KwaZulu-Natal Province)

Water levels indicate that the water table is higher in the eastern dune and slopes towards the west throughout the year. Water table levels are displayed in **Figure 2.48** and **Figure 2.49**. Water levels were higher during the autumn months of both monitoring years. The water table was lowest in the summer of the 2020/21, before heavy rainfall was experienced in later summer and early autumn, and in the spring of 2020. During the summer and autumn of the 2020/21 hydrological year, surface water was present in the parts of the peatland that experienced fires. In areas that did not burn, the water table was over 1 m below the surface.

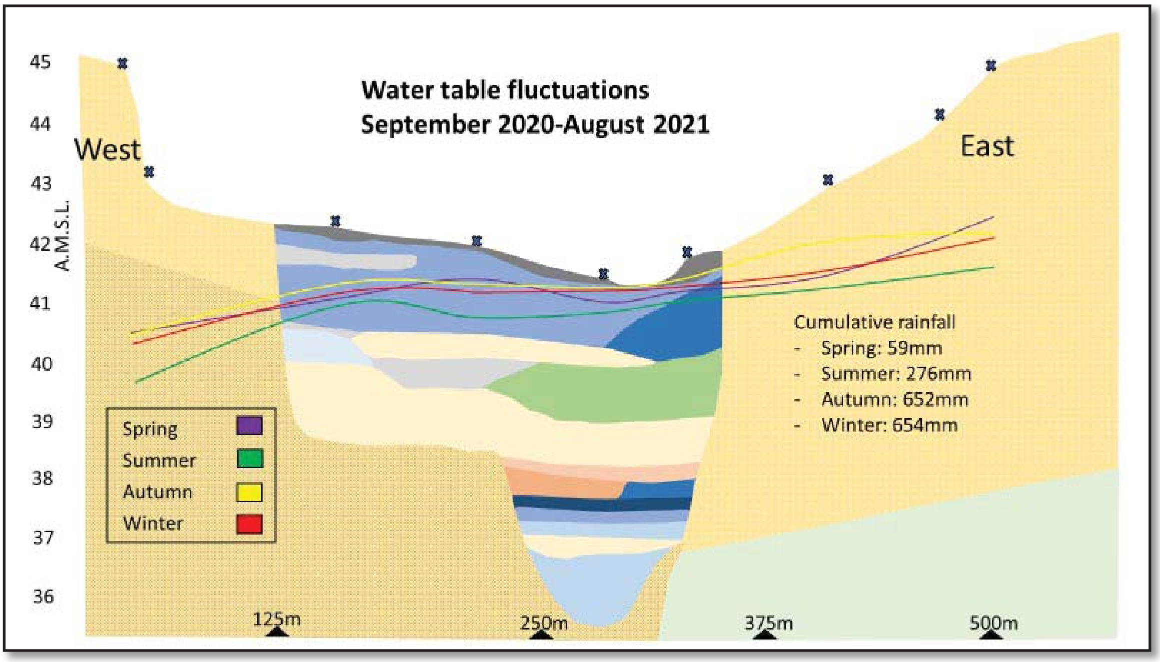


Figure 2.48 Water table levels of Muzi Peatland (September 2020 - August 2021).

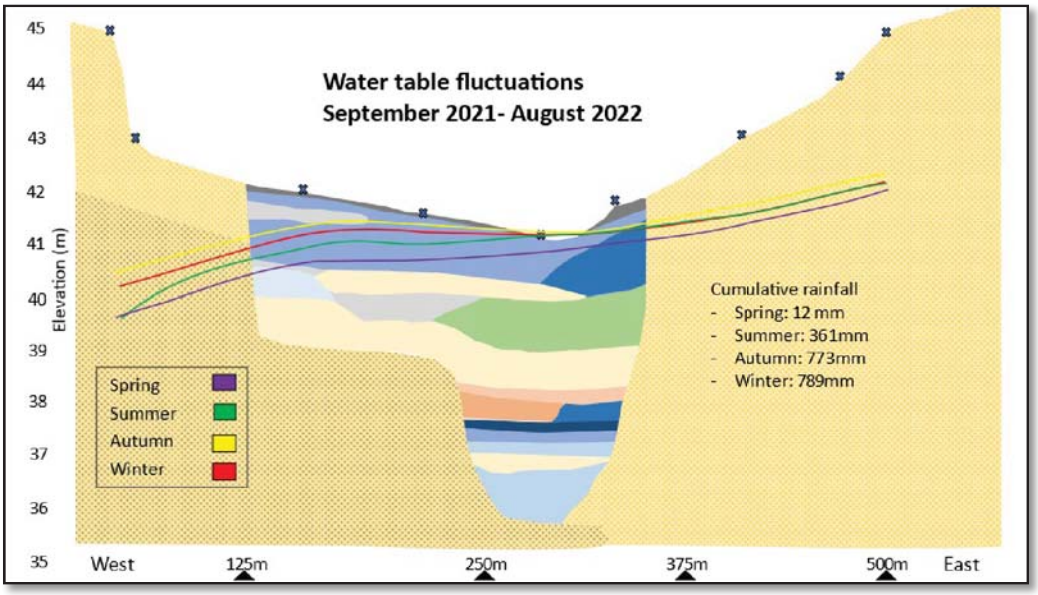


Figure 2.49 Water table levels of Muzi Peatland (September 2021 - August 2022).

2.4.3.3.3 Water flow paths and signatures of the Muzi Peatland (KwaZulu-Natal Province)

Dry season

Dry season flow paths are displayed in **Figure 2.50**. The piezometric pressures confirm a water table gradient from east to west in the peatland, with the pressure being higher in the eastern dune and eastern sections of the peatland, and lower towards the west. However, it is important to note the upwelling of groundwater from the bottom of the eastern side of the peatland. Chemistry and isotope analysis (**Figure 2.51**) indicates that the water in the eastern dune and the uppermost parts of the peatland is more recent water, as the various water signatures are closely aligned to rainwater, whilst the values in the lower and western parts of the peatland display a water signature more closely aligned with groundwater. The upwelling of groundwater in the eastern parts of the peatland is also evident in the groundwater and isotope analysis of the top of the peatland.

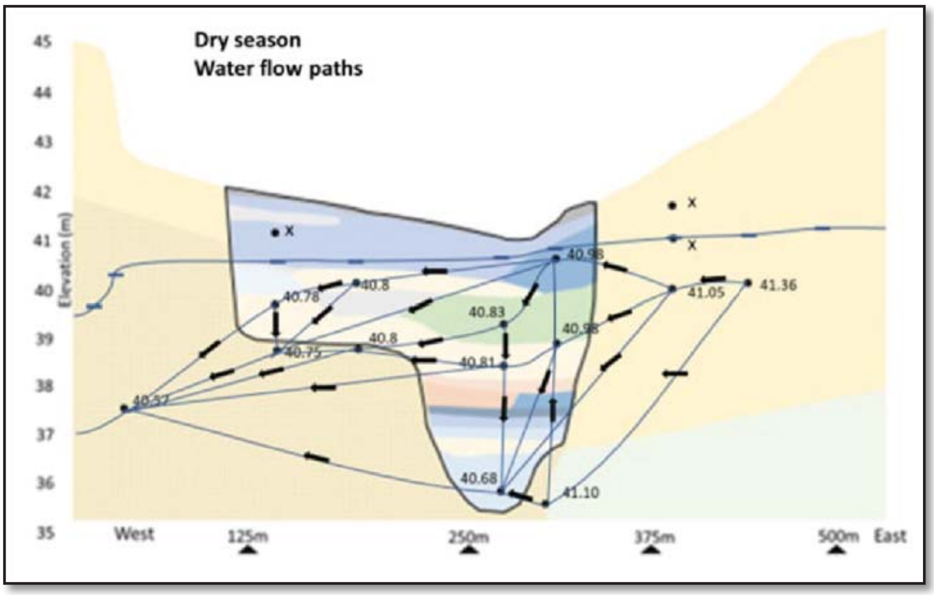


Figure 2.50 Dry season water flow paths in and around the Muzi Peatland.

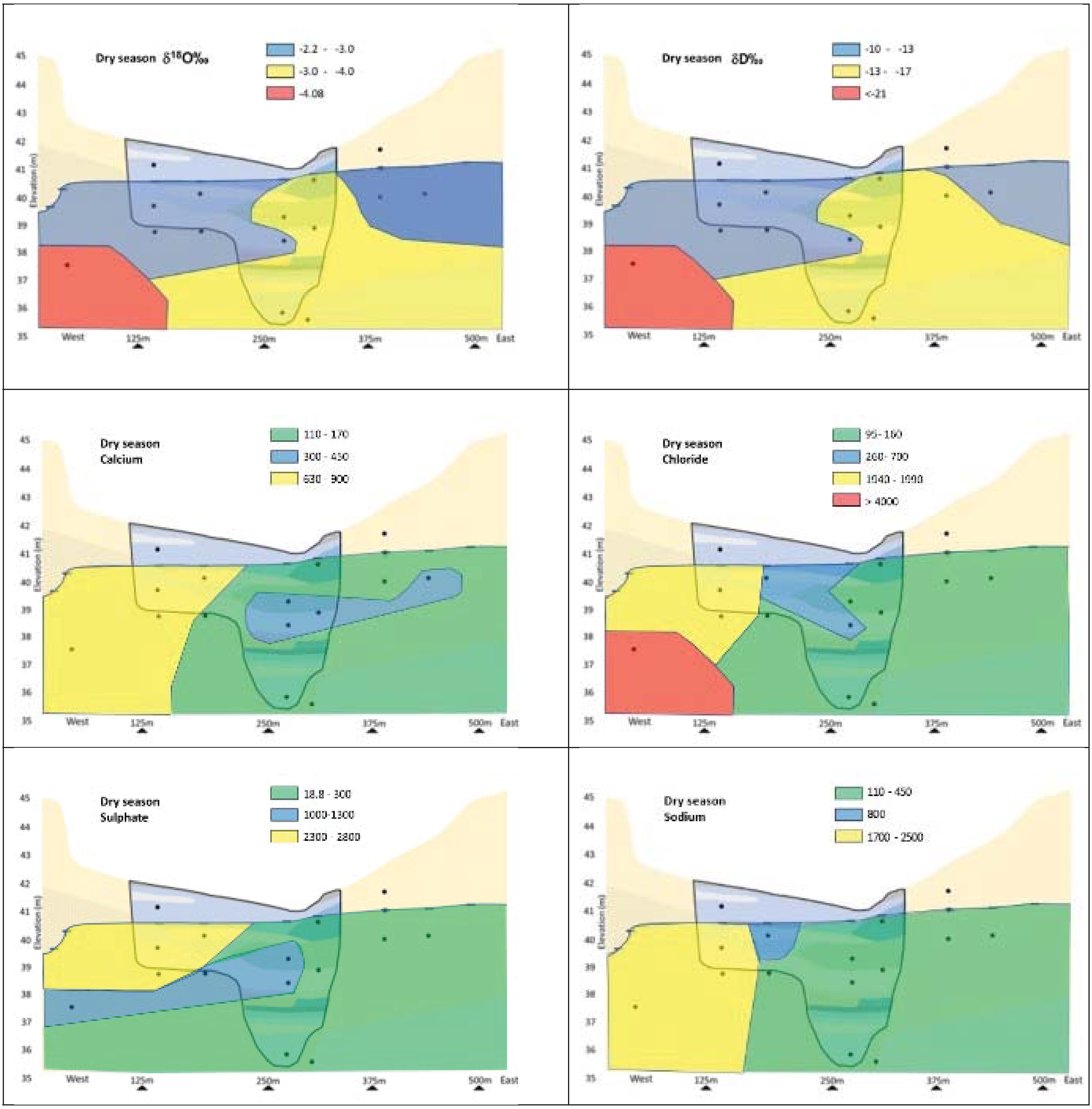


Figure 2.51 Dry season water signatures (isotope and chemical properties) in and around the Muzi Peatland.

Wet season

Wet season flow paths are displayed in **Figure 2.52** and indicate that water continues to flow from the eastern dune into the peatland. However, instead of the water continuing to flow through the peatland into the western dune, it now also flows from the western dune into the peatland. The influence of rainfall can also be seen where water in the eastern parts of the peatland flows in a downward direction. Chemistry and isotope analysis (**Figure 2.53**) indicates that the peatland exhibits a different water signature in the centre.

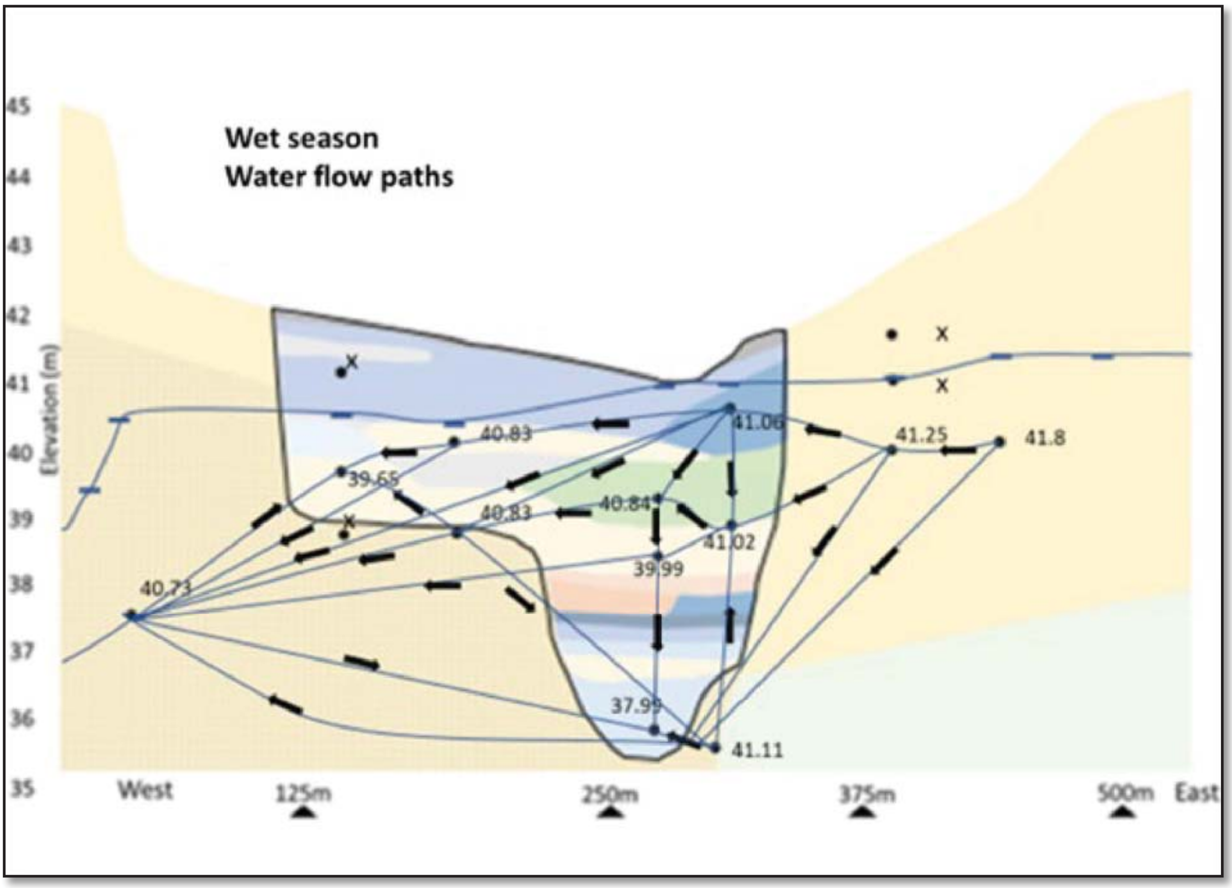


Figure 2.52 Wet season flow paths in and around the Muzi Peatland.

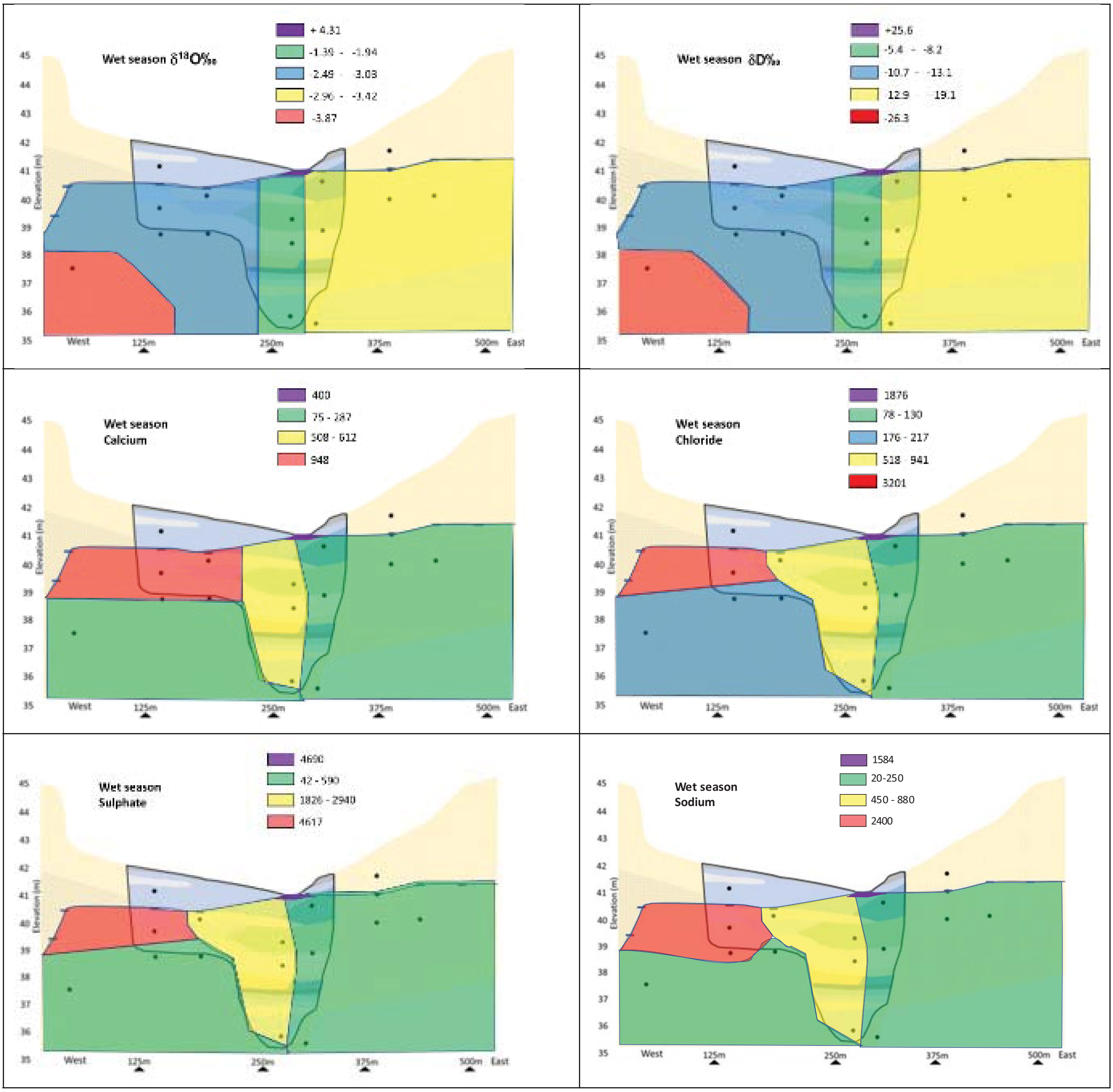


Figure 2.53 Wet season water signatures (isotope and chemical properties) in and around the Muzi Peatland.

2.4.3.3.4 Stratigraphy of the Vasi Peatland (KwaZulu-Natal Province)

The stratigraphy of the Vasi Peatland is displayed in **Figure 2.54**. The eastern parts of the underlying basin are deeper and are comprised of sandy organic gyttja. This is overlain by Von Post H4 sedge peat, followed by a transition zone into a highly compacted H10 layer which is overlain by earthified peat. The depth of desiccation cracks slope from shallow in the west (5 cm) to deep (over 1 m) in the east. The historic peat surface is also indicated by red marks and is higher in the west than the east.

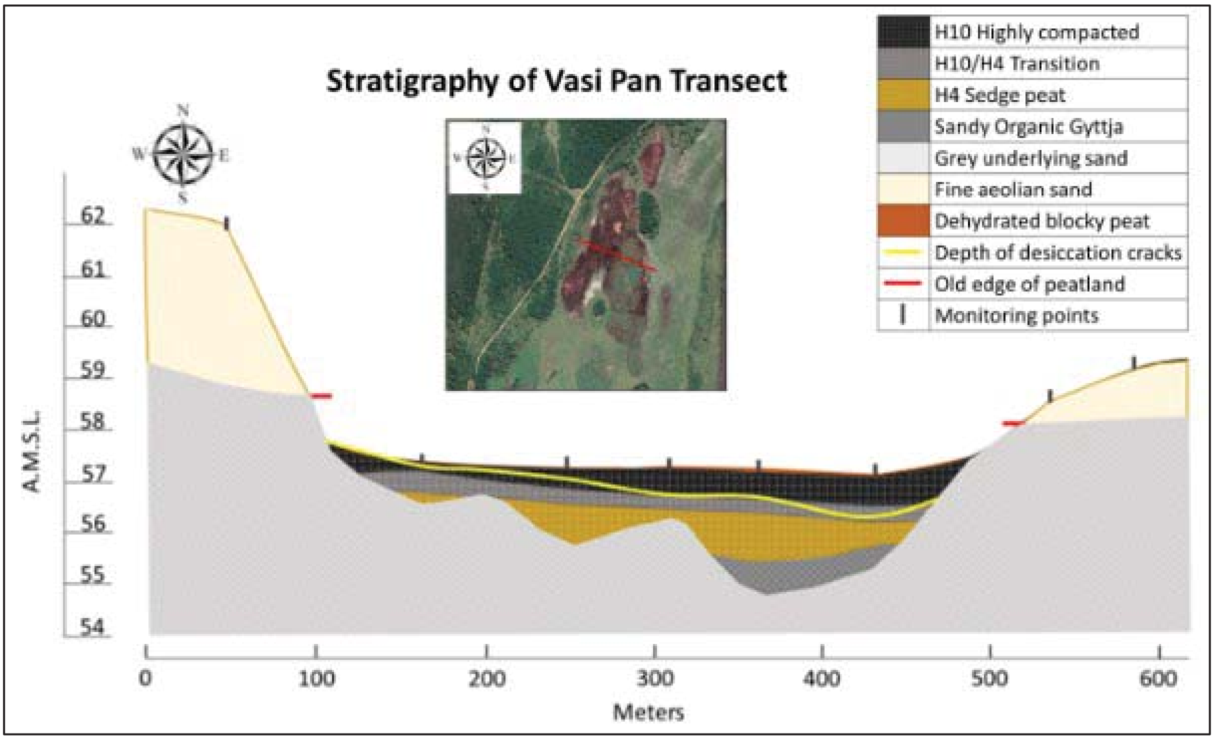
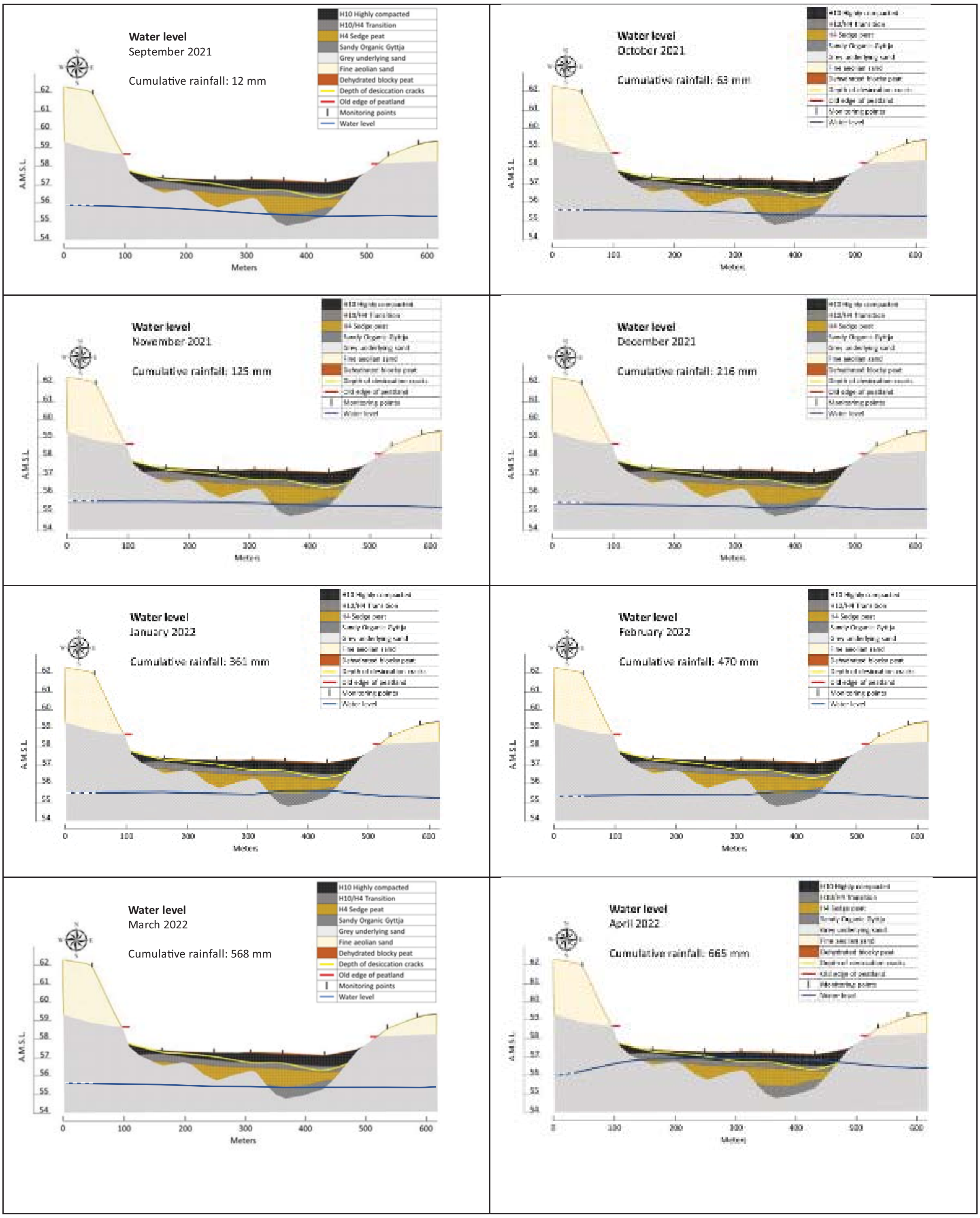


Figure 2.54 The stratigraphy of the transect in Vasi Peatland. The historic surface elevation of the peatland is indicated by the red marks.

2.4.3.3.5 Water level of the Vasi Peatland (KwaZulu-Natal Province)

A time series analysis of the water levels in Vasi Peatland is displayed in **Figure 2.55**. At the start of the monitoring period in September 2021 the water level sloped from west to east in the peatland. Water levels were 1.5 m below the surface in the west and up to 2 m below the surface in the east. The slope of the water table continued in October and November but was raised slightly due to the rainfall received during this period. From December 2021 to February 2022, where an increase in rainfall occurred, the general slope of the water table remained the same, although there was a rise in the eastern parts of the peatland. In March, this upward trend in the east of the peatland was no longer present. After the heavy rainfall received in April 2022, a large increase in the water table was observed. Notably surface water was present in the peatland in the desiccation cracks. In June 2022 the water levels dropped again to resemble the summer water table trend, but without the increase in water levels in the east of the peatland.



Water level
September 2021
Cumulative rainfall: 12 mm
Water level
October 2021
Cumulative rainfall: 63 mm
Water level
November 2021
Cumulative rainfall: 125 mm
Water level
December 2021
Cumulative rainfall: 216 mm
Water level
January 2022
Cumulative rainfall: 361 mm
Water level
February 2022
Cumulative rainfall: 470 mm
Water level
March 2022
Cumulative rainfall: 568 mm
Water level
April 2022
Cumulative rainfall: 665 mm
H10 Highly compacted
H10/H4 Transition
H4 Sedge peat
Sandy Organic Gyttja
Grey underlying sand
Fine aeolian sand
Dehydrated blocky peat
Depth of desiccation cracks
Old edge of peatland
Monitoring points
Water level
A.M.S.L.
Meters

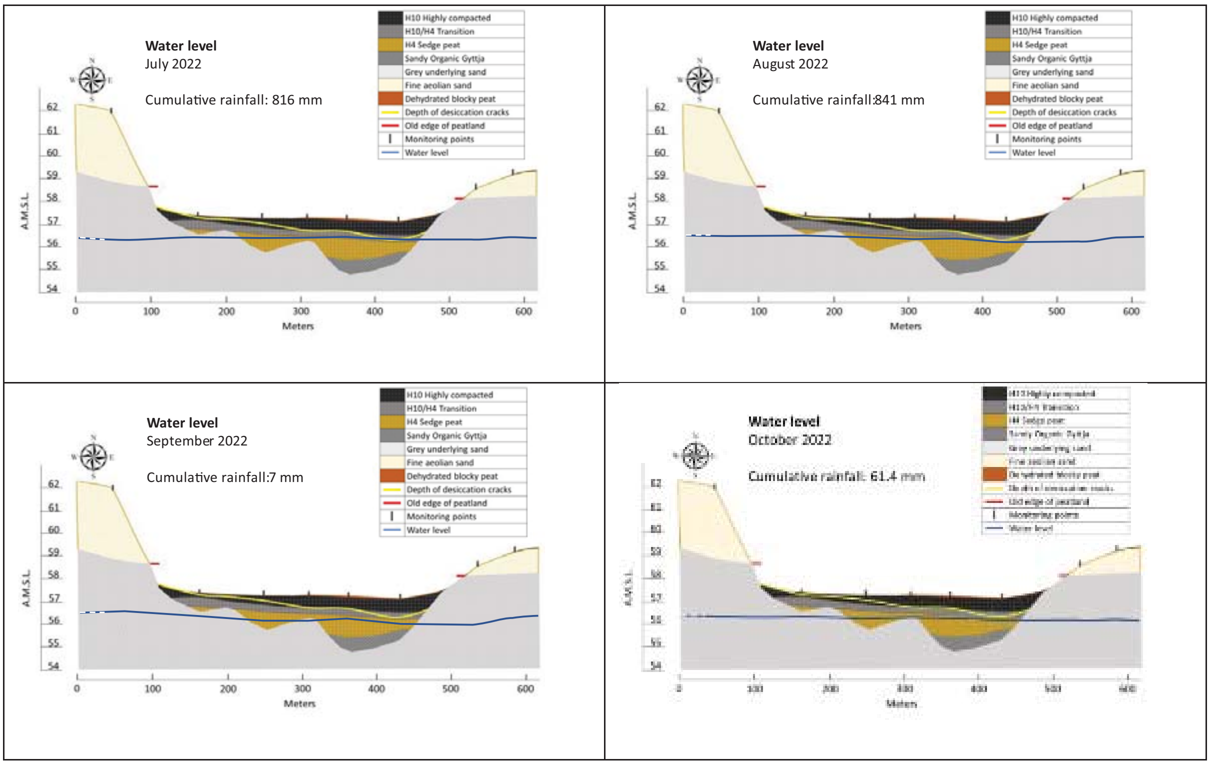


Figure 2.55 A time series analysis of the water levels in Vasi Peatland. The historic surface elevation of the peatland is indicated by the red marks.

2.4.3.3.6 Water flow paths and signatures of the Vasi Peatland (KwaZulu-Natal Province)

Water chemistry analysis, as well as temperature and electrical conductivity measurements taken in March and June 2022 (**Figure 2.56** and **Figure 2.57**), indicate that the eastern and wetland dunes contain water that shows similar characteristics to rainfall, whilst in the peatland the water chemistry values show a groundwater signature. Colder temperatures are also evident in the eastern parts of the peatland.

March 2022

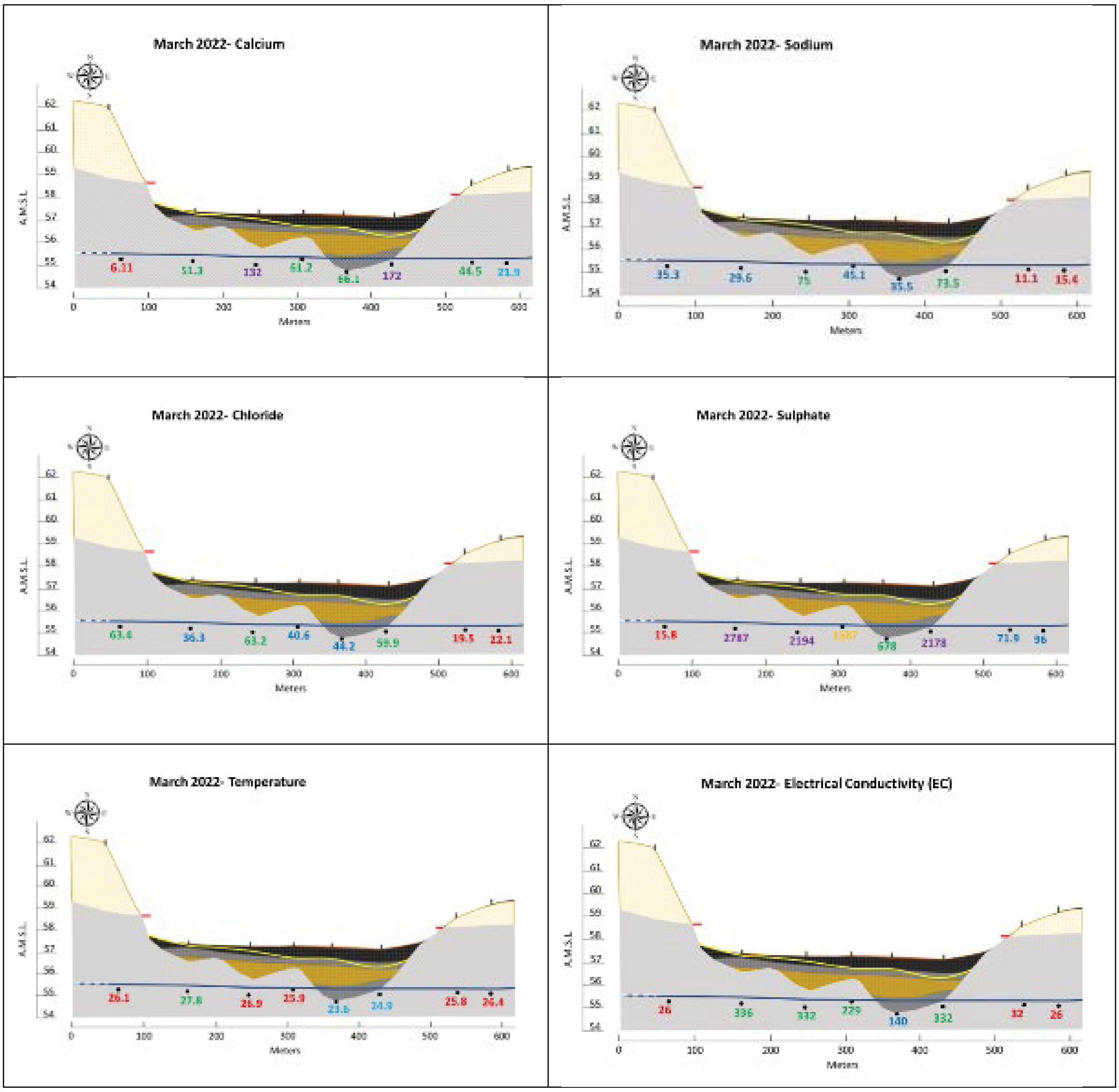


Figure 2.56 March 2022 water chemistry, temperature and electrical conductivity values of Vasi Peatland. The historic surface elevation of the peatland is indicated by the red marks.

June 2022

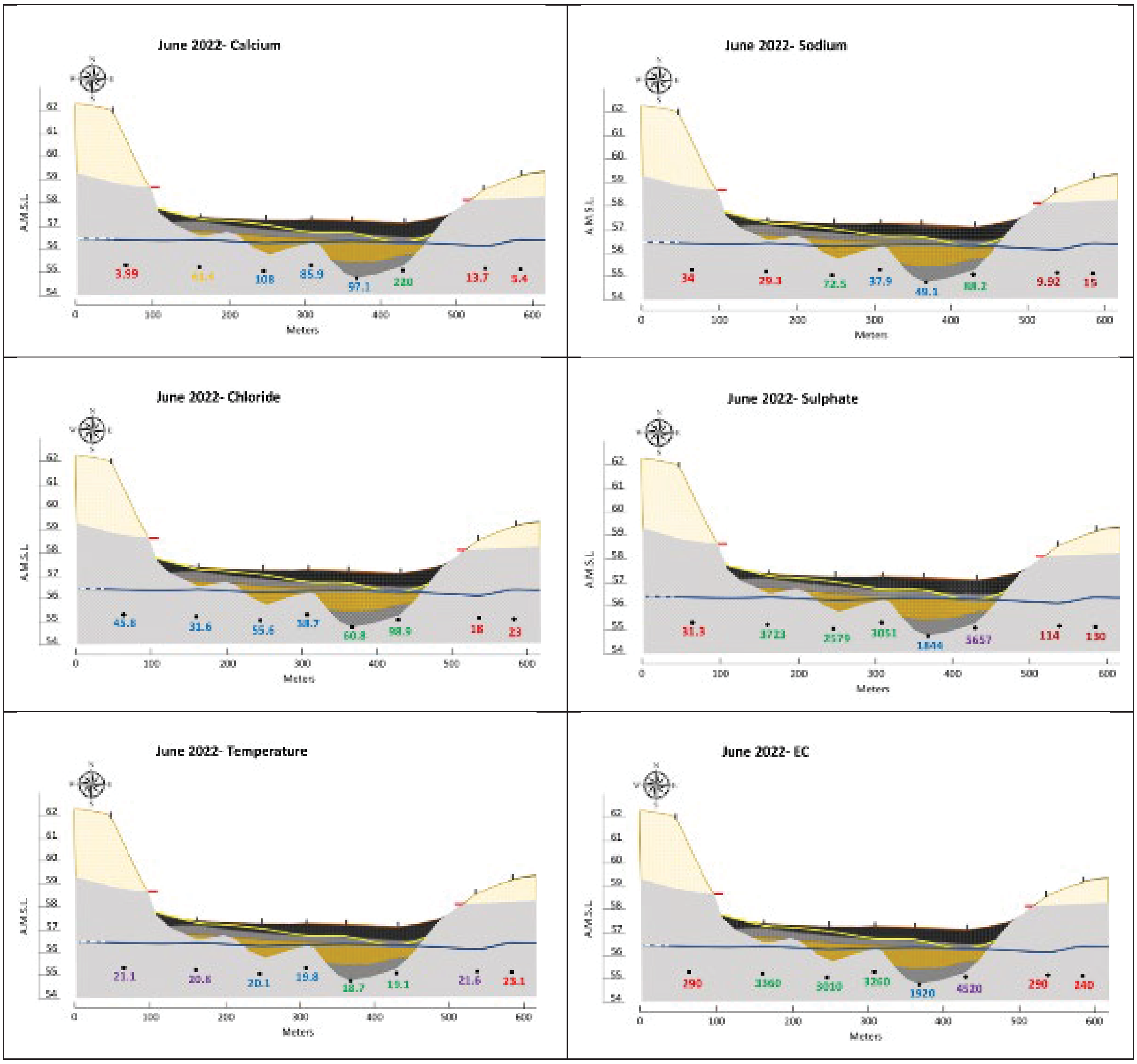


Figure 2.57 June 2022 water chemistry, temperature and electrical conductivity values of Vasi Peatland. The historic surface elevation of the peatland is indicated by the red marks.

2.4.3.3.7 Discussion on peat characteristics and hydrology of the Muzi and Vasi Peatlands (KwaZulu-Natal Province)

Muzi Peatland

Water levels and signatures of the Muzi Peatland indicate that the dominant water flows from the east to the west of the peatland, originating from the eastern dune. The upwelling of groundwater in the eastern parts of the peatland, confirmed by the water signatures, indicate that the peatland is also reliant on deeper groundwater. With regard to surface water in the peatland, only sections of the peatland that experienced peat fires had surface water present during the monitoring period. This shows that the lowering of the peatland surface due to peat fires has aligned the surface of the peatland with the current water table, which should increase the biodiversity function of the peatland. The justification for this is that although peat fires result in a significant loss in carbon, they realign the surface level of the peatland to that of the water table. In a situation such as Tembe Elephant Park where the Muzi Peatland is the only permanent source of water, the peat fire was shown to have some positive influence on the functioning of the system, given the lowered water tables within the peatland. In the unburnt sections of the peatland, water tables were sometimes up to 1 m below the surface.

Vasi Peatland
Results from the hydrological assessment at the Vasi Peatland illustrated that the dominant water flow in the peatland is from west to east, with a different water signature in the adjacent dunes. The fact that the water signature in the western and eastern dunes are similar indicates that water does not flow through the peatland, but rather that groundwater discharges into the peatland system. Different temperatures and the significant rise in groundwater in the east of the peatland indicate that a potential different source of water is also present.

The depth of desiccation cracks increases from the west to the east and mirrors the long-term water table slope. The east of the peatland therefore exhibits deeper desiccation cracks due to the lower water table in these parts. As the desiccation cracks are deeper, the surface level in the cracks is nearer to the water level. The opposite effect is seen in the west of the peatland where surface water was only present during the heavy rainfall experienced in April 2022. Without the peat fires, the water table would not have reached the surface of the peatland. This can be seen in **Figure 2.56** and **Figure 2.57**, where the historic surface elevation of the peatland is indicated by red marks. The desiccation, notably burning and cracking, has therefore served in lowering the surface level of the peatland, more closely aligning it to the present water table.

2.4.4 Socio-economic Impact of Peat Fire

2.4.4.1 Tier 1: Molopo Peatland (North West Province)

2.4.4.1.1 Demographics

The 17 people who participated in the survey comprised 12 males and 5 females between 38 and 65 years old. Most of the respondents are currently employed (64.7%), with the remainder (35.3%) having permanently retired to their homes in Molopo Private Park. Only one person from the group generates a proportion of their income from the peatland itself, and this activity comprises 21-40% of their monthly income. Nearly one third (29.4%) of the respondents have resided in the park for over 10 years, 41.2% have resided there for 5-9 years, and 29.4% have lived there for 4 years or less. With reference to how far they reside from the peatland itself, 64.7%, 29.4% and 5.9% indicated that they reside within 0.5, 0.5-1 and 1-2 km from the peatland respectively.

2.4.4.1.2 Conditions and benefits

When asked whether they were aware of the presence of peat in the wetland, 58.8% of the respondents indicated that they were aware that the system is a peatland. All respondents indicated that there was freestanding water in the system before the onset of degradation. They also indicated that the peatland was a source of biodiversity, including fish, fish eagles, ducks and ospreys. One participant suggested that the peatland was special as they spotted "*special frogs*" from time to time. Some respondents mentioned that they used to ride their boats on the system and appreciate nature, and in the words of one respondent: "*now all that remains are the pictures I shared on social media*".

All respondents stated that they benefited from the well-functioning Molopo Peatland in one way or another. One of these benefits was the fresh clean air from the peatland, noted by 17.6% of the respondents. The scenic beauty of the area, including the view of the water and birdlife was noted by 47.1% of the respondents, while 35.3% said they benefited from the relaxation that the peatland offered, some even calling it "*a paradise*". All respondents mentioned that the high property value attributed to the proximity to the peatland was a major attraction to purchase houses in the area. One of the respondents observed that the peatland and life it housed provided a sense of safety for them.

2.4.4.1.3 Changes and effects

Notable changes took place in the peatland system before the fire event. All but one of the respondents noted these changes. The most noticeable change was a decline in water levels in their boreholes as well as in the peatland. All respondents attributed this to the construction of the weir upstream that cut off the flow from the Molopo Eye, an artesian spring that fed the wetland. Many respondents (58.8%) stated that they were aware that the government is extracting water from the spring and supplying the town of Mahikeng with water for human consumption and the ecological reserve is not being honoured. One respondent mentioned that with a decline in the water levels, they noticed that there were more reeds in the system, obstructing the view of the water and making boating challenging.

Respondents observed that a loss of aquatic life accompanied the decline water in the peatland. This was then followed by migration of bird species that depended on the fish and frog populations that the peatland sustained. Another resident suggested that the presence of reeds in the peatland provided a habitat for different species of birds, which were pests to the adjacent farmers. One respondent described the change as gradual, from: "*a beautiful paradise, to green, to now being grey*". The decline in water level led to the drying, desiccation and subsequent burning of peat which resulted in a more detrimental impact on residents in the short term in terms of air quality and related health risks (**Figure 2.58**).

Figure 2.58 A resident of Molopo Private Park incurred an injury walking on the burnt peatland *(Photo: Eddie Leighton, Nov/Dec 2019)*.

The effects of the peat fires and degradation varied based on how far the respondents resided from the peatland. The closer they were, the greater the number of negative effects they noted (**Table 2.2**). Respondents who resided near the peatland expressed how they feared for their lives thinking that the fire would spread to their thatched roof houses. Only one person said that they did not feel threatened by the fire because they do not walk around the peatland, though they were concerned that strong winds would propel the fire in their direction, especially since the location of their house was in the dominant (northerly) wind direction. One person mentioned that they feared more for their animals, adding: "*all fires make you feel threatened*".

Table 2.2 Summary of effects of peat degradation/fire relative to the distance of respondents' homes to the Molopo Peatland

Distance from peatland (m)	Effects of peat fire	No. of respondents (%)
0-500	Fire threat to thatched roofs Loss of wildlife Smoke inhalation Air pollution / bad smell from peat Loss of scenery / sense of place Decreased property value Decreased borehole water levels	64.7
500-1 000	Loss of wildlife Air pollution Decreased property value Decreased borehole water levels	29.4
1 000-2 000	Decreased property value Decreased borehole water levels	5.9

One of the residents indicated that they have asthma and the smoke inhaled during the peat fire posed 'serious' health implications for her and her family. Two respondents stated that they started experiencing nosebleeds after inhaling smoke from the peat fire and have had sinus issues ever since. All respondents had breathing difficulties when the fire and smoke was at its peak, but most of them recovered when the smoke dissipated. Residents also indicated that the smoke released by the smoldering subsurface fire had a very unpleasant smell that remained in the air for months after the fire, with one even stating that the smell is still apparent 5 years later. One resident said: "*The effect of the fire on nature and ecology is heartbreaking, especially the gases that people inhale leaving all these health problems*". Others referenced an unpleasant smell that still hangs over their properties in the mornings and evenings.

A majority of the respondents (88.2%) stated that the wetland was an important factor in their decision to acquire property in the park. The changes noted in the peatland have left the system "*distasteful to look at*", as one mentioned, while another added how they feel bad for the youth who were never able to enjoy the wetland. "*There is no water and almost no life in the wetland*" the respondents stated. A large number of them (70.6%) attempted to sell their property since the fires, many of which are currently on the market. This includes the former chair of the Molopo Private Park body corporate who sold their property earlier in 2021. Respondents mentioned that it has been very difficult to sell property in the area as it has become unpopular since the peat fires and the installation of the weir.

2.4.4.1.4 Rehabilitation

One respondent mentioned that, in conjunction with the management of the Molopo Private Park, they were involved in getting a court order issued to the Department of Water and Sanitation (DWS) to open the locks in the weir and release 40% of the water to the wetland. This process has, however, yielded no results. Some respondents indicated that they are part of a committee that is in communication with the local authorities, engaging in water negotiations with the DWS and working with the 'Working for Wetlands' programme for the wetland to be declared a protected area. One stated that they cut the reeds from the peatland to combat the risk of veld fires. Only three of the respondents (17.7%) indicated that they have not been involved in any initiatives to try to rehabilitate or restore the wetland.

All respondents indicated that they would welcome any help in trying to rehabilitate the system, especially support in reinstating the ecological reserve. They also stated that they would be willing to become actively involved in rehabilitating the peatland. When asked how their lives would change if the wetland ceased to exist, 76.5% responded that they would be forced to move from the area, even if it meant selling their properties at a lower value. One commented: "*it is very sad to see the wetland go to waste, especially because of lack of* [a lack in] *government intervention*".

2.4.4.2 Tier 2: Onrus Peatland (Western Cape Province)

Findings of the stakeholder engagement are presented below and include the experiences of the local fire brigade who attempted to extinguish the peat fire, as well as the effects of the fire on local communities and businesses.

Experiences of the fire brigade

On the 25th of December 2018, a veld fire blazed through the Overstrand Municipality in the Western Cape. A few days after the fire, on the 11th of January 2019, smoke was seen coming from a piece of land and reported to the local fire brigade. They subsequently responded and went to the site to extinguish the fire, but upon their arrival there was no smoke in sight so they withdrew. A few days later the fire brigade received another phone call reporting that the same piece of land was burning. Upon arrival, this time they did see smoke and extinguished it by spraying water from the road. Later that week, another call came through reporting that this piece of land was burning. Again, the fire brigade extinguished the smoke. Thereafter they started receiving more and more phone calls that smoke was coming out of the peatland, and the fire brigade realized that they were dealing with something out of the ordinary. When spraying the area that smoke was coming out of with water, it became apparent that the water did not penetrate the surface and that the ash would 'spray back'. Signs of erosion also became evident when water would run downstream. The site also continued to burn despite the area receiving rain and escalated from small patches into thick clouds of smoke. The fire brigade subsequently requested the Senior Environmental Manager of the Overstrand Municipality, Ms Liezl de Villiers, to accompany them to the site and she identified the piece of land as a peatland. Government experts, Dr Piet-Louis Grundling from the Department of Forestry, Fisheries and the Environment and Mr Michael Bolton from Working on Fire, then became involved to assist in extinguishing the peat fire by using a spike tool (designed by Mr Bolton) that sprays water below the surface to 1.5 m depth (Grundling et al., 2019). The Working on Fire team arrived on site on the 1st of May 2019 and succeeded in extinguishing the fire by the 30th of June. In total, the peat fire at the Onrus Peatland burnt for a period of 6 months.

Local perspectives on the degradation of the Onrus Peatland

The general consensus as to the reason why the water table dropped and the peat became susceptible to subsurface fires includes the infestation of alien invasives (predominantly *Euculyptus* sp.), the upstream dam, erosion within the peatland, and over-abstraction of groundwater from boreholes. Stakeholders explained that it was unusually hot at the time of the fire and there were water restrictions in place. Many also questioned whether the dam's management adhered to maintaining the ecological reserve for years preceding the peat fire. In addition, stakeholders could not recall water being released from the dam into the peatland in the weeks preceding the fire due to water shortages at the time.

As to the causes of the erosion, some speculated that the dam, when releasing water, does so in a short time span (once a month), creating flows in the water that are of a very high velocity and resulting in erosion gullies. Subsequent to boreholes being sunk in the catchment, many locals have also noticed a drop in water levels on their farms. There is also speculation of illegal boreholes and over-abstractions of licensed boreholes. The challenges presented by climate change were also noted. In the years preceding the peat fire some of the stakeholders noticed that the alien invasive plants continued to expand, whilst others stated that the area was so infested with alien invasives that they did not see any changes. Increases in the size and width of erosion gullies were also noted by those who entered the wetland.

Effects on local communities

The peat fire mainly impacted the two adjacent properties which included the Hamilton Russell Vineyards and Camphill Farm. The adjacent wine farm lost most of their Pinot noir harvest of the year, as the grapes were contaminated with the smell of smoke. Whilst it is unknown whether the grapes were contaminated with the smell due to the peat fire (which lasted for 6 months) or veld fire (which lasted a few minutes), the estimated financial loss of the Pinot noir harvest was R16.8 million. The wine farm also continuously kept three workers on the border of their vineyards and orchards as spotters to alert management if the fire were to spread onto their farm.

The manager of Camphill Farm community explained that it was a continuous effort to keep their adult residents away from the peat fire for fear that they might fall into the fire and burn themselves. The school for intellectually disabled children, which is located next to the peatland, needed to evacuate for the duration of the peat fire as the smoke became too much to bear. Due to financial constraints, a facility suited for their needs could not be sourced which resulted in the school renting halls for teaching and accommodation. The rented halls were often noisy and did not allow for much privacy, which is required for intellectually disabled individuals. The reason for this is that if one learner experiences a negative episode, it negatively effects most of the other learners in the room. This frequently occurred in the rented halls and often resulted in turmoil. The rented learning space proved problematic as learners could not receive the therapy that they required and additional financial costs were also incurred through having to transport food daily and learning materials to the rented space. Although many of the items were charged at a discounted rate, the total financial cost incurred to the school because of the peat fire was R240 000.

Other stakeholders that were directly affected by the peat fire include the fire brigade who spent numerous hours trying to extinguish the fire with little to no success and many firefighters experiencing headaches whenever working on site. A local runner and their dog also fell into the peat fire. The runner suffered burns across their body and unfortunately the dog died from its injuries.

It is clear that the peat fire had many negative impacts on those living in the area, emotionally, socially and economically.

2.4.4.3 Tier 3: Muzi Peatland (KwaZulu-Natal Province)

Le Roux et al. (2021) reported on the Muzi Peatland reed cutters and their perspectives on a subsurface peat fire. The group was composed entirely of women aged between 28 and 61 (averaging about 50) from five wards around KwaMsomi (**Figure 2.59**). Some of the respondents have been harvesting reeds in Tembe Elephant Park for as long as 45 years as a few were born on the land before it was a protected area and have been harvesting reeds since they were little girls. They travel an average of 2 hours to and from the park during harvesting days, and walk around an hour to where they harvest the reeds in the wetland. Reed bundles are sold from R15.00 to R30.00 each, depending on the length and quality of reeds, and are bought by local community members for construction and thatching purposes. In a good month they can make up to R400.00, but in some months, not a single bundle is sold. Reeds and sedges are harvested using pangas and are bound into bundles or batches using rope. The rope used in this process is made from sedge leaves, also collected from the wetland, that are woven together. Gumboots are needed to walk on the wetland, but only three of the respondents had gumboots to wear during harvesting as the rest could not afford them.

When the reed cutters were asked who controls where and when they are allowed to harvest reeds, they stated that it is the Park regulations, and that they are not happy with them. The reason is that for many of the reed cutters, the money generated from the sale of the reeds is the only source of income for their households, which range from 4 to over 10 people (averaging 8). When asked about the peat fires, the reed cutters said that whilst they did not feel physically threatened by the fire, they feared for their livelihoods as the subsurface fire was burning the roots of the reeds. It frightened them that the fires took so long to die out and why they were so difficult to extinguish. For these reasons, the peat fires are seen as a mystery amongst locals. They also reported that because of these fires, the reeds do not grow anymore and that grass has taken over. When asked what would happen if the wetland ceased to exist, the reed cutters said that it would lead to extreme poverty, whilst some even said that it would lead to death.

The reed cutters went on to explain that the Muzi Peatland in Tembe Elephant Park is the only wetland in the region where reeds still grow, even though the reed beds have been severely degraded. Most of the reed cutters believe that the degradation is caused by the drying out of the wetland due to the plantations adjacent to the park that pump out water, although some are of the impression that the game in the park consumes all the water in the wetland and that the park pumps the water of the wetlands into waterholes for the animals. They also acknowledged that the drought in the area has dried out all local open water sources and that they buy their potable water from neighbours who have installed boreholes on their properties.

Figure 2.59 The reed cutters from five wards around KwaMsomi.

3 PEATLAND MANAGEMENT AND REHABILITATION: CASE STUDIES OF THE PALMIETRIVIER AND ONRUS PEATLANDS

By Donovan Kotze with inputs from Jason Le Roux, Althea Grundling, Piet-Louis Grundling, Trevor Hill and Tsepo Sekaleli based on a joint peatland assessment study.

3.1 INTRODUCTION

Palmiet (*Prionium serratum*) is a robust wetland plant that can withstand high energy events. It occurs endemically in the Western Cape and parts of the Eastern Cape and KwaZulu-Natal provinces. Some wetland systems that contain palmiet stands are associated with peat (i.e. accumulated organic material under saturated conditions) while others may only have pockets of peat but are associated with or dominated by organic soils (i.e. mineral dominated). Palmiet wetlands with peat or organic soils are important stores of carbon and can assimilate nutrients and toxicants. However, if a wetland is degraded by erosion, alien invasive vegetation or a combination thereof, its peat and/or organic soils can be rapidly lost, along with related ecosystem services.

Some key palmiet wetlands in the Western Cape have been identified which have been degraded to varying degrees by erosion and alien invasive tree infestation: the Onrus Peatland with advance stages of degradation and the Palmietrivier wetland with early stages of degradation. In response to this degradation and the threat of much further degradation/loss occurring, the land-holders and other partners such as Working for Wetlands need to arrest degradation and secure these wetlands and their associated stores of carbon. To date, determinations of the level of degradation of palmiet wetlands in South Africa have been limited. Different types of palmiet wetlands require different management interventions.

3.2 AIM

To compare palmiet wetlands in the Western Cape, namely the Onrus Peatland in the Hemel-en-Aarde valley near Hermanus and the Gourtiz Cluster Biosphere Reserve centred around the Langeberg Mountain foothills in the Herbertsdale area, as a basis to address degradation, secure the wetlands and their associated stores of carbon, and to make recommendations for management interventions for the different types of palmiet wetlands.

3.3 METHODOLOGY

Peat profile descriptions were done along transects using a Russian peat auger during February 2022 at the Onrus Peatland (**Figure 2.20**) and July 2022 at the Palmietrivier Wetland (**Figure 3.1**) from which organic sediment depths were determined. At both Onrus and Palmietrivier, samples were analysed using the Loss of Ignition method, to provide an indication of how carbon content varied down the profile.

The volumes of organic sediment were converted into mass of carbon using a percentage organic matter measure of 25% (given that the majority of organic sediment samples in the study analysed for carbon content fell between 20 and 30%), converted to percentage soil organic carbon based on the Van Bemmelen Factor:

$$\%\ \text{Soil Organic Carbon} = \frac{\%\ \text{Soil Organic Matter}}{1.724} = \frac{25\%}{1.724} = 15\%$$

Bulk density data were not available for any of the selected wetlands, and thus the bulk density trend related to increasing percentage soil organic matter content reported by Grundling et al. (2017) was used in the conversion of volume of organic sediment to mass of carbon.

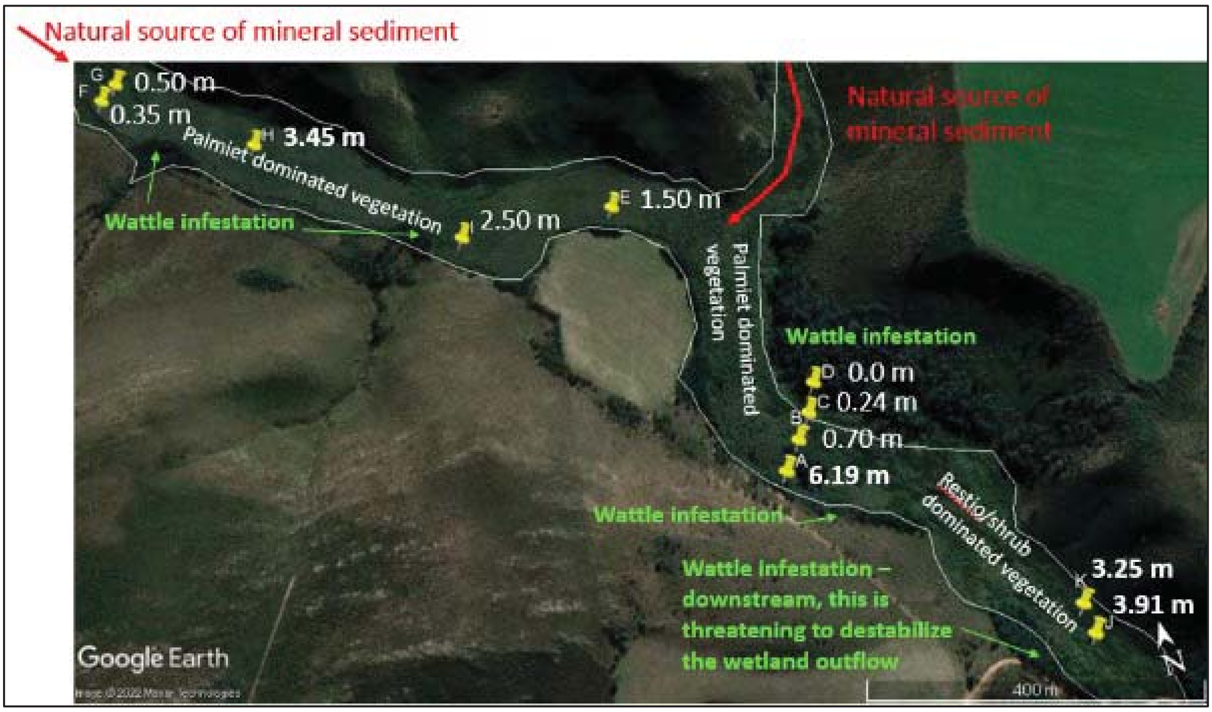


Figure 3.1 Palmietrivier Wetland, showing location of cores and the overall depth of organic sediment recorded for each core.

Landscape setting was described from topographical maps and Google Earth to map the wetland area against longitudinal slope. There is the natural propensity of a valley bottom wetland to erode/incise based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope (adapted from Ellery et al., 2009 and Macfarlane et al., 2020).

In addition, for each of the wetland organic sediment areas, disturbance unit types were identified using the approach of WET-Health (Kotze et al., 2012) and the spatial extents of the identified disturbance types were determined. A disturbance unit refers to an area within a wetland that has been subject to similar types and levels of human impact. The first step in identifying disturbance units is to identify land cover types in the wetland, some of which may need to be sub-divided into separate disturbance units where the land cover type is heterogeneous in terms of type and level of human impact (Macfarlane et al., 2020).

Within each disturbance unit, the level of degradation of the organic sediment was rated and likely factors contributing to the degradation were identified. The ratings, which reflect the consensus of three practitioners experienced in the field assessment of organic sediment wetlands, were based primarily on the following field observations: evidence of physical loss of organic sediment to erosion; evidence of surface "sagging" of the cross-sectional profile of the land surface; anthropogenic disturbance (notably through tillage) of the organic sediment; the presence of erosion gullies, drainage furrows and other features likely to increase the natural drainage of the unit; as well as considering water abstraction and other potential impacts arising from the upstream catchment. The rating was informed by the results of existing relevant studies such as Six et al. (2002).

A projection of future degradation was then undertaken, based on a plausible future scenario for the next 30 years. This was strongly informed by observed changes over the previous 30 years and considering factors likely to continue reinforcing the past trend, or alternatively, constraining further degradation. For example, a wetland through which gully erosion has advanced and for which no obstructions are present preventing it from continuing to erode an equivalent area, is assumed to undergo a similar level of erosion in the next 30 years. However, if the erosional advance has already been halted by a strong geological obstruction that blocks its further advance, a much-reduced level of erosional advance is assumed for the next 30 years. In the case of alien invasive plant infestations, limited expansion of alien invasive plants is anticipated over the next 30 years in an intact wetland organic sediment area with currently very high levels of wetness and robust cover of palmiet that act to restrict expansion of black wattle (*Acacia mearnsii*) infestations and within which few young black wattle plants are present. In contrast, a much higher level of expansion is anticipated where the level of wetness is inadequately high to significantly restrict establishment of black wattles, which are currently present as many young plants are scattered widely throughout the wetland organic sediment area.

Finally, recommendations were developed to minimize any further organic sand degradation/loss and consider the costs of management/rehabilitation options. These recommendations were informed by all the above assessments, comparing the current scenario with the projected future scenario and identifying which specific factors are anticipated to result in the greatest degradation. The recommendations were informed by considering threats (e.g. global climate change) not included or fully manifest in the future scenarios.

3.4 RESULTS

3.4.1 Detailed Assessment of the Palmietrivier Wetland

The eleven cores described in the wetland (**Table 3.1**) show a high level of heterogeneity in terms of the overall depth of organic sand, ranging from 0.24 to 6.69 m. The deepest organic sand was in the lower portion of the wetland on its southern margin, where the two greatest depths, namely 6.69 m (A) and 3.91 m (J) were recorded. Depth changed dramatically at a local level along a cross-valley transect located on a bend in the wetland, beginning with core A on the outer side of the bend and ending with D on the inner side of the bend. Core B, which was only a short distance in from A, had a considerably shallower depth than A, and declined further at C, while organic sand was altogether absent at D. Straighter portions of the wetland appeared less heterogeneous in terms of lateral variation in organic sand depth, with cores F and G and J and K respectively having similar organic sand depths (**Table 3.1**).

The cores varied in terms of the character of the mineral component (**Figure 3.2**). In most of the profiles, the material was predominantly fine, but in some profiles (notably A, C, H, I and K) sand was abundant. A few profiles included gravel. In core A, on the outer incisional side of the bend where the edge of the wetland lies close against a steep hillslope “carved” on the outer bend of the stream, this gravel is sharp edged, and is therefore assumed not be river worn but rather to be of colluvial origin from the adjacent hillslope. In contrast, in cores C and K near the centre of the cross-sectional profile through the wetland, gravel is rounded in nature and therefore assumed to be river worn. **Table 3.1** shows that the organic content of the sediment varied with depth of individual profiles and between overall profiles. In the organic layers, it ranged between 20 and 77%, although most of the organic sand ranged between 20 and 30%, and therefore was not true peat. Where sandy mineral layers occurred within the profile, organic content was typically <5%. Silty mineral layers within the profile were more variable in terms of organic content: those below the last of the organic sand layers were generally <5%, while those “sandwiched” within the organic layers generally ranged between 5 and 20%.

While areas with palmiet-dominated vegetation contained the greatest areal extent of organic sediment, the second deepest organic sand deposit recorded in the Palmietrivier Wetland occurred outside of the palmiet vegetation zone and the deepest organic sand deposit was on the edge of the palmiet zone. This highlights that one should not use the vegetation zone alone to extrapolate the likely occurrence of organic sediment. It is important to consider the influence of hydrogeomorphic features. As expected, organic sand was predominantly absent from the primary areas of mineral sediment deposition at the upstream inflow to the wetland and where the main tributary enters midway into the wetland on the northern margin, likely influencing core D most strongly, and progressively weakening in its influence towards the southern margin where core A was located.

The location of the deepest organic sand on the southern margin of the wetland highlights the importance of addressing impacts to the margins, presently mainly from wattle infestations within the margins and upslope areas, which would be the priority wattle areas to clear. At the end of the following section, priorities for management action are elaborated upon for Palmietrivier and the remaining three sites.

Two of the cores, A and D, are directly impacted by black wattle, with core D appearing to naturally lack organic sand. Core A shows earthification in the uppermost 0.15 cm of organic sand in the profile, which may possibly be attributed, at least in part, to the black wattle. However, earthification was not noted any deeper in the profile, and currently observable manifestations of the black wattle on the organic sand of the intact portions of the Palmietrivier Wetland appear to be limited. Nonetheless, as elaborated upon in the following section, black wattle is likely having significant (albeit currently localized) drying effects on some of the organic sediment, which may manifest more strongly in the future.

Table 3.1 A summary of the cores described in the Palmietrivier Wetland

Core no.	Coordinates	Vegetation	HGM setting & water table depth	Summarized profile description	Overall depth of organic sand (m)
A	-33.946096° 21.817201°	Black wattle, palmiet (*Prionium serratum*) sedge	Lower portion of wetland; southern margin of valley bottom (weakly channelled) on the “carved” outer bend of the valley floor	0-0.15 m: Organic, somewhat earthified 0.15-0.76 m: Mineral, silty[1] over sandy 0.76-1.20 m: Organic 1.20-1.35 m: Mineral, sandy 1.35-2.80 m: Organic 2.80-3.00 m: Mineral, sandy 3.00-4.70 m: Organic 4.70-5.00 m: Mineral, organic-rich, silt, sand & gravel up to 2 cm and angular 5.00-6.60 m: Organic, fine charcoal at 5.80-5.85 m 6.60-7.75 m: Organic with embedded sharp angular gravel 7.75 m: Bedrock	6.69
B	-33.945807° 21.817486°	*Carpha glomerata* with restios	Lower portion of wetland; valley bottom, south-central	0-0.20 m: Organic, earthified 0.20-1.60 m: Mineral, silty 1.60-1.80 m: Organic 1.80-2.50 m: Mineral, sandy with organic-rich sandy layers 2.50-2.80 m: Organic 2.80-3.40 m: Mineral, silty	0.70

Core no.	Coordinates	Vegetation	HGM setting & water table depth	Summarized profile description	Overall depth of organic sand (m)
C	-33.945562° 21.817730°	Restios, *Platycaulis catlystachys*, *Carpha glomerata*, *Cliffortia strobolifera*	Lower portion of wetland; valley bottom, north-central	0-0.12 m: Organic with charcoal fragments 0.12-1.03 m: Mineral, sandy loam becoming increasingly sandy with depth 1.03-1.15 m: Mineral, light grey coarse sandy alluvium with moderate amount of well-rounded white quartz gravel 1.15-1.62 m: Mineral, organic-rich silty loam 1.62-1.83 m: Organic, silty 1.83-2.40 m: Mineral, organic-rich silty loam 2.40-2.55 m: Mineral, sandy silty loam 2.55-2.93 m: Mineral, organic-rich silty loam 2.93-3.50 m: Mineral, silty loam	0.24
D	-33.945202° 21.817932°	Black wattle, *Carpha glomerata, Cliffortia strobolifera, Restio paniculata*	Lower portion of wetland; northern margin of valley bottom	0-0.05 m: Mineral organic-rich sandy loam 0.05-01.20 m: Mineral, silty somewhat organic-rich 1.20-1.50 m: Mineral, silty somewhat organic-rich with orange mottles 1.50-2.00 m: Mineral silty with orange mottles	0.00
E	-33.942662° 21.816091°	Palmiet	Upper portion of wetland; southern margin of valley bottom, straight section	0.0-0.80 m: Mineral, organic-rich silty 0.70-0.80 m: Mineral silty 0.80-0.90 m: Mineral, organic-rich silty 0.90-2.40 m: Organic, silty, floating mat 2.40-3.10 m: Mineral, silty	1.50
F	-33.939655° 21.809650°	Palmiet	Upper portion of wetland near inflow; sthn. margin of valley bottom	0.0-0.15 m: Organic, earthified 0.15-0.35 m: Organic 0.35-0.70 m: Mineral, organic-rich silty 0.70-0.80 m: Mineral, sandy	0.35
G	-33.939510° 21.809891°	Palmiet	Upper portion of wetland near inflow; valley bottom, central	0.0-0.40 m: Organic 0.40-0.50 m: Organic, with silt 0.50-0.60 m: Mineral, organic-rich silty 0.60-0.75 m: Mineral, organic-rich silty, sandy 0.75-1.00 m: Mineral	0.50
H	-33.940700° 21.811574°	Palmiet	Upper portion of wetland; valley bottom, central	0.0-0.65 m: Organic 0.65-0.95 m: Mineral, silty 0.95-1.30 m: Mineral, silty sand 1.30-4.10 m: Organic, liquid 4.10-4.30 m: Mineral, organic-rich silty 4.30-4.50 m: Mineral, silty fine sand grading into coarse sand with increasing depth	3.45
I	-33.942536° 21.813984°	Palmiet	Upper portion of wetland; valley bottom, margin	0.0-1.85 m: Organic, predominantly liquid material in floating mat 1.85-1.95 m: Mineral, sandy layer with well-preserved rhizomes 1.95-2.60 m: Organic with little sand 2.60-3.00 m: Mineral sandy silt, well preserved rhizomes 3.00-3.30 m: Mineral, organic-rich, silty 3.30-3.40 m: Mineral, silty	2.50
J	-33.948639° 21.820306°	*Cliffortia stobo*lifera, *Cliffortia odorata* shrubs and cf. *Isolepis* sp. sedge	Lower portion of wetland; interface of southern margin of central valley bottom and	0-0.10 m: Organic 0.10-0.25 m: Mineral, organic-rich & silty 0.26-0.35 m: Organic 0.35-0.83 m: Mineral, organic-rich & silty 0.83-1.18 m: Organic 1.18-1.37 m: Mineral, organic-rich & silty 1.37-4.67 m: Organic	3.91

Core no.	Coordinates	Vegetation	HGM setting & water table depth	Summarized profile description	Overall depth of organic sand (m)
			the adjacent hillslope seep	4.67-5.23 m: Mineral, organic-rich & silty 5.23-5.30 m: Organic 5.30-6.20 m: Mineral, organic-rich & silty 6.20 m: Bedrock	
K	-33.948333° 21.820306°	Palmiet	Lower portion of wetland; valley bottom, central	0-0.4 m: Organic 0.4-0.7 m: Mineral, organic-rich sand with gravel 0.7-1.2 m Organic with sand particles 1.2-1.4 m: fine sandy with moderately worn gravel 1.4-2.3 m: Mineral, organic-rich sand with limited gravel 2.3-4.65 m: Organic with sand particles 4.65-5.15 m: Mineral organic-rich sand with limited gravel increasing with depth 5.15 m: Bedrock	3.25

[1]Soil texture determinations were based on a qualitative field determination, and as such, material referred to as silty may also contain a moderate proportion of clay.

Figure 3.2 Spatial variation of peat/organic material. The peat/organic sediment layers were interrupted by mineral sediments (predominantly fine grained but with some sandy layers) suggesting a "punctuated/interrupted" aggradation of the peat/organic sediments.

3.4.2 Detailed Assessment of the Onrus Peatland

Refer to Chapter 2 (section 2.4.3.2) pertaining to the detailed work done on the Onrus Peatland.

3.4.3 Comparison between the two Wetlands

The Palmietrivier Wetland had the deepest recorded organic sand and its mean depth was lower than that of the Bergfontein Peatland, since most of the organic sand deposit was otherwise much shallower than the maximum.

3.5 CURRENT IMPACTS AND FUTURE RISKS TO THE ONRUS PEATLAND AND PALMIETRIVIER WETLAND

By using wetland size (a simple surrogate for mean annual runoff) and the wetland's longitudinal slope one can determine the natural propensity of a valley bottom wetland to erode/incise (adapted from Ellery et al., 2009 and Macfarlane et al., 2020), as shown in **Figure 3.3** for the Onrus Peatland and Palmietrivier Wetland. The current impacts and future threats to the Onrus Peatland and Palmietrivier Wetland are listed in **Table 3.2**.

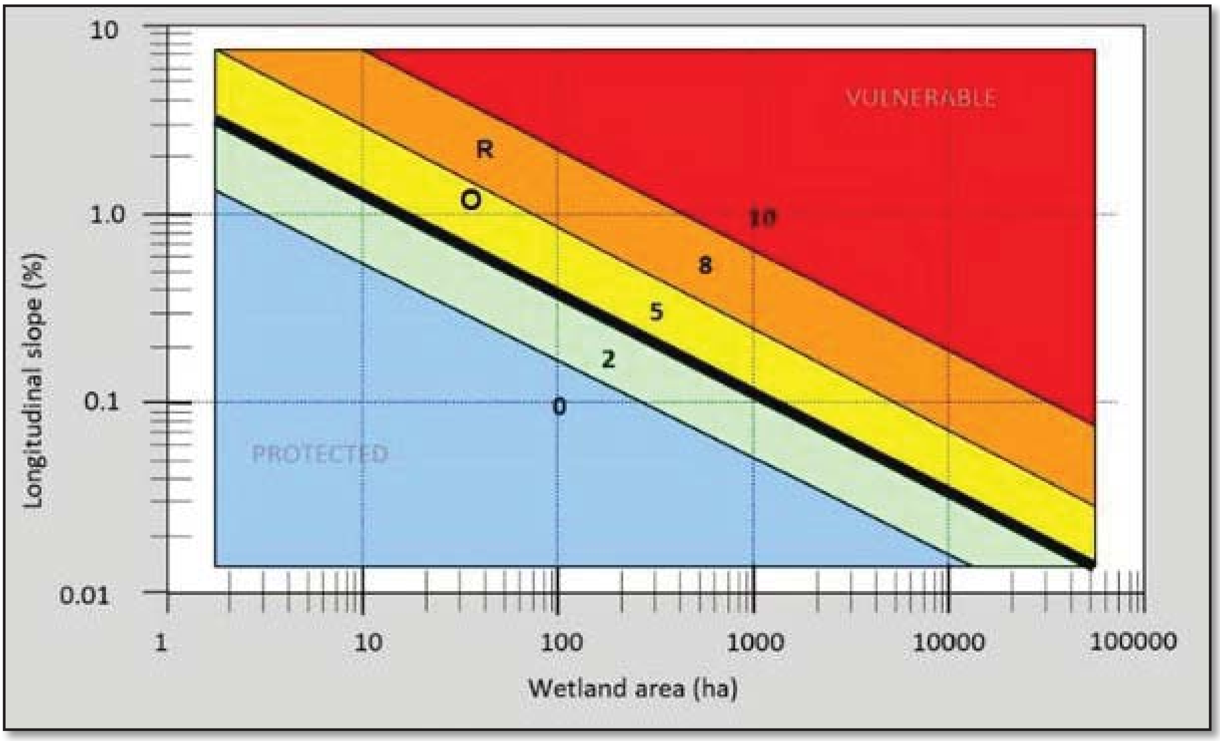


Figure 3.3 Natural propensity of a valley bottom wetland to erode/incise based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope (adapted from Ellery et al., 2009 and Macfarlane et al., 2020) and determined for: (O) Onrus Peatland and (R) Palmietrivier Wetland.

Table 3.2 Current and impacts and future threats to the Onrus Peatland (OP) and Palmietrivier (PR) Wetland

	Onrus Peatland: Advanced stages of degradation	**Palmietrivier Wetland: Early stages of degradation**
Current impacts		
Extent of wetland and its organic sediment/peat still intact and minimally impacted	73%	86%
Extent of wetland **moderately** impacted by black wattle (PR) / blue gum (OP) before the peat fire	0%	6%
Extent of wetland **severely** impacted by black wattle (PR) / blue gum (OP) before the peat fire, and erosion	43%	8%
Extent of wetland impacted by peat fires	27%	0%
Under alien invasive infestation (upper part of the system 6 ha)	19%	
Remainder of the peatland is threatened by erosion	73%	
Future threats		
Increased extent of alien invasive species Erosion poses threat Secondary impacts such as wetland desiccation and peat fires	Much of the remaining 73% is under threat	Much of the remaining 86% is under threat

3.6 PEATLAND REHABILITATION PROTOCOLS

As highlighted in the introduction, if a palmiet wetland is degraded (e.g. eroded, invasive vegetation infested or a combination thereof), its peat and/or organic soils can be rapidly lost, along with related ecosystem services (Rebelo et al., 2019). Conserving these systems would likely best be achieved through a pre-emptive approach which focusses on investing in preventing degradation rather than in attempting to restore highly degraded portions of the respective wetlands. Guided by this approach, a set of management goals and recommendations has been developed (**Table 3.3**).

Table 3.3 Management goals and recommendations for the five wetland organic sand sites

Goals	Recommendations	Rationale and further notes
Control alien invasive plants, notably black wattle, in the wetlands	The highest priority and most urgent need for control is where the black wattle are directly threatening the geomorphological integrity of the wetland.	As described in the previous section, a great deal of the existing (and projected future) degradation and loss of organic sand in the five wetlands can be linked to black wattle infestations in the wetland. Thus, the primary management recommendation for the sites is for their effective control, with particular priority afforded to where vulnerability to impacts is highest, which from a geomorphological perspective is typically where naturally diffuse flow transitions into confined strongly channelled flow.
Maintain sustained water supply from the wetlands' catchments	Minimize any further reduction in water yield from overall catchments of all the five sites. In addition, it is a high priority to maintain an adequate buffer around the wetland organic sediment, especially adjacent to the deepest organic sand deposits.	Wetlands dominated by organic sand are considered to generally be strongly dependent on groundwater supplied from its catchment. Wetland organic sand areas are vulnerable to both on-site impacts and impacts arising upstream or from the immediate upslope areas. That much of the deepest organic sand is on the margins of the organic sand deposits highlights their particular vulnerability to impacts from the immediate upslope areas, e.g. from alien invasive plants encroaching into the wetland and land conversion impinging into the wetland.
Where appropriate, include structural interventions to control erosion	Structural intervention would contribute to significantly reducing the risks of future erosion.	The intact area of Onrus Peatland remains on a strong trajectory of degradation, and the advancing erosion threatening to severely degrade this area is on such a major scale that it is now far too late for low-key/bioengineering interventions to halt further degradation. Instead, a major structural intervention will be required, which has been designed by Working for Wetlands.
Implement an appropriate fire management regime	A planned burning regime should be implemented with a burning interval of 12 to 18 years, and preferably avoiding droughts. Following any planned or unplanned burn of the wetland, examine the wetland for any ground fires, and if any are detected urgently contact the local Fire Protection Association to determine the best course of action.	Given its location in mountain fynbos, the Palmietrivier Wetland evolved under a regime of periodic fires and requires fire to maintain its natural composition and structure. Nevertheless, especially where they have been compromised by desiccating anthropogenic impacts, organic sand wetlands with pockets of peat may be very vulnerable to ground fires, especially during drought periods, when the wetlands will be most susceptible to ground fires.
Control cultivation in the wetlands	Prevent any further expansion of cultivation into the wetlands. For the existing cultivated area, e.g. wetlands on the Maputaland Coastal Plain, which has been under cultivation for several decades, promote minimum	As described in the preceding section, cultivation occurs within only one of the wetlands and the extent of this cultivation has not increased for several decades. However, it is recognized that with a shift in the socio-economic situation and attitudes of land-

Goals	Recommendations	Rationale and further notes
	tillage as opposed to conventional tillage, thereby contributing to reduced soil organic matter depletion.	holders, the pressure to cultivate the wetlands in the future may increase greatly.
Control rural development models	Prevent any further expansion or development of housing estates or pockets of residential development within or around the peat wetland areas, within the catchment areas of these systems or within the recharge areas of these systems.	As the available land within the towns becomes less, the development potential is moving towards the outer edged of the rural areas, which pushes heavily on the little and remaining natural corridors and open spaces which are the support areas for our natural systems that provide the important ecosystem services. Development around these green lungs should be minimized as much as possible or it will allow further decrease of water recharge areas and increase the risk of invasive species and risk of fire in the buffer areas.

3.6.1 Recommendations for Refining Wetland Assessments

As previously indicated, Palmietrivier Wetland was sampled more intensively than the other four sites. From the sediments which were collected, good opportunities exist to undertake further analyses beyond that of organic content. These include particle size analysis and pollen-based paleoecology assessment, from which an enhanced understanding of the origin and evolution of the wetland could be derived. Especially through the pollen which they contain, organic sediments are recognized as particularly valuable repositories of information on the history for not only the wetland from which they were sourced but also reflect the past history of the local climate of the general area in which they occur. Further, a pollen-based analysis could be used to infer a more regional palaeo-ecological signature and linked to the on-going archaeological research at Boomplaas Cave (approx. 70 km away).

The results of the assessment show that the occurrence and depth of organic sand can be heterogenous within the same wetland, including: (1) within the same hydrological and/or vegetation zone; (2) down the length of the wetland; and (3) along the lateral profile of the wetland. Therefore, if additional cores could be added to those sampled in the study, a more refined and higher confidence estimate could be made of the carbon stocks in all the respective wetlands. The primary focus of the sample locations in the current assessment was within the intact wetland areas given the need to determine the inherent organic sand quantity for different wetlands. If additional cores were added, it would be useful to include impacted areas to a greater extent to gain an improved understanding of the long-term effects of different anthropogenic factors impacts on organic sand stores. Effects of dense infestations of alien invasive plants would be of particular interest.

4 DISCUSSION AND RECOMMENDATIONS

4.1 RECOMMENDATIONS FOR CONTROLLING PEATLAND FIRES

At the formal stakeholder workshops conducted at the Overstand Municipality and with Ezemvelo KwaZulu-Natal Wildlife, as well as observations at different peat fires across South Africa, certain points were raised concerning the lessons from managing peat fires. These would have aided those who managed the Onrus and Muzi Peatland fires and could aid others in the same situation. Concerns raised include the following:

4.1.1 How to Prevent a Peat Fire?

The water tables of peatlands should not be allowed to drop for extended periods. Peatlands require near constant levels of saturation to form and preserve the accumulated peat. While natural, relatively minor fluctuations in a peatland's water table are common, extended periods of lowered water tables due to anthropogenic modifications make peatlands vulnerable to burning. High water tables present in peatlands act as a natural buffer against subsurface fires and are the reason that peatlands have existed for thousands of years (Joosten & Clarke, 2002).

Peatlands differ from wetlands dominated by mineral soils in that the peat present governs the hydrology of the peatland system and surrounding hillslopes (Joosten, 2016). When peat begins to dry it loses this ability and changes to the peat's hydraulic properties become irreversible. Therefore, peatlands need to be given priority in terms of management interventions regarding site selection for rehabilitation planning.

Regular monitoring of peatlands (and wetlands) needs to be implemented. It is often the case that a small (and relatively cheap) intervention can take place when the onset of degradation begins. If degradation (e.g. an erosion channel) is allowed to expand, the costs of rehabilitation or stopping the degradation from becoming worse can significantly increase.

4.1.2 How to Identify a Peat Fire?

Identifying a peatland begins with the identification of peat. Peat is characterized by its high organic matter content. In South Africa, a soil with an organic matter content of over 30% is classified as peat (Soil Classification Working Group, 2018). A sample of the substrate can be sent to a soil laboratory to test for soil organic matter.

In-field identification of peat is also possible. Peat is generally dark in colour, and in a pristine state, plant remains can be seen with the naked eye. Peat that is more humified/degraded begins to resemble black clay and becomes difficult to distinguish from the latter. One method that can be used is to place a small sample in one's mouth. If the material dissolves it is most likely high in organic matter and if it does not, then it is more likely to be clay. Degraded peatlands can often be identified by the presence of desiccation cracks and a crumbly texture in the upper peat layers.

Peat fires are not always easily identifiable because they can burn below the surface, making their presence unknown. Smoke is most visible in the early hours of the morning and late afternoon but is not always present. Peat fires are often distinguished by a distinctive smell that can be described as burning rotten eggs or coal. The presence of ash is also an indicator (**Figure 4.1**).

Figure 4.1 A burning peatland in the Maputland Coastal Plain *(Photo: Jason le Roux)*.

4.1.3 Make People Aware of a Peat Fire and the Risks Involved

Due to the difficulty in identifying whether a peatland is burning, it is possible that a person or animal may enter a burning peatland, unaware of the subsurface fire. Peat fires often create underground cavities where peat has been burnt that cannot be seen from the surface. These cavities are highly unstable and pose a risk to people falling into them, where the fire could still be active. The unstable nature of these cavities, due to the presence of ash, makes it difficult for a person to get out once they have fallen in. For this reason, the public needs to be made aware of burning peatlands through means such as signboards and other forms of public notifications. The smoke from burning peatlands can be toxic and should therefore be avoided.

4.1.4 Who to Contact if a Peatland is Burning?

The local fire department, fire warden, district and provincial municipality should be made aware of a peat fire. Landowners should ideally be a part of a Fire Protection Association which will assist in combating a peat fire. A peat fire should also be reported to the National Environmental Crimes and Incidents hotline (0800 205 005) or the DWS hotline (0800 200 200).

Further details regarding the management of a peat fire can be obtained from The National Veld and Forest Fire Act (no. 101 of 1998) which explains compliance with environmental requirements as well as for the management of risk to life and property.

4.1.5 Safety Precautions when Entering a Burning Peatland

As mentioned previously, due to the difficulty in identifying whether a peatland or part of a peatland is burning, there is a risk to entering a burning peatland. The Overstrand Fire Department explained that they sent out a scout very early each morning to identify the places where the Onrus Peatland was burning in order to extinguish the fire. They explained that after 9 am, smoke was no longer visible. The scout would then place droppers in the areas where they saw smoke. When entering the burning peatland, the Overstrand Fire Department placed steel sheets on the ash to walk over it, due to the unstable nature of the site.

When one enters a burning peatland, it is useful to take a thin metal rod which can be inserted into the burnt peat to determine whether any subsurface cavities are present. The temperature of the rod can also be felt (with caution) for signs of subsurface burning. Fire resistant clothing (PPE) and respiratory masks should be used when entering a burning peatland. A drone fitted with a thermal sensor is also useful to identify hotspots in the peatland; however, the depth range of the sensor needs to be considered when establishing the presence of subsurface burning.

4.1.6 Extinguishing a Peat Fire

Many peatlands in South Africa eventually stop burning after sustained heavy rainfall events. However, peat fires can often persist through rainfall events as they burn below the surface. If the surface of a peatland is burnt, the residual ash can be compacted by rainfall, thereby forming an impermeable layer to water penetration. For this reason, using high pressure hoses to extinguish peat fires can be ineffectual, as well as compacting unburnt peat, resulting in subsequent erosion, which is what happened in the Onrus Peatland.

The spike tool designed by Mr Michael Bolton from Working on Fire is to date the most effective tool in extinguishing peat fires (**Figure 4.2**). The tool consists of a perforated metal rod attached to a pressured water supply that gets inserted into the burning peat. In this way, water can be supplied to subsurface layers of the burning peatland. Digging trenches around a peat fire, to the depth of the current water table, also serves to stop the spread of the fire. Trenches can be filled with water, sand or chalk (depending on whether sand or chalk occur naturally in the peatland). However, authorization needs to be obtained under section 30 of the National Environmental Management Act (NEMA, no. 107 of 1998).

On a smaller scale, a soil auger (or a metal rod) can be used to make holes in a burning peatland, and water can then be poured into these holes to reach the subsurface layers. This method was used successfully by one of the authors of this report (Mr Jason le Roux) to extinguish a peat fire in the Waterberg Mountains in Limpopo Province.

Figure 4.2 The spike tool designed to extinguish peat fires (Grundling et al., 2019).

4.2 RECOMMENDATIONS FOR THE PREVENTION, MANAGEMENT AND REHABILITATION OF DEGRADED PEATLANDS

From the findings in this report, the following recommendations are made concerning the management of peatlands and peat fires in South Africa, with reference being made to the reported case studies.

4.2.1 Peatlands across South Africa should be identified, and people made aware of them and the Ecosystem Services that they provide through signboards, etc.

If stakeholders are made aware of a peatland's presence and importance (for example, that the Onrus Wetland contained peat and that it was in fact a wetland), peat degradation and fires could be avoided as interventions could take place before the peatland reaches a stage of degradation where it becomes vulnerable to peat fires. At Onrus, once community members became aware of the peatland and its value, their mindset towards stopping further degradation of the peatland changed.

4.2.2 A Directive needs to be put into place with regard to reporting Peat Fires

Whilst it can be argued that a degraded peatland can ecologically benefit from a peat fire, the tipping point where peat becomes degraded to the extent that it has a negative effect on the remaining parts of a peatland has not yet been determined. Furthermore, it is possible that a sudden drop in a peatland's water table (for example, due to an extreme weather event) may expose relatively pristine (undisturbed) peat to the atmosphere where it becomes vulnerable to burning, which will only result in negative effects on the environment. Burning peatlands are also a safety risk to people and animals, due to peat fires being hard to identify and the associated subsurface cavities that people or animals can fall into (**Figure 4.3**) which necessitates warning people about them.

Figure 4.3 Cavities formed due to subsurface burning at the Bergfontein Peatland in the Western Cape *(Photo: Jason le Roux)*. Burning was commonly active in the bottom of the cavities.

In the case of the peat fire in the Muzi Peatland, only when individuals working at the National Department of Environmental Affairs (now DFFE) became aware of the peat fire, did interventions begin to take place to extinguish the fire. At the time of the peat fire, Tembe Elephant Park went through numerous park managers. Some did not attempt to extinguish the fire due to the dangers associated with entering a burning peatland. Others held the view that fire is a natural process and should be allowed to take its course. There was also a reluctancy to report the peat fire due to fears of being held liable for the costs incurred in extinguishing the fire.

4.2.3 Educate Stakeholders about Peat Fires

People need to be educated that degraded peatlands are prone to peat fires, and the dangers associated with burning peatlands. Some of the stakeholders reported that they were laughed at when they told other relevant stakeholders that the ground was burning. The Overstrand Fire Department could not understand why their attempts to extinguish the Onrus Peatland fire using conventional techniques would not work, and wasted a lot of time and effort attempting to extinguish the fire.

In a small peatland known as the Sehlakwane Peatland located in the town of Zaaiplaas in Limpopo Province, community members attributed the subsurface fires to spiritual connotations. However, after a site visit to the burnt peatland by two of the authors of this report (Mr Jason le Roux and Mr Ayabonga Gangathele), they identified numerous boreholes around the peatland which provide water to residents.

If people are aware that peat fires are a reality, and the consequences of not acting sooner, responses could be faster, less peat would burn, and numerous losses could be avoided. Municipalities should therefore be aware of degraded peatlands under their administrative region, and landowners should be aware if they have a peatland on their property.

4.2.4 A Contact List should be made available in the event that a Peatland starts to burn

Comprehensive lists should be made available for the different regions in South Africa containing the contact details of relevant personnel who could assist with managing and extinguishing a peat fire.

4.2.5 Emergency Procedures and Protocols should be put in place

If a peat fire needs to be contained or extinguished, a lot of time can be saved by having emergency procedures in place before the peatland starts burning. These procedures include identifying water sources to extinguish the fire, maps of access roads and potential helicopter landings for external parties. Following the Onrus peat fire, local community members prepared all the above in the event that the peatland burns again.

4.2.6 Peatland Training needs to be made available

Peatland management is a specialized field and not all municipalities, landowners, or even wetland specialists have the knowledge or capacity to identify, let alone manage degraded peatlands. Wetland and peatland training needs to be made available.

4.2.7 Landowner reluctance to mitigate against Environmental Degradation and the need for a simplified version of South Africa's Environmental Law

Landowners often indicated their willingness to mitigate against peatland degradation and other environmental concerns, but find the number of environmental laws, authorizations and administration processes to be quite daunting. As a result, landowners do not understand the laws applicable to them and fear prosecution for implementing illegal mitigation measures, which reduces stakeholder willingness to implement measures to reduce the degradation of a peatland. In addition, landowners are reluctant to ask authorities for help with environmental problems as they fear prosecution if government becomes aware of a problem.

4.2.8 Ecological Reserves of Peatland and Enhanced Catchment-based Water Resource Management

The ecological reserve of a peatland needs to be scientifically calculated, taking the peatland's surrounding land use and groundwater abstractions into account. Management protocols and the ecological reserve should take states of disaster such as drought periods into account. Stakeholders at the Onrus Peatland could not recall water being discharged from the De Bos Dam into the Onrus Peatland during the drought experienced by the Western Cape at the time during the peat fire. Given the state of the Molopo Peatland and the presence of the upstream weir, adherence to the peatland's water requirements are questionable. Ecological reserves also need to be recalculated on a periodic basis following future land use changes, groundwater abstractions and climatic cycles. In the case of the burning peatlands of the Maputaland Coastal Plain, water use licences for land uses such as forestry should be examined based on the ecological reserve required for peatlands to remain saturated.

At the stakeholder workshop for the Onrus Peatland it was reported that after new boreholes were sunk in the area, many farmers noticed an immediate drop in the water levels on their properties. This indicates that groundwater allocations may be incorrectly determined and therefore require attention. Catchment management agencies need to inspect borehole abstractions and intervene against illegal groundwater abstractions. The dam also needs to be monitored to determine whether it adheres to maintaining the ecological reserve.

4.2.9 Government should aid Mitigation against Environmental Problems before they escalate, and work towards Positive Engagement with Landowners

With regard to the Onrus Peatland, if the alien invasive trees, the correct determination and adherence to the ecological reserve of the upstream dam, and the erosion in the peatland had been mitigated before the peat fire started, it could have been prevented. This would have avoided the financial losses incurred by nearby landowners. Once a positive relationship was established between the landowners and the local municipality, stakeholders began to work together to solve the environmental problems after realising who can contribute towards different aspects of extinguishing the fire.

Many landowners do not have the financial means to eradicate alien invasive plants from their properties. Whilst it is often possible to cut down invasive trees, it is the removal of those trees from the property that becomes a costly exercise. Unless a catchment-based alien invasive control plan is established, removing invasive plants from a downstream property will have little effect in the long run, as new seeds will simply wash down and establish on the newly cleared land. Government needs to become involved through providing a catchment-based management solution, and to provide resources to landowners who cannot afford to remove alien invasive species. The same principles apply to mitigating against erosion.

4.2.10 Environmental Degradation does not wait for Rehabilitation Measures

It has been three years since the peat fire at the Onrus Peatland and no rehabilitation has occurred. Bank collapses of peat in erosion channels and headward migration continue to negatively affect the peatland, through draining and the loss of peat due to erosion. This also makes the peatland prone to experiencing subsurface fires once again.

If small-scale interventions had taken place immediately after the fire, some of the degradation could have been halted. Whilst small-scale interventions would most likely not have lasted the test of time, it would have been better than nothing.

4.2.11 Those responsible for Environmental Problems should be held accountable

Just because there is erosion or alien invasive plants on a landowner's or municipality's land does not mean that the respective landowner caused the problem. Erosion could be the result of increased water flow from an upstream piece of land, and alien invasives could have washed downstream from another property. Landowners should not be held accountable for environmental problems on their property if they are not directly responsible for the causes.

4.2.12 Should valuable Watercourses belong to private individuals?

There were split opinions whether valuable watercourses such as the Onrus Peatland should belong to private individuals. Those who expressed that they should be in the custodian of the state explained that they are too valuable to belong to private individuals, and that watercourses are connected regardless of landownership boundaries which would enhance holistic watercourse catchment management. On the other hand, stakeholders who were in favour of valuable watercourses belonging to private landowners explained that they want to look after their watercourses, but that they need government's assistance with regard to education as to how to manage these ecosystems, and to provide financial assistance where necessary.

4.2.13 People need to be educated on Emergency Environmental Impact Assessment needs

The Overstand Municipality needed to figure out how an Emergency Environmental Impact Assessment works as they had never previously completed one. They also needed to guide the landowner in completing it. Valuable time was lost due to this.

4.3 PROTOCOLS FOR THE PREVENTION, MANAGEMENT AND REHABILITATION OF DEGRADED PEATLANDS AS WELL AS FOR CONTROLLING PEAT FIRES

The third aim of this project was to develop draft protocols for the prevention, management and rehabilitation of degraded peatlands, as well as for controlling peat fires. Based on the findings from this research project, as well as the collective experience of the project team, two draft frameworks were developed which may be used as protocols by regulators (i.e. mandated authorities), managers, landowners or communities to prevent peatland degradation (Framework 1, **Figure 4.4**) and for controlling peat fires (Framework 2, **Figure 4.5**). These frameworks are in “decision tree” format.

Given the short duration of this project, the frameworks are presented as drafts and we propose that they should be further workshopped with key stakeholders for refinement and finalization in a follow-up project. We recommend that one key stakeholder group could be the Department of Water and Sanitation and another could be the Department of Forestry, Fisheries and the Environment.

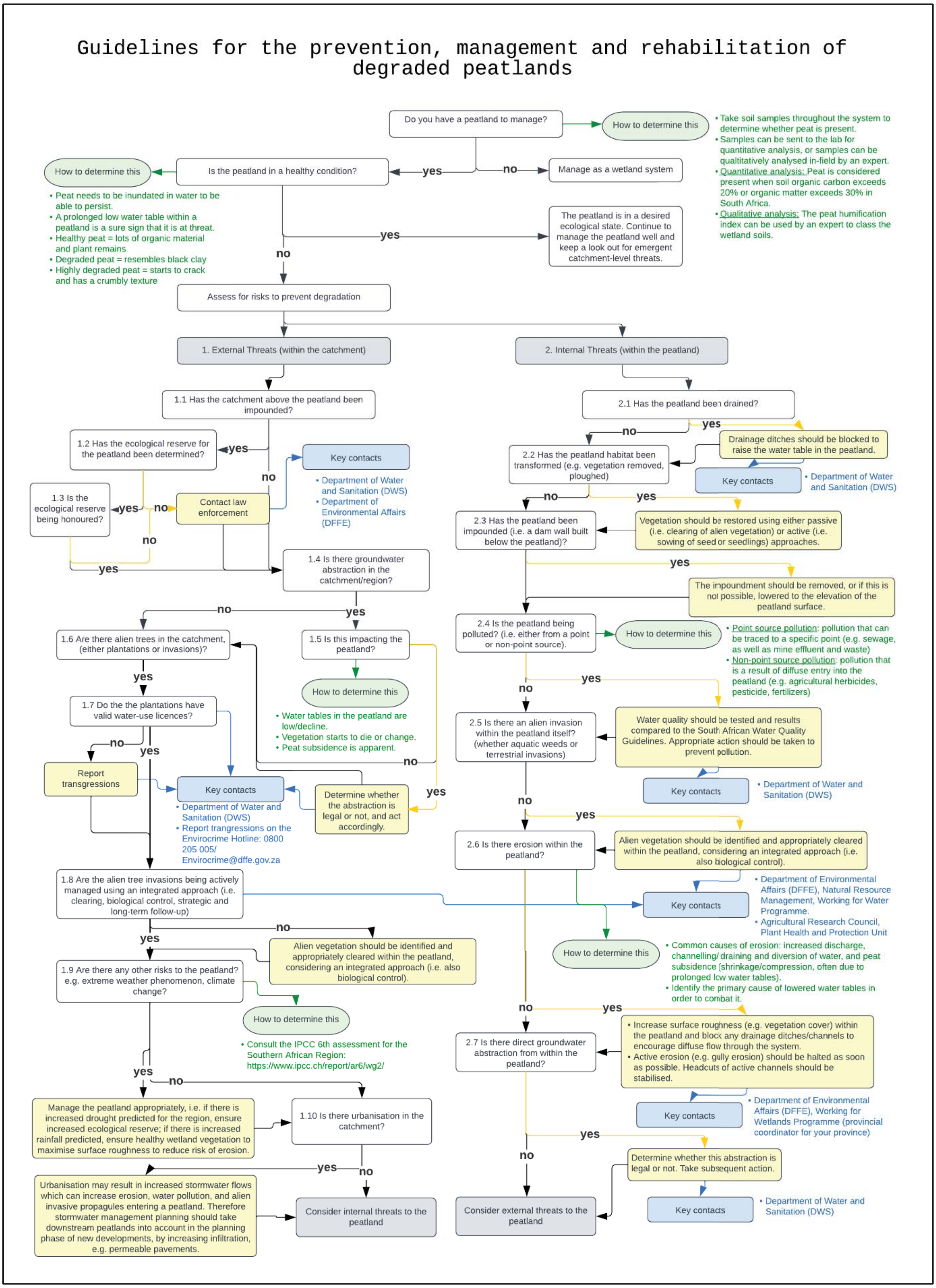


Figure 4.4 Draft framework with protocols for the prevention, management and rehabilitation of degraded peatlands.

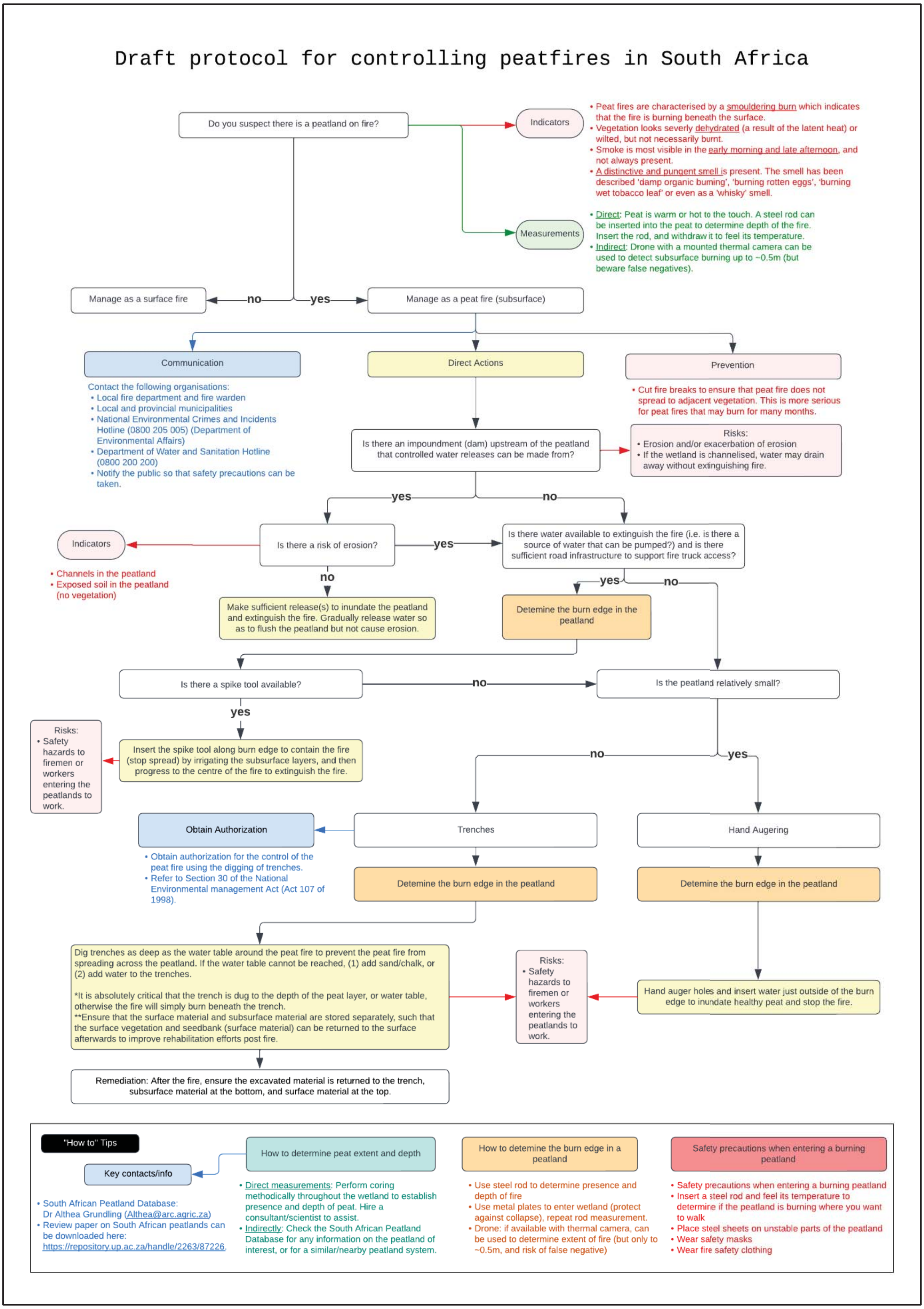


Figure 4.5 Draft protocol for controlling peat fires.

5 CONCLUSION

This research project was aimed at, firstly, estimating the potential peat lost in selected peatlands; secondly, identifying ecosystem services lost through fire and desiccation and the impacts thereof to local communities; and lastly, developing draft protocols for the prevention, management and rehabilitation of degraded peatlands. The study demonstrated the application of a systematic approach, beginning with a catchment/landscape-scale and the land use/cover change detection from 1994 to 2022.

The results showed that the city of Mahikeng (and surrounds) in North West Province grew by 121.41 km^2 over 26 years, which increased the demand for water, hence the diversion of water resources to Mahikeng and cascading the degradation and subsequent burning of the Molopo Peatland. For the Onrus Peatland in the Western Cape there was a steady increase in catchment NDVI from 2000 to 2021, which indicates that with the building of the De Bos Dam in 1977, irrigation of the catchment above the dam became feasible, resulting in an increase in catchment NDVI over the specified time.

On the Maputaland Coastal Plain in KZN the land use/cover comparison from 1994 to 2022 shows a decrease in wetland extent and cultivated area and an increase in the forested plantations impacting on the primary aquifer. The increase in forested plantations is not reflected in the land cover classes as it forms part of the natural forest class. The land use/cover changes over the 26-year period indicate that there was a decrease in the natural forests and wetland area with an increase in barren land and grasslands. This increase was brought about by a decline in wetlands, leading to a change in land cover with some wetlands left bare and some taken over by *Cynodon dactylon* (such is the case with the burnt section of the Muzi Peatland), making them fall under the class of grasslands.

These changes in land use in the respective catchments have had direct impacts on the hydrology of the catchments and peatlands. When the hydrology is changed (e.g. interruption of flow through abstraction, diversion, impoundments, drainage and erosion), the negative impacts cause the degradation of peatlands (i.e. erosion and fires), resulting in the loss of various ecosystem services to the communities that were previously provided by the peatlands. Based on the assessment of the three case studies, the ecosystem services lost include “a sense of place”, clean water (water storage), vegetation cover and biodiversity, as well as the amount of peat that was lost through erosion and fire, thereby emitting carbon to the atmosphere and contributing to climate change.

A substantial amount of peat was lost in the three case study sites through erosion, desiccation and fire, with the Molopo Peatland having the highest estimated value (344 437.5 m^3). There is currently little to no peat left in the Molopo Peatland with evidence suggesting that about 1.67 m of peat has been lost from the system. The Vasi Peatland is estimated to have lost the second largest quantity of peat (129 094 m^3), indicating severe degradation of the peatland system with the continued land use changes to the catchment. The Onrus Peatland has some peat remaining following the peat fire in 2019, after which approximately 12 571 m^3 of peat was lost from the study area.

As a peatland degrades, the structure and functioning of the peat changes, bringing about changes in the hydrology of the system. A healthy peatland can shrink and lower its surface elevation and adjust to a lower than average water table, which maintains the peat’s structure and functioning. When the water table drops beyond the peat’s ability to self-regulate and becomes exposed to oxygen, the structure of the peat changes, thus changing the hydrology of the wetland. The changes in land use in all three case studies have brought about lowering of the water table which has changed the hydrology of these systems.

The Molopo Peatland has little subsurface water flowing to the desiccation of the peat that remains in the system, allowing water movement through the sand and gravel matrix. As such, the water that reaches the peatland from the weir flows on the surface, increasing the erosion that the system is exposed to. The Onrus Peatland is a groundwater recharge point dependent on the surface water supply from the De Bos Dam as well as hillslope contribution. This makes this system highly susceptible to further erosion and desiccation as the groundwater table lies significantly below the surface. The Muzi Peatland showed some groundwater discharge from the western dune, feeding into the peatland. The water table lies below the peat surface for most of the monitoring points but shows positive input from the groundwater. The lowest water levels in the Muzi and Vasi Peatlands were observed in spring, which is also the same time that the Vasi Peatland experienced a peat fire. This signifies severe reliance on groundwater in the catchment as this is the driest time of year in the area, leading the local communities to exhaust the groundwater resources. The changes in the peat properties brought about by desiccation and fire create a positive feedback loop which increases the system's vulnerability to peat fires.

The communities that surround these peatland systems are most affected by their degradation and burning. The degradation of the Molopo Peatland not only posed risks for the flora and fauna that inhabit the peatland, but the residents of the Molopo Private Park as well. The impacts of the peat fire were not limited to the physical danger posed by the fire, but also the dangers of smoke inhalation. Furthermore, the burning of the peatland affected the market value of the properties in the park, while the change in physical appearance changed the perception of many residents about the area such that most people sold their properties and moved elsewhere. The current residents of the park are hopeful that the system will be rehabilitated and return to its former glory, especially now that it is inundated with water once again.

The residents around the Onrus Peatland were also severely affected by the peat fire and the residents of Camphill Farm had to be temporarily relocated as they were experiencing respiratory problems after inhaling smoke from the fire. This relocation greatly affected many of the Camphill residents as it is a care facility and school for intellectually disabled adults and children, who tend to be negatively affected by abrupt changes. The peat fire in the Muzi Peatland threatened the livelihood of the reed cutters as many of them stated that their primary source of income was from reed sales. Many of the reed cutters actively practised reed harvesting during the peat fire, risking their lives in the process.

To further understand how palmiet systems such as the Onrus Peatland work, the Palmietrivier Wetland was studied to see how it functions compared to the Onrus Peatland and make recommendations for management interventions for the different types of palmiet wetlands in the Western Cape. The assessment results provide a defensible basis for directing the attention and resources of managers to where the greatest benefits can be leveraged in terms of risk reduction and the resulting increased long-term resilience of the peatlands and palmiet wetlands with organic sands. This, at its core, is a pre-emptive management/rehabilitation approach, which the project demonstrates in a practical way, supported by the *in situ* peat core and water table measurements that helped us to understand the peat characteristics and hydrology of the sites rather than just as a theoretical concept and desktop analysis.

The results of this research project assist not only in the management and rehabilitation of the peatland systems but also add to the national peatland protocol on lessons learned from the different case studies and the socio-economic impact the peat fires had on the communities who depend on the peatlands for ecosystem services.

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APPENDICES

Appendix 1: Technology Transfer

Conferences:

Mr Jason le Roux and Mr Ayabonga Gangathele presented at the **Society of South African Geographers (SSAG) & Southern African Association of Geomorphologists (SAAG) 2021 Joint Biennial Conference** online (6-8 September 2021) and at the **Land Rehabilitation Society of Southern Africa (LaRSSA) Conference** (14-15 September 2021):

- Mr Gangathele presented an oral and poster presentation on "*Peatland response to degradation: A case of Kgaswane Mountain Reserve*" at SAAG and LaRSSA respectively.
- Mr le Roux presented an oral presentation at SAAG on *"Changing weather, a trigger for peat weathering?"*.
- Mr le Roux presented an oral presentation at LaRSSA on "*The restoration of burnt peatlands: Lessons to be learnt concerning potholes, sinkholes and ash holes"*.

Mr le Roux and Mr Gangathele were invited to make a presentation at the **50th celebration of the WRC** on 20 September 2021 on the socio-economic aspects of peat fires.

Four presentations were given at the **National Wetlands Indaba 2021** held online on 20-21 October 2021:

- Mr Ayabonga Gangathele presented an oral presentation on "*Socio-economic impacts of peat fires: A case of Molopo Peatland and Muzi Peatland"* and won the award for Best Student Presentation.
- Mr Jason Le Roux presented an oral presentation on "*Towards understanding the hydrology and hydrodymanics of the Muzi peatland*".
- Dr Althea Grundling presented an oral presentation on "*Pressures and protection of South African peatlands – Situation analysis South Africa*".
- Dr Althea Grundling also co-authored two other presentations:
    - "*Integrated monitoring framework for peatland degradation: Peat fire susceptibility*".
    - "*Peatland hydrological processes in Malolotja Nature Reserve, Eswatini*".

Presentations were given at the **International Mire Conservation Groups Field symposium** held in March 2022 at the Marakele Nature Researve, Thabazimbi.

Two presentations were made at the North West Parks Board Scientific Conference held on 19-20 September 2022.

Four presentations were made at the **National Wetlands Indaba 2022** held at Golden Gate Highlands National Park from 24-27 October 2022 and three prizes were won by the students:

- **Oral Presentation** – "*Management of Palmiet wetland types in South Africa*" by Althea Grundling, Donovan Kotze, Piet-Louis Grundling, Jason le Roux and Ts'epo Sekaleli.
- **Best Student Paper Presentation at the National Wetland Indaba 2022** – **Mr Ayabonga Gangathele** – "*Gully erosion impact on selected peat properties: A case study of the Waterkloofspruit peatland in Kgaswane Mountain Reserve*" by Ayabonga Gangathele, Althea Grundling, Piet-Louis Grundling and Jay le Roux.
- **Follow-up Best Student Paper Presentation at the National Wetland Indaba 2022** – **Mr Jason le Roux** – "*The patterns of degradation and recovery at the Vasi peatland*" by Jason le Roux, Althea Grundling and Piet-Louis Grundling.
- **Best Student Poster at the National Wetland Indaba 2022** – **Ms Rebecca Stephenson** – "*Hydrology and Peat Characteristics of the degraded Onrus Peatland, Western Cape, South Africa*" by Rebecca Stephenson, Althea Grundling, Suzanne Grenfell, Lesley Gibson, Jason le Roux and Piet-Louis Grundling.

Mr Ayabonga Gangathele receiving prize for best student paper presentation from Mr Bonani Madikizela (WRC).

Mr Jason le Roux won follow-up prize for best student paper presentation. All students mentored by Dr Althea Grundling.

Ms Rebecca Stephenson receiving prize from Mr Umesh Bahadur (DFFE, Working for Wetlands)

Ezemvelo KwaZulu-Natal Wildlife Scientific Conference in November 2022 – Presentation by Mr Jason le Roux.

Combined Congress 2023 held at University of Pretoria from 23-26 January 2023 – Presentation by Dr Althea Grundling, Mr Jason le Roux, Mr Ayabonga Gangathele, Dr Piet-Louis Grundling, Mr Donovan Kotze, Ms Rebecca Stephenson and Dr Alanna Rebelo on "*Management and rehabilitation of peatlands in South Africa*".

Overstrand Environment Conference on 16 February 2023 – Presentation by Dr Althea Grundling, sharing research results from the study to various stakeholders in the Hemel-en-Aarde Valley.

The Western Cape Wetlands Forum hosted a **World Wetlands Day** event at the Onrus Peatland on 18 February 2023. During this event, Dr Althea Grundling and Ms Rebecca Stephenson spoke to the attendees on various aspects of peatlands and groundwater monitoring.

Publications:

Grundling P, Grundling AT, Van Deventer H & Le Roux JP (2021). Current state, pressures and protection of South African peatlands. *Mires and Peat* 27 (26): 1-25; doi: 10.19189/MaP.2020.OMB.StA.2125

Le Roux JP, Gangathele AM, Hanekom C & Grundling AT (2021). The Muzi peatland reed cutters and their perspectives on a subsurface peat fire. *The Water Wheel* 20(1): 36-39.

Appendix 2: Capacity Building

South African students that form part of the project team

No	Name	University	Department	Degree	Student No	Start	End
1	Mr Jason le Roux	University of the Free State	Centre for Environmental Management Faculty: Natural and Agricultural Sciences	PhD	0886270	Jan 2021	Dec 2023
2	Mr Ayabonga Gangathele	University of the Free State	Geography	MSc	2015230432	Jan 2020	March 2023
3	Ms Rebecca Stephenson	Stellenbosch University	Geography and Environmental Studies	MSc	26776537	Jan 2022	Dec 2023

Community/Institutional Empowerment:

- ☐ **WC Field trip 22 Oct 2021 (Onrus Peatland)**

Dr Lesley Gibson attended a field excursion to the Onrus Peatland as part of the National Wetlands Indaba post-conference excursions.

- ☐ **NW Field trip 22-24 Oct 2021 (Molopo and Molemane Peatlands)**

Specific examples of stakeholder engagements conducted by the ARC project team (Dr Althea Grundling and Mr Jason le Roux) to disseminate information, train and build capacity regarding wetlands and peatlands in the North West Province as part of the National Wetlands Indaba post-conference excursions.

- ☐ **WC Training and Survey 29 Nov-1 Dec 2021 (Onrus Peatland)**

Peat training for the Overstrand Municipality officials and peat survey conducted at the Onrus Peatland.

- ☐ **KZN Workshop 7 April 2022 (Muzi Peatland)**

Mr Jason le Roux shared his research findings with Ezemvelo KZN Wildlife officials and discussed the management implications for the Muzi Peatland (Muzi Swamp Management: reed harvesting, fire prevention).

- ☐ **Limpopo 16 Aug 2022 (Sehlakwane Peat Fire)**

Mr Jason le Roux (PhD student), Mr Ayabonga Gangathele (MSc student) and Ms Koketso Madimabe (PhD student) presented at a **wetland awareness and training campaign** at the Zaaiplaas Peatland in Limpopo. Their talks aimed at educating the local municipality about peatland functioning and the implications of degradation for this peatland. Mr le Roux also took part in a tree planting ceremony. The event was attended by more than **140 people**. The community has livestock owners that utilize the wetland for grazing and water.