Queen Elizabeth Park peatland survey

David McQueen
Environmental Science Department

For more information, contact the Greater Wellington Regional Council:

Wellington
PO Box 11646

T 04 384 5708
F 04 385 6960
www.gw.govt.nz

Masterton
PO Box 41

T 06 378 2484
F 06 378 2146
www.gw.govt.nz

GW/ESCI-G-21/36

January 2022

www.gw.govt.nz
info@gw.govt.nz

Report prepared by:	D McQueen	Environmental Monitoring Officer	
Report reviewed by:	P Crisp	Team Leader, Land, Ecology and Climate	
Report approved for release by:	L Baker	Manager, Environmental Science	**Date**: January 2022

The report may be cited as: McQueen D. 2021. Queen Elizabeth Park peatland survey. GW/ESCI-G-21/36

Summary

The key objective of this survey was to map the areal extent and volume of peat within the largest peat area in Queen Elizabeth Regional Park. The condition of the peat soils and the degree of changes that have occurred since the modification of the land for agriculture were examined to address concerns about the potential to successfully return the peatland to a functional wetland ecosystem. The peat deposits detailed in this report were contained within Queen Elizabeth Park, a Regional Park on the Kapiti Coast, administrated by Greater Wellington Regional Council. The peat deposits lie between Paekakariki and Raumati South, bounded on the east by State Highway 1 and the Main Trunk railway line, and bounded on the west by sand dunes laid down during the Holocene epoch which have migrated inland following the marine regression post 6,500 BP.

The areal extent and depth of the peat deposits were assessed by probing at 100 m intervals on a rectangular grid sampled across an area previously mapped as containing peat. Soil characteristics were noted at each point and specific sites were revisited for soil physical and chemical sampling, and to describe the soil profile. Soils were subsequently classified and mapped. Acid Mesic and Mellow Humic Organic soils were mapped interspersed with the peat soils, while buried peat and Hydric Soils (imperfectly drained soils capable of supporting wetland vegetation) were identified adjacent to the peat soils. Extensive areas of woody peat were encountered in the northern section of the peatland suggesting the presence of an ancient swamp forest at one stage.

The organic soils, including the peat soils, were found to have been modified, with the depths to the water table being in excess of 800 mm in parts of the peatland during summer. Modifications included: increased bulk density due to consolidation, oxidation of organic matter, and changes in pore size distribution. These modifications could lead to less plant-available water storage in the upper soil horizons, lower water contents throughout the soil profile, and increased soil strength. Soil fertility and pH were higher than for undisturbed peatlands, which could adversely affect the growth of native wetland species.

The organic soils were deeper, less decomposed and less modified in the northern end of the peat deposits. Overall, the organic soils have reacted to modification, becoming more robust and resistant to further change, which has perhaps slowed further decomposition. The effects of modification were concentrated at relatively shallow depths, meaning that plants were still able to access deeper, less disturbed peat soil horizons.

Soil water table solutions differed across the peatland, with higher nutrient concentrations on the peatland boundary, declining into the centre of the peatland. As with the soil structure, the soil water table solutions at the northern end of the peat deposits showed less modification. Minimising the addition of nutrient-enhanced water would increase the range of wetland species that could be reintroduced.

Based on the state of the peat deposits, raising the water table and appropriate planting should allow for the successful rehabilitation of the Queen Elizabeth Peatland. This could allow modifications of the soil properties to be reverted and prevent the continuing decomposition of the peat deposits that is releasing greenhouse gases into the atmosphere. Furthermore, it is anticipated that rehabilitation of the peatland could lead to the renewed accumulation of organic matter. Consequently, it is recommended that the soil evolution and carbon sequestration be monitored along with the biodiversity to quantify the value of the rehabilitation programme.

Contents

1. Introduction

A survey of the major peatlands in Queen Elizabeth Park, Kapiti Coast was conducted in February 2020 to provide information for a restoration project that aimed to rehabilitate the peatland to restore its natural biodiversity and function. To achieve this a number of factors need to be considered, including:

- The growth media for wetland plants (including soil, water and other plant substrates).
- The hydrological regime required to facilitate the growth of wetland plants.
- Control of pest plants and animals.
- Re-introduction of desirable plants and animals where these are not able to reoccupy the restored environment without assistance.

The aim of this study was to investigate the state of the growth media, particularly the soil, to support wetland plants in the areas with peat soils and to assess its potential to support the restoration of the wetland's biodiversity. This was prompted by decades of modification of the peat soils by burning, drainage and vegetation management. Restoring the function of the peatland was also seen as an opportunity to address the potential for further loss of the stored soil organic carbon and to encourage renewed carbon sequestration. This required the baseline measurement of the areal extent and volume of peat.

2. Background

2.1 Peatland soils

Peat soils, which make up the vast majority of the area surveyed, are important plant growth media. They can retain large amounts of water and organic matter and are valuable but also vulnerable resources. Issues that need to be considered include:

- the possibility of irreversible drying i.e. water repellency,
- changes to soil pore size-distribution and water availability (as the volume of soil available to store water can have implications for the soil water balance and water deficits in organic soils),
- changes in soil hydraulic conductivity (which may have implications for drainage rates in the peatland), and
- the degree of nutrient availability and pH changes (which have implications for competiveness of wetland species and biodiversity).

2.2 Soil development

Peat soils develop when the rate of organic matter accumulation exceeds the rate of decomposition by oxidation. Inundating a soil with water reduces the availability of atmospheric oxygen to support oxidation. Assisted by acidic conditions, vegetation deposited into peatlands resists decay, so accumulating peat deposits. When peatlands are drained, the rate of oxidation typically rises to exceed the rate of organic matter accumulation and their soils become modified. Likewise, if the contribution of the vegetation to the organic component of the soil is reduced, as typically happens with the conversion of peatlands to grazing lands, the rate of oxidation can also exceed the rate of organic matter accumulation. The peatland at Queen Elizabeth Regional Park has been both drained and converted to grazing, so impacting on the peat forming processes.

When considering the appropriate interventions for rehabilitation it is important to understand the type of wetland. Each wetland type exists within different sets of environmental parameters, supporting different species assemblages that work together with the climate to determine the rate of organic matter accumulation. Peatlands typically occur in bogs, fens and swamps. Bogs are characterised by the water supply coming predominantly from rainfall, but at the margins there may be influence of runoff and groundwater. Fens receive their main water supply from rainfall, groundwater and seepage from adjacent hillslopes. Swamps receive some water from rainfall, but most comes from surface and groundwater. These different water sources and flow rates influence the nutrient status and pH of the various wetland types. Bogs typically have the lowest productivity, but accumulate the highest proportion of organic matter due to higher stable water tables and acidic conditions which, along with humic acids and phenolic compounds, inhibit the rate of decomposition. In contrast, swamps have higher nutrient inputs, higher productivity, less stable water tables and more basic conditions leading to lower rates of organic matter accumulation (Johnson and Gerbeaux

2004**).** Consequently, it is important to understand the type of wetland as this will influence its restoration approach.

2.3 Soil deterioration

Peat soils are complex porous media with some pores not contributing to water and solute flow. The normal soil physical relationships between porosity and conductivity may not apply in peat soils, as horizontal conductivity may be higher than vertical leading to anisotropy (Rezanezhad et al 2016). As peat degrades, the pore size distribution also may shift to smaller pores further reducing lateral water movement, so acting as a stabilising element in reducing drainage rates so that drains may not be effective over long distances. However lower water tables lead to greater aeration resulting in greater peat degradation and reduction in peat surface elevation. Countering this is the capillary rise phenomenon where a soil moisture matric potential gradient can result in upward transport of soil water under slightly non-saturated conditions which can result in reduced opportunity for drying and oxidation.

Subsidence of the peat surface may also be the result of densification as a result of wetting and drying cycles. This increase in bulk density needs to be taken into account when carbon storage balances are made, as carbon needs to be accounted for on a mass per volume basis or mass per area basis. Peat decomposition and mineralisation resulting from drainage and fires release nutrients which may lead to new species such as introduced plants being more competitive in the peatland. Peat subsidence has been studied extensively in New Zealand with a study published by Pronger et al (2014) concentrating on peatland in the Waikato region. Rates of 19 mm per year were recorded which were significantly lower than initial rates. For optimum pasture production without excessive shrinkage, Bowler (1980) advocated maintaining the water table at 450mm but noted that water table depths below 300-500mm increased subsidence markedly.

2.4 Peatland restoration

In order to restore a wetland to as much as possible to original condition, a number of factors need to be considered as mentioned in the introduction. These include soils, water, wetland vegetation requirements and the hydrological regime. Techniques to achieve restoration in peatlands degraded by drainage often begin with blocking drains to reduce water flow out of the peatland. Nutrient availability may have increased due to mineralisation and farming practices. However retirement from agriculture and increased wetness should help stabilise these levels. Inflow of nutrients from surrounding land sources may result in continued nutrient input and diversion of these sources may be need as part of the restoration programme. It may not be possible to fully restore the peatland back to its original condition due to some of the factors mentioned above. However establishing a fully functional peatland with active peat formation and sequestering of carbon and establishment of wetland species is the ultimate goal of a restoration programme.

2.5 Previous studies

The major previous study of the peatlands in the eastern side of Queen Elizabeth Park was carried out by Neville Moar in 1951 (Moar 1954) A more general survey of areas to the north of the study area (Moar 1952) was carried out at the same time. Moar (1954) reported that the peatlands in what is now Queen Elizabeth Park had been heavily modified by farming activities including: burning, stump removal, drainage and vegetation modification. Farming in the Whareroa area began in the mid nineteenth century and has continued ever since that time. However by 1951, the drainage system in the northern part of the peatland was not maintained and areas were dominated by manuka with bracken in drier areas. In the southern section, introduced pasture grasses were more common.

Moar conducted a series of peat corings from the northern to the southern end of the peatland and found that peat bodies were dominated by woody vegetation including swamp forest species overlying sedge components near the base of the peat profile. He found that peat depths were shallower south of Whareroa Stream, North Branch and that woody peat was not common in this southern section. The pollen samples collected at the same time have been recently analysed by Wilmeshurst and Bolstridge (2019) and provide a comprehensive picture of forest and wetland specialist plants including *Sphagnum* and *Cyperaceae* species.

2.6 Location

The study area is located within Queen Elizabeth Regional Park with the area bounded by the Kapiti Expressway on the east and coastal sand dunes on the west. It extends from Mackays Crossing in the south to Poplar Avenue in Raumati South in the north. It is the largest contiguous area of peatland in the park. The area in question extends west from the coastal cliffs last developed at the end of the marine transgression 6500 years BP to the present day dune system behind the current coastline. During the marine transgression, wave energy eroded the coastline forming a sea cliff. This sea cliff provides a marker line, against which the late Holocene sediments of the coast have accumulated. Indications are that there has been uplift during the Holocene at the southern end as evidenced by the Te Pari Pari cliffs and subsidence north at Peka Peka area (McFadgen 2010) with little change at Paraparumu Airport. The peatland area would have been therefore subject to some uplift. A tsunami may have affected the area in the 15th century and pumice deposits which occur in the area may be from Taupo 1764 BP (Before Present) or Waimihia eruption 3550 BP, both from the Taupo volcanic centre. Coastal dunes developed after the marine transgression and a series of dune systems moved inland until they stabilised leaving a low lying area between the dunes and the coastal cliffs where peat could accumulate. Wood fibres from Wainui Stream to the south of the peatland area were dated 2337 ± 22 BP. (Fleming 1972). The Ohariu fault runs through area with the last movement in 1050-1000 BP with return period of 6,500 years.

2.7 Topography

The elevation of the peatland area between seven to five meter contours in metres above mean sea level is shown in Figure 2.1. There is a very gradual decline from north to the stream running east to west that bisects the peatland. This stream which has been channelized takes water from across the Kapiti Expressway and Waterfall Road Catchment and is often referred to as Waterfall Stream. However it is also referred to as Whareroa Stream and has been gazetted as such. In the southern part of the peatland there is a slight rise in elevation, but at the western edge there are areas below 4.5m above mean sea level (asml). The major drainage channel here on the western side is also referred to as Whareroa Stream. To clarify nomenclature the report will refer to the major watercourses as Whareroa Stream North Branch and Whareroa Stream South Branch.

In Figure 2.1, the elevation of surface of land is given in metres above mean sea level (amsl), while major streams and drainage ditches are shown in blue. Whareroa Stream North Branch is the channelized watercourse running east-west in the centre of the figure from Waterfall Road to the confluence with Whareroa Stream South Branch which is the major south-western watercourse. A DEM (Digital elevation Model) was used to generate relief profiles of the peatland surface. Profiles from the DEM of QE Park with locations are shown in Figure 2.2. The lines of the profile are shown in black on the map and the longitudinal elevation profiles detailed in Figures 2.3, 2.4, 2.5 and 2.6. What is noticeable is the relative lack of variation in elevation. Most of the major changes are cultural features i.e. drains and causeways. There is a decline south of the North Branch of Whareroa Stream but this is soon restored to the previous elevation (Figure 2.3).

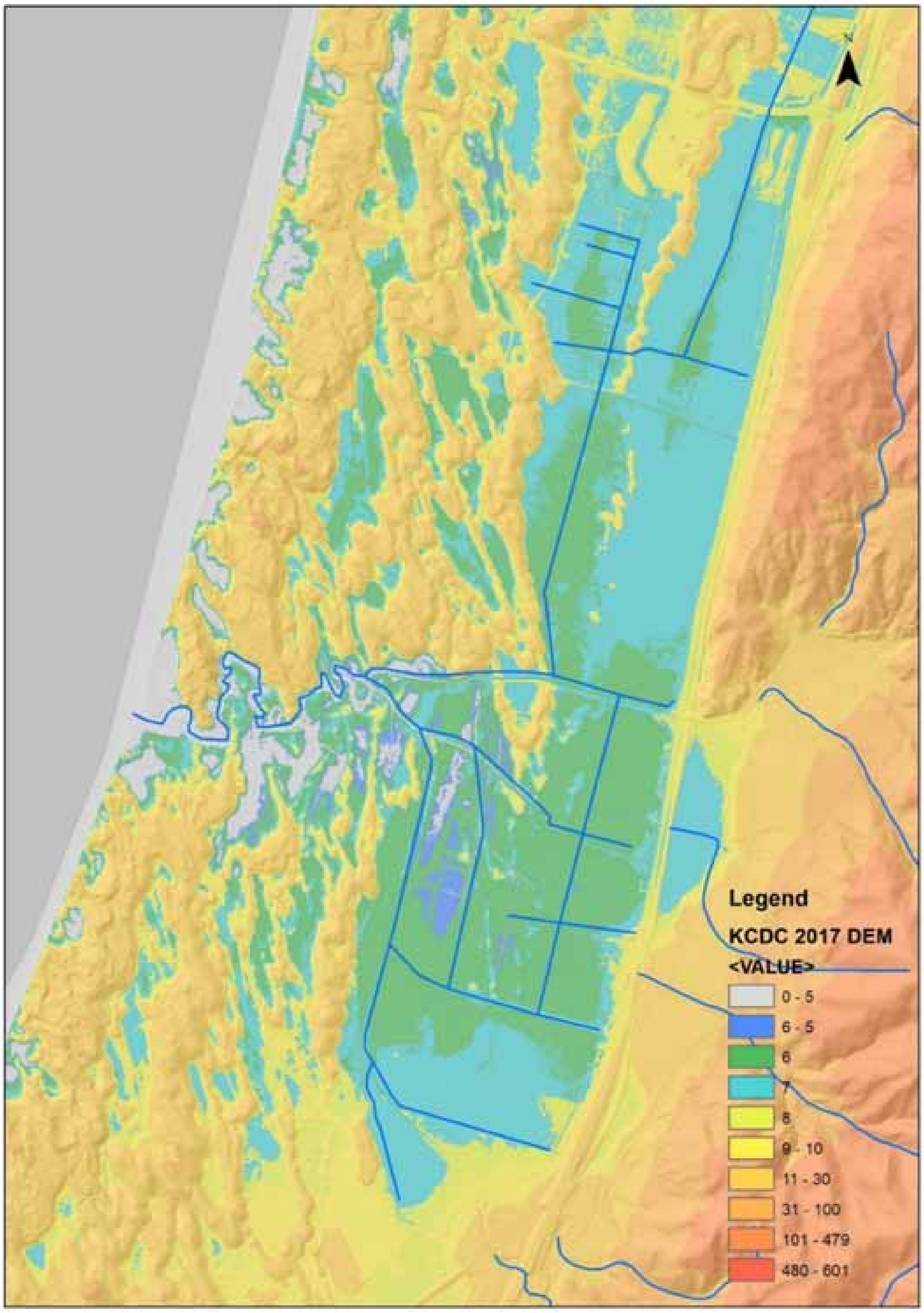

Figure 2.1: Topography of a section of Queen Elizabeth Regional Park which includes the peatland

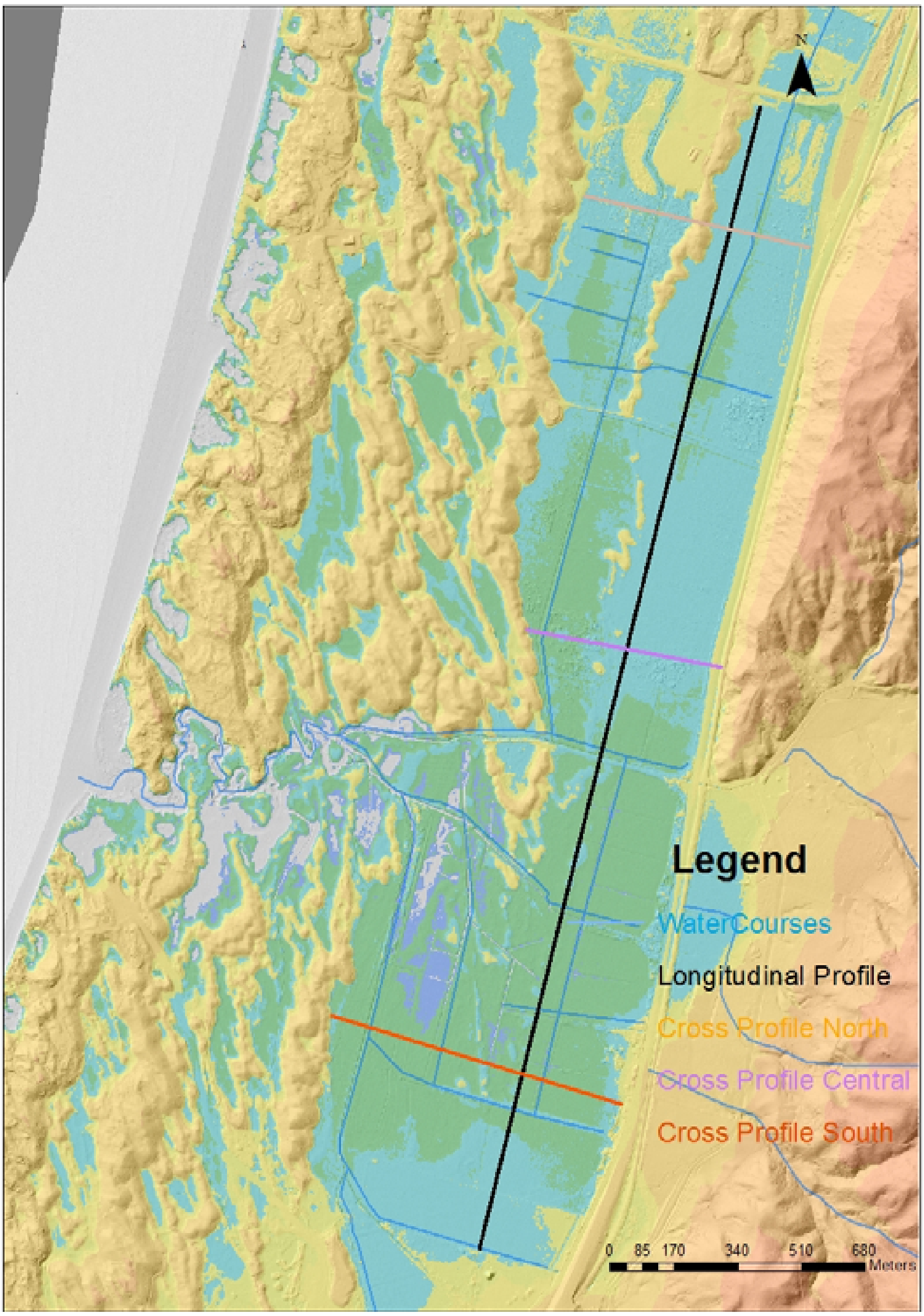

Figure 2.2: Relief profile locations Queen Elizabeth Regional Park derived from digital elevation model (DEM)

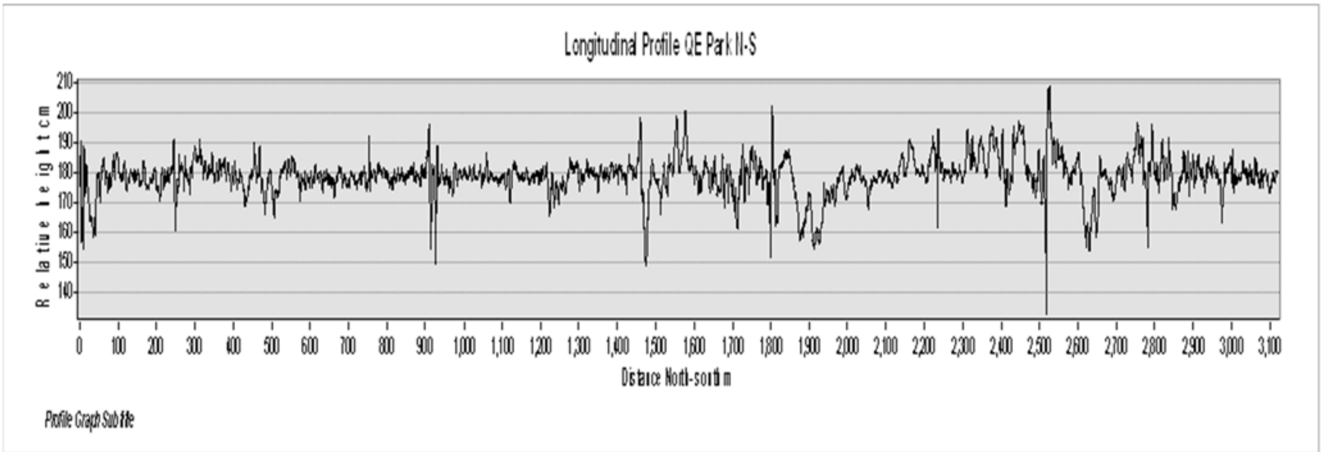

Figure 2.3: Longitudinal elevation profile of Queen Elizabeth Regional Park peatland, horizontal units in metres. Relative elevation is in cm.

There is little more variation in the western peatland before the sand ridge at 300-320m (Figure 2.4). East of that feature, the main changes are due to drains. There is very little variation in the central zone (Figure 2.5). A deeper drain feature is noted at the western end and then little change until the edge of the expressway in the east is reached. A similar pattern was found in the southern Cross Profile, (Figure 2.6).

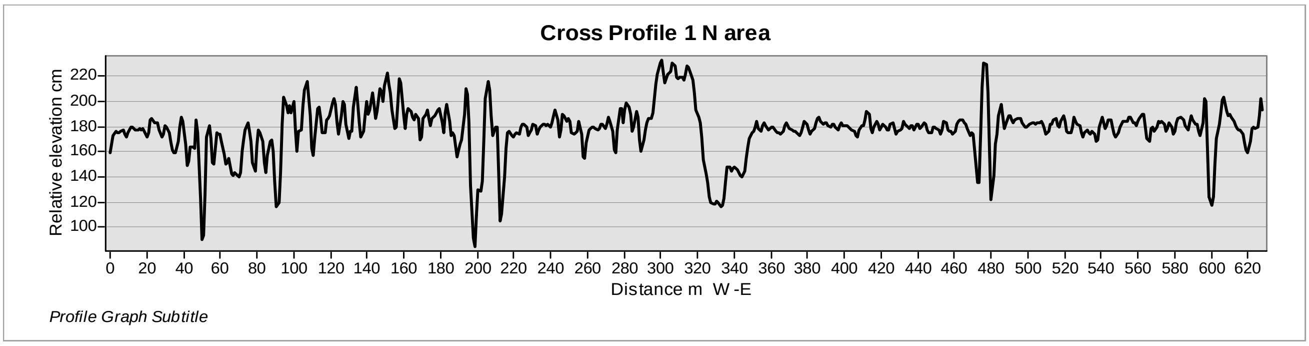

Figure 2.4: Cross Profile North, Queen Elizabeth Regional Park peatland

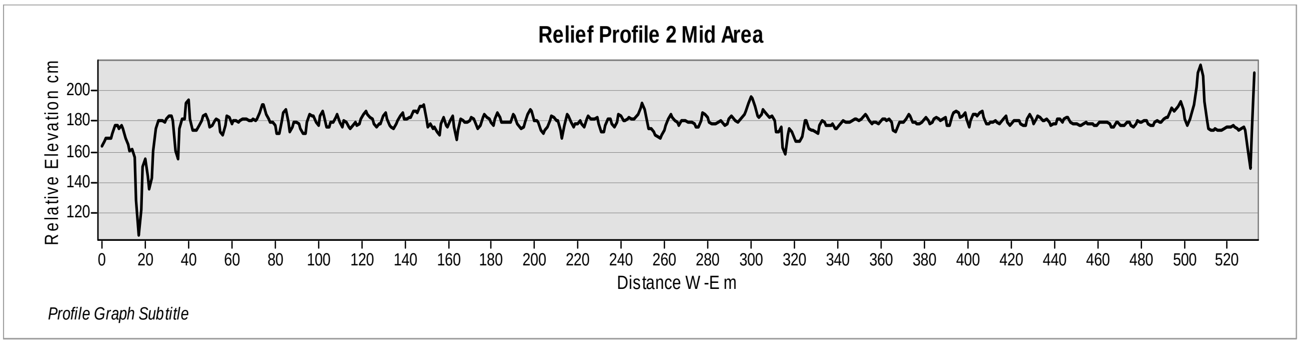

Figure 2.5: Cross Profile Central zone, Queen Elizabeth Regional Park peatland

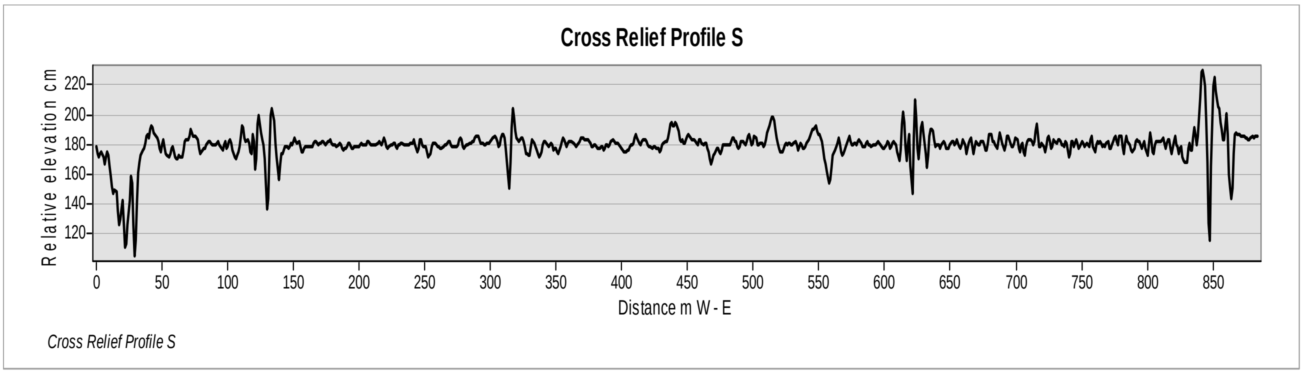

Figure 2.6: Cross Profile South, Queen Elizabeth Regional Park peatland

2.8 Watercourses

The main water courses that pass through the peatlands have been modified and deepened, as mentioned in Section 2.6. Drainage ditches have been connected to these channels as shown in Figure 2.1. A major drain termed North Whareroa Drain runs from north of Poplar Avenue and terminates at the Whareroa Stream North Branch before the confluence of the two branches with the stream then meandering through the coastal dunes to discharge into the Tasman Sea. These streams and drains being entrenched are less likely to bring water and nutrients into the peatlands as in general peatlands have been observed as gaining reaches of Kapiti Coast waterways while fan deposits traversed by waterways are generally losing reaches. Gains are where water flow into waterways and losses are where water flows from waterways into surrounding land. Blocking or restricting any of these waterways is likely to have a knock-on effect in reducing hydraulic gradients and reducing flow rates from peatland and hence water table fluctuations.

2.9 Vegetation

Vegetation has been discussed in other publications in detail so a general overview only is given here. Although peatlands and wetlands can coincide, not all peatlands are wetlands and not all wetlands are peatlands. Historic vegetation coverage is provided by Moar (1954) where vegetation cover in 1951 is discussed and the northern area was dominated by *Leptospermum scoparium* and *Pteridium aquilinum*. Gorse, *Ulex europaeus*, at that time was absent. The southern area was dominated by pasture species.

Currently the north eastern section of the peatland has common rush species along with introduced grasses and gorse. Within this area, plantings of native species including manuka (*Leptospermum scoparium*) and flax (*Phormium tenax*) have been made. The north-western area has a higher proportion of gorse and introduced pasture species with over-sowing with grasses and herbs such as plantain. In terms of land management, low intensity grazing with sheep and cattle has been practised but is currently being phased out. South of North Branch Whareroa Stream, more intensive agriculture has been practised with crops of brassicas and pasture renovation has also occurred extensively. The abundance of Juncus species changes from north to south with the order being *Juncus pallidus*, *J. australis, J. effusus, Juncus edgariae* with *Juncus sarophorus* being more common in the southern section.

3. Methods

3.1 Extent and depth of peat deposits

A probing survey was undertaken in February/March 2020 with a 245 hectare grid being laid down over the area under investigation, extending beyond the likely boundaries of the peatland. The grid extended 800 metres in an East to West direction and 3.2 km in a West South West to North North East direction. Site observations were made at 100 m intervals. Criteria for inclusion as peatland included predominately organic soil horizons in the 0-60 cm depth range thus meeting the definition of Organic soil (i.e. 30 cm or more in the upper 60 cm consisting of Organic soil horizons) (Hewitt 2010). If peat was first encountered below 60 cm or organic matter levels did not meet criteria above that depth, then the point was not classified as peatland. Hence a number of peaty and hydromorphic soils were not included in the area total for organic soils although they are potential wetland and carbon sequestering sites and will be identified in the final soil map of the area.

An initial drilling down to 1.2 m was carried out by using a Dutch clay auger of 65 mm diameter, and soil horizons as well as presence of wood were noted. This drilling was followed by probing using a 10 mm diameter aluminium probe in one metre sections which could be extended by screwing additional sections together. This was inserted until it meet total resistance. Maximum peat depth reached exceeded 3.6 m. The presence of wood during probing was indicated by hollow thumping impact, sand by rasping impact on rotation and silt by dull thumping impact. When wood was encountered the probe was withdrawn and reinserted nearby. If after multiple attempts wood was still encountered the maximum depth reached was recorded and a note made. The presence of wood in the soil profile was added to a spreadsheet on a three point scale, using 0 for no wood encountered, 1 for some wood encountered but probing to bottom continued and 2 where so much wood was encountered that probing underestimated total depth (Figure 3.1).

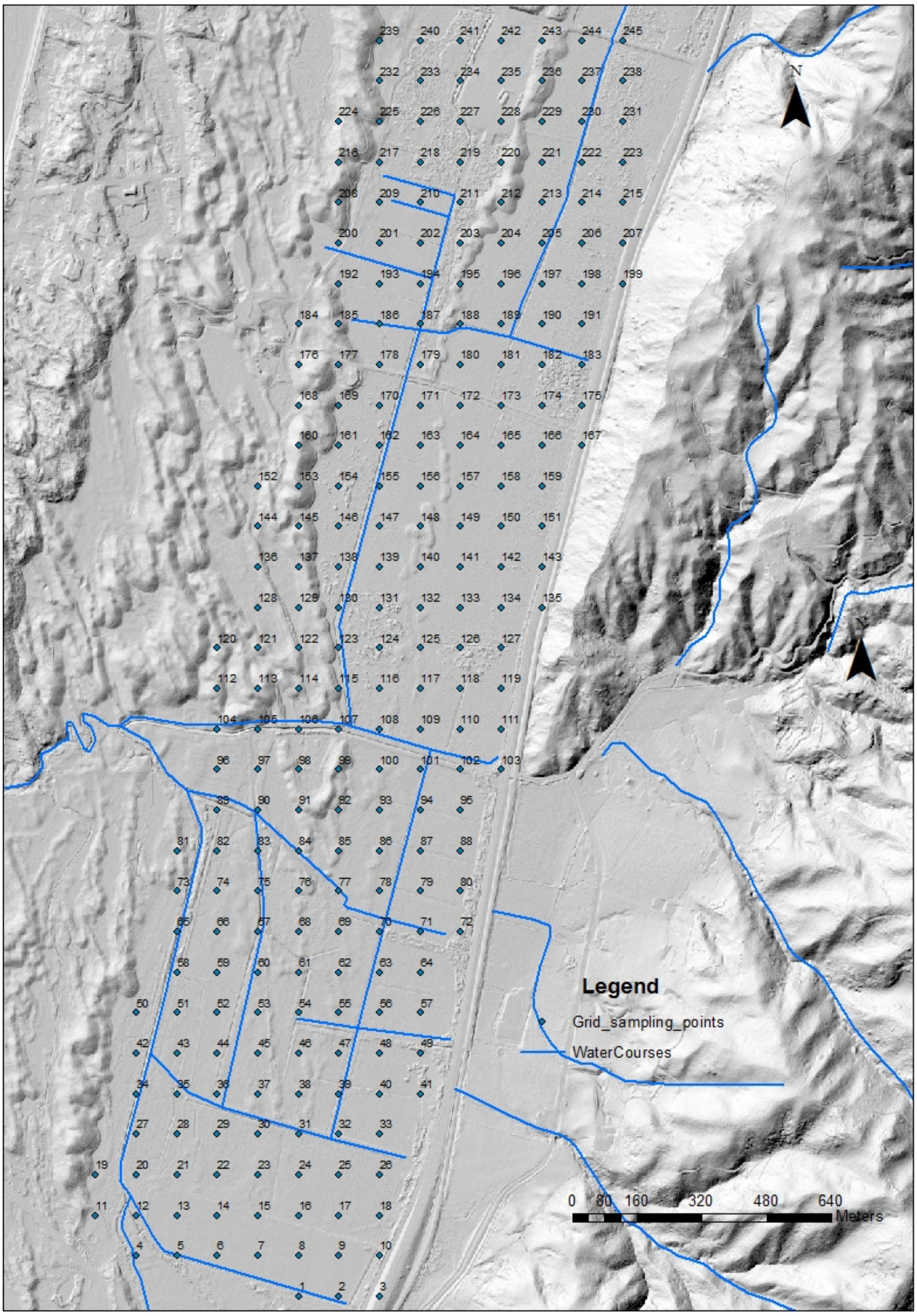

Figure 3.1: Grid locations of regular points for peat probing survey, probing points are at 100 m intervals, resulting in one probe point per hectare

3.2 Peatland condition

3.2.1 Soil chemical and physical analyses

Soil samples were collected for chemical and physical analyses at seven sites (33, 22, 47, 139, 155, 221 and 226) (Figure 3.2). Some sites were also used for soil profiles as detailed in Section 3.2.5.

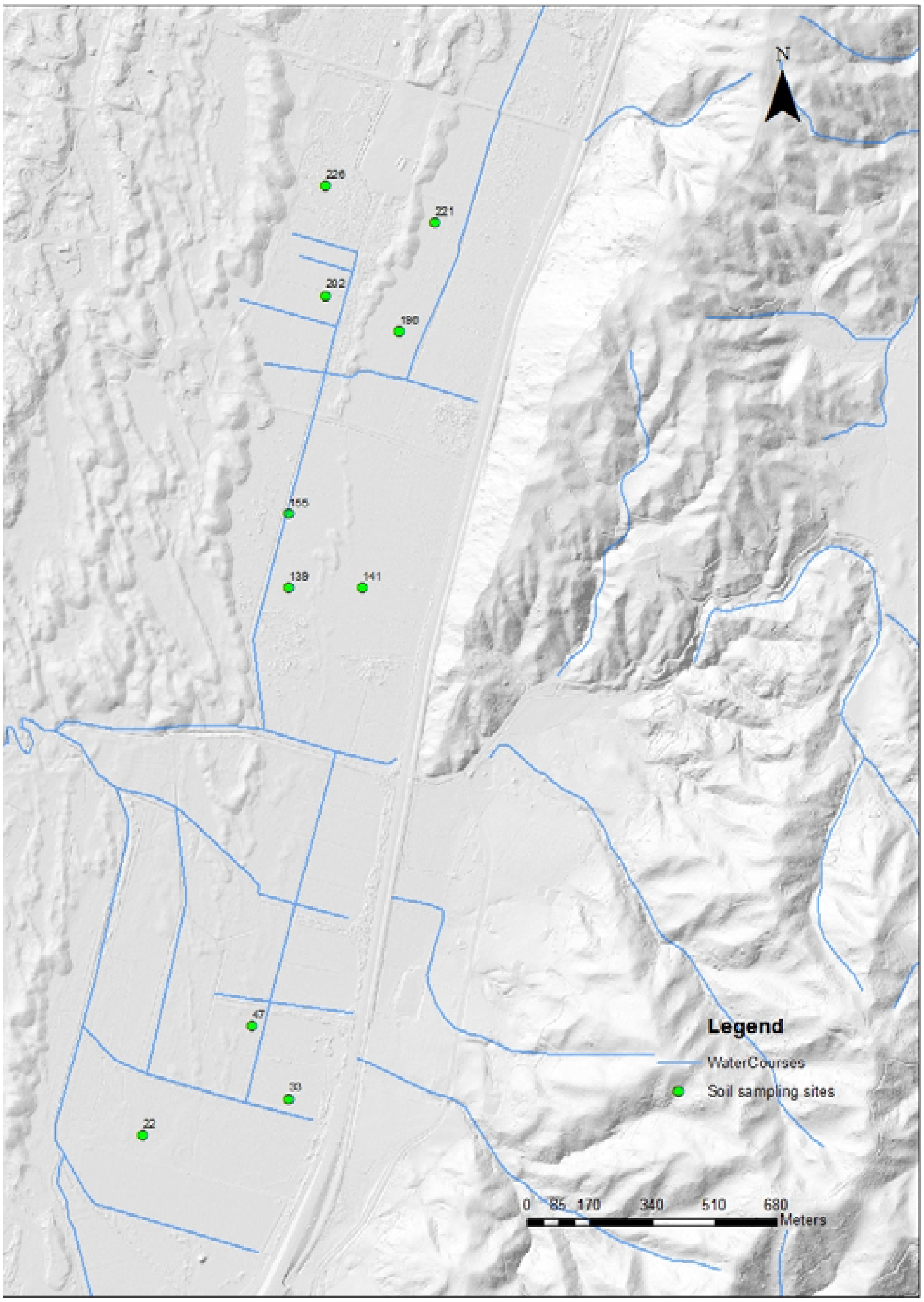

Figure 3.2: Soil sampling and soil profile

Soil chemical analyses were undertaken by Manaaki Whenua Landcare Research to determine soil pH, electrical conductivity, organic carbon%, total nitrogen, Kjeldahl phosphorus and Olsen available phosphorus. Details of methodologies and literature sources may be found on the Manaaki Whenua Landcare Research website for environmental chemistry. Methods for soil physical analyses carried out by Manaaki Whenua Landcare Research including bulk density, particle density, moisture release characteristics followed

Gradwell (1973). Manaaki Whenua Landcare Research terminology and definitions for these physical analyses followed McQueen (1993).

3.2.2 Soil and drain water chemistry analyses

Soil and drain water samples were taken from four sites across the peatland. Soil groundwater was extracted after purging from bores BP32/0117, BP32/0119 (Figure 3.3). A groundwater sample was also taken the Northern Whareroa Drain and from bore R26/6503 (a bore slightly to the south of the peatland).

Figure 3.3: Location of piezometers in north-eastern section of peatland and sites where groundwater samples were collected

Water chemistry methods for analyses were carried out by Hill Laboratories Hamilton with details of analytical method used being included in Appendix A.

3.2.3 Soil field determinations of water characteristics

Field determinations of water characteristics: pH, electrical conductivity, temperature, dissolved oxygen and oxygen reduction potential were made with a YSI Pro Plus multi-probe. Calibration of the instrument followed NEMS protocols (NEMS 2019). Eleven sites were sampled as shown in Figure 3.4.

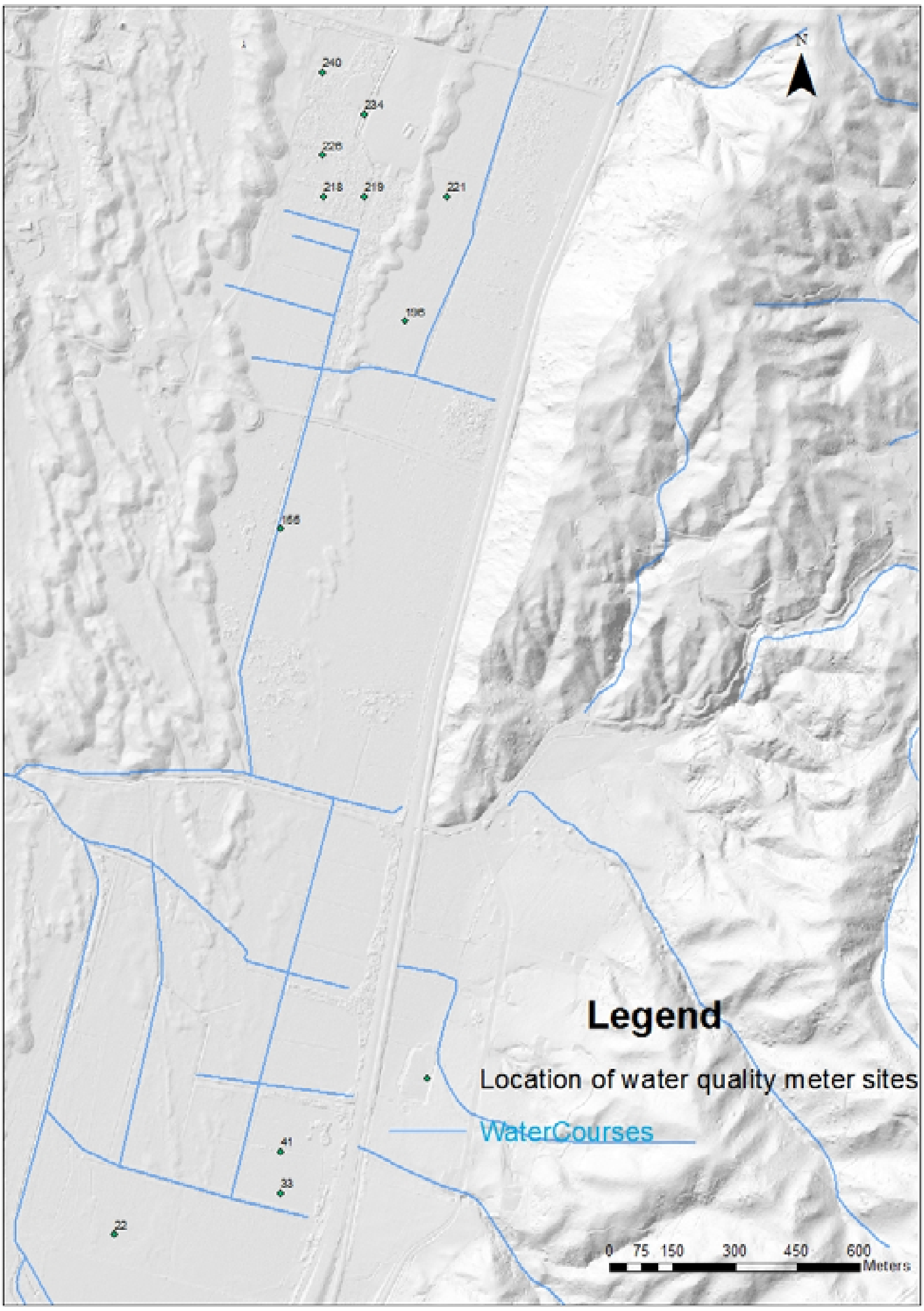

Figure 3.4: Sites where general soil water table properties and soil water quality were measured

3.2.4 Climatic information

Climatic information was used to construct a water balance at Queen Elizabeth Park. The factors of ET (evapotranspiration) and rainfall can be extrapolated from the nearest comprehensive climatic station at Paraparaumu Airport (NIWA data).

3.2.5 Soil description and mapping methodologies

Ten of the grid sites were selected for detailed soil descriptions and sampling within the peatland (Figure 3.2). Profiles were exposed by digging a profile face down to the water table if present. Auger descriptions extended down to a maximum of 120 cm using a 65 mm diameter Dutch clay auger. Description terms followed Soil Description handbook (Milne et al 1995) while soil classification followed the NZ Soil Classification (Hewitt 2010). All sites were on very gently sloping peatland. Organic soil horizons were defined using criteria from Hewitt (2010) including at least one of the following; >18% total Carbon, 31% Organic matter, unrubbed fibre >20% and soil colour value 4 or less if dry and 3 or less if wet. The distinction between acidic and mellow Organic subgroups in the NZ soil classification is based on a soil profile pH of < or > than 4.5. The distinction between humic, mesic and fibric groups is based on the degree of decomposition of the peat material with humic showing the greatest decomposition. Fibre tests followed Milne et al 1995 (p 151) and von Post assessment (op. cit. p.54). Soil mapping was based on the interpretation of profile classifications from soil pits and auger observations to construct soil mapping units which may contain minor areas of other soil types which could not be displayed on the final soil maps. Photographs associated with the Queen Elizabeth peatland site are shown in Appendix B.

4. Results

4.1 Extent and depth of peat deposits

The peat depths encountered north of Waterfall Stream (North Branch of Whareroa Stream) are shown in Figure 4.1, while peat depths south of Waterfall Stream (North Branch of Whareroa Stream) are displayed in Figure 4.2. The pattern is summarised in Figure 4.3 where peat contours are displayed. Peat was present up to the 3.5 m depth interval, as averaged by the contouring process. The deeper peat deposits occurred in the northern eastern part of the peatland closer to the Holocene relic coastal cliffs. The peat deposits were generally shallower to the west where they lay between sand dune ridges and also shallower to the south. There were occasional deeper peat deposits in the southern area as well, again mainly on the eastern side. While most of the western side was delineated by the presence of sand dunes, in the central zone where North Branch of Whareroa Stream exists the eastern hill country, deposition of sediment overlaid possible extensive areas of peat.

The extent of peat coverage as well as buried peat that could be identified by augering and probing is shown in Figure 4.4. Buried peat could not identified if the surface layer of mineral sediment was greater than 1.2 m. At the southern edge of the peatland, the same pattern of deposition of more recent sediment from the Whareroa Stream had created the same pattern of buried peat underneath a mineral soil. One hundred and eleven of the grid points met the peat criteria described above, with an average peat depth of 2.4 m and an estimated volume of 2,639,580 m^3.

The presence of wood in the peat profiles is shown in Figure 4.5. Wood was much more common in the northern area and concentrated in the area of deeper peats. Wood was encountered at a range of depths including tree stumps located at the current peat surface.

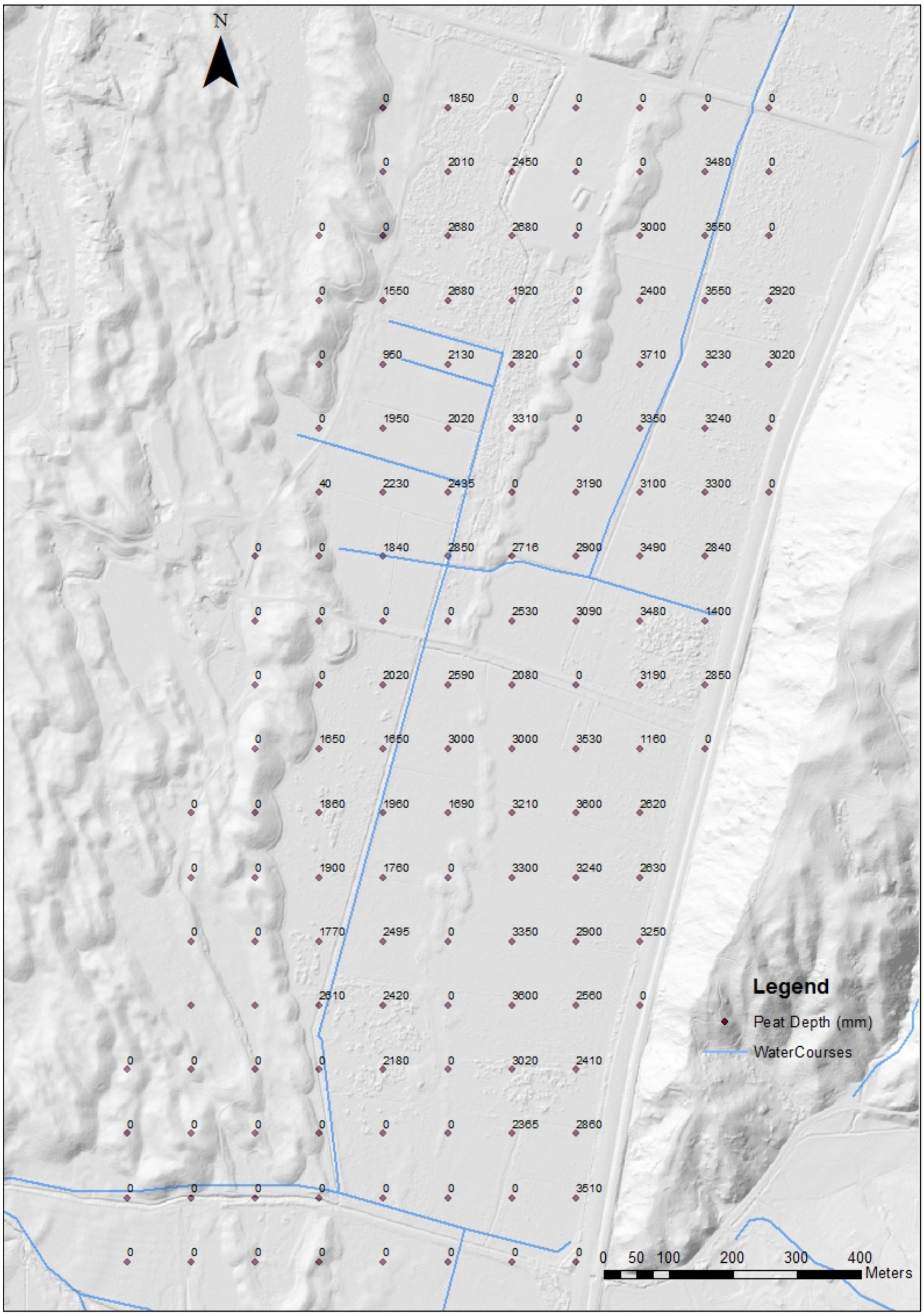

Figure 4.1: Peat depths north of Waterfall Stream (aka North Branch Whareroa Stream) measured by probing survey

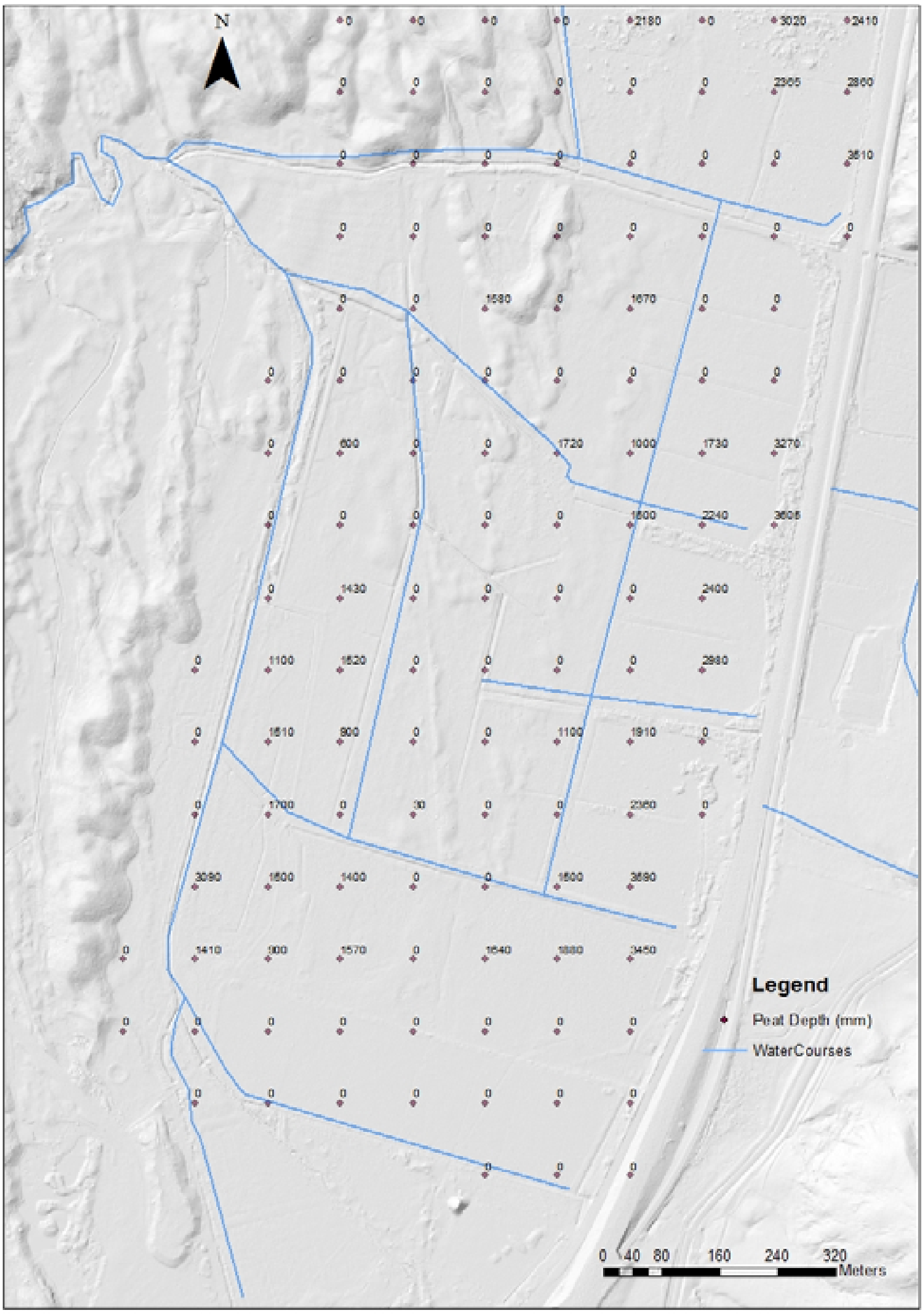

Figure 4.2: Peat depths north of Waterfall Stream (aka North Branch Whareroa Stream) measured by probing survey. North Branch Whareroa Stream runs east to west at top of figure.

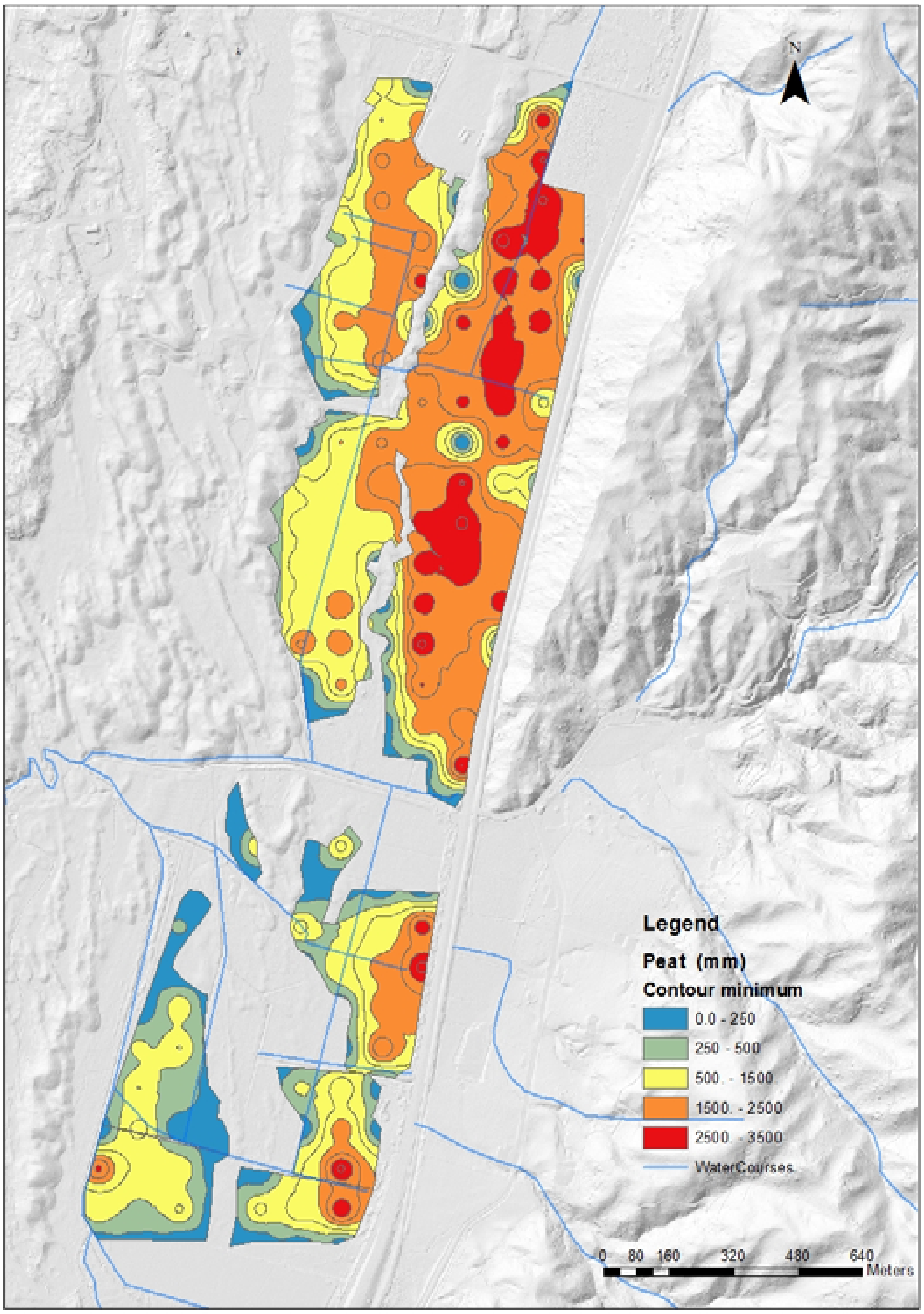

Figure 4.3: Peat depth contours (mm) in the peatland survey area of Queen Elizabeth Regional Park

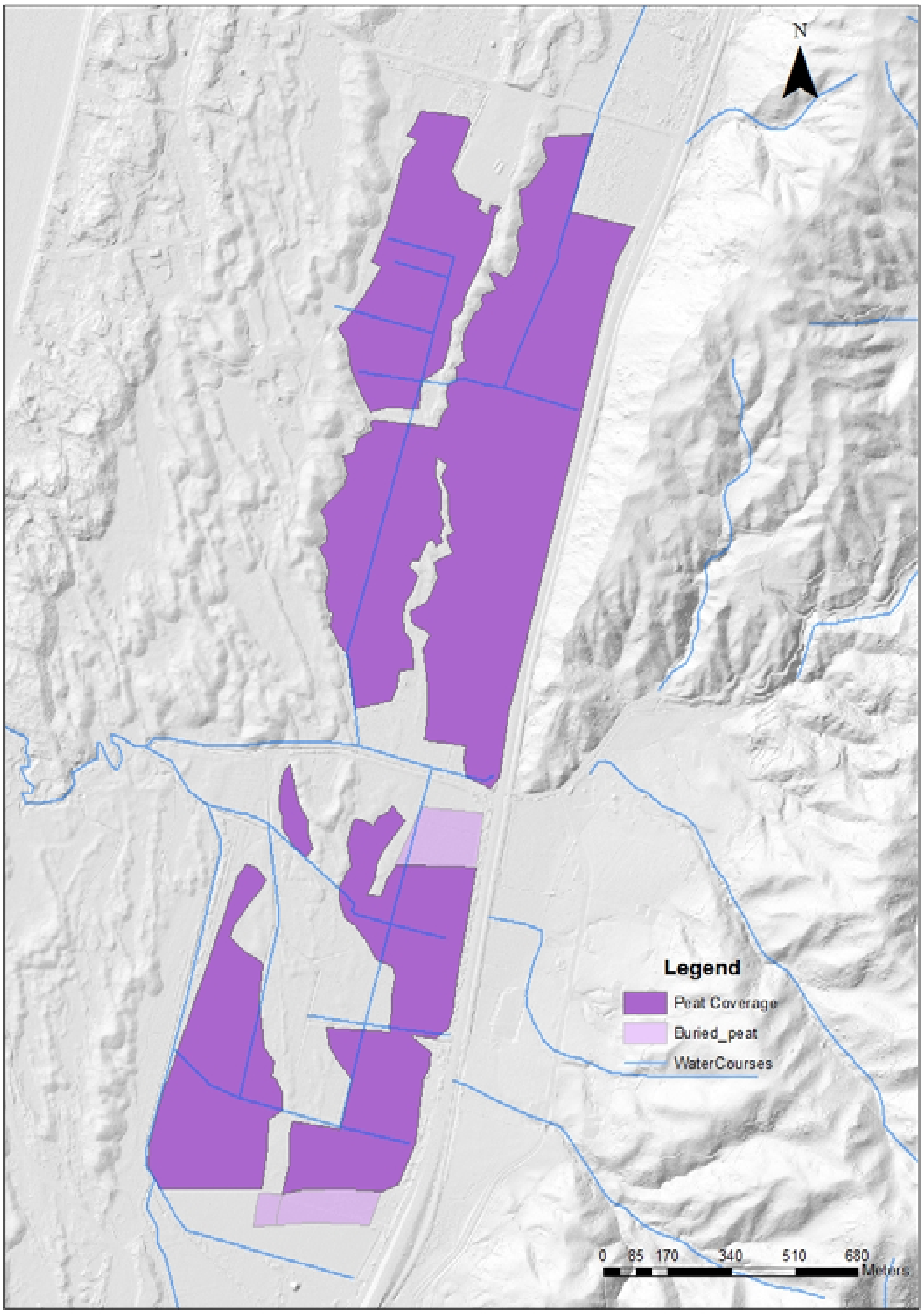

Figure 4.4: Extent of peat deposits within surveyed area, Queen Elizabeth Park. Buried peat occurs where the upper 600 mm of the soil profile is predominately mineral material

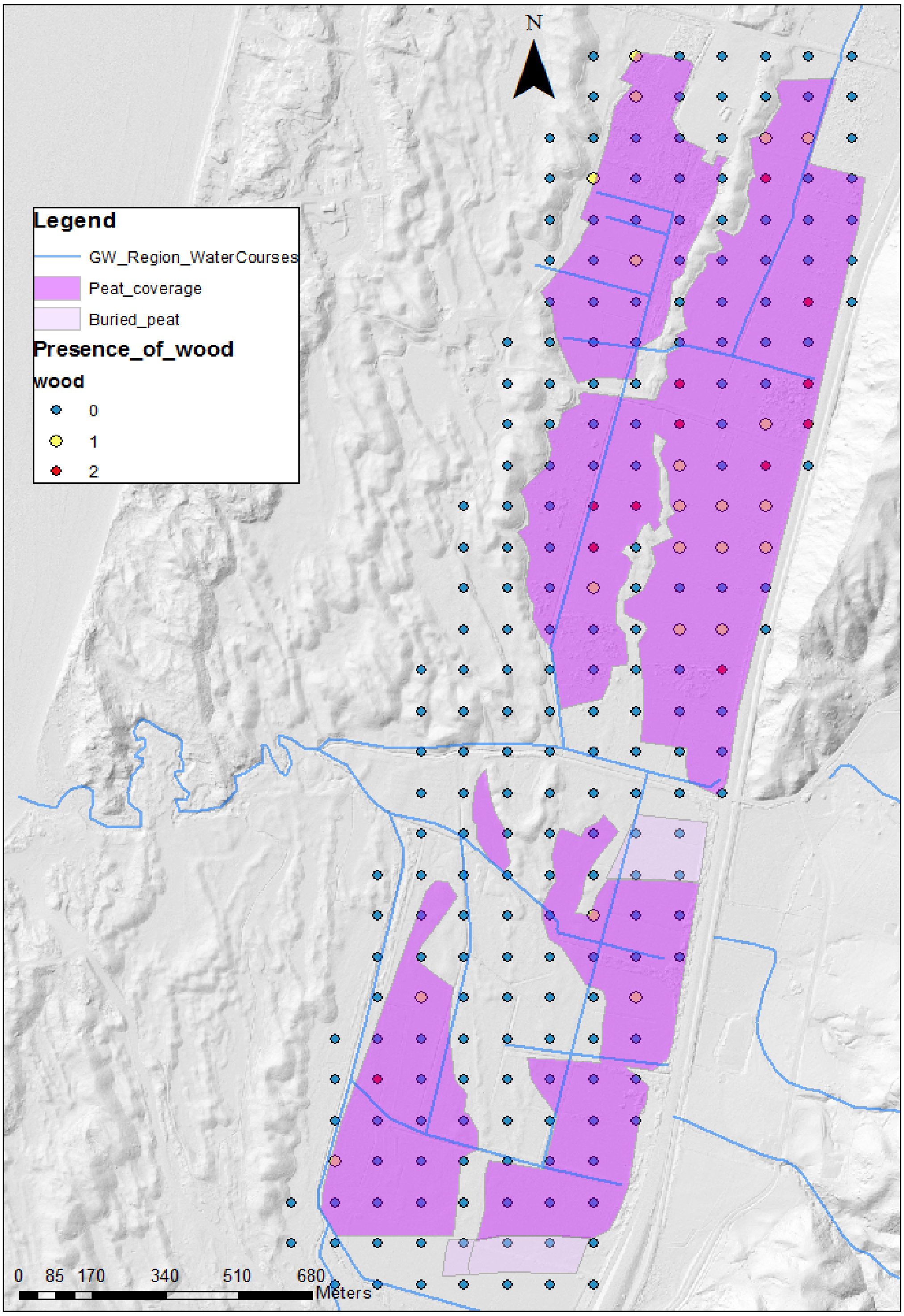

Figure 4.5: Wood detected in peat profile during probing. 0 = no wood, 1 = some wood and 2 = a high concentration of wood

4.2 Peatland condition

4.2.1 Soil chemical analyses

Soil chemical analyses were undertaken at seven of the sampling points (33, 22, 47, 139, 155, 221 and 226) (Figure 3.2, Table 4.1). Three sampling sites located in the southern section of the peatland (south of Whareroa Stream) had higher pH levels than those normally associated with bogs, which typically range between pH 3 and 4.8 (Johnson and Gerbeaux 2004). When the pH average throughout the active soil profile is less than 4.5, the soil is assigned to an acid subgroup. Topsoil samples with the exception of site 226 are equal to or greater than pH 4.5. There was also a considerable decline in pH recorded between the upper and lower profile horizons. Horizons below 250 to 400 mm depth frequently had pH in the 3 to 4 range.

Table 4.1: Soil chemistry analyses at selected sites in the peatland

Site and Depth (mm)		pH	Subgroup	C%	Total N (%)	C/N	Total Kjeldahl P (%)	Olsen P (mg/kg)
33	0-200	5.1	Mellow	13.4	1.10	12	0.180	26
	200-400	4.9		12.4	0.98	13	0.160	21
22	50-250	4.8	Mellow	8.37	0.71	12	0.100	11
	250-540	4.4		27.7	1.44	19	0.102	22
	1200			34	0.99	35		
47	0-180	5.0	Mellow	13.5	1.07	13	0.153	24
	310-430	4.7		18.3	1.02	18	0.109	22
	430-700	4.1		44.1	1.87	24	0.070	16
139	40-240	4.9	Acid	35.6	1.30	27	0.069	15
	240-600	3.7		63.7	0.87	73	0.013	82
	1100-1200			51.9	1.06	49		
155	100-400	4.5	Acid	43.8	1.58	28	0.071	14
	400-540+	3.6		55.0	1.25	44	0.024	23
221	0-110	5.1	Acid	52.3	1.73	30	0.063	6
	110-250+	4.4		60.6	1.15	53	0.026	17
	800-1000			62.1	0.86	72		
226	0-200	4	Acid	47.7	1.80	27	0.078	22
	1000			57.5	1.28	45		

The C/N ratio can be seen as an index of the degree of decomposition and the availability of N. Ratios of greater than 40 would be favourable for low nutrient demanding species. The data showed that this was not achieved in the southern sites (33, 22 and 47), but the northern sites (139, 155, 221 and 226) had higher C/N ratios. Olsen P values indicate that the southern sites had higher than desirable Olsen P levels, while the northern sites showed lower Olsen P levels.

Total Kjeldahl P values were also significantly higher in the southern areas but showed more consistency than Olsen P measures.

4.2.2 Soil physical analyses

The results of soil physical analyses completed on samples taken from nine sampling sites are shown in Table 4.2, with the locations of those sampling points shown in Figure 3.2. The physical properties of soil profiles in the southern part of the peatland area; sites 22, 33 and 47 show different characteristics to the more northern sites. The soil particle density values at the southern sites tend to be greater than 1.75 t/m^3 indicating notable mineral addition to most soil horizons. However total porosity still remains high and the predominance of organic matter content contributes to high total available water capacity and moderately low bulk density. The northern sites have lower particle densities more characteristic of pure peats being in the range 1.4 to 1.7 t/m^3 (Yulianto et al. 2019).

Peat soils normally have a wide distribution of pore sizes. These vary from very large pores which drain at only -1 kPa to pores which drain at between -100 and -1500 kPa and provide water to plants after more easily drained water has been removed (McQueen1993). Soil shrinkage can occur in peatland where the topsoil has been exposed to drying as has occurred at Queen Elizabeth Park. A shrinkage test of the soil cores obtained from the sample sites indicated that the samples outlined in green in Table 4.2 and Figure 4.6 showed the greatest shrinkage. These were Site 139 24-60 cm depth, Site 202 28-54 cm depth and Site 141 19-45 cm depth. Relatively pure undisturbed peats normally show shrinkage on drying and this is evident in Queen Elizabeth Park peat soils.

Figure 4.6: Soil cores from 2020 sampling – the ring in the foreground indicates the original volume of soil

Table 4.2: Physical properties of soils sampled

Client	Horizon	Sample	C % w/w	C%v/v	Initial	Initial	Initial	Dry Bulk	Particle	Total	VLP	Macro	Air	Vol. WC	Vol. WC	Vol. WC	Vol. WC	Vol. WC	Vol. WC	Vol. WC	Readily	Total	Visual assessment of					
ID	Depth	Depth			Water	Water	water	Density	Density	Porosity	0--1kPa	Porosity	Filled	1 kPa	5kPa	10kPa	20kPa	40kPa	100kPa	1500kPa	Available	Available	Shrinkage	PAW	Hardening	PR		
					Content	Content	Pot			"Saturation"		0 to -5kPa	Porosity			Field			Stress	Wilting	Water	Water		mm		MPa		
													0 to - 10kPa			Capacity			Point	Point	-10 to 100	10 to 1500						
	(cm)	(cm)			(%, w/w)	% v/v	kPa	(t/m^3)	(t/m^3)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)						
Site 33	0-20		13.4	4.8	191.1	68.8	3.0	0.36	2.19	83.8	12.8	21.2	26.4	71.0	62.5	57.3	53.5	49.7	45.2	21.4	12.2	35.9	med			**0.2**		
Site 33	20-40		12.4	6.2	139.2	69.6	<1	0.50	2.25	78.0	9.7	13.1	16.2	68.3	64.9	61.8	58.8	55.4	50.7	31.1	11.1	30.7	med	**195**		**0.5**		
Site 22	0-25	5-25	8.37	8.0	36.0	34.5		0.96																		**2.9**	mineral	
Site 22	25-60	25-54	27.7	8.0	258.5	75.0	1.0	0.29	1.95	85.3	10.5	19.2	24.2	74.8	66.1	61.1	56.7	53.6	50.2	28.7	10.9	32.4	med	**183**		**0.6**		
Site 22	120		34.7	6.8				0.20																				
Site 47	0-18	6-13	13.5	11.2	44.6	37.0	>100	0.83	2.32	64.3	4.8	11.9	15.4	59.5	52.4	48.9	47.1	45.2	42.3	33.7	6.6	15.2	low		**hardened**	**2.5**	reasonably mineral cont	
	18-33																								**hardened**		Blocks used for rewetting	
Site 47	31-43	34-40	18.3	12.4	52.5	35.7	>100	0.68	2.26	69.7	12.0	20.4	24.0	57.7	49.3	45.7	43.4	41.8	39.9	34.4	5.8	11.3	low v low	**101**	**not harde**	**0.4**		
Site 47	43-70	56-63	44.1	11.5	159.5	41.5	80.0	0.26	1.72	84.7	19.0	30.8	35.9	65.7	53.8	48.8	45.6	43.5	40.8	32.0	7.9	16.7	med			**0.4**		
						0.0																						
Site 139	4-24		35.6	17.8	40.5	20.3	>1500	0.50	1.71	70.6	17.3	25.6	32.2	53.3	45.0	38.4	34.2	31.4	28.3	21.6	10.1	16.8	med low	**185**	**quite firm**	**1.4**		
Site 139	24-60		63.7	13.4	323.4	67.9	20.0	0.21	1.40	85.1	8.8	13.9	16.2	76.3	71.2	68.8	67.2	65.4	63.5	28.6	5.3	40.2	high			**0.4**		
Site 139	110-120		51.9	10.4				0.2																				
Site 141	4-19		30	14.7	98.6	48.3	>100	0.49	1.73	71.8	1.6	5.0	13.2	70.2	66.7	58.6	55.4	51.9	49.2	30.8	9.4	27.8	low	**251**		**1.4**		
Site 141	19-45		60	10.2	416.2	70.8	10.0	0.17	1.48	88.2	7.0	15.7	18.1	81.2	72.5	70.2	68.4	67.3	65.9	22.0	4.3	48.2	high			**0.2**		
Site 141	110-120		64.3	10.9		0.0		0.17																				
Site 155	0-10					0.0																				**1.1**		
Site 155	10-40		43.8	17.5	61	24.4		0.4																	**some harc**	**1.8**		
Site 155	40-54		55	11.0	371	74.2		0.2																		0.5		
						0.0																						
Site 202	0-23	7-14	50	21.5	47.5	20.4	>1500	0.43	1.58	72.6	28.6	32.0	36.7	44.0	40.6	37.5	35.5	34.2	31.2	25.7	4.7	10.1	med	**175**	**some harc**	**1.5**		
Site 202	28-54	37-44	55	12.7	303.1	69.7	15.0	0.23	1.47	84.0	8.0	10.4	12.6	76.0	73.6	71.5	69.1	66.2	63.7	30.4	7.8	41.0	high			**0.4**		
Site 202		110-120	59.9	12.0		0.0		0.20																				
Site 221	0-11		52.3	19.4	135.5	50.1	30.0	0.37	1.59	77.0	13.2	19.0	25.8	63.8	58.0	51.2	50.4	49.0	48.2	23.3	2.9	27.8	low	**136**	**few hard ;**	**1.2**		
Site 221	11-25		60.6	14.5	142.1	34.1	>100	0.24	1.43	83.3	30.5	40.5	44.1	52.8	42.8	39.2	37.6	36.4	35.2	29.1	4.1	10.1	med -low			1.1		
Site 221	80-100		62.1	12.4		0.0		0.20																				
Site 226	0-20		47.7	16.4	230.0	78.9		0.34																		**0.7**		
Site 226	100		58	11.5				0.20	ıg 0.2t/m^3 for density at depth based on measured at site 22																			

Macro-porosity cited here is determined between total porosity and tension of -5 kPa, for consistency with the National Soils Database of New Zealand (NSD).

PAW based on extrapolation to upper 600mm of soil profile

There were no consistent changes in overall porosity in the affected horizons, but an increase in large pores can be at the expense of fine pores which are used to store plant available water. The shift in pore size distribution is contrary to what is normally expected with wetting/ drying cycles and densification reported in the literature where large pores are disproportionally lost.

Additional physical changes have been identified in the surface peat horizons which are subject to long term wetting and drying cycles. These include relatively high penetration resistance levels for an organic horizon, with the formation of large, stable, very firm clods. Penetration resistances are high in these clods in the range of limiting root distributions. However roots appear to be able to descend to deeper less restrictive horizons by exploiting gaps between clods. In an experiment, a hardened clod from Site 47 depth 18-33 cm (bulk density 0.878 t/m^3) was submerged in water for over 4 weeks. Initial water content was 20% v/v, i.e. below wilting point. After removal from container the clods were still very firm but water content had risen to 36% v/v which was in the range of readily available water for similar horizons. This recovery of water content is encouraging for eventual rewetting of modified peat soil horizons

Water conductivity is also reported to be reduced as a result of wetting and drying cycles. There were no conductivity measurements made on these surface horizons but it may be that these pores are not continuous as compared to biopores which frequently extend through soil horizons. Biopores often are large >750µm pores also referred to as K_{-40} pores (McQueen 1993) which drain at less than -0.4 kPa. These are within the range of the Very Large Pores 0-1.0 kPa which were found to have also greatly increased in the pore size shifted horizons. K_{-40} unsaturated hydraulic conductivity is the water flow through all the pores < 750µm.

Biopores are good conductors of water but there is no evidence that these new large pores will function in the same way. They have been formed in a different process and whether they are connected has not been established. In general these changes occur in surface horizons, one subsoil horizon at Site 47 depth 43-70 cm shows significant pore size shift but this is a shallow peat profile 70 cm deep with lower water contents throughout the profile. The horizon in question has lower particle density of 1.72 t/m^3 so belongs in the purer peat category.

Peat soils are often moist to near the soil surface even if the water table has been lowered. Capillary rise occurs when moisture is wicked up by surface tension above a water table. Capillary rise may be an important additional source of moisture to peat soils during periods of moisture stress. Nugraha et al. (2016) report rises of up to 50 cm in peat soils with height of rise being affected by bulk density and pore size distribution. The sites where capillary rise behaviour are summarised below and grouped by whether or not high contrasts were observed in water content were observed above and below the capillary fringe boundary (Table 4.3).

Table 4.3: Contrast in water content above and below the capillary fringe boundary

High contrast sites	
Site 155	Moisture difference across capillary rise boundary at 40 cm depth is difference between 24 v/v% above and 74 v/v% which is the same difference between -1500kPa and -5 kPa with a water table depth at 54 cm
Site 221	Sharp capillary rise boundary at 25 cm with moisture levels -100kPa to -1500kPa above boundary with profile description is very moist to saturated below water table at 42 cm depth.
Site 202	Horizon less than 28 cm has pore size shift and field water content >1500 kPa. Very moist in horizon at 28 to 54 cm, water table estimated at around 100-110 cm.
Low contrast sites	
Site 226	Water table at 37cm at site where capillary rise zone reaches 20 cm but very moist above capillary fringe estimated at -1 kPa, so no evidence of sharp water change across boundary. A capillary fringe boundary does not always indicate absence of moist conditions above the visually obvious line,
Site 33	Water table at 38 cm but no sharp capillary zone boundary observed. Horizons above water table are at -1 and -3 kPa matric potential, so very moist and close to saturation. Where water tables were observed in the soil profile, capillary rise zones were also commonly observed

In some cases there was a sharp drop in water content above the boundary, but the sharp decrease in water content only occurred in horizons where soil pore sizes distribution shift had occurred. These horizons may act as a barrier to upward movement of capillary water. In cases where this was not observed water table depths were also less than 38 cm. Upward fluxes of water which are adequate to maintain plant growth have been found in peats in New Zealand for at least 1 m above water table. (D. McQueen, pers com.).

Capillary rise is an important component in maintaining water content in the peat soils of Queen Elizabeth Park. Where significant pore size redistribution leads to an increase in large pores this upward movement of water is reduced. This occurs however only in surface and near surface horizons and in sites where water tables are the deepest. It is likely that plant roots are able to penetrate into deeper horizons below 30 cm to obtain sufficient moisture and with rising water tables into 25- 30 cm depth zones these horizons may be rehabilitated through rehydration.

4.2.3 Soil and drain water chemical analyses

The results of the groundwater and drain water sampling are shown in Table 4.4. The northern bore BP32/0117 water had very high levels of organic carbon, nitrogen and phosphorus, which indicated a high level of biological activity. Phosphorus was not limiting, with a N/P ratio of less than 10. Mineralised nitrogen levels were relatively low, with a combined level of ammoniacal N and nitrate N of 0.71 g/m³, compared to a non-mineralised N level of 13.15 g/m³. Most N was therefore in an organic form. Dissolved reactive phosphorus (DRP) levels were high, again indicating an active metabolising system.

The North Whareroa Drain values for total N and P were high, with the drain having a particularly high DRP value, a significant level of organic carbon and a level of nitrate indicating a degree of aerobic behaviour. The majority of N was biological however (3.76 g/m³). The pH in the drain was 3.9, a level of acidity comparable to soil water pH levels. The more southern BP32/0119 site had noticeably lower levels of P (some of which would have restricted biological activity), with similar levels of N to the North Whareroa Drain. A greater proportion of the mineralised N was in the ammoniacal form, indicating a less aerobic environment.

Table 4.4: Groundwater and drain water chemical analyses of samples taken May 2020

Sample site	Total P (g/m³)	Total N (g/m³)	Ratio N/P	Total organic C (g/m³)	C/N (g/m³)	Ammoniacal N (g/m³)	DRP (g/m³)	Nitrate (g/m³)
BP32/0117	2.00	13.86	6.93	225	16.2	0.4	0.25	0.31
North Whareroa Drain	0.91	5.39	5.92	155	28.8	0.4	0.84	1.76
BP32/0119	0.11	5.64	51.2	21	3.8	1.456	<.004	1.39
R26/6503	0.03	0.12	5.5	2.9	26	0.11	0.03	0.007

4.2.4 General soil water table properties and soil water quality – field sampling

The results of the soil water table and soil water quality measurements completed using field sampling methods as detailed in section 3.2.3 are shown in Table 4.5, with sampling points shown in Figure 3.4. As expected, water table depths decreased from an average of 0.61 to 0.45m between February and May. The spot checks of groundwater depths across the peatland from 0.37 m to 0.73 m for late summer to autumn show a relatively consistence water table surface across the whole peatland with likely considerably higher levels in winter when checks were not made. They also show similar values to those recorded in piezometers so extrapolation of piezometer data to the whole peatland is reasonable. Two sites show noticeably shallower groundwater levels. Site 33 in the south eastern corner shows autumn groundwater levels of

0.38 m. Soil water pH is relatively high and specific conductivity is low compared to other sites, indicating that this site may be obtaining relatively fresh groundwater possibly from hillside shallow groundwater and expressway drainage. Site 226 in the north eastern corner of the peatland had comparable autumn groundwater depth of 0.37m with soil water pH value of 3.73 and a conductivity that was indicative of groundwater with noticeable peat influence. This is possibly due to groundwater movement from peat areas north of Poplar Avenue.

Acidity (pH) values at sites south of Nth Branch Whareroa Stream had an average of 5, while in the northern area, the pH was below 4. Specific conductivity was greater than 200 µS/cm in the northern area, while in the southern area it was more variable with one value at site 22 being 853 µS/cm. This latter site is the closest to the coast and the result may indicate a saline influence on groundwater at this location. In terms of anaerobic status, the dissolved oxygen levels were not particularly low but readings were taken from recently disturbed excavated sites. Relatively high water conductivity values are usually found in peat. ORP values were also not low but pH values less than 4 would have elevated the ORP levels. The presence of low pH levels in the northern area indicate an environment more conducive to lower decomposition of organic matter and beneficial to terrestrial wetland vegetation species.

Table 4.5: Environmental indicators from water quality field meter sampling at selected locations

Site #	E	N	Date	Water table depth m	Temp ^{0}C	Cond µS/cm	O2%	O2 ppm	pH	ORP
22	1766618	5463274	4/3/2020	0.7	18	853	87.1	8.22	5.1	155.2
33	1767018	5463374	18/2/2020	0.61						
33	1767018	5463374	5/3/2020	0.38	16.1	166.1	4.7	0.47	4.93	155.4
41	1767018	5463474	18/2/2020	0.51						
47	1766918	5463574	5/03/2020	0.67	16.4	292.9	10.1	1.01	5.08	171.9
155	1767018	5464974	7/5/2020	0.54	16.3	390	21.6	2.6	3.76	354.7
196	1767318	5465474	7/5/2020	0.46	15.5	279.4	28.9	2.89	3.62	374.8
218	1767120	5465774	20/2/2020	0.73	17.6	281	16	1.53	3.82	193.4
219	1767218	5465774	20/2/2020	0.46	14.7	221.3	34.1	3.47	3.68	338.6
221	1767418	5465774	8/5/2020	0.42	14.7	221.3	34.1	3.47	3.68	338.6
226	1767118	5465874	8/5/2020	0.37	14.9	312	10.9	1.11	3.73	127.0
226	1767118	5465874	20/2/2020	0.68						
234	1767218	5465973	28/2/2020	0.82	17.1	206.5	14.2	1.37	4.11	225.3

240	1767018	5466074	28/2/2020	0.55						
	In stream by 240		28/2/2020		17.2	208.2	20.2	1.95	5.05	207.3
BP32/0117	1767458	5465820	28/2/2020	0.97						
BP32/0119	1767459	5465571	19/2/2020	0.64						
BP32/0121	1767396	5465181	19/2/2020	0.66						
BP32/0122	1767396	5465181	19/2/2020	0.84						
	Average water table depth for Feb March			0.611						
	10 sites	St Dev		0.14						
	Average water table depth for early May			0.45						
	4 sites	St Dev		0.07						

4.2.5 Soil water balance modelling and field water content

Climatic data obtained from the Paraparaumu Aero weather station, as detailed in Section 3.2.4 are shown in Table 4.6 with soil water deficit for the last 10 years shown in mm. The average annual rainfall for the area is 1118 mm.

Table 4.6: Water deficit (mm) modelling results from Paraparaumu Aero weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
2010	82.3	122.4	127.3	120.5	73.1	3.8	1.1	1.7	2.6	15.1	83.3	106.2	**61.6**
2011	109.9	117.7	109.7	47.6	3.1	1	2.8	6.2	18.7	7.9	23.2	71.3	**43.3**
2012	73.1	106.7	63.3	86.8	53.8	7.3	2.8	1	8.2	27	81.5	103.1	**51.2**
2013	89.9	100.6	102.7	81.4	12.5	1.1	3	3.3	6.5	10.9	52.3	111.1	**47.9**
2014	104.7	129.2	127.7	99.1	12.4	2.4	3.4	4.4	18.1	35.5	85.6	71.7	**57.9**
2015	119.9	137.4	121	32.6	5.3	2.7	1.8	1.9	5.8	48.6	70.1	116.5	**55.3**
2017	106.2	89.5	62.7	9.9	1.1	4.9	1.2	1.8	3.3	29.6	107.7	141.6	**46.6**
2018	123.4	93.4	57	17.8	9.3	1.7	0.9	1.6	21.1	59.9	56.2	92.2	**44.5**
2019	127.5	140.6	105.8	72.4	47.2	1.1	1.1	4.4	21.1	20.1	36.9	51.8	**52.5**
Average	**104.1**	**115.3**	**97.5**	**63.1**	**24.2**	**2.9**	**2.0**	**2.9**	**11.7**	**28.3**	**66.3**	**96.2**	**51.2**

In the winter the soils maintain their water contents with very little loss but in the summer months (December to March), there is a significant water loss. The balance is based on the assumption that the soil profile in the upper 600 mm can store 150 mm of water.

A soil water balance model was run using the 10 years of monthly data from Paraparaumu Airport, four km NW from Queen Elizabeth Park. The inputs to the model were: rainfall data, ET (evapotranspiration) and profile soil water capacity (PAW). The model output shows a water deficit if rainfall input is less than the losses (Figure 4.7). The balance depends significantly on the degree of soil water storage.

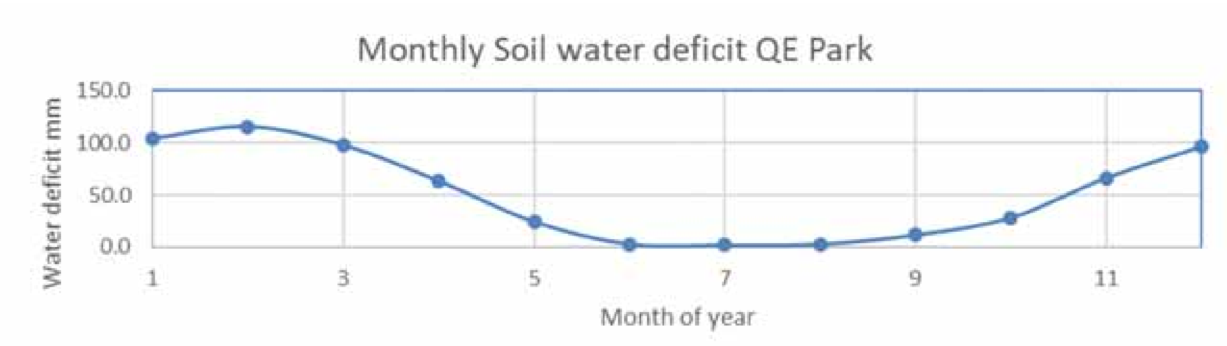

Figure 4.7: Monthly average Soil water deficit QE Park based on 150 mm storage in 0-600 mm depth range

Soil samples collected from Queen Elizabeth Park have been analysed to establish their water holding capacity as this will have a major bearing on the level of water deficit which is 4.6 % of annual rainfall. The results indicate that the actual Profile Available Water of the peatland at Queen Elizabeth Park is 175 mm with a standard deviation of 47 mm as compared to NIWA assumed value of 150 mm. Hence monthly deficits would be reduce from about 100 mm in summer to 84 mm. If all the runoff was captured by preventing flow out of the peatlands, there would be an average excess of 58 mm. This also ignores any excess water entering through seepage from surrounding areas. In essence this shows how finely balanced the water status of the peatland would be in the absence of artificial drainage.

Table 4.7: Models of 2020 Water Deficit mm Paraparaumu Aero weather station based on two PAW values (NIWA assumed value of 150 mm and actual value of 175 mm)

Month	January	February	March	Apr	May	June
PAW 150mm	117.1	71.9	36.8	5.6	0.8	0
PAW 175mm	92	47	12	0	0	0

The values shown in Table 4.7 indicate that PAW Profile Available Water is only 6% below maximum in March and not reduced at all in May. So soil horizons should be at Field Capacity (-10 kPa) in May and at 94% of Field Capacity in March. However surface and near surface horizons are considerably drier than this, being at or below Wilting Point (-1500kPa) in March, (see Table 4.2).

In summary, the reduction in HAW (Horizon Available Water) for surface horizons in the peatland reduces the average PAW for the soil profiles. Overall PAW is still 175 mm with standard deviation 47 mm in the upper 600 mm of the soil. This is still significantly higher than the 150 mm used as an approximation in NIWA water balance modelling and shows that even modified peat soils are still able to retain substantial amounts of water. The major reductions in available water capacity (AWC) are in the surface horizons but plant roots are able to bypass these areas and extend deeper into the subsoil to extract water from less modified deeper horizons. It is to be expected that water extraction would be greater in the surface horizons due to abundant roots densities, however root concentrations are still common in deeper horizons throughout the peat soil profiles.

4.2.6 Soil description and mapping

Soils in different parts of the peatland were able to be grouped according to the degree of modification, whether or not organic horizons had become hardened, and whether or not mineral matter additions had occurred. Hardening or induration that was noticed in the upper organic soil horizons creates hard clods that cannot be crushed. Examination by hand lens indicated that there were no visible large biopores and that fine roots, if present, were restricted to the surfaces between soil plates. Clods from profile site 47 were placed in water to see what changes would occur. Clods submerged without difficulty, so were not hydrophobic, however after several months the clods were still very firm. The dry bulk density was determined to be 0.88 g/cm^3, which is not high by mineral soil standards but is very high for an organic soil. By comparison, a sample from 1200 mm depth in the same area, recovered from well below the permanent water table, was little modified and had a dry bulk density of 0.197 g/cm^3. Hence densification has occurred but may be reversible in the long term with rewetting and soil biological activity. Hardening tends to be restricted to the upper subsoil less than 400 mm deep which is a zone above capillary rise in sites where summer water tables are deeper and dryness is more common.

The key attributes of the peatland soils are summarised in Table 4.8. Peat colour varied between blackish and reddish hues. In profiles where wood was uncovered, the wood fragments were reddish so this was a likely source of the peat colouration. The profiles from the southern zone of the peatland, i.e. south of North Branch Whareroa Stream, all had blackish peat colours and this coincided with very little wood being detected in the probing surveys from this zone. Decomposition of the peat was more advanced, with most sites belonging to the Humic Organic group. Peat depths also tend to be shallower than in the more northern zones. Soil and soil water pH values were less acidic than in the other areas. These features were consistent with peat decomposition rates being higher in the southern zone.

It is not surprising that peat decomposition was more advanced in areas where there was proximity to less acidic soil water and a greater availability of nutrients from surrounding mineral soils. Organic horizon hardening occurred in one site in this area. One exception was site 22 that had a cap of wet gleyed mineral soil which would have dampened fluctuations in soil moisture and so reduce chances of hardening occurring.

In the central and northern zones, north of North Branch Whareroa Stream there was a pattern of more reddish peat on the eastern side where wood was more common in the profile and hardening only occured on the western side where peat depths also tended to be shallower. Soil water acidity was also higher in these western areas. The great majority of the soils in these areas were classified as belonging to Mesic Organic group, indicating an intermediate level of peat decomposition. Profiles that exhibit hardening of the organic horizons only occurred in the western sites and were associated with the Humic Organic group classification.

Table 4.8: Summary table of key Peatland Organic soil attributes

Site No.	Classification	Location zone	Location side	Peat Colours	Horizon Hardened	Water Table mm	Comment
22	Mellow Humic	South	West	Blackish	See comment	-700	Surface almost 30 cm of gley mineral soil so no organic hardening.
33	Mellow Mesic	South	East	Blackish	No	380	Best wetland vegetation character of profile sites, a few hard granules
47	Mellow Humic	South	West	Blackish	Yes	-	Some sand in topsoil
139	Acid Mesic	Central	West	Blackish over reddish	No	-900	Minor sand in topsoil
141	Mellow Mesic	Central	East	Reddish	No	-	Minor sand in topsoil
155	Acid Mesic	Central	West	Reddish over blackish	Yes	-540	Minor sand in topsoil
196	Acid Mesic	North	East	Blackish over reddish	No	-460	Minor sand in topsoil
202	Mellow Humic	North	West	Reddish over blackish	Yes	-	No sand observed
221	Acid Mesic	North	East	Reddish	No	-420	No sand observed a few hard granules
226	Acid Mesic	North	West	Blackish	No	-370	Minor sand in topsoil

4.2.7 Soil mapping units identified

The majority of points on the grid surveyed were classified as peat soils, totalling 122 ha. Within the peat there were differences in fibre content and acidity - the major factors influencing the group and sub group soil classification. These organic soil boundaries were not easily field mapped in the time available however and instead soil profiles were described at a range of sites across the area and some general conclusions were drawn. The soil classification was complicated by the degree of cultural (agricultural) modification that had occurred within the peatland, as this was not uniform and was as important as differences in soil classification. Soils were classified down to subgroup level where possible. Soil descriptions are detailed in Appendix C.

A distinction could be drawn between organic soils south of Whateroa Stm Nth branch and the more northern organic soils as a result of the chemical analyses that had been completed The southern soils had higher pH, lower C/N ratios and higher Olsen P (see also Table 4.1). They could be classified as Mellow while the northern peats were predominately acidic however, as mentioned above, the topsoils were predominately > 4.5 pH. The southern peats were described as humic due to fibre determinations, although there were exceptions to this. Many soil horizons were close to the humic/mesic boundary but, in general, the two organic soil groupings were Acid Mesic in the north and Mellow Humic in the south.

Other soils identified in the area surrounding the peatlands were further separated into hydric and non-hydric categories (Table 4.9). Hydric soils are poorly drained (Fraser et al. 2018) and indicate areas where wetland vegetation should develop when normal soil hydrological conditions are restored, e.g. when the effects of drainage has been reversed. The soils assigned to the Hydric category totalled 14 ha. This meant that the total wetland area could potentially be 136 ha of combined organic and hydric soils if normal hydrologically conditions were restored and if irreversible changes have not significantly occurred in the hydric and organic soils. In addition 5.9 ha of mineral soils had buried peat within 1.2 m of the soil surface.

The soil pattern in the northern section (Figure 4.8) revealed two belts of organic soils, the western and eastern, separated by a ridge of varying elevation of sand dune material of Typic Sandy Brown soil corresponding to Foxton Soils (Bruce 2000). Peaty Fluvial Recent Soils were encountered closer to the Whareroa Stream North Branch. Deeper sediment deposits formed Typic Fluvial Recent and Mottled Fluvial Recent soils where the streams exited the eastern hills and sediments were deposited over the pre-existing peat material. South of the Whareroa Stream North Branch peat once again formed the soil surface until at the southern border of the area a mixed zone appeared with poorly drained mineral soils and peat layers intermingled as a result of stream deposition of sediments over peat (Figure 4.9). The western side also had some better drained fluvial soil near the Whareroa Stream South Branch but the majority of the stream edges were occupied by imperfectly drained Mottled Fluvial Recent soils. A pattern of organic soils inter-fingering with low dune sand ridges was also present in this area. The pattern of alternating peat and fluvial and or dune sand deposits was replicated through the geological column during the Pleistocene in the Kapiti Coast lowlands. As with all soil maps the soil boundaries were generalised and the soil mapping units may have included minor inclusions of other soil types that were not shown. This was most likely to have occurred in the south-western section of the peatland.

Table 4.9: Soil types present in the Queen Elizabeth Park study area

Organic Soils mapped
Acidic Mesic Organic Soil North of Whareroa Stream Nth Branch 81 ha
Mellow Humic Organic Soil South of Whareroa Stream Nth Branch 41ha
Hydric Soils mapped
These soils are located at in central and southern end of the study area.
Peaty Recent Gley: 2.3 ha
Typic Recent Gley 3.6 ha
Peaty Fluvial Recent 8.1 ha
Peaty Recent Gley: Recent Gley soils that have a peaty topsoil at the surface or buried within 60 cm of the soil surface. They occur in the southern section of the area, often peat is buried under a layer of mineral soil.
Typic Recent Gley. Also in southern section bordering the organic soils with less humic material in the soil profile but showing hydromorphic features of poor drainage.
Peaty Fluvial Recent. In southern and central sections. Mineral soils overlying humic/peaty horizons but have not developed hydromorphic features at present in the mineral soil.
Non hydric soils mapped
Mottled Fluvial Recent, Typic Fluvial Recent, Typic Sandy Recent, Typic Sandy Brown.
Mottled Fluvial Recent. Imperfectly drained but do not have hydromorphic profile features, located on southern margin of peat area as well as marginal to Whareroa Stream.
Typic Fluvial Recent. In the central and southern sections of the peatlands, near streams have built up enough sediment to be free draining in the upper soil profile.
Typic Sandy Recent Formed from more recently deposited dune sand and some fluvial sediments. Do not show the more developed profile form of the Typic sandy Brown soils which are less mobile.
Earthy Fill Anthropic. An artificial soil in the extreme north of the study area, without pedogenic horizons, in this case created by dumping of fill.
Typic Sandy Brown. The dominant soil type of the non-peat areas show signs of subsoil development where aeolian sand is relatively stable’

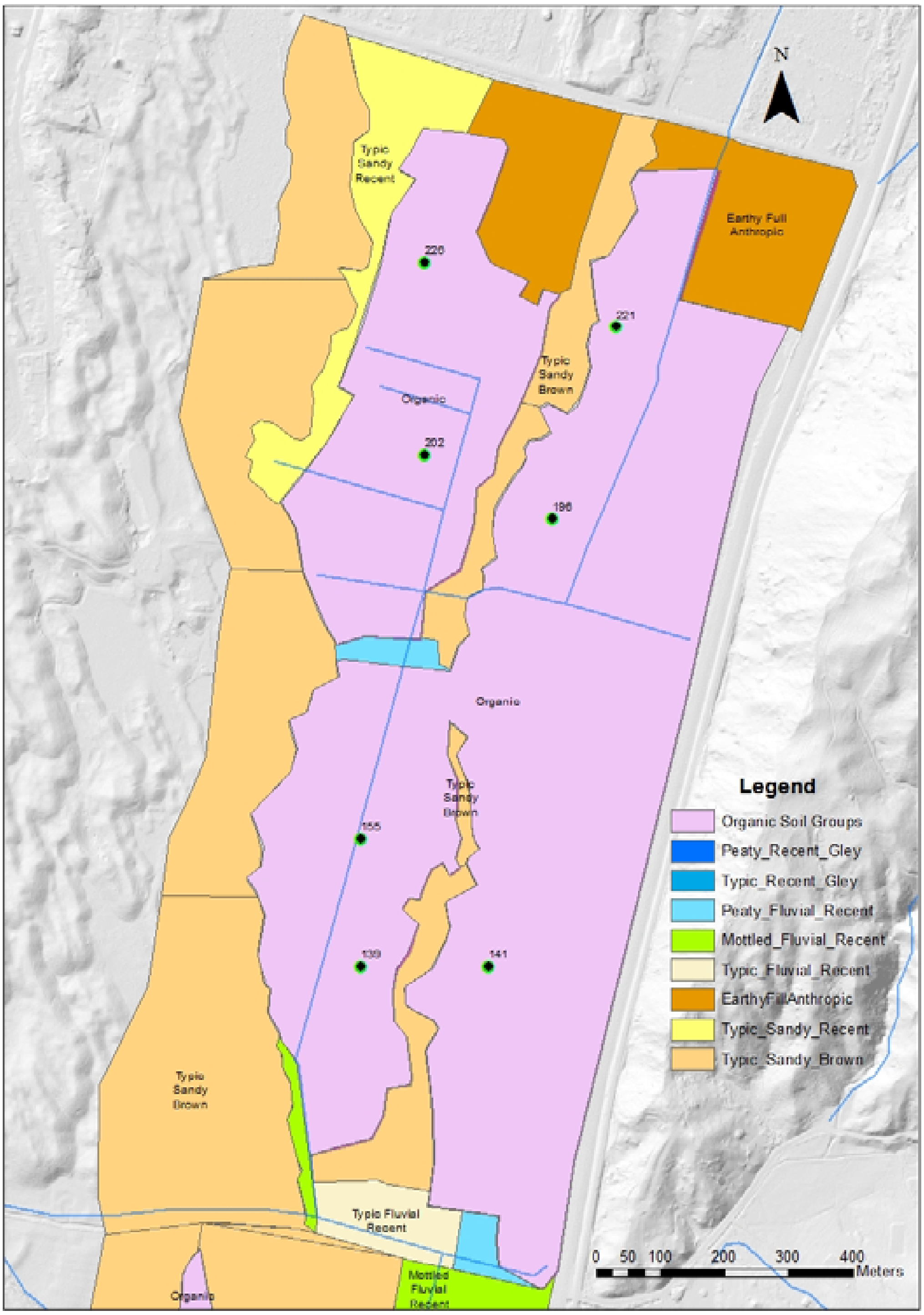

Figure 4.8: Soil map of northern section of peatland survey area. Organic soil in this area has been classified as Acid Mesic Organic, soil types shown in blue are hydric soils. Scale 1:14,000.

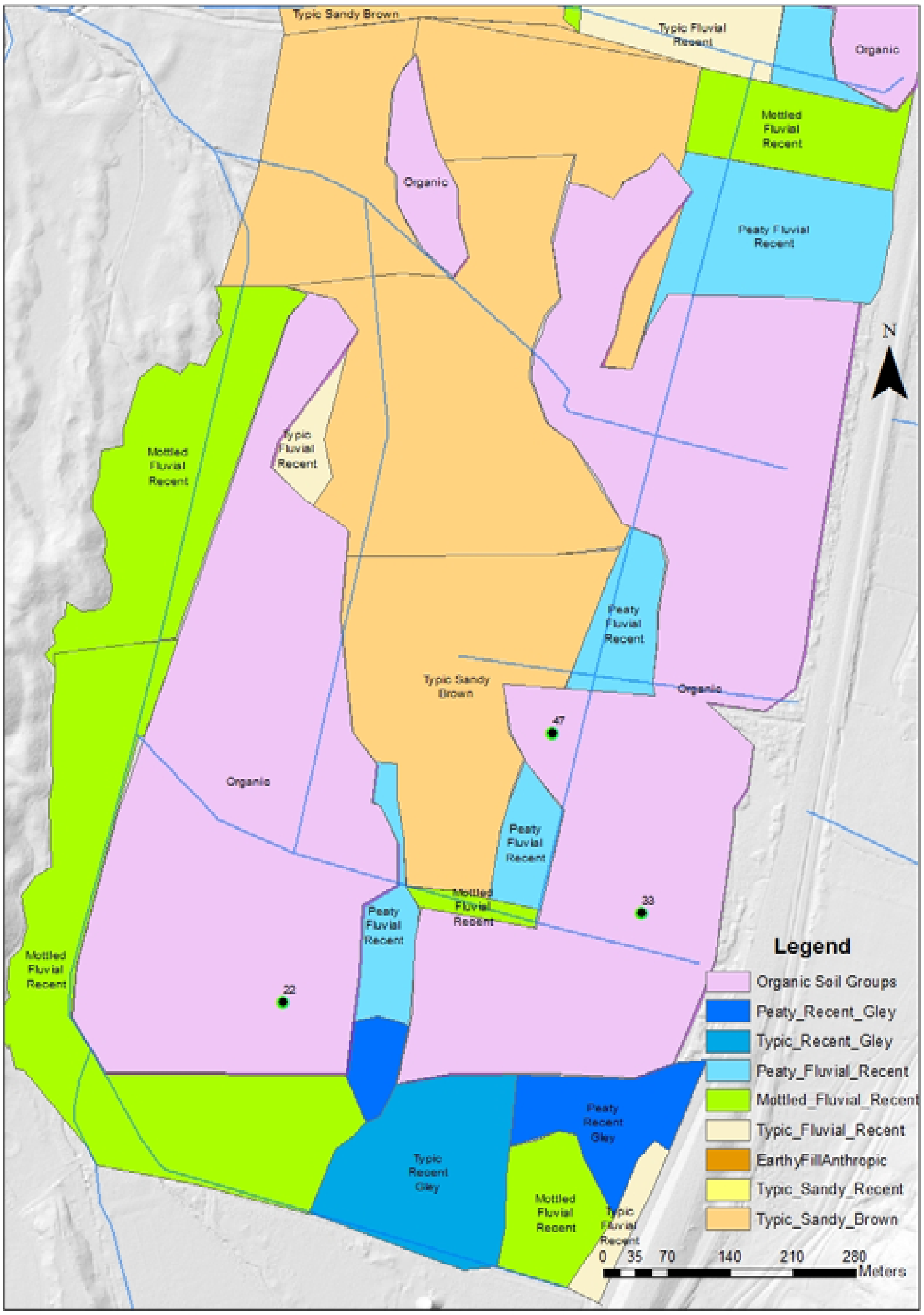

Figure 4.9: Soil map of southern section of peatland survey area south of North Branch Whareroa Stream. Organic soil in this area has been classified as Mellow Humic Organic, soil types shown in blue are hydric soils. Scale 1:10,000.

5. Discussion

An area of 122 hectares of Organic peat soils up to 3.6 m deep was identified at Queen Elizabeth Regional Park during an investigation of peatland extent and soil mapping completed in 2020. Buried peat zones and Hydric Soils which showed evidence of water logging were also noted. Peat depths were greater in the north-eastern section of the peatland. This area also had the highest concentration of well-preserved woody material indicating that this area had once supported swamp forest. While organic soils were mapped throughout the peatland, the composition differed especially between southern and northern sections. In the southern section the peat depth was shallower, with less organic matter and a higher proportion of mineral content as well as higher fertility and pH.

Drainage by lowering water tables has led to peat shrinkage and higher bulk densities in surface soil horizons. The effect of shrinkage alone is estimated by bulk density changes to equate to a 38 cm reduction in soil surface level as compared to the original undisturbed state. Soil pore size distributions have changed in the organic soils and contrary to what might have been forecast, there has been a shift to larger pore sizes and a reduction in pores suitable for storing water available to plants. Surface soil horizons especially in the mesic peats have become hardened with drying and surface water content levels are anomalously low which may reflect water repellency or by pass flow to deeper horizons. Soil trafficability has been increased due to a rise in soil bearing capacity. The organic soil surface horizons could be characterised as acting like Styrofoam blocks. Capillary rise within the peat soils has been observed, which to a degree offsets drainage effect.

There is little historical information available on rates of organic matter decomposition within the peatland but one comparison of peatland depths in the north-eastern section of the wetland indicated no substantial changes in peat depth in the last seventy years. It is likely that the surface level of the peat has stabilised due to the degree of earlier modifications. Raising water tables would therefore have little effect on land surface levels until new peat accumulation occurs. Most of the modification to the peatland has occurred in the upper soil profile, predominately within 25 cm of the soil surface. The deeper horizons, which are still within the depth range of surface plant roots, have been relatively unaffected.

Measurements of soil water and surface water quality were available mostly from the north-eastern section of the peatland. These indicate high nutrient levels within the soil water table and surface water near the northern boundary of the peatland, declining with increasing distance from the edge of the peatland. More generally, soil water acidity, as an indication of peat forming processes, was in the pH 3-4 range in the northern section of the peatland and approximately pH 5 in the southern section. Soil fertility analyses confirmed this picture of higher nutrient availability of phosphorus in the southern peatland soils along with lower C/N ratios. Both P and C/N were more favourable for native wetland species in the northern peatland section. The highest fertility was in the topsoils where pH was also generally greater than pH 4.5. Exotic pasture species are advantaged at a pH higher than 5 and these sites occurred more frequently in the southern section. Overall fertility was higher than ideal throughout the peatland but this could decline with higher soil water levels and cessation of further fertiliser addition. That being said, a site in the south-eastern zone of the peatland, retired since 2015, showed a high degree of wetland vegetation character along with relatively high pH, Olsen P, Total Kjeldahl P and low C/N ratio suggesting that at least some wetland vegetation species are competitive within these levels of soil fertility. Wetland species with different pH and nutrient tolerances may be needed for the restoration to take into account their fertility requirements and competitiveness with non-wetland species.

Soil physical analysis has revealed that the peat soils of the southern area of the peatland have more mineral content than the northern soils which act more like pure peats. However the southern soils still have sufficient organic matter to have the water holding capacity to provide adequate moisture for wetland plants as demonstrated by site 33 which may have become more hydromorphic with time. The northern peat sites show a degree of peat degradation in the upper soil which is not evident in the southern sites perhaps due to the lower carbon content of the southern sites. This includes changes in pore size distribution to become more coarse-pored, a reluctance to rewet after drying and formation of very firm stable clods. Plant roots however are able to bypass these disturbed zones and surface plants are able to extract water from deeper zones in the soil profile and PAW is adequate. It is fortuitous that the depth to groundwater has not been greater as that may have made the degradation depth zone significantly larger. Raising of water tables into the bottom of this zone or shallower will help in the process of rewetting these disturbed surface horizons.

Rehydration may be encouraged with shallow to near surface water tables at least in the short term. It would be useful to monitor soil water contents within the soil matrix in the surface horizons in addition to only measuring water table levels to assess if barriers to rewetting have been overcome. The near saturation hydraulic conductivity of the affected pores size shifted soil horizons should have been improved however conductivity measurements would need to be carried out and the degree of pore connectivity assessed. The soil surface and near surface horizons have a high bearing capacity which is reflected in penetration resistance values and profile description notes on the presence of hardened soil clods. The improved trafficability of the soils due to hardening may continue for some time after rewetting by raising water table levels. The low water content values noted above may also have had an effect of reducing peat oxidation rates due to sub optimal water contents. Compared to other peatlands in the Wellington Region Queen Elizabeth Park peatlands have relatively high bulk densities and carbon content resulting in higher carbon densities per unit volume.

In conclusion, the past management of the peatlands with drainage, burning, cultivation and introduction of exotic species both accidently and deliberately has modified the chemical, physical and biological properties of the surface horizons of the peat soils. These changes have made them less suitable to sustain and encourage native wetland plant species at the expense of other species. However, the soils have also reacted by becoming more robust and resistant to further change, perhaps slowing down further decomposition. The effects are concentrated at relatively shallow depths meaning that the majority of deeper horizons within peat soil profiles are less affected. So there are good indications that the soil health and peat forming processes can be restored by rewetting and re-establishing appropriate native species.

Acknowledgements

During the field survey I received valuable assistance from Rob Craven (GWRC), in the probing survey with his companionship in the field, botanical discussions and especially his ability to manoeuvre an aluminium probe between wood branches and roots to a satisfactory thump at the bottom of the peat body. Landcare Research at Palmerston North and Hamilton provided soil analysis for chemistry and physics samples. Hill Laboratories analysed soil water chemistry samples. I also appreciated the presence of Neville Moars' 1951 field work as an example of what could be done during a peatland survey. At various stages during the write up of this survey I felt that I was confirming what a resourceful scientist had previously discovered.

References

Bowler DG. 1980. *The Drainage of Wet Soils.* Hodder and Stoughton. 259p.

Bruce J. 2000. The Soils of Wellington. In: (Eds) McConchie J, Willis R and Winchester J. *Dynamic Wellington, a contemporary synthesis and explanation of Wellington*. Institute of Geography, Victoria University of Wellington. Wellington.

Fleming CA. 1972. The contribution of C14 dates to the quaternary geology of the "Golden Coast", western Wellington. *Tuatara, Journal of the Biological Society Victoria University Wellington* 19(2): 61-69

Fraser S, Singleton P, Clarkson B. 2018. *Hydric soils – field identification guide*. Contract Report LC 3233. Tasman District Council.

Gradwell MW. 1972. *Methods for physical analysis of soils*. New Zealand Soil Bureau Scientific Report 10C.

Hewitt AE. 2010. *New Zealand Soil Classification.* Landcare Research science series; no.1 (3rd ed.)

Johnson P and Gerbeaux P. 2004. *Wetland Types in New Zealand*. Department of Conservation Landcare Research website – https://www.landcareresearch.co.nz/

McFadgen, B G 2010. Archaeoseismology – A New Zealand Perspective. In: A Salute to the Captain – Celebrating the 100th Birthday of Emeritus Professor J B Mackie, 3 September 2010. Festschrift to J B Mackie, University of Otago School of Mines. pp.85-100.

McQueen, D. J. 1993: *Glossary of soil physical terms*. 28p. Landcare Research, Lower Hutt New Zealand. ISBN 0-478-04504-2

Milne JDG, Clayden B, Singleton,PL and Wilson AD.1995. *Soil Description Handbook,* rev. ed. Manaaki Whenua Press, Lincoln New Zealand.

Moar NT.1952. A botanical survey of a peat area between Raumati South and Paraparaumu. *New Zealand Journal of Science and Technology A. Agricultural Section* 33(5): 78-89.

Moar NT. 1954. Peat profiles Whareroa Block, Paekakariki, New Zealand. *New Zealand Journal of Science and Technology A. Agricultural Section* 36(3):221-231.

NEMS 2019. National Environmental Monitoring Standards Water Quality Part 1 Groundwater March 2019 Version 1.0.0 http://www.nems.org.nz

Nugraha MI, Annisa W, Syaufina L and Anwar S 2016. Capillary water rise in peat soil as affected by various groundwater levels. Agricultural Science Vol 17; No 2.

Pronger J, Schipper LA, Hill RB, Campbell DI and Mcleod M.2014. Subsidence rates of drained agricultural peatlands in New Zealand and the relationships with time since drainage. *Journal of Environmental Quality:*43: 1442-1449.

Rezanezhad R, Price JS, Quinton W L, Lennartz B, Milojevic T, Van Cappellen P. 2016. Structure of peat soils and implications for water storage, flow and solute transport: A review update for geochemists. *Chemical Geology,* 429 p75-84.

Wilmshurst JM, Bolstridge N. 2019. *Reconstructing baseline vegetation for restoration using pollen records: Paekakariki, Wellington. Landcare Research Contract Report LC3449* for Greater Wellington Regional Council.

Yulianto FE, Harwardi F and Rusdiansyahi 2019. Characteristics of Palangkaraya fibrous peat. MATEC Web of Conferences 276, 0https://doi.org/10.1051/matecconf /20192760 0 ICAnCEE 2018

Appendix A: Soil and water quality sampling results

https://www.landcareresearch.co.nz/partner-with-us/laboratories-and-diagnostics/environmental-chemistry-laboratory/soil-testing/#

Table A1.1: Chemistry and Physics data Landcare research

Client ID	Sample No.	Water Content (method 105) (% dry wt)	Dry Bulk Density (method 105) (T/m^3)	pH (1:5 Water) (method 106(ii))	Ratio used for pH/EC (soil: water) 1:	EC (1:5) (method 110) (dS/m)	Organic C (method 114) (%)	Total N (method 114) (%)	C/N ratio (calculation)*	Total Kjeldahl P (method 116) (%)	Olsen P (method 124) (mg/kg)	Air-dried Soil Water Content (method 104(i) mod)* (% dry wt)
Testing start date		17/06/2020	17/06/2020	22/09/2020		22/09/2020	31/07/2020	31/07/2020		12/08/2020	10/08/2020	30/07/2020
Testing end date		18/06/2020	18/06/2020	8/10/2020		8/10/2020	4/08/2020	4/08/2020		17/08/2020	11/08/2020	31/07/2020
Accreditation status		accredited	accredited	accredited		accredited	accredited	accredited	non-accredited	accredited	accredited	non-accredited
Site 33 GW020	M19/4315	not requested	not requested	5.1	5.0	0.24	13.4	1.10	12	0.180	26	6.4
Site 33 GW025	M19/4316	not requested	not requested	4.9	5.0	0.22	12.4	0.98	13	0.160	21	6.1
Site 22 GW045	M19/4317	36	0.958	4.8	5.0	0.20	8.37	0.71	12	0.100	11	4.4
Site 22 GW063	M19/4318	not requested	not requested	4.4	5.0	0.38	27.7	1.44	19	0.102	22	7.8
Site 22 120	M19/4319	not requested	not requested	not requested		not requested	34.7	0.99	35	not requested	not requested	8.3
Site 141 GW015	M19/4320	not requested	not requested	4.7	5.0	0.10	35.9	1.61	22	0.084	5	8.5
Site 141 GW042	M19/4321	not requested	not requested	3.6	5.0	0.28	61.4	1.15	53	0.024	15	9.4
Site 141 110-120	M19/4322	not requested	not requested	not requested		not requested	64.3	0.95	68	not requested	not requested	9.0
Site 47 GW060	M19/4323	not requested	not requested	5.0	5.0	0.20	13.5	1.07	13	0.153	24	5.5
Site 47 GW062	M19/4324	not requested	not requested	4.7	5.0	0.10	18.3	1.02	18	0.109	22	6.6
Site 47 GW084	M19/4325	not requested	not requested	4.1	5.0	0.34	44.1	1.87	24	0.070	16	9.9
Site 202 GW047	M19/4326	not requested	not requested	5.1	5.0	0.07	49.7	1.56	32	0.084	33	11.0
Site 202 GW051	M19/4327	not requested	not requested	3.9	6.2	0.25	63.2	0.87	73	0.018	60	9.6
Site 202 110-120	M19/4328	not requested	not requested	not requested		not requested	59.9	1.08	56	not requested	not requested	11.6
Site 139 GW074	M19/4329	not requested	not requested	4.9	5.0	0.10	35.6	1.30	27	0.069	15	8.6
Site 139 GW099	M19/4330	not requested	not requested	3.7	5.0	0.28	63.7	0.87	73	0.013	82	8.7
Site 139 110-120	M19/4331	not requested	not requested	not requested		not requested	51.9	1.06	49	not requested	not requested	11.8
Site 155 GW003	M19/4332	61	0.400	4.5	5.0	0.19	43.8	1.58	28	0.071	14	10.3
Site 155 GW077	M19/4333	371	0.204	3.6	5.0	0.43	55.0	1.25	44	0.024	23	12.1
Site 226 226/1	M19/4334	230	0.343	4.0	5.0	0.22	47.7	1.80	27	0.078	22	10.4
Site 226 100	M19/4335	not requested	not requested	not requested		not requested	57.5	1.28	45	not requested	not requested	13.5
Site 221 221/1	M19/4336	not requested	not requested	5.1	6.0	0.12	52.3	1.73	30	0.063	6	12.6
Site 221 221/2	M19/4337	not requested	not requested	4.4	6.2	0.10	60.6	1.15	53	0.026	17	10.5
Site 221 80-100	M19/4338	not requested	not requested	not requested		not requested	62.1	0.86	72	not requested	not requested	11.8

Table A 1.2: Soil Physical Properties analysed by Landcare Research

Moisture Release & Solid/Void Characterisation

Project Name: Greater Wellington Regional Council Peat Sampling 2020
Contact Name: David McQueen
Job Number: PRJ959
Date: 21/12/2020

Lab Number	Client ID	Horizon Depth (cm)	Sample Depth (cm)	Sampled Liner Number	Lab Liner Number	Initial Water Content (%, w/w)	Dry Bulk Density (t/m^3)	Particle Density (t/m^3)	Total Porosity (%, v/v)	Macro Porosity (%, v/v)	Air Filled Porosity (%, v/v)	Vol. WC 0.4 kPa (%, v/v)	Vol. WC 0.7 kPa (%, v/v)	Vol. WC 1 kPa (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)	Vol. WC 20kPa (%, v/v)	Vol. WC 40kPa (%, v/v)	Vol. WC 100kPa (%, v/v)	Vol. WC 1500kPa (%, v/v)	Readily Available Water (%, v/v)	Total Available Water (%, v/v)
HP9077	Tauherenikau 25-75mm			GW092	916	12.7	1.27	2.67	52.5	14.3	18.2			45.2	38.1	34.3	31.3	28.8	25.6	14.3	8.7	20.0
HP9078	Tauherenikau 270 - 340mm			GW036	912	6.0	1.35	2.74	50.6	25.7	30.3			35.9	25.0	20.4	16.7	14.3	11.8	7.3	8.6	13.1
HP9079	Tanawa Hut 50-120mm			GW006	915	45.2	1.03	2.47	58.4	7.5	10.9			55.9	50.9	47.5	44.6	42.4	40.8	22.7	6.7	24.8
HP9080	Tanawa Hut 220 - 290mm			GW007	925	20.7	1.16	2.59	55.3	11.1	13.8			50.8	44.2	41.5	39.2	37.0	33.6	26.1	7.9	15.4
HP9081	Tanawa Hut 320-550mm			GW009	910	39.1	1.20	2.62	54.1	10.0	12.2			49.6	44.1	41.9	39.8	38.1	35.7	30.3	6.2	11.6
HP9082	Site 33			GW020	918	191.1	0.36	2.19	83.8	21.2	26.4			71.0	62.5	57.3	53.5	49.7	45.2	21.4	12.2	35.9
HP9083	Site 33			GW025	914	139.2	0.50	2.25	78.0	13.1	16.2			68.3	64.9	61.8	58.8	55.4	50.7	31.1	11.1	30.7
HP9084	Site 22			GW063	919	258.5	0.29	1.95	85.3	19.2	24.2			74.8	66.1	61.1	56.7	53.6	50.2	28.7	10.9	32.4
HP9085	Site 141			GW015	905	98.6	0.49	1.73	71.8	5.0	13.2			70.2	66.7	58.6	55.4	51.9	49.2	30.8	9.4	27.8
HP9086	Site 141			GW042	911	416.2	0.17	1.48	88.2	15.7	18.1			81.2	72.5	70.2	68.4	67.3	65.9	22.0	4.3	48.2
HP9087	Site 47			GW060	906	44.6	0.83	2.32	64.3	11.9	15.4			59.5	52.4	48.9	47.1	45.2	42.3	33.7	6.6	15.2
HP9088	Site 47			GW062	913	52.5	0.68	2.26	69.7	20.4	24.0			57.7	49.3	45.7	43.4	41.8	39.9	34.4	5.8	11.3
HP9089	Site 47			GW084	900	159.5	0.26	1.72	84.7	30.8	35.9			65.7	53.8	48.8	45.6	43.5	40.8	32.0	7.9	16.7
HP9090	Site 202			GW047	902	47.5	0.43	1.58	72.6	32.0	36.7			44.0	40.6	37.5	35.5	34.2	31.2	25.7	4.7	10.1
HP9091	Site 202			GW051	901	303.1	0.23	1.47	84.0	10.4	12.6			76.0	73.6	71.5	69.1	66.2	63.7	30.4	7.8	41.0
HP9092	Site 139			GW074	904	40.5	0.50	1.71	70.6	25.6	32.2			53.3	45.0	38.4	34.2	31.4	28.3	21.6	10.1	16.8
HP9093	Site 139			GW099	917	323.4	0.21	1.40	85.1	13.9	16.2			76.3	71.2	68.8	67.2	65.4	63.5	28.6	5.3	40.2
HP9094	Site 221			221/1	907	135.5	0.37	1.59	77.0	19.0	25.8			63.8	58.0	51.2	50.4	49.0	48.2	23.3	2.9	27.8
HP9095	Site 221			221/2	908	142.1	0.24	1.43	83.3	40.5	44.1			52.8	42.8	39.2	37.6	36.4	35.2	29.1	4.1	10.1

Notes: Macro-porosity cited here is determined between total porosity and tension of -5 kPa, for consistency with the National Soils Database of New Zealand (NSD).

Air-filled porosity cited here is determined between total porosity and tension of -10 kPa. This can be referred to as Macro-porosity.
It is important to be aware what tension has been used, particularly when data is compared with historical or NSD data.

Several of the samples were wrapped in cling film that was not sealed properly. Some of the samples looked to have dried. No known replicates were collected at any of the sites.

For Site 202 (HP9090) following analysis and calculation of the moisture release data the points were checked and appeared to be erroneous for 10 and 20 kPa. The full moisture release curve was plotted and the volumetric water contents at 10 and 20 kPa were interpolated. Those interpolated values are included above.

Table A 1.3(i): Water quality sample from piezometer BP32/0117 analysed by Hill Laboratories, Hamilton

Certificate of Analysis

Page 1 of 3

Client:	Greater Wellington Regional Council	**Lab No:**	2380655 DWSSP-8v1
Contact:	GWRC - Ground Water Samples	**Date Received:**	09-Jun-2020
	C/- Greater Wellington Regional Council	**Date Reported:**	22-Jun-2020
	PO Box 11646	**Quote No:**	99479
	Manners Street	**Order No:**	252434
	Wellington 6142	**Client Reference:**	GW Wellington Run Day 2
		Submitted By:	David McQueen

Sample Type: Aqueous

	Sample Name:	BP32/0117 14-May-2020 9:00 am	Guideline Value	Maximum Acceptable Values (MAV)
	Lab Number:	2380655.8		
pH	pH Units	6.6	7.0 - 8.5	-
Total Alkalinity	g/m³ as $CaCO_3$	260	-	-
Bicarbonate	g/m³ at 25°C	320	-	-
Electrical Conductivity (EC)	mS/m	36.1	-	-
Total Dissolved Solids (TDS)	g/m³	470	-	-
Dissolved Boron	g/m³	0.081	-	1.4
Dissolved Calcium	g/m³	6.3	-	-
Dissolved Iron	g/m³	1.66	< 0.2	-
Dissolved Magnesium	g/m³	5.7	-	-
Dissolved Manganese	g/m³	0.020	< 0.04 (Staining) < 0.10 (Taste)	0.4
Dissolved Potassium	g/m³	3.3	-	-
Dissolved Sodium	g/m³	17.5	< 200	-
Chloride	g/m³	35	< 250	-
Total Nitrogen	g/m³	13.9	-	-
Total Ammoniacal-N	g/m³	0.40	< 1.2	-
Nitrite-N	g/m³	0.015	-	0.06 0.91 (short term)
Nitrate-N	g/m³	0.31	-	11.3
Nitrate-N + Nitrite-N	g/m³	0.33	-	-
Total Kjeldahl Nitrogen (TKN)	g/m³	13.5	-	-
Dissolved Reactive Phosphorus	g/m³	0.25	-	-
Total Phosphorus	g/m³	2.0	-	-
Sulphate	g/m³	4.3	< 250	-
Total Organic Carbon (TOC)	g/m³	230	-	-

Note: The Guideline Values and Maximum Acceptable Values (MAV) are taken from the publication 'Drinking-water Standards for New Zealand 2005 (Revised 2018)', Ministry of Health. Copies of this publication are available from https://www.health.govt.nz/publication/drinking-water-standards-new-zealand-2005-revised-2018

The Maximum Acceptable Values (MAVs) have been defined by the Ministry of Health for parameters of health significance and should not be exceeded. The Guideline Values are the limits for aesthetic determinands that, if exceeded, may render the water unattractive to consumers.

Under Section 69ZZ (2) of the Health Act (1965), the laboratory is required to report the results of any analysis or test carried out (for the purposes of testing for compliance with the New Zealand Drinking Water Standards 2005 (Revised 2018)) that indicates any non-compliance (transgression) with the Maximum Acceptable Values (MAVs) to the Drinking Water Assessor.

Table A 1.3(ii): Water quality sample from piezometer BP32/0119 analysed by Hill Laboratories, Hamilton

Certificate of Analysis

Page 1 of 3

Client:	Greater Wellington Regional Council	**Lab No:**	2380655 DWSSP-9v1
Contact:	GWRC - Ground Water Samples	**Date Received:**	09-Jun-2020
	C/- Greater Wellington Regional Council	**Date Reported:**	22-Jun-2020
	PO Box 11646	**Quote No:**	99479
	Manners Street	**Order No:**	252434
	Wellington 6142	**Client Reference:**	GW Wellington Run Day 2
		Submitted By:	David McQueen

Sample Type: Aqueous

	Sample Name:	BP32/0119 14-May-2020 11:00 am	**Guideline Value**	**Maximum Acceptable Values (MAV)**
	Lab Number:	2380655.9		
pH	pH Units	6.6	7.0 - 8.5	-
Total Alkalinity	g/m³ as $CaCO_3$	189	-	-
Bicarbonate	g/m³ at 25°C	230	-	-
Electrical Conductivity (EC)	mS/m	56.3	-	-
Total Dissolved Solids (TDS)	g/m³	410	-	-
Dissolved Boron	g/m³	0.010	-	1.4
Dissolved Calcium	g/m³	1.70	-	-
Dissolved Iron	g/m³	0.18	< 0.2	-
Dissolved Magnesium	g/m³	1.42	-	-
Dissolved Manganese	g/m³	0.044	< 0.04 (Staining) < 0.10 (Taste)	0.4
Dissolved Potassium	g/m³	1.20	-	-
Dissolved Sodium	g/m³	11.8	< 200	-
Chloride	g/m³	85	< 250	-
Total Nitrogen	g/m³	5.6	-	-
Total Ammoniacal-N	g/m³	1.46	< 1.2	-
Nitrite-N	g/m³	0.005	-	0.06 0.91 (short term)
Nitrate-N	g/m³	1.39	-	11.3
Nitrate-N + Nitrite-N	g/m³	1.39	-	-
Total Kjeldahl Nitrogen (TKN)	g/m³	4.2	-	-
Dissolved Reactive Phosphorus	g/m³	< 0.004	-	-
Total Phosphorus	g/m³	0.111	-	-
Sulphate	g/m³	0.7	< 250	-
Total Organic Carbon (TOC)	g/m³	21	-	-

Note: The Guideline Values and Maximum Acceptable Values (MAV) are taken from the publication 'Drinking-water Standards for New Zealand 2005 (Revised 2018)', Ministry of Health. Copies of this publication are available from https://www.health.govt.nz/publication/drinking-water-standards-new-zealand-2005-revised-2018

The Maximum Acceptable Values (MAVs) have been defined by the Ministry of Health for parameters of health significance and should not be exceeded. The Guideline Values are the limits for aesthetic determinands that, if exceeded, may render the water unattractive to consumers.

Under Section 69ZZ (2) of the Health Act (1965), the laboratory is required to report the results of any analysis or test carried out (for the purposes of testing for compliance with the New Zealand Drinking Water Standards 2005 (Revised 2018)) that indicates any non-compliance (transgression) with the Maximum Acceptable Values (MAVs) to the Drinking Water Assessor.

Table A 1.3(iii): Water quality sample from North Whareroa Drain analysed by Hill Laboratories, Hamilton

Certificate of Analysis

Page 1 of 3

Client:	Greater Wellington Regional Council	**Lab No:**	2380655 DWSSP-7v1
Contact:	GWRC - Ground Water Samples	**Date Received:**	09-Jun-2020
	C/- Greater Wellington Regional Council	**Date Reported:**	22-Jun-2020
	PO Box 11646	**Quote No:**	99479
	Manners Street	**Order No:**	252434
	Wellington 6142	**Client Reference:**	GW Wellington Run Day 2
		Submitted By:	David McQueen

Sample Type: Aqueous

	Sample Name:	North Whareroa Drain 14-May-2020 10:00 am	Guideline Value	Maximum Acceptable Values (MAV)
	Lab Number:	2380655.7		
pH	pH Units	3.9	7.0 - 8.5	-
Total Alkalinity	g/m³ as $CaCO_3$	< 1.0	-	-
Bicarbonate	g/m³ at 25°C	< 1.0	-	-
Electrical Conductivity (EC)	mS/m	24.4	-	-
Total Dissolved Solids (TDS)	g/m³	420	-	-
Dissolved Boron	g/m³	0.061	-	1.4
Dissolved Calcium	g/m³	9.6	-	-
Dissolved Iron	g/m³	0.43	< 0.2	-
Dissolved Magnesium	g/m³	10.5	-	-
Dissolved Manganese	g/m³	0.111	< 0.04 (Staining) < 0.10 (Taste)	0.4
Dissolved Potassium	g/m³	4.0	-	-
Dissolved Sodium	g/m³	19.1	< 200	-
Chloride	g/m³	23	< 250	-
Total Nitrogen	g/m³	5.4	-	-
Total Ammoniacal-N	g/m³	0.40	< 1.2	-
Nitrite-N	g/m³	0.057	-	0.06 0.91 (short term)
Nitrate-N	g/m³	1.76	-	11.3
Nitrate-N + Nitrite-N	g/m³	1.81	-	-
Total Kjeldahl Nitrogen (TKN)	g/m³	3.6	-	-
Dissolved Reactive Phosphorus	g/m³	0.84	-	-
Total Phosphorus	g/m³	0.91	-	-
Sulphate	g/m³	37	< 250	-
Total Organic Carbon (TOC)	g/m³	155	-	-

Note: The Guideline Values and Maximum Acceptable Values (MAV) are taken from the publication 'Drinking-water Standards for New Zealand 2005 (Revised 2018)', Ministry of Health. Copies of this publication are available from https://www.health.govt.nz/publication/drinking-water-standards-new-zealand-2005-revised-2018

The Maximum Acceptable Values (MAVs) have been defined by the Ministry of Health for parameters of health significance and should not be exceeded. The Guideline Values are the limits for aesthetic determinands that, if exceeded, may render the water unattractive to consumers.

Under Section 69ZZ (2) of the Health Act (1965), the laboratory is required to report the results of any analysis or test carried out (for the purposes of testing for compliance with the New Zealand Drinking Water Standards 2005 (Revised 2018)) that indicates any non-compliance (transgression) with the Maximum Acceptable Values (MAVs) to the Drinking Water Assessor.

Table A 1.4: Summary of methods used for soil analysis

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
pH	pH meter. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	7
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (modified for Alkalinity <20) 23rd ed. 2017.	1.0 g/m^3 as $CaCO_3$	7
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 23rd ed. 2017.	1.0 g/m^3 at 25°C	7
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 23rd ed. 2017.	0.1 mS/m	7
Total Dissolved Solids (TDS)	Filtration through GF/C (1.2 µm), gravimetric. APHA 2540 C (modified; drying temperature of 103 - 105°C used rather than 180 ± 2°C) 23rd ed. 2017.	10 g/m^3	7
Dissolved Boron	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.005 g/m^3	7
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.05 g/m^3	7
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.02 g/m^3	7
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.02 g/m^3	7
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.0005 g/m^3	7
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.05 g/m^3	7
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.02 g/m^3	7
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3.	0.05 g/m^3	7
Total Ammoniacal-N	Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23rd ed. 2017.	0.010 g/m^3	7
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	7
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3	7
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) 23rd ed. 2017.	0.10 g/m^3	7
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m^3	7
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis and also modified to include a reductant to reduce interference from any arsenic present in the sample) 23rd ed. 2017. NWASCO, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3	7
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	7

Lab No: 2380655 v 1 Hill Laboratories Page 2 of 3

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Total Organic Carbon (TOC)	Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC.The uncertainty of the calculated result is a combination of the uncertainties of the two analytical determinands in the subtraction calculation. Where both determinands are similar in magnitude, the calculated result has a significantly higher uncertainty than would normally be achieved if one of the results was significantly less than the other. In such cases, the elevated uncertainty should be kept in mind when interpreting the data. APHA 5310 C (modified) 23rd ed. 2017.	0.5 g/m^3	7

Appendix B: Photographs of the Queen Elizabeth peatland survey site

Figure A2.1: Peat Profile showing presence of water table and height of capillary rise

Figure A2.2: Confluence of Whareroa Stream Nth Branch and North Whareroa Drain, notice the indication of humic stained discharge from the drain while the Whareroa stream on the left is running clear. Direction of flow is westward away from camera underneath the fence battens.

Figure A2.3: Probing survey underway. The depth of peat at this site is indicated by position of clothes-peg attached to upper section of probe.

Figure A2.4: View of part of northern section of peatland proposed for restoration. Looking eastward from median sand ridge towards Kapiti Expressway. Acid Mesic Organic soils are in the middle distance.

Figure A2.5: View southward in northern peatland area with sand ridge in foreground, which are Typic Sandy Brown Soil. On the right, paddocks of pasture species are developed on Acid Mesic Organic soils.

Figure A2.6: View south over trenched Whareroa Stream, North Branch. In foreground are Typic Sandy Brown soils, while Hydric soils are to the south. Near the shelter belt, Mellow Humic Organic soils are present.

Figure A2.7: Site in northern section of peatland with high concentration of stumps and buried wood (Acid Mesic Organic soil) in south-western part of northern section of peatland

Figure A2.8: Material from site 139, area shown in Figure A2.7

Figure A2.9: Site 33 in the south-eastern section of peatland, Mellow Humic Organic soils, retired from grazing with shallow water table and range of wetland plants

Appendix C: Soil descriptions

Grid site: 22
Grid Reference: E1766618 N5463274
Vegetation: Buttercups, broadleaved weeds, ryegrass, tall fescue, docks, *Juncus edgariae*
0-5 cm **Horizon A_1** Moisture status dry; Brown 10YR4/3; silt loam; moderate developed very fine nut and crumb; Penetrometry 1.5MPa low[X]; abundant fine roots; permeability good; firm in place.
5-25 cm **Horizon AC_g** dry to slightly moist; Dark greyish brown matrix 10YR 4/2 70% ; yellowish red 5YR4/6 mottles 30%; clay loam; well developed very coarse blocks, breaks to well developed medium to fine block; Penetrometry 2.85MPa high (limiting to plant growth); many fine and medium roots; permeability poor; very firm; plastic and slightly sticky.
25-54 cm **Horizon O_{h1}** moist; black 10YR 2/1; peat well decomposed less than 15% rubbed fibre, (humic);
54-70 as above with many root remnants
70-90 as above with fewer root remnants water table at 70 cm
90-120+ cm **Horizon O_{h2}** saturated ,; peat; very dark grey to black 10YR 3/1 to 2/1; von Post 8-9, 20% volume retained on squeezing.
Comment: This site has had addition of mineral alluvial material from a stream deposition over the peat deposit. High penetration resistance restricted to mineral horizon.
[X]*Penetrometry resistance to roots values of high or greater are limiting to root growth, see Milne et a l(1995) pg.86.*
Average soil pH is 4.6 so mellow classification.
Classification: Mellow Humic Organic **OHM** still keys out as an Organic soil but more weathered and decomposed than other soils of the area being on the edge of the peatland.
Note, also have high water specific conductivity below 70 cm implying some saline influence in groundwater.

Grid Reference N1767018 E5463374
Vegetation: Significant proportion of wetland species including: *Carex virgata, C. geminata, J. sarophorus, J. edgariae, Isolepis prolifera*

-3-0 cm **Horizon O_f**, Moisture, moderate; Undecomposed rush stems and rhizomes

0-20 cm **Horizon O_{m1}** moderate moist to very moist, Very dark greyish brown, 10YR 3/2; peat; Fibre Unrubbed 58%, Rubbed 16%(mesic class); weakly developed fine nut structure; many roots Penetrometry 0.22MPa extremely low ,(pg 86 Milne *et al* 1995) weak soil strength; permeability high; many native *Megascolecidae* earthworms 80-100 mm in length.
20-40 cm **Horizon O_{m2}** Very moist to saturated, Water table at 38 cm; very dark grey, 10YR3/1; peat; Fibre unrubbed 58%, rubbed 28% (mesic); weakly developed granular & well developed fine nut; Penetrometry 0.45 MPa extremely low; many roots; permeability very high.

Comment: This site has a high proportion of wetland species, there are some indurated residual hard granular lumps in the profile indicating some drying and rewetting has occurred, no evidence of mineral addition from alluvial or aeolian sources. As mentioned above there are present abundant NZ native earthworms Megascolecidae family of unknown species.

Classification: Mellow Mesic Organic Soil **OMM**. Field soil water pH 4.93 would indicate mellow and not acid.

Grid Site 47
Grid Reference: E1766918 N5463574

Vegetation: mainly pasture species with a few clumps of J. edgariae.
0-18 cm **Horizon O_{hp}** Dry to slightly moist; dark greyish brown 10YR 4/2; zones around roots yellowish red to strong brown 7.5 YR to 5YR 4/6; peat well decomposed; massive in place breaks to well developed fine granular structure if crushed blows in wind; Penetrometry 2.48 MPa *high*, limiting to plant growth; roots abundant fine; permeability moderate to high; firm; charcoal fragments up to 2 cm dimeter; earthworms estivating;
18-31 cm **Horizon O_{h1}** Dry to slightly moist; dark grey 10YR3/1; zones around roots 7.5YR4/6 to 10YR 4/4, strong brown to yellowish brown, well decomposed peat; occasional inclusions of fine yellow sand 2.5YR; very coarse block in place breaks to well developed coarse to fine granular; Penetrometry 2.61 MPa *high* limiting to plant growth; many fine roots; Permeability moderately high at least interpedal, roots may also be avoiding very firm peds;
31-43 cm **Horizon O_{h2}** Moderately moist; very dark grey 10YR3/1; reddish roots but no stain zones around them; Very fine crumb and occasional medium nut structures; Penetrometry 0.37 MPa, very low; many fine roots occ. old coarse roots; weak crumbly.
43-70 cm **Horizon O_{h3}** Moist to very moist; Peat well decomposed; dark grey 10YR3/1; medium nut structure; Penetrometry 0.40 MPa, very low; many fine roots and some coarse roots; Permeability high;
Fine sand layers mixed into peat in fine layers, dark yellowish brown to brown 10YR 4/4 to 4/3; probably flood deposits;
70+ cm **Horizon C** stones over grey black gravels up to 30mm diameter
Comment: Profile shows effect of dehydration in 0-31 cm depth range causing hardened aggregates possibly aggravated as the result of fires as evidenced by charcoal. Peat layers have become hardened by modification. Little mineral content in upper 60 cm. This soil is notable for having very firm hardened peat horizons.
Classification: Mellow Humic organic **OHM**

Grid site 139
Grid Reference: E1767018 N5464774
Vegetation: pasture species with some rushes. Evidence of forest trees in recent history with many stumps in evidence
0- 4 cm **Horizon O_p** Slightly moist to moist (description date 6 March 2020 few mm rain in previous few days); very dark grey 10YR3/1; loamy peat; well developed fine

crumb; Penetrometry 0.52 MPa very low; abundant fine roots; Permeability high.

4-24 cm **Horizon O_h** Dry to slightly moist; very dark greyish brown 10YR 3/2 to 2/2; fine sandy peat; relatively massive in place breaks to well dev med & fine nut; Penetrometry 1.39 MPa low; Permeability high. abundant fine roots Quite firm, hard lumps of dried peat 2-3 mm granules.

24-60+ cm **Horizon O_m** Moist to very moist; dark reddish brown 5YR 3/2 to 3/3; peat; unrubbed fibre 68%, rubbed 16% mesic just; Penetrometry 0.36 MPa extremely low; peat from decomposed roots and wood fragments; common coarse & medium roots; distinct boundary.

90cm free water in profile

110-120 cm **Horizon O_h** Saturated; dark brown 7.5YR 3/2 to 3/4 distinctly darker than upper horizon; peat von Post 8-9 O_m to O_h ; many fine roots.

Comments: Acid Mesic organic Soil **OMA** due to presence of slowly decomposing wood material; Some mineral contribution to topsoil; little hardening.

Grid site 141

Grid Reference: E1767218 N5464774

Vegetation: Pasture species, gorse.

0-4 cm **Horizon A_p** Dry to slightly moist; dark brown 10YR 3/2; peaty loam sand grains visible, very weakly developed fine crumb; Penetrometry 0.91 MPa very low; abundantly fine and medium low roots; permeability appears high;

4-19 cm **Horizon AC** Dry to slightly moist; very dark grey 10YR 3/1; peaty loam with fine aeolian sand; weakly developed coarse granular breaks to weakly developed crumb and structureless; Penetrometry 1.4 MPa low; many fine and medium roots; high permeability.

19-45+ cm **Horizon O_m** Very moist; dark brown 7.5YR 3/2; peat unrubbed fibre 78%, rubbed fibre 28% (mesic); very weak coarse prismatic; Penetrometry 0.23 MPa extremely low; many coarse common fine and medium many are slight to moderately decomposed fibrous roots.

120 cm **Horizon O_h** Saturated; dark reddish brown 5YR3/2; von Post 8-10 20% remains after squeezing.

Comments: mineral inclusions, no hardening, colour indicative of reddish peat

Classification: Mellow Mesic Organic Soil **OMM**

Grid Site 155

Grid Reference: E1767018 N5464974

Vegetation: Closely grazed pasture species and rushes

0-10 cm **Horizon O_p** Slightly to moderately moist; very dark greyish brown to dark brown 10YR3/2-2/2; sandy peat with obvious sand grains; massive in place breaks to weakly developed coarse nuts and dust. Penetrometry 1.08 MPA low; firm but low density; many fine roots; Permeability variable predominately flow down root channels 70 mm of rain since May 1, visit date 7 May,

10-40 cm **Horizon O_{m1}** Slightly to moderately moist; dark brown 7.5YR 3/4; peaty loam to peat, some less obvious sand grains ;massive in place breaks to weakly developed coarse nuts. Penetrometry 1.77 MPa moderate; overall firm but some of the nuts are very hard, Inclusions of reddish materials probably old wood pieces; common fine roots.

40+ cm **Horizon O_{m2}** moist to very moist; black 10YR2/1; peat unrubbed 80% rubbed 41% so mesic; weakly developed coarse block breaks to moderately well developed fine block; Penetrometry 0.51 MPa very low; weak non-plastic common roots, permeability high

54 cm water table capillary rise of 14 cm coincides with O_h boundary, below water table material still to firm to carry out von Post measure of decomposition, so rewetting of previously dried layers has not removed all induration.

120 cm O_{m2} black 10YR2/1 von Post 6-7 40-50 % remaining so mesic

Comment: A profile with two distinct peat materials, the O_{m1} reddish-brown peat material derived from coarse wood fragments is less rapidly decomposed than the underlying black peat O_h which in turn is less decomposed at depth.

Classification: preliminary Acid Mesic Organic Soil **OMA** this is based on pH of soil water at the site being 3.76 but this may not be representative on the upper soil horizons.

Grid Site 196

Grid Reference 1767418 5465474

Vegetation: grasses, rushes

-3 -0 cm **Horizon O_f** root mat

0-11 cm **Horizon O_{m1}**moist; black 10YR 2/1; decomposed peat with traces of sand, unrubbed fibre 44%, rubbed 26 % mesic; moderately developed crumb structure; Penetrometry O.8 MPa very low; soft; abundant fine roots Permeability high; very distinct boundary

11- 46 cm + **Horizon O_{m2}** moist, water table at 46 cm and capillary fringe boundary at 30 cm increasingly moist below this depth; 5YR 3/3 to 3/2 dark reddish brown; woody peat with some inclusions of black peat, unrubbed fibre76% and rubbed peat 36% mesic; ; Penetrometry 0.5 MPa extremely low; many fine roots; below 30 cm Penetrometry 0.22 extremely low

120 cm **Horizon O_{m3}** saturated dark reddish brown 5YR 3/2, von Post 8 mesic

Comment: Absence of any induration and sharp contrast between peat materials with woody reddish colours overlined by black peat Soil water pH 3.6

Classification: Acid Mesic Organic soil OMA

Grid Site 202

Grid Reference: E 1767118 N5465584 10 m north of original site due to proximity of drain

Vegetation: Recently drilled with plantain and pasture grasses

0-23 cm Oh_p Dry to slightly moist; very dark greyish brown, 10YR 3/2; peaty silt loam; massive in place breaks to well developed fine crumb plus small fragments of indurated peat. Fibre test unrubbed 68% rubbed 38% but remaining material hard granules so humic assignment. Penetrometry 1.46 MPA low, moderately firm; abundant fine roots Horizon has been cultivated.

23-28 cm O_{h1} Slightly moist to moist; dark reddish brown to dark brown 5YR 3/3 to 7.5 YR 3/2; peat; well developed coarse blocks; Penetrometry 1.54 MPa moderate ;

very firm indurated from consistency test, appears to be hydrophobic but blocks contain intrapedal roots; horizon below cultivation zone.

28- 54+ cm O_{h2} Moderate moist to very moist; dark reddish brown matrix 5YR 3/2, wood fragments yellowish red 5YR 4/6; peat unrubbed fibre 64%, rubbed fibre 8% humic; well decomposed peat with moderately developed coarse block in place breaking to structureless; Penetrometry 0.72 MPa extremely low; few fine pasture roots.

110-120 cm O_m Saturated below water table; peat von Post 7-8 (mesic).

Comment: A site that has been intensively managed for pasture and cropping. Cultivation may have broken down some of the hardened granules. Soil shows signs of hardening /induration, below 28 cm although summer drying occurs below this depth it does not appear sufficient to cause induration. Peat is relatively decomposed.

Classification: Mellow Humic Organic Soil OHM

Grid Site 221

Grid Reference: E 1767418 N5465774

Vegetation: Thick long grasses, numerous rushes and gorse.

0-11 cm **Horizon O_h** Moderately moist; Black 10YR2/1; peat, well decomposed humic, no mineral sand visible; Coherent in place breaks to weakly developed crumb; Penetrometry 1.19 MPa low; abundant fine and medium roots. Permeability high

11-25 cm **Horizon O_{m1}** Slight to moderately moist; dark reddish brown 5YR 3/4 slightly fibrous peat mesic; Weakly developed fine nut and crumb, a few hard granules; Penetrometry 1.06 MPa low; lumps of wood > 100mm present; many fine roots; Permeability high

25-42 cm **Horizon O_{m1}** Capillary rise zone, water table at 42 cm, very distinct moisture boundary at top of capillary rise zone of 17 cm, dark reddish brown 5YR 3/4 (slightly lower chroma possibly due to higher moisture content); peat with some fibre unrubbed 52% rubbed 18 % (mesic); fine nut;

42 – 100 cm+ **Horizon O_{m2}** peat low density, von Post 60% retained H8 so mesic

Comments: The higher level of moisture in the topsoil is likely result of rain in early May, 7 days before examination. A distinctly reddish brown peat with the blacker surface horizon possibly showing influence of non woody peat parent material.

Classification: Soil water at water table pH 3.68 so probably acid, Acid Mesic Organic OMA

Grid Site 226

Grid Reference: E1767118 N5465874

Vegetation: grasses and rushes

0-20 cm **Horizon O_h** Moist to very moist; black 10YR 2/1 to 7.5YR 2/1; decomposed peat with some sand grains; Penetrometry 0.65 MPa very low; abundant roots,

20-37 cm **Horizon O_{m1}** Capillary rise zone, water table at 37 cm very wet to saturated ; black 10YR 2/1 to 7.5YR 2/1, more roots and fibre than surface horizon; Permeability high. One large wood fragment.

37- 100+ **Horizon O_{m2}** Saturated; black 5YR2/1 to 7.5YR 2/1; peat von Post H8-H9 mesic

Comments: A profile with predominately black peat parent material, Classification: Soil water at surface of water table pH 3.76 so possibly acidic Acid Mesic Organic OMA

Sand Dune Site

A representative dune sand profile was also described as this is the other major soil type in the area as compared to organic soils.

Grid Reference: E 1767168 N5465274

Vegetation: introduced grasses

0-4 cm **Horizon** A_1 dry; root mat, abundant roots; high permeability

4-20 cm **Horizon A_2** moist; dark brown 10YR3/2 to 3/3; humic fine sand; many roots; many roots

20-34 cm **Horizon B_{w1}** slightly moist to moderately moist; light olive to yellowish brown 2.5Y5/6 to 10YR 5/6; fine sand many fine roots; high permeability

34-45+ cm **Horizon B_{w2}** slightly moist; ; light olive to yellowish brown 2.5Y6/6 to 10YR5/8;

Comment: Shows signs of B horizon colour development but not significant physical weathering.

Classification: Typic Sandy Brown, characteristic of Foxton Soil Series.