Viking Energy Partnership

Viking Wind Farm

Technical Appendix 14.1
Peat Stability Assessment

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Viking Energy Partnership
The Gutters' Hut
North Ness Business Park
Lerwick
Shetland
ZE1 0LZ

Mouchel Ltd
Unit 11 Scion House
Stirling University Innovation Park
Stirling
FK9 4NF

Tel. 01786 449 131
Fax. 01786 449 852

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Prepared by	Catherine Isherwood		31/03/2009
Checked by	Malcolm Macfie		31/03/2009
Approved by	Malcolm Macfie		31/03/2009

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PLEASE NOTE: Section 8 DETAILED ASSESSMENT of this report is contained with the A3 figures and technical drawings in Volume 4b as Figure 14.1.PS.

APPENDICES

See Environmental Statement Volume 3 and Volume 4b for all A3 Figures

1 INTRODUCTION

This report forms a Technical Appendix to Chapter 14 (Soil and Water) of the Environmental Statement for Viking Wind Farm (Mouchel, 2009) and should be read with reference to this chapter.

Viking Energy Partnership is currently progressing proposals for a wind farm on North Mainland in the Shetland Islands. The proposed wind farm site is located in an area of extensive and highly variable peat cover and it was considered important that the risk of peat instability as a consequence of the wind farm construction is assessed.

Mouchel was commissioned in 2006 to undertake the peat stability assessment for the Viking Wind Farm site, in conjunction with the soil and water element of the Environmental Impact Assessment.

This document presents Mouchel's methodology for peat stability risk assessment, the analysis performed and results obtained.

1.1 Aims

The aims of this Peat Stability Assessment are to:

- Undertake a review of available relevant site information;
- Undertake site survey work to characterise the prevailing ground conditions and identify existing or potential peat instability;
- Detail the findings of the above, reporting on any existing or potential instability, the likely causes and contributory factors;
- Assess the risk of instability, including estimating impacts of potential peatslides;
- Provide recommendations on further work, mitigation measures and specific construction methodologies that should be implemented pre-construction to minimise the risk of peat instability at the development site.

1.2 Methodology

The methodology adopted by Mouchel for the peat stability assessment of the Viking Wind Farm site has involved the following stages:

- Desk study;
- Site reconnaissance;
- Peat depth survey;
- Preliminary stability analysis;
- Preliminary hazard ranking;
- Ground investigation;
- Detailed assessment;
- Mitigation.

Further detail on each of these stages is provided in the following sections.

A phased approach has been taken to the peat stability assessment, which has been undertaken concurrently with the layout design of the wind farm and the Environmental Impact Assessment. The process is necessarily iterative; in consequence, the peat depth survey and stability analysis work have been revisited and refined as the project has progressed.

The desk study, site reconnaissance and preliminary peat depth survey were carried out prior to the design of the wind farm layout. The resulting data were used to inform the layout design, providing guidance on areas of potentially deep or unstable peat that should be avoided wherever practical.

Following the design of the layout, further peat depth probing was carried out at the infrastructure locations. These data were used to carry out preliminary slope stability analysis and to identify areas at potentially higher risk of instability. Using all the collated data, a preliminary assessment of hazard ranking was made and areas of concern identified.

Owing to the large site area it was not possible to undertake ground investigation work at all areas identified as being of concern after the preliminary hazard ranking assessment. In place of this, representative areas from across the whole site were selected on the basis of their hazard rank. These cover areas with different levels of hazard rank, including some identified as having no significant risk of peat slide to act as control sites.

Further stability analysis was carried out using the ground investigation data and a semi-quantitative evaluation of peat landslide risk at each location was made, considering both hazard and exposure. Following the evaluation, recommendations on further work and mitigation measures were provided as necessary.

2 DESK STUDY

2.1 Information Sources

A desk study was undertaken, reviewing available information on the ground conditions at the Viking Wind Farm site. Information sources included:

- Ordnance Survey Landranger Map 3: Shetland North Mainland;
- Ordnance Survey 1:10,000 and 1:50,000 digital raster mapping;
- Ordnance Survey 1:10,000 digital elevation model (DEM) data;
- XYZ Mapping (May 2008) orthorectified aerial photography, 0.25m resolution;
- British Geological Survey DiGMap GB 1:50,000 digital geological mapping, bedrock and superficial;
- British Geological Survey Hydrogeological Map of Scotland;
- Groundwater Vulnerability Map of Scotland;
- Soil Survey of Scotland 1:250,000 Sheet 1 Orkney & Shetland;
- Flood Estimation Handbook CD-ROM (v2);
- LowFlows2000 software.

2.2 Context

The development site, known as Viking Wind Farm, is located on North Mainland in the Shetland Islands, approximately 27km north of the main town, Lerwick. The site is roughly centred on the settlement of Voe (grid reference HU 4077 6320). The area of interest is divided into four quadrants, with two quadrants to either side of the main A970/A968 route which runs north–south across the island. The quadrants are known as Delting, Collafirth, Kergord and Nesting.

All four quadrants of the proposed 150-turbine wind farm comprise areas of open peat moorland used mainly for rough grazing. Kergord and Nesting include large freshwater lochs whereas Delting and Collafirth have only very small amounts of standing freshwater. At the margins of the site, in particular near the settlements, there is some semi-improved grassland. Some areas have evidence of historic peat cutting, although this tends to be fairly limited. Many of the waterbodies have fisheries interests, especially for trout.

2.3 Historical Information

There is documented evidence of peat slides across the Shetland Islands for nearly a century (Halcrow, 2004). Three peat slide events in particular are reported: an event in 1935 in the Weisdale area, one in 1950 and the recent series of peat slides at Channerwick in 2003.

On 19 September 2003 a series of peat slides occurred at Channerwick on South Mainland, resulting in temporary closure of the main A970 between Levenwick and Cunningsburgh. The peat slides caused the mobilisation of large volumes of peat across a large area, with consequent direct and indirect impacts on the natural environment and local infrastructure.

Halcrow Group Ltd was appointed by the Shetland Islands Council to undertake an investigation of the area in order to determine failure mechanisms and causes of the event. The following information is summarised from the Halcrow report (Halcrow, 2004) with supporting information from the Shetland Times (2008).

The peat slides at Channerwick occurred during a period of very intense rainfall, although records of duration and intensity are not available for the event. The preceding winter and summer had been unusually dry, causing drying and cracking of the peat mass. The sudden, high intensity rainstorm is believed to have caused build-up of water pressure within the peat cracks, the underlying network of peat pipes and along the peat-bedrock interface. The site investigation indicated that slopes in the area are convex, leading from broad summits to steeper valley sides.

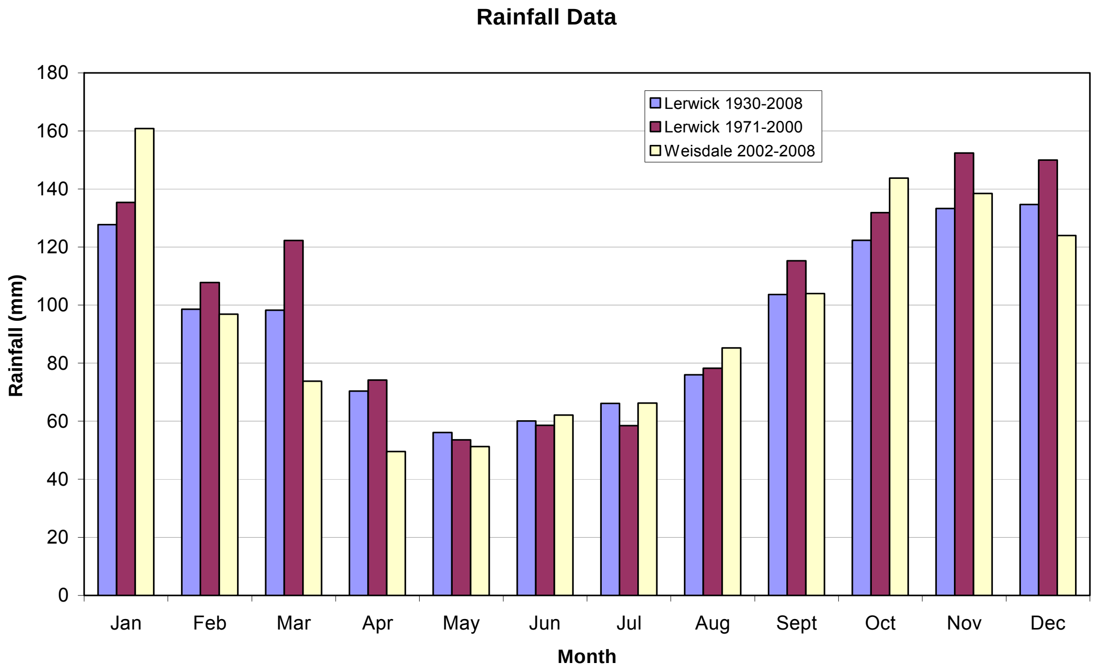
Halcrow conclude that slopes such as those found at Channerwick are likely to be stable under normal climatic conditions. It is suggested that the interface between the peat and the underlying weathered schist bedrock represents the weakest plane and that failure at this interface can be initiated through excessive build-up of water along the interface. Convexity of slope is considered to be an important control on peat failure.

2.4 Climate

The Shetland Islands have a temperate maritime climate, characterised by cool, short summers and mild, wet winters.

Two monitoring stations have rainfall data relevant to the Viking Wind Farm site. The closer of these, at Weisdale near the southern boundary of the site, began operation in 2002. Monthly average rainfall has been calculated from daily rainfall data collected between April 2002 and November 2008. The Lerwick rain gauge currently has monthly average rainfall data records from December 1930 through to December 2008. These data are represented graphically in Figure 1. The 30-year long-term average monthly rainfall for Lerwick has also been included as this is the standard reporting period for long-term rainfall data.

Figure 1 Average monthly rainfall data for Lerwick and Weisdale monitoring stations



Based on data collected from 1931 to the present day, the annual average rainfall for Lerwick is 1147mm. Average annual rainfall from the Weisdale monitoring station for the years with a complete dataset (2003-2007) is 1180mm. To put these data into a national context, rainfall in Scotland varies from over 3000mm per year in the Western Highlands to less than 800mm per year in eastern Scottish mainland areas.

For comparison, the average annual rainfall at Lerwick over the 1971-2000 reporting period is 1238mm, indicating a trend of increasing rainfall over recent decades. Changes in rainfall patterns between the different datasets suggest a slight decrease in rainfall in the summer months and an increase in the winter months, in addition to the increase in total annual rainfall.

2.5 Topography & Slope

The topography of the site is dominated by a series of steep-sided north–south trending ridges and valleys, becoming north-east trending in the northern part of the site. The ridges tend to have narrow, nearly flat summit areas defined by distinct breaks in slope. East and west from the central part of the site the ridges become less well defined although the north–south trend remains distinct throughout.

Elevations across the development site vary from sea level to 281m AOD, the highest point being Scalla Field in the Kergord quadrant. The study area is divided into four sections by prominent breaks in the landscape. The topographic cross-sections included below give examples of the terrain in each quadrant.

The site centres on the settlement of Voe, HU 4086 6359, with two quadrants lying on either side of the A970-A968 route. The two quadrants west of this line, Delting to the north and Kergord to the south, typically show steeper slopes and higher elevations than the eastern quadrants. The eastern quadrants, Collafirth to the north and Nesting to the south, are characterised by more broken ridge lines with rounded hills and less pronounced valley sections.

Slope angles across the site are very variable. Owing to the prevailing topography of long, flat topped ridges and wide valleys, much of the area is made up of flat or nearly flat ground (0-3°). Analysis of the slope angle map, derived from the DEM data, shows that just over 60% of the site has a slope angle of less than 6° and 86% of the site has a slope angle of 12° or less. The steepest areas are typically confined to the long ridge sides, as shown on Figure 14.1.PS03 (in Volume 4b).

Cross sections across the quadrants have been generated from the DEM and are presented in Figure 2 to Figure 5 below, to give a clearer illustration of the site topography. Locations of the cross section lines are shown in Figure 14.1.PS06 (in Volume 4b).

Figure 2 Cross section through Delting quadrant, from Scatsta (NW) to Dales Voe (SE)

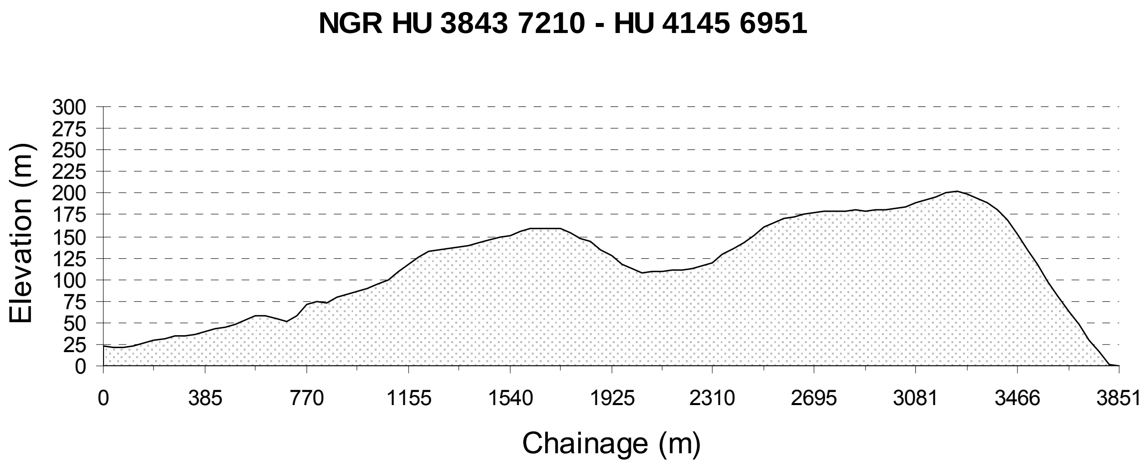


Figure 3 Cross section through Kergord quadrant, from the South Burn of Burrafirth (W) to East Kame (E)

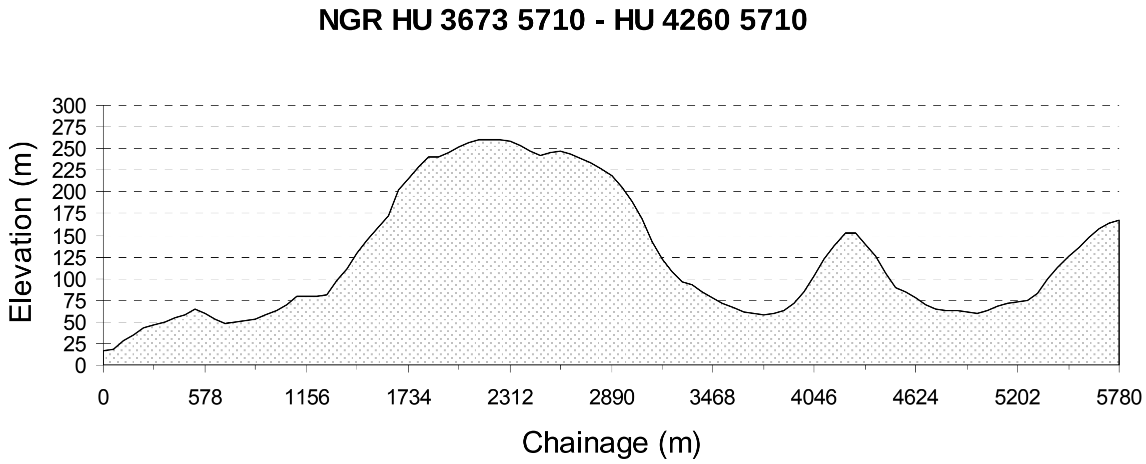


Figure 4 Cross section through Collafirth quadrant, from Susetter (W) to Laxo Water (E)

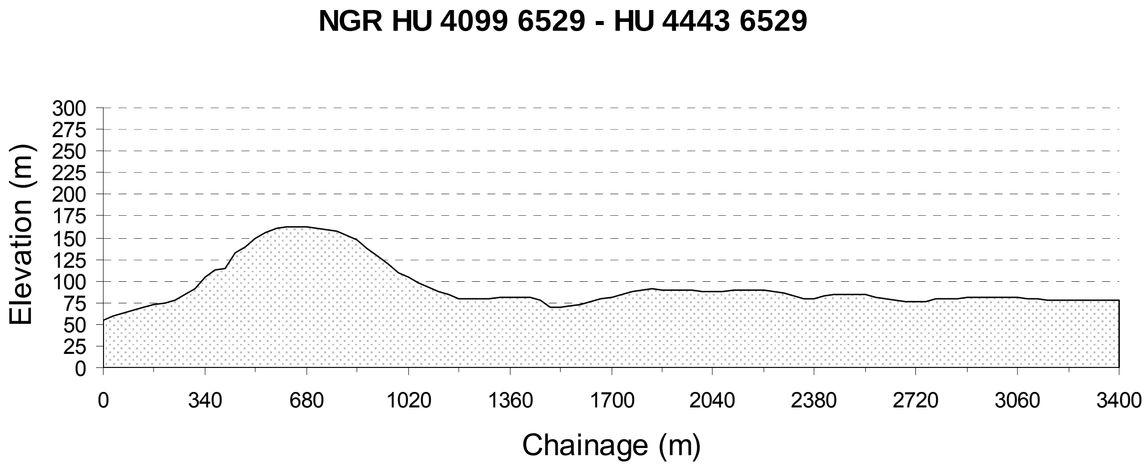
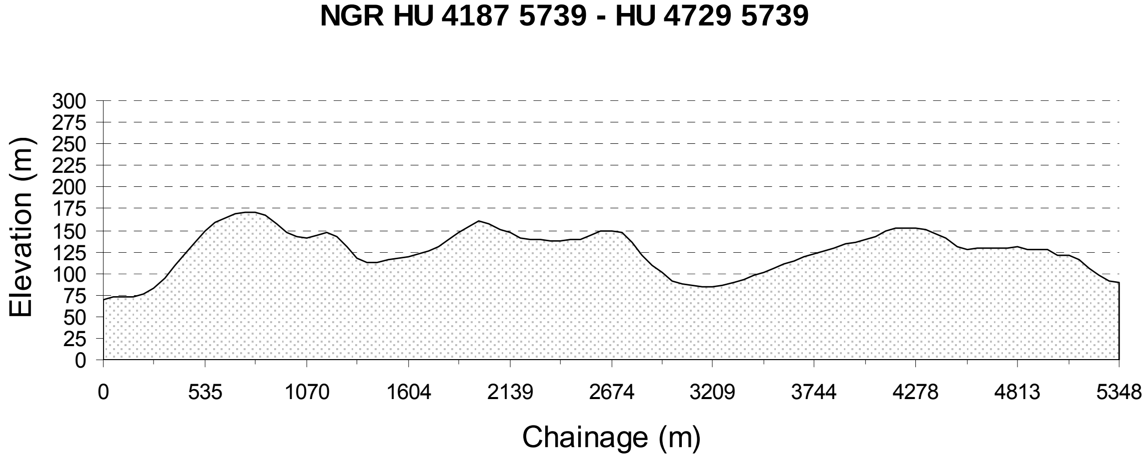


Figure 5 Cross section through Nesting quadrant, from Petta Dale (W) to Brettabister (E)



2.6 Geology

The geology of Shetland consists partly of metamorphosed sedimentary rocks of Moinian and Dalradian age, and partly of sedimentary and igneous rocks of Devonian age. The Shetland Islands are elongate and dominated by north–south trending geological units cut by a series of similar trending faults. The site exhibits variable amounts of outcrop, some drift deposits and very extensive peat cover.

North Mainland is cut by several major strike-slip faults trending north–south, in particular the Walls Boundary Fault (WBF), the Nesting Fault and the Melby Fault. The WBF is thought to be the northward extension of the Great Glen Fault and has undergone several phases of movement during its geological history. These fault planes have a vertical or near-vertical dip. The rocks within the proposed development area lie predominantly between the Walls Boundary Fault to the west and the Nesting Fault to the east, with a small section of the Nesting quadrant lying to the east of the Nesting Fault.

Shetland is divided into two geologically distinct sections, typically called East and West Shetland and separated by the WBF. The East Shetland succession, east of the WBF, consists of a thick sequence of north–south trending metasediments with a vertical or steep dip, younging to the east. The rock types vary from schist and gneiss to quartzite and metalimestone. The sequence has been intruded by plutonic igneous complexes of variable composition, and is cut by a sequence of sills and dykes. The development area lies entirely within the East Shetland succession.

This combination of major faulting and near-vertically dipping strata form the principal controls on the landscape and drainage systems, which are dominated by a series of parallel north-south trending ridges and valleys.

The bedrock geology is extensively covered by superficial deposits, mostly composed of blanket peat and glacial drift material. Blanket peat is fairly extensive across the development area, forming a nearly unbroken cover over much of the site. There has been significant erosion on some hill and ridge tops, in places exposing the mineral soil. The peat is slightly more broken further south, giving more bedrock exposure especially in the Kergord quadrant and the area to the east of the Nesting Fault in the Nesting quadrant.

The peat is often underlain by a thin irregular layer of glacial till; the till is sometimes exposed in stream and road sections, especially in areas where peat is absent. Hummocky till or moraine deposits are noted in some localised areas with thin peat. Alluvium is present in small amounts in some river valleys but is very minor in extent, as are the occasional lacustrine deposits. Marine beach deposits are present along much of the coastline with minor blown sand in places. Glaciofluvial material is confined to a small area south of the Kergord quadrant. Rock falls have been noted in places, although these are usually small and infrequent.

Overview maps of the bedrock and superficial geology are presented in Figures 14.1 and 14.2 (in Volume 3).

2.7 Soils and Peat

The distribution of soils is dependent on the geology, topography and drainage regime of the local area. Regional soils consist predominantly of blanket peat and peaty units of the Arkaig Association. Some further information on the main soil types identified is provided below:

- *Blanket peat*: organic material generated from the remains of bog and/or fen vegetation. The wetness of the substrate leads to anaerobic acid conditions inhibiting the decay process.
- *Deep and eroded blanket peat*: deep blanket peat which may display extensive erosion features such as gullies and haggs.
- *Peaty gleys*: slowly permeable, seasonally waterlogged clay-like soils with a peaty surface horizon. Saturation of the soil results in a lack of oxygen and reducing conditions, the subsequent reduced iron within the soil takes on a bluish colour. In the upper soil horizons, where the water table fluctuates, the soil has a mottled appearance.
- *Peaty podzols*: leached soils with a peaty surface layer. The drainage of these soils is dependent on the level of leaching. Peaty podzols are normally free-draining; however, where strong leaching has occurred sufficient deposition of iron and aluminium in the lower soil horizons may cement the material into a hard impermeable layer, or ironpan, resulting in waterlogging of the profile above. The product of this is a soil intermediate between podzol and gley.
- *Peaty rankers*: very shallow soils over rocks with a peat surface layer but no subsoil.

There are ten main soil units found on the Viking Wind Farm site, based on the Soil Survey of Scotland digital mapping. Each soil unit consists of varying proportions of the soils described above. The proportion of each soil type within a soil unit is dictated by the local topography and drainage conditions, so each soil unit is associated with a particular geographical situation. The soil units found at Viking and the percentage of the wind farm footprint underlain by each are displayed in Figure 14.8 (in Volume 3) and summarised in Table 1. The information on the soil mapping correlates closely with the superficial deposits map (Figure 14.2, Volume 3).

Table 1 Summary of regional soil types

Component Soils	Soil Unit	Associated Landform	% Regional Coverage
Deep and eroded blanket peat	605	Uplands and northern lowlands with gentle and strong slopes	68.1
Deep blanket peat	604	Uplands and northern lowlands with gentle and strong slopes	11.4
Peat with peaty gleys with peaty podzols	24	Hills and valley sides with steep and very steep slopes: non-rocky	5.6
Peaty gleys with peat: peaty podzols with peaty rankers	29	Undulating hills with gentle and strong slopes: moderately rocky	5.4
Basin with valley peats	3	Basins and valleys	5.2
Peaty gleys with peaty podzols with peaty rankers	31	Hill sides with steep and very steep slopes: moderately and very rocky	1.8
Brown forest soils: brown rankers with noncalcareous gleys	165	Undulating lowlands and hills with gentle and strong slopes: slightly rocky to rocky	1.2
Noncalcareous gleys with peaty gleys: humic gleys with peat	19	Hills and valley sides with gentle to strong slopes: non-rocky	0.6
Peaty podzols with peat: peaty gleys with humus-iron podzols	320	Hills and lowlands with gentle to steep slopes: non-rocky	0.4

Component Soils	Soil Unit	Associated Landform	% Regional Coverage
Peat with subalpine soils: alpine soils	193	Hill and mountain summits with gentle and strong slopes: slightly and moderately rocky	0.2

2.8 Hydrogeology

Groundwater at the site is largely restricted to the superficial peat deposits, as the Viking Wind Farm site is mostly underlain by impermeable Pre-Cambrian basement rocks.

These basement rocks are crystalline metamorphic and igneous strata which have extremely restricted groundwater flow and storage potential. What storage and flow capacity they exhibit is limited to near-surface fracture systems, joints and fault lines. In some areas the presence of a thin weathered horizon provides some limited groundwater storage capacity although the quartz-rich nature of most of the rocks restricts weathering to the very top layer. Notable exceptions are the meta-granite exposed at NBP04, which is quite deeply weathered in places, and the bands of metalimestone which are subject to chemical weathering and dissolution by acidic waters.

There is likely to be some groundwater present within the glacial till deposits that are present across the site. However, these are mainly discontinuous within the wind farm site and are generally confined to steeper slopes or lower-lying areas around the site margins.

Groundwater within site peat aquifers is generally perched on the less permeable basement strata which they overlie. These aquifers may be thick where they are located in areas of low relief, such as valley floors and cols in elevated areas. In these situations they will provide baseflow to local streams. While peat aquifers in some areas have sufficient storage to ensure perennial flow, in the majority of peat aquifer-fed watercourses flow appears to be more intermittent.

The occurrence and behaviour of the water table within the peat is also of significance. In lower-lying areas of lesser relief and where peat is relatively thick, the water table generally occurs at or near the surface. In areas of higher relief groundwater occurs at greater depth and in some instances may only be present for short periods on a seasonal basis.

2.9 Hydrology

There is a considerable number of small streams, rivers, lochs and lochans throughout the site, although these water features are not uniformly distributed. In particular, when considering lochs, the majority of waterbodies visible on the 1:50,000 scale map lie within Kergord quadrant, whereas Delting quadrant has the fewest lochs. In addition to lochs shown at 1:50,000 scale, there are numerous lochans found particularly in the southern sector of the study area. Many of these are ‘perched’ in depressions within the predominantly peat-covered terrain. There are also numerous peat bodies, flush zones and other areas of diffuse surface runoff.

All site catchments display upland moor characteristics, with the main hydrological control across the site being the impermeable bedrock geology and the resulting extensive peat deposits. As peat deposits are generally fully saturated but have a low permeability, the water is effectively ‘locked’ into the peat, restricting direct rainfall infiltration to groundwater. As a result there is little storage capacity and a large proportion of rainfall would become surface runoff, giving catchments a very ‘flashy’ response to rainfall events. This response is characterised by rapid response times and high peak flows. Catchments with larger lochs, such as those within Kergord quadrant, may have a dampened response owing to the additional storage capacity provided by the lochs. During extended periods of dry weather there are very low flows in the streams in consequence of the small seepage rates from the peat deposits.

Hydrological catchment boundaries relating to the site were mapped, with catchments shown in Figure 14.13 (in Volume 3). Numerical identifiers for the catchments are based on unit area, where Catchment 1 the largest and Catchment 30 the smallest. Examples from each quadrant are presented below, with additional hydrological information provided in Chapter 14 of the Environmental Statement (Mouchel, 2009).

Catchment 1: Laxo Burn/Gossawater Burn (Collafirth & Nesting quadrants)

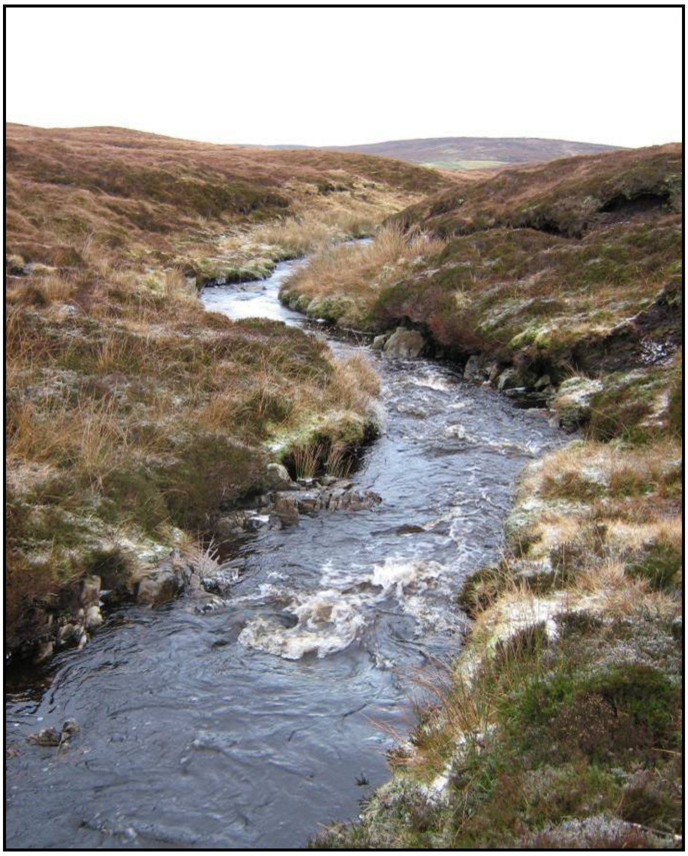
The largest of the study area catchments, the Laxo Burn/Gossawater Burn catchment covers an extent of approximately 20.86km^2 (2086 hectares). This catchment is characterised by rounded hills and dendritic stream channels with peat haggs and gullies. There is also a number of lochs of varied size within the catchment. Within this large area there are two distinct subcatchments, situated north and south of the settlement of Laxo.

Based on surface area, the largest of the lochs are Gossa Water (0.23km^2) in the southern subcatchment and Laxo Water (0.17km^2) in the northern subcatchment. Both of these lochs are fed via direct stream flow and outflows from smaller lochs upstream.

In addition to the outflows from the lochs identified above, the main watercourses in the catchment are the Seggie Burn, the Gossawater Burn and Easter Filla Burn. These form the principal tributaries to the Laxo Burn, which reaches the sea at the settlement of Laxo on the east coast. Examples of watercourses from this catchment are shown in Figure 6 and Figure 7 below.

Figure 6 View west (upstream) along the Seggie Burn from Kingshouse (HU 4360 6484)

Figure 7 View north (downstream) along the Gossawater Burn (HU 4352 6175)



Catchment 2: Burn of Lunklet/South Burn of Burrafirth (Kergord quadrant)

This large catchment covers an area of approximately 18.47km^2 (1847 hectares) and includes a number of large freshwater lochs, including Maa Water which is the largest in the study area. The watercourses in this catchment drain the western slopes of West Kame, Scalla Field and West Hill of Weisdale. The main streams in the catchment are the South Burn of Burrafirth, Burn of Lambawater, Burn of Lunklet (Figure 8) and Burn of Marrofield, which converge to form the Burn of Burrafirth within 500m of the coast. The Burn of Burrafirth flows into the sea at East Burrafirth.

Figure 8 View upstream (east) along the Burn of Lunklet (HU 3699 5735)

Figure 9 View north-west across Lamba Water (HU 3828 5521)

This catchment contains most of the major lochs within the Kergord quadrant, Maa Water ($0.25km^2$), Lamba Water ($0.15km^2$, Figure 9), Truggles Water ($0.07km^2$), Marrofield Water ($0.06km^2$) and Loch of Lunklet ($0.03km^2$). This dominant presence of standing waterbodies is expected to regulate the flow into the outflowing streams, which will have a steadying influence on the overall catchment flow characteristics.

Catchment 3: Burn of Sandwater/Burn of Pettawater (Kergord & Nesting quadrants)

This catchment covers an area of approximately 14.69km^2 (1469 hectares) within the fjord-like valley of Petta Dale. Petta Dale forms the major north–south boundary between Kergord and Nesting quadrants and drains the eastern side of Mid Kame and the western side of East Kame. The main streams within the catchment are the Burn of Pettawater and the Burn of Sandwater, with two notable waterbodies, Petta Water (0.11km^2) and Sand Water (0.37km^2). The Burn of Pettawater provides the main inflow to Sand Water (Figure 10), which then feeds the Burn of Sandwater which flows south to meet the sea at Stromfirth.

The catchment topography is dominated by the wide, flat floor and steep bounding slopes. Owing to the gentle slope on the valley floor, the catchment is dominated by boggy ground with an intricate network of small channels. Sand Water is a shallow loch and its size will provide a moderating influence on the catchment flow characteristics.

Figure 10 View south-west across Petta Dale to Sand Water (HU 4099 5624)

Catchment 5: Burn of Laxobigging (Delting quadrant)

The upper reaches of this catchment are drained by the Burns of Easterbutton and Westerbutton (Figure 11), which form a confluence at the Meadow of Fitchen. The topography in this area is gently sloping to the north-east and these watercourses follow this, meeting with other drainage features to become the Burn of Laxobigging. The catchment covers an area of approximately 11.33km^2 (1133 hectares).

The catchment drains the western slopes of the Hill of Dale, Hill of Oxnabool and Hill of Neegarth. The Burn of Laxobigging enters the sea at Garths Voe, adjacent to the settlement of Laxobigging on the west coast.

Figure 11 View down the Burn of Westerbutton towards the Burn of Laxobigging (HU 3965 7018)

The Burn of Laxobigging has a redundant dam in its lower reaches, situated near the village of Graven (HU 4166 7261). This artificial feature forms pool habitats upstream which may be considered of value and may contribute to water flow moderation at higher water levels. There are no significant standing waterbodies in the catchment.

Figure 12 Dam on the Burn of Laxobigging (HU 4166 7261)

Flow statistics for the all the site catchments are provided in Table 2. The mean daily flow and low flow figures have been calculated using LowFlows 2000 software (Wallingford

HydroSolutions, 2007) and the peak runoff figures have been calculated using the Flood Estimation Handbook (FEH). The low flow estimate is given as $Q_{95}(10)$ and represents the flow exceeded 95% of the time as observed over a 10-day period. For very small catchments, less than $0.5km^2$ in area, where the FEH software is not able to provide information a pro-rata interpolation on unit runoff was made and results extrapolated from other watercourses.

Table 2 Estimated mean daily flow, low flow (Q_{95}) and peak runoff rates (m^3/s) for site catchments

Catchment ID	Area (km^2)	Mean Daily Flow (m^3/s)	Q_{95} (10)	Estimated Peak Runoff (m^3/s) for each Return Period (years)						
			(m^3/s)	2	5	10	25	50	100	200
1	20.86	0.578	0.115	10.32	14.04	16.31	19.46	22.11	24.70	28.59
2	18.47	0.489	0.108	9.60	13.16	15.33	18.36	20.92	23.32	26.69
3	14.69	0.399	0.0792	6.42	8.74	10.16	12.13	13.78	15.55	18.01
4	13.17	0.385	0.0514	5.66	7.70	8.95	10.68	12.15	13.52	16.06
5	11.33	0.302	0.0493	5.39	7.34	8.53	10.18	11.57	12.87	14.79
6	10.60	0.265	0.0423	5.11	6.98	8.12	9.72	11.06	12.31	14.22
7	6.79	0.181	0.0249	3.64	4.99	5.82	6.98	7.95	8.87	10.12
8	5.88	0.164	0.0218	2.68	3.67	4.27	5.11	5.82	6.48	7.36
9	4.82	0.145	0.018	2.62	3.60	4.19	5.03	5.73	6.39	7.26
10	4.72	0.127	0.0202	2.75	3.78	4.42	5.31	6.06	6.76	7.69
11	4.46	0.126	0.0273	2.586	3.556	4.150	4.979	5.678	6.335	7.20
12	4.27	0.111	0.0167	2.59	3.57	4.18	5.02	5.73	6.40	7.29
13	4.04	0.125	0.015	1.82	2.49	2.91	3.49	3.98	4.44	5.05
14	3.95	0.12	0.0183	1.76	2.41	2.81	3.37	3.84	4.28	4.86
15	3.26	0.0843	0.0214	2.16	2.99	3.50	4.20	4.80	5.36	6.11
16	2.90	0.079	0.0171	1.84	2.53	2.95	3.55	4.05	4.51	5.13
17	2.91	0.0744	0.00879	1.65	2.28	2.66	3.19	3.64	4.07	4.63
18	2.69	0.0665	0.0123	1.43	1.97	2.30	2.76	3.15	3.52	4.01
19	2.61	0.062	0.0121	1.51	2.09	2.44	2.93	3.35	3.74	4.23
20	2.69	0.0689	0.0088	1.65	2.28	2.66	3.30	3.77	4.21	4.52
21	2.13	0.0493	0.00980	1.35	1.87	2.19	2.64	3.02	3.37	3.88
22	2.01	0.0569	0.00856	1.25	1.72	2.01	2.41	2.75	3.07	3.50
23	1.66	0.0561	0.0108	1.14	1.57	1.84	2.21	2.52	2.82	3.21
24	1.69	0.0446	0.00598	1.08	1.49	1.75	2.11	2.41	2.69	3.07
25	1.73	0.0438	0.0066	1.20	1.66	1.94	2.34	2.67	2.99	3.41
26	1.34	0.0385	0.00276	0.82	1.14	1.33	1.60	1.83	2.04	2.33
27	0.93	0.0238	0.0028	0.41	0.56	0.66	0.79	0.91	1.02	1.16
28	0.51	0.0123	0.00165	0.38	0.53	0.63	0.76	0.87	0.97	1.11
29	0.43	0.0111	0.00167	0.40	0.53	0.67	0.85	1.03	1.11	1.34
30	0.36	0.0096	*	0.37	0.49	0.57	0.74	0.90	1.02	1.23

*Too small a catchment for LowFlows software to generate a value

The rural location of the site and the number of small lochs and burns in the region means it is not possible to monitor all watercourses in the area. Within the area of interest, several watercourses have been classified as having A2 (good) water quality status and the Burn of Laxobigging has been assigned A1 (excellent) status.

A suite of water samples has been collected for quality monitoring purposes and preliminary results indicate that 22 out of 30 samples have A1 (excellent) quality, four sites have A2 (good) quality and four have B (moderate) quality. Further details are provided in Chapter 14 of the Environmental Statement (Mouchel, 2009).

Taking this information into consideration, and using a precautionary approach, it has been assumed that all unclassified watercourses have at least A2 (good) water quality status.

2.10 Aerial Photography

High resolution orthorectified colour aerial photography was made available in late summer 2008, having been flown in May 2008 by XYZ Mapping. The photography is at a resolution of 25cm. Analysis of the aerial photography of the site (Figure 14.1.PS04, in Volume 4b) reveals that the site has a remarkably uniform character. The site is for the most part mid- to dark grey-brown in colour, indicative of the extensive blanket peat.

Very pale green or straw-coloured areas tend to mark river channels, usually indicative of deeper peat. These areas show that watercourses almost invariably start upstream of the ‘source’ marked on OS 1:10,000 base mapping and typically have a dendritic network that converges to form the main stream. Burns across the site have variable character, with some forming narrow channels within the peat and others cutting through into the bedrock to form narrow almost gorge-like valleys. The larger burns and lochs are well-defined

Better-drained areas following river valleys and along ridgelines appear as greener sections, broken in places by pale grey or white indicating mineral soils or bedrock exposure. In places, these pale sections are extensive, typically marking hill or ridge tops where the peat is heavily eroded. Remnant peat in these sections shows a dark red-brown to nearly black in places, indicating the extensive peat hagging in these areas. Peat dissected by networks of drainage channels has the standard grey-brown colouration with the channels indicated by irregular dark lines.

Brighter green areas around the flanks of the site indicate improved or semi-improved grassland for livestock grazing. Straight line traces across the photographs typically show the positions of fences, across which vegetation patterns can be distinct as representing a change in grazing patterns or other land use.

A small peatslide was identified south of Aith, on the flank of Whitelaw Hill, and a recent landslide is visible below the main road A971 above Weisdale Voe.

2.11 Vegetation

Vegetation mapping of the site has been carried out as part of the Environmental Impact Assessment. The site vegetation is dominated by blanket mire interspersed with smaller areas of wet and dry heath, grassland and bog pool habitats. Blanket mire vegetation covers the vast majority of the site.

Areas of grassland tend to be found on the steeper slopes along ridge sides, such as Mid Kame ridge and around Scalla Field in Kergord quadrant. In these areas the slope angles are generally too steep to allow waterlogging and development of peat. Grassland communities are also found around the site margins in areas of semi-improved grassland with artificial drainage. Other steep slope areas have wet or dry heath vegetation, with the wet heath tending to occur on shallower or more broken slopes.

Bog pool communities are more frequent in Nesting and Kergord quadrants, tending to occur along ridge tops in the gaps and hollows of the eroded peat. These quadrants also have small areas of limestone grassland corresponding with the bedrock outcrops of marble across the southern half of the site; particular examples occur around NBP01 in Nesting quadrant.

3 SITE RECONNAISSANCE

Subsequent to the desk study a walkover survey was carried out in March 2006, prior to the initial wind farm layout being produced. The walkover survey consisted of traverses across the original study area with the intention to gather representative regional data from areas across the site. The scope of the site visit included reconnaissance survey and mapping of the geology, geomorphology and hydrology of the site area. Following the walkover, a preliminary peat probing survey was undertaken in April 2006. The routes probed were designed to provide good representation of regional features in North Mainland, including ridge lines, rounded hills and various valleys. Owing to the extent of the site it was not possible to visit the whole site. Traverses and walkover routes were carefully planned to ensure a good coverage and that a range of representative areas were visited directly. Weather conditions during the initial field surveys were varied, including clear sunny days, heavy rain, low cloud and snow.

Following the production of the initial 171 turbine layout, further site investigations were carried out in November 2007, and January and February 2008. These visits were primarily to undertake further peat probing, discussed below, and to assess potential borrow pit and stream crossing locations. Additional features of relevance to the peat stability assessment were also recorded during this stage of the field investigation.

Despite this work being undertaken during the winter months, the weather was generally fair although strong winds impeded progress at times. Some days were wet with poor visibility and hail showers were common at times. A short thunderstorm occurred during the February fieldwork.

A final layout was produced in October 2008, necessitating additional fieldwork to provide information on areas where the infrastructure layout had been modified. This fieldwork was undertaken between 17 and 28 November 2008. In addition to peat probing, further information was collected for potential borrow pit and stream crossing locations to supplement that obtained previously. Concurrent with this work, peat coring was undertaken at 15 locations across the site which had been identified for ground investigation work; the remainder of the ground investigation work was undertaken during December 2008 and January 2009.

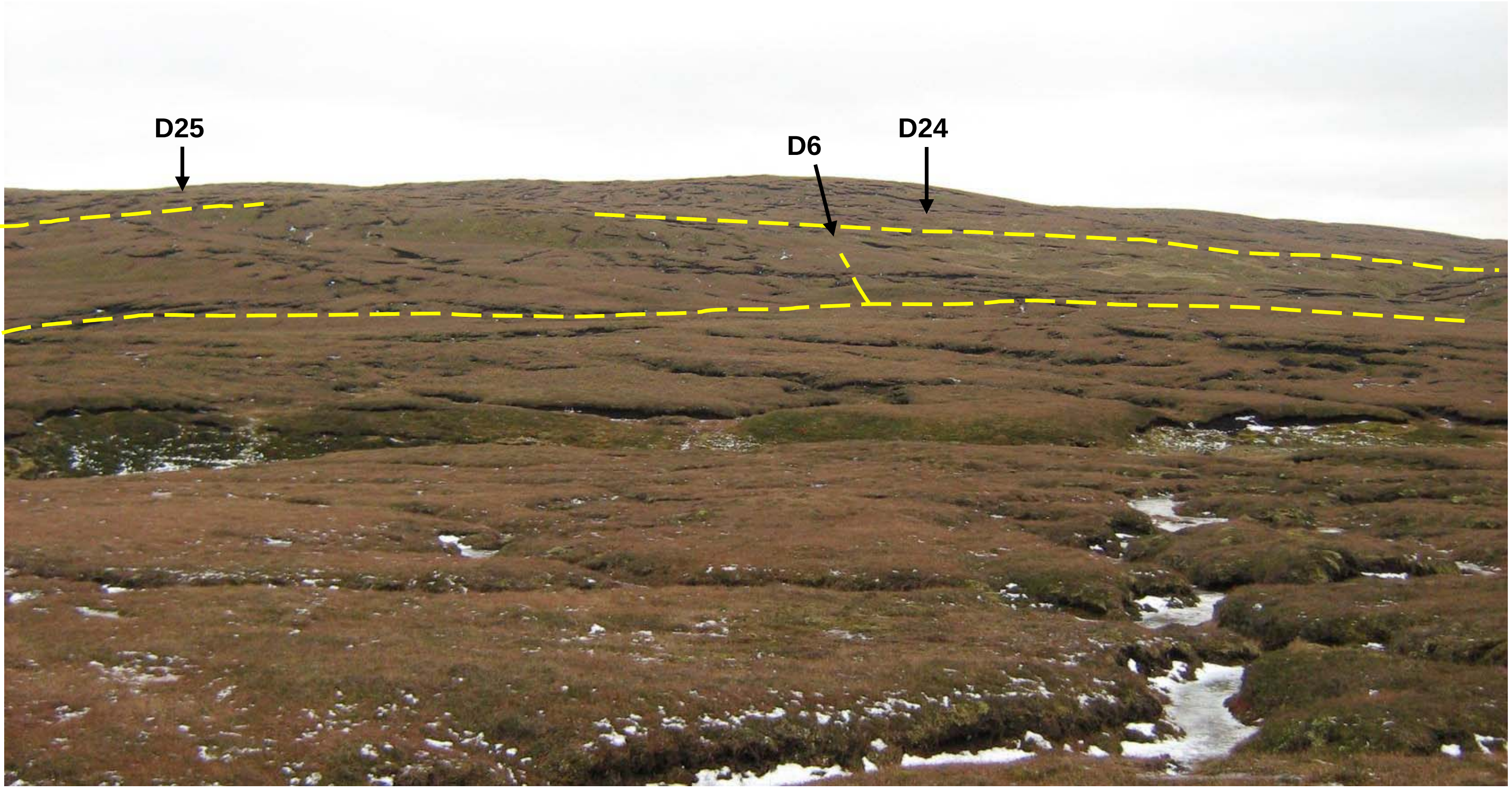
As has proved typical for this site, weather conditions were very variable during the field survey. Strong winds were common and fieldwork was restricted during the mid and later section of the visit owing to significant snowfall and icy conditions, resulting in dangerous and very slippery underfoot conditions. Low cloud and periodic blizzard conditions necessitated leaving the field early on three occasions. Low air temperatures combined with substantial wind chill provided an extra concern.

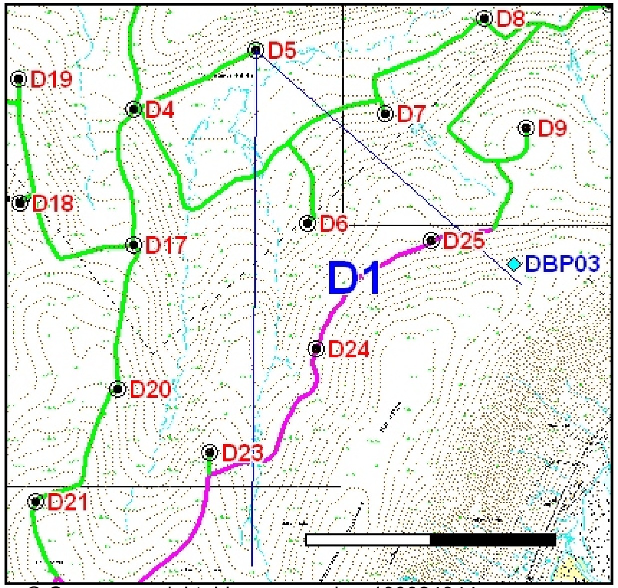
The areas described below provide a representative sample of the wind farm site, detailing the range of landforms, vegetation and erosion patterns encountered. Each detailed description is accompanied by a photograph giving an indication of the infrastructure proposed for the area, plus a location map and notes pertaining to the area. The locations of the areas and the boundaries are shown in Figure 14.1.PS06, in Volume 4b.

3.1 Area D1

Area D1 is situated in the central part of Delting quadrant, on the south-east flank of the Burn of Laxobigging valley. The area provides a typical overview of central Delting showing variation from the nearly flat river valley rising to steep slopes along the ridge lines. Slopes are generally smooth in character although prominent breaks in slope are present along the valley and ridge sides. Figure 13 shows a view across the area from Turbine D5.

Figure 13 View south-east over Area D1 from Turbine D5 (HU 3967 7067). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: 4.0; minimum: 0.0; average: 1.9

Erosion patterns: Dissected by drainage channels; more extensive gullying at higher levels

Instability: No signs of instability in the area

Notes:

The Burn of Laxobigging channel is visible in the foreground. The near track route runs approximately parallel to the stream channel in the middle distance. A second, higher level track runs along the valley side below the Hill of Dale in the distance.

Figure 13 indicates that this area has a fairly uniform cover of blanket peat. Peat probing indicates that peat in the valley floor is generally in excess of 1.5m deep with areas deeper than 2.5m.

The peat is dissected to varying degrees by drainage channels at the lower levels; at higher elevations has it has been subjected to considerable erosion and hagging. This is visible in the area near Turbine D24 in Figure 13.

Small, ice-smoothed knolls and spurs are present in places; an example can be seen immediately right of Turbine D25 in Figure 13. These sometimes expose small areas of bedrock in the steeper sides.

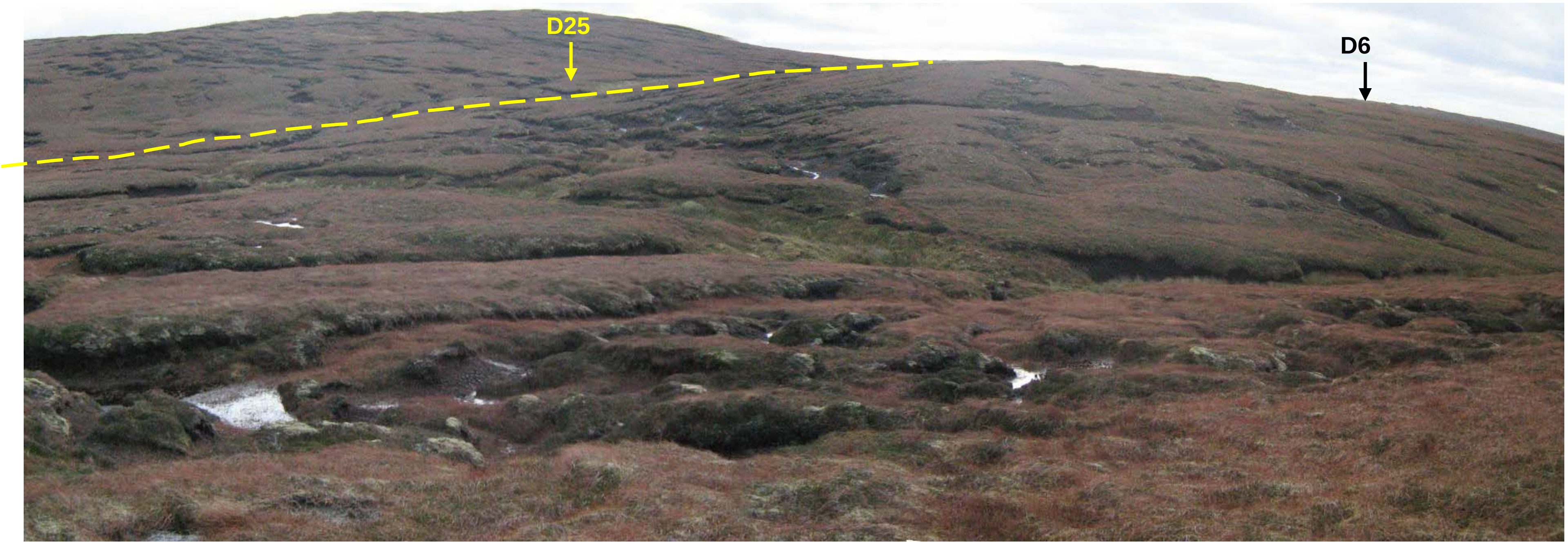
Areas of lighter green vegetation, for example between the two track lines towards the right hand side of Figure 13, indicate dryer areas where the peat is shallower and vegetation is more grass-dominated. For the most part the vegetation cover is a typical blanket mire mix of heather, sedges, grass and moss.

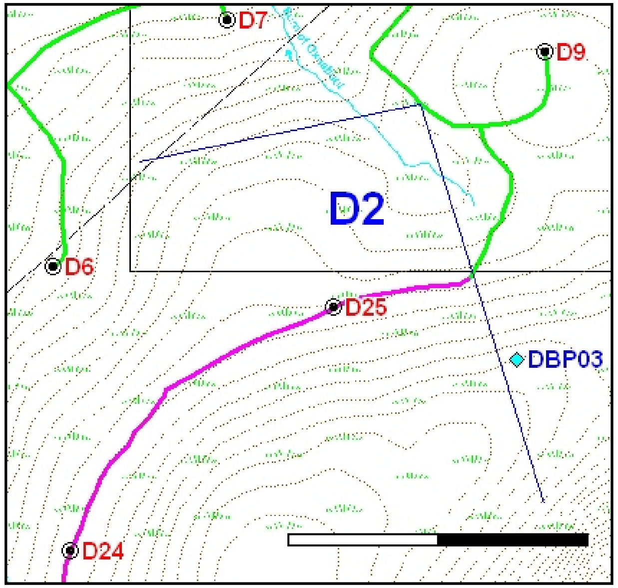
Track lines have been routed where possible to avoid steeper slopes and to minimise damage to intact blanket bog. Given the prevalence of deep peat it has not been possible to site turbines on shallow peat, although their locations avoid the deeper peat areas as far as this is practicable.

3.2 Area D2

Area D2 is also in the central part of Delting. This area includes the headwaters and upper part of the Burn of Oxnabool, the channel of which is visible in the right half of Figure 14. The topography is dominated by a shallow bowl, which is crossed by the track alignment, rising quite steeply to the Hill of Dale in the south-east and confined to the north-west by a broad spur and hill. The spur and hill are separated by the Burn of Oxnabool.

Figure 14 View south-west over Area D2 from north-eastern side of the Burn of Oxnabool (HU 4050 7028). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 500m).





Habitat type/vegetation:	Blanket mire; sedge/grass, moss, heather
Peat depths (m):	Maximum: 3.3; minimum: 0.0; average: 2.0
Erosion patterns:	Widespread gullying with exposed bare peat
Instability:	No signs of instability in the area

Notes:

The Burn of Oxnabool channel is visible in the centre of Figure 14, draining to the right hand side. The track route crosses a shallow bowl that forms the source region for the burn.

Peat probing in this area indicates that peat within the bowl area is mainly deeper than 1.5m. The top of the Hill of Dale, behind the track, has mostly shallow peat. Pockets of shallow peat are present across the area.

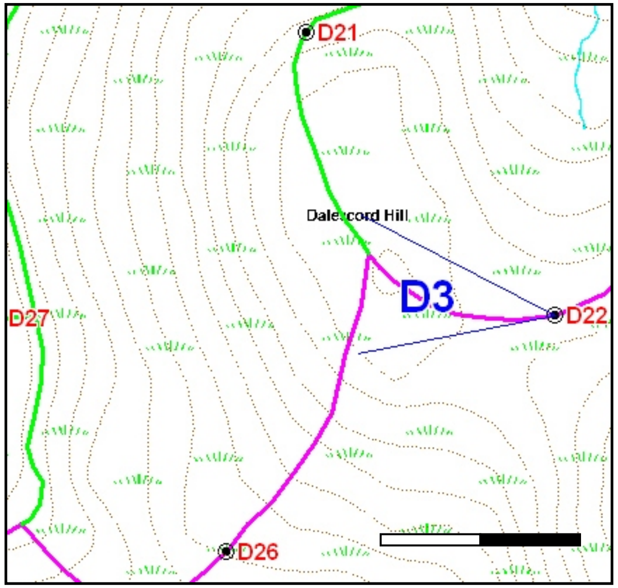
The blanket peat cover in this area has been subjected to extensive erosion, resulting in widespread gullying. The spur between Turbines D25 and D6 has a wide, nearly flat summit with steepening slopes towards the Burn of Oxnabool and down towards the west. The peat in this area is less eroded than in the main bowl, with only a few drainage channels running down-slope.

There is a fair amount of exposed bare peat, some of which is being recolonised by lichens, visible in the left foreground of Figure 14. Vegetation is otherwise dominated by the heather, sedges, grass and moss characteristic of blanket mire. Drier areas, such as the burn valley, are indicated by greener colouration.

3.3 Area D3

Many of the hill and ridge tops are characterised by extreme peat erosion where peat has mostly been removed to expose mineral soil and, in places, bedrock and leaving only isolated peat haggs and banks. Area D3 provides a good example of this terrain (Figure 15).

Figure 15 View west over Area D3 from Turbine D22 (HU 3913 6858). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 250m).



Habitat type/vegetation: Blanket mire & wet heath; heather, sedge/grass, moss

Peat depths (m): Maximum: 1.5; minimum: 0.2; average: 0.7

Erosion patterns: Isolated haggs with bare peat and mineral soil

Instability: No signs of instability in the area

Notes:

Area D3 includes a col leading up to Dalescord Hill, immediately west of Turbine D22. The track route follows the top of the col and runs along the summit of Dalescord Hill.

Peat probing indicates that peat depths across the col are shallow, mainly less than 0.5m, as are the peat depths across the summit of Dalescord Hill. Remaining peat banks stand to around 1.5m above the erosion surface.

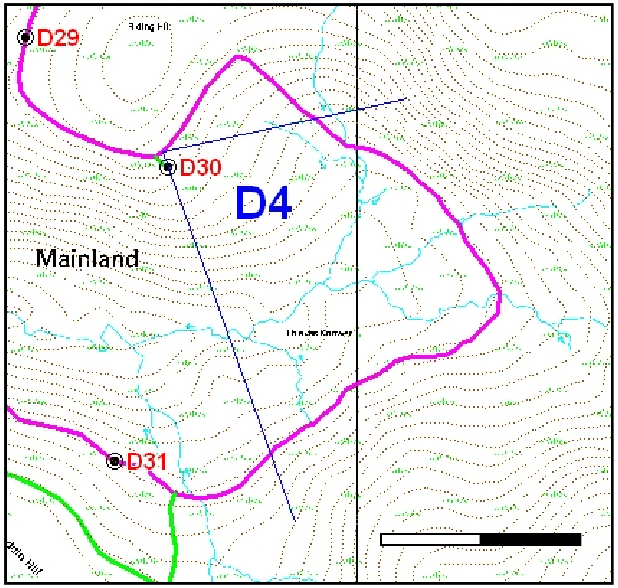
The col itself has fairly intact peat with occasional eroded channels and peat banks; an example can be seen in the foreground of Figure 15. The summit area of Dalescord Hill has largely been eroded to mineral soil or bare peat with a few remnant peat haggs particularly around the edges. These show clearly along the skyline in Figure 15.

Vegetation in the area is mainly sedges and grass with subordinate moss and heather, clearly visible in the foreground of Figure 15. Bare peat surfaces have in places become recolonised by lichens. Heavily eroded sections mostly remain unvegetated although some areas are showing signs of early regrowth of grasses & sedges.

3.4 Area D4

Situated in the southern part of Delting quadrant, Area D4 includes the headwaters of the Burn of Skelladale and across to Button Hills to the north-east and Souther Hill to the south-east (Figure 16). The head of the valley forms a shallow bowl surrounded on three sides by higher ground, similar in form to Area D2 but on a larger scale. A narrow terrace runs around the head of the valley at the base of the main slope up to Button Hills. This slope is cut by several streams which form tributaries to the Burn of Skelladale.

Figure 16 View east over Area D4 from the eastern slope of Riding Hill (HU 3855 6783). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 500m).



Habitat type/vegetation:	Blanket mire; heather, sedge/grass, moss
Peat depths (m):	Maximum: 3.3; minimum: 0.1; average: 1.4
Erosion patterns:	Smooth vegetated slopes with drainage channels & gullying
Instability:	No signs of instability in the area

Notes:

The Burn of Skelladale valley can be seen in the middle distance at the right hand side of Figure 16. The track line follows a narrow but distinct terrace around the head of the valley.

Measured peat depths on the south-east slope of Riding Hill indicate that the peat here is deeper than along the other slopes in the area. The site of Turbine D30, on the right-hand edge of Figure 16, gives depths ranging from 1.1m to 3.2m. Peat probing along the track line indicates that peat depths are mostly moderate to shallow (less than 2m) whereas across the valley floor peat depths are in places in excess of 4m.

The blanket peat is variably dissected by drainage channels and small watercourses. Below the track line these drainage channels and gullies become more frequent and the peat is more dissected in this area. A similar network of small interconnected channels in the peat is visible in the foreground and also on the slopes of Souther Hill, towards the right-hand side of Figure 16.

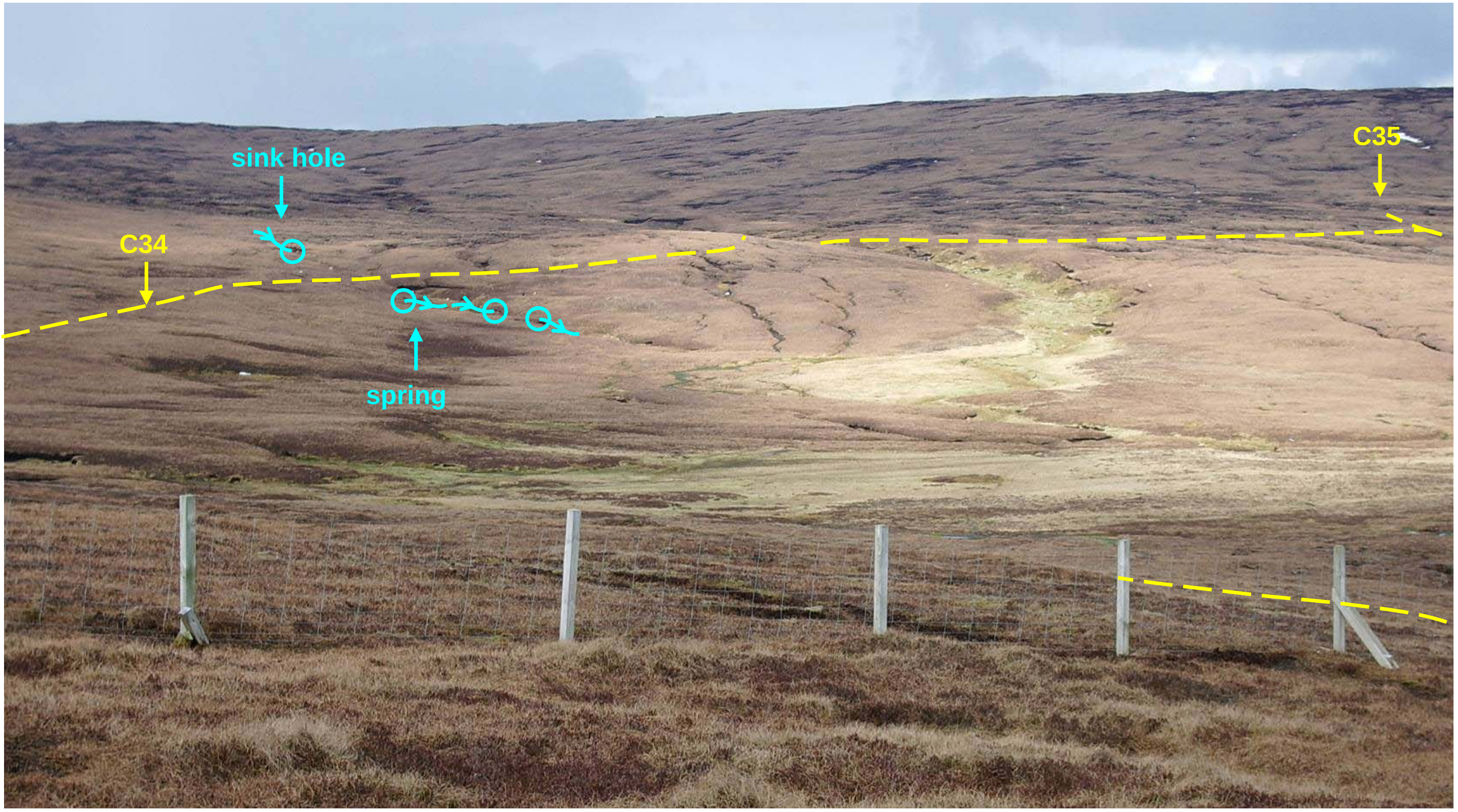
Positions of streams and other well-drained areas are marked by areas of paler vegetation in Figure 16, showing that they have a wide distribution across the steeper slopes of Button Hills and Souther Hill. The lower slopes of Riding Hill in the foreground generally slope at shallower angles and have vegetation characteristic of blanket peat, dominated by sedges, grasses, heather and moss, with bare peat exposed in some of the drainage channels and peat banks.

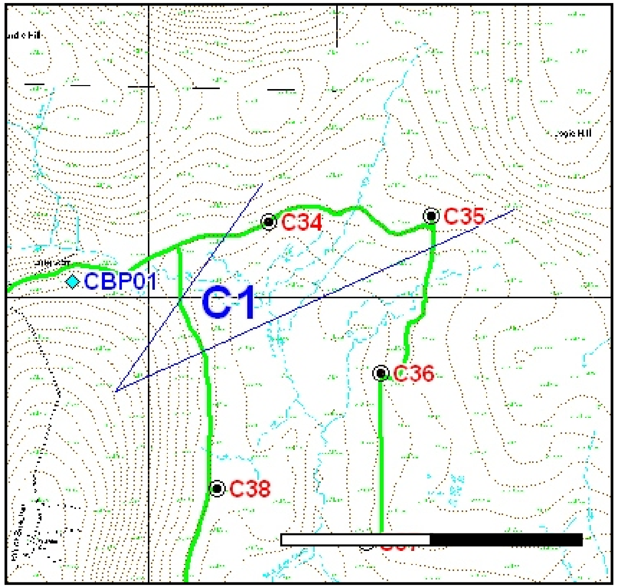
The track line has been routed to avoid the deeper peat present in the main valley floor and to avoid steeper slope angles.

3.5 Area C1

Area C1 covers the northern part of Collafirth quadrant. This area includes the upper part of the wide valley of the Seggie Burn, which is characterised by smooth slopes, a flat valley floor and a network of streams. A view across the area is shown in Figure 17.

Figure 17 View north-east across Area C1 from the flank of Hill of Susetter (HU 4189 6570). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; heather, sedge/grass, moss; subordinate acid grassland

Peat depths (m): Maximum: 3.0; minimum: 0.2; average: 2.0

Erosion patterns: Smooth vegetated slopes with drainage channels; more prominent gullying at higher levels

Instability: Large partially collapsed peat pipe; no other signs of instability

Notes:

The Collafirth infrastructure is situated predominantly within the wide valley of the Seggie Burn, which runs left to right across Figure 17. Significant tributaries are also visible.

This area has a fairly uniform cover of blanket peat, especially at lower levels (Figure 17). Peat probing in the area indicates that peat is mainly deeper than 1.5m, and in places in excess of 4m. The prominent stream in the middle distance of Figure 17, crossed by the track route, is incised to bedrock so consequently peat depths within this valley are shallow.

The mainly smooth lower surfaces give way to more dissected peat visible above the track line, on the side of Logie Hill, where a more extensive network of drainage channels has developed.

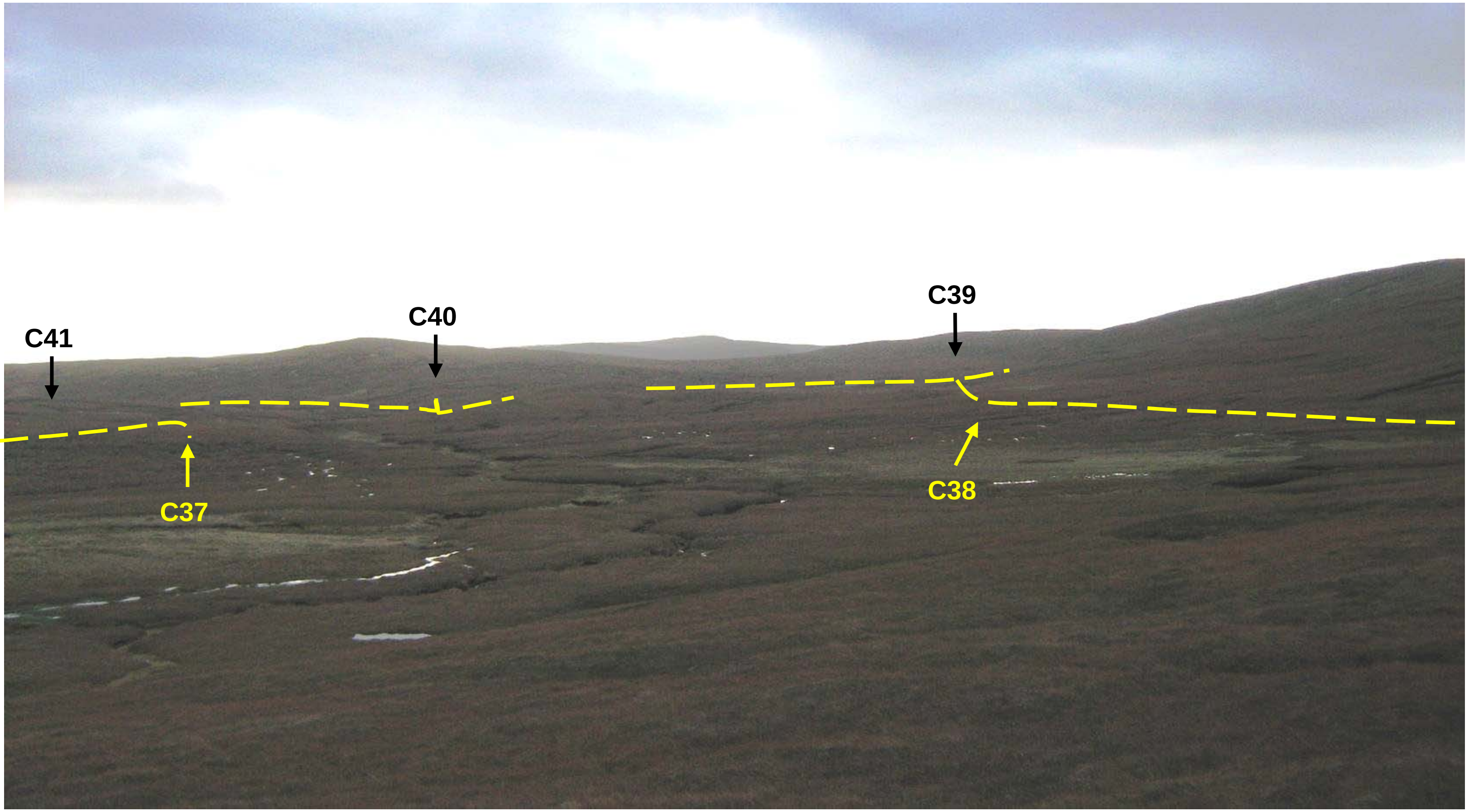
A large, partially collapsed peat pipe is present within this area and crosses the proposed track line. Its position is indicated in Figure 17. The first sink hole, just to the right of Turbine C34, marks the first entry of the stream into the peat. The sink hole here is nearly 3m deep by 2.5m wide and reaches to the peat-substrate interface. Further downhill the watercourse emerges before going underground again for a short section.

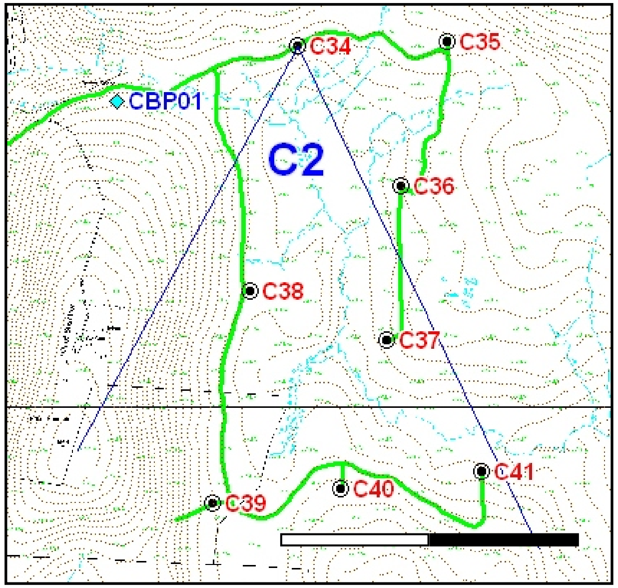
Vegetation on the lower hill slopes is dominantly typical blanket mire vegetation, with the darker areas representing dryer ground and a higher proportion of heather. The very light area in the middle distance corresponds with an area of acid grassland, crossed by dark green acidic flushes where inflowing watercourses cross the area.

3.6 Area C2

The southern part of Collafirth quadrant is covered by Area C2 and is shown in Figure 18. The area provides a typical overview of the Collafirth quadrant, with the contrast between the nearly flat-lying ground on the valley floor and the steep hill slopes around the sides.

Figure 18 View south across Area C2 from Turbine C34 (HU 4237 6623). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation:	Blanket mire; sedge/grass, moss, heather; subordinate acid grassland
Peat depths (m):	Maximum: 4.0; minimum: 0.5; average: 2.3
Erosion patterns:	Smooth vegetated slopes with drainage channels
Instability:	Several partially collapsed peat pipes; old crack parallel to hillside above Turbine C39

Notes:

The Seggie Burn is visible in Figure 18 crossing the area from just below the track line at the right-hand margin, with its principal tributary joining from the middle distance on the left. Additional small waterbodies are visible in Figure 18.

Peat probing across the area indicates that peat is predominantly deep, especially below the Hill of Susetter (right hand side of Figure 18) where depths are mostly over 2m and in places in excess of 4m. Slightly shallower peat was encountered along Laxo Knowe between Turbines C40 and C41 where depths were typically less than 2m.

As with the northern part of the quadrant, this area is characterised by flat or shallow slopes with a fairly uniform coverage of blanket bog broken in places by drainage channels. Unlike the northern end, the higher slopes remain fairly smooth and unbroken, in particular on the Hill of Susetter to the west. The area between Turbines C40 and C41 on the lower slopes of Laxo Knowe is more dissected with a more interconnected network of gullies through the peat.

Some of the drainage channels down the Hill of Susetter form collapsed or partially collapsed peat pipes where the slope angle changes, just above the track line. One particular pipe is adjacent to Turbine C38. There may be other intact pipes that have no visible surface expression in this area.

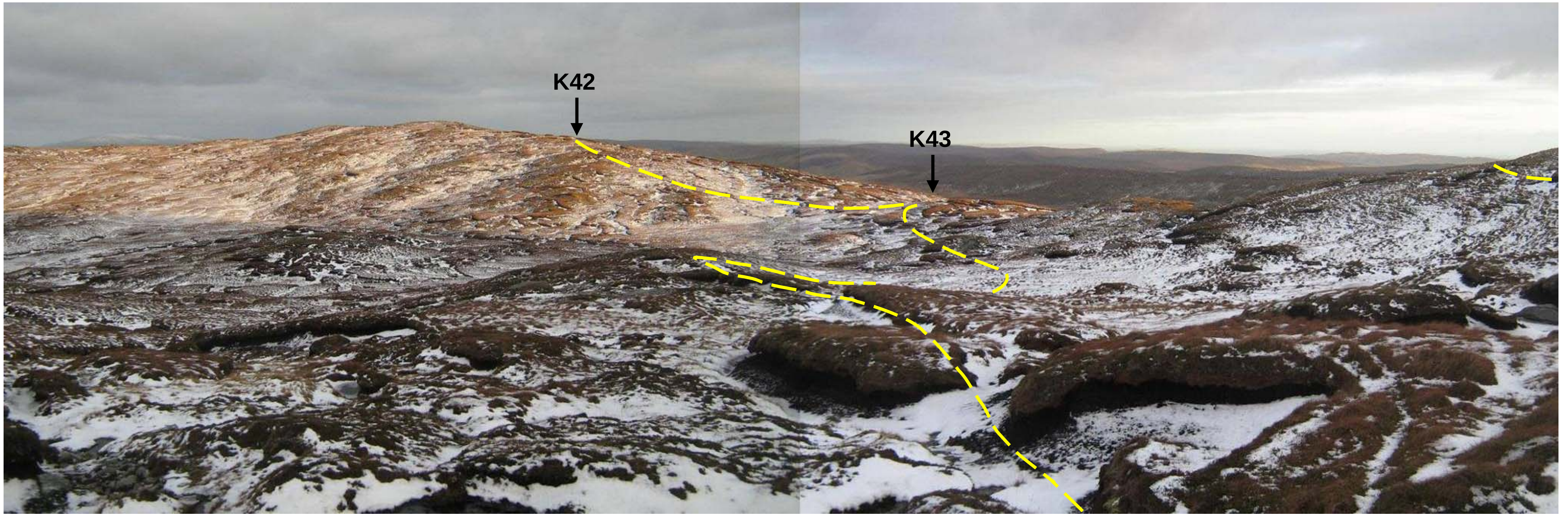
The flat-lying ground immediately adjacent to both watercourses is demarcated by pale vegetation. The area in the left foreground is the acid grassland mentioned in Area C1. Otherwise, vegetation is characterised by typical blanket mire species.

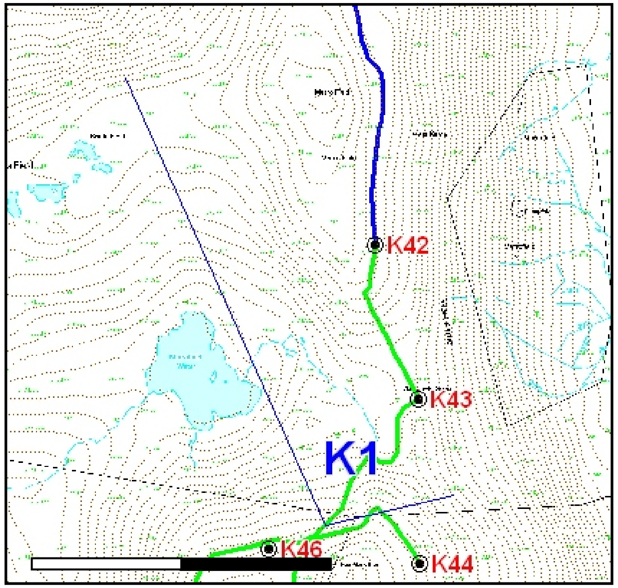
The track lines have been routed to take advantage of the nearly flat ground around the margins of the valley, even though the area is dominated by deep peat. It is likely that most of the track within this quadrant will be of floating construction because of the combination of deep peat and frequent large peat pipes.

3.7 Area K1

Area K1 is in the northern part of Kergord quadrant and encompasses the col of Marrofield Scord and part of West Kame ridge (Figure 19). This col includes a mixture of deep and eroded peat and exposed bedrock. Good examples of peat banks can be seen in the foreground of Figure 19. The small knoll in the central foreground, along the track line, has excellent bedrock exposure as rocksteps on the northern face and slabs across the summit. The area around Turbine K43 also exposes bedrock as a series of smoothed slabs within the col itself and on the south side.

Figure 19 View north-east across Area K1 from the flanks of Gruti Field (HU 3904 5884). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; heather, sedge/grass, moss

Peat depths (m): Maximum: 4.0; minimum: 0.0; average: 1.0

Erosion patterns: Irregular peat banks & gullies

Instability: Small collapsed peat pipe; no other instability observed

Notes:

Marrofield Water is just off-picture to the left; tributaries to the loch follow the lower ground down from the col by Turbine K43.

Figure 19 shows clearly that the peat has been subjected to considerable erosion. Measured peat depths across the area are variable but mainly fairly shallow (<1.5m), although occasional points have depths up to 4m. The extent of rock outcrop and variability of peat depth within a short distance indicate that peat has mainly developed in pockets in the land surface and deep peat consequently has limited extent.

Drainage channels are clearly visible on the lower slopes of Marro Field, below Turbine K42. Exposed peat banks are visible in the foreground. A small collapsed peat pipe is present in the left foreground, although not clearly visible.

Small ice-smoothed knolls are present in some areas; an example can be seen in the middle distance down to the left from Turbine K42.

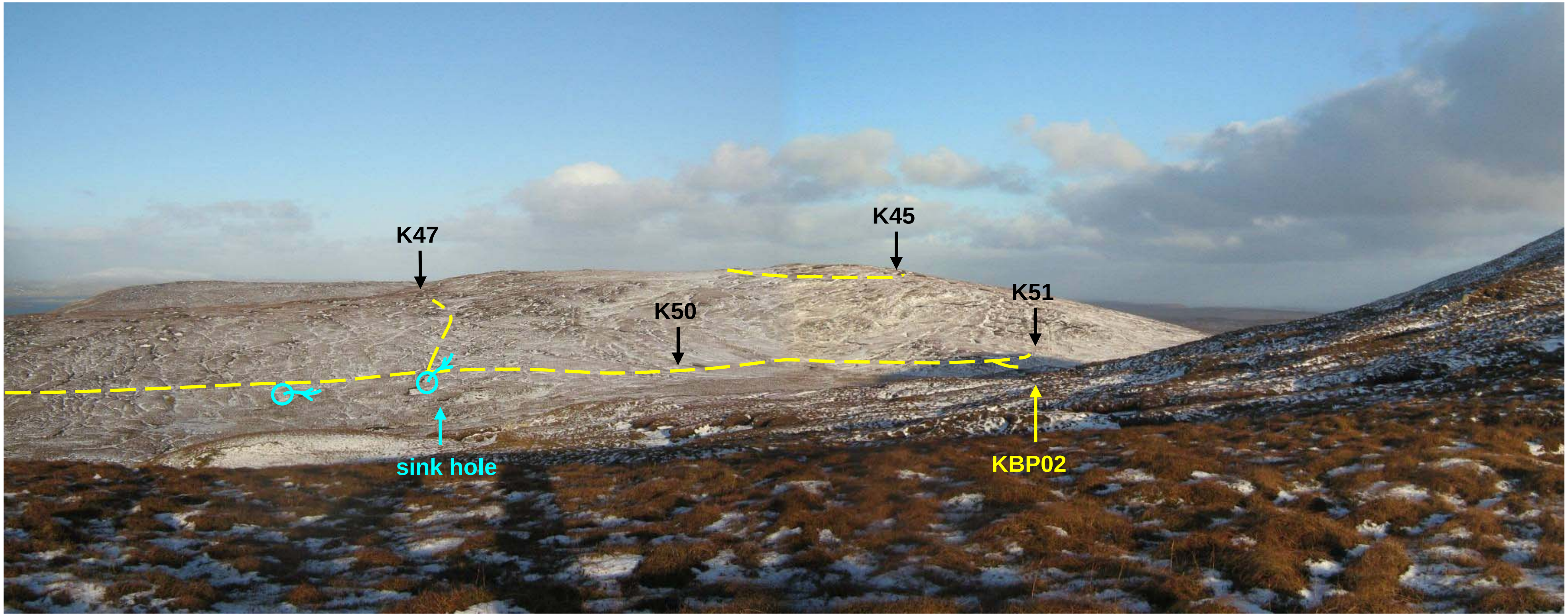
Areas of paler vegetation in the left foreground mark places with mixed vegetation cover and rock exposure, as does the section between the two track lines in the right middle distance. Vegetation is dominated by blanket mire species of grass, sedges, moss and some heather.

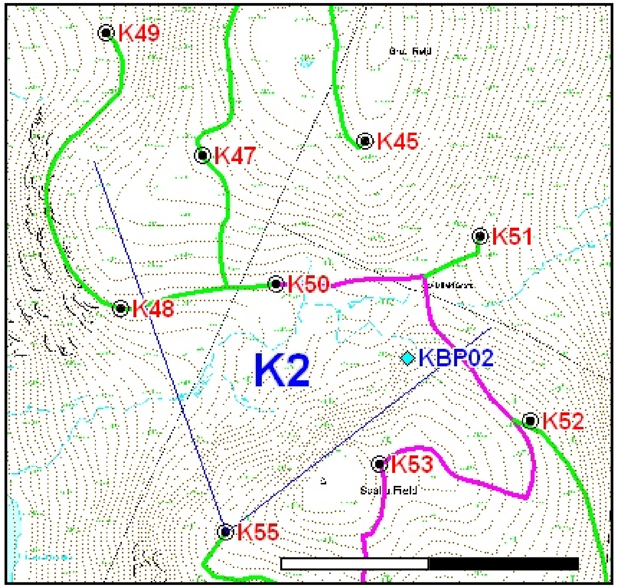
The track line has been planned to take advantage of the rocky ground and shallower peat where this is possible.

3.8 Area K2

Area K2 has a similar topographical setting to Area K1, encompassing Scallafield Scord col with Turbine K51 and Gruti Field with Turbine K45. The northern slopes of Scalla Field, visible in the right middle distance of Figure 20, are steep with angles up to 40° and have fairly substantial exposures of bedrock. These continue northwards to the site of proposed borrow pit KBP02, just south of Scallafield Scord, which has excellent bedrock exposed as rocksteps and slabs.

Figure 20 View north-east across Area K2 from the west ridge of Scalla Field, at Turbine K55 (HU 3863 5710). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation:	Blanket mire; heather, sedge/grass, moss
Peat depths (m):	Maximum: 4.0; minimum: 0.0; average: 1.6
Erosion patterns:	Smooth vegetated slopes with drainage channels
Instability:	Partially collapsed peat pipe; no other instability observed

Notes:

The main watercourse, the Red Burn, follows the prominent valley down west from Scallafield Scord, near Turbine K51 (Figure 20). The track route runs along the valley side approximately parallel to the burn.

Figure 20 indicates that the area has extensive peat cover. Peat probing indicates that the main valley has fairly deep peat, especially within the valley floor where peat is largely in excess of 1.5m deep. Across the top of Gruti Field, around Turbine K45, peat depths are all <1m although these show a slight increase in the area around Turbine K47 with depths up to 1.7m at the turbine itself.

The peat cover is mostly fairly smooth although it is dissected in places by drainage channels. These are clearly visible around the track line towards the left hand side of Figure 20. A partially collapsed peat pipe has been identified in the area west of Turbine K50, marked by sink holes (Figure 20).

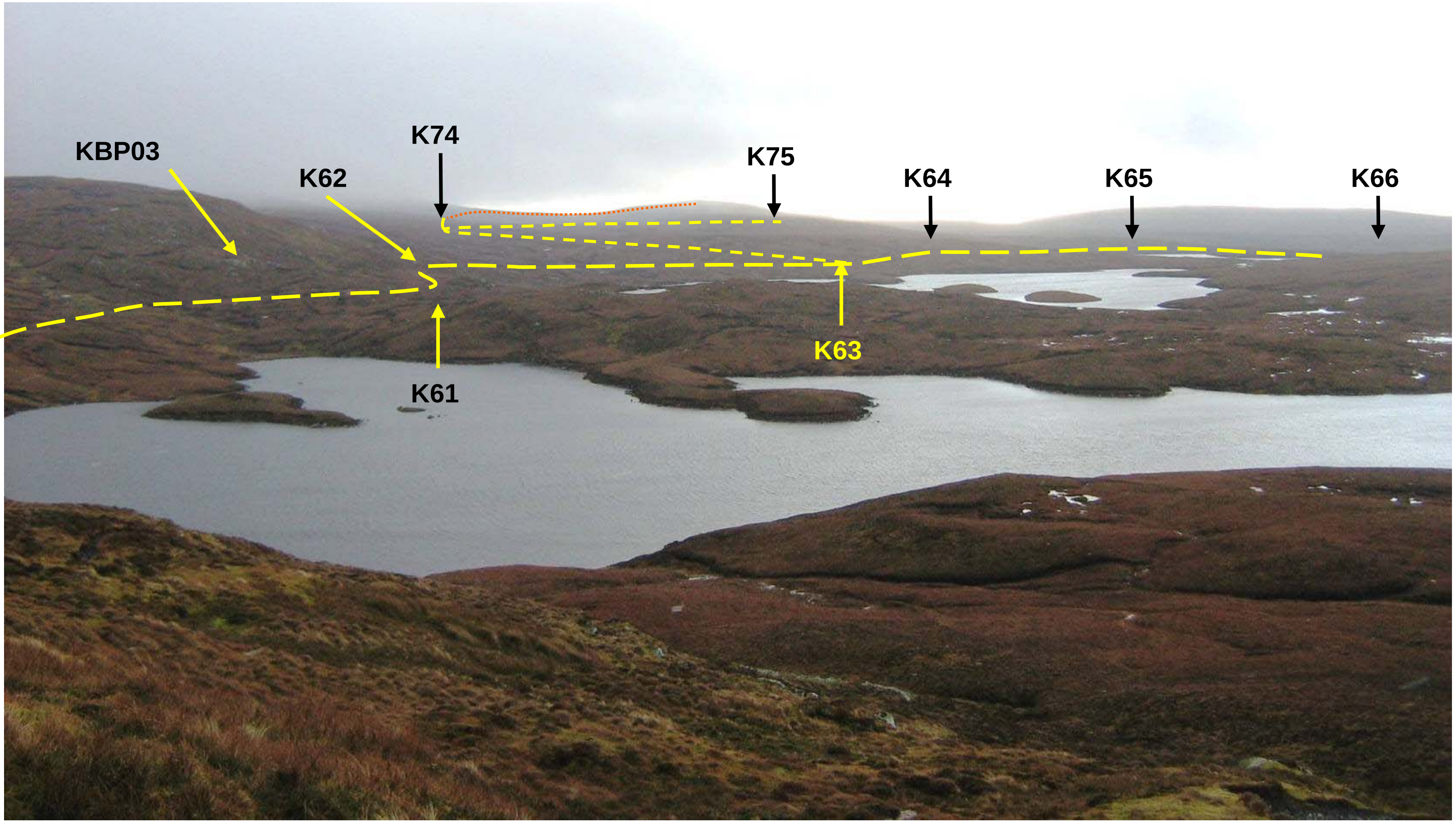
Pale vegetation visible on the hilltops and steeper slopes is indicative of dryer conditions where the peat is thinner. Most vegetation in the area consists of a typical blanket bog mix of grass, sedges, heather and moss.

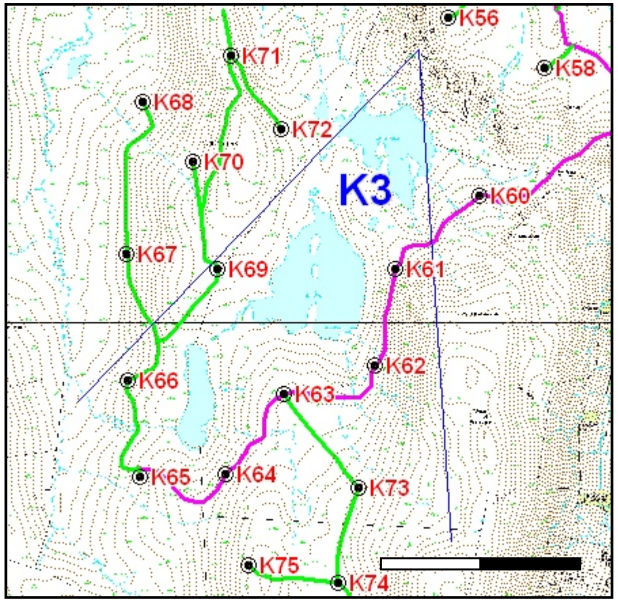
The track has been routed to skirt the main valley, taking advantage of shallowing peat along the valley sides but also modest slope angles along the hillside.

3.9 Area K3

The central part of Kergord quadrant includes several lochs of varying sizes and the wind farm infrastructure has been positioned carefully with respect to these important hydrological features. Area K3 covers part of central Kergord and is shown in Figure 21.

Figure 21 View south-west across Area K3 from the flanks of Scalla Field (HU 3833 5644) over Lamba Water and Maa Water. Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: 4.0; minimum: 0.4; average: 1.9

Erosion patterns: Smooth vegetated slopes with drainage channels and exposed bedrock

Instability: Minor cracking on steep slopes of Scalla Field; no other instability observed

Notes:

Lamba Water is clearly visible in the middle distance of Figure 21, with Maa Water behind. An area of low-lying boggy ground links the two lochs at the western side

Area K3 has extensive but variable peat cover and areas with good rock exposure. Rock outcrop is visible in the foreground of Figure 21 and proposed borrow pit KBP03 is indicated in the photograph; this site exposes extensive slabs of bedrock which continue along the slopes of the hill both north-east and south of the borrow pit site. The ridge of higher land between the two lochs has good exposure of bedrock.

Peat probing along the tracks indicates that peat is mainly between 1 and 2.5m deep with areas of both deeper and shallower peat. The area behind Maa Water, around Turbine K63, is mainly deeper as this is fairly flat and provides most of the headwaters for the loch. The track between Turbines K63 and K74 crosses an area of more uniform blanket peat and has measured depths to 3.2m.

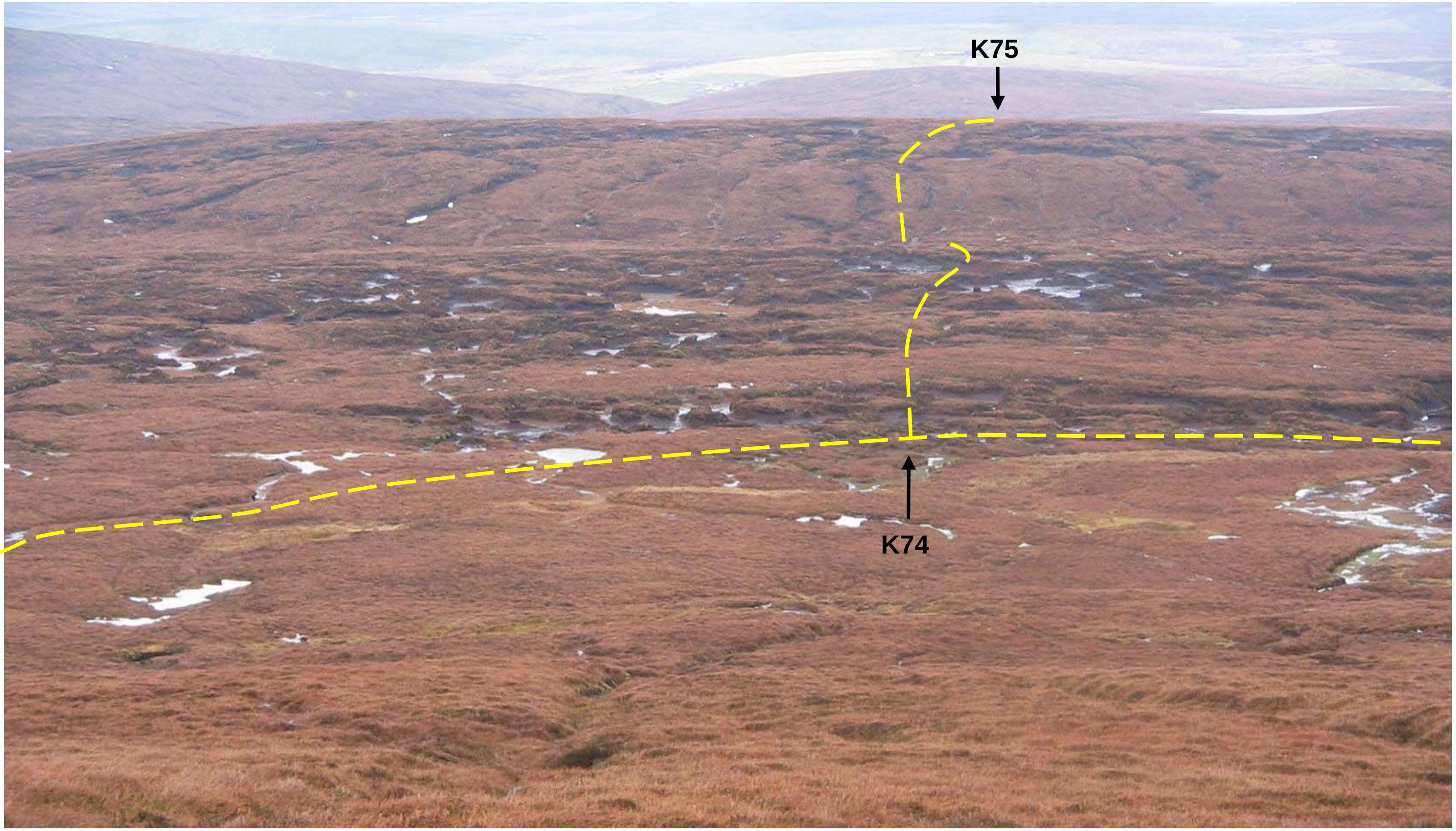
The mixed vegetation visible in the foreground indicates that peat cover is generally thinner and the drainage better in this part of the area. Similar vegetation patterns can be seen on other rocky parts of the area, for example around KBP03. Most of the area vegetation is dominated by the typical blanket mire mix of grass, sedges, moss and heather.

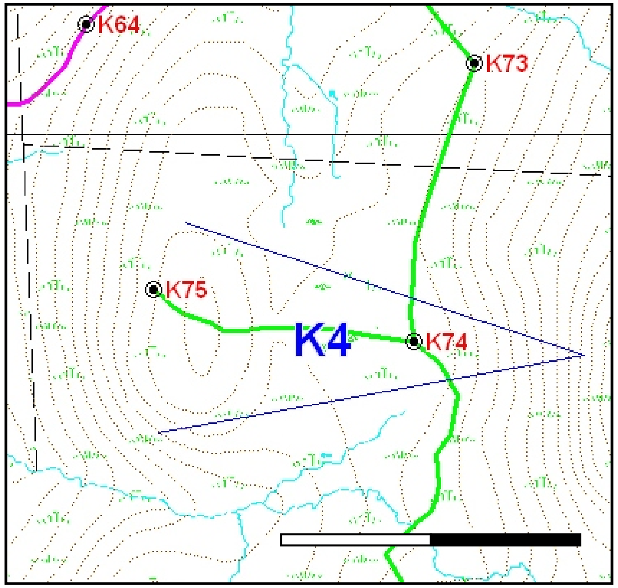
For the most part, the track has been routed to take advantage of the break in slope between the steeper hills and the flatter area immediately around the lochs, whilst maintaining a buffer zone between the lochs and the track line.

3.10 Area K4

Towards the southern part of Kergord, blanket peat becomes dominant again. This is clearly shown in Figure 22 with a view across Area K4.

Figure 22 View west across Area K4 from the flank of West Hill of Weisdale (HU 3821 5360). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 500m).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: >4.0; minimum: 0.8; average: 2.4

Erosion patterns: Extensive gullying and erosion with exposed bare peat

Instability: No signs of instability in the area

Notes:

Area K4 is situated on a shallow col with watercourses draining to north and south. The track line crosses the col and continues on over a low hill to the west, with Turbine K75 just over the summit. A distinct break in slope is visible in the foreground of Figure 22 before Turbine K74.

This area has extensive peat coverage with widespread erosion and gullying across the col area and distinctive drainage channels visible on the sides and summit of the hill to the west (Figure 22). In contrast, the lower slopes in the foreground are fairly smooth and continuous.

Peat depths in this area are generally deep, mainly in excess of 2m and in places more than 4m. Track construction is consequently most likely to be floating.

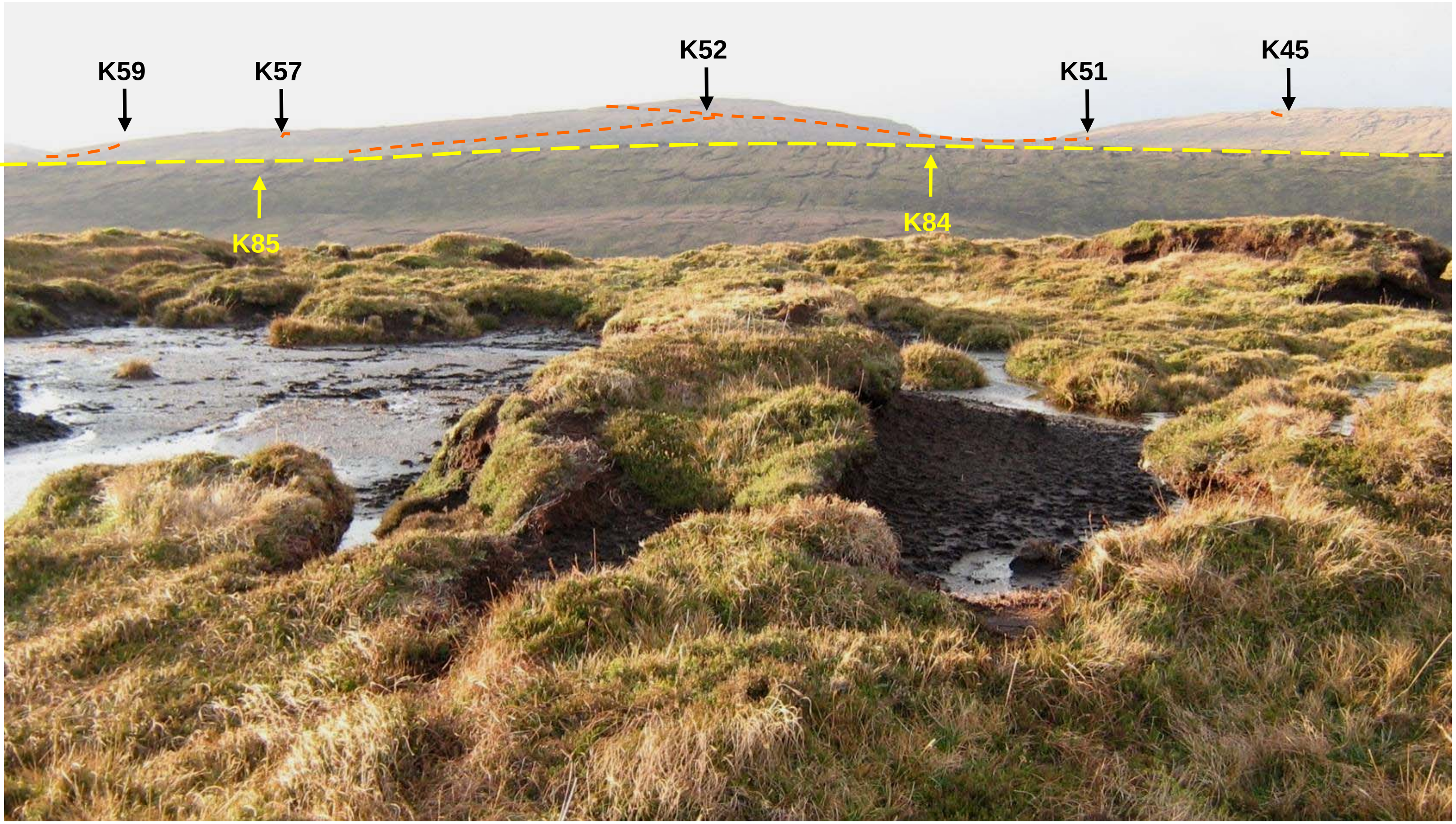
Vegetation in the area is dominated by typical blanket mire vegetation consisting of grass, sedges and moss. Subordinate heather is present in places. Paler green areas demark deep bog channels, characterised by floating mats of *Sphagnum* moss, and eroded areas expose large amounts of bare peat. In general, the bare peat is not showing signs of significant revegetation in this area.

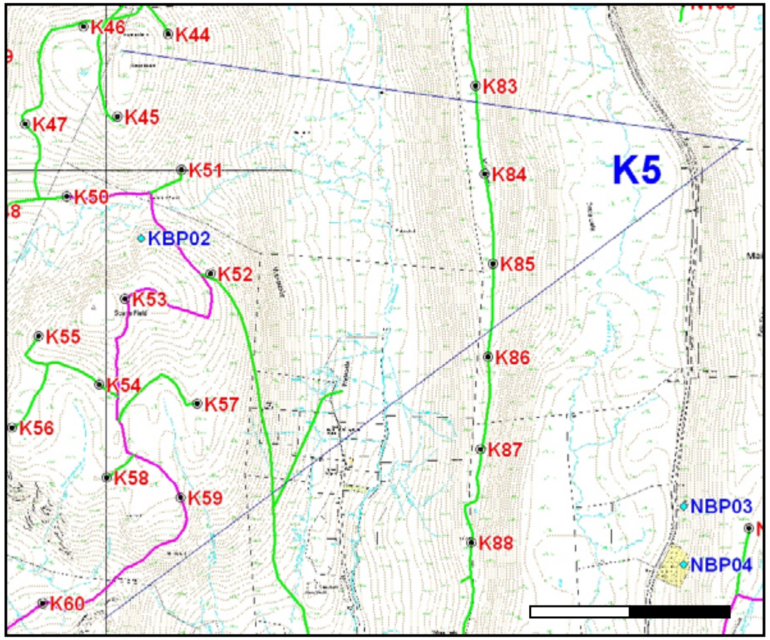
Owing to the prevalence of deep peat in this area it is not possible to route the track so as to avoid it. The track line follows areas with shallow slope angles as far as possible and is confined to the crest of the col between Turbines K74 and K75.

3.11 Area K5

Mid Kame dominates the eastern side of Kergord quadrant and forms a long, straight and steep-sided ridge with prominent breaks in slope at the top and bottom of each side. Figure 23 shows a view across Mid Kame to Scalla Field from the western side of Nesting quadrant.

Figure 23 View west across Area K5 from East Kame (HU 4242 5815) to Mid Kame and Scalla Field. Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation:	Blanket mire; sedge/grass, moss, heather; subsidiary grassland
Peat depths (m):	Maximum: >4.0; minimum: 0.0; average: 1.4
Erosion patterns:	Dissected by drainage channels; extensive hagging along ridge and hill tops
Instability:	No signs of instability in the area

Notes:

Area K5 includes parts of East Kame (foreground), Mid Kame (centre) and West Kame (including Scalla Field) ridges, separated by Petta Dale and the Valley of Kergord respectively. Proposed infrastructure is mostly restricted to the higher ground.

Peat depths are very variable across this area, owing to the variable topography. The steeper slopes have peat depths up to 1m; in the valley floors peat is in places in excess of 4m and mostly more than 2m deep.

The summit of Mid Kame has been extensively eroded for most of its length, down to bare mineral soil, with remnant peat haggs up to 2m in height in places. The ridge sides show distinct drainage channels, although the steepness of the slopes precludes build-up of substantial peat deposits. The steep sides of Gruti Field, around Turbine K45, show similar drainage channel patterns to Mid Kame.

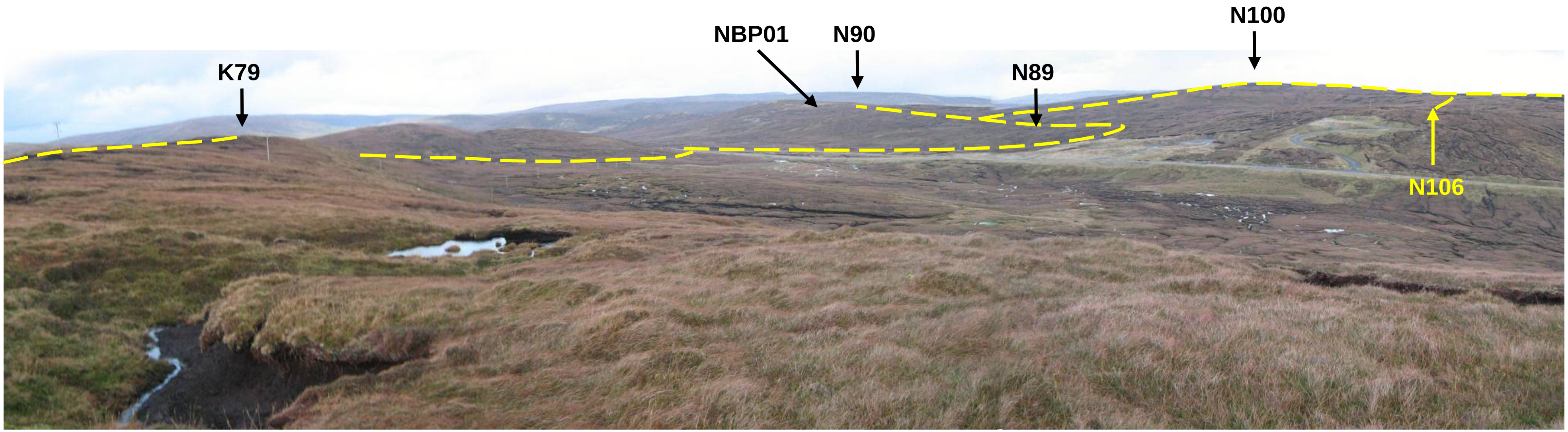
Vegetation along the side of Mid Kame appears greener than the typical tawny blanket mire vegetation. This reflects the thinner peat and better drainage of this area, giving rise to a dominant grassland vegetation. The foreground is characterised by eroded peat with mossy vegetation.

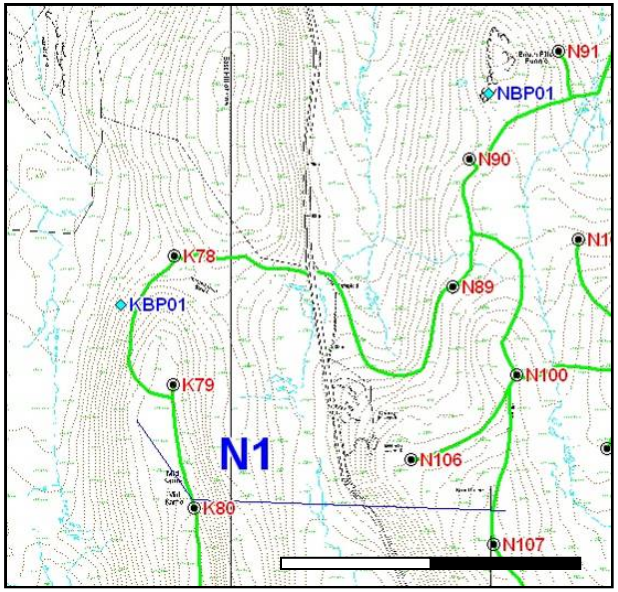
Track lines have been routed to take advantage of ridge lines where possible, in particular along Mid Kame ridge. West Kame is less continuous, although the track follows the high ground as far as is practicable.

3.12 Area N1

Area N1 encompasses the northern end of Mid Kame ridge and the north-western section of Nesting quadrant. The main road A970 can be seen crossing Figure 24 and dividing Kergord and Nesting quadrants. The break in slope that defines the summit line of Mid Kame is clearly visible running from the right of Turbine K79 across the foreground of Figure 24.

Figure 24 View north-east across Area N1 from Mid Kame ridge (HU 4084 5994). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation:	Blanket mire; sedge/grass, moss, heather; subsidiary grassland
Peat depths (m):	Maximum: >4.0; minimum: 0.2; average: 1.8
Erosion patterns:	Dissected by drainage channels; eroded to mineral soil & bare peat in places
Instability:	No signs of instability in the area

Notes:

The headwaters of the Burn of Pettawater and the Wester Filla Burn are visible in the middle distance, just below the A970. An overhead power line can be seen crossing Mid Kame in front of Turbine K79.

Figure 24 indicates that the blanket peat cover in this area has been subject to considerable erosion. Measured peat depths across this area are variable, with deeper peat (in excess of 2m) occurring mainly on the valley floors. Shallower peat, mainly less than 1.5m, is found on the steep sides of Mid Kame.

Along Mid Kame, towards Turbine K79, bare peat is exposed and a peat bank is visible in the foreground. In places peat has been eroded to mineral soil. Similar erosion patterns are apparent on hill tops in north Nesting. Extensive erosion to form drainage channels can be seen around Turbine N106, at the right-hand side of Figure 24.

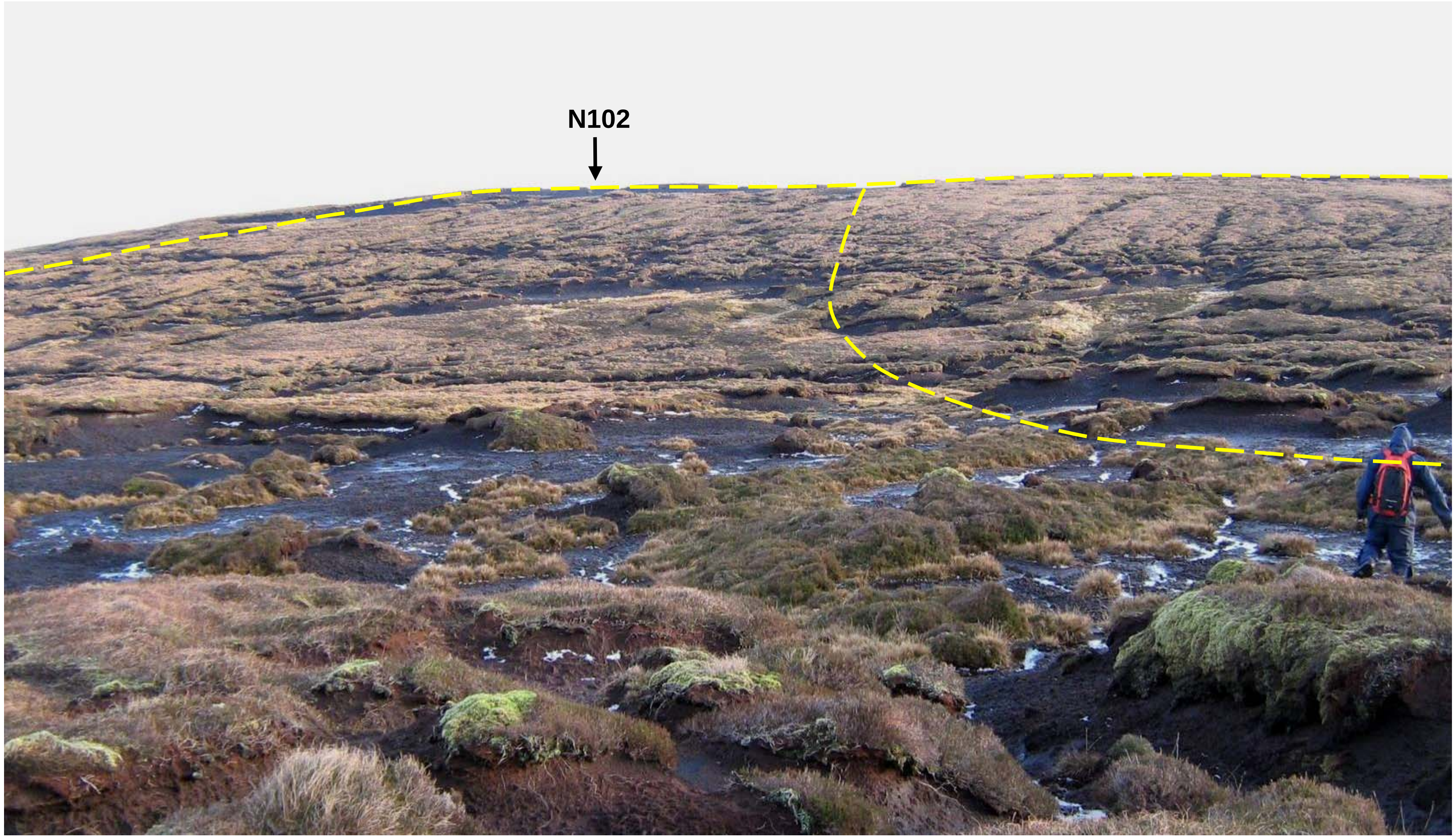
Vegetation is dominated across the area by tawny-coloured blanket mire vegetation. Paler green to straw-coloured areas are dryer, such as the quarry and track area immediately below Turbine N100, where grassland species are prevalent. An area of greener vegetation around borrow pit NBP01 marks the presence of marble bedrock which has a distinct natural flora.

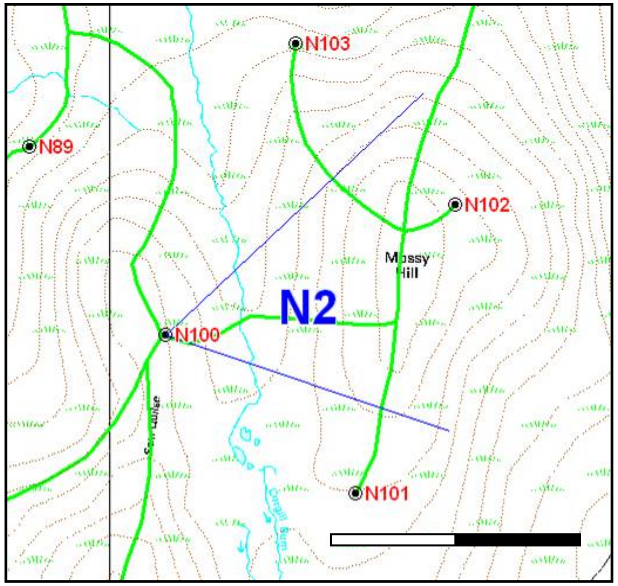
Track lines have been routed to avoid the wetter areas and deeper peat where possible.

3.13 Area N2

Many of the cols and valleys in Nesting quadrant are characterised by extensive peat erosion and gullying. Area N2, shown in Figure 25, provides a good example of this. Slopes in this area are fairly smooth with moderate slope angles and no clearly defined breaks in slope.

Figure 25 View east across area N2 from Turbine N100 (HU 4209 6042). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 500m).





Habitat type/vegetation:	Blanket mire; sedge/grass, moss, heather
Peat depths (m):	Maximum: 3.7; minimum: 0.6; average: 1.9
Erosion patterns:	Extensive erosion and gullying to mineral soil & bare peat; drainage channels in places
Instability:	No signs of instability in the area

Notes:

The headwaters of the Easter Filla Burn cross the col although, as the watercourse is not well-developed in this section, this is not clear in Figure 25.

This area has undergone extensive erosion, particularly within the valley floor. Measured peat depths within the valley are mostly in excess of 2m. Some peat on Mossy Hill, around Turbine N102, and in the left foreground of Figure 25 is shallower than 1m.

The peatland in this area has been heavily eroded, with expanses of bare peat and mineral soil visible in places especially in the valley floor and on hill tops. Along the slopes of Mossy Hill distinct drainage channels are clear.

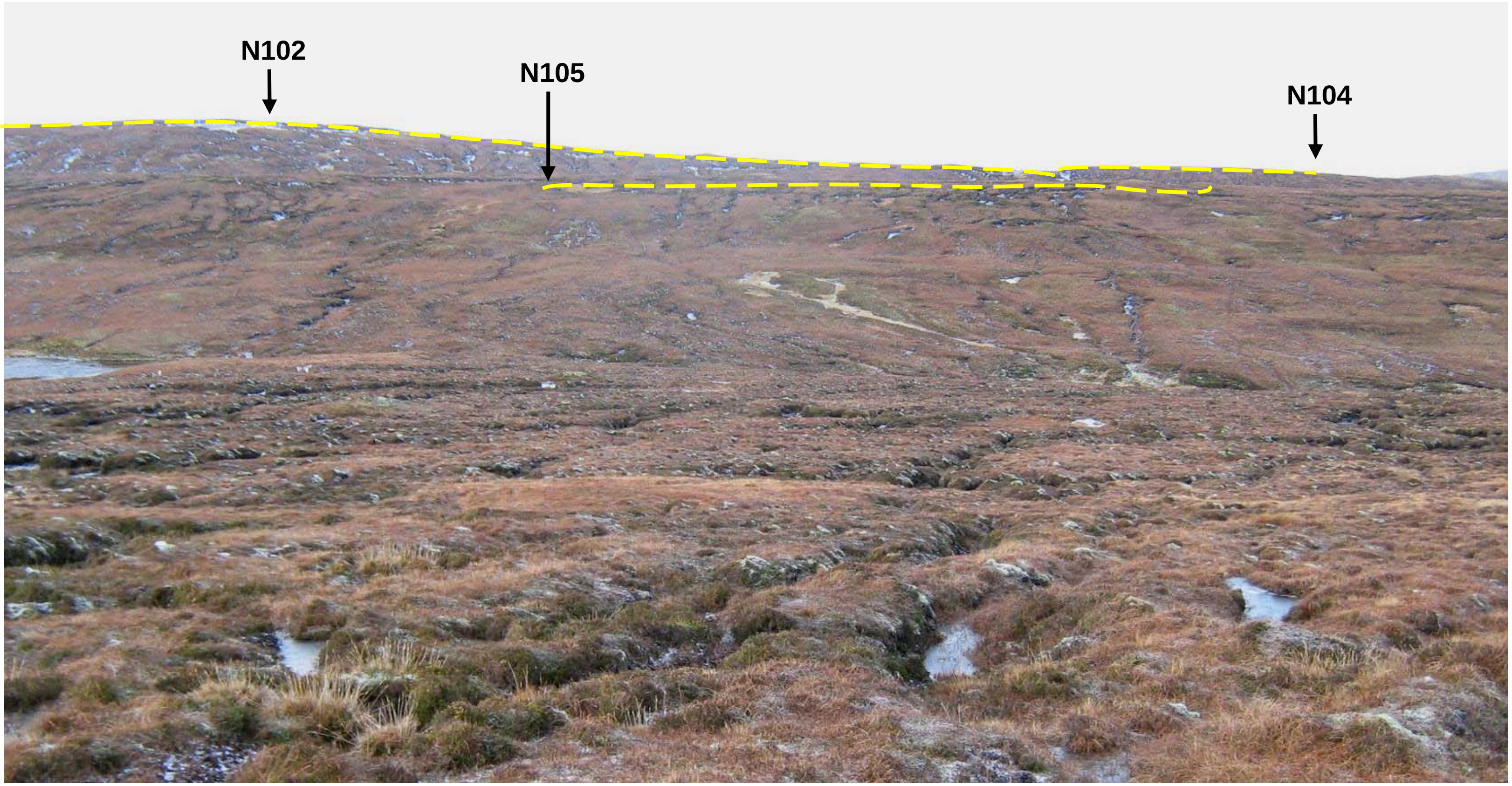
Areas of bare peat are showing little sign of revegetation although some peat banks in the foreground have lichen and new moss growth. Most of the area has typical blanket mire vegetation dominated by grass, sedges, moss and heather.

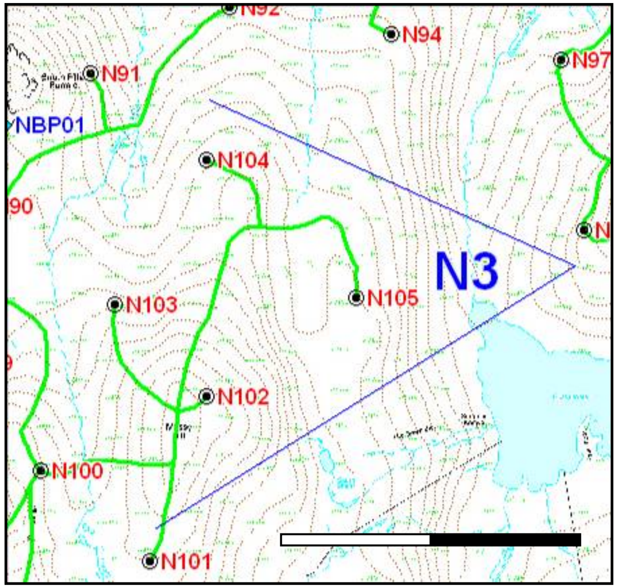
The track route crosses just below the summit of the col, to avoid the deep and extensive hagging and boggy ground in this area. An additional track follows the eroded ground along the summit of Mossy Hill between Turbines N101 and N102.

3.14 Area N3

Area N3 covers part of northern Nesting showing a typical example of the peatland present. This area includes the upper part of the Burn of Gossawater valley, with Gossa Water itself visible at the left-hand side of Figure 26.

Figure 26 View west across Area N3 from the south-west slopes of Strani Field (HU 4377 6107). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: 2.7; minimum: 0.2; average: 1.5

Erosion patterns: Dissected by drainage channels & gullies

Instability: No signs of instability in the area

Notes:

The Burn of Gossawater valley runs from Gossa Water, to the left-hand side of Figure 26, across to the right. Minor tributaries are visible on the slope below Turbine N105, one of which is marked by a distinct pale green channel.

The peat in this area is heavily dissected by drainage channels, mostly running directly down-slope. Peat probing indicates that peat depths are quite variable and mostly within the range of 1-2m. Pockets of deeper peat and areas of shallow peat are present in some places but are generally small.

More extensive hagging can be found along ridge tops, in particular around Turbine N102. Areas with more gentle slopes tend to have more intact blanket peat; this is clear from the mid-section of Figure 26 where slope angles become slightly shallower.

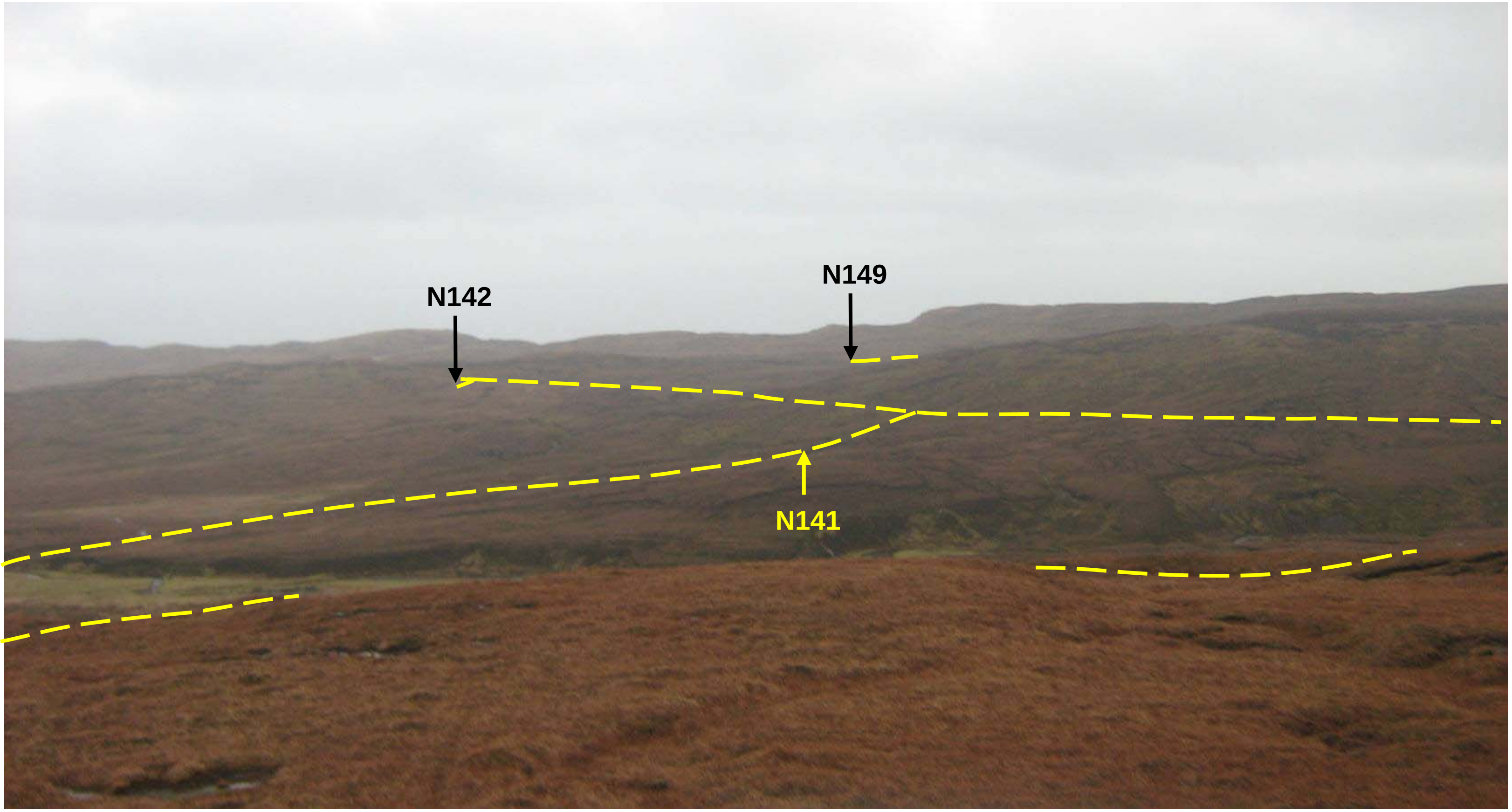
In addition to the distinct pale green watercourse channel mentioned above, areas of brighter green mark wet and boggy sites. Dryer areas are marked by an increase in heather; an example is visible in the foreground of Figure 26.

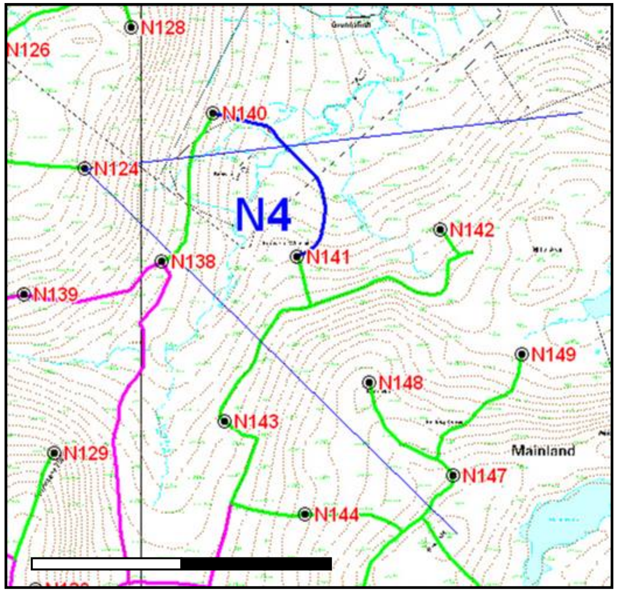
Track lines mainly follow ridge and hill crests as the peat tends to be thinner and more eroded in these areas.

3.15 Area N4

Area N4 provides a representative view across the eastern part of Nesting quadrant (Figure 27). In the middle distance, the incised valley contains the Burn of Grunnafirth which is one of the larger watercourses in this quadrant.

Figure 27 View east across Area N4 from Turbine N124 (HU 4480 5864). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: >4.0; minimum: 0.0; average: 1.8

Erosion patterns: Smooth vegetated slopes with some drainage channels

Instability: Small slumps along incised river valleys; no other instability observed

Notes:

The Burn of Grunnafirth valley crosses the area flowing roughly south–north. The valley is quite incised with steep sides. The burn itself, with its tributaries, drains much of the central and eastern part of Nesting quadrant. The track crosses the burn at the northern margin of the area.

As indicated in Figure 27, this area has a fairly uniform cover of blanket peat. Measured peat depths are quite variable, with pockets of deep peat (in excess of 2.5m) and areas of shallow peat (less than 1m). Most of the area has peat probing depths between 1 and 2m.

Although the slopes are mostly smooth and well-vegetated, there are some drainage channels in addition to the main burn valley. Minor slumping scars are visible on the east bank of the Burn of Grunnafirth, below and right of Turbine N141; these are a result of bank undercutting on the stream bend.

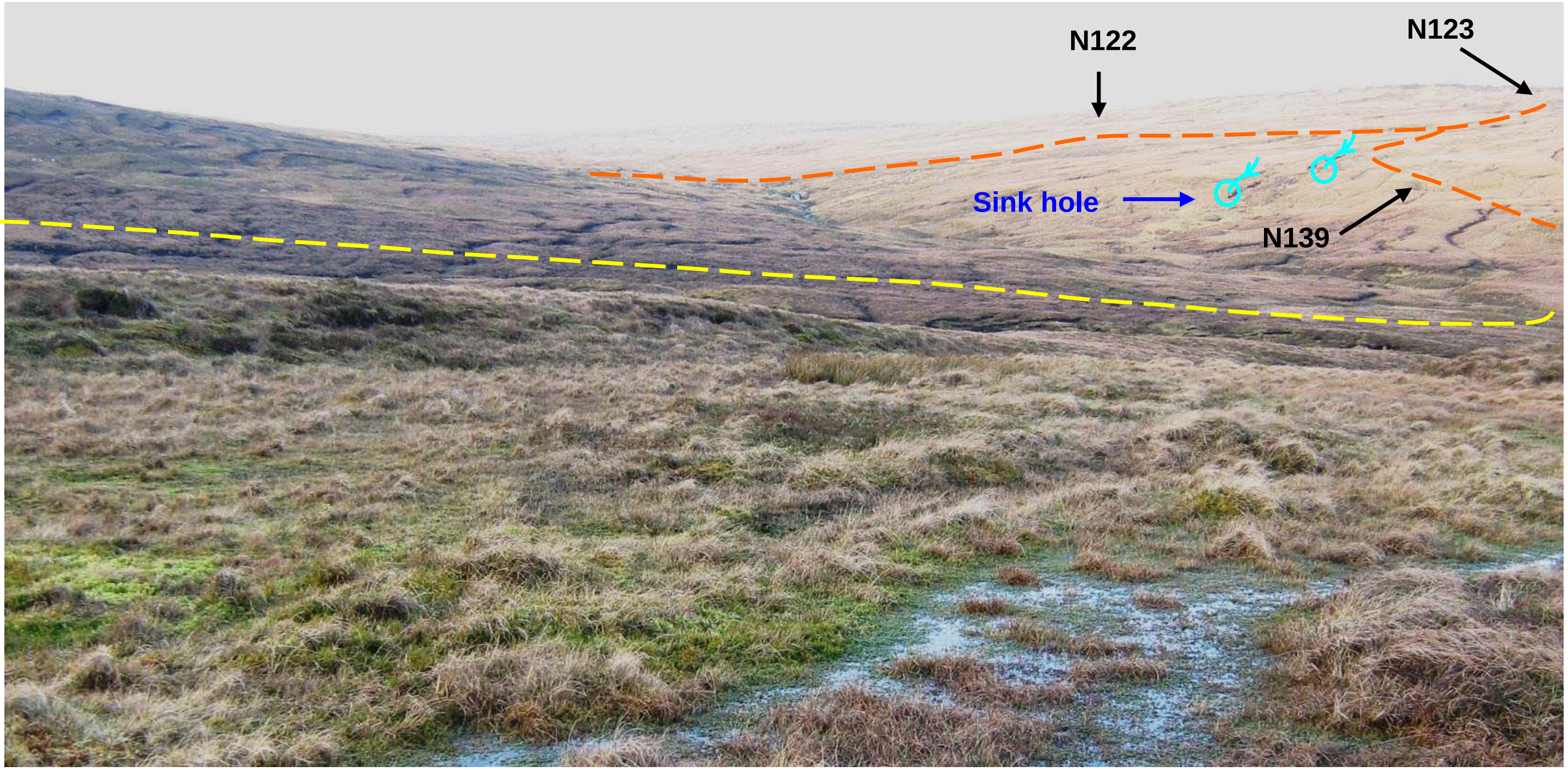
Areas of greener vegetation indicate better drainage and development of grassland habitat; an example of this can be seen towards the left-hand side of Figure 27 in the Burn of Grunnafirth valley. The area is dominated by typical blanket mire vegetation of grass, sedges, moss and heather.

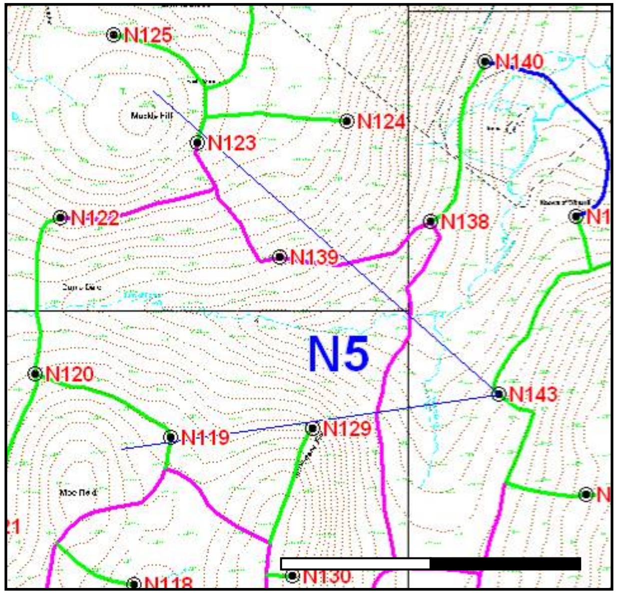
The track lines have been routed to follow the stream valley whilst maintaining a buffer zone around the stream. Tracks have been routed to avoid deep peat and steeper slopes where possible.

3.16 Area N5

Area N5 covers the Burn of Forse valley, which is one of the principal tributaries to the Burn of Grunnafirth. This area includes part of the central Nesting infrastructure, as shown in Figure 28.

Figure 28 View west across Area N5 from Turbine N143 (HU 4530 5772). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: 3.9; minimum: 0.1; average: 1.5

Erosion patterns: Dissected by drainage channels and streams

Instability: Collapsed peat pipes; no other instability observed

Notes:

The Burn of Forse valley runs through the centre of Area N5, with a small tributary stream channel visible in the foreground of Figure 28. The Burn of Forse is fairly incised with waterfalls in places.

Area N5 has extensive blanket peat cover. Peat probing indicates that peat within the main valley is generally deeper than 1.5m although shallower areas are present in places. On the side slopes peat depths are variable with pockets of deep peat and areas of shallow peat widely distributed across the area.

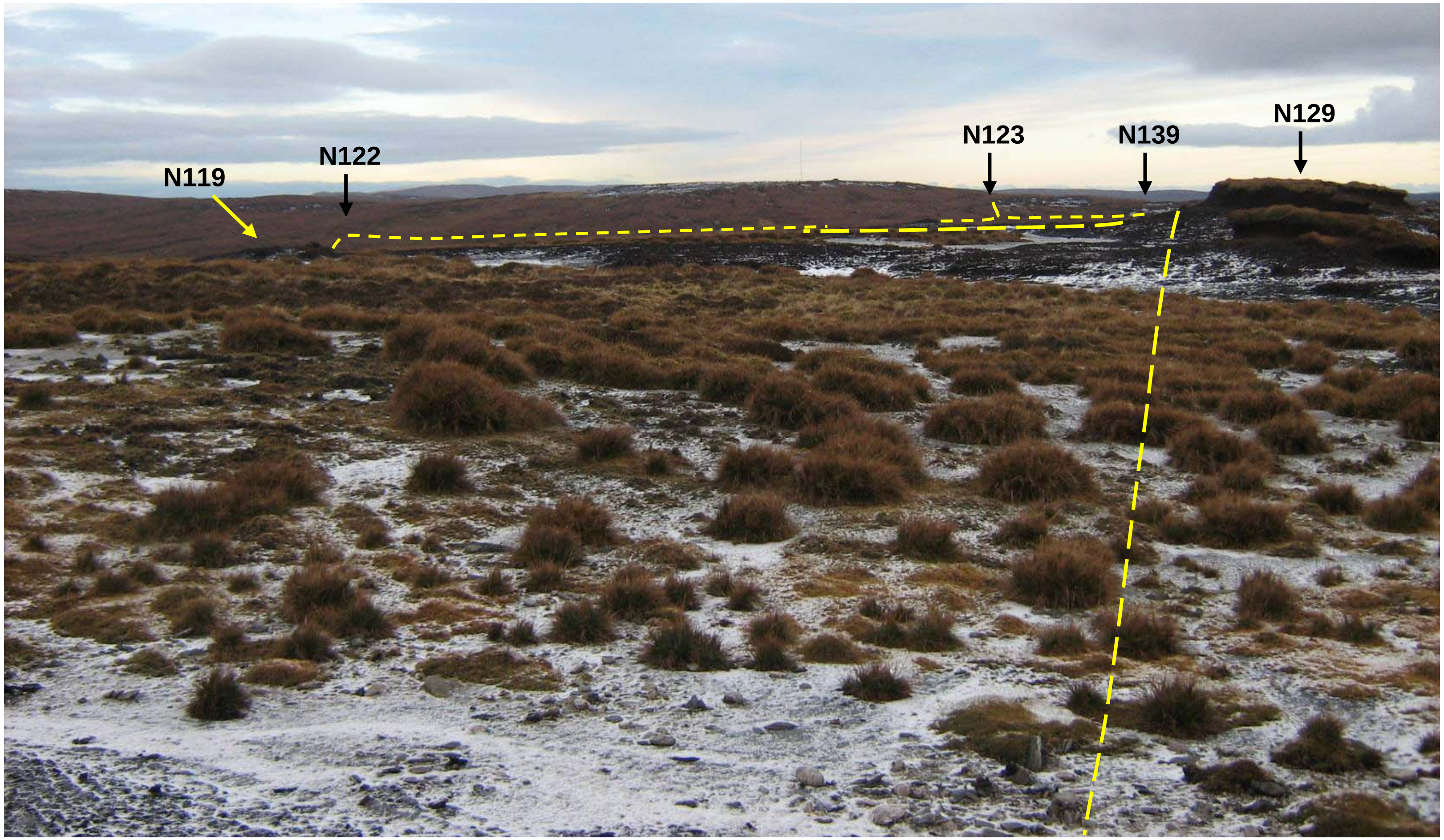
The peat is dissected by drainage channels and streams, some of which take the form of collapsed or partially collapsed peat pipes. Additional unidentified peat pipes may exist in the area. Boggy areas, such as the one visible in the foreground of Figure 28, occur in places.

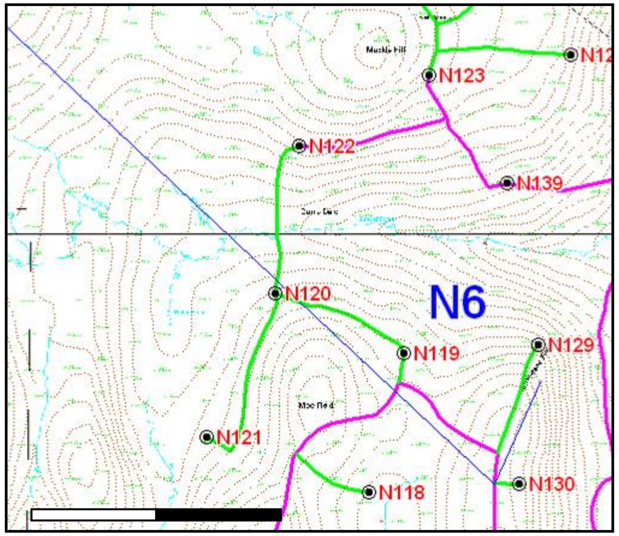
Most of the area has typical blanket mire vegetation of grasses and mosses with heather in places. Boggy areas are indicated by brighter green vegetation, mostly *Sphagnum* mosses; a good example is visible in the foreground of Figure 28.

3.17 Area N6

Many if the ridge and hill tops within Nesting quadrant have been subject to extensive erosion. Area N6 provides a good example of this terrain with isolated haggs, exposed bare peat and some revegetation surfaces (Figure 29).

Figure 29 View north across Area N6 from Turbine N130 (HU 4452 5711). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation: Blanket mire; sedge/grass, moss, heather

Peat depths (m): Maximum: 3.9; minimum: 0.0; average: 1.6

Erosion patterns: Extensive bare peat & isolated haggs; some revegetation

Instability: No signs of instability in the area

Notes:

The Burn of Forse valley runs through Area N6, although it is not clearly visible in Figure 29. The area includes the northern half of the Hill of Flamister, and across to Muckle Hill on the north side of the Burn of Forse.

Peat probing indicates that peat depths across the Hill of Flamister are generally shallow, mainly less than 1m. Remaining peat banks stand to around 1.5 to 2m above the erosion surface. Peat depths along the side of Muckle Hill, in the distance of Figure 29, are mostly within the range 1-2.5m deep.

The summit areas of both the Hill of Flamister and Muckle Hill have undergone severe peat erosion, leaving expanses of bare peat with isolated peat haggs in places; an example is visible to the right-hand side of Figure 29. The peat has been eroded to mineral soil in places.

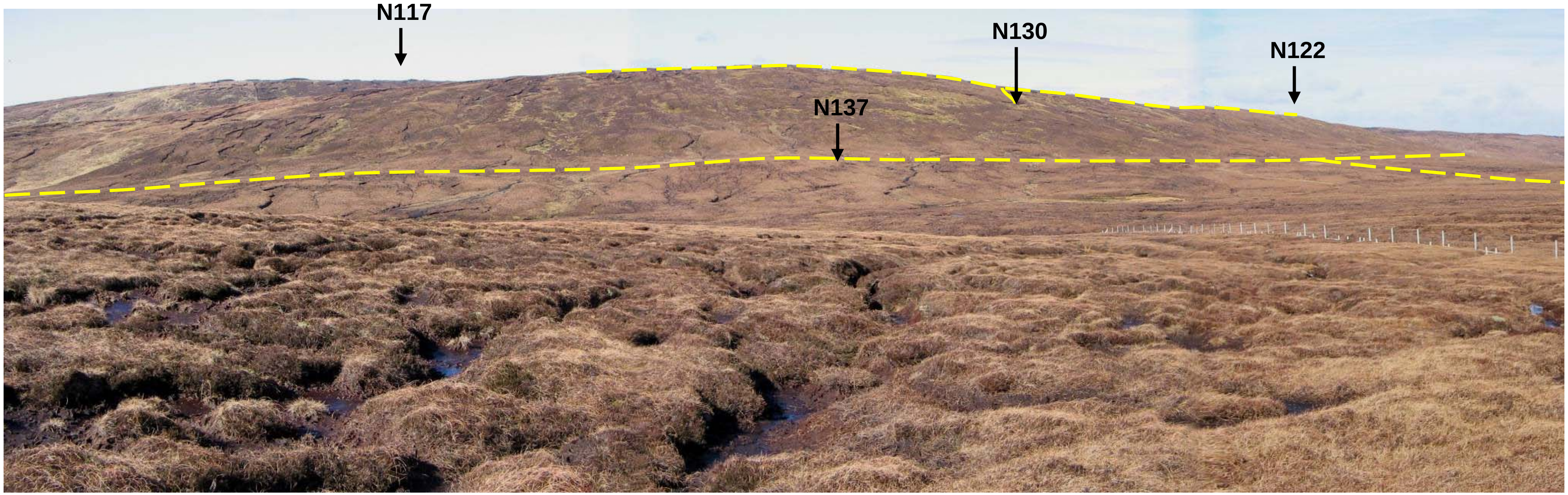
Some erosion surfaces are showing signs of revegetation; this is clear in the foreground of Figure 29 where moss and tufts of sedge and grass cover some of the exposed peat. Remnants of blanket mire vegetation can be seen on top of the isolated haggs.

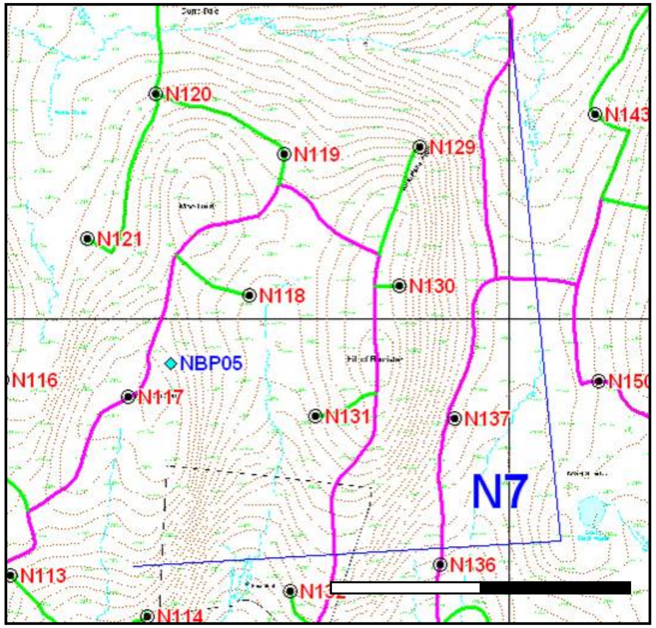
Tracks have been routed to take advantage of the thin and eroded peat along ridge and hill tops to minimise impacts on intact and active blanket mire.

3.18 Area N7

Area N7 covers a wide section in the southern part of Nesting quadrant, including the Hill of Flamister and part of the Dud of Flamister. Figure 30 shows a view across the area. Both of the main hills are defined by distinct breaks in slope at the top and bottom. The lower, concave, break in slope lies above and behind the proposed track line.

Figure 30 View north-west across Area N7 from South Black Water (HU 4517 5622). Approximate positions of tracks and turbines are shown for reference; lines of sight are indicated in the accompanying map (scale bar 1km).





Habitat type/vegetation:	Blanket mire; heather, sedge/grass, moss
Peat depths (m):	Maximum: >4.0; minimum: 0.0; average: 1.2
Erosion patterns:	Dissected by drainage channels; extensive hagging at high levels
Instability:	No signs of instability in the area

Notes:

Area N7 includes a col between Bow Field and the Hill of Flamister, visible to the right-hand side of Figure 30. Down to the left from the col are the headwaters to the Burn of Quoys.

Figure 30 indicates that the area has fairly uniform coverage of blanket peat. Measure peat depths along the lower track section are mostly within the range 1-2.5m with occasional deep and shallow measurements. Along the summit of the Hill of Flamister peat depths are generally less than 1m owing to the extensive erosion that has occurred here.

Although the hill and ridge tops have undergone extensive erosion, visible along the skyline around Turbine N117, the lower slopes are characterised by drainage channels and gullies. These cause dissection of the peatland and expose bare peat in the banks and gully bases, as shown in the foreground of Figure 30.

Larger watercourses on the Hill of Flamister are indicated by lines of pale green vegetation. Otherwise, the area is dominated by the typical blanket mire vegetation of grass, sedges, moss and heather. These are clearly visible in the foreground of Figure 30.

The track lines follow the eroded hill crests where possible, to take advantage of the less active peat in these areas. The lower track line follows the side of the valley, where the slope angles remain moderate but to avoid the deeper peat present in the main valley floor.

4 PEAT DEPTH SURVEY

The peat depth survey for the Viking Wind Farm was carried out using a two-phase approach. During March 2006 a team visited the wind farm site prior to the production of an infrastructure layout and undertook peat probing at 1762 locations across the site. The peat probing data were collected along selected transects across the proposed site at a mixture of 20m and 50m spacings. This sampling allowed the characterisation of peat depths in different topographical settings, such as on ridge lines and summits, in valleys and on cols, and on slopes of varying angles. The position of each probing location was identified using a handheld GPS with a typical accuracy or +/-7m and peat depths were measured to an accuracy of +/-5cm to a maximum of 4m depth. Where peat deeper than 4m was encountered, the depth was recorded as >4m.

The peat depths were measured using 2m long, 10mm diameter steel rods, connected together into a 4m length where necessary, and marked in 10cm intervals. The rods were pushed into the ground until they could be pushed no further, when the depth was recorded. The underlying substrate can be estimated from the feel of the rod reaching total depth; for example, the rod suddenly hitting a solid surface with a ringing sensation would suggest bedrock, a ‘gritty’ feel at total depth suggests sandy or gravelly material, and a gradually increasing difficulty in pushing in the rod suggests clayey material underlying the peat.

The collected data from the Phase 1 survey are summarised in Table 3. Locations with deep peat tend to coincide with flat valley floors and cols. Deep peat deposits in higher areas have often been subject to substantial erosion, resulting in extensive exposure of mineral soil and areas of bare peat with isolated haggs and peat banks. The areas with steeper slopes and frequent outcrop were confirmed as having generally shallow peat. The probing results also serve to demonstrate that peat depths can vary substantially over very short distances.

Table 3 Results of Phase 1 peat probing

Peat Depth Range (m)	No. of Points	Percentage of Points
0 – <0.5	299 (194)	17 (11)
0.5 – <1.0	334 (281)	19 (16)
1.0 – <1.5	383 (334)	22 (19)
1.5 – <2.0	317 (364)	18 (21)
2.0 – <2.5	245 (311)	14 (18)
2.5 – <3.0	98 (135)	6 (8)
3.0 – <3.5	32 (60)	2 (3)
3.5 – <4.0	19 (33)	1 (2)
4.0 +	34 (49)	2 (2)
Totals	**1761**	**100**

With reference to Table 3, the results given in parentheses represent a ‘processed peat depth’ which takes into account the local micro-topography of the peat at the probing point. This information was gathered to allow for the highly eroded nature of the blanket peat in many areas across the wind farm site, to assist with describing the peat depth to a nominal ‘surface level’. Processing of the peat depths followed the rules below:

- For a probing point on a uniform, uneroded surface: no adjustment is made;
- For a probing point in a gully: the processed result adds the gully depth to the peat depth result;

- For a probing point on an isolated hagg: the height of hagg is subtracted.

Examples of gully and hagg environments are given in Figure 31 and Figure 32 repectively. The use of processed probing data tends to increase the numbers of deeper peat points and is consequently considered a more conservative approach for peat depth assessment.

Figure 31 Example of a peat gully, Turbine C41 (HU 4300 6478). At this point, the measured peat depth was 0.2m and the gully depth was 2m, giving a processed peat depth of 2.2m.

Figure 32 Example of isolated haggs, near Turbine N117 (HU 4365 5672). The measured peat depth was 1.8m, and the peat hagg height was 1.5m, giving a processed peat depth of 0.3m.

To provide feedback to the client, to aid in the design of the wind farm layout, the results of the first phase of peat depth probing were used to produce an extrapolated indicative peat depth map for the entire study area. A grid of 100m x 100m cells was overlaid across the site and a peat depth range assigned to each cell. The peat depth ranges used are given in Table 4 below.

Table 4 Indicative peat depth categories

Peat Depth Category Number	Peat Depth Category	Peat Depth Range
1	Very Shallow	<0.5m
2	Shallow	0.5 – <1.0m
3	Moderate	1.0 – <1.5m
4	Deep	1.5 – <2.5m
5	Very Deep	2.5m +

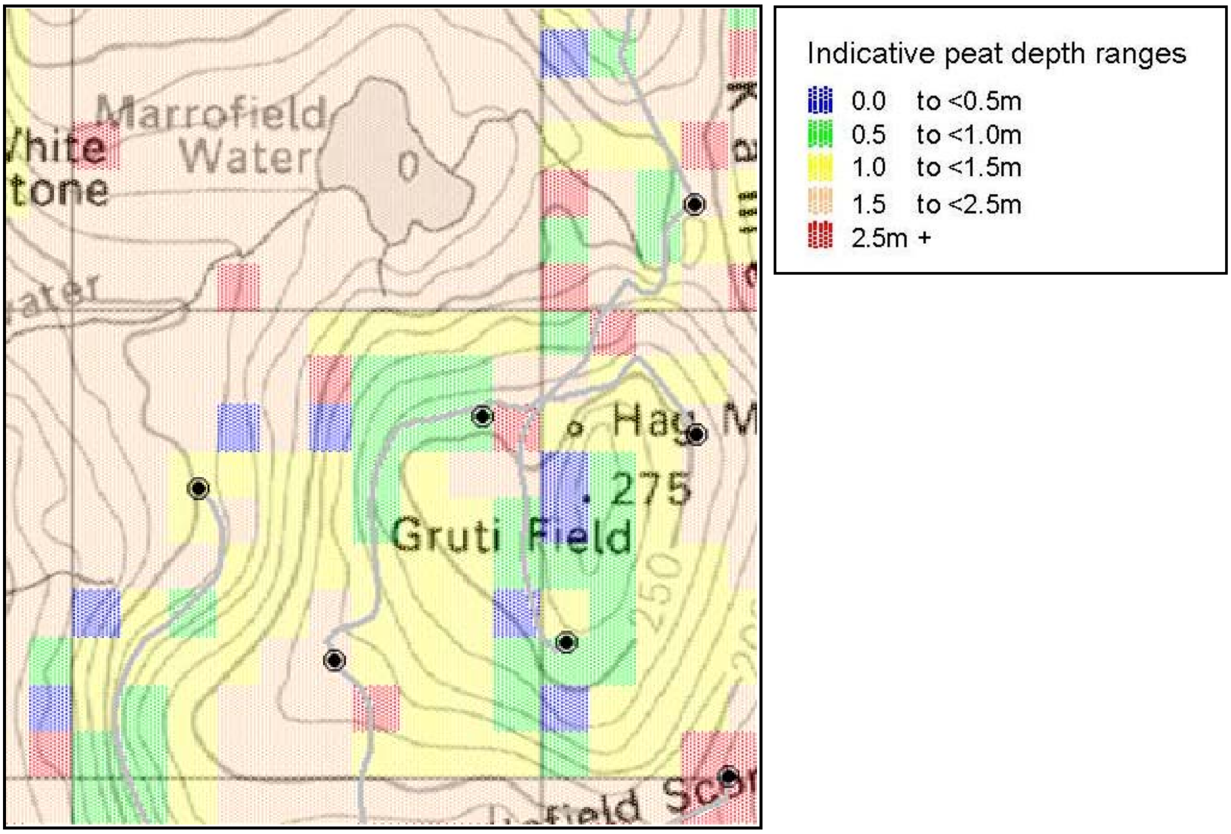
The use of a regular grid for terrain analyses of this type is a standard recognised GIS technique and is widely applied in a range of situations. A grid system allows the application of a systematic process across the landscape, where a set of relevant properties need to be assigned to each particular location. In this analysis, these properties include slope angle and peat depth.

Selection of grid resolution is necessarily a balance between granularity of the underlying data and the volume of information returned in the analysis. The resolution of DEM and base mapping must be taken into account, as using a very fine grid with a resolution identical to or finer than the DEM will return spurious results with a false indication of accuracy. For Viking Wind Farm, a 100m x 100m grid was selected as this allows a reasonable degree of accuracy whilst also producing a manageable volume of data to be used within the analyses.

Blanket peat, as found on Shetland, tends to form in areas with high rainfall and low temperatures. Peat deposits in the Shetland Islands have been recorded to depths of 6m (Mykura, 1976) in hollows and valleys but are generally not much more than 2-3m deep and often much less. Peat depth category names and ranges were chosen in the context of wind farm construction; for example a peat depth of 1m represents approximately the cut-off between cut-and-fill and floating track construction. Equally, the practicalities of constructing turbine foundations in peat more than 2.5m deep make this a less attractive option. The cut-off for very shallow peat of 0.5m is based on the Soil Survey of Scotland definition of peat, as used in the Scottish Executive guidelines (Scottish Executive, 2006).

Figure 33 shows an enlarged portion of the indicative peat depth mapping. Each square is 100m x 100m with very shallow peat coloured blue, shallow peat coloured green, moderate peat coloured yellow, deep peat shown in orange and very deep peat in red. It should be emphasised that processed peat depth values have been used throughout.

Figure 33 Sample of indicative peat depth map



The full indicative peat depth map is included as Figure 14.1PS08 (in Volume 4b). Measured peat depth data are not included on this figure for purposes of clarity. From observation it is clear that both slope and elevation have an influence on the development of peat, although the exact mechanism is not well understood and there is no mathematical growth/decay model for the development and depth of peat. However, slope and elevation factors may be used intuitively when extrapolating from peat sampling data in the creation of an indicative peat depth map. It can be seen that the deeper peat is to be found in flatter areas, such as cols, plateaux and valley floors. Flat areas on hill summits have often been subject to extensive erosion, with little remaining peat except as isolated haggs (Figure 32). In other areas peat formation on the summits has been very limited, possibly owing to a combination of exposure, slow growth rate and better drainage (Figure 34). Steep slopes tend also to have less peat, owing for the most part to their better drainage and more rapid runoff.

Figure 34 Example of a hill top area with very limited peat development, Delting quadrant (HU 4114 6998)

As can be seen from the map, where a cluster of peat probing points is all within the same peat depth category this has been taken to be a good indication of the general peat depth in the surrounding area and the indicative peat depth map has been coloured accordingly. Where clusters of peat probing points have returned depths across a range of peat depth categories a cautious approach has been taken, with the indicative peat depth map being classified with the deeper category of peat found in the area. This has led to a conservative indicative peat depth map, as demonstrated clearly by the peat depth category breakdown for both the actual probing data and for the extrapolated grid. These data are compared in Table 5. The conservative nature of the extrapolated map is apparent from the underestimation of very shallow peat and the overestimation of moderate and deeper peat, compared with the breakdown of the actual probing data.

Viking Energy used the indicative peat depth map to inform the design of the wind farm layout. Areas identified as having deep peat were identified where possible; however, the dominance of deep blanket peat in some parts of the site has meant this was not possible in all places. In addition, other constraints such as areas of ornithological importance or archaeological features have necessitated compromise in the siting of infrastructure.

Table 5 Peat depth category breakdown

Peat Depth Category (m)		<0.5	0.5 - <1.0	1.0 - <1.5	1.5 - <2.5	2.5 +	Total
Actual Probing Data	No. of points	931 (616)	1095 (915)	1176 (1137)	1929 (2294)	614 (783)	**5745**
	% of points	16 (11)	19 (16)	20 (20)	34 (40)	11 (14)	**100**
Indicative Peat Depth Grid	No. of cells	157	2364	3996	7308	1422	**15,247**
	% of cells	1	16	26	48	9	**100**

Please note: the above data include all the peat probing data measured on the site.

The second phase of peat depth surveying was undertaken between November 2007 and February 2008, with additional supporting work in November 2008. This phase of peat depth sampling was carried out after Viking Energy had produced a layout of roads and turbines for the proposed wind farm. Peat depth measurements were taken at 50m intervals along the proposed track layout and at each turbine base location. At each turbine point, a further four peat depths were recorded 20-25m to the north, east, south and west of the centre point to give a better indication of peat depths at each turbine base. These data are also useful to provide information on depth trends to inform micrositing, where applicable. As before, probing locations were determined using handheld GPS units and peat depths were recorded up to a maximum of 4m.

All the collated peat depth data are presented in Figure 14.1.PS07 (in Volume 4b).

5 PRELIMINARY STABILITY ANALYSIS

With the collated peat depth data, a preliminary analysis of slope stability can be carried out using the infinite slope model. The stability of a slope can be assessed by calculating the Factor of Safety *F* which is the ratio of the sum of resisting forces (shear strength) and the sum of the destabilising forces (shear stress):

$$F = \frac{c' + (\gamma - m\gamma_w) z \, Cos^2\beta \, Tan\phi'}{\gamma \, z \, Sin\beta \, Cos\beta}$$

In this equation, c' is the effective cohesion, γ is the unit weight of saturated peat, γ_w is the unit weight of water, m is the height of the water table as a fraction of the peat depth, z is the peat depth in the direction of normal stress, β is the angle of the slope from the horizontal and φ' is the effective angle of internal friction.

The Factor of Safety (FoS), F, represents the ratio of the forces resisting a slide divided by the forces causing the material to slide. Clearly, if F > 1 then the slope is stable, and normally if F > 1.3 then there is a degree of comfort that the slope will not fail.

To get an indication of the stability of the peat at the proposed wind farm infrastructure locations, the factor of safety can be calculated for each Phase 2 peat probing location. In addition, to gain a better view of peat stability in the areas surrounding the infrastructure, factor of safety calculations can be carried out for the grid cells of the indicative peat depth map in the vicinity of the infrastructure.

In order to do this, we must know or be able reasonably to infer the parameters for the FoS equation for each probing location and grid cell under consideration.

The slope angle, β, can be derived from the DEM for the site. With the peat probing locations, a single slope angle value is generated for each point, whilst the DEM is interrogated for minimum, maximum and average slope values for each grid cell. The average slope angle has been used in the grid FoS calculations, although the other statistics provide useful supporting information on the variability of slope within the cells.

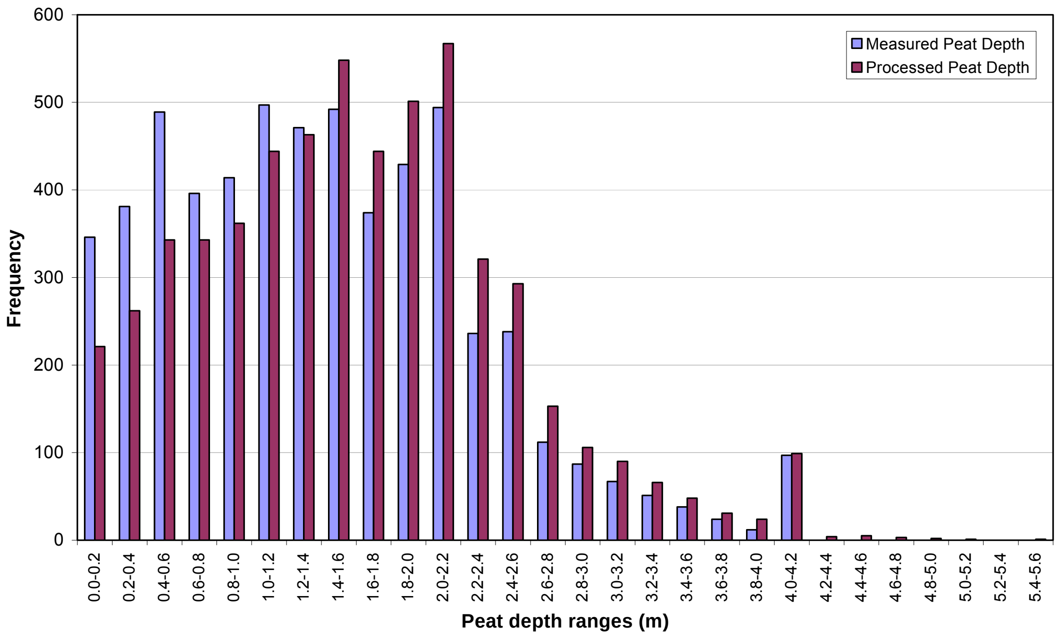
The actual peat depth measurements recorded for each probing location are used in calculating the point FoS values. For the grid-based FoS assessment it is necessary to convert the indicative peat depth ranges into a specific figure for each range for use within the calculation. Taking a conservative approach, the upper bound of each range has been used. In the case of 'Very Deep' peat (>2.5m), selecting the maximum depth is complicated by the fact that measurement of peat depths was limited to 4m. However, the peat depth histogram in Figure 35 shows that the frequency of deeper peat tails off rapidly, suggesting that 4m is close to the likely maximum peat depth and therefore represents a reasonable figure to use.

It should be noted that the small spike on the histogram at 4.0-4.2m peat depth is owing to the number of locations where peat depths were recorded as greater than 4m, which have been treated as being exactly 4m for ease of numerical analysis.

The small number of points returning results deeper than 4m in the processed dataset is a consequence of the data processing. For example, a measured peat depth of 3.8m in a gully with a measured bank height of 1m would return a processed depth of 4.8m.

Figure 35 shows both measured and processed peat depth data to allow comparison of the two datasets. The histogram indicates clearly that the processed data generally return deeper peat depths, and provide confirmation that use of processed peat depths in the analysis is the more conservative technique.

Figure 35 Histogram of measured and processed peat depth data



The unit weight of water, γ_w, is known to be 1.0Mg/m^3. The bulk density of peat varies with the level of decomposition. A literature review has found quoted *in situ* undrained bulk densities ranging from 0.5Mg/m^3 to 1.4Mg/m^3, with a typical value of 1.2Mg/m^3. This typical value has been used in the FoS calculations.

If it is assumed that the site is covered with active blanket mire, it follows that the peat must be completely saturated with a water table at or very close to the surface. On-site observations support this assumption as ground conditions were wet underfoot across most of the site. Consequently, a water table ratio, *m*, of 1 has been chosen.

The angle of internal friction in peat also varies, decreasing with increasing decomposition and moisture content. In some instances, 'quaking bog' has been observed where the peat takes the form of a slurry beneath a surface mat of vegetation. In such a situation the angle of internal friction will be very low. For the FoS calculations a *φ'* value of 5° has been selected in line with the conservative approach.

Finally, a value for the effective cohesion, *c'*, must be derived. Literature values for *c'* in peat vary widely, ranging from 4.5kN/m^2 to 60kN/m^2. To provide an indication of the cohesive strength of the peat at Viking a back calculation using the FoS equation and actual peat depth probing data for the site has been used. The techniques involved are discussed below.

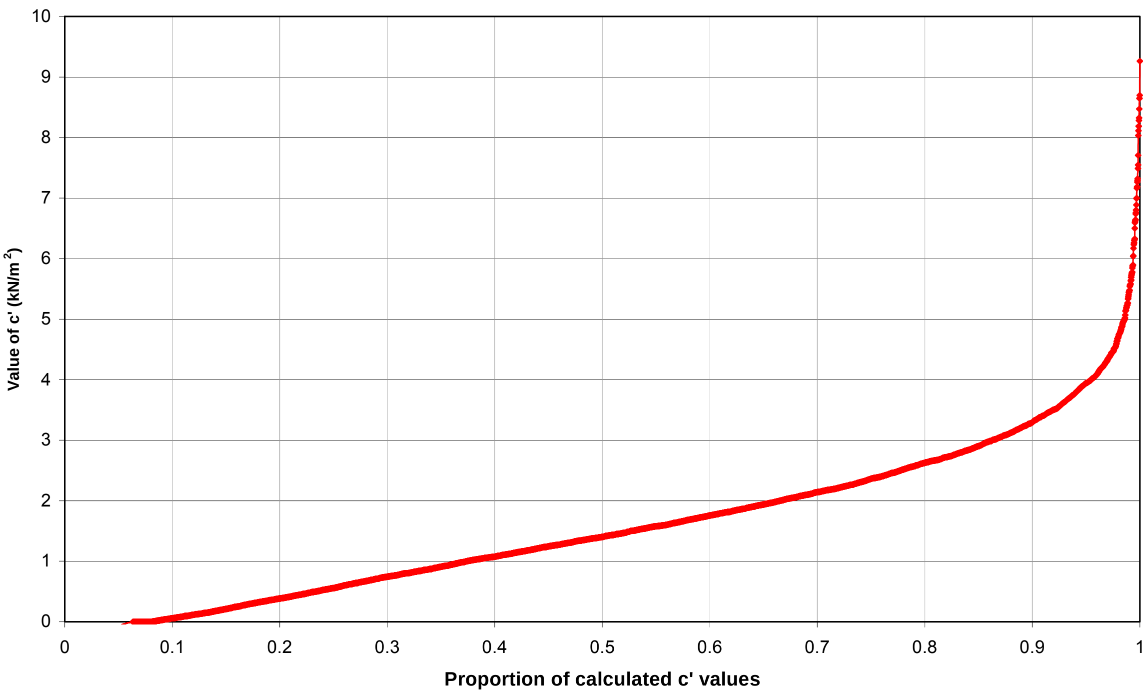
5.1 Estimation of Cohesive Strength

A range of field and laboratory tests can be carried out to determine the effective cohesion of a material. However, owing to its fibrous and thixotropic nature and the variation in strength with decomposition, peat is a particularly difficult material to analyse both in the field and in the laboratory. An alternative approach to assessing the strength of the peat is to rearrange the FoS equation to calculate a value of *c'* at actual peat probing locations. Essentially, this approach assumes that if the hillside is stable then the material must have at least a certain minimum strength.

Each peat probing location has been visited, is known to have been stable at the time of the visit and therefore must have a FoS of at least 1. If we assume conservatively that *F*=1 and use values for the other parameters as discussed above, the FoS equation can be rearranged to allow derivation of a value for *c'* at each probing location. Slope angles for the probing points are generated from the DEM. It is important to note that the value of *c'* calculated for each location represents the *minimum* cohesive strength necessary for the peat to be stable at that location. In fact, the shear strength may be, and in most cases probably is, considerably higher.

At Viking 5745 locations have been probed during the different phases of fieldwork. *c'* values for each of these have been calculated and the distribution of these values is shown in Figure 36. For example, reading from the graph, 0.8 (or 80%) of the probing locations required a *c'* value of 2.63kN/m^2 or less to be stable and retain peat on the slope.

Figure 36 Estimate of minimum cohesive strength, *c'*



From this work it is possible to state, with considerable confidence, that across the site as a whole the shear strength of the peat is unlikely to be less than 5.45kN/m^2 as this is the value of the 99 percentile point on the graph. The basis for making this statement depends on:

- The deliberate choice of conservative values for assumed parameters such as bulk density and water table level, coupled with the assumption of a FoS equal to one when back calculating c' values;
- Recognition of what the calculations are stating, which is that these are the minimum strengths that would be required, not the actual in situ strengths. Therefore, where slopes are gentle and the peat shallow, very little shear strength is required to ensure stability of the slope. This accounts for the vast majority of the lower values;
- Assuming a reasonable degree of homogeneity for peat properties, in particular strength, across the site. This seems reasonable, except for very shallow peat

where the acrotelm, which is more fibrous, represents a significant proportion of the total depth. Such areas are, in any case, unlikely to be areas of concern;

- Given the above considerations, it is the higher strength values that are relevant. If this were not the case then one would expect large areas of the site to be denuded of peat as it would not have the strength to adhere to the hillsides.

For the purposes of the Factor of Safety Assessment a *c'* value of 5.45 kN/m^2 has been used. This value is in reasonable agreement with estimates derived from other similar sites around Scotland. The actual effective cohesion of the peat at Viking is likely to be higher than 5.45 kN/m^2; however, this value has been chosen to ensure a conservative assessment whilst also using data from the site.

5.2 Preliminary Stability Analysis Results

Having assigned, measured or inferred values for each parameter in the FoS equation it is now possible to calculate a FoS value for each probing location coinciding with proposed infrastructure and for each cell of the indicative peat depth grid in the vicinity of the infrastructure. The FoS assessment maps generated with these values are given in Figure 14.1.PS09 (in Volume 4b).

In selecting the 99 percentile value of the back calculated *c'* strengths one is implicitly condemning 1% of the sample locations to failure, plus any similar cells across the site as a whole. As can be seen, there is a small number of cells with a FoS value of less than 1; in theory these should either have failed or currently be failing. In reality this is unlikely to be the case and these results are a consequence of the conservative approach adopted.

A number of points and cells have a FoS between 1.0 and 1.3, where stability can be considered marginal. The cells that fall into both these categories are scattered in clusters across the site. 90% of the site has a FoS of greater than 1.3, where stability can be assumed with a degree of comfort. The results of the FoS assessment for the probing points and site grid are summarised in Table 6.

Table 6 Summary of quantitative assessment

Factor of Safety	No. of Points	% of Points	No. of Cells	% of Cells
2.5 +	3920	68	1996	38
1.3 - <2.5	1610	28	2544	48
1 - <1.3	158	3	480	9
<1	57	1	212	4

The results demonstrate that the majority of the wind farm infrastructure will be built in areas where there is a degree of comfort in inferring stability. Comparison of the point and grid cell results highlights the conservative nature of the grid assessment. The cells identified as having marginal stability are generally clustered into areas where very deep peat and moderate or steep slopes occur within the same grid cell.

6 HAZARD RANKING

Based on the data collated from the desk study, reconnaissance survey, peat probing and preliminary stability analysis the peat landslide hazard across the site can be ranked. The Scottish Government guidance (Scottish Executive, 2006) defines the hazard ranking as a function of hazard and exposure:

$$\text{Hazard Ranking} = \text{Hazard} \times \text{Exposure}$$

where Hazard is defined as the likelihood of a (peat) landslide occurring and Exposure is the impact and consequences that the event may have.

Both Hazard and Exposure are determined using expert judgement based on the collated data, and are given qualitative ratings as shown in Table 7 and Table 8 respectively. Hazard and Exposure ratings have been assigned to each cell in the peat assessment grid. In determining the Hazard, the number of peat landslide indicators present in each cell has been taken into account. As this peat slide risk assessment has been carried out in support of an EIA the Exposure rating relates to the environmental impact a peat landslide could have. In considering the Exposure rating, the proximity to waterbodies has been taken into consideration, as has the steepness of intervening slopes.

The maps of Hazard and Exposure zonation are given in Figures 14.1.PS10 and 14.1.PS11 respectively (in Volume 4b) and the results summarised in Table 7 and Table 8.

Table 7 Qualitative rating scale for Hazard

Scale	Hazard	No. of Grid Cells	Percentage of Grid Cells
5	Almost certain	0	0
4	Probable	207	4
3	Likely	485	9
2	Unlikely	2645	51
1	Negligible	1895	36

Table 8 Qualitative rating scale for Exposure

Scale	Exposure	No. of Grid Cells	Percentage of Grid Cells
5	Extremely high impact	0	0
4	Very high impact	75	1
3	High impact	1623	31
2	Low impact	3076	59
1	Very low impact	458	9

The results of the Hazard and Exposure zonation reflect the nature of the site. The dominant topography of long flat-topped ridges and wide valleys means that much of the side has very low slope angles. This combines with the smooth character of the erosion profile and variability of the bedrock to give limited rock exposure across much of the site. Where bedrock is exposed there is often considerable outcrop across a short distance, coinciding with a particular resistant rock unit. Consequently, areas with good bedrock exposure have been considered to have a lower peat slide hazard as the presence of bedrock exposure indicates discontinuous peat formation.

The prevalence of low slope angles has allowed development of fairly extensive areas with deep or very deep peat. The distinct ridge lines are often marked by very distinct breaks in slope, which indicate not only the change from shallow to steep slope but also tend to coincide with the change from deeper to shallower peat. This juxtaposition of deep peat and steep slopes has resulted in a comparatively high hazard rating for the site.

The remote nature of the site means that, for most of the site a peat landslide occurrence would have no impact upon human habitation, transport routes or drinking water supplies. However, there are some areas around the margins of the site where a peat slide, should one occur, could have a direct impact on these factors and the exposure rating has been graded to take this into account. Waterbodies throughout the site have been assigned high quality status and support a range of fisheries interests. There is a risk that they may be impacted upon by a peat landslide occurring nearby. In addition, some areas of the blanket peat across the site have been assigned high activity status and would be adversely affected by a peat slide. In consequence of these factors, much of the site has been assessed as potentially having a high impact exposure rating.

Multiplying the Hazard and Exposure ratings together gives the Hazard Ranking for each cell. The qualitative categories of hazard ranking, the results and appropriate mitigation actions are shown in Table 9. The resulting Hazard Ranking map is shown in Figure 14.1.PS12 (in Volume 4b).

Table 9 Hazard Ranking and Appropriate Mitigations

Hazard Ranking		No. of Grid Cells	% of Grid Cells	Appropriate Mitigation
17 - 25	Serious	0	0	Avoid project development at these locations
11 - 16	Substantial	60	1	Project should not proceed unless hazard can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce hazard ranking to significant or less
5-10	Significant	1392	27	Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation and re-design at these locations
1 - 4	Insignificant	3780	72	Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate

As can be seen, the majority of the site has been assessed as having an insignificant risk of peat landslide hazard. The grid cells identified with significant or substantial risk tend to cluster together across the site, and some of the clusters coincide with areas of infrastructure. A total of 272 cells, grouped into 51 areas, have been identified as meriting further discussion.

7 GROUND INVESTIGATION

Following the hazard ranking assessment, a number of areas were highlighted as having significant or substantial risk of peat landslide. Owing to the large area of the site and the difficulties of access to large areas it was decided after discussion with Viking Energy to select representative areas from across the whole site to undertake ground investigations. These included 4 control points assessed as having an insignificant hazard ranking, and a range of locations assessed as having significant or substantial hazard ranking. The locations are detailed in Table 10.

Table 10 Ground investigation locations

Location ID	Grid reference	Quadrant	Comment
1	HU 4049 7028	Delting	
2	HU 3844 6714	Delting	
3	HU 3760 6730	Delting	Control
4	HU 4185 6608	Collafirth	
5	HU 4216 6583	Collafirth	
6	HU 4164 6042	Nesting	
7	HU 4605 5817	Nesting	
8	HU 4573 5660	Nesting	
9	HU 4413 5556	Nesting	Control
10	HU 4071 6080	Kergord	
11	HU 3903 6084	Kergord	Control
12	HU 4002 5683	Kergord	
13	HU 4085 5520	Kergord	Control
14	HU 3824 5535	Kergord	
15	HU 3784 5214	Kergord	

The ground investigation work was carried out in two stages. The first stage was undertaken by Mouchel in November 2008, when peat samples were taken by Russian Corer. Weather conditions were variable, mostly windy and cold with snow showers and snow cover at times. The second stage was undertaken by Fugro Engineering Services in December 2008 and January 2009. The weather conditions during this work were poor, generally wet, overcast and fairly windy, with wet conditions underfoot.

At each location measurements were made or samples taken to determine the following parameters:

- In-situ shear strength, determined by vane test;
- Peat / Soil stratigraphy, determined by Russian Corer;
- Von Post classification;
- Bulk density.

A probing rod was used to determine the total peat depth prior to the shear vane testing. Shear strength was measured at 1m depth intervals to the base of the peat, with the final measurement being taken at or close to the base of the peat. At least two separate vane tests were carried out at each depth, with a third undertaken if the first two were dissimilar, to provide some confidence on the repeatability of the tests. The nature of the test requires separate holes within close proximity for each test at a given depth. Most of the tests were undertaken using a large vane of 200mm x 100mm owing to the expected low shear strength of the peat. In some areas, where the shear strength was higher, a smaller vane of 100mm x 50mm was used.

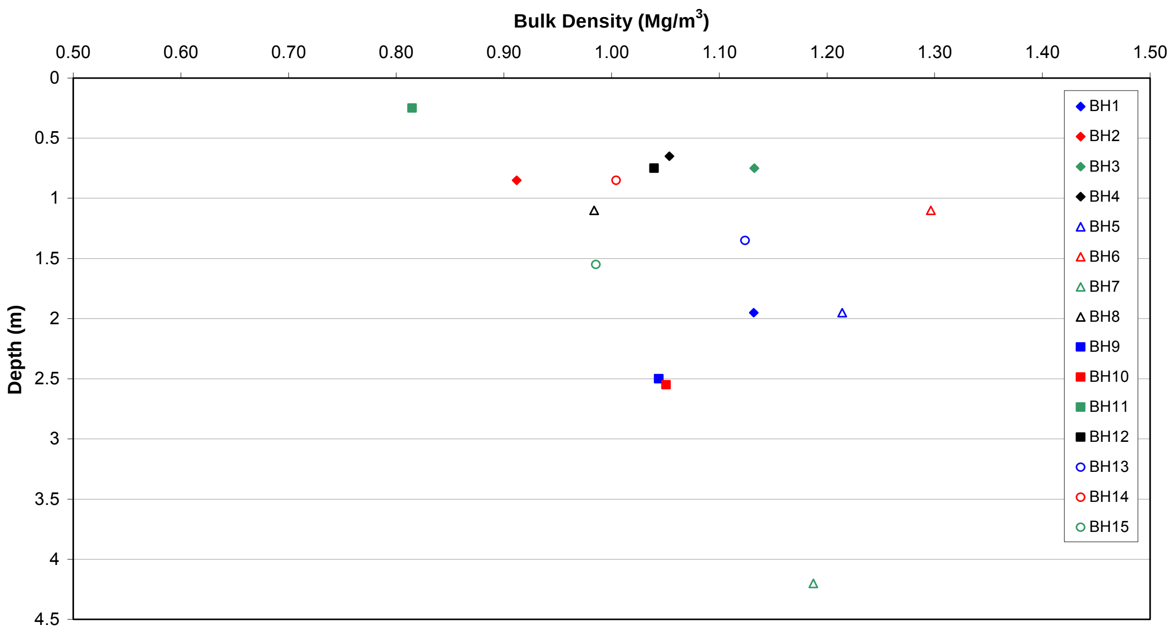
From previous site visits and peat probing it was known that the peat was very deep and soft at some of the GI locations. As a result, trial pits were not considered appropriate owing to the significant health and safety risks associated with pit wall stability, precluding manual digging, and use of a mechanical digger in these conditions. A Russian corer was used instead to take samples of the peat from just above the base of the peat column. The peat stratigraphy and Von Post classification of each sample were determined in the field, while a known volume of the sample was collected for laboratory analysis of bulk density.

7.1 Results

The full results of the shear vane testing are presented in the FES factual site investigation draft report presented in Appendix A. Results obtained from the peat coring are presented in Appendix B.

Bulk density was found to vary from 0.81 to 1.30Mg/m^3, with an average value of 1.06 Mg/m^3. Previous investigations have indicated that bulk density is generally lowest close to the surface and increases with depth and these findings are supported by this work, as shown is Figure 37. The lower bulk densities at shallow depth are a reflection of the relatively undecomposed nature of the peat in the upper layers. Comparing the bulk density values at similar depths, it can be seen that the scatter decreases with depth although this may in part be a result of the greater number of samples at shallower depths.

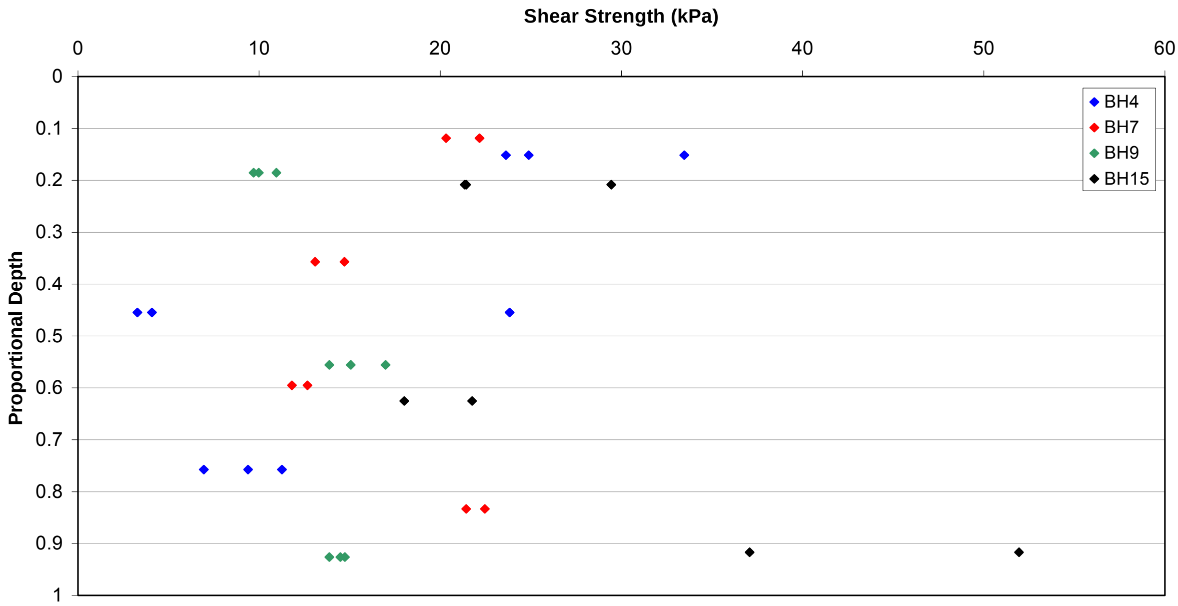
Figure 37 Bulk density variation with depth



The von Post classification of the peat showed a strong correlation with depth, with the degree of decomposition increasing with depth as would be expected. Shallow cores, up to 1m in depth, had von Post classifications between H2 and H4 (almost undecomposed to weakly decomposed), whilst cores from around 2m or greater depth returned von Post classifications of H6 to H8 (strongly to very strongly decomposed).

The recorded peak shear strengths varied between 3.27 and 51.95kPa. Generally, high shear strengths were recorded in the upper 0.5m of peat, owing to the more fibrous nature of the peat at this depth. For locations where shear strength was measured at more than two depths, minimum strength was typically recorded in the central part of the peat column with a slight increase close to the total depth. As this occurred regardless of the total depth of peat, this is best demonstrated by comparing shear strength with proportional depth, where the ground surface is 0 and the base of the peat is 1. The results are shown in Figure 38. The other test sites, where measurements were taken at one or two depths, indicated a general trend for shear strength to decrease with depth.

Figure 38 Shear strength variation with proportional depth



In most cases the slight increase in shear strength at the base of the peat may result from the presence of a transitional gley-like material. The exceptionally high results returned from the base of BH15 are more likely to represent shear strength of the underlying drift material rather than peat as they are outwith the usual range of peat shear strength values.

These results suggest that the weakest material within the peat itself may not necessarily be at the peat-substrate interface. The recorded history of peat slides does, however, indicate that failures tend to occur at or very close to this interface. Many of these events have been linked to abnormal rainfall conditions and in such circumstances it is conceivable that increased porewater pressures and uplift would operate at the interface, combining with increased weight of the overburden and the down-slope component of force to cause destabilisation of the slope (e.g. Halcrow, 2004).

8 DETAILED ASSESSMENT

Please note: Section 8 DETAILED ASSESSMENT of this report is included within Volume 4b as Figure 14.1.PS and should be referred to at this point. The introductory section is duplicated here for ease of reference.

Following the ground investigation works a more detailed assessment of the peat landslide hazard has been carried out for each of the locations previously identified.

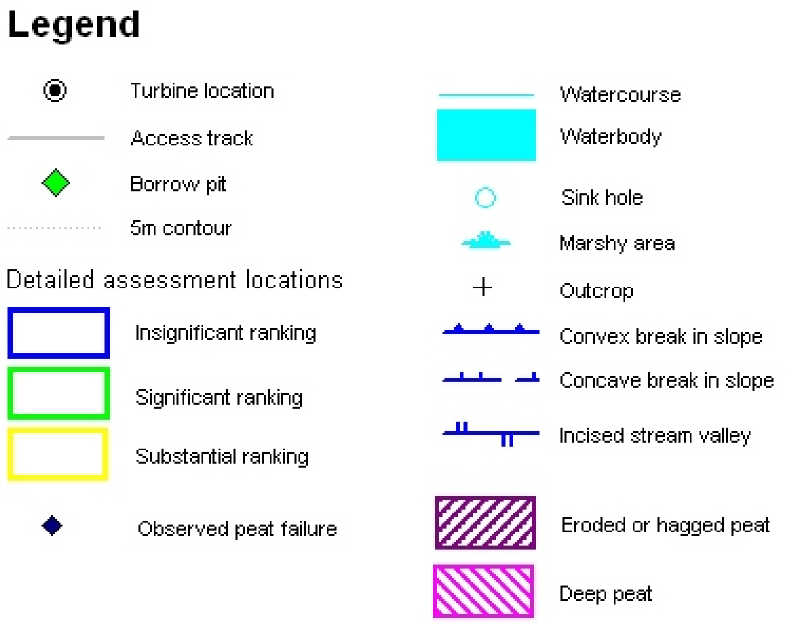
The following pages contain detailed information on each of the locations, including the collated results of the ground investigation works where applicable, calculated factors of safety based on these results, aerial photography of the location overlaid with pertinent geomorphological information, and a discussion/interpretation of the presented information. An indication of possible peat slide parameters is given for reference. This assumes that the peat will fail for the full length of the slope and is considered to give a worst-case estimate.

Where relevant, mitigation measures are recommended. Finally, the hazard ranking of each location has been reappraised in the light of the presented information and proposed mitigation.

The factor of safety calculations presented are based on the collated GI data. FoS values have been calculated for each measured shear strength value and using the bulk density value from the relevant peat sample. The minimum calculated FoS value has been taken into account when reappraising the hazard ranking at each location. FoS calculations are provided in Appendix C.

In the following pages, the insert maps are a composite of aerial photography and geomorphological information. The wider context may be viewed if required by reference to Figures 14.1.PS04 and 14.1.PS05 in Volume 4b. A legend for the symbols used in the insert maps is given in Figure 39 below. The detailed assessment locations are based on 100m x 100m cells, giving an idea of scale on the associated images.

Figure 39 Legend for the detailed assessment insert maps



Mitigation measures have been recommended for a number of the locations assessed in detail. In several cases the primary mitigation recommendation has been micrositing of the access track away from the area of concern.

9 MITIGATION

Specific mitigation measures have been detailed, where appropriate, in the preceding Detailed Assessment section. These measures, which are primarily micrositing of track or use of floating track construction, should be implemented to ensure that the risk of a peat landslide is reduced.

In addition to these specific measures, there are a number of good practice measures that will be implemented across the site. The following list contains some of these measures but is not exhaustive:

- A geotechnical risk register or similar management system will be created and maintained throughout the detailed design and construction phases;
- This risk assessment will be re-visited and re-appraised during the detailed design and construction phases as new information becomes available. The risk register will be updated with this information;
- A geotechnical specialist will be on-site during the construction phase to undertake advance inspection, carry out regular monitoring and provide advice;
- Micrositing will be used, in consultation with the statutory consultees, to maximise avoidance of possible problem areas;
- Construction staff will be made aware of peat slide indicators and emergency procedures *(see below);*
- Emergency procedures will include steps to be taken upon detection of an incipient peat slide or of the event occurring;
- Site drainage will be appropriately designed and installed to ensure flows are not concentrated onto slopes or into excavations;
- Stand pipes or piezometers will be installed to monitor groundwater levels and pore water pressures;
- Sediment control measures will be incorporated into all artificial drainage measures;
- Earthmoving activities will be restricted during and immediately after intense and prolonged rainfall events;
- The extent and duration of open excavations and bare ground will be minimised;
- The volume and storage timescale for excavated material will be minimised;
- Excavated material or other forms of loading will not be placed on or close to breaks in slope or other potentially unstable slopes;
- Vegetation cover will be re-established as soon as possible to improve slope stability and provide sediment transport control. This will largely be done by relaying the peat turf previously excavated. This turf will be stored separately, in such a way as to maintain its integrity;
- Grazing pressure, including grazing by sheep, rabbits or other animals, will be reduced to minimise damage to the surface layers of the peat.

On-site staff who are close to the project are often the best placed to provide advance notification of potential problems, provided they are trained to do so and there is a reporting mechanism in place. There are a number of recognised indicators for slope failures and these may indicate the potential for, or the commencement of, a peatslide event. The suspected identification of any of these indicators should be assessed by specialist geotechnical personnel. The factors discussed below are particularly applicable to low velocity peatslides:

- The development of tension fracture cracking across the slope or in semi-circular patterns;
- Boggy ground or new springs appearing at base of slopes;
- Sudden reactivation of spring lines;
- Creep and bulging of ground;

- Unusual displacement and leaning of trees, fence posts, dykes etc.;
- Breaking of underground services.

9.1 Additional Ground Investigation Work

Additional ground investigation work is recommended for areas highlighted in the initial hazard ranking as at 'substantial' risk of peatslide but that were not surveyed under the first phase of ground investigation work (Dc, Dh, Nb). Investigation is also recommended for Location Db, owing to the presence of an observed instability and suggested track realignment for this location. Site-specific information in all cases would enable the peat stability assessment to be revised further to address the local situation.

Whilst it was decided to be inappropriate to undertake trial pitting at this stage in the investigation, such intrusive work will be required to inform the detailed design stage of the project. Extra care will be required to ensure the safety of on site staff during the excavation and surveying of trial pits owing to the soft consistency of the peat in parts of the site. This work will enable collection of samples from the material underlying the peat in these areas, for geotechnical testing in the laboratory.

Areas to be included in such additional investigations would be borrow pit sites and sites identified for watercourse crossings. Site-specific data are required for such locations to provide a detailed assessment of aggregate quality and quantity for borrow pits, and for detailed design of foundations for watercourse crossings. Excavations in both situations may increase the risk of peat landslide and consequently the peat landslide risk assessment should be revisited in the light of such ground investigation work and updated as appropriate.

10 CONCLUSIONS

A multi-stage assessment of peat slide risk has been carried out for the proposed Viking Wind Farm. This initially involved desk study, interpretation of aerial photography, site reconnaissance and geomorphological mapping, extensive peat depth probing and preliminary slope stability calculations. Based on these collated data an initial assessment of peat stability was made, with 50 locations identified as having a significant or substantial risk of peat landslide.

The size of the wind farm site is such that it was not practicable to conduct ground investigation works for all highlighted significant or substantial risk locations. Fifteen areas were selected from across the site on the basis of their hazard rank, to provide a representative cross section of areas with different hazard rankings. These included three with insignificant risk of peat slide, to act as control sites.

Ground investigation works were commissioned for the 15 selected locations. During the ground investigation works, *in-situ* shear vane measurements were made, the peat was sampled and classified using the von Post classification system and lab tests to determine bulk density were commissioned.

The data from these investigations and the information previously collated were used for a detailed assessment of the 50 locations highlighted as being at risk of peat instability. In a number of cases it was found upon detailed inspection of the location that there was insignificant risk of peat landslide; these included the 'control' locations as well as several others. In such situations no specific mitigation was required to reduce the peat instability risk. The confirmation of the insignificant risk of peat landslide at the 'control' locations provides confidence in the initial assessment, particularly the preliminary slope stability calculations.

10.1 Delting Quadrant

In Delting quadrant it has been recommended that micrositing is carried out to move sections of access track away from potential risk areas in six locations (Db, Dc, Dd, Dh, Di and Dl). Micrositing has also been recommended for three turbines (Turbines D3, D7 and D23); this is of particular importance with respect to Turbine D7 as its current location has been highlighted as having substantial risk of peat instability. Micrositing has also been suggested for Location Dn and the presence of peat pipes in or adjacent to Locations Dd, De, Dh and Dl has been identified. The peat pipe locations will require further investigation at the detailed design stage in order to minimise the chance of collapse or failure during construction.

Locations Db and Dh both include substantial sections of proposed micrositing owing to the local settings at these locations and the hazard ranking of substantial for these locations. Turbine D7 lies within Location Dh.

Three locations (Dd, Dh and Dj) have recommendations relating to the use of floating track construction, including the use of suitable drainage measures to ensure that subsurface flow is not disrupted.

10.2 Collafirth Quadrant

Five detailed assessment locations are present in Collafirth. Of these, micrositing of access track has been recommended for one location (Location Cd) to avoid an area where a tension crack was identified within the peat. Micrositing of track alignment has been suggested for Locations Cb and Ce and the presence of peat piping in or adjacent to Locations Cb and Cc has been highlighted. As before, the locations of peat pipes will require further investigation at the detailed design stage to minimise the chance of collapse or failure during construction.

Floating construction is recommended for three locations (Locations Cb, Cc and Cd), including the use of suitable drainage measures to maintain continuity of subsurface flow.

10.3 Kergord Quadrant

Kergord has 20 detailed assessment locations, of which micrositing of access track has been recommended for three locations (Locations Kc, Ki and Km) in order to move the track away from identified risk areas. Micrositing of access track and/or turbines has been suggested as potential mitigation at ten locations (Locations Kc, Ke, Kg, Kh, Kk, Km, Kn, Kp, Kr and Ks). Peat pipes have been identified in or adjacent to five locations (Locations Kd, Kf, Kh, Ki and Kl); these locations will require further investigation during the detailed design stage to minimise the chance of collapse or failure during construction.

Floating track construction has been recommended for five locations (Locations Kd, Kf, Kk, Kn and Kt), which should include the use of appropriate drainage measures to ensure that subsurface flow is not disrupted. Suitable drainage will also be required at Locations Kg and Ko, as these areas both have considerable numbers of drainage channels within the peat.

10.4 Nesting Quadrant

Fourteen detailed assessment locations occur within Nesting. These include four locations (Nb, Nd, Nj and Nm) where micrositing of access track sections has been recommended in order to move the track away from identified risk areas. Of these, Location Nb contains quite a substantial section of proposed micrositing owing to the local setting in this area and the location’s hazard ranking of substantial. Micrositing suggestions have been made for five locations, Na, Nd, Ne, Nk and Nn. This includes micrositing both for sections of access track and for turbine positions. Peat pipes have been identified within or adjacent to only two locations, Na and Nn; further investigation will be required during the detailed design stage to minimise the chance of collapse or failure during construction.

For eight locations the use of floating track construction has been recommended (Locations Na, Nb, Nc, Nh, Ni, Nk, Nm and Nn). This is coincident with the need for the use of appropriate drainage measures to maintain continuity of subsurface flow across the area.

10.5 Site-wide Conclusions

In addition to the location-specific mitigation recommendations, site-wide best practice measures have been outlined. These include the need for ongoing re-appraisal of the peat landslide risk assessment throughout the detailed design and construction stages. A geotechnical engineer should be employed on site during construction to undertake advance inspection, carry out regular monitoring and provide advice.

The hazard ranking of the 50 locations identified for detailed assessment has been re-appraised. Providing that the recommended mitigation measures are put in place, the risk of peat landslide occurring at any of these locations is insignificant.

11 REFERENCES

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Author Background and Experience

The author of this report, Catherine Isherwood, is a qualified geologist with an MA and PhD in Geological Sciences from Cambridge University. She has been a Fellow of the Geological Society since 2007 and is currently working towards Chartership. She has two and a half years' experience in environmental impact assessment and peat stability assessment with Mouchel and worked previously in environmental education and ecological habitat assessment. Catherine is currently studying part-time for an MSc in Hydrogeology at Newcastle University.

The work in this report has been extensively supported and reviewed by senior members of the team. Details of the principal members involved in assessment methodology and production of this report are included below.

Robert Bone is a Chartered Engineer with over 30 years' experience in civil and hydraulic design, hydrology and environmental impact assessment. He has considerable experience of working on soil mechanics and slope stability problems and has worked on peat stability assessment since it was raised as an issue related to wind farm developments. He has recently been involved in landslide susceptibility mapping in Ireland.

Sarah Sutherland has ten years' experience in water and environmental consultancy with a specific focus on environmental impact assessment and hydrological and hydrogeological assessments. She has worked on more than 20 wind farm EIAs in the last six years and has been involved in peat stability assessment since 2005.

Stuart Bone is a Chartered Environmentalist with ten years' experience in the water industry, with specific focus on environmental management and environmental impact assessments. He has been responsible for Project Managing the deliverables for Mouchel's involvement with Viking Wind Farm.

Malcolm Macfie is a Chartered Chemist and Chartered Scientist with over 20 years' experience in the chemical industry and environmental consultancy, with specific focus on environmental management and environmental impact assessments. He has been involved in a number of wind farm EIAs and peat stability assessments since 2005.

APPENDIX A

Fugro Engineering Services
Factual Report on Ground Investigation

APPENDIX B

Peat Coring Field Notes

Bam Ritchies
Laboratory Analyses

Peat Coring Field Notes

Sample ID	Grid Reference	Location	Von Post Classification	Peat Depth (m)	Sample Length (m)	Description
BH01	HU 4049 7028	Delting North	H6	1.95	0.3	Dark brown strongly decomposed amorphous PEAT. Few fine and coarse fibres. Some indication of horizontal banding in upper levels. Possible woody fragments near base of core.
BH02	HU 3844 6714	Kergord South	H4-5	0.85	0.3	Very dark brown weakly to moderately decomposed fibrous to amorphous PEAT. Few fine and coarse fibres. Some horizons contain sand-size grains, especially towards base of sample.
BH03	HU 3760 6730	Delting South	H4	0.75	0.3	Mid- to dark brown weakly decomposed fibrous PEAT. Some fine and coarse fibres. Strongly banded in lower half of sample, indicating changes in *Sphagnum* content.
BH04	HU 4185 6608	Collafirth South	H2	0.65	0.3	Mid-brown almost undecomposed fibrous PEAT. Many fine and coarse fibres. Plant material dominated by *Sphagnum* with some *Eriophorum* stems present.
BH05	HU 4216 6583	Collafirth South	H6	1.95	0.3	Mid- to dark brown strongly decomposed amorphous PEAT. Few fine and coarse fibres. Indistinct colour banding present throughout.
BH06	HU 4164 6042	Nesting North	H3	1.10	0.2	Very dark brown very weakly decomposed fibrous PEAT. Many fine and coarse fibres. Plant material dominated by *Sphagnum* with some *Eriophorum* stems present.
BH07	HU 4605 5817	Nesting North	H8	4.20	0.24	Mid- to dark brown very strongly decomposed amorphous PEAT. Few fine and coarse fibres. Some indistinct colour banding in mid-section of sample with possible woodly fragments present.
BH08	HU 4573 5660	Nesting South	H5-6	1.10	0.23	Mid- to dark brown moderately to strongly decomposed PEAT. Some fine and coarse fibres. Some colour banding in lower half of sample.

Sample ID	**Grid Reference**	**Location**	**Von Post Classification**	**Peat Depth (m)**	**Sample Length (m)**	**Description**
BH09	HU 4413 5556	Nesting South	H8	2.50	0.25	Dark to very dark brown very strongly decomposed amorphous PEAT. Few fine and coarse fibres. Sample is fairly uniform with very minor indistinct banding.
BH10	HU 4071 6080	North Mid Kame, Kergord	H6	2.55	0.3	Dark brown strongly decomposed amorphous PEAT. Few fine and coarse fibres. Very little indistinct banding. Plant material dominated by *Sphagnum*.
BH11	HU 3903 6084	Kergord North	H4	0.25	0.1	Dark brown weakly decomposed fibrous PEAT. Many fine and coarse fibres with roots in upper section. Clear remains of *Calluna, Sphagnum* and *Eriophorum* throughout sample.
BH12	HU 4002 5683	Kergord South	H3	0.75	0.3	Mid- to dark brown very weakly decomposed fibrous PEAT. Many fine and coarse fibres. Sample is fairly uniform with plant material dominated by *Sphagnum* especially in lower levels.
BH13	HU 4085 5520	South Mid Kame, Kergord	H5-7	1.50	0.3	Dark brown moderately to strongly decomposed amorphous PEAT. Some fine and coarse fibres. Indistinct colour banding throughout. Sample almost clay-like in consistency. Plant material dominated by *Sphagnum*.
BH14	HU 3824 5535	Kergord South	H4	0.85	0.3	Dark brown weakly decomposed fibrous PEAT. Many fine and coarse fibres. Clear remains of *Sphagnum* and *Eriophorum* throughout sample.
BH15	HU 3784 5214	Kergord South	H4	1.55	0.3	Mid-brown weakly decomposed fibrous PEAT. Many fine and coarse fibres. Plant material dominated by *Sphagnum* with possible woody or *Calluna* fragments in central section, some roots near top of sample.

APPENDIX C

Detailed Assessment Slope Stability Calculations

Bore-hole	Location ID	Slope Angle (°)	Corer Base Depth (m)	Bulk Density (Mg/m^3)	Bulk Density (kg/m^3)	Moisture Content (%)	Dry Density (Mg/m^3)	Von Post	Vane Centre Depth (m)	Peak Shear 1 (kPa)	Peak Shear 2 (kPa)	Peak Shear 3 (kPa)	FoS 1	FoS 2	FoS 3	Min. FoS
BH1	Dj	0.815	1.95	1.13	1131.91	234	0.04	H6	0.5	11.03093	9.92280	13.9523	140.4	126.4	177.4	126.4
BH1	Dj	0.815	1.95	1.13	1131.91	234	0.04	H6	1.5	8.915412	8.61319	9.46947	38.4	37.1	40.7	37.1
BH2	Dm	9.077	0.85	0.91	911.83	283	0.06	H4	0.5	21.91076	13.8264	15.1108	31.4	19.8	21.6	19.8
BH3	Do	12.584	0.75	1.13	1132.46	570	0.04	H4	0.5	8.00876	29.4158	16.9241	6.8	25.0	14.4	6.8
BH4	Ca	4.533	0.65	1.05	1053.64	604	0.04	H2	0.5	33.47057	24.8825	23.6233	82.3	61.2	58.1	58.1
BH4	Ca	4.533	0.65	1.05	1053.64	604	0.04	H2	1.5	4.079934	3.27402	23.8248	3.4	2.7	19.6	2.7
BH4	Ca	4.533	0.65	1.05	1053.64	604	0.04	H2	2.5	11.2576	6.95099	9.39392	5.6	3.5	4.7	3.5
BH5	Cb/Cc	8.041	1.95	1.21	1214.20	365	0.07	H6	0.5	24.78182	30.121	31.4054	30.2	36.6	38.2	30.2
BH5	Cb/Cc	8.041	1.95	1.21	1214.20	365	0.07	H6	1.5	23.8248	13.2471	17.8308	9.7	5.5	7.3	5.5
BH6	Nc	13.39	1.1	1.30	1296.37	756	0.03	H3	0.5	8.487271	19.5937	23.5477	6.0	13.8	16.5	6.0
BH7	Nh	5.742	4.2	1.19	1187.34	536	0.04	H8	0.5	22.16261	20.3241		38.4	35.2		35.2
BH7	Nh	5.742	4.2	1.19	1187.34	536	0.04	H8	1.5	14.70791	13.0960		8.6	7.7		7.7
BH7	Nh	5.742	4.2	1.19	1187.34	536	0.04	H8	2.5	11.81166	12.6679		4.2	4.5		4.2
BH7	Nh	5.742	4.2	1.19	1187.34	536	0.04	H8	3.5	22.46482	21.4322		5.7	5.4		5.4
BH8	Nj	11.002	1.1	0.98	983.77	552	0.03	H5	0.5	12.51684	11.4338	12.4161	13.8	12.6	13.7	12.6
BH8	Nj	11.002	1.1	0.98	983.77	552	0.03	H5	1.1	8.109499	4.23104	8.05912	4.1	2.1	4.0	2.1
BH9	Nl	0.8995	2.5	1.04	1043.77	680	0.03	H8	0.5	9.973173	9.69614	10.9553	124.3	120.9	136.6	120.9
BH9	Nl	0.8995	2.5	1.04	1043.77	680	0.03	H8	1.5	13.87681	16.9745	15.0605	57.8	70.6	62.7	57.8
BH9	Nl	0.8995	2.5	1.04	1043.77	680	0.03	H8	2.5	13.87681	14.7331	14.4812	34.8	36.9	36.3	34.8
BH10	Ks	11.347	2.55	1.05	1050.52	592	0.04	H6	0.5	24.55516	47.5740	24.3033	24.7	47.9	24.5	24.5
BH10	Ks	11.347	2.55	1.05	1050.52	592	0.04	H6	1.5	14.12866	14.2294	11.7361	4.8	4.8	4.0	4.0
BH11	Kb	6.523	0.25	0.81	814.68	843	0.01	H4	0.5	29.41582	36.1149	24.3788	65.0	79.9	53.9	53.9
BH12	Kj	10.483	0.75	1.04	1039.44	669	0.03	H3	0.5	36.2409	45.0303	37.3742	39.7	49.4	41.0	39.7
BH12	Kj	10.483	0.75	1.04	1039.44	669	0.03	H3	1.5	>518			>189			
BH13	Kq	6.331	1.5	1.12	1123.90	619	0.04	H5	0.5	14.45606	14.1286	14.0782	24.0	23.5	23.4	23.4
BH13	Kq	6.331	1.5	1.12	1123.90	619	0.04	H5	1	12.51684	14.2042	12.4161	10.4	11.8	10.4	10.4
BH14	Kl	10.962	0.85	1.00	1004.19	711	0.03	H4	0.4	17.64655	15.0689	18.8362	24.0	20.5	25.6	20.5

Bore-hole	Location ID	Slope Angle (°)	Corer Base Depth (m)	Bulk Density (Mg/m^3)	Bulk Density (kg/m^3)	Moisture Content (%)	Dry Density (Mg/m^3)	Von Post	Vane Centre Depth (m)	Peak Shear 1 (kPa)	Peak Shear 2 (kPa)	Peak Shear 3 (kPa)	FoS 1	FoS 2	FoS 3	Min. FoS
BH14	Kl	10.962	0.85	1.00	1004.19	711	0.03	H4	0.8	36.08621	17.25	32.1206	24.5	11.7	21.8	11.7
BH15	Kp	11.681	1.55	0.99	985.40	643	0.03	H4	0.5	21.35669	21.4322	29.4410	22.3	22.4	30.7	22.3
BH15	Kp	11.681	1.55	0.99	985.40	643	0.03	H4	1.5	21.75965	18.0071		7.6	6.3		6.3
BH15	Kp	11.681	1.55	0.99	985.40	643	0.03	H4	2.2	51.94828	37.0775		12.3	8.8		8.8

For all above assessments, the Factor of Safety equation, given below, has been used. Parameter values are defined below, with values as given.

$$F = \frac{c' + (\gamma - m\gamma_w) z \, Cos^2\beta \, Tan\phi'}{\gamma \, z \, Sin\beta \, Cos\beta}$$

F factor of safety (calculated value)
c' shear strength (kPa); measured value
γ bulk density of peat, undrained in situ (kg/m^3); measured value
γ_w bulk density of water (kg/m^3); measured value
m water table elevation as a ration of peat depth (m); taken as 1 for all calculations
z peat depth perpendicular to slope (m); vane centre depth used for all calculations
β slope angle (degrees); derived from DEM
φ' angle of internal friction (degrees); taken as 5 for all calculations