Appendix 12.1 Peat Landslide Hazard and Risk Assessment

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Appendix 12.1 Peat Landslide Hazard and Risk Assessment

1. Introduction

Background

ITPEnergised were commissioned by Nisthill Wind Farm Limited (the Applicant) to undertake a Peat Landslide Hazard and Risk Assessment (PLHRA) at the proposed Nisthill Wind Farm (the Proposed Development), located 5 km west of Birsay, Orkney, shown in Figure 1**.**

The Proposed Development will comprise 4 No. turbines and associated infrastructure, shown in Figure 2.

The PLHRA was led by David Nisbet, Head of Geology & Peat at ITPEnergised. David has a BSc in Earth Science and 10 years' experience in geology and environmental consultancy. David has led geology and peat assessments on many renewable energy and electrical transmission projects across the United Kingdom and Ireland, including PLHRA, Peat Management, Engineering Geological Assessment and Carbon Balance calculations.

The assessment has been undertaken in line with best practice guidance[1] [2], issued by the Scottish Government for investigation, assessment, and reporting for wind farms in peat areas. Where relevant, reference is also made to guidance published by, the Scottish Environmental Protection Agency (SEPA) and wind farm constriction good practice guidance[3].

Although peat slides are naturally occurring, in the wake of high-profile peat slides arising during construction of Derrybrien Wind Farm in 2003 (and more recently at Meenbog in 2020) further consideration of the impact on peat instability of siting developments on peatlands is required.

Blanket bog is the most common peat habitat in the UK and is associated with thick peat deposits. Renewable energy developments, including wind farms, and transmission projects are commonly located on upland moorland terrain comprising blanket bog (though raised bogs, intermediate bogs and fens may also be impacted).

Within these settings, peat instability can occur, particularly where thick peat deposits (> 1 m) are present. Peat instability is impacted by numerous factors, including but not limited to:

- Peat thickness;
- Gradient;
- Climate (and rainfall);

[1] Energy Consents Unit Scottish Government., (April 2017) Peat Landslide Hazard and Risk Assessment: Best Practice Guide for Proposed Electricity Generation Developments, Second Edition.

[2] Scottish Government, SNH, SEPA., (2017) Peatland Survey. Guidance on Developments on Peatland, online version only.

[3] Scottish Renewables, SNH, SEPA, Forestry Commission Scotland, Historic Environment Scotland, Marine Scotland Science, AEECoW (2019), Good Practice During Wind Farm Construction, Fourth Edition.

- Underlying geology; and
- Subsurface hydrology.

Other anthropogenic factors may also increase the likelihood of peat instability events occurring, which are explored further within this report.

Objectives

The PLHRA aims to assess the influence of peat on the Proposed Development and the potential for instability. The objectives have been achieved by completion of the following:

- Geomorphological mapping of the site to identify the prevailing conditions;
- Reporting on evidence of any active, incipient or relict peat instability and the potential risk of future instability, describing the likely causes and contributary factors;
- Identification of potential mitigation and controls to be imposed on the contractors for the works to minimise the risk of peat instability occurring at the site;
- Peat Probing to full depth across the Proposed Development site;
- Recommendation for further work or specific construction methodologies to suit the ground conditions at the site to mitigate any unacceptable risk of potential peat instability.

This report summarises the findings of the desk study and peat surveys and provides an assessment of the prevailing ground conditions at the site and how they relate to peat stability issues.

The results of this assessment have been used through the iterative design process to avoid areas of increased likelihood of a peat slide and avoid areas of thicker peat.

Development Description

The Proposed Development comprises four turbines and associated infrastructure, as summarised below:

- Four turbines with internal transformers and related switchgear;
- Associated turbine foundations and hardstanding areas;
- A total of approximately 0.65 km of upgraded and 2.5 km of newly constructed track;
- One proposed borrow pit location (extension of existing former quarry site);
- A substation compound; and
- Two temporary construction compounds.

A full description of the Proposed Development is provided in **Chapter 3** of the EIA Report.

2. Peat Instability

Background Information on Peat

Peat is found in extensive areas in the upland and lowland regions of the UK and is defined as the partly decomposed plant remains that have accumulated in-situ, rather than being deposited by sedimentation. When peat forming plants die, they do not decay completely as their remains become waterlogged due to regular rainfall. The effect of waterlogging is to exclude air and hence limit the degree of decomposition. Consequently, instead of decaying to carbon dioxide and water, the partially decomposed material is incorporated into the underlying material and the peat 'grows' in-situ.

Lindsay[4] defined two main types of peat bog, raised bog and blanket bog, which are prevalent on the west coast of Europe along the Atlantic seaboard. In Britain, the dominant peatland is blanket bog which occurs on the gentle slopes of upland plateaux, ridges and benches and is predominately supplied with water and nutrients via precipitation. Blanket peat is generally considered to be hydrologically disconnected from the underlying mineral layer.

There are two distinct layers within a peat bog, the upper acrotelm layer and the lower catotelm. The acrotelm is the fibrous surface to the peat bog, typically less than 0.5 m thick; which exists between the growing bog surface and the lowest position of the water table in dry summers. Below this are various stages of decomposition of the vegetation as it slowly becomes assimilated into the body of the peat.

The degree of humification (decomposition) can be measured in the field via the von Post scale of humification[5] [6]. The 'squeezing test' undertaken in the field provides humification values ranging from H1 (minimal decomposition) to H10 (highly decomposed).

The relative position of the water table within the peat controls the balance between accumulation and decomposition, and therefore its stability, hence artificial adjustment of the water table by drainage can have significant impacts.

Peat Shear Strength

In geotechnical terms, the shear strength of a soil is the maximum stress that a soil can sustain without experiencing failure. The physical characteristic of a soil impacts on the overall shear strength. For mineral soils such as clay or sands, such strength is variously given by an interparticle friction value and cohesion. Whether the mineral soil is predominately cohesive (clay) or non-cohesive (sand & gravels) governs which of the component strengths control the behaviour of the soil.

In the case of peat soils, where the major constituent is organic, there is likely to be little or no mineral component, the geotechnical definition of shear strength therefore does not strictly apply. At present, there is no real alternative to defining shear strength of peat, therefore the geotechnical definition is usually adopted, in the knowledge that it should be used with caution.

As noted, the acrotelm or near surface peat comprises a tangle of fresh and slightly rotted roots and plant fibres. These roots and fibres impart a significant tensile strength capacity to the material which provides it with a significant load carrying capacity. The acrotelm is in effect, a fibre reinforced soil.

In the more decomposed catotelm, the tensile shear strength is reduced as the roots and fibres become increasingly rotted. However, the loss of strength is offset to a limited degree, by a gain in

[4] Lindsay, R.A, (1995), Bogs: The ecology, classification and conservation of ombrotrophic mires. Scottish Natural Heritage. Perth.

[5] Von Post, L and Grunland, E., (1926) Sodra Sveriges torvillganger 1, Sverges Geol. Unders. Avh., C335, 1-127.

[6] Hobbs, N.B. (1986) Mire morphology and the properties and behaviour of some British and foreign peats. Quarterly Journal of Engineering Geology, London, 19, 7-80).

strength due to the overburden pressure. In geotechnical engineering there is an established relationship for recently deposited soils, between the shear strength of a sample and thickness of overburden above it.

Consequently, it is almost impossible to predict a shear strength profile in peat and attempts to measure the shear strength using normal geotechnical methods can be misleading (Evans & Warburton 2007[7] ; Gosling and Keeton 2008[8] , Winter et al 2005[9]). Typical values of shear strength from hand shear vanes would be in the range 10-60 kilopascal (kPa) although values of over 100 kPa have been recorded in peat elsewhere. The higher strengths are almost certainly influenced by the roots or other non-decomposed material. It is believed that the strength of peat should be quoted as a cohesion value as there are few, if any, discrete particles to give the material a significant frictional resistance. It should be noted that any quotation of shear strength for peat should be treated with extreme caution.

Peat Failure Characteristics/Mechanisms

This section reviews the nature of peat and how current and past activities can influence stability.

The PLHRA Best Practice Guide for Proposed Electricity Generation Developments, published by the then Scottish Executive (2006, updated by the Scottish Government April 2017[1]) determines peat landslide (instability) in two categories, 'peat slides' and 'bog bursts'. It is indicated that peat slides have a greater risk of occurrence in areas where peat depth is shallow (up to 2 m) and slope gradients are steep (5 to 15⁰). Bog bursts, however, are indicated to have a greater risk of occurrence in areas where peat depth is deep and slope gradients are shallow. As recorded in the Best Practice Guide[1], bog burst events have generally only been reported in Irish and Northern Irish peat bogs. They are uncommon in Scotland and therefore are not considered to attribute significant risk in relation to this assessment. It is noted that peat instability events (including bog bursts), although extremely uncommon, may occur outside the limits mentioned above.

Further to the definition above, a number of natural factors are considered to interact and create the potential for peat instability to occur. These natural factors would typically include:

- Slope Gradient: As noted in the Best Practice Guide[1], peat slides have a greater likelihood of occurrence where slope angles range from 5 to 15⁰. Deposits with shallower slope gradients are less susceptible to failure due to the reduced influence of gravity. Deposits with steeper slope gradients are less susceptible to failure due to the general lack of peat presence (although peaty debris slide may occur).
- Peat Depth: Boylan et al. (2008)[10] describes three common types of peat, controlled to an extent by rainfall and elevation:

[7] Evans, E. and Warburton, J (2007). Geomorphology of Upland Peat: Erosion, Form and Landscape Change. John Wiley & Sons.

[8] Gosling, D., and Keeton, P. (2008). Problems with Testing Peat for Stability Analysis. Paper presented at Reinforced Water, Geological Society Conference.

[9] Winter, M.G., MacGregor, F. and Shackman, L. (2005) Scottish Road Network Landslides Study, ISBN 0 7559 4649 9.

[10] Boylan, N., Jennings, P., Long, M. (2008). Peat Slope Failure in Ireland. Quarterly Journal of Engineering Geology and Hydrogeology.

- Upland Blanket Bog: blanket bogs are typically about 3 m thick, however, they can be up to 5 m thick, generally thinning at higher elevations.
- Lowland Blanket Bog: similar to the upland version, however, they form around sea level in areas of very high rainfall.
- Raised Bog: generally 3-12 m thick, averaging 7 m, with growth occurring above the water table.

Peat depth can give an indication of peat strength and the potential magnitude of a slide, where the generalisation can be made that the potential for peat instability increases with peat depth provided gradients exist to allow movement. However, when combined with other instability indicators, any depth of peat can fail. Factors that influence the potential include:

- Peat Strength: the shear strength of peat is an important aspect in assessing the risk of landslip in blanket peat areas, with areas of lower shear strength likely to be the cause of any peat slide. However, due to the influence of fibres within the deposits and of stratification with depth, reliable values of shear strength are difficult to near impossible to obtain, using common place in situ and laboratory soil strength tests. Where data is available, it can be used, with extreme caution, to assist in assessing likely risk.
- Relief: the combination of slope gradient and variation in elevation can result in confined and unconfined zones i.e., where undulating or hummocky terrain (confined) exists, the natural relief has the potential to mitigate the occurrence of a peat slide. However, convex sloping hillsides (unconfined) can increase the slide potential.
- Evident and/or Potential Areas of Instability: the presence of certain geomorphological characteristics may signify an increased risk of peat instability. However, peat instability events may occur in areas where no such geomorphological characteristics are present, if the general characteristics match those mentioned above.
- Vegetation Cover: the vegetation cover of an area of bog/mire gives an indication as to its hydrological setting and therefore physical characteristics, as noted in the Best Practice Guide[1] and detailed by Hobbs, 1986[9].
- Peat Stratification: the peat formation process causes peat to show natural anisotropic strength. The interface between the three distinct layers (indicating three hydroseral stages) within a peat mass is defined by hydrology. The three layers are:
  - Top Mat: living vegetation of herbaceous plants, grasses and mosses;
  - Acrotelm: decomposing peat which is saturated periodically and is of relatively high permeability; and
  - Catotelm: permanently saturated dense peat of relatively low permeability.

Peat stratification is linked to peat depth (Dykes, 2006[11]), with thinner peat deposits having a thinner or no catotelm layer. A minimal or absent catotelm layer leads to peat mass having a higher shear strength, as the overlying top mat and acrotelm layers are more fibrous in nature compared to the underlying catotlem layer.

- Hydrology (Surface and Subsurface): surface (seeps and springs, wet flushes, watercourses, concentration of drainage networks etc.) and subsurface (pipe systems, underground channels

[11] Dykes, A.P. and Kirk, K.J. (2006) Slope Instability and Mass Movements in Peat Deposits. In Martini, I.P., Martinez Cortizas, A. and Chesworth, W. (Eds.) Peatlands: Evolution and Records of Environmental and Climatic Changes. Elsevier, Amsterdam.

etc.) drainage pathways can provide areas of peat with a water supply which may be absorbed by and potentially increase the mass of the peat. This can cause pooling/piping within the peat mass, or an increase in water at the base of the peat mass, each of which increases the susceptibility of the peat mass to failure.

The presence of a number of the above natural factors may create the potential for peat instability to occur, however, the actual instability is generally the result of a combination of further contributing factors. These factors have been grouped into two categories within the Best Practice Guide[1] described as preparatory and triggering factors.

Preparatory factors, which affect the stability of peat slopes in the medium to long-term (tens to hundreds of years), are:

- increase in mass of the peat through peat formation;
- increase in mass of the peat through increase in water content;
- increase in mass of the peat through afforestation;
- reduction in shear strength from changes in the physical structure of the peat due to creep, weathering or vertical tension cracks of the material;
- loss of surface vegetation and associated tensile strength (e.g. deforestation);
- changes in the subsurface hydrology (water filled pools and/or pipes etc.); and
- afforestation reducing the water held in the peat body, increasing the potential for formation of desiccation cracks which can be exploited by rainfall on forest harvesting.

Triggering factors, which can have an immediate effect on peat stability and act on susceptible slopes, include:

- intensive rainfall or snow melt causing development of high porewater pressures within the peat;
- alterations to drainage patterns generating high porewater pressures within the peat;
- peat extraction at the toe of the slope i.e. fluvial incision, cut slopes etc. reducing the support of the upslope material;
- peat loading commonly due to stockpiling or plant during construction (or natural causes i.e. landslide) causing an increase in shear stress;
- changes to the vegetation cover i.e. by stripping the surface cover or afforestation; and
- earthquakes or man-made rapid ground accelerations, such as blasting or mechanical vibrations, causing an increase in shear stress.

Evidence of the potential for peat instability within an area may be observed through the recording of the geomorphological conditions of the area. These existing geomorphological characteristics may indicate the presence of existing or historical failures or areas of future potential instability. The characteristics of particular interest include the presence of the following:

- historical failure scars and debris;
- tension cracking and tearing;
- compression ridges/thrusts or extrusion;
- peat creep;
- subsurface drainage (pools and/or piping);

- seeps and springs;
- cracking related to drying;
- concentration of surface drainage networks; and
- the presence of organic clays at the peat and bedrock interface.

Types of Failures

The result of peat instability is the down-slope mass movement of the peat material. There are several definitions of peat instability which are used to characterise the type of failure, briefly mentioned above but detailed below.

Bog Bursts (or Bog Flows)

Particularly fluid (amorphous) failures involving rupture of the peat blanket surface or margin due to subsurface creep or swelling, with liquefied basal material expelled through surface tears followed by settlement of the overlying peat mass, in-situ (Hemingway and Sledge, 1941-46[12] , Bowes, 1960[13]).

Accounts of bog bursts are generally associated with very wet climates or areas which have received storm rainfall events. Bog bursts can be associated with particularly wet peat landscapes; therefore, it is possible to identify broad regions of a higher susceptibility to these failures. The constraints used to identify the areas of higher susceptibility to bog burst failures are given below:

- peat thicknesses >1.5 m;
- shallow gradients, ranging from 2 - 10^{o} (peat thicknesses associated with bog bursts are generally not observed on slopes steeper than 10^{o}, where moisture content is reduced due to natural drainage;
- ground which is annually waterlogged to within the upper 1 m below ground level (the groundwater level may rise but rarely falls below this level (Crisp et al, 1964[14]);
- greater humification of the lower catotelm within the waterlogged ground; and
- lower surface tensile strength of the fibrous peat and vegetation.

The humified mass can be considered as analogous to a heavy liquid and the stability of this mass is maintained by the strength of the surface or acrotelm peat. Should the surface become weakened through erosion or desiccation or the construction of a surface drainage ditch for agricultural or forestry reasons or through turbary (peat cutting), failure is made more likely.

Peat Slides

Peat slides tend to be translational failures with a defined shear surface at or close to the interface with the substrate. The factors generally considered to influence susceptibility to peat slide failures are listed below:

- Peat depth up to 2 m;

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[12] Hemingway, J.E. and Sledge, W.A. (1941-46) A Bog Burst near Danby in Cleveland. Proceedings of the Leeds Philosophical and Literature Society, Science 4, pp276 – 288.

[13] Bowes, D.R. (1960) A bog burst in the Isle of Lewis. Scottish Geographical Magazine, 76, pp21-23.

[14] Crisp, D.T., Dawes, M. & Welch, D. (1964), ‘A Pennine Peat Slide’, The Geographical Journal, Vol 130, No4, pp519-524.

- Slope gradients between 5 and 15^{o};
- Natural or artificial drainage cut into the surrounding peat landscape;
- Greater humification of the lower catotelm within the waterlogged ground; and
- Lower surface tensile strength of the fibrous peat and vegetation.

It is noted that some of the factors causing instability are common to both bog bursts and peat slides. The peat – substrate interface is the primary zone of failure and is enhanced by elevated water content at this boundary and softening or weathering of the lower mineral surface. For this reason, any investigation or probing should try to distinguish the nature of the lower mineral substrate.

Bog Slides

A bog slide is a variation on a peat slide where part of the peat mass is subject to movement, usually on an internal layer of material, which may be more prone to movement, such as an interface between the acrotelmic and catotelmic layer.

Natural Instability

The stability of a peat mass is controlled by a complex interrelationship of factors. Key factors include sloping rock head, and proximity to water bodies. Rainfall often acts as a trigger after the slope has been conditioned to fail by natural processes.

It should also be remembered that peat bogs are growing environments and that there would come a time, on sloping ground, where the forces causing instability, the weight of the bog, can no longer be resisted by the internal strength of the peat and its interface with the underlying mineral surface. At this point, failure would occur.

The weight of the peat bog or any soils mantling steep hill slopes would be increased during periods of very heavy rain and it is common to see landslips occurring following extreme rain events. This may be a concern for future developments where one of the predicted effects of global warming is greater frequency of extreme weather, including intense storm events.

3. Desk Based Assessment

A desk-based review of the site and its condition has been conducted by the use of the following sources of information:

- British Geological Survey (BGS) mapping and data;
- Scottish Natural Heritage (SNH) Carbon and Peatland Map, 2016;
- Hydrogeological Map of Scotland, British Geological Survey, 1988;
- Soil Survey of Scotland Maps, James Hutton Institute;
- Habitat and botanical survey data (refer to **Chapter 7**);
- Aerial photography;
- Ordnance Survey and topographic maps; and
- Historical mapping.

Baseline Conditions

Geological Setting

Superficial Geology

Published geological mapping from the British Geological Survey (BGS) at 1:50,000 scale indicates that much of the site area has little or no superficial geology, i.e. bedrock is anticipated to be at the surface or overlain by thin soils (Figure 3). The north-central and eastern parts of the site are indicated to have peat deposits overlying bedrock, with more extensive peat recorded off-site to the southeast. Till deposits (typically a clay matrix with variable sand, gravel, cobbles and boulders) are recorded in the far south of the site. An area of alluvial deposits (clay, silt, sand and gravel), is located at the far northwest edge of the site, extending to the northwest along the low ground north of Loch of Hundland.

Soils

The SNH Carbon and Peatlands Map 2016 shows does not identify any Class 1 or Class 2 peat (both classifications considered to be nationally important) within the site boundary, with the exception of the furthest southeast corner. Most of the site area is classified as Class 4 (unlikely associated with peatland habitats, unlikely to include carbon-rich soils) and the western site area is identified as being underlain by mineral soils.

A peat survey (100m grid) was undertaken to gather site specific information of the presence and condition of peat soils and/or peat and is described further in Section 4.

Bedrock Geology

Bedrock is indicated on BGS mapping to comprise the Devonian age Upper Stromness Flagstone Formation (siltstone, mudstone and sandstone) across the entire site (Figure 4).

Mining and Quarrying

The site is not located within a historical mining area. There is evidence of small-scale historical stone quarries/borrow pits, but no reason to expect any larger-scale excavation has taken place.

Hydrology and Climate

Hydrology

The Loch of Swannay is located immediately east of the site. The Loch of Hundland is located 50 m west of the site boundary at its nearest point. Apart from the two lochs there are no major surface water features on the site or within 1km of the site boundary.

There are additionally several modified field drains and ditches across the site. Traversing the northwestern part of the site a drain bounds the field where the constriction compound and hardstanding for T1 is located and will require diversion. North and west of T3 drains flows east, perpendicular to the existing track, towards the Loch of Swannay.

Hydrogeology

The groundwater body at this location is the Orkney Groundwater, classified by SEPA as having an overall status of Good and a quantitative status of Good. The Hydrogeology Map of Scotland identifies the site as being in the category headed “Middle Old Red Sandstone – Aquifers in which flow is dominantly in fractures and other discontinuities”. The map provides some additional information on the hydrogeology in Caithness, likely to be similar to that found in the Nisthill area, given proximity and similar rock type (sandstone and flagstone formations within Middle Old Red

Sandstone). It states, "In Caithness, groundwater is largely confined to a shallow zone of weathered rock, and borehole yields are limited".

Rainfall

Periods of intense, heavy rainfall are often seen as triggers for instability events. The nearest Met Office weather station to the Proposed Development site is approximately 1 km southwest at Loch of Hundland (National Grid Reference 329780 1025774). The average annual rainfall is 1056.01 mm, which is 38% less than the Scotland North regional average, and 33% less than the Scotland-wide average.

Monthly rainfall averages at Loch of Hundland range from 53 mm in June to 127.58 mm in November. The wettest months are October, November and January.

Land Use and Topography

The site is located between Loch of Swannay to the east, and Loch of Hundland to the west, in the northeast part of the Orkney Mainland. The topography of the site rises from approximately 50 m above Ordnance Datum (AOD) on the shore of Loch of Swannay at the eastern site boundary, to a high point of 107 m AOD at Hundland Hill in the west of the site. Hundland Hill is the main topographical feature, with the land sloping down in all directions from that high point.

The site has been characterised into slope classes based on 5m Digital Terrain Model (DTM) and is shown in Figure 6.

The site is mainly agricultural pastureland, with the upper slopes of Hundland Hill and the eastern area nearest Loch of Swannay having more of a moorland character.

Aerial Photography and site History

Aerial Photography Interpretation

The aerial photography indicates limited changes in vegetation on the ground, it is however possible to identify stream courses, drainage ditches and roads/tracks from the photographs. The aerial photographs were used in conjunction with the site DTM data to identify the major geomorphological features, mainly as breaks of slope. The site was further assessed during site visits when more detailed mapping was undertaken.

Interpretation of available aerial photographs was undertaken to assess and identify (where present) evidence of historic peat instability. The photographs were examined to highlight features of interest, where present, including:

- Possible extension and/or compression features;
- Areas of historic failure scars and debris;
- Evidence of soil/peat creep;
- Areas with apparent poor drainage;
- Areas with concentrations of surface drainage networks; and
- Steeply incised stream cuttings within peat deposits.

The aerial photography, DTM and data gathered on site have been used in conjunction to create a geomorphological interpretation of the site, presented in Figure 8.

There was no evidence visible in the historic photographs of any extension or compression features in the peat. It was not possible to identify evidence of any significant historic peat failures or slides from the aerial photographs. There was no evidence from aerial photographs or ground survey of significant features of this nature and no slumping of peat/soil was present.

Historic Mapping

Freely available historic OS mapping has been reviewed, there was no evidence of historic instability identified.

Local Knowledge

No anecdotal background from landowners or past site users has been provided to suggest there has been a history of peat instability on the site.

Surface Water and Sensitive Receptors

The effects of peat failures are felt locally, both in the long and short term, but they can also have wider off-site implications.

A key part of the risk assessment process is to identify the potential scale of peat failure, should it occur, and identify the potential environmental effects as well as the receptors of such an event.

Peat failure associated with the Proposed Development could affect the following key receptors:

- The Proposed Development itself including associated infrastructure;
- Property and infrastructure, for example roads or utilities;
- Land based ecological effects (damage to habitats);
- On-site and downstream watercourses;
- Archaeological assets; and
- Visual amenity (scarring of the landscape).

4. Site Work

Peat Depth Survey

Peat probing was undertaken by ITPEnergised in January 2022, with the site probed across a 100 m grid in line with best practice guidance.

Methodology

The survey carried out followed best practice guidance for development on peatland.

The thickness of the peat/soils was assessed using a graduated fibre glass peat probe. This was pushed vertically into the peat/soil to refusal and the depth recorded using a handheld Trimble Global Positioning System instrument (GPS), reaching an accuracy of <1.5 m.

Alongside desk-based information, the 'feel' on refusal was used to interpret the underlying substrate. The following criteria was used in the field:

- Solid and abrupt refusal – Rock
- Solid but less abrupt refusal with grinding or crunching sound – Granular (sands, gravel, weathered rock)
- Gentle refusal – Cohesive (Clay/Silt)

Peat Depth Analysis

A summary of the peat depths encountered during probing is detailed in Table 1 below and within Figure 5.

Table 1 Distribution of Peat Depth Recorded at the Site

Peat Depth Interval (m)	Number of Occurrences	% of Probes
Nil	0	0
0.01 to 0.49	114	88.4
0.50 to 1.00	12	9.3
1.01 to 1.50	3	2.3
Total	129	-

The results of the probing show that there are very limited peat deposits across the site, with 88% of probes identifying thin soils (<0.5 m). Just three probe locations identified thick peat (>1 m), to a maximum depth of 1.5 m.

The proposed infrastructure generally avoids areas of thick peat.

5. Peat Landslide Hazard and Risk Assessment

The Best Practice Guide[1] acknowledges that there is no universal agreed definition of hazard and risk that can be applied in the context of peat landslides.

The guidance describes the calculation of risk from the following formula:

Risk = Likelihood of a Peat Landslide x Adverse Consequence

The guidance provides examples of assessment methodology to be used. ITPEnergised have reviewed the guidance and the approach of other leading experts and has undertaken the assessment using the following methodology.

Firstly, it is important to note that the Proposed Development layout, including siting of turbines and other infrastructure, resulted from an iterative process which took into account the findings from peat survey work. Deeper peat was avoided wherever possible, in order to minimise the requirement to disturb and/or excavate peat, and to minimise peat slide risk associated with construction across and within peat.

The first phase of assessment is to identify the susceptibility or likelihood of a peat landslide occurring based on existing conditions and parameters that influence peat landslide occurrence (prior to influence of construction).

Once areas of increased likelihood of a peat slide occurring have been identified, an assessment of adverse consequence (impact) and risk assessment is undertaken on these areas, assessing the impact of a potential peat slide on identified receptors. For this further assessment, impact coefficient scores were determined, combined with an assessment of the vulnerability of receptors to establish a final risk score.

Likelihood Assessment

The susceptibility or likelihood of a peat slide occurring is controlled by a number of natural controlling and trigger factors. These are typically:

- Slope gradient;

- Peat depth;
- Peat strength;
- Nature of the substrate beneath peat deposits;
- Relief;
- Evidence of historical failures/potential instability (e.g. tension cracks, creep, compression ridges);
- Vegetation cover;
- Land use; and
- Hydrology.

The most important of the above controlling factors are considered by the assessor to be peat depth, slope gradient, underlying substrate and evidence of potential instability (which is controlled by the former). Without peat and slope, the risk of a peat slide would be unlikely to exist.

Key parameters influencing peat stability have been scored and provided a coefficient value.

The Best Practice Guide[1] relates the likelihood of a peat landslide to a scale of 1 to 5, with 1 being negligible (very low likelihood) and 5 being almost certain (very high likelihood). This scale relates to the likelihood of instability for all the controlling factors under consideration.

It is important to note that this study only focuses on peat soils and the criteria used is specifically tailored to the key factors affecting peat stability. As such it does not account for the stability of other mineral soils or rock.

Peat strength has not been included as a factor in the likelihood scoring process. Site-specific peat strength data was not collated for the site given the difficulty in obtaining reliable values of shear strength using common place in situ and laboratory soil strength tests (as described in Section 2). The shear strength is also linked to peat depth as strength is considered to decrease **with** thickness. As such this parameter is considered to be factored into the risk scoring for peat depth.

Input Data

The input data sets used for the analysis were as follows:

- Slope gradient: Terrain 5 DTM with a 5 m grid size;
- Peat depth: Site survey information for peat depth and site observations;
- Nature of substrate: Surveyor observations of substrate “feel” at the refusal point during probing, together with BGS geological mapping and surveyor observations of exposed substrate at the site;
- Emerging Instability: Where there is evidence of instability or factors which may increase the likelihood of a slide event occurring e.g. soil creep, slumping, possible extension/compression features, poor drainage etc.

The assessment firstly considers the likelihood of instability occurring, based on a series of input factors. These factors were attributed coefficient scores based on their influence on peat stability.

There is no guidance available on how to combine the likelihood scoring for each of the factors used in the assessment. The assessment team have used the methodology set out below.

For each of the factors noted, a score/coefficient of zero to three has been assigned. A zero score reflects no contribution to peat slide likelihood, with a score of three indicating a high peat slide likelihood associated with that particular factor.

The total likelihood ranking is the product of the four individual factor scores.

Slope Angle

The limiting factor governing the formation of thick peat deposits is topography. In the case of blanket peat, it tends to be deepest in closed depressions, and typically thin as the slope angle increases (Boylan et al. 2008[13]). The Best Practice Guide[1] details that a PLHRA is not needed for blanket bog sites with slopes less than 2° and as such, a score of zero has been assigned for slopes less than 2°. For slopes greater than 2°, scores have been assigned based on the type and nature of peat slides reported for different slope conditions.

A slope angle GIS layer was generated from the DTM at a 5 m cell resolution. The source DTM is also at a 5 m resolution. The slope angle details are illustrated in Figure 6.

This slope, calculated in degrees, was identified at each probe location and scored as shown in Table 2.

Table 2 – Coefficient for Slope

Slope (degrees)	Slope Coefficient	Notes
2.0 or less	0	Failure unlikely due to flat ground
2.1 – 5.0	2	Failure in blanket bog areas would typically occur as peat slides and peaty debris slides, due to low slope angle.
5.1 – 15.0	3	Failure in blanket bog areas would typically occur as peat slides, bog slides or peaty-debris slides. This is the key slope range for reported peat failures.
15.1 – 20.0	2	Failure would typically occur as peaty debris slides due to low thickness of peat on steeper slopes.
>20.0	1	Failure would typically occur as peaty debris slides due to low thickness of peat on steeper slopes.

Peat Depth

Peat thickness is seen as one of the key factors associated with peat stability. Typically, the deeper the peat the more humified, and therefore potentially weaker and unstable it is. Peat depth surveys have been completed on the site and these data were then interpolated using the Spline interpolation function within the Spatial Analyst Tools of ArcMap 10.3 (see Figure 5).

The highest hazard scores have been assigned to peat depth ranges most frequently associated with peat slides on upland sites (Evans and Warburton, 2007[10]).

The peat depth was identified at each probe location and scored as shown in Table 3.

Table 3 – Coefficient for Peat Depth

Peat Depth (m)	Depth Coefficient	Notes
Nil	0	No peat/organic soil therefore no potential for peat slide
<0.5	1	Peaty/organic soil rather than peat, therefore failures would be peaty-debris slides
0.5 – 1.5	3	Sufficient peat thickness for peaty debris or peat slide
>1.5	2	Sufficient peat thickness for peat slide however less often recorded at this thickness, due to thicker peat generally occurring in areas of shallow gradients

Substrate

The nature of the substrate beneath peat deposits can have a bearing on the likelihood of instability arising, with failure often occurring at the interface between the base of the peat mass and the top of the substrate.

Where granular soils (sand/gravel derived from glacial till) or weathered rock form the substrate, the effective strength of the interface can be considered to be good, with comparatively high friction values. Under these conditions, failure of likely to occur in a zone within the peat, just above the interface. Further factors are necessary to cause a failure of this nature (increased pore pressures within the peat) and occurrence of such events is rare.

Where cohesive soils (clay) form the interface, there is likely to be a significant zone of softening in the clay (due to saturation at low normal stresses, poor or non-existent vertical drainage and the effect of organic acids), resulting in either very low undrained shear strength of low effective shear stress parameters. The result is that potential shearing could occur either in the peat, or in the interface or in the clay; all three possibilities have been documented in peat slides.

A rock substrate provides a high strength stratum, however, the rock surface can be smooth, with a relatively impermeable surface which can result in a 'slippery' interface, accumulation of groundwater and/or low shear strength at the interface, resulting in a higher susceptibility for the overlying peat mass to fail.

The nature of the substrate was inferred at each probe location, based on surveyor observations and BGS geological mapping, and scored as shown in Table 4.

Table 4 – Coefficient for Substrate

Substrate	Substrate Coefficient	Notes
Granular Sands/Gravels/Weathered Rock	1	Peat failures sometimes associated with bedrock or granular till substrate.
Cohesive (clay)	2	Peat failures often associated with cohesive till substrate
Rock (smooth interface)	2	Peat failures often associated with impermeable 'smoot' bedrock surface.
Not proven	3	If the overall thickness of the peat had not been proven, the risk associated with the significant thickness and the unknown substrate would be given a high rating to accommodate unknown factors.

Evidence of Existing or Emerging Instability

Geomorphological considerations such as peat erosion, hagging, peat pipes, pools, and evidence of existing instability, can contribute to the potential for instability to arise.

Where evidence of existing or emerging instability was identified by surveyor observations or through mapping and aerial photography a coefficient score has been assigned, as shown in Table 5.

Table 5 – Coefficient for Existing or Emerging Instability

Evidence of Existing/Emerging Instability	Existing or Emerging Instability Coefficient	Notes
Yes	2	Failures likely to occur where evidence of emerging/ developing instability is observed (peat pipes/collapsed pipes, areas of diffuse surface drainage such as flushes and pools, tension cracks, compression ridges, bulging, quaking bog) or in areas in close proximity to previous failure events.
No	1	No impact on likelihood of peat slide

Likelihood Rating

The coefficient scores assigned for each of the above factors were multiplied to give a likelihood rating.

Identification of the likelihood of a peat landslide occurring is the first step of the assessment, allowing areas of potential concern to be identified.

Table 6 sets out the ranking system employed in this assessment.

Table 6 – Likelihood of a Peat Landslide Occurring

Likelihood Rating Coefficient	Likelihood of Instability	Action
1 - 5	Negligible	No mitigation required, good construction practices should be followed.
>5 - 15	Low	Further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations.
>15 - 30	Medium	Should not proceed unless risk can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce likelihood score to low or negligible.
>30 - 36	High	Avoid project development at these locations
>36 - 54	Very High	Area should be avoided due to very high level of risk and almost certain likelihood of a peat slide occurring.

The assessment of all probe locations is included in Appendix 2. The results show that of the 129 probe locations within the extent of the DTM, the following likelihood ratings were identified:

- Negligible likelihood at 125 locations;
- Low likelihood at 4 locations; and
- No medium, high or very high likelihood locations.

Figure 7 provides the interpreted likelihood of peat stability based on the rating calculated from the above factors. A summary of the likelihood of peat instability at infrastructure locations is shown in Table 7 below.

Table 7 – Likelihood or Peat Instability Rating at Infrastructure Locations

Infrastructure Element	Instability Rating	Average Peat Depth (m)	Slope (degrees)	Suitability of Location
Turbines and Hardstandings				
T1	Negligible	0.18	3.9	Suitable
T1 Hardstanding	Negligible	0.15	3.6	Suitable
T2	Negligible	0.17	7.4	Suitable
T2 Hardstanding	Negligible	0.19	7.8	Suitable
T3	Low	0.45	6.8	Suitable
T3 Hardstanding	Low	0.58	3.7	Suitable
T4	Negligible	0.67	0.4	Suitable
T4 Hardstanding	Negligible	0.36	1.0	Suitable
Construction Compound W	Negligible	0.16	3.9	Suitable
Construction Compound E	Negligible	0.3	6.3	Suitable
Substation	Negligible	0.2	3.8	Suitable
Borrow Pit	Negligible	0.1	2.8	Suitable
New Access Track	Negligible	0.23	-	Suitable
Upgraded Access Track	Negligible - Low	0.36	-	Suitable

As can be seen from Table 5-6, all infrastructure elements have been assigned likelihood rankings of negligible or low. The generally negligible rankings across the proposed infrastructure locations accord with minimal peat deposits identified on site, with no evidence of historical failures where peat is present.

Results

The likelihood assessment has determined that the majority of the site lies within an area of negligible likelihood of a peat landslide occurring (Figure 7).

Impact Assessment

In line with best practice guidance[1], should areas with medium or higher likelihood of instability be identified, further assessment would have been undertaken to identify the overall risk by considering the impact (adverse consequence) should a peat landslide occur.

The assessment would follow the methodology outlined below, and consider the sensitivity of the receptor, the distance between the potential source of instability and the receptor, and the relative elevation of the source compared to the receptor. This is considered to be a more realistic and suitable analysis than considering distance alone, given that a receptor which is close to a source area but is up-gradient from it, would not be affected by run-out from the resultant failure.

The impact rating is derived by multiplying the receptor sensitivity coefficient by the receptor proximity coefficient and the relative elevation coefficient. The following sections detail the methodology for assigning coefficient scores.

For example, a highly sensitive watercourse (6) at 250 m from the source of potential peat slide (2) at a relative elevation of <10 m (1) would be scored an impact rating of 12 (low), as detailed in Table 11.

Receptor Sensitivity Ranking

Should a peat landslide occur, nearby structures or features may be impacted. Generally, only features down-gradient should be considered, therefore a review of topography and geomorphological features need to be identified prior to identifying receptors. However, it should be noted that instability occurring on steep slopes do risk the back scarp of instability migrating up-slope, affecting areas not previously considered to be at risk. The receptors detailed in Table 8 have been ranked according to their size and sensitivity with corresponding coefficients assigned.

Table 8 Coefficients for Receptor Sensitivity

Receptor	Receptor Sensitivity Coefficient
Minor infrastructure e.g. private roads/tracks, including Proposed Development track	1
Watercourses, and critical infrastructure (roads/ services, individual dwellings and business properties)	3
High sensitivity watercourses (e.g national/international designations)	6
Communities (over approximately 10 dwellings)	8

Receptor Proximity

The proximity of a receptor should be considered to assess the likely level of disruption should a peat landslide occur. Predicting the size of a failure and the distance it may travel is very difficult. The high moisture content of peat makes it especially mobile once it fails and the structure of the peat breaks down. If a peat slide enters a watercourse this can mobilise the slide further and have impacts many kilometres beyond the bounds of the site. In many instances, minor slumps are localised and have little or no impact. Other failures may travel at 100 – 200 m and those entering watercourses, many miles, as was the case of the Derrybrien failure in Co. Galway, Ireland in 2003 (Lindsay & Bragg 2005[5]).

The distance from the source and the relative elevation of the receptor have been assigned coefficients as detailed in Table 9 and 10.

Table 9 Coefficient for Receptor Proximity

Distance from Coefficient Feature	Distance Coefficient
More than 1 km	1
100 m to 1 km	2
10 m to 100 m	3
Less than 10 m	4

Table 10 Coefficient for Relative Elevation

Relative Elevation of Receptor	Relative Elevation Coefficient
Less than 10 m	**1**
10 m to 50 m	**2**
50 m to 100 m	**3**
More than 100m	**4**

The results of the likelihood and impact assessment have been normalised into a numerical score, detailed in Table 11. The overall risk ranking (detailed in Table 12) is determined from the product of the likelihood rating coefficient (normalised) and the Impact rating coefficient (normalised).

Where a risk ranking is greater than negligible, qualitative assessment would then be undertaken to determine if the ranking can be revised to an acceptable level through appropriate mitigation or re-design.

Table 11 Rating Normalisation

Likelihood		Impact	
Current Scale	**Normalised Scale**	**Current Scale**	**Normalised Scale**
Negligible (≤5)	1	Very Low (<10)	1
Low (>5 – 15)	2	Low (11 – 20)	2
Medium (>15 – 30)	3	Moderate (21 – 30)	3
High (>30 – 36)	4	High (31 – 50)	4
Very High (>36)	5	Extremely High (>51)	5

Table 12 Risk Ranking

Risk Ranking	Risk Ranking Level	Action
1-4	Negligible	No mitigation required, good construction practices should be followed.
5-10	Low	Further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations.
11-16	Medium	Should not proceed unless risk can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce risk score to low or negligible.
17-25	High	Avoid project development at these locations.

Assessment of Increased Likelihood Locations

As noted above, should areas of increased likelihood (medium or higher) of a peat slide occurring be identified (Figure 7), an assessment of the impact of the peat slide and overall risk would be undertaken.

Where the likelihood assessment identified areas of negligible and low likelihood of instability, no specific mitigation measures are considered necessary. However, best practice construction methodology should be adopted with ongoing monitoring of ground conditions.

No locations of medium or higher likelihood have been identified and therefore no further assessment of the impact of a peat slide is required.

6. Proposed Development Design and Mitigation

Detailed Design and Site Investigation

A detailed site investigation would be required to assist detailed design, comprising intrusive ground investigations at infrastructure locations prior to construction commencing, to ascertain depth to bedrock and suitable founding conditions.

A detailed stability analysis can then be completed at all infrastructure locations using the increased confidence in the shear strength/peat depth data and site-specific topographical survey data, to provide added robustness to the stability assessment.

Turbines and Hardstandings

Design

This PLHRA has identified that all turbines and hardstandings are at low or negligible likelihood of a peat slide occurring.

Mitigation

The infrastructure would not be constructed on peat, rather peat would be excavated to allow founding onto a suitable stratum i.e. bedrock.

It is anticipated that extraction of rock will be required in at least some areas to create suitable levels for founding turbines and hardstandings.

Prior to construction, a specific construction method statement would be produced which would draw on the findings of intrusive investigations. The method statement would detail the exact construction methodology to be used, in line with the Peat Management Plan and taking into account:

- Opportunities for micro-siting turbines and hardstandings to further minimise risk where possible;
- A geotechnical analysis for each turbine base;
- The method of excavation and the location for placing and storing excavated material to ensure that these operations do not give rise to slope or site instability;
- Methodology for storing and watering surface vegetated turves, for re-sodding bare areas;
- Details of how excavated spoil would be stored;
- Avoidance of construction (if possible) on wet areas, flushes and easily eroded soils;
- Adequate drainage design to cater for expected heavy rainfall events; and
- Monitoring of ground movement and water levels.

The Construction Method Statement would also detail how pumped water from excavated bases would be controlled and monitored to ensure it is appropriately managed and if directed into or conveyed to existing drains/watercourses, to ensure that all have adequate treatment beforehand and capacity to deal with the volumes of water encountered.

Access Tracks

Design

Areas of deep peat have been avoided with respect to access track routing. Only limited sections of track and infrastructure are anticipated to cross peat depths ranging from 0.5m to 1.0m (Figure 5).

Mitigation

It is not considered practical to construct floated road sections across such short lengths and across relatively shallow peat depths, however if pre-construction detailed site investigation work identifies longer stretches of track needing to cross deep peat, with no opportunity for micro-siting (considered an unlikely scenario based on survey findings), then tracks would be floated to reduce the requirement for excavation of peat.

Assuming tracks will generally not be floated, mitigation measures are set out below, to ensure suitable construction of tracks and minimising risk of instability:

- Road alignments would be micro-sited to further reduce risk where possible and appropriate, based on detailed site investigation findings;
- Roads would be constructed to take the required vehicular loadings, having due regard to overall site stability;
- Machinery and vehicles used in track construction would be operated from the already constructed sections of the road as it progresses;

- Good quality rock would be used to construct roads where applicable;
- Ground movement and water level monitoring would be carried out at all times;
- All machinery and construction methods on-site would be selected with a view to minimising impact on the surrounding habitat; and
- All roads would have sufficiently sized culverts (where required), permeable fill or cross drains at the location of the water crossings (limited to minor field drains), flush or other hydrological features in order to allow the natural flow of water across the area and prevent ponding and the generation of pore pressures which may initiate instability.

Peat Storage

The principles of temporary peat storage are discussed in **Appendix 12.2**. Detailed requirements for any appropriate mitigation measures would be set out in the Construction Environmental Management Plan (CEMP).

Best practice measures for temporary and permanent peat storage during construction would be followed, in accordance with guidance including Developments on Peatland: Guidance on the Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Waste (Scottish Renewables and SEPA, 2012). This includes:

- selecting suitable temporary storage areas with relatively low ecological value, and low stability risk i.e. not at the crest of a slope or in areas identified as being at higher risk of instability;
- reuse of temporarily stored peat as soon as possible after excavation;
- dressing and reinstating peat used for road verges and infrastructure batters (as part of site landscaping works) as soon as practicable after construction; and
- suitably limiting the angle of reinstated slopes to reduce run-off and erosion.

Drainage Areas

Design and construction of a suitable drainage system for the proposed Development would follow Sustainable Drainage Systems (SuDS) principles and would ensure natural drainage without significant alteration of the hydrological regime of the site area.

Any construction activity relating to or undertaken in the vicinity of watercourses would be carried out in general accordance with relevant guidelines and legislation.

Borrow Pit

Pre-construction site investigation works would be undertaken to further assess the borrow pit search area and to identify the specific excavation locations and extents within the search area. This would be based on peat depth and distribution, with any deep peat avoided, and suitability of rock for excavation. These further investigations would also establish the method of extraction, determining whether any blasting is required. If blasting is required, further analysis of potential impacts on peat stability in the vicinity would be undertaken and appropriate mitigation stipulated.

Monitoring and Management

A line of surveyed and levelled pegs and visual monitoring is an acceptable method of monitoring movement adjacent to roads, excavations and stockpile areas.

Thus, as construction activities commence, the appearance of the area and surrounding land would be monitored visually by installing a line of levelled pegs adjacent to the activity location. Specifically, the following signs would be looked for:

- increased rate of sinking or tilting;

- The rising of adjacent peat/peaty soils;
- Cracking and lateral movement of the soil surface; and
- A rise in water levels.

The Principal Contractor would ensure that suitably qualified and experienced construction staff are engaged on the project, including a senior geotechnical engineer with extensive practical knowledge and experience of similar conditions to those at the site. The senior geotechnical engineer would have responsibility for maintaining and actively monitoring a geotechnical risk register for the construction works.

Additionally, all staff would undergo a site induction and suitable training relating to construction on peatland sites. This would raise awareness of ground instability indicators, best practice construction techniques, mitigation and emergency procedures. All staff should be responsible for observational monitoring and reporting.

7. Conclusion

The Proposed Development has been assessed for potential peat instability through consideration of the likelihood of a peat slide occurring based on existing site conditions, the potential impact on identified receptors and the overall risk associated.

The overall conclusions show that there is a negligible to low likelihood of peat instability over the majority of the site, with the proposed layout avoiding areas of increased likelihood.