Appendix 11.1 Peat Slide Hazard and Risk Assessment

Contents

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1 Introduction

1.1 This Peat Slide Hazard and Risk Assessment (PSHRA) report provides an overview of peat slide mechanisms, desk study information relating to the site and survey results to highlight any risk of peat slide within the Proposed Development area.

1.2 The peat slide risk assessment was led by Jenny Hazzard, Environmental Planning Director at ITPEnergised. Jenny has a BSc in Geological Engineering and an MSc in Engineering Geology, and she is a Practitioner Member of IEMA. Jenny has 20 years of experience in environmental consultancy including EIA, geo-environmental assessment, ground investigations, and assessment of geology, hydrology and hydrogeology impacts. She has led on hydrology, hydrogeology and peat assessment work for several renewable energy and transmission & distribution projects across Scotland, including peat slide risk assessments and peat management plans for several proposed Scottish windfarm projects.

1.3 Field surveys were directed by Jenny and undertaken by members of the ITPEnergised Environmental Planning team, with suitable experience of peat probing and habitat survey work.

2 Peat Failure Characteristics/Mechanisms

2.1 The Peat Landslide Hazard and Risk Assessments Best Practice Guide for Proposed Electricity Generation Developments, published by the then Scottish Executive (2006, updated by the Scottish Government April 2017) 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 15^{o}). 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, 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.

2.2 Further to the simple 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, peat slides have a greater likelihood of occurrence where slope angles range from 5 to 15^{o}. 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:** Boyland et al. (2008) describes three common types of peat, controlled to an extent by rainfall and elevation:
    - 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 (note, the Proposed Development site is considered to be an upland blanket bog site).
    - Lowland Blanket Bog: similar to the upland version, however, they form around sea levels in areas of very high rainfall.
    - Raised Bog: generally 3-12 m thick, averaging 7 m, with growth occurring above the water table.

2.3 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.

- **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 hazard potential.
- **Evident and/or Potential Areas of Instability:** the presence of certain geomorphological characteristics (refer to Paragraph 2.7 below) 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 and detailed by Hobbs, 1986.
- **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), 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 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.

2.4 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 described as preparatory and triggering factors.

2.5 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.

2.6 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.

2.7 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.

3 Sources of Data

3.1 A desk study was undertaken to examine documentary information relating to the site. This included the following data sources:

- British Geological Survey, DiGMap and GeoIndex;
- 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 8: Ecology and Figures 8.2 and 8.3); and
- Aerial photography.

4 Baseline Conditions

Geography, Topography and Geomorphology

4.1 The Proposed Development site lies approximately 1.3 km west of the village of Lyness on the island of Hoy, and comprises moorland with coastal pastures in the east and south. The site lies within a sloping landscape area with a ridge running its full northern extent at an elevation of approximately 180 m Above Ordnance Datum (AOD). The site drops to elevations of approximately 30 m AOD within the valley towards the Burn of Ore (which forms the southern boundary of the western site area) and rises again to the south to approximately 100 m AOD.

4.2 Photographs providing an overview of the moorland character and sloping topography of the site are given in Chapter 11 of the EIA Report.

4.3 The landform across the site comprises slopes of variable steepness, particularly steep near the hilltops at and beyond the northern site boundary, and at Binga Fea to the south of the site. Ground slopes trend mainly to the south and to the east within the site. Slopes become gentler towards the Burn of Ore valley, particularly on the north side of the watercourse.

4.4 Slopes across the site are mainly confined, i.e. they are steepest in the higher reaches and become shallower towards the base. This would typically have the effect of limiting the extent of runout from any peat slide, as materials would tend to settle on the shallower slopes. However, the slopes southeast of T2 and T4 display a convex nature.

4.5 Aerial photography displays evidence of historical movement of materials downslope in the northeast of the site (east of T1 and north of the borrow pit search area), however no clear evidence of peat slide. The images suggest soil erosion, rather than failure of the peat mass (which, in this area is generally limited to shallow peaty soils, based on survey findings).

4.6 Review of aerial photography and site reconnaissance also identified evidence of recent and older peat cutting at the site. The area displaying the clearest evidence is in the north, between T1 and T6. Evidence of what may be older cuttings is observable further south, around T2.

4.7 The remnants of numerous historical wartime features are evident on site, including bunkers/lookouts, and a large underground oil storage tank system.

4.8 A map illustrating some of the key geomorphological features is given as **Figure 1**.

Vegetation

4.9 Ecological surveys undertaken have identified that the site largely comprises bog and heath habitats. Much of the area where proposed infrastructure is proposed has been identified as comprising wet dwarf shrub heath, or a mosaic of blanket bog and wet dwarf shrub heath. The central site area, mainly within the proposed access track ‘ring’, comprises blanket bog.

4.10 A narrow strip of coniferous plantation woodland is present adjacent to the south of the northern access into the site. A localised area of marshy grassland is adjacent to the woodland, to the north.

Rainfall

4.11 Rainfall data has been obtained from the nearest Met Office weather station at Kirkwall, approximately 23 km northeast of the Proposed Development site. The average annual rainfall over the period 1981 to 2010 was 1,038.5 mm. The wettest months are recorded as being October and November (each 126 mm), with the driest month being May (48 mm).

Geological Conditions

4.12 Based on BGS digital mapping, the bedrock geology underlying the site comprises Upper Old Red Sandstone, with superficial geological predominantly comprising peat. BGS mapping shows peat to be absent from the northeast corner of the site, at the site access and T1, and at T6, where there is indicated to be little or no superficial deposits overlying bedrock. However, further detail on the distribution of peat deposits at the site has been obtained by site survey, described in the section below.

4.13 BGS mapping shows the presence of till overlying bedrock in the far east of the site, specifically along the access. Alluvial deposits are shown to be present along the banks of the Burn of Ore in the south of the site, only in the eastern site area.

4.14 The SNH Carbon and Peatlands Map (2016) has also been consulted although it is noted that this provides much higher-level, overview information than the larger-scale BGS mapping and indeed site-specific survey work. For completeness, information from the SNH Carbon and Peatlands Map is provided here. The site area is shown as being mostly contained within areas of Class 1 Peat. This is defined as "*nationally important carbon-rich soils, deep peat and priority peatland habitat; areas likely to be of high conservation value*." Two isolated areas of Class 5 Peat are present within the site area, which are stating as having "*no peatland habitat recorded. May also include areas of bare soil. Soils are carbon-rich and deep peat*". These areas are located directly to the east of the Burn of Longigill and the north of the Burn of Ore, and at the source of the Burn of Longigill, stretching northwards to the site boundary.

4.15 Site observations broadly support the mapping, with peat recorded to variable depth across much of the site, although observed to have been subject to cutting in some areas.

4.16 Peat depth surveys were undertaken as described in Section 5, to identify the extent, depth and nature of peat across the site. Peat depths were recorded varying from nil to over 3 m.

Surface Water and Sensitive Receptors

4.17 The Burn of Ore is the largest watercourse on the site. It rises in the sloping ground towards the western edge of site, on the southern site boundary. From there, it flows eastward, forming the southern boundary of the western part of the site and then cutting through the south-eastern area of the site. It continues off-site to the east, discharging into Ore Bay on the east coast of Hoy, approximately 850 m east of the site boundary.

4.18 Three small burns flow from north to south across the central and western part of the site, into the Burn of Ore. The westernmost and central burns are unnamed, and the easternmost is the Burn of Longigill. These all rise on the southward facing slopes of the site.

4.19 The watercourses on site feature gently sloping banks overgrown with vegetation and not deeply incised. Standing water/ small pools were observed on the flat ground within the valley adjacent to the Burn of Ore.

4.20 In the northern part of the study area, the Burn of Moifea rises in the high ground north of the central part of the site boundary, and flows initially to the southeast, turning east and then northeast to meet the Mill Burn and discharge into Mill Bay approximately 850 m north-northeast of the site boundary.

4.21 Virtually the entire site area where any infrastructure is proposed is within the Burn of Ore catchment, with the land draining to the south and east. The only proposed infrastructure features which are not considered to be within the Burn of Ore catchment are the proposed borrow pit search area, the proposed substation compound, the short stretch of track (existing but requiring upgrade) to the east of the substation, and the northern section of the proposed temporary construction compound. This localised area is expected to drain to the northeast, into the confluence of the Burn of Moifea and Mill Burn.

4.22 All site drainage is ultimately to the sea on the east coast of Hoy.

4.23 The Mill Burn in the north of the study area has a SEPA classification of Good overall (2014), with both physical condition and water quality classified as Good. No update subsequent to 2018 is shown on the SEPA website.

4.24 None of the other surface watercourses within the study area, including the Burn of Ore, are classified by SEPA under the WFD.

4.25 The coastal water body at the Bay of Ore (Scapa Flow) is classified by SEPA as having an overall condition of Good (2014), therefore, it can be assumed that the Burn of Ore and its tributaries also exhibit good quality.

Hydrogeology

4.26 The groundwater body at this location is the Hoy Groundwater, classified by SEPA as having an overall status of Good (2014), with both water quality and water flows and levels classified as Good.

4.27 The Hydrogeology Map of Scotland identifies the site as being underlain by Upper Old Red Sandstone, a moderately productive aquifer in which flow is virtually all through fractures and other discontinuities.

4.28 Peat and peaty soils would also be expected to inhibit groundwater flow. Till, where present, is also anticipated to be relatively low permeability, inhibiting groundwater flow. The alluvial deposits on the banks of the Burn of Ore may exhibit higher permeability.

4.29 There are no Private Water Supplies (PWS) identified within a 1 km radius of the site boundary.

Human Receptors

4.30 Human receptors that may be at risk from peat slide include: construction staff during construction of the development; the farm workers accessing the site; and recreational users of on-site and adjacent paths. Given the transient use of the site by these receptors, risk of harm from peat slide is considered to be negligible and is not considered further in this assessment.

Ecology

4.31 No terrestrial protected species have been identified as likely to be impacted by peat slide within the study area. Therefore, these have not been considered further in this assessment. The Hoy Site of Special Scientific Interest (SSSI)/Special Area of Conservation (SAC) adjacent to the site boundary is internationally designated for its blanket bog and heath habitats and is therefore a highly sensitive receptor. However, it is relatively remote from, and in a different catchment to, the proposed turbines and other infrastructure. It is therefore not considered further in this assessment.

4.32 Ecological resources associated with watercourses are considered as part of the identified surface water receptors noted in the Hydrology section above.

Archaeology

4.33 There are numerous heritage assets on and near the site, described in detail in Chapter 10.

4.34 There are two designated heritage assets within the site boundary (refer to Figure 10.1 and Figure 10.2). These are:

- the Category A Listed Former Naval Headquarters and Communications Centre, located at the northeast corner of the site, approximately 35 m east of the proposed temporary construction compound; and
- the Category A Listed Underground Fuel Reservoir, located in the northeast part of the site, roughly between proposed Turbine 1 and Turbine 6, with underground tunnels extending out to the northeast and southwest.

4.35 The former naval headquarters building is considered to be a sensitive receptor which could potentially be affected by peat slide, and it has been considered in this assessment. The fuel reservoir infrastructure is below ground and would not likely be adversely affected by a peat slide, which could potentially result in movement of or deposition of superficial material at ground level above the tank structure but would not affect the tank structure itself.

4.36 Other assets on the site are undesignated and, although notable, are not considered highly sensitive to potential impact by localised peat slide.

Infrastructure and Built Environment

4.37 There are existing minor tracks/footpaths in the northeast and eastern parts of the site, which could potentially be impacted by peat slide and are considered in the assessment.

4.38 There are individual residences and the B907 downslope from the site, to the east. These potential receptors are in the order of 1 km or more from any proposed infrastructure, however being downslope from the site, they are considered in the assessment.

5 Peat Depth Survey

5.1 Based on a desk study review of published geological mapping and an earlier site visit during site feasibility work, the presence of peat had been identified across at least parts of the Proposed Development site. A programme of peat depth survey work was therefore devised, in line with Guidance on Developments on Peatland - Site Surveys (Scottish Natural Heritage, SEPA and The James Hutton Institute, 2017).

5.2 Stage 1 peat depth probing was undertaken by a team of suitably qualified and experienced surveyors, on 29th and 30th October 2019. The surveys aimed to provide a 100 m spaced grid, as per the above-noted guidance. This was achieved across the full area of the site which had previously been identified as 'developable', i.e. other constraints prohibitive to development were not known to be present.

5.3 Data obtained from the peat depth surveys were used to plot the presence and distribution of peat across the proposed infrastructure development areas at the site, create a contour plan, and feed into detailed design iteration.

5.4 Following extensive design iteration work (refer to Chapter 2 of the EIA Report), a 'design chill' was agreed, considered by the project team to represent the best possible turbine and infrastructure layout to optimise yield whilst minimising environmental effects, including effects on geology, hydrology, hydrogeology and soils resources. It should be noted that the Stage 1 survey identified relatively shallow peat across much of the site, and taking account of the extent of other technical and environmental constraints guiding layout and design decisions, those other constraints have largely over-ridden potential impacts associated with encountering localised pockets of deeper peat. However, Stage 2 peat surveys were required to confirm and expand on Stage 1 findings, and refine the assessment of peat slide risk, and estimates of the volume of peat requiring excavation to build the development.

5.5 A Stage 2 peat depth probing exercise was undertaken on 13th to 15th July 2020, to record peat depth at each proposed turbine and hardstanding location, along the route of proposed access tracks, and at proposed infrastructure locations including the temporary construction compound, substation compound, permanent met mast, and borrow pit search area. The following pattern of probing was adopted for Stage 2:

- probe at each proposed turbine location with a 10 m spaced cross-grid out to 50 m from the turbine centre to the north, south, east and west;
- approximately 10 additional probes at each proposed turbine hardstanding area;
- nine probes at the proposed substation compound location;
- approximately 25 probes at the proposed temporary construction compound;
- approximately 18 probes at the proposed borrow pit search area;
- five probes at the proposed permanent met mast location; and
- generally every 50 m along proposed new access tracks, plus approximately 10 m either side of each probe, perpendicular to the route of the track.

5.6 In total, data has been obtained from 772 peat probe locations across the site area. **Figure 2** shows the peat survey locations, and Annex 1 provides the full set of peat survey data (probe locations and recorded depths).

5.7 Peat sampling was undertaken using a hand auger, at proposed turbine and infrastructure locations. Samples retrieved from hand augering were examined to provide additional information and understanding of the nature of peat at varying depths and locations. Selected peat samples, from locations where peat depth greater than 0.5 m was recorded, were dispatched to Envirolab laboratory and tested for moisture content, bulk density, and carbon content. Table 1 provides information on the location and depth of peat samples tested, and a selection of photographs is provided below Table 1 to show the nature of peat and peaty soils extracted by hand auger at these locations. The laboratory testing report is provided as Annex 2.

Table 1 – Locations of Peat Samples Collected for Laboratory Analysis

Reference	Location	Easting	Northing	Depth (m below ground)	Notes
469	T1	329095	994396	0.5	Fibrous in upper part only, possible acrotelm/catotelm boundary
358	T2	328746	993899	0.5	Medium brown, somewhat fibrous
359	T3	328341	993650	1.0	Medium brown, somewhat fibrous
470	T4	327865	993632	1.0	Brown, somewhat partly fibrous
453	Borrow pit search area	329292	994610	0.5	Medium brown, somewhat fibrous

Photograph 1 – Auger from T1

Photograph 2 – Auger from T2

Photograph 3 – Auger from T3

Photograph 4 – Auger from T4

Survey Results

5.8 The peat depth survey identified that, as expected following the desk study and reconnaissance walkover, much of the site area is underlain by peat deposits. However, substantial areas of the site were identified as having peat depth less than 50 cm and most of the remainder of the area within which proposed infrastructure is sited was found to have peat depth less than 1 m. Pockets of peat with depth over 1 m were identified in parts of the north and central site area, and wider areas of deep peat were identified towards the south, on the flatter ground near the Burn of Ore (particularly towards the west).

5.9 The general distribution of depth of penetration recorded during the peat survey is summarised in Table 2 and presented in **Figure 2**.

Table 2 – Distribution of Peat Depth Recorded at the Site

Peat Depth Interval (m)	Number of Occurrences	% of Probes
Nil	76	9.8
0.01 to 0.49	300	38.9
0.50 to 0.99	233	30.2
1.00 to 1.49	86	11.1
1.50 to 1.99	58	7.5
2.00 to 2.49	13	1.7
2.50 to 2.99	2	0.3
3.0 or more	4	0.5
Total	**772**	**100**

5.10 The Peat Landslide Hazard Best Practice Guidance (2017) uses the following Joint Nature Conservation Committee (JNCC) report 445 'Towards an Assessment of the State of the UK Peatlands' definition for classification of peat deposits:

- Peaty (or organo-mineral) soil: a soil with a surface organic layer less than 0.5 m deep;
- Peat: a soil with a surface organic layer greater than 0.5 m deep which has an organic matter content of more than 60 %;
- Deep Peat: a peat soil with a surface organic layer greater than 1.0 m deep.

5.11 Applying these definitions indicates that the deposits underlying around 49% of the surveyed site area comprise peaty or organo-mineral soil. The above definition of peat applies to conditions recorded at around 30% of probes, with the remaining 21% of probes encountering deep peat.

Peat Contour Mapping

5.12 **Figure 2** shows the interpreted peat depth, both as individual data points and as a contour plan based on interpolation of those peat sampling data points. The contouring has been undertaken using Natural Neighbour Interpolation which finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas in order to interpolate a value.

5.13 The peat contour mapping shows localised pockets of deep peat in the north and central areas, and larger areas in the northwest and towards the south on the flatter ground near the Burn of Ore. Peat tends to be relatively shallow on the sloping ground in the east, northeast, and west-central parts of the site.

6 Peat Stability Hazard Scoring

Introduction

6.1 The Best Practice Guide defines the hazard scoring assessment as 'the likelihood of a peat landslide event occurring'. It states that there are a number of possible methods for hazard scoring and that an initial qualitative hazard scoring matrix methodology be employed using professional judgement on hazard based on qualitative scoring scales.

Methodology

6.2 The allocation of hazard score values for the various parameters which influence peat landslide occurrence (e.g. slope gradient, peat depth) is not defined in the Best Practice Guide and there is no published guide specifically relating to this issue. As such, it is left to the assessment teams to develop their own approach for categorising the hazard scoring for the Site and the following outlines the approach used for this specific Site.

6.3 The potential for a peat slide to occur is controlled by a number of natural controlling factors. These are typically:

- Slope gradient;
- Peat depth;
- Peat strength;
- Relief;
- Evidence of historical failures/potential instability (e.g. tension cracks, creep, compression ridges);
- Vegetation cover; and
- Hydrology.

6.4 The most important of the above controlling factors are considered by the assessor to be peat depth and slope gradient as without both of these elements a risk of peat slide would be unlikely to exist. No clear evidence of potential peat instability (e.g. major tension cracks, creep, compression ridges etc.) were observed. These controlling factors have therefore not been utilised as part of this assessment.

6.5 The Best Practice Guide relates peat landslide hazard to a scale of 1 to 5, with 1 being negligible likelihood and 5 being almost certain. This scale relates to the final hazard potential for all the controlling factors under consideration. No guidance is provided on how the various factors should be combined to derive a final hazard scoring and the assessment team has derived a numerical scoring system as detailed in the following sections.

6.6 Consideration/discussion of the natural controlling factors (excluding peat depth, slope gradient and geomorphological evidence) for this site in relation to developing an appropriate hazard scoring provided below:

- **Peat Strength:** 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 (refer to Paragraph 2.3 above). 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 hazard scoring for peat depth.
- **Relief** – this factor is considered relevant as some of the slopes on or adjacent to the site are unconfined, however development of a justifiable scoring system for this parameter is complex. Additionally, given that observed convex slopes at the site correspond well to the locations of steeper gradients, it is considered that the slope gradient parameter assessment also covers relief.

- **Vegetation Cover** – The absence of a justifiable scoring system for this parameter prevents the inclusion of this factor in the assessment. There is no forestry at the site, and neither deforestation nor any proposed afforestation need be considered as hazard factors.
- **Hydrology** – No detailed investigation of peat pipe networks (if present) has been completed for the site given the constraints of dense surface vegetation cover likely masking the presence of such features. During survey work, no evidence was identified of any substantial network of natural or man-made drains, other that the watercourses described in Paragraphs 4.17 to 4.25. These natural surface water features have been considered in the assessment of exposure as these are considered to be a sensitive receptor to peat slide.

6.7 The following hazard scoring and assessment mapping was conducted using the Spatial Analyst extension of ArcGIS 10.3. This is a qualitative approach utilising available data sets within a multicriteria analysis.

6.8 Two GIS layers have been developed for the key controlling factors of peat depth and slope angle. The scoring attributed to each is outlined in the following sections.

6.9 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.

Input Data Sets

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

- Terrain 5 DTM with a 5 m grid size; and
- Site survey information for peat depth and site observations.

6.11 The assessment has been undertaken at each peat probe location to evaluate the spatial distribution of the hazard factors around the proposed infrastructure. The DTM represents the bare terrain with any surface object elevations omitted.

Layers and Score Ranking

Peat Depth Layer

6.12 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 as described above, and the data were then interpolated using the Natural Neighbour method (see **Figure 2**).

6.13 The Best Practice Guide details that peat slide risk assessment is needed for sites with peat greater than a depth of 0.5 m and as such this is taken as the lower boundary for the hazard scoring (i.e. negligible likelihood – Score 1). It also states that slides tend to occur in peat up to 2 m deep therefore this has been taken as the upper level for the hazard scoring as almost certain (Score 5).

6.14 Intermediate peat depths have been assigned corresponding scores of 2, 3, and 4 assuming peat slide likelihood increases with peat depth.

6.15 The depth GIS layer was then given hazard scoring attributes as shown in Table 3.

Table 3 – Peat Stability Hazard Scoring (Peat Depth)

Score	Peat Depth (m)	Hazard (Likelihood)
1	<0.5	Negligible
2	0.50 – 1.00	Unlikely
3	1.00 – 1.50	Likely

Score	Peat Depth (m)	Hazard (Likelihood)
4	1.50 – 2.00	Probable
5	>2.00	Almost Certain

Slope Angle Layer

6.16 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).

6.17 The Best Practice Guide details that peat slide hazard risk assessment is not needed for blanket bog sites with slopes less than 2° and as such this is taken as the lower boundary for the hazard scoring (i.e. negligible likelihood – Score 1). It states that the majority of recorded failures are on slopes with gradients typically 4° to 8°. The lower end of this range is therefore taken as the break point between an "unlikely" and "likely" hazard ranking. Less frequent peat slides may be recorded on steeper slopes; however this is considered more likely to be related to the typical absence of or limited peat on such slopes. For conservatism, higher hazard rankings are assigned to slopes with steeper gradients above this 4° threshold level.

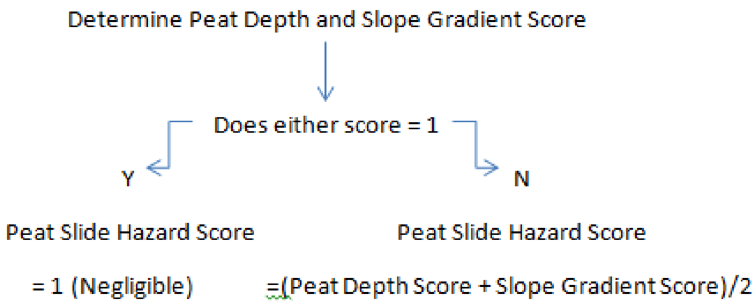
6.18 A slope angle GIS layer was generated from the DTM at a 5 m cell resolution. The source DTM is also at a 5 m resolution. This slope, calculated in degrees, was ranked as shown in Table 4. The slope angle details are provided in **Figure 3**. To assess the Slope Gradients, the following table was used:

Table 4 – Peat Stability Hazard Scoring (Slope)

Score	Slope (degrees)	Hazard (Likelihood)
1	<2	Negligible
2	2 – 4	Unlikely
3	4 – 6	Likely
4	6 – 15	Probable
5	>15	Almost Certain

6.19 There is no guidance available on how to combine the hazard scoring for each of the factors used in the assessment. The assessment team have used a dual-criteria analysis approach whereby both factors are equally weighted and averaged. The exception to this is when either the peat depth or slope angle has a score of 1, then the hazard will be classed as 1.

6.20 The rule illustrated by the formula below has been applied, as peat slide on a blanket bog site is considered to be unlikely in the instance that the slopes are less than 2° and/or the peat depth is less than 0.5 m.



6.21 In addition to this scoring system, professional judgement can be applied when experience of the site and local peat conditions are known, if a separate score is deemed to be more appropriate.

Peat Slide Hazard Scoring Summary

6.22 Table 5 below presents a summary of the Peat Slide Hazard scoring for the site, using the decision tree described above. Note that for conservatism, all peat slide hazard scores are rounded up to the nearest whole number. The hazard scores for all probe points are illustrated on **Figure 4**.

Table 5 – Peat Stability Hazard Scoring (Summary)

Peat Slide Hazard Score	Hazard (Likelihood)	% Occurrence
1	Negligible	52.7
2	Unlikely	2.6
3	Likely	38.1
4	Probable	6.6
5	Almost Certain	Nil

6.23 As can be seen from Table 5 and **Figure 4**, over half the survey points returned a hazard score of 1 or 2 indicating negligible or unlikely probability of peat slide. However, given the proportion of the points assessed as having a hazard score of 3 or 4 (likely or probable), further analysis was carried out in respect of proposed infrastructure locations specifically.

6.24 Based on all the peat depth survey data collected, each proposed turbine, hardstanding, and other infrastructure element was analysed to identify the hazard score at that infrastructure location. Table 6 provides a summary.

Table 6 – Peat Hazard Score at Proposed Infrastructure Locations

Infrastructure Feature	Hazard Score	Notes
T1	1	
T1 hardstanding	2	Most points are hazard score 1 but a small number are hazard score 3
T2	3	
T2 hardstanding	3	
T3	3	

Infrastructure Feature	Hazard Score	Notes
T3 hardstanding	2	
T4	3	
T4 hardstanding	3	
T5	1	
T5 hardstanding	1	
T6	2	Most points are hazard score 1 but a small number are hazard score 3
T6 hardstanding	3	
Substation	1	
Construction compound	1	
Borrow pit search area	3	Most points are hazard score 1 but several are 3 and two points are 4
Met mast	2	3 points are hazard score 1 and 2 points are hazard score 3
1 – Site entrance to T1	1	
2 - T1 to T2	1	
3 - T2 to T3	3	Most of the points on this stretch are hazard score 1 but points in the southwest section are hazard score 3 or 4
4 - T3 to W bend	2	Most of the points on this stretch are hazard score 1 but some points at the western bend are hazard score 3
5 - W bend to T5	1	
6 - T5 to T6	3	Most of the points on this stretch are hazard score 1 but points in the northeast section are hazard score 3 or 4

7 Exposure Scoring

Consequences of Peat Failure (Exposure)

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

7.2 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.

7.3 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 (Bragg & Lindsay 2005).

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

- Property and infrastructure, for example roads;
- Site workers and plant (risk of injury/death or damage to plant);
- Land based ecological effects (damage to habitats);
- Effects on the quality of on-site and downstream watercourses;
- Site drainage (blocked drains/ditches leading to localised flooding and/or erosion);

- Archaeological assets; and
- Visual amenity (scarring of the landscape).

7.5 The assessment of "consequence" of a peat slide has been undertaken based on a combination of the **sensitivity** of identified receptors to a peat slide event, and the potential severity of that event. The potential severity has been determined by identifying the **proximity** and **relative elevation** of the receptor to the potential origin of the slide, i.e. the proposed infrastructure location. For example, a receptor which is in close proximity to and downslope of a proposed turbine is likely to be more severely affected by a peat slide originating from that turbine location, than a receptor further away from and/or on the level with the proposed turbine location.

7.6 The following tables illustrate the scoring mechanism that has been adopted to determine peat slide consequence. This method is based on the experience of the assessors, gained through completion of numerous peat slide risk assessments for wind energy projects, consultation and feedback from relevant regulatory bodies, and review of assessments undertaken by others to maintain understanding of good industry practice.

7.7 The scale of 1 to 5 shown in Table 7 below has been qualitatively determined and used to score the sensitivity of receptors to potential peat slide originating from proposed infrastructure construction locations at the site. Tables 8 and 9 show the scoring adopted for consideration of potential severity of a slide on the receptor, taking account of proximity and relative elevation of the receptor to the potential slide origin (proposed infrastructure location).

Table 7 – Peat Slide Sensitivity Scoring

Receptor	Sensitivity Score	Comment
Minor infrastructure e.g. private roads/tracks	1	Includes existing on-site tracks at the Proposed Development site.
Local drainage systems, rural land	2	Includes unnamed field drains, arable land (the latter not applicable to the Proposed Development site).
Watercourses, local roads/ services, individual dwellings and business properties	3	Includes all watercourses within the catchment of the Proposed Development (noting that watercourses within the Hoy SAC are in a different catchment), and the individual properties downslope to the east.
High-sensitivity watercourses (e.g. national/international designations), major roads/motorways, pipelines, small settlements (up to approximately 10 dwellings)	4	Includes the Category A listed former naval headquarters building in the northeast of the site.
Communities (over approximately 10 dwellings)	5	None present in the close proximity of the Proposed Development.

Table 8 – Proximity Scoring

Proximity of Receptor to Proposed Infrastructure Location	Proximity Score
More than 1 km	1
100 m to 1 km	2
50 m to 100 m	3
10 m to 50 m	4
Less than 10 m	5

Table 9 – Relative Elevation Scoring

Relative Elevation of Receptor below Proposed Infrastructure Location	Relative Elevation Score
Less than 10 m	1
10 m to 50 m	2
50 m to 100 m	3
100 m to 150 m	4
More than 150 m	5

7.8 The overall exposure score has been calculated by combining the sensitivity, proximity and relative elevation scores as such:

Exposure = cube root of (sensitivity score x proximity score x relative elevation score)

7.9 Table 10 describes the overall exposure categories. This has been used as a guide to continually check that the quantitative categorisation of exposure is considered appropriate based on the experience of the assessor and taking account of site-specific conditions.

Table 10 – Exposure Scoring

Exposure Score	Exposure (Impact)	Consequence
1	Low	Minor restoration of works/land
2	Low-Medium	Blockage of minor roads/tracks, local drainage systems
3	Medium	Damage to rural lands/property and localised pollution to watercourses
4	Medium-High	Blockage of public roads, short to medium-term pollution incident
5	High	Loss of life, major damage to property, public roads and major pollution incident to watercourses

8 Risk Assessment

Risk Scoring Methodology

8.1 The overall risk score for each proposed infrastructure element has been determined by multiplying the hazard score (refer to paragraph 6.20) by the exposure score (refer to paragraph 7.8):

Risk = Hazard (likelihood) x Exposure (consequence)

8.2 Table 11 provides a categorisation of the resultant risk scores.

Table 11 – Peat Slide Risk Score Categories

Risk Score	Risk Category	Notes
1-4	Negligible	Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate
>4 to 8	Low	Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations

Risk Score	Risk Category	Notes
>8 to 15	Medium	Project 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
>15	High	Avoid project development at these locations

Risk Assessment for the Proposed Development

8.3 The overall risk score for each proposed infrastructure element at the Proposed Development is set out in Table 12.

Table 12 – Peat Slide Risk Score at Proposed Infrastructure Locations

Infrastructure Feature	Risk Score (Worst Case)	Risk Category
T1	2.62	Negligible
T1 hardstanding	5.24	Low
T2	7.85	Low
T2 hardstanding	7.85	Low
T3	6.86	Low
T3 hardstanding	4.58	Low
T4	6.86	Low
T4 hardstanding	6.86	Low
T5	2.29	Negligible
T5 hardstanding	2.29	Negligible
T6	5.24	Low
T6 hardstanding	7.85	Low
Substation	2.62	Negligible
Construction compound	2.62	Negligible
Borrow pit search area	7.85	Low
Met mast	5.24	Low
Track Segments		
1 – Site entrance to T1	2.62	Negligible
2 - T1 to T2	2.62	Negligible
3 - T2 to T3	7.85	Low
4 - T3 to W bend	5.24	Low
5 - W bend to T5	2.62	Negligible
6 - T5 to T6	7.85	Low

8.4 As illustrated by the above table, all proposed infrastructure elements are assessed as having a Negligible or Low risk.

8.5 The assessment has therefore identified that the development, as currently proposed, is suitable for development pending further investigation to refine the assessment and mitigate hazards.

9 Proposed Development Design and Mitigation

Detailed Design and Site Investigation

9.1 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.

9.2 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

9.3 This peat slide hazard risk assessment has identified that turbines T1 and T5 are at negligible risk and the remaining four turbines are at low risk.

9.4 All hardstandings are at low risk locations except the T5 hardstanding which is at negligible risk.

Mitigation

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

9.6 It is anticipated that extraction of rock will be required in at least some areas to create suitable levels for founding turbines and hardstandings. This may require localised blasting, and further analysis of potential impacts on peat stability in the vicinity would be undertaken and appropriate mitigation stipulated following pre-construction site investigation works and detailed design.

9.7 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:

- 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.

9.8 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

9.9 Areas of deep peat have been avoided wherever possible with respect to access track routing. It has not been possible to entirely avoid all areas of deep peat, however the stretches of track anticipated to cross peat depths slightly over 1 m are limited to a length of less than 150 m in the south just east of T3, and a length of less than 50 m in the north just west of T6.

Mitigation

9.10 It is not considered practical to construct floated road sections across such short lengths, 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 (refer to Section 11.10 of Chapter 11 for further detail).

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

- 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 (anticipated to only be required for one water crossing), permeable fill or cross drains at the location of the water crossing, 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.

Drainage Areas

9.12 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.

9.13 Any construction activity relating to, or undertaken in the vicinity of watercourses would be carried out in general accordance with relevant SEPA Pollution Prevention Guidelines, The Water Framework Directive (WFD), The Water Environment and Water Services (Scotland) Act 2003 (WEWS) and the Controlled Activities Regulations (CAR) 2011 (as amended).

Borrow Pit

9.14 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

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

9.16 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:

- An 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.

9.17 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.

9.18 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.

10 Conclusion

10.1 Based on desk study, site reconnaissance and peat depth survey findings, the Proposed Development is characterised as a blanket bog site with variable peat depths. The Proposed Development layout, including turbines and associated infrastructure, has been designed to avoid the areas of deep peat wherever possible and areas where peat landslide may occur. Further detailed design would be informed by detailed ground investigations to be undertaken prior to commencement of any works onsite.

10.2 The peat side risk assessment has identified that all proposed turbines and infrastructure locations are in areas assessed as low or negligible peat slide risk.

10.3 Mitigation measures would assist overall in reduction of any potential risks associated with construction activities causing ground instability, including undertaking detailed intrusive ground investigations to clarify risks and allow stipulation of specific geotechnical mitigation measures and/or micro-siting as required.

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