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Appendix 8.2

Peat Stability Assessment

Contents

A8.1 INTRODUCTION

A8.1.1 Natural Power has undertaken a Peat Stability Assessment (PSA) for the proposed Daer Wind Farm project.

A8.1.2 This PSA is a technical appendix to the EIA report Chapter 8.

A8.1.3 The Proposed Development is located within South Lanarkshire and Dumfries & Galloway, Scotland, approximately 10 km west of the town of Moffat.

Statement of Competence

A8.1.4 The Report Author is a Principal Geotechnical Engineer at Natural Power and engineering geologist by training (MSc Engineering Geology) with twenty years industry experience in engineering geology and geotechnical engineering, and is a Fellow of the Geological Society of London. He has experience of carrying out on site assessments, site investigations and peat stability assessments for wind energy projects across the UK.

A8.1.5 The Report Reviewer is a Geotechnical Project Engineer at Natural Power and was the lead geologist of the team who carried out the field work at the Proposed Development from which the PSA was developed. He has over 8 years' experience in peat studies on wind farm sites across the UK.

Objectives

A8.1.6 This peat stability assessment details the distribution of peat deposits on a development wide scale. This informs map-based semi-quantitative peat stability risk assessment to the Proposed Development. The primary objectives of this study are:

- Present a desk study pertinent to the subject of peat stability assessment.
- Report on walkover and geomorphological mapping exercise to inform the assessment.
- Identify any areas of existing instability or which may pose high risk of instability in the future.
- Provide robust and targeted recommendations for any future construction process and mitigate any potential contributory factors to peat instability.

A8.1.7 This report has been undertaken in general accordance with the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Development, second edition, published by the Scottish Government in April 2017.

Scope of Work

A8.1.8 The peat stability assessment utilises information (peat data and visual assessment) collected during the site surveys. This data and information are combined with desk-based study and review of all published materials relevant to the development. The following data sources have been integrated into this assessment:

Table 8.1: Desk study data sources

Data Source	Location	Date
British Geological Survey – Onshore Geological Map Data: Linear features, mass movement deposits, artificial ground, superficial deposits, bedrock geology, faulting,1:50,000 scale	http://mapapps2.bgs.ac.uk/geoindex/home.html	2020
British Geological Survey – Engineering Geology Viewer: 1:1M Superficial Engineering Geology. 1:1M Bedrock Engineering Geology	http://mapapps.bgs.ac.uk/engineeringgeology/home.html	2020

Data Source	Location	Date
British Geological Survey – Hydrogeological Map of Scotland: 1:625,000 Scale	http://www.largeimages.bgs.ac.uk/iip/hydromaps.html?id=scotland.jp2	1988
National soil map of Scotland – main soil types originally mapped at 1:250,000 scale	http://soils.environment.gov.scot/maps/	1947-1981
National Library of Scotland, Historical mapping	https://maps.nls.uk/	Various
Aerial Photograph Data	Google Earth pro/ Bing maps	2020
Online news archival search	-	-

Source: Natural Power

Site survey data:

- Stage 1 (100 m grid) peat probing survey to ascertain the depth and distribution of peat deposits across the development.
- Site walkover/ reconnaissance surveys across the Proposed Development area.
- Stage 2 peat survey, focusing on the proposed site layout and including in-situ strength testing, peat coring and sampling at targeted deep peat locations across the development.

Proposed Development

A8.1.9 The Proposed Development comprises the construction of seventeen wind turbines and associated infrastructure. A detailed description of the proposed wind farm development is provided in the EIAR.

A8.1.10 The Proposed Development layout is shown on the site layout map (EIAR Figure 1.1: Site LayoutA).

A8.1.11 Up to four temporary borrow pits are proposed. Borrow pit investigation and assessment of suitable extractive methods are outwith the scope of works of the peat stability assessment. Appraisal of suitable extraction methods and any effect on ground stability would be carried out following intrusive ground investigation and civil earthworks design.

A8.2 METHODOLOGY

Data Review

A8.2.1 In preparation of this report, an initial desk-based assessment has been undertaken to allow subsequent surveys to be targeted across the development (Section A8.4). Table 8.1 highlights the key sources of information for this study.

A8.2.2 Limited historical aerial imagery records were available for the development area. Available records typically corroborate with the findings of the historical mapping review and confirm the general area has been undeveloped.

A8.2.3 Natural Power can confirm online searches for newspaper articles regarding peat slides and local knowledge did not yield any salient information relevant to the peat stability assessment.

A8.2.4 Natural Power's project directory was searched for reports of peat slide incidents on adjacent wind farm developments. These searches did not provide any records of relevant information.

Geomorphological Mapping

A8.2.5 Reconnaissance and geomorphological mapping were carried out in conjunction with phased peat surveys at the development. This exercise provided opportunity for geotechnical engineers to visualise the terrain, assess geological and soil exposures, examine slope systems, vegetation cover and record any hydrological features impacting peat stability.

A8.2.6 The culmination of this survey was the production of a geomorphology map(Daer PSA1). Further description of the development is also provided in Section A8.3.

Peat Survey

A8.2.7 Natural Power carried out the stage 1 probe survey in 2019, implementing a 100 m grid of probes across the development infrastructure areas. The results of which were used to inform the preliminary design.

A8.2.8 Subsequently, Natural Power carried out a stage 2 detailed probe survey in August/September 2020, implementing a 195 m long cross hair of probes at 15 m centres at the proposed turbine areas and set of three probes at 50 m spacing on the tracks.

A8.2.9 Peat depths were recorded using probes inserted into the peat and measuring the depth to refusal. This provides a wide-ranging dataset, but the data carries the following limitations:

- Peat probes may record depth to obstructions (e.g. tree roots, rock clasts) and not the true depth of the peat.
- Peat probes may over-estimate peat depth where the underlying soil strata is very soft.
- Peat probes can underestimate peat depth in very dry peat deposits due to early refusal of the probe.

A8.2.10 A detailed peat investigation was focussed at locations of deeper peat. In-situ hand shear vane tests were conducted to provide an estimate of undrained shear strength within the peat. Supplementary to this, peat cores have been taken at select locations to provide confirmation of peat depth, material classification and morphology. Peat samples were retained as part of this exercise and subject to laboratory testing for determination of bulk density and carbon content.

A8.2.11 The in-situ test and peat coring locations are shown on the peat depth interpolation map (EIAR Figure 8.6: Peat Depth Interpolation).

A8.3 PROJECT DETAILS

Location

A8.3.1 The Proposed Development is located within South Lanarkshire and Dumfries & Galloway, Scotland, approximately 10 km west of the town of Moffat. It is directly adjacent to the southeast of the Daer Reservoir.

A8.3.2 The centre of the development area is approximated to National Grid Reference (NGR): [298896, 605666].

A8.3.3 Diagram 8.1 provides an overview of the Proposed Development Area.

Source: Natural Power/QGIS

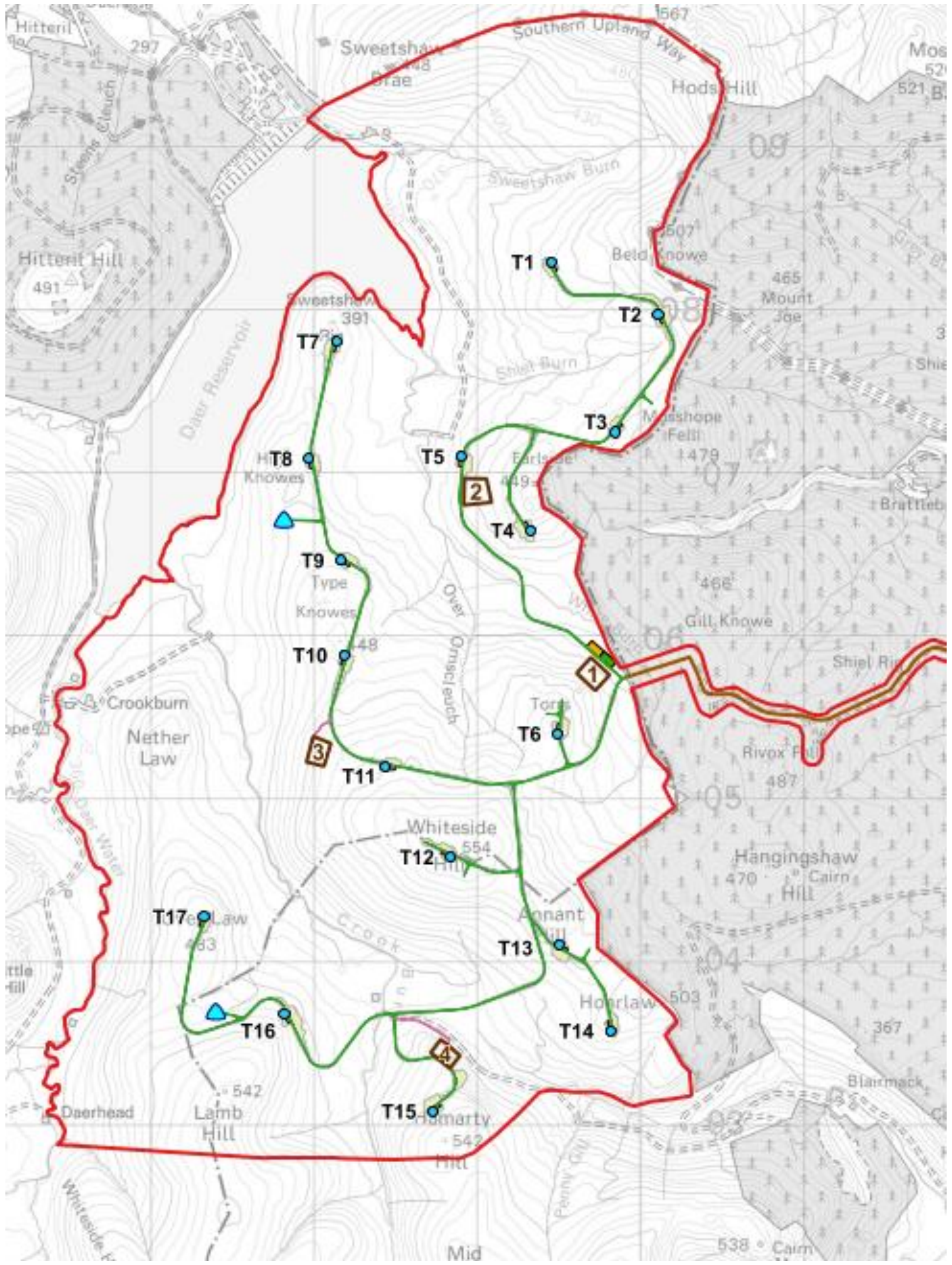


Diagram 8.1: Proposed Development Area (not to scale, extract from EIAR Figure 1.1: Site Layout)

Site Description

A8.3.4 The site description was informed by the site walkover survey and desk study material.

A8.3.5 The site is located in in an upland setting and comprises open moorland with hills forming a complex topography of plateaus, valleys, and ridges. There are several watercourses on the site, including the Crook Burn, Black Burn, Shiel Burn and Sweetshaw Burn and their various tributaries.

A8.3.6 The maximum topographic height of the site approaching 600 m AOD around Earnscraig Hill, at the south of the site, and several other peaks on site over 500 m AOD.

A8.3.7 Due to the upland setting, steep slopes are evident across much of the site, but are especially prevalent at the southern end of the development area. Elsewhere the slopes are typically undulating with the flatter tops of the ridge systems being selected for proposed wind farm infrastructure.

A8.3.8 The north western turbine array follows a broad ridge line stretching from Whiteside Hill to Type Knowes, High Knowes and Sweetshaw Rig.

A8.3.9 The north eastern turbine array skirts along the north eastern side of Torrs, and western side of Earlside, Mosshope Fell and Beld Knowe hills.

A8.3.10 The southern turbine array is located in the most variable topography which descends from the highest point at Whiteside Hill and crosses the wide Crook Burn valley before climbing up to the turbine locations further south, although again most of the turbines in this array are located on elevated plateau areas.

A8.3.11 A network of natural channels and cut artificial drainage ditches are present throughout the site, and are suspected as having a significant desiccating effect of the peat. The ditches are generally more concentrated in some areas, for example on the northern turbine arrays, and slightly less prevalent in the south of the site.

A8.3.12 Along some watershed areas discrete areas of peat hags have developed, however there are no signs of active mass movement. Rather a slower active erosion of the peat is evident in places. Peat hags was most prevalent on the tracks around turbines T16 and T17.

A8.3.13 The key findings of the site reconnaissance are represented on the geomorphology map (Daer PSA 1: Geomorphology).

A8.3.14 A selection of photographs taken during the site walkover survey which depict general environs of the site are shown below.

Source: Natural Power

Diagram 8.2: View from turbine T11 location looking north west towards Daer Reservoir

Source: Natural Power

Diagram 8.3: View from turbine T16 location looking south east towards T14 and T15

A8.4 GEOLOGY & ENVIRONMENT

Bedrock Geology

A8.4.1 According to the British Geological Survey (BGS), and as illustrated in Diagram 8.4, the site is underlain by Silurian age bedrock.

A8.4.2 The majority of the site is underlain with Queensberry Formation - Sandstone, Mudstone, Siltstone and Conglomerate.

A8.4.3 BGS lithological description for this formation is Sandstone, typically medium- to coarse-grained but ranging from fine- to very coarse-grained, locally pebbly. Generally medium- to very thick-bedded or massive over thicknesses of tens of metres, units up to few metres thin-bedded. Interbedded siltstone or silty mudstone generally thin to medium beds but siltstone units range up to several tens of metres locally. Rare conglomerate and intraclast-rich sandstone occur locally. Sandstone and siltstone typically bluish grey when fresh, darker grey when weathered. Although of similar facies, the mid-Llandovery Queensberry Formation is younger than the adjacent early Llandovery Mindork Formation. Sandstone in both formations is predominantly quartzo-feldspathic, but is distinguished by accompanying volcanic debris; the Mindork Formation sandstone commonly contains sparse intermediate volcanic lithic debris and associated mafic crystal material (typically pyroxene); volcanic debris may be more common in the Queensberry Formation and tends to be more basic (spilitic) in character, mafic crystal material occurs locally but is relatively rare

A8.4.4 At the north western side of the site the bedrock comprises Gala Unit 4 - Wacke.

A8.4.5 BGS lithological description for this formation is Graded beds that may include wacke sandstone, siltstone and mudstone in variable proportions, interpreted as turbidites. Conglomeratic beds are a feature of this unit. Siltstone interbeds yielded fauna of the cyphus to triangulatus Biozones.

A8.4.6 The BGS data indicates several regional fault structures intersecting the bedrock geology, with a number of faults crossing the southern end of the site. These faults are predominately NE-SW trending thrust faults. The faults are likely to be associated with fracture zones and smaller local scale faulting and rock shatter zones.

Superficial Deposits

A8.4.7 The BGS map data for superficial deposits confirms no superficial deposits are recorded over the majority of the development area. This implies that there is not expected to be a significant thickness of superficial deposits present.

A8.4.8 Peat deposits are indicated at the south of the site in the lower lying areas crossed by the proposed tracks between turbines T13 and T17.

A8.4.9 Small discrete areas of glacial deposits (including Devensian glacial till and hummocky glacial deposits) and alluvium (river deposits) are also indicated on parts of the site. These would be expected to comprise a mix of clay, silt, sand and gravel.

Hydrology

A8.4.10 A summary of the Proposed Development's hydrological regime is presented below, however a detailed description of the project hydrology is given in the EIA document Chapter 8.

A8.4.11 Hydrologically, the Proposed Development spans two main hydrological networks; Daer Water (River Clyde) and the upper River Annan. There are several burns which supply these networks situated in and around the Proposed Development area, including:

- Sweetshaw Burn
- Shiel Burn
- Black Burn
- Crook Burn
- Garpool Water
- Cloffin Burn
- Kinnel Water
- The distance from each of the turbines to the nearest watercourse is given in the table below:

Table 8.2: Distance from turbine to nearest watercourse

Turbine ID	Turbine distance from watercourse (m)	Turbine ID	Turbine distance from watercourse (m)
1	268	10	184
2	152	11	455
3	309	12	435
4	264	13	337
5	221	14	276
6	261	15	301
7	291	16	204
8	447	17	357
9	454	-	-

Source: Natural Power/ QGIS

Hydrogeology

A8.4.12 In examination of the bedrock geology, the 1:625,000 scale BGS Hydrogeology Sheet has been reviewed for the development.

A8.4.13 The site is underlain by a low productivity aquifer with limited resource potential. This is on account of both the Queensberry Formation and the Gala Unit 4 bedrock being highly indurated and consequently very low in permeability. Notwithstanding, it is possible that groundwater may exist within the weathered zones, in tectonic features, or in superficial sands and gravel deposits.

A8.4.14 The hydrogeological regime within superficial deposits at the site vary significantly by deposit. The peat is likely to have very low to moderate permeability with flow though the matrix of the peat soil and higher flows anticipated where peat is less humified and comprising fibrous material. The glacial till is anticipated to have a wide-ranging permeability with flow focused through lenses and interbedded sand and gravel layers. Alluvial deposits are likely to have a high to very high permeability with groundwater flow directed though the soil matrix.

Source: Natural Power/ British Geological Survey

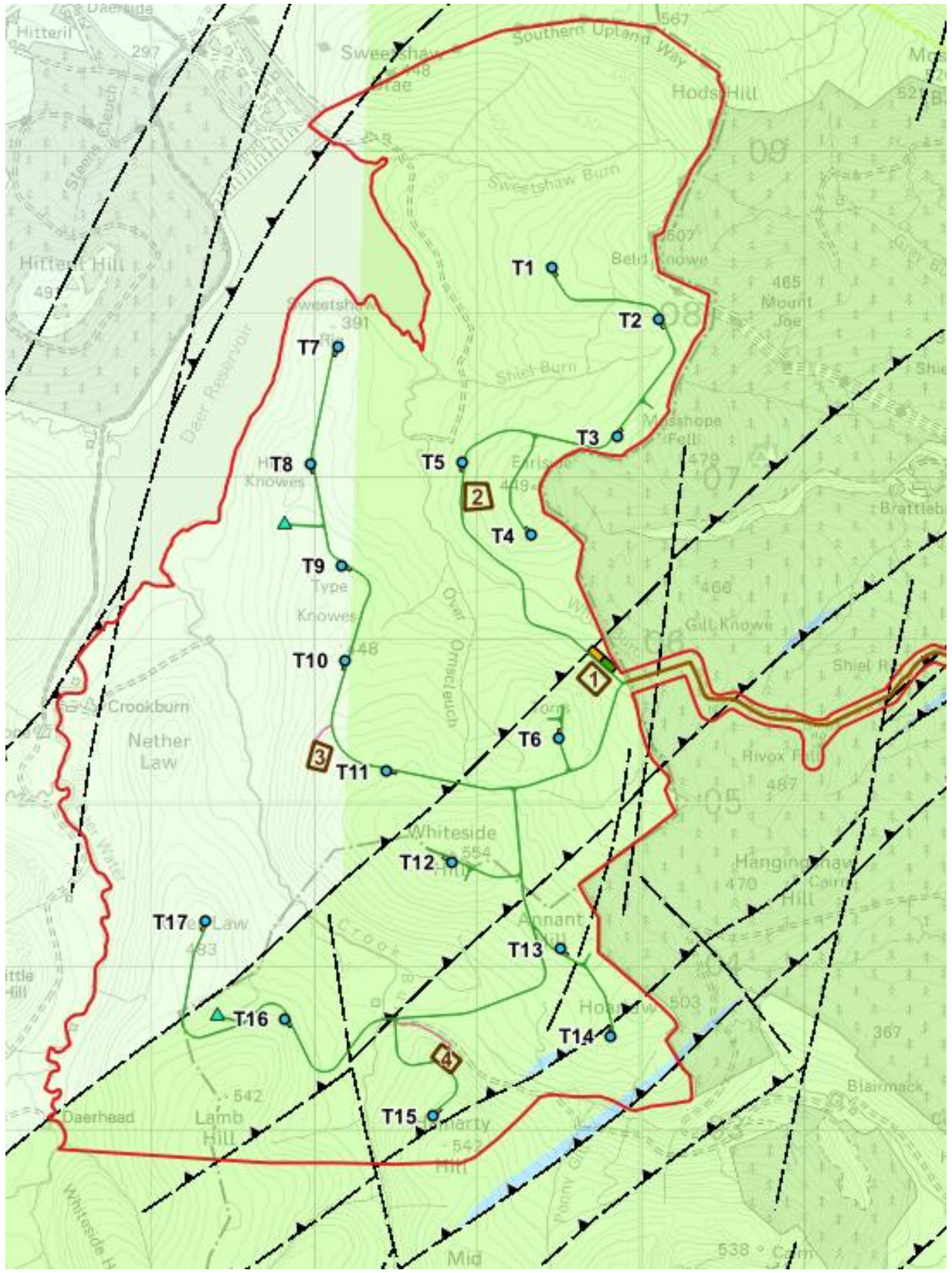


Diagram 8.4: Bedrock Geology (not to scale, extract from EIAR Figure 8.2)

Source: Natural Power/ British Geological Survey

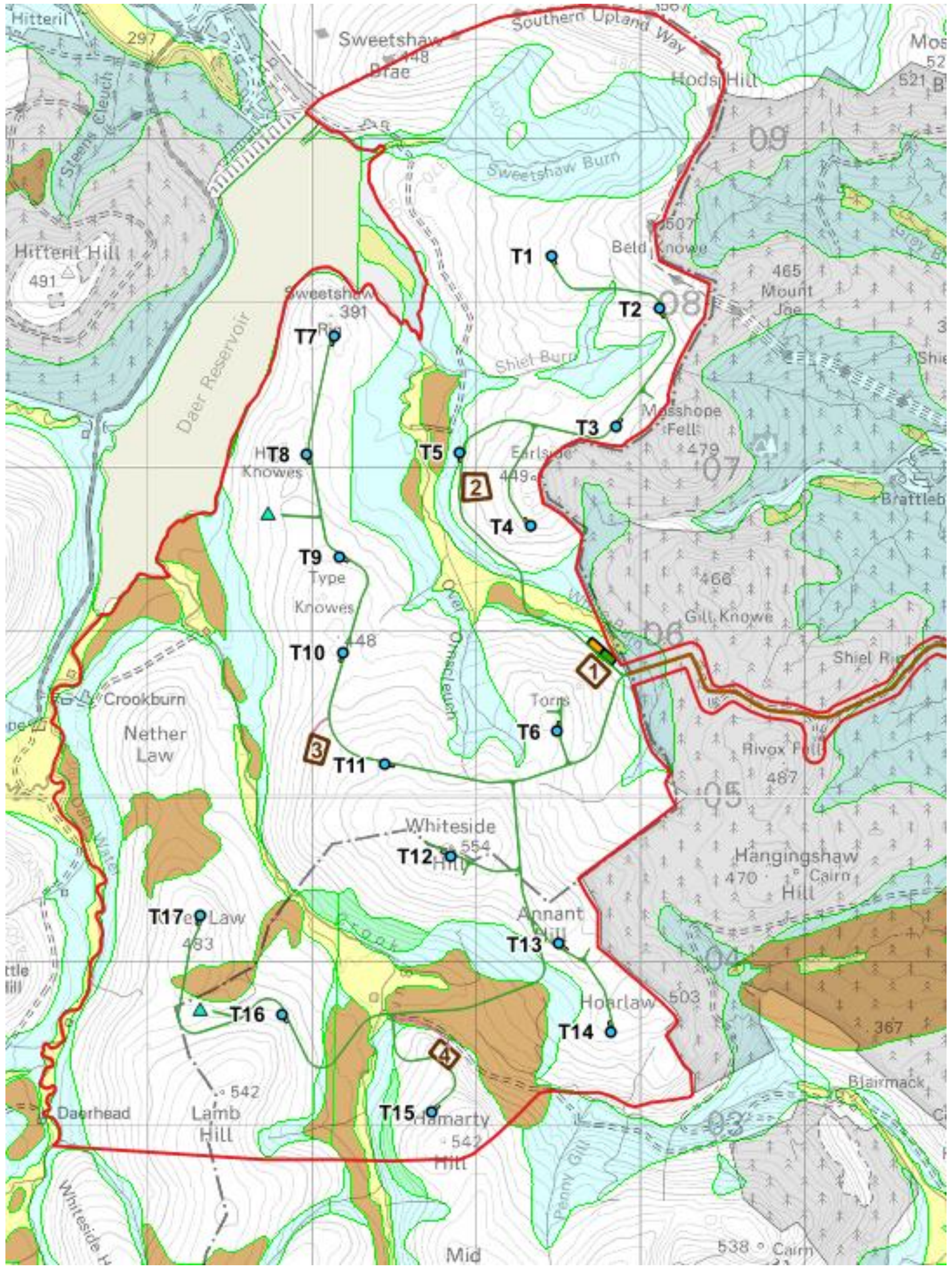


Diagram 8.5: Superficial Geology (not to scale, extract from EIAR Figure 8.3)

Topography

A8.4.15 The topography has been fully represented in the slope angle map (Daer PSA 2: Slope Angle). This has been derived from Ordnance Survey 'OS Terrain5' digital terrain model (DTM) data. Ground surface elevations have been obtained across a 5 m grid for the development.

Site History

A8.4.16 Historical mapping for the site has been reviewed from the National Library of Scotland archive. Earliest mapping available was from Ordnance Survey 1861-63 'six inch' series. Available mapping was limited but they indicated the development area has been undeveloped open upland.

A8.4.17 The site walkover survey has identified an extensive network of artificial cut drainage ditches which are not evident on the historical mapping. It is assumed due to their position at the highest elevations, these were implemented to improve drainage conditions possibly for livestock grazing.

A8.4.18 Limited aerial imagery records were available for the development area; however, available records typically corroborate with the findings of our historical mapping review and confirm the general area has been largely undeveloped.

Designated Sites

A8.4.19 It is understood that the southern part of the site is located in a regional scenic area. No other designations were indicated during searches.

A8.5 PEAT SLIDE RISK ASSESSMENT

Framework

A8.5.1 Natural Power has undertaken this assessment following the principles of the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive 2017). Updated as a second edition in April 2017, this guide provides best practice methods which should be applied to identify, mitigate and manage peat slide hazard and associated risks in respect of consent application for electricity generation projects in the UK. This guidance clearly acknowledges risk assessment as an iterative process and as such these assessments should be updated throughout the development should more information become available particularly as pre-construction phases are reached.

Peat Distribution

A8.5.2 In total, 3905 locations were surveyed for peat depth across the Proposed Development.

A8.5.3 The surveys consisted of completing stage 1 peat depth investigations across a 100 m gird of the Proposed Development area. Follow up stage 2 surveys involved the collection of peat cores and detailed peat depth surveys at the key infrastructure locations.

A8.5.4 The probe data indicated an average peat depth of 0.56 m.

A8.5.5 Table 8.3 provides a summary of the peat depths recorded during the peat surveys. An interpolated peat depth map (EIAR Figure 8.6: Peat Depth Interpolation) shows the distribution of peat depths in relation to infrastructure elements.

Table 8.3: Peat Depth Summary

Peat Depth Range (m)	Results	% of points
≤0.5	2434	62
>0.5 – 1.0	906	23
>1.0 – 1.5	317	8
>1.5 – 2.0	148	4
>2.0 – 3.0	86	2
> 3.0	14	<1
TOTAL	3905	100

Source: Natural Power

A8.5.6 The majority (~62%) of the recorded peat depths fell within the shallow ≤0.5 m range, and were therefore classified as peaty soils. The next highest proportion of probes (~23%) were within the >0.5 – 1.0 range. Only 15% of the probes recorded peat depths >1.0 m.

A8.5.7 The areas of deep peat (greater than 1.0 m) were predominantly located in the elevated plateau areas across the Proposed Development.

Peat Morphology

A8.5.8 As highlighted above, approximately 62% of the probe data indicated depths of ≤0.5 m, so the dominant morphology of the soils is essentially a peaty soil rather than a true peat deposit. A peat deposit is defined as being organic soil which contains more than 60 per cent of organic matter and exceeds 50 centimetres in thickness.

A8.5.9 A 25 mm hand shear vane was used to record the undrained shear strength of the in-situ peat deposits in selected locations where the depth was >0.5 m. The location of hand shear vanes undertaken is shown on the peat depth interpolation map (EIAR Figure 8.6 Peat Depth Interpolation).

A8.5.10 The method of determining un-drained shear strength was carried out by inserting a steel vane vertically into the peat deposit. At increasing depth increments within the peat, a torque head is turned at the surface which rotates the shear vane within the peat deposit. The maximum shearing resistance is recorded on the torque head which is calibrated to the peak un-drained shear strength of the peat. Once the peak un-drained shear strength was determined the shearing resistance of the free turning shear vane was recorded and is representative of the re-moulded un-drained shear strength.

A8.5.11 It is highlighted that the shear vane has a small surface area compared to the scale of the soil structure within the peat. This scale factor is highlighted as the main limitation of this in-situ test method. The scale effect can lead to an underestimation of peat strength. The hand shear vane therefore only provides a preliminary and conservative estimate of peak and re-moulded un-drained shear strength.

A8.5.12 Shear vane testing was undertaken at twenty-two locations, targeted mostly within deeper areas of peat. Where a significant increase in the un-drained shear strength was recorded at the basal contact of the peat, it is inferred from peat cores derived from the same location that the highest un-drained shear strength values represent the glacial till interface. Unrepresentative high values were removed from the analysis.

A8.5.13 The recorded peak un-drained shear strength (Cu) ranged from **17 kPa to 80 kPa** with a mean value of **45 kPa**.

A8.5.14 Figure 8.6 below depicts the peak un-drained shear strength with depth at the shear vane locations.

A8.5.15 Peat coring was undertaken at eighteen of the shear vane locations to record the characteristics of the peat and the degree of humification. The peat was characterised according to the Von Post Classification (Von Post & Granland, 1926).

A8.5.16 Table 8.4 below presents the peat classifications at the locations where peat coring was undertaken coinciding with the proposed wind turbines. The results demonstrate that the peat deposits at the Proposed Development are variable but generally characterised as soft, dark brown, pseudo-fibrous (occasionally amorphous) peat with Von Post classification codes ranging from H2 to H8.

A8.5.17 Example core photos of the typical peat deposits on site are presented below (Figure 8.7 and 8.8).

Source: Natural Power

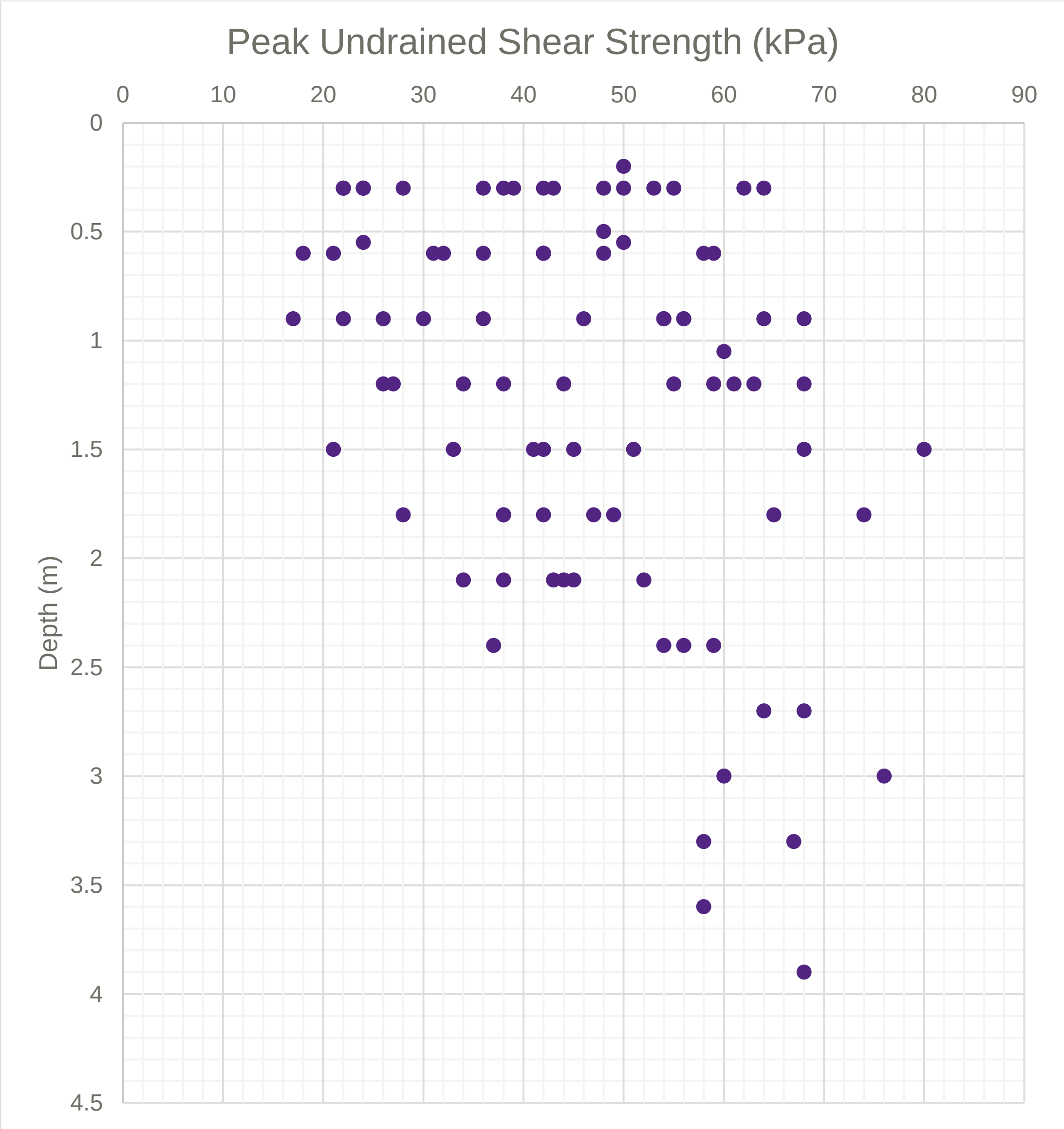


Diagram 8.6: Peak undrained shear strength at shear vane locations.

Table 8.4: Von Post Classifications of peat cores across the site.

WTG ID	Core peat depth (m)	Von Post degree of decomposition	Sample description
T3	0.6	H4/ H6	Soft dark brown pseudo-fibrous peat with moderate moisture content, becoming softer at the base. 0.5-0.6 m Becoming pseudo-fibrous to amorphous.
T8	0.55	H5	0.0-0.05 m Rooty. Soft dark brown pseudo-fibrous peat with high to moderate moisture content. Lower moisture content towards base.
T9	1.1	H4/ H7/ H5	0.0-0.5 m Light brown slightly decomposed peat containing lots of Rooty plant material with low moisture content 0.5-0.65 m softer dark brown more humified peat with high moisture content. 0.65-1.0 m less humified lighter brown peat with moderate moisture content
T10	0.6	H2	Undecomposed peat, lots of plant material, low moisture content
T11	2.0	H4/ H5/ H7/ H8	Soft dark brown pseudo-fibrous peat with moderate moisture content: 0.0-0.3 m slightly decomposed/ 0.3-0.6 m moderately decomposed/ 0.6-1.0 m highly decomposed. 1.0-2.0 m pseudo-fibrous to amorphous very highly decomposed peat.
T13	0.4	H5	Brown peaty topsoil. Rooty in upper 10 cm amorphous lower 10cm lower organic content in lower 10cm
T15	0.5	H5	Brown humified peat but still rooty material present. Low moisture content
T17	0.8	H3/ H5/ H6	Soft dark brown fibrous to pseudo fibrous peat with moderate to high moisture content: 0.0-0.2 m very slightly decomposed/ 0.2-0.4 m moderately decomposed. 0.4-0.8 m Soft dark brown moderately highly decomposed amorphous peat with low moisture content.

Source: Natural Power

Source: Natural Power

Diagram 8.7: Peat Core at T9 0-0.65 m

Source: Natural Power

Diagram 8.8: Peat Core at T3 0.0-0.6 m

Contributory Factors

A8.5.18 To provide a framework for the assessment; the key principles of the peat slide risk assessment are presented here. Discussions of the factors which contribute to peat failure have been presented below (Table 8.5) in order to provide a basis for understanding the assessment process.

Table 8.5: Contributory Factors to Peat Instability

Factor	Discussion
Groundwater Infiltration	There are two processes which may facilitate groundwater infiltration: periods of drying, resulting in cracking of the peat surface and slope creep resulting in additional tension cracks. Drying out of the upper peat, particularly in areas of thinner peat, is likely to result in the development of near-surface cracks which could facilitate ingress of water into the peat.
Surface Loading	Any mechanisms which increase the surface load on a peat deposit can increase the likelihood of failure. This can include surface water ponding and surcharge loading, for example, construction works, stockpiling and forestry operations.
Vegetation Loss	Loss of vegetation can have a negative effect, making the peat susceptible to weathering, increasing rates of infiltration and a loss of strength.
Soil Weathering/Erosion	Weathering can weaken in-situ peat materials and destabilise a slope system. This may be in the form of weathering of peat or underlying mineral soils which could reduce shear strength at the peat/ mineral soil interface. Vertical cracking and slope creep may slowly break down peat structure over long periods of time. This can develop into peat 'hagging', which is a strong indication that natural weathering processes are ongoing. Peat hags expose the peat to increased weathering rates and may provide preferential surface water flow pathways.
Precipitation	The likely failure mechanism following a period of heavy rainfall is linked to the infiltration of surface water. There is a resulting build-up of pore water pressures within the soils and therefore reduced effective shear strength. This may be focussed within the peat deposit or at the interface between the peat and underlying mineral soil. Secondary effects may include swelling of the peat deposit and increased loading due to surface water ponding. Snow and subsequent melt can have a similar effect.
Slope Morphology	There are three main effects arising from slope morphology: Firstly, the concentration of tensile stress at the apex of a convex slope predisposes the slope for failure initiation at that point. In a convex slope the material lower down supports the material above which is held in compression. A concave slope has the opposite characteristics as material at the base maintains the apex in tension. Secondly, at the point of maximum slope convexity, because of favourable down-slope drainage conditions, a body of relatively well-drained and relatively strong peat material develops. This body of peat acts as a barrier providing containment for growth of peat upslope. This relatively well drained body of peat can subsequently fail due to a build-up of lateral pressure on the upslope face. In this scenario the slope is not supported from below so eventually the lateral pressures exceed the forces resisting sliding. The apex or point of convexity is also a likely initiation point for slope failure due to the slope tension being concentrated at this point. Thirdly a failure mechanism, analogous to a piping failure underneath dams, is postulated where springs are present in locations immediately down-slope of the relatively well drained peat body. Under these circumstances high pore pressure gradients within the peat can lead to hydraulic failure and undermining of the relatively well drained peat body

Factor	Discussion
	resulting in a breach and loss of lateral support to peat upslope. Evolving slope morphology can be significant; for example, in the case of slope undercutting by water erosion. Any mechanism by which mass is removed from a slope toe or deposited on a slope crest will contribute to instability.
Peat Depth & Slope Angle	Peat slides correspond in appearance and mechanism to translational landslides and tend to occur in shallow peat (up to 2.0m) on slopes between (5° – 15°). A great majority of recorded peat landslides in Scotland, England & Wales are of the peat slide type. MacCulloch, (2005) highlights that a slope angle of 20° appears to be the limiting gradient for the formation of deep peat. Therefore, the risk assessment has assigned slope angles >20° to be an unlikely contributory factor to failure. Slope angle indicators and corresponding probability factors have been similarly adapted from MacCulloch, (2005). Boylan et al, (2008) indicates that most peat failures occur on slope angles between 4° and 8°. It is postulated that this may correspond to the slope angles that allow a significant amount of peat to develop that over time becomes potentially unstable. The same author also stipulates that a number of failures have been recorded on high slope angles (>20°) but, based on the authors' inspection of such failures, peat cover is generally thin and the failure tends to involve underlying mineral soils, as opposed to peat deposits.
Hydrology	Natural watercourses and artificial drainage measures have often been identified as a contributory factor of peat failure. Preferential drainage paths may allow the migration of water to a failure plane therefore triggering failure when groundwater pressures become elevated. Within a peat mass, sub surface peat pipes can enable flow into a failure plane and facilitate internal erosion of slopes. It is also noted that in some instances, agricultural works can lead to the disturbance of existing drainage networks and cause failures. Forestry preparations and harvesting may also impact upon surface hydrology where suitable controls are not in place.
Existing / Relict Failures	The presence of relict failures and any indication of previous instability are often important, indicating that site conditions exist that are conducive to peat failure. Relict peat slides may be dormant over long periods and be re-activated by any number of the contributory factors discussed in this table.
Anthropogenic Effects	Human impact on peat environments can include a range of effects associated with wind farm construction. Activities such as drainage, access tracks across peat, peat cutting, and slope loading are all examples. Rapid ground acceleration is one such example where shear stress may be increased by trafficking or mechanical vibrations.

Source: Natural Power

Definitions

A8.5.19 Peat failure in this assessment refers to the mass movement of a body of peat that would have a significant adverse effect on the surrounding environment. This definition excludes localised movement of peat, for example movement that may occur below an access track, creep movement or erosion events and failures in underlying mineral soils.

A8.5.20 The potential for peat failure at this site is examined with respect to the activities envisaged during construction and operation of the proposed wind farm

A8.5.21 Hutchinson (1988)[1] defines the two dominant failure mechanisms namely peat flows and peat slides:

- **Peat Flows & Bog Bursts**: are debris flows involving large quantities of water and peat debris. These flow down slope using pre-existing channels and are usually associated with raised bog conditions.
- **Peat Slides**: comprise intact masses of peat moving bodily down slope over comparatively short distances. A slide which intersects an existing surface water channel may evolve into a debris flow and therefore travel further down-slope. Slides are historically more common within blanket bog settings.

Geotechnical Principles

A8.5.22 The main geotechnical parameters that influence peat stability are:

- Shear strength.
- Peat depth.
- Pore water pressure (PWP).
- Slope geometry.
- Loading conditions.

A8.5.23 The stability of any slope is defined by the relationship between resisting and destabilising forces. In the case of a simplified infinite slope model with a translational failure mode, sliding is resisted by the shear strength of the basal failure plane and the element of self-weight acting normal to the failure plane. The stability assessments within this study considers an undrained 'total stress' scenario when the internal angle of friction (φ') = zero.

A8.5.24 An undrained peat deposit may be destabilised by; mass acting down the slope, angle of the basal failure plane and any additional loading events. The ratio between these forces is the Factor of Safety (FoS). When the FoS is equal to unity (1) the slope is in a state of 'limiting equilibrium' and is sensitive to small changes in the contributory factors leading to peat failure.

Slope Stability Model

A8.5.25 The infinite slope model as defined in Skempton et al. (1957)[2] has been adapted to determine the FoS of a peat slope.

A8.5.26 The infinite slope analysis is based on a translational slide, which represents the prevalent mechanism for peat failures. This analysis adopts total stress (undrained) conditions in the peat. This state applies to short-term conditions that occur during construction and for a time following construction until construction induced pore water pressures (PWP) dissipate. (PWP requires time to dissipate as the hydraulic conductivity can be low in peat deposits). The following assumptions were used in the numerical slope stability analysis:

- The groundwater is resting at ground level.
- Minimum acceptable factor of safety required is 1.3.

[1] Hutchinson, J.N., 1988, General Report: morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. In Bonnard, C. (Editor), Proceedings, Fifth International Symposium on Landslides, A.A.Balkema, Rotterdam, Vol.1, pp. 3-36.

[2] Skempton, A.W., DeLory, F.A., 1957. Stability of natural slopes in London clay. Proceedings 4th International Conference on Soil Mechanics and Foundation Engineering, vol. 2, pp. 378 – 381.

- Failure plane assumed at the basal contact of the peat layer.
- Slope angle on base of sliding assumed to be parallel to ground surface and that the depth of the failure plane is small with respect to the length of the slope.
- Thus, the slope is considered as being of infinite length with any end effect ignored.
- The peat is homogeneous.

A8.5.27 The analysis method for a planar translational peat slide along an infinite slope was for calculated using the following equation in total stress terms highlighted by MacCulloch, (2005) and originally reported by Barnes, (2000)[3]:

$F = Cu / (\gamma * z * \sin\beta * \cos\beta)$

A8.5.28 Where:

- **F** = Factor of Safety (FoS)
- **Cu** = Undrained shear strength of the peat (kPa)
- **γ** = Bulk unit weight of saturated peat (kN/m^3)
- **z** = Peat depth in the direction of normal stress
- **β** = Slope angle to the horizontal and hence assumed angle of sliding plane (degrees)

A8.5.29 Undrained shear strength values (Cu) are used throughout this assessment. Effective strength values are not applicable for the case of rapid loading of the peat during short term construction phase of works hence the formula cited above, has been adopted throughout. Where a measured Cu value is not available, a highly conservative value of 10kPa was used in the assessment.

Risk Assessment Criteria

A8.5.30 A semi quantitative risk assessment has been used to determine the risk of peat failure. The methodology follows Governmental guidance defined in PLHRAG, (2017)[35] and has been further augmented with methods set out by Clayton (2001)[4]. Risk factors are summarised on Table 8.6.

A8.5.31 The assessment approach combines the numerical slope stability analysis with a qualitative assessment of the slope angle, peat depth and key geomorphological features. A peat stability risk map has been produced using GIS computation of these factors (Daer PSA 4: Peat Stability Risk). The risk mapping is a useful tool for screening large areas; however, engineering judgement has been applied according to discrete conditions. Thus, the risk mapping relays the unmitigated risk assessment and should eb viewed in context of this report and the stated control measures.

Table 8.6: Risk Factors

Factors	Comment	Criteria	Probability	Scale
Peat Depth (A)	Peat slides tend to occur in shallow peat (up to 2.0m) on A great majority of recorded peat landslides in Scotland, England & Wales are of the peat slide type.	0 – 0.5m >3.0m 0.5 – 1.0m 2.0 – 3.0m 1.0 – 2.0m	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Slope Angle (B)	It has been acknowledged that peat slide tends to occur in shallow peat (up to 2.0m) on slopes between 5o and 15o. Slopes above 20o tend to be devoid of peat or only host a thin veneer deposit.	0 – 3o >20o 4 – 9o 16 – 20o 10 – 15o	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
FoS* (C)	Values are from Infinite slope model using Cu derived from hand shear vane in-situ testing. Slope angle and peat depth also input to this factor.	≥ 1.3 1.29-1.20 1.10-1.19 1.00-1.09 <1.0	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Cracking (D)	Visual assessment undertaken in the field during detailed probing survey and covers the same extends of this survey. Field workers examined for evidence of any major crack networks which may allow surface water to penetrate the peat mass. Reticulate cracking was not investigated as this normally requires intrusive ground investigation to remove the surface fibrous layer. This may be a more important consideration for forested areas or previously forested areas of a development site. For surficial cracks, depth and cause of cracking are important to determine e.g. tension cracks appear as excess tension is released due to movement. Cracks can form during dry period and provide a water ingress pathway. Subjective requiring interpretation.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Groundwater (E)	Challenging to evaluate without very detailed mapping and/or intrusive data. Look for entry / exit points. Evidence of surface hollows, collapse features at surface reflecting evidence of sub-surface peat pipe network, audible indicators including the sound of sub-surface running ground water surrounding proposed infrastructure locations.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Surface Hydrology (F)	Ranging from wet flushes to running burns to hags. Must be evaluated in conjunction with the season and weather preceding the site visit.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5

[3] Barnes, G.E., (2000), Soil Mechanics, Principles and Practice, 2nd Edition, Palgrave Macmillan.

[4] Clayton, C.R.I. (2001). Managing Geotechnical Risk. Institution of Civil Engineers, London.

Factors	Comment	Criteria	Probability	Scale
Previous Instability (G)	Visual survey, scale and age are important as small to medium relict failures may be easy to detect but very large ones may require remote imaging. Recent failures should be obvious due to the scar left.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Land Management (H)	Anthropogenic influences such as forestry operations, felling and removal of vegetation can be associated with de-stabilising peat deposits. This can occur as a result to surface disturbance and remoulding of peat through excavation, vehicle movements and loading. Changes in land use activities may also be associated with changes in drainage conditions. Criteria based on evidence of disturbance of peat deposit, i.e. broken surface, scarring or disrupted hydrology. At the Proposed Development land management factors were introduced using a subjective judgement.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5

Source: Natural Power

A8.5.32 Environmental impact zones based on proximity buffer zones applied to the sensitive watercourses within the Proposed Development. Watercourses have been determined to be a primary sensitive receptor and pathway of a peat failure event to reach planned site infrastructure. Table 8.7 denotes the potential impact scales to the environment.

Table 8.7: Impact Scale

Criteria/Exposure	Potential Impact	Impact Scale (Ei)
Proposed access road/turbine within 50m of watercourse	High	4
Proposed access road/turbine within 50-100m of watercourse	Medium	3
Proposed access road/turbine within 100-150m of watercourse	Low	2
Proposed access road/turbine greater than 150m from watercourse	Negligible	1

Source: MacCulloch, (2005)[5]

A8.5.33 A qualitative Risk Ranking is assessed from the combined probability of occurrence for the main contributory factors which are greater than (1), multiplied by the highest impact scale. Table 8.8 identifies the risk ranking based on concepts of PLHRAG, (2017)[27].

Risk Rank = ((Sum A:H) if (A:H>1)) x (Ei)

Table 8.8: Risk ranking and controls

Risk Ranking Zone	Control Measures
17 - 25	High: Avoid project development at these locations.
11 - 16	Medium: Project should not proceed unless risk can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce risk ranking to low or negligible.
5 - 10	Low: Project may proceed pending further investigation to refine risk assessment and mitigate hazard through relocation or re-design at these locations.
1 - 4	Negligible: Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate.

Source: PLHRAG, 2017[36]

A8.5.34 Table 8.9 below further breaks down the Risk Ranking score into a risk rating matrix adapted from Clayton, (2001):

Table 8.9: Risk Rating

Highest Probability for Contributory Factor to Peat Failure						
Environmental Impact Scale	Score	1	2	3	4	5
	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

Source: Clayton, 2001[6]

Numerical Slope Stability Analysis

Introduction

A8.5.35 Assessing the desk study information, infrastructure layout and peat survey data; a preliminary slope stability analysis has been undertaken. Slope stability was assessed at each turbine location using slope angle measurements, peat depth, and undrained shear strength measured using in-situ hand shear vane values.

A8.5.36 For each proposed location, the peak undrained shear strength values have been input into the infinite slope model in order to calculate the potential factor of safety against peat slide.

Undrained Slope Stability Analysis

A8.5.37 The current baseline peat condition is assumed to be in a state of equilibrium at the infrastructure locations. Surcharge loading has been considered to demonstrate the potential effect of construction works proposed as part of the development.

A8.5.38 The factor of safety (FoS) against sliding has been calculated at the centre of proposed turbine locations. Table 8.10 below summarises the results.

A8.5.39 A slope factor of safety map (Daer PSA 3: Slope Factor of Safety) has been produced to map the calculated factor of safety across the development. The FoS calculation has been established within GIS software allowing development wide input of peat depth and slope angle parameters.

[5] MacCulloch, F. (2005). Guidelines for the Risk Management of Peat Slips on the Construction of Low Volume/Low Cost Roads over Peat. Road Ex 11 Northern Periphery.

[6] Clayton, C.R.I. (2001). Managing Geotechnical Risk. Institution of Civil Engineers, London.

Table 8.10: Slope Stability Analysis for wind turbines

Location	Average Peak Shear Strength (kPa)	Unit Weight, γ (kN/m3)	Average peat depth, z (m)	Slope Geometry (β°)	Factor of Safety, (FoS = Cu / γ z sinβ cosβ)		Min Safe Shear Strength (Cumin) (kPa)
					No applied load	Surcharge 20kPa	
T01	10*	10.00	0.55	8	13.8	3.0	4.3
T02	10*	10.00	0.19	11	29.5	2.5	5.2
T03	47	10.00	0.58	6	74.9	16.7	3.7
T04	10*	10.00	0.22	13	20.9	2.1	6.3
T05	10*	10.00	0.33	10	17.5	2.5	5.2
T06	50	10.00	0.34	6	141.8	20.9	3.1
T07	10*	10.00	0.42	9	15.5	2.7	4.9
T08	33	10.00	0.79	8	32.0	9.0	4.7
T09	64	10.00	0.67	9	65.0	16.2	5.1
T10	55	10.00	0.34	7	130.7	19.1	3.7
T11	47	10.00	1.31	6	35.2	13.9	4.4
T12	10*	10.00	0.50	6	20.2	4.0	3.2
T13	25	10.00	0.49	11	27.0	5.3	6.1
T14	10*	10.00	0.75	9	8.7	2.4	5.5
T15	48	10.00	0.64	11	38.8	9.4	6.6
T16	10*	10.00	0.32	10	18.3	2.5	5.2
T17	41	10.00	0.63	9	42.3	10.1	5.3

** Site specific shear vane field test not suitable, therefore conservative shear strength values used (10kPa).*

Discussion

A8.5.40 The numerical stability analysis indicates no potential for translational peat slide at proposed turbine locations under current equilibrium or modelled surcharge loading conditions.

A8.5.41 In the absence of more detailed sub-surface data, the surface slope angle has been used as a reference to the likely slope surface angle at the base of the peat in the analysis.

A8.5.42 Further advanced in-situ test methods should be considered as part of a detailed site investigation phase usually carried out post-consent.

A8.5.43 **Wind Turbines:** FoS values for the turbine locations, when allowing for a 20kPa surcharge load have been derived. The lowest FoS was calculated was 2.1 for proposed turbine T04. The natural slope condition has been calculated to be stable and was observed to be so around the wind turbine locations during the field survey.

A8.5.44 The FoS accounts for a 20 kPa surcharge representing scenarios at infrastructure such as temporary storage stockpiles. The Peat Management Plan (PMP) accounts mitigation measures for peat stockpiling. Slope stability assessments will usually be carried out during design phase where required for site tracks, hardstands and other relevant structures ensuring the proposed design results are safe, stable and environmentally compliant.

A8.5.45 **Access tracks:** Proposed access tracks are proposed across areas not conducive to large scale peat instability. Areas of track with an elevated risk are represented on the peat stability risk map (Daer PSA 4: Peat Stability Risk). This is primarily attributed close-proximity or crossing of watercourses. These elements can be mitigated and managed through detailed engineering design incorporating watercourse protection measures. These would be fully defined as part of the construction environmental management plan and detailed civil infrastructure design.

Risk Assessment of Peat Slide

A8.5.46 The potential effect of a peat slide triggered by the Proposed Development is obtained from assessing the proximity to watercourses -as defined in Table 8.7. Probability values were assessed for salient contributory factors (see Table 8.6).

A8.5.47 Risk rankings for the proposed turbine positions are presented in Table 8.11, along with an aerial photograph showing the location

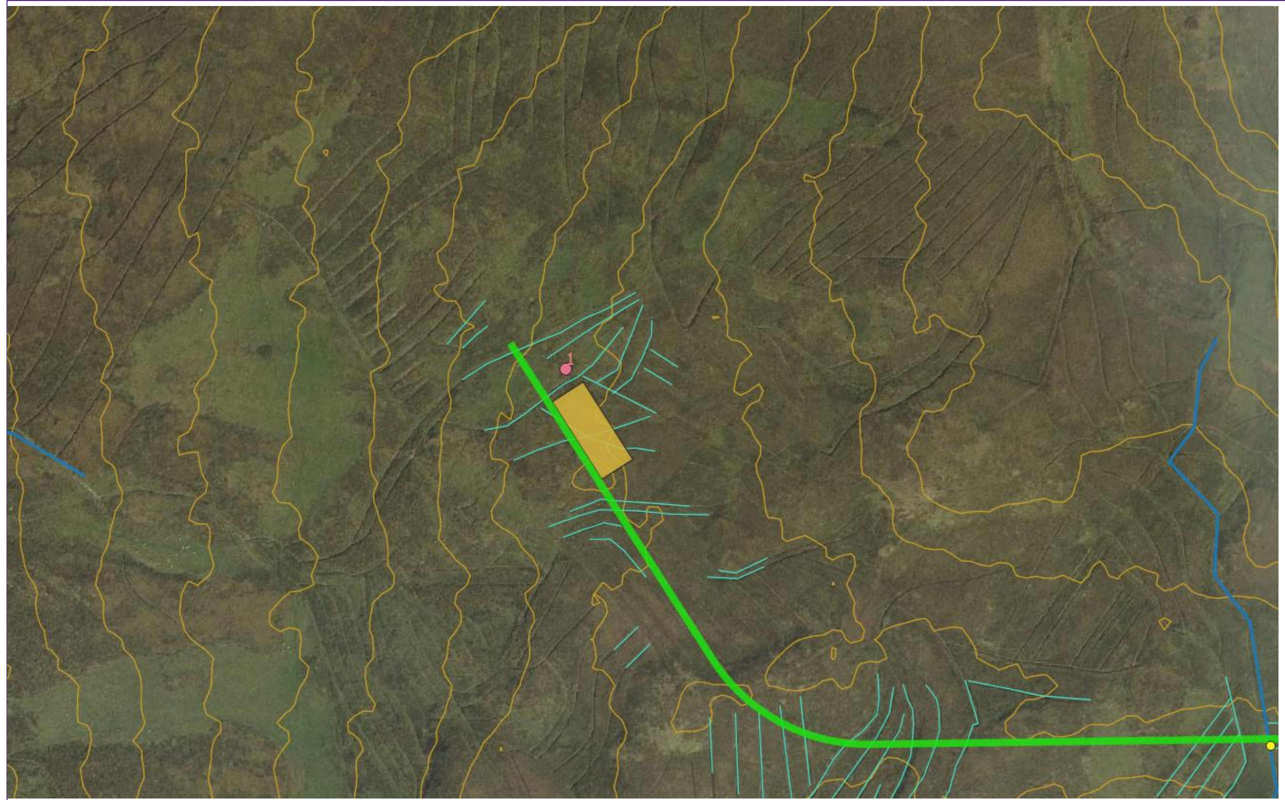
A8.5.48 The risk ranking map is appended to this report (Daer PSA 4: Peat Stability Risk). The risk map provides a representation of the risk zonation across the development area. The map is based on a development wide GIS analysis and should not be viewed in isolation without the narrative of this report.

A8.5.49 The risk assessment reflects the probability of peat material entering a surface watercourse and being entrained to an offsite receptor without any mitigation. The wider geomorphological assessment and evidence from recorded peat depths would indicate that a large-scale translational mass movement of peat deposits is unlikely. Areas close to watercourses would therefore be the focus of mitigation measures.

A8.5.50 Further detail of the risk assessment and possible mitigation/ control measures is highlighted within the preliminary geotechnical risk register presented in Table 8.14.

Table 8.11: Hazard Ranking Proposed Turbine Locations

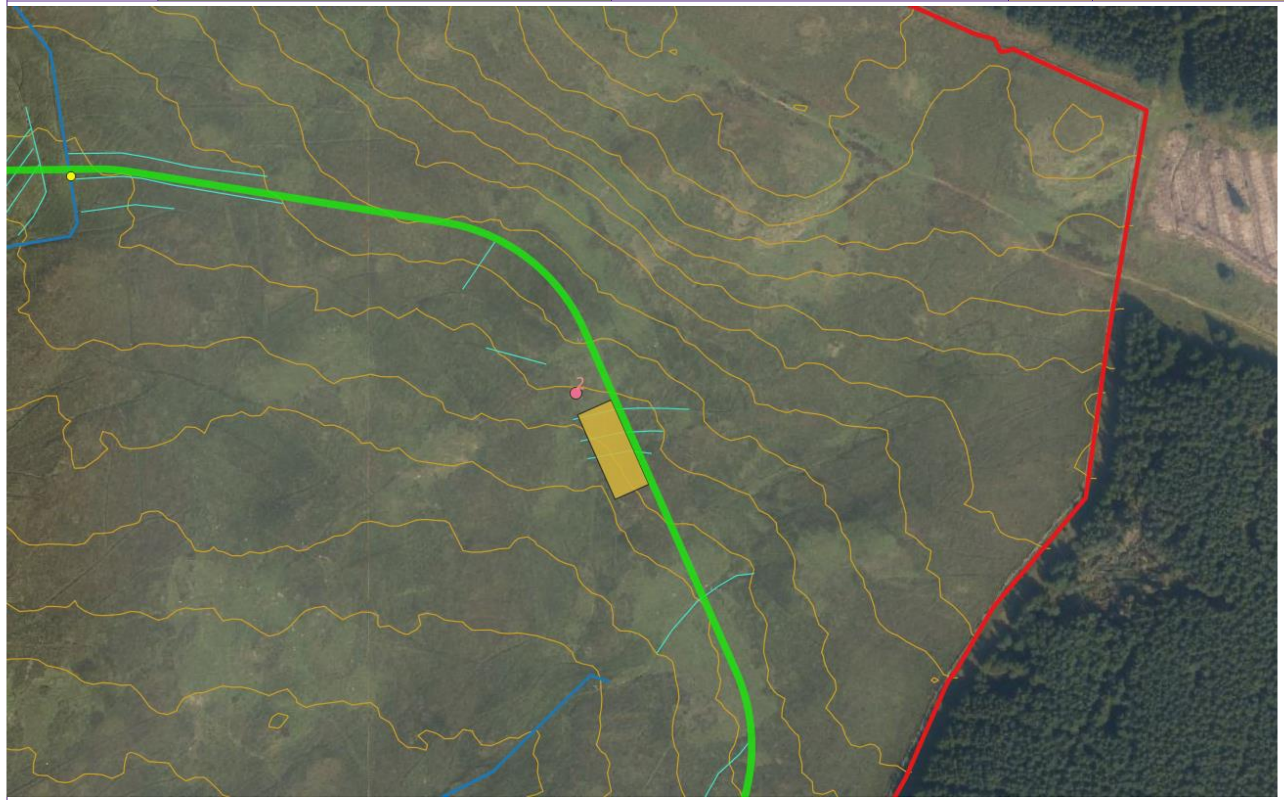
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T1	1 (268 m from watercourse)	Peat Depth (Mean = 0.55 m)	3	8x1=8 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

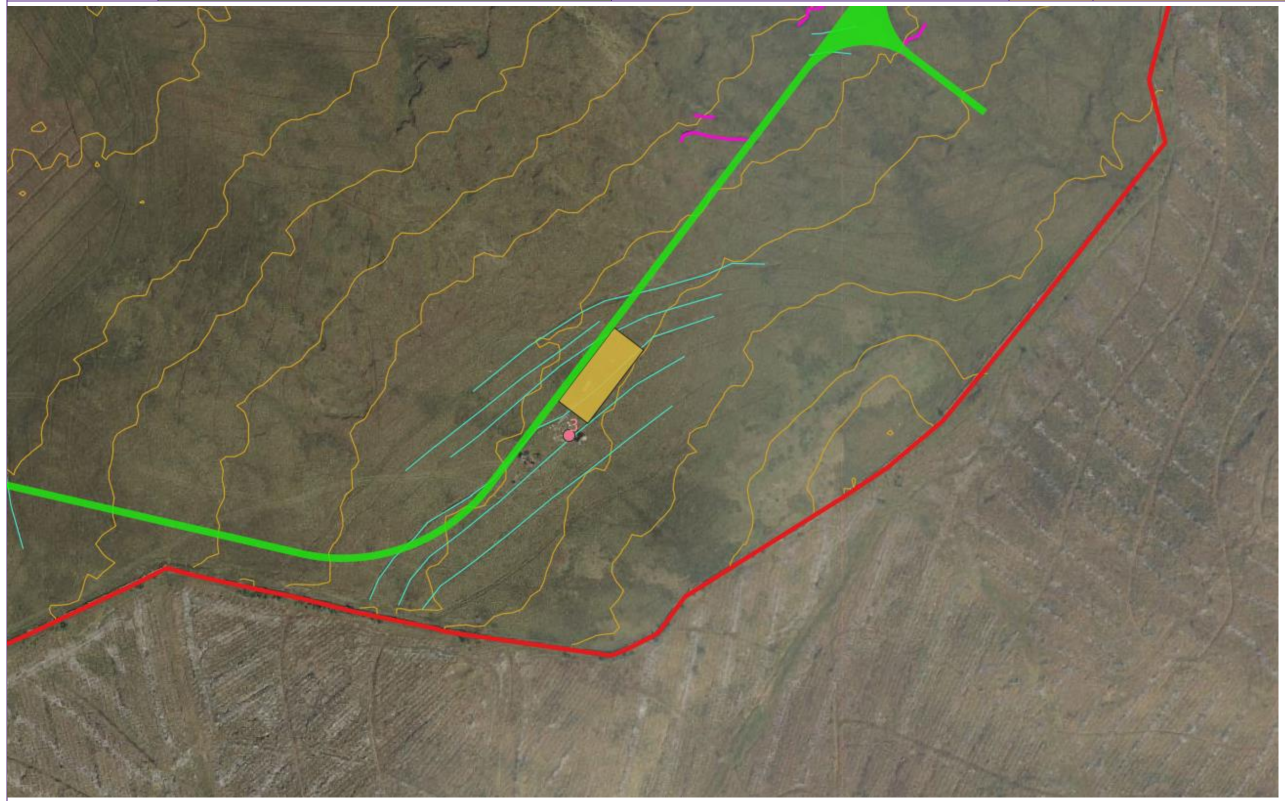
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T2	1 (152 m from watercourse)	Peat Depth (Mean = 0.19 m)	1	7x1=7 (Low)
		Slope Angle (10-15 deg)	5	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the very limited thickness of peat at this location.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.
- Detailed design should consider whether it is possible to microsite the turbine to a shallower angle terrain to reduce the risk factor.

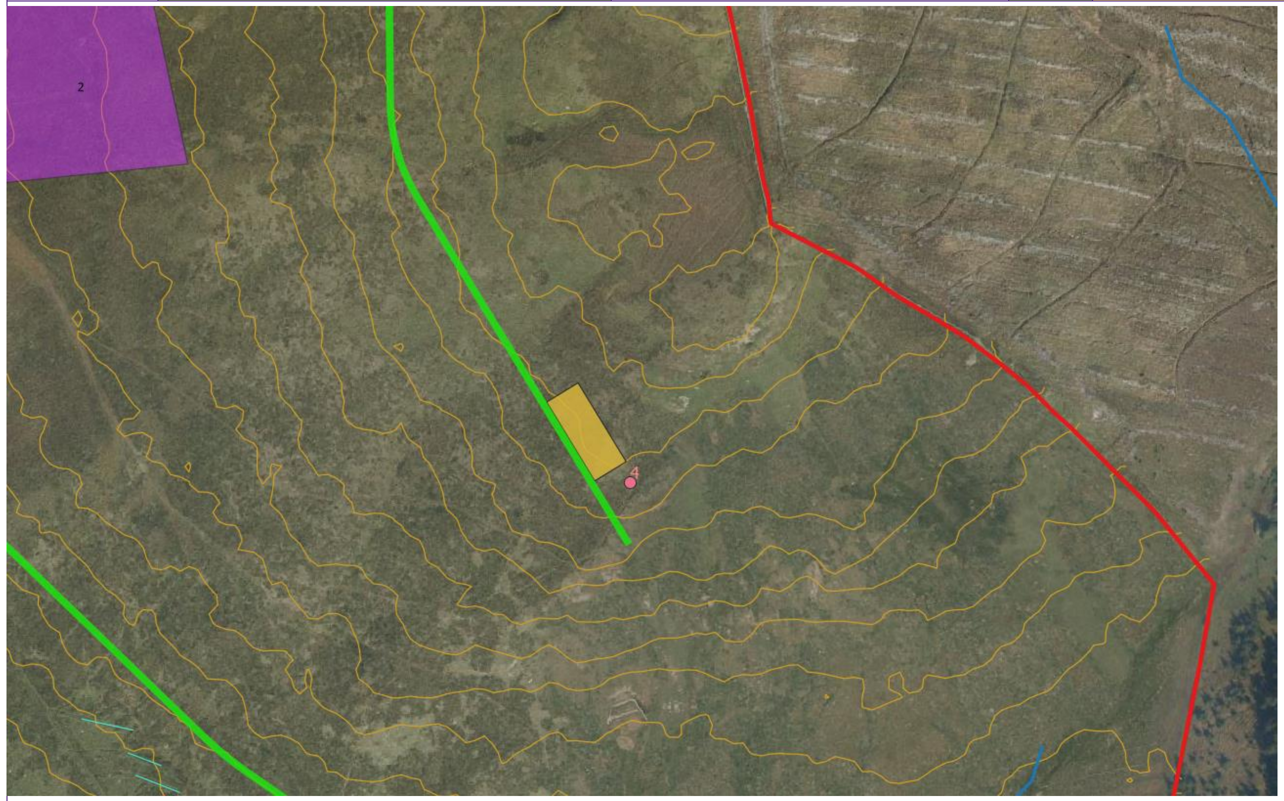
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T3	1 (309 m from watercourse)	Peat Depth (Mean = 0.58 m)	3	8x1=8 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T4	1 (264 m from watercourse)	Peat Depth (Mean = 0.22 m)	1	5x1=5 (Low)
		Slope Angle (10-15 deg)	5	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	



Location Specific Mitigation:

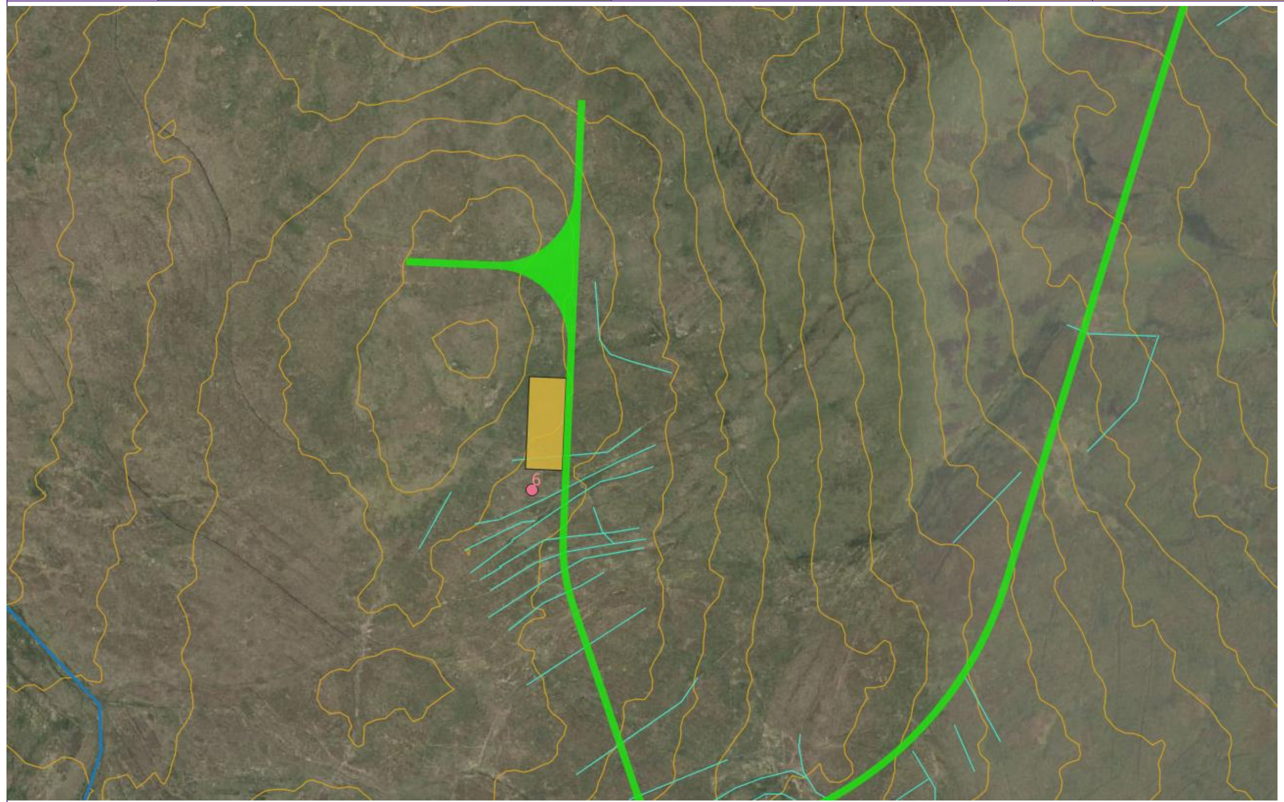
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the very limited thickness of peat at this location.
- Detailed design should consider whether it is possible to microsite the turbine to a shallower angle terrain to reduce the risk factor.

Location	Environmental Impact Scale	Contributory Factors (Probability/Exposure)		Risk Ranking
T5	1 (221 m from watercourse)	Peat Depth (Mean = 0.33 m)	1	7x1=7 (Low)
		Slope Angle (10-15 deg)	5	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the very limited thickness of peat at this location.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.
- Detailed design should consider whether it is possible to microsite the turbine to a shallower angle terrain to reduce the risk factor

Location	Environmental Impact Scale	Contributory Factors (Probability/Exposure)		Risk Ranking
T6	1 (261 m from watercourse)	Peat Depth (Mean = 0.34 m)	1	5x1=5 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the very limited thickness of peat at this location.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T7	1 (291 m from watercourse)	Peat Depth (Mean = 0.42 m)	1	3x1=3 (Negligible)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	

Location Specific Mitigation:

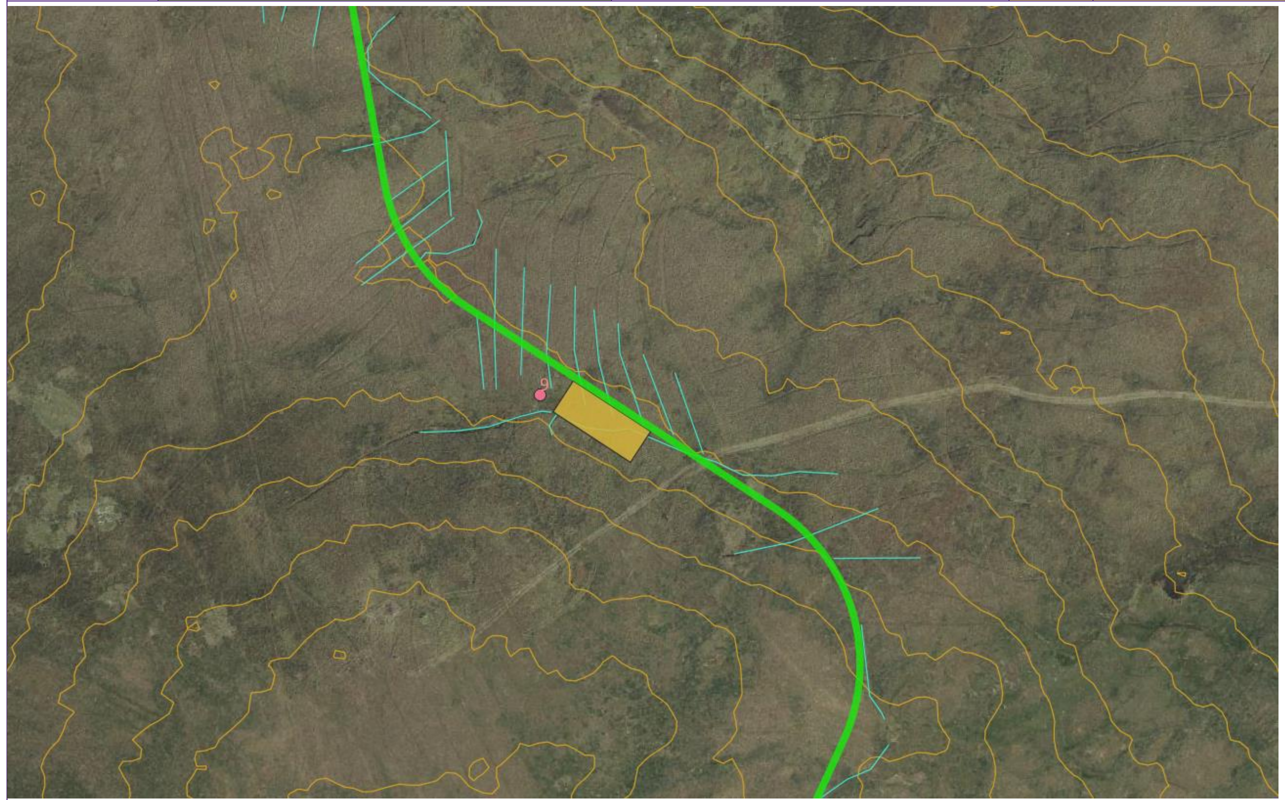
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain negligible given the limited thickness of peat at this location.

Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T8	1 (447 m from watercourse)	Peat Depth (Mean = 0.79 m)	3	8x1=8 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T9	1 (454 m from watercourse)	Peat Depth (Mean = 0.67 m)	3	8x1=8 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

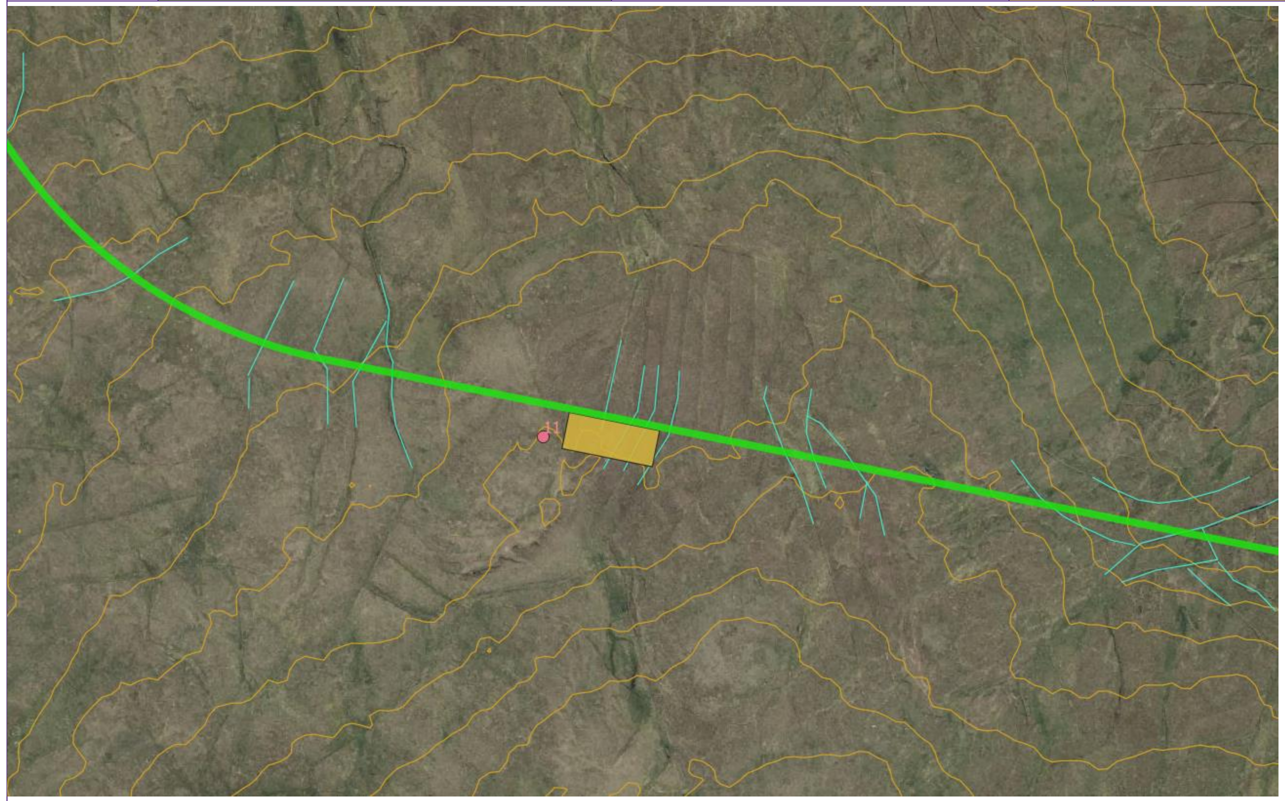
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T10	1 (184 m from watercourse)	Peat Depth (Mean = 0.34 m)	1	3x1=3 (Negligible)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain negligible given the very limited thickness of peat at this location.

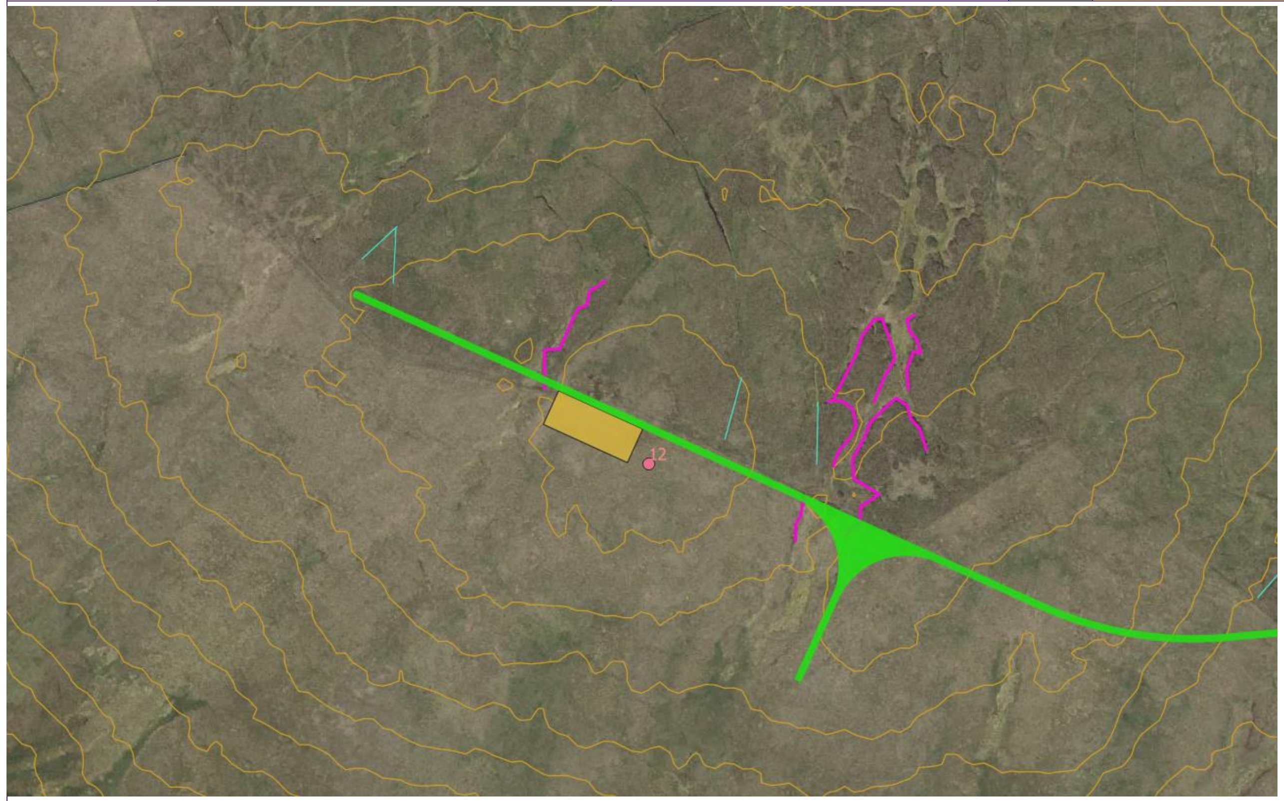
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T11	1 (455 m from watercourse)	Peat Depth (Mean = 1.31 m)	5	10x1=10 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Consider additional detailed peat probing and micrositing the turbine location to avoid excavations within the deepest peat areas.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

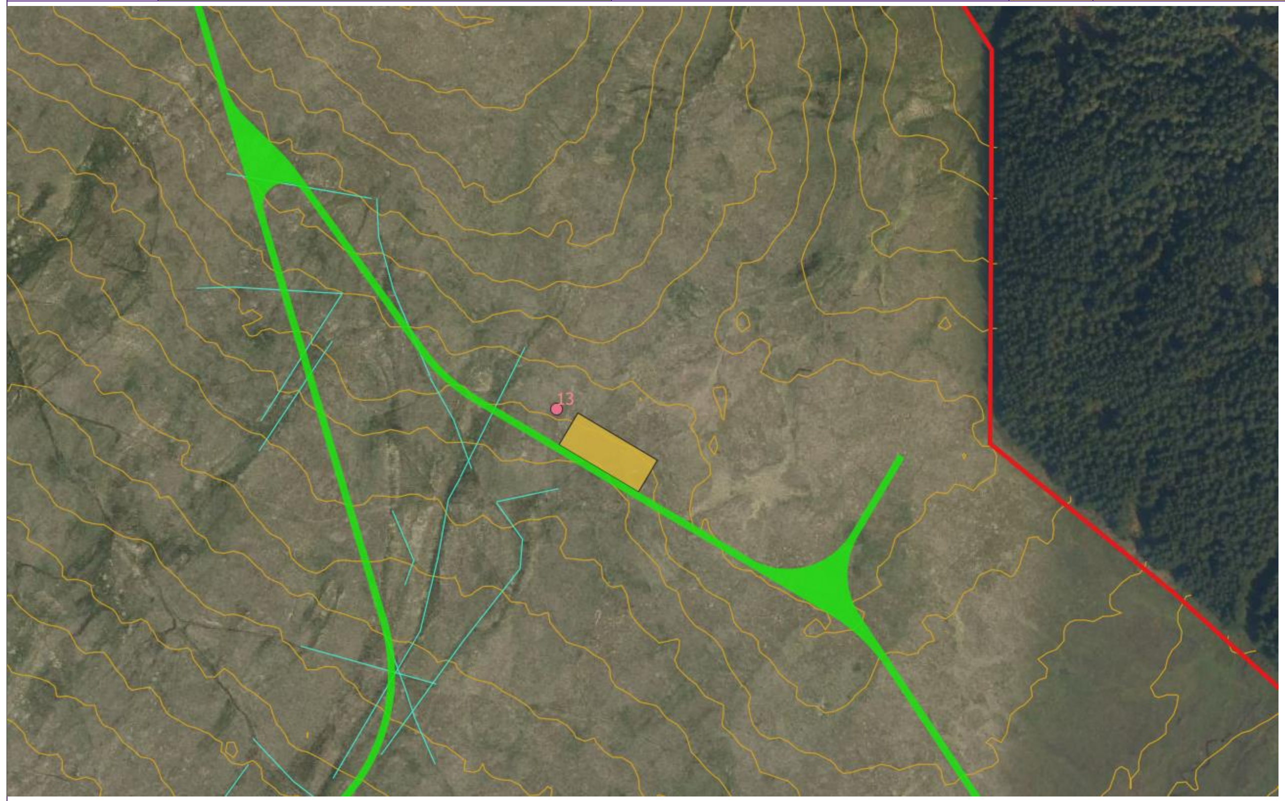
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T12	1 (435 m from watercourse)	Peat Depth (Mean = 0.50 m)	3	8x1=8 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability (peat hags)	2	
		Land Management	1	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Protect area of peat hags in vicinity of turbine against accelerated erosion and surface water run-off. Re-direct surface run-off and integrated track drainage away from area of peat hags.

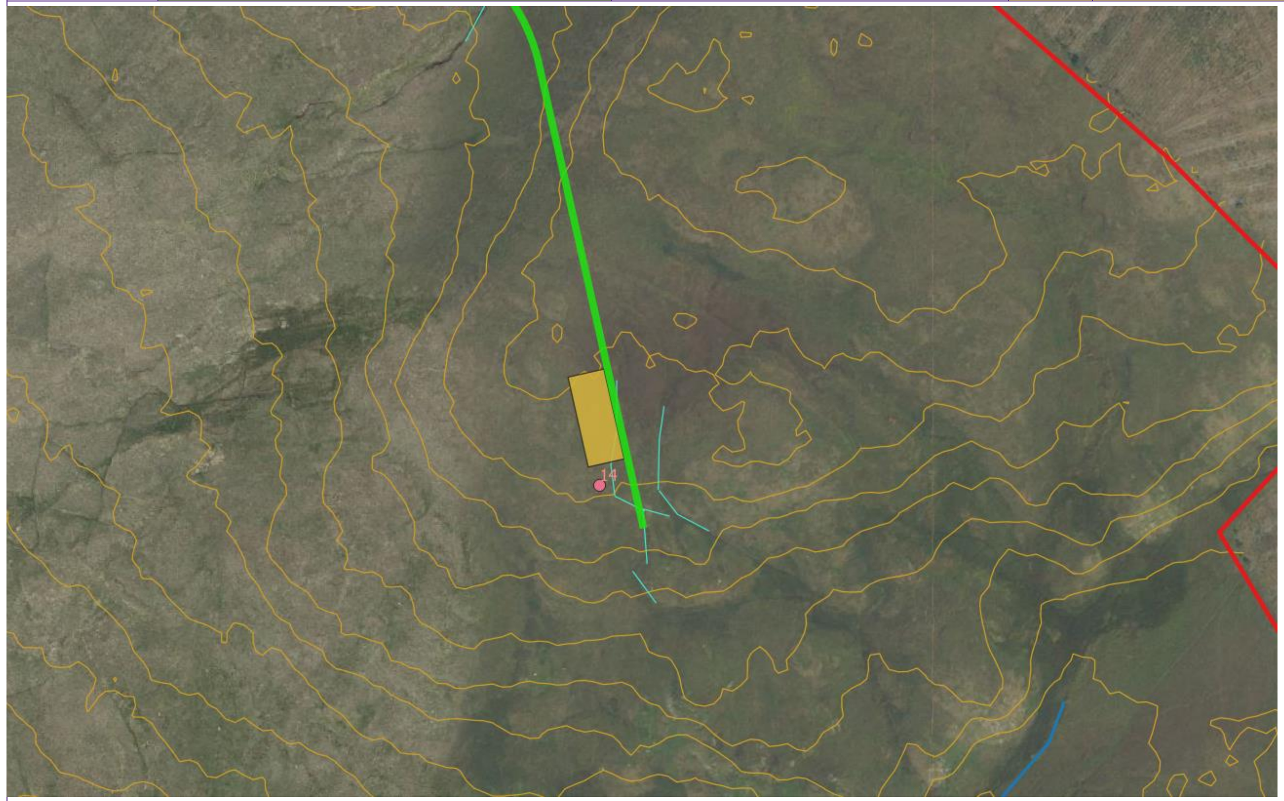
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T13	1 (337 m from watercourse)	Peat Depth (Mean = 0.49 m)	1	**7x1=7** **(Low)**
		Slope Angle (10-15 deg)	5	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.
- Detailed design should consider whether it is possible to microsite the turbine to a shallower angle terrain to reduce the risk factor.

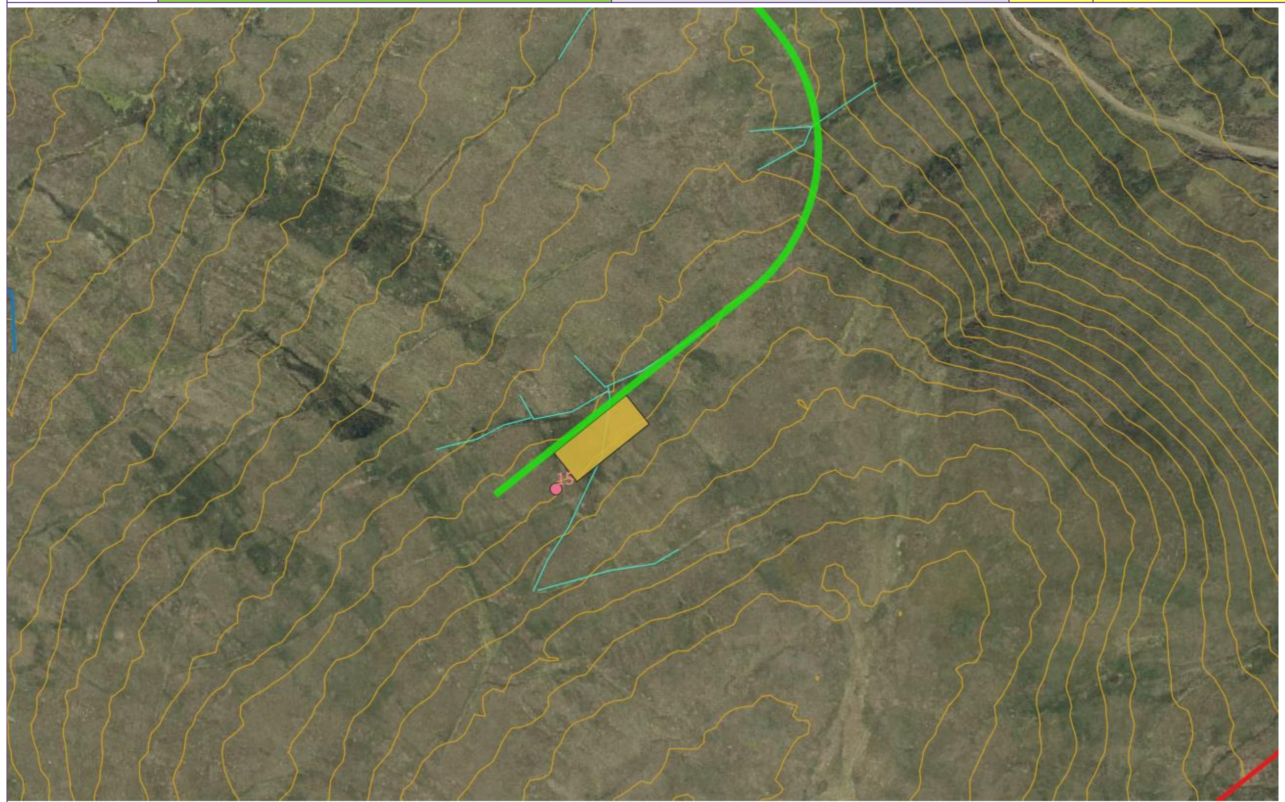
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T14	1 (276 m from watercourse)	Peat Depth (Mean = 0.75 m)	3	**8x1=8** **(Low)**
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.

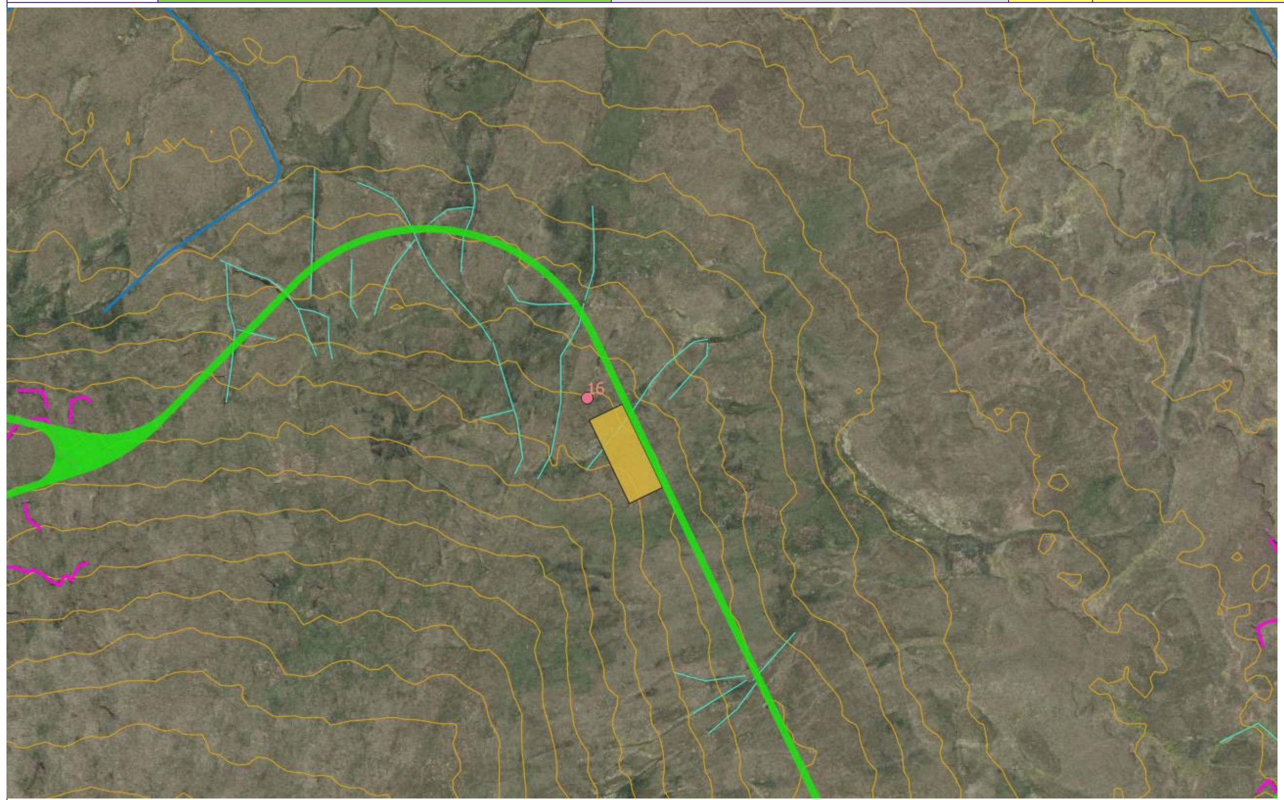
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T15	1 (301 m from watercourse)	Peat Depth (Mean = 0.64 m)	3	**10x1=10 (Low)**
		Slope Angle (10-15 deg)	5	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.
- Detailed design should consider whether it is possible to microsite the turbine to a shallower angle terrain to reduce the risk factor.

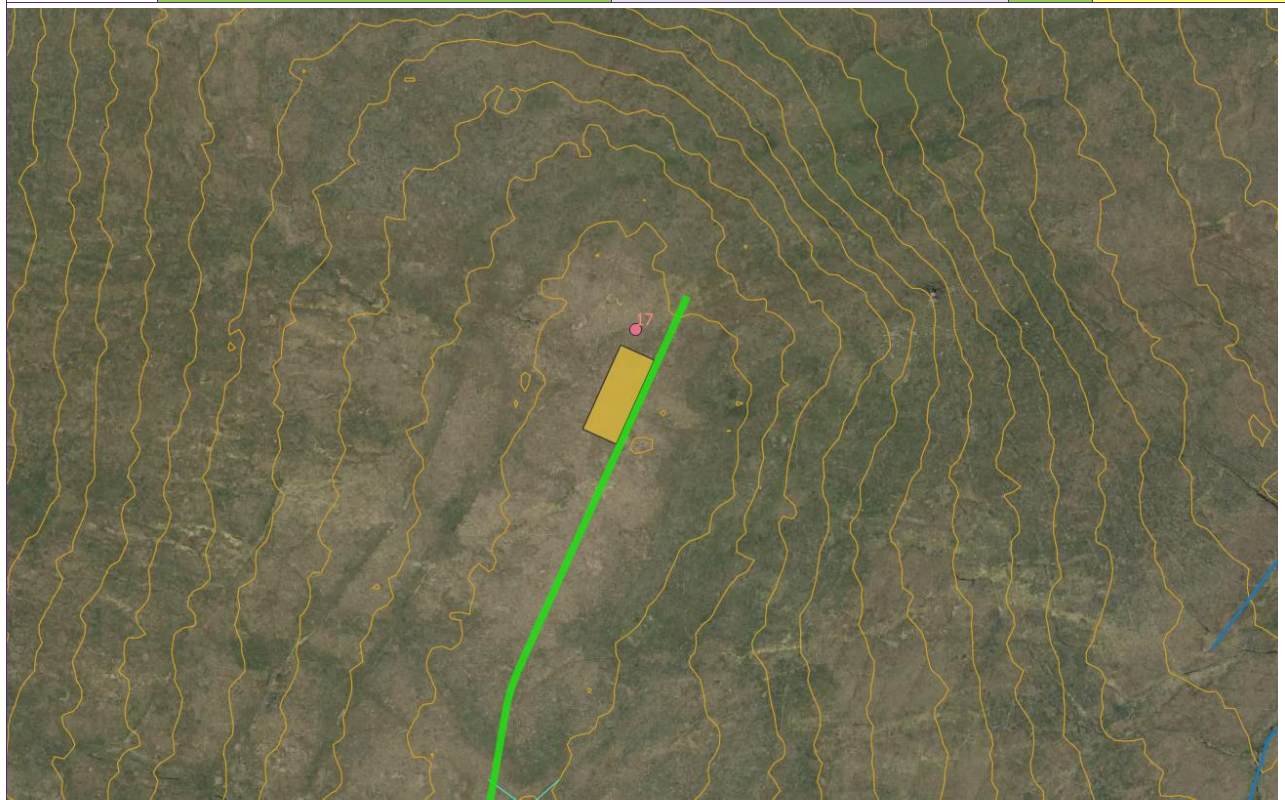
Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T16	1 (204 m from watercourse)	Peat Depth (Mean = 0.32 m)	1	**7x1=7 (Low)**
		Slope Angle (10-15 deg)	5	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the very limited thickness of peat at this location.
- Maintain surface water flow regime established by drainage network and prevent blockage and ponding of surface water at infrastructure location.
- Detailed design should consider whether it is possible to microsite the turbine to a shallower angle terrain to reduce the risk factor.

Location	Environmental Impact Scale	Contributary Factors (Probability/Exposure)		Risk Ranking
T17	1 (357 m from watercourse)	Peat Depth (Mean = 0.63 m)	3	6x1=6 (Low)
		Slope Angle (4-9 deg)	3	
		FoS (Min = >1.5)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	



Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.

Turbine Bases

A8.5.51 Table 8.12 below summarises the hazard ranking assignments for each turbine location. The principal contributory factors used to derive these assignments are also listed.

Table 8.12: Risk Ranking Summary – Wind Turbine Locations

WTG	Risk Ranking	Factors where Elevated Risk
T1	Low	Peat depth; Slope angle
T2	Low	Slope angle
T3	Low	Peat depth; Slope angle
T4	Low	Slope angle
T5	Low	Slope angle
T6	Low	Slope angle
T7	Negligible	-
T8	Low	Peat depth; Slope angle
T9	Low	Peat depth; Slope angle
T10	Negligible	-
T11	Low	Peat depth; Slope angle
T12	Low	Peat depth; Slope angle
T13	Low	Slope angle
T14	Low	Peat depth; Slope angle
T15	Low	Peat depth; Slope angle
T16	Low	Slope angle
T17	Low	Peat depth; Slope angle

Source: Natural Power

Access Tracks & Ancillary Infrastructure

A8.5.52 In addition to the turbine bases, the access tracks and ancillary infrastructure have also been reviewed.

A8.5.53 Locations with medium or high risk of instability are presented in Table 8.13. The highest risk areas would be where track alignments cross watercourses and where steep slopes are present around the watercourses.

A8.5.54 The areas of highest risk can be seen on the peat stability risk map (Daer PSA 4: Peat Stability Risk).

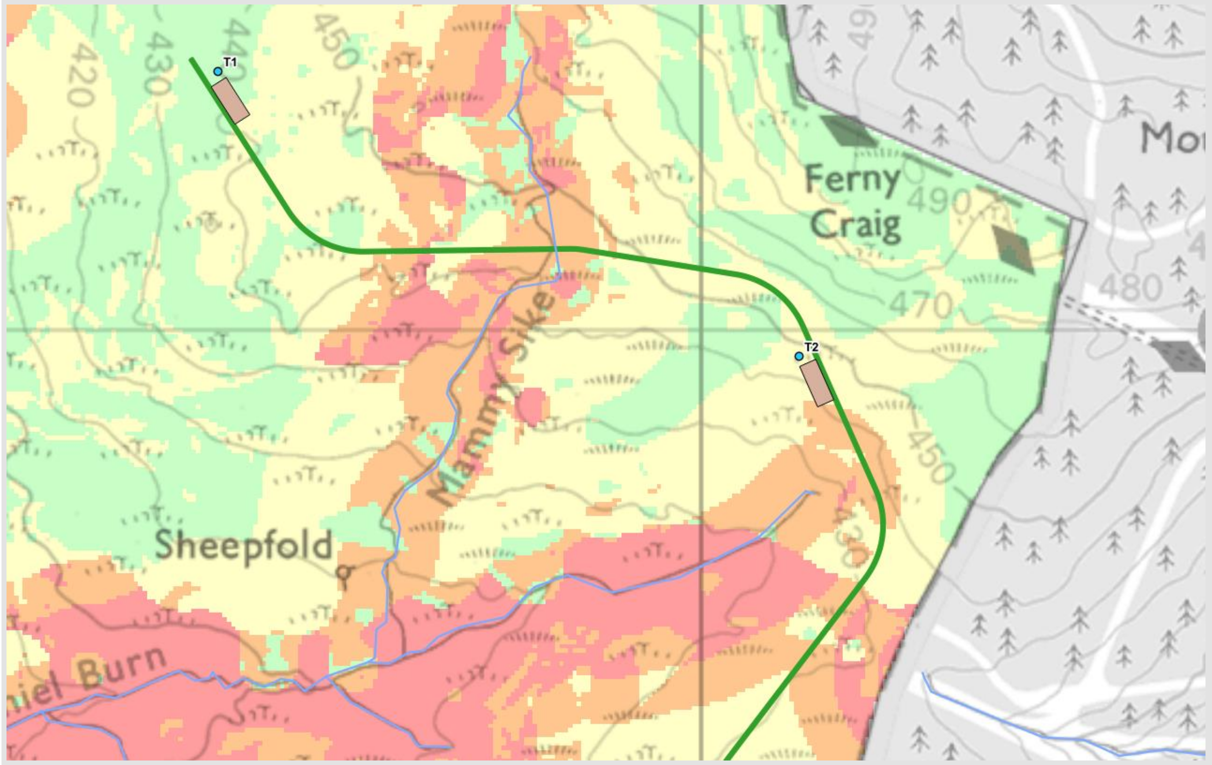
Table 8.13: Medium/ High Risk Areas

Track Section: T1-T2 and area south of T2

Discussion / Contributors to elevated peat slide risk:

- Watercourse crossing Mammy Sike/ proximity to other watercourses
- Localised area of peat 0.5 to 1.0 m south of turbine T2
- Slope angle > 9 degrees adjacent to turbine T2

Extract from peat stability risk map:



Recommended Location Specific Mitigation:

This track section is required to traverse Mammy Sike and comes within ca. 75 m of the mapped location of the head of another watercourse. The route has been carefully chosen to balance the risks of peat slide and minimise the environmental effects of earthworks, and is constrained by the site boundary, so micrositing options are limited.

The following mitigation is recommended along this track section in order to reduce the peat stability risk:

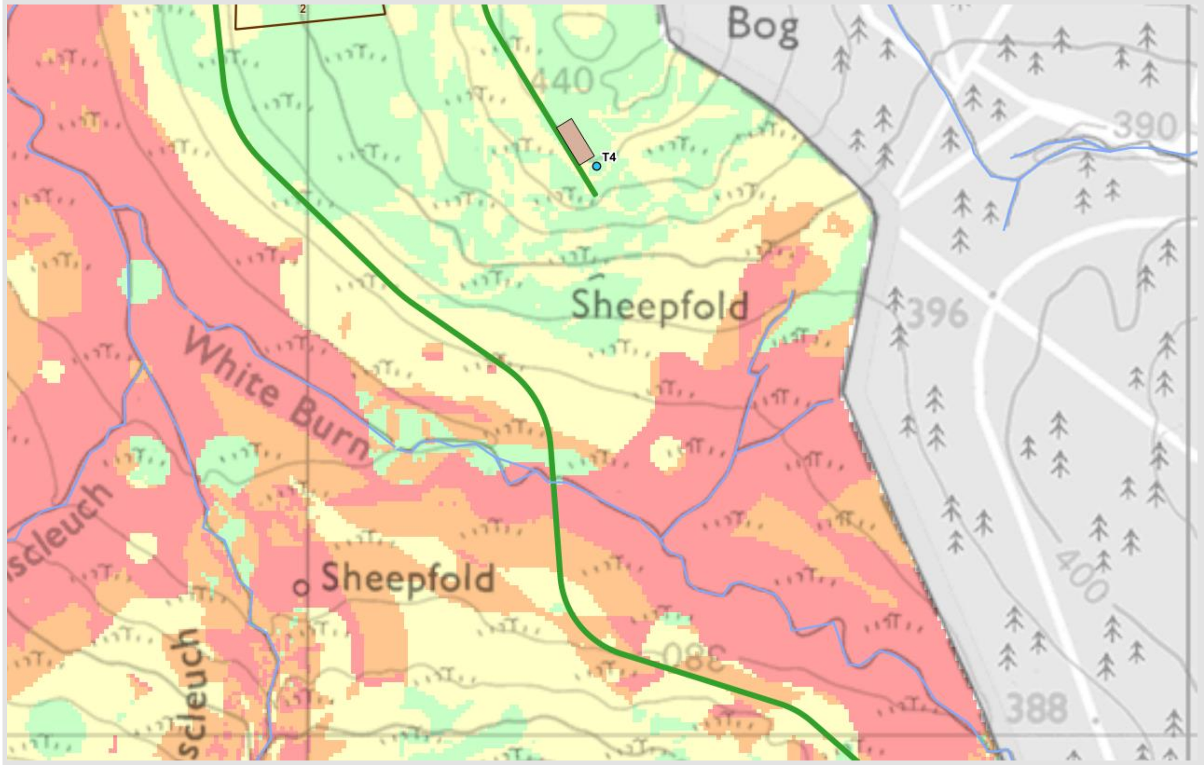
1. Detailed design should consider whether it is possible to microsite the short section of the track on the approach to turbine T2 ca 30 m north west into the low risk area. This may also need a slight adjustment to orientation of T2 crane pad.
2. The water crossing will require detailed design including slope retaining structures to prevent effects to the watercourse from entrained peat deposits.
3. Install cross track drainage which prevents any ponding or build up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained.
4. No stockpiling or surcharging of the peatland in the medium/ high risk areas.
5. A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat and condition of the watercourse. A rapid reaction strategy should be in place during construction to ensure measures can be deployed to protect the watercourse in the event of any movement.

Track Section: White Burn water crossing

Discussion / Contributors to elevated peat slide risk:

- Watercourse crossing White Burn
- Peat depth – 0.5 to 1.5 m

Extract from peat stability risk map:



Recommended Location Specific Mitigation:

This track section is required to traverse White Burn. The watercourse crossing is unavoidable because the burn bisects the site, however the route has been carefully chosen to minimise the effects of construction and risk of peat slide.

The following mitigation is recommended along this track section in order to reduce the peat stability risk:

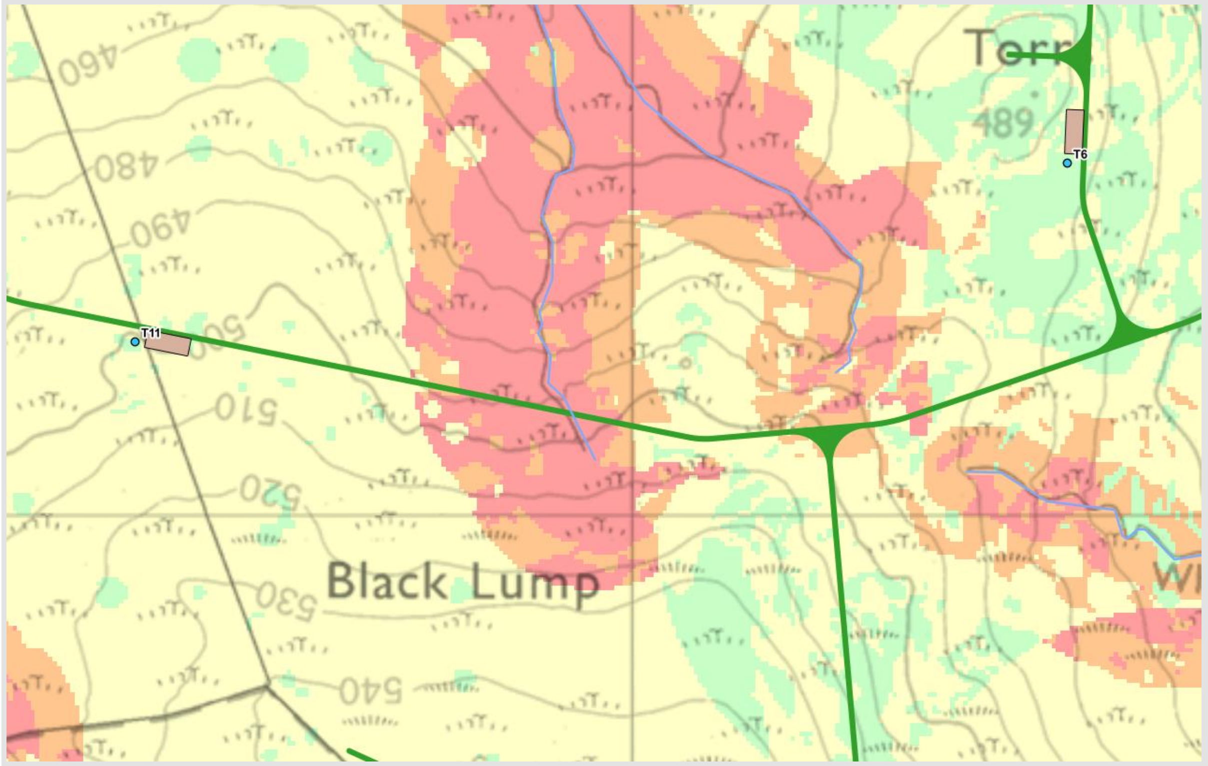
1. The water crossing will require detailed design including slope retaining structures to prevent effects to the watercourse from entrained peat deposits.
2. Install cross track drainage which prevents any ponding or build up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained.
3. No stockpiling or surcharging of the peatland in the medium/ high risk areas.
4. A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat and condition of the watercourse. A rapid reaction strategy should be in place during construction to ensure measures can be deployed to protect the watercourse in the event of any movement.

Track Section: East of T11

Discussion / Contributors to elevated peat slide risk:

- Watercourse crossing Over Ornscleuch
- Peat depth – 0.5 to 1.0 m
- Slope angle > 9 degrees adjacent to watercourse

Extract from peat stability risk map:



Recommended Location Specific Mitigation:

This track section is required to traverse the mapped location of the head of Over Ornscleuch watercourse. The route has been carefully chosen to balance the risks of peat slide and minimise the environmental effects of earthworks, so micrositing options are limited.

The following mitigation is recommended along this track section in order to reduce the peat stability risk:

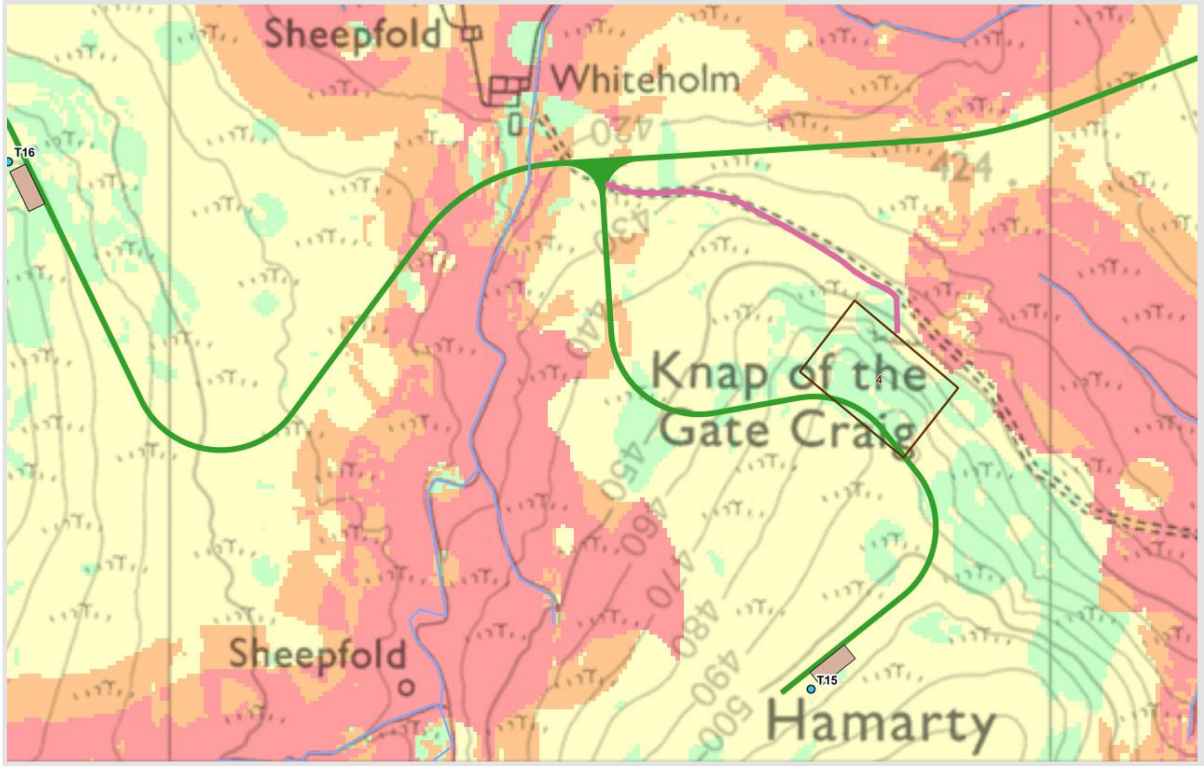
1. The water crossing will require detailed design including slope retaining structures to prevent effects to the watercourse from entrained peat deposits. Detailed design should consider whether it is possible to move the track alignment south on Black Lump to avoid the need for a watercourse crossing.
2. Install cross track drainage which prevents any ponding or build up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained.
3. No stockpiling or surcharging of the peatland in the medium/ high risk areas.
4. A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat and condition of the watercourse. A rapid reaction strategy should be in place during construction to ensure measures can be deployed to protect the watercourse in the event of any movement.

Track Section: Crook Burn water crossing

Discussion / Contributors to elevated peat slide risk:

- Watercourse crossing Crook Burn
- Slope angle > 9 degrees localised slopes adjacent to watercourse

Extract from peat stability risk map:



Recommended Location Specific Mitigation:

This track section is required to traverse Crook Burn. The watercourse crossing is unavoidable because the burn bisects the site, however the route has been carefully chosen to minimise the effects of construction and risk of peat slide.

It is noted the track is situated within predominately low risk terrain, and the peat is thin (0-0.5 m depth) at the water crossing location. Therefore, although the peat stability risk map has flagged this short section of track as potentially medium/ high risk location, this is likely to be an overestimation of the true risk of peat side as they are unlikely to occur in shallow peat scenarios.

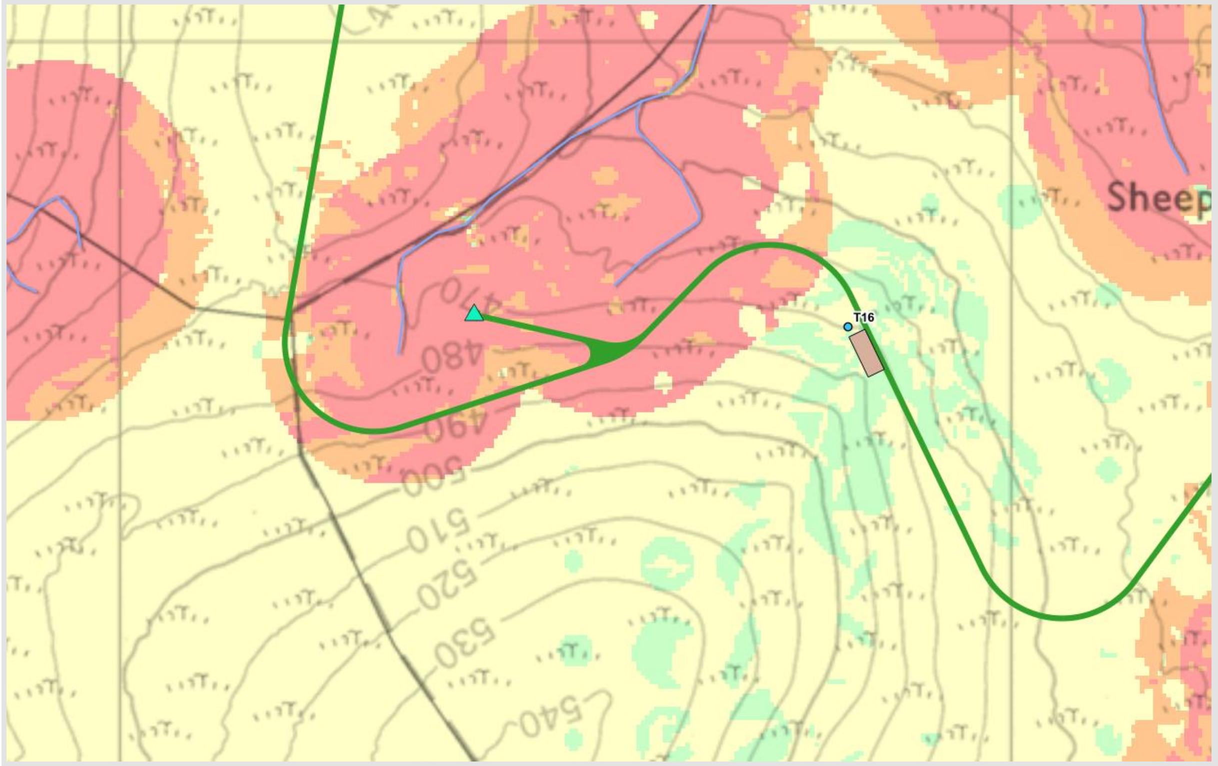
Normal construction mitigation measures are recommended for this location. The water crossing will require detailed design including slope retaining structures to prevent effects to the watercourse from entrained peat deposits.

Track Section: T16-T17 & Met Mast

Discussion / Contributors to elevated peat slide risk:

- Close proximity to watercourses
- Peat depth – 0.5 to 1.5 m
- Slope angle > 9 degrees on some sections of the track

Extract from peat stability risk map:



Recommended Location Specific Mitigation:

This track section comes within ca. 50 m of the mapped location of the headwaters of the Crook Burn watercourse. The route has been carefully chosen to balance the risks of peat slide and minimise the environmental effects of earthworks, and is constrained by steep topography, so micrositing options are limited.

The following mitigation is recommended along this track section in order to reduce the peat stability risk:

1. Detailed design should consider whether it is possible to move this section of the track to the south away from the watercourses into the low risk area. Although it is recognised this may not be achievable due to the steep topography and the need to limit track gradients.
2. Alternatively, consider installation of downslope retaining systems to prevent peat material entering the watercourse.
3. If detailed design proves floating road is safe to use, this should be the preferred method of track construction to reduce the effects on the peatland by avoiding excavations.
4. Detailed design should consider whether it is possible to move the met mast and its link track to the south of the main track into the low risk area.
5. Install cross track drainage which prevents any ponding or build up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained.
6. No stockpiling or surcharging of the peatland in the medium/ high risk areas.

Track Section: T16-T17 & Met Mast

7. A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat and condition of the watercourse. A rapid reaction strategy should be in place during construction to ensure measures can be deployed to protect the watercourse in the event of any movement.

A8.6 RISK CONTROL MEASURES

- A preliminary risk register for the development wide hazards are listed in Table 8.14 below. Key mitigation/ control measures for these hazards have also been identified. A geotechnical risk register should be utilised throughout the construction phase and amended accordingly if/ when new information is received.

Table 8.14: Preliminary risk register

Hazard	Cause	Consequence
Peat Landslide / Bog Burst / Peat Flow	High rainfall, and increased surface water infiltration leading to build up of pore water pressure	• Instability of peat deposits and underlying superficial deposits around earthworks. • Contamination of natural watercourses and damage to hydrological systems. • Harm to personnel and damage to plant / equipment. • Destruction of built infrastructure
Mitigation	• Due consideration given to prevailing ground and weather condition when scheduling construction works. i.e. avoid opening new excavation during heavy precipitation and ensure sufficient drainage measures are in place to support construction activities. Ensure a contingency is in place to concentrate on more suitable construction activities during wet weather. • The drainage design should be such that its construction is in sequence with providing necessary drainage to new areas of excavation and construction in advance of works. I.e. ensure cut-off ditches are in place prior to opening new excavation. • The drainage design should as far as practicable preserve the natural hydrological regime and should not inundate areas with run-off which were previously not subjected to such affects. • Monitoring weather forecast with site specific weather station. • Monitoring (visual) regular site inspection to detect early indications of ground movement (tension cracks, groundwater issues). •	
Peat Landslide / Bog Burst / Peat Flow	Concentrated loads placed at the top of slope system or on marginally stable peat deposits	• Contamination of natural watercourses and damage to hydrological systems. • Rapid ground movement and mobilisation of material down slope of construction operations; Harm to personnel, plant and equipment. • Destruction of temporary or permanent construction works;
Mitigation	• At these locations, robust and strict controls on the phasing and pace of construction must be in place. This would be most effectively managed through the CMS. Plant operatives should be briefed in detail regarding the side-casting and stockpiling of materials. Medium to high risk areas particularly should be demarked by high visibility ticker tape or similar as a warning not to stockpile any materials in the deeper peat areas. • Ensure the peat depth contour mapping is available and has a high visibility during construction.	

Hazard	Cause	Consequence
	• A programme of frequent inspections should be implemented during excavation and access track construction works. This should be carried out by suitably experienced and qualified personnel. • Where stockpiles are placed in suitable areas, these should be closely monitored through the use of high accuracy GPS level and visual survey. •	
Peat Landslide / Bog Burst / Peat Flow	Uncontrolled surface water flows	• Rapid erosion around and within temporary and permanent earthworks leading to a destabilising effect on peat slopes, loss of toe support and or increase of pore pressures through increased rates of infiltration.
Mitigation	• Detailed drainage design undertaken with sufficient capacity to buffer the effects of short periods of high intensity rainfall, perhaps though the implementation of buffer/ settlement ponds to collect surface run-off and release at a slower rate. The positioning of such elements should be at locations at low risk of peat instability. • Geotechnical supervision of major de-watering operations should be in place to ensure outflows are not being directing into terrain at higher risk of peat instability. • Due consideration should be given to prevailing ground and weather conditions when scheduling construction works.	
Peat Landslide / Bog Burst / Peat Flow	Inadvertent removal of toe support to slope system	• Localised instability associated with temporary and permanent earthworks. • Harm to personnel and equipment/plant through mass movement of peat and spoil. • Long term ground movements/ creep, causing deterioration and damage to temporary and permanent earthworks. • Contamination of natural watercourses and damage to hydrological systems from peat material mobilised down slope;
Mitigation	• Avoidance action during geotechnical design stage. • Routine geotechnical inspection. • Contingency plans for slope stabilisation measures. This could involve the provision of engineered toe support to affected slopes comprising gabion style retaining structures.	
Peat Landslide / Bog Burst / Peat Flow	Increased subsurface groundwater flow and 'piping' failure beneath natural peat deposits, temporary and permanent earthworks	• Localised instability associated with temporary and permanent earthworks. • Triggering of mass movement of peat material down slope causing harm to personnel, plant and equipment;
Mitigation	• Ensure geotechnical design prevents blockages of groundwater flow. This may be achieved through the use of free draining fills and ensuring temporary and permanent earthworks do not cause the build-up of groundwater pressures.	

Hazard	Cause	Consequence
	• A programme of geotechnical inspections should be implemented throughout construction phase. Ensuring focus extends beyond immediate areas of construction, both up-slope and down-slope to detect any unforeseen effects on stability.	
Bearing Capacity Failure (Peat Surface)	Increased loading of low shear strength deep peat deposits	• Localised instability and settlement associated with temporary and permanent earthworks. • Triggering of mass movement of peat material down slope causing harm to personnel, plant and equipment. • Contamination of natural watercourses and damage to hydrological systems from peat material mobilised down slope;
Mitigation	• Due consideration given to the prevailing ground and weather conditions when scheduling site works. • Ensure detailed peat depth contour plan to be used in construction planning and design. • Use of appropriate plant machinery (low ground pressure and long reach to avoid over loading peat deposits). • A programme of geotechnical inspections will be implemented during excavation works. • Geotechnical monitoring post-construction. •	
Peat Failure	Mass movement of temporary storage mounds and bunds	• Localised instability and settlement associated with temporary and permanent earthworks. • Triggering of mass movement of peat material down slope causing harm to personnel, plant and equipment.
Mitigation	• Storage site selection and stockpile design by a suitably qualified and experienced geotechnical engineer. • In general, the temporary storage of peat in a single dedicated are shall be avoided wherever possible. • Peat storage height shall not exceed 1 m. • Routine maintenance and inspection of peat storage mounds. • Additional mitigation measures as described in Peat Management Plan for Proposed Development. •	
Creep, long term settlement of structures	Tracks or hardstand founded on peat and or poor or variable foundation soils	• Ongoing settlement and damage of infrastructure, e.g. damage to access track running surface.
Mitigation	• Contingency of routine maintenance of infrastructure and drainage elements to ensure longer term issues do not cause a build-up of effects leading to higher level consequences e.g. larger scale instability.	

Source: Natural Power

A8.7 CONCLUSIONS & RECOMMENDATIONS

Conclusions

A8.7.1 The peat depths across the site are predominantly in the range 0.0-0.5 m, with a mean peat depth calculated to be 0.56 m. It should be noted that where peat probes indicate shallow depths 0.1 m to 0.3 m that the deposits are likely to be composed of a topsoil and mineral subsoil.

A8.7.2 The recorded peak un-drained shear strength (Cu) ranged from 17 kPa to 80 kPa with a mean value of 45 kPa. This indicates peat of low to medium shear strength.

A8.7.3 The assigned risk rankings are a combination of the overall likelihood with the potential effect of a peat landslide event. With increased proximity to watercourses exposure of such an event is vastly increased as watercourses act as a sensitive off-site receptor and pathway to affect infrastructure downstream.

A8.7.4 The initial risk rankings are based on the risk of peat failure occurring without appropriate mitigation and control measures in place during construction. It should be highlighted that through geotechnical risk management, strict construction management and implementation of relevant control measures, this shall reduce the risk of peat failure across the development to residual low to negligible levels.

A8.7.5 The risk assessment should be reviewed following intrusive ground investigation. The respective risk ratings should be central to development of the Construction Method Statement (CMS) in order to ensure that extra care is taken with respect to the contributory factors at the time of the construction process and that geotechnical risk is adequately managed.

Recommendations

A8.7.6 The risk assessment cites key control measures which are required to reduce the risk of peat slide to acceptable residual levels. However, there should be wider consideration of these measures across all areas of the Proposed Development which may be influenced by the proposed construction. This is critical where infrastructure may affect terrain and slope conditions beyond the proposed working areas.

A8.7.7 It is recommended that detailed design should consider whether it is possible to microsite or realign those sections of track identified as being within medium and high risk ranking areas, and also move the met mast adjacent to turbine T16. However, any alterations to the proposed layout must be considered in the context of the overall site design.

A8.7.8 The use of floating tracks is also recommended in areas of deep peat to minimise construction effects.

A8.7.9 The following risk mitigation should be in place with regards to peat storage locations / techniques:

- Storage site selection and stockpile design would be undertaken by a suitably qualified and experienced engineer, and should be in accordance with the rules set out in the project PMP.
- In general, the temporary storage of peat in a single dedicated area shall be avoided.
- Peat storage on areas of low / negligible peat slide risk only.
- Peat storage height shall not exceed 1 m.
- Routine maintenance and inspection of peat storage areas would be undertaken.

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A8.9 GLOSSARY

Term	Definition
Acrotelm	The thin aerobic zone at the surface of the mire usually fibrous and containing the majoring of groundwater flow through the peat mass, underlain by the thick anaerobic zone called the catotelm, usually a higher degree of humification and lower shear strength.
Bog Burst / Flow	Failure of a raised bog (i.e. bog peat) involving the break-out and evacuation of (semi-) liquid basal peat. A flow is formed of highly humified basal peat from a clearly defined source area.
Bulk Density	The normal in situ density of a soil, i.e. its mass divided by its volume.
Catotelm	see acrotelm.
Consolidation	The process by which a soil decreases in volume.
Construction Method Statement	(CMS), a detailed written description of how a particular construction activity will be carried out safely and in an environmentally compliant manner.
Diamicton	Glacially derived soil which is poorly sorted and contains soil particles ranging in size from clay to boulders.
Geographical Information System (GIS)	Form of technology capable of capturing, storing, retrieving, editing, analysing, comparing and displaying spatial environmental information.
Geo-hazard	Geological hazard, either natural or man-made, which threatens either humans or the environment in which they live.
Geo-membrane	Non-porous sheet that has a very low permeability (in engineering terms impermeable) usually formed of polyethylene.
Geo-textiles	Man-made fabrics, generally made from plastics but also may be made from natural materials, used in construction.
Groundwater	Water located beneath the ground surface in soil pore spaces and in the fractures of rock formations.
Ground Investigation	Specialist intrusive phase of site investigation with associated monitoring, testing and reporting to a national standard.
Hagg	Natural gully or weathering structure in surface of peat mass.
Hazard	Something with a potential for adverse consequences / harm.
Humification	The process of decomposition of a peat soil.
Hydrological regime	The statistical pattern of a river's constantly varying flow rate.
Mitigation	The limitation of undesirable effects / impact of a particular event.
Mitigation Measures	Actions in place to limit the undesirable effects / impact of a particular event.
Peat Slide	Failure of a blanket bog involving sliding of intact peat and the mineral substrate material or immediately above the contact with the underlying mineral soil substrate.
Peat debris slide	Shallow translational failure of a hillslope with a mantle of blanket peat in which failure occurs by shearing wholly within the mineral substrate and at a depth below the interface with the base of the peat such that the peat is only a secondary influence on the failure.
Permeability	The rate at which water and air moves through a soil.
Pore water	The water filling the voids between grains of soil
Primary consolidation	The process by which a soil decreases in volume through the expulsion of internal pore water
Overland flow	Water passing rapidly over or through the surface layer of soil.
Peat	A largely organic substrate formed of partially decomposed plant material
Precipitation	Deposition of moisture including dew, hail, rain, sleet and snow.
Quartzite	A metamorphic rock composed primarily of quartz and formed from the metamorphism of sandstone.
Risk	The combination of the probability of an event and the magnitude of its consequences
Residual Risk	The risk remaining after mitigation measures have been undertaken.
Rockhead	The upper surface of rock mass beneath the superficial soil cover.
Runoff	Surface runoff is the flow of water over the surface that can result due to the surrounding soils lacking the capacity to infiltrate further water or due to the surface water flowing off infrastructure such as access tracks and hardstands.
Secondary Consolidation	The compression of a soil that takes place after primary consolidation due to creep, compression of organic matter etc.
Sedimentation	The tendency for particles in suspension to settle out of the fluid in which they are entrained.
Site Investigation	The overall process of discovery of information concerning a site, the appraisal of data, assessment and reporting. Can include desk, non-intrusive and intrusive investigation.
Shear strength	The maximum shear stress which a material can withstand without rupture/ failure
Shear vane	In situ test using a x4 blade steel vane pushed into the ground and rotated to provide an indication to the undrained shear strength of a soil.
Superficial Deposits	Young, sediments and soil deposits occurring at the surface.
Surcharge	An additional mass of material or load applied to an existing soil or structure
Topography	The physical features of a geographical area.
Undisturbed Sample	A sample of soil whose condition is sufficiently close to the actual condition of the soil in situ to be used to approximate the properties of the soil in the ground.
Water resources	The supply of groundwater and surface water in a given area.