Bloch Wind Farm

Technical Appendix 9.3: Peat Slide Risk Assessment

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Renewables Energy System Limited

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Contents

1. Introduction

This report details the Peat Stability Risk Assessment undertaken for the proposed Bloch Wind Farm (here after referred to as the proposed development). The proposed development comprises 21 wind turbines and ancillary infrastructure, including access tracks, borrow pits, substation and battery energy storage system compounds.

This document is a Technical Appendix to Chapter 9: Hydrology, Hydrogeology, Geology and Soils of the Environmental Impact Assessment (EIA) Report and should also be read in conjunction with Technical Appendix 9.2: Peat Management Plan (PMP).

The layout of the proposed development and relevant mapping is presented in Volume 2 of the EIA Report:

- Figure 9.6: Peat Depth Interpolation
- Figure 9.7: Peat Slide Risk
- Figure 9.9: Bedrock Geology
- Figure 9.10: Superficial Geology
- Figure 9.11: Slope Angle Map
- Figure 9.12: Artificial and Natural Drainage Networks

1.1. Reporting Author

Report Author – Allan Rutherford is a Principal Geotechnical Engineer at Natural Power and engineering geologist by training (MSc Engineering Geology) and is a Fellow of the Geological Society of London. Allan has over twenty years industry experience in engineering geology and geotechnical engineering, including 11 years working for Natural Power on wind energy projects. He is experienced of carrying out on site assessments, terrain evaluation, site investigations and peat stability risk assessments for sites across the UK.

1.2. Summary of Development

The proposed development will comprise of up to 21 wind turbines. Wind farm infrastructure will also be required in the form of external wind turbine transformer housings, crane hardstand areas, substation and battery energy storage system compounds, underground electricity cables between the wind turbines, access tracks, water crossings and drainage measures. A full description of the proposed development is provided in Chapter 3: Project Description of the EIA Report.

1.3. Peat Slide Hazard – Risk Assessment Method

Natural Power Consultants carried out the peat stability assessment following the principles of the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Government 2017) hereafter referred to as PLHRAG, (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.

Assessment of potential instability at the proposed development was carried out according to the following work programme:

- Desk Study and review of existing site information.
- Web searches, local knowledge and discussions with adjacent operational wind farm operators.
- Site reconnaissance survey (August 2022). This comprised a walkover survey of the site and identification of potential geo-hazards.
- Desk based aerial image review of open-source available Google Earth and Bing Aerial Images (August 2022).
- Review of historical mapping and historical aerial imagery.
- Site-wide peat probing survey comprising: An initial site wide peat probe survey on a grid resolution of 100m (March 2022), Phase 1 survey.
- Detailed peat probing survey covering the proposed development at higher resolution (August 2022), Phase 2 survey.
- Assessment of peat undrained shear strength through in-situ hand shear vane testing across representative wind turbine locations (August 2022), Phase 2 survey.
- Site-wide mapping and assessment of salient features such as active, incipient or relic instability within the peat deposits, geomorphological features, peat depth and composition (August 2020), Phase 2 survey.
- Peat coring at selected wind turbine locations and targeted wider across the site. Peat coring including Von Post humification classifications with depth to inform the Peat Management Plan. Core samples were examined by hand, and samples were submitted to the laboratory for testing for Carbon content of dry peat (% by weight) and Dry soil bulk density (g/cm^3) for input into Technical Appendix 9.7: Carbon Balance Assessment.
- Quantitative slope stability assessment based on in-situ shear strength data.
- Assessment of the potential risk of peat failure across the site.
- Comparison of the potential risk of peat failure with the site hydrological model including proximity to watercourses and sensitivity of those features.
- Recommendations for detailed design and construction control with specific examination the need for measures to mitigate potential peat failure as part of any future wind farm development.

1.4. Processes Contributing to Peat Instability

To provide a framework for the assessment this report highlights peatland processes which influence peat failure. Discussion of the destabilising factors which can contribute to peat failure are discussed below:

Groundwater Infiltration

There are two main processes which control groundwater infiltration: These are periods of drying, resulting in cracking of exposed peat surfaces and slope creep resulting in additional tension cracks.

Surface Loading

Any mechanism which increases the load on peat can increase the likelihood of failure. This can include continued peat growth, increased water content and surcharge loading. For example, construction works, stockpiling and forestry operations. Unloading can cause failures. for instance, the cutting of peat causing removal of a toe slope support to the upslope material. Cyclical loading over a short frequency (e.g., repeat heavy vehicle movements) may also contribute to peat failure through strain softening of the peat.

Vegetation

Factors which alter the surface vegetation are important particularly if the vegetation provides strength to the peat deposit through a dense fibrous root network. Loss of vegetation can therefore have a negative impact, making the peat susceptible to weathering and increased rates of infiltration.

Weathering

Weathering can weaken in-situ peat materials and destabilise a slope system. This may be in the form of weathering of exposed peat or the underlying mineral soils which could reduce shear strength at the basal contact with the peat. Internal 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 long-term weathering processes are active. Peat hags expose the peat to increased weathering rates and may provide preferential surface water flow pathways.

Base of Peat Soil/Rock Interface

Peat slides can occur at the interface with the underlying soil substrate such as soft clays. The presence of peat over time can lead to softening of underlying clays. The underlying material may also provide a layer with very little frictional resistance for which the peat to slide on. These are often referred to as ‘impermeable iron-pans’ or for example where peat is resting on a planar bedrock interface.

Precipitation

A dominant trigger for peat failures are intense rainfall events. Documented failures are associated with extreme rainfall events; reference is made to the Llyn Ogwen peat failure documented by Nichol et al., (2007). The Derrybrien Wind Farm final report on landslide of October 2003 AGEC, (2004) provides further evidence. An example is also highlighted in the characteristics of the Shetland Isles (UK) Peat Slides of 19 September 2003, Dykes & Warburton, (2008). The aforementioned ‘A5’ Llyn Ogwen Peat Slide of 2005 is a useful example of a rainfall induced slide. Peat deposits were approximately 1m thick with undrained shear strength of 10-15kPa.

The likely failure mechanism following a period of heavy rainfall is linked to the infiltration of surface water into the ground. There is a resulting build-up of pore water pressures 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 and is a potential factor across upland terrain.

Slope Morphology

Several case studies on peat failures note the presence of a convex break in slope (Dykes & Warburton 2008). There are three main effects of such terrain 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 below the ‘roll-over’ maintains the apex in tension. The roll over is particularly vulnerable to additional destabilising forces in addition to propagation of tension cracks.
- Secondly, it can be postulated that at the point of maximum slope convexity, because of the favourable down-slope drainage conditions (below the roll over), 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 a dam, 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 resulting in a breach and loss of lateral support to peat upslope.

The assessment seeks to identify any significant slope features where these are coincident with proposed development infrastructure.

Peat Depth & Slope Angle

The PHLRAG, (2017) guidance provides the following information on peat slides with respect to peat depth and slope angle:

'Peat slide – slab like shallow translational failure, with a shear failure mechanism operating within a discrete shear plane at the peat substrate interface, below this interface, or more rarely within the peat body. The peat surface may break up into large rafts and smaller blocks which are transported down slope mainly by sliding. Rapid re-moulding during transport may lead to the generation of organic slurry in which blocks of peat are transported.'

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, (2006) 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, (2006).

For the purpose of this technical appendix 'deep peat' is defined as any peat deeper than 1.0m as defined in PHLRAG, (2017).

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 several 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.

Peat depth and slope angle indicators for probability of peat failure have been similarly adapted from MacCulloch, (2006). Maps showing the interpolated peat depth (Figure 9.6) and slope angle (Figure 9.11) across the proposed wind farm development site are appended to this report.

To prepare the "Interpolated Peat Depths" a spatial interpolation method termed 'Ordinary Kriging' was applied. Ordinary Kriging, as opposed to other types of Kriging, assumes spatial autocorrelation but does not assume any overriding trends or directional drift. This is therefore considered a good option for contours of peat depth. The output cell size was set at 10m, the search radius fixed at 100m with a spherical semi-variogram model used. The Kriging algorithm considers multiple data points close together, giving greater weight to the points most proximal.

The Slope Angle Map is comprised from the Digital Terrain Model derived from Ordnance Survey 'OS Terrain 5', carrying a grid resolution of 5m. The risk assessment considers slope angle across two areas. Firstly, the slope angle is used to screen the site for instability within the slope analysis numerical calculation. This is adjoined to assessment of the slope angle category in terms of a contributory factor to failure. This combined approach ensures a robust assessment of the risk and increases the sensitivity of the assessment to characterise risk more accurately across an expansive area.

Drainage

Natural and artificial drainage measures designed to reduce the water content in the peat 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 over time. Within a peat mass, 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 man-made drainage networks, although it is noted no forested areas are present within the site.

Recurrent Failures

The clustering 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 here.

Pre-existing Weak Layers

Several peat failure reports identify the possibility of relative weaker layers within the peat mass (AGEC, 2004). In most cases, these weak layers are at the base of the peat deposit where there is usually the highest degree of peat humification and lowest relative peat strength. Alternatively, where failure is triggered by the ingress of water into the peat, there is a tendency for water to build-up at the base of the peat causing a reduction in effective stress at the base of the peat which can contribute to eventual failure. During construction existing peat drains are likely to be altered and care will need to be taken to avoid increased ingress of water.

Anthropogenic Effects

Man-made impacts on peat environments can include a range of affects associated with wind farm construction. Activities such as drainage, 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.

1.5. Peat Failure Definitions

Peat failure in this assessment refers to the mass movement of a body of peat that would have a significant adverse impact 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.

The potential for peat failure at this site is examined with respect to the activities envisaged during construction and operation of the proposed Bloch Wind Farm. There are several classification systems for the mass movement of peat that were drawn together by PLHRAG, (2017) and by AGEC at Derrybrien in Ireland.

Hutchinson (1988) 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. Bog Bursts occur at slope ranges of 2°-5° while peat flows are not constrained by slope angle.
- **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.

Due to the largely open topographic relief across the proposed development, peat slides are considered the dominant mode of potential peat failure. Where impacting a watercourse these would potential evolve into a peat flow. Bog bursts are rare across the UK but have the potential to occur locally. Consideration should be given to the potential for peat slides as a result of the slope geometry over discrete parts of the development area. Peat depths are generally shallow (<1.0m) across most of the proposed development and when possible infrastructure has been positioned away from the deepest zones of peat.

1.6. Geotechnical Principles

The main geotechnical parameters that influence peat stability are:

- Shear strength of peat.
- Peat depth.
- Pore water pressure (PWP).
- Loading conditions.

The stability of any slope is defined by the relationship between resisting and destabilising forces. In the case of a simple 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.

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.

The infinite slope model as defined in Skempton et al. (1957) has been adapted to determine the FoS of a slope. A modified approach has been used; assuming a minimum FoS (Typically 1.3 after, BS6031: 2009).

Infinite Slope Analysis

The purpose of the analysis is to identify the baseline FoS at each proposed wind turbine foundation. A Factor of Safety (FoS) of 1.3; based on BS6031:2009: Code of practice for Earthworks (BSI, 2009) has been used.

The infinite slope analysis is based on modelling 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 PWP dissipate. (PWP requires time to dissipate as the hydraulic conductivity can be low in peat deposits). The following assumptions were used in the analysis of peat deposits across the proposed development:

- The groundwater is resting at ground level.
- Minimum acceptable factor of safety required is 1.3.
- 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.
- In the surcharged case a 20kPa stress is modelled, this is approximately equivalent to a 2m high peat stockpile or 1.5m high subsoil stockpile.

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, (2006) and originally reported by Barnes, (2000):

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

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).

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.

1.6.1. Assumptions

The slope angle of the ground surface does not necessarily represent the true slope angle at the base of the peat. In the absence of more detailed intrusive site investigation data, the surface slope angle gives an indication of the likely slip surface angle at the base of the peat. It should be highlighted that a key controlling factor on potential instability may be the internal structure of the peat and not the underlying interface with the superficial deposits.

The occurrence of a severe rainstorm event controlled by meteorological factors is only in-directly evaluated by this assessment. Natural Power considers blanket peat on upland sites would be more susceptible to intense rainstorm events due to the larger catchment potential across the peat surface. The wide range of contributory factors included in this assessment are indirectly linked to rainfall and precipitation.

The thinning and cracking of peat can allow ready ingress of surface water into the base of the peat mass. Deeper deposits of peat may therefore be less likely to be affected by cracking. The preliminary analysis assumes that the groundwater rests at ground level. This is conservative and considered a worst-case scenario for the proposed wind farm development.

For the numerical analysis; the assumption was made that the ground surface is loaded by a nominal vertical 20kPa surcharge. Vehicle trafficking, construction of access roads and stockpiling of peat/soil during excavations all cause an increase in applied stress which can, without engineering control, increase the risk of peat slide. Surface loading in particular has been shown to have resulted in a number of construction stage related peat failures. The effects of cyclic loading are also not covered by the scope of the slope stability model. It is further highlighted that loading rates can be important in managing peat deformation under construction conditions.

1.7. Assessment Methodology

A semi-quantitative risk assessment has been used to determine the risk of peat failure and hence impact on the proposed development and surrounding environment. The methodology is well defined in PLHRAG, (2017) and has been further augmented with methods set out by Clayton (2001). It is important to highlight the assessment draws upon experiential and subjectively assigned parameters.

This assessment has analysed terrain conditions across the proposed development and utilised this information to create the *preliminary* peat slide risk map, (Figure 9.7).

In support of the peat slide risk mapping, the Environmental Impact Zonation (EIZ) has assessed the potential for a peat failure to detrimentally impact surface water courses. The EIZ is based on proximity buffer zones applied to the main sensitive watercourses within the proposed development. The mapped water courses at 1:25,000 scale have been determined to be the primary sensitive receptors to a peat failure event. Table 1.1 and Table 1.2 denote the impact scales (adverse consequence) to the *environment and to the development.*

Table 1.1: *Environmental Impact Scales*

Criteria / Exposure	Environmental Impact (Ei)	Impact Scale
Infrastructure <50m of watercourse	**High**	**4**
Infrastructure within 50-100m of watercourse	**Medium**	**3**
Infrastructure 100-150m of watercourse	**Low**	**2**
Infrastructure >150m from watercourse	**Negligible**	**1**

Source: MacCulloch (2006)

Table 1.2: Development Impact Scales

% of damage to (or loss of) receptor	Impact Level (Adverse Consequence)	Impact Scale
> 100% of asset	**Extremely High**	**5**
10% - 100%	**Very High**	**4**
4% – 10%	**Medium**	**3**
1% - 4%	**Low**	**2**
< 1% of asset	**Very Low**	**1**

Source: PLHRAG (2017)

The proximity values are developed from a literature review and designed such that this parameter does not skew the assessment or override other key contributing factors. Where this linear approach leads to an overstating of the risk, the assessor has applied corrective factors to ensure results are not unrealistic.

Risk Assessment Ranking across the wind turbine locations is presented in Table 4.1. The assessment uses the following contributory factors to peat failure, identified from desk study and the detailed peat survey:

- Slope angle evaluated during field reconnaissance and OS digital elevation model (Volume 2, Figure 9.11);
- Peat depth determined during a multi-phased probing survey (Volume 2, Figure 9.6);
- FoS evaluated from infinite slope analysis;
- Limited evidence of groundwater flow;
- Surface water flow from maps and site walkover observations (Volume 2, Figures 9.1 & 9.12);
- Evidence of previous slope instability within the site wide geomorphological setting; and
- Land management, qualitative based on previous site use.

Probability values for each contributory factor are summarised on Table 1.3 along with a brief discussion of the influencing factors.

Table 1.3: Contributary Factors and Probability Values

Contributing 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	Negligible	1
		>3.0m	Unlikely	2
		0.5 – 1.0m	Likely	3
		2.0 – 3.0m	Probable	4
		1.0 – 2.0m	Almost certain	5
Slope Angle **(B)**	It has been acknowledged that peat slide tends to occur in shallow peat (up to 2.0m) on slopes between 5° and 15°.	0 – 3°	Negligible	1
		>20°	Unlikely	2
		4 – 9°	Likely	3

Contributing Factors	Comment	Criteria	Probability	Scale
	Slopes above 20° tend to be devoid of peat or only host a thin veneer deposit.	16 – 20°	Probable	4
		10 – 15°	Almost certain	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	Negligible	1
		1.29-1.20	Unlikely	2
		1.10-1.19	Likely	3
		1.00-1.09	Probable	4
		<1.0	Almost certain	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.	None	Negligible	1
		Few	Unlikely	2
		Frequent	Likely	3
		Many	Probable	4
		Continuous	Almost certain	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	Negligible	1
		Few	Unlikely	2
		Frequent	Likely	3
		Many	Probable	4
		Continuous	Almost certain	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. Artificial drains (grips) have also been identified across the site. Their presence is generally linked to historical peat cutting sites or land drainage which are factored into the risk assessment.	None	Negligible	1
		Few	Unlikely	2
		Frequent	Likely	3
		Many	Probable	4
		Continuous	Almost certain	5
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	Negligible	1
		Few	Unlikely	2
		Frequent	Likely	3
		Many	Probable	4
		Continuous	Almost certain	5
Land Management **(H)**	Anthropogenic influences: forestry operations 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. **For this project the assessment identifies artificial peat drains – where these are mapped as an extension to the head of natural water courses on 1:10,000 scale dataset, a land management scale of '2' has been chosen.**	None	Negligible	1
		Few	Unlikely	2
		Frequent	Likely	3
		Many	Probable	4
		Continuous	Almost certain	5

Source: Natural Power

Table 1.4 below provides an illustration of how the qualitative description of likelihood relates to the numerical probability of a peat landslide occurring.

Table 1.4: Peat Landslide Probability Ranges

Scale	Likelihood	Probability of Occurrence
5	Almost certain	>1 in 3
4	Probable	1 in 10 – 1 in 3
3	Likely	1 in 10^2 – 1 in 10
2	Unlikely	1 in 10^7 – 1 in 10^2
1	Negligible	< 1 in 10^7

Source: PLHRAG (2017)

The aforementioned factor of safety has been introduced for two reasons: to rapidly assess the stability condition of the terrain across the proposed infrastructure elements and; allow a holistic ground model, through the use of the basal shear strength values to indicate propensity for failure along the basal peat interface. It is acknowledged that inclusion of FoS captures the slope angle and peat depth parameters a second time in the assessment. Natural Power considers this approach to provide a robust and conservative approach where the FoS factor has an ability to resolve multiple factors and their contribution to risk where otherwise standalone, each factor may have a lower contributing effect on the assessment.

The FoS analyses the ratio of ground resistance to disturbing forces and its use was introduced to the assessment following review of the guidance produced by MacCulloch, (2006). Where ground resistance is equal to disturbing forces, the FoS is at unity (equal to 1.0) and the ground should be considered to be at a point of limiting equilibrium and failing. A FoS greater than 1.0 would indicate a stable slope, and a FoS less than 1.0 would indicate an unstable slope.

Adoption of a narrow range in FoS values as indicated in Table 1.3 is derived from a ground engineering perspective. British Standard BS 6031, (2009), provides guidance on the design of both temporary and permanent earthworks. A design FoS of 1.3-1.4 is cited. The peat stability assessment has taken the upper bound value of 1.3 and a lower bound value of 1.0 to frame the FoS assessment as a contributory factor to failure. This range is considered to be in line with engineering best practice. Expanding this range beyond 1.3 would have a limited effect on highlighting any unstable slope conditions.

Additionally, the FoS approach used in the assessment ignores any passive resistance which would likely be present at the toe of a slope system. MacCulloch, (2006) to this effect states that: the FoS is a conservative estimate which considering the non-linear geotechnical behaviours of peat adds a degree of confidence to this aspect of the assessment.

Furthermore, the in-situ hand shear vane testing covered the deepest representative deposit of peat at each test location where peat depth was sufficient to carry out these tests, due to shallow peat depths spanning the site this was only possible at four wind turbine locations.

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 1.5 identifies the hazard ranking based on concepts of PLHRAG, (2017).

$$\textbf{Risk = Probability x Adverse Consequence}$$

$$\textbf{Risk Ranking = ((Sum A:H) if (A:H>1)) x (Ei)}$$

Table 1.5: Risk Ranking and Suggested Actions

Risk Ranking Zone	Control Measures
17 - >25	**High:** Avoid proposed 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)

Table 1.6 below further breaks down the Risk Ranking score into a risk matrix adapted from Clayton, (2001):

Table 1.6: 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)

Using the equation and scoring present in the above tables, a Peat Slide Risk Map (Figure 9.7) is created using raster calculations in QGIS. Each individual contributary layer is scored using Table 1.3, with scores of 1 being reset to 0 as they present a negligible risk and are not required to feed into the model. The layers are then ingested into the model using the Risk Rank Equation above. All information contributing to the peat slide risk map is pre-mitigation, i.e., the map does not consider any mitigation measures.

The map is then checked against manually calculated risk scores in Table 4.1.

2. Site Information

Location and Topography

The proposed development is located within an area of upland terrain dominated by higher ground to the north and the existing Solwaybank Wind Farm to the south/ south west.

The proposed development primarily occupies a broad undulating ridge line stretching from Collin Hags in the west to Bloch Hill in the east, with slopes aspects generally facing to the north or south of the highest ground leading downhill to various watercourses. The proposed development rises from approximately 160m AOD elevation in the centre of the site at Standing Bog, to a height of 271m AOD at Bloch Hill, which is the highest point at the eastern end of the site. There are occasional channels cutting across the slopes, and these are formed by small upland streams.

Site photos taken during the peat probing surveys are included within Appendix A to provide an overview of the general ground conditions and topography encountered.

Source: Google Earth Professional/ Natural Power

Figure 2.1: Aerial view across the proposed development

2.1. Desk Study and Site Reconnaissance

Desk Study

A desk study was completed as part of the peat stability risk assessment incorporating the geology, hydrology and hydrogeology. All relevant background data, including geomorphology, peat depths and water course information has been reviewed. This review of available literature, maps, and data was undertaken together with a general review of peat failures across the British Isles. The primary data sources with respect to the proposed development include:

- Historical Ordnance Survey Map review
- British Geological Survey (BGS) geology map data and historical borehole records.
- Aerial photographic records assessed on Google Earth Professional.
- SEPA Flood Map.

Review of the historical maps for the area dating back to 1885 confirmed the site has been largely undeveloped except for hill farming and occasional localised areas of forestry.

No significant changes were observed on the historical aerial maps between 1985 to present day. However extensive networks of peat drainage ditches can be seen all the way back to the earliest available photography.

No significant flooding risks were identified on the SEPA maps.

Further information on the baseline environment for the site is presented in Section 9.5, Chapter 9 of the EIA Report.

Site geology is discussed in detail in Section 2.2.

Site Reconnaissance

The site reconnaissance included a visual assessment of the superficial ground conditions across the site supplemented with peat probing and hand shear vane testing. Field investigation was carried out in accordance with PHLRAG, (2017). Disturbed samples were also acquired for visual inspection using a Russian peat corer. Samples were classified using the Von Post scale as outlined in Hobbs, (1986). The testing, sampling and probing methodology is summarised as follows:

- Peat probing at 100m intervals across the full preliminary site boundary (phase 1 survey).
- Peat probing at a minimum of 50m intervals; three probe locations aligned perpendicular to the access track alignment, one at the centre of the access track with two further probes spaced 10m from the centre on either side of the access track.
- Peat probing at all wind turbine foundations and crane hardstands across a 70m radius from the wind turbine centre at 20m probe spacing.
- Peat probing at the substation compound at 20m probe spacing.
- Peat probing at borrow pit search areas at 50m grid probe spacing.
- Peat coring at each wind turbine location where the peat probes confirmed peat depth was >0.5m, and selected access track sections of deeper peat (Appendix A). Peat coring including Von Post humification classifications with depth to inform the Peat Management Plan. Core samples were examined by hand, and samples were submitted to the laboratory for testing for Carbon content of dry peat (% by weight) and soil bulk density (g/cm^3) for input into Technical Appendix 9.7: Carbon Balance Assessment.
- Hand shear vane testing at wind turbine locations and along access track alignment where the peat probes confirmed peat depth was >0.5m to establish the approximate range of undrained shear strength values and variability with depth or humification (Appendix A).

Volume 2 Figure 9.6: Peat Depth Interpolation presents the interpolated peat depth across site. A total of 2,568 peat probe data points were acquired.

The largest area of deep peat was recorded in the central area of the site at Bloch Flow. The proposed development has been designed to avoid this area. Other smaller localised areas of deep peat were recorded around the fringes of the site.

The site walkover was used to identify key surface features across the development and determine the wider geomorphological features across the site.

2.2. Geology

Superficial Deposits

Peat is identified across the site as shown in the superficial geology map, in Volume 2: Figure 9.10: Superficial Geology. It is noted that the areas of peat align well with the data shown on peat depth interpolation map.

Peat forms a relatively shallow blanket deposit across higher plateau areas of the site. The blanket peat has formed deeper deposits in discrete areas across the site often in topographic depressions and near water courses.

Smith (2006) describes peat as a form of organic soil and is typically almost entirely comprised of lightly to fully decomposed vegetation. Peat can exist in one of three forms:

- Fibrous – Non plastic with a firm structure and only slightly altered by decomposition.
- Pseudo-fibrous – Peat in this form still has a fibrous appearance but is much softer and more plastic than fibrous peat. The change is due to more prolonged sub-mergence in airless water than to decomposition.
- Amorphous – With this type of peat decomposition has destroyed the original fibrous vegetation structure so that it has virtually become organic clay.

The peat encountered across the development was typically soft to firm dark brown, pseudo-fibrous, plastic, PEAT Von Post classes were variable in the range H4 – H8 (average H6 moderately highly decomposed peat), and with moderate moisture content estimated from visual assessment.

Two photos of typical peat cores taken across the site are presented below.

Source: Natural Power

Photograph 2.2: Peat Core at Wind Turbine T12

Source: Natural Power

Photograph 2.3: Peat Core at Wind Turbine T20

Peat core samples were submitted to the laboratory for Carbon content (% by weight) and dry soil bulk density testing.

Gretna Till Formation (Glacial Till) covers most of the site and is expected to be present below the peat. British Geological Survey (BGS) describes the formation as Reddish brown, sandy, silty, clayey diamicton with clasts of greywacke, red sandstone, siltstone and grey granodiorite. Uppermost 3m generally quite variable in lithology and compactness, with lenses of sand, gravel, silt and clay. Commonly becoming more compact and stony with depth.

Small, localised areas of moraine and sand and gravel deposits are also shown on the BGS mapping.

The total thickness of the Gretna Till Formation is indicated to be 20m, although the thickness of the glacial till deposits at the site is unconfirmed and likely to be variable. An historical BGS borehole located at Blochburnfoot to the north of the site (BNG ref 333230, 582290) recorded 8.25m thick superficial deposits.

Bedrock Geology

The 1:10,000 scale BGS data for the area shows the bedrock geology across the site to comprise three sedimentary rock formations:

- Ballagan Formation – covering the north west area of the site, described as grey mudstones and siltstones, with nodules and beds of ferroan dolomite (cementstones), the beds generally less than 0.3m thick.
- Border Group – covering the south area of the site, described as interbedded sandstones, siltstones and limestones, with conglomerate and ferroan dolostone ("cementstone").
- Whita Sandstone Beds – covering the north east area of the site, described as Medium to thickly bedded, fine- to coarse-grained white, grey and pink sandstones with a few thin siltstones and sandy cementstones.

The bedrock geology is shown in Figure 9.9.

2.3. Hydrogeology

The BGS Hydrogeological Map of Eastern Dumfries and Galloway (1990) indicates there are few records of wells boreholes in the sedimentary rocks underlying the site, with sustainable borehole yields of 3l/s and 5l/s having been proved in the region, and spring discharges through till north of Langholm amount to 10l/s of potable groundwater from a total of 22 sources.

Smaller scale maps indicate the bedrock geology to be a moderately productive aquifer with fracture flow and variable yields up to 6l/s to 10l/s.

2.4. Hydrology, Flooding and Draining

Detailed assessment of the hydrology, flooding and drainage of the site is provided in Chapter 9 the EIA Report.

The position of watercourses and their proximity to proposed development is a prominent criterion within this peat slide risk assessment. From this standpoint, Volume 2 Figure 9.7 clearly identifies the main surface watercourses across the site. The watercourses and how they pertain to peat slide risk is set out clearly in the assessment methodology. Surface water courses are a primary receptor when considering peat slide events and as such the position and proximity from proposed infrastructure is central to this assessment.

There are instances where the proposed development is within 150m of a mapped watercourse, however where these watercourses are minor and no off-site run-off is possible, the environmental hazard rating has been reviewed and reduced where considered appropriate.

Watercourses mapped at 1:25,000 scale have been used for the peat stability risk analysis in this report. This has been adopted because following detailed review of the 1:10,000 scale dataset and on site mapping it was clear that man-made peat drains have been mapped as watercourses. However, the man made drains are ephemeral and not considered to be sensitive environmental receptors in the context of the detailed risk assessment. Further information regarding the identification of natural and articial drainage features is presented in Technical Appendix 9.6: Watercourse Assessment.

An example of this can be seen at wind turbine T5: Photograph 2.4 shows a man-made peat drain which is mapped as a watercourse on 1:10,000 scale data running through the centre of wind turbine T5; however, the closest natural water course receptor is >150m away based on the 1:25,000 scale data and confirmed by on site mapping and on the ground observations.

Source: Natural Power

Photograph 2.4: Man-made peat drain at wind turbine T5 which is mapped as a watercourse on 1:10,000 scale data

2.5. Peat Data Analysis

Peat Probe Data

In total 2,568 peat probes were acquired across the site from the phase 1 and phase 2 surveys combined data. As can be seen in Chart 2.1, the majority of the peat depths recorded were less than 0.5m, with 77% of the total probes undertaken being between 0.0m to 1.0m in depth. A peat depth interpolation map was generated from the peat data and is presented in Volume 2: Figure 9.6.

Source: Natural Power

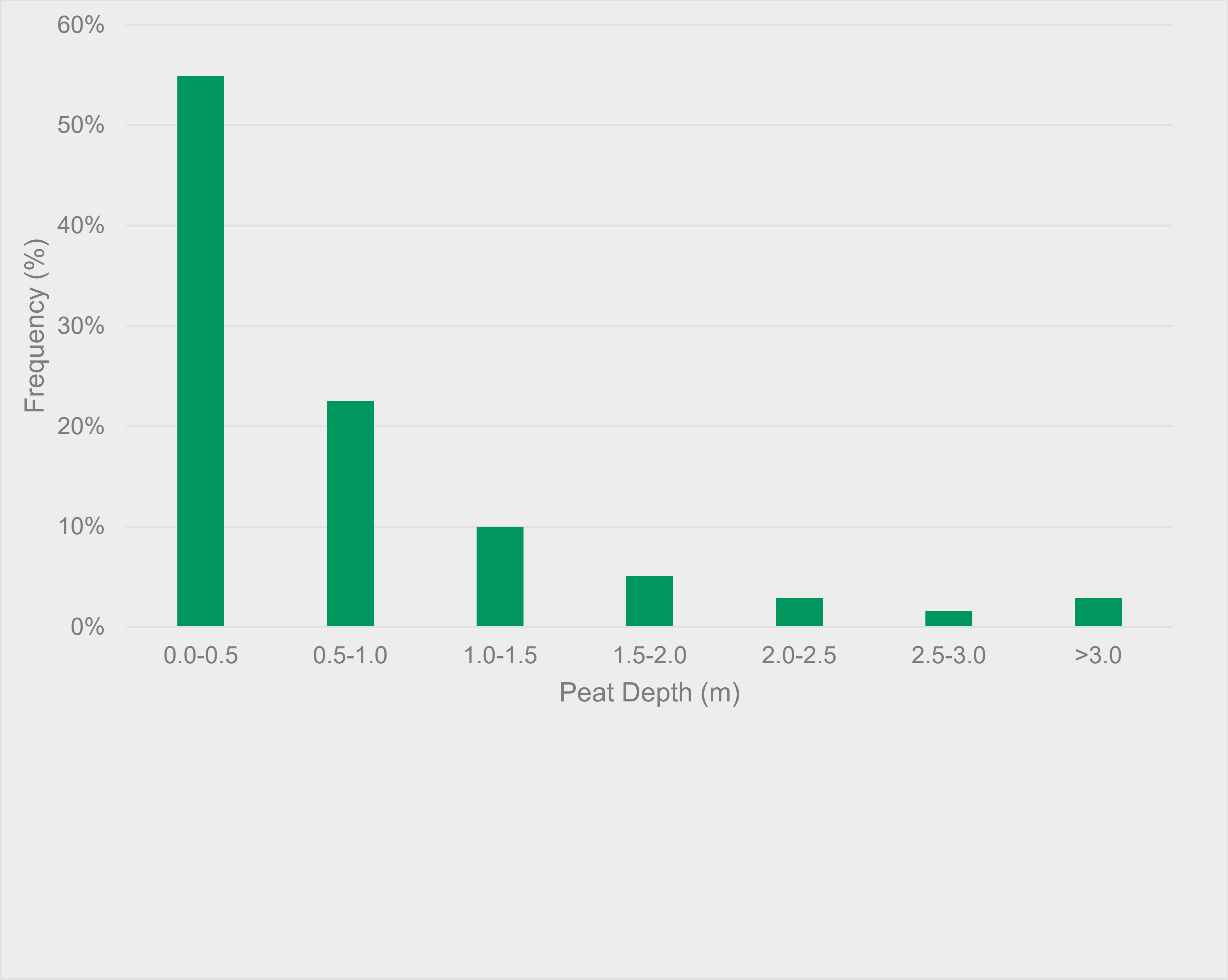


Chart 2.1: Peat Probe Depth

Peat Depth at Selected Locations

Table 2.1 summarises peat depths recorded across the proposed wind turbine locations and substation.

Table 2.1: Overview of Peat Depths at Wind Turbines and Substation

Depth Range	**0 – 1.0m**	**1.0 – 2.0m**	**2.0 – 3.0m**	**> 3.0m**

Location	**Mean Peat Depth (m) 50m radius**
T1	1.1
T2	1.6
T3	1.0
T4	0.3
T5	0.5
T6	0.7
T7	0.2
T8	0.4
T9	0.47
T10	0.4
T11	0.5
T12	0.33
T13	0.3
T14	0.2
T15	0.5
T16	0.3
T17	0.6
T18	0.3
T19	0.9
T20	1.4
T21	0.8

Source: Natural Power

Estimation of Peat Shear Strength

During Phase 2 surveys a 25mm ‘Geonor’ hand shear vane was used to record the undrained shear strength of the in-situ peat deposits at selected locations. The hand shear vanes (HSV) were only undertaken in areas where the peat was deeper than 0.50m and within 50m radius of the proposed wind turbine location. Additional tests were carried out along access track sections where deep peat was recorded. A total of 35 HSV tests were undertaken.

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 of 0.5m a torque head is rotated at the surface which turns the shear vane within the peat deposit. The maximum shearing resistance is recorded on the torque dial. This is representative of 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.

The shear vane has a small surface area compared to the larger scale soil structures 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 HSV therefore provides a preliminary value of peak and re-moulded un-drained shear strength. The peak un-drained shear strength (Cu) ranges from **26kPa to 64kPa** with a mean value of **43kPa**.

Chart 2.2 depicts the peak un-drained shear strength data with depth:

Source: Natural Power

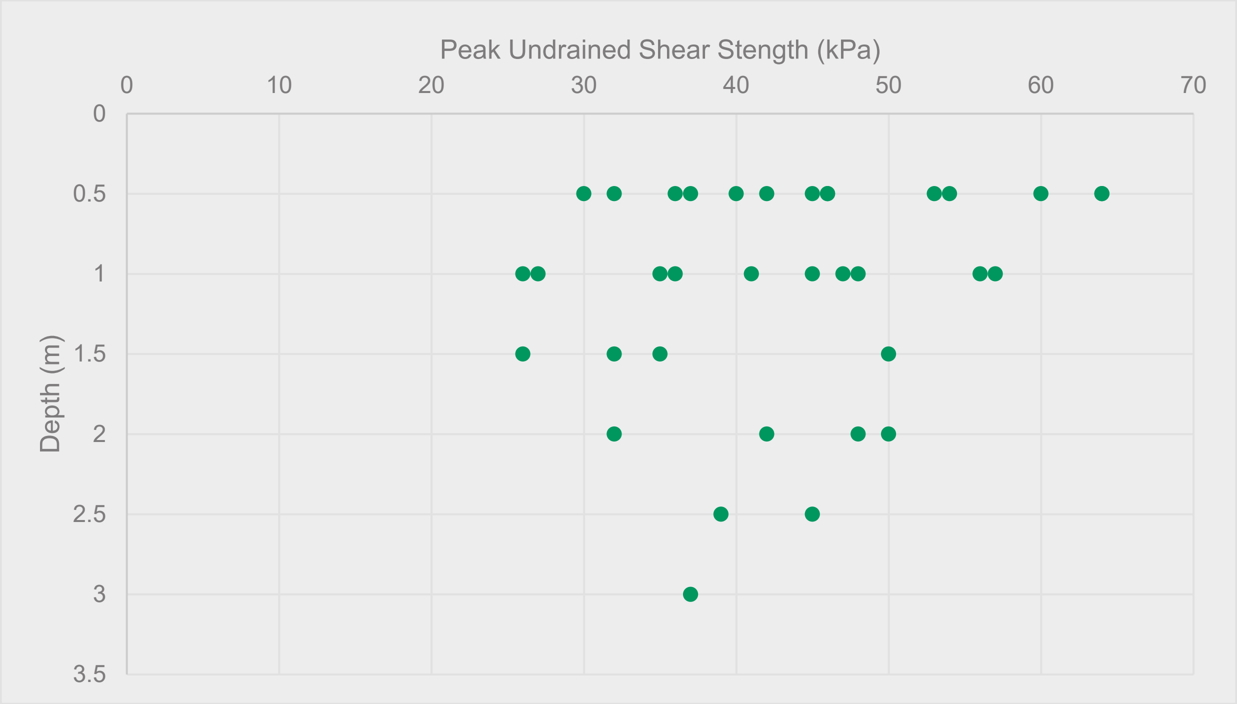


Chart 2.2: **Undrained Shear Strength of Peat Soils**

Humification of Peat

The material characteristic of the peat and specifically the degree of humification has been recorded at locations where peat was deep enough to obtain a core sample. The peat has been characterised according to the von Post Classification (Von Post & Granland, 1926). Table 2.2 sets out the classification and Table 2.3 presents the classifications at each location where a peat coring was undertaken. Peat coring was not undertaken at wind turbines T4, T5, T7, T8, T10, T11, T13, T14, T15, T16, T18 and T19 due to shallow depths of peat encountered.

Table 2.2: **Von Post Classification**

Degree of Humification	Peat Description
H1	Completely unconverted and mud-free peat which when pressed in the hand only gives off clear water. Plant remains are easily identified.
H2	Practically unconverted and mud free peat which when pressed in the hand gives off almost clear colourless water. Plant remains are still easily identifiable.
H3	Very slightly decomposed or very slightly muddy peat which when pressed in the hand gives off marked muddy water, but no peat substance passes through the fingers. The pressed residue is thickish. Plant remains have lost some of their identifiable features.
H4	Slightly decomposed or slightly muddy peat which when presses in the hand gives off marked muddy water. The pressed residue is thick. Plant remains have lost more of their identifiable features.
H5	Moderately decomposed or muddy peat. Growth structure evident but slightly obliterated. Some amorphous peat substance passes through the fingers when pressed but, mostly muddy water. The pressed residue is very thick.
H6	Moderately decomposed or very muddy peat with indistinct growth structure. When pressed approximately 1/3 of the peat substance passes through the fingers. The remainder extremely thick but with more obvious growth structure than in the case of unpressed peat

Degree of Humification	Peat Description
H7	Fairly well decomposed or markedly muddy peat but the growth structure can just be seen. When pressed about half the peat substance passes through the fingers. If water is also released this is dark and peaty.
H8	Well decomposed or very muddy peat with very indistinct growth structure. When pressed about 2/3 of the peat substance passes through the fingers and at times a thick liquid. The remainder consists mainly of more resistant fibres and roots.
H9	Practically completely decomposed or mud-like peat in which almost no growth structure is evident. Almost all the peat substance passes through the fingers as a uniform paste when pressed.
H10	Completely decomposed or mud peat where no growth structure can be seen. The entire peat substance passes through the fingers when pressed.

Source: Von Post and Granland (1926)

Table 2.3: Von Post Classification at Wind Turbine Locations

Location	Von Post Degree of Humification	Description
T1	**H6-7 / B2**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT
T2	**H7 / B2**	Soft to firm dark brown plastic, PEAT
T3	**H4-6 / B2**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT
T6	**H4-6 / B2-3**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT. 0.3-0.9m some woody material.
T9	**H7-8 / B3**	Soft to firm dark brown, plastic, PEAT. 0.4-1.2m with some wood then hits clay/sand.
T12	**H6-7 / B3**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT
T17	**H5 / B3-4**	Soft dark brown, pseudo-fibrous, plastic, PEAT. Water table just below surface.
T20	**H6-8 / B2-3**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT
T21	**H5 / B2**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT
Track T8-T9	**H8 / B4-5**	Soft dark brown, plastic, PEAT. 2.0-2.8m Difficult to get a decent core as it is so wet. Very homogenous getting wetter in lowest m. Water table at surface.
Track T6-T7	**H4-7 / B2-3**	Soft to firm dark brown, pseudo-fibrous, plastic, PEAT. more woody material in lower 1m.
Track T7-T8	**H4-9 / B3-5**	Soft dark brown, pseudo-fibrous, plastic, PEAT. Difficult to core lower parts due to water content.
Track T15-T17	**H5-8 / B3-4**	Soft dark brown, pseudo-fibrous, plastic, PEAT
Track T20	**H8 / B2-3**	Soft to firm dark brown, plastic, PEAT

Source: Natural Power

3. Stability Analysis of Peat Slopes

3.1. Introduction

Assessing the desk study information, site layout and survey data; a preliminary infinite slope stability analysis and peat slide risk assessment has been undertaken. Slope stability was assessed at each wind turbine location using slope angle measurements, peat depth, and the recorded undrained shear strength. This assessment is semi-quantitative drawing on both qualitative assumptions and numerical parameters.

For each proposed wind turbine location, the recorded 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.

3.2. Undrained Slope Analysis

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 effect of construction works proposed as part of the proposed development.

As previously discussed, it should be acknowledged that the in-situ measurement of undrained shear strength of peat is preliminary and shall be taken with caution, due to scale effects of shear vane testing.

The factor of safety (FoS) against sliding has been calculated at the centre of proposed wind turbine locations. Table 3.1 below summarises the results.

Table 3.1: Infinite Slope Analysis Wind Turbines

Location	Average Peak Shear Strength (kPa)	Unit Weight, y (kN/m^3)	Depth, z (m)	Estimated Slope Geometry (β°)	FoS = Cu/ yz sin β cos β	FoS = Cu/ ((yz)+20) sin β cos β
					No applied load	Surcharge 20kPa
T1	50	10	1.18	9	27.4	10.2
T2	42	10	1.37	4	43.5	17.7
T3	64	10	1.01	3	121.2	40.7
T4	20*	10	0.32	10	36.5	5.0
T5	20*	10	0.47	6	40.9	7.8
T6	64	10	0.65	10	57.6	14.1
T7	20*	10	0.22	4	130.6	12.9
T8	20*	10	0.38	6	50.6	8.1
T9	47	10	1.04	3	86.5	29.6
T10	20*	10	0.47	4	61.2	11.6
T11	20*	10	0.47	10	24.9	4.7
T12	46	10	0.47	9	63.3	12.1
T13	20*	10	0.28	10	41.8	5.1
T14	20*	10	0.15	10	78.0	5.4
T15	20*	10	0.47	6	40.9	7.8
T16	20*	10	0.37	6	52.0	8.1
T17	46	10	0.66	4	100.2	24.9
T18	20*	10	0.31	9	41.8	5.6
T19	20*	10	0.79	4	36.4	10.3
T20	38	10	1.27	5	34.5	13.4
T21	60	10	0.76	6	75.9	20.9

** Shallow depths of peat at these locations meant a reliable shear vane field test was not possible, therefore conservative shear strength values taken from guidance literature and other conservative shear vane results from site, have been used to infer an estimated shear strength at these locations.*

Source: Natural Power

The factor of safety across the site is a lumped factor of safety and is calculated to inform the semi quantitative risk assessment. Detailed numerical slope stability analysis adopting national design codes should be applied following intrusive geotechnical investigations and to inform the detailed design of the infrastructure.

3.3. Discussion of Stability Analysis

The preliminary stability analysis above indicates no potential for translational peat slide at proposed wind turbine locations under current equilibrium or modelled surcharge loading conditions.

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.

Advanced in-situ test methods should be considered as part of a detailed site investigation phase usually carried out post-consent. This may include large size shear vane apparatus which allows a greater volume of peat to be tested. This may offer more representative results of mass behaviour and reduce the smaller scale fabric effects within the peat.

Un-disturbed sampling with thin-walled samplers could allow for laboratory testing to be undertaken. However, issues of sample preservation and disturbance are important factors to address. Such methods are generally suited to deep peat deposits (i.e.,>2m) and require plant mobilisation. The potential of disturbing sensitive peat deposits during pre-construction survey access should be considered during future phases of work.

Wind Turbines: FoS values for the wind turbine locations, when allowing for a 20kPa surcharge load have been derived. The lowest FoS was calculated was **4.7** for proposed wind turbine **T11**. The FoS values allowing for a 20kPa surcharge load are high. It should be reiterated that 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.

The FoS accounts for a 20kPa surcharge representing scenarios at infrastructure such as: temporary storage areas where peat can be excavated out and temporary stockpiled. The Peat Management Plan (PMP) will detail mitigation measures for peat stockpiling. Slope stability assessments shall be carried out further during design phase for access tracks, hardstands and other relevant structures ensuring the proposed design results safe, stable and environmentally compliant. It is Natural Power’s view that, if during design phase structures are proposed (i.e., floating tracks) additional numerical stability assessment shall be carried out.

Access Tracks: The majority of proposed access track is within low-risk areas. Areas of access track with an elevated risk of peat slide instability can be seen on Volume 2 Figure 9.7 and this is primarily attributed to being near or crossing a watercourse.

4. Peat Slide Risk Assessment

4.1. Risk Assessment of Peat Failure

The potential environmental impact (adverse consequence) of a peat slide triggered by proposed development is obtained from assessing the proximity to the main watercourses on site. The peat stability assessment also includes consideration for the potential impact (adverse consequence) to the proposed development (scored 1 – 5) from peat slide (See Table 1.5). Assessment of the proposed development with respect to peat failure risk zones was considered. If for example infrastructure was down-slope of a potential failure site, the development impact scale is increased. This is based on a subjective assessment of a resultant peat slide inundating infrastructure and rendering damage. The time and cost for the proposed development would be increased due to the requirement for remediation.

Probability values were assessed for combined contributory factors recorded across the wind turbine locations and added together where values were >1 (See Table 4.1). The highest impact rating (either development infrastructure or environmental) is then combined with the cumulative effects of the contributory factors. This is to convey the overall risk rank.

Detailed assessment of risk rankings for the proposed wind turbine positions are summarised in Table 4.2 . The risk ranking map is presented in Volume 2: Figure 9.7. The Peat Slide Risk map presents the *preliminary* peat slide risk assessment prior to implementation of any mitigation methods and the detailed assessment. The risk map provides a representation of the risk zonation across the site and includes all infrastructure elements. The map is based on a site wide GIS analysis and should not be viewed in isolation without the narrative of this report. An indicative residual risk rating is also provided assuming implementation of appropriate mitigation measures.

Further detail of the risk assessment is highlighted within the preliminary geotechnical risk register presented in Table 4.3.

Table 4.1: **Hazard Ranking Proposed Wind Turbine Location**

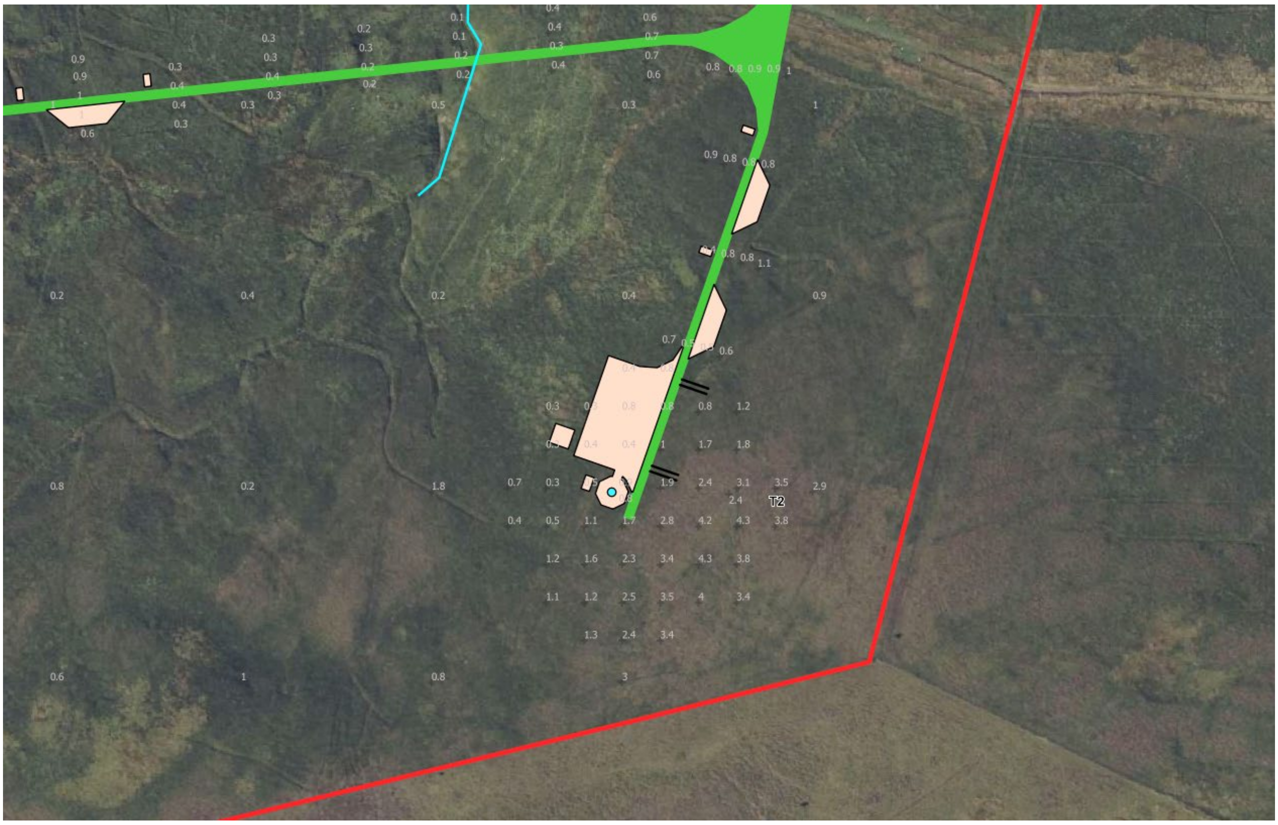
	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
T1	1	3	Peat Depth (Mean = 1.1m)	5	**Risk = 3 x 8 = 24 (High)**
			Slope Angle (9°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T1 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Current turbine position is optimised to reduce impacts on areas of deeper peat to the south and watercourse to the north. Additional peat depth surveys should be undertaken to the south within micro siting allowance post-consent during detailed design. Depending on findings, and if possible, microsite the wind turbine location ca. 80m south, away from the high risk ranking area into a low risk ranking area.
- If micrositing is not possible, consider implementing engineering mitigation measures such as rock fill embankment to protect the watercourse from a potential peat slide event, and implementing an inspection programme to regularly monitor the area around the works for signs of instability during construction.
- Avoiding placing stockpiles on areas of deep insitu peat and within the high or medium risk ranking areas.
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
T2	1	1	Peat Depth (Mean = 1.6m)	5	**Risk = 1 x 8 = 8 (Low)**
			Slope Angle (4°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

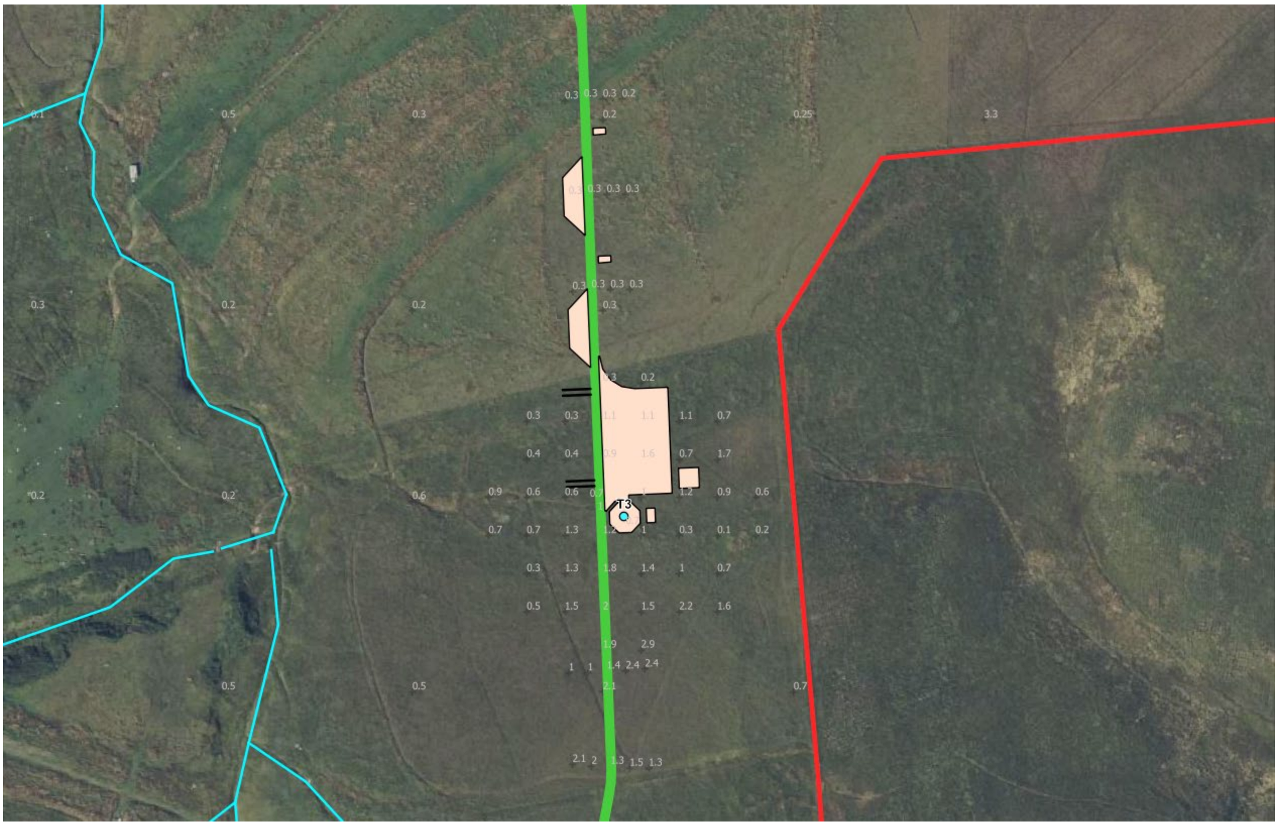


T2 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Avoiding placing stockpiles on areas of deep insitu peat and within the high or medium risk ranking areas.
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
T3	1	1	Peat Depth (Mean = 1.0m)	5	**Risk = 1 x 7 = 7 (Low)**
			Slope Angle (3°)	1	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	2	



T3 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Avoiding placing stockpiles on areas of deep insitu peat and within the high or medium risk ranking areas.
- Drainage design should include consideration of the existing man-made land drains, to prevent uncontrolled surface water flows onto peat.
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
T4	1	3	Peat Depth (Mean = 0.3m)	1	**Risk = 3 x 5 = 15 (Medium)***
			Slope Angle (10°)	5	
			FoS (Min = Cu$_{min}$ > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T4 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

*Medium risk ranking has been identified due to the proximity to watercourses and steep slope angle, but due to the absence of peat this is considered too conservative. Residual risk should be reduced to low/ negligible, provided normal protection measures are in place to protect the watercourses during construction.

Location Specific Mitigation:

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

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
T5	1	1	Peat Depth (Mean = 0.5m)	1	**Risk = 1 x 5 = 5 (Low)**
			Slope Angle (6°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	2	

T5 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.
- Drainage design should include consideration of the existing man-made land drains, to prevent uncontrolled surface water flows onto peat.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
T6	1	1	Peat Depth (Mean = 0.7m)	3	**Risk = 1 x 8 = 8 (Low)**
			Slope Angle (10°)	5	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T6 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
T7	1	1	Peat Depth (Mean = 0.2m)	1	**Risk = 1 x 3 = 3 (Negligible)**
			Slope Angle (4°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T7 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

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

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
T8	1	3	Peat Depth (Mean = 0.4m)	1	**Risk = 3 x 3 = 9 (Low)**
			Slope Angle (6°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T8 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.
- Consider micrositing the wind turbine slightly north if possible to reduce the risk ranking further still.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
T9	1	1	Peat Depth (Mean = 0.47m)	1	**Risk = 1 x 1 = 1 (Negligible)**
			Slope Angle (3°)	1	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T9 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Avoiding placing stockpiles on areas of deep insitu peat.
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
10	1	1	Peat Depth (Mean = 0.4m)	1	**Risk = 1 x 3 = 3 (Negligible)**
			Slope Angle (4°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T10 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

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

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
11	1	2	Peat Depth (Mean = 0.5m)	1	**Risk = 2 x 5 = 10 (Low)**
			Slope Angle (10°)	5	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T11 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
12	1	1	Peat Depth (Mean = 0.33m)	1	**Risk = 1 x 3 = 3 (Negligible)**
			Slope Angle (9°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T12 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

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

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
13	1	3	Peat Depth (Mean = 0.3m)	1	**Risk = 3 x 5 = 15 (Medium)**
			Slope Angle (10°)	5	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T13 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

*Medium risk ranking has been identified due to the proximity to watercourses and steep slope angle, but due to the absence of peat this is considered too conservative. Residual risk should be reduced to low/ negligible, provided normal protection measures are in place to protect the watercourses during construction.

Location Specific Mitigation:

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

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
14	1	3	Peat Depth (Mean = 0.2m)	1	**Risk = 3 x 5 = 15 (Medium)**
			Slope Angle (10°)	5	
			FoS (Min = Cu$_{min}$ > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T14 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

*Medium risk ranking has been identified due to the proximity to watercourses and steep slope angle, but due to the absence of peat this is considered too conservative. Residual risk should be reduced to low/ negligible, provided normal protection measures are in place to protect the watercourses during construction.

Location Specific Mitigation:

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

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
15	1	2	Peat Depth (Mean = 0.5m)	1	**Risk = 2 x 3 = 6 (Low)**
			Slope Angle (6°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T15 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
16	1	2	Peat Depth (Mean = 0.3m)	1	**Risk = 2 x 3 = 6 (Low)**
			Slope Angle (6°)	3	
			FoS (Min = $\mathrm{Cu_{min}}$ > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T16 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
17	1	1	Peat Depth (Mean = 0.6m)	3	**Risk = 1 x 8 = 8 (Low)**
			Slope Angle (4°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	2	

T17 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.
- Drainage design should include consideration of the existing man-made land drains, to prevent uncontrolled surface water flows onto peat.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
18	1	2	Peat Depth (Mean = 0.3m)	1	**Risk = 2 x 5 = 10 (Low)**
			Slope Angle (9°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	2	

T18 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.
- Drainage design should include consideration of the existing man-made land drains, to prevent uncontrolled surface water flows onto peat.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
19	1	1	Peat Depth (Mean = 0.9m)	3	**Risk = 1 x 6 = 6 (Low)**
			Slope Angle (4°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T19 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributary Factors (Probability/Exposure)**		**Risk Ranking**
20	1	1	Peat Depth (Mean = 1.4m)	5	**Risk = 1 x 10 = 10 (Low)**
			Slope Angle (5°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	2	

T20 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Avoiding placing stockpiles on areas of deep insitu peat and within the high or medium risk ranking areas.
- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.
- Drainage design should include consideration of the existing man-made land drains, to prevent uncontrolled surface water flows onto peat.

	Adverse Consequence				
WTG ID	**Development Infrastructure**	**Environmental**	**Contributory Factors (Probability/Exposure)**		**Risk Ranking**
21	1	1	Peat Depth (Mean = 0.8m)	3	**Risk = 1 x 6 = 6 (Low)**
			Slope Angle (6°)	3	
			FoS (Min = Cu_{min} > site mean)	1	
			Peat cracking / Infiltration	1	
			Groundwater Flow	1	
			Hydrology	1	
			Previous Instability	1	
			Land Management	1	

T21 Location – QGIS/ Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. A higher confidence in the geometry of the basal peat interface and understanding of the geotechnical properties of the underlying superficial deposits will allow for more confidence in the risk ranking.

Table 4.2 below summarises the risk assessment outcome and hazard ranking assignments for each wind turbine location. The principal contributory factors used to derive these assignments are also stated. An indicative residual risk rating is also provided assuming implementation of appropriate targeted mitigation measures.

Table 4.2: Risk Assessment Outcome and Hazard Ranking Assignment

Wind Turbine ID	Risk Ranking Baseline	Principal Contributary Factors in Risk Assessment	Residual Risk Ranking with Targeted Mitigation
T1	High	Proximity to WC Peat depth Slope angle	Low (if microsited)
T2	Low	Peat depth Slope angle	Low
T3	Low	Peat depth Artificial drains	Low
T4	Medium	Proximity to WC Slope angle	Negligible
T5	Low	Slope angle Artificial drains	Negligible
T6	Low	Peat depth Slope angle	Low
T7	Negligible	-	Negligible
T8	Low	Proximity to WC Slope angle	Negligible
T9	Negligible	-	Negligible
T10	Negligible	-	Negligible
T11	Low	Proximity to WC Slope angle	Negligible
T12	Negligible	-	Negligible
T13	Medium	Proximity to WC Slope angle	Negligible
T14	Medium	Proximity to WC Slope angle	Negligible
T15	Low	Proximity to WC Slope angle	Negligible
T16	Low	Proximity to WC Slope angle	Negligible
T17	Low	Peat depth Slope angle Artificial drains	Negligible

Wind Turbine ID	Risk Ranking Baseline	Principal Contributary Factors in Risk Assessment	Residual Risk Ranking with Targeted Mitigation
T18	Low	Proximity to WC Slope angle Artificial drains	Negligible
T19	Low	Peat depth Slope angle	Negligible
T20	Low	Peat depth Slope angle Artificial drains	Low
T21	Low	Peat depth Slope angle	Negligible

Source: Natural Power

The baseline risk assessment reflects the probability of peat material entering the surface water course and being entrained to an offsite receptor without any mitigation. The wider geomorphological assessment and evidence from recorded peat depths at infrastructure locations 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 set out within the geotechnical risk register.

4.1.1. Access Tracks

In addition to the wind turbine bases the sections of access track have also been reviewed across the site. The highest risk areas would be where access track alignments cross the watercourses and the steep slopes around the watercourse. The areas of highest risk can be seen in Volume 2: Figure 9.7, these sections are primarily:

- *Spur to T1 including Hope Burn crossing.*
- *Hope Burn crossing on Spur to T4.*
- *Part of Spur T6-T7.*
- *Standing Bog crossing (on main spine track - west of the proposed substation location).*
- *Yellow Sike crossing (on Spur to T16).*

Examples of potential options for mitigation measures that may be considered for the high/ medium risk areas of new tracks are listed below:

- Micrositing away from the high and medium risk areas to low risk areas.
- Utilising floating access tracks to reduce the impact on peatland by avoiding excavation.
- Installing cross track drainage to prevent ponding or build-up of groundwater pressure within the peat upslope or beneath the access infrastructure, and maintaining existing local drainage networks to prevent concentrated surface water outflows entering the system.
- In high risk areas, implementing engineering mitigation measures such as rock fill embankments to protect the watercourses in the event of a peat slide event.
- Avoiding placing stockpiles within the high or medium risk areas.
- Implementing a suitable inspection programme to regularly monitor the areas for signs of instability during construction.

4.2. Preliminary Geotechnical Risk Register

A preliminary Geotechnical Risk Register has been produced for the proposed development locations (Table 4.3). The risk register is intended for use by the applicant and future Principal Contractor appointed for the construction of the proposed infrastructure. A complete geotechnical risk register should be utilised throughout the construction phase and amended accordingly as new information is received. Key mitigation control measures for each hazard are highlighted.

Table 4.3: Preliminary Geotechnical Risk Register

Hazard	Cause	Location	Consequence
Peat Landslide / Bog Burst / Peat Flow	High rainfall, and increased surface water infiltration leading to build up of pore water pressure	**Site Wide**	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	**Site Wide**	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 CEMP. 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; 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	Increased subsurface groundwater flow and 'piping' failure beneath natural peat deposits, temporary and permanent earthworks	**Site Wide**	Localised instability associated with temporary and permanent earthworks; Triggering of mass movement of peat material down slope causing harm to personnel, plant and equipment;

Hazard	Cause	Location	Consequence
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. 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	**Site Wide**	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	**Site Wide**	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; Routine maintenance and inspection of peat storage mounds		
Creep, long term settlement of structures	Tracks or hardstand founded on peat and or poor or variable foundation soils	**Site Wide**	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

5. Conclusions & Recommendations

5.1. Conclusions

Natural Power Consultants has carried out this peat stability assessment following the principles of the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Government 2017).

The peat depths across the site are variable but predominantly (77% of the total probes) were in the range 0.0-1.0m. It should be noted that where peat probes indicate shallow depths 0.0-0.5m that the deposits are likely to be composed of a peaty topsoil.

The peat encountered across the site was typically soft to firm dark brown, pseudo-fibrous, plastic, PEAT Von Post classes were variable in the range H4 – H8 (average H6 moderately highly decomposed peat).

The peak un-drained shear strength was measured in-situ where possible, and an average value of 43 kPa was obtained. At shallow peat locations where a reliable shear vane field test was not possible, conservative shear strength values, taken from guidance literature and other conservative shear vane results from site, have been used to infer an estimated shear strength of 20kPa. This is considered a conservative value and models peat of low shear strength.

The preliminary stability analysis indicated no potential for translational peat slide at proposed wind turbine locations under current equilibrium or modelled surcharge loading conditions.

The peat stability risk rankings identified on Volume 2: Figure 9.7 are a combination of the overall likelihood with the potential impact of a peat landslide event. The risk is increased with closer proximity to watercourses which act as a sensitive receptor and pathway to affect habitat and infrastructure downstream. This has had a significant effect on the analysis for wind turbines T1, T4, T8, T13 and T14, plus some sections of the proposed access track.

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 should reduce the risk of peat failure to acceptable (low or negligible) levels, which is reflected in the residual risk rankings.

The risk assessment should be reviewed following any additional intrusive ground investigations. The respective risk ratings should be central to development of the Construction Environmental Management Plan (CEMP) 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.

5.2. Recommendations

It is recommended that the applicant take cognisance of the initial risk rankings identified within this PSRA within their designs and implement sufficient mitigation measures to reduce the risk ranking to acceptable residual levels.

There should also 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 impact terrain and slope conditions beyond the proposed working areas.

It is recommended that detailed design should consider whether it is possible to microsite wind turbine T1 and realign sections of access track identified as being within medium and high-risk ranking areas.

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

The following risk mitigation is recommended with regards to peat storage locations / techniques:

- Storage site selection and stockpile design should be undertaken by a suitably qualified and experienced engineer, and 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 where possible.
- Peat storage on areas of low / negligible peat slide risk only.
- Peat storage height shall not exceed 1.0m.
- Provision of adequate cut-off drainage and suitable outflows.
- Routine maintenance and inspection of peat storage areas should be undertaken.

Further information on peat handling and storage is presented in Technical Appendix 9.2: Peat Management Plan.

Appendices

A. Site Photographs & Peat Cores

Landscape view of Bloch Flow, an area of deeper peat in the central site

Landscape view of Bloch Flow and bog pool in the central site

T1 Core 1.3m Core: 0.0-0.5m - H6 B2 0.5-1.1m - H7 B2 1.1 -1.3m - Clay HSV: 0.5m - 53/29 1.0m - 47/28

T2 Core: 0.0-1.3m - H7 B2 1.3-1.6m - unsure, much more compact peat then clay at base, but doesn't escape between fingers. HSV: 0.5m - 42/21 1.0m - 41/28

T3 Core 0.85m Core: 0.0-0.2m - H4 B2 0.2-0.85m - H6 B2 HSV: 0.5m - 64/32 note depths ranged over a few cm at the surface from 0.6 to 0.85 m

T6 Core (15 m NW of turbine centre): 0.9m core: 0.0-0.3m H4 B2 0.3-0.9m H6 B3 and some woody material HSV: 0.5m - 64/39

T9 Core: 1.2m total 0.0-0.4m - H7 B3 0.4-1.2m - H8 B3 with some wood then hits clay/sand HSV: 0.5m - 37/28 1.0m - 57/37

T12. Core: gave a 25cm core, H4, B2, with some mineral soi

T17. Core just less than 0.7m before hitting solid ground. Sample taken from lower end of core. Water table just below surface. HSV: 0.5m - 46/34 Core: 0.0-0.4 H5 B3 0.4-0.7 H7 B4

T19. Corer only went to 0.4m. Sample taken from available peat avoiding clay. HSV 0.25m 56/32 0.0-0.1m H3 B1 0.1-0.3m H5 B1 0.3-0.42 Mineral soil/ clay

T20. HSV: 50cm - 40/15 100cm - 36/19   Probe depth 1.4m Core: 0.0-0.2m H6 B2 0.2-1.4m H8 B3

T21. Coring consistently only went to 0.6m HSV: 0.5m - 60/32 Probe depth: 0.6m Core: 0.0-0.6 m H5 B2

Area of raised bog ~50m SE of T12

Access track T6 to T7 Core depth 2.6m Core 0.0-0.5m H4 B2 0.5 -1.0m H6 B3 1.0-2.6m H7 B3 note more woody material in lower 1m HSV: 0.5m - 54/32 1.0m - 48/40 1.5m - 50/32 2.0m - 50/38.

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