APPENDIX 11.1: PEAT STABILITY RISK ASSESSMENT

Executive Summary

An Executive Summary has been included in the Chapter 11 (Geology, Soils and Hydrogeology).

1.1 Introduction

1.1.1 This report details the Peat Stability Risk Assessment undertaken at the proposed Tangy III Wind farm (hereafter referred to as the proposed development) on behalf of SSE Renewables. As part of this assessment, the Technical Assessment previously undertaken in 2014 has been reviewed and included in its entirety, but, reviewed in line with the new guidance Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive, 2017) and a detailed description of the proposed development has been included in Chapter 5 (Description of Development). The following assessment is based on previous work submitted for the site and has not been altered significantly from previous findings as there are no major changes or time factors which impact the previous study.

1.2 Scope of Assessment

Study Area

1.2.1 The proposed development is located in Argyll, approximately 9km north-west of Campbeltown. The site is located within an upland moorland terrain setting which transitions to a commercial forestry plantation. The study area within the proposed development extends across the existing and operational Tangy I and II Wind Farm, extending into the commercial forestry planation to the north and outside of the boundaries of the existing operational Tangy I and II Wind Farm. Figure 11.5 enclosed with this report (EIA Report Volume 3a: Figures) shows the extent of the peat stability study area.

Scoping and Consultation

1.2.2 The previous peat stability risk assessment followed the principles of the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive, 2007) hereafter referred to as PLHRAG, (2007). The guide provided best practice methods which were applied to identify, mitigate and manage peat slide hazard and associated risks in respect of consent application for electricity generation projects in Scotland.

1.2.3 The assessment of potential instability at the proposed development was carried out according to the following work programme which incorporated the peat survey elements agreed with the Scottish Environment Protection Agency (SEPA) prior to being undertaken. A phased approach was used to provide relevant information as the design layout was optimised:

- Geotechnical Desk Study and review of existing site information.
- Site reconnaissance survey (September 2013). This comprised a walkover survey of the study area and identification of potential geo-hazards.
- First pass probing survey comprising: An initial development focussed peat probe survey within the accessible turbine envelope on a grid resolution of 100m (September 2013).
- Assessment of peat undrained shear strength through in-situ hand shear vane testing and hand cores across proposed turbine locations within the design envelope (November 2013, January 2014 and June 2014).

- Development-wide check of salient features such as active, incipient or relic instability within the peat deposits, geomorphological features, peat depth and composition (November 2013 – January 2014 and June 2014).
- Quantitative slope stability assessment based on in-situ shear strength data.
- Assessment of the potential risk of peat failure across the proposed development.
- Comparison of the potential risk of peat failure with the site hydrological model including proximity to watercourses and sensitivity of those features.
- Risk assessment of potential environmental and developmental (infrastructure).
- Recommendations for detailed design/construction control with specific examination the need for measures to mitigate potential peat failure as part of any future Wind farm development.

Table 1: Consultation Response

Consultee	Summary Response	Comment/ Action Taken
SEPA	The following provides a summary of SEPA's consultation response with regards to survey of peat conditions across the proposed development: SEPA would prefer that all peat probes are carried out to full depth. This may not always be possible in all cases, particularly in forestry plantations where access is limited, or the ground may be obscured by tree roots and forestry waste. If probing to full depth is not possible then SEPA will be content with figures based on the best available information, i.e. national peat survey information. SEPA's main concern regarding peat will be from a waste perspective. SEPA will likely require figures for the total amount of peat (or best estimate given survey results) to be excavated. An understanding of the make-up of excavated peat for acrotelmic and catotelmic peat will also be required to inform site restoration planning. As a general rule SEPA expect borrow pits to be restored to a depth of no more than 2 -3m unless demonstrable benefit can be shown, e.g. ecosystem benefits. To re-use peat for road verges dimensions of approximately 0.5 – 1m in height by 1.5- 2m in width are generally considered suitable. Anything larger than this may be considered waste disposal. Where SEPA is not satisfied that all excavated peat will have a legitimate re-use, SEPA may advise that a Waste Exemption needs to be registered or, if there are likely to be large amounts of excavated peat, it may be advised that a Waste Management Licence (WML) or a Pollution Prevention Control (PPC) permit is required to dispose of any peat on site.	Scope of peat survey and risk assessment has been devised in accordance with Scottish Government Guidelines (2011)1 to meet the requirements of SEPA's response. Further information on the scope of the peat surveys has been provided in Table 11.3.2.2 below. Issues of peat restoration have been further considered as part of the Peat Management Plan and Borrow Pit Search Report provided as Appendices 11.2 & 11.3.

1Scottish Government (2011) Developments of Peatland: Site Surveys

Table 2: Peat Survey Scope

Infrastructure Element	Peat Survey Coverage
Proposed Access Tracks	Peat depth probes collected along the centreline of proposed access tracks at 50m intervals. An additional probe has been collected either side of the track, perpendicular to the track centre probe at a distance of 20m. This provides a 40m corridor for the access track routes to be refined.

Table 2: Peat Survey Scope	
Wind Turbines	Peat depth collected at the turbine centre coordinate and at the following intervals: north, east, south & west of turbine centre at 10, 25 & 50m.
Potential Borrow Pit Areas	Peat depth probes collected in a grid pattern at 25m intervals, where access allows and where access restricted by using the method detailed above for wind turbines.
Construction Compound Lay-down Area Substation Operations Building	Peat depth probes collected in a grid pattern of 25m intervals where access allows.
Shear Vane & Peat Coring	A minimum of 3 hand shear vane locations and three equivalent core locations explored at each turbine location. Shear strength and von post classification correlated at 300mm depth intervals at each point to understand the material classification of peat deposits and the acrotelmic and catotelmic structure.

1.2.4 The assessment recognises that the proposed development infrastructure needs to be designed, whilst taking into account the sensitivity of the underlying peat deposits and associated environment. Therefore, the scope of the peat survey has been set, so that an iterative layout design approach is adopted throughout the wider environmental impact assessment process, with the ultimate aim of accounting for the sensitivities of the peat land environment and interconnected systems.

1.3 Layout Design Consideration

1.3.1 Peat slide risk assessment was a key consideration throughout the iterative wind farm layout design process. Wider EIA considerations were integrated into this process. Principally the environmental constraints of the watercourse valley to the north (Allt nan Creamh) and the areas of significant peat depth to the south of turbines T9 & T10 proved to be overriding constraints on turbine placement. The proposed turbine locations for T9 & T10 remain in elevated peat slide hazard zones due to these factors. Ultimately it is proposed that with further assessment as part of a detailed phase of site investigation (post consent) along with application of specialist control measures (Table 13) the turbine locations at elevated peat stability hazard will be reduced to an acceptable level of risk. This is demonstrated in Figure 11.7 as an overview and Figure 11.8 providing further detail of how minor micro-siting following investigation and design can further reduce the risk levels. This approach is further advocated in the peat landslide hazard and risk assessment guidance PLHRAG, (2007).

1.3.2 It is noted that WTG 8 was inaccessible at the time of the survey due to impassable forestry wind blow. Therefore, this assessment shall be refined following a forestry felling phase. Additional site survey will be required to accurately determine the peat depth and terrain morphology across this area. A serious hazard ranking has been applied as a conservative measure taking into account the interpolation of peat depth and slope geometry across this area.

1.4 Peat Slide Hazard – Risk Assessment Method

Processes Contributing to Peat Instability

1.4.1 To provide a framework for the stability assessment; it is important to highlight the key principals of the peat slide risk assessment set out in PLHRAG, (2007). The guidance describes ongoing natural peatland processes which can influence forces leading to peat slope failure. A discussion of the factors which can contribute to peat failure have been reiterated below in order to provide a basis for understanding the assessment process:

Groundwater Infiltration

1.4.2 There are two processes which may facilitate groundwater infiltration: These are periods of drying, resulting in cracking of the peat surface and slope creep resulting in additional tension cracks. Drying out of the upper peat, particularly in areas of thinner peat, is likely to result in the development of near-surface cracks which could facilitate ingress of water into the peat.

Surface Loading

1.4.3 Any mechanisms which increase the load on a peat deposit 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.

Vegetation

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

Weathering

1.4.5 Weathering can weaken in-situ peat materials and destabilise a slope system. This may be in the form of weathering of peat or underlying mineral soils which could reduce shear strength. Vertical cracking and slope creep may slowly break down peat structure over long periods of time. This can develop into peat 'hagging', which is a strong indication that natural weathering processes are active. Peat hags expose the peat to increased weathering rates and may provide preferential surface water flow pathways.

Precipitation

1.4.6 A dominant trigger for peat failures are intense rainfall events. Many 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, (Nichol et al., 2007).

1.4.7 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, which 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 sites such as the proposed development.

Slope Morphology

1.4.8 A number of case studies on peat failures note the presence of convex break in slopes (Dykes & Warburton 2008). There are three main effects of such slope morphology:

1.4.9 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.

1.4.10 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.

1.4.11 Thirdly a failure mechanism, analogous to a piping failure underneath dams, is postulated where springs are present in locations immediately down-slope of the relatively well drained peat body. Under these circumstances high pore pressure gradients within the peat can lead to hydraulic failure and undermining of the relatively well drained peat body resulting in a breach and loss of lateral support to peat upslope. Evolving slope morphology can be significant; for example, in the case of slope undercutting by water erosion. Any mechanism by which mass is removed from a slope toe or deposited on a slope crest will have some destabilising impact. This would include the case of material deposited by landslides as noted in PLHRAG, (2007).

Peat Depth & Slope Angle

1.4.12 The PHLRAG, (2007) guidance provides the following information on peat slides with respect to peat depth and slope angle.

1.4.13 'Peat slide – slab like shallow translational failure, (Hutchinson, 1988) 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, (Warburton et al., 2004). 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.'

1.4.14 Peat slides correspond in appearance and mechanism to translational landslides, (DoE, 1996) and tend to occur in shallow peat (up to 2.0m) on slopes between (5° – 15°). A great majority of recorded peat landslides in Scotland, England & Wales are of the peat slide type. MacCulloch, (2005) highlights that a slope angle of 20° appears to be the limiting gradient for the formation of deep peat. Therefore, the risk assessment has assigned slope angles >20° to be an unlikely contributory factor to failure. Slope angle indicators and corresponding probability factors have been similarly adapted from MacCulloch, (2005).

1.4.15 Boylan et al, (2008) indicates that the vast majority of peat failures occur on slope angles between 4° and 8°. It is postulated that this may correspond to the slope angles that allow a significant amount of peat to develop that over time becomes potentially unstable. The same author also stipulates that a number of failures have been recorded on high slope angles (>20°) but, based on the authors' inspection of such failures, peat cover is generally thin, and the failure tends to involve underlying mineral soils, as opposed to peat deposits.

1.4.16 Peat depth and slope angle indicators for probability of peat failure have been similarly adapted from MacCulloch, (2005). These are set out in Table 2.5.2.

Drainage

1.4.17 Natural and poorly executed man-made 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. 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. See Warburton et al., (2004). Forestry preparations and harvesting may also impact upon man-made drainage networks.

1.4.18 The clustering of relict failures and any indication of previous instability are often important, indicating that particular 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.

Recurrent Failures

1.4.19 The clustering of relict failures and any indication of previous instability are often important, indicating that particular 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

1.4.20 Several peat failure reports identify the possibility of relative weaker layers within the peat (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.

Anthropogenic Effects

1.4.21 Man-made effects on peat environments can include a range of affects associated with Wind farm construction where uncontrolled. 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. The peat failure at Derrybrien, County Galway is one such example where construction activity has been cited as a contributing factor during Wind farm construction (AGEC, 2004).

Peat Failure Definitions

1.4.22 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.

1.4.23 The potential for peat failure at this site is examined with respect to the activities envisaged during construction and operation of the proposed development. There are several classification systems for the mass movement of peat that were drawn together by PLHRAG, (2007) and by AGEC at Derrybrien in Ireland, (Boylan et al., 2008).

1.4.24 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.
- **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.

1.4.25 Due to the open topographic relief across the proposed development and a prevalence of surface watercourses, peat flows are considered the dominant mode of potential peat failure. However, consideration should be given to the potential for peat slides as a result of the slope geometry over some parts of the proposed development. There are deep peat areas across the proposed development which may present raised bog condition which may be susceptible to bog burst events. These conditions are assessed in detail.

1.5 Geotechnical Principles

1.5.1 The main geotechnical parameters that influence peat stability are understood to be:

- Shear strength of peat.
- Peat depth.
- Pore water pressure (PWP).
- Load conditions (applied stress).

1.5.2 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.

1.5.3 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.

1.5.4 The infinite slope model (Skempton & DeLory, 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) and back calculating minimum undrained shear strength (Cumin) for stability. Thus, establishing the likely potential for peat sliding based on the measured in-situ values for undrained shear strength or Cumin value for peat depth and slope angle parameters.

Infinite Slope Analysis

1.5.5 The purpose of the slope analysis is to identify the baseline FOS and the minimum undrained shear strength (Cumin) required for stability of peat deposits at each proposed turbine base and sensitive access track sections. When in-situ measured peat undrained shear strength values (Cu) exceed the minimum value (Cumin) there is limited potential for peat failure to occur. The Cumin analysis adopts a Factor of Safety (FoS) of 1.3; based on BS6031:2009: Code of practice for Earthworks (BSI, 2009).

1.5.6 The infinite slope analysis (Skempton and DeLory, 1957), as recommended in PLHRAG, (2007) is based on a translational slide, which represents the prevalent mechanism for peat slide failures. This analysis adopts total stress (undrained) conditions in the peat. This state applies to short-term conditions that occur during construction and for a time following construction until construction induced pore water pressures dissipate (PWP takes 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 after, (BS6031:2009).
- Failure plane assumed at the basal contact of the peat layer.
- Slope angle on base of sliding assumed to be parallel to ground surface and that the depth of the failure plane is small with respect to the length of the slope.
- Thus, the slope is considered as being of infinite length with any end effect ignored.
- The peat is homogeneous at each location.
- 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.

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

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

Where:

F = Factor of Safety (FOS)Cu = Undrained shear strength of the peat (kPa).

γ = Bulk unit weight of saturated peat (kN/m3).

z = Peat depth in the direction of normal stress.

β = Slope angle to the horizontal and hence assumed angle of sliding plane (degrees).

1.5.8 Undrained shear strength values (Cu) are used throughout this assessment and derived from in-situ hand vane test data. Effective strength values are not applicable for the case of rapid loading of the peat during short term construction phase of works hence the Barnes, (2000) formula cited above, has been adopted throughout.

1.6 Contributory Factors to Peat Failure – Further Assumptions

1.6.1 The analysis is termed preliminary due to the nature of the in-situ strength testing. The low peat strengths are at the lower detectable limit for light weight hand shear vanes used during the field surveys. Therefore, any error in the preliminary Cu value will have a proportionally large effect on the overall sensitivity of the slope stability analysis.

1.6.2 Furthermore, 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 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.

1.6.3 The occurrence of a severe rainstorm event controlled by meteorological factors and to a lesser degree topography is not factored by the assessment. NPC considers blanket peat on upland sites would be considered to be more susceptible to intense rainstorm events due to the larger catchment potential across the peat surface. However, the wide range of contributory factors included in this assessment can be indirectly linked to rainfall and precipitation.

1.6.4 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 development.

1.6.5 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 related peat failures (AGEC, 2004). The effects of cyclic loading are also not covered by the slope stability model. It is further highlighted that loading rates can be important in managing peat deformation under construction conditions.

Drained Shear Strength

1.6.6 A drained slope stability analysis requires effective cohesion (c’) and effective friction angle (ϕ’) parameters. These values can be difficult to obtain because of disturbance experienced when sampling peat. There are also difficulties in interpreting test results due to the excessive strain induced within the peat during test failure. During a laboratory test the point of failure may be arbitrary as a threshold strain measurement. To highlight suitable drained strength values a review of published information on peat has been outlined below.

1.6.7 Obtaining effective stress parameters for peat is difficult to achieve with confidence due to aforementioned problems such as sample disturbance, low stress and high strain behaviour, reliability of standard test methods etc. A summary of literature values is presented in Table 3 below:

Table 3: Literature Review of Effective Stress (Drained) Parameters

Reference	**Effective Cohesion C' (kPa)**	**Effective Friction Angle Ø'(°)**	**Test Method / Comment**
Hanrahan et al (1967)	5 - 6	36 to 43	Triaxial
Rowe and Mylleville (1996)	2.5	28	Simple shear apparatus
Landva (1980)	2 - 3	27.1 – 32.5	Ring shear with normal stress >13 kPa
Landva (1986)	5 - 6	-	Ring shear with zero normal stress
Carling (1986)	6.5	0	-
Farrell and Hebib (1998)	0	38	Ring shear and shear box, results considered unrealistic.
Rowe, McLean & Soderman (1984)	1.1	26	Simple Shear
	3	27	Direct Simple Shear
Sandorini et al (1984)	4.5	28	Triaxial
Hunger & Evans (1985)	3.3	-	Back analysis
Dykes and Kirk (2006)	3.2	30.4	Acrotelm
	4	28.8	Catotelm
Warburton et al (2003)	5	23.9	Basal Catotelm
	8.74	21.6	Fibrous Acrotelm
NPC (2009)	3	28	Advanced in-situ CPT testing
	Mean	Mean	
	4kPa	28	

1.6.8 From Table 4.2.1 the values for c' ranged from 0 to 9kPa and ϕ' ranged from 0 to 43°. The average c' and ϕ' values are 4kPa and 28° respectively. Based on the above data review, it is recommended to adopt a conservative approach and to use design values below the averages. However, it was not deemed appropriate to undertake effective stress analysis at this stage. An effective stress analysis may be considered if required as part of detailed design prior to construction and as part of detailed ground investigation. The values presented here may provide a useful starting point to continue the detailed design assessment or further investigations as part of detailed site investigation post consent.

1.7 Peat Slide Risk Assessment Methodology

1.7.1 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, (2007) and has been further augmented with methods set out by Clayton (2001).

1.7.2 The assessment approach combines infinite slope stability analysis with qualitative probability contributory factors to peat failure. The assessment combines contributor factors to peat failure with impact assessment based on an environmental impact scale. Hence providing a hazard ranking which relates to the required level of control and mitigation. This assessment has analysed terrain conditions across the proposed development and utilised this information to clarify the preliminary peat slide hazard zonation map (Figure 11.6).

1.7.3 Across the proposed development the environmental impact scale has been assessed on the potential for a peat failure to detrimentally impact surface water courses. Table 4 depicts the Environmental Impact Zones based on proximity buffer zones applied to the mapped sensitive watercourses within the proposed development. Water courses have therefore been determined to be a primary sensitive receptor to a peat failure event. Table 2.5.1 denotes the potential impact scales to the environment.

Table 4: Environmental Impact Scales, after MacCulloch, (2005)

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

*Buffer zones defined by peat slide risk assessment method and not directly related to hydrological impact assessment, see Chapter 12 of EIA Report for further details on Hydrological impact assessment.

1.7.4 An assessment of the peat stability Hazard Ranking across the proposed turbine locations is presented in Section 11.14. 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 digital elevation models;
- Peat depth determined during a multi-phased full depth probing survey;
- FOS evaluated from infinite slope analysis;
- Evidence of groundwater flow;
- Surface water flow from maps and site walkover observations;
- Evidence of previous slope instability within the site wide geomorphological setting; and
- Land management, qualitative based on previous land use.

1.7.5 Probability values for each contributory factor are summarised on Table 5 below along with a brief discussion of the influencing factors.

Table 5: Contributory 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, (PHLRAG, 2007).	0 – 0.5m >3.0m 0.5 – 1.0m 2.0 – 3.0m 1.0 – 2.0m	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5
Slope Angle (B)	It has been acknowledged that peat slide, tend to occur in shallow peat (up to 2.0m) on slopes between 5o and 15o. Slopes above 20o tend to be devoid of peat or only host a thin veneer deposit.	0 – 3o >20o 4 – 9o 16 – 20o 10 – 15o	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5
FOS (C)	Values are from Infinite slope model using Cu derived from hand shear vane in-situ testing. Slope angle and peat depth also input to this factor.	? 1.3 1.29-1.20 1.10-1.19 1.00-1.09 <1.0	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5
Cracking (D)	Depth and cause of cracking are important. E.g. tension cracks appear as excess tension is released. Cracks can form during dry period and provide a water ingress pathway. Subjective requiring interpretation.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5
Groundwater (E)	Difficult to evaluate without detailed mapping. Look for entry / exit evidence. Often collapsed pipes are the first sign. May hear running water during wet periods.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5
Surface Hydrology (F)	Ranging from wet flushes to running burns to peat hags. Must be evaluated in conjunction with the season and weather preceding the site visit.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Very likely	1 2 3 4 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 Few Frequent Many Continuous	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5
Land Management (H)	Anthropogenic influences such as forestry operations, felling and removal of vegetation can be associated with de-stabilising peat deposits. This can occur as a result to surface disturbance and re-molding of peat through excavation, vehicle movements and loading. Changes	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Very likely	1 2 3 4 5

Table 5: Contributory Factors and Probability Values				
	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.			

1.7.6 A qualitative Hazard Ranking is assessed from the combined probability of occurrence for the main contributory factors which are >1, multiplied by the highest impact scale. Table 6 identifies the hazard ranking based on PLHRAG, (2007).

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

Table 6: Risk Rating and Control Measures	
Hazard Zone Ranking	**Control Measures**
>17	Serious: re-location and or specialist control measures.
11 - 16	Substantial: specialist control measures required (Project should not proceed unless hazard can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce hazard ranking to significant or less).
5 - 10	Significant: routine control measures required. (Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations).
1 - 4	Insignificant: none or only routine measures (Project should proceed with monitoring and mitigation or peat landslide hazards at these locations as appropriate).

Site Information

1.7.7 All relevant background data to the proposed development including any information regarding peat and the wider geological setting has been reviewed. The review of available literature, maps and salient third-party data sources was undertaken together with a general case review of peat failures across the British Isles. The primary data sources with respect to the proposed development include:

- 1:50,000 Scale solid and drift digital geology map data, British Geological Survey (BGS).
- Ordnance Survey map plans including review of historical maps where available.
- Digital Terrain Model (5m grid resolution).
- Contemporary Aerial Photographic Records.
- Literature review of peat failures and Wind farm peat slide risk assessments (Section 11.4).

1.7.8 It is highlighted that peat deposits across the site are not accurately represented by the available BGS map data. Therefore, in line with the environmental impact assessment methodology and published guidance; a programme of detailed peat survey has been implemented across the proposed development."

1.8 Location

1.8.1 A description of the location has been included in Chapter 11 (Geology, Soils and Hydrogeology).

1.9 Site Description

1.9.1 A site description has been included in Chapter 11 (Geology, Soils and Hydrogeology). Figures11.3 & 11.4 depicts the British Geological Survey mapped units for superficial and solid geology across the proposed development.

Topography

1.9.2 A description of the topography has been included in Chapter 11 (Geology, Soils and Hydrogeology). Figure 11.1 depicts the key geomorphological features identified across the site. This map data has been established from a combination site reconnaissance and aerial photograph analysis. It shall be acknowledged that due to the dense forestry cover the geomorphological map carries degree of uncertainty. Figure 11.2 provides a terrain slope angle model, and, has been derived from 5m resolution digital elevation data. Plate 1 below provides a 3D terrain model to place the site in context of the surrounding landforms.

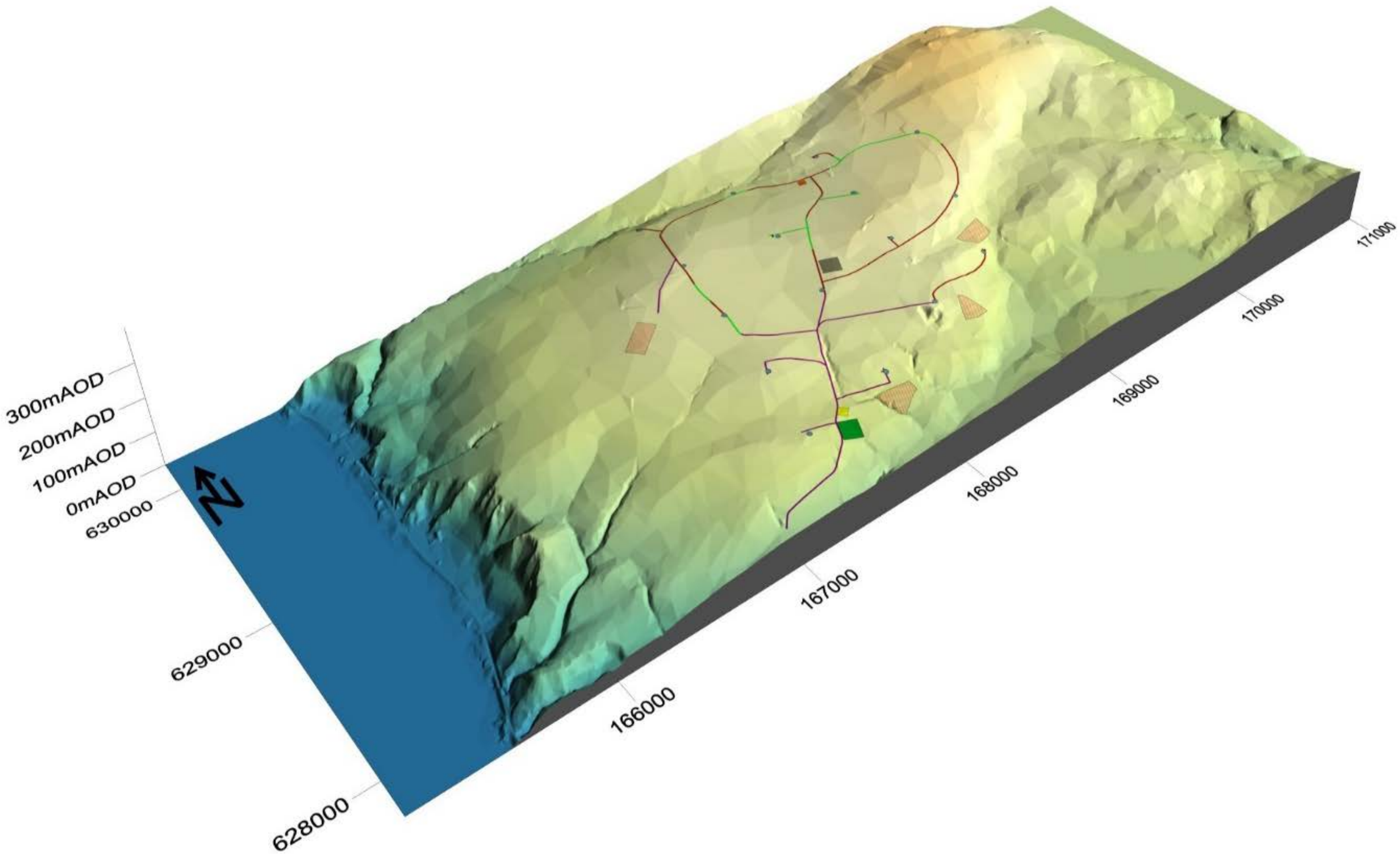
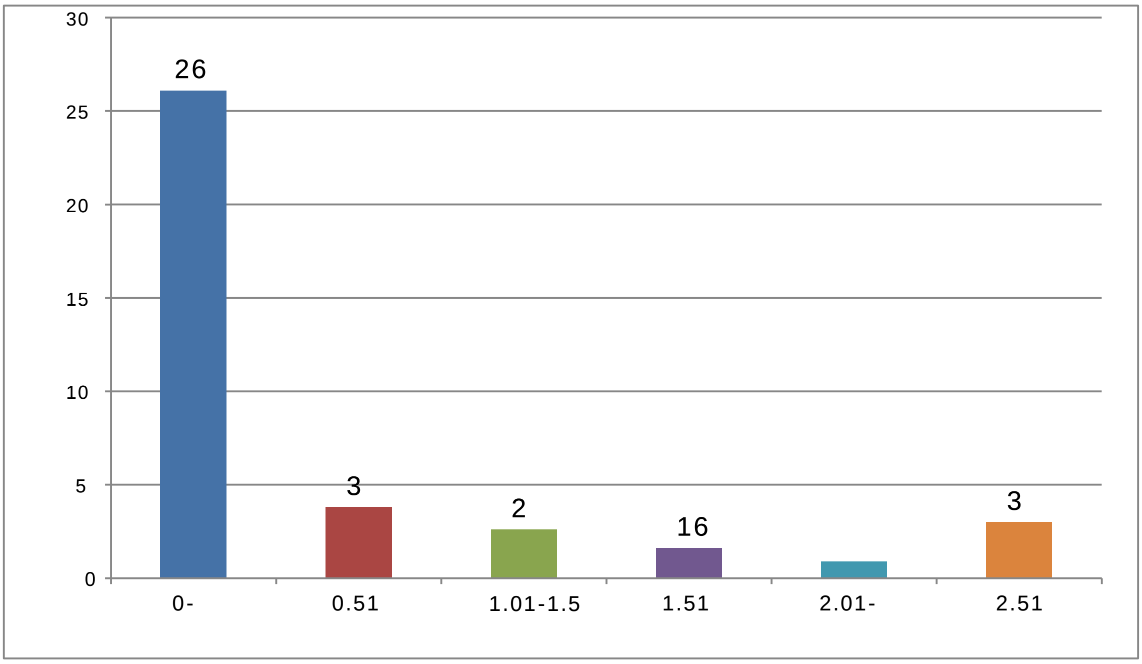


Plate 1: 3D terrain model

1.10 Peat Depth Analysis

1.10.1 Analysis of the range of peat depths encountered as part of the initial 100m grid probe survey is provided as a graphical representation below. A total of 380 peat probe data points have been collected in line with the scope presented in Section 11.4. The calculated mean peat depth across the study area is 0.6m. A maximum peat depth of 3.6m has been recorded. Plate 2 below provides a graphical representation of the distribution of peat depths.

Plate 2: Histogram Summary of Peat Depth Data (100m Grid Data)



1.10.2 The available peat probe data has been plotted with surface modelling software determining the macro scale distribution of peat deposits across the proposed development. A comprehensive peat depth contour map is provided as Figure 11.5.

1.10.3 Following detailed peat depth probing across the proposed infrastructure locations a complete dataset comprising 1880 data points was compiled. The mean peat depth from this dataset remains at the 0.6m range.

1.11 Peat Depth-Turbine Centres

1.11.1 Table 7 below summarises peat depths recorded across the proposed wind turbine locations. The maximum slope angle and down slope direction has also been indicated.

Table 7: Overview of Peat Depths-Representative Wind Turbine Locations

Location	Peat Depth Centre (m)	Peat Depth Range 100x100m Area (m)	Maximum Slope Geometry (degrees)	Peat Classification
WTG 1	0	0	2	N/A
WTG 2	0	0	10	N/A
WTG 3	0.2	0.1	4	[H4]
WTG 4	0.4	1.5	6	[H8]

Table 7: Overview of Peat Depths-Representative Wind Turbine Locations				
WTG 5	0	0	16	N/A
WTG 6	0.7	0.8	4	[H4]
WTG 7	0.8	0.6	4	[H5]
WTG 8	Access restricted due to dense wind-blown forestry.	0.5 -1.0 interpolated data	8	N/A
WTG 9	0.8	2.8	4	[H7]
WTG 10	1.0	1.6	6	[H7]
WTG 11	0.8	1	4	[H8]
WTG 12	0.4	0.3	10	[H9]
WTG 13	1.3	1	6	[H5]
WTG 14	0.2	0.2	4	[H5]
WTG 15	1.8	1.8	4	[H4]
WTG 16	1.8	1.8	6	[H6]

1.12 Estimation of Peat Shear Strength

1.12.1 As part of the detailed peat survey a 25mm ‘GeoNor’ hand shear vane was used across each proposed wind turbine centre to record the un-drained shear strength of the in-situ peat deposits. No laboratory-based shear strength testing has been currently undertaken. This is due to the inherent difficulties in obtaining undisturbed samples of peat through the use of hand operated instruments.

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

1.12.3 The re-moulded shear strength represents the residual undrained shear strength of re- worked peat throughout which all internal structure is destroyed and would be typically accompanied by an increase in moisture content. The result of poorly executed civil engineering operations can have the potential to reduce the peat deposit to its re-moulded shear strength through re-working, cyclic loading and rapid load application. Therefore, determination of this parameter is considered an important aspect of the stability assessment.

1.12.4 Shear vane tests were generally undertaken within the deepest representative deposit of peat at each proposed wind turbine location. Where a significant increase in the un-drained shear strength was recorded at the basal contact of the peat, it is inferred that the highest un-drained shear strength values represent the glacial substrate interface.

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

1.12.6 The undrained shear strength (Cu) results for peat range from 14 to 60kPa with a mean value of 33kPa. This is compared to a minimum Cu recorded for the Derrybrien case study of 3kPa. The re-moulded shear strength (Cur) results for peat range from 4 to 35kPa with a mean value of 20kPa.

1.13 Slope Stability Analysis

Introduction

1.13.1 Drawing on the desk study and field reconnaissance data; a preliminary infinite slope analysis and subsequent peat failure risk assessment has been undertaken. Slope stability was assessed at each proposed turbine location initially using slope angle measurements, peat depth, and undrained shear strength measured using an in-situ hand shear vane. A wider zoned assessment has followed the same principles and assessed discrete terrain units across the proposed development for peat stability. Figure 11.6 has applied digital terrain model, peat depth and proximity to sensitive watercourses to establish peat slide hazard zones across the proposed development. It is noted that this PLHRAG, (2007) assessment should be viewed as semi – quantitative as it draws on both qualitative assumptions and numerical material and slope parameters.

1.13.2 For each proposed 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. For those turbines with very shallow peat depths where re-moulded and peak undrained shear strength values could not be taken Cumin values were used. The Cumin values are calculated for the factor of safety to be equal to 1.3 when a 20kPa surcharge load is applied. This value is calculated based on the measured peat depth and ground slope parameters only.

Slope Stability Analysis-Results

1.13.3 No peat failures have been observed across the proposed development site. The current baseline peat condition is therefore assumed to be in a state of equilibrium. Surcharge loading has been considered to demonstrate and model the effect of construction works proposed as part of the proposed development.

1.13.4 It should be acknowledged that the in-situ measurement of undrained shear strength of peat is problematic due to scale effects of shear vane testing. Hence the use of Cumin allows additional judgement to be made on peat slide likelihood and slope sensitivity to loading. Is it reiterated that the Cumin is calculated based on the depth of peat and surface slope geometry only and therefore this method is a simple means of screening slope sensitivity across the proposed development. The factor of safety (FOS) against sliding has been calculated at the centre of representative turbine locations. Table 8 below summarise the results:

Table 8: Infinite Slope Analysis

Location	Cu_r (kPa)	Cu (kPa)	Depth (m)	Slope (ß°)	Factor of Safety (FOS = Cu / γ z sinβ cosβ)			Cu_{min} kPa
					No Applied Load	Surcharge 20kPa	Cu_r Surcharge	
WTG 1	-	-	0	2	-	-	-	-
WTG 2	-	-	0	10	-	-	-	-
WTG 3	16	52	0.1	4	743.7	35.4	10.9	1.9
	24	54	0.2	4	389.8	35.4	15.7	2.0
WTG 4	10	25	0.1	6	240.5	11.5	4.6	2.8

Table 8: Infinite Slope Analysis								
	17	46	0.4	6	110.6	18.4	6.6	3.2
WTG 5	-	-	0	16	-	-	-	-
WTG 6	14	38	0.1	4	542.9	25.9	9.6	1.9
	26	47	0.5	4	135.1	27.0	14.7	2.3
	28	40	1.0	4	63.1	19.6	13.8	2.6
	25	28	1.5	4	26.8	11.5	10.3	3.2
WTG 7	6	17	0.1	4	242.7	11.6	4.4	1.9
	21	37	0.6	4	87.4	20.2	11,3	2.4
	18	32	0.8	4	57.5	16.4	9.2	2.5
WTG 8	-	-	NA	8	-	-	-	-
WTG 9	24	39	0.1	4	560.5	26.7	16.4	1.9
	15	19	0.6	4	45.5	10.5	8.3	2.4
	11	31	1.1	4	40.5	14.4	5.1	2.8
WTG 10	4	14	0.1	6	134.7	6.4	1.8	2.8
	12	22	0.6	6	35.3	8.1	4.4	3.5
	22	49	0.8	6	58.9	16.8	7.6	3.8
WTG 11	8	14	0.1	4	207.6	9.9	5.2	1.9
	16	27	0.6	4	65.7	15.2	8.8	2.3
	28	49	1.0	4	70.1	23.4	13.2	2.7
	22	26	1.6	4	23.4	10.4	8.8	3.3
	30	37	2.1	4	25.3	13.0	10.5	3.7
WTG-12	11	21	0.1	10	122.8	5.8	3.0	4.7
	26	38	0.3	10	73.6	9.6	6.7	5.1
WTG-13	6	14	0.1	6	132.5	6.3	2.9	2.8
	18	26	0.6	6	41.9	9.7	6.5	3.5
	29	60	1.0	6	57.6	19.2	9.4	4.1
	28	38	1.5	6	26.3	10.8	7.9	4.6
	29	38	1.9	6	19.2	9.4	7.2	5.3
WTG-14	11	29	0.1	4	415.2	19.8	7.3	1.9
	27	50	0.4	4	178.0	29.7	16.4	2.2
	18	35	1.1	4	45.7	16.2	8.3	2.8
	18	30	1.6	4	26.9	12.0	7.2	3.3
	22	38	1.7	4	32.1	14.8	8.5	3.3
WTG-15	7	14	0.1	4	194.8	9.3	4.9	1.9
	14	19	0.6	4	45.8	10.6	7.5	2.4
	17	25	1.1	4	33.1	11.7	7.8	2.8

Table 8: Infinite Slope Analysis

	23	28	1.5	4	27.3	11.7	9.4	3.2
	27	29	2.0	4	21.0	10.5	9.5	3.6
WTG-16	11	26	0.1	6	246.9	11.8	5.2	2.8
	21	24	0.6	6	38.1	8.8	7.8	3.5
	35	40	1.1	6	35.1	12.4	10.8	4.2
	42	44	1.6	6	26.7	11.9	11.1	4.9
	21	30	1.8	6	16.2	7.7	5.3	5.1

Table 9: Shear Strength Correlated with Von Post Classification

Location	Depth (m)	Cur (kPa)	Cu (kPa)	Von Post Classification
WTG 1	0	-	-	N/A
WTG 2	0	-	-	N/A
WTG 3 (Core 1)	0.1	10	45	[H4]
	0.2	30	55	[H4]
WTG 3 (Core 2)	0.1	18	54	[H2]
	0.2	22	54	[H2]
	0	-	-	N/A
WTG 4 (Core 1)	0.1	10	25	[H5]
	0.4	17	46	[H8]
WTG 4 (Core 2)	0.1	6	24	[H6]
	0.2	10	39	[H7]
WTG 4 (Core 3)	0.1	17	31	[H7]
	0.6	22	38	[H7]
	0.7	21	29	[H7]
WTG 5	0	-	-	N/A
WTG 6 (Core 1)	0.1	6	12	[H4]
	0.6	22	39	[H4]
	0.7	21	38	[H4]
WTG 6 (Core 2)	0.1	14	40	[H5]
	0.35	28	70	[H5]
WTG 6 (Core 3)	0.1	16	42	[H4]
	0.6	24	26	[H6]
	1.1	30	40	[H6]
	1.5	25	28	[H6]
WTG 7 (Core 1)	0.1	2	8	[H5]

Table 9: Shear Strength Correlated with Von Post Classification				
	0.6	10	20	[H5]
	0.8	18	32	[H5]
WTG 7 (Core 2)	0.1	4	14	[H1]
	0.1	10	22	[H5]
	0.6	24	42	[H5]
WTG 8	No access due to dense wind-blown forestry.			
WTG 9 (Core 1)	0.10	24	39	[H8]
	0.60	15	19	[H7]
	1.10	11	31	[H7]
WTG 9 (Core 2)	0.10	6	21	[H6]
	0.60	11	30	[H6]
	1.10	14	41	[H6]
	1.80	19	43	[H6]
WTG 9 (Core 3)	0.10	4	14	[H8]
	0.60	14	40	[H6]
	1.10	31	54	[H6]
WTG 10 (Core1)	0.1	4	14	[H7]
	0.6	12	22	[H7]
	0.8	22	49	[H7]
WTG 10 (Core2)	0.1	9	53	[H8]
	0.6	21	41	[H8]
	0.8	27	61	[H8]
WTG 10 (Core3)	0.1	4	7	[H7]
	0.6	9	29	[H8]
	0.8	28	56	[H8]
WTG 11 (Core1)	0.1	9	26	[H8]
	0.6	15	31	[H8]
	0.8	24	35	[H8]
WTG 11 (Core2)	0.1	11	23	[H8]
	0.6	18	29	[H8]
	1.1	23	31	[H8]
	1.6	22	26	[H8]
	2.1	30	37	[H8]
WTG 11 (Core3)	0.1	4	3	[H7]
	0.6	14	25	[H7]
	0.9	33	70	[H7]

Table 9: Shear Strength Correlated with Von Post Classification				
WTG 12 (Core1)	0.1	4	12	[H6]
	0.4	30	40	[H9]
WTG 12 (Core2)	0.1	13	24	[H8]
	0.3	25	37	[H8]
WTG 13 (Core1)	0.1	4	4	[H5]
	0.6	10	19	[H5]
	1.1	19	27	[H5]
	1.2	27	48	[H5]
WTG 13 (Core2)	0.1	7	12	[H8]
	0.6	21	35	[H8]
	0.9	40	96	[H8]
WTG 13 (Core3)	0.1	6	18	[H6]
	0.6	16	19	[H6]
	1.1	21	32	[H6]
	1.6	28	35	[H6]
	1.9	29	38	[H6]
WTG 14 (Core1)	0.1	16	48	[H5]
	0.2	18	46	[H5]
WTG 14 (Core2)	0.1	12	38	[H4]
	0.3	22	60	[H4]
WTG 14 (Core3)	0.1	8	15	[H4]
	0.6	35	40	[H4]
	1.1	18	35	[H4]
	1.6	18	30	[H4]
	1.7	22	38	[H4]
WTG 15 (Core1)	0.1	9	14	[H6]
	0.6	10	20	[H4]
	1.1	16	24	[H4]
	1.6	21	28	[H4]
	1.8	22	36	[H4]
WTG 15 (Core2)	0.1	4	12	[H5]
	0.6	14	18	[H4]
	1.1	16	27	[H4]
	1.6	18	25	[H4]
	2.1	28	27	[H4]
WTG 15	0.1	10	15	[H8]

Table 9: Shear Strength Correlated with Von Post Classification				
(Core3)	0.6	14	20	[H5]
	1.1	18	24	[H6]
	1.4	28	32	[H8]
WTG 16 (Core1)	0.1	10	27	[H6]
	0.6	17	23	[H6]
	1.1	17	25	[H6]
	1.6	30	36	[H6]
	1.8	27	40	[H6]
WTG 16 (Core2)	0.1	15	40	[H6]
	0.6	34	46	[H6]
	1.1	56	62	[H6]
	1.5	68	68	[H6]
WTG 16 (Core3)	0.1	8	11	[H6]
	0.6	9	17	[H6]
	1.1	18	22	[H6]
	1.6	18	23	[H6]
	1.8	19	27	[H6]

1.13.5 The Von Post Scale has been adopted in order to understand the changing peat material across the proposed development. Table 10 below defines the Von Post classification scheme.

Table 10: Adopted Von Post Classification				
H Value	**Qualitative Sample Description**	**Proportion of Peat Extruded when Squeezed**	**Vegetation / Structure**	**Degree of Decomposition**
H1	Clear, Colourless	None	Plant structure unaltered Fibrous, elastic.	Undecomposed
H2	Almost clear, yellow-brown	None	Plant structure distinct, almost unaltered.	Almost undecomposed
H3	Slightly turbid, brown	None	Plant structures distinct, most remains easily identifiable.	Very weakly decomposed
H4	Strongly turbid, brown	None	Plant structure distinct, most remains identifiable.	Weakly decomposed
H5	Strongly turbid, contains a little peat in suspension	Very little	Plant structure clear but indistinct and difficult to identify.	Moderately decomposed
H6	Muddy, much peat in suspension	One third	Plant structure indistinct but clearer	Well decomposed

Table 10: Adopted Von Post Classification

			in residue, most remains undefinable.	
H7	Strongly muddy	One half	Plant structure indistinct.	Strongly decomposed
H8	Thick mud, little free water	Two thirds	Plant structure very indistinct – only resistant material such as roots.	Very strongly decomposed
H9	No free water	Nearly all	Plant structure almost unrecognisable.	Almost completely decomposed
H10	No free water	All	Plant structure not recognisable, amorphous.	Completely decomposed

1.13.6 Across the proposed development there is a wide range of decomposition states exhibited in the cored peat samples. However, within individual peat samples there was no consistent vertical variation between acrotelmic and catotelmic peat units. A full analysis of the acrotelmic and catotelmic peat structure based on the collected peat coring is included within the Peat Management Plan (Appendix 11.3).

Slope Stability Analysis-Discussion

1.13.7 The preliminary slope analysis indicates limited potential for translational peat slide at the proposed development under current equilibrium conditions. The slope stability analysis is termed 'preliminary' as the nature of input parameters are index values only. The lower bound undrained shear strength recorded across the proposed development is at the lower detectable limit for the light weight portable shear vane apparatus. It is highlighted that any inaccuracy in the preliminary Cu value will have a proportionally large effect on the slope stability analysis results.

1.13.8 It is further highlighted that the slope angle of the ground surface does not necessarily represent the slope angle of a potential failure surface within the peat. In the absence of more detailed sub-surface intrusive ground investigation 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. It is this basal peat interface which has been assumed as a potential slip plane by the slope stability analysis.

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

1.13.10 Cone penetration testing (CPT) which uses a full flow ball penetrometer or 'T-bar' penetrometer may be specified to allow for higher repeatability and accurate in-situ test results. Un-disturbed sampling with thin walled samplers will allow for laboratory testing to be undertaken. However, issues of sample preservation and disturbance are important factors to address. Both methods are generally suited to deep peat deposits (i.e.>2m) and require major plant mobilisation. The potential of disturbing sensitive peat deposits during pre-construction survey access should be taken as a future consideration in investigation planning.

Stability Analysis-Turbines

1.13.11 Factor of Safety (FOS) values for the turbine locations have been derived with reference to BS6031:2009 Code of Practice for Earth Works. The lowest FOS was calculated is 5.8 for proposed turbine location WTG 12 under a surcharged condition at peak undrained shear strengths recorded in the peat deposit at this location.

1.13.12 It is clearly evident that where peat deposits approach re-moulded undrained states, the strength of the material decreases as the structure is lost. This trend is reflected by the value of FOS results calculated across the proposed development for the remoulded surcharge slope condition. Under such material conditions, marginal stable peat deposits are predicted. For example, at WTG10, where a FOS of 1.8 has been calculated for this condition.

1.13.13 It can be seen in Table 9 that there is no clear trend between Von Post class and undrained shear strength across the results taken for each turbine location. This may be an indication that the peat mass is relatively homogeneous in its material behaviour.

1.13.14 It should be reiterated that the natural slope condition has been calculated to be stable and this has been confirmed by the field survey observations. It is however important to highlight that the majority of the proposed development remains obscured by commercial forestry plantation. This state makes large scale visual observations of terrain and geomorphological elements difficult. It will therefore follow that a continued ground stability assessment approach be adopted where periodic inspections are carried out following key phases of proposed development. This may be following felling operations, pre-construction and as required throughout the operational phase of proposed development.

1.14 Peat Slide Risk Assessment

1.14.1 In line with the recommendations set out in PLHRAG, (2007); the potential environmental impact rating for proposed wind farm infrastructure is obtained from assessing the proximity to watercourses and drainage ditches (Table 11).

1.14.2 Probability values have been assessed for combined contributory factors to peat failure recorded across the proposed turbine locations. The environmental impact rating is then multiplied with this probability of peat slide based on the cumulative contributory factors recorded. This approach conveys the overall hazard ranking and accounts for increased susceptibility where multiple contributor factors are identified.

1.14.3 Hazard rankings for the proposed turbine positions are presented in Table 11. Figure 11.6 depicts the peat stability hazard zonation map for the proposed development. This hazard zonation map is based on the risk assessment process documented in this report. Figure 11.7 has been produced to reflect the peat hazard zonation map post mitigation. A review of the peat depth map and slope map has been applied. Discrete terrain units have been assessed with regards to land use, hydrology, hydrogeology, slope geometry, peat depth and evidence of past failure. A geomorphological map is provided as Figure 11.1.

1.14.4 Further detail of the risk assessment is highlighted within the preliminary geotechnical risk register (section 6).

Table 11: Risk Assessment & Hazard Ranking Proposed Wind Turbine Locations				
WTG ID	**Impact Scale Environment**	**Contributory Factors (Probability to Failure)**		**Hazard Ranking**
WTG 1	1 (>150m of nearest watercourse)	Peat Depth (Mean = 0m)	1	INSIGNIFICANT (NO PEAT RECORDED)
		Slope Angle (Max = 2 º)	1	
		FOS (Min = N/A)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 2	1 (157m NE of nearest watercourse)	Peat Depth (Mean = 0m)	1	INSIGNIFICANT (NO PEAT RECORDED)
		Slope Angle (Max = 10 º)	5	
		FOS (Min = N/A)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	
WTG 3	2 (140m SE of nearest watercourse)	Peat Depth (Mean = 0.1m)	1	(3+2) x 2 = 10 SIGNIFICANT
		Slope Angle (Max = 4 º)	3	
		FOS (Min = 35.4)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 4	2 (145m SE of nearest watercourse)	Peat Depth (Mean = 0.4m)	1	(3+2) x 2 = 10 SIGNIFICANT
		Slope Angle (Max = 6º)	3	
		FOS (Min = 11.5)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
		Peat Depth (Mean = 0m)	1	
		Slope Angle (Max = 16 º)	4	

Table 11: Risk Assessment & Hazard Ranking Proposed Wind Turbine Locations				
WTG ID	**Impact Scale Environment**	**Contributory Factors (Probability to Failure)**		**Hazard Ranking**
WTG 5	3 (80m W of nearest watercourse)	FOS (Min = N/A)	1	INSIGNIFICANT (NO PEAT RECORDED)
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	
WTG 6	1 (>150m of nearest watercourse)	Peat Depth (Mean = 0.8m)	3	(3+3+2) x 1 = 8 SIGNIFICANT
		Slope Angle (Max = 4 °)	3	
		FOS (Min = 11.5)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 7	1 (>150m of nearest watercourse)	Peat Depth (Mean = 0.6m)	3	(3+3) x 1= 6 SIGNIFICANT
		Slope Angle (Max = 4 °)	3	
		FOS (Min = 11.6)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	
WTG 8	3 (90m S of nearest watercourse)	Peat Depth (Mean = 0.5 – 1.0m)	-	INACCESSABLE, Interpolated Ranking = SERIOUS Preliminary and conservative assessment requiring re-assessment following clear access.
		Slope Angle (Max = 8 °)	-	
		FOS (Min = -)	-	
		Cracking / Infiltration	-	
		Groundwater Flow	-	
		Hydrology	-	
		Previous Instability	-	
		Land Management	-	
		Peat Depth (Mean = 1.4m)	5	
		Slope Angle (Max = 10 °)	3	
		FOS (Min = 10.5)	1	

Table 11: Risk Assessment & Hazard Ranking Proposed Wind Turbine Locations

WTG ID	Impact Scale Environment	Contributory Factors (Probability to Failure)		Hazard Ranking
WTG 9	3 (75m S of nearest watercourse)	Cracking / Infiltration	1	(5+3+3) x 3 = 33 SERIOUS
		Groundwater Flow	1	
		Hydrology	3	
		Previous Instability	1	
		Land Management	1	
WTG 10	3 (80m of nearest watercourse)	Peat Depth(Mean = 0.8m)	3	(3+2) x 3 = 15 SUBSTANTIAL
		Slope Angle (Max = 3 º)	1	
		FOS (Min = 6.4)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 11	1 (>150m of nearest watercourse)	Peat Depth (Mean = 1m)	5	(5+3) x 1 = 8 SIGNIFICANT
		Slope Angle(Max = 4 º)	3	
		FOS (Min = 9.9)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	
WTG 12	1 (>150m of nearest watercourse)	Peat Depth (Mean = 0.3m)	1	(5+2) x 1 = 7 SIGNIFICANT
		Slope Angle (Max = 10 º)	5	
		FOS (Min = 5.8)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 13	1 (>150m of nearest watercourse)	Peat Depth (Mean = 1m)	5	(5+3+2) x 1 = 10 SIGNIFICANT
		Slope Angle (Max = 6 º)	3	
		FOS (Min = 6.3)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	

Table 11: Risk Assessment & Hazard Ranking Proposed Wind Turbine Locations				
WTG ID	**Impact Scale Environment**	**Contributory Factors (Probability to Failure)**		**Hazard Ranking**
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 14	1 (>150m of nearest watercourse)	Peat Depth (Mean = 0.2m)	1	3 x 1 = 3 INSIGNIFICANT
		Slope Angle (Max = 4 °)	3	
		FOS (Min = 12.0)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	
WTG 15	1 (>150m of nearest watercourse)	Peat Depth (Mean = 1.8m)	5	(5+3+2) x 1 = 10 SIGNIFICANT
		Slope Angle (Max = 4 °)	3	
		FOS (Min = 9.3)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	
WTG 16	1 (>150m of nearest watercourse)	Peat Depth(Mean = 1.8m)	5	(5+3+2) x 1 = 10 SIGNIFICANT
		Slope Angle (Max = 6 °)	3	
		FOS (Min = 7.7)	1	
		Cracking / Infiltration	1	
		Groundwater Flow	1	
		Hydrology	2	
		Previous Instability	1	
		Land Management	1	

1.14.5 Table 12 below summarises the risk assessment outcome and hazard ranking assignments for each turbine location. The principal contributory factors and impact scales used to derive these assignments are also stated with a post mitigation hazard ranking indicated.

Table 12: Summary of Hazard Ranking-Proposed Wind Turbine Locations			
Turbine ID	**Hazard Ranking**	**Principal Contributory Factors in Risk Assessment**	**Hazard Ranking with Applied Control Measures**
WTG 1	Insignificant	No Peat Cover.	Insignificant
WTG 2	Insignificant	No Peat Cover.	Insignificant
WTG 3	Significant	Slope angle and surface hydrology.	Insignificant
WTG 4	Significant	Slope angle and surface hydrology.	Insignificant
WTG 5	Insignificant	No Peat Cover	Insignificant
WTG 6	Significant	Peat depth, slope angle and surface hydrology.	Insignificant
WTG 7	Significant	Peat depth and slope angle.	Insignificant
WTG 8	Serious	Environmental impact scale. Interpolated Hazard Zone – Peat Depth, Slope Angle.	Significant
WTG 9	Serious	Environmental impact scale, peat depth, slope angle and surface hydrology.	Significant
WTG 10	Substantial	Environmental impact scale, peat depth.	Significant
WTG 11	Significant	Peat depth and slope angle.	Insignificant
WTG 12	Significant	Slope Angle and surface hydrology.	Insignificant
WTG 13	Significant	Peat depth, slope angle and surface hydrology.	Insignificant
WTG 14	Insignificant	Slope angle.	Insignificant
WTG 15	Significant	Peat depth, slope angle and surface hydrology.	Insignificant
WTG 16	Significant	Peat depth, slope angle and surface hydrology.	Insignificant

1.14.6 The risk assessment reflects the probability of peat material polluting a surface water course and being entrained to an offsite receptor without any mitigation. The effect on proposed onsite infrastructure has also been integrated into the assessment. Risk ratings should be reduced to a residual level where targeted and appropriate mitigation measures are incorporated into the construction environmental management plan (CEMP). However, it is strongly highlighted that this preliminary assessment provides the indication that the proposed development is at insignificant to significant risk of peat slide hazard with application appropriate control measures. Figures 11.7 and 11.8 provide detailed and site wide hazard zonation views for pre and post mitigation peat stability assessment.

1.15 Geotechnical Risk Register

1.15.1 A preliminary Geotechnical Risk Register has been produced for the proposed wind turbine locations (Table 13). This risk register is intended for use by the Developer and future Principal Contractor who may be appointed for the construction of the site. A complete geotechnical risk management process should be utilised throughout the construction phase and amended accordingly as new information is received.

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
WTG 1	Peat Depth (Mean = 0m)	Negligible	No	1	2	1 (>150m of nearest watercourse)
	Slope Angle (Max = 2^{0})	Negligible	No	1		
	Factor of Safety (Min FOS 20kPa surcharge = N/A)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Artificial drain	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					NO PEAT RECORDED **(INSIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
WTG 2	Peat Depth (Mean = 0m)	Negligible	No	1	7	**1** (157m NE of nearest watercourse)
	Slope Angle (Max = 10^{o})	Very Likely	Yes	5		
	Factor of Safety (Min FOS 20kPa surcharge = N/A)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Artificial drain	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					NO PEAT RECORDED **(INSIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 3	Peat Depth (Mean = 0.1m)	Negligible	No	1	5	**2** (130m SE of nearest watercourse)
	Slope Angle (Max = 4^{o})	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 35.4)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Artificial drain	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(3+2) x 2 = 10 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 4	Peat Depth (Mean = 0.4m)	Negligible	No	1	5	**2** (145m SE of nearest watercourse)
	Slope Angle (Max = 6^{o})	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge =11.5)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology -Ditch with saturated vegetation in bog pools	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(3+2) x 2 = 10 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 5	Peat Depth (Mean = 0m)	Negligible	No	1	4	3 (80m W of nearest watercourse)
	Slope Angle (Max = 16°)	Probable	Yes	4		
	Factor of Safety (Min FOS 20kPa surcharge = N/A)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - None Evident	Negligible	No	1		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					NO PEAT RECORDED **(INSIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	B) Optimise turbine location and or design following ground investigation.			G) Use experienced geotechnical personnel throughout investigation and monitoring.		
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.			H) Use experienced civil contractor with trained operators to design and implement CEMP.		
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 6	Peat Depth (Mean = 0.8m)	Likely	Yes	3	8	1 (149m NW of nearest watercourse)
	Slope Angle (Max = 4°)	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 11.5)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Artificial drains	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(3+3+2) x 1 **(SIGNIFICANT)**
	Control Measures			E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.		
	A) Pre-construction detailed geotechnical investigation and design.			F) Consider the changing properties of stockpiled materials including weathering protection.		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	B) Optimise turbine location and design following ground investigation.			G) Use experienced geotechnical personnel throughout investigation and monitoring.		
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.			H) Use experienced civil contractor with trained operators to design and implement CEMP.		
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 7	Peat Depth (Mean = 0.6m)	Likely	Yes	3	6	1 (>150m of nearest watercourse)
	Slope Angle (Max = 4^{o})	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 11.6)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - None Evident	Negligible	No	1		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					6 x 1 = 6 **(SIGNICICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	A) Pre-construction detailed geotechnical investigation and design.	F) Consider the changing properties of stockpiled materials including weathering protection.				
	B) Optimise turbine location and design following ground investigation.	G) Use experienced geotechnical personnel throughout investigation and monitoring.				
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.	H) Use experienced civil contractor with trained operators to design and implement CEMP.				
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 8	Peat Depth (Mean = 0.5-1.0)	Likely	YES	3	6	**=6x3 = 18** (90m S of nearest watercourse)
	Slope Angle (Max = 8^{o})	Likely	YES	3		
	Factor of Safety (Min FOS 20kPa surcharge = N/A)	NA	NA	NA		
	Peat Cracking - None Evident	NA	NA	NA		
	Groundwater flow - None Evident	NA	NA	NA		
	Surface Hydrology - None Evident	NA	NA	NA		
	Previous Instability - None Evident	NA	NA	NA		
	Land Management	NA	NA	NA		
	Hazard Ranking					(6 x 3 = 18) **(SERIOUS)**

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**SIGNIFICANT**
WTG 9	Peat Depth (Mean = 1.4m)	Very Likely	Yes	5	11	3 (75m S of nearest watercourse)
	Slope Angle (Max = 4º)	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 10.5)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Drainage ditch and wet flush areas	Likely	Yes	3		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(5+3+3) x 3 = 33 **(SERIOUS)**

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(SIGNIFICANT)**
WTG 10	Peat Depth (Mean = 0.8m)	Likely	Yes	3	5	3 (80m N of nearest watercourse)
	Slope Angle (Max = 3^{o})	Negligible	No	1		
	Factor of Safety (Min FOS 20kPa surcharge = 6.4)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - None Evident	Unlikely	No	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Hazard Ranking					(3+2) x 3 = 15 **(SUBSTANTIAL)**
	A		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location following detailed ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(SIGNIFICANT)**
WTG 11	Peat Depth (Mean = 1m)	Very Likely	Yes	5	8	1 (>150m of nearest watercourse)
	Slope Angle (Max = 4°)	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 9.9)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - None Evident	Negligible	No	1		
	Previous Instability - None Evident	Negligible	No	1		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Land Management	Negligible	No	1		
	Hazard Ranking					(5 + 3) x 1 = 8 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 12	Peat Depth (Mean = 0.3m)	Negligible	No	1	7	1 (>150m of nearest watercourse)
	Slope Angle (Max = 10^{o})	Very Likely	Yes	5		
	Factor of Safety (Min FOS 20kPa surcharge = 5.8)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Drainage Ditches	Unlikely	Yes	2		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(5+2) x 1 = 7 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
WTG 13	Peat Depth (Mean = 1m)	Very Likely	Yes	5	10	**1** (>150m of nearest watercourse)
	Slope Angle (Max = 6^{o})	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 6.3)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
	Surface Hydrology - Artificial drains	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(5+3+2) x 1 = 10 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
	Peat Depth (Mean = 0.2m)	Negligible	No	1	3	**1** (>150m of nearest watercourse)
	Slope Angle (Max = 4^o)	Likely	No	3		
	Factor of Safety (Min FOS 20kPa surcharge = 12.0)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		
	Groundwater flow - None Evident	Negligible	No	1		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
WTG 14	Surface Hydrology -Artificial drain	Negligible	No	1		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(3) x 1 = 3 **(INSIGNIFICANT)**
	Control Measures			E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.		
	A) Pre-construction detailed geotechnical investigation and design.			F) Consider the changing properties of stockpiled materials including weathering protection.		
	B) Optimise turbine location and design following ground investigation.			G) Use experienced geotechnical personnel throughout investigation and monitoring.		
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.			H) Use experienced civil contractor with trained operators to design and implement CEMP.		
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
	Peat Depth (Mean = 1.8m)	Very Likely	Yes	5		
	Slope Angle (Max = 4^{o})	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 9.3)	Negligible	No	1		
	Peat Cracking - None Evident	Negligible	No	1		1

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
WTG 15	Groundwater flow - None Evident	Negligible	No	1	10	(>150m of nearest watercourse)
	Surface Hydrology - Wet flushes and minor pooling	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(5+3+2) x 1 = 10 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**
	Peat Depth (Mean = 1.8m)	Very Likely	Yes	5		
	Slope Angle (Max = 6^{o})	Likely	Yes	3		
	Factor of Safety (Min FOS 20kPa surcharge = 7.7)	Negligible	No	1		

Table 13: Preliminary Geotechnical Risk Register (Peat)

WTG ID	Contributory Factors to Potential Peat Failure	Probability of Causing a Peat Failure	Specific Control Required?	Probability Scale For Contributory Factors	Cumulative Rating	Environmental Impact Scale
WTG 16	Peat Cracking - None Evident	Negligible	No	1	10	**1** (>150m of nearest watercourse)
	Groundwater flow - None Evident	Negligible	No	1		
	Surface Hydrology - Peat pipe, small tributary	Unlikely	Yes	2		
	Previous Instability - None Evident	Negligible	No	1		
	Land Management	Negligible	No	1		
	Hazard Ranking					(5+3+2) x 1 = 10 **(SIGNIFICANT)**
	Control Measures		E) For overburden and dedicated peat storage areas calculate the factor of safety against failure.			
	A) Pre-construction detailed geotechnical investigation and design.		F) Consider the changing properties of stockpiled materials including weathering protection.			
	B) Optimise turbine location and design following detailed ground investigation.		G) Use experienced geotechnical personnel throughout investigation and monitoring.			
	C) Maintain hydrology of local area to prevent ponding or 'dam' effect'.		H) Use experienced civil contractor with trained operators to design and implement CEMP.			
	D) Prevent surcharge loading of peat slopes.					
	Hazard Ranking with applied Control Measures					**(INSIGNIFICANT)**

1.16 Construction & Geotechnical Risk Management

Construction Mitigation

1.16.1 The factors which influence natural and induced peat slope failures have been discussed in detail in Section 11.4 (Peat Slide Hazard-Risk Assessment Method). The following construction related factors are highlighted for further consideration:

- Peat movement can occur following over-loading of peat slopes, e.g. by placement of fill, stockpiling and end-tipping directly onto peat slopes.
- Suitability of drainage measures and the prevailing groundwater conditions are key factors to consider during construction. Increasing pore water pressures within peat deposits decreases the stability of a slope.
- In extreme events, peat can act as a viscous fluid and travel over very shallow slopes. The re-working or excessive handling of peat can reduce the shear strength to residual levels and hence lead to 'liquid' peat behaviour.
- The rate of construction can have a major influence on the stability of peat land environments. Rapid loading and limited time for excess pore pressure dissipation can also decrease the stability state of peat slopes.
- Excavation across a side slope, in particular a convex slope / break in slope can induce peat failure.

1.16.2 The consequence of peat failure at the proposed development may result in a number of negative effects; external public infrastructure has been excluded due to the remote nature of the proposed development. Therefore, the most significant but unlikely impact is considered to be death or injury to site personnel. More likely is disruption to the proposed infrastructure through damage leading to time and cost effects on the proposed development.

1.16.3 Impact through degradation of the hydrological and peatland environment has been considered as a primary overriding concern. Effects such as the contamination of surface water courses are also considered as this may in turn impact ground water supplies. The following mitigation measures, when incorporated into the design and construction of the project will assist in the management of the risk from peat instability during Wind farm construction:

- The use of experienced and competent civil construction contractors adopting best practice methods.
- Review turbine location and appropriate design where further detailed ground investigation analysis allows for a refinement of the risk assessment.
- Detailed monitoring programme of geomorphology and hydrology across the critical areas as part of the construction management. This shall be focussed across all infrastructure elements where a hazard ranking of 'Significant' or higher has been identified.
- Figure 11.6 and Figure 11.7; provides a detailed interpretation of the hazard zones for pre and post mitigation scenarios respectively. This information will hence be used to develop detailed construction planning and be a key driver for active risk management.
- Refine the environmentally sensitive zones across the site and integrate these areas into the detailed Construction Environmental Management Plan (CEMP).
- Apply conservative design parameters across the elevated hazard zones.
- Produce a robust drainage design which preserves the natural hydrological regime across the proposed development. The control of silt and suspended solids shall be carefully planned to avoid detrimental environmental effects. All drainage discharges shall be under consent from the relevant SEPA control unit and performed in an environmentally compliant manner.

- A documented procedure shall be in place and rapid reaction strategy in place prior to the commencement of construction on peat land. This strategy shall be enacted should signs of peat movement be recorded across the proposed development. This approach requires periodic and continued monitoring of the construction process by a suitably qualified geotechnical engineer.
- A detailed Construction Environmental Management Plan (CEMP) shall be produced and incorporate the conclusions of the peat stability report, continuously update the assessment and develop appropriate mitigations to respond to the peat slide risk as development proceeds.
- The Geotechnical Risk Register shall be maintained as a 'live' document and updated and amended as required throughout the pre-construction and construction phase of development.

Operational Phase Mitigation

1.16.4 It will be best practice for post construction peat slide risk management to take the form of periodic inspections undertaken by a suitably qualified geotechnical engineer. Across the site this process will aim to identify any signs of developing instability at the earliest possible stage and where required remedial action can be taken to prevent peat slide.

1.16.5 This activity would generally take the form of infrastructure inspections of surrounding peat slope stability, with recording of any visual signs of ground movement including identification of tension cracking or slumping of peat material. Future inspection frequency would be determined post construction and be dependent upon meteorological conditions.

1.17 Conclusions

1.17.1 The proposed development occupies an upland area with complex terrain and widespread hill peat cover. This preliminary assessment has examined 16 No. proposed wind turbine locations and associated infrastructure locations.

1.17.2 The mean peat depth recorded across the proposed infrastructure is 0.6m. A maximum peat depth 5.0m has been recorded in a discrete pocket south – west and away from access infrastructure to WTG 6. The proposed layout and construction methods have been demonstrated to avoid impact on the deeper peat areas.

1.17.3 Based on visual inspection and desk study review, there are concluded to be little to no signs of active peat instability, and tension cracking of sloping peat deposits. This point is countered by the fact there is reduced visibility of wider large-scale terrain features across the forested environment.

1.17.4 A possible relict slide identified on the geomorphological map (Figure 11.1) is considered to be a minor feature associated with a slow process of natural erosion close to a main watershed area. The feature is considered to be of relatively limited extent with no further evidence of existing slides across the surveyed areas or within the areas of proposed infrastructure. The presence of the existing turbine ~75m west from the relict slide feature with no observed effect on the stability of peat in this area adds some weight to this analysis. The risk assessment methodology provides the opportunity to include existing evidence of instability however since no features were recorded across the proposed layout this was not applied as a contributory factor for the proposed turbine locations.

1.17.5 Peat depth, slope angle and in-situ un-drained shear strength have been analysed using the infinite slope model. This has been used to calculate the Factor of Safety (FOS) against a translational peat slide. For the current equilibrium case all representative turbine locations were calculated to be stable. Where re-moulded shear strengths are adopted, all failure likelihoods are negligible apart from one case of marginal stability predicted at WTG 12. The specified control measures are therefore proposed to prevent the in-situ peat deposits every reaching a re-moulded or highly disturbed condition.

1.17.6 In general, the risk assessment has assigned insignificant to significant ranking for peat failure events at the proposed development without any control measures. Two proposed turbine locations (WTG 8 & 9) have been designated as a serious hazard due to the combination of peat depth, slope angle and close proximity to a main watercourse. This is due to both the likelihood and the impact and consequences of a peat instability occurring. The iterative layout design process has accounted for this situation with the proposed location optimised from the highest risk and deepest peat areas as far as practicable. The outstanding contributory factors to peat slide risk remain the proximity to watercourses and the slope angle range across the higher risk areas. Figure 11.8 provides a detailed peat stability hazard zonation map (pre-mitigation) for turbines T9 and T10. This serves to highlight the importance of targeted control measures at these locations which will focus on maintaining the hydrological regime in order to protect the sensitive watercourse to the north of these locations.

1.17.7 Specialist control measures highlighted within Table 13 will need to be carefully applied to these and all proposed infrastructure locations in order to mitigate the hazard and risk, ensuring the lower acceptable residual risk. Figure 11.7 provides a clear overview of the peat stability hazard zonation for the site following application of control measures.

1.17.8 The specified control measures will also strictly apply to all pre-construction activities including forestry clearance and intrusive site investigation. The presence of the commercial forestry and potential changing ground conditions associated with clear felling of infrastructure areas will need to be considered as part of a refined peat stability risk assessment carried out following ground investigation.

1.17.9 Across the wider setting of the proposed development, there are prevailing peat depths of 0-0.5m which as stated in PHLARG, (2007) is of negligible likelihood to cause peat failure. In addition to this the vast majority of the site is also within a slope angle of 4-9°, an angle at which shallow peat (up to 2.0m), which is observed on site, has only a moderate propensity to fail. In terms of the impact or exposure; the frequency of watercourses on site means that the environmental impact scale ranks ‘significant’ for the majority of the development. The impact of a peat failure event would be high as the watercourses would act as an offsite receptor with material being entrained within them without any applied control measures.

1.17.10 A potential infrastructure impact has been acknowledged through the assessment, however the environmental impact given the sensitive nature of the hydrological systems across the site have in general been assigned a higher weighting and therefore are the primary driver in the risk assessment process.

1.17.11 The layout of the proposed development has been developed through an iterative design approach encapsulating a wide variety of environmental constraints. The phased acquisition of peat survey data has assisted in establishing the optimised infrastructure layout to ensure where possible impact on deeper areas of peat has been minimised and higher risk peat stability areas have been avoided.

1.18 Recommendations

General

1.18.1 The preliminary geotechnical risk register for peat at the proposed development cites key control measures which will be required to reduce the risk of peat slide to residual levels. These control measures apply to the proposed turbine locations. However, there should be wider consideration of these measures across all areas of the proposed development which may be influenced by the proposed construction. This is critical where infrastructure may impact terrain and slope conditions beyond the proposed working areas.

1.18.2 A detailed intrusive ground investigation will be carried out (post-consent) and as part of the pre-construction phase of the proposed development. This investigation will seek to further characterise the peat deposits with emphasis on, advanced in-situ shear strength testing and targeted undisturbed sampling and laboratory testing.

1.18.3 Groundwater level information will be collated as part of any future ground investigation.

1.18.4 The results of a detailed ground investigation will be assessed with respect to refining the peat stability assessment at all infrastructure locations. All pertinent control measures and mitigation measures will be revised, and their implementation supervised following the results of the ground investigation and construction design phase of works.

1.18.5 Continued assessment and monitoring throughout the construction phase of works and at suitable intervals post construction will be implemented to ensure the control measures are suitable and are providing adequate mitigation against peat slide.

1.19 Construction Environmental Management Plan (CEMP)

1.19.1 Construction practices shall be managed through the Construction Environmental Management Plan (CEMP). The CEMP will be prepared by the appointed principal contractor and reviewed by a suitably experienced geotechnical engineer who has read and understood this report. The following general recommendations are provided in line with the Good practice during Wind farm construction, (2010) guidance which should be incorporated into any future CEMP document:

- Avoidance of arisings being placed as local concentrated loads on peat slopes without first establishing the stability condition of the ground and slope system. Stockpiling on areas of deep peat and in close proximity to steep slopes will be avoided.
- Avoidance of uncontrolled and concentrated surface water discharge onto peat slopes as this may act as contributory factor to failure. All water discharged from excavations during construction phase will be directed away from all areas identified as susceptible to peat failure and will be managed by a suitably designed site drainage management plan.
- All excavations where required will be adequately supported to prevent collapse and the destabilising peat deposits adjacent to excavations.
- A system of daily reporting will be established during construction and utilised to monitor the geotechnical performance of slopes including peat, sub-soil and bedrock. This shall be implemented and undertaken by a suitable experienced and qualified geotechnical engineer. Post construction this monitoring procedure shall be curtailed to allow for annual or ad-hoc inspection or as recommended by the geotechnical engineer.

Floating Access Track Construction

1.19.2 MacCulloch, (2005) advises that a 'floating' type road construction which leaves the peat deposits in situ may be advantageous with respect to preventing peat failure. This method of construction has a lower impact on the internal groundwater flow within the peat land. However, there are cases where groundwater flow within the peat can be detrimentally affected by floating track. The following control measures should be implemented as part of the design and construction of 'floating' access track:

- Prevent the rupture of vegetation surface of the peat by avoiding the use of large sharp rock fill.
- Prevent the overloading and subsequent shearing of the peat throughout construction and use of the 'floating' track.

- Prevent the collapse of integral drainage channels through ongoing monitoring and maintenance.
- Monitoring of the long-term settlement of the 'floating' track, necessary to predict the effects of reducing permeability within the peat and hence increasing groundwater pressures beneath the track construction. Through ongoing monitoring additional drainage relief measures can be implemented when conditions for peat failure are predicted.
- Do not position 'floating' access track on or adjacent to convex side slopes.

1.19.3 An additional control on the construction and use of 'floating' track is through the strict management of construction traffic loading. This may involve the timing between heavy traffic to be staggered to prevent the effect of cyclic loading over short time periods reducing the shear strength of the peat. In order to assess the maximum loading rate or timing between heavy construction traffic it may be necessary to monitor the vertical deformation of the 'floating' track sections following loading and recording the time taken for recovery of vertical deformation. The use of simple settlement plates and survey pegs can be used to achieve this. The frequency of trafficking for heavy loads must then be timed to allow deformation of the 'floating' road to recover its deformation. MacCulloch, (2005) generally advises that in order to prevent injury or an environmental incident, it is important that there is a robust procedure in place should it become apparent that a peat failure is imminent.

Cut Track Construction

1.19.4 Across areas of the proposed development not mantled by deep blanket peat the construction of proposed access tracks shall be considered by excavation and replacement method, (MacCulloch, 2005). Excavated peat is carefully placed along bunds at either side of the access track. Imported aggregate would be used to form the subgrade and running surface of the track.

1.19.5 For 'Cut' track construction the risk of peat failure is therefore focussed on the peat deposits adjacent to the access track, and the placement of peat arisings. In these areas the following control measures are listed by MacCulloch, (2005):

- Careful excavation of peat deposits by appropriate machine excavator to limit localised peat failures which can occur on the edge of the track excavation. This is in order to prevent a minor failure triggering retrogressive peat failure affecting a larger area of peat adjacent to the track.
- Temporary drainage systems followed by establishment of a permanent drainage network. Silt traps and small retaining structures may be required especially in proximity to water crossings to prevent siltation and blockage of watercourses.
- Ongoing monitoring and on demand maintenance when silt traps require emptying and temporary drainage reinstated if blocking occurs. This will assist in maintaining hydrology baseline conditions.
- The permanent drainage system must direct surface water flow away from the 'cut' track to prevent peat failure within the track bunds.

Foundation Excavations & Crane Hardstand

1.19.6 Where excavation into deep areas of peat is unavoidable; the use of a rock cofferdam or rock fill ring structure around the excavation shall be considered. The rock retaining wall should be designed to retain peat and groundwater from an excavation and prevent ingress or failure on the periphery of the working area. This technique may not be required for the proposed turbine locations where there is a shallow depth of peat. This should be re- assessed following detailed site investigation (post-consent).

1.19.7 Piling of turbine foundations shall also be considered at the detailed design stage. This method of foundation construction can reduce the requirement for deep and large excavations within peat and hence reduce the associated risk of failure when excavating. Full consideration must however be given to the plant requirements and working area which may need to be formed on a 'floated' hard standing or working platform.

1.19.8 Rock fill displacement methods, which are sometimes employed for crane pads in deep peat, shall be subject to thorough risk assessment, particularly in the vicinity of slope crests where the lateral loading may add to slope destabilising forces.

Civil Earthworks

1.19.9 It has been identified that there is a likely requirement for the excavation of considerable volumes of peat and superficial deposits during construction of the Wind farm. The CEMP shall contain details of this process incorporating the following recommendations. Initially the vegetated peat layer and any topsoil will be stripped and temporarily stockpiled away from areas of deep peat. The design of this stockpile must be agreed by a suitably qualified geotechnical engineer. When working in areas of deep peat (i.e. >1.5m) no peat or overburden will be stored on such deposits as this may lead to instability.

1.19.10 The following options for peat storage may be considered:

- Dedicated peat storage areas, designed under the advisement of a suitable qualified geotechnical engineer and conform to up to date SEPA regulations and waste directives.
- Removal of excess material off site to a licensed disposal area. (This option has been discounted following a detailed review of the peat excavation and re-use volumes. A dedicated Peat Management Plant (Appendix 11.3) indicates there is significant capacity for re-use of excavated peat as part of a best practice re-use strategy).
- Re-use of peat in dressing off of batters on access tracks, finishing of cable trenching works, the landscaping of turbine bases. Excavated glacial till and weathered rock may be used as backfill to turbine bases should material be deemed geotechnically suitable. All related works will be carried out in accordance with an agreed CEMP and conform to site restoration plans.
- For in-situ and undisturbed peat; site vehicle movements will be minimised across such areas, throughout construction and post construction. Observation and monitoring for settlement, deformation or signs of failure along access tracks and critical working areas will be implemented. This may be achieved with a network of settlement plates and survey markers which can be periodically re-surveyed, and any differential movements identified.
- It is recommended that all earthworks are designed in accordance with current standards. Suitable guidance for temporary workings in peat is outlined in Table 14 below, after Construction Health and Safety, Earthworks, (2005). Observations suggest 'soft non-fibrous wet peat' is predominant on site.

Table 14: Recommended Temporary (1-14 days) Peat Cutting Geometry

Peat Type	'Dry' Site*	'Wet' Site**
	Degrees from horizontal (min/max)	
Soft non-fibrous	10/20	5/10
Firm non-fibrous	15/25	5/10
Firm fibrous	35/40	20/25
Stiff fibrous	35/45	25/35

*'Dry' Site: minor or no seepage from excavation faces, with minor or no surface runoff.
**'Wet' Site: submerged or widespread seepage from excavated faces.

Drainage

1.19.11 Environmentally compliant drainage designs for the proposed development will form a primary control and mitigation for maintaining surface hydrology and shallow groundwater flow across the proposed development.

1.19.12 Some of the key responses to minimising the effect on the hydrology of the proposed development are reiterated below:

- Check dams, silt traps, settlement ponds and buffer strips will be incorporated into the drainage system as necessary and will serve the dual purpose of attenuating peak flows, by slowing the flow of runoff through the drainage system, and, allowing sediment to settle before water is discharged from the drainage system.
- The constructed drainage system shall not discharge directly to any natural watercourse, but, should instead discharge to buffer strips. These buffers will act as filters and minimise sediment transport, attenuate flows prior to discharge and maximise infiltration back into the soils and peat. Erosion protection shall be installed at discharge points.
- To reduce the impact of the proposed development on the natural hydrological regime, the site design will aim to mimic the greenfield runoff response at source through the use of sustainable drainage practices.
- Ponds and basins that can store water at the ground surface can be designed to control flow rates by storing floodwater and releasing it slowly once the risk of flooding has passed.

1.19.13 All watercourse crossing structures will be designed and constructed using best practice techniques and will be of sufficient capacity to accommodate storm flows for a 1 in 200-year storm event, with an allowance for increased flows that may occur as a result of climate change. By ensuring that structures have sufficient capacity the risk of upstream flooding and increased erosion and sedimentation will be reduced.

1.19.14 All drainage management plans including any proposed drainage blocking shall be agreed with SEPA and the relevant statutory bodies prior to starting construction.

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Web Resources

1: http://www.bgs.ac.uk/lexicon

2: http://www.sepa.org.uk/flooding/flood_extent_maps.aspx