Craiginmoddie Wind Farm

Peat Stability Risk Assessment

December 2022

CONTENTS

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

Reporting Experience

1.1 Report Author – Chris McCulla is a geotechnical engineer at Natural Power and geologist by training (BA Environmental Science & Geology) and Fellow of the Geological Society of London with over 5 years of relevant geotechnical experience. On behalf of Natural Power, Chris has been involved in field work and reporting of multiple peat slide risk assessments for renewable energy projects across the UK.

1.2 Report Approver - Gavin Germaine is a principal geotechnical engineer at Natural Power and engineering geologist by training (MSc Engineering Geology) with greater than 15 years of relevant geotechnical experience. Gavin is a Chartered Geologist (CGeol) and a Fellow of the Geological Society of London. Over the last decade has completed multiple peat slide risk assessments for wind energy projects across the UK and Ireland. Gavin has further provided expert technical advice as part of public inquiry and joined international teams examining new geotechnical investigation techniques for in-situ testing and sampling of peat.

Objectives

1.2 This Peat Stability Assessment details for the development a semi-quantitative peat stability risk assessment. The primary objectives of this study are:

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

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

1.4 Peat surveys have been carried out in line with Scottish Government guidance: Scottish Government, Scottish Natural Heritage, SEPA (2017) Peatland Survey, Guidance on Developments on Peatland.

Updates 2022

1.5 This report was updated in late 2022 following the collection of additional soil probing information. Natural Power the author of the original Peat Slide Risk Assessment did not consider the collection of additional probe information to be a requirement and stand-by the original risk analysis. However, the additional detailed probing survey has been undertaken based on the external recommendations of Ironside Farrar in their Checking Report (Ref: 50787).

1.6 Additional detailed soil probe data points were collected across the proposed infrastructure layout targeting areas to increase the density of recorded data points where access on foot was possible. The finding of this additional probing correlates with the existing conclusions on peat depth and distribution across this development. At main infrastructure locations there was an overall lowering in calculated average peat depths.

1.7 Following review of this additional probing information. Natural Power has not found any increase in the overall risk for the development and stands by the conclusions of the original report. The risk assessment has been reviewed and key risk mapping inputs updated to reflect the increased density of soil probes.

Scope of Work

1.3 The peat stability assessment utilises data and visual assessment collected during two phases of site survey. This data and information are combined with desk study and review of all salient published materials. The following data sources have been integrated into this assessment: (Table 1.1).

Table 1.1: Data Sources

Data Source	Location	Date
British Geological Survey – Onshore Geological Map Data: (Linear Features, Mass movement deposits, Artificial ground, superficial deposits, bedrock geology, faulting,1:50,000 scale)	http://mapapps2.bgs.ac.uk/geoindex/home.html	2020
British Geological Survey – Engineering Geology Viewer: 1:1M Superficial Engineering Geology; 1:1M Bedrock Engineering Geology	http://mapapps.bgs.ac.uk/engineeringgeology/home.html	2020
British Geological Survey – Hydrogeological Map of Scotland: 1:625,000 Scale	http://www.largeimages.bgs.ac.uk/iip/hydromaps.html?id=scotland.jp2	1988
National soil map of Scotland – main soil types originally mapped at 1:250,000 scale	http://soils.environment.gov.scot/maps/	1947-1981
National Library of Scotland, Historical mapping	https://maps.nls.uk/	Various
Historical Aerial Photograph Data **ESRI Satellite World Imagery**	https://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer/tile/{z}/{y}/{x}	2020
Online news archival search	Various	2020
Liaison with adjacent wind farm site operators	-	2020
SEPA rainfall data	www.sepa.org.uk/rainfall/	2020

1.4 The work programme:

- Stage 1: (100m grid, development wide) peat probing survey to ascertain the depth and distribution of peat deposits (Q2 2020);
- Stage 2 detailed peat survey across infrastructure location where peat depth of >0.5m was predicted in Stage 1 (Q3 2020);
- In-situ strength testing, peat coring and sampling at targeted deep peat locations (November 2020);
- Site walkover, reconnaissance survey: These surveys conducted by a principal geotechnical engineer and geotechnical engineer, covering all key aspects and locations across the proposed development (November 2020);
- Stage 3 detailed peat survey infilling areas previously inaccessible and increasing probing in-line with ECUBPG. (Q3 2022)

Description of Development

1.5 The Proposed Development will consist of the erection, 35-year operation, and subsequent decommissioning of up to 14 wind turbines, with tip height of 180 to 200m (likely to be 4x 180m, 10x 200m). The Proposed Development includes associated turbine foundations and transformers, battery storage, hardstanding areas for erecting cranes at each turbine location, a series of on-site tracks connecting each turbine, underground cables linking the turbines to the grid connection, an on-site substation, a construction compound, up to two borrow pits, and a new access into the Site.

1.6 Wind turbines are likely to be installed on reinforced concrete slab foundations depending on ground conditions. It is anticipated that aggregate can be won on-site.

1.7 Each wind turbine requires an area of hard standing (a "crane pad") to provide a level and firm base for the cranes at the location of each turbine. Each would be approximately of 55m x 35m and surfaced with coarse aggregate.

1.8 There would be a temporary construction compound / storage area to provide a secure area for site office facilities and storage of materials and compounds. This would be constructed adjacent to the site track, with a hardcore base of up to 100mx50m, surrounded by a security fence and locked gates. The fence and gates would be removed at the end of the construction phase and the hardcore base retained but allowed to revegetate.

1.9 Transformers to step-up the voltage exported from each turbine (from 690V to 33kV) would either be placed within the wind turbines themselves, or in a small secure external transformer housing placed next to each wind turbine tower, depending on the final turbine choice.

1.10 High voltage and control cables would be placed in trenches (dimensions to be determined by the ground conditions, but typically 0.5m x 1m deep) routed alongside the access tracks.

1.11 An approximately 15m long x 15m wide single storey substation building would be built and will house the switchgear and control equipment, in addition to acting as a secure storage space. Parking spaces will be included in the design.

1.12 A grid connection would be required to feed the electricity generated by the wind farm into the distribution network for the operational period of the wind farm. The final details of the grid connection including the precise route and an assessment of any impacts on the environment would be determined by the Distribution Network Operator (DNO) at a later date. The new grid connection may be subject to a separate design and consent process under Section 37 of the Electricity Act 1989. Wind farms are typically connected to the grid via underground cable connections. It is expected that Craiginmoddie Wind Farm will be connected via an underground cable to the GSP at Maybole.

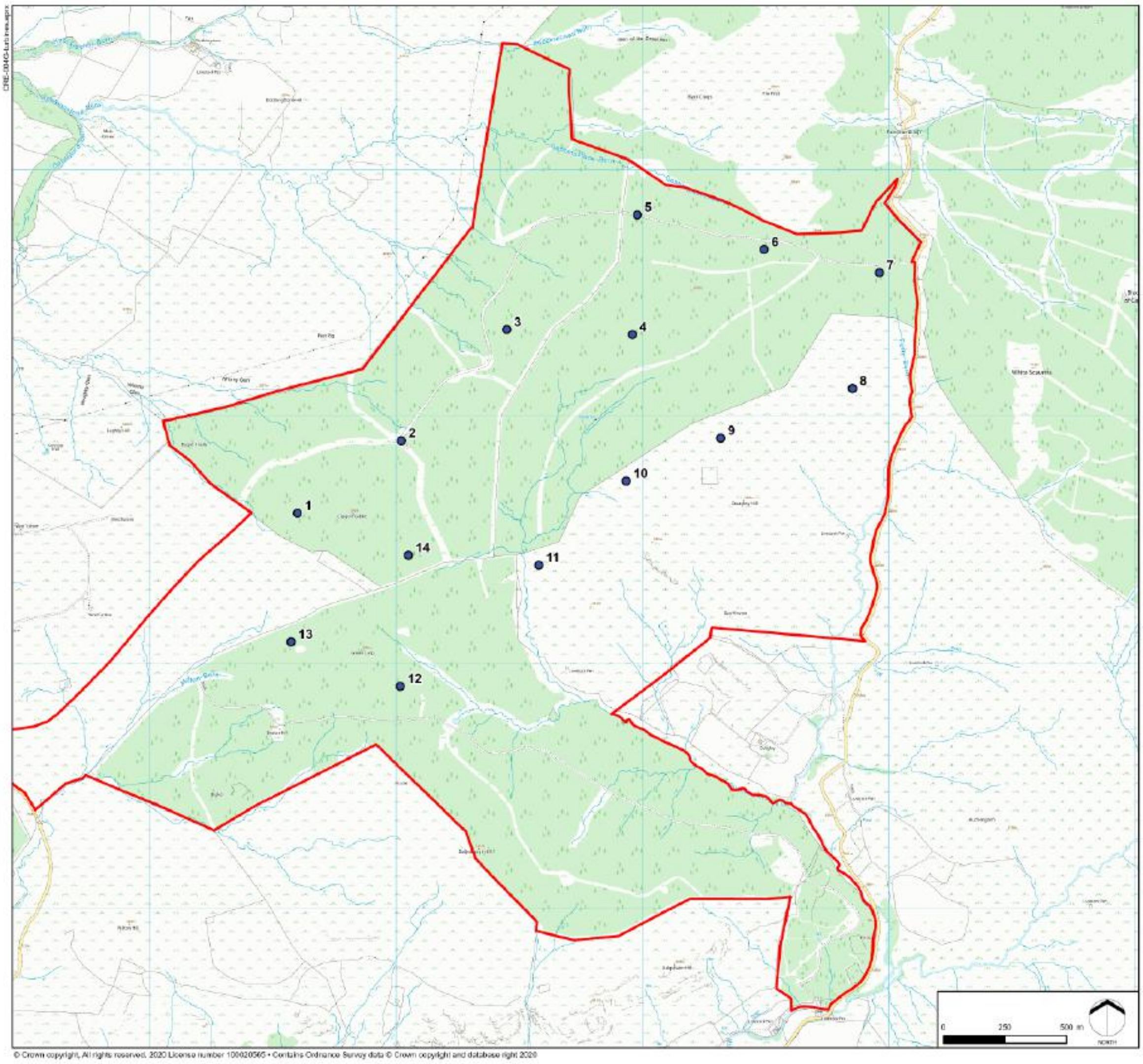
Location

1.13 The development is located approximately 12km east from the town of Girvan, in South Ayrshire, Scotland. The centre of the development is approximated to National Grid Reference (NGR) [232000, 599000]. All site visits must be coordinated with the relevant landowner and stakeholder groups.

1.14 Survey Access Points:

- Eastern access by proposed turbine T7 [233054, 599555]
- Western access by proposed construction compound [229407, 597708]

Figure 1.1: Development Area:

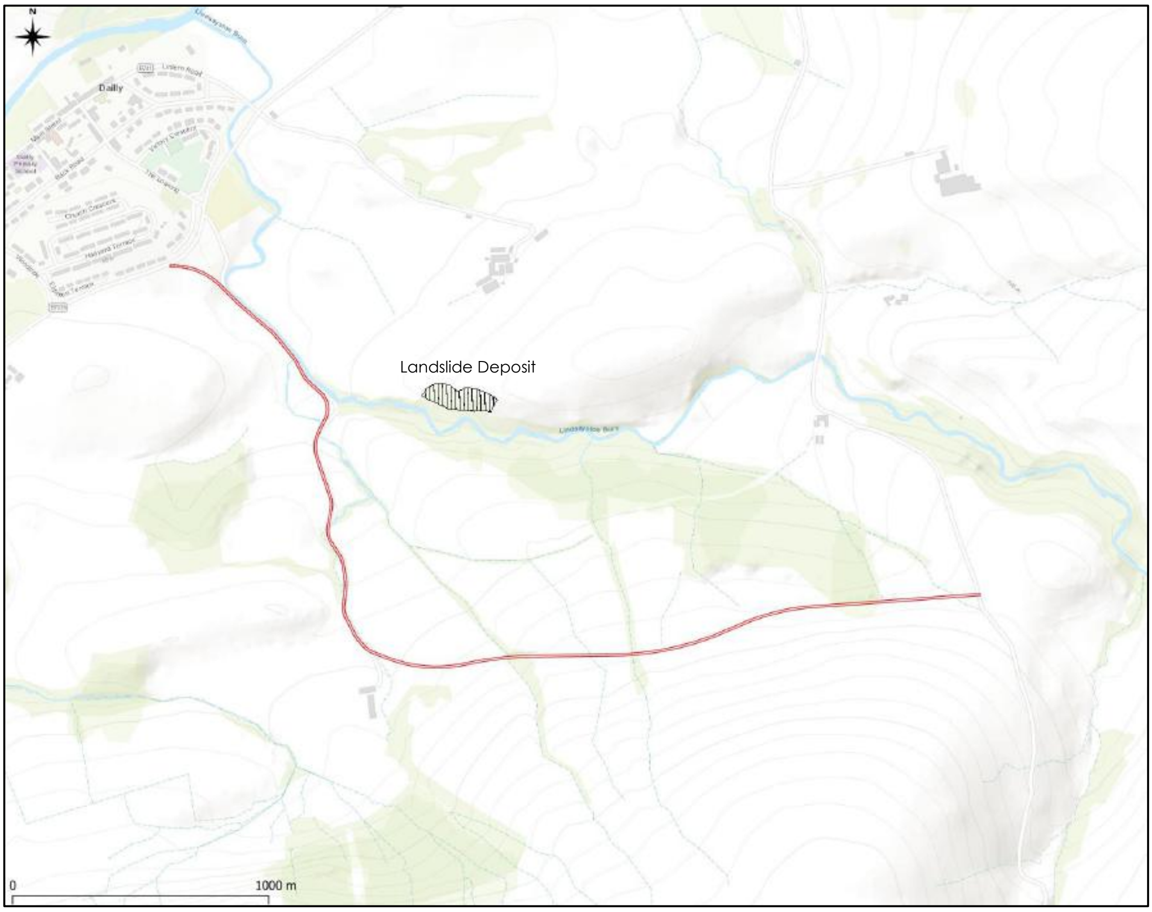


1.15 Figure 1 above provides a depiction of the development area with proposed turbine locations.

Offsite Access

1.16 A section of new access is proposed which spurs from the B7035 at the village of Dailly. Adopting the alignment of an existing farm access and then east across open farmland this new track section is approximately 400m in length. Site surveys did not record any peat across this area and thus the area indicated in Figure 1.2 below has been excluded from the assessment:

Figure 1.2: Offsite Access (©ESRI 2020)



1.17 The western part of the offsite access traverses a side slope on which there is extensive agricultural drainage ditches. To the north and across the Linsayston Burn is a landslide deposit mapped in the BGS database. This appears to be an arcuate rotational landslip within the glacial soil deposits. Likely to be associated with removal of toe support from the slope system by the erosional actions of the watercourse. Out-with the scope of this peat slide risk assessment the underlying stability of glacial subsoils would be the focus of intrusive geotechnical investigation in a pre-construction phase of works. There should therefore be detailed assessment where the access track runs parallel to the river valley at this locality.

Terrain Description

1.18 The proposed infrastructure locations occupy elevated positions across commercial coniferous forestry and open moorland. The highest elevations are focussed to the north of Doughty Hill in the central eastern zone of the site around turbine T4 (370mAOD) and in the west around Craiginmoddie (rising to 380mAOD).

1.19 The terrain slopes in a variable manner with broad open slopes. Sharply incised valley forms and forested valleys. Elevations fall away from the central plateau to the north, south and west. A primary incised valley, channels from the centre of the development towards the south carrying the Auchengairn Burn. This feature bisects the principle high ground of Doughty Hill in the East and Craiginmoddie in the west.

1.20 Four turbines T8, 9, 10 & 11 are proposed across the open moorland to the south of the main forestry stands. It was noted that the open ground has been recently planted for forestry. All other turbines are sited within the forested land. Small tributary watercourses drain the development land flowing towards the north and coalescing into the Dobbingstone Burn. There are ubiquitous artificial drainage ditches which are implemented across the development to facilitate the timber production. Ditches are typically cut through the full depth of peat deposits and are arranged in a geometric grid to focus surface and groundwater within the peat into the natural watercourses across the site.

1.21 There are areas of raised bog across the higher moorland plateau with peatland more variable in thickness throughout the forested sections of the development. Generally, peat growth has focussed on the shallower slopes and within topographic depressions to form raised bog profiles.

1.22 More generally the landscape has been formed from a process of post glacial land evolution following the retreat of the last major glaciation. These processes have resulted in a relatively uniform terrain classification however the depth of peat and thickness of underlying glacial sub-soils are likely to be highly variable.

1.23 Visibility across the forested section of the development was restricted due the dense vegetation. In this regard the reports' findings should be considered with the understanding that larger scale terrain features may be hidden by the forestry and not fully apparent until felling and open access becomes available.

1.24 The key findings of the site reconnaissance are represented on the Geomorphological Map (14090UKC_PSRA_005, Appendix A). A selection of photographs taken during the walkover survey depict the range of site environs, provided below.

Photo 1: View north from T8 – Open Ground, recently planted

Photo 2: View north from T9 – Open Ground Raised Bog

Photo 3: Borrow Pit Search Area south from T6

Photo 4: Forested location at T12 – Thin peat soil and steep slopes

2 SURVEY METHODOLOGY

Data Review

2.1 In preparation of this report, an initial desk-based assessment has been undertaken to allow subsequent surveys to be targeted. Table 1.1 highlights the key sources of information for this study.

2.2 Online searches for local peat or major landslides returned several instances within the region. None however had similar ground conditions or were in close proximity to the proposed development.

2.3 Readily accessible aerial imagery records dating to 2004, and do not show any major changes occurring through to the present day. Hadyard Hill Wind farm to the west was commissioned in 2006. There are small areas of instability which have developed within the forestry stands, manifesting as windblown trees. These may be indication of underlying soil instability. Further small sub-soil instability can be identified on the margins of some of the watercourse channels which intersect the development.

2.4 Natural Power's project directory and online sources were searched for reports of peat slide incidents on adjacent wind farm developments. These searches did not provide any pertinent information.

Geomorphological Mapping

2.5 Reconnaissance and geomorphological mapping were carried out at the development during November 2020. This exercise provided opportunity for geotechnical engineers to visualise the terrain, access geological and soil exposures, examine slope systems, vegetation cover and record any hydrological features impacting peat stability.

2.6 The culmination of this survey and desk-based review of aerial photographs was the production of a geomorphology map, 14090UKC_PSRA_005, Appendix A.

Peat Surveys

2.7 Natural Power carried out the Stage 1 probe survey implementing a 100m grid of probes across the development infrastructure areas. Peat depths were recorded using probes inserted into the peat and measuring the depth to refusal. This provides a wide-ranging dataset, but the data carries the following limitations:

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

2.8 Thus, detailed peat probing survey was focussed at locations of deeper peat (>0.5m). In-situ hand shear vane tests were conducted to provide an estimate of undrained shear strength within the peat at relevant turbine locations. Supplementary to this, peat cores have been taken at select locations to provide confirmation of peat depth, material classification and morphology. Peat samples were retained as part of this exercise and subject to laboratory testing for determination of bulk density and carbon content.

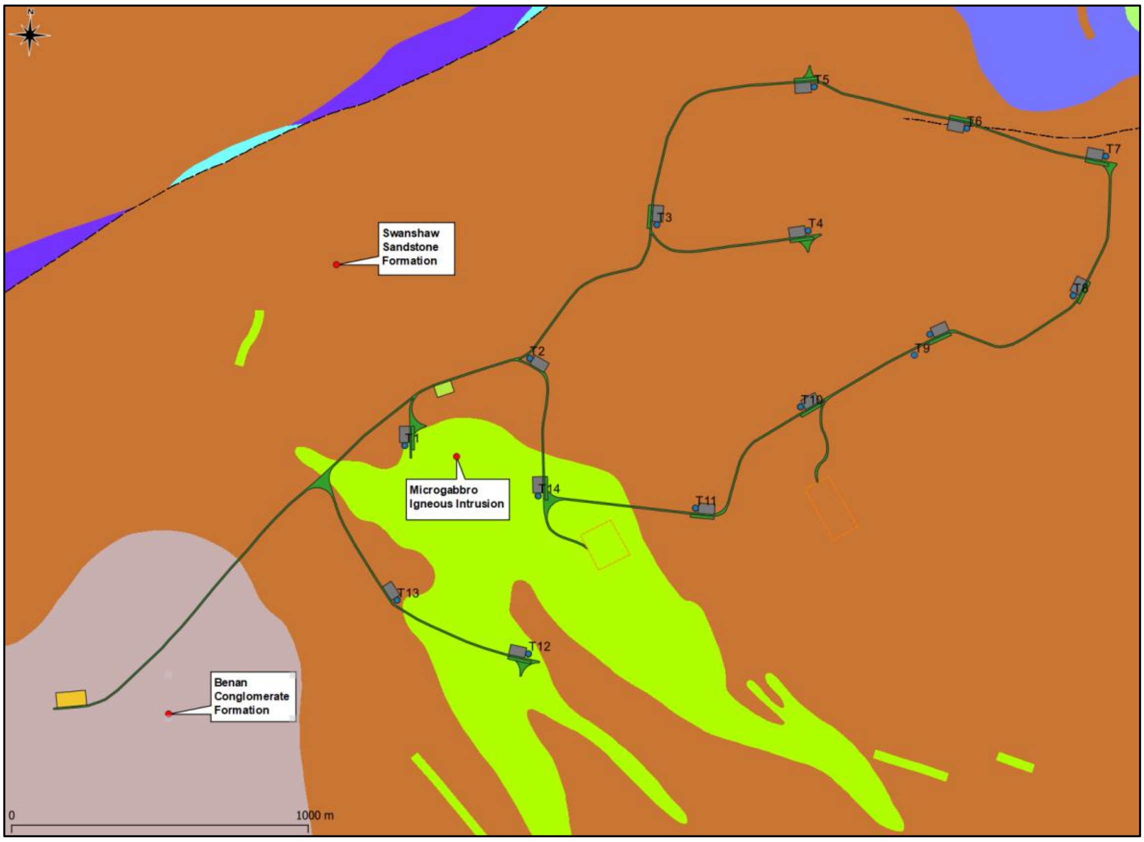
2.9 Peat depth mapping is shown on drawing:14090UKC_PSRA_003, Appendix A. To prepare the interpolated peat depth mapping; a spatial interpolation method termed 'Ordinary Kriging' was applied.

2.10 Terrain Slope Angle Map (14090UKC_PSRA_004) is comprised from digital elevation model data, carrying a grid resolution of 2m. The risk assessment considers slope angle across two areas. Firstly, the slope angle is used to screen the site for instability within the slope analysis numerical calculation. This is adjoined to qualitative assessment of the slope angle category in terms of a contributory factor to failure. This combined approach ensures a robust assessment of the risk and increases the sensitivity of the assessment to more accurately characterise risk across the expansive area.

3 GEOLOGY & ENVIRONMENT

Solid Geology

Figure 3.1: Exert 1:50,000 scale Solid Geology Map Data (©NERC 2020)



3.1 According to the British Geological Survey (BGS), and as illustrated in Figure 3.1; the rock units across the development are predominantly sedimentary (fluvial and shallow marine) in origin. The Swanshaw Sandstone Formation (Early Devonian) comprises coarse to fine grained sandstone in beds and lenses reflecting channels and floodplain modes of deposition.

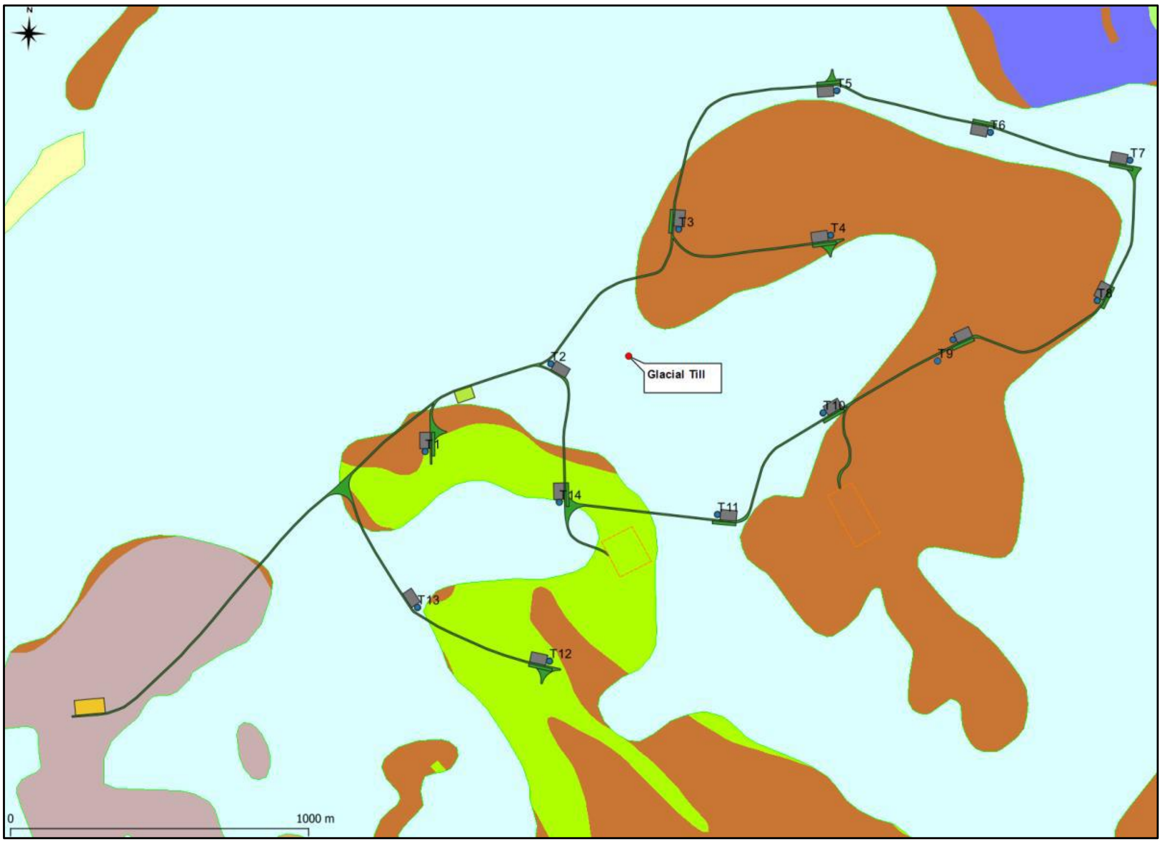
The Benan Conglomerate Formation (Ordovician) is detrital and formed from poorly sorted coarse to fine grained rocks which are interbedded with carbonate rock units.

The interceding Microgabbro Igneous Intrusion is a crystalline rock of magmatic origin. It is likely of a higher strength and competence to the surrounding sedimentary rock units.

There are no mapped faults or fissures within the development.

Bedrock outcrops were not apparent during field survey due to the superficial deposit cover.

Figure 3.2: Exert 1:50,000 scale Superficial Geology Map Data (©NERC 2020)



3.2 The BGS map data for superficial deposits only includes glacial deposits. The valley forms on site are anticipated to be the focus for the deepest glacial soils. Peat soils are also known to be presented and depicted on the peat depth mapping (Appendix A).

3.3 There are no BGS mapped mass movement (landslide deposits) within the development.

Hydrology

3.4 A summary of the hydrological regime is presented below. It is highlighted that a separate hydrology baseline study has been undertaken by Natural Power. The details are provided in the main Chapter 12 for Geology, Hydrology & Hydrogeology.

3.5 The development lies within the catchment for the River Stinchar (south from the development) & the Dobbingstone Burn and Water of Girvan to the north and west. Multiple ephemeral watercourses and minor tributaries arise within the development. Where appropriate these receptors have been used to assess the risk of peat slide with the watercourses alongside windfarm and roads infrastructure identified as sensitive receptors.

3.6 Annual average rainfall data recorded at the nearest SEPA rain gauge (Kirriereoch) is 2,197mm.

Hydrogeology

3.7 Examination of the bedrock geology on the 1:625k BGS aquifer map provides an overview of the hydrogeological regime across the development.

3.8 The site is predominantly classified under the Lanark Ground of rocks: a moderately productive regional aquifer of sandstones, in places flaggy, with siltstones, mudstones and conglomerates and interbedded lavas. Locally yields up to 12 L/s. The igneous rock units are understood to have low productivity.

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

Site History

3.10 Historical mapping for the site has been reviewed from the National Library of Scotland archive. Earliest mapping available was from Ordnance Survey 1888-1900 'Outline' series. Indications are that the development area has largely been unchanged and dedicated to upland farming and estate agricultural practices.

3.11 There has been significant development of commercial forestry from the 1970's onwards. The site walkover survey has identified an extensive network of artificial cut drainage ditches which are not evident on the historical mapping and thought to be contemporaneous with the forestry development. No evidence of instability is recorded on the historical mapping.

3.12 Limited aerial imagery records were available for the development area; however, available records typically corroborate with the findings of our historical mapping review and confirm the general area has been subject to notable commercial forestry development.

Designated Sites

3.13 The development is within the Galloway & Southern Ayrshire Biosphere Reserve (Scotland). No other designations were indicated during searches.

4 PEAT SLIDE RISK ASSESSMENT

Peat Distribution

4.1 In total 1,193 locations were surveyed for peat depth across the development. The mean peat depth is calculated to be 0.75m. This data combines Stage 1 and Stage 2 detailed probing.

4.2 Table 4.1 below provides a summary of the peat depths recorded across both stages of survey. A peat depth interpolation map (14090UKC_PSRA_003) is provided within Appendix A.

Table 4.1: Peat Depth Summary:

Peat Depth Range	No. of Results	%
≤0.5m	543	46
>0.5 – 1.0	464	39
>1.0 – 1.5	96	8
>1.5 – 3.0	62	5
>3.0	28	2
Total	**1,193**	**100%**

The highest proportion (46%) of recorded peat depths were shallow (≤0.5m). The areas of deep peat are focused on the highest reaches of the main plateau north from Doughty Hill and towards the centre of the forestry land.

Peat Morphology

4.3 A 25mm hand shear vane was used to record the undrained shear strength of the in-situ peat deposits. Vane testing was undertaken at Turbines T9, T11, T14, & T7 where peat conditions were of sufficient depth.

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

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

4.6 Where a significant increase in the un-drained shear strength was recorded at the basal contact of the peat, it is inferred from peat cores derived from the same location that the highest un-drained shear strength values represent the glacial till interface. This material comprises sandy, gravelly clay soil.

4.7 The un-drained shear strength (Cu) ranges from **13kPa to 60kPa** with a mean value of **34kPa**. The mean re-moulded shear strength is recorded at **19kPa**. Indications are the peat has very low to low shear strength with the lowest values recorded in the deep peat in the vicinity to T9.

4.8 The degree of humification has been recorded at locations where deep peat was core sampled (T9, T11, T14, & T7). The peat has been characterised according to the Von Post Classification (Von Post & Granland, 1926). Table 4.2 below presents the classifications.

Table 4.2: Von Post Classification of Peat Cores

Turbine ID	Peat Depth	Von Post Class	Description
T8	-	-	0.0-0.1m – Brown TOPSOIL 0.1 – 0.3m – Light brown, slightly clayey SAND
T7	1.6	H6 / B2	0.0 – 1.0m: Soft, brown, pseudo fibrous to plastic PEAT (H6/B2) 1.0 – 1.6m – No recovery in corer due to high water content
T9	3.6	B3/H3 B2/H5	0.0 – 1.0m: Soft, brown, fibrous PEAT (B3/H3) 1.0-2.0m: No recovery in corer due to high water content; 2.0 – 3.6m: Very soft, brown pseudo fibrous to plastic PEAT (B2/H5) 3.6 – 3.7m: Soft, light grey CLAY
T11	1.0	H4/B2 H6/B2	0.0-0.5m: Soft, brown fibrous PEAT (H4/B2) 0.5 – 0.95m: Firm, brown pseudo fibrous to plastic PEAT (H6/B2) 0.95-1.0m: Firm, brown, sandy CLAY.
T14	-	-	0.0-1.0m – Light brown slightly clayey SAND

The peat encountered across the development is typically soft to very soft and fibrous in the acrotelmic surface layer. In the deeper deposits, characteristically humification increases with depth at the catotelmic layer and there is a reduction in shear strength. This is most evident at the T9 sample location.

The photographs 5 -10; below provide a visual record of the peat core samples:

Photo 5: T9 0.0-1.0m

Photo 6: T9: 2.0-3.0m

Photo 7: T9: 3.0-3.7m

Photo 8: T8 – 0.0-0.3m

Photo 9: T11 – 0.0-1.0m

Photo 10: T7: 0.0-1.0m

Risk Assessment method

4.9 Natural Power has undertaken this assessment following the principles of the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive 2017). Updated as a second edition in April 2017, this guide provides best practice methods which should be applied to identify, mitigate and manage peat slide hazard and associated risks in respect of consent application for electricity generation projects in the UK.

4.10 This guidance clearly acknowledges risk assessment as an iterative process and as such this assessment should be updated throughout the development and as more information becomes available particularly as pre-construction phases are reached.

Processes Leading to Peat Slide

4.11 To provide a framework for the assessment; the key principals of the peat slide risk assessment are presented below. Discussions of the factors which contribute to peat failure have been presented below (Table 4.3).

Table 4.3: Contributory Factors to Peat Instability

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

Factor	Discussion
	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 contribute to instability.
Peat Depth & Slope Angle	Peat slides correspond in appearance and mechanism to translational landslides and tend to occur in shallow peat (up to 2.0m) on slopes between (5° – 15°). A great majority of recorded peat landslides in Scotland, England & Wales are of the peat slide type. MacCulloch, (2005) highlights that a slope angle of 20° appears to be the limiting gradient for the formation of deep peat. Therefore, the risk assessment has assigned slope angles >20° to be an unlikely contributory factor to failure. Slope angle indicators and corresponding probability factors have been similarly adapted from MacCulloch, (2005). Boylan et al, (2008) indicates that most peat failures occur on slope angles between 4° and 8°. It is postulated that this may correspond to the slope angles that allow a significant amount of peat to develop that over time becomes potentially unstable. Thus, for this assessment <3degrees has been assigned a low risk.
Hydrology	Natural watercourses and artificial drainage measures have often been identified as a contributory factor of peat failure. Preferential drainage paths may allow the migration of water to a failure plane therefore triggering failure when groundwater pressures become elevated. Within a peat mass, sub surface peat pipes can enable flow into a failure plane and facilitate internal erosion of slopes. It is also noted that in some instances, agricultural works can lead to the disturbance of existing drainage networks and cause failures. Forestry preparations and harvesting may also impact upon surface hydrology is implemented poorly. Multiple drainage ditch networks are present across the development as a result of the commercial forestry activity.
Existing / Relict Failures	The presence of relict failures and any indication of previous instability are often important, indicating that site conditions exist that are conducive to peat failure. Relict peat slides may be dormant over long periods and be re-activated by any number of the contributory factors discussed in this table.
Anthropogenic Effects	Human impact on peat environments can include a range of affects associated with wind farm construction. Activities such as drainage, access tracks across peat, peat cutting, and slope loading are all examples. Rapid ground acceleration is one such example where shear stress may be increased by trafficking or mechanical vibrations.

Peat Failure Definitions

4.12 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 or infrastructure. 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.

4.13 The potential for peat failure at the development is examined with respect to the activities envisaged during construction and operation of the wind farm. There are several classification systems for the mass movement of peat that were drawn together by PLHRAG, (2017).

4.14 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.

4.15 Due to the raised bog morphology at the proposed development and proximity of surface watercourses / head waters, peat flows are considered the dominant mode of potential peat failure.

Geotechnical Principles

4.16 The main geotechnical parameters that influence peat stability are:

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

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

4.18 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.

4.19 The infinite slope model as defined in Skempton et al. (1957)[1] has been adapted to determine the FoS of a peat slope. A modified approach has been used; assuming a minimum FoS (Typically 1.3 after, BS6031: 2009).

4.20 The infinite slope analysis is based on a translational slide. This analysis adopts total stress (undrained) conditions in the peat. This state applies to short-term conditions that occur during construction and for a time following construction until construction induced pore water pressures (PWP) dissipate. (PWP requires time to dissipate as the hydraulic

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

conductivity can be low in peat deposits). The following assumptions were used in the analysis of peat deposits across the proposed wind farm development:

- The groundwater is resting at ground level;
- Minimum acceptable factor of safety required is **1.3**;
- Failure plane assumed at the basal contact of the peat layer;
- Slope angle on base of sliding assumed to be parallel to ground surface and that the depth of the failure plane is small with respect to the length of the slope;
- Thus, the slope is considered as being of infinite length with any end effect ignored;
- The peat is homogeneous;

4.21 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):

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

4.22 Where:

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

4.23 Undrained shear strength values (Cu) are used throughout this assessment. Effective strength values are not applicable for the case of rapid loading of the peat during short term construction phase of works hence the formula cited above, has been adopted. Drawing 14090UKC_PSRA_001, Appendix A maps out the calculated FoS for the development when applying a conservative 15kPa as the undrained shear strength for peat soils. This mapping includes the predicted FoS where a 20kPa surcharge is applied to the surface.

Risk Assessment Method

4.24 A semi quantitative risk assessment has been used to determine the risk of peat failure. The methodology is defined in PLHRAG, (2017) and has been r augmented with methods set out by Clayton (2001). Given the remote location of the site, and proximity from major trunk roads or residences, environmental receptors have been the primary focus of our assessment. Risk factors are summarised on Table 4.4.

4.25 The assessment uses the infinite slope stability analysis and presents analysis of factor of safety (FoS) across the development. The calculated FoS, is complimented with an assessment of the slope angle, peat depth and key geomorphological features. A peat slide risk map has been produced using GIS computation of these factors. (14090UKC_PSRA_002, Appendix A). The risk map is a highly useful tool for screening wide areas of the site, additional engineering judgement has been applied according to discrete conditions within Table 4.7 of this report.

Table 4.4: Risk Factors

Contributory Factor	Comment	Criteria	Probability	Scale
Peat Depth* **(A)**	Peat slides tend to occur in shallow peat (up to 2.0m) on A great majority of recorded peat landslides in Scotland, England & Wales are of the peat slide type.	0 – 0.5m >3.0m 0.5 – 1.0m 2.0 – 3.0m 1.0 – 2.0m	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Slope Angle* **(B)**	It has been acknowledged that peat slide tends to occur in shallow peat (up to 2.0m) on slopes between 5° and 15°. Slopes above 20° tend to be devoid of peat or only host a thin veneer deposit.	0 – 3° >20° 4 – 9° 16 – 20° 10 – 15°	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
FoS **(C)**	Values are from Infinite slope model using Cu characteristic value of 15kPa derived from hand shear vane in-situ testing. Slope angle and peat depth also input to this factor.	≥ 1.3 1.29-1.20 1.10-1.19 1.00-1.09 <1.0	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Cracking **(D)**	Visual assessment undertaken in the field during detailed probing survey and covers the same extends of this survey. Field workers examined for evidence of any major crack networks which may allow surface water to penetrate the peat mass. Reticulate cracking was not investigated as this normally requires intrusive ground investigation to remove the surface fibrous layer. This may be a more important consideration for forested areas or previously forested areas of a development site.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Groundwater **(E)**	Challenging to evaluate without very detailed mapping and/or intrusive data. Look for entry / exit points. Evidence of surface hollows, collapse features at surface reflecting evidence of sub-surface peat pipe network, audible indicators including the sound of sub-surface running ground water surrounding proposed infrastructure locations	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5
Surface *Hydrology **(F)**	Ranging from wet flushes to running burns to hags. Must be evaluated in conjunction with the season and weather preceding the site visit. Artificial drains (grips) have also been identified across the site. Their presence is generally linked to historical peat cutting sites which are factored into the risk assessment.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	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 Almost certain	1 2 3 4 5
Land Management **(H)**	Anthropogenic influences: forestry operations and removal of vegetation can be associated with de-stabilising peat deposits. This can occur as a result to surface disturbance and remoulding of peat through excavation, vehicle movements and loading. Changes in land use activities may also be associated with changes in drainage conditions. Criteria based on evidence of disturbance of peat deposit, i.e. broken surface, scarring or disrupted hydrology. For Craiginmoddie Wind Farm a land management scale of '2' has been chosen where significant tree felling is required as this has potential to disturb the peat deposits. This assessment should be updated following the site investigation and felling.	None Few Frequent Many Continuous	Negligible Unlikely Likely Probable Almost certain	1 2 3 4 5

*Denotes where used in GIS risk mapping exercise (14090UKC_PSRA_002, Appendix A)

4.26 Environmental Impact Zones based on proximity buffer zones applied to the sensitive watercourses within the proposed development. Watercourses have been determined to be a primary sensitive receptor to a peat failure event. Table 4.5 denotes the potential impact scales to the environment. Location of existing or planned infrastructure downslope from proposed development is assessed in Table 4.7.

Table 4.5: Watercourse Impact Buffers

Criteria	Potential 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

4.27 A qualitative Risk Ranking is assessed from the combined probability of occurrence for the main contributory factors which are greater than (1), multiplied by the highest impact scale. Table 4.6 identifies the risk ranking based on concepts of PLHRAG, (2017).

Table 4.6: Risk Ranking & Actions

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

Numerical Slope Stability Analysis

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

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

4.30 The factor of safety (FoS) against sliding has been calculated for all positions where peat depth has been recorded. 14090UKC_PSRA_001, Appendix A; has been produced to map the calculated factor of safety across the development using GIS analysis tool to apply the stability equation. For the GIS analysis slope geometry has been established from 2m resolution digital terrain model and characteristic undrained shear strength of 15kPa to ensure the model is conservative. In addition, a 20kPa surcharge has been modelled thus the sensitivity of slopes to failure is assessed under construction conditions.

Stability Analysis Discussion

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

4.32 In the absence of more detailed sub-surface data, the surface slope angle has been used as a reference to the likely slope surface angle at the base of the peat in the analysis. Further advanced in-situ test methods should be considered as part of a detailed site investigation phase usually carried out post-consent. The potential of disturbing sensitive peat deposits during pre-construction survey access should also be considered during future phases of work.

4.33 **Wind Turbines:** FoS values for the turbine locations, when allowing for a 20kPa surcharge load have been derived. The lowest FoS was calculated was 3.40 for proposed turbine T12. The natural slope condition has been calculated to be stable and was observed to be so around the wind turbine locations during the field survey.

4.34 **Access tracks:** Where slope and peat conditions permit; access track will be constructed of the floating type construction to reduce impacts on peat. Areas of track with an elevated risk of can are discussed in Table 4.8. This is primarily attributed close-proximity or crossing of watercourses, slope gradient and peat depth. These elements should be mitigated and managed through detailed engineering design incorporating watercourse protection measures, slope stabilisation and micro-siting of the routes. These would be fully defined as part of the construction environmental management plan and detailed civil infrastructure design. This report should therefore be reviewed as part of the pre-construction design phase.

4.35 The FoS accounts for a 20 kPa surcharge representing scenarios at infrastructure such as temporary storage stockpiles. The Peat Management Plan (PMP) details mitigation measures for peat stockpiling. Slope stability assessments will be carried out during design phase for site tracks, hardstands and other relevant structures ensuring the proposed design results are safe, stable and environmentally compliant. It is Natural Power’s view that, if during design phase structures are proposed (i.e. floating tracks) additional numerical stability assessment should be carried out by the appointed designer.

Peat Slide Risk Assessment

4.36 The potential environmental impact of a peat slide triggered by proposed wind farm infrastructure is obtained from assessing the proximity to watercourses as the primary sensitive receptor within the development. The position of proposed infrastructure has also been considered in Table 4.7/4.8 below. It is highlighted that an unclassified public road runs immediately to the east of the development boundary and downslope from turbines T7, T8, T9, T10 & T11. The nearest habitations are Doughty Farm approximately 1km down the valley east of T11. To the west and down the Whinny Glen valley is Delamford Farm, approximately 1.6km west of T2.

4.37 Probability values were assessed for the contributory factors recorded across the turbine locations (See Table 4.4). The impact rating is then combined with the cumulative effect of the contributory factors. This is to convey the initial unmitigated risk ranking.

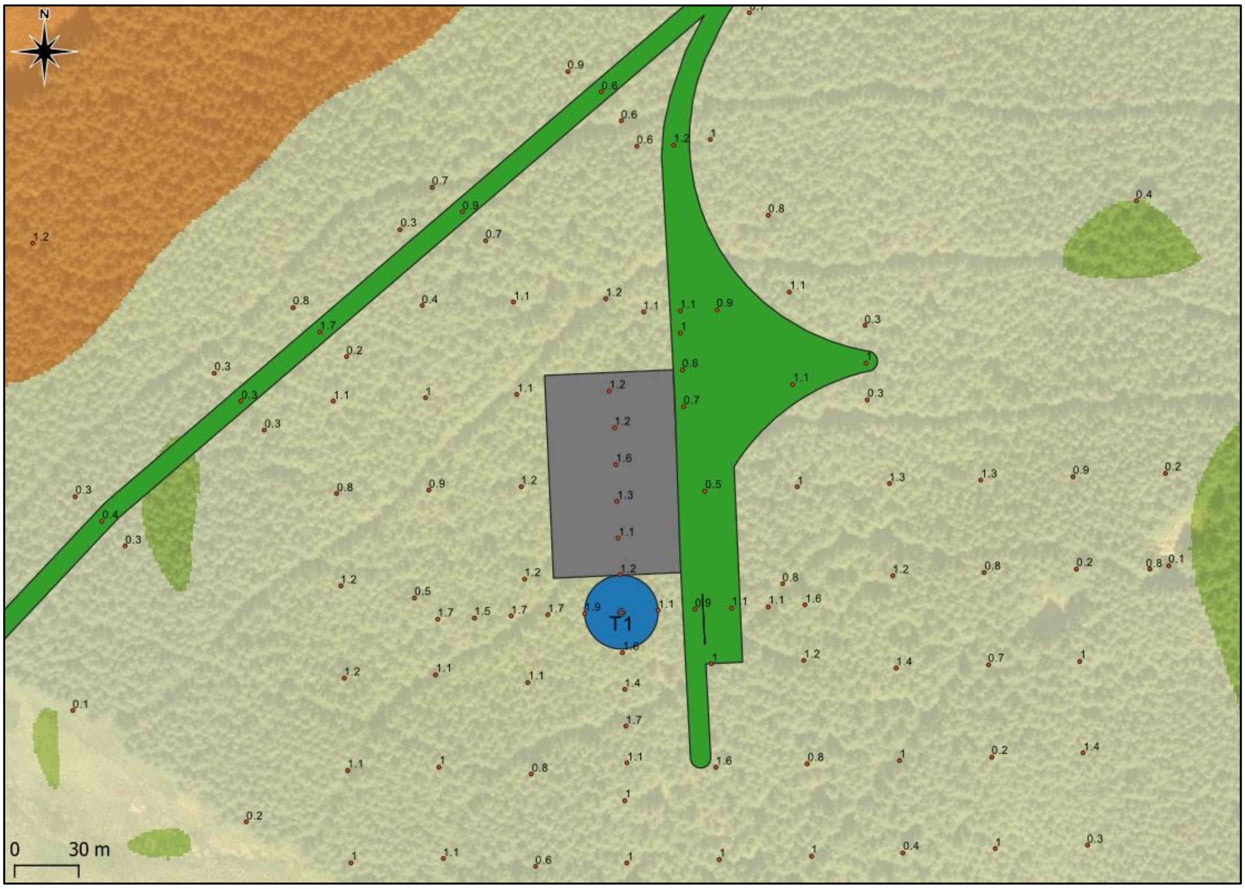
4.38 Risk rankings for the proposed turbine positions are presented in Table 4.7. Across each turbine the risk scoring has been provided along with aerial photo information.

4.39 The risk ranking map is appended to this report (14090UKC_PSRA_002). The risk map provides a representation of the risk zonation across the site and includes all infrastructure elements. The map is based on a development wide GIS analysis and should not be viewed in isolation without the narrative of this report. The Risk Mapping further does not show residual risk following implementation of control measures.

4.40 The indicative residual risk rating is provided assuming implementation of appropriate mitigation measures. Further detail of the risk assessment is highlighted within the preliminary geotechnical risk register presented in Table 5.1.

Table 4.7: Infrastructure Risk Assessment

WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure		Risk Ranking Residual Risk
T01	1	Peat Depth (1.2m)	5	Low 10
		Slope Angle (9°)	3	
		FoS (5.48)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low 10
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



T01 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- There shall be no temporary storage or stockpiling of material in the vicinity of turbine T01;
- Existing drainage ditches and hydrological regime should be maintained and prevented from blocking leading to increased power water pressures in surrounding peatland;
- Following forestry clearance location should be re-assessed.

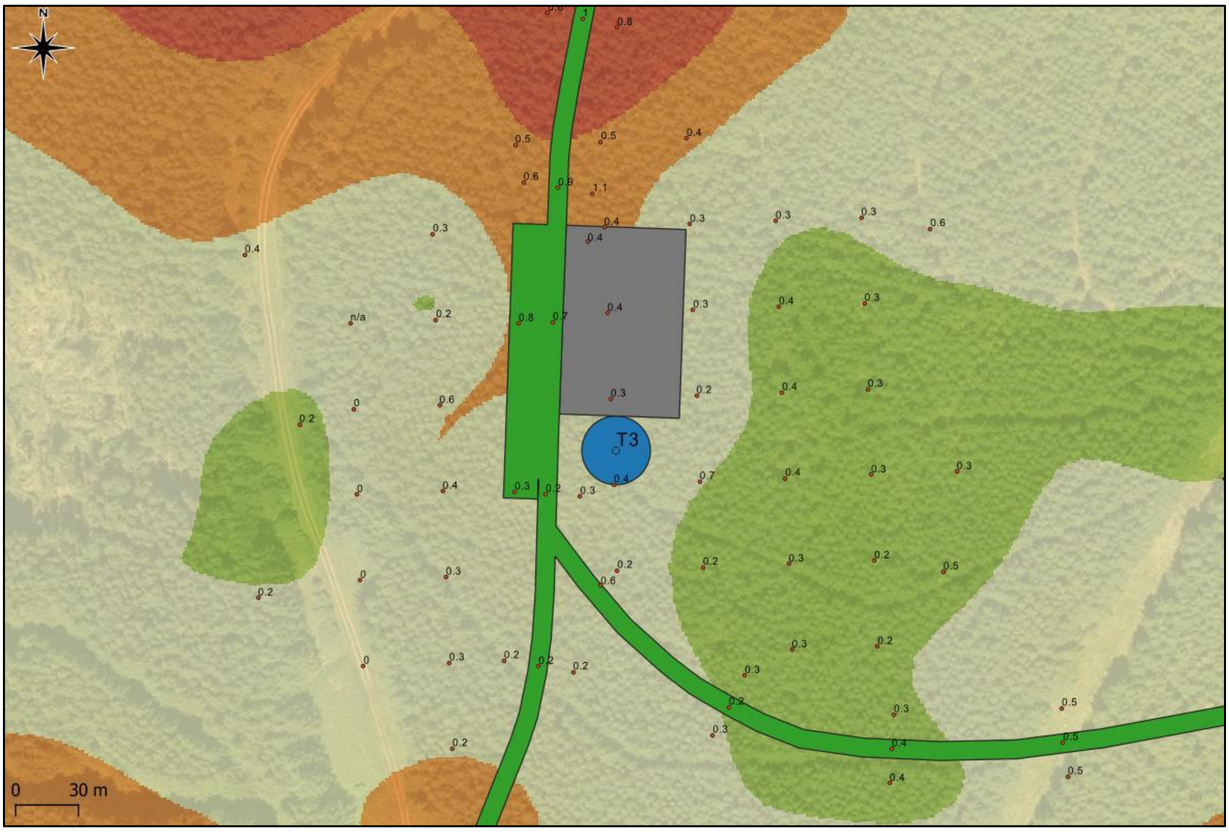
WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure		Risk Ranking Residual Risk
T02	**1**	Peat Depth (0.6m)	3	**Low 10**
		Slope Angle (10°)	5	
		FoS (6.20)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	**Low 10**
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

T02 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- Implement down-slope watercourse protection measures to remove possibility of mobilised peat entering watercourse i.e. temporary bunds or retaining structure to the north;
- No temporary storage or stockpile of earthworks material downslope to the north of the turbine position.
- Following forestry clearance location should be re-assessed.

WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure		Risk Ranking Residual Risk
T03	1	Peat Depth (0.4m)	1	(Low/Med) 5
		Slope Angle (10°)	5	
		FoS (9.85)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

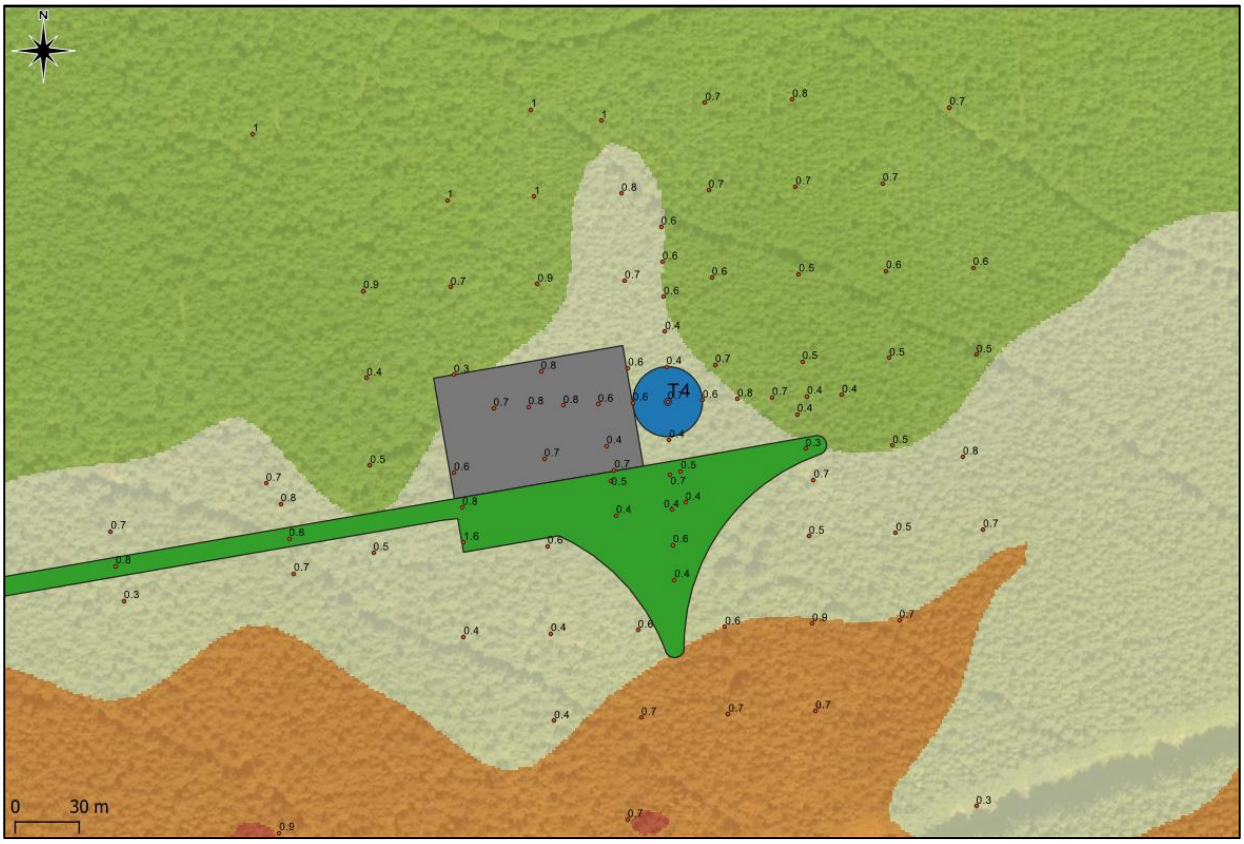


T03 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- Implement down-slope access track protection measures to remove possibility of mobilised intersecting existing forestry access, e.g. through the use of rock fill retaining structures;
- No temporary storage or stockpile of earthworks material downslope or to the north of the turbine position as indicated by risk mapping;
- Following forestry clearance location should be re-assessed.

WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure		Risk Ranking Residual Risk
T04	1	Peat Depth (0.6m)	3	(Low) 8
		Slope Angle (7°)	3	
		FoS (4.70)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	(Low)
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

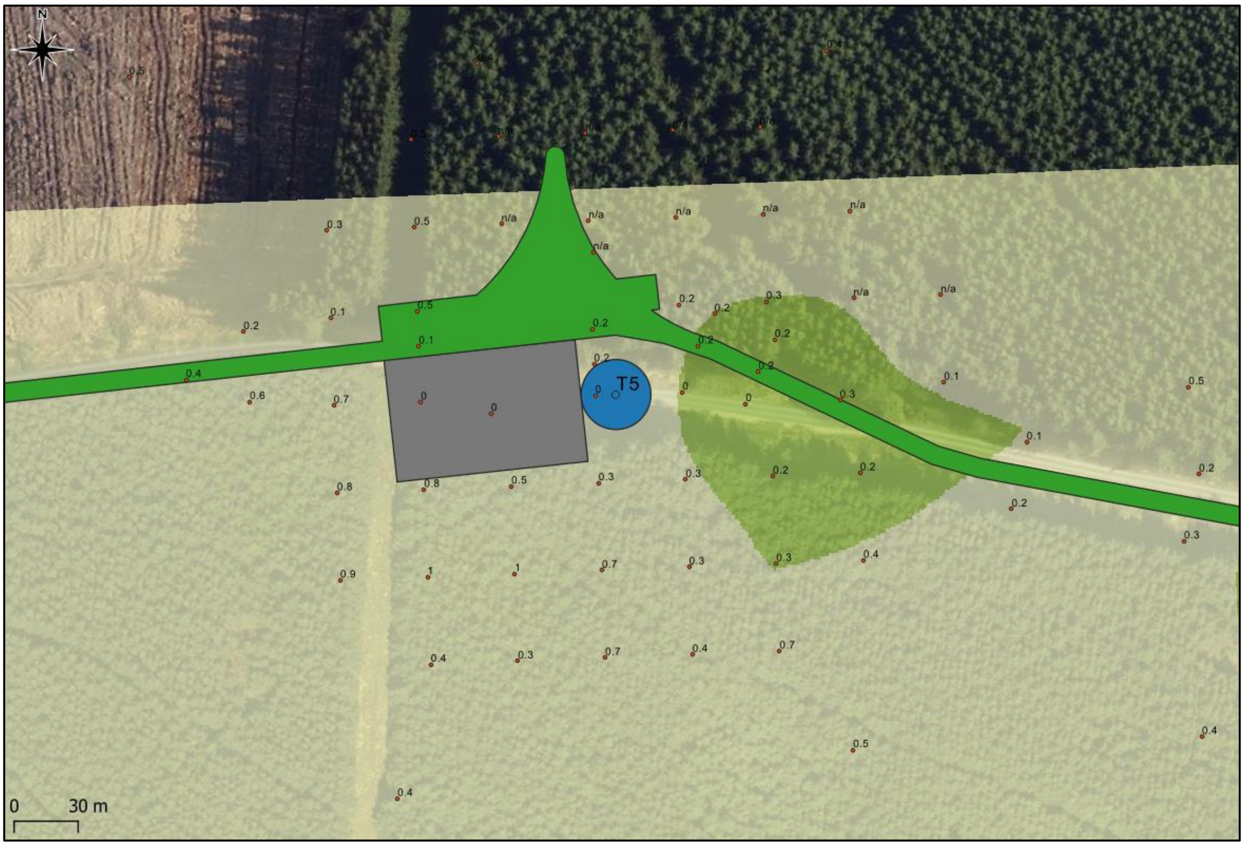


T04 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- No temporary storage or stockpile of earthworks material downslope to the south of the turbine position as indicated by risk mapping;
- Following forestry clearance location should be re-assessed.

WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure		Risk Ranking Residual Risk
T05	0.5 *(Modified due to absence of peat)*	Peat Depth (Mean = 0.2m)	1	(Negligible) 4
		Slope Angle (15°)	5	
		FoS (4.64)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Negligible
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

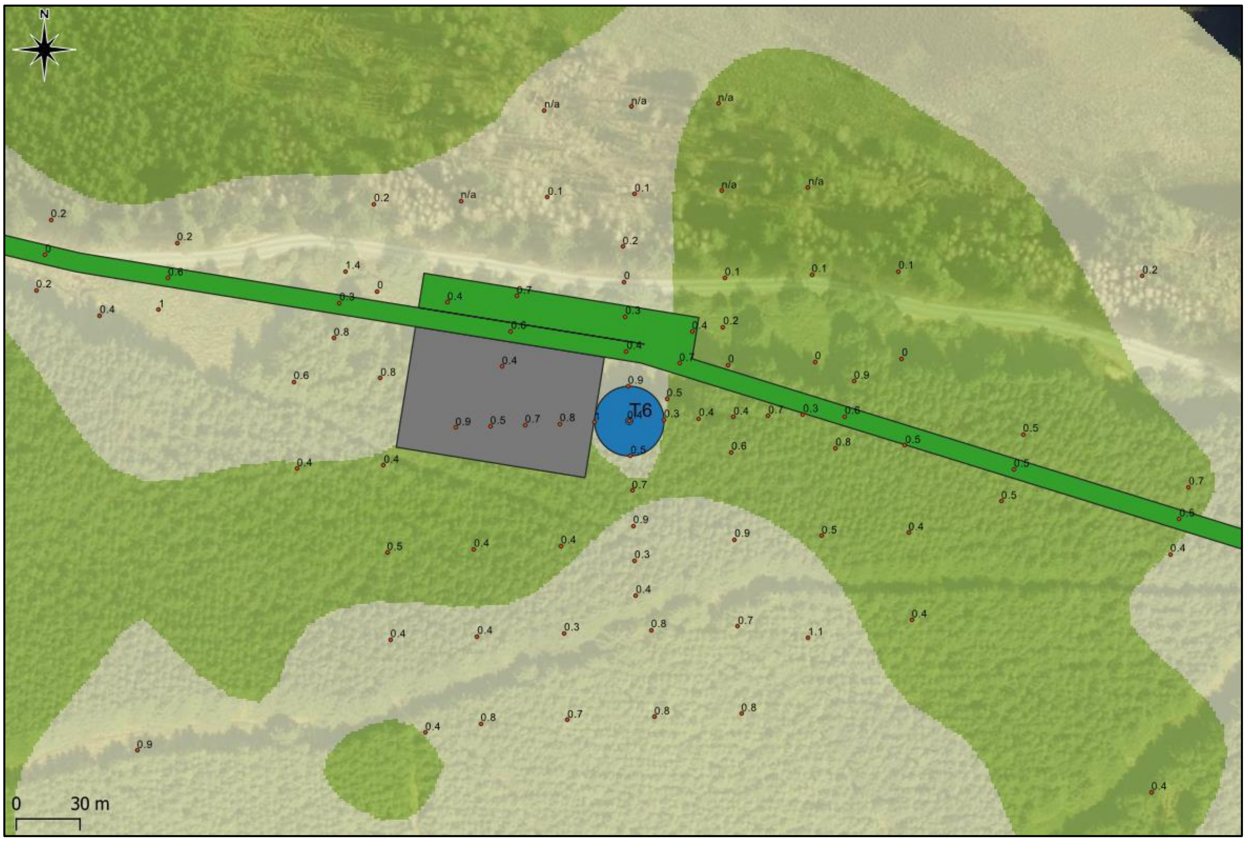


T05 Location – Bing Aerial Imagery – 1:2500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low due to the absence of any significant peat at this location.
- Ensure N-S trending existing drainage does not become blocked during construction
- Following forestry clearance location should be re-assessed. Peat data to the north was not collected due to the dense and difficult access into the forestry.

WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure)		Risk Ranking Residual Risk
T06	**1**	Peat Depth (0.6m)	3	**(Low)** **7**
		Slope Angle (23°)	2	
		FoS (4.59)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	**Negligible**
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



T06 Location – Bing Aerial Imagery – 1:2500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- Following forestry clearance location should be re-assessed.

WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
T07	1	Peat Depth (Mean = 0.9m)	3	(Low) 8
		Slope Angle (4°)	3	
		FoS (Min = Cu_{min} > site mean)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	(Low)
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

T07 Location – Google Aerial Imagery – 1:5,000 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- No temporary storage or stockpile of earthworks material downslope or to the east of the turbine position towards the public road; It shall be noted that the public road is at higher elevation that the planned turbine position.
- Following forestry clearance location should be re-assessed.

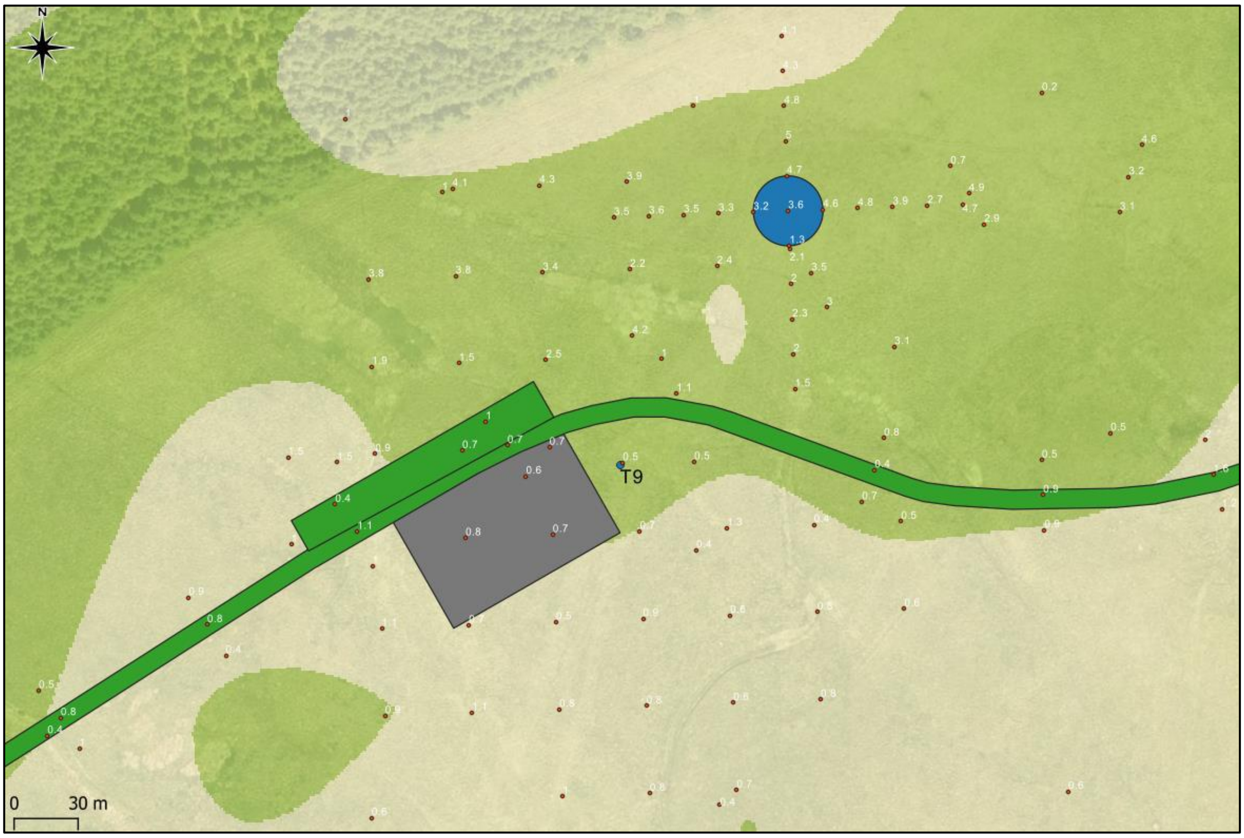
WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure		Risk Ranking Residual Risk
T08	1	Peat Depth (0.8)	3	(Low) 6
		Slope Angle (8°)	3	
		FoS (8.37)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	(Negligible)
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	

T08 Location – Google Aerial Imagery – 1:5,000 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the absence of peat / thin peat topsoil recorded at the turbine location during core sampling.
- Artificial drainage ditches are prevalent in the area surrounding this location, care must be taken not to disrupt the established hydrological equilibrium.
- The risk mapping should be reviewed with respect to adjoining infrastructure towards the north-east.
- There should be no temporary stockpiling of peat materials down slope from the infrastructure. Public infrastructure to south east but on separated terrain unit across main watercourse.

WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
T09	1	Peat Depth (Mean = 0.9m)	3	Low 6
		Slope Angle (4°)	3	
		FoS (7.95)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	



T09 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low given the shallow terrain slope angle;
- There should be no temporary stockpiling of peat materials down slope from the infrastructure which may pose a threat to raised bog and the headwaters of the Ferly Burn located to the south east;
- There should be no stockpiling of peat or earthworks on the deep peat deposits towards the north east of the turbine position;
- Drainage outflows should be directed away from the raised bog and area of deep peat to the northeast of the turbine position.

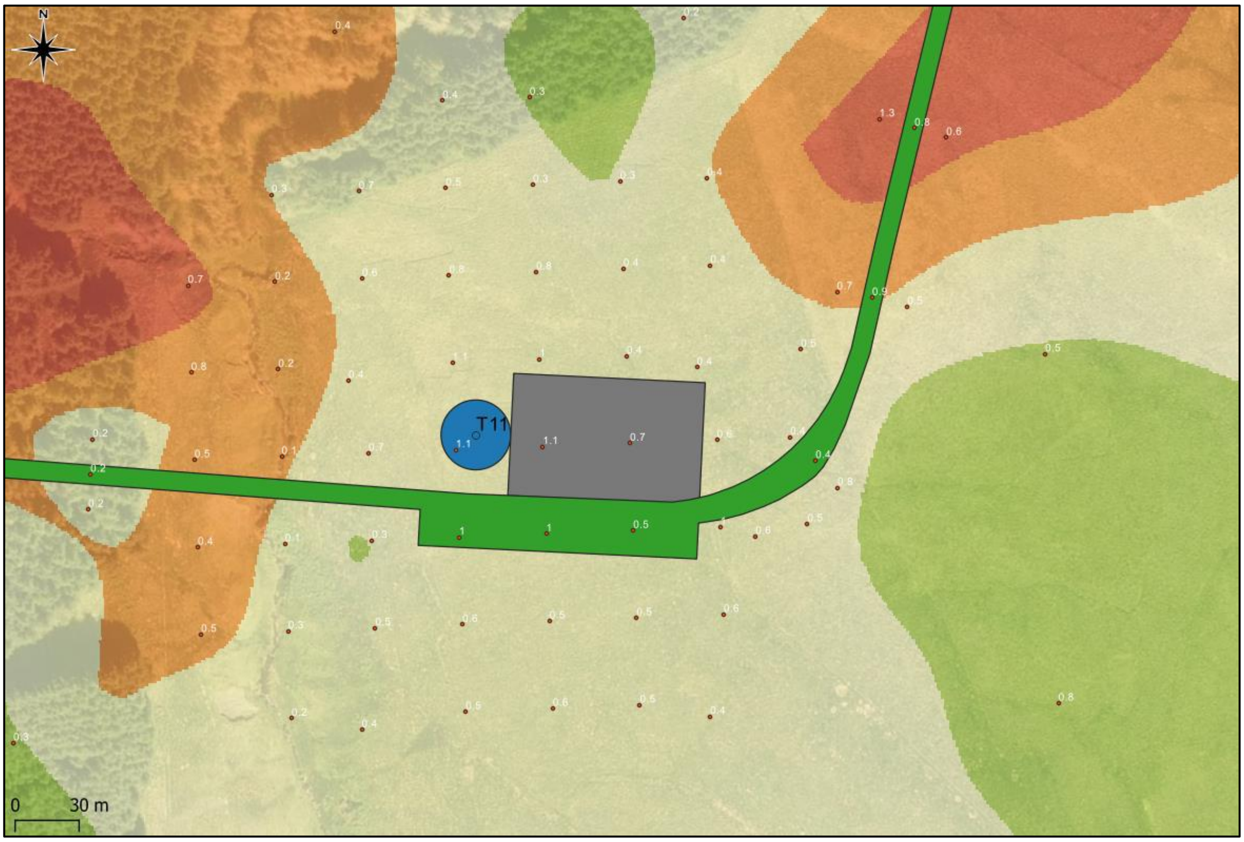
WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure)		Risk Ranking Residual Risk
T10	1	Peat Depth (1.1m)	5	(Low) 8
		Slope Angle (9°)	3	
		FoS (6.42)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	

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

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- There should be no temporary stockpiling of peat materials down slope from the infrastructure which may pose a threat to the tributary watercourse towards the west.
- Risk increases along the access towards the south-west thus control measures implemented at that location should consider potential affects on the location of T10. In particular the disruption of the artificial drainage system should be avoided at this location.
- There should be no focus of drainage outfalls towards the south-west and the area of high risk.

WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
T11	**2-1** *(Modified due to shallow peat depth within wider area – mean 0.5m)*	Peat Depth (0.8m)	3	(Low) 6
		Slope Angle (6°)	3	
		FoS (3.48)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	

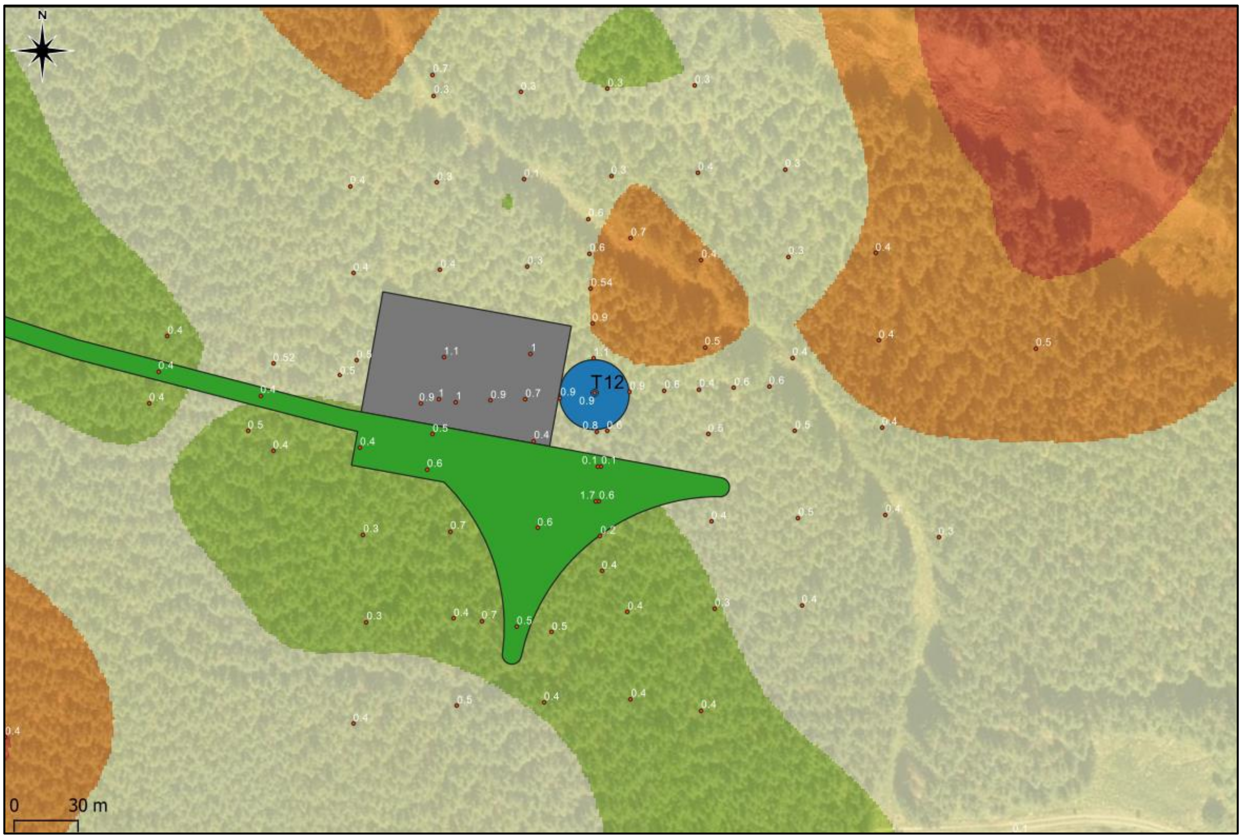


T11 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- There should be no temporary stockpiling of peat materials down slope from the infrastructure towards the main water-crossing.
- Installation of watercourse protection measures as a precaution against entrainment of material and suspended sediment entering the main watercourse would ensure the negligible residual risk.

WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure)		Risk Ranking Residual Risk
T12	**2** (Existing Forestry Access to South)	Peat Depth (0.7m)	3	(Low) 10
		Slope Angle (3°)	1	
		FoS (3.40)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Negligible
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



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

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk can be reduced to a low level through the use of low impact construction techniques and best practice methods for construction over peatland. In addition:
- There shall be no temporary storage or stockpiling of material north of the turbine towards the nearest watercourse;
- Existing drainage ditches and hydrological regime should be maintained and prevented from blocking leading to increased power water pressures in surrounding peatland;
- Following forestry clearance location should be re-assessed.

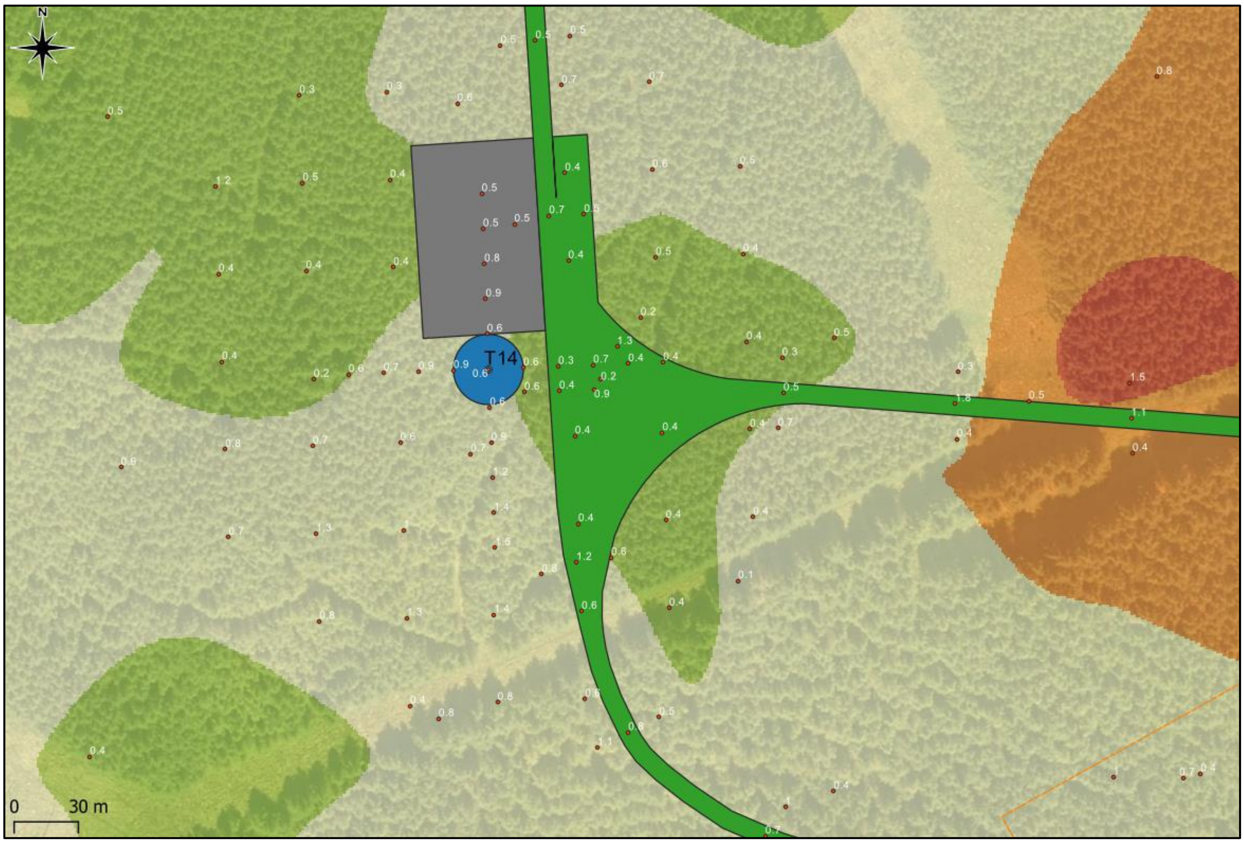
WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
T13	**1**	Peat Depth (0.4m)	1	**Low/Neg** **5**
		Slope Angle (8°)	3	
		FoS (6.03)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	**Negligible**
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

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

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- Following forestry clearance location should be re-assessed.

WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
T14	1	Peat Depth (0.6m)	3	Low/Neg 8
		Slope Angle (7°)	3	
		FoS (5.02)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	

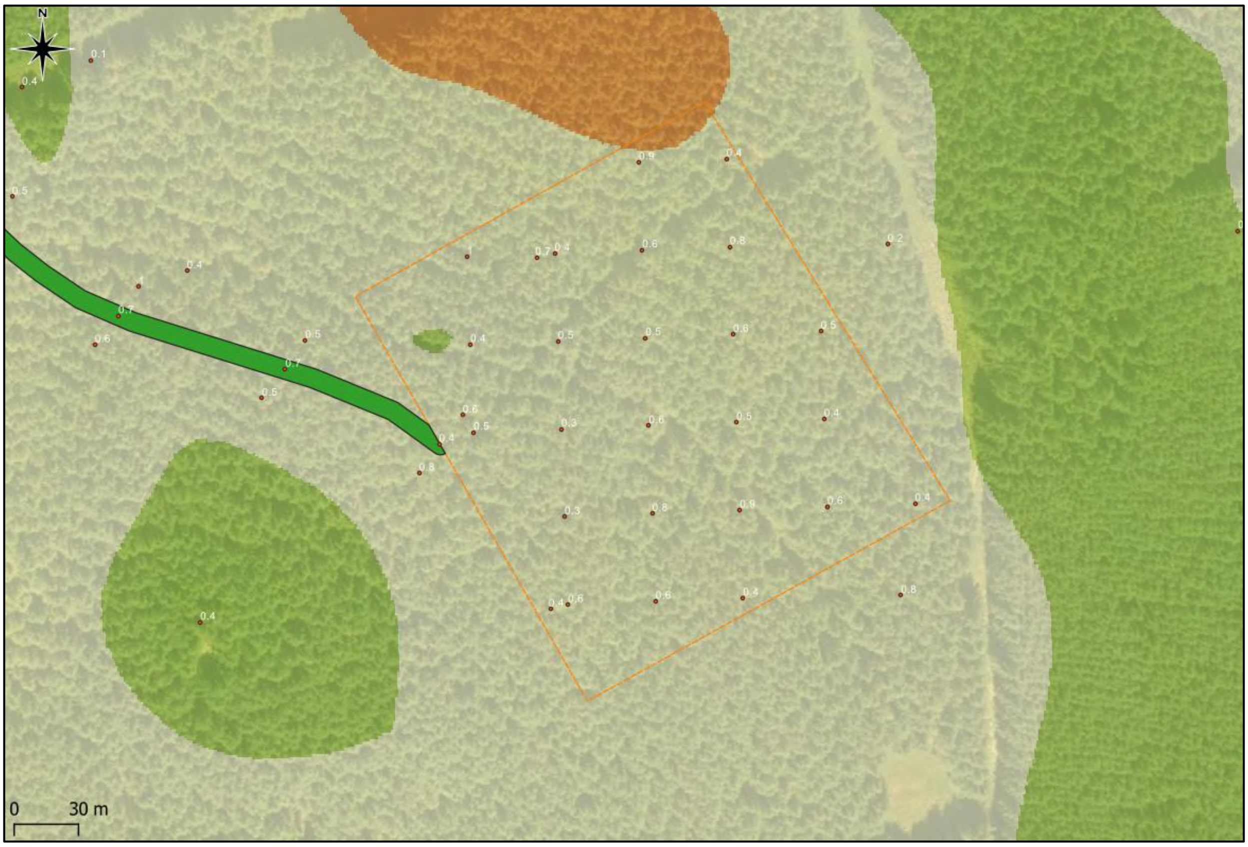


T14 Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- There shall be no temporary storage or stockpiling of material east from the turbine towards the head of the steepening slope system;
- Existing drainage ditches and hydrological regime should be maintained and prevented from blocking. No outfalls shall be directed onto the head slope area of the adjoining access track
- Following forestry clearance location should be re-assessed.

WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
BP Search Area A	1	Peat Depth (0.6m)	3	Low 10
		Slope Angle (10°)	5	
		FoS (>1.3)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low-Negligible
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



BPA Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- There shall be no temporary storage or stockpiling of material north and east from the borrow pit workings;
- Existing drainage ditches and hydrological regime should be maintained and prevented from blocking. No outfalls shall be directed downslope towards the west.
- Following forestry clearance location should be re-assessed.

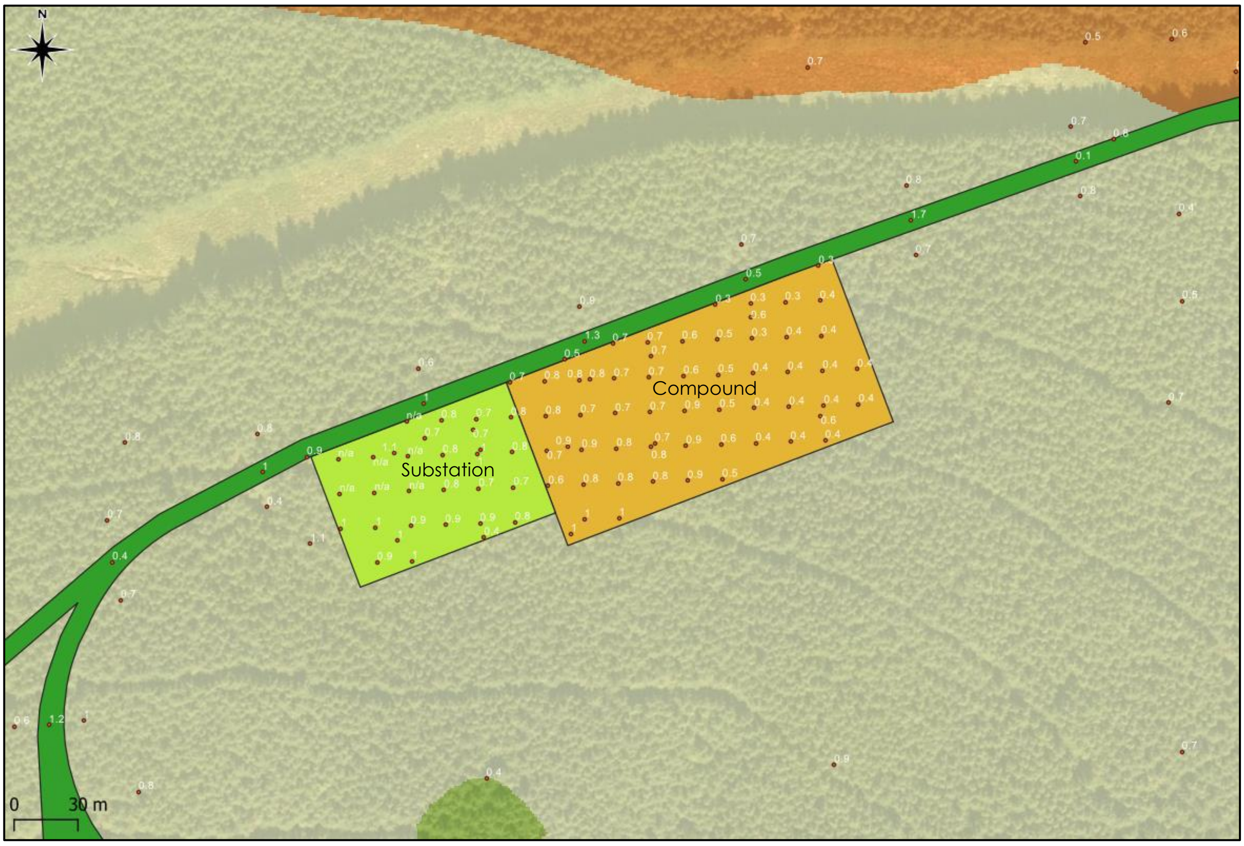
WTG ID	Impact Scale Environment & Infrastructure	Contributory Factors (Probability/Exposure)		Risk Ranking Residual Risk
BP Search Area B	1	Peat Depth (0.6m)	3	**Low**
		Slope Angle (10-15°)	5	
		FoS (>1.3)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	1	

BPB Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- The risk mapping should be reviewed when selecting the final BP working area. Risk increases towards the east with proximity to the tributary watercourses.
- There shall be no temporary storage or stockpiling of material east or west from the borrow pit workings where instability risk increases;

WTG ID	Impact Scale Environment & Infrastructure	Contributary Factors (Probability/Exposure		Risk Ranking Residual Risk
Substation/ Compound	1	Peat Depth (0.8m)	3	**Low** **10**
		Slope Angle (13°)	5	
		FoS (>1.3)	1	
		Peat cracking / Infiltration	1	
		Groundwater Flow	1	Low
		Hydrology	1	
		Previous Instability	1	
		Land Management	2	



Substation Location – Bing Aerial Imagery – 1:2,500 Scale

Location Specific Mitigation:

- Following further intrusive site investigation post-consent, the risk ranking should be re-evaluated. The risk should remain low through the use of low impact construction techniques and best practice methods for construction over peatland.
- There shall be no temporary storage or stockpiling of material north from the substation due to slope system and increased risk of instability
- Existing drainage ditches and hydrological regime should be maintained and prevented from blocking. No outfalls shall be directed downslope towards the north.
- Following forestry clearance location should be re-assessed.

Risk Summary – Wind Turbines & Ancillary Infrastructure

4.41 Table 4.8 below summarises the risk ranking for each turbine location. The principal contributory factors are also stated.

Table 4.8: Risk Ranking by Turbine Location

Turbine ID	Risk Ranking	Residual Risk	Factors
T1	Low	Low	Peat depth, slope angle, forestry clearance
T2	Low	Low	Peat depth, slope angle, forestry clearance
T3	Low	Low	Peat depth, slope angle, forestry clearance
T4	Low	Low	Peat depth, slope angle, forestry clearance
T5	Negligible	Negligible	No peat soil recorded at turbine
T6	Low	Low	Peat depth, slope angle, forestry clearance
T7	Low	Low	Peat depth, slope angle, forestry clearance
T8	Low	Negligible	Peat soil recorded at turbine
T9	Low	Low	Peat depth
T10	Low	Low	Peat depth, slope angle
T11	Low	Negligible	Thin peat soil, proximity of incised watercourse channel
T12	Low	Negligible	Peat depth, forestry clearance, proximity of infrastructure
T13	Low	Negligible	Slope angle
T14	Low	Low	Peat depth, slope angle
BPA	Low	Low	Peat depth, slope angle
BPB	Low	Low	Peat depth, slope angle
Substation	Low	Low	Peat depth, slope angle
Compound	Low	Low	Peat depth, slope angle

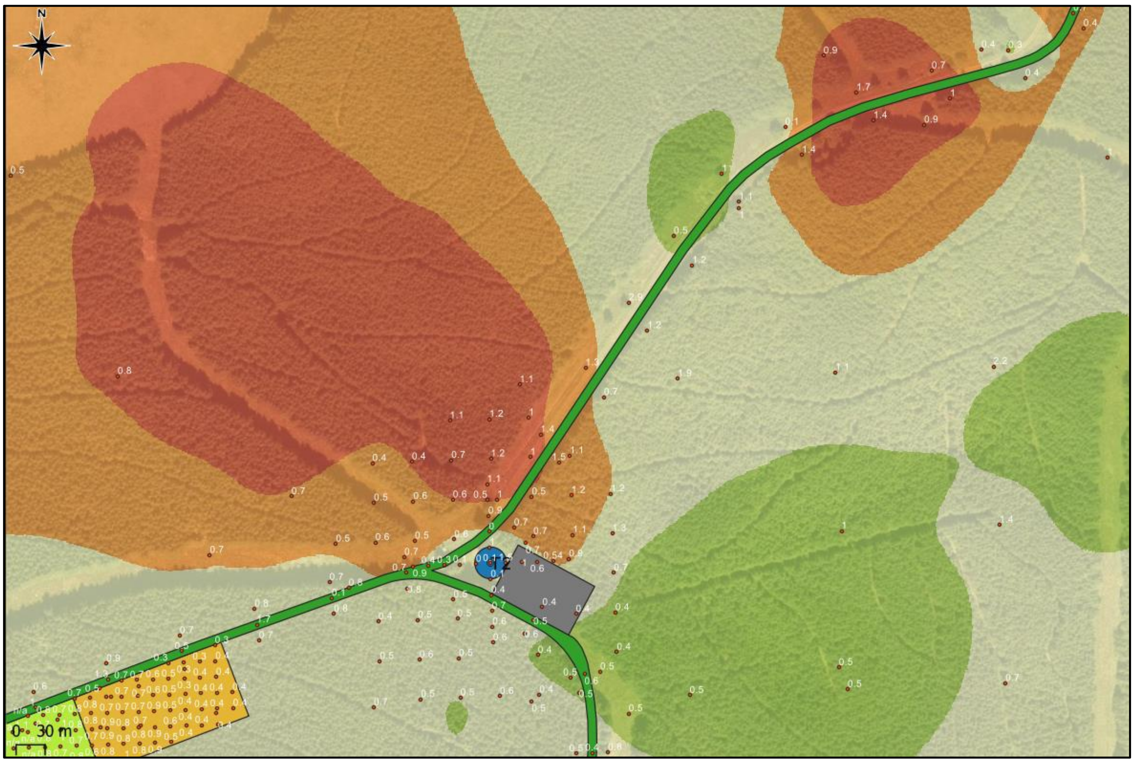
4.42 The risk assessment reflects the probability of peat material entering the surface watercourse and being entrained to an offsite receptor without any mitigation. The assessment also considers potential for peat slides to affect existing infrastructure. Areas close to watercourses would therefore be the focus of mitigation measures set out within the geotechnical risk register. Discussion on potential run-out of peat slide/failure events is provided in Section 4.46.

Risk Summary – Access Tracks

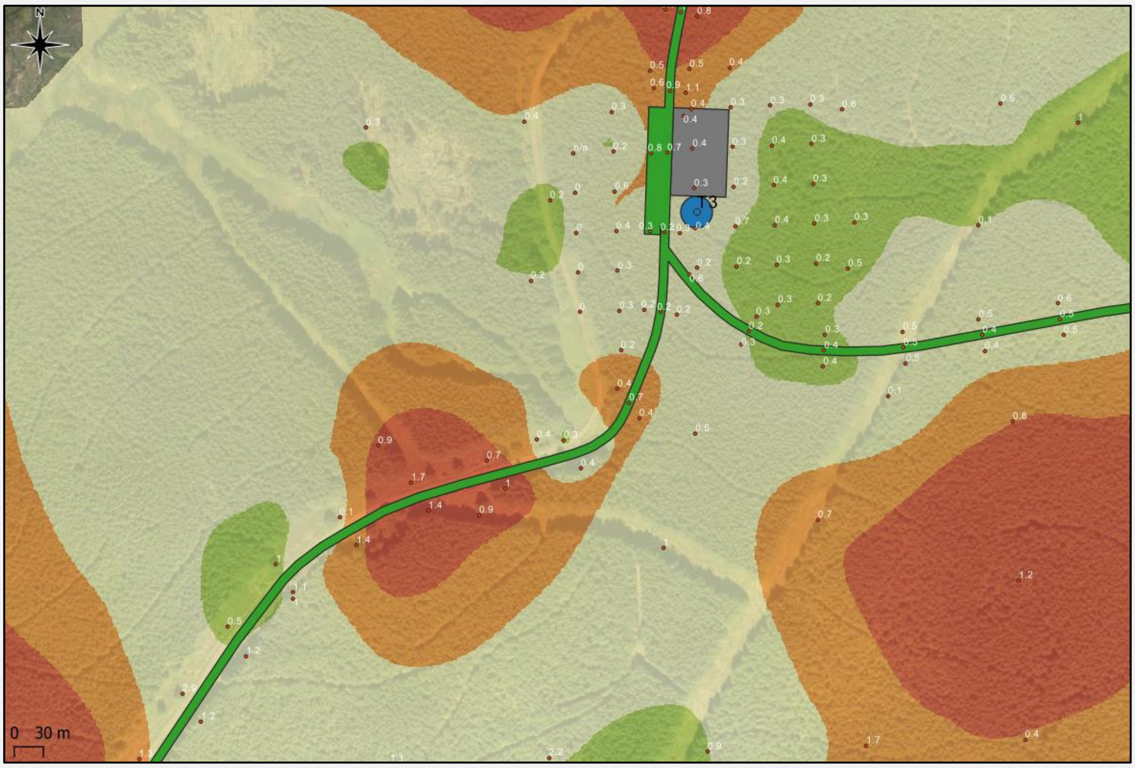
4.43 Proposed access track configurations have also been reviewed across the site. The highest risk areas would be where track alignments cross the watercourses and are coincident with steep slopes and moderate peat depths. The areas of unmitigated high risk can be seen in 14090UKC_PSRA_002 included in the appendix.

4.44 Table 4.9 below highlights several discrete track sections which indicate elevate risk of peat instability and therefore will require targeted mitigation to ensure peat slides can be prevented and risk reduced to the low category

Table 4.9: Access Track Risk Summary

Track Element
Track Section – Adjacent to T2

Discussion / Contributors to elevated peat slide risk: •Proximity to headwaters of tributary watercourse •Peat depth – up to 1.4m •Slope angle •New access track elements will require integration and upgrade of existing
Specific Mitigation: The following mitigation is therefore required along this track section in order to reduce the risk to low: Cross track drainage which prevents any ponding or build-up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained; No stockpiling or surcharging of the peatland along this specific access track section; Where detail design proves floating access, track is safe to use, this should be the preferred method of track construction to reduce the impact on peatland by avoiding excavation. A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat. A rapid reaction strategy should be development to ensure measures can be deployed to protect the watercourse in the event of any movement. This may include installation of downslope retaining systems to prevent peat material entering the watercourse.

Track Element
Track Element
Track Section – Approach to T3



Discussion / Contributors to elevated peat slide risk:

- Proximity to headwaters of tributary watercourse
- Peat depth – up to 1.7m
- Slope angle
- New access track elements will require integration and upgrade of existing infrastructure

Specific Mitigation:

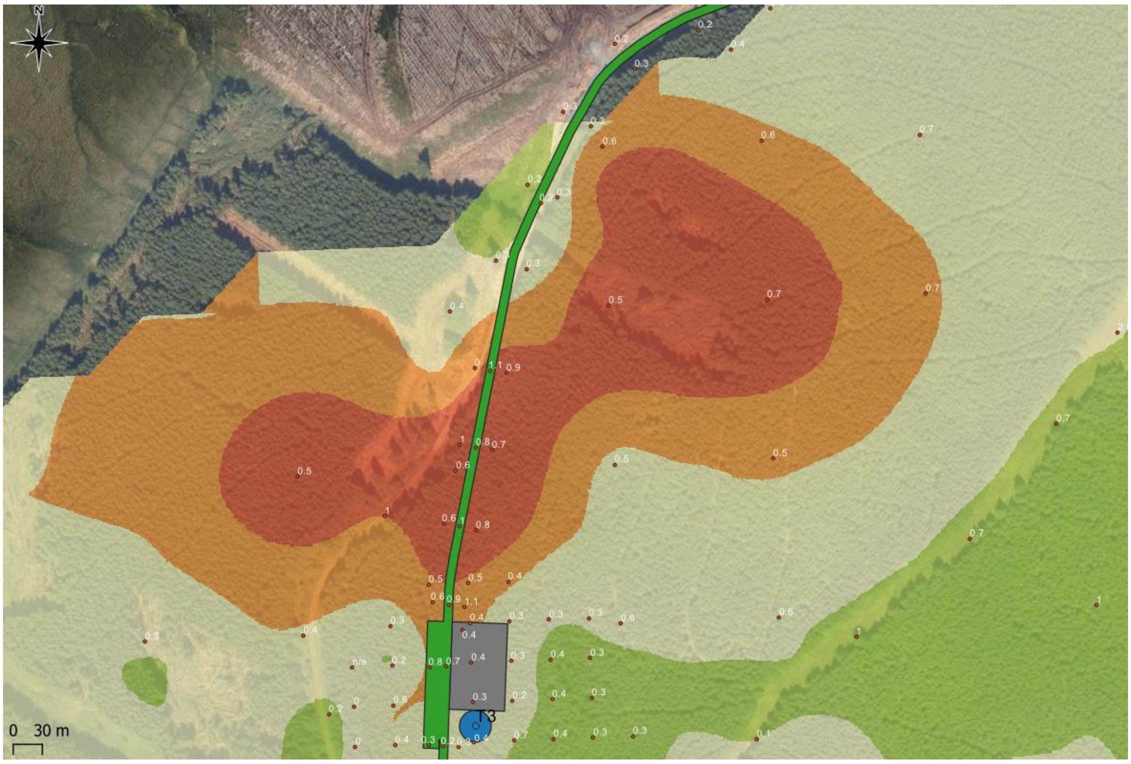
The following mitigation is therefore required along this track section in order to reduce the risk to low:

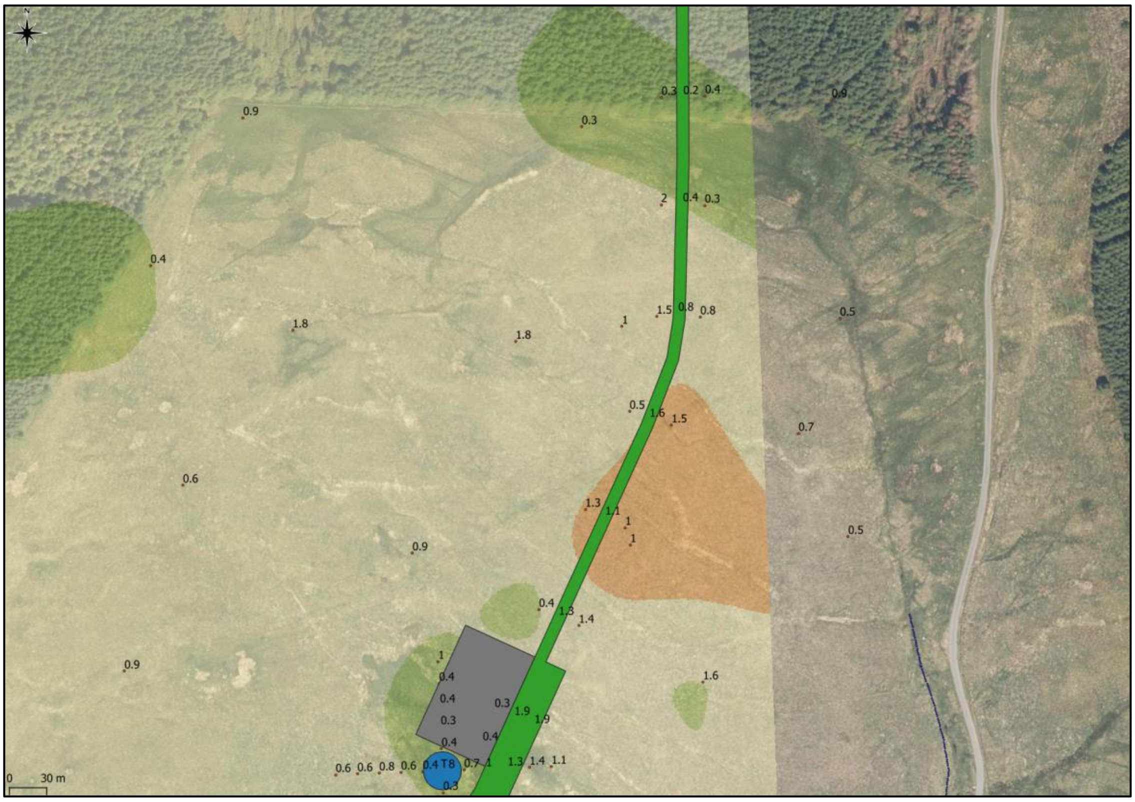
Cross track drainage which prevents any ponding or build-up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained;

No stockpiling or surcharging of the peatland along this specific access track section;

Where detail design proves floating access, track is safe to use, this should be the preferred method of track construction to reduce the impact on peatland by avoiding excavation.

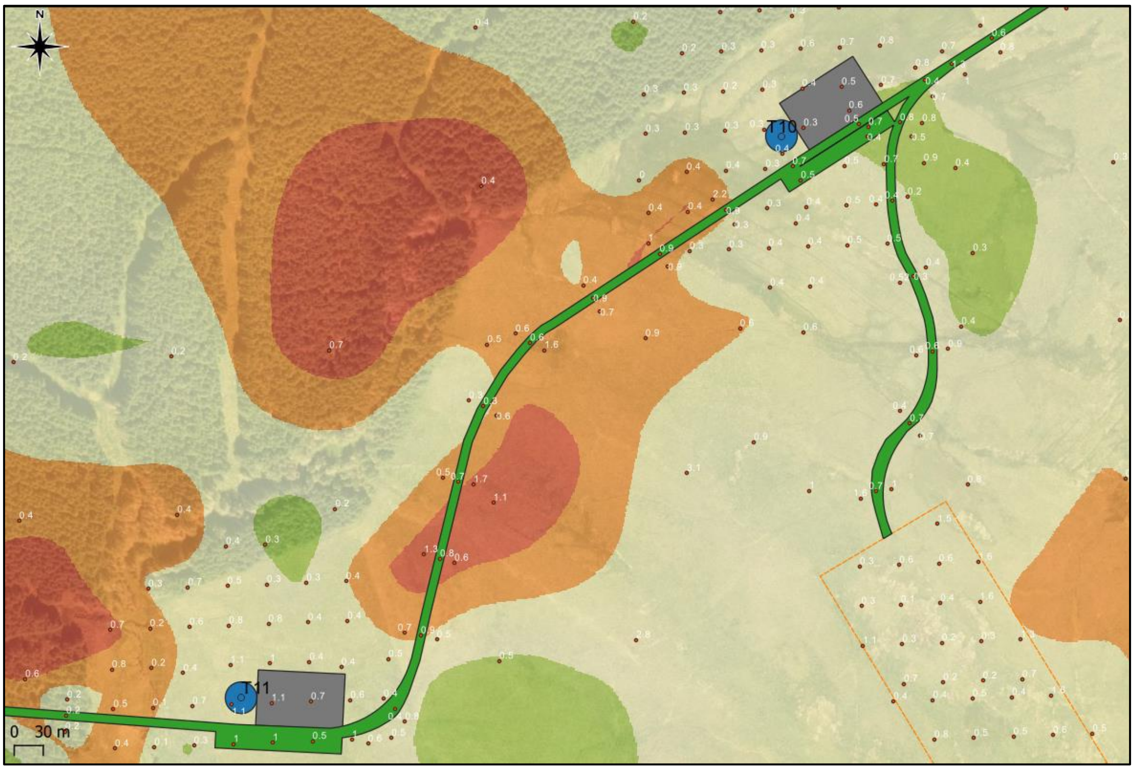
A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat. A rapid reaction strategy should be development to ensure measures can be deployed to protect the watercourse in the event of any movement. This may include installation of downslope retaining systems to prevent peat material entering the watercourse.

Track Element
Track Section – North from T3

Discussion / Contributors to elevated peat slide risk: •Peat depth – up to 1.1m •Slope angle
Specific Mitigation: The following mitigation is therefore required along this track section in order to reduce the risk to low: Cross track drainage which prevents any ponding or build-up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained; No stockpiling or surcharging of the peatland along this specific access track section; A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat. A rapid reaction strategy should be development to ensure measures can be deployed to protect the watercourse in the event of any movement. This may include installation of downslope retaining systems to prevent peat material entering the watercourse.

Track Element
Track Section – North from T8

Discussion / Contributors to elevated peat slide risk: •Peat depth – up to 1.6m •Slope angle •Proximity of main watercourse (down-slope) and the adjacent public road
Specific Mitigation: The following mitigation is therefore required along this track section in order to reduce the risk to low: Cross track drainage which prevents any ponding or build-up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained; No stockpiling or surcharging of the peatland along this specific access track section; Where detail design proves floating access, track is safe to use, this should be the preferred method of track construction to reduce the impact on peatland by avoiding excavation. A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat. A rapid reaction strategy should be development to ensure measures can be deployed to protect the watercourse in the event of any movement. This may include installation of downslope retaining systems to prevent peat material entering the watercourse.

Track Element

Track Section – T10 – T11



Discussion / Contributors to elevated peat slide risk:

•Peat depth – up to 1.7m

•Slope angle

•Proximity of main watercourse (down-slope)

Specific Mitigation:

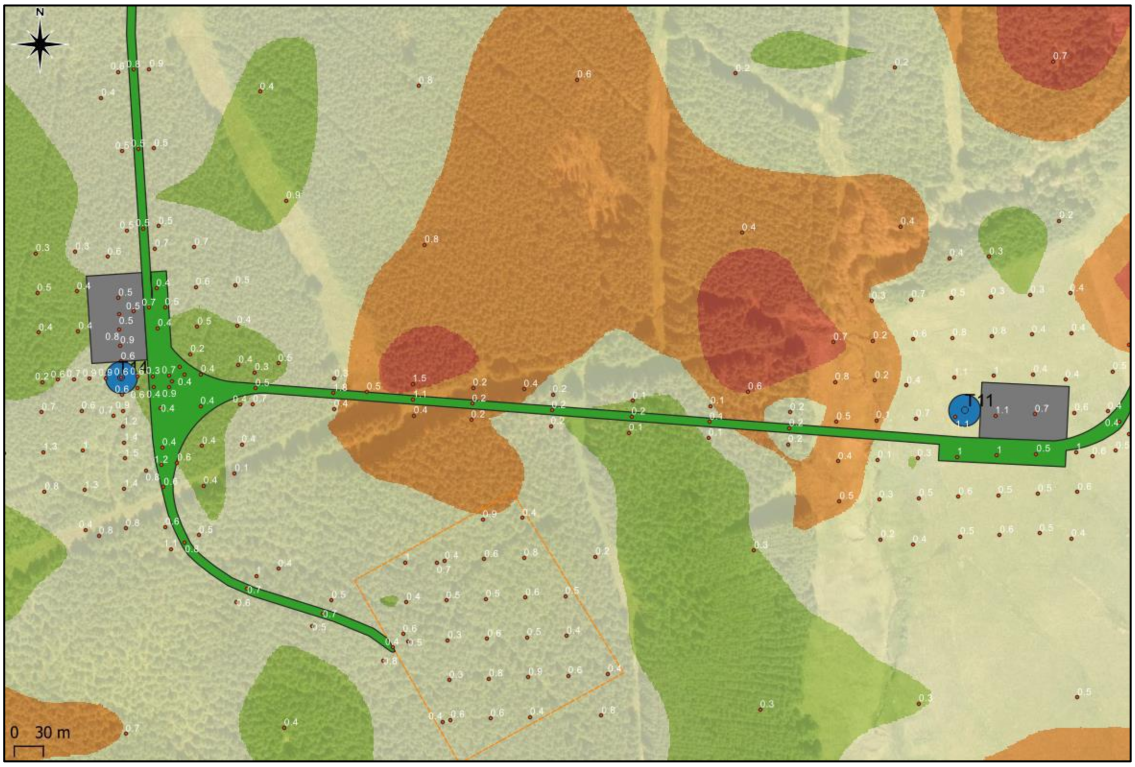
The following mitigation is therefore required along this track section in order to reduce the risk to low:

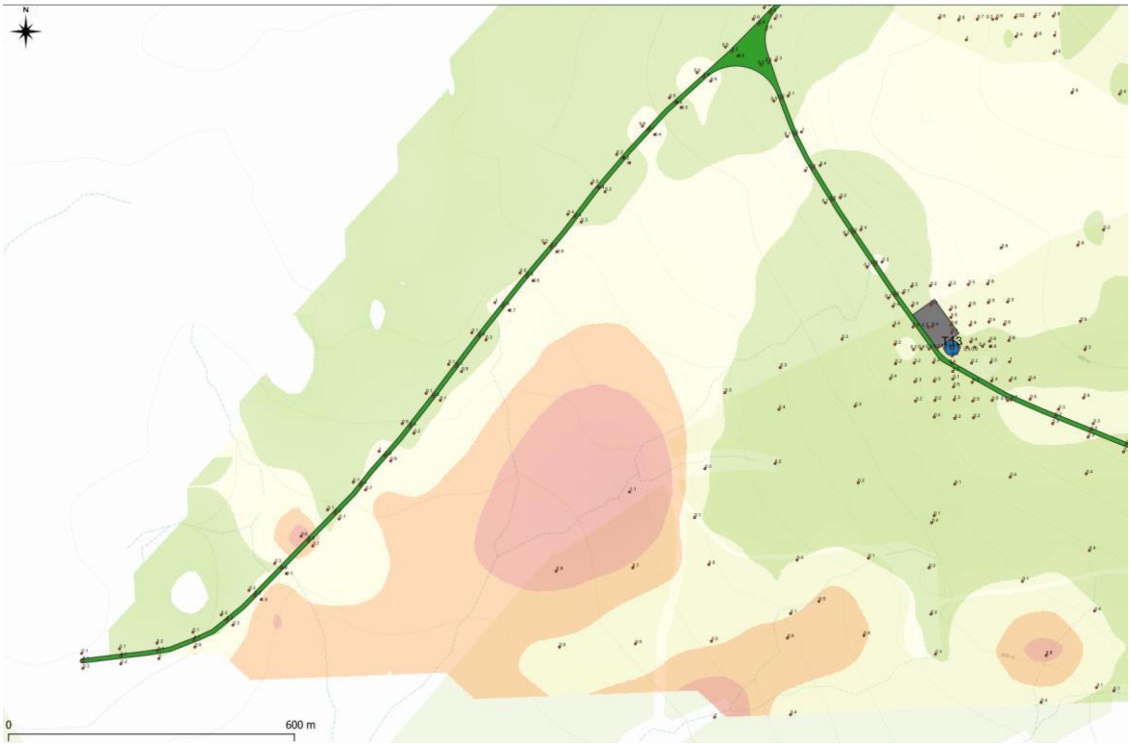
Cross track drainage which prevents any ponding or build-up of groundwater pressure within the peat upslope or beneath the access infrastructure. Where possible existing drainage systems should be utilised and maintained;

No stockpiling or surcharging of the peatland along this specific access track section;

Where detail design proves floating access, track is safe to use, this should be the preferred method of track construction to reduce the impact on peatland by avoiding excavation.

A system of ongoing monitoring throughout the construction phase should be in effect to monitor any movement in the peat. A rapid reaction strategy should be development to ensure measures can be deployed to protect the watercourse in the event of any movement. This may include installation of downslope retaining systems to prevent peat material entering the watercourse.

Track Element
Track Section – T11 – T14

Discussion / Contributors to elevated peat slide risk: •Peat depth – up to 1.5m •Slope angle (Slope system is sustained) •Proximity of main watercourse •Evidence of active erosion and possible movement along the north-south trending forestry drainage system
Specific Mitigation: The following mitigation is therefore required along this track section in order to reduce the risk to low: This track section will be one the most challenging infrastructure element to construct within the development. The track ascends a significant slope system which is mantled by peat of a depth which may contribute to instability. It is recommended that micro-siting is explored to situate the track further south and onto shallower peat deposits. This would also increase proximity from the main east-west trending watercourse. Active measures otherwise may be required in the form of soil reinforcement systems (e.g. soil nailing) installed in advance of the track installation to stabilise the underlying soils. Track drainage will be required to not outflow onto the slope system where inundation of the peat deposits could occur and trigger instability. **Down slope catch-wall systems such as rock fill retaining structures and embankments should also be considered at the base of the slope to attenuate any potential slide or release of peat material which could form a debris flow and transport material down into the Auchengairn Burn system.** The design and construction should be undertaken by a suitably experienced entity familiar with slope stabilisation and engineering of steep slopes.

Track Element
Track Section – Main Entrance Track

Discussion / Contributors to elevated peat slide risk: •Peat depth – up to 0.8m, deeper zone of peat potential to the south. •Slope angle (Slope system is sustained) •Proximity of main watercourse •Evidence of active erosion and possible movement along the north-south trending forestry drainage system
Specific Mitigation: The following mitigation is therefore required along this track section in order to reduce the risk to low: It is recommended that micro-siting is explored to situate the track away from discrete areas of deep peat and onto shallower peat deposits. This would also increase proximity from the main east-west trending watercourse. Active measures otherwise may be required in the form of soil reinforcement systems (e.g. soil nailing) installed in advance of the track installation to stabilise the underlying soils particularly focussed at the deep peat crossing. Track drainage will be required to not outflow onto the slope system where inundation of the peat deposits could occur and trigger instability to the south. The design and construction should be undertaken by a suitably experienced entity familiar with slope stabilisation and engineering of steep slopes.

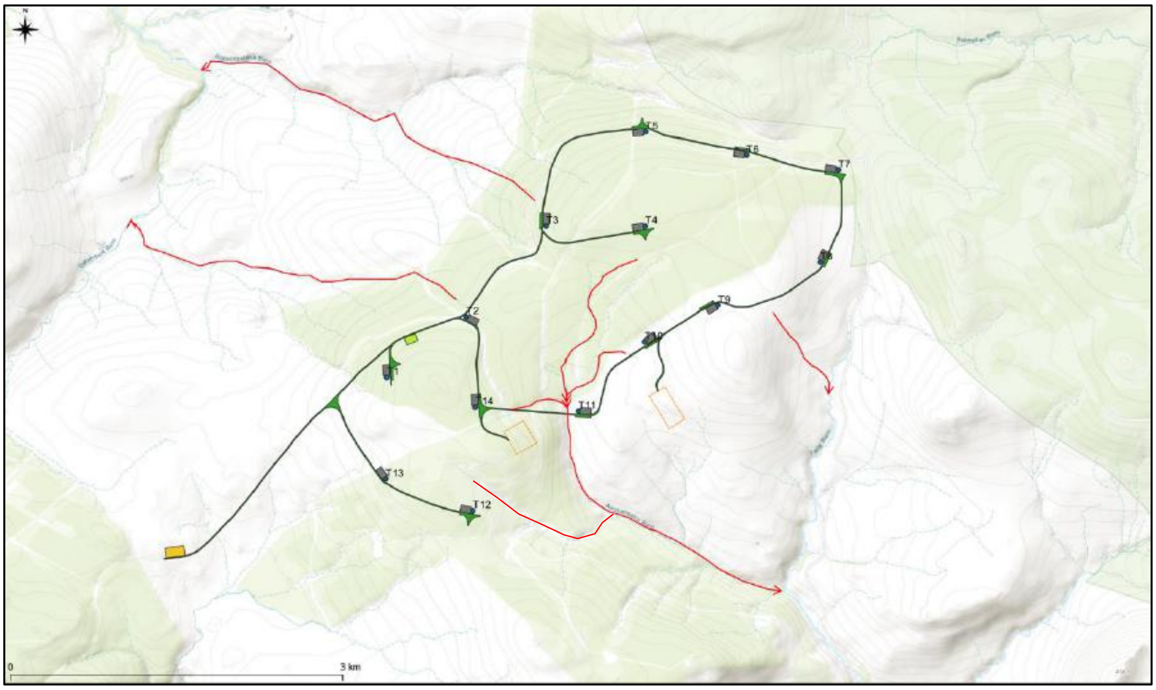
Peat Slide Run-Out

4.46 The assessment considers environmental receptors (main watercourses) to be the primary focus of the risk assessment. Minor or ephemeral watercourses have been assessed not to be primary receptors or unlikely to transmit peat slide material to offsite receptors, these have been excluded.

4.47 Notwithstanding the point above this report examines the terrain and the potential evolution of any triggered peat slide event. The determination has been that entrained peat flows would primarily be channelled along watercourses downslope of proposed infrastructure. As run-out pathways are generally in excess of 1km before a larger watercourse is reached or road infrastructure it is postulated that surface water pollution would be the primary hazard rather than mass movement and destruction or severing of existing infrastructure.

4.48 The risk assessment therefore has relied on the mapping of watercourses within the development to establish impact scales. Figure 4.1 below traces the run-out course of potential peat slide events which may enter a watercourse on site and be entrained to an offsite receptor.

Figure 4.1: Peat Slide/Debris Flow Run-Out Pathways



The risk of run out and significant damage to the wider hydrological environmental is deemed low, providing the relevant control measures outlined in his report are implemented at the development.

Preliminary Risk Register

4.49 A preliminary risk register for development wide hazards are listed in Table 5.1 below. Key. Control measures for the hazards have also been identified. A complete geotechnical risk register should be utilised on an individual turbine basis throughout the construction phase and amended accordingly as new information is received.

Table 5.1: Preliminary risk register

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

Hazard	Cause	Consequence
		support and or increase of pore pressures through increased rates of infiltration.
Mitigation	Detailed drainage design undertaken with sufficient capacity to buffer the effects of short periods of high intensity rainfall, perhaps though the implementation of buffer/ settlement ponds to collect surface run-off and release at a slower rate. The positioning of such elements should be at locations at low risk of peat instability. Geotechnical supervision of major de-watering operations should be in place to ensure outflows are not being directing into terrain at higher risk of peat instability. Due consideration should be given to prevailing ground and weather conditions when scheduling construction works.	
Peat Landslide / Bog Burst / Peat Flow	Inadvertent removal of toe support to slope system	Localised instability associated with temporary and permanent earthworks; Harm to personnel and equipment/plant through mass movement of peat and spoil; Long term ground movements/ creep, causing deterioration and damage to temporary and permanent earthworks; Contamination of natural watercourses and damage to hydrological systems from peat material mobilised down slope;
Mitigation	Avoidance action during geotechnical design stage; Routine geotechnical inspection; Contingency plans for slope stabilisation measures. This could involve the provision of engineered toe support to affected slopes comprising gabion style retaining structures.	
Peat Landslide / Bog Burst / Peat Flow	Increased subsurface groundwater flow and 'piping' failure beneath natural peat deposits, temporary and permanent earthworks	Localised instability associated with temporary and permanent earthworks; Triggering of mass movement of peat material down slope causing harm to personnel, plant and equipment;
Mitigation	Ensure geotechnical design prevents blockages of groundwater flow. This may be achieved through the use of free draining fills and ensuring temporary and permanent earthworks do not cause the build-up of groundwater pressures. A programme of geotechnical inspections should be implemented throughout construction phase. Ensuring focus extends beyond immediate areas of construction, both up-slope and down-slope to detect any unforeseen effects on stability.	
Bearing Capacity Failure (Peat Surface)	Increased loading of low shear strength deep peat deposits	Localised instability and settlement associated with temporary and permanent earthworks; Triggering of mass movement of peat material down slope causing harm to personnel, plant and equipment; Contamination of natural watercourses and damage to hydrological systems from peat material mobilised down slope;
Mitigation	Due consideration given to the prevailing ground and weather conditions when scheduling site works; Ensure detailed peat depth contour plan to be used in construction planning and design; Use of appropriate plant machinery (low ground pressure and long reach to avoid over loading peat deposits); A programme of geotechnical inspections will be implemented during excavation works; Geotechnical monitoring post-construction.	
Peat Failure	Mass movement of temporary storage mounds and bunds	Localised instability and settlement associated with temporary and permanent earthworks.