Appendix 13.1

Peat Stability Report

STATKRAFT

PEAT STABILITY REPORT FOR THE PROPOSED DERNACART WIND FARM, CO. LAOIS

DECEMBER 2019

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1 INTRODUCTION

1.1 General

Statkraft proposes to develop the Dernacart Wind Farm which is located in Co. Laois. It is proposed to supply the power from Dernacart Wind Farm to the Irish electricity network via underground cable to the proposed substation at Bracklone, Co. Laois. This report details the Peat Stability Assessment undertaken at the proposed site and is based on a detailed walkover and intrusive surveys of peat deposits within the study area. Figure 1.1 displays the location of the site.

The Peat Stability & Risk Assessment was required due to the presence of peat across the site and the potential risks posed to peat stability and particularly the risk of peat slides from development on peatlands and the associated infrastructure on existing peatlands. The potential for a landslide risk is defined in the Scottish Executive Best Practice Guide for Proposed Electricity Generation Developments (2017) [(1)] as the following:

- *Peat is present at the development site in excess of 0.5m depth,*

and;

- *There is evidence of current or historical landslide activity of the site,*

or;

- *Slopes > 2^{o} are present on-site,*

or;

- *The works will impinge on the peat covered areas and cannot be relocated to avoid peat covered areas.*

A site walkover and preliminary ground investigation for the proposed development was undertaken during July and August 2019 to determine the presence/depth of peat and/or soft soils on the site along with slope angles and potential geotechnical instability.

Path: R:\Map Production\2018\P1892\Workspace\EIAR\Appendix\Peat Stability Report\P1892_Fig1-1_SiteLocation_A3.mxd

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community
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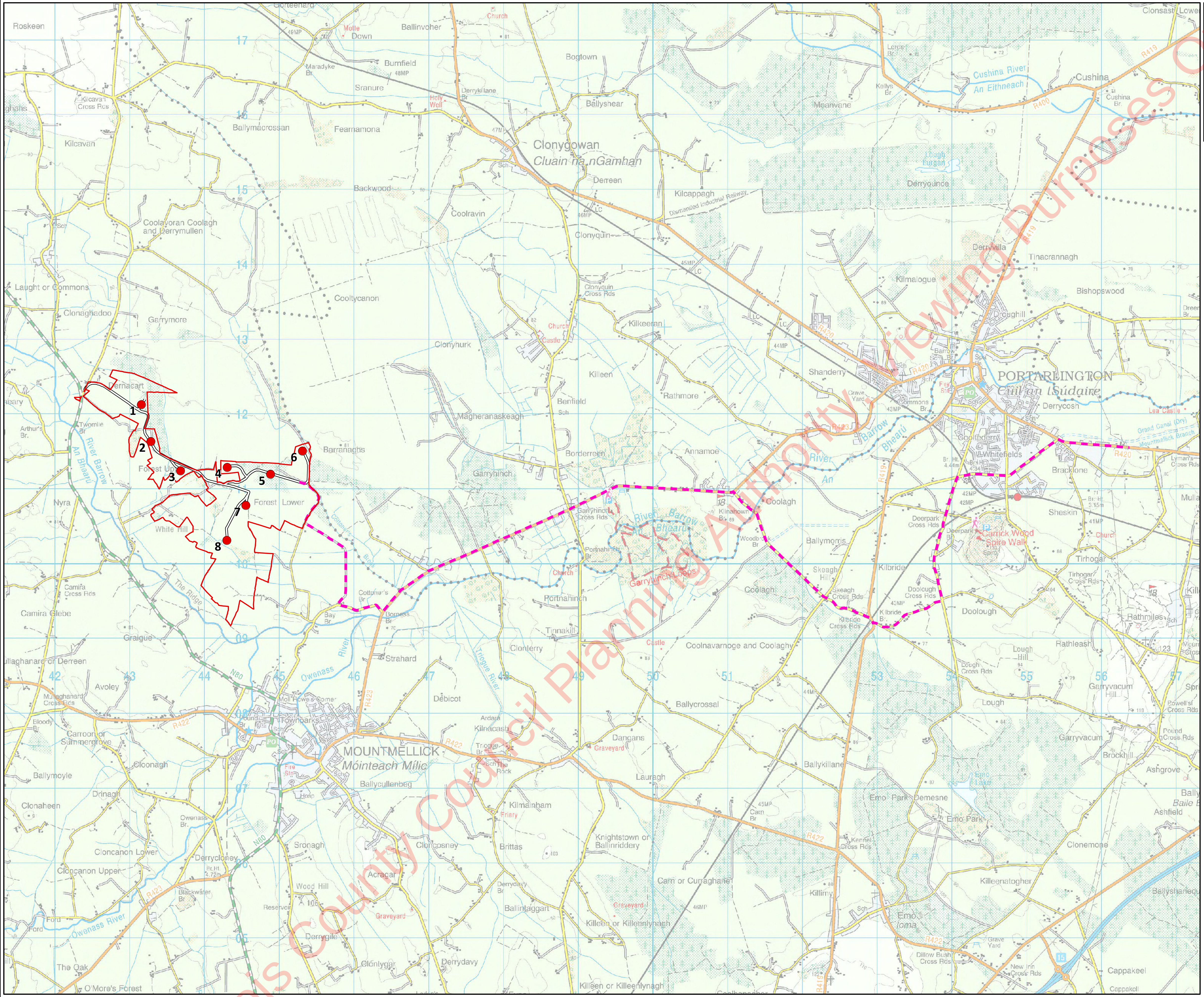

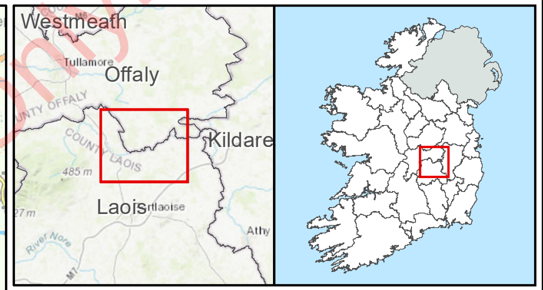

- Proposed Turbines
- Proposed Site Boundary
- Proposed Cable Route
- Proposed Access Tracks

TITLE:	Site Location
PROJECT:	Dernacart Wind Farm
FIGURE NO:	1.1
CLIENT:	Statkraft
SCALE: 1:50000	**REVISION:** 0
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2 PEAT STABILITY & RISK ASSESSMENT METHODOLOGY

The Peat Stability Assessment was carried out by an Engineering Geologist from Fehily Timoney & Company (FT) following the guidance and principals outlined in the Scottish Executive Best Practice Guide for Proposed Electricity Generation Developments (2017) (1). The guide provides best practice information and methods for identifying, mitigating and managing peat slide hazards and associated risks with reference to on-shore electricity generation projects.

In addition to the above guidance the Peat Stability Assessment was undertaken with particular reference to the following reports, papers and guide documents:

- General Soil Map of Ireland (2)
- IGI – Geology in Environmental Impact Statements (5)
- Scottish Executive – Peat Landslide Hazard and Risk Assessments (1)
- Welsh DoE - PPG14 – Development on Unstable Land (6)
- Landslides in Ireland (7)
- Guidelines for the risk management of peat slips on the construction of low volume/low cost roads over peat (8)
- Hydrological controls of surficial mass movements in peat (9)
- Slope Instability in Ireland with particular reference to peat failures (10)
- Peat slope failure in Ireland (11)
- Eurocode 7: Geotechnical Design (12)

The assessment of current peat stability and potential impacts from the development included the following work stages:

1. A desk study and review of existing geological conditions at the proposed site location including Geological Survey of Ireland digital map databases;
2. Site reconnaissance survey to include geomorphological features and peat depth survey across the proposed development site;
3. Assessment of peat shear strength using hand held shear vane testing equipment;
4. In-situ peat stability assessment based on shear strength data;
5. Assessment of potential triggering factors at proposed infrastructure locations; and
6. Recommendation for design/construction control to mitigate against potential peat failure.

2.1 Peat Characteristics & Properties

Peat is defined by The Soil Survey of Scotland as having a surface horizon greater than 0.5m thick with an organic content of more than 60%, dry peat can typically have an organic content of 90-95%. Peat also has a very low density, is often very fibrous in nature and has a high-water content (90%).

Peat is formed where the natural decay processes fail to keep up with the volumes of organic being produced - often in waterlogged, oxygen starved land. This prevents the dead organic matter from decaying as normal and instead accumulates year on year as layers of peat. Within peatlands the in-situ peat is often highly variable, both horizontally and vertically. Variations occur from the origins of the peat, plant type it was formed from, mineral content and degree of decay or humification. This heterogeneity is noticeable with depth with fresh fibrous peat occurring at the top of the deposit (Acrotelm) with the underlying layers (Catotelm) comprising soft, relatively dense highly humified material.

2.2 Peat Landslide Mechanisms

2.2.1 Mechanisms and Morphology of Peat Landslides

Two main failure mechanisms are identified in the Scottish Executive Best Practice Guide for Proposed Electricity Generation Developments and are described below:

- **Peat Slide** used to describe a slab-like, shallow translational failure with the shear failure usually within a discrete shear plane at the base of the peat deposit, or more rarely within the peat body. Peat slides tend to occur in shallow peat (<2.0m) and on steeper slopes (5 - 15°).
- **Bog Bursts** is used to describe more fluid failures involving the failure of the peat surface due to subsurface creep or swelling. Liquefied basal peat is expelled through surface tears followed by the settlement of the overlying peat mass. Bog bursts tend to occur in deeper peat (>1.5m) and on shallow slopes (2 - 10°) where deeper peat deposits are typically found.

Due to the low topographic relief and the depth of peat deposits (average 1.0m, maximum 1.6m) peat slides would be considered unlikely with bog bursts considered to be the likely potential mechanism of peat failure.

2.2.2 Factors Influencing Peat Instability

The characteristics and properties of peat make peat susceptible to instability from a number of preparatory factors which increase the risk of peat instability. These preparatory factors which can reduce the stability of peat in the medium to short term are outlined below:

- Increases in peat mass through progressive vertical accumulation (peat formation)
- Increases in peat mass through increases in water content
- Changes in physical structure of the peat caused by progressive creep, tension cracking and chemical or physical weathering;
- Loss of surface vegetation and associated tensile strength;
- Increase in buoyancy of a peat slope through the formation of sub-surface pools or water filled pipe networks

These underlying factors can be assessed through desk and field surveys and a risk rating calculated.

2.2.3 Triggering Factors

Triggering factors change the state of the slope and can be considered to be causes of a failure in a peat slope. The trigger factors acting to initiate such failures may be natural or anthropogenic (human induced).

Natural triggers include the following:

(i) Intense rainfall events;
(ii) Rapid ground accelerations (earthquakes);
(iii) Unloading of peat mass by a fluvial incision of a peat slope;
(iv) Loading of a peat mass by landslide debris causing an increase in shear strength.

Anthropogenic triggers include some of the following:

(i) Alteration of drainage patterns focusing drainage and generating high pore water pressures along pre-existing or potential slip surfaces;
(ii) Rapid ground accelerations (blasting or mechanical vibrations) causing an increase in shear stresses;
(iii) Unloading of peat mass by cutting of peat at the toe of the slope;
(iv) Loading of peat mass by heavy plant, structures or overburden;

(v) Digging and tipping undermining or loading the peat mass during building, engineering, farming or mining activities;

(vi) Afforestation of peat areas reduces water held in the peat body and increases the potential for the formation of desiccation cracks which are exploited by rainfall on forest harvesting; and

(vii) Changes to vegetation cover or stripping of surface peat cover, reducing tensile strength.

2.2.4 Indicators of Pre-Failure Instability

The presence of indicators prior to failure are often indicated by ground conditions and can be mapped through aerial photography or identified by site walkovers. The nature and indicators of instability may vary depending on the type and scale of failure. The Scottish Executive Best Practice Guide for Proposed Electricity Generation Developments identifies the following critical features that are indicative of potential peat failure and should be assessed during desk study and site walkovers:

- Evidence of historical and recent failure scars and debris;
- Evidence of tension features;
- Evidence of compression features;
- Evidence of creep;
- Presence of subsurface drainage networks or water bodies;
- Presence of seeps and springs;
- Presence of surface cracking;
- Concentration of surface drainage networks; and
- Presence of clay with organic staining at the peat/bedrock interface

2.3 Geotechnical Risk Assessment Methodology

The methodology for the risk assessment used to determine the risk of peat failure and potential impacts is defined by The Scottish Executive Best Practice Guide for Proposed Electricity Generation Developments (2017) and Clayton (2001). This approach was used in a detailed assessment of the potential for peat failure and resultant impacts at infrastructure locations at the proposed site as outlined below.

The assessment combines infinite slope stability analysis with the potential probability of contributory factors to peat failure. The purpose of the risk assessment is to identify the likely hazards associated with the proposed development, identify the likely cause and describe the potential impact of the hazards. Probability and impact scores are set out on a qualitative scale as shown below in Table 2-1.

Table 2-1: Probability and Impact Scales

Score	Probability	Impact
5	Highly Likely	Very High
4	Likely	High
3	Possible	Medium
2	Unlikely	Low
1	Highly Unlikely	Very Low

By identifying the potential impact of the hazard, the design and construction controls are identified which are to be implemented in order to reduce the risk of peat failure during the proposed development. The purpose of the Peat Stability Risk Registers is to identify and communicate risks and should referred to during the detailed design and construction stages of the project. The Hazard Rank is determined by combining the probability and impact assessments (Clayton 2001):

Risk (R) = Probability (P) x Impact (I)

The risk matrix derived from combining the probability and impacts score is shown in Table 2-2 with the qualitative Hazard Ranking and recommended mitigation measures are outlined in Table 2-3.

Table 2-2: Risk Matrix

		Probability (P)				
		1	2	3	4	5
Impact (I)	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Table 2-3: Hazard Rating & Control Measures

Hazard Ranking	Mitigation Measures
15 - 25	High (Unacceptable Risk) - Consider relocation or specialist mitigation measures.
7 - 14	Medium – Special mitigation measures required to reduce hazard ranking to Low
1 -6	Low – None or routine mitigation measures required

3 DESK STUDY & SITE WALKOVER

3.1 Site Location and Description

The proposed development is an eight-turbine wind farm located at Dernacart, Co. Laois, with a total Maximum Export Capacity of up to 50MW. The wind farm will be connected by a 38/110kV underground cable to the proposed Bracklone substation. A detailed description of the proposed development is set out in Chapter 4: Description of the Proposed Development, of Volume 2 of this EIAR.

3.2 Geology

The geological conditions present within the site boundary are outlined in the sections below.

3.2.1 Quaternary Deposits

The Quaternary Deposits underlying the proposed site location and the proposed grid connection route are summarised in the sections below.

3.2.1.1 Site Boundary

The Quaternary Deposits underlying the study area, as taken from the GSI online mapping, comprise:

- Cut over raised peat (Cut)
- Till derived from Limestones (TLs)
- Gravels derived from Limestones (GLs)

The site boundary is predominantly covered by cut over raised peat. The area north of the site boundary is a peat bog. Each of the proposed turbine locations are located in an area of cut over raised peat. There are pockets of Till derived from limestones located predominantly in the agricultural land in the southern part of the site. The Gravels derived from limestone are located in an area to the north of T07.

Based on the GSI aquifer vulnerability mapping, overburden deposits are generally between 5 and 10 m deep across the site. Fieldwork confirmed the presence of peat over a large proportion of the site area. Peat depths varied from 0.3m to depths of up to 1.6m.

Figure 3.1 presented an overview of the peat depths encountered across the site.

3.2.1.2 Grid Connection

The Quaternary Geology underlying the grid connection, as taken from the GSI online mapping, comprise:

- Cut over raised peat (Cut)
- Till derived from Limestones (TLs)
- Gravels derived from Limestones (GLs)
- Alluvium
- Urban sediments

The proposed Bracklone 110 kV cable route is predominately covered by Cut Over Raised Peat, Till derived from limestones, and Gravels derived from limestones. The urban sediments are found at the eastern section of the grid connection at the town of Portarlington. There are small sections of Alluvium located along the river Barrow.

A summary of the main Quaternary deposits are shown in Figure 13.1, Chapter 13 of the EIAR.

3.2.2 Solid Geology

The GSI 1:100,000 scale bedrock geology map is the reference source for the description of the bedrock geology of the region as outlined below.

Figure 13.2 of Chapter 13 of the EIAR, shows the bedrock geology of the site and surrounding area.

3.2.2.1 *Site Boundary*

The Geological Survey of Ireland (GSI) 1:100,000 scale bedrock geology map shows that the proposed wind farm site and associated access tracks are underlain by the Carboniferous Ballysteen Formation. The Ballysteen Formation is described as comprising bioclastic argillaceous limestone with oolitic limestones occurring through the formation. The bedrock geology of the site and surrounding area is displayed in Figure 13.2 in the EIAR.

3.2.2.2 _*Grid Connection*

The proposed Bracklone 110 kV cable route is predominately underlain by:

- Ballysteen formation
- Waulsortian formation
- Allenwood formation
- Calp formation

The Waulsortian Limestone is described by the GSI as dominantly pale-grey, crudely bedded or massive limestone.

The Allenwood Formation is described as pale-grey, generally massive shelf limestones and their dolomitised equivalents.

The Calp Formation comprises dark-grey to black, fine-grained, occasionally cherty, micritic limestones that weather paler, usually to pale grey.

There are 2 unnamed faults within the grid connection, both trending northeast – southwest, and separate stratigraphic sequences such as the Waulsortian and the Allenwood. However, these faults are no longer active and do not present an issue for construction of the proposed wind farm or the associated grid connection.

3.3 Hydrogeology

The following GSI online datasets and mapping were reviewed to assess the existing hydrogeological conditions within the study area:

- Catchment & Management Units;
- Drinking Water Protection Units;
- Groundwater Resources (Aquifers);
- Groundwater Wells and Springs;
- Karst Features; and
- Groundwater Vulnerability

The study area site is located within the Portlaoise Groundwater Body and is shown in Figure 13.5 in Chapter 13 of the EIAR.

Groundwater is an important natural resource, with increasing dependence on it as a drinking water supply source. The proposed wind farm site is located within the Portlaoise groundwater body as shown in Figure 13.5 in Chapter 13 of the EIAR.

The GSI classifications for the aquifers in the study area, including the principle aquifer characteristics are summarised in Table 3.1, and shown on Figure 13.6 in Chapter 13 of the EIAR. The Portlaoise aquifer in the study area is a bedrock aquifer.

Table 3-1: Summary of Aquifer Classifications & Characteristics

Aquifer Name	GSI Aquifer Classification	Groundwater Body	Transmissivity (m^2/day)
Unnamed	Locally important aquifer – bedrock which is moderately productive only in local zones (Ll)	Portlaoise	1 – 10m^2/day

Figure 13.6 in Chapter 13 also shows the location of groundwater wells included in the GSI dataset. There may be other wells in the study area in additional to those included in the GSI dataset. The available details for these wells are summarised in Table 3.2.

Table 3-2: Summary of Wells within the Study Area

Well ID	Grid Co-ordinates	Distance to site	Well Type	Well Use	Total Depth (m)	Depth to Bedrock (m)	Yield (m3/day)	Yield Class
2321SEW034	E: 245197.00 N: 210362.00	On site	Dug well	Domestic use	3.4	3.4	44	Moderate
2321SEW033	E: 245231.00 N: 210483.00	On site	Dug well	Domestic use	3.4	3.4	44	Moderate
2321SWW055	E: 243485.00 N: 211028.00	On site	Dug well	Unknown	2.7	2.7	38.2	Poor
2321SWW032	E: 241224.00 N: 211594.00	1.5 km to West	Dug well	Unknown	4.9	4.9	32.7	Poor
2321SWW031	E: 241244.00 N: 211663.00	1.5 km to West	Dug well	Unknown	6.1	6.1	27.3	Poor
2321SWW037	E: 242,200.00 N: 210,770.00	1 km to West	Borehole	Unknown	10.4	6.1	27.3	Poor
2321SWW033	E: 241,500.00 N: 212,430.00	1 km to West	Dug Well	Unknown	4.6	4.6	38.2	Poor

Well ID	Grid Co-ordinates	Distance to site	Well Type	Well Use	Total Depth (m)	Depth to Bedrock (m)	Yield (m3/ day)	Yield Class
2321SWW056	E: 241,500.00 N: 212,380.00	1 km to West	Dug Well	Unknown	4.6	4.6	32.7	Poor
2321SWW059	E: 242,190.00 N: 212,510.00	300 m to West	Borehole	Unknown	220	6	-	-
2321SWW038	E: 242,420.00 N: 213,710.00	1 km to North	Borehole	Unknown	13.7	2.7	32.7	Poor
2321SWW039	E: 242,420.00 N: 213,660.00	1 km to North	Borehole	Unknown	5.8	2.4	27.3	Poor
2321SWW044	E: 242,410.00 N: 213,610.00	1 km to North	Borehole	Unknown	5.5	-	78.6	Moderat e
2321SWW060	E: 241720.00 N: 210920.00	1.5 km to West	Borehole	Unknown	80	15.5	-	-

According to the GSI datasets, there are no karst features recorded within the study area.

The Groundwater Vulnerability is classified by the GSI as ranging from 'Low' to 'High' across the site. The GSI distribution of groundwater vulnerability for the site area is shown in Figure 13.7 in Chapter 13 of the EIAR.

A summary of the groundwater vulnerability for the site is presented in Table 3.3. This table outlines the standard ratings of vulnerability used by the GSI, with the existing site conditions highlighted based on the findings of the site investigations.

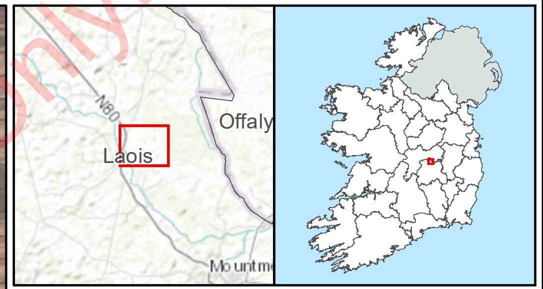
Table 3-3: Groundwater Vulnerability

Vulnerability Rating	Hydrogeological Conditions		
	Subsoil Permeability (Type) and Thickness		
	High Permeability (sand/gravel)	Moderate Permeability (sandy soil)	Low Permeability (clayey subsoil, clay, peat)
extreme (E)	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m
high (H)	> 3.0 m	3.0 -10.0 m	3.0 - 5.0 m
moderate (M)	N/A	>10.0 m	**5.0 - 10.0 m**
low (L)	N/A	N/A	>10 m

Notes: 1. N/A = not applicable.
2. Precise permeability values cannot be given at present.

3.4 Hydrology & Drainage

Geomorphology and drainage features were noted from aerial photographs and during the site assessment. The bog drainage comprises a (mostly) regular pattern of shallow ribbon drains running east west at 15 to 20 metre intervals across the site. These flow in a westerly direction towards a deeper bog drainage network which then subsequently flows in a southerly direction towards the discharge location. The drainage network within this site is described in more detail in Section 14.3.5 in Chapter 14 of the EIAR.



- Proposed Turbines
- Proposed Site Boundary
- Proposed Turbine Hardstanding Areas
- Proposed Temporary Compound
- Proposed Access Tracks

Peat Depth (m)

- 0.10 - 0.20
- 0.21 - 0.50
- 0.51 - 0.80
- 0.81 - 1.20
- 1.21 - 1.60

TITLE: Peat Depth	
PROJECT: Dernacart Wind Farm	
FIGURE NO: 3.2.1	
CLIENT: Statkraft	
SCALE: 1:5000	**REVISION:** 0
DATE: 06/09/2019	**PAGE SIZE:** A3

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4 PEAT SURVEY ANALYSIS

A site assessment survey was carried out by an FT Engineering Geologist during July and August 2019. The assessment included a total of 100 No. peat probes and 32 No. hand shear vanes across the proposed wind farm site to confirm the depth, shear strength and classification of the peat. An assessment of the cable route was also carried out and this established that the presence of peat along this route is minimal (small pockets of peat ranging in depth from 0.2-0.3m).

During the assessment, records were made of the land use, peat depth, drainage features, geomorphology, slope, and any other features that could affect slope stability, such as streams, flushes etc.

4.1 Peat Probe Data

Peat probing (depth to bedrock and/or competent subsoils) was carried out across the proposed development area. Hand shear vane readings were taken at the probe locations and measurements of slope were made using a hand-held inclinometer. The findings of the site assessment survey at the proposed infrastructure locations are summarised in Table 4.1 below.

The assessment and preliminary ground investigations found extensive cut peat across the site with an average depth of 1.0m. The maximum peat depth recorded was 1.6m and the minimum peat depth was 0.2m.

Table 4-1: Peat Depths at Probe Locations

Location	Depth (m)
T01	0.8
T02	0.2
T03	1
T04	1
T05	1
T06	1.2
T07	0.2
T08	0.2
101	0.2
102	0.3
103	0.2
104	0.1
105	0.3
106	0.2
107	0.2
108	0.2
109	0.2
110	0.2
111	0.4
112	0.3
113	0.3
114	0.2
115	0.3
116	1.4

Location	Depth (m)
117	1.2
118	1.5
119	0.8
120	1.6
121	1.2
122	0.5
123	1
124	1.2
125	0.8
126	0.4
127	1
128	1.5
129	1.2
130	1
131	0.8
132	0.8
133	0.8
134	1
135	0.8
136	1
137	1
138	1.2
139	1
140	1.2

Location	Depth (m)
141	0.8
142	1
143	1.5
144	1
145	0.8
146	0.6
147	1.2
148	1.2
149	1
150	0.8
151	1
152	1.5
153	0.5
154	1.2
155	0.8
156	1
157	1
158	1.1
159	0.8
160	0.5
161	0.2
162	0.4
163	0.2
164	0.2
165	0.2
166	0.2

Location	Depth (m)
167	0.2
168	0.4
169	0.4
170	0.2
171	0.6
172	0.8
173	0.1
174	0.1
175	0.2
176	0.1
177	0.6
178	0.2
179	0.2
180	0.2
181	0.3
182	1.2
183	0.8
184	1
185	1.2
186	1
187	1.2
188	0.8
189	1
190	0.8

4.2 Peat Shear Strength

Hand shear vane tests were carried out by FTC using a Geonor H-60 shear vane and provide indicative results for the in-situ shear strength of the peat at preliminary investigation stage. The uncorrected shear strength values recorded ranged from 8kPa to 24kPa with an average of 16.9kPa.

To account for the fibrous and heterogeneous nature of peat, a correction factor of 0.4 to 0.6 is recommended by Mesri and Ajlouni(15).

In the absence of site-specific laboratory data, a conservative correction factor of 0.4 has been applied to the field vane shear strengths during slope stability calculations. The corrected shear strengths range from 3.2 to 9.6kPa with the mean corrected shear strengths shown in Table 4.3.

4.3 Peat Humification

The peat encountered was described using the Von Post Humification Scale as a method of describing the physical characteristics of peat material. The Von Post scale uses the unit's H and B, whereby H ranges from 1 to 10 and describes the humification of the peat material and the B units range from 1 to 5 and describe the moisture content of the peat. In the Von Post scale H1 describes completely undecomposed peat with H10 describing completely decomposed peat. In the moisture content scale B1 describes dry peat and B5 denoting peat with a very high moisture content. Table 4.2 outlines the classification:

Table 4-2: Von Post Classification (Ekono 1981)

Symbol	Description
H1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.
H2	Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains still identifiable, and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.
H5	Moderately decomposed peat which, when squeezed, releases very "muddy" water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.
H6	Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing.
H7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
H8	Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.
H9	Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

Symbol	Description
B1	Dry peat
B2	Low moisture content
B3	Moderate moisture content
B4	High moisture content
B5	Very high moisture content

The peat encountered during the site assessment was classified as having a humification scale of H4 to H6 (slightly decomposed peat to moderately highly decomposed peat) and a moisture scale of B3 to B4(low moisture content to moderate moisture content).

Table 4-3: Peat Shear Strength & Von Post Classification

Location	Measured Cu	Corrected Cu	Factored Cu	Von Post Classification
T01	12	4.8	3.4	H6 and B4
T01	14	5.6	4.0	H6 and B4
T01	12	4.8	3.4	H6 and B4
T01	16	6.4	4.6	H6 and B4
T02	20	8	5.7	H4 and B3
T02	22	8.8	5.0	H4 and B3
T02	16	6.4	5.0	H4 and B3
T02	20	8	5.7	H4 and B3
T03	12	4.8	3.4	H6 and B4
T03	14	5.6	4.0	H6 and B4
T03	12	4.8	3.4	H6 and B4
T03	12	4.8	3.4	H6 and B4
T04	10	4	2.9	H6 and B4
T04	8	3.2	2.3	H6 and B4
T04	14	5.6	4.0	H6 and B4
T04	12	4.8	3.4	H6 and B4
T05	16	6.4	4.6	H6 and B4
T05	16	6.4	4.6	H6 and B4
T05	18	7.2	5.1	H6 and B4
T05	14	5.6	4.0	H6 and B4
T06	20	8	5.7	H6 and B4
T06	20	8	5.7	H6 and B4
T06	20	8	5.7	H6 and B4
T06	18	7.2	5.1	H6 and B4
T07	20	8	5.7	H4 and B3
T07	22	8.8	6.3	H4 and B3
T07	22	8.8	6.3	H4 and B3
T07	20	8	5.7	H4 and B3
T08	22	8.8	6.3	H4 and B3
T08	20	8	5.7	H4 and B3
T08	24	9.6	6.9	H4 and B3
T08	24	9.6	6.9	H4 and B3

5 QUANTITATIVE SLOPE STABILITY ANALYSES

Total stress analyses for translational slides within the peat have been undertaken in accordance with the principles of Eurocode 7-1: Geotechnical Design (IS EN 1997-1) Design Approach 3[(12)]. This design approach is considered to be the most logical approach for slope stability analysis as it includes partial factors for both material properties and variable loads (for example traffic loads).

In accordance with the principles of the Eurocode, rather than using a global factor of safety as per previous design codes, partial factors are applied to the chosen characteristic values to obtain design values. Actions (influences) are multiplied by the partial factors, while resistances are divided by the partial factors.

Table 5.1 shows the partial factors that have been applied to the characteristic values to give the design values used in the slope stability analyses.

Table 5-1: IS EN 997-1 Partial Factors Used to Derive Design Parameters

Set	Partial Factor		Parameter
M2	γ_{cu}	1.4	Corrected undrained shear strength, C_u
	γ_{γ}	1	Soil density
A2	γ_Q	1.3	Traffic Loading (variable unfavourable)
R3	$\gamma_{R;e}$	1	Earth resistance

In accordance with Eurocode 7, geotechnical checks must be carried out to ensure that the resistance preventing a slide is greater than or equal to the actions which cause a slide, i.e.:

$$E_d <= R_d$$

Where:

E_d = Sum of design actions
R_d = Sum of design resistances

In order to verify that this condition is met, the following formula has been applied, using the design values obtained using the partial factors given in Table 5.1. The resulting "safety ratio" must be equal to or greater than 1.0 in order to verify that the above condition is met [(9,12)]. i.e.:

$$\frac{C_u}{\gamma z \cos\beta \sin\beta} => 1.0$$

Where:

C_u = corrected shear strength of peat (value obtained from hand shear vane)
γ = density of peat (normally assumed to be 1.0 Mg/m^3)
z = thickness of peat layer in metres (measured from probes)
β = slope angle at turbine location (measured with hand held inclinometer)

In order to replicate the effect of traffic loading or temporary stockpiling of peat during construction, a surcharge load of 20kPa has been applied to the calculation. After applying a partial factor of 1.3, as per IS EN 1997-1 Design Approach 3 (variable, unfavourable action), a design load of 26kPa has been applied to the models as shown in the following formula.

$$\frac{C_u}{\gamma z \cos\beta \sin\beta} => 1.0$$

Where:

C_u = corrected shear strength of peat (value obtained from hand shear vane)
γ = surcharged load (2.6 Mg/m^3)
z = thickness of peat layer in metres (measured from probes)
β = slope angle at turbine location (measured with hand held inclinometer)

5.1 Limitations of Slope Stability Analyses

The application of traditional stability analysis such as this should be used with caution due to the compressibility of peat and because the analysis does not account for the fibrous nature of the peat.

Cognisant of the organic and highly variable nature of peat, uncertainties related to the directional dependence on which the strength of peat is based, the reliability of traditional methods of field shear strength measurement, presence of gas within the peat and the combination of factors (some not quantifiable or applicable in a calculation matrix) triggering slope failure, the failure mechanisms being employed in the traditional analysis may not necessarily be representative of in-situ failure mechanisms.

Despite the limitations outlined above, this method of slope analysis is still considered useful as an indicator of possible areas of instability as it models a translational failure, which is the most probable failure in peat. Its use is in accordance with current industry best practice.

5.2 Shear Strength Values

The shear strength values were obtained using a Geonor H-60 hand-held shear vane with a correlation factor of 0.4 as discussed in Section 4.1.

Shear strength at the base of a peat mass is often the governing factor in peat stability and analysis; therefore, shear strength values chosen for the stability analysis are based on a characteristic value representative of the shear strength of the peat recorded generally within 0.5m of the base of the peat body, unless this is significantly higher than the typical shear strengths recorded at shallower depths, in which case the lower value is normally used.

Based on the field vane shear strength data, corrected shear strength values of 3.2kPa to 9.6kPa were determined as the characteristic values for the slope stability analysis. No differentiation between the upper acrotelm (where present) and lower catotelm layers has been assumed for the purpose of the stability analysis in order to provide a more conservative analysis.

5.3 Slope Stability Analyses Results

The calculated in-situ factor of safety ratios (FoS) at the proposed site located in peat (greater than 0.5m depth) are presented in Table 5.2 along with the typical peat depth, characteristic corrected shear strength and slope angle.

A ratio of less than 1.0 indicates that the slope currently has an inadequate FoS against failure and therefore is potentially unstable in the long term. Ratios greater than 1.0 indicate an adequate factor of safety against failure and indicates that the location is considered stable.

In order to replicate the effect of traffic loading or temporary stockpiling of peat during construction, a surcharge load of 20kPa has been applied to the calculation. This is the equivalent load of approximately 2m of peat or the effect of heavy traffic. After applying a partial factor of 1.3, as per IS EN 1997-1 Design Approach 3 (variable, unfavourable action), a design load of 26kPa has been applied to the models. The FoS outputs from the surcharging of in-situ peat across areas of peat across the site are shown in Table 5.2. The resulting safety ratio is also presented in Table 5.2. This is considered to represent the worst-case scenario during construction.

Table 5-2: Slope Stability Inputs and Safety Ratios

Location	Slope	Depth	Measured Cu	Corrected Cu	Factored Cu	FOS (insitu)	FOS+20kPa Surcharge
T01	0.2	0.8	12	4.8	3.4	122.8	28.9
T01	0.2	1.2	14	5.6	4.0	95.5	30.2
T01	0.2	1.2	12	4.8	3.4	81.9	25.8
T01	0.2	1.5	16	6.4	4.6	87.3	31.9
T02	0.2	0.2	20	8	5.7	818.5	58.5
T02	0.2	0.2	22	8.8	5.0	716.2	51.2
T02	0.2	0.4	16	6.4	5.0	358.1	47.7
T02	0.2	0.1	20	8	5.7	1637.0	60.6
T03	0.2	1	12	4.8	3.4	98.2	27.3
T03	0.2	1.2	14	5.6	4.0	95.5	30.2
T03	0.2	0.5	12	4.8	3.4	196.4	31.7
T03	0.2	0.8	12	4.8	3.4	122.8	28.9
T04	0.3	1	10	4	2.9	**54.6**	15.2
T04	0.3	0.8	8	3.2	2.3	**54.6**	**12.8**
T04	0.3	1.2	14	5.6	4.0	63.7	20.1
T04	0.3	0.6	12	4.8	3.4	109.1	20.5
T05	0.2	1	16	6.4	4.6	131.0	36.4
T05	0.2	1	16	6.4	4.6	131.0	36.4
T05	0.2	0.8	18	7.2	5.1	184.2	43.3
T05	0.2	0.8	14	5.6	4.0	143.2	33.7
T06	0.3	1.2	20	8	5.7	90.9	28.7
T06	0.3	0.8	20	8	5.7	136.4	32.1
T06	0.3	1.6	20	8	5.7	68.2	26.0
T06	0.3	0.5	18	7.2	5.1	196.4	31.7
T07	0.2	0.2	20	8	5.7	818.5	58.5
T07	0.2	0.4	22	8.8	6.3	450.2	60.0
T07	0.2	0.2	22	8.8	6.3	900.4	64.3
T07	0.2	0.2	20	8	5.7	818.5	58.5
T08	0.2	0.2	22	8.8	6.3	900.4	64.3
T08	0.2	0.1	20	8	5.7	1637.0	60.6
T08	0.2	0.4	24	9.6	6.9	491.1	65.5
T08	0.2	0.8	24	9.6	6.9	245.6	57.8

Note:* *Values in* ***bold* *indicate lowest recorded result.*

5.4 Discussion of Stability Analysis

5.4.1 Proposed Infrastructure Locations

The preliminary peat stability analysis indicates that the in-situ peat stability condition of the peat deposits within the study area are currently stable.

Based on the analyses presented, no data points were recorded to have a FoS of less than 1.0 with the lowest in-situ FoS of 54.6 recorded at probe location T04. The results give rise to in-situ safety ratios for translational slides which are above the minimum required value for all infrastructure locations analysed.

Calculated safety ratios when an additional design load of 20kPa is included in the analysis gave rise to lower safety ratios as shown in Table 5.2. No FoS results are recorded below 1.0 with the with the lowest surcharged FoS of 12.8 recorded at probe location T04.

Figure 5.1 displays the results of the Factor of Safety analysis plotted within the site boundary.

Path: R:\Map Production\2018\P1892\Workspace\EIAR\Appendix\Peat Stability Report\P1892_Fig5-1_FactorOfSafety_A3.mxd

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community
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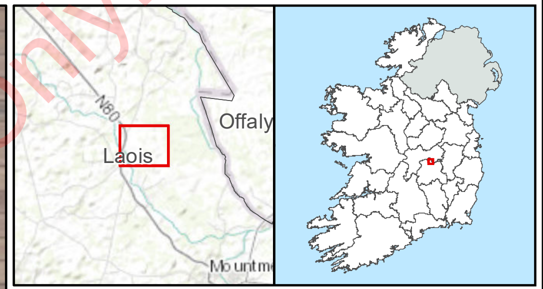

- Proposed Turbines
- Proposed Site Boundary
- Proposed Access Tracks
- Proposed Turbine Hardstanding Areas
- Proposed Temporary Compound

Factor of Safety

- 0 < 1.0
- >= 1.0 < 1.3
- >= 1.3

TITLE: Factor of Safety	
PROJECT: Dernacart Wind Farm	
FIGURE NO: 5.1.1	
CLIENT: Statkraft	
SCALE: 1:5000	**REVISION:** 0
DATE: 17/12/2019	**PAGE SIZE:** A3

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6 CONCLUSIONS

The peat stability assessment identified extensive cut peat across the site with an average depth of 0.7m. The maximum peat depth recorded was 1.6m and the minimum peat depth recorded was 0.2m.

The peat encountered during the site assessment was classified as having a humification scale of H4 to H6 (slightly decomposed peat to moderately highly decomposed peat) and a moisture scale of B2 to B3 (low moisture content to moderate moisture content).

Hand shear vane tests were carried out by FTC using a Geonor H-60 shear vane and provide indicative results for the in-situ shear strength of the peat at preliminary investigation stage. The uncorrected shear strength values recorded ranged from 8kPa to 24kPa with an average of 16.9kPa.

To account for the fibrous and heterogeneous nature of peat, a correction factor of 0.4 to 0.6 is recommended by Mesri and Ajlouni[15]. A conservative correction factor of 0.4 has been applied to the field vane shear strengths during slope stability calculations with corrected shear strengths ranging from 3.2 to 9.6kPa.

The results of the slope stability analysis give rise to in-situ safety ratios for translational slides which are above the minimum required FoS value of 1.0 for all infrastructure locations analysed. Calculated FoS ratios when an additional design load of 20kPa is included in the analysis give rise to lower safety ratios with no FoS results falling below 1.0. The preliminary peat stability analysis indicates that the in-situ peat stability condition of the peat deposits within the study area are currently stable.

The Preliminary Geotechnical Risk Register in Appendix 1 highlights the Hazard Rating and Mitigation Measures to reduce the risk of peat failure to residual and manageable levels at proposed infrastructure locations. It is considered that by using appropriate design mitigation and construction control measures as outlined in the risk register the development can be constructed with minimal risk of peat failure.

The risk register should be reviewed prior to detailed design and reviewed and updated as more site data is collected.

7 RECOMMENDATIONS

The peat stability assessment indicates that the site has an acceptable margin of safety with regard to peat stability a number of mitigation/control measures are given to ensure that all works adhere to an acceptable standard of safety for work in peatlands. The Preliminary Geotechnical Risk Register outlines key Mitigation Measures which are required to reduce the risk of peat failure to residual levels. Mitigation/control measures identified in the risk assessment should be taken into account and implemented throughout design and construction works (Appendix 1).

As mentioned in Section 13.4.2 of Chapter 13 in the EIAR, there will be approximately 6 km of internal access tracks associated with the proposed wind farm development. This will consist of a combination of existing track upgrade and construction of new tracks; 5.5 km of new track construction and approximately 0.88 km of existing track upgrade. Hardstand areas will be provided at each turbine location.

It is envisaged that the track construction will consist of up to 500 mm hardcore on geogrid after removal of peat and / or soft soils. The construction methodology for new tracks and hardstand will generally be as follows:

- Peat/topsoil will be excavated and locally placed and graded to one or both sides of the track / hardstand
- Formation will be prepared to receive geogrid
- Granular Fill will be placed and compacted in layers to approximately 500 mm depth (or competent material for founded road)
- A drainage ditch will be formed, within the excavated width, along the sides of the tracks / hardstand, Surplus peat/clay excavated shall be used as impermeable layer and ditch shaping.
- Surplus excavated material will be placed along each side of the track / hardstand and dressed to blend in with surrounding landscaping and to provide screening.
- Where suitable, surplus excavated material will also be used for reinstatement purposes around turbine bases and hardstands.

Floating roads may be required if the necessary excavation to competent ground is deeper than expected. Floating roads are constructed without excavating the existing ground and shall only be used where site conditions allow. The construction methodology for floating roads will generally be as follows:

- A layer of combined geotextile will be laid directly on the existing surface.
- Granular Fill will be placed on the geotextile and compacted in layers to the required depth with additional geogrid reinforcement as required.
- A 300mm layer of compacted Type B material (Clause 804) will be placed on top to provide a suitable surfacing layer.

Surplus Peat and Glacial Till recovered from excavations will be used for landscaping berms along the proposed internal access tracks and for reinstatement purposes around turbine bases and hardstands. These berms will be created from suitable excavated material and will be located on the opposite site of infrastructure to any interceptor drains. The berms will therefore not obstruct flow or risk siltation to interceptor drains. Berms will be placed outside the roadside drains that will drain the new access tracks.

Turbines of the size proposed for the Dernacart Wind Farm typically have foundations heights in the order of 2 m and diameters in the order of 20 m, depending on the manufacturer and ground conditions. Ideally, a suitable bearing stratum is encountered within 3 m from ground surface so that the turbine foundation can be finished at / near existing ground level. Where deeper excavations are required to reach a suitable bearing stratum, soil replacement (engineered fill) is used to bring up the excavation so that the turbine foundation is finished at or near existing ground level. Flexibility of $^{+}/_{-}$ 1.5 m in the finished levels is required to allow for sloping topography and ground conditions.

Where excavations beyond 5m below ground level are required to reach a suitable bearing stratum, piled foundations may be required. Piles used for turbine foundations are either pre-cast driven piles or bored piles.

Pile length is site-specific but tends to be approximately 12 m to 20 m long. The turbine foundation requirements will be determined following the detailed site investigation at pre-construction stage.

To minimise the risk of construction activity causing potential peat instability it is recommended that the Construction Method Statements (CMSs) for the project take into account, but not be limited, to the recommendations above. This will ensure that best practice guidance regarding the management of peat stability will be inherent in the construction phase.

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APPENDIX 1

Geotechnical Risk Register




No.	Hazard	Cause	Risk (i.e. Potential Impact)	Risk Rating			Potential Control Measures	Risk Rating		
				P	I	R		P	I	R
1	Unexpected Obstructions in Excavations (boulders, rock outcrops)	Ground conditions differing from those indicated from site investigation	Delays to work and increased excavation and backfilling requirement	3	3	9	Reporting of any change in ground conditions from those predicted. Advance notice of change in ground to be passed to designers Supervision to ensure construction is carried out as agreed in MS	1	2	2
2	Instability of peat due to failure of underlying ground	Unexpected soft ground conditions Over loading of under-lying ground	Risk of injury by collapse Damage to plant Neighbouring ground affected Loss and cessation of works	2	4	8	All staff to be fully briefed on loading limits and construction methodology for arisings Comprehensive and regular monitoring of arisings Supervision to ensure construction carried out as detailed in MS	1	4	4
3	Instability of peat due to excessive rainfall/ run-off	Excessive rainfall Overly softened arisings	Risk of injury by collapse Damage to plant Neighbouring ground affected Loss and cessation of works	3	4	12	Inspection after any significant rainfall event Preparation of areas if any significant rainfall forecasted Regular monitoring of arisings Drainage ditches and watercourses to be maintained	1	4	4
4	Working in areas of soft ground/ peat	Unexpected soft ground conditions Upper strong vegetated layer in peat has been broken Plant too heavy Excessive water logging due to rainfall	Plant sinking Personnel falling into soft ground areas Access for plant/ personnel not possible Loss and cessation of works	2	3	6	Site staff briefed on ground conditions including induction Walkover of relevant areas at start of each day to inspect ground conditions and to identify 'potential risk' areas Cordon-off areas unsuitable for works	1	3	3

No.	Hazard	Cause	Risk (i.e. Potential Impact)	Risk Rating			Potential Control Measures	Risk Rating		
				P	I	R		P	I	R
5	Flooding due to rainfall	Extended periods of wet weather	Risk of drowning Risk of injury by collapse of excavations Damage to plant Excessive runoff into surface watercourses Loss and cessation of works	2	4	8	Staff aware of weather forecast No access into excavations Pumping facilities to be put in place during construction Agree unacceptable work conditions	1	4	4
6	Presence of Clay beneath peat	Unexpected loss of strength	Risk of injury Damage to plant Collapse of excavation Peat slide	2	4	8	Staff to inspect excavations No access into excavations Avoid excessive loading and/or vibration	1	4	4
7	Peat slide/ Slope stability	Unexpected weak ground conditions Intense rainfall event Improper construction Peat movement from outside of site	Risk of injury Environmental damage Damage to persons, plant, property and livestock Loss and cessation of works Adjacent land affected due to peat/ground movement	2	5	10	Staff fully briefed on ground conditions Provision and monitoring of geotechnical instrumentation to record ground movement and groundwater pressures where appropriate Control of all construction practices so that all works on site are within design conditions Continuous site inspection to assess ground for evidence of any movement Sheet piles readily available	1	5	5

No.	Hazard	Cause	Risk (i.e. Potential Impact)	Risk Rating			Potential Control Measures	Risk Rating		
				P	I	R		P	I	R
8	Failure of slopes In excavations	Excavations for foundations cut too steep for peat leading to collapse Peat movement from outside of site	Risk of injury Environmental damage Damage to persons, plant, property and livestock Loss and cessation of works Adjacent land affected due to peat/ground movement	2	5	10	Control of all construction practices so that all works on site are within design conditions, including all temporary and permanent slopes in peat. Continuous site inspection to assess ground for evidence of any movement/ signs of failure	1	5	5