APPENDIX 6-1

PEAT STABILITY RISK ASSESSMENT REPORT PERMITTED DEVELOPMENT (2017)

PEAT STABILITY ASSESSSMENT REPORT

FOR

MEENBOG WIND FARM, CO. DONEGAL

Prepared for:

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ACRONYMS AND SYMBOLS

AGEC	Applied Ground Engineering Consultants Ltd
BS	British Standard
c’	Effective cohesion
CMS	Construction Method Statement
c_u	Undrained strength
EC7	Eurocode 7
FoS	Factor of Safety
GSI	Geological Survey of Ireland
kPa	Kilopascals
m bgl	Metres below ground level
m	Metres
mm	Millimetres
mOD	Metres ordnance datum
ø’	Effective angle of shearing resistance
PHRAG	Peat Hazard and Risk Assessment Guide

1 NON-TECHNICAL SUMMARY

Applied Ground Engineering Consultants Ltd (AGEC) was engaged by McCarthy Keville O'Sullivan to undertake an assessment of the proposed Meenbog wind farm site with respect to peat stability. In accordance with planning guidelines compiled by the Department of the Environment, Heritage and Local Government (DoEHLG), where peat is present on a proposed wind farm development, a peat stability assessment is required.

The findings of the peat assessment, which involved analysis of over 500 locations, showed that the site has an acceptable margin of safety and is suitable for the proposed wind farm development. The findings include recommendations and control measures for construction work in peat lands to ensure that all works adhere to an acceptable standard of safety.

The proposed wind farm comprises 19 no. wind turbines with associated infrastructure including access roads (new and upgrading of existing roads), substation, construction compound/carpark, met mast, underground cables and borrow pits.

The site is an upland blanket peat area with extensive forestry. The blanket peat areas contain typically shallow peat with typically deeper peat deposits in the flatter areas on site. The forested areas contain both young and mature forestry. Up to 15km of existing access tracks are present across the site and have been in use for a number of years.

Peat thicknesses recorded during the site walkovers from over 500 probes ranged from 0 to 5.8m with an average of 1.7m. Over 80 percent of the probes recorded peat depths of less than 2.5m. Over 96 percent of peat depth probes recorded peat depths of less than 4.0m. A number of localised readings were recorded where peat depths of between 4.0 and 5.8m are present. The deeper peat areas were generally avoided when optimising the wind farm layout for site.

A walkover including intrusive peat depth probing, desk study, stability analysis and risk assessment was carried out to assess the susceptibility of the site to peat failure following the principles in Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive, 2007).

The purpose of the stability analysis is to determine the stability i.e. Factor of Safety (FoS), of the peat slopes. The FoS provides a direct measure of the degree of stability of a peat slope. A FoS of less than 1.0 indicates that a slope is unstable; a FoS of greater than 1.0 indicates a stable slope. An acceptable FoS for slopes is generally taken as a minimum of 1.3.

Based on the stability assessment carried out on the peat slopes the calculated FoS's with respect to peat instability have an acceptable margin of safety and is suitable for the proposed wind farm development. Localised areas of deeper peat deposits are present which may require specific construction methods, but do not represent a peat slide risk. The risk assessment at each infrastructure location includes a number of mitigation/control measures to ensure the continued stability of the site.

2 INTRODUCTION

2.1 Background and Experience

Applied Ground Engineering Consultants Ltd (AGEC) was initially engaged in September 2014 by McCarthy Keville O'Sullivan to undertake an assessment of the proposed wind farm site with respect to peat stability. AGEC were subsequently engaged in March 2017 by McCarthy Keville O'Sullivan to carry out an assessment of a revised wind farm layout for the Meenbog site with respect to peat stability.

AGEC have been involved in over 125 wind farm developments in both Ireland and the UK at various stages of development i.e. preliminary feasibility, planning, design, construction and operational stage and have established themselves as one of the leading engineering consultancies in peat stability assessment, geohazard mapping in peat land areas, investigation of peat failures and site assessment of peat.

The proposed Meenbog site is located approximately 8km southwest of Ballybofey, Co. Donegal.

The proposed wind farm comprises 19 no. wind turbines with associated infrastructure including access roads (new and upgrading of existing roads), substation, construction compounds, met mast and borrow pits.

A number of walkover surveys of the Meenbog wind farm site were carried out by McCarthy Keville O'Sullivan. The peat depth data recorded by McCarthy Keville O'Sullivan (2014a, 2014b & 2014c) during these walkover surveys has been used in the assessment of peat stability for the proposed wind farm site.

A number of walk-over surveys of the site was carried out by AGEC between the 29th September & 3rd October 2014 and between 20th to 24th and 28th to 29th March 2017. The peat depth data recorded by AGEC will also be used in the assessment of peat stability for the proposed wind farm site.

2.2 Peat Stability Assessment Methodology

AGEC undertook the assessment following the principles in Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive, 2007). The Peat Hazard and Risk Assessment Guide (PHRAG) is used in this report as it provides best practice methods to identify, mitigate and manage peat slide hazards and associated risks in respect of consent applications for electricity generation projects.

The best practice guide was produced following peat failures in the Shetland Islands, Scotland in September 2003 but more pertinently following the peat failure in October 2003, during the construction of a wind farm at Derrybrien, County Galway, Ireland.

The assessment of peat stability at the proposed site included the following activities:

(1) Desk study

(2) Site reconnaissance including shear strength and peat depth measurements

(3) Peat stability assessment of the peat slopes on site using a deterministic and qualitative approach

(4) Peat depth contour plan – is compiled based on the peat depth probes carried out across the site by AGEC and McCarthy Keville O'Sullivan

(5) Factor of safety plan – is compiled for the short term critical condition (undrained) for over 500 no. FoS points analysed across the site

(6) Construction buffer zone plan – identifies areas with an elevated or higher construction risk where mitigation/control measures will need to be implemented during construction to minimise the potential risks and ensure they are kept within an acceptable range

(7) A risk register is compiled to assess the potential design/construction risks at the infrastructure locations and determine adequate mitigation/control measures for each location to minimise the potential risks and ensure they are kept within an acceptable range, where necessary

A flow diagram showing the general methodology for peat stability assessment is shown in Figure 1. The methodology illustrates the optimisation of the wind farm layout based on the findings from a site reconnaissance and subsequent feedback from the peat stability and risk assessment results.

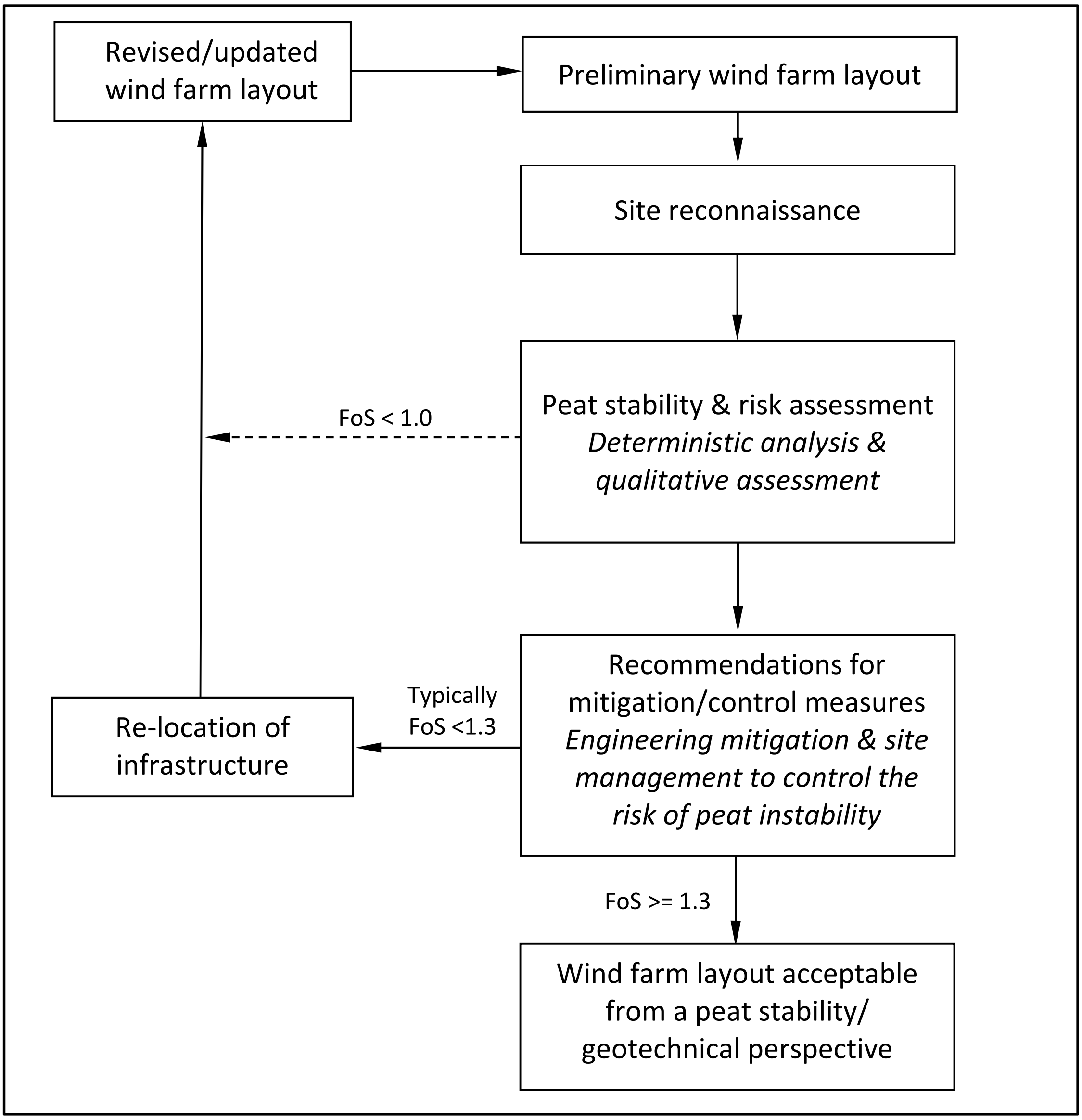

Figure 1 Flow Diagram Showing General Methodology for Peat Stability Assessment

2.3 Peat Failure Definition

Peat failure in this report refers to a significant mass movement of a body of peat that would have an adverse impact on proposed wind farm development and the surrounding environment. Peat failure excludes localised movement of peat that would occur (say) below an access road, creep movement or erosion type events.

The potential for peat failure at this site is examined with respect to wind farm construction and associated activity.

2.4 Main Approaches to Assessing Peat Stability

The main approaches for assessing peat stability for wind farm developments include the following:

(a) Geomorphological

(b) Qualitative (judgement)

(c) Index/Probabilistic (probability)

(d) Deterministic (factor of safety)

Approaches (a) to (c) listed above would be considered subjective and do not provide a definitive indication of stability; in addition, a high level of judgement/experience is required which makes it difficult to relate the findings to real conditions. AGEC apply a more objective approach, the deterministic approach (as discussed in section 2.4).

As part of AGEC's deterministic approach, a qualitative risk assessment is also carried out taking into account qualitative factors, which cannot necessarily be quantified, such as the presence of mechanically cut peat, quaking peat, bog pools, sub peat water flow, slope characteristics and numerous other factors. The qualitative factors used in the risk assessment are compiled based on AGEC's experience of assessments and construction in peat land sites and peat failures throughout Ireland and the UK. This approach follows the guidelines for geotechnical risk management as given in Clayton (2001), as referenced in the best practice for Peat Hazard and Risk Assessment Guide (Scottish Executive, 2007), and takes into account the approach of MacCulloch (2005).

The risk assessment uses the results of the deterministic approach in combination with qualitative factors, which cannot be reasonably included in a stability calculation but nevertheless may affect the occurrence of peat instability to assess the risk of instability on a peat land site.

2.5 Peat Stability Assessment – Deterministic Approach

The peat stability assessment is carried out across a wide area of peatland to determine the stability of peat slopes and to identify areas of peatland that are suitable for development; this allows the layout of infrastructure on a particular wind farm site to be optimised. The assessment provides a numerical value (factor of safety) of the stability of individual parcels of peatland. The findings of the assessment discriminate between areas of stable and unstable peat, and areas of marginal stability where restrictions may apply. This allows for the identification of the most suitable locations for turbines, access roads and infrastructure.

A deterministic assessment requires geotechnical information and site characteristics which are obtained from desk study and site walkover, e.g. properties of peat/soil/rock, slope geometry, depth of peat, underlying strata, groundwater, etc. An adverse combination of the factors listed above could potentially result in instability. Using the information above a factor of safety is calculated for the stability of individual parcels of peatland on a site (as discussed in section 8).

The factor of safety is a measure of the stability of a particular slope. For any slope, the degree of stability depends on the balance of forces between the weight of the soil/peat working downslope (destabilising force) and the inherent strength of the peat/soil (shear resistance) to resist the downslope weight, see Figure 2.

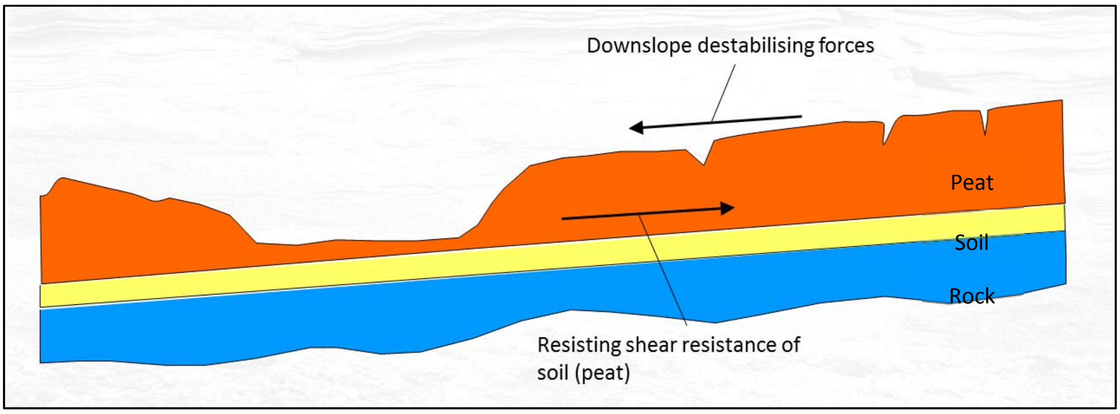

Figure 2 Peat Slope Showing Balance of Forces to Maintain Stability

The factor of safety provides a direct measure of the degree of stability of a slope and is the ratio of the shear resistance over the downslope destabilising force. Provided the available shear resistance is greater than the downslope destabilising force then the factor of safety will be greater than 1.0 and the slope will remain stable. If the factor of safety is less than 1.0 the slope is unstable and liable to fail. The acceptable range for factor of safety is typically from 1.3 to 1.4.

2.6 Applicability of the Factor of Safety (Deterministic) Approach for Peat Slopes

The factor of safety approach is a standard engineering approach in assessing slopes which is applied to many engineering materials, such as peat, soil, rock, etc.

The factor of safety approach is included in The Peat Landslide Hazard and Risk Assessments Best Practice Guide for Proposed Electricity Generation Developments (Scottish Executive, 2007); see section 5.2.2 of the guide. This guide provides best practice methods to identify, mitigate and manage peat slide hazards and associated risks in respect of consent applications for electricity generation projects.

Furthermore, the best practice guide notes that the results from the factor of safety approach 'has provided the most informative results' with respect to analysing peat stability (section 5.2.2 of the guide).

The factor of safety approach in this report includes undrained (short-term stability) and drained (long-term stability) analyses. The undrained condition is the critical condition for the development. The purpose of the drained analysis is to identify the relative susceptibility of rainfall-induced failures at the site.

Notwithstanding the above, the stability analysis used by AGEC in this report also includes qualitative factors to determine the potential for peat stability i.e. the analysis used does not solely rely on the factor of safety approach.

The deterministic analysis would be considered an acceptable engineering design approach. This concurs with best practice guidelines as referenced above.

2.7 Assessment of Intense Rainfall and Extreme Dry Events on the Peat Slopes

The deterministic approach carried out by AGEC examines intense rainfall and extreme dry events. The deterministic approach includes an undrained (short-term stability) and drained (long-term stability) analysis to assess the factor of safety for the peat slopes against a peat failure.

The drained loading condition applies in the long-term. This condition examines the effect of in particular, the change in groundwater level as a result of rainfall on the existing stability of the natural peat slopes. For the drained analysis the level of the water table above the failure surface is required to calculate the factor of safety for the peat slope.

In order to represent varying water levels within the peat slopes, a sensitivity analysis is carried out which assesses varying water level in the peat slopes i.e. water levels ranging between 0 and 100% of the peat depth is conducted, where 0% equates to the peat been completely dry and 100% equates to the peat been fully saturated.

By carrying out such a sensitivity analysis with varying water level in the peat slopes, the effects of intense rainfall and extreme dry events are considered and analysed. The results of which are presented in section 7 of this report.

3 DESK STUDY AND SITE RECONNAISSANCE

3.1 Desk Study

The main relevant sources of interest with respect to the site include:

- Geological plans
- Ordnance survey plans
- Literature review of peat failures

The Geological Survey of Ireland (GSI, 1999) geological plans for the site were used to verify the bedrock conditions.

The ordnance surveys plans were reviewed to determine if any notable features or areas of particular interest (from a geotechnical point of view) are present on the site.

The desk study also included a review of both published literature and GSI online dataset viewer (GSI, 2017) on peat failures/landslides in the vicinity of the site.

3.2 Site Reconnaissance

As part of the assessment of potential peat failure at the proposed site, AGEC carried out a site reconnaissance. This comprised walk-over inspections of the site with recording of salient geomorphological features with respect to the wind farm development and to provide peat thickness and preliminary assessment of peat strength.

The following salient geomorphological features were considered:

- Active, incipient or relict instability (where present) within the peat deposits
- Presence of shallow valley or drainage line
- Wet areas
- Any change in vegetation
- Peat depth
- Slope inclination and break in slope

The survey covered the proposed locations for the turbine bases and associated infrastructure.

The method adopted for carrying out the site reconnaissance relied on practitioners carrying out a visual assessment of the site supplemented with measurement of slope inclinations.

4 FINDINGS OF SITE RECONNAISSANCE

4.1 Previous Failures

The investigation works carried out at the study area have been used in conjunction with a desk study review to assess the susceptibility of the study area to peat failure.

There are no recorded peat failures at the Meenbog wind farm site (GSI, 2006 & GSI, 2017).

The nearest documented peat failure is located approximately 1km west of the study area. The failure recorded occurred at Barnesmore, Co. Donegal in 1963. The failure mechanism is described as a flow and the material and terrain type were described as peat and blanket bog respectively.

Another recorded failure located approximately 16km southwest of the study area occurred in Donegal town in 1999. No failure mechanism, material or terrain type is given for the failure.

Based on the review carried out no other peat failures occurred within a 20km radius of the site.

The presence, or otherwise, of relict peat failures or clustering of relict failures within an area is an indicator that particular site conditions exist that pre-dispose a site to failure or not as the case may be. Hence based on the historical data reviewed above it can be concluded that site conditions in the area of the Meenbog site have low potential for peat failure.

Based on a broad assessment of landslide susceptibility the site is classified by the GSI (2017) as ‘low’ to ‘moderately low’ and locally ‘moderately high’ susceptibility. It should be noted that the land susceptibility bands typically relates to the material type, topography in an area and incidences of landslides. For example, a rating of ‘moderately high’ is typically assigned where rock is close to the surface and slope angles range from 10 to 20 degrees. Hence the rating of ‘moderately high’ does not necessarily relate to the risk of peat failure. From the walkover survey of the site carried out by AGEC no peatland areas with a ‘moderately high’ susceptibility were identified.

4.2 Ground Conditions along Grid Connection

It is intended that the proposed wind farm will connect to the national grid via the existing Clogher 110 kV Electricity Substation (Clogher Substation), located in the townland of Cullionboy, Co. Donegal. The Clogher Substation is located approximately 6.2km southwest of the proposed development at its closest point.

The route will originate from the proposed substation and run northwest along the proposed wind farm access track for approximately 1.65km before turning southwest off the track for approximately 300m and will then cross under the N15 corridor via a directionally-drilled duct. The cable will emerge on to private lands northwest of the N15, where it will link into the Drumnahough cable (PI. Ref 17/50543, ABP Ref. PL05E.248796) approximately 300m southwest of the N15 crossing point.

It is proposed to excavate the trenches for the underground cable at a uniform level in peat or other overburden material. The trenches will be 600mm wide and 1250mm deep.

No peat stability or geotechnical issues are envisaged as a result of the proposed grid connection works.

4.3 Findings of Site Reconnaissance

A number of walk-over surveys of the site was carried out by AGEC between the 29th September & 3rd October 2014 and between 20th to 24th and 28th to 29th March 2017.

The walkovers were carried out by geotechnical engineers experienced in peat failure assessment. The findings from the site reconnaissance have been used to optimise the layout of the infrastructure on site.

The main findings of the site reconnaissance are as follows:

(1) The site is an upland blanket peat area with extensive forestry. The blanket peat areas contain typically shallow peat with typically deeper peat deposits in the flatter areas on site. The forested areas contain both young and mature forestry (Appendix A – Photos 1 and 2).

(2) Peat depths recorded during the site reconnaissance vary from 0 to 5.8m with an average of 1.7m (Figure 3). A total of over 500 no. peat depth probes were carried out on site.

The deeper peat deposits locally present in the flatter areas on site have been identified and are highlighted on the construction buffer zone plan (Figure 4). The deeper peat areas were generally avoided when optimising the wind farm layout for site.

(3) The peat depths recorded at 17 of the 19 no. turbine locations varied from 0 to 2.7m with an average depth of 1.3m. At the remaining 2 no. turbines T3 and T5 maximum peat depths of between 4.5 and 4.7m were recorded. The turbines where deeper peat deposits are present have shallow slope angles typically 1 degree.

(4) The access roads for the wind farm comprise upgrading of existing access tracks and construction of new proposed access roads. The existing access tracks have been constructed using both excavate and replace and floated construction techniques (Photos 3 and 4). The upgrading works and construction of new proposed access roads will be carried out using both excavate and replace and floated construction techniques.

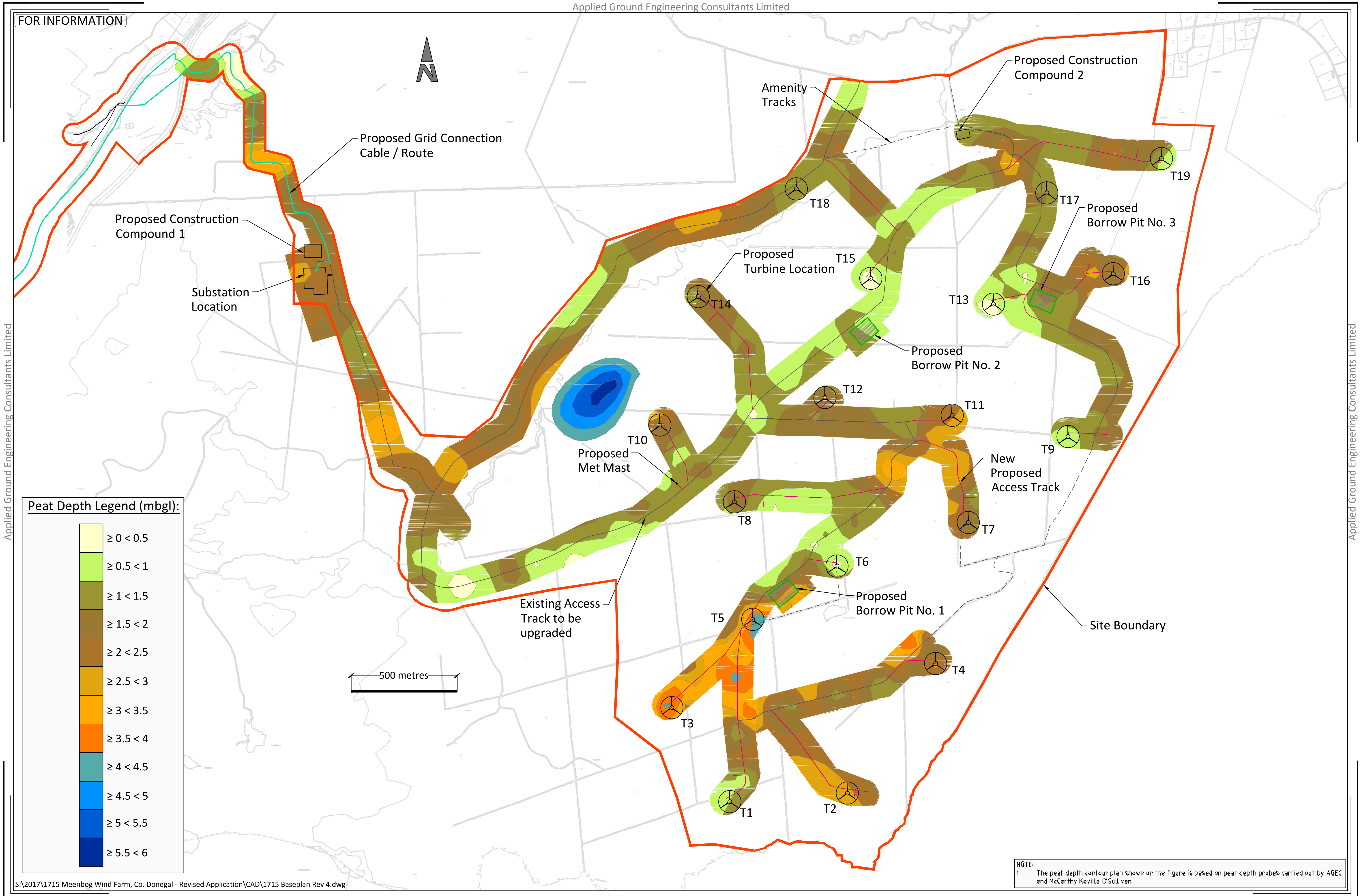

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Figure 3 Peat Depth Contour Plan

(5) With respect to the existing access tracks, peat depths are typically less than 2.0m with localised depths of up to 3.5m recorded. Up to 15km of existing access tracks are present across the site and have been in operation for a number of years.

(6) The typical make-up of the existing floating access tracks on site appears to be (locally) tree brash/trunks laid directly onto the peat surface and/or (locally) geogrid overlain by up to 500mm of coarse granular fill. The make-up of the existing floating access tracks varies across the site.

(7) With respect to the new proposed access roads, peat depths are typically less than 3.0m with localised depths of up to 4.5m recorded.

(8) Slope angles at the turbine locations range from 1 to 9 degrees with an average of 3 degrees. At turbine T6 a slope angle of 15 degrees was recorded, it should however be noted that 0.2m of peaty topsoil is present at this location and hence is not considered a peat stability risk. The slope angle readings are based on site recordings and were obtained during site reconnaissance by AGEC using handheld equipment, namely Silva Clino Master which has an accuracy of +/- 0.25 degrees. The slope angle quoted reflects the slope within the footprint of each infrastructure location.

(9) Localised areas of waterlogged peat and surface water are present at numerous areas across the site. This is not unexpected given the type of terrain present on site.

(10) A number of deep weak peat areas were identified outside the development footprint during the site walkovers (Figure 4). Locally the peat in these areas was recorded as quaking (or buoyant) indicating highly saturated peat, which would be considered to have low strength. These areas are located outside the proposed development footprint for the site and hence do not represent a peat slide risk.

(11) No evidence of past failures or any significant signs of peat instability were noted on site.

(12) A number of potential borrow areas have been identified across the site. The potential borrow areas identified are deemed suitable for the placement of excavated peat and spoil. Further information on the management of peat and spoil within the borrow areas is given in the Peat & Spoil Management Plan for site (AGEC, 2017).

(13) The findings of the site reconnaissance are as follows:

(a) The peat depths recorded at 17 of the 19 no. turbine locations varied from 0 to 2.7m with an average depth of 1.3m. At the remaining 2 no. turbines T3 and T5 maximum peat depths of between 4.5 and 4.7m were recorded. The turbines where deeper peat deposits are present have shallow slope angles typically 1 degree.

(b) Although greater peat depths were recorded at turbines T3 and T5 these are not considered to represent a peat slide risk due to the flatter topography. The peat depths at these two locations contribute to an elevated construction risk and will be subject to additional mitigation/control measures (see Appendix B).

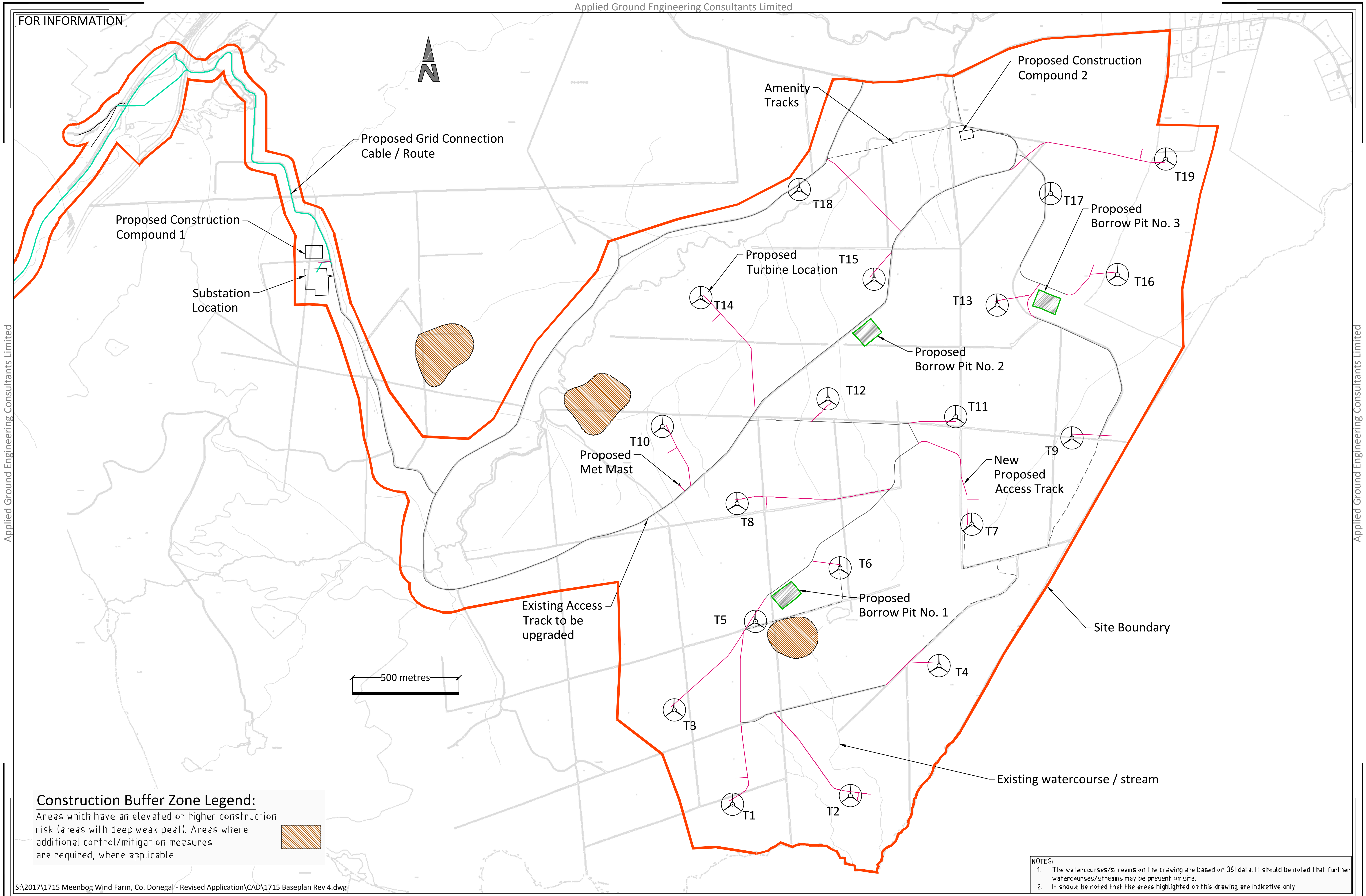

Figure 4 Construction Buffer Zone Plan

(c) A construction buffer zone plan has been produced for the site (Figure 4). This Figure shows areas which have an elevated or higher construction risk due to the terrain and features encountered during the site reconnaissance. Additional mitigation/control measures will be implemented in these areas, as required (see Appendix B).

5 SITE GROUND CONDITIONS

5.1 Soils & Subsoils

The site is an upland blanket peat area with extensive forestry. The blanket peat areas contain typically shallow peat with typically deeper peat deposits in the flatter areas on site. The forested areas contain both young and mature forestry. Peat depths recorded across the site ranged from 0 to 5.8m with an average of 1.7m.

Based on the site walkover and the exposures present at the site the superficial deposits were typically described as firm brown/black fibrous Peat (in the shallow peat areas) and spongy and plastic black amorphous Peat (in the deeper peat areas), overlying firm and stiff light brown/grey sandy gravelly Clay with cobbles and boulders and/or overlying weathered bedrock (Photos 5 & 6).

A review of the GSI subsoils map indicates that the site is underlain by predominantly blanket peat with some till derived from metamorphic rock and occasional outcrops of rock at the surface.

5.2 Bedrock

The underlying bedrock was described by the Geological Survey of Ireland (GSI, 1999) and shown on sheet 3 and part of sheet 4 (Geology of South Donegal). In the area of the Meenbog site, sheet 3 and part of sheet 4 show two dominant bedrock formations.

The dominant bedrock formations are:

- Lough Eske Psammite Formation – feldspathic psammite, marble
- Lough Mourne Formation – quartz & feldspar pebbles, green matrix

Localised bedrock formations noted in the west of the site include Barnesmore granite.

One mapped fault is shown running across the western area of the site. The fault line has a north to south trend.

No karst features were identified on the site following a review of the GSI database or during the site walkover.

6 PEAT DEPTHS, STRENGTH & SLOPE AT PROPOSED INFRASTRUCTURE LOCATIONS

As part of the site walkover, peat depth, in-situ peat strength and slope angles were recorded at various locations across the site.

6.1 Peat Depth

Peat depth probes were carried out at/near to proposed turbine locations and access roads. At turbine locations up to 5 probes were carried out around the turbine location, where accessible, and an average peat depth was calculated.

6.2 Peat Strength

The strength testing was carried out in-situ using a Geonor H-60 Hand-Field Vane Tester. From AGEC's experience hand vanes give indicative results for in-situ strength of peat and would be considered best practice for the field assessment of peat strength.

6.3 Slope Angle

The slope angles at each of the main infrastructure locations were generally obtained during the site reconnaissance by AGEC using handheld equipment, such as Silva Clino Master which has an accuracy of +/- 0.25 degrees. The slope angles quoted reflect the slope within the footprint of each infrastructure location. Slope angles derived from contour survey plans would be considered approximate, as such surveys are dependent on the density of survey data and do not always reflect local variations in ground topography.

The slope angles used in the peat stability assessment and associated report for the main infrastructure locations were generally recorded during the site reconnaissance by AGEC using handheld equipment and would be deemed more accurate and representative of local topography than slope angles derived from contour plans.

6.4 Summary of Findings

Based on the peat depths recorded across the site by AGEC and McCarthy Keville O'Sullivan (2014a, 2014b & 2014c), the peat varied in depth from 0 to 5.8m with an average of 1.7m. All peat depth probes carried out on site have been utilised to produce a peat depth contour plan for the site (Figure 3).

A summary of the peat depths at the proposed infrastructure locations is given in Table 1. The data presented in Table 1 is used in the peat stability assessment of the site; see Section 7 of this report.

Table 1 Peat Depth & Slope Angle at Proposed Infrastructure Locations

Turbine	Easting	Northing	Peat Depth Range (m) (1)	Average Peat Depth (m)	Slope Angle (°) (2)
T1	207133	384174	0.1 to 1.0	0.3	1
T2	207689	384214	2.3 to 2.7	2.5	1
T3	206859	384619	2.8 to 4.5	3.5	1
T4	208106	384826	2.5 to 2.7	2.6	1
T5	207241	385035	3.9 to 4.7	4.3	1
T6	207639	385286	0.1 to 0.2	0.1	15
T7	208261	385494	1.1 to 1.7	1.4	5
T8	207155	385589	1.6 to 2.0	1.8	5
T9	208732	385899	0.3 to 0.5	0.4	9
T10	206803	385952	1.8 to 2.5	2	2
T11	208183	385999	1.4 to 2.1	1.8	3
T12	207583	386083	0.9 to 1.7	1.4	6
T13	208379	386526	0.1 to 0.3	0.2	2
T14	206983	386559	0.7 to 1.3	0.9	1
T15	207800	386648	0.1 to 0.2	0.2	2
T16	208946	386668	0.3 to 1.0	0.8	3
T17	208631	387052	0.8 to 1.5	1.1	6
T18	207448	387070	0 to 1.0	0.3	3
T19	209173	387212	0 to 0.3	0.1	3
Substation	205184	386668	1.3 to 2.6	2.2	4
Met Mast	206885	385678	1.0 to 1.5	1.2	3

Note (1) Based on probe results from the site walkovers. The range of peat depths for the infrastructure locations are based on a 10m grid carried out around the infrastructure element, where accessible.
Note (2) The slope angles at each of the main infrastructure locations were obtained during site reconnaissance by AGEC using handheld equipment, such as the Silva Clino Master which has an accuracy of +/- 0.25 degrees. The slope angle quoted reflects the slope within the footprint of each infrastructure location.
Note (3) The data presented in the Table above is used in the peat stability assessment of the site; see Section 8.0 of this report.

In addition to probing, in-situ shear vane testing was carried out as part of the ground investigation. Strength testing was carried out at selected locations across the site to provide representative coverage of indicative peat strengths. The results of the vane testing are presented in Figure 5.

The hand vane results indicate undrained shear strengths in the range 5 to 50kPa, with an average value of about 16kPa. The lower bound strengths recorded would be typical of deep weak saturated peat and were recorded in the deeper peat deposits in the flatter areas of the site. These areas have been identified and are highlighted on a construction buffer zone plan for site (Figure 4).

Peat strength at sites of known peat failures (assuming undrained loading failure) are generally very low, for example the undrained shear strength at the Derrybrien failure (AGEC, 2004) as derived from essentially back-analysis, though some testing was carried out, was estimated at 2.5kPa.

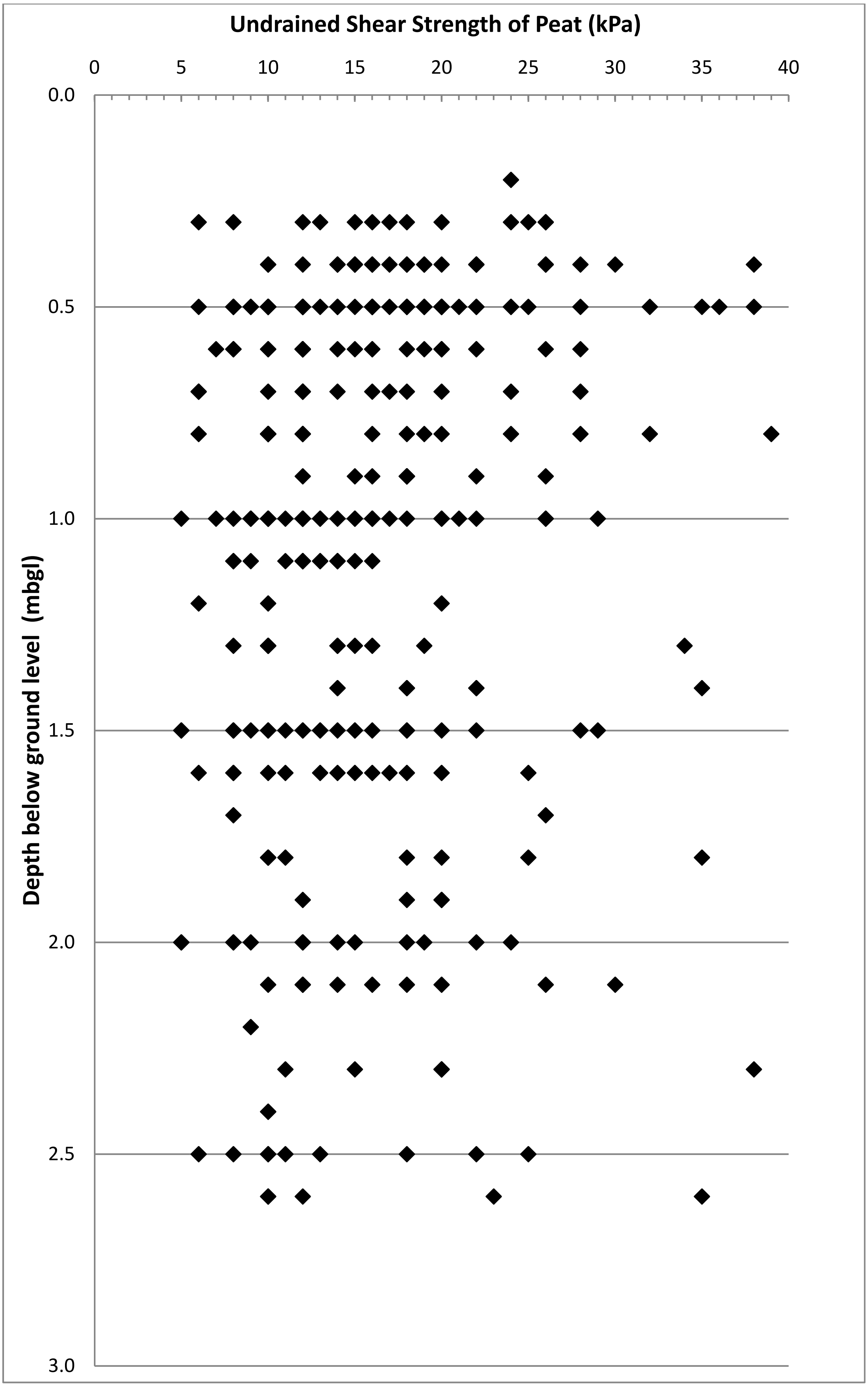

Figure 5 Undrained Shear Strength (C_u) Profile for Peat with Depth

7 PEAT STABILITY ASSESSMENT

The peat stability assessment analyses the stability of the natural peat slopes for individual parcels across the site including at the turbine locations and along the proposed access roads. The assessment also analyses the stability of the natural peat slopes with a surcharge loading of 10kPa, equivalent to placing 1m of stockpiled peat on the surface of the peat slope.

7.1 Methodology for Peat Stability Assessment

Stability of a peat slope is dependent on several factors working in combination. The main factors that influence peat stability are slope angle, shear strength of peat, depth of peat, pore water pressure and loading conditions.

An adverse combination of factors could potentially result in peat sliding. An adverse condition of one of the above-mentioned factors alone is unlikely to result in peat failure. The infinite slope model (Skempton and DeLory, 1957) is used to combine these factors to determine a factor of safety for peat sliding. This model is based on a translational slide, which is a reasonable representation of the dominant mode of movement for peat failures.

To assess the factor of safety for a peat slide, an undrained (short-term stability) and drained (long-term stability) analysis has been undertaken to determine the stability of the peat slopes on site.

1. The undrained loading condition applies in the short-term during construction and until construction induced pore water pressures dissipate.
2. The drained loading condition applies in the long-term. The condition examines the effect of in particular, the change in groundwater level as a result of rainfall on the existing stability of the natural peat slopes.

Undrained shear strength values (c_u) for peat are used for the total stress analysis. Based on the findings of the Derrybrien failure, undrained loading during construction was found to be the critical failure mechanism.

A drained analysis requires effective cohesion (c') and effective friction angle (ø') values for the calculations. These values can be difficult to obtain because of disturbance experienced when sampling peat and the difficulties in interpreting test results due to the excessive strain induced within the peat. To determine suitable drained strength values a review of published information on peat was carried out.

Table 2 shows a summary of the published information on peat together with drained strength values.

Table 2 List of Effective Cohesion and Friction Angle Values

Reference	Cohesion, c' (kPa)	Friction Angle, ø' (degs)	Testing Apparatus/ Comments
Hanrahan et al (1967)	5 to 7	36 to 43	From triaxial apparatus
Rowe and Mylleville (1996)	2.5	28	From simple shear apparatus
Landva (1980)	2 to 4	27.1 to 32.5	Mainly ring shear apparatus for normal stress greater than 13kPa
	5 to 6	-	At zero normal stress
Carling (1986)	6.5	0	-
Farrell and Hebib (1998)	0	38	From ring shear and shear box apparatus. Results are not considered representative.
	0.61	31	From direct simple shear (DSS) apparatus. Result considered too low therefore DSS not considered appropriate
Rowe, Maclean and Soderman (1984)	1.1	26	From simple shear apparatus
	3	27	From DSS apparatus
Sandorini et al (1984)	4.5	28	From triaxial apparatus
McGreever and Farrell (1988)	6	38	From triaxial apparatus using soil with 20% organic content
	6	31	From shear box apparatus using soil with 20% organic content
Hungr and Evans (1985)	3.3	-	Back-analysed from failure
Madison et al (1996)	10	23	-
Dykes and Kirk (2006)	3.2	30.4	Test within acrotelm
Dykes and Kirk (2006)	4	28.8	Test within catotelm
Warburton et al (2003)	5	23.9	Test in basal peat
Warburton et al (2003)	8.74	21.6	Test using fibrous peat
Entec (2008)	3.8	36.8	Generalised values derived from various peat tests (shear box and triaxial)

From Table 2 the values for c' ranged from 1.1 to 10kPa and ø' ranged from 21.6 to 43°. The average c' and ø' values are 5kPa and 30° respectively. Based on the above, it was considered to adopt a conservative approach and to use design values below the averages.

For design the following general drained strength values have been used for the site:

c' = 4kPa
ø' = 25 degrees

7.2 Analysis to Determine Factor of Safety (Deterministic Approach)

The purpose of the analysis was to determine the Factor of Safety (FoS) of the peat slopes using infinite slope analysis. The analysis was carried out at the turbine locations, along the proposed access roads and at various locations across the site.

The FoS provides a direct measure of the degree of stability of the slope. A FoS of less than unity indicates that a slope is unstable, a FoS of greater than unity indicates a stable slope.

The acceptable safe range for FoS typically ranges from 1.3 to 1.4. The previous code of practice for earthworks BS 6031:1981 (BSI, 1981), provided advice on design of earthworks slopes. It stated that for a first time failure with a good standard of site investigation the design FoS should be greater than 1.3.

As a general guide the FoS limits for peat slopes in this report are summarised in table 3.

Table 3 Factor of Safety Limits for Slopes

Factor of Safety (FoS)	Degree of Stability
Less than 1.0	Unstable (red)
Between 1.0 and 1.3	Marginally stable (yellow)
1.3 or greater	Acceptable (green)

Eurocode 7 (EC7) (IS EN 1997-1:2005) now serves as the reference document and the basis for design geotechnical engineering works. The design philosophy used in EC7 applies partial factors to soil parameters, actions and resistances. Unlike the traditional approach, EC7 does not provide a direct measure of stability, since global Factors of Safety are not used.

As such, and in order to provide a direct measure of the level of safety on a site, EC7 partial factors have not been used in this stability assessment. The results are given in terms of FoS.

A lower bound undrained shear strength, c_u for the peat of 5kPa was selected for the assessment based on the c_u values recorded at the site. An undrained shear strength of 5kPa was the lowest value recorded on site. It should be noted that a c_u of 5kPa for the peat is considered a conservative value for the analysis and is not representative of all peat present across the site. In reality the peat generally has a higher undrained strength.

The formula used to determine the factor of safety for the undrained condition in the peat (Bromhead, 1986) is as follows:

$$F = \frac{c_u}{\gamma z \sin\alpha \cos\alpha}$$

Where,

F = Factor of Safety
c_u = Undrained strength

γ = Bulk unit weight of material
z = Depth to failure plane assumed as depth of peat
α = Slope angle

The formula used to determine the factor of safety for the drained condition in the peat (Bromhead, 1986) is as follows:

$$F = \frac{c' + (\gamma z - \gamma_w h_w)\cos^2\alpha \tan\phi'}{\gamma z \sin\alpha \cos\alpha}$$

Where,

F = Factor of Safety
c' = Effective cohesion
γ = Bulk unit weight of material
z = Depth to failure plane assumed as depth of peat
γ_w = Unit weight of water
h_w = Height of water table above failure plane
α = Slope angle
ø' = Effective friction angle

For the drained analysis the level of the water table above the failure surface is required to calculate the factor of safety for the slope. Since the water level in blanket peat can be variable and can be recharged by rainfall, it is not feasible to establish its precise location throughout the site. Therefore a sensitivity analysis using water level ranging between 0 and 100% of the peat depth was conducted, where 0% equates to the peat been completely dry and 100% equates to the peat been fully saturated.

The following general assumptions were used in the analysis of peat slopes at each location:

(1) Peat depths are based on the maximum peat depth recorded at each location from the walkover survey.
(2) A lower bound undrained shear strength, c_u for the peat of 5kPa was selected for the assessment based on the c_u values recorded at the site. An undrained shear strength of 5kPa was the lowest value recorded on site. It should be noted that a c_u of 5kPa for the peat is considered a conservative value for the analysis and is not representative of all peat present across the site. In reality the peat generally has a higher undrained strength.
(3) Slope angle on base of sliding assumed to be parallel to ground surface.

For the stability analysis two load conditions were examined, namely;

Condition (1): no surcharge loading

Condition (2): surcharge of 10 kPa, equivalent to 1 m of stockpiled peat assumed as a worst case.

7.3 Results of Analysis

7.3.1 Undrained Analysis for the peat

The results of the undrained analysis for the natural peat slopes are presented in Appendix C and the results of the undrained analysis for the most critical load case (load condition 2) are shown on Figure 6. The undrained analysis for load condition 2 is considered the most critical load case as most peat failures occur in the short term upon loading of the peat surface. The results from the main infrastructure locations are summarised in Table 4.

The calculated FoS for load condition (1) is in excess of 1.30 for each of the 540 no. locations analysed with a range of FoS of 1.69 to in excess of 10, indicating a low risk of peat instability.

The calculated FoS for load condition (2) is in excess of 1.30 for each of the 540 no. locations analysed with a range of FoS of 1.31 to in excess of 10, indicating a low risk of peat instability.

Table 4 Factor of Safety Results (undrained condition)

Turbine No./Waypoint	Easting	Northing	Factor of Safety for Load Condition	
			Condition (1)	Condition (2)
T1	207133	384174	28.65	14.33
T2	207689	384214	10.61	7.74
T3	206859	384619	6.37	5.21
T4	208106	384826	10.61	7.74
T5	207241	385035	6.10	5.03
T6	207639	385286	10.00	1.67
T7	208261	385494	3.39	2.13
T8	207155	385589	2.88	1.92
T9	208732	385899	6.47	2.16
T10	206803	385952	5.73	4.10
T11	208183	385999	4.56	3.09
T12	207583	386083	2.83	1.78
T13	208379	386526	47.79	11.03
T14	206983	386559	22.04	12.46
T15	207800	386648	71.68	11.95
T16	208946	386668	9.57	4.78
T17	208631	387052	3.21	1.92
T18	207448	387070	9.57	4.78
T19	209173	387212	31.89	7.36
Substation	205184	386668	2.76	2.00
Met Mast	206885	385678	6.38	3.83

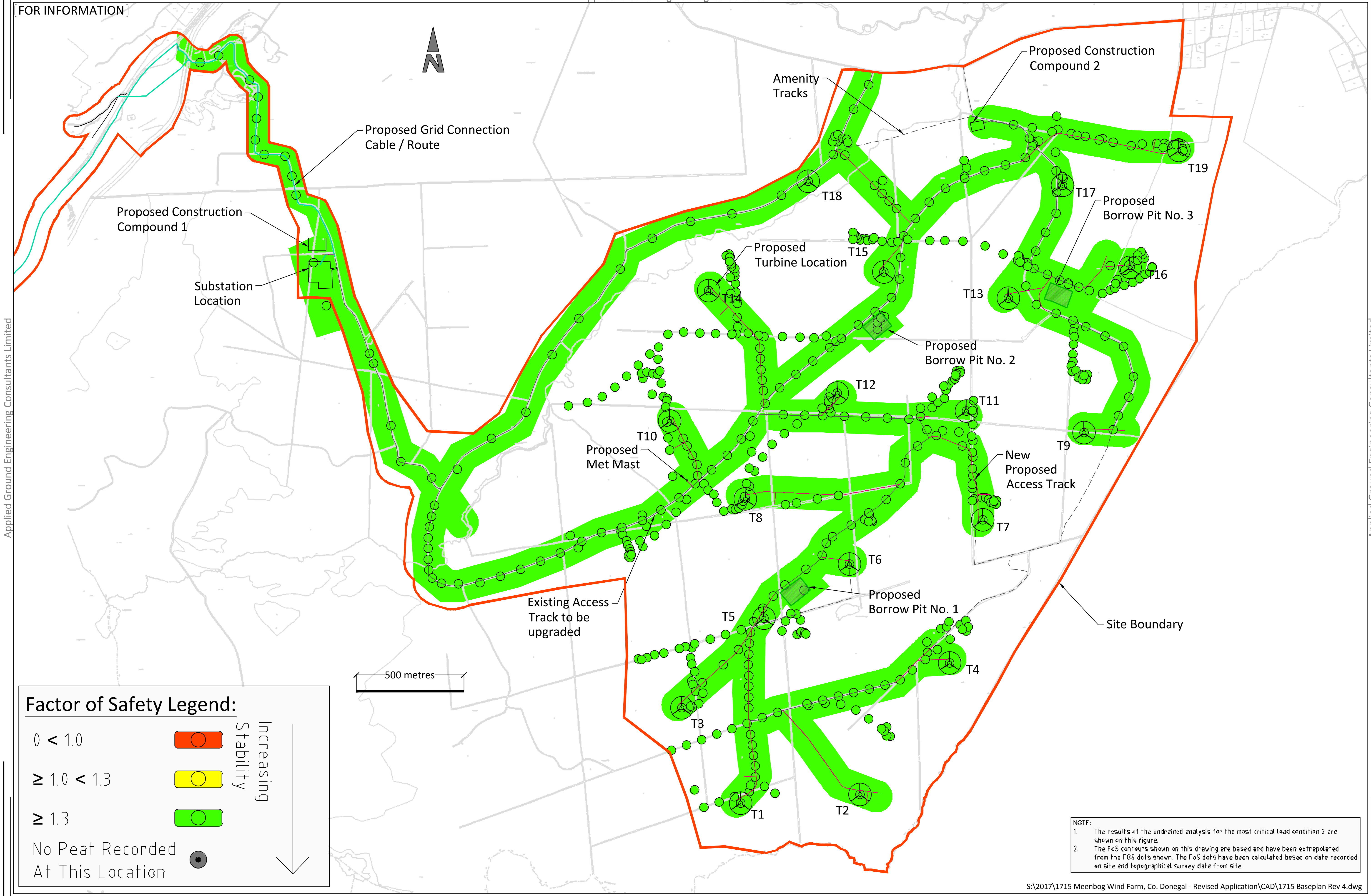

Figure 6 Factor of Safety Plan

7.3.2 Drained Analysis for the peat

The results of the drained analysis for the peat are presented in Appendix C. The results from the main infrastructure locations are summarised in Table 5. As stated previously, the drained loading condition examines the effect of, in particular, rainfall on the existing stability of the natural peat slopes.

The calculated FoS for load condition (1) is in excess of 1.30 for each of the 540 no. locations analysed with a range of FoS of 1.36 to in excess of 10, indicating a low risk of peat instability.

The calculated FoS for load condition (2) is in excess of 1.30 for each of the 540 no. locations analysed with a range of FoS of 2.26 to in excess of 10, indicating a low risk of peat instability.

Table 5 Factor of Safety Results (drained condition)

Turbine No./Waypoint	Easting	Northing	Factor of Safety for Load Condition	
			Condition (1)	Condition (2)
T1	207133	384174	22.92	24.82
T2	207689	384214	8.49	13.42
T3	206859	384619	5.09	9.03
T4	208106	384826	8.49	13.42
T5	207241	385035	4.88	8.71
T6	207639	385286	8.00	2.78
T7	208261	385494	2.71	3.68
T8	207155	385589	2.30	3.31
T9	208732	385899	5.18	3.69
T10	206803	385952	4.59	7.09
T11	208183	385999	3.64	5.34
T12	207583	386083	2.26	3.07
T13	208379	386526	38.23	19.09
T14	206983	386559	17.63	21.58
T15	207800	386648	57.34	20.68
T16	208946	386668	7.65	8.28
T17	208631	387052	2.57	3.31
T18	207448	387070	7.65	8.28
T19	209173	387212	25.51	12.73
Substation	205184	386668	2.21	3.45
Met Mast	206885	385678	5.10	6.62

8 RISK ASSESSMENT

A risk assessment was carried out for the main infrastructure elements at the proposed wind farm development. This approach follows the guidelines for geotechnical risk management as given in Clayton (2001), as referenced in PHRAG, and takes into account the approach of MacCulloch (2005).

The risk assessment uses the results of the stability analysis (deterministic approach) in combination with qualitative factors, which cannot be reasonably included in a stability calculation but nevertheless may affect the occurrence of peat instability to assess the risk for each infrastructure element.

For each infrastructure element, a risk rating (product of probability and impact) is calculated and rated as shown in Table 6. Where an infrastructure element is rated 'Substantial' or 'Unacceptable', control measures are required to reduce the risk to at least a 'Tolerable' risk rating. Where an infrastructure element is rated 'Trivial' or 'Tolerable', only routine control measures are required.

Table 6 Risk Rating Legend

10 to 20	Unacceptable: re-location or significant control measures required
5 to 9	Substantial: notable control measures required
3 to 4	Tolerable: only routine control measures required
1 to 2	Trivial: none or only routine control measures required

A full methodology for the risk assessment is given in Appendix D.

8.1 Summary of Risk Assessment Results

The results of the risk assessment for potential peat failure at the main infrastructure elements is presented as a Geotechnical Risk Register in Appendix B and summarised in Table 7.

The risk rating for each infrastructure element at the Meenbog wind farm is designated trivial and tolerable following some mitigation/control measures being implemented. Sections of access roads to the nearest infrastructure element should be subject to the same mitigation/control measures that apply to the nearest infrastructure element.

Details of the required mitigation/control measures can be found in the Geotechnical Risk Register for each infrastructure element (Appendix B).

Table 7 Summary of Geotechnical Risk Register

Infrastructure	Pre-Control Measure Implementation Risk Rating	Pre-Control Measure Implementation Risk Rating Category	Notable Control Measures Required	Post-Control Measure Implementation Risk Rating	Post-Control Measure Implementation Risk Rating Category
Turbine T1	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T2	Tolerable	3 to 4	No	Tolerable	3 to 4
Turbine T3	Tolerable	3 to 4	Yes	Trivial	1 to 2
Turbine T4	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T5	Tolerable	3 to 4	Yes	Trivial	1 to 2
Turbine T6	Tolerable	3 to 4	No	Trivial	1 to 2
Turbine T7	Substantial	5 to 9	No	Tolerable	3 to 4
Turbine T8	Tolerable	3 to 4	No	Trivial	1 to 2
Turbine T9	Substantial	5 to 9	No	Tolerable	3 to 4
Turbine T10	Substantial	5 to 9	Yes	Tolerable	3 to 4
Turbine T11	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T12	Substantial	5 to 9	No	Tolerable	3 to 4
Turbine T13	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T14	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T15	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T16	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T17	Trivial	1 to 2	No	Trivial	1 to 2
Turbine T18	Substantial	5 to 9	No	Tolerable	3 to 4
Turbine T19	Trivial	1 to 2	No	Trivial	1 to 2
Substation	Substantial	5 to 9	Yes	Tolerable	3 to 4
Met Mast	Tolerable	3 to 4	No	Tolerable	3 to 4

9 SUMMARY AND RECOMMENDATIONS

9.1 Summary

The following summary is given.

AGEC was engaged by McCarthy Keville O'Sullivan to undertake an assessment of the proposed wind farm site with respect to peat stability.

The findings of the peat assessment, which involved analysis of over 500 locations, showed that the site has an acceptable margin of safety and is suitable for the proposed wind farm development. The findings include recommendations and control measures for construction work in peat lands to ensure that all works adhere to an acceptable standard of safety.

The site is an upland blanket peat area with extensive forestry. The blanket peat areas contain typically shallow peat with typically deeper peat deposits in the flatter areas on site. The forested areas contain both young and mature forestry. Up to 15km of existing access tracks are present across the site and have been in operation for a number of years.

Peat thicknesses recorded during the site walkovers from over 500 probes ranged from 0 to 5.8m with an average of 1.7m. The deeper peat areas were typically avoided when optimising the wind farm layout for site.

Based on a broad assessment of landslide susceptibility the site is classified by the GSI as 'low' to 'moderately low' and locally 'moderately high' susceptibility. As outlined in the report, from the walkover survey of the site carried out by AGEC no peatland areas with a 'moderately high' susceptibility were identified.

An analysis of peat sliding was carried out at the main infrastructure locations across site for both the undrained and drained conditions. The purpose of the analysis was to determine the Factor of Safety (FoS) of the peat slopes.

An undrained analysis was carried out, which applies in the short-term during construction. For the undrained condition, the calculated FoS for load conditions (1) & (2) for the 540 no. locations analysed, shows that at all locations an acceptable FoS of greater than 1.3 was calculated, indicating a low risk of peat instability.

A drained analysis was carried out, which examines the effect of in particular, rainfall on the existing stability of the natural peat slopes on site. For the drained condition, the calculated FoS for load conditions (1) and (2) for the 540 no. locations analysed, shows that at all locations an acceptable FoS of greater than 1.3 was calculated, indicating a low risk of peat instability.

The risk assessment at each infrastructure location identified a number of mitigation/control measures to reduce the potential risk of peat failure. Sections of access roads to the nearest infrastructure element should be subject to the same mitigation/control measures that apply to the nearest infrastructure element. See Appendix B for details of the required mitigation/control measures for each infrastructure element.

In summary the findings of the peat assessment, which involved analysis of over 500 locations, showed that the proposed Meenbog wind farm site has an acceptable margin of safety and is suitable for the proposed wind farm development. The findings include recommendations and control measures for construction work in peat lands to ensure that all works adhere to an acceptable standard of safety.

9.2 Recommendations

The following general recommendations are given.

Notwithstanding that the site has an acceptable margin of safety a number of mitigation/control measures are given to ensure that all works adhere to an acceptable standard of safety for work in peatlands. Mitigation/control measures identified for each of the infrastructure elements in the risk assessment should be taken into account and implemented throughout design and construction works (Appendix B).

Recommendations and guidelines given in AGEC's report 'Peat & Spoil Management Plan - Meenbog Wind Farm, County Donegal' (AGEC 2017) should be taken into consideration during the design and construction stage of the wind farm development.

A construction buffer zone plan has been produced for the site (Figure 4). This Figure shows areas which have an elevated or higher construction risk due to the terrain and features encountered during the site reconnaissance. Additional mitigation/control measures will be implemented in these areas, as required (see Appendix B).

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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