Appendix 9-2

Peat Stability Report

Malachy Walsh and Partners

Consulting Engineers

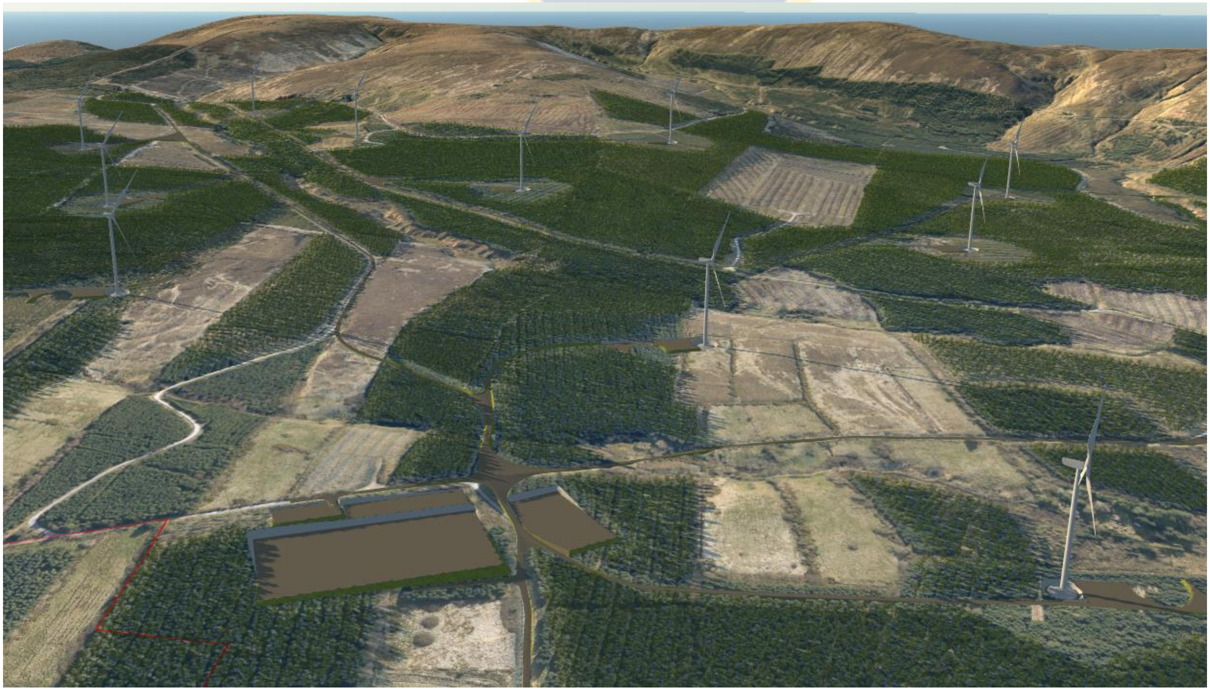
Cork | Tralee | Limerick | London

Carrownagowan Wind Farm

County Clare

Peat Stability Risk Assessment

Coillte



Project	Document	Prepared	Checked	Date
19107	6015	Cormac Murphy	Jack O'Leary	12th December 2019

Table of Contents

Table of Figures

List of Tables

Executive Summary

Coillte engaged Malachy Walsh & Partners (MWP) to complete a Peat Stability Risk Assessment as part of the EIAR for the proposed Carrownagowan Wind Farm Development.

The Carrownagowan Wind Farm infrastructure was designed from the outset with a constraints driven approach to place turbines in low risk areas.

MWP completed extensive walkovers and surveys of the site.

MWP completed 790 peat probes across the site with peat depths ranging from 0.05m to 4m.

Shear strengths were recorded ranging from 4kPa to 62kPa.

MWP employed high resolution LiDAR data to create an accurate Digital Elevation Model (DEM) of the Site.

An iterative design methodology was adopted using a constraints driven approach where ground slope was used as a primary constraint.

Slope analysis from the DEM was used to place infrastructure in areas of the site with low ground slope.

MWP completed a Risk Assessment using the Peatslide Hazard Rating System (PHRS) (Nichol, 2006).

The findings of the PHRS were that the risk ranged from **Negligible** (Substation, PMM, T18, BP1,BP3) through **Very Low** for the majority of the site to **Low** (T5 and T14). The recommended Engineering Response to a finding of a Low Hazard rating is that *Further investigation of the peat slide hazard may be required*.

Following on from the PHRS, MWP conducted an Infinite Slope Stability Analysis (ISSA) for the entire site using the peat probe data and slope data from the LiDAR DEM to calculate the Factor of Safety (FoS) against peatslide for each location probed.

The ISSA output was that the majority of the site had a FoS against peatslide in excess of 4 with no infrastructure placed in areas with a FoS less than 2.

MWP completed assessments of the risk presented using the industry best practice guidance of the Scottish Executive and Scottish Government guidelines for Peat Landslide Hazard and Risk Assessments.

The outcome of the risk assessment was that landslide presented a **Negligible Level of risk to the Wind Farm Infrastructure**.

A further risk assessment for the risk of landslide to surrounding environment found a **Negligible Level of risk.** This is an outcome consistent with an iterative constraints driven approach to wind farm infrastructure design.

Design measures in the form of peat stability monitoring programme during construction has been proposed in order to mitigate this low level of risk.

1 Peat Stability Risk Assessment

1.1 Project Overview

The project includes the Carrownagowan Wind Farm, which comprises of the construction of 19 no. Wind Turbines, a meteorological mast, a substation and their respective associated roads, hardstands, cabling and drainage infrastructure in the townlands of Caherhurley, Coumnagun, Carrownagowan, Killokennedy and Ballydonaghan.

Coillte have requested Malachy Walsh and Partners (MWP) complete the Peat Stability Risk Assessment (PSRA) as part of the EIAR for the project.

The study area is presented below in Figure 1-1 through to Figure 1-4. The study area that is relevant to the Peat Stability Risk Assessment is the proposed development lands where the wind farm will be located. These lands are relevant to the assessment due to the slopes, presence of peat and presence of rivers on the site. The PSRA is not relvant to the grid connection, turbine delivery route or replacement forestry lands.

MWP have extensive experience in completing PSRA's in upland peat areas, having completed PSRA's on over 20 planning applications and the construction of in excess of 30 wind farms located in peatland throughout Ireland.

MWP adhere to the industry standard of utilising the guidance of the Scottish Government publication "Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments" in completing PSRA's.

Figure 1-1 – Site location map(Study Area boundary shown in red)

Figure 1-2 - Study Area Aerial Imagery

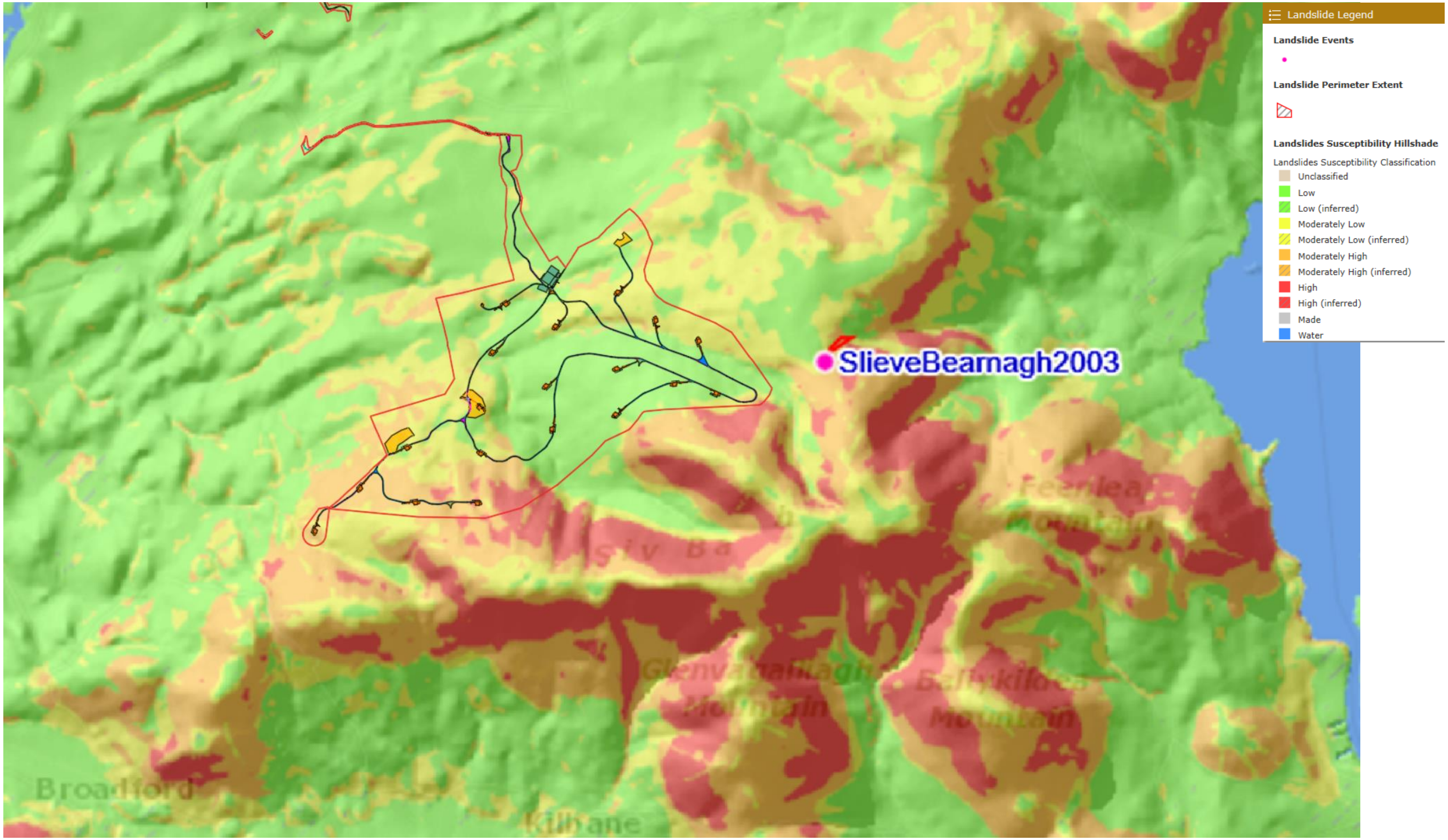


Figure 1-3 – GSI Landslide Susceptibility Mapping

Figure 1-4 – Typical photo of study area

1.2 Desk Study

The desk study for the Peat Stability Risk Assessment consisted of the following main elements:

- Review of existing site information including:
  - Study of Aerial photography from the Geological Survey Ireland (GSI), Ordnance Survey Ireland (OSI) and publicly available ortho rectified aerial imagery.
  - Examination of Geological records from the GSI, Teagasc and Biodiversity mapping resources
- Review of data from Ecological studies completed to date
- Review of site reconnaissance data

1.2.1 Geological Survey Ireland Dataset

The GSI dataset includes landslide susceptibility mapping. This susceptibility mapping for the Carrownagowan is illustrated above in Figure 1-3.

From Figure 1-3 – GSI Landslide Susceptibility Mapping above it can be seen that the majority of the site is in areas identified as Low susceptibility except for the area from T1 to T4.

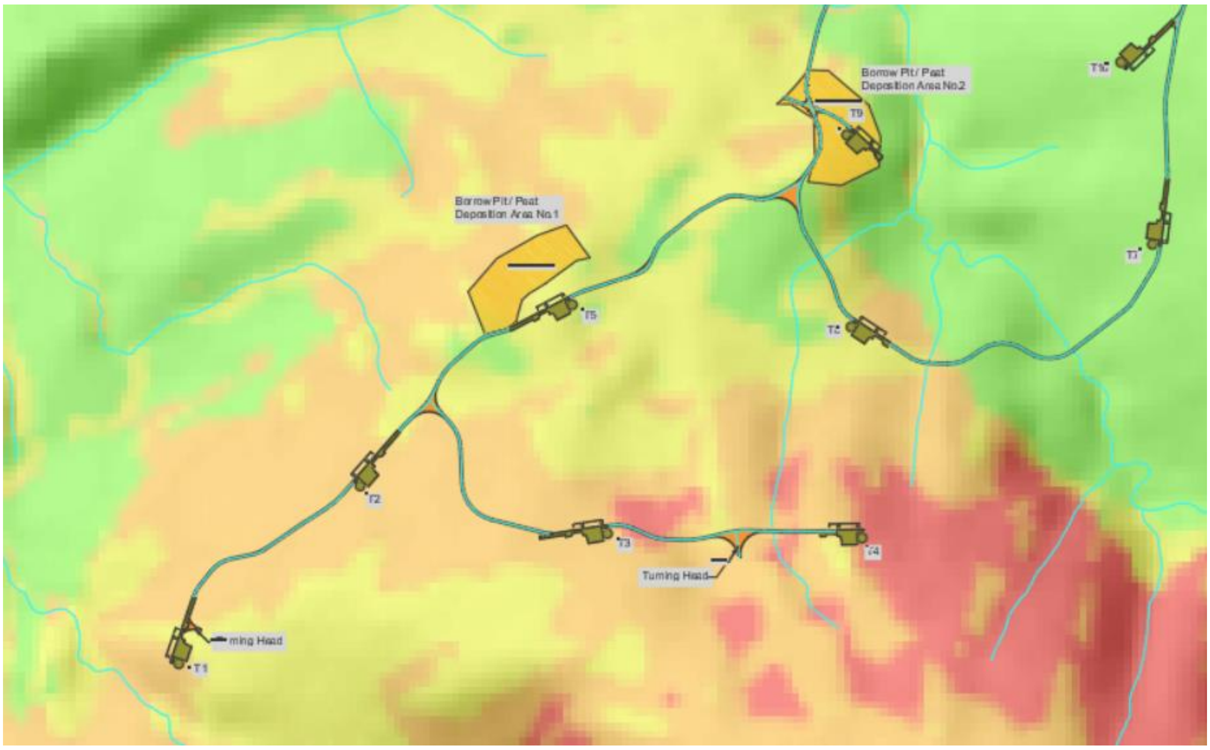


Figure 1-5 – GSI Landslide Susceptability Mapping where route passes through ares of Moderate to High Susceptibility

The GSI dataset lists no landslide events in the study area and 2no. in the wider locality. The relevant recorded landslide events are illustrated below Figure 1-6

Figure 1-6 – GSI Recorded Landslide Events for Gleensk Section

The Fort Henry 1948 landslide was a failure of an earth embakment constructed between 1926 and 1928 and has no further significance in terms of this report as a peat landslide risk assessment.

The Slieve Bearnagh slide of 2003 was a peat slide which occured during a period of road construction associated with forestry.

Figure 1-7 Existing Slieve Bearnagh Slide

MWP visited and investigated the slide area in 2018. Peat depths were generally in excess of 2m with a maximum depth of 3.7m encoutered. Shear strengths ranged from 8kPa to 16kPa. The slide area coincided with a break in slope going from gently sloping 3.5deg to sloping at 7.5deg. From the site visit and analysis of data gathered MWP concluded that the slide was most likely triggered by excessive surchage caused by side cast material along the road edge. The slide ran out along an existing firebreak cutting and was arrested with a berm approx 350m from the slide head. The GSI list the impact of the landslide as having ‘No apparent impact’.

The GSI dataset lists the soil cover in the area as belonging to the Peat Group. The Teagasc soils mapping is included below in Figure 1-8.

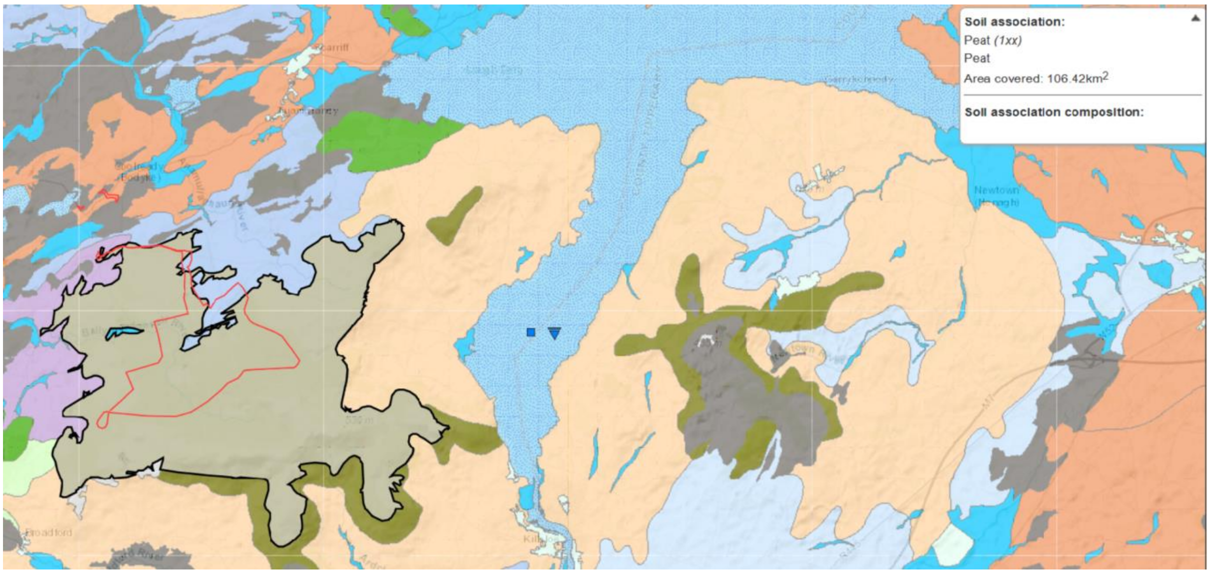


Figure 1-8 – GSI Teagasc Soils Description

As can be seen from Figure 1-8 the majority of the site is under peat cover.

1.2.2 Existing Land use

The majority of the site is in commercial forestry managed by Coillte. There are some isolated pockets of farm land within the overall site

1.2.3 Site Reconnaissance

The initial site reconnaissance survey by MWP for this report was carried out in May 2018. Site investigations were carried on through to November 2019 as part of an iterative design and ground proof process.

1.2.4 Review of Data from Desk Study

From the desk study it is clear that while most of the site is in low susceptibility, parts of the site are in moderate to high susceptibility from landslide events. Therefore a dedicated peat stability risk assessment should be carried out for the site.

2 Site Walkover

The key objective of the Site Walkover is to obtain reliable information from which an accurate analysis of the site can be performed.

Malachy Walsh and Partners undertook a number of site reconnaissance walkovers of the site and proposed infrastructure prior to undertaking the assessment and completing this report. The interpretations and conclusions of this report are made in light of these walkovers and the resultant analytical assessment.

The site is predominantly under commercial forestry management with stands of forestry with a wide range of tree types and ages with much of the forestry in second rotation.

The majority of the site has had extensive drainage works associated with commercial forestry with a full forestry rill and collector network of drains in all the areas under forestry.

For the extent of the southern perimeter a large, deep firebreak has been dug into the peat cover essentially splitting the site hydrologically from the surrounding peat land.

Figure 2-1 Firebreak cut along southern boundary

3 Constraints Managed Infrastructure Design

For the design of the Carrownagowan Wind Farm MWP adopted a constraint driven approach to identifying areas suitable for the construction of civil infrastructure associated with wind turbine delivery and erection. The objective was to reduce the site to areas requiring further detailed assessment.

To this end MWP buffered all existing watercourses, designated areas, areas of high conservation forestry and areas of ecological interest.

Coillte procured high resolution LiDAR topographical surveying of the entire area with associated high resolution aerial photography.

Using the LiDAR data MWP completed slope analysis for the entire site as illustrated below in Figure 3-1.

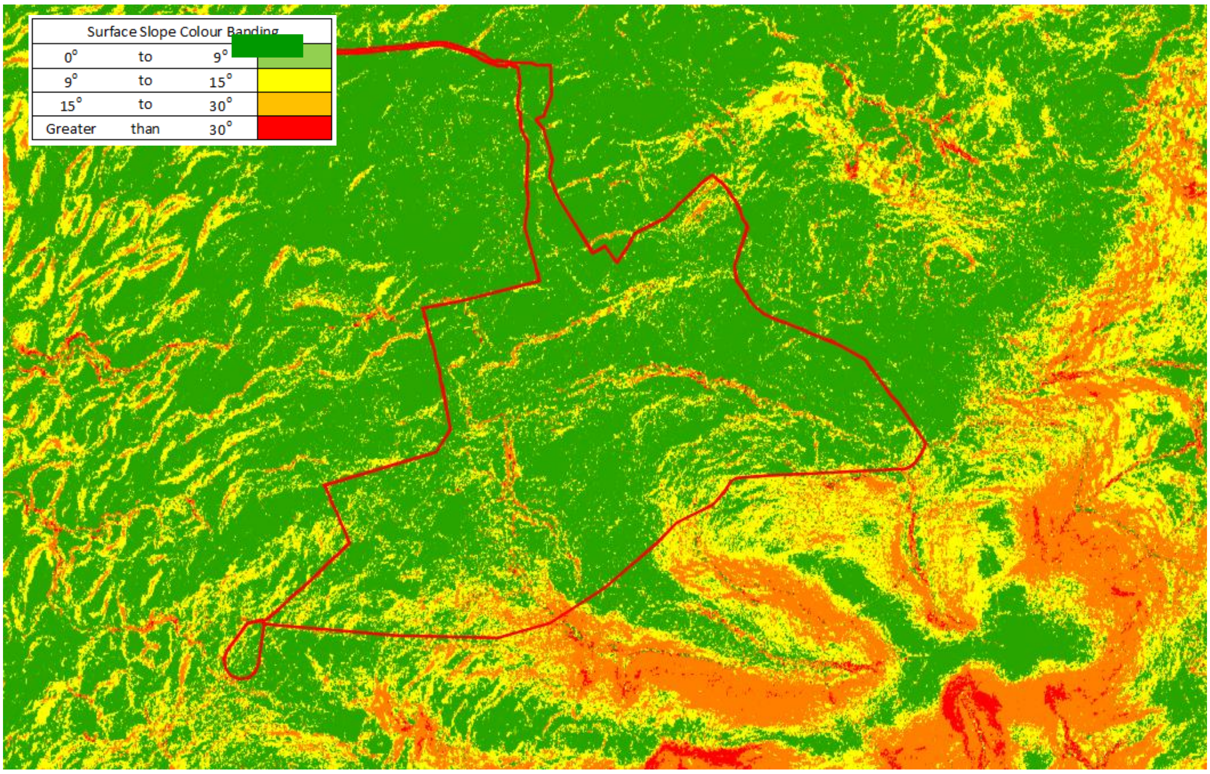


Figure 3-1 – Slope Analysis forinitial study area from High Resolution LiDAR data

MWP used the slope analysis overlapping with other buffers such as stream buffers, housing setback, Designated Area setback to identify areas preferential for turbine infrastructure construction.

3.1 Ground Investigation

MWP completed extensive peat probing of the study area over the course of 16 months from May 2018.

The ground investigation was carried out in an iterative approach where turbine infrastructure locations were proposed using the constraints approach and then ground proofed using peat probing.

The iterative approach to infrastructure layout design using ground slope as one of the primary constraint drivers ensured that the infrastructure location would be suitable for development subject to a peat depth-shear strength combination.

In total 790 peat probes were taken across the study area. The maximum peat depth encountered was 4.0m deep, the minimum depth of peaty cover was 0.05m. The average for the data set across the study area was 1.25m.

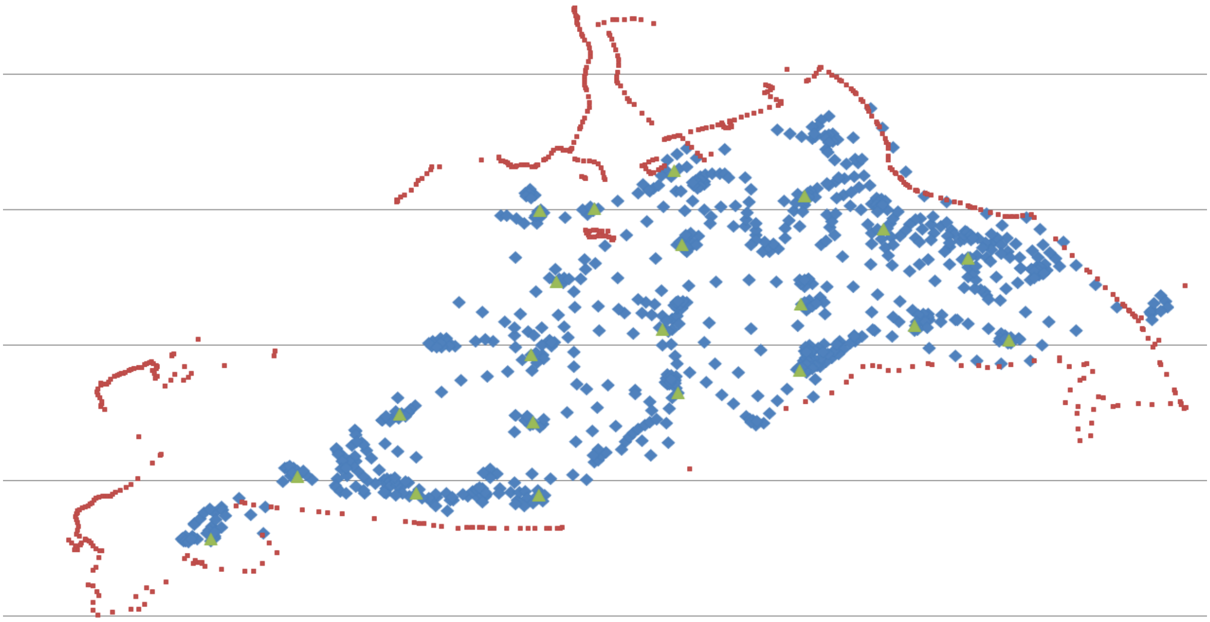


Figure 3-2 - Peat Probing Locations

Shear values were collected at 489 probe locations using a hand shear vane with results which range from 4kPa to 62kPa across the site.

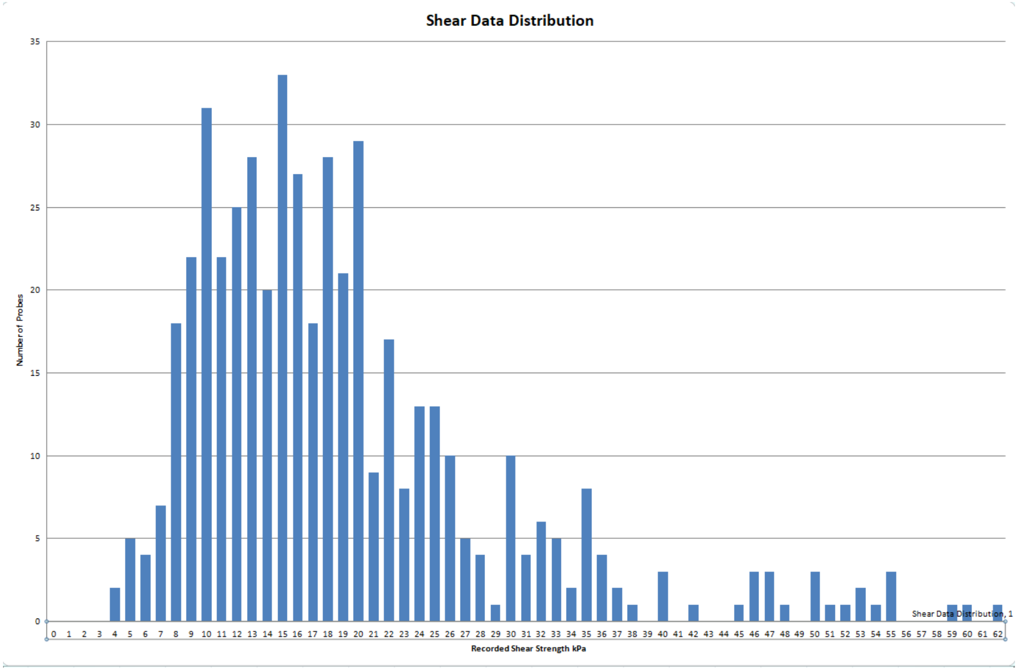


Figure 3-3 Shear data

3.2 Ground Assessment Conclusion

The conclusion of the ground assessment is that the majority of the site is under peat cover. The average peat depth is relatively low at 1.25m but there are areas of deeper peat across the site. While the majority of the site has gentle slopes, there are areas of the site with relatively steep ground gradients. The peat across the site exhibits relatively general high shear strengths but there are pockets of relatively weaker peat present. There are no recorded instances of peat instability within the site but there has been a historic slide on an adjacent hillside.

Due to the presence of areas of deeper peat, steeper ground and some instances of weaker peat within the site it is concluded that a peat stability risk assessment should be undertaken.

4 Peat Stability Risk Assessment

The method chosen for this Assessment, one of the more conservative approaches in terms of incorporating historical land use risk, is the Peatslide Hazard Rating System (Nichol, 2006), which provides a pseudo-quantitative method of assessing the influence of the following hazards, which are widely acknowledged to contribute to an increased risk of peat slide.

1. Rainfall and climate
2. Presence of water on the slope
3. Peat/Sub-strata interface
4. Peat profile and thickness
5. Shear strength of peat
6. Surface slope gradient and regularity
7. Geomorphology and Site History
8. The extent and condition of subterranean drainage pipes
9. Peatslide history
10. Potential impact of peatslides

The impact of each hazard factor is assessed against a cubic exponential scoring system, which reflects the disproportionate increase in risk associated with adverse indicators for each category. Guidance on the selection of scores for each category is provided in the technical paper entitled Peatslide Hazard Rating System (PHRS) for Wind Farm Development Purposes (Nichol, 2006). A common scale of scores is adopted for each category, as follows:

Low Risk – 3 points

Moderate Risk – 9 points

High Risk – 27 points

Very High Risk – 81 points

The rating system provides scope for the discretionary adjustment of scores in some instances. For any given location, the overall risk rating is defined by the sum of the scores assigned to all hazard factors.

This approach is acknowledged as being systematic and compliant with industry best practice guidance, as published by the Scottish Executive (2006).

Table 4-1 Hazard Rating Criteria

Category	Rating Criteria and Score			
	Points 3	Points 9	Points 27	Points 81
Rainfall and climate	Low to moderate precipitation	Moderate precipitation	High precipitation	High precipitation
Presence of water on slope	No water on slope	Intermittent water on slope	Continual water on slope	Continual water on slope
Rockhead or subsoil	Rough and irregular rockhead or granular subsoil of sand & gravel	Undulating rockhead or granular subsoil	Planar and regular rockhead or cohesive subsoil	Smooth, polished and regular rockhead or cohesive clay subsoil
Peat profile and depth	Single layer profile less than 1 m deep	Double layer profile less than 2 m deep	Triple layer profile greater than 2 m deep	Complex profile greater than 4 m deep
Peat strength (vane test)	40 kPa	30 kPa	20 kPa	10 kPa
Slope and slope regularity	2° ; even	5° ; uneven	10° ; irregular	15° ; very irregular
Geomorphology and site history	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
Sub-profile drainage	Few pipes	Occasional pipes	Many pipes	Many pipes and sinkholes
Peatslide history	Few slides	Occasional slides	Many slides	Major peatslides
Potential peatslide severity	Few consequences; small impacted area	Minor consequences; minor impacted area	Many consequences; large impacted area	Major consequences; large impacted area

4.1 Peat Stability Hazard Ranking Assessment

The Hazard rankings for each of the headings in Table 4-1 above are discussed below.

4.1.1 Rainfall and Climate

Rainfall data was obtained from Met Éireann for the study area and is given as 1414mm/Year.

This represents a moderate precipitation hazard for this assessment.

4.1.2 Presence of water on slope

The gradients in the study area are such that water does not persist on slopes but during periods of heavy rainfall saturation of the ground occurs.

This represents an intermittent rating hazard for this assessment.

4.1.3 Rockhead or subsoil

From the peat probing data and trial holes a mixture of rock, granular soils with some cohesive soils were encountered. The rock head observed in road cuttings and existing borrow pits as illustrated below in Figure 4-1 is rough and undulating.

Figure 4-1 Typical soil profile

This represents a low to moderate risk rating for most areas in this assessment.

4.1.4 Peat profile and depth

Peat probing was carried out across the site. The depth and nature of the cover is a blanket peat. The maximum depth to rock or subsoil encountered was 4m with an average cover depth of less than 1.25m.

The profile in terms of this risk assessment is identified for each individual area assessed.

4.1.5 Peat Strength

MWP recorded shear strengths ranging from 4 to 62kpa.

The profile in terms of this risk assessment is identified for each individual area assessed.

4.1.6 Slope and Slope regularity

The slopes ranged from 0° to 25° in localised areas.

The profile in terms of this risk assessment is identified for each individual area assessed.

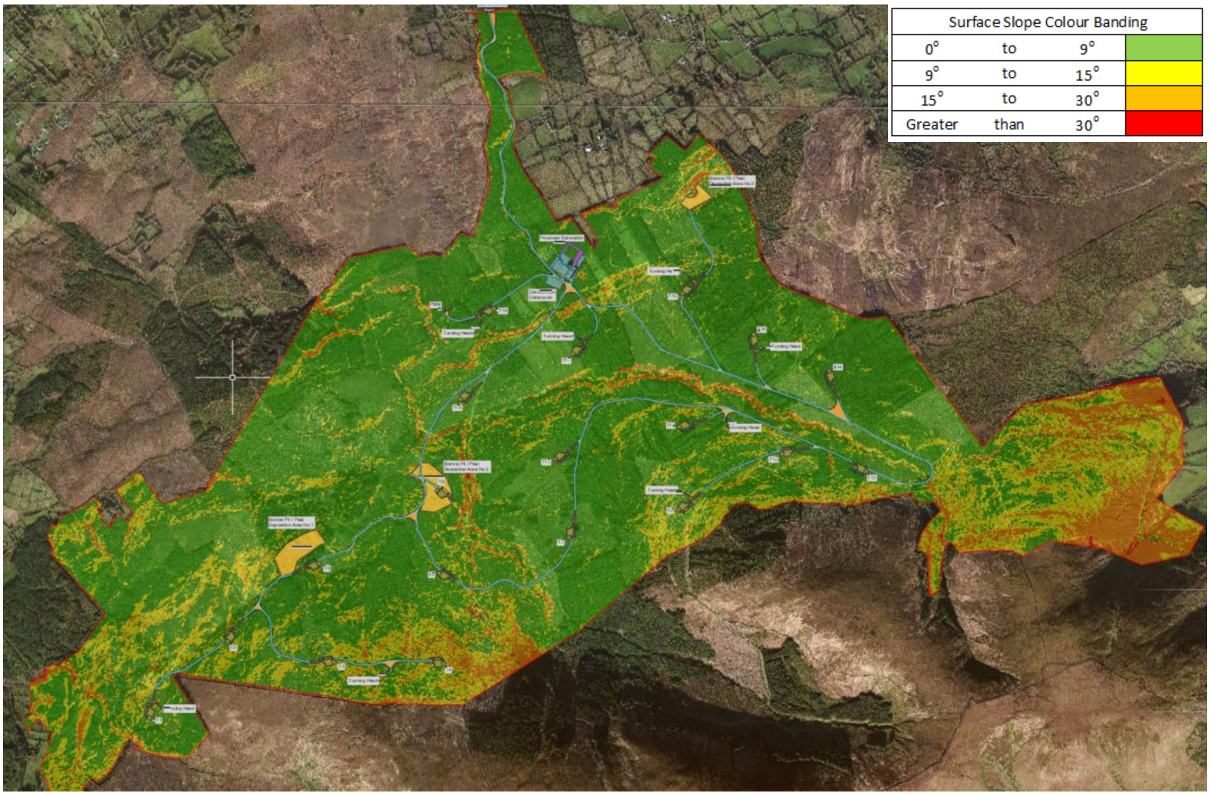


Figure 4-2 – Photo illustrating the slope gradient

4.1.7 Geomorphology and Site History

Natural erosion features such as hags, mounds, ridges, pools and incised streams, as well as disruption of the ground surface by grazing, burning, forestry, drainage ditches, tracks, fence lines and man-made cuttings for fuel, all affect the integrity of the near surface layers of peat and the tensile strength of the root-mat, in particular. In addition, they may create localised over-steepening of slopes or unsupported blocks of peat.

The degree of hazard caused by erosion and degradation, and thus the score given in this category, should reflect how quickly erosion and degradation are taking place, the size of the blocks or units being exposed, and the amount of material being released.

The peaty surface in the study area displays few of the above erosion features. The main geomorphological feature is that the majority of the site has been cut with drains for forestry. The scoring for each area reflects the reletive impact of these drains.

4.1.8 Sub-profile drainage

As a blanket bog develops, over millennia, a network of peat pipes will also develop naturally, with new tributary pipes forming as branches of the primary pipe. The principal pipes within a drainage network may grow to such diameter that the peat forming the roof of the pipe is no longer able to bridge across the void, resulting in collapse. If the debris resulting from roof collapse forms a blockage within a pipe network, groundwater pressures upstream of the blockage may build to such levels that a new spring is formed, and porewater pressures are redistributed within the peat mass, such that the continued development of the critical internal drainage network takes on a new direction.

Within the downstream reaches of a bog drainage network, pipe collapses may join together, so that an open drainage gulley is formed. Such gullies receive and convey both surface water runoff and shallow groundwater flow, emerging from peat pipes. The network of pipes and gullies enable a blanket bog to remain stable under a wide range of groundwater conditions. When a drainage network is interrupted, either due to a natural event, such as pipe collapse or landslide, or due to construction works, an increase in the risk of peat instability will result from the destabilising build-up of elevated porewater pressure within the peat mass.

Few of the above features were observed in the study area.

4.1.9 Peatslide History

There are no recorded peatslide events within the proposed development area. There was one recorded peatslide in Slieve Bearnagh adjacent to the site.

4.1.10 Potential Peatslide Severity

The potential severity of a slide event at each location of infrastructure has been assessed on an individual basis. The potential severity reflects the likelihood of a propagating peat slide to develop a large volume of debris, where that debris trail might run, the ability of a developer to implement containment measures (i.e access roads downslope of infrastructure would allow a quick response for the construction of containment berms), and the proximity of watercourses. The existing slide in Slieve Bearnagh was stopped relatively quickly and the GSI considered it had ‘no apparent impact’.

4.2 Calculation of Overall Peat Stability Hazard Ranking

MWP tabularised the hazard rankings in accordance with the assessment criteria in Table 4-1 Hazard Rating Criteria above.

The findings of the hazard ranking are presented below in Table 4-2 for the area around each element of infrastructure. The ranking for each element considers the roads associated with its construction.

Table 4-2 Hazard Ranking Scores

Hazard Category	Hazard Factor Scores																							
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	BP1	BP2	BP3	PMM	Substation
Rainfall and climate (1414mm/year)	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Presence of Water on Slope	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3	3	3
Peat/Sub-strata interface	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3	3	9	3	3	3
Peat profile and thickness	6	11	10	11	32	29	9	14	11	19	24	34	13	34	5	9	4	5	3	3	6	5	5	3
Shear strength of peat	27	34	65	30	81	3	34	42	30	27	30	42	4	65	27	47	3	81	27	3	30	8	9	27
Surface slope gradient and regularity	12	15	20	31	3	14	11	14	5	5	13	15	5	3	10	7	7	7	3	11	5	13	3	9

Hazard Category	Hazard Factor Scores																							
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	BP1	BP2	BP3	PMM	Substation
Geomorphology and Site History	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3	9	9	3	3	3	3	3
The extent and condition of subterranean drainage pipes	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Peatslide history	3	3	3	3	3	3	3	3	3	3	3	3	9	9	3	3	3	3	3	3	3	3	3	3
Potential impact of peatslides	9	3	3	9	9	3	9	3	15	3	3	3	15	9	9	9	15	3	9	9	9	3	15	3
Peatslide Hazard Rating Score	**96**	**105**	**140**	**123**	**167**	**91**	**105**	**115**	**103**	**96**	**112**	**136**	**85**	**159**	**93**	**114**	**65**	**138**	**78**	**56**	**86**	**53**	**56**	**66**
Peatslide Hazard Ranking	**2**	**2**	**2**	**2**	**3**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**2**	**2**	**1**	**2**	**2**	**1**	**2**	**1**	**1**	**1**

PHRS scores are intended as a means of comparing different sites and as a tool for prioritising mitigation works. The PHRS system itself does not attach any particular significance to the total score for each site and leaves it to the project engineers to draw their own conclusions, based on an understanding of the local conditions that apply. However, industry practice is that sites with an average rating of less than 200 are assigned a low priority, while those with an average rating of more than 400 are identified for urgent attention. All of the PHRS scores assessed for proposed Wind Farm infrastructure locations fall within the Negligible to Low priority range with regard to peatslide risk.

4.3 Peat Stability Risk Assessment

Risk Class	Hazard	Engineering Response
Risk Level 1 (0 to 70)	Negligible	Do nothing. Acceptable.
Risk Level 2 (71 to 140)	Very Low	Monitor and review. Manage by normal slope maintenance procedures.
Risk Level 3 (141 to 200)	Low	Further investigation of the peat slide hazard may be required. Manage by normal slope maintenance procedures.
Risk Level 4 (201 to 300)	Low-Moderate	Peatslide stabilisation works may be required.
Risk Level 5 (301 to 400)	Moderate	Peatslide stabilisation works may be required. Further studies required to refine judgements.
Risk Level 6 (401 to 500)	High	Peatslide stabilisation works likely to be required. Further investigations will be required, including a comprehensive assessment of risks.
Risk Level 7 (>500)	Very High	Large scale mitigation works will be required. Urgent requirements for further investigations, including a comprehensive assessment of risks.

Table 4-3 Risk Assessment Matrix Summary

As can be seen from the PHRS table, with the application of conservative risk ranking criteria for each area of infrastructure, the hazard ranking for the site under this methodology is calculated as **Negligible to Low**.

Hazard Ranking	Area of Infrastructure
Negligible	T17,BP1, BP3, PMM, Substation
Very Low	T1,T2,T3,T4,T6,T7,T8,T9,T10,T11,T12,T13,T15,T16T18,T19
Low	T5,T14

Table 4-4 Hazard Ranking Infrastructure Summary

The Engineering Response for a **Low** hazard rating is that Further investigation of the peat slide hazard may be required.

MWP completed a Further Investigation using Infinite Slope Stability Analysis in accordance with the guidance of the Scottish Government PLHRA (2nd Ed 2017).

4.3.1 Infinite Slope Stability Analysis

The Scottish Executive Guidelines for Peat Landslide Hazard and Risk Assessments recommends the use of Infinite Slope Stability Analysis to calculate a Factor of Safety (FoS) for each area of a study site.

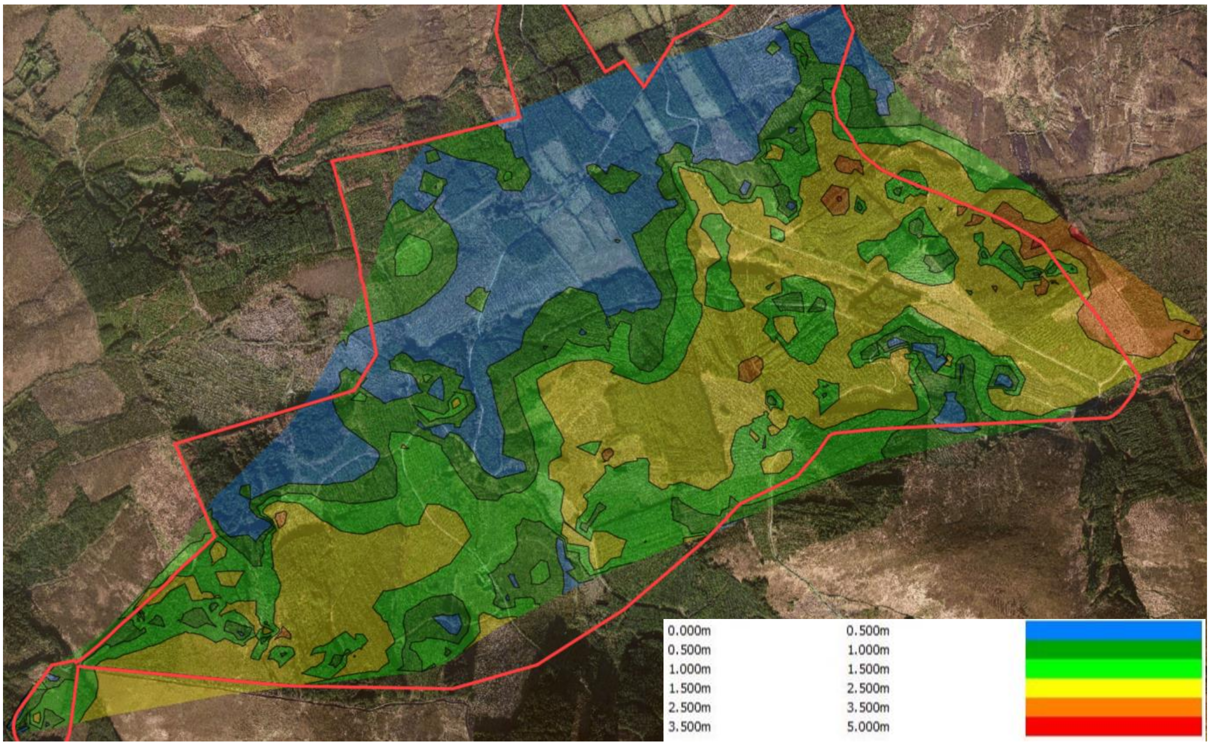
Factors of safety were calculated for the un-drained condition using the equation:

$$FoS = \frac{S_u}{\gamma z Sin\theta Cos\theta}$$

where S_u= Shear Strength, γ = Density, z = depth, θ = Slope Angle

4.3.1.1 Peat Depth Data

As described above a data set of 790 peat probes was collected with their GPS coordinates logged for incorporation into peat stability analysis. The maximum peat depth encountered was 4.0m deep, the minimum depth of peaty cover was 0.05m



4-3 Peat Depth Spatial Distribution

4.3.1.2 Slope Angle

For the purpose of calculating slope angle for each data point of the peat probe dataset MWP employed the Digital Elevation Model (DEM) created using the LiDAR data. For each peat probe point the software interrogated the DEM at 3 points on a 9m radius around the peat probe (identified in red circles in the screenshot below). The software uses the elevation of those three points to create an inclined plane centred on the peat probe, shaded in purple below. The geometric slope of that inclined plane is then calculated mathematically to give the ground slope for each peat probe in the data set.

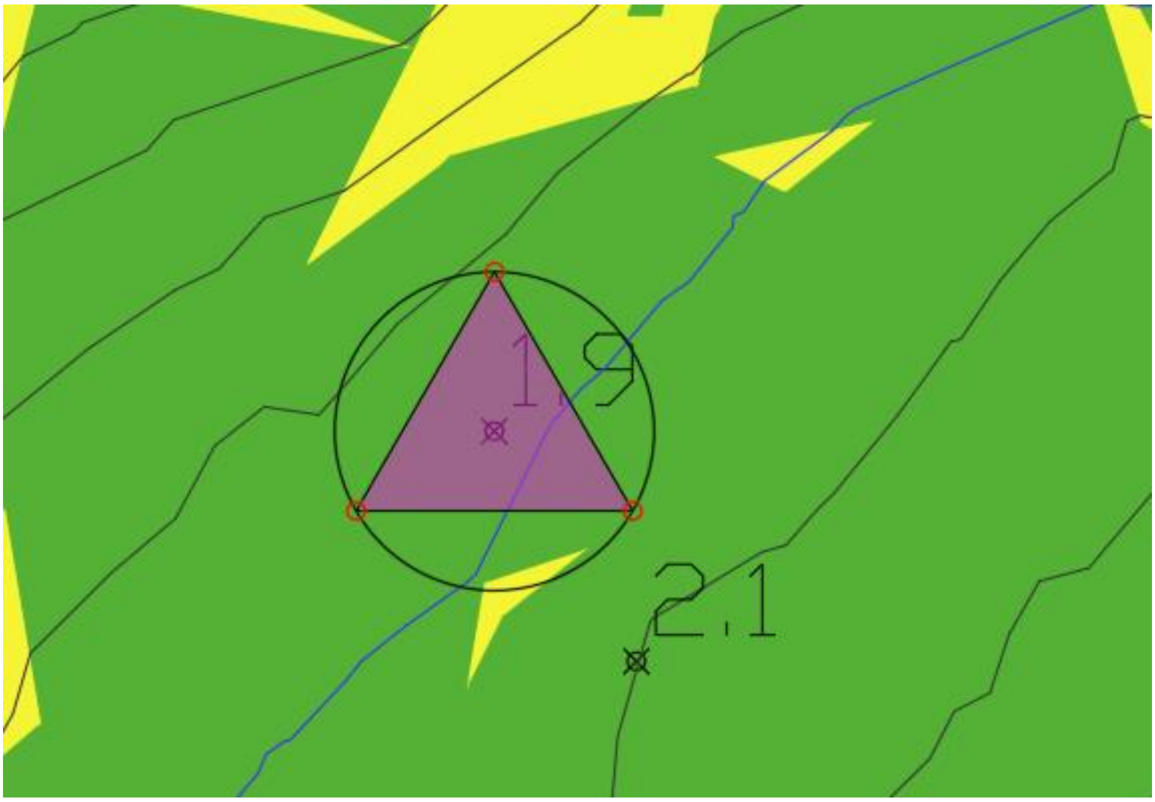


Figure 4-4 Example of DEM interrogation for slope dataset calculation

4.3.1.3 Shear Strength

Shear values were collected at 489 probe locations which range from 4kPa to 62kPa. Where shear data was not collected a default shear value of 7kPa (this represents a value where more than 95% of recorded shear strengths are greater than this value) was allocated to the datapoint for the purpose of calculating a FoS for that data point.

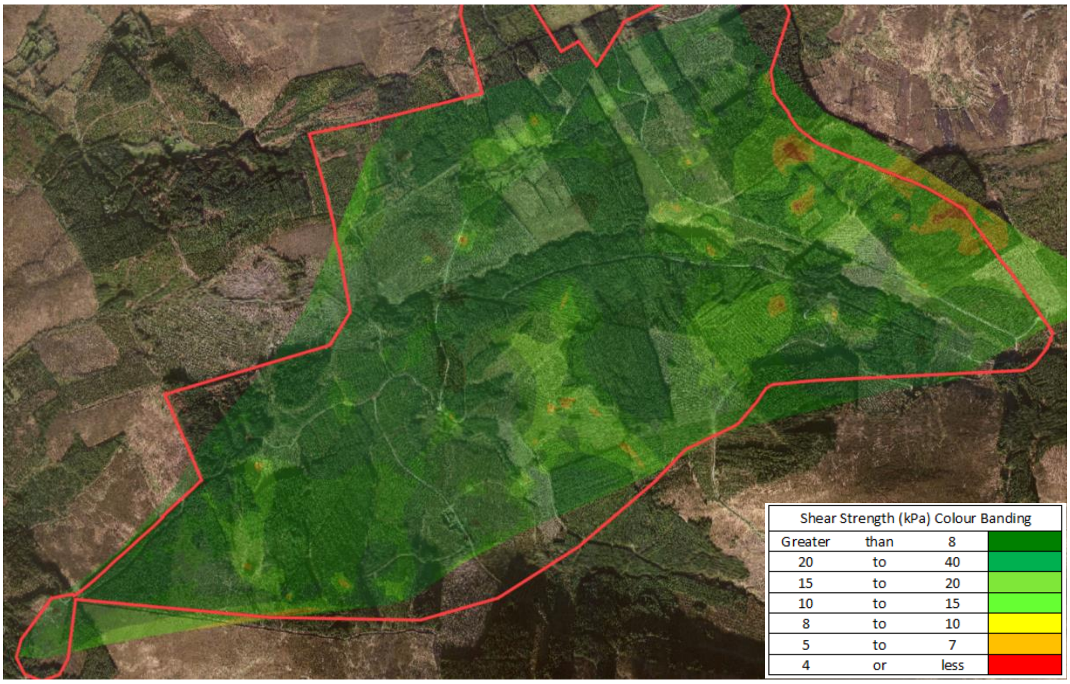


Figure 4-5 Shear Strength Spatial Distribution

4.3.1.4 Density

For the purpose of calculating FoS a density of 10kN/m^3 was employed.

4.3.1.5 Factor of Safety Analysis Output

For the purposes of the stability check the FoS was calculated with 0.5m of peat surcharge across the site.

FoS Analysis was completed for each data point in the peat probe data set. The outputs of these calculations are presented graphically below with colour contouring to illustrate the spatial distribution of calculated FoS across the site.

Factor of Safety Colour Banding			
Greater	than	8	
4	to	8	
2	to	4	
1	to	2	
Less	than	1	

Table 4-5 Factor of Safety Colour Banding

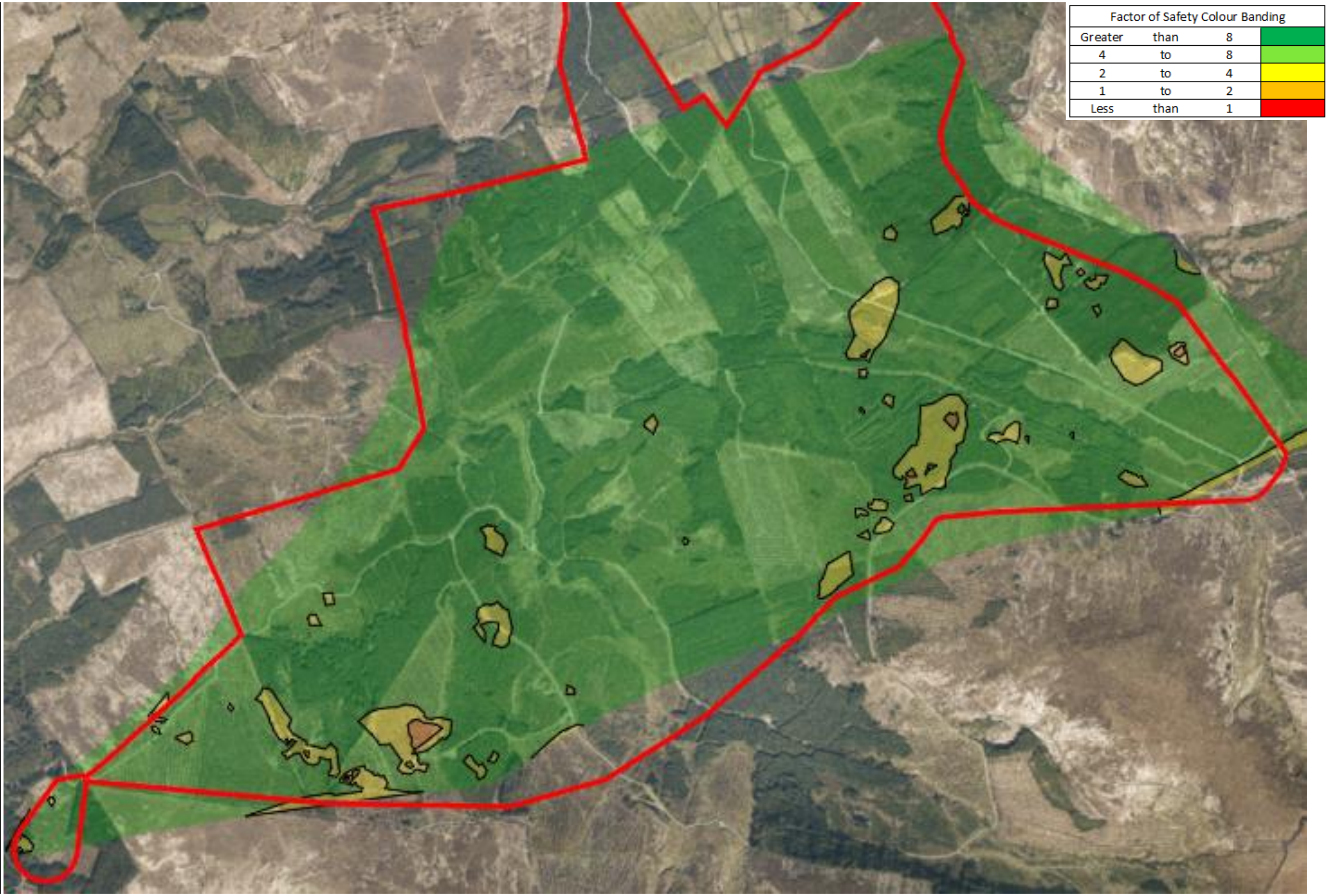


Figure 4-6 Factor Of Safety Mapping for Site

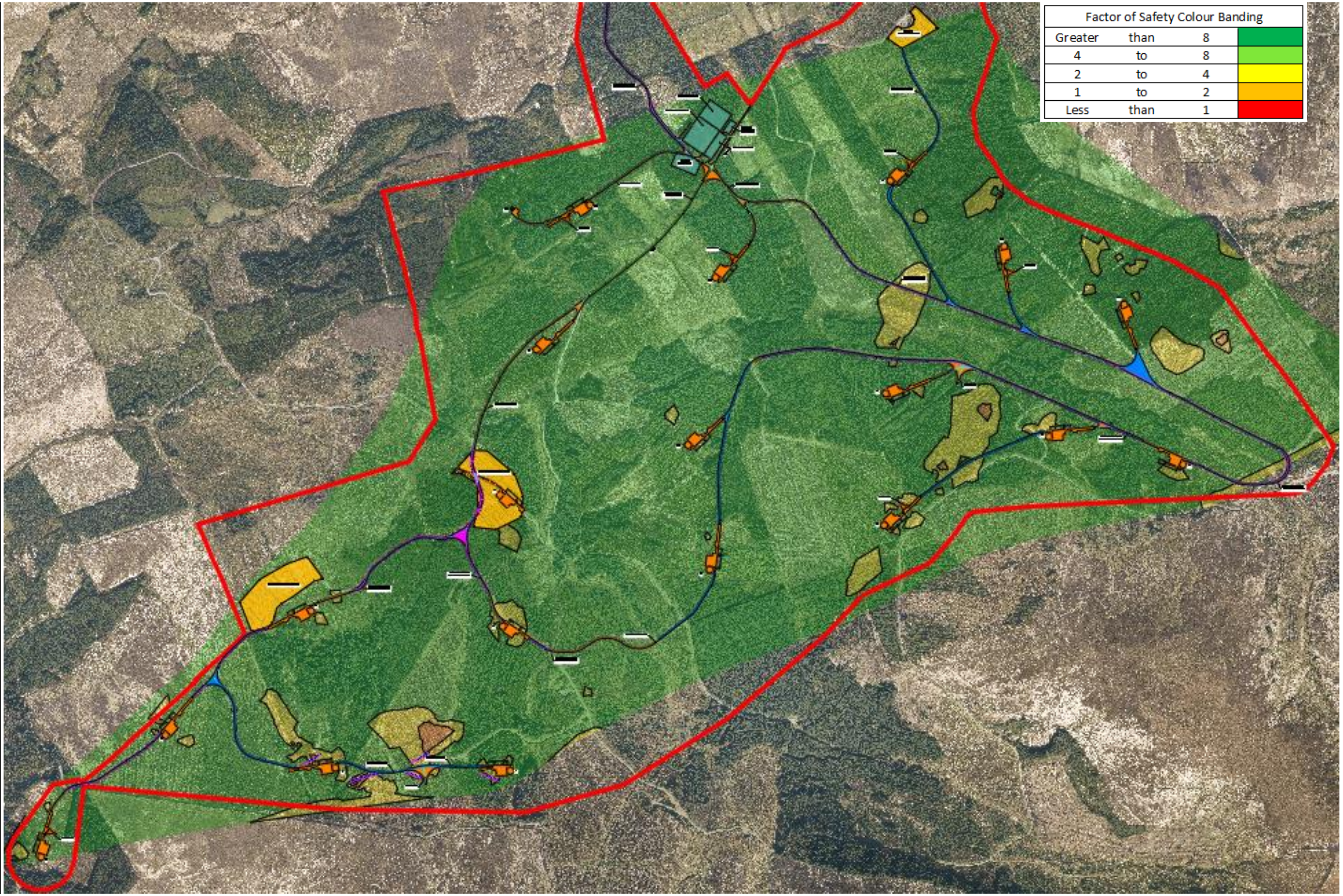


Figure 4-7 Site Layout overlaid on Factor of Safety Mapping

As illustrated in Figure 4-6 above the majority of the site has a Factor of Safety (FoS) against a peatslide greater than 4. This confirms the findings of the Risk Assessment above for the majority of the site. The roads were not broken out and dealt with explicitly in the PHRS table above but the FoS calculations for all the roads are illustrated in the graphical presentations above.

The strategy of identifying areas of the site with lower slopes and peat depths has resulted in the infrastructure located in in areas of low risk. This is illustrated in Table 4-7 Factor of Safety Analysis summary Table below where FoS outputs for baseline condition, and a surcharged condition (1m surcharge for this table) are presented for the 24 no. infrastructure locations used in Table 4-2 above.

Figure 4-7 illustrates the placement of infrastructure in relation to calculated FoS for the Surcharged condition with the majority of the wind farm in areas with a FoS against a peatslide greater than 4. None of the wind farm infrastructure is sited in areas with a FoS less than 2.

4.3.1.6 Factor of Safety assessment per BS6031:1981

The minimum required Factor of Safety (FoS) based on BS6031:1981: Code of Practice for Earthworks (BSI, 2009) is 1.3. The assigned probability of instability associated with a given FoS value is described in below.

Table 4-6: Probability Scale for Factor of Safety.

Scale	Factor of Safety	Probability
1	1.30 or greater	Negligible/None
2	1.29 to 1.20	Unlikely
3	1.19 to 1.11	Likely
4	1.01 to 1.10	Probable
5	<1.0	Very Likely

Employing the BS6031:1981 criteria for probability of instability Table 4-7 Factor of Safety Analysis summary Table has been compiled below for the major infrastructure locations across the site to illustrate the low probability of instability presented by proposed layout design.

Table 4-7 Factor of Safety Analysis summary Table

Infrastructure Location	Easting	Northing	Factor of Safety for Load Condition	
			Baseline (Load Condition 1)	Surcharged (Load Condition 2)
T1	559385	675575	27.99	11.03
T2	559850	676030	11.90	6.49
T3	560484	675908	7.26	3.80
T4	561137	675897	8.68	4.73
T5	560394	676494	12.47	8.69
T6	561109	676437	21.71	14.71
T7	561881	676649	18.21	9.11
T8	562533	676815	9.45	5.51
T9	561098	676928	26.36	14.38
T10	561800	677115	20.79	13.09
T11	562539	677308	8.51	5.57
T12	563149	677146	5.22	3.68
T13	563650	677042	46.01	26.01
T14	563431	677641	12.47	8.80
T15	562982	677858	40.47	13.49
T16	562556	678103	20.78	10.39
T17	561903	677741	262.09	43.68
T18	561234	677472	23.14	6.61
T19	561435	678011	95.51	52.10
PMM	561144	677998	859.61	143.27
BP1	560270	676570	115.43	32.98
BP2	561098	676928	45.19	18.61
BP3	562640	678660	66.88	19.11
Substation	561890	678280	287.41	26.13

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.

4.3.1.7 GSI identified areas of high susceptibility

The GSI identified a portion of the Western site as having high landslide susceptibility. This portion of the site has been investigated in detail and its susceptibility has been assessed and quantified. The Wind Farm Infrastructure has been designed to avoid areas of ground with a FoS less than 2 when analysed with surcharge (Condition2) as illustrated below in Figure 4-8.

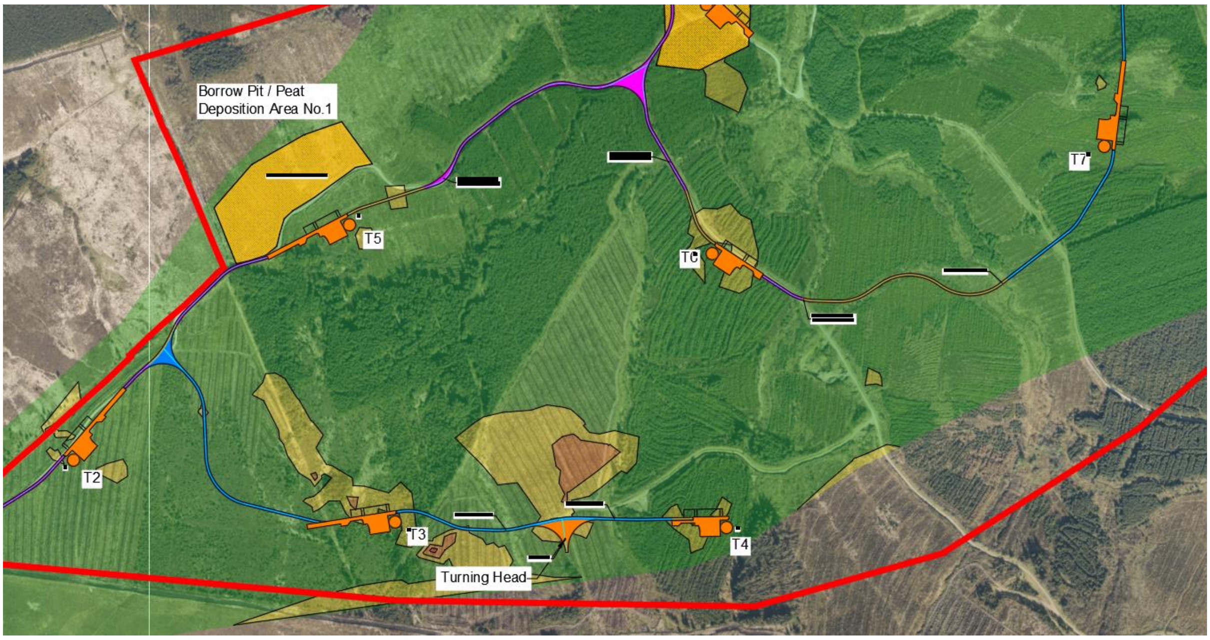


Figure 4-8 FoS Output for Western Turbines

Figure 4-9 Turbine T3 Location from 3D model

Figure 4-10 Turbine T4 from 3D model

4.3.1.8 Nichol PHRS areas requiring further investigation

The Nichol PHRS identified T5 and T14 as having a Low risk requiring further investigation. As illustrated above in Figure 4-8, T5 is located in an area with a FoS greater than 4.

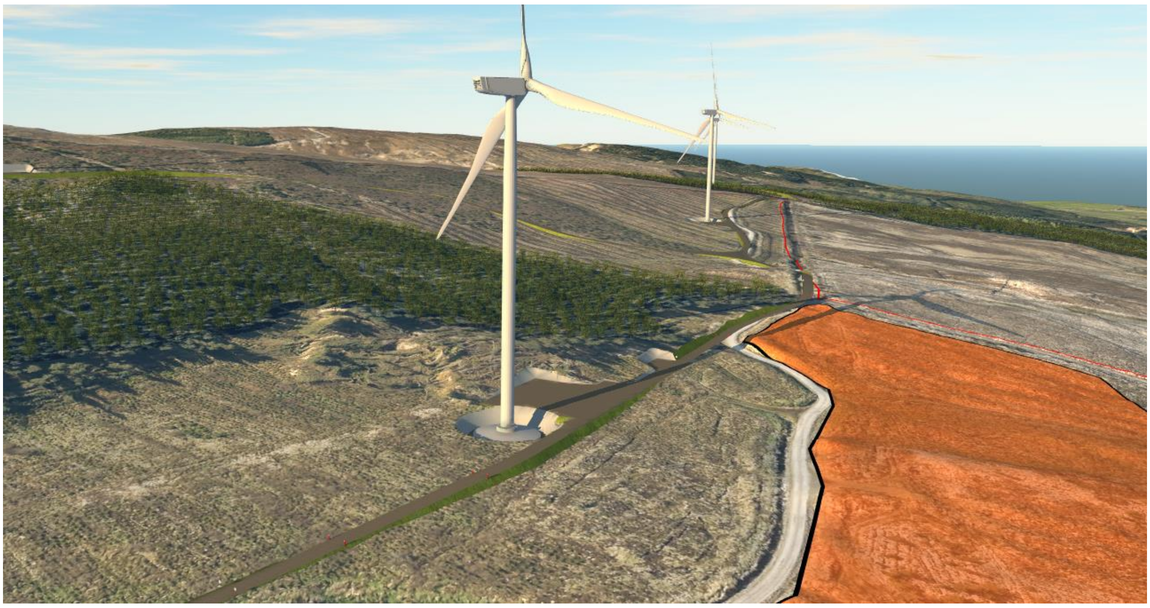


Figure 4-11 T5 Location from 3D Model with BP1 shaded in orange

As illustrated below in Figure 4-12 T14 is located in an area with a FoS greater than 4.

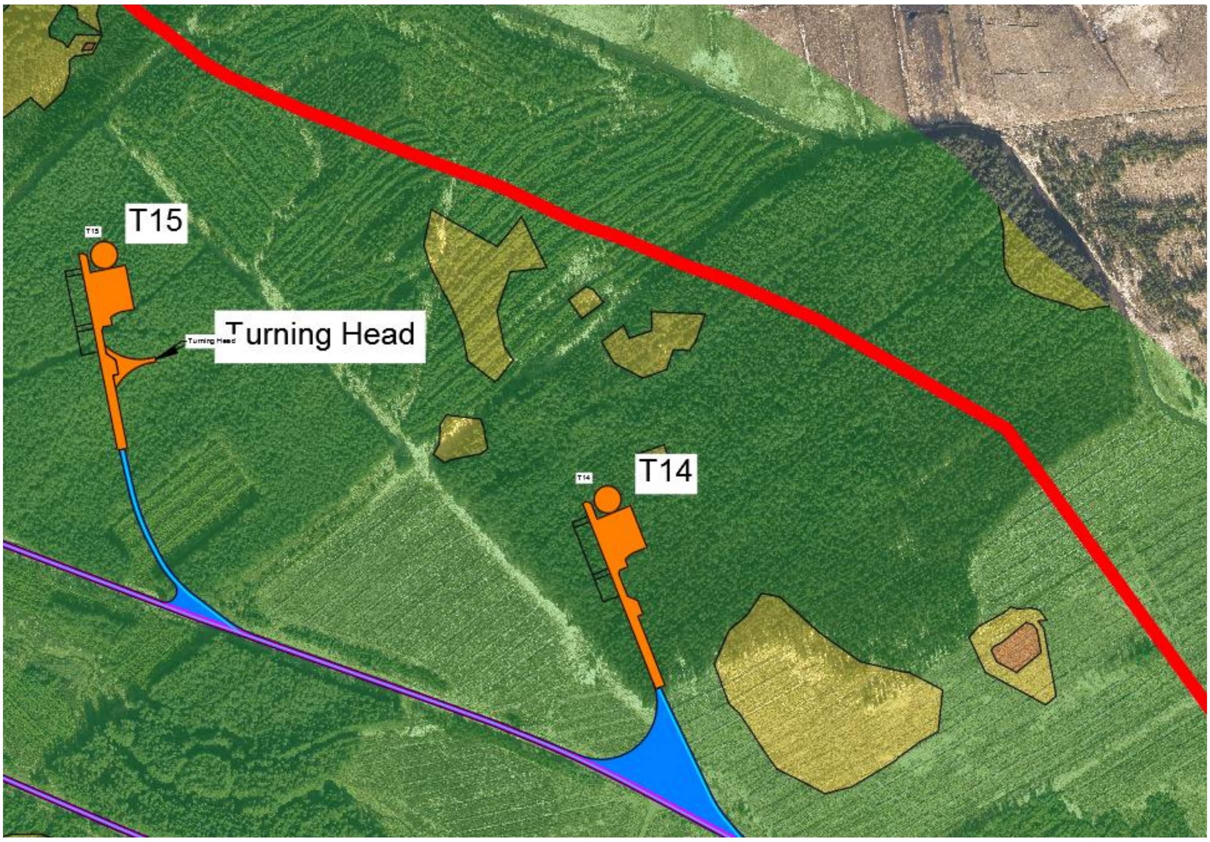


Figure 4-12 T14 FoS calculation output

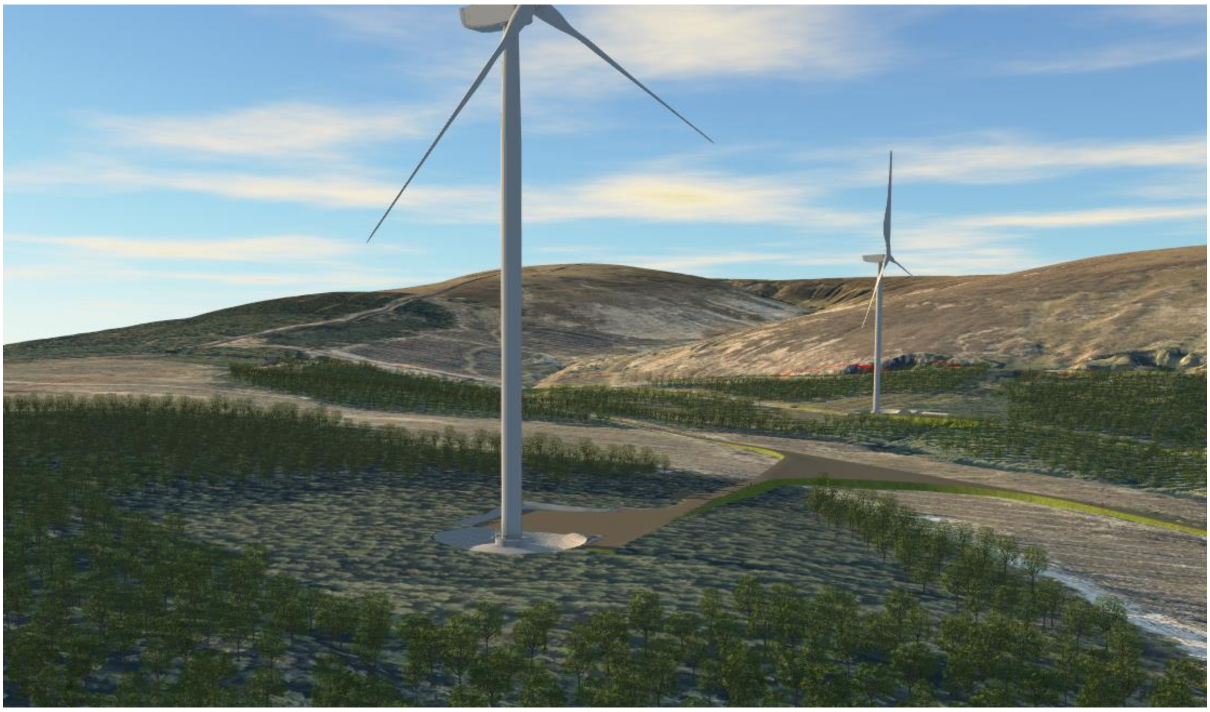


Figure 4-13 T14 Location from 3D model

4.4 Impact Assessment.

The findings of the Peat Stability Risk Assessment is that there is a **Negligible to Low** risk of a peat slide event. This finding is consistent with the initial design constraints approach to identify areas of the site where slope gradients were low and place infrastructure in those areas.

The Scottish Government PLHRA (2nd Ed 2017) offers guidance on Risk Determination. The following tables are taken from that guidance.

Table 4-8 Likelihood Ranking

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

In the case of the study area it is reasonable to rate the likelihood of a landslide run-out occuring on the site over the life of the project as being **Unlikely**

Table 4-9 Impact Ranking

Scale	Adverse consequences	Impact as % damage to (or loss of) receptor
5	Extremely high	> 100% of asset (e.g. infrastructure or habitat)
4	Very high	10% - 100%
3	High	4% - 10%
2	Low	1% - 4%
1	Very Low	< 1% of asset (e.g. infrastructure or habitat)

With no history of slides within the site, examination of the run-out on the existing slide in the adjacent area indicates that the consequence of a slide will impact on a small portion of the surrounding area, <4%, therefore the scale of consequence is defined as **Low.** This finding concurs with the GSI assessments of "No apparent impact" in the landslide records.

The Risk Ranking Matrix is presented below in Table 4-10

Table 4-10 Risk Ranking Matrix

		Adverse consequence				
		Extremely High	High	Moderate	Low	Very Low
Peat landslide probability or likelihood	Almost certain	High	High	Moderate	Moderate	Low
	Probable	High	Moderate	Moderate	Low	Negligible
	Likely	Moderate	Moderate	Low	Low	Negligible
	Unlikely	Low	Low	Low	Negligible	Negligible
	Negligible	Low	Negligible	Negligible	Negligible	Negligible

Table 4-11 Risk Level Action Table

Risk Level	Action suggested for each zone
High	Avoid project development at these locations
Medium	Project should not proceed unless risk can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce risk ranking to low or negligible
Low	Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations
Negligible	Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate

4.4.1 Risk to the Wind Farm Infrastructure

The infrastructure of the Wind Farm itself is robust and would suffer little consequence to a peatslide run-out.

The output of the Risk Ranking matrix is that an **Unlikely** event with a **Low** impact is it represents a **Negligible Risk** level to the project.

The output of a Risk Assessment carried out in accordance with the Scottish Guidance on Best Practice is that peat landslide represents a **Negligible Risk** to the Wind Farm Infrastructure and that the project should proceed with monitoring and appropriate mitigation.

4.4.2 Risk to surrounding Environment

In assessing the risk to receiving Environment, while the likelihood of a slippage remains unlikely, the adverse outcome could be more significant. A peat slide would result in run out of peaty water which would make its way to the streams ultimately draining the area. A set back buffer of 75m has been incorporated to all natural streams in the site.

- In view of the minor scale of landslides to date it is considered that consequences for the receiving environment will still affect less than 4% of the site in such an event and can be considered as a **Low** consequence.

Applying the above criteria to the risk represented by a landslide to the Carrownagowan Site will output an **Unlikely** likelihood of a **Low** consequence which outputs a **Negligible Risk** level. This low risk of a peatslide warrants assessment of mitigation measures as per the recommendations of the Scottish Executive guidelines.

4.5 Mitigation

The findings of the Peat Stability Risk Assessment is that there is a **Negligible Risk** to the project therefore no further design measures are considered necessary.

The level of peat monitoring recommended for the site reflects the strategy of placing infrastructure in low risk areas of the site. With the systematic siting of infrastructure using *mitigation by avoidance* ensuring that deep peat has been avoided, peat stability monitoring methodology relevant to deep peat such piezometry is not considered necessary. Where there are areas of identified higher risk adjacent to work zones the precautionary principle dictates that monitoring should still be carried out in these areas. The most effective monitoring regime is one that is self evident. For the low risk presented on the Carrownagowan site it is considered that this can best be achieved using Sightline Monitoring.

Monitoring by sightlines entails driving a series of posts at approx 5m centres, exactly aligned, across the section of bog being monitored. An illustration of this approach is given below in Figure 4-14 Example of monitoring post layout. Any signs of distress or deformation in the bog will quickly manifest itself by some of the posts moving out of alignment. Early discovery of stress in the peat will give the developer a chance to implement emergency procedures to prevent the onset of a bog burst or localised peat slide. While the risk of such occurrence is low in this instance, the precautionary principle dictates that monitoring posts should be installed in work areas where there are areas of lower Factor of Safety adjacent to the works areas, as defined above.

The Construction Manager for the project should impart the philosophy that everyone on the site is aware of peat stability and report any sign of misalignment in monitoring posts. Vigilance is a fundamental requirement when working on peat where inappropriate construction methodology can cause instability in otherwise benign conditions. A geotechnical engineer experienced in working in the upland peat environment should be employed full time to ensure the implementation of best practice in this environment. The methodology of all civil works should be reviewed by this engineer and the monitoring posts should be the subject of a dedicated inspection on a weekly basis by the geotechnical engineer.

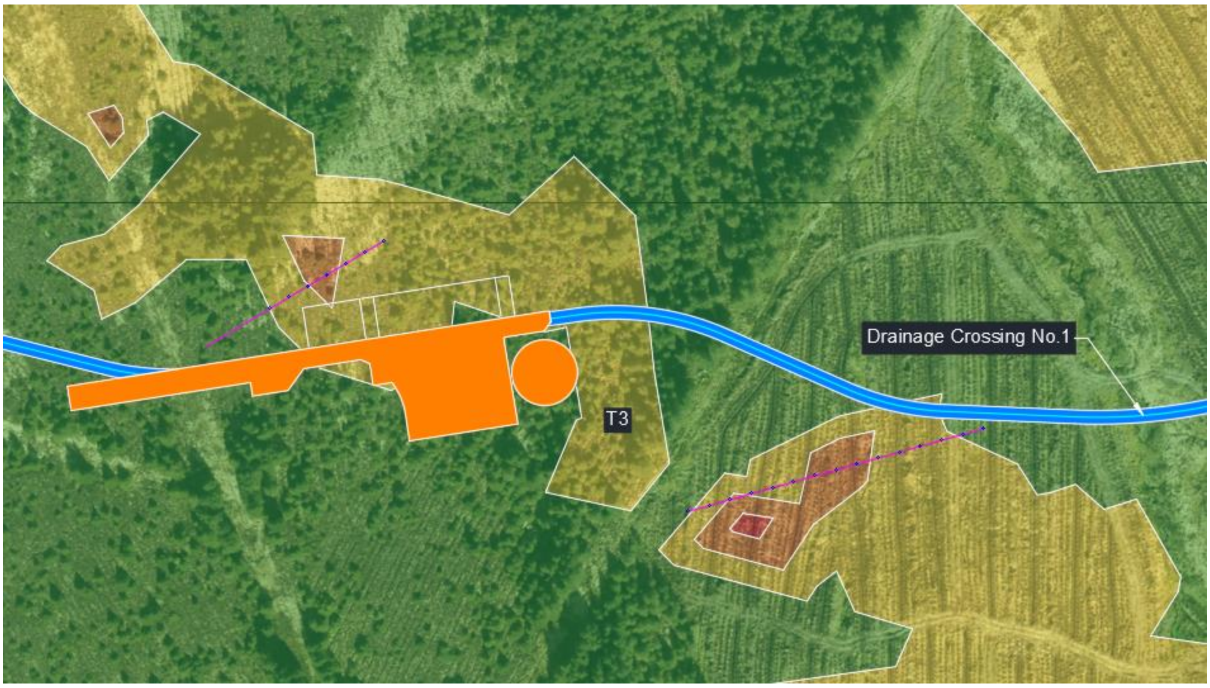


Figure 4-14 Example of monitoring post layout

5 Conclusions

MWP completed a rigourous site investigation and study to compile a comprehensive and extensive data set from which to complete a peat assessment. The study used a combination of analyses to identify the level of risk from peat landslide for the study area site.

From the desk study the GSI identified an area of the site with high susceptibility to landslide. This area was investigated in detail and areas of risk identified were avoided with infrastructure.

MWP employed the Peatslide Hazard Rating System for Wind Farm Development Purposes (Nichol, 2006) to assess the hazard ranking of the study area. The output of this method of analysis was that the area represented a **Negligible to Low Hazard Rating** for peatslide. The findings reflect the mitigation by design philosophy adopted in designing the wind farm infrastructure of avoiding areas of steeper slopes from the outset.

The Engineering Response for a **Negligible to Low** rating in the Nichol PHRS ranges from 'Do Nothing' for a Negligible Risk Level finding to 'Further investigation of the peat slide hazard may be required. Manage by normal slope maintenance procedures' for a Low Risk Level.

MWP completed this further investigation in the form of a stability analysis carried out in accordance with the guidance of the Scottish Government PLHRA (2^{nd} Ed 2017).

As part of the PLHRA assessement an Infinite Slope Stability Assessment was completed and a Factor of Safety (FoS) against slope failure was calculated for the infrastructure. Areas identified for further investigation in the Nichol PHRS were confirmed as suitable with all having a FoS greater than 4.

When assessed using the BS6031:1981: Code of Practice for Earthworks (BSI, 2009) the infrastructure layout has a **Negligable** probability of instability.

MWP progressed the site to a Risk Assessment carried out in accordance with the guidance of the Scottish Government PLHRA (2^{nd} Ed 2017).

The output of the PLHRA was that peat landslide at Carrownagowan presented a **Negligible Risk** to the infrastructure of the Wind Farm and surrounding area.

MWP are satisfied that the risk of peat instability at Carrownagowan has been assessed in accordance with current best practice and that the wind farm infrastructure as designed presents a negligible risk of peatslide.

Appendix 1: Peat Probe Data