Technical Appendix 6.1

Peat Stability Assessment

SCOTTISHPOWER RENEWABLES

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1 Peat Stability Assessment

1.1 Introduction

1. This report forms an appendix to EIA Report **Chapter 6: Hydrology, Hydrogeology, Geology and Soils** and should be read with reference to this chapter and associated figures.

2. The Proposed Development comprises eight wind turbines and associated infrastructure including access tracks and borrow pits. The Proposed Development is located approximately 13km north of Dumfries, entirely within the Dumfries and Galloway Council area, and is described more fully in **Chapter 4: Development Description**. The Site consists mainly of commercial conifer plantation, with clear-felled areas predominantly in the north east. Peat is notable in open areas, such as forestry rides, clearings and in the vicinity of surface water bodies.

3. There are a number of existing tracks within the Site due to current forestry activities and the operational Harestanes Windfarm.

4. WSP was commissioned in 2020 to undertake a peat stability assessment for the Proposed Development, in conjunction with the soil and water elements of the Environmental Impact Assessment.

5. This document presents WSP's method for peat stability assessment, the analyses performed and results obtained.

1.1.1 Aims

6. The broad aims of this assessment were to:

- provide a good level of understanding of site baseline (pre-development) peat stability conditions;
- aid the development design in order to reduce development activities that could cause an increased likelihood of peat stability, by careful consideration of infrastructure location and also construction techniques employed;
- identify the receptors that would be subject to adverse consequences, should a peatslide occur; and
- report peat stability risk assessment outcomes of the final design following the principles of the Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (Scottish Government, 2017b).

1.1.2 Methods

7. The methods adopted by WSP for the peat stability assessment of the Proposed Development has involved the following stages:

- desk study review of peat stability literature and available site data;
- aerial photography review;
- site reconnaissance including peat depth survey to characterise the prevailing ground conditions and identify existing or potential peat instability;
- Ground Investigation (GI) at specific locations of concern to provide additional data;
- initial stability analysis to identify likelihood, using a purposefully cautious factor of safety method;
- identification of receptors;
- initial risk assessment undertaken to identify locations of concern (Moderate or High initial risk level);
- revised risk assessment based on additional site information and visits to locations of concern, presented as datasheets detailing local characteristics and appropriate mitigation for specific locations of concern; and
- summarising key findings, including appropriate recommendations for further investigations at later stages of the development, subject to planning consent.

8. The peat stability assessment applied a phased approach, with findings at each phase feeding into the iterative design process and associated Environmental Impact Assessment (EIA). This included gathering further site information as the design progressed and revising stability calculations using the best information available.

9. Further detail on each of these stages is provided in the following sections, with Geographical Information System (GIS) software employed to manage and identify relationships between the various spatial datasets.

1.2 Desk Study

1.2.1 Literature Review of Peat Stability

10. Peat is a soft to very soft, highly compressible and highly porous organic material which can consist of up to 90% water by volume. Scottish Government guidance defines peat as a soil with a surface organic layer greater than 0.5m depth, which has an organic matter content of more than 60%. Unmodified peat typically has two layers:

- Acrotelm (surface layer) - often around 0.3m thick (but can vary widely in depth depending on local conditions), highly permeable and receptive to rainfall. It generally has a high proportion of fibrous material and often forms a crust under dry conditions.
- Catotelm (base layer) – in deeper peat deposits, this layer lies beneath the acrotelm and forms a stable colloidal substance which is generally impermeable. As a result, the catotelm usually remains saturated with little groundwater flow. A sub-division in catotelmic peat may occur, but is not always present, with fibrous catotelmic peat above amorphous catotelmic peat. Amorphous catotelmic peat is characterised as highly decomposed plant matter, with low structural integrity and may act as a liquid in terms of physical or geotechnical qualities, with associated challenges in terms of excavation, handling and storage.

11. The peat on the Site, where present, is predominantly characterised as peaty podzols and peaty gleys (with associated habitat known forestry plantations, wet heathland, rough grassland communities). They are characteristic of any topographic position where aerobic conditions prevail and water can percolate freely through the upper part of the profile. Podzols are formed in acid, coarse textured, well drained materials. Podzols are widespread throughout Scotland.

12. Small pockets of blanket peat were also noted. Blanket peat tends to form in areas with high rainfall and low temperatures. In the Scottish context, blanket peat can be 5m or more in thickness, especially in hollows or valleys, but is generally not much more than 3m deep and often much less.

13. Peat is thixotropic, meaning that its viscosity decreases under applied stress. This property may be considered less important where the peat has been modified through artificial drainage and is drier but can be an important factor when the peat body is saturated and is an important issue to consider in relation to potential peat stability failures.

14. Peat movements can be small-scale or large-scale. Small-scale movements include slope terracing, slumps, collapse of peat banks and collapses above peat pipe features. These small-scale events are relatively widespread in peatland environments and have limited consequences to receptors, although they do provide useful indicators of peatland morphology and processes which may influence large-scale peat instability.

15. A series of large scale (mass movement) peat events in autumn 2003, including at Derrybrien and Dooncanton in the Republic of Ireland and South Shetland, Scotland, led to an increased recognition of the mass movement hazard, particularly in relation to development design and construction of wind farm projects on peatland. This led to Scottish Government Guidance for energy developments being published in 2006 and updated in 2017 (Scottish Government, 2017b) to assess development risk of peat landslide.

16. Peat mass movement events have been classified by geomorphologists (Dykes & Warburton, 2007), within a Scottish context the primary processes of concern are peat landslides and peaty debris slides, with limited evidence of historic bog bursts and other phenomena. These features are defined below:

- Peat landslide – failure of a blanket bog slope, involving intact peat material shearing and sliding along at, or immediately above, the interface with underlying mineral soil, bedrock or boulder clay substrate (Dykes & Warburton, 2007). The peat above the shear plane generally initially moves as an intact mass, then breaks into smaller pieces and may then act as a liquid flow and follow drainage routes until material has been deposited (Boylan et al., 2008).

- Peaty debris slides - shallow translational failure of a slope, often on very steep gradients, with the failure zone occurring wholly in mineral soil substrate below a shallow organic soil surface layer which may be less than 0.5m depth. Surface peat is sheared and displaced due to failure of underlying material, rather than inherent peat instability (Dykes & Warburton, 2007).

17. In comparison with other peat mass movement phenomena described by Dykes & Warburton (2007), peat landslides and peaty debris slides typically involve lower volumes of material, estimated as 500 - 50,000m^3, with estimated velocities of 0.1 - 5m/s for peat landslides and 0.1 - >10m/s for peaty debris slides.

18. Peatland characteristics that may initially suggest a higher likelihood of peat mass movement, i.e. pre-disposition, include:

- increasing depth of peat;
- increasing slope angle;
- the presence of amorphous peat (well humified/decomposed); with less structural integrity and cohesion to remain on slope;
- convex slopes; instability may occur at or immediately downhill of the 'break of slope', often at the interface of deeper peat on a lower slope angle plateau or ridge; and
- waterlogged peat conditions; providing extra weight upon slope and lubricating transition zone/basal surface between peat and underlying materials, such as clay, mineral soil or bedrock.

19. Specific conditions that are generally recognised as triggers for mass movement of peat include:

- Removal of slope support; reduces slope stability by natural or anthropogenic removal of support material below peat body. Could also be caused by decreased strength of slope materials on a temporal basis.
- Additional loading of slope; reduction in slope stability due to increasing of mass of slope above the peat body. This could be a result of development design or ancillary activities such as stockpiling of materials or heavy plant movement.
- Alteration to drainage patterns; increasing the mass of the peat body and lubricating the transition zone, potentially also increasing pore-water pressure at base of peat body. Can be a particular concern when intense rainfall follows a prolonged dry period, as fissures in peat body may enable rapid ingress to the transition zone. Prolonged wet periods in autumn and winter months in Ireland are considered as having a greater probability for peatslide events (Boylan et al., 2008) and seasonal accumulation of snow may also be a factor, in terms of both weight and snowmelt input.
- Vibration; construction activities such as piling, stockpiling of materials or traffic, including heavy plant, movement. Potentially also caused by earth movement at susceptible geological locations.

20. Examples of mass peat instability can occur involving peat of less than 1.0m depth and on relatively low gradient slopes (<5°), where appropriate combinations of conditions occur. Where depths are relatively shallow and gradients relatively shallow, events may be expected to be more limited in terms of area, volume of material and run-out distance. Peatslide events often commence on a susceptible slope and then follow drainage pathways downslope, with sediment release into such receptors.

21. There are a number of geotechnical variables in relation to peat properties. Those applicable to the Factor of Safety (FoS) stability methodology applied by WSP are detailed below. The FoS calculation and method is discussed further in section 4 of this report. These variables include both site data and values based on academic literature. Where using literature values, conservative values are typically applied as a precautionary approach, which can then be potentially refined where there is justification to do so from further site information:

- Depth of peat - measured on site, to full depth with an accuracy of +/- 0.05m.
- Slope angle – measured using site Digital Terrain Model data at 5m resolution, for both peat probes and using mean values for grid cells.
- Shear strength of peat – shallow shear vane tests were undertaken on site as part of the detailed assessment, but fibre content in peat is likely to over-estimate results and data was not available from base of peat body. Literature values suggest an expected pressure (expressed as force per area) range between 4 - 20kN/m^2 (Boylan et al., 2008), with higher values for less humified/decomposed peat.
- Cohesive strength of peat – back-calculated using site-specific data using a 99th percentile value from the site depth data, this parameter largely dictates the shear strength of the peat in the factor of safety calculation. As above, literature values of shear strength suggest a range between 4 - 20kN/m^2 (Boylan et al., 2008).
- Undrained bulk density of peat – values for *in situ* peat range from 900 - 1300kg/m^3 quoted in various papers and reports, with a typical value of 1,000kg/m^3 (1.0Mg/m^3) referenced in a number of papers (Dykes, 2006 & Boylan et al., 2008).
- Bulk density of water – Standard scientific value of 1,000kg/m^3.
- Water table depth as ratio of peat depth – a value of 1 represents water level being constantly at surface, this is conservative as the water level will vary temporally and geographically across the site, often dropping below ground level.
- Angle of internal friction – this is a difficult item to generalise with variables present in peat (particularly fibre content and water content), a lower angle is more susceptible to movement on a slope. At 'quaking bog' locations, where the peat takes the form of a slurry beneath a surface mat of vegetation, the angle of internal friction will be very low (less than 5°) as the peat will effectively act as a fluid, however peat values of up to 58° are quoted in literature (Boylan et al., 2008).

22. It is important to note that there are a number of limitations and concerns with regard to use of *in situ* shallow shear vane testing of peat and peaty soils, including the presence and orientation of fibres (e.g. vegetation matter) which may lead to an over-estimation of shear strength and that shear vane results from greater depth would be anticipated to record lower shear strength, due to higher level of decomposition and associated loss of structural integrity. The degree of peat decomposition, i.e. classified via Von Post, is considered to be a better practical indicator of shallow shear strength for peat bodies. However, it is considered that shallow shear vane data can provide useful data to enable comparison of different locations across a project area.

23. The Von Post classification system is a field-based method for characterising the level of peat humification/decomposition across 10 classes, with H1 categorised as completely undecomposed peat and H10 categorised as completely decomposed peat. Amorphous catotelmic peat is generally considered to be classified as H6 - H10, i.e. strongly decomposed or greater on this scale (Scottish Government, 2017a).

24. There are a number of recognised indicators that may occur in advance of mass peat instability, with the factors below particularly applicable to low velocity peatslides:

- the development of tension fracture cracking across the slope or in semi-circular patterns, particularly if these reach to base of peat;
- boggy ground or new springs appearing at the base of slopes;
- sudden reactivation of spring lines;
- peat creep or compression features, such as bulging of ground;
- displacement and leaning of trees, fence posts, dykes etc.; and
- breaking of underground services.

1.2.2 Information Sources

25. A desk study was undertaken, reviewing available information on the ground conditions within the development site. Sources included:

- Ordnance Survey digital raster mapping, 1:50,000 and 1:10,000 scale;
- Ordnance Survey Terrain 5 Digital Terrain Model (DTM) data (5m resolution);
- British Geological Survey DiGMap-GB 1:50,000 digital geological mapping, bedrock, superficial and linear geology;
- British Geology Survey GeoSure Landslide Hazards dataset 1:50,000 digital mapping;
- British Geological Survey Hydrogeological Map of Scotland, 1:625,000 scale;
- Ordnance Survey Mastermap Aerial photography;
- Soil Survey of Scotland 1:250,000 Sheet 6 South-West Scotland, mapping of soil types.

1.2.3 Site Context

26. The Proposed Development is located approximately 13km north of Dumfries, entirely within the Dumfries and Galloway Council area. There are a number of existing tracks within the Site due to current forestry activities and the operational Harestanes Windfarm.

27. The Site consists mainly of commercial conifer plantation, with clear-felled areas predominantly in the north east. Peat is present in various pockets across the Site.

28. Elevation of the Site undulates, reaching a peak at Pumro Fell, 393m AOD. There are a number of watercourses which are situated within or border the Site, with the majority of the Site within the Water of Ae catchment. Further geomorphology and hydrology information is provided within EIA Report **Chapter 6: Hydrology, Hydrogeology, Geology and Soils**.

29. Site access is from the A701 at Burrance Bridge, approximately 3.5km north of Parkgate. The Site access then utilises a combination of existing forestry tracks, operational Harestanes Windfarm tracks and new tracks. Existing forestry and operational Harestanes Windfarm tracks shall require upgrade and widening. There will be a requirement for a network of new access to be created within the turbine area to service the infrastructure. These are shown on **Figure 6.1.1 Bedrock Geology** and a number of other figures.

30. From the A701 the access track extends to the north, through an area of forestry and open grassland before reaching a junction north of Whitefauld Hill, to Turbines 5 and 6. The notable steeper slopes are located to the north of the access track, adjacent to the Tor Linn. This watercourse and its tributaries (including Black Linn) drain the majority of the southern access tracks.

31. From the Whitefauld Hill Junction, the track extends to the north first, then west into the western section of the Site where Turbines 1 and 2 are located on higher ground on either side of the Clachanbirnie Burn. The majority of this region of the Site comprises forestry plantation, with some open land in the vicinity of the Clachanbirnie Burn. Slope gradients are mostly gentle, with some steeper slopes within the Clachanbirnie Burn valley and the Clachanbirnie Rig east of Turbine 2. This watercourse drains the western section of the Site and is crossed by the existing track between Turbine 1 and 2.

32. From the track junction north of Whitefauld Hill, additional access tracks extend to the north east and south west through areas of standing forestry and clear-felled areas. Turbines 7 and 8 are located on higher ground on the north east section of the Site. Slope gradients are mostly gentle, with some steeper slopes west of Turbine 7. This area is drained by the Garrel Water tributaries (including Yellowtree Grain). The south west section of the Site extends through a clear-felled area and forestry, with steep slopes in the Glenkiln Burn valley, west of Turbine 3. The track to Turbines 3 and 4 is located parallel to the Glenkiln Burn valley and crosses a number of its tributaries.

1.2.4 Baseline Conditions

33. Baseline conditions in the Site are discussed in detail within **Chapter 6: Hydrology, Hydrogeology, Geology and Soils of the EIA Report**. This chapter should be referred to for this information.

34. **Appendix 6.2 Soil and Peat Management Plan** includes details of peat depths at various infrastructure locations and an analysis of the potential locations where catotelmic/amorphous peat may be anticipated.

35. Cross-sections of Site topography showing infrastructure and Site photographs have been provided in **Chapter 6: Hydrology, Hydrogeology, Geology and Soils**.

1.2.4.1 Geology and Hydrology

36. Baseline information for geology and hydrology is provided in **Chapter 6: Hydrology, Hydrogeology, Geology and Soils**.

37. Bedrock geology, superficial deposits (superficial geology) and hydrology features are presented on **Figure 6.1.1 Bedrock Geology**, **Figure 6.1.2 Superficial Geology** and **Figure 6.1.3 Hydrology Overview** respectively.

38. The distribution of rainfall is provided in Chapter 6 of the EIA Report, however, it is considered that extreme rainfall events are more likely triggers for mass peat instability, as identified in Section 1.2. Such events can occur at any time of year, although those occurring after prolonged dry periods may introduce higher risk as dry peat conditions may be more vulnerable to water ingress to base.

39. Drains are present in areas of afforestation, including clear-fell locations, these have not been mapped for the project, with OS 1:10,000 mapped channels used in GIS and discussed during the assessment. Local drainage channels would be anticipated to reduce slope soil moisture content and reduce mass of peat, however, it is acknowledged that cut drainage channels could remove slope support (if located mid-slope or at base of slope). Drainage discharge locations can exacerbate erosion processes if flows converge at sensitive locations.

40. With much of the Site being subject to afforestation, some of which subsequently felled, the current ground conditions are heavily influenced by forestry practices (particularly drainage and ploughing). Post-felling, stumps and roots have typically been retained *in situ*, potentially acting as limiting factors in terms of potential instability occurrence and also the extent of any mass movement if it were to occur.

1.2.4.2 Carbon Rich Soils, Deep Peat and Priority Peatland Habitats

41. The Carbon and Peatland Map (Scottish Natural Heritage, 2016), a GIS vector dataset covering Scotland, presents the importance of these environmental interests. They have been derived using a matrix of soil carbon categories (derived from Soil Survey of Scotland maps) and peatland habitat types (derived from Land Cover of Scotland 1988 map).

42. With regard to Scottish Planning Policy 2014, carbon-rich soils, deep peat and priority peatland habitat importance categories 1 and 2 from the Carbon and Peatland Map are within Group 2 ('areas of significant protection'), where development should demonstrate that effects can be substantially overcome by siting, design or other mitigation.

43. No Class 1 or Class 2 have been identified within the Site (as shown within **EIA Report Figure 6.4 Soils**). Approximately 17.5% of the Site within Class 0 and 63.8% within Class 5. These classes do not indicate peatland habitat. Class 5 predominates within the Forest of Ae and Class 0 around the perimeter, typically where steeper slopes occur.

44. The outcomes of the more detailed peat survey, discussed below, provide site-specific peat depth information which supersedes the higher-level characterisation from the SNH (NatureScot) Carbon and Peatland Map dataset. This more detailed peat information was used to inform the design of the layout of the Proposed Development and the subsequent assessment. Further information on peat management is provided in **Appendix 6.2 Soil and Peat Management Plan**.

1.2.4.3 Aerial Photography

45. Using the OS Mastermap Aerial photography provided, areas within the Site and particularly within 100m of planned infrastructure were reviewed for potential instability features.

46. Aerial imagery was reviewed for features such as peat landslides, peaty debris slides, gully head failures and collapsing peat banks. Some peaty debris slides were noted on the incised valley of the Glenkiln Burn, these are considered as directly related to fluvial erosion undercutting supporting banks, confirmed during site visit.

47. Aerial Photography of the Site is provided as **Figure 6.1.4 Aerial Photography**.

1.2.4.4 GeoSure Landslide Hazards

48. GeoSure Landslide Susceptibility data from the British Geological Survey was entered into GIS and areas identified as being categorised as GeoSure Landslide Susceptibility Classes D or C were related to the Site and latterly to infrastructure locations. The definitions for these classes are as follows:

- GeoSure Landslide Susceptibility Class D; slope instability problems are probably present or have occurred in the past. Land use should consider specifically the stability of the Site.

- GeoSure Landslide Susceptibility Class C; slope instability problems may be present or anticipated. Site investigation should consider specifically the slope stability of the Site.

49. A number of locations were identified within the Site within Class C and a smaller number within Class D, with this dataset identifying all forms of land instability, including the aforementioned fluvial erosion related peaty debris slides, site visits were undertaken to verify peat instability features.

50. The GeoSure hazard dataset has been incorporated alongside other geomorphology Site data collated and presented on **Figure 6.1.12 Geomorphology Overview** and on datasheets provided in Annex B.

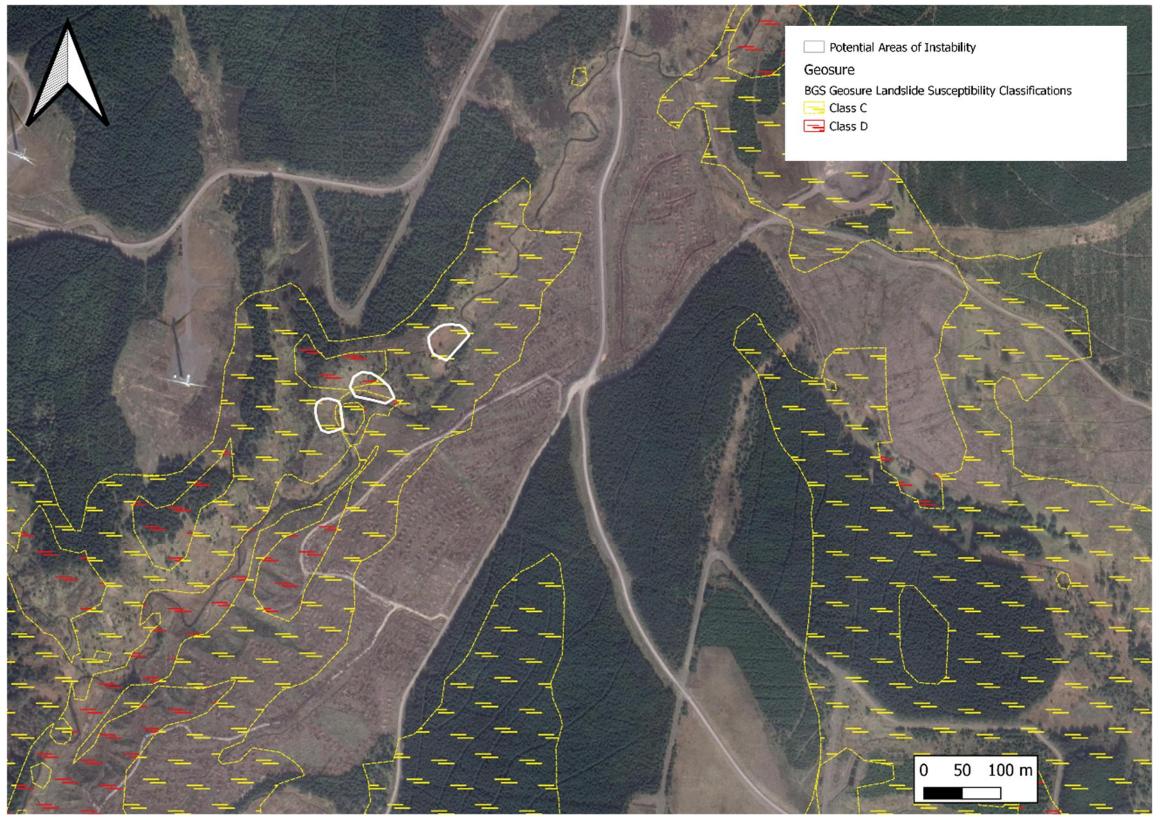

Illustration 6.1: GeoSure and Aerial Image Data, Whitefauld Hill

1.2.4.5 Historical Information

51. The GeoSure dataset alongside the aerial photography provided a useful indication of landslide or potential landslide locations. **Illustration 6.1** displays site aerial imagery with areas of potential instability adjacent to the Glenkiln Burn identified from this data by WSP and GeoSure data overlain.

52. There is evidence of slope instability (peaty debris slides) on steep incised valley slopes within the Site, noted from mapping, GeoSure Landslide Hazard dataset and aerial photography. Representative locations were visited, targeting those in closest proximity to planned infrastructure, to establish any causal relationship with peat at such locations during the assessment process.

53. No major peat instability was noted within or on the margins of the Proposed Development, including an extensive forestry track network. No mass peat instability was recorded at the adjacent operational Harestanes Windfarm which has been operational since 2014, with ScottishPower Renewables also developing the neighbouring project.

1.2.5 Forestry

54. Forestry within the site covers an area of 6,943.7ha and is discussed in detail in **Appendix 13.1 Forestry**. Forestry is located across the whole Site. The forests are planted on blanket peat, peaty podzols and peaty gleys.

55. The Proposed Development would use a ‘keyhole’ approach to the siting of turbines within the forest, to retain as much forestry as possible. It is anticipated that construction of the Proposed Development would require approximately 82.23ha of mostly commercial plantation woodland to be felled to facilitate construction works and installation of permanent features such as the turbines and access tracks; some of which would be subsequently restocked.

56. As a result of the construction of the Proposed Development, there would be a net loss of woodland area. The area of stocked woodland in the study area would decrease by approximately 61.23ha. In order to comply with the criteria of the Scottish Government's Control of Woodland Removal Policy offsite compensation planting would be required. The Applicant is committed to providing appropriate compensatory planting. The extent, location and composition of such planting would be agreed with Scottish Forestry.

57. In relation to impacts from felling in afforested peatlands, impacts may include water level rising post felling, peat cracking due to drying out of the surface peat, and drainage changes causing peat to dry and shrink (Lindsay & Bragg, 2004). This may cause peat to become more unstable and such areas require consideration in relation to the proposed scheme infrastructure.

58. Some areas of the Site have been felled, with it likely that further felling will occur as crop reaches maturity or for other forestry management requirements, regardless of the proposed application.

1.3 Site Reconnaissance and Field Surveys

59. Walkover and peat probing surveys were carried out at various stages between March and September 2020. These surveys focused on gaining a good overall understanding of the site and collecting representative peat depth data, where forest access was possible, including all infrastructure locations and nearby areas highlighted for further investigation from desk study or earlier phases of the peat stability assessment. The weather during the site visits was generally good, although heavy rain conditions did occur during some visits. There were no occasions where frozen conditions prevented peat depth results being accurately recorded.

60. Site visits often collated multiple sets of site data concurrently, for example peat probing alongside peat coring and visits to areas suspected of instability from aerial photography. These items have been discussed separately but integrated visits enabled a better understanding of peat features at specific locations.

1.3.1 Site Reconnaissance

61. **Photographs 6.1** to **6.9** provide images and descriptive text of a representative sample of the Site, identifying the range of landforms observed. It should be noted that these photos provide context and do not necessarily indicate the location of infrastructure, which has been located to avoid the steepest and deeper peat areas, where possible. Additional photographs are provided in Annex B.

62. There were locations on site where peat instability such as peat debris slides or other evidence of peat erosion caused by fluvial erosion was noted.

Photograph 6.1: Looking north towards the Tor Linn from the break of slope at NGR 303696, 590745.

Photograph taken at approximately 155mAOD on the southern banks of Tor Linn in the southern part of the Site, looking north from the break of slope. This location was identified for its steep gradient using OS mapping and Digital Terrain Model (DTM) and visited due to the proximity of the proposed track to be upgraded. Measured peat depths in the area are generally less than 0.5m. At the location where the photograph is taken, the slope angle is approximately is 25 degrees, decreasing to 10 degrees upslope of the break of slope. Although fallen trees were abundant on this steep slope, there were no signs of peat instability or mass movement.

This area is discussed in Peat Stability Assessment (PSA) Area A in Annex B.

Photograph 6.2: View south west to Whitefauld Hill from top of existing quarry, from NGR 302484, 593948

Photograph taken at approximately 355mAOD at the top of the existing quarry in the eastern part of the Site, where steep gradients were identified using OS mapping and DTM. Measured peat depths in the area were up to 0.9m at the top of the slope. At the location where the photograph is taken, the slope angle is approximately 14 degrees, increasing to 44 degrees downslope when entering the quarried area. Although afforestation masks the topography, this image also shows the typically gentle slopes identified across the majority of the Site.

The northern extent of PSA Area B including Peat Core PC03 location is shown in the background of this image; as the clear-felled area to the right of the parked vehicles.

Photograph 6.3: View north west from top of steep slope towards the Glenkiln Burn, from NGR 301717, 593217

Photograph taken at approximately 290mAOD, east of the Glenkiln Burn in the central part of the Site. This location was identified for its steep gradient using OS mapping and DTM and visited due to the proximity of Turbine 4. The slope at this break of slope location is approximately 32 degrees, decreasing to 10 degrees downslope. Measured peat depths at the top of the slope are between 0.2m and 0.4m and therefore not considered a peat zone. Evidence of slope instability were noted within these incised banks of the Glenkiln Burn (also see Photograph 6.4).

Photograph 6.4: View west towards eroding channel bank of the Glenkiln Burn, from NGR 301909, 593478

Photograph taken at approximately 305mAOD in the central part of the Site, showing recent and active erosion as the less vegetated surface immediately below the break of slope (tree zone), on the right Glenkiln Burn bank. This more recent slope instability has occurred within an incised valley region where numerous historic features were noted, with a range of sizes. The average slope gradient derived from the DTM at the eroding bank location is 15 degrees. This is considered a debris slide, other locations nearby where peat is present may be considered as peaty debris slides, where the underlying materials and slope are the causal factors, rather than surface peat.

This area is discussed in PSA Area B in Annex B.

Photograph 6.4: View west towards eroding channel bank of the Yellowtree Grain, from NGR 303228, 593371

Photograph taken at approximately 305mAOD in the central part of the Site, showing active erosion on the right Yellowtree Grain bank, with a shallow surface peat layer underlain by boulder clay containing mineral soil material. The average slope gradient derived from the DTM at the eroding bank location is 10 degrees. This is a non-peat failure.

Photograph 6.6: View looking north upstream on the Ox Cleuch, from NGR 301660, 593821

Photograph taken at approximately 320mAOD at the proposed crossing location of the Ox Cleuch, in the northern central part of the Site. Measured peat depth at this crossing was 1.40m. The slope gradient is gentle and the flow observed was slow at the time of visit. The watercourse is located within an incised channel and downstream there is evidence of bank collapse, as a non-peat failure.

Photograph 6.7: View looking north from PC01 at NGR 300492, 593418

Photograph taken at approximately 340mAOD at the proposed PC01 location, showing a semi-natural forestry drainage channel within conifer plantation in the north western part of the Site. Measured peat depths in the area ranged between 0.1m and 2.75m. The slope gradient is gentle and no apparent runoff was noted at the time of the visit.

Photograph 6.8: View looking east within the existing quarry from NGR 162216, 162230

Photograph taken at approximately 365mAOD showing exposed peat bank within the existing quarry. This horizon shows approximately 0.5m of peat, overlying boulder clay and sandstone material. This situation is typical on this site, based on depth records.

Photograph 6.9: Looking west at existing track embankment at NGR 303641, 590718, as per the viewpoint shown.

Photograph taken at approximately 170mAOD, looking west along existing track embankment to the north of the track to be upgraded.

This location was identified as an Initial Risk concern due to its steep gradient using OS mapping and DTM, in tandem with the proximity of the proposed track to be upgraded. Measured peat depths in the area are generally less than 0.5m. Such bankings were noted in various trackside locations and may skew slope stability results when combining the artificially engineered slope angle with the depth of banked material. At the location where the photograph was taken, the slope angle is approximately is 5 degrees, increasing to 15 degrees at the break of slope. Although fallen trees were abundant on the steep slope below, there were no signs of peat instability or mass movement.

This area is discussed in PSA Area A in Annex B.

Photograph 6.10: View west towards eroding channel bank of the Glenkiln Burn, from NGR 302099, 593853.

Photograph taken at approximately 305mAOD in the central part of the Site, showing active fluvial erosion on the right bank of the Glenkiln Burn, with a shallow surface peat layer (approximately 0.5m depth) underlain by boulder clay containing mineral soil material. The average slope gradient derived from the DTM at the eroding bank location is 5 degrees. This is a non-peat failure.

This area is discussed in PSA Area B in Annex B.

1.3.2 Peat Depth Survey

1.3.2.1 Fieldwork

63. The peat depth survey for the Proposed Development was undertaken in a number of phases. Initially, peat probing was undertaken between March and July 2020 focussing on the areas in which the Proposed Development infrastructure corridors were proposed. This allowed a representative dataset of peat depths on a variety of landforms, adjacent to stream channels, adjacent to existing tracks and across slopes where potential infrastructure would be required. The provisional turbine layout provided by the Design Team was also probed.

64. Following data gathering and processing of the peat depth results, areas of confirmed or suspected deeper peat were identified and initial observations relating to peat stability were made (using the factor of safety technique detailed later in this report but with the abbreviated dataset available at this stage).

65. Following this feedback, plus input from other disciplines, a number of changes were suggested for the design and the site was revisited during August 2020 and further peat data gathered to refine our knowledge of conditions in specific areas. Infrastructure locations were probed, with the strategy to gain depths every 50m along track routes with additional depth data at turbine and borrow pit locations. This information fed into the final design decision.

66. Upon provision of the final design, the complete layout was reviewed to identify locations where further data was required, with revisions to turbines, tracks and crane hardstandings visited in July 2020. During this visit, further peat probe records were also gathered at locations where there was potentially deeper peat or stability concerns at locations close to planned infrastructure.

67. Additional peat probing was undertaken as part of the peat stability risk assessment visit in September 2020, alongside other peat-related data collation, including aerial photography verification, shallow shear vane tests and peat coring for Von Post assessment and laboratory analysis, to further inform the understanding of peat characteristics and stability factors at identified locations of concern.

68. The peat depths were measured using Van Walt peat probing rods, consisting of multiple connecting 0.94m fibreglass sections, with depths measured via tape measure to an accuracy of ±0.05m. The rods were pushed into the ground until they could be pushed no further, with the depth recorded. There were 1,207 peat depths recorded on the Site, with no results exceeding the depth of peat probes, the deepest record being 3.4m, located 480m from the nearest infrastructure, north east of Main Rig in the east of the Site.

69. The collected data from the initial peat probing survey are summarised in **Table 6.1**; 65% of the points probed had a peat depth result of less than 0.5m, with 89% of the results less than 1.0m and the average peat depth was 0.48m. The peat depth results are mapped and presented as **Figure 6.1.5 Peat Overview**.

70. Note that no peat probing was undertaken adjacent to the cable routes to the existing substation to the north of the Site, as the existing access track is generally considered ‘fit for purpose’ for access requirements for the Proposed Development, with a small number of road widening requirements. Peat, should it be present at these locations, would be expected to be shallow and not subject to stability concern given existing infrastructure adjacent and no previous peat instability noted.

Peat/Soil Depth Range (m)	Number of locations surveyed	Percentage of locations surveyed	Average depth in range (m)
0.0 to <0.5	779	64.5%	0.22
≥0.5 to <1.0	294	24.4%	0.65
≥1.0 to <1.5	65	5.4%	1.18
≥1.5 to <2.0	28	2.3%	1.70
≥2.0 to <2.5	19	1.6%	2.20
≥2.5 to <4.0	22	1.8%	2.75
≥4.0	0	0.0%	N/A
Total / Aggregate	**1,207**	**100.0%**	**0.48**

Table 6.1: Results of the Peat Probing Survey

1.3.2.2 Indicative Peat Depth Mapping

71. The use of a regular grid for terrain analyses of this type is a standard recognised GIS technique and is widely applied in a range of situations. A grid system allows the application of a systematic process across the landscape, where a set of relevant properties need to be assigned to each particular location. In this analysis, these properties include slope angle and peat depth.

72. The resolution of DTM and base mapping must be taken into account, as using a very fine grid with a resolution identical to or finer than the DTM will return spurious results with a false indication of accuracy. For the Proposed Development, a 50m grid was used in line with WSP's established peat stability analysis method as this is a fine enough scale to provide an appropriate level of detail for analysis but also sufficiently large to gain meaningful results from the 5m resolution DTM and derived slope model.

73. To inform the refinement of the infrastructure layout, the results of the initial peat probing survey were used to produce an extrapolated indicative peat depth map for the Study Area. A grid of 50m x 50m cells was overlaid across the Site and a peat depth range assigned to each. The peat depth ranges used are detailed in **Table 6.2**. Following final design, the peat depth grid was cropped to limit data to that within 250m of the Site boundary, expanded beyond this where peat probing data was available, this dataset includes all Site infrastructure and also peat survey data collated from earlier design iterations.

74. As discussed previously, no peat probing was undertaken adjacent to the cable route as any peat present was anticipated to be shallow and not subject to stability concern, therefore, the peat grid was limited to the area considered of peat stability concern where new tracks, turbines and associated infrastructure are proposed.

Peat Depth Range (m)	Peat Depth Category Number	Peat Depth Category
0.0 to <0.5	1	No Peat
0.5 to <1.0	2	Shallow
1.0 to <1.5	3	Moderate
1.5 to <2.0	4	Moderately Deep
≥2.0 to <2.5	5	Deep
2.5 to <4.0	6	Very Deep
≥4.0	7	Exceptionally Deep

Table 6.2: Indicative Peat Depth Categories

75. Peat depth category names and ranges were chosen in the context of windfarm construction; for example, the threshold between cut-and-fill and floating track construction is typically around 1.0m or 1.5m peat depth. Equally, the practicalities of constructing turbine foundations in peat more than 2.5m deep makes this a less attractive option. The threshold for very shallow peat of 0.5m is based on the Soil Survey of Scotland definition (The James Hutton Institute 1982), as used in the Scottish Government guidelines (Scottish Government, 2007).

76. **Illustration 6.2** shows an enlarged portion of the peat depth mapping. Each cell is 50m x 50m with peat categories colour-coded as per **Table 6.2**. The full indicative peat depth map across the Site is included as **Figure 6.1.5 Peat Overview** and **Figures 6.1.5a-c.**

77. From observation, it is clear that both slope and elevation have an influence on the development of peat, although the exact mechanism is not definitive and there is no mathematical growth/decay model for the development and depth of peat. However, slope and elevation factors may be used intuitively when extrapolating from peat sampling data in the creation of an indicative peat depth map. It is often evident that deeper peat is generally found in flatter areas such as valleys, plateaux and hollows. Flat areas on hill summits tend to have relatively little peat; this is possibly due to a combination of exposure and slow growth rate as well as better drainage. Steep slopes also generally have less peat, owing for the most part to their better drainage and more rapid runoff.

78. As can be seen from **Illustration 6.2** and **Figure 6.1.5 Peat Overview, Figure 6.1.5a Peat Western, Figure 6.1.5b Peat Eastern,** and **Figure 6.1.5c Peat Southern**, where a cluster of peat probing points is all within the same peat depth category this has been taken as a good indication of the general peat depth in the surrounding area and the indicative peat depth map has been coloured accordingly. However, where clusters of peat probing points have returned depths in a range of depth categories a cautious approach has been taken, with the indicative peat depth map being classified in line with the deepest category of peat found in the area. This leads to a conservative indicative peat depth map.

79. The peat depth category breakdown for both the actual probing data and the extrapolated grid is given in **Table 6.3**. On **Table 6.3**, the rows representing indicative peat depth grid data for 'measured depths' represents those cells generally closest to the planned infrastructure and thus more representative of site conditions underlying and close to the Proposed Development.

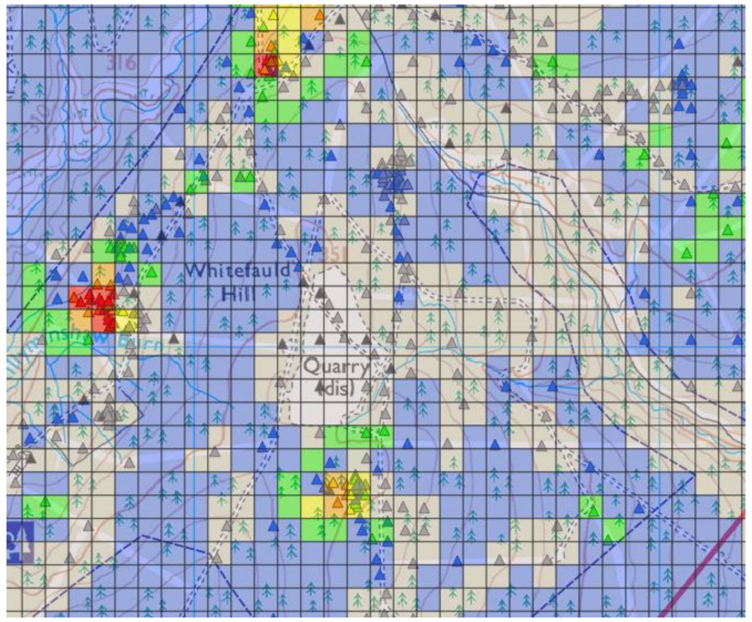

Illustration 6.2: Sample of Indicative Peat Depth Map, Whitefauld Hill

Peat Depth Range (m)		<0.5	0.5 - <1.0	1.0 - <1.5	1.5 - <2.0	2.0 - <2.5	2.5 - <4.0	≥4.0	Total
Probing Data	No. of points	779	294	65	28	19	22	0	1,207
	% of points	64.5%	24.4%	5.4%	2.3%	1.6%	1.8%	0.0%	**100.0%**
Indicative Peat Depth Grid	No. of cells	2,191	4,737	153	35	18	11	0	7,145
	% of cells	30.6%	66.3%	2.1%	0.5%	0.3%	0.2%	0.0%	**100.0%**
Indicative Peat Depth Grid (measured depths)	No. of cells	534	227	48	22	12	11	0	854
	% of cells	62.5%	26.6%	5.6%	2.6%	1.4%	1.3%	0.0%	**100.0%**

Table 6.3: Peat Depth Category Breakdown

1.3.3 Peat Cores and Shear Vane Data

80. Peat core locations were selected to specifically target areas where peat depths had previously been recorded that exceeded 1.0m, close to the final design, with core data collected on 23rd September 2020 using a Russian corer and details provided in **Table 6.4**.

81. From Site samples, one location exhibited a Von Post value of H6 humification (PC01a), suggesting that amorphous catotelmic peat may be present at a depth of 1.7m but less humified material was identified at the same core location at a depth 3.0m (PC01b), this is unusual as typically deeper peat would be expected to display a greater degree of humification. This outcome suggests the threshold for this material can be expected to vary with local conditions, perhaps with the lower material subject to differing drainage or vegetation inputs than the layer above or the presence of the local drainage channel may have altered shallow peat water content.

82. Wet bulk density results from the four cores issued to the laboratory ranged from 0.89 - 1.15Mg/m^3, these undrained bulk density values correlate well with the literature value of 1.0Mg/m^3. Dry bulk density was analysed as ranging from 0.11 - 0.15Mg/m^3. The bulk density laboratory outcomes are based on remoulded samples of peat presented, with this technique likely to lead to slightly greater bulk density outcome than *in situ* conditions (remoulded due to laboratory error). Core pH values were between 5.3 - 7.6 and total organic content (TOC) ranged from 16 - 19%.

83. Shear vane results provide information on the shear strength of the soil, which for peat is typically dictated by cohesive strength characteristics (Boylan et al., 2008). Shear strength of peat is generally considered to range between 4 - 20kN/m^2 (Boylan et al., 2008), with Site results of 6 - 27kN/m^2, similar to the literature expectation. These were collected adjacent to core locations at shallow depths (0.3m to 1.0m). However, it is important to note that there are a number of limitations and concerns with regard to use of *in situ* shallow shear vane testing of peat and peaty soils, as discussed in the Literature Review section, with a lower bound value of 4kN/m^2 from literature review considered more appropriate and conservative. The shear vane used was calibrated in 2016, however, this equipment is not in regular use and is considered reasonably accurate for the purpose of establishing general peat characteristics. The Von Post classification is considered a more pragmatic indicator of shear strength characteristics from field data.

84. The level of decomposition at the representative peat core locations are less than may be typically expected in peat, indicating that some core locations would be expected to have a greater structural integrity and of less sensitivity in terms of excavation and re-use. The laboratory bulk density data is inconclusive but the pH and TOC analysis indicates that the cores collected represent peaty soils, with peat expected to have more acidic characteristics and a greater content of organic material.

85. Amorphous catotelmic peat has been considered present for the Proposed Development and various threshold depths discussed in **Appendix 6.2 Soil and Peat Management Plan**, with a conservative threshold depth between acrotelmic and catotelmic peat suggested as 1.5m, however Site data suggests non-catotelmic material is often present at deeper threshold depths.

86. The geotechnical input provided to date does not replace geotechnical site investigations that would take place prior to construction commencing to inform the detailed site design, with the above information intended to provide design advice and the basis for assessment for the purposes of the application submission.

87. Peat core locations are presented on **Figure 6.1.6 Peat Core Locations**, with photographs for PC01-PC04 provided in Annex D. Data from these sources were applied to the datasheet locations provided in Annex B.

Peat Core ID	National Grid Reference	Core Depth (m)	Core Description and Results	Core Location Information
PC01a	NGR 300492, 593418	1.7	Von Post H6 - Strongly Decomposed. Considered amorphous catotelmic peat. Approximately one third of peat expressed, wetter peat probably due to the core being located within a watercourse. Shallow shear vane results taken at 0.3m depth: - 34 division: 11kN/m^2; - 42 division: 14kN/m^2; - 22 division: 7kN/m^2. Peat core shown on **Photograph 6.13**, Annex D.	No visual evidence of instability, low gradient, even slope. Conifer plantation, with moss carpet. Forestry drainage present.
PC01b	NGR 300492, 593418	3.0	Von Post H5 - Moderately Decomposed. Root fibres evident. Small amount of peat expressed, no water expressed. Laboratory analyses undertaken on sample returned: - Bulk density = 1.15Mg/m^3 - Dry density = 0.13Mg/m^3 - pH = 7.6 - Total Organic Carbon (TOC) = 19% Peat core shown on **Photograph 6.14**, Annex D.	No visual evidence of instability, low gradient, even slope. Conifer plantation, with moss carpet. Forestry drainage present.

Peat Core ID	National Grid Reference	Core Depth (m)	Core Description and Results	Core Location Information
PC02	NGR 302120, 593758	1.4	Von Post H5 – Moderately Decomposed. Root fibres evident. High plasticity and mouldable, peat expressed through fingers. Shallow shear vane results taken at 0.3m depth: - 42 division: 14kN/m^2; - 34 division: 11kN/m^2; - 84 division: 27kN/m^2. Laboratory analyses undertaken on sample returned: - Bulk density = 0.89Mg/m^3 - Dry density = 0.11Mg/m^3 - pH = 6.1 - TOC = 16% Peat core shown on **Photograph 6.15**, Annex D.	No visible evidence of instability in vicinity to the core. Signs of fluvial erosion related slope instability on opposite bank of Glenkiln Burn channel. Topography is steeper towards the watercourse. Artificial embankment on the track, which might affect the factor of safety calculations. Clear felled area, with forestry drains. This core location is noted on PSA Area B in Annex B.
PC03a	NGR 302172, 593616	1.5	Von Post H4 - Weakly decomposed. Expressed brown turbid water, no peat expressed. Shallow shear vane results taken at 0.3m depth: - 38 division: 12kN/m^2; - 40 division: 13kN/m^2; - 58 division: 19kN/m^2. Peat core shown on **Photograph 6.16**, Annex D.	No visible signs of instability in the surroundings. Topography is relatively level, sloping from south to north towards the track. Clear felled area with legacy forestry drainage. Tree roots are likely to bind the surface soil. This core location is noted on PSA Area B in Annex B.
PC03b	NGR 302172, 593616	3.0	Von Post H4 – Weakly Decomposed. Some peat expressing through fingers, turbid water and plant structure very distinct. Shallow shear vane results taken at 1.0m depth within a drainage channel: - 20 division: 6kN/m^2; - 52 division: 17kN/m^2; - 54 division: 17kN/m^2. Laboratory analyses undertaken on sample returned: - Bulk density = 1.10Mg/m^3 - Dry density = 0.13Mg/m^3 - pH = 6.0 - TOC = 17%	No visible signs of instability in the surroundings. Topography is quite flat, sloping from the south to the north towards the track. Clear felled area with legacy forestry drainage. Tree roots are likely to bind the surface soil. This core location is noted on PSA Area B in Annex B.
PC04	NGR 302338, 592682	1.7	Von Post H5 - Moderately Decomposed. Some peat expressing through fingers, little plant material on the sample and not water coming through. Shallow shear vane results taken at 0.3m depth: - 45 division: 15kN/m^2; - 62 division: 20kN/m^2; - 50 division: 16kN/m^2. Laboratory analyses undertaken on sample returned: - Bulk density = 1.10Mg/m^3 - Dry density = 0.15Mg/m^3 - pH = 5.3 - TOC = 16% Peat core shown on **Photograph 6.17**, Annex D.	No visible evidence of instability. Topography is flat. Forestry plantation with moss carpet. This core location is shown on **Photograph 6.7** in the Site Reconnaissance Section.

Table 6.4: Peat Core and Additional Ground Investigation Data

1.4 Factor of Safety Analysis

88. To establish the stability of peatland areas, WSP applies the 'Factor of Safety' methodology. This procedure involves the application of site data (peat depth and slope angle) alongside 'values for a number of further variables, with the more sensitive of these being the values allocated for cohesive strength and *in situ* (undrained) bulk density of peat. The values applied are based on literature review and are generally considered conservative, in accordance with a purposefully precautionary approach.

89. This peat stability assessment initially determines areas considered of greatest risk of slope failure, based on factor of safety slope stability calculations, these areas were then considered in greater detail, including site visits to gather further information.

90. Using the collated data an initial analysis of slope stability can be carried out using the infinite slope model. The stability of a slope can be assessed by calculating the factor of safety F which is the ratio of the sum of resisting forces (shear strength) and the sum of the destabilising forces (shear stress):

$$F = \frac{c' + (\gamma - m\gamma_w) z \, Cos^2\beta \, Tan\phi'}{\gamma z \, Sin\beta \, Cos\beta}$$

91. Where c' is the effective cohesion, γ is the unit weight of saturated peat, γ_w is the bulk density of water, m is the height of the water table as a fraction of the peat depth, z is the peat depth in the direction of normal stress, β is the angle of the slope to the horizontal and φ' is the effective angle of internal friction.

92. The Factor of Safety (FoS), F, represents the ratio of the forces resisting a slide to the forces causing the material to slide. If F > 1 then the slope is stable and normally if F >1.4 then there is a degree of comfort that the slope will not fail. The boundary value of 1.4 is in agreement with the current recommendations of Eurocode 7 (BSI, 2004 & 2007).

93. To get an indication of the stability of the peat at the proposed windfarm infrastructure locations, the factor of safety can be calculated for each peat probing location. In addition, to gain a better view of peat stability in the areas surrounding the infrastructure, factor of safety calculations can be carried out for the grid cells of the indicative peat depth map in the vicinity of the infrastructure.

94. To do this, we must know or be able reasonably to infer the parameters for the FoS equation for each probing location and grid cell under construction.

95. The slope angle, β, can be derived from the DTM for the Site. With the peat probing locations, a single slope angle value is generated for each point, whilst the DTM is interrogated for maximum, minimum and mean slope values for each grid cell. The mean slope angle has been used in the grid FoS calculations, although the other statistics provide useful supporting information on the variability of slope within the cells.

96. The actual peat depth measurements recorded for each probing location are used in calculating the point FoS values. For the grid-based FoS assessment it is necessary to convert the indicative peat depth ranges into a specific figure for each range for use within the calculation (where no measured depth was recorded) and using the maximum depth record for cells with measured depths. Taking a conservative approach, the upper bound of each range has been used, where actual data is not held. Measured peat probing depth records are presented as a histogram in **Illustration 6.3**, with 65% results less than 0.5m and 89% less than 1.0m.

97. The bulk density of water, γ_w, is known to be 1.0Mg/m^3.

98. The bulk density of peat is known to vary with the level of decomposition. A literature review has found quoted *in situ* undrained bulk densities ranging from 0.5 to 1.4Mg/m^3. Laboratory analyses undertaken on samples collected by or on behalf of WSP from other projects have returned bulk density values generally ranging between 0.8 and 1.4Mg/m^3, with results for this Site within this range, recorded as between 0.89 and 1.15Mg/m^3. Based on this experience and also after reviewing externally published values (Lindsay, 2010 / Scottish Government, 2017a / Dykes & Warburton, 2007 / Boylan et al., 2008) an average wet bulk density value of 1.0Mg/m^3 has been applied for the initial FoS calculations.

99. If it is assumed that the Site is covered with active blanket bog, it follows that the peat must be completely saturated, with a water table at or close to the surface. On-site observations indicate that this assumption is only valid on limited, low slope angle, areas of the site as ground conditions were fairly dry underfoot across much of the Site. Consequently, a water table ratio, m, of 1.0 has been chosen, which is considered conservative given most of the Site exhibits drier conditions, but may occur locally during or following heavy rainfall 'trigger' events.

100. The angle of internal friction in peat also varies, decreasing with increasing decomposition and moisture content. For the FoS calculations, a φ' value of 5° has been selected as per WSP's conservative approach.

101. Finally, a value for the effective cohesion, c', must be derived. Literature values for c' in peat vary widely, generally ranging from 4 - 20kN/m^2. To provide an indication of the cohesive strength of the peat at this Site, a back-calculation using the FoS equation and actual peat depth probing data for the Site has been completed. The techniques involved are discussed below.

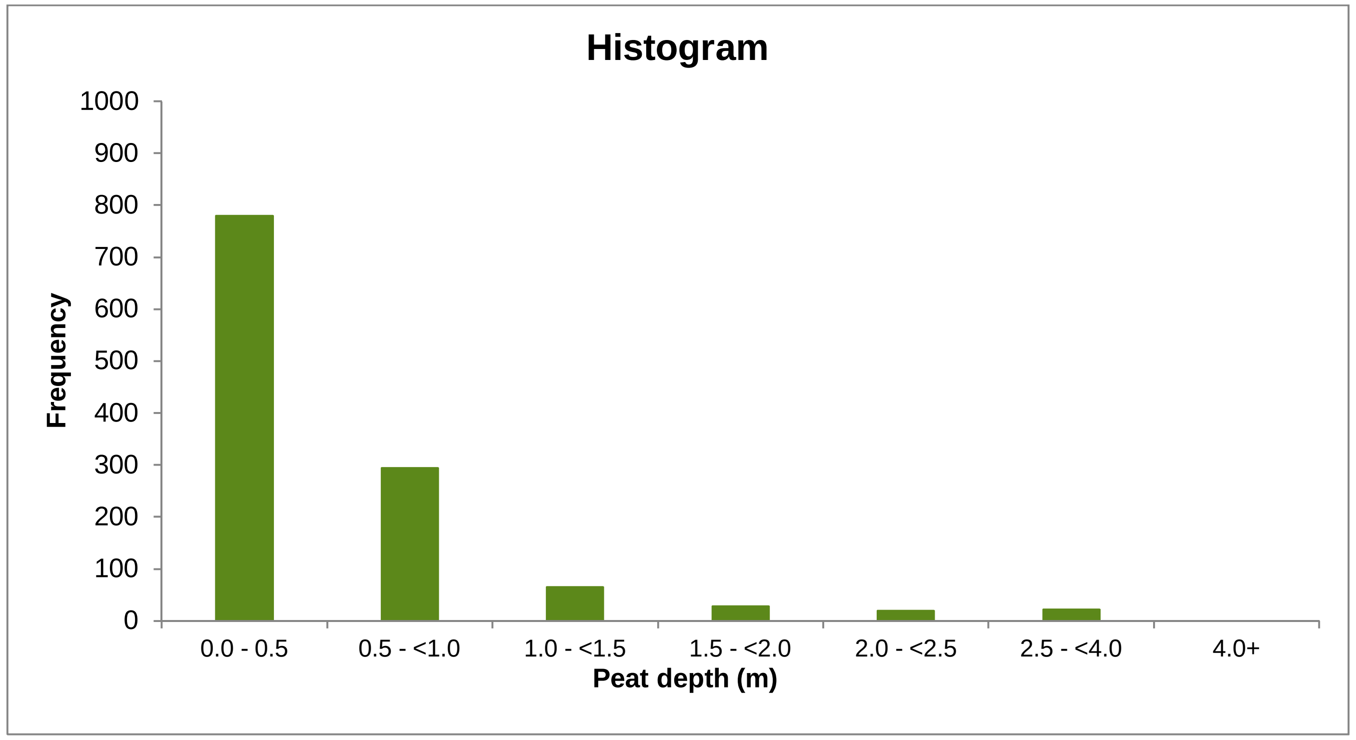

Illustration 6.3: Peat Probe Depth Histogram

1.4.1 Estimation of Cohesive Strength

102. A range of field and laboratory tests can be carried out to determine the effective cohesion of a material. However, owing to its fibrous and thixotropic nature and the variation in strength with decomposition, peat is a particularly difficult material to analyse both in the field and in the laboratory. An alternative approach to assessing the strength of the peat is to rearrange the FoS equation to calculate a value of c' at actual peat probing locations. Essentially, this approach assumes that if the hillside is stable then the material must have at least a certain minimum strength.

103. Each peat probing location visited is known to have been stable at the time of the visit and therefore must have a FoS of at least 1. If we assume conservatively that F=1 and use values for the other parameters as discussed above, the FoS equation can be rearranged to allow derivation of a value for c' at each probing location. Slope angles for the probing points are generated from the DTM. It is important to note that the value of c' calculated for

each location represents the minimum cohesive strength necessary for the peat to be stable at that location. In fact, the shear strength may be, and in most cases probably is, considerably higher.

104. In the survey area 1,207 locations have been probed during the different phases of fieldwork, c' values for each of these have been calculated and the distribution of these values is shown in **Illustration 6.3**. For example, reading from the graph, 0.8 (or 80%) of the probing locations require a theoretical c' value of 0.72kN/m^2 or less to be stable and retain peat on the slope.

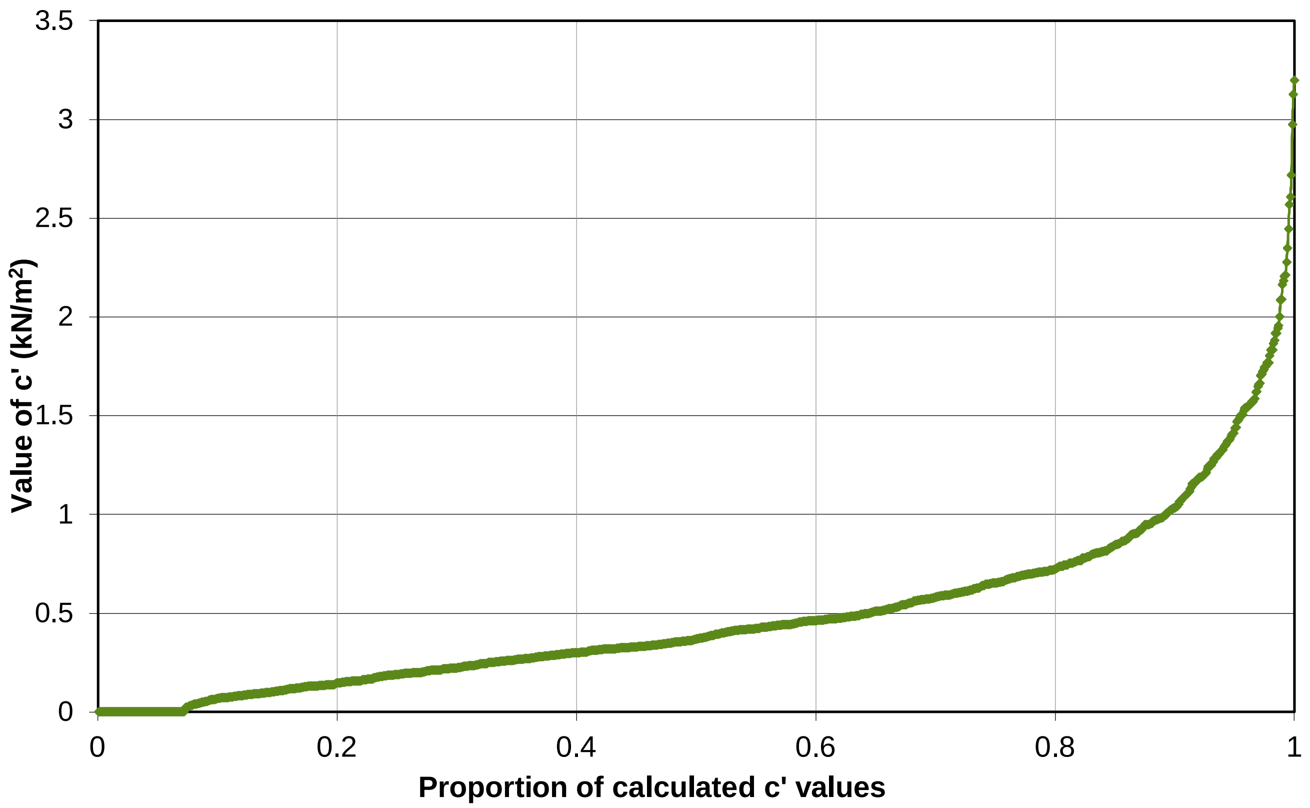

Illustration 6.4: Estimate of Minimum Cohesive Strength, c'

105. From this work it is possible to state, with reasonable confidence, that across the Site as a whole the shear strength of the peat is unlikely to be less than 2.15N/m^2 as this is the value of the 99th percentile point on the graph.

106. A similar approach was undertaken for determining the 99th percentile for grid cells, determined as 3.60, this value being slightly higher than the point data due to inclusion of indicative depths for a number of cells.

107. The basis for applying these calculation details depends upon:

- The deliberate choice of conservative values for assumed parameters such as bulk density and water table level, coupled with the assumption of an FoS of 1 when back-calculating c' values.
- Recognition of what the calculations are stating, which is that these are the minimum strengths that would be required, not the actual *in situ* strengths. Therefore, where slopes are gentle and the peat shallow, very little shear strength is required to ensure stability of the slope. This accounts for the vast majority of the lower values.
- Assuming a reasonable degree of homogeneity for peat properties, particularly strength, across the Site. This seems reasonable, except for very shallow peat where the acrotelm, which is more fibrous, represents a significant proportion of the total depth. Such areas are, in any case, unlikely to be areas of concern.
- Given the above considerations, it is the higher strength values that are relevant. If this were not the case then one would expect large areas of the Site to be denuded of peat as it would not have the strength to adhere to the hillsides.

108. For the purposes of the Factor of Safety Assessment c' values of 2.15kN/m^2 and 3.60kN/m^2 have been used. These values are conservative in comparison with estimates derived from other sites around Scotland, largely due to the shallow peat found on most site slopes. The actual effective cohesion of the peat at the Site is therefore likely to be higher than 2.15kN/m^2, with 3.60kN/m^2 being more representative (compared with literary values of 4 - 20kN/m^2), with the application of these Site-derived values ensuring a reasonably conservative initial assessment using data from the Site in tandem with an understanding of literary values.

1.4.2 Factor of Safety (FoS) Stability Results

109. Having assigned measured or inferred values to each parameter in the FoS equation, it is now possible to calculate the FoS value for each probing location coinciding with proposed infrastructure and for each cell of the indicative peat depth grid in the vicinity of the infrastructure. The results of the FoS assessment for the probing points and site grid are summarised in **Table 6.5**. The FoS assessment maps generated with these values are shown across the Site as series **Figure 6.1.7 Factor of Safety**.

110. Once again, the grid cell values where measured data is available is considered more representative as is generally closer to the planned infrastructure.

Factor of Safety	No Peat in Grid (less than 0.5m)	≥3.0	1.4 - <3.0	1.0 - <1.4	<1.0	Total
Probing Data (points)	779	232	148	35	13	1,207
% of Probing Points	64.5%	19.2%	12.3%	2.9%	1.1%	100.0%
Grid Cells	2,191	3,029	1,593	260	72	7,145
% of Grid Cells	30.7%	42.4%	22.3%	3.6%	1.0%	100.0%
Grid Cells (with measured data)	534	259	58	3	0	854
% of Grid Cells (with measured data)	62.5%	30.3%	6.8%	0.4%	0.0%	100.0%

Table 6.5: Summary of Factor of Safety Assessment

111. In selecting the 99th percentile value of the back-calculated c' strengths, one is implicitly condemning 1.0% of the sample locations to failure, plus any similar cells across the Site as a whole. As can be seen, there are a very small number of cells with a FoS value of less than 1; in theory these should either have failed or currently be failing. In reality this is unlikely to be the case and these results are a consequence of the conservative approach adopted. A similarly low number of points and cells have a FoS between 1.0 and 1.4, where stability can be considered marginal. The cells that fall into both these categories are scattered in clusters across the Site, the majority are a reasonable distance from Site infrastructure and therefore based upon conservatively estimated, rather than actual, peat depths.

112. Note that where peat depth is less than 0.5m, these cells were not considered as peat and are removed from further stability investigation.

113. To summarise, 96% of the peat probing locations on the Site have a FoS of 1.4 or greater, where stability can be assumed with a degree of comfort. Related to grid cells with measured depths (i.e. predominantly those grid cells closest to infrastructure), cell locations with FoS values greater than 1.4 (including cells with peat less than 0.5m depth) represent 99.5% of the Site, again these are locations where stability can be assumed with a degree of comfort.

114. The results demonstrate that the vast majority of the windfarm infrastructure will be built in areas where there is a degree of comfort in inferring stability. The cells identified as having marginal stability are generally clustered into areas where deeper peat are coincident with moderate slopes, or very steep slopes occur with >0.5m peat present.

1.5 Initial Risk Assessment

115. Based on the data collated from the desk study, reconnaissance survey, peat probing and FoS stability analysis the peat stability risk across the site can be classified. The Guidelines (Scottish Government, 2017b) define risk as a function of likelihood and consequence and this has been applied by WSP as:

Risk = Likelihood x Adverse Consequence

116. The risk level is derived by applying a matrix of likelihood and consequence outcomes to derive a risk value ranging from 'Negligible' to 'High Risk'. Additionally, where peat is not present (such as organic soils with depth less than 0.5m) these areas were identified as 'N/A – Not Peat'.

117. Central to WSP's analysis is a grid model of the Study Area, using 50m x 50m individual cell dimensions. It is therefore essential to have processes that assign likelihood and consequence ratings to the cells and build a map of spatial variability across the Study Area. The rationale for evaluating likelihood and consequence is given in the following sections.

1.5.1 Likelihood

118. In WSP's method, the primary and non-subjective measure of likelihood of slope stability is the Factor of Safety (FoS) calculation. Low FoS value slopes are of greater stability concern, slopes with FoS values greater than 1.4 are generally regarded as 'safe'.

119. Within FoS analysis, the parameter which may be considered to have the greatest uncertainty is the shear strength of the peat. The derivation of this parameter has been discussed above. The back-calculation approach is more conservative (i.e. gives a safer assumption) than that commonly derived from *in situ* shear vane tests, which have known limitations when applied to peat. For the initial risk assessment the likelihood is based solely on FoS, enabling an objective, reasonably cautious initial 'screening' approach to likelihood. The initial likelihood criteria and classification of cells is provided on **Tables 6.6** and **6.7**, respectively.

120. The initial likelihood classification of grid cells across the Site is presented as **Figure 6.1.8 Initial Likelihood**.

Likelihood	Factor of Safety
Almost certain	Not applied at initial likelihood stage, better determined in conjunction with additional data available from a specific peat stability survey of such areas
Probable	FoS <1.0
Likely	FoS is between 1.0 and 1.4
Unlikely	FoS is between 1.4 and 3.0
Negligible	FoS > 3.0
N/A – Not Peat	Soil at depth shallower than 0.5m or confirmed as non-peat material

Table 6.6: Criteria Relating to Initial Likelihood Values

	Likelihood						
	Almost Certain	Probable	Likely	Unlikely	Negligible	Not Peat	Total
No. of Grid Cells	*Not Applied*	72	260	1,593	3,029	2,191	7,145
% of Grid Cells	*Not Applied*	1.0%	3.6%	22.3%	42.4%	30.7%	100.0%
No. of Grid Cells (with measured peat depth)	*Not Applied*	0	3	58	259	534	854
% of Grid Cells (with measured peat depth)	*Not Applied*	0%	0.4%	6.8%	30.3%	62.5%	100.0%

Table 6.7: Summary of Initial Likelihood Grid Classification

1.5.2 Adverse Consequence

121. The Guidelines (Scottish Government, 2017b), identify that 'Consequence' relates to impact upon receptors, this would include property, existing infrastructure and assets, environmental features and/or the Proposed Development infrastructure. These terms need to be taken in their broader context if an itemised list of receptors is to be considered which would include:

- existing public and private infrastructure (roads, bridges, buildings, business facilities, etc.);
- terrestrial ecology;
- aquatic ecology and water quality;
- archaeology; and
- proposed internal infrastructure (access tracks, turbines, control building, cabling, etc.).

122. These features have varying dimensions of costs and magnitude caused by an occurrence of mass peat instability, but in addition there may be irretrievable personal, societal or habitat losses.

- Costs: the only quantification provided within the Guidelines is in terms of project costs, which are easier to apply to infrastructure assets than to ecology. If ecology is of relatively minor importance for a particular site, economic impacts or delays in the construction programme may be the main drivers.
- Magnitude: naturally occurring peatslides have been observed to range in size from small-scale, localised slides involving tens of square metres to large-scale slides involving thousands of square metres and with run-out distances of kilometres. Consequently, magnitude may be expressed in terms of area, peat volume and run-out distance and receptor. Provided sufficient peat probing has been undertaken and an indicative peat depth map produced, areas and peat volumes can be derived using professional judgement given local ground conditions. The associated run-out distance is of less significance than the receptor damaged and again should be considered taking account of local conditions to arrive at a realistic outcome.

123. **Table 6.8** assembles the above considerations to outline the degrees of consequence. Using the table, the three columns are considered and professional judgement applied, to identify the appropriate 'Consequence' rating. The consequence values were identified and applied using mapping software to escalate the value based on local receptors, with the default (starting) position being that each grid cell was considered of 'Low' consequence, taking a reasonably precautionary approach. The consequence classification of cells is provided in **Table 6.9**. The consequence classification of grid cells is presented as **Figure 6.1.9 Consequence**.

Consequence	Habitat	Internal Infrastructure	Public/Private Infrastructure
Extremely High	Large loss/damage to valued terrestrial and/or aquatic habitat, i.e. within designated site. Large loss/damage to archaeological designated sites.	N/A	Damage to property: domestic/public building or business (*within 100m*); Impact on railways or A class road or bridges, including lower category roads which provide key transport corridors in remote locations (*within 100m*); Impact on public utilities, water, gas, electricity, telecoms, etc. (*within 100m*).
High	Medium loss/damage to valued terrestrial and/or aquatic habitat, i.e. designated site (*within 100m*).	Damage to substation and/or control building *(within 100m).*	Damage to minor/ unclassified roads or bridges *(within 100m)*; Impact on private utilities, local electrical connection, water and wastewater *(within 100m).*
Moderate	Small loss/damage to valued terrestrial and/or aquatic habitat Large loss/damage to common terrestrial and/or hydrology features shown on 1:10,000 OS mapping (*within 50m*). Peat grid cells identified with peat depth 1.5m+.	Damage to planned or operational turbine or base *(within 100m)*. Damage to section of new access track, bridge or hardstanding *(within 50m)* which would require repair to enable functionality. Damage to car parking, met mast or cable route (within 50m). Interruption to construction or operation of development.	Damage to section of existing unclassified track, or bridge *(within 100m).*
Low *Default Position*	Medium loss/damage to common terrestrial and/ or hydrology features shown on 1:10,000 OS mapping.	Minor damage to section of access track which does not necessitate immediate repair for access.	N/A
Very Low *Not Applied*	Small temporary loss/damage to common terrestrial and/or aquatic habitat.	No damage to assets.	No damage to assets.

Table 6.8: Criteria Relating to Consequence Values

	Consequence					
	Extremely High	**High**	**Moderate**	**Low**	**Very Low**	**Total**
No. of Grid Cells	194	30	5,146	1,775	*Not Applied*	**7,145**
% of Grid Cells	2.7%	0.4%	72.1%	24.8%	*Not Applied*	**100.0%**
No. of Grid Cells (with measured peat depth)	22	13	719	100	*Not Applied*	**854**
% of Grid Cells (with measured peat depth)	2.6%	1.5%	84.2%	11.7%	*Not Applied*	**100.0%**

Table 6.9: Summary of Consequence Grid Classification

1.5.3 Initial Risk Assessment Outcomes

124. The likelihood (solely based on FoS) and consequence values were applied to the Site for the initial risk assessment, with the results shown on **Figures 6.1.8 Initial Likelihood** and **6.1.9 Consequence**, respectively, provided in Annex A of this document. A summary of the cell counts was provided in **Tables 6.7** and **6.9** for each classification.

125. In order to include nearby receptors, the assessed area (grid) extends 250m beyond the Site boundary, further where peat point data was collated outside this zone. This enables consideration of features outwith the Site boundary, such as archaeological sites, watercourses or properties. For example, Wallace's House Scheduled Monument is thus discussed within PSA Area A.

126. The results of the initial likelihood and consequence grid cell categorisations reflect the characteristics of the Site. The topography generally exhibits less than 15 degree slope angles, intersected by a series of incised valleys with distinct convex breaks of slope where gradients may exceed 20 degrees for extended distances. Measured peat depths confirm that much of the steeper areas of the Site have shallow or no peat recorded (i.e. less than 0.5m depth), with peat depths often greater than 1.5m on slope angles of less than 5 degrees. Isolated zones of deeper peat are found occasionally at breaks of slope (top of slope) or at bases of steep slopes, with these coincident locations being the main driver for peatslide likelihood at this Site. The fairly remote nature of the Site means that the locations with high or extremely high consequence of a peat landslide are focused upon archaeological features, properties and their private water supply locations.

127. The Guidelines' risk scoring is determined via a matrix table, combining likelihood and consequence. This has been provided as **Table 6.10** and replicates Table 5.3 in the Guidance (Scottish Government, 2017b). An initial risk value has been derived for each grid cell through combining the Likelihood and Consequence ratings using the matrix in **Table 6.10**. A summary of the grid cell counts for each risk category is provided in **Table 6.11**.

128. As can be seen on **Table 6.11**, the vast majority of the Site has been assessed as having either 'No Risk' or 'Negligible' risk of peatslide hazard at the initial risk assessment stage. 'Moderate' and 'High' risk cells tend to cluster together and are typically located close to steeper slopes or where peat depths greater than 1.5m were recorded, in close proximity to the planned infrastructure or watercourse receptors. All the 'High' risk cells are located within 100m of the Wallace's House and The Knock Scheduled Monuments, on the southern extent of the Site, which was evaluated as a receptor with extremely high consequence.

129. When considering the grid cells with measured peat depth, which are cells where peat probing data was collected and include all cells where infrastructure is planned, no cells recorded a 'High' initial risk and 0.2% of cells recorded a 'Moderate' initial risk.

		Adverse Consequence				
		Extremely High	High	Moderate	Low	Very Low
Peat Landslide Likelihood (over Development Lifetime)	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 6.10: Risk Matrix Based on Likelihood and Consequence Values

Initial Risk	Number of Grid Cells	% of Grid Cells	Number of Grid Cells (with measured peat depth)	% of Grid Cells (with measured peat depth)	Suggested 'Guideline' Actions (Table 5.4, Scottish Government, 2017b)
High	7	0.1%	0	0.0%	*"Avoid project development at these locations".*
Moderate	76	1.1%	1	0.2%	*"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	1,439	20.1%	58	6.8%	*"Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations*".
Negligible	3,432	48.0%	261	30.5%	*"Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate*".
N/A – No Risk (Not Peat)	2,191	30.7%	534	62.5%	Non-peat material, no peat slide risk.
Total Cells:	**7,145**	**100.0%**	**854**	**100.0%**	

Table 6.11: Summary of Initial Risk Assessment Outcomes and Actions

130. **Figure 6.1.10 Initial Risk** shows the planned infrastructure layout overlaid on the Initial Risk mapping, from which 'High' or 'Moderate' risk of peat instability are identified as red or orange cells, respectively.

131. After review of Initial Risk locations to exclude those outwith close proximity to planned infrastructure, regarded as highly unlikely to be adversely affected by the Proposed Development, the remaining cells cluster into two areas (PSA Areas A and B) and further location-specific information has been focused on these in the Revised Risk Assessment and datasheets provided in Annex B:

- Two areas were initially identified as being at potentially High and Moderate risk of peat landslide (red and orange cells), with likelihood defined by factor of safety values between 1 and <1.4 combined with consequence values – Peat Stability Assessment (PSA) Areas A and B.
- The three cells initially identified as being at High risk of peat landslide (red cells) within PSA Area A, where likelihood defined by factor of safety values of <1 combined with consequence values, were assessed further. However, peat depths were not taken within these cells due to safety concerns and potential probing damage to the Wallace's House Scheduled Monument.
- Two High risk and five Moderate risk grid cells adjacent to The Knock Scheduled Monument, located north of PSA Area A, were not assessed further. These cells are positioned away from infrastructure, with the closest 200m north of the access track to be upgraded and without measured peat depths at their locale.

1.6 Detailed Assessment and Revised Risk Assessment

132. For each of the two PSA Areas, A and B, identified as being of 'High' or 'Moderate' risk from the initial risk assessment, a Detailed Assessment has been undertaken and reported on individual datasheets. This includes description of the peat depths, factor of safety values, local characteristics including geomorphology and geotechnical information, aerial images and available photographs. These datasheets also identify site-specific mitigation and a revised risk level, considering the additional information gathered at each of the PSA Areas. The individual datasheets are provided in Annex B, with an overview of the locations presented in **Figure 6.1.11 Detailed Assessment Areas**.

133. The detailed assessment datasheets display the initial risk values for grid cells (each cell measuring 50m x 50m), with cells highlighted bordered in red (High risk) and orange (Moderate risk). The probe location triangles are coloured to represent peat depth ranges (as per colour-coding on **Tables 6.1** – **6.3**) and each probe point also includes a background square coloured to identify the FoS category, using the FoS colour range previously displayed on **Table 6.6**. Other appropriate GIS data provided on the aerial background image is listed on the legend at the beginning of Annex B.

134. The FoS value was the primary driver for assigning a likelihood to each grid cell in the model, as discussed for the initial risk assessment, however, regional and local context information may provide additional data that justifies changing the likelihood category at the revised risk assessment stage for locations of concern. These contextual factors are consolidated into **Table 6.12**, which provides rationale to assigning revised likelihood values to refine the assessment process:

- Regional context; in a regional context some areas have a higher propensity for peatslide events than others and this may be evident from historical records, if reliable. Regional climatic factors influence the development of peat, its coverage and depth; at a site-level peat depths are determined from peat probing fieldwork rather than generalisations. Although the regional context does not provide any spatial differentiation within the Study Area, it may influence the level of caution applied.
- Local context; the variability of local factors material to the development of peatslides may be considered. The primary local factors not already incorporated into the FoS calculations include convex slopes, breaks of slope, drainage patterns, landuse, grazing intensity and incidental events such as fire, which may alter the likelihood of peatslides. These factors may operate across the whole Study Area, in which case they offer no spatial differentiation, but if localised to specific parts of the Site may be helpful in spatial characterisation. Identification of instability identified from aerial photography and confirmed by 'ground truthing' as non-peatslide events, such as peaty debris slides, may be relevant as these forms of instability are not caused by peat instability (rather, are due to the slope failure of material underlying the peat layer). The Guidance (Scottish Government, 2017b) included suggestions of probability values, these have been included in italics as a contextual reference.

135. To aid the revised risk assessment process, geomorphology data was collated to identify grid cells with potential landslide features identified on aerial photography, grid cells with peat depths greater than 1.5m, BGS GeoSure

Landslide Hazard classes D and C, slope angles greater than 8º and detailed assessment-specific locations where convex breaks in slope were apparent from digital terrain model data. These features are displayed with planned infrastructure on **Figure 6.1.12 Geomorphology Overview**.

136. Where aerial photography and/or GeoSure Landslide Hazards noted features close to infrastructure but not previously flagged by the initial likelihood approach (i.e. not initially classed as 'High' or 'Moderate' risk based solely on FoS values), enlarged Detailed Assessment datasheet locations were included to confirm local characteristics and check appropriate revised risk level. PSA Areas A and B incorporate GeoSure and Aerial Photography data.

137. In addition to good practice and design measures, there are also a number of area-specific mitigation measures that are proposed to be deployed to reduce risk (generally the likelihood aspect) at particular locations, with further details in Section 1.7.

138. The revised risk information on the two individual datasheets (Annex B) reflects refinement, following consideration of specific characteristics for each area, using applicable ground investigation information and the identification and application of any appropriate mitigation measures during design, construction and operation.

139. Potential runout distances and volumes of material for each datasheet have been estimated, factoring-in local conditions, with these estimates recorded within the Detailed Assessment datasheets, alongside identified receptors within and outwith the site boundary.

Likelihood/ Hazard	Regional Context	Local Context
Almost Certain	The wider region (if it consists of similar condition units to the Study Area) has several historic peatslides. Study Area has several historic peatslides.	FoS <1.0 **Ancillary considerations:** Locally, indications of incipient mass peat instability such as tension cracks, bulges, misaligned fences or trees etc; Peat depths on slopes consistently over 1.5 m; Topography: convex breaks in slope; extensive unconfined slopes; Drainage: converging flow paths; large contributing area; peat pipes; GeoSure Landslide Hazard Class D; *Probability of mass peat instability event occurrence during lifetime of scheme considered greater than 1 in 3.*
Probable	Study Area has evidence of historic peatslide	FoS <1.0 **Ancillary considerations:** Locally, indications of incipient mass peat instability; Peat depths on slopes consistently over 1.0m; Topography: convex breaks in slope; extensive unconfined slopes; Drainage: converging flow paths; large contributing area; peat pipes; GeoSure Landslide Hazard Class D; *Probability of mass peat instability event occurrence during lifetime of scheme considered between 1 in 3 – 1 in 10.*
Likely	Study Area has evidence of historic peatslide	FoS is between 1.0 and 1.4 **Ancillary considerations:** Locally, no adjacent indications of incipient mass peat instability but some within 100m; Peat depths on slopes consistently over 1.0m; Topography: generally rounded/undulating landforms; Drainage: suspicious absence of surface channels indications of peat pipes; GeoSure Landslide Hazard Class C; *Probability of mass peat instability event occurrence during lifetime of scheme considered between 1 in 10 – 1 in 100.*
Unlikely	Study Area has no evidence of past peatslides.	FoS is between 1.4 and 3.0 **Ancillary considerations:** Locally, no indications of incipient mass peat instability Isolated peat depths over 1.0m on slopes; Topography: generally rounded/undulating landforms; Drainage: natural well defined channels; artificial improvements to drainage; Not GeoSure Landslide Hazard Class D or C; *Probability of mass peat instability event occurrence during lifetime of scheme considered between 1 in 100 – 1 in 10,000,000.*
Negligible	The wider region (if it consists of similar condition units to the Study Area) has no historic peatslides. Study Area has no evidence of historic peatslides.	FoS > 3.0 **Ancillary considerations:** Locally, no indications of incipient mass peat instability; Peat depths less than 1.0m on slopes; Topography: concave or no break in slope; small confined slopes or pockets; Drainage: diverging flow paths; small contributing area; natural well defined channels; artificial improvements to drainage; Not GeoSure Landslide Hazard Class D or C; *Probability of mass peat instability event occurrence during lifetime of scheme considered less than 1 in 10,000,000.*
N/A – Not Peat		Soil at depth shallower than 0.5m or confirmed as non-peat material.

Table 6.12: Criteria Relating to Revised Likelihood Values

1.6.1 Revised Risk Assessment Outcomes

140. Following the revised risk assessment process, **Table 6.13** records the updated risk outcomes and these are also shown across the Site on **Figure 6.1.13 Revised Risk**. There are no revised 'High' or 'Moderate' risk cells close to infrastructure or which have measured peat depths.

141. Following detailed assessment, of the two PSA Areas highlighted in the initial risk assessment procedure, taking account of local ground conditions and application of appropriate good practice and area-specific mitigation measures, two initial 'High' risk and eight initial 'Moderate' risk locations have all been revised to 'Low' risk.

142. Therefore, there are no locations of revised 'High' or 'Moderate' risk specific to peat instability at locations of Proposed Development infrastructure, or within 50m.

Revised Risk	Number of Grid Cells	% of Grid Cells	Number of Grid Cells (with measured peat depth)	% of Grid Cells (with measured peat depth)	Suggested 'Guideline' Actions
High	4	0.1%	0	0.0%	*"Avoid project development at these locations".*
Moderate	68	0.9%	0	0.0%	*"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	1,450	20.3%	59	6.9%	*"Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations".*
Negligible	3,432	48.0%	261	30.6%	*"Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate".*
N/A – No Risk (Not Peat)	2,191	30.7%	534	62.5%	Non-peat material, no peat slide risk.
Total Cells:	7,145	100.0%	854	100.0%	

Table 6.13: Revised Risk Outcomes

1.7 Assessment Assumptions

143. Following previous peat stability report feedback from IronsideFarrar from similar sites, this section identifies key assumptions which have been applied during the preparation of this deliverable.

144. The key variables and most sensitive factors in the factor of safety analysis are peat depth and slope angle, which are directly applied using a large dataset of site information focussed on planned infrastructure positions, applying a back-calculated c' specific to site data and conservative lower-bound literature values for other calculation inputs. Thus, the assessment of peat stability at this EIA Report stage follows an inherently conservative approach. The site visits to ascertain revised risk act as a form of sensitivity analysis, as the method bases initial probability directly upon factor of safety outcomes for the initial risk stage and typically leads to the identification of locations which can be justifiably reduced to a lower probability and lower revised risk, following the collation of ancillary local information.

145. This assessment focussed upon undrained peat, at the detailed design stage it may be deemed appropriate to also conduct analysis drained peat for selected representative locations including PSA Areas A and B.

146. Existing drainage features have been identified, where relevant, in the Annex B Datasheets and would be included in the Geotechnical Risk Register. Similarly, forestry drains are recorded where applicable to PSA Datasheets. These channels are not all shown on mapping, with maps using OS information. Should additional channel mapping be considered appropriate at the detailed design stage, this could be undertaken.

147. Without detailed Ground Investigation information, all borrow pits remain subject to potential blasting operations, with each area subject to appropriate detailed planning for environmental sensitivities and rock recovery. Borrow pit BP01 is located approximately 290m north east of PSA Area B, with no other borrow pits within 500m of any PSA Area. The methodologies adopted for each borrow pit would be included and assessed in the Geotechnical Risk Register, with appropriate techniques adopted depending on rock characteristics, local constraints and project requirements.

148. Excavated peat would be reused locally, with side-casting during cut track construction anticipated. Peat would be re-used in as short a timescale as feasible and follow principles provided in **Appendix 6.2 Soil and Peat Management Plan**. Post-consent, the detailed design would include details of plans for temporary storage of peat and associated methodologies for excavation/transfer/storage/reuse. The Geotechnical Risk Register would include peat storage as a specific risk, with applicable controls that would be kept up-to-date with current good practice and lessons learned from Site works.

1.8 Mitigation and Good Practice Measures

149. The purpose of the peat slide risk assessment is to identify areas of the Site which are potentially at most risk of peat instability and thereafter assess potential construction impacts. Where avoidance through design is not possible, mitigation measures require to be implemented to avoid or reduce the risk of peat instability. In addition to specific mitigation measures which may be deployed at particular locations, itemised in the specific detailed assessment datasheets, there are a number of generic construction good practice measures that will be applied. A number of these are set out in **Table 6.14**.

150. Good practice guidance documents, such as Floating Roads on Peat (FCE & SNH, 2010), Managing Geotechnical Risk (Clayton, 2001) and Peat Landslide Hazard and Risk Assessments: Best Practice guide for Proposed Electricity Generation Developments (Scottish Government, 2017b) will be consulted to inform the design and construction processes. All site investigation work will be undertaken in compliance with relevant British Standards, including BS 5930:1999 and BS 6031:2009.

151. The application of good practice techniques during forestry clearance necessary at this Site will also act to reduce the potential for peat instability, in terms of both likelihood of occurrence and magnitude of any event that does occur. Following forestry clearance, in areas with previously restricted access coincident with infrastructure plans, surveys shall be undertaken to record peat depths and any evidence of historic or potential peat instability.

152. On-site construction staff are often the best placed to provide advance notification of potential problems, provided sufficiently trained and with an appropriate reporting mechanism. There are a number of recognised indicators for slope failures and these may indicate a potential peatslide or the commencement of a peatslide event, as outlined in Section 1.2.1 of this report. The suspected identification of any of these indicators should be assessed by specialist peat stability or geotechnical personnel.

153. With reference to **Table 6.14**, the area-specific mitigation measures identified for Harestanes South Windfarm Extension are 1, 2, 9, 12, 13, 17 and 20.

Potential Actions	Good Practice	Area-Specific Mitigation Measures, as applicable
1. Geotechnical specialist on-site during the construction phase to undertake advance inspection, carry out regular slope monitoring and provide ongoing advice at locations of concern.	P	P
2. Maintain and update geotechnical risk register or similar management system.	P	P
3. Construction staff should be made aware of peatslide indicators and emergency procedures (see below).	P	P
4. Emergency procedures should include steps to be taken on detection of any evidence of potential peat instability.	P	
5. Microsite the turbine base or access track in order to avoid the area of concern (subject to non-violation of other constraints).	P	
6. Ensure that good groundwater and surface water control, such as moor gripping or drainage ditches, is in place in advance of construction activities.	P	
7. Installation of stand-pipes / piezometers to monitor ground water levels and pore pressures.		P
8. Ensure artificial drainage does not concentrate flows onto slopes, gully heads or into excavations.	P	
9. Ensure that sediment control measures are incorporated into all artificial drainage measures and including specific scour protection mitigation where steep slopes or high activity erosion processes are identified. Concrete aprons, rip rap, gabion/reno mattress or geotextile mats may be applicable options, depending on watercourse characteristics and sensitivities.	P	P
10. Earthmoving activities should be restricted during and immediately after heavy and/or prolonged rainfall events, including use of weather forecasting and re-programming of construction activities as applicable. Particular care should be taken when heavy rainfall events are predicted following a prolonged dry spell.	P	
11. The construction plan should minimise the extent and duration of open excavations and bare ground.	P	
12. Avoid placing excavated material or other forms of loading on or immediately above breaks of slope or any other potentially unstable slopes.	P	P
13. Avoid removing slope support, particularly where slope stability has been highlighted as of concern.	P	P
14. Establish / re-establish vegetation as soon as possible to improve slope stability and provide sediment transport control.	P	
15. Consider limiting loads crossing newly created peat embankments to enable pore water pressure in both embankment and underlying peat to reduce to pre-construction levels and original shear strength.		P
16. Modify slope geometry to provide a 'weighted toe'.		P
17. Use of retaining structures, such as gabion terracing to support specific slopes.		P
18. In locations where limited opportunity for avoidance or other mitigation to reduce likelihood, the application of debris nets, catch fences, catch ditches and/or deflection systems to protect receptors and reduce adverse consequences. Such installations should be subject to routine inspection and maintenance.		P
19. Forestry clearance activities should be undertaken following good practice, including careful positioning of log piles to avoid overloading of slope, sediment control and consideration of retaining tree roots *in situ* for soil stabilisation in appropriate locations.	P	
20. Borrow pit blasting activities to take account of any peat stability locations of concern in the proximity, including seeking alternative methods that avoid blasting. If sensitive peat stability receptors are identified, there are a number of methods to manage, mitigate and monitor, such as careful placement, charge size, vibration monitoring and pre- and post-blasting slope monitoring.	P	P

Table 6.14: Good Practice and Mitigation Measures

1.9 Summary and Recommendations

154. Peat depth probing in conjunction with slope angle mapping is a cost-effective method to establish peat depth and peat stability profiles across large areas. Combining this with aerial photograph interpretation and GeoSure datasets enables potential evidence of mass movement events to be efficiently identified.

155. The Proposed Development is underlain by peat of varying depths and shallower peaty soil, with an average depth across the Study Area of 0.48m. There are a number of steep slopes related to incised watercourse channels. Where deeper peat coincides with these slopes, especially at convex break of slope positions, the risk of peat slide increases. Areas identified as of higher likelihood for instability were primarily related to locations at or below convex breaks of slope or due to isolated deeper peat deposits recorded.

156. The conservative nature of the methodology applied leads to initial risk identification, based on factor of safety analysis, of the least stable areas on any specific site, initially considered of 'Moderate' or 'High' risk, with this risk level relative to the remainder of the Site. Areas with initial 'High' or 'Moderate' risk were highlighted and considered further in the revised risk process, with two locations of concern identified, taking account of site data and that collated from GeoSure Landslide Hazard and aerial photography evidence.

157. Site visits occurred at various phases of the Proposed Development design, between March 2020 and September 2020, to inform evolving iterative design, assessment and reporting processes. A further specific peat stability assessment visit was undertaken in September 2020 for 'ground truthing' to establish peatland and stability characteristics at particular locations of concern, including the two PSA Areas initially identified of concern. Further site data collated included humification testing, using the von Post classification system to establish fibrous and structural condition of peat at various locations and depths, laboratory analysis of cores, landform descriptions, additional peat probing and shallow shear vane data.

158. PSA Area A was evaluated as of initial 'High' risk and PSA Area B was evaluated as of initial 'Moderate' risk, including extended coverage where GeoSure data suggested potential instability. At the two locations further site information was collated to refine the risk, with individual datasheets prepared to provide local details and discuss initial and revised risk assessment outcomes.

159. A number of non-peat related slope failures were observed on the Site, such as the collapsing watercourse channel banks caused by fluvial erosion adjacent to the incised valley of the Glenkiln Burn tributary (PSA Area B). These locations have clear failure zones below the peat, as noted during the site visit.

160. Following the Detailed Assessment process, taking account of local ground conditions plus appropriate micrositing to avoid key landform features, alongside slope monitoring, slope support measures and drainage controls as area-specific mitigation, no areas of the Site, in vicinity to the infrastructure, are considered to be above 'Low' revised risk (with the vast majority of the site considered 'Negligible' risk or non-peat) in terms of peat stability assessment.

161. The Guidelines (Scottish Government, 2017b) quote the following requirements:

> High risk - '*Avoid project development at these locations*'
>
> Moderate risk - '*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 risk - '*Project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations*'
>
> Negligible risk - '*Project may proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate'*

162. Further geotechnical investigation is proposed as part of the site geotechnical investigations, which will take place post-consent and prior to construction. This is standard practice and will inform the final, detailed design of the Development, along with detailed mitigation, such as specific drainage designs including routes and discharge locations, to be implemented during construction, undertaken by an appropriately qualified geotechnical engineer. Any additional areas of concern identified by surveys following forestry clearance, should be added to the areas for further investigation.

163. Whilst mitigation measures have been identified in this document, the suggested techniques are not exhaustive and it is expected that a design consultancy and contractor will use these and other techniques, as appropriate, to effectively manage the peat stability risk.

164. Management of peat stability risk will remain a consideration throughout the subsequent detailed design processes, including additional site investigation, pre-construction activities and during construction, subject to the development receiving consent. A key issue is that the design remains 'live' and subject to ongoing optimisation, with the iterative design process continuing into construction phase. The contractor is able to microsite to reduce peat instability risk, whilst taking account of other local environmental and engineering constraints.

165. The need for risk management has been emphasised throughout this report and forms a standard part of any wind farm construction project. Risk management will include the regular review of the Geotechnical Risk Register, supported by appropriate actions within the contractor's Construction Method Statement (CMS), in due course.

1.10 Technical Authors and Experience

166. The joint authors of this report were Stuart Bone BSc (Hons.) MSc PIEMA CWEM CEnv and Marta Ibanez Garcia BSc MSc PIEMA.

167. Stuart Bone is a Chartered Environmentalist (CEnv) and Chartered Water and Environmental Manager (CWEM) holding chartered status since 2005 and is also a Practitioner Member of the Institute of Environmental Management & Assessment (PIEMA). Stuart has a BSc (Hons.) in Environmental Geography from the University of Aberdeen and a MSc in Marine Resource Development and Protection from Heriot-Watt University. Stuart has over 20 years environmental experience, since 2006 focused on delivering peat stability assessment and other soil and water EIA deliverables in the renewable energy sector and highways. He has been involved in the delivery of Peat Stability Assessments since working on the original Harestanes Wind Farm in 2006, becoming a technical lead on these deliverables in 2012. Stuart has a strong understanding of peat morphology, geomorphological processes, environmental data collection, factor of safety stability analysis and risk assessment both from project experience and from his academic background. Stuart has a good understanding of the latest guidance and promotes early data collation and stability interpretation to inform the iterative design process in accordance with good risk management principles. Stuart has provided technical reporting and guidance, supervision and in-depth review at every stage of this peat stability assessment process.

168. Marta Ibanez Garcia is a qualified Environmental Scientist with a BSc and MSc in Environmental Management from Abertay University. She has been a Practitioner Member of the Institute of Environmental Management & Assessment (PIEMA) since 2017 and is currently working towards Chartership. She has five years' experience in environmental impact assessment, working on peat stability assessments since 2018. She worked previously in Quality and Environmental Management Systems implementation. Marta has been the joint report author and also responsible for planning peat surveys, conducting fieldwork, data interpretation and processing peat stability outcomes using QGIS software.

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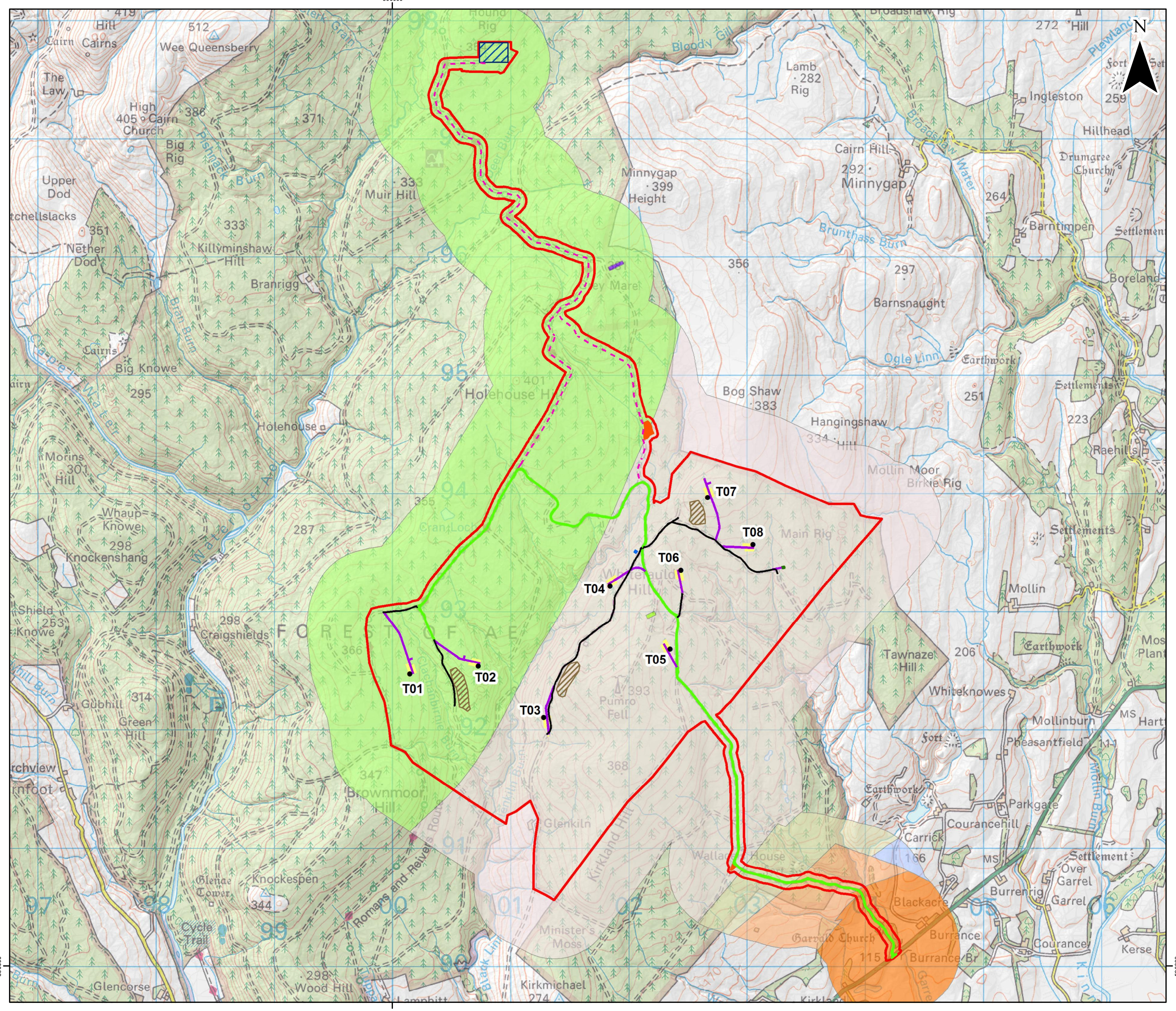
Annex A. Peat Stability Assessment Figures



Legend

- Application Boundary
- Proposed Turbine Location
- Proposed Crane Pad
- Proposed Control Building
- Proposed Met Mast
- Proposed Borrow Pit Search Area
- Operational Harestanes Access – To be Upgraded
- Proposed New Access Track
- Existing Forestry Track - To be Upgraded
- Cable Route
- Existing Construction Compound / Hardstanding
- Existing Substation

Bedrock Geology (1:50,000)

ETTRICK GROUP
- GLENDEARG FORMATION
  Sandstone, mudstone and siltstone
- SELCOTH FORMATION
  Sandstone, mudstone and siltstone

GALA GROUP
- QUEENSBERRY FORMATION
  Sandstone, mudstone, siltstone and conglomerate

HAWICK GROUP
- CARGHIDOWN FORMATION
  Metasandstone and metamudstone

NORTH BRITAIN SILURO-DEVONIAN CALC-ALKALINE DYKE SUITE
- Microdioritic-rock
- Microgabbroic-rock

STEWARTRY GROUP
- CORNCOCKLE SANDSTONE FORMATION
- HARTFIELD FORMATION
  Sandstone, pebbly sandstone and angular pebble-grade

Km: 0 | 0.75 | 1.5

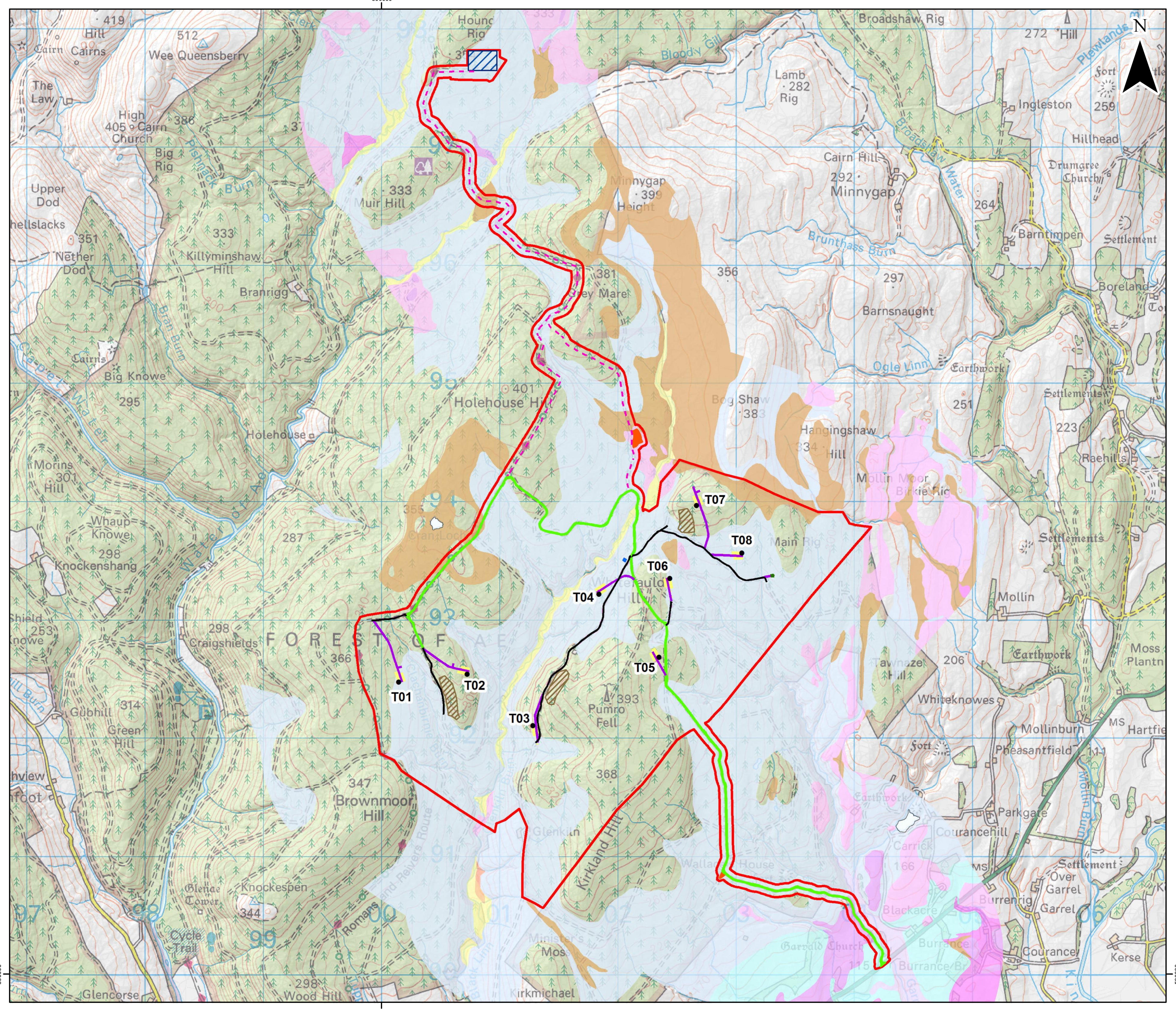
Rev	Date	By	Comment
A	07/10/2020	VK	First Issue.

SCOTTISHPOWER RENEWABLES

Harestanes South Windfarm Extension

Figure 6.1.1: Bedrock Geology

Drg No	HARESTANES_WSP_I_186
Rev	A
Date	13/11/2020
Scale	1:30,000 @ A3



Legend

- Application Boundary
- Proposed Turbine Location
- Proposed Crane Pad
- Proposed Control Building
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- Operational Harestanes Access – To be Upgraded
- Proposed New Access
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- Cable Route
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- Existing Construction Compound / Hardstanding
- Existing Substation

Superficial Geology (1:50,000)

ALLUVIAL FAN DEPOSITS
- Clay and silt

ALLUVIUM
- Gravel, sand, silt and clay

GLACIOFLUVIAL DEPOSITS
- Gravel, sand and silt

GRETNA TILL FORMATION
- Diamicton

KILBLANE SAND AND GRAVEL FORMATION
- Sand, gravel and boulders

KIRKBEAN SAND AND GRAVEL FORMATION
- Gravel, sand and silt
- Sand and gravel
- Sand, gravel and boulders
- Sand gravelly
- Silt, sand and gravel

LANGHOLM TILL FORMATION
- Diamicton

RIVER TERRACE DEPOSITS (UNDIFFERENTIATED)
- Gravel, sand, silt and clay

TILL, DEVENSIAN
- Diamicton

PEAT

SUPERFICIAL DEPOSITS/SUPERFICIAL THEME NOT MAPPED
- Sediment Unknown/Unclassified Entry

0 0.75 1.5 Km

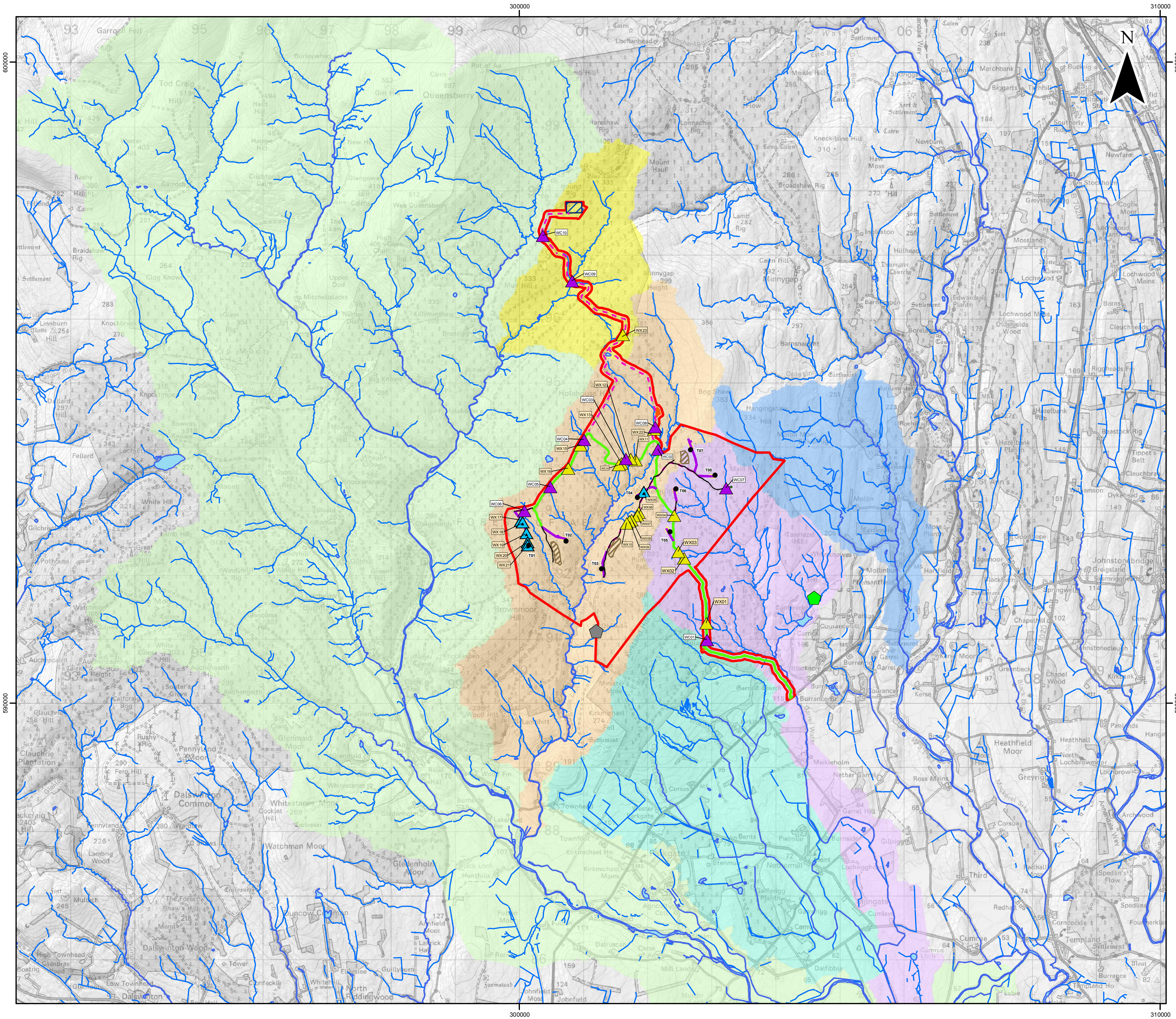
Rev	Date	By	Comment
A	07/10/2020	VK	First Issue.

SCOTTISHPOWER RENEWABLES

Harestanes South Windfarm Extension

Figure 6.1.2: Superficial Geology

Drg No	HARESTANES_WSP_I_187
Rev	A
Date	09/11/2020
Scale	1:30,000 @ A3



Legend

- Application Boundary
- Proposed Turbine Location
- Proposed Crane Pad
- Proposed Control Building
- Proposed Met Mast
- Proposed Borrow Pit Search Area
- Operational Harestanes Access – To be Upgraded
- Proposed New Access Track
- Existing Forestry Track - To be Upgraded
- Cable Route
- Existing Construction Compound / Hardstanding
- Existing Substation

Hydrology

- Controlled Activities Regulation Crossing - Existing Crossing
- Non-Controlled Activities Regulation Crossing - Existing Crossing
- Non-Controlled Activities Regulation Crossing - New Crossing

Private Water Supply Sources

- Burrance
- Glenkiln - Not valid

River Catchments

- Deer Burn (Subcatchment of Water of Ae)
- Kirkland Burn (Subcatchment of Water of Ae)
- Garrel Water (Subcatchment of Water of Ae)
- Glenkiln Burn (Subcatchment of Water of Ae)
- Molin Burn (Subcatchment of Kinnel Water)
- Water of Ae (Subcatchment of Kinnel Water)
- OS Watercourse (1:10,000)
- OS Water Body (1:10,000)

0 1.5 3 Km

Rev	Date	By	Comment
A	07/10/2020	VK	First Issue.

SCOTTISHPOWER RENEWABLES

Harestanes South Windfarm Extension

Figure 6.1.3: Hydrology Overview

Drg No	HARESTANES_WSP_I_188
Rev	A
Date	13/11/2020
Scale	1:55,000 @ A3