Appendix 12.3**:**

Peat Landslide Hazard and Risk Assessment (PLHRA)

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EAST POINT GEO
An ABL Group Company

Consulting Report

TA12.3 - Peat Landslide Hazard and Risk Assessment
Shepherds' Rig Wind Farm

Dumfries & Galloway, Scotland
Boralex

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1. INTRODUCTION

1.1. Background

SETT Wind Development (the Applicant) is seeking consent under Section 36C of the Electricity Act 1989 for construction of the Shepherds' Rig Wind Farm, Dumfries & Galloway (hereafter the 'Proposed Varied Development').

The site for the Proposed Varied Development lies approximately 5 km to the east of Carsphairn and is approximately 7.52 km^2 (c. 752 ha) in area (Plate 1.1**Error! Reference source not found.**). The site is bordered to the north and east by commercial forestry, to the south by Kendoon Loch, and to the west by the hill summits of Beninner and Knockwhirn.

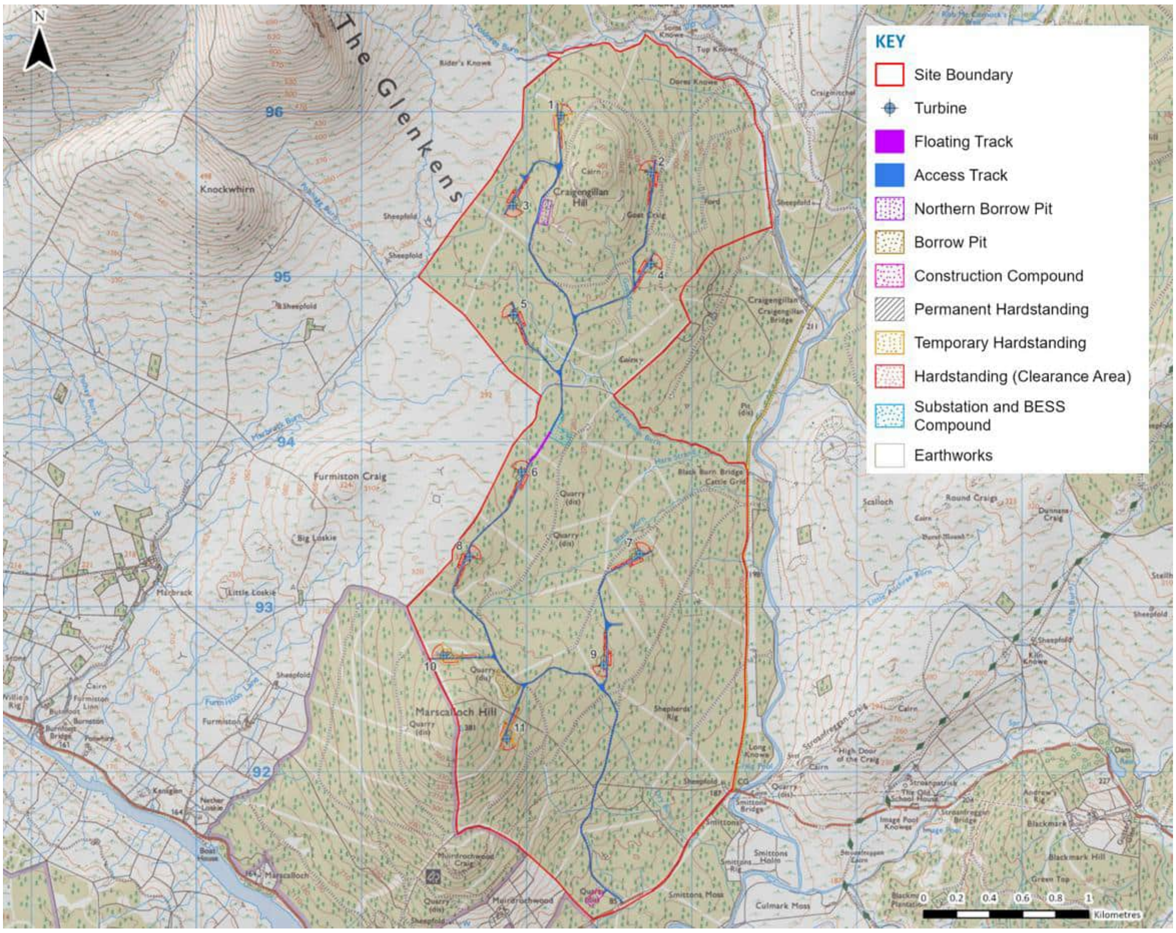

Plate 1.1 Proposed location of Shepherds Rig wind farm

The Proposed Varied Development will comprise:

- 11 turbines, comprising foundations, main hardstandings, ancillary hardstandings and associated earthworks;
- A construction compound in the south of the site and two borrow pits;
- One Substation and Battery Energy Storage System (BESS) compound;
- A network of access tracks of both cut and fill and floating construction; and
- Cabling (typically arranged alongside access tracks).

The Scottish Government Best Practice Guidance (BPG) provides a screening tool to determine whether a peat landslide hazard and risk assessment (PLHRA) is required (Scottish Government, 2017). This is in the form of a flowchart, which indicates that where blanket peat is present, slopes exceed 2° and proposed infrastructure is located on peat, a PLHRA should be prepared. These conditions exist at the Proposed Varied Development site and therefore a PLHRA is required.

1.2. Scope of Work

The scope of the PLHRA is as follows:

- Characterise the peatland geomorphology of the site to determine whether prior incidences of instability have occurred and whether contributory factors that might lead to instability in the future are present across the site.
- Determine the likelihood of a future peat landslide under natural conditions and in association with construction activities associated with the Proposed Varied Development.
- Identify potential receptors that might be affected by peat landslides, should they occur, and quantify the associated risks.
- Provide appropriate mitigation and control measures to reduce risks to acceptable levels such that the Proposed Varied Development is developed safely and with minimal risks to the environment.

The contents of this PLHRA have been prepared in accordance with the BPG, noting that the guidance "*should not be taken as prescriptive or used as a substitute for the developer's [consultant's] preferred methodology*" (Scottish Government, 2017). The first edition of the Scottish Government Best Practice Guidance (BPG) was issued in 2007 and provided an outline of expectations for approaches to be taken in assessing peat landslide risks on wind farm sites. After ten years of practice and industry experience, the BPG was reissued in 2017, though without fundamental changes to the core expectations. A key change was to provide clearer steer on the format and outcome of reviews undertaken by the Energy Consents Unit (ECU) checking authority and related expectations of report revisions, should they be required.

In section 4.1 of the BPG, the key elements of a PLHRA are highlighted, as follows (Scottish Government, 2017):

i. An assessment of the character of the peatland within the application boundary including thickness and extent of peat, and a demonstrable understanding of site hydrology and geomorphology.

ii. An assessment of evidence for past landslide activity and present-day instability e.g. pre-failure indicators.

iii. A qualitative or quantitative assessment of the potential for or likelihood of future peat landslide activity (or a landslide susceptibility or hazard assessment).

iv. Identification of receptors (e.g. habitats, watercourses, infrastructure, human life) exposed to peat landslide hazards; and

v. A site-wide qualitative or quantitative risk assessment that considers the potential consequences of peat landslides for the identified receptors.

Section 1.3 describes how this report addresses this indicative scope.

1.3. Report Structure

This report is structured as follows:

- Section 2 gives context to the landslide risk assessment methodology through a literature based account of peat landslide types and contributory factors, including review of any published or anecdotal information available concerning previous instability at or adjacent to the site.
- Section 3 provides a site description based on desk study and site observations, including consideration of aerial or satellite imagery, digital elevation data, geology and peat depth data.
- Section 4 describes the approach to and results of an assessment of peat landslide likelihood under both natural conditions and in association with construction of the Proposed Varied Development.
- Section 5 describes the approach to and results of a consequence assessment that determines potential impacts on site receptors and the associated calculated risks.
- Section 6 provides mitigation and control measures to reduce or minimise these risks prior to, during and after construction.

Assessments within the PLHRA have been undertaken alongside assessments for the Peat Management Plan (Appendix 12.2) and have been informed by results from the Peat Survey (Appendix 12.1). Where relevant information is available elsewhere in the Environmental Impact Assessment Report (EIA-R), this is referenced in the text rather than repeated in this report.

1.4. Approaches to assessing peat instability for the Proposed Varied Development

This report approaches assessment of peat instability through both a qualitative contributory factor-based approach and via more conventional stability analysis (through limit equilibrium or Factor of Safety (FoS) analysis). The advantage of the former is that many observed relationships between reported peat landslides and ground conditions can be considered together where a FoS is limited to consideration of a limited number of geotechnical parameters. The disadvantage is that the outputs of such an approach are better at illustrating relative variability in landslide susceptibility across a site rather than absolute likelihood.

The advantage of the FoS approach is that clear thresholds between stability and instability can be defined and modelled numerically, however, in reality, there is considerable uncertainty in input parameters and it is a generally held view that the geomechanical basis for stability analysis in peat is limited given the nature of peat as an organic, rather than mineral soil.

To reflect these limitations, both approaches are adopted and outputs from each approach integrated in the assessment of landslide likelihood. **Error! Reference source not found.**Plate 1.2 shows the approach:

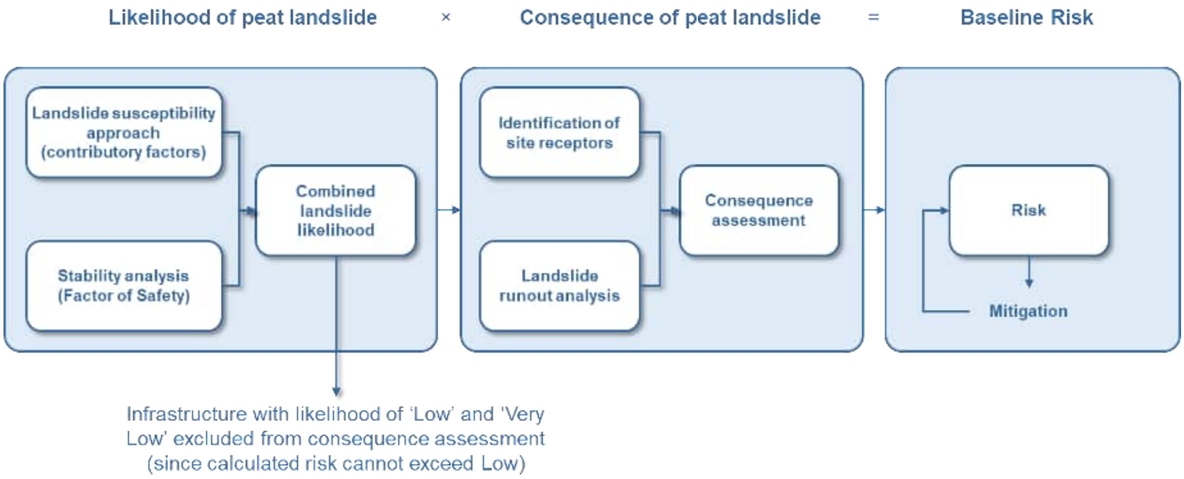

Plate 1.2 Risk assessment approach

1.5. Team competencies

This PLHRA has been undertaken by a chartered geologist with 25+ years experience of mapping and interpreting peatland terrains and peat instability features. Geomorphological walkover survey was undertaken by the same individual. Peat depth probing was undertaken by Fluid Environmental Consulting, a highly experienced peatland survey team, and additional site observations and photographs were made available from these surveys to the PLHRA team.

2. BACKGROUND TO PEAT INSTABILITY

2.1. Peat Instability in the UK and Ireland

This section reviews published literature to highlight commonly identified landscape features associated with recorded peat landslides in the UK and Ireland. This review forms the basis for identifying similar features at the Proposed Varied Development and using them to understand the susceptibility of the site to naturally occurring and human induced peat landslides.

Peat instability, or peat landslides, are a widely documented but relatively rare mechanism of peatland degradation that may result in damage to peatland habitats, potential losses in biodiversity and depletion of peatland carbon stores (Evans & Warburton, 2007). Public awareness of peat landslide hazards increased significantly following three major peat landslide events in 2003, two of which had natural causes and one occurring in association with a wind farm.

On 19th September 2003, multiple peat landslide events occurred in Pollatomish (Co. Mayo, Ireland; Creighton and Verbruggen, 2003) and in Channerwick in the Southern Shetland Islands (Mills et al, 2007). Both events occurred in response to intense rainfall, possibly as part of the same large-scale weather system moving northeast from Ireland across Scotland. The former event damaged several houses, a main road and washed away part of a graveyard. Some of the landslides were sourced from areas of turbary (peat cutting) with slabs of peat detaching along the cuttings. The landslides in Channerwick blocked the main road to the airport and narrowly missed traffic using the road. Watercourses were inundated with peat, killing fish inland and shellfish offshore (Henderson, 2005).

In October 2003, a peat failure occurred on an afforested wind farm site in Derrybrien, County Galway, Ireland, causing disruption to the site and large-scale fish kill in the adjoining watercourses (Lindsay and Bragg, 2004).

The Derrybrien event triggered interest in the influence of wind farm construction and operation on peatlands, particularly in relation to potential risks arising from construction induced peat instability. In 2007, the (then) Scottish Executive published guidelines on peat landslide hazard and risk assessment in support of planning applications for wind farms on peatland sites. While the production of PLHRA reports is required for all Section 36 energy projects on peat, they are now also regarded as best practice for smaller wind farm applications. The guidance was updated in 2017 (Scottish Government, 2017).

Since then, a number of peat landslide events have occurred both naturally and in association with wind farms (e.g. Plate 2.1). In the case of wind farm sites, these have rarely been reported, however landslide scars of varying age are visible in association with wind farm infrastructure on Corry Mountain, Co. Leitrim, at Sonnagh Old Wind Farm, Co. Galway (near Derrybrien; Cullen, 2011), and at Corkey Wind Farm, Co. Antrim. In December 2016, a plant operator was killed during excavation works in peat at the Derrysallagh wind farm site in Co. Leitrim (Flaherty, 2016) on a plateau in which several published examples of instability had been previously reported. A peat landslide was also reported in 2015 near the site of a proposed road for the Viking Wind Farm on Shetland (The Shetland Times, 2015) though this was not in association with construction works.

Other recent natural events include another failure in Galway at Clifden in 2016 (Irish News, 2016), Cushendall, Co. Antrim (BBC, 2014), in the Glenelly Valley, Co. Tyrone in 2017 (BBC, 2018), Drumkeeran in Co. Leitrim in July 2020 (Irish Mirror, 2020) and Benbrack in Co Cavan in July 2021 (The Anglo-Celt, 2021). Noticeably, the vast majority of reported failures since 2003 have occurred in Ireland and Northern Ireland, with one reported Scottish example occurring on the Shetland Islands

(Mid Kame), an area previously associated with peat instability. Two occurrences of instability in association with construction works on the Viking Wind Farm have been reported (July 2022 and May 2024), though in both cases, these have involved failure of peat or mineral spoil at track margins rather than the triggering of a new 'peat slide' by groundworks.

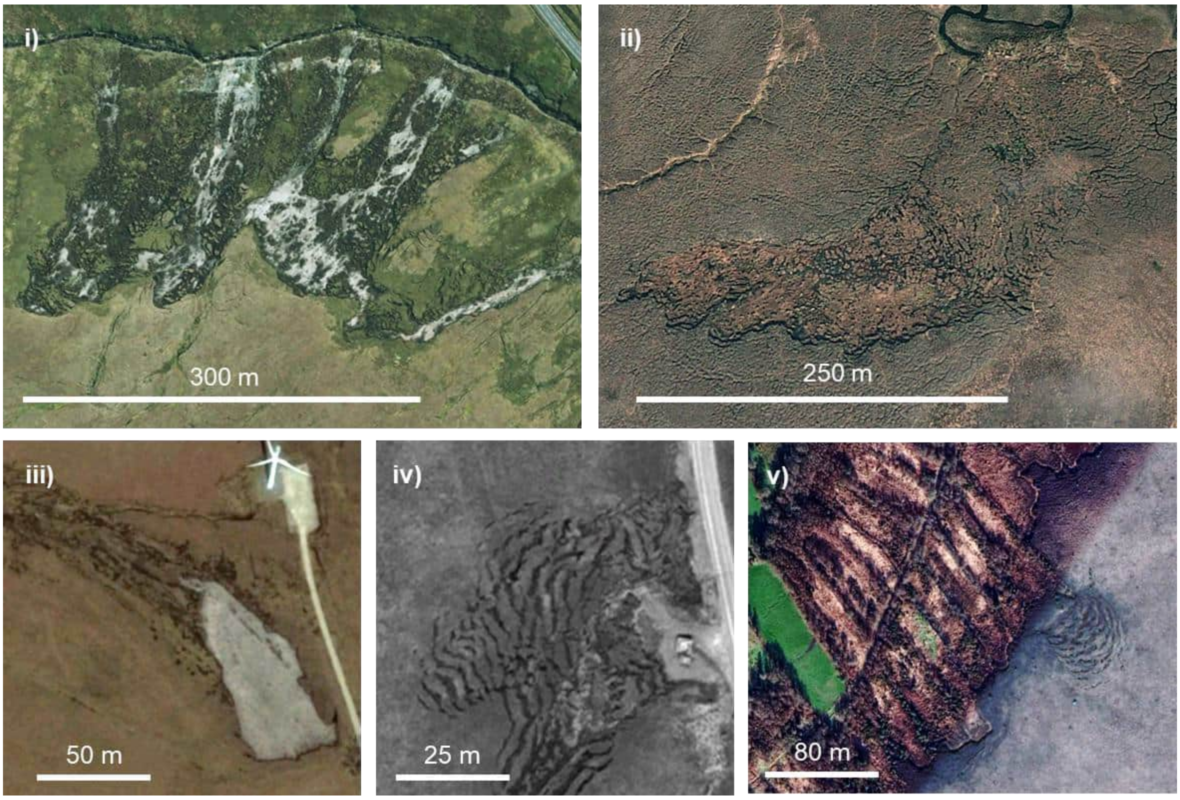

Plate 2.1 Characteristic peat landslide types in UK and Irish peat uplands: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: iii) peat slide adjacent to turbine foundation, iv) spreading around foundation, v) spreading upslope of cutting

This section of the report provides an overview of peat instability as a precursor to the site characterisation in Section 3 and the hazard and risk assessment provided in Sections 4 and 5. Section 2.2 outlines the different types of peat instability documented in the UK and Ireland. Section 2.3 provides an overview of factors known to contribute to peat instability based on published literature.

2.2. Types of Peat Instability

Peat instability is manifested in a number of ways (Dykes and Warburton, 2007) all of which can potentially be observed on site either through site walkover or remotely from high resolution aerial photography:

- **minor instability:** localised and small-scale features that are not generally precursors to major slope failure and including gully sidewall collapses, pipe ceiling collapses, minor slumping along diffuse drainage pathways (e.g. along flushes); indicators of incipient instability including development of tension cracks, tears in the acrotelm (upper vegetation mat), compression ridges, or bulges / thrusts (Scottish Government, 2017); these latter features may be warning signs of larger scale major instability (such as landsliding) or may simply represent a longer term response of the hillslope to drainage and gravity, i.e. creep.

- **major instability:** comprising various forms of peat landslide, ranging from small scale collapse and outflow of peat filled drainage lines/gullies (occupying a few-10s cubic metres), to medium scale peaty-debris slides in organic soils (10s to 100s cubic metres) to large scale peat slides and bog bursts (1,000s to 100,000s cubic metres).

Evans and Warburton (2007) present useful contextual data in a series of charts for two types of large-scale peat instability – peat slides and bog bursts. The data are based on a peat landslide database compiled by Mills (2002) which collates site information for reported peat failures in the UK and Ireland. Separately, Dykes and Warburton (2007) provide a more detailed classification scheme for landslides in peat based on the type of peat deposit (raised bog, blanket bog, or fen bog), location of the failure shear surface or zone (within the peat, at the peat-substrate interface, or below), indicative failure volumes, estimated velocity and residual morphology (or features) left after occurrence.

For the purposes of this assessment, landslide classification is simplified and split into three main types, typical examples of which are shown in Plate 2.1. Dimensions, slope angles and peat depths are drawn from charts presented in Evans and Warburton (2007). The term "peat slide" is used to refer to large-scale (typically less than 10,000 of cubic metres) landslides in which failure initiates as large rafts of material which subsequently break down into smaller blocks and slurry. Peat slides occur 'top-down' from the point of initiation on a slope in thinner peats (between 0.5 m and 1.5 m) and on moderate slope angles (typically 5°-15°, see Plate 2.2).

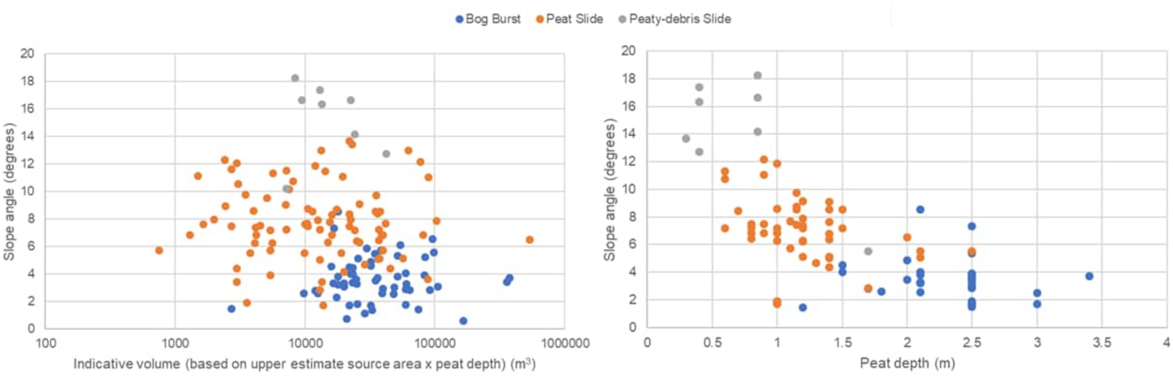

Plate 2.2 Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)

The term "bog burst" is used to refer to very large-scale (usually greater than 10,000 of cubic metres) spreading failures in which the landslide retrogresses (cuts) upslope from the point of failure while flowing downslope. Peat is typically deeper (greater than 1.0m and up to 10m) and more amorphous than sites experiencing peat slides, with shallower slope angles (typically 2°-5°). Much of the peat displaced during the event may remain within the initial failure zone. Bog bursts are rarely (if ever) reported in Scotland other than in the Western Isles (e.g. Bowes, 1960).

The term "peaty soil slide" is used to refer to small-scale (1,000s of cubic metres) slab-like slides in organic soils (i.e. they are <0.5 m thick). These are similar to peat slides in form, but far smaller and occur commonly in UK uplands across a range of slope angles (Dykes and Warburton, 2007). Their small size means that they often do not affect watercourses and their effect on habitats is minimal.

Few if any spreading failures in peat (i.e. bog bursts) have been reported in Scotland, with only one or two unpublished examples in evidence on the Isle of Lewis and Caithness. There are no published failures or news reports of landslides in proximity to the Proposed Varied Development.

2.2.1. Factors Contributing to Peat Instability

Peat landslides are caused by a combination of factors – triggering factors and reconditioning factors (Dykes and Warburton, 2007; Scottish Government, 2017). Triggering factors have an immediate or rapid effect on the stability of a peat deposit whereas preconditioning factors influence peat stability over a much longer period. Only some of these factors can be addressed by site characterisation.

Preconditioning factors may influence peat stability over long periods of time (years to hundreds of years), and include:

i. Impeded drainage caused by a peat layer overlying an impervious clay or mineral base (hydrological discontinuity).

ii. A convex slope or a slope with a break of slope at its head (concentration of subsurface flow).

iii. Proximity to local drainage, either from flushes, pipes or streams (supply of water).

iv. Connectivity between surface drainage and the peat/impervious interface (mechanism for generation of excess pore pressures).

v. Artificially cut transverse drainage ditches, or grips (elevating pore water pressures in the basal peat-mineral matrix between cuts, and causing fragmentation of the peat mass).

vi. Increase in mass of the peat slope through peat formation, increases in water content or afforestation.

vii. Reduction in shear strength of peat or substrate from changes in physical structure caused by progressive creep and vertical fracturing (tension cracking or desiccation cracking), chemical or physical weathering or clay dispersal in the substrate.

viii. Loss of surface vegetation and associated tensile strength (e.g. by burning or pollution induced vegetation change).

ix. Increase in buoyancy of the peat slope through formation of sub-surface pools or water-filled pipe networks or wetting up of desiccated areas.

x. Afforestation of peat areas, reducing water held in the peat body, and increasing potential for formation of desiccation cracks which are exploited by rainfall on forest harvesting.

Triggering factors are typically of short duration (minutes to hours) and any individual trigger event can be considered as the 'straw that broke the camel's back':

i. Intense rainfall or snowmelt causing high pore pressures along pre-existing or potential rupture surfaces (e.g. between the peat and substrate).

ii. Rapid ground accelerations (e.g. from earthquakes or blasting).

iii. Unloading of the peat mass by fluvial incision or by artificial excavations (e.g. cutting).

iv. Focusing of drainage in a susceptible part of a slope by alterations to natural drainage patterns (e.g. by pipe blocking or drainage diversion).

v. Loading by plant, spoil or infrastructure.

External environmental triggers such as rainfall and snowmelt cannot be mitigated against, though they can be managed (e.g. by limiting construction activities during periods of intense rain). Unloading of the peat mass by excavation, loading by plant and focusing of drainage can be managed by careful design, site specific stability analyses, informed working practices and monitoring.

2.2.2. Consequences of Peat Instability

Both peat slides and bog bursts have the potential to be large in scale, disrupting extensive areas of blanket bog and with the potential to discharge large volumes of material into watercourses.

A key part of the risk assessment process is to identify the potential scale of peat instability should it occur and identify the receptors of the consequences. Potential sensitive receptors of peat failure are:

- The development infrastructure and turbines (damage to turbines, tracks, substation, etc).
- Site workers and plant (risk of injury / death or damage to plant).
- Wildlife (disruption of habitat) and aquatic fauna.
- Watercourses and lochs (particularly associated with public water supply).
- Site drainage (blocked drains / ditches leading to localised flooding / erosion); and
- Visual amenity (scarring of landscape).

While peat failures may cause visual scarring of the peat landscape, most peat failures revegetate fully within 50 to 100 years and are often difficult to identify on the ground after this period of time (Feldmeyer-Christe and Küchler, 2002; Mills, 2002). Typically, it is short-term (seasonal) effects on watercourses that are the primary concern or impacts on public water supply.

3. BASELINE CONDITIONS

3.1. Topography

The Proposed Varied Development is distributed on rolling hills between two summits, Marscalloch Hill (381 m AOD) in the south and Craigengillan Hill (401 m AOD) in the north (Figure 12.3.1). A gentle saddle extends from Furmiston Crag outside the site to the west towards the Water of Ken in the east. The main site access ascends the eastern flank of Marscalloch Hill from the B729 in the south before running along the saddle towards Craigengillan Hill. Plate 3.1 shows a perspective view of the Site with key geographical features identified.

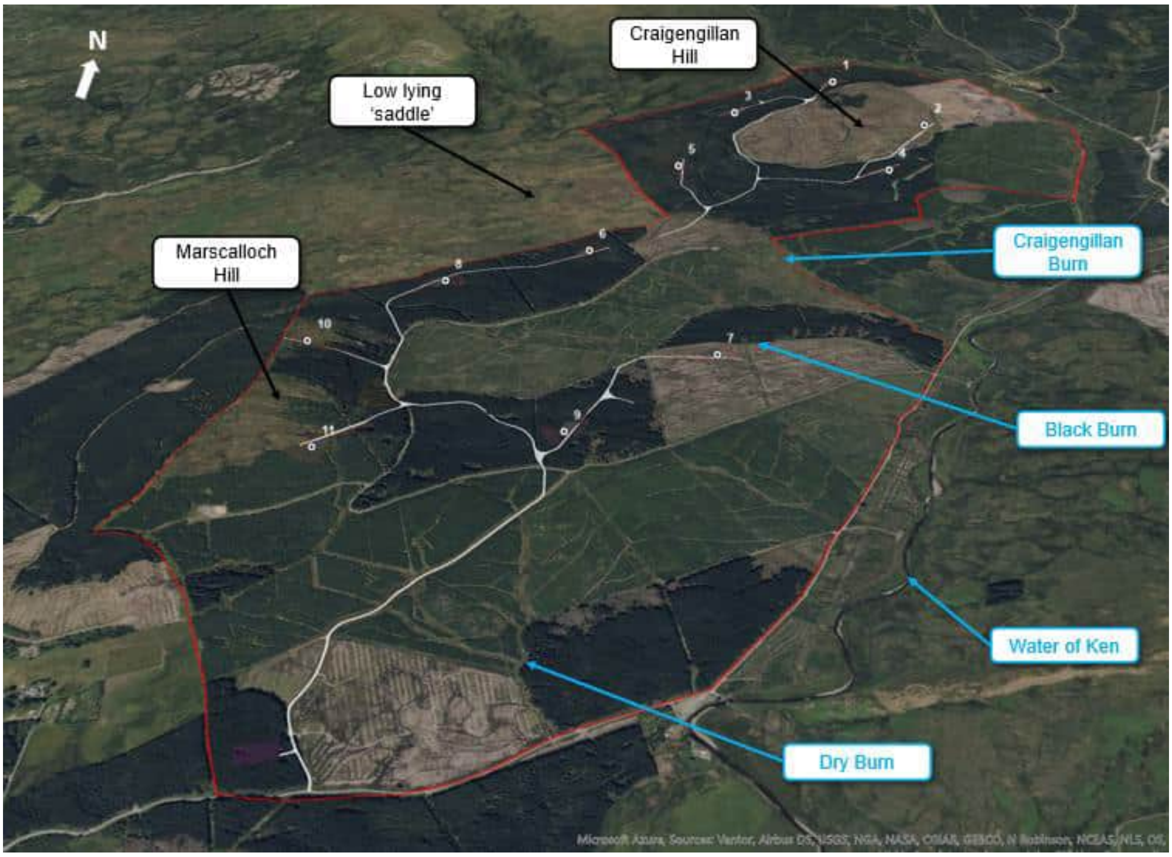

Plate 3.1 Perspective view of the site and the proposed infrastructure layout

Slopes are generally very gentle on the saddle (<2.5°) steepening to >10° over a series of southwest-northeast aligned ridges inherited from the bedrock geology, which exerts a strong control over the local landform of the Site (Figure 12.3.2). Slopes are steepest on the sides of Craigengillan Hill, and infrastructure has typically been placed to minimise overlap with steep slopes by being distributed around the base of the hill or on localised benches on the hillsides. Axes of convexity and concavity are typically aligned along the contours on each hillside.

3.2. Geology

Figures 12.3.3 and 12.3.4 show the solid and superficial geology of the site mapped from 1:50,000 scale publicly available BGS digital data and indicate the site to be entirely underlain by wacke of the Portpatrick Formation. These are sedimentary rocks of marine origin, comprising coarse to fine-grained rocks with distinctive graded beds.

The Portpatrick Formation is overprinted with peat and Devensian Till, while the lower slopes towards the valley floor in the east exhibit hummocky glacial deposits of sand and gravel with this material reworked as silty, sandy and gravelly alluvium along the margins of the Water of Ken (Figure 12.3.4).

There are no geological designations within the Site boundary.

3.3. Hydrology

The site drains from west to east towards the Water of Ken via a series of minor tributaries that rise within the middle of the site between the two hill summits (Figure 12.3.5). In the north, Goat Strand is the only named minor watercourse, flowing south from Craigengillan Hill to join Craigengillan Burn, with several other minor unnamed watercourses joining from the north side of the saddle. Hare Strand flows north from the centre of the site to join Craigengillan Burn c. 0.5 km upstream of its confluence with the Water of Ken. The Water of Ken flows into Kendoon Loch, which is dammed to supply water to Kendoon hydroelectric power station.

In the south of the site, the lengthy and sinuous Black Burn flows from the saddle to join the Water of Ken directly, while further south, below Marscalloch Hill, Dry Burn is joined by an unnamed minor tributary before flowing into the Water of Ken around 2-3 km upstream of Kendoon Loch. Only two minor watercourses less than 0.5 km in length are present on the south side of Marscalloch Hill, both well away from infrastructure. Typical hydrological features are shown on Plates 3.2 a to d.

Plate 3.2 a) Craigengillan Burn in its upper reaches, b) Craigengillan Burn in its lower reaches, c) a forest drain, self-blocked by roots and litter, d) a partially recovered drain

The streams within the site vary in size, with many of the minor tributaries within the forestry having limited capacity to convey material. Where away from the forest margins (e.g. Plate 3.2a and b), the watercourses are less constrained and have the potential to convey debris for some distance downstream, in likelihood into the Water of Ken.

Due to the widespread presence of commercial forestry across the Site, there are extensive drain networks cut into the hillsides to support forest growth. These typically run along slope or oblique to contour (Figure 12.3.5). Approximately 120 km of artificial drains have been mapped across the Site.

3.4. Land Use

Land use is primarily commercial forestry. Conditions within the forestry are shown on Plates 3.3a to d. Given the relatively limited peat depths across the Site (see section 3.5), vegetation under the canopy is limited, with ample needles and bare ground. The best habitats are found within rides and glades or in larger open areas.

Plate 3.3 a) Felled plantation forestry, b) better quality habitat under more open forest in an area of checked growth, c) typical understorey conditions in more mature forestry, d) good quality habitat in forest ride

3.5. Peat Depth and Character

Peat depth probing was undertaken in several phases between 2013 and 2026 in accordance with Scottish Government (2017) guidance.

An initial Phase 1 survey at a resolution 100 m grid was undertaken by Arcus in October 2013, with more detailed probing supporting an early design layout undertaken in August and September 2018; 1,421 probes were collected in total.

Fluid Environmental Consulting Ltd (Fluid) then undertook four phases of survey between May 2024 and October 2024 supporting iterative design of the original submitted layout. The scope of these surveys were:

- 173 probes collected in May 2024 to further characterise three main areas in which turbines are proposed.
- 2,388 probes collected in June 2024 along track alignments (including centrelines and offsets) while 10 m grids were collected across all other infrastructure locations.

- 760 probes collected in August 2024 following layout iterations post-dating the June acquisition, including further trackside locations.
- Following a review of layouts, a further 662 probes were collected in October 2024.

To reflect recent changes in the layout design, further probing was undertaken by Fluid during the period November 2025 to March 2026. This resulted in a further 2,390 probes being acquired across the site, focused specifically on changes to the layout design.

In total, 7,778 locations were probed across the original Arcus and subsequent Fluid probing campaigns.

Over 5,500 probes were in non-peat soils (Table 1, Appendix 12.1). 22 cores taken across the site indicated an absence of acrotelmic peat under forestry and an absence of amorphous peat at the base of the peat profile. Based on the refusal method, substrate was interpreted to comprise rock (c. 56% of locations), silt (c. 25%), grit (c. 7%), gritty silt (c. 11%) and combinations of silt, sand and clay at the remaining locations (c. 1%).

Interpolation of peat depths was undertaken in the ArcGIS Pro GIS environment using a natural neighbour approach. This approach was selected because it preserves recorded depths at each probe location, unlike some other approaches (e.g. kriging), is computationally simple, and minimises 'bullseye' effects. The approach was selected after comparison of outputs with three other methods (inverse distance weighted, kriging and TIN).

The peat depth model is shown on Figure 12.3.6 with probing locations superimposed. Peat depth variation across the site can be summarised as follows:

- Peat is generally absent over large areas due to moderate to locally steep slopes, with the majority of deposits in the west and centre of the site in the saddle between the two hill summits.
- Where peat is present, it is relatively shallow, <2.0 m for the most part, but very locally >3.0 m.
- There are isolated pockets of peat adjacent to watercourses and in hollows, though the 100 m grid that identifies these deposits in likelihood overstates their extents.

The peat probing largely confirms the Carbon and Peatland Map (2016) categories with the presence of peat corresponding to Class 5 (peat soil, no peatland vegetation) within the forestry, although the presence of peat is probably overstated. Areas of Class 4 (predominantly mineral soil with some peat soil) correspond well to the non-peat areas, though should probably be more extensive given the probing results.

Comparison of the peat depth model with the layout indicates that significant efforts have been made during layout design to site infrastructure out of the deepest peat areas and to route access tracks onto shallower peat. Specifically:

- All of the deepest areas have been avoided - including areas deep peat, west of Turbine 1, south-west of Turbine 3, north and south of Turbine 5, and north of Turbine 6.
- Most of the turbines are located outside peat areas, or if peat is overlapped, temporary hardstandings are sited within the peat such that full reinstatement of temporarily excavated peat can be achieved.
- Tracks have generally been routed to avoid deeper peat, and, where possible to do so (limited by gradient and length) floating track has been specified. One section of floating track of 213 m in length has been specified immediately north-west of Turbine 6, running as far as the proposed substation and BESS compound.

3.6. Peatland Geomorphology

Satellite imagery available as an ArcGIS Basemap layer was used to interpret and map features within the site boundary. Additional imagery from different epochs available on both Google Earth™ and Azure Maps imagery was also assessed to validate the satellite imagery interpretation. Satellite imagery was supplemented with 0.5 m resolution LiDAR data, which provided visibility of the ground surface below the forest canopy. The resulting geomorphological map (Figure 12.3.5) was subsequently verified during a site walkover undertaken in June 2024 by a Chartered Geologist and peatland geomorphologist with over 27 years' experience of assessing peat landslides. Morphological linework shows key changes in slope convexity and concavity over the site.

Figure 12.3.5. shows the key features of the site. The presence, characteristics and distribution of these features can be helpful in understanding the hydrological function of a peatland, the balance of erosion and peat accumulation (or condition), and the sensitivity of a peatland to potential land-use changes.

The site is almost entirely devoid of geomorphological features typical of upland peatlands in the UK due to the ubiquitous tree cover. There are very few glades indicating natural conditions, which likely reflects the relatively shallow peat and soil and therefore optimal planting conditions for forestry. The only unplanted areas or areas unmodified by forestry are along watercourses, where fluvial geomorphological features dominate.

Outside the site to the west, the Carbon and Peatland (2016) Map indicates Class 1 peat, which is typically associated with natural peatland terrain. Where Class 1 abuts Class 5 in forestry, the Class 1 areas are usually a good indicator of what the pre-forestry conditions might have been. In this case, the unplanted area to the west shows patterned ground (hummocky terrain) with vegetated gullies and artificial drainage (not for forestry). It is likely that some of the gully forms originating in this area were present within the forestry prior to ridge and furrow ground preparations for planting.

The next section integrates the desk and field assessments described above to identify the spatial variation in landslide likelihood across the site.

4. ASSESSMENT OF PEAT LANDSLIDE LIKELIHOOD

4.1. Introduction

This section provides details on the landslide susceptibility and limit equilibrium approaches to assessment of peat landslide likelihood used in this report. The assessment of likelihood is a key step in the calculation of risk, where risk is expressed as follows:

Risk = Probability of a Peat Landslide x Adverse Consequences

The probability of a peat landslide is expressed in this report as peat landslide likelihood, and is considered below.

Due to the combination of moderate slopes and thinner peat at this site, the most likely mode of failure is peat slides, and this is the failure mechanism considered in this report. This is in keeping with the most likely mode of failure for the peat depths and slope angles present at the site (see Plate 2.2 and Figures 12.3.2 and 12.3.6).

4.2. Limit Equilibrium Approach

4.2.1. Overview

Stability analysis has been undertaken using the infinite slope model to determine the Factor of Safety (FoS) for a series of 25 m x 25 m grid cells within the Proposed Varied Development boundary. This is the most frequently cited approach to quantitatively assessing the stability of peat slopes (e.g. Scottish Government, 2017; Boylan et al, 2008; Evans and Warburton, 2007; Dykes and Warburton, 2007; Creighton, 2006; Warburton et al, 2003; Carling, 1986). The approach assumes that failure occurs by shallow translational landsliding, which is the mechanism usually interpreted for peat slides. Due to the relative length of the slope and depth to the failure surface, end effects are considered negligible and the safety of the slope against sliding may be determined from analysis of a 'slice' of the material within the slope.

The stability of a peat slope is assessed by calculating a Factor of Safety, F, which is the ratio of the sum of resisting forces (shear strength) and the sum of driving forces (shear stress) (Scottish Government, 2017):

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

In this formula c' is the effective cohesion (kPa), γ is the bulk unit weight of saturated peat (kN/m^3), γw is the unit weight of water (kN/m^3), z is the vertical peat depth (m), h is the height of the water table as a proportion of the peat depth, β is the angle of the substrate interface (°) and ϕ' is the angle of internal friction of the peat (°). This form of the infinite slope equation uses effective stress parameters, and assumes that there are no excess pore pressures, i.e. that the soil is in its natural, unloaded condition. The use of cut and fill foundations and tracks across almost the whole construction footprint suggest this is an appropriate approach. The choice of water table height reflects the full saturation of the soils that would be expected under the most likely trigger conditions, i.e. heavy rain.

Where the driving forces exceed the shear strength (i.e. where the bottom half of the equation is larger than the top), F is < 1, indicating instability. A factor of safety between 1 and 1.4 is normally taken in engineering to indicate marginal stability (providing an allowance for variability in the strength of the soil, depth to failure, etc). Slopes with a factor of safety greater than 1.4 are generally considered to be stable.

There are numerous uncertainties involved in applying geotechnical approaches to peat, not least because of its high water content, compressibility and organic composition (Hobbs, 1986; Boylan and Long, 2014). Peat comprises organic matter in various states of decomposition with both pore water and water within plant constituents, and the frictional particle-to-particle contacts that are modelled in standard geotechnical approaches are different in peats. There is also a tensile strength component to peat which is assumed to be dominant in the acrotelm, declining with increasing decomposition and depth. As a result, analysis utilising geotechnical approaches is often primarily of value in showing relative stability across a site given credible and representative input parameters rather than in providing an absolute estimate of stability. Representative data inputs have been derived from published literature for drained analyses considering natural site conditions.

4.2.2. Data Inputs

Stability analysis was undertaken in ArcGIS Pro GIS software. A 25 m x 25 m grid was superimposed on the full site extent and key input parameters derived for each grid cell. In total, c. 12,400 grid cells were analysed. A 25 m x 25 m cell size was chosen because it is sufficiently small to define a credible landslide size and avoid 'smoothing' of important topographic irregularities.

Three forms of analysis have been undertaken:

i. **Baseline stability:** input parameters correspond to undisturbed peat, prior to construction, and under water table conditions typically associated with instability (i.e. full saturation). Effective stress parameters are used in a drained analysis.

ii. **Vehicle loaded stability:** input parameters correspond to either 12 t axle loads on sections of floating track (if this were to be used) or to low ground pressure excavators ('LGPE') moving on bog mats or directly over the ground surface on cutting temporary access routes. The floating track analysis includes track and vehicle loads.

iii. **Sidecast:** input parameters correspond to 0.5 m, 1.0 m and 1.5 m loads of peat placed in layers directly onto the *in-situ* peat surface; the assessment assumes drained conditions as the slow build of layers will allow sufficient time for pore pressures to dissipate.

Table 4.1 shows the input parameters and assumptions for the baseline stability analysis. The shear strength parameters c' and ϕ' are usually derived in the laboratory using undisturbed samples of peat collected in the field and therefore site specific values are often not available ahead of detailed site investigation for a development. Therefore, for this assessment, a literature search has been undertaken to identify a range of credible but conservative values for c' and ϕ' quoted in fibrous and humified peats. FoS analysis was undertaken with conservative ϕ' of 20° and values of 2 kPa and 5 kPa for c'. These values fall at the low end of a large range of relatively low values (when compared to other soils).

Table 4.2 shows the input parameters and assumptions for the modified stability analysis. The analysis employs a 5 m wide floating track, and assumes representative loads for a multi-axle crane with maximum axle load of 12 t moving over the floated surface.

The analysis assumes pre-loading of the peat by floating track during which the track is built in layers and pore pressures are allowed to dissipate. The combined weight of the track and peat are then modelled in an undrained analysis utilising the heaviest vehicle loads likely to use the access the track.

4.2.3. Results

The outputs of the drained analysis (effective stress) are shown for both parameter combinations in Figures 12.3.7. Both the best estimate and conservative (minimum c' and ϕ', inset panel) suggest that the site is stable, which is consistent with site observations and with the stability of peat in general – peat landslides are very rare occurrences given the wide distribution of peat soils in England, Scotland and Wales.

Parameter	Values	Rationale	Source
Effective cohesion (c')	2, 5	Credible conservative cohesion values for humified peat based on literature review	5, basal peat (Warburton et al., 2003) 8.74, fibrous peat (Carling, 1986) 7 - 12, H8 peat (Huat et al, 2014) 5.5 - 6.1, type not stated (Long, 2005) 3, 4, type not stated (Long, 2005) 4, type not stated (Dykes and Kirk, 2001)
Bulk unit weight (γ)	10.5	Credible mid-range value for humified catotelmic peat	10.8, catotelm peat (Mills, 2002) 10.1, Irish bog peat (Boylan et al 2008)
Effective angle of internal friction (ϕ')	20, 30	Credible conservative friction angles for humified peat based on literature review (only 20° used in analysis)	40 - 65, fibrous peat (Huat et al, 2014) 50 - 60, amorphous peat (Huat et al, 2014) 36.6 - 43.5, type not stated (Long, 2005) 31 - 55, Irish bog peat (Hebib, 2001) 34 - 48, fibrous sedge peat (Farrell & Hebib, 1998) 32 - 58, type not stated (Long, 2005) 23, basal peat (Warburton et al, 2003) 21, fibrous peat (Carling, 1986)
Slope angle from horizontal (β)	Various	Mean slope angle per 25 m x 25 m grid cell	Resampled to 5 m LiDAR digital terrain model
Peat depth (z)	Various	Mean peat depth per 25 m x 25 m grid cell	Interpolated peat depth model of site
Height of water table as a proportion of peat depth (h)	1	Assumes peat mass is fully saturated (normal conditions during intense rainfall events or snowmelt, which are the most likely natural hydrological conditions at failure)	
Depth of overburden (m)	0.5, 1.0, 1.5	Assumes target overburden depth sidecast onto peat is built up in layers such that underlying peat is in a drained condition	

Table 4-1 Geotechnical parameters for drained infinite slope analysis (including sidecasting)

Parameter	Values	Rationale	Source
Undrained shear strength (Su)	5	Published values show undrained shear strength is typically very similar to effective cohesion (c')	4-30, medium and highly humified (Boylan et al, 2008) 4, more humified (Boylan et al, 2008) 5.2, peat type not stated (Long et al, 2005) 5, Irish bog peat (Farrell and Hebib, 1998)
Bulk unit weight (γ)	10.5	Reduction in volume under floating road is balanced by	See Table 4-1

		increased density, so pre-load parameters are used	
Slope angle from horizontal (β)	Various	Credible slope angles for which floating tracks are proposed	See Table 4-1
Peat depth (z)	Various	Reduction in volume (i.e. depth) under floating road is balanced by increased density, so pre-load parameters are used	See Table 4-1
Crane axle load (t)	12 t	Maximum haul weight that is not considered an "abnormal load", corresponds to 8 axle 96 t (800 t capacity) crane	

Table 4-2 Geotechnical parameters and assumptions (floating road)

For a section of floating track to be considered as a potential source zone, two or more contiguous 25 m cells must have Factors of Safety of <1.4. This reflects the tendency of regularised grids to produce single cell outliers in results. Two contiguous cells of similar value would indicate a trend more reflective of the locality.

The outputs of the undrained analysis incorporating crane loads on floating track are shown in the inset panel on Figure 12.3.7. This is centred on the single length of floating track which will be constructed between Turbine 6 and the planned substation and BESS. This general area has a crane loaded Factor of Safety exceeding 1.4, which indicates stability.

Figure 12.3.8 shows sidecasting results for the areas in which peat may be placed directly (or sidecast) by excavators positioned on access tracks and hardstandings across the site. The 0.5 m panel (left) indicates stability across the site. The 1.0 m panel (centre) indicates general stability across the site though with reduced stability around T11. The 1.5 m panel shows reduced stability and marginal stability in a number of locations, particularly around T11, to the east of T8, on the upslope side of T2 and on the upslope side of T1 and its access. It is recommended that sidecasting to these depths in these locations is avoided.

4.3. Landslide Susceptibility Approach

4.3.1. Overview

The landslide susceptibility approach is based on the layering of contributory factors to produce unique 'slope facets' that define areas of similar susceptibility to failure. These slope facets vary in size and are different to the regular grid used for the FoS approach. The number and size of slope facets varies from one part of the site to another according to the complexity of ground conditions. In total, 17,255 facets were considered in the analysis, with an average area of c. 450m^2 (or an average footprint of c. 21 m x 21 m, consistent with smaller to medium scale peaty soil or peat slides reported in the published literature.

Eight contributory factors are considered in the analysis: slope angle (S), peat depth (P), substrate geology (G), peat geomorphology (M), drainage (D), slope curvature (C), forestry (F), and land use (L). For each factor, a series of numerical scores between 0 and 3 are assigned to factor 'classes', the significance of which is tabulated for each factor. The higher a score, the greater the contribution of that factor to instability for any particular slope facet. Scores of 0 imply neutral / negligible influence on instability.

Factor scores are summed for each slope facet to produce a peat landslide likelihood score (S_{PL}), the maximum being 24 (8 factors, each with a maximum score of 3).

$$S_{PL} = S_S + S_P + S_G + S_M + S_D + S_C + S_F + S_L$$

In practice, a maximum score is unlikely, as the chance of all contributory factors having their highest scores in one location is very small. The following sections describe the contributory factors, scores and justification for the Proposed Varied Development.

4.3.2. Slope Angle (S)

Table 4-3 shows the slope ranges, their association with instability and related scores for the slope angle contributory factor. Slope angles were derived from the 5 m digital terrain model shown on Figure 12.3.2 and scores assigned based on reported slope angles associated with peat landslides rather than a simplistic assumption that 'the steeper a slope, the more likely it is to fail' (e.g. Plate 2.2).

Slope range (°)	Association with instability	Peat slide
≤2.5	Slope angle ranges for peat slides are based on lower and upper limiting angles for observations of occurrence (see Plate 2.2 and increase with increasing slope angle until the upper limiting angle e.g. peat slides are not observed on slopes <2.5°).	0
2.5 - 5.0		1
5.0 – 7.5		3
7.5 - 10.0		3
>10.0		3

Table 4-3 Slope classes, association with instability and scores

Figure 12.3.9 shows the distribution of slope angle scores across the site. Slopes are generally moderate to steep over much of the site, however, where peat is most widespread, slopes are lower and scores reduced (e.g. on the edges of the saddle along the western site boundary).

4.3.3. Peat Depth (P)

Table 4-4 shows the peat depths, their association with instability and related scores for the peat depth contributory factor. Peat depths were derived from the peat depth model shown on Figure 12.3.6 and reflect the peat depth ranges most frequently associated with peat landslides (see Plate 2.2).

Peat depth range (m)	Association with instability	Peat slide
>1.5	Bog bursts are the dominant failure mechanism in this depth range where basal peat is more likely to be amorphous	1
0.5 - 1.5	Peat slides are the dominant failure mechanism in this depth range where basal peat is less likely to be amorphous	3
<0.5	Organic soil rather than peat, failures would be peaty-debris slides rather than peat slides or bog bursts and are outside the scope	0

Table 4-4 Peat depth classes, association with instability and scores

The distribution of peat depth scores is shown on Figure 12.3.9. Due to the absence of peat, much of the site has the lowest score. Where peat is present, it is shallow to moderate in depth and therefore generally corresponds to the highest score.

4.3.4. Substrate Geology (G)

Table 4-5 shows substrate type, association with instability and related scores for the substrate geology contributory factor. The shear surface or failure zone of reported peat failures typically overlies an impervious clay or mineral (bedrock) base giving rise to impeded drainage. This, in part, is responsible for the presence of peat, but also precludes free drainage of water from the base of the peat mass, particularly under extreme conditions (such as after heavy rainfall, or snowmelt).

Peat failures are frequently cited in association with glacial till deposits in which an iron pan is observed in the upper few centimetres (Dykes and Warburton, 2007). They have also been observed over glacial till without an obvious iron pan, or over impermeable bedrock. They are rarely cited over permeable bedrock, probably due to the reduced likelihood of peat formation.

Substrate Geology	Association with instability	Peat slide
Cohesive (clay) or iron pan	Failures are often associated with clay substrates and/or iron pans	3
Granular clay or clay dominated alluvium	Failures are more frequently associated with substrates with some clay component	2
Granular or bedrock	Failures are less frequently associated with bedrock or granular (silt / sand / gravel) substrates	1

Table 4-5 Substrate geology classes, association with instability and scores

Probing undertaken across the site indicated primarily bedrock or granular substrates using the refusal method, and coring at 22 locations confirmed this. While much of the west of the site has been scored 1 (granular or bedrock), parts of the site including till and alluvium with some granular content have been assigned a score of 2 (Figure 12.3.9).

4.3.5. Peat Geomorphology (M)

Table 4-6 shows the geomorphological features typical of peatland environments, their association with instability and related scores. Being an afforested site, there are very few natural features present and much of the site has a zero score (forestry being considered under a separate factor).

Geomorphology	Association with instability	Peat slide
Incipient instability (cracks, ridges, bulging)	Failures are likely to occur where pre-failure indicators are present	3
Planar with pipes	Failures generally occur on planar slopes, and are often reported in areas of piping	3
Planar with pools / quaking bog	Bog bursts are more likely in areas of perched water (pools) or subsurface water bodies (quaking bog)	2
Flush / Sphagnum lawn (diffuse drainage)	Peat slides are often reported in association with areas of flushed peat or diffuse drainage	3
Planar (no other features)	Failures generally occur on planar slopes rather than dissected or undulating slopes	2
Peat between rock outcrops	Failures are rarely reported in areas of peat with frequent rock outcrops	1
Slightly eroded (minor gullies)	Failures are rarely reported in areas with gullying or bare peat	1

Heavily eroded (extensive gullies) / bare peat	Failures are not reported in areas that are heavily eroded or bare	0
Afforested / deforested peatland	Considered within Forestry (F), see below	0

Table 4-6 Peat geomorphology classes, association with instability and scores

Figure 12.3.9 shows the geomorphological classes from Figure 12.3.5 re-coloured to correspond with Table 4-6. All peatland outside the afforested areas is either planar (largely featureless) peat or non-peatland geomorphology (river valley sides, etc).

4.3.6. Artificial Drainage (D)

Table 4.7 shows artificial drainage feature classes, their association with instability and related scores. Transverse (or contour aligned) / oblique artificial drainage lines may reduce peat stability by creating lines of weakness in the peat slope and encouraging the formation of peat pipes. A number of peat failures have been identified in published literature which have failed over moorland grips (Warburton et al, 2004). The influence of changes in hydrology becomes more pronounced the more transverse the orientation of the drainage lines relative to the overall slope.

Drainage Feature	Association with instability	Peat slide
Drains aligned along contours (<15 °)	Drains aligned to contour create lines of weakness in slopes	3
Drains oblique (15-60°) to contour	Most reports of peat slides and bog bursts in association with drainage occurs where drains are oblique to slope	2
Drains aligned downslope (<30° to slope)	Failures are rarely associated with artificial drains parallel to slope or adjacent to natural drainage lines	1
No / minimal artificial drainage	No influence on stability	0

Table 4-7 Drainage feature classes, association with instability and scores

The effect of drainage lines is captured through the use of a 30 m buffer on each artificial drainage line (producing a 60 m wide zone of influence) present within the peat soils at the site. Each buffer is assigned a drainage feature class based on comparison of the drainage axis with elevation contours (transverse, oblique or aligned, as shown in Table 4-7). The site is heavily modified by forest drains, and buffers are shown on Figure 12.3.9.

4.3.7. Slope Curvature (C)

Table 4-8 shows slope (profile) curvature classes, association with instability and related scores. Convex and concave slopes (i.e. positions in a slope profile where slope gradient changes by a few degrees) have frequently been reported as the initiation points of peat landslides by a number of authors. The geomechanical reason for this is that convexities are often associated with thinning of peat, such that thicker peat upslope applies stresses to thinner 'retaining' peat downslope. Conversely, buckling and tearing of peat may trigger failure at concavities (e.g. Dykes & Warburton, 2007; Boylan and Long, 2011). However, review of reported peat landslide locations against Google Earth elevation data indicates that the majority of peat slides occur on rectilinear (straight) slopes and that the reporting of convexity as a key driver may be misleading. Accordingly, rectilinear slopes are assigned the highest score.

Profile Curvature	Association with instability	Peat slide
Rectilinear Slope	Peat slides are most frequently reported on rectilinear slopes, while bog bursts are often reported on rectilinear slopes	3
Convex Slope	Peat slides are often reported on or above convex slopes while bog bursts are most frequently associated with convex slopes	2
Concave Slope	Peat failures are occasionally reported in association with concave slopes	1

Table 4-8 Slope curvature classes, association with instability and scores

An ArcGIS geoprocessing model was used to calculate slope curvature and subdivide slopes into concave, convex and rectilinear slopes, and 'flat' areas, i.e. those with minimal rate of gradient change on subdued terrain. The results are shown on Figure 12.3.9.

4.3.8. Forestry (F)

Table 4-9 shows forestry classes, their association with instability and related scores. A report by Lindsay and Bragg (2004) on Derrybrien suggested that row alignments, desiccation cracking and loading (by trees) could all influence peat stability.

Forestry Class	Association with instability	Peat slide
Deforested, rows oblique to slope	Deforested peat is less stable than afforested peat, and inter ridge cracks oblique to slope may be lines of weakness	3
Deforested, rows aligned to slope	Deforested peat is less stable than afforested peat, but slope aligned inter ridge cracks have less impact	2
Afforested, rows oblique to slope	Afforested peat is more stable than deforested peat, but inter ridge cracks oblique to slope may be lines of weakness	2
Afforested, rows aligned to slope	Afforested peat is more stable than deforested peat, but potentially less stable than unforested (never planted) peat	1
Windblown	Windblown trees have full disruption to the underlying peat and residual hydrology due to root plate disturbance	0
Not afforested	No influence on stability	0

Table 4-9 Forestry classes, association with instability and scores

Almost the entire site is, or has been, afforested. Scores have been assigned in accordance with Table 4.3.8 above (see Figure 12.3.9).

4.3.9. Land use (L)

Table 4-10 shows land use classes, association with instability and related scores. A variety of land uses have been associated with peat failures (see 2.2.1).

Land Use	Association with instability	Peat slide
Machine cutting	Machine cutting may compartmentalise slopes, but has been reported primarily in association with peat slides	3
Quarrying	Quarrying may remove slope support from upslope materials, and has been observed with spreading failures (bog bursts)	2
Hand cutting (turbary)	Hand cutting may remove slope support from upslope materials, and has been reported with raised bog failures	1

Burning (deep cracking to substrate)	Failures are rarely associated with burning, but deep desiccation cracking will have the most severe effects	2
Burning (shallow cracking)	Failures are rarely associated with burning, shallow desiccation cracking will have very limited effects	1
Grazing	Failures have not been associated with grazing, no influence on stability	0

Table 4-10 Land use classes, association with instability and scores

Forestry is the primary land use on site and therefore, given that this is considered in the forestry factor, a score of 0 is assigned to the full site extent.

4.3.10. Generation of Slope Facets

The eight contributory factor layers shown on Figure 12.3.9 were combined in ArcGIS Pro to produce 17,255 slope facets. Scores for each facet were then summed to produce a peat landslide likelihood score. These likelihood scores were then converted into descriptive 'likelihood classes' from 'Very Low' to 'Very High' with a corresponding numerical range of 1 to 5 (in a similar format to the Scottish Government BPG).

Summed Score from Contributory Factors	Typical site conditions associated with score	Likelihood (Qualitative)	Landslide Likelihood Score
≤ 7	Unmodified peat with no more than low weightings for peat depth, slope angle, underlying geology and peat morphology	Very Low	1
8 - 12	Unmodified or modified peat with no more than moderate or some high scores for peat depth, slope angle, underlying geology and peat morphology	Low	2
13 - 17	Unmodified or modified peat with high scores for peat depth and slope angle and / or high scores for at least three other contributory factors	Moderate	3
18 - 21	Modified peat with high scores for peat depth and slope angle and several other contributory factors	High	4
> 21	Modified peat with high scores for most contributory factors (unusual except in areas with evidence of incipient instability)	Very High	5

Table 4-11 Likelihood classes derived from the landslide susceptibility approach

Table 4-11 describes the basis for the likelihood classes. A judgement was made that for a facet to have a moderate or higher likelihood of a peat landslide, a likelihood score would be required exceeding both the worst case peat depth and slope angle scores summed (3 in each case, i.e. 3 x 2 classes) alongside three intermediate scores (of 2, i.e. 2 x 3 classes) for other contributory factors. This means that any likelihood score of 13 or greater would be equivalent to at least a moderate likelihood of a peat landslide. Given that the maximum score attainable is 24, this seems reasonable.

4.4. Results

Figure 12.3.10 shows the outputs of the landslide susceptibility approach for peat slides. The results indicate that most of the site has a Very Low or Low likelihood, with small areas of Moderate likelihood. The areas of Moderate likelihood are typically on moderately steep slopes with moderate peat depths and where drain orientation is oblique to slope.

The Factor of Safety and Landslide likelihood results were also reviewed to identify any proposed areas of infrastructure of greater than 25 m in length, which intersected areas of moderate or higher landslide susceptibility (from the contributory factor approach) or Factor of Safety of 1.4 or less (from the various limit equilibrium approaches). A 25 m overlap has been selected as this is considered the minimum size of a potentially environmentally significant landslide.

This review established that there were no infrastructure locations, which overlapped an area of "Moderate" landslide likelihood or where the Factor of Safety was calculated to be 1.4 or less.

		Adverse Consequence (scores bracketed)				
		Very High (5)	High (4)	Moderate (3)	Low (2)	Very Low (1)
Peat landslide likelihood (scores bracketed)	Very High (5)	High	High	Medium	Low	Low
	High (4)	High	Medium	Medium	Low	Negligible
	Moderate (3)	Medium	Medium	Low	Low	Negligible
	Low (2)	Low	Low	Low	Negligible	Negligible
	Very Low (1)	Low	Negligible	Negligible	Negligible	Negligible

Score	Risk Level	Action suggested for each zone
17 - 25	High	Avoid project development at these locations
11 - 16	Medium	Project should not proceed in MEDIUM areas unless risk can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce risk ranking to LOW or NEGLIGIBLE.
5 - 10	Low	Project may proceed pending further post-consent investigation in LOW areas to refine risk level and/or mitigate any residual hazards through micro-siting or specific design measures
1 - 4	Negligible	Project should proceed with good practice monitoring and mitigation of ground instability / landslide hazards at these locations as appropriate

Plate 4.1 Top: risk ranking as a product of likelihood and consequence; Bottom: suggested action given each level of calculated risk

In order for risks to exceed Low, likelihood must be Moderate or higher, either through the Moderate likelihood results or through FoS <1.4 from the baseline, vehicle loaded or sidecast assessments. In addition, consequences of an event need to be Moderate or higher (see **Plate 4.1** above).

Consequences depend on the receptors present within runout distance of landslides that might be sourced within the study area and which might occur as a consequence of construction activity (noting it is not the role of the PLHRA to de-risk a site from naturally occurring landslides).

While risks exceeding Low are not anticipated, Section 5 of this PLHRA provides an overview of potential receptors in order to provide context to this aspect of the risk assessment.

5. ASSESSMENT OF CONSEQUENCE AND RISK

5.1. Introduction

In order to calculate risks, the potential consequences of a peat landslide must be determined. This requires identification of receptors and an assessment of the consequences for these receptors should a peat landslide occur. This section describes the consequence assessment and then provides risk results based on the product of likelihood and consequence.

5.2. Receptors

Peat uplands are typically host to the following receptors: watercourses and associated water supplies (both private and public), terrestrial habitats, and infrastructure, both those that are related to the wind farm and other infrastructure, e.g. roads and power lines. These are considered for the Proposed Varied Development below.

5.2.1. Watercourses

The Proposed Varied Development site is drained by a number of watercourses, a majority of which drain into the Water of Ken. None of the watercourses are designated, and many are of poor or moderate ecological condition only. Accordingly, all watercourses have been assigned a Moderate consequence score (3) (Table 5.1).

5.2.2. Habitats

Blanket bog habitats are generally absent over the majority of the site due to forestry, and therefore a low consequence score of 2 has been assigned for habitats (Table 5.1)

Receptor and type	Consequence	Score	Justification for Consequence Score
Watercourses (aquatic habitats)	Short term increase in turbidity and acidification, potential fish kill	3	Undesignated watercourse, no sensitive species noted
Terrestrial habitats	Short to medium term loss of vegetation cover, disruption of peat hydrology, carbon release	2	Habitats are generally poor across the site due to the widespread presence of forestry
Wind farm infrastructure (Project)	Damage to infrastructure, injury to site personnel, possible loss of life	5	Loss of life, though very unlikely, is a severe consequence; financial implications of damage and re-work are less significant

Table 5-1 Receptors considered in the consequence analysis

5.2.3. Infrastructure

The Proposed Varied Development site is relatively isolated, with non-wind farm infrastructure limited to forestry roads and the public road in the east of the site.

Infrastructure that would be most affected in the event of a peat landslide would be the Proposed Varied Development infrastructure. These effects would be most likely during construction, at which time personnel would be using the access track network or be present at infrastructure locations for long periods. While commercial losses would be important to the Applicant, loss of life / injury would be of greater concern, and a consequence score of 5 is assigned for any infrastructure locations subject to potential peat landslides (Table 5-1). However, risks to life can be mitigated through safe systems of working including the use of toolbox talks to raise awareness, banksmen during construction and post-consent ground investigation to further mitigate risks to personnel and the infrastructure they are constructing.

5.3. Consequence Assessment

On the basis of the combined likelihood assessment described in Section 4, construction activities will not take place in areas of Moderate likelihood and therefore even with Very High consequence receptors, **risks will not exceed Low** (see Plate 4.1). As a result, site-wide good practice measures are considered sufficient to manage these Low risks, and these are described in Section 6.

6. RISK MITIGATION

6.1. Overview

A number of mitigation opportunities exist to further reduce the risk levels identified at the Proposed Varied Development site. These range from infrastructure specific measures (which may act to reduce peat landslide likelihood, and, in turn, risk) to general good practice that should be applied across the site to engender awareness of peat instability and enable early identification of potential displacement and opportunities for mitigation.

Risks may be mitigated by:

i. Post-consent site specific review of the ground conditions contributing to Moderate likelihoods which may result in a reduced likelihood, and in turn, further reduction in risk; an example would include artificial drains aligned oblique to contour.

ii. Precautionary construction measures – including use of monitoring, good practice and a geotechnical risk register relevant to all locations.

Based on the analysis presented in this report, risks are calculated to be "Low" or "Negligible" across the site, and site-specific mitigation is not required to reduce risks pre-consent. Sections 6.2 to 6.4 provide information on good practice pre-construction, during construction and post-construction (i.e. during operation).

6.2. Good Practice Prior to Construction

Site safety is critical during construction, and it is strongly recommended that detailed intrusive site investigation and laboratory analysis are undertaken ahead of the construction period in order to characterise the strength of the peat soils in the areas in which excavations are proposed, particularly where these fall in areas of Moderate (or greater, if present) likelihood. These investigations should be sufficient to:

1. Determine the strength of free-standing bare peat excavations.
2. Determine the strength of loaded peat (where excavators and plant are required to operate on floating hardstandings or track, or where operating directly on the bog surface).
3. Identify sub-surface water-filled voids or natural pipes delivering water to the excavation zone, e.g. through the use of ground penetrating radar or careful pre-excavation site observations.

A comprehensive Geotechnical Risk Register should be prepared post-consent, but pre-construction, detailing sequence of working for excavations, measures to minimise peat slippage, design of retaining structures for the duration of open hole works, monitoring requirements in and around the excavation and remedial measures in the event of unanticipated ground movement. The risk register should be considered a live document and updated with site experience as infrastructure is constructed. Ideally, a contractor with experience of working in deep peat should be engaged to undertake the works.

6.3. Good Practice During Construction

The following good practice should be undertaken during construction:

For excavations:

- Use of appropriate supporting structures around peat excavations (e.g. for turbines, crane pads and compounds) to prevent collapse and the development of tension cracks.
- Avoid cutting trenches or aligning excavations across slopes (which may act as incipient back scars for peat failures) unless appropriate mitigation has been put in place.
- Implement methods of working that minimise the cutting of the toes of slope, e.g. working up-to-downslope during excavation works.
- Monitor the ground upslope of excavation works for creep, heave, displacement, tension cracks, subsidence or changes in surface water content.
- Monitor cut faces for changes in water discharge, particularly at the peat-substrate contact.
- Minimise the effects of construction on natural drainage by ensuring that natural drainage pathways are maintained or diverted such alteration of the hydrological regime of the site is minimised or avoided; drainage plans should avoid creating drainage/infiltration areas or settlement ponds towards the tops of slopes (where they may act to both load the slope and elevate pore pressures).

For cut tracks:

- Maintain drainage pathways through tracks to avoid ponding of water upslope.
- Monitor the top line of excavated peat deposits for deformation post-excavation.
- Monitor the effectiveness of cross-track drainage to ensure water remains free-flowing and that no blockages have occurred.

For floating tracks:

- Allow peat to undergo primary consolidation by adopting rates of road construction appropriate to weather conditions.
- Identify 'stop' rules, i.e. weather dependent criteria for cessation of track construction based on local meteorological data.
- Run vehicles at 50% load capacity until the tracks have entered the secondary compression phase.
- Prior to construction, setting out the centreline of the proposed track to identify any ground instability concerns or particularly wet zones.

For storage of peat and for restoration activities:

- Ensure stored peat is not located upslope of working areas or adjacent to drains or watercourses.
- Undertake site specific stability analysis for all areas of peat storage (if on sloping ground) to ensure the likelihood of destabilisation of underlying peat is minimised.
- Where possible, avoid storing peat on slope gradients >3° and preferably store on ground with neutral slopes and natural downslope barriers to peat movement.
- Monitor effects of wetting / re-wetting stored peat on surrounding peat areas, and prevent water build up on the upslope side of peat mounds.
- Undertake regular monitoring of emplaced peat in restoration areas to identify evidence of creep or pressure on retaining structures (dams and berms).

- Maximise the interval between material deliveries over newly constructed tracks that are still observed to be within the primary consolidation phase.

In addition to these control measures, the following good practice should be followed:

- The geotechnical risk register prepared prior to construction should be updated with site experience as infrastructure is constructed.
- Full site walkovers should be undertaken at scheduled intervals to be agreed with the Local Authority to identify any unusual or unexpected changes to ground conditions (which may be associated with construction or which may occur independently of construction).
- All construction activities and operational decisions that involve disturbance to peat deposits should be overseen by an appropriately qualified geotechnical engineer with experience of construction on peat sites.
- Awareness of peat instability and pre-failure indicators should be incorporated in site induction and training to enable all site personnel to recognise ground disturbances and features indicative of incipient instability.
- A weather policy should be agreed and implemented during works, e.g. identifying 'stop' rules (i.e. weather dependent criteria) for cessation of track construction or trafficking.
- Monitoring checklists should be prepared with respect to peat instability addressing all construction activities proposed for site.

It is considered that taken together, these mitigation measures should be sufficient to reduce risks to construction personnel to Negligible by reducing consequences to minor injury or programme delay (i.e. Moderate consequences) with a Very Low likelihood of occurrence.

6.4. Good Practice Post-Construction

Following cessation of construction activities, monitoring of key infrastructure locations should continue by full site walkover to look for signs of unexpected ground disturbance, including:

- Ponding on the upslope side of infrastructure sites and on the upslope side of access tracks.
- Changes in the character of peat drainage within a 50 m buffer strip of tracks and infrastructure (e.g. upwelling within the peat surface upslope of tracks, sudden changes in drainage behaviour downslope of tracks).
- Blockage or underperformance of the installed site drainage system.
- Slippage or creep of stored peat deposits.
- Development of tension cracks, compression features, bulging or quaking bog anywhere in a 50 m corridor surrounding the site of any construction activities or site works.

This monitoring should be undertaken on a quarterly basis in the first year after construction, biannually in the second year after construction and annually thereafter; in the event that unanticipated ground conditions arise during construction, the frequency of these intervals should be reviewed, revised and justified accordingly.

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Figure 12.3.1: Elevation

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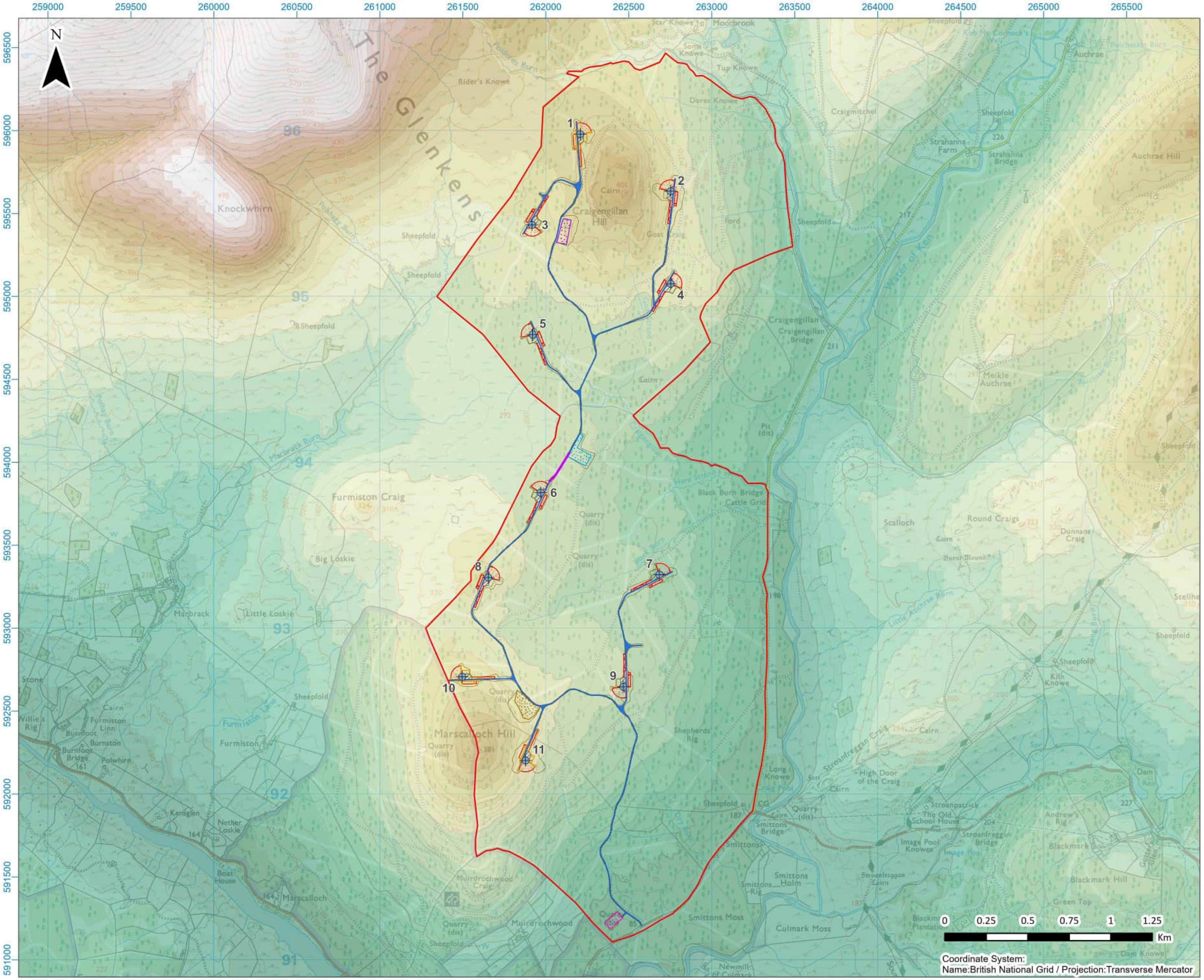

KEY

- Site Boundary
- Turbine
- Floating Track
- Access Track
- Northern Borrow Pit
- Borrow Pit
- Construction Compound
- Permanent Hardstanding
- Temporary Hardstanding
- Hardstanding (Clearance Area)
- Substation and BESS Compound
- Earthworks

Elevation (m)

- <180
- 180 - 200
- 200 - 220
- 220 - 240
- 240 - 260
- 260 - 280
- 280 - 300
- 300 - 320
- 320 - 340
- 340 - 360
- 360 - 380
- 380 - 400
- 400 - 420
- 420 - 440
- 440 - 460
- 460 - 480
- 480 - 500

Title

Elevation

Project:

Shepherds' Rig Wind Farm Section 36C

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Figure 12.3.2: Slope Angle

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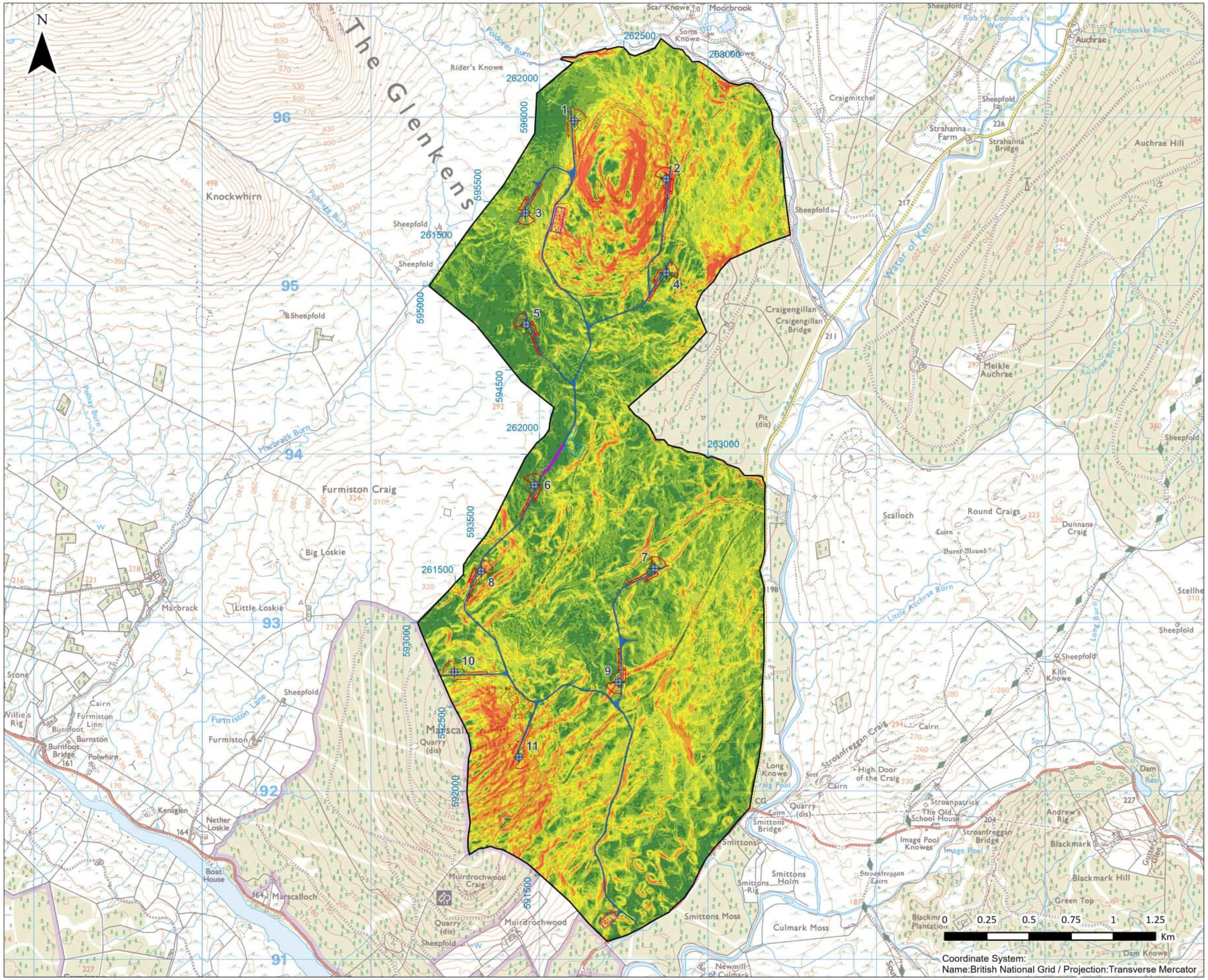

KEY

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- Turbine
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- Borrow Pit
- Construction Compound
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Slope (°)

- 0.0 - 2.5
- 2.5 - 5.0
- 5.0- 7.5
- 7.5 - 10.0
- 10.0- 15.0
- > 15.0

Title

Slope Angle

Project:

Shepherds' Rig Wind Farm Section 36C

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Figure 12.3.3: Bedrock Geology

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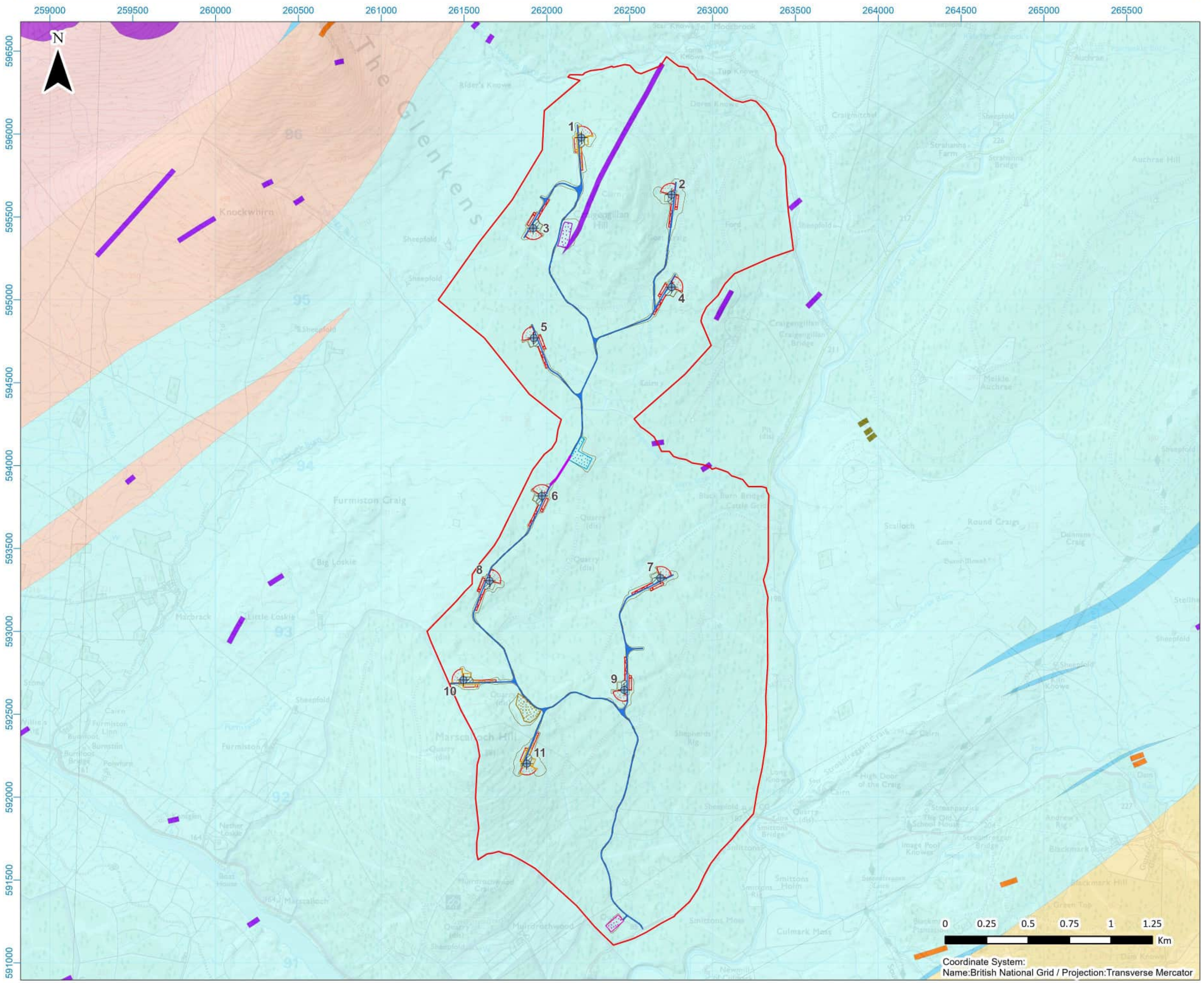

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- Silurian/Devonian - Igneous Calc-Alkaline Dyke Suite-Porphyritic microdiorite
- Silurian - Moffat Shale Group-Mudstone, chert and smectite-claystone
- Ordovician - Sedimentary - Glenwhargen Formation-Wacke
- Ordovician - Sedimentary - Portpatrick Formation-Wacke
- Ordovician - Sedimentary - Shinnel Formation-Wacke

Title

Bedrock Geology

Project:

Shepherds' Rig Wind Farm Section 36C

Source:

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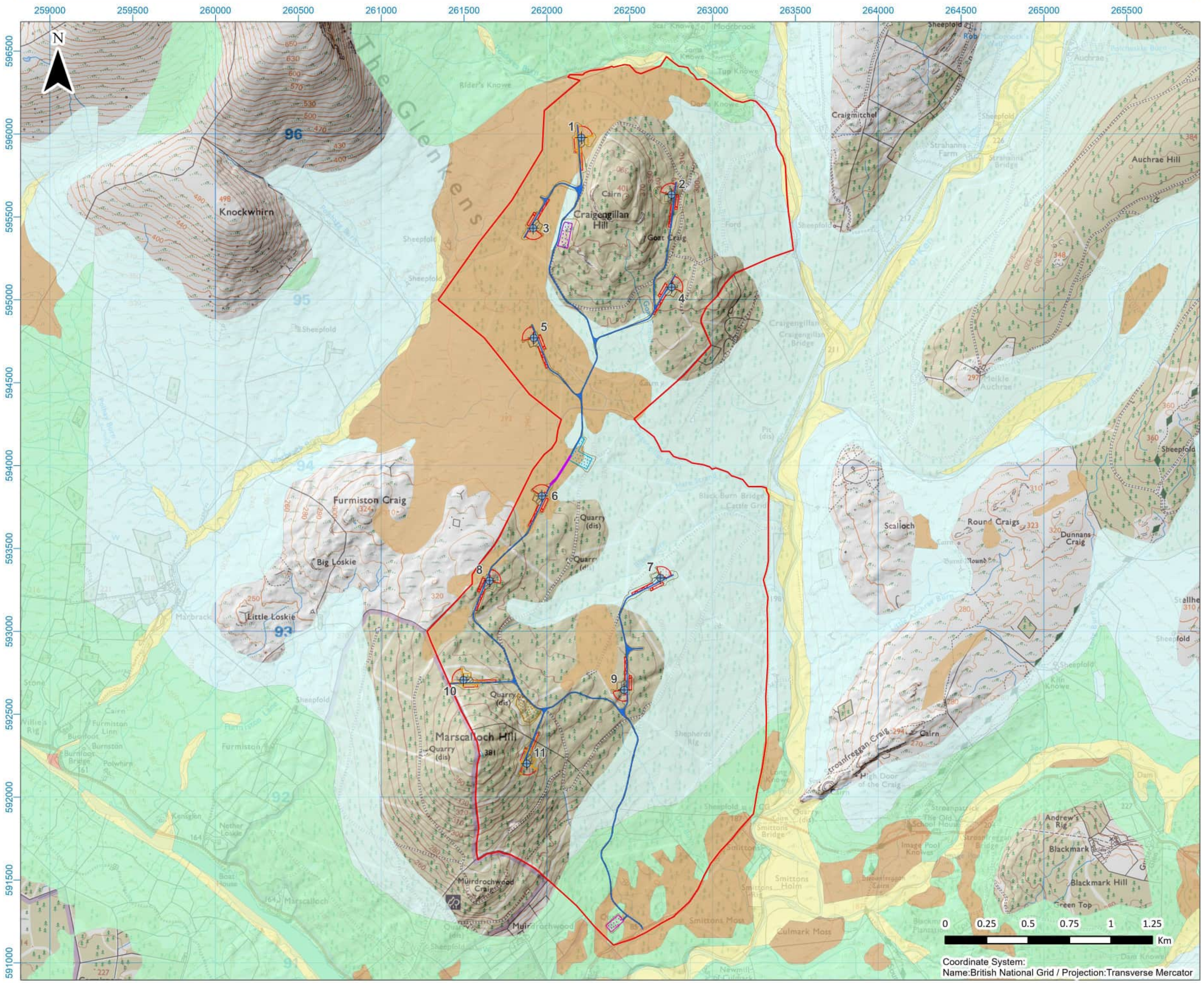

KEY

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- Borrow Pit
- Construction Compound
- Permanent Hardstanding
- Temporary Hardstanding
- Hardstanding (Clearance Area)
- Substation and BESS Compound
- Earthworks
- Alluvium-Silt, sand and gravel
- Hummocky Glacial Deposits - sand and gravel.
- Peat
- Till, Devensian-Diamicton

Title

Superficial Geology

Project:

Shepherds' Rig Wind Farm Section 36C

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Figure 12.3.5: Geomorphology, land use and hydrology

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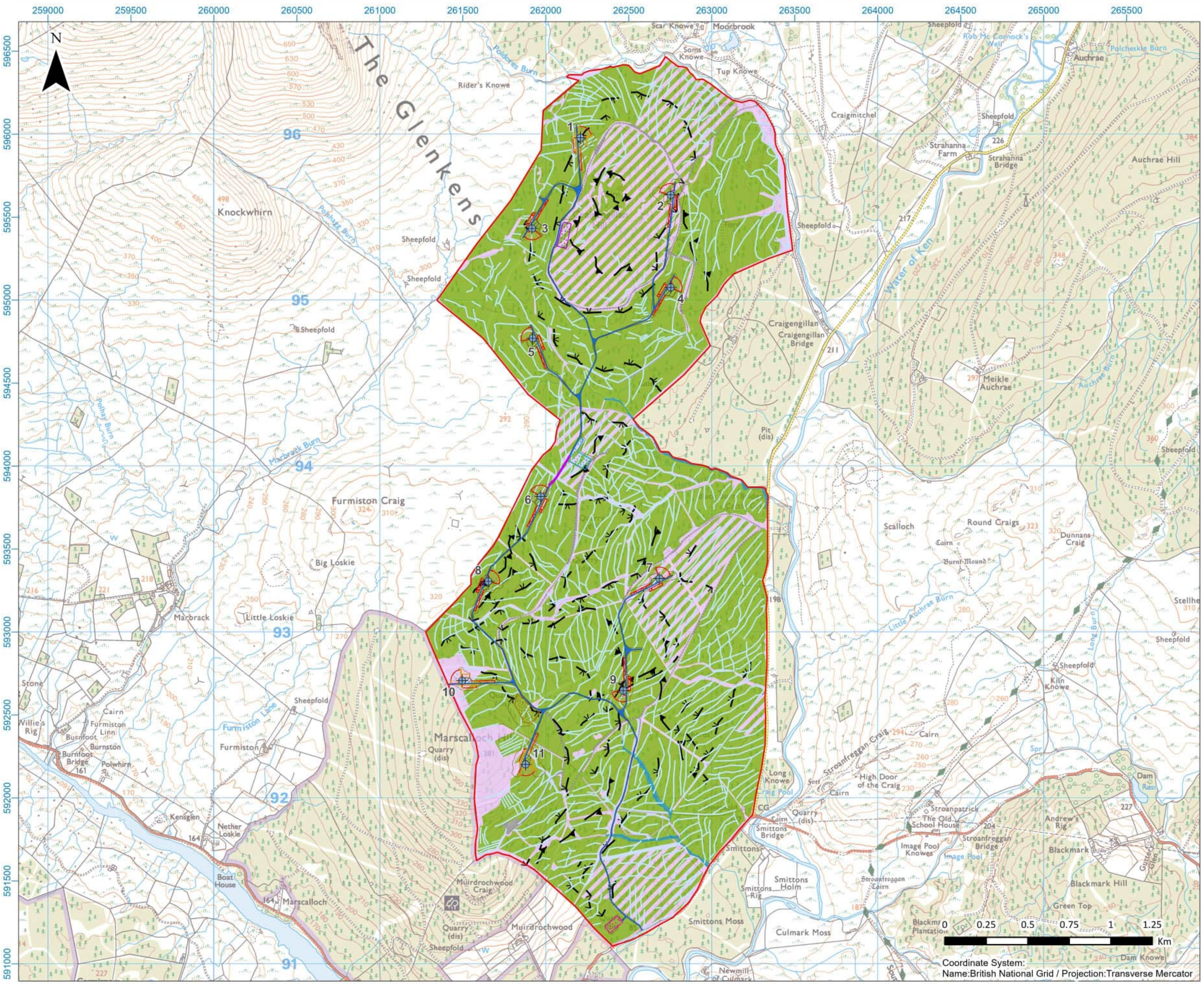

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Geomorphology, hydrology and land use

- Planar
- Deforested
- Wind blown
- Afforested
- Made ground
- River valley
- Drains

Morphology

- Concave change of slope
- Convex change of slope

Title

Geomorphology, land use and hydrology

Project:

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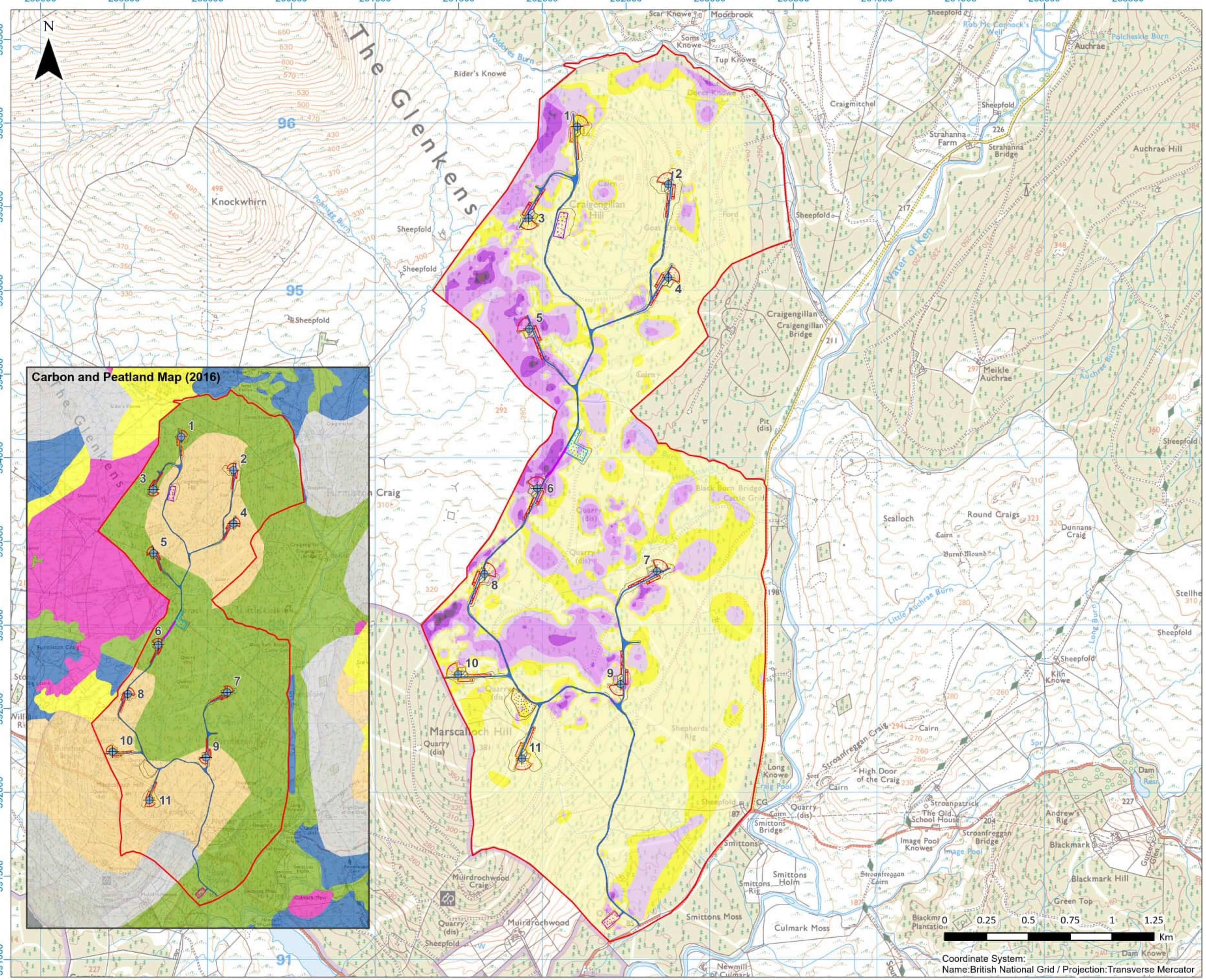
Figure 12.3.6: Peat depth



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Peat Depth (m)

- 0.0 - 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- > 4.0

Carbon and Peatland (2016)

- Class 1
- Class 2
- Class 3
- Class 4
- Class 5
- Mineral Soil
- Unknown Soil
- Non Soil

Title

Peat depth

Project:

Shepherds' Rig Wind Farm Section 36C

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Figure 12.3.7: Factor of Safety - Best Estimate, Lower Bound and Crane Loaded estimates

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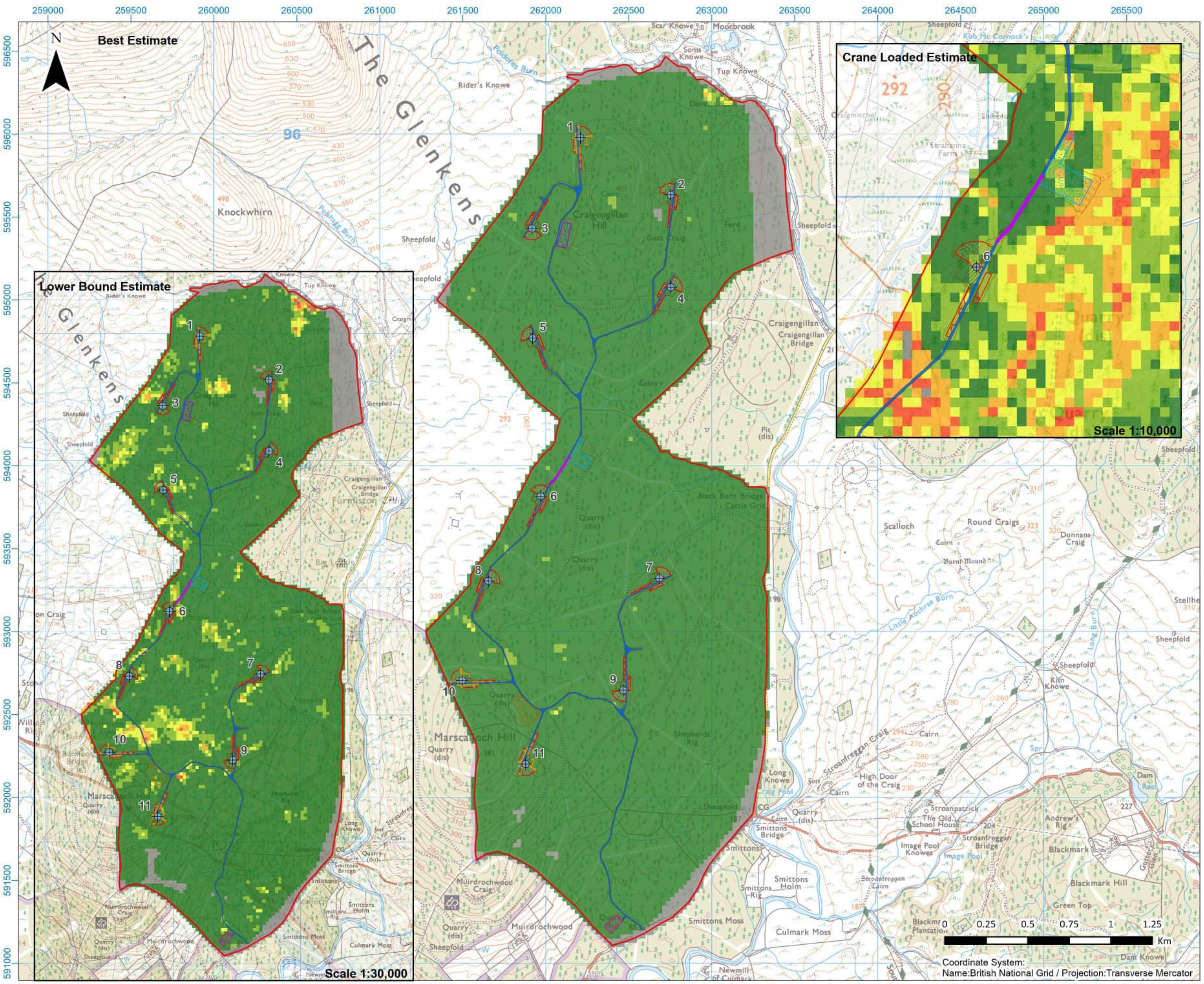

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Factor of Safety

- < 1.00 "Unstable"
- 1.01 - 1.40 "Marginally Stable"
- 1.41 - 2.00 "Stable"
- 2.01 - 3.00 "Stable"
- > 3.01 "Stable"
- No Calculation

Title

Factor of Safety - Best Estimate, Lower Bound and Crane loaded estimates

Project:

Shepherds' Rig Wind Farm Section 36C

Source:

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Figure 12.3.8: Factor of Safety - Sidecast Calculations

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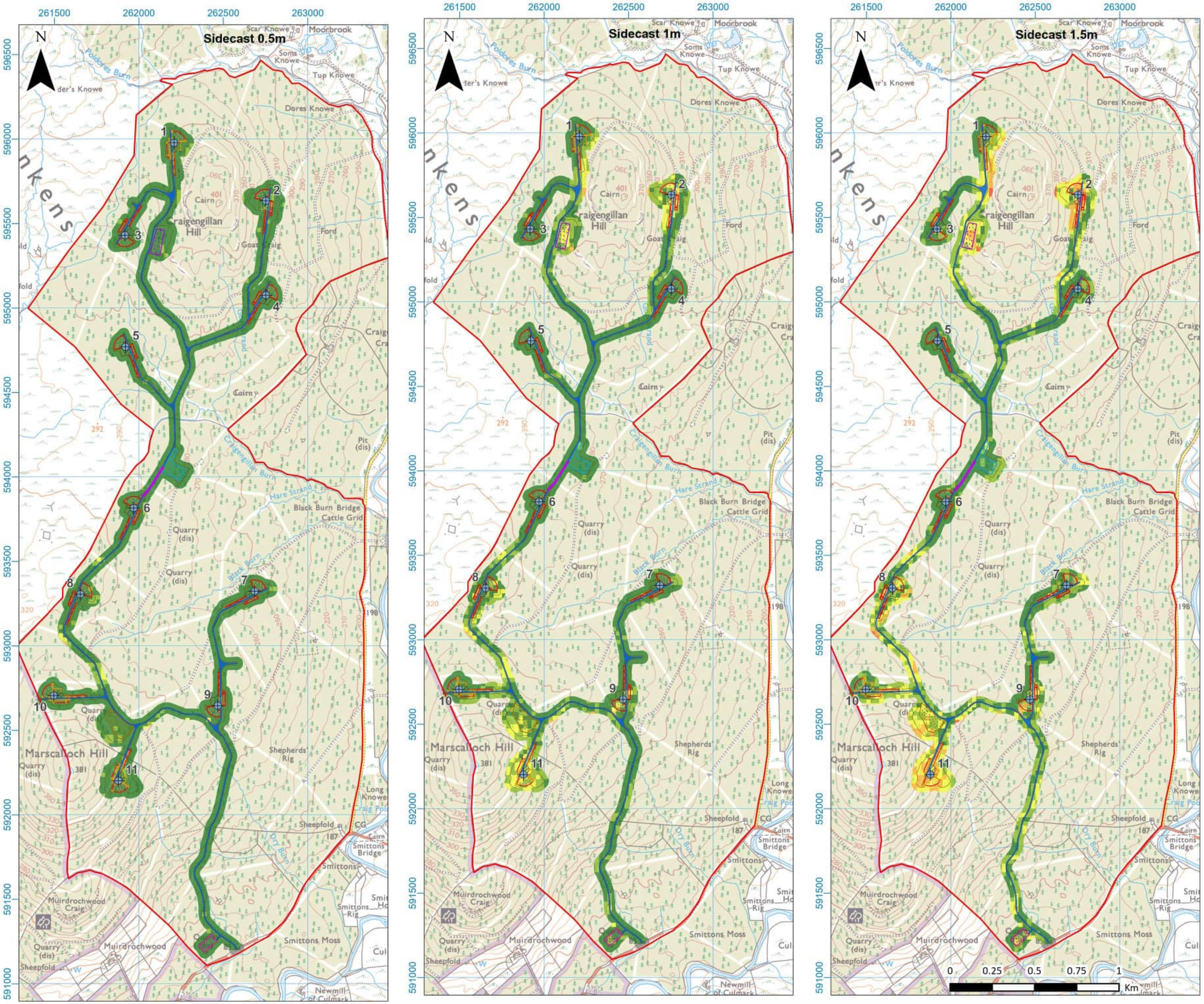

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- Earthworks

Factor of Safety

- < 1.00 "Unstable"
- 1.01 - 1.40 "Marginally Stable"
- 1.41 - 2.00 "Stable"
- 2.01 - 3.00 "Stable"
- > 3.01 "Stable"
- No Calculation

Title	Factor of Safety - Sidecast Calculations
Project:	Shepherds' Rig Wind Farm Section 36C
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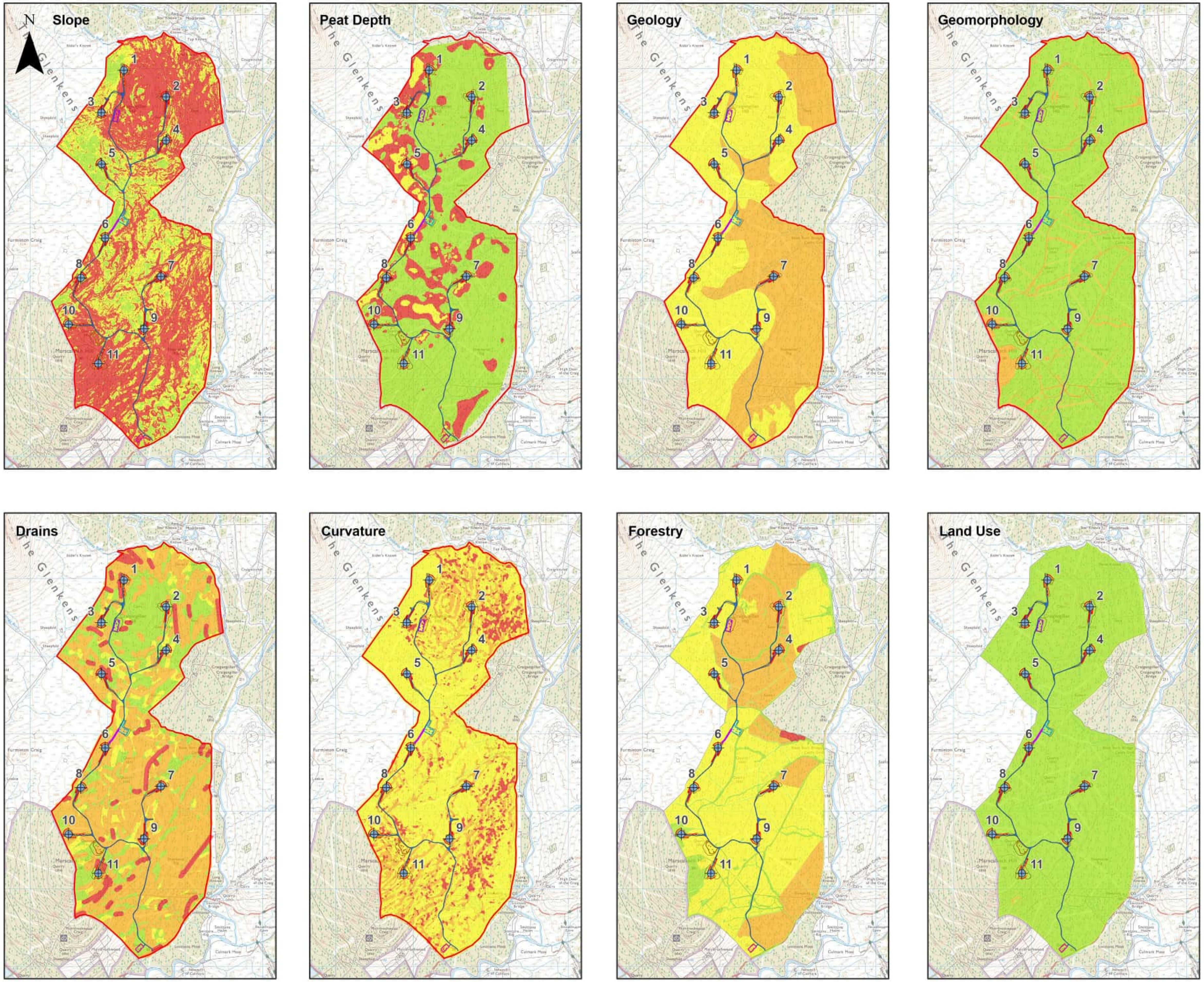
Figure 12.3.9: Contributory Factors



KEY

Site Boundary

Contributory Score

- 0
- 1
- 2
- 3

0 0.5 1 1.5 2 Km

Title

Contributory Factors

Project:

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Figure 12.3.10: Landslide likelihood

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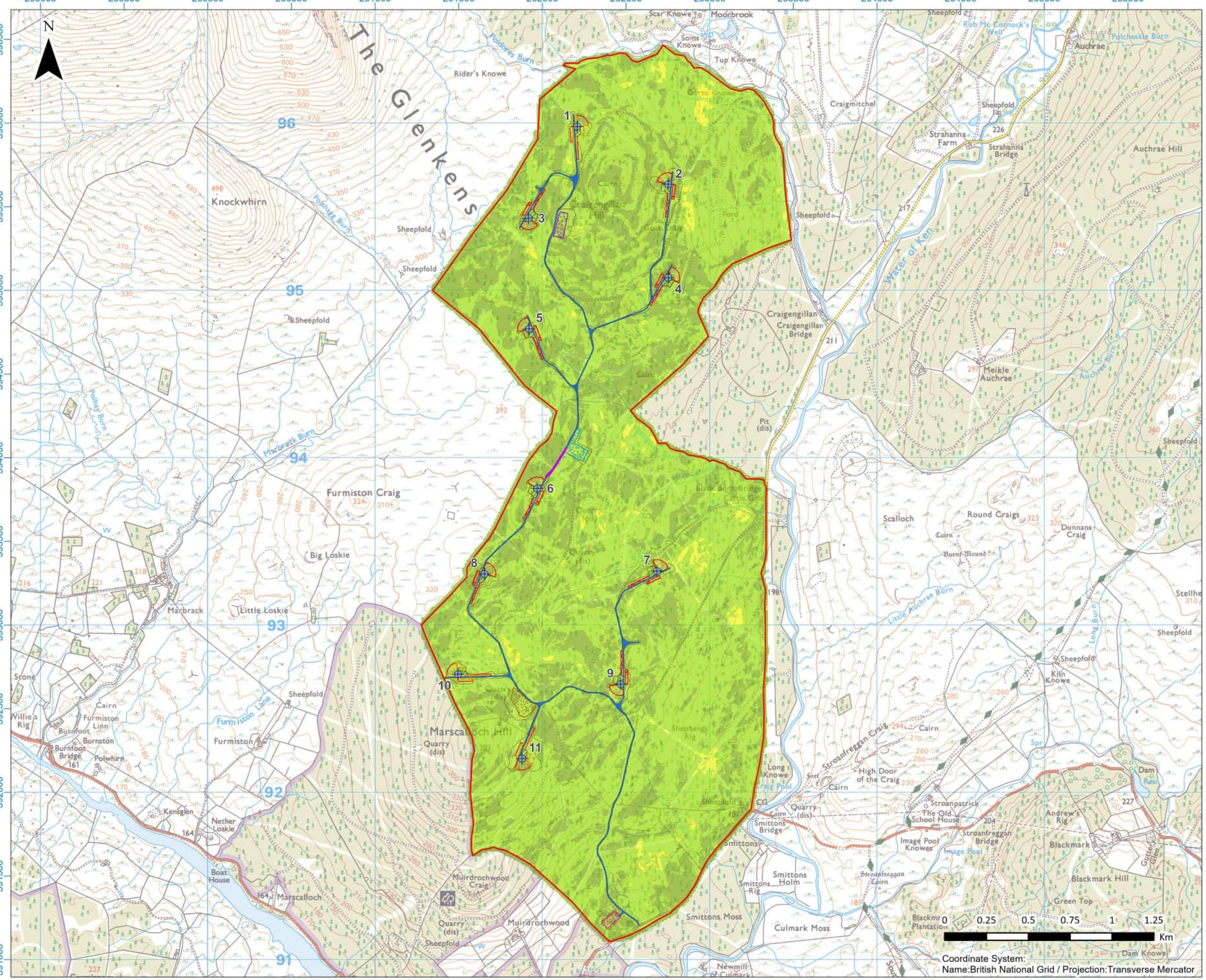

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- Earthworks

Landslide likelihood

- Very Low
- Low
- Moderate
- High (none calculated)
- Very High (none calculated)

Title

Landslide likelihood

Project:

Shepherds' Rig Wind Farm Section 36C

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