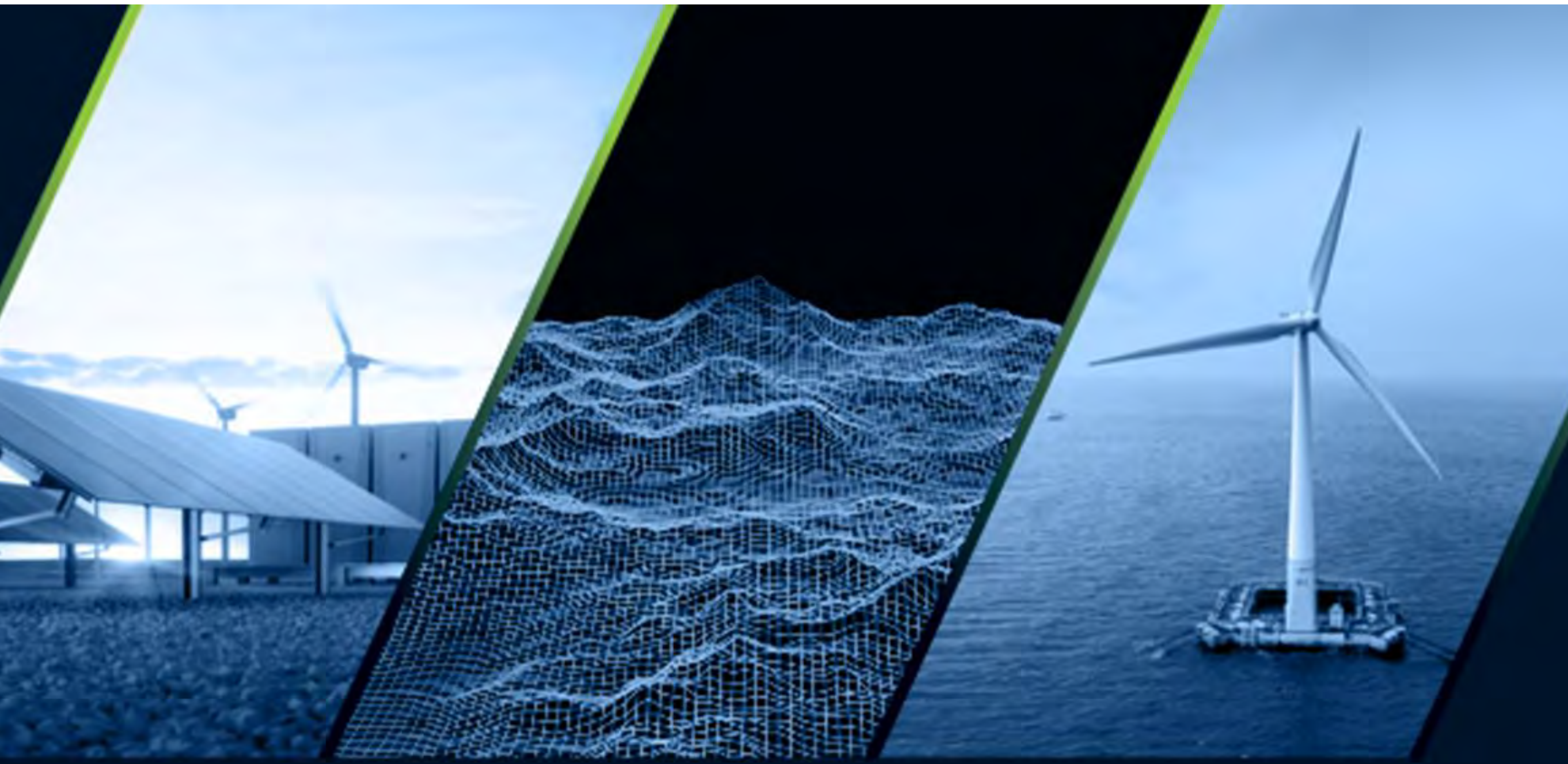
Technical Appendix 9.4: Peat Landslide Hazard and Risk Assessment

The Renewable Energy Consultants.



Glenouther Wind Farm EIA Report
Peat Landslide Hazard and Risk Assessment

Client	:	LUC
Document No.	:	Technical Appendix 9.4
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Document Notes

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Table of Contents

1 Introduction

1.1 Background

Wind Power North Four Ltd ('the Applicant') is seeking planning permission under the Town and Country Planning (Scotland) Act 1997 (as amended) to construct and operate the Glenouther Wind Farm ('the Proposed Development'), in East Ayrshire, Scotland. Plate 1.1 shows the location of the Site.

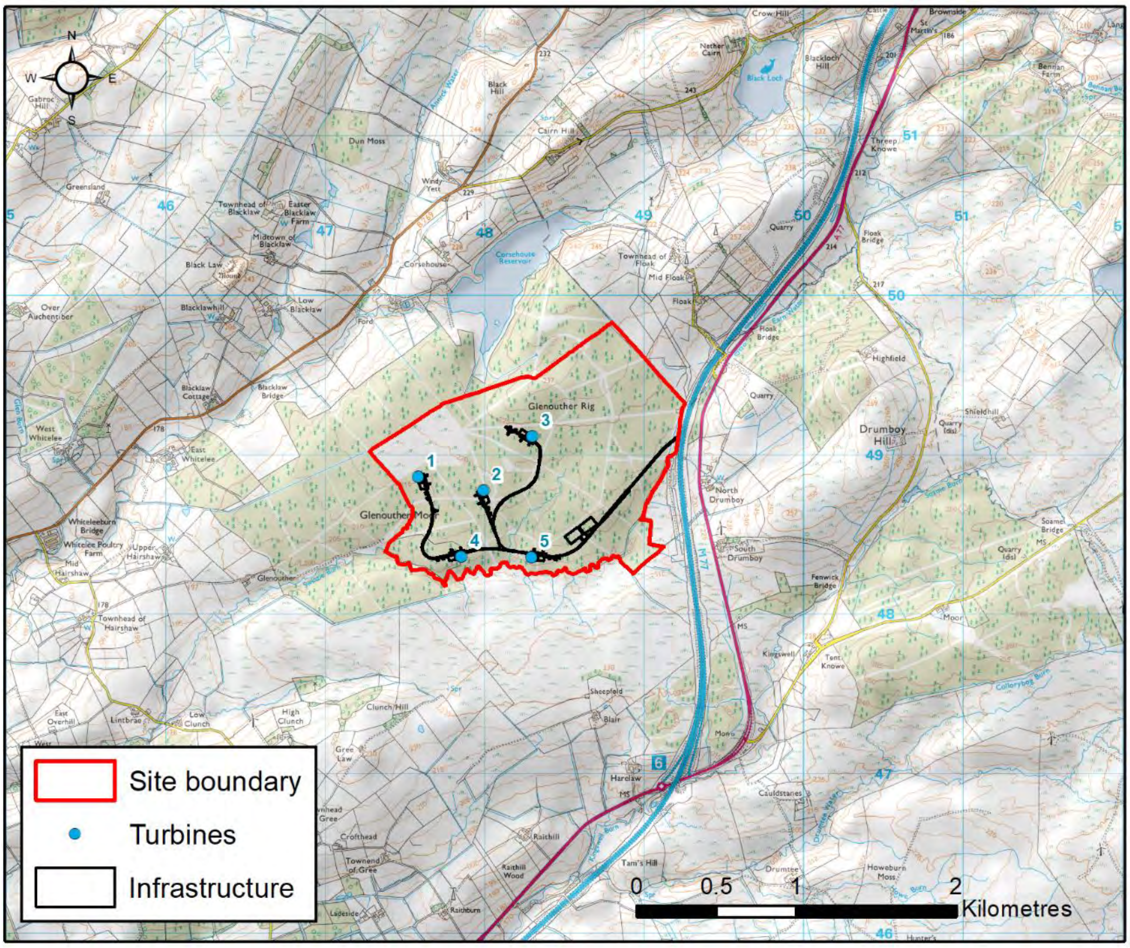

Plate 1.1 Site location

The Site is located on land at Glenouther Moor, south of Corsehouse reservoir and west of the M77 motorway, the closest settlement being Stewarton, approximately 4.5 km to the south-west.

The Proposed Development will comprise:

- Up to five wind turbines with an individual maximum height of up to 200 metres (m) to blade tip and an indicative combined site output capacity of 36 megawatts (MW);
- Foundations supporting each turbine (comprising a mixture of piled and excavated construction methods);
- Permanent crane hardstandings at each turbine location (comprising a mixture of piled and excavated construction methods);

- Approximately 4.1 kilometres (km) of new access track comprising approximately 1.3 km of excavated track and approximately 2.8 km of floated track.
- Up to 12 new watercourse crossings (of which two are mapped watercourses and five are unmapped minor watercourses, and five artificial drains);
- A control building and substation;
- A network of underground cables to connect turbines to a substation;
- Forestry works; and
- A Biodiversity Enhancement Management Plan (BEMP).

The Scottish Government Best Practice Guidance (BPG) provides a screening tool to determine whether a peat landslide hazard and risk assessment (PLHRA) is required [1]. 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 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 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 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*" [1]. 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 [1]:

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 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 Outline Peat Management Plan (OPMP) (see **Technical Appendix 9.3: Outline Peat Management Plan**) and have been informed by results from the Peat Survey (see **Technical Appendix 9.2: Peat Survey Report**). Where relevant information is available elsewhere in the Environmental Impact Assessment Report (EIA Report), this is referenced in the text rather than repeated in this report

1.4 Approaches to Assessing Peat Instability for the Proposed 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:

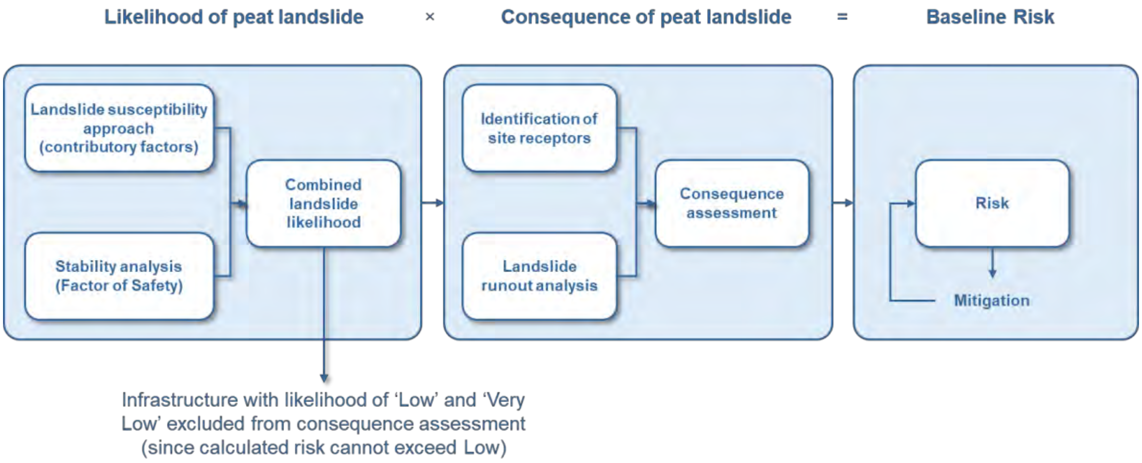

Plate 1.2 Risk assessment approach

1.5 Team Competencies

This PLHRA has been undertaken by Dr Andy Mills BSc MSc PhD, a Chartered Geologist (Geological Society of London) with 27+ 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 Kaya Consulting Limited, and 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 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 [2]. 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 north-east 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**) and other non-wind farm infrastructure. 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, which had yet to commence. Subsequently, a second failure, this-time construction-induced, was recorded in Mid-Kame at Viking in 2022 (Shetland News, 2022), and more recently a failure was reported in association with interconnector works for Viking (The Shetland Times, 2024). Neither of the latter two construction-related failures were true peat slides (in morphological terms); but nevertheless, significant volumes of peat were displaced in both cases.

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.

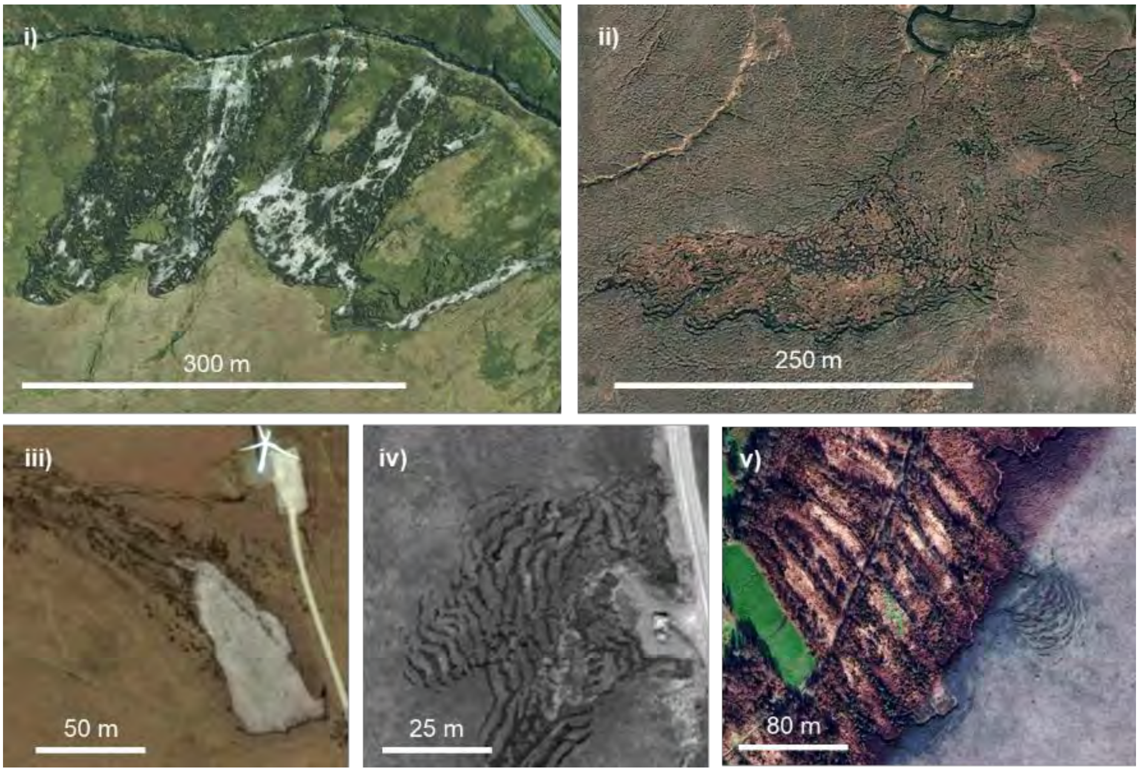

Plate 2.1 Characteristic peat landslide types in UK and Irish peat uplands: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: 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**).

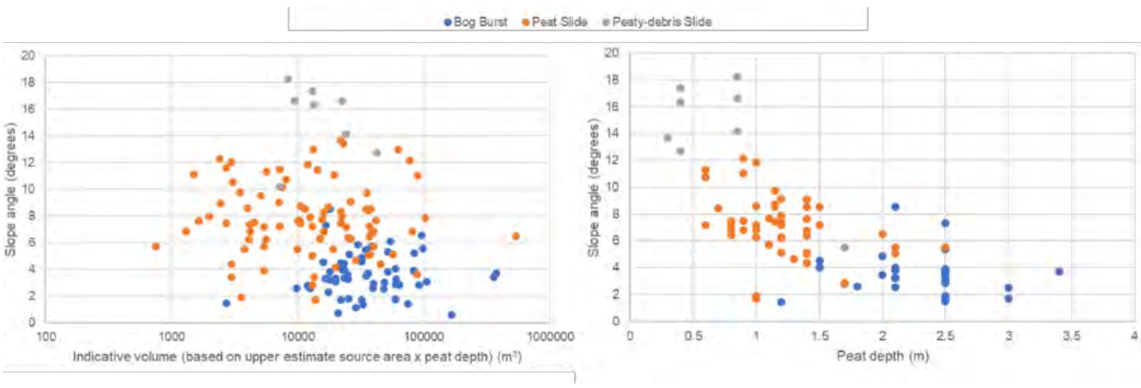

Plate 2.2 Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)

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 1.0 m and up to 10 m) 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.

Due to the very gentle slope angles present over much of the Site, potential for both bog bursts and peat slides are considered in this PLHRA.

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 al4ong 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 (including peat) 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.

- Site workers and plant (risk of injury / death or damage to plant).
- Wildlife (disruption of habitat) and aquatic fauna, including designated sites.
- Watercourses and lochs (particularly associated with public water supply), included designated watercourses.
- Site drainage (blocked drains / ditches leading to localised flooding / erosion);
- Public properties and publicly used infrastructure (such as roads and railways); 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, while the cost, programme and reputational implications of cleaning up a pollution event may be significant for the project owner.

3 Site Characterisation

3.1 Topography

The Proposed Development is located on gently undulating ground on Glenouther Moor. The study area is shown on **Figure 9.4.1**, and falls from c. 240 m AOD in the north of the Site on Glenouther Rig to c. 210 m AOD at Swinzie Burn in the south.

Slope angles are generally very gentle across the Site (<2.5°), with locally steeper areas associated with the sides of Glenouther Rig in the north and with the Swinzie Burn valley in the south and west of the Site. Generally, slopes do not exceed 7.5°. **Figure 9.4.2** shows slope categories based on a composite of publicly available LIDAR data and OS Terrain 5 DTM data. Plate 3.1 shows a 3D perspective view of the Proposed Development superimposed on satellite imagery.

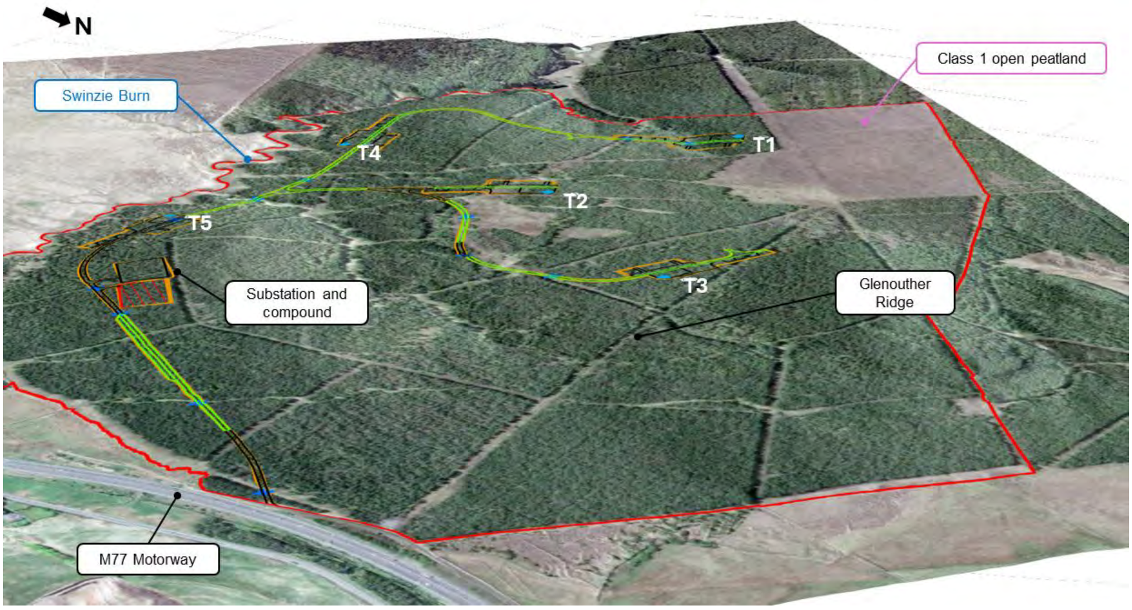

Plate 3.1 3D perspective view of Proposed Development noting key geographical features referenced in the report (note 2x vertical exaggeration)

3.2 Geology

Review of BGS 1:50,000 scale solid geology maps indicates the Site to be underlain by the Harelaw Lava Member (Trachyte) and the Flow Moss Lava Member (Olivine), igneous rocks that are extrusive in origin (main panel of **Figure 9.4.3**).

BGS superficial geology mapping (insert panel of **Figure 9.4.3**) shows the majority of the Site to be peat with areas of Devensian-Diamicton Till and localised alluvium in and around Swinzie Burn.

Substrate was also determined using the refusal method during peat depth probing (see section 3.4 below). Clay substrate was identified at points across the Site. The rest of the Site was characterised as having a gravel/bedrock substrate.

3.3 Hydrology

Swinzie Burn is the only named watercourse within the study area (**Figure 9.3.4**). Within the Site, two minor watercourses drain into Swinzie Burn, one in the centre of the Site and one in the west. 12 watercourse crossings have been identified as part of the Proposed Development, these including the aforementioned minor watercourses and artificial drains associated with forest plantation (see **Technical Appendix 9.1: Watercourse Crossings and Buffer Assessment**). Satellite imagery indicates numerous artificial drains cut into peat within the forestry and more widely in the landscape (**Figure 9.3.4**). In some locations these have self-recovered due to the very low gradients and are *sphagnum* rich.

Plate 3.2 a) Swinzie Burn in open ground, b) self-recovered forest drain with rich *sphagnum* cover, c) standing water in void left by root plate

During field survey, the ground was frequently very wet under foot, with standing water in voids left by the root plates of fallen trees. The area in the vicinity of T1 was noted to be very wet at surface in line with the marked watercourse.

There are no lochans within the Site Boundary.

3.4 Peat Depth

Peat depth probing was undertaken in multiple phases in accordance with Scottish Government (2017) guidance. A peat survey report (**Technical Appendix 9.2**) documents the findings of these site investigations:

- An initial Phase 1 survey was undertaken prior to scoping by MacArthur Green (part of SLR) on a 100 m grid, collecting 378 probes.

Post-scoping, two subsequent phases of Phase 2 probing were undertaken on 10 m grids within infrastructure footprints, on wider 20 m grids to support micro-siting and at 25 m intervals with 10 m offsets along access tracks. These were undertaken by Kaya Consulting Limited with each phase corresponding to layout changes:

- Phase 2 August 2025 where an additional 1,339 probes were collected.
- Phase 2 top-up January 2026 where an additional 445 probes were collected.

In total 2,162 points were collected, 378 at Phase 1 and 1,784 at Phase 2.

Interpolation of peat depths was undertaken in the ArcMap GIS environment using a natural neighbour approach. The resulting peat depth model is shown on **Figure 9.4.5** along with the supporting peat probe locations. In summary:

- Peat is present across the Site, and for the most part exceeds 1.0 m in depth.
- A large part of the Site exceeds 4.0 m in depth, putting it far beyond depths appropriate for cut and fill foundations of tracks.
- While peat is locally shallow along the margins of Swinzie Burn, such areas are few and far between.

Design mitigation has focused on avoiding the deepest peat on Site, adopting peat-sensitive construction methodologies (such as piling and floating track) and implementing compensatory habitat management works to offset unavoidable impacts on local areas of open peatland habitat.

For comparison, the Carbon and Peatland (2016) Map insert on **Figure 9.4.5** shows the Site to comprise mostly Class 5 soil i.e. areas where no peatland habitat is recorded but soils are carbon-rich and deep peat. An area of Class 1 peat is shown in the west of the Site, this corresponding to a deep pocket of peat that exceeds 4.0 m in depth. This area does not overlap with proposed infrastructure. Class 4 is also present but does not overlap with proposed infrastructure.

3.5 Peat Geomorphology and Condition

Geomorphological mapping from satellite imagery and LiDAR data (**Figure 9.4.4**) indicates most of the Site to be afforested by commercial conifer plantation with areas of planar peatland in rides and glades between afforested areas. The large area of Class 1 peat in the west of the Site indicates likely former bog condition prior to forestry.

A small number of gullies are identified across the Site, primarily from LiDAR data with little obvious surface expression on satellite imagery. Scattered areas of checked growth in the middle of the Site (away from infrastructure) may indicate former hagged areas where ploughing and planting was difficult or where particularly wet ground has impeded growth.

Plates 3.3 a to d show typical Site conditions observed during field survey.

Morphological linework (concave and convex changes of slope) on Figure 9.4.4 show gully locations and the gross morphology of the underlying hillside over which peat has formed and forest has subsequently grown.

3.6 Land Use

The dominant land use type of the Site is forestry. Self-seeding of conifers is occurring into the Class 1 area of the Site and within the numerous forest rides. A small hardstanding of c. 600 m^2 is identified at the Site entrance, attached to the unnamed track that runs parallel to the M77.

Drains have been cut into peat, mostly along rides between forestry which further modifies the Site.

Plate 3.3 a) Ground conditions in an open ride (including some natural regeneration of conifers from self-seeding, b) the margin of Class 1 peatland in the west of the Site, c) locally higher quality bog habitat in an open glade within forestry, d) poor habitat within forest

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.

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 Development Site. 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 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. The formula used is unfactored, and in the event of consent, location site-specific site stability analysis conforming to the requirements of EC7 design would be advised in all locations where peat is subject to groundworks or loading.

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 ArcPro 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 3,446 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.

Two 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).

The vehicle loaded (floating track) 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 (**Table 4.2**). 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 (12 t axle weight). In practice, due to the proposed wood pole construction and the lack of requirement for heavy cranes, haulers and dumpers, vehicle loads will in all probability be significantly less. Bog mats are assumed to apply negligible loads and therefore loads for the LGPE analysis are equivalent to the published vehicle loads only.

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	5 m digital terrain model of site and partial 1 m LiDAR coverage (downsampled to 5 m)
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)	

Table 4.1 Geotechnical parameters for drained infinite slope analysis

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 & Hebib, 1998)

Parameter	Values	Rationale	Source
Bulk unit weight (γ)	10.5	Reduction in volume under floating road is balanced by increased density, so pre-load parameters are used	See Table 4.1
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
Vehicle 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	
Sidecast depths (m)	0.5, 1.0, 1.5	Typical sidecast depths for peat, bulk unit weight as per Table 4.1	

Table 4.2 Geotechnical parameters for vehicle loaded scenarios

4.2.3 Results

The outputs of the drained analysis (effective stress) are shown for best estimate and worst case (conservative) parameter combinations in **Figure 9.4.6.** The more conservative combination (minimum c’ and ϕ’, inset panel) suggests that only very localised parts of the Site are of marginal stability (F < 1.4), primarily around T1 and in isolated areas along track margins near the Site entrance.

The best estimate parameters indicate stability over the full extent of the Proposed Development. These results are 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.

Figure 9.4.7 shows loaded stability for construction vehicles on floating track (top left panel) and stability for sidecasting to depths of 0.5 m, 1.0 m and 1.5 m. The analysis shows all routes to be stable under loads associated with floating track construction. The 0.5 m panel (top right) also includes sidecasting results over the full extent of felling for construction, since reuse of peat may be appropriate to support forest-to-bog restoration in any of these areas. While reuse of peat for this purpose is generally limited to 0.3 m in successful trials, 0.5 m provides an additional level of precaution for this scenario. Translocation of peat over these footprints is indicated to be stable given the assumptions described previously.

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. In total, c. 1,738 facets were considered in the analysis, with an average area of c. 2,373 m^2 (or an average footprint of c. 48 m x 48 m, consistent with medium scale peat slide or bog burst scars 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 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 downsampled LiDAR digital terrain model shown on **Figure 9.4.2** 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'. A differentiation in scores is applied for peat slides and bog bursts reflecting the shallower slopes on which the latter are most frequently observed.

Slope range (°)	Association with instability	Peat slide	Bog burst
≤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
2.5 - 5.0		1	3
5.0 – 7.5		3	n/a
>7.5		3	n/a

Table 4.3 Slope classes, association with instability and scores

Figures 9.4.8 and 9.4.9 show the distribution of slope angle scores across the Site. As slopes are mostly gentle across the Site, peat slide scores are low, increasing with locally steep hillsides. Bog burst slope scores are higher, reflecting the greater likelihood of this form of instability at these slope ranges.

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 9.4.5** and reflect the peat depth ranges most frequently associated with peat landslides (see Plate 2.2).

Peat depth (m)	Association with instability	Peat slide	Bog burst
>1.5	Bog bursts are the dominant failure mechanism in this depth range where basal peat is more likely to be amorphous	1	3
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	1
<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	0

Table 4.4 Peat depth classes, association with instability and scores

The distribution of peat depth scores is shown on **Figures 9.4.8 and 9.4.9**. Bog burst scores are high across the Site due to depths exceeding 1.5 m in many places. Moderate depths associated with peat slides are fewer across the Site and therefore the peat slide scores are lower.

4.3.4 Substrate Geology (G)

Table 4.4 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	Bog burst
Cohesive (clay) or iron pan	Failures are often associated with clay substrates and/or iron pans	3	3
Granular clay or clay dominated alluvium	Failures are more frequently associated with substrates with some clay component	2	2
Granular or bedrock	Failures are less frequently associated with bedrock or granular (silt / sand / gravel) substrates	1	1

Table 4.5 Substrate geology classes, association with instability and scores

Probing undertaken across the Site indicated a primarily gravel/bedrock substrate using the refusal method. Points at which clay were identified using the refusal method have been buffered 6.0 m to extend the point measurements to wider areas and link adjacent 10 m grid points with contiguous clay recordings, and then have been given a score of 2. The rest of the Site is scored 1 to reflect the lower likelihood of failures over bedrock/granular substrates (**Figure 9.4.8** and **9.4.9**).

4.3.5 Peat Geomorphology (M)

Table 4.5 shows the geomorphological features typical of peatland environments, their association with instability and related scores.

Geomorphology	Association with instability	Peat slide	Bog burst
Incipient instability (cracks, ridges, bulging)	Failures are likely to occur where pre-failure indicators are present	3	3
Planar with pipes	Failures generally occur on planar slopes, and are often reported in areas of piping	3	3
Planar with pools / quaking bog	Bog bursts are more likely in areas of perched water (pools) or subsurface water bodies (quaking bog)	2	2
Flush / Sphagnum lawn (diffuse drainage)	Peat slides are often reported in association with areas of flushed peat or diffuse drainage	3	3
Planar (no other features)	Failures generally occur on planar slopes rather than dissected or undulating slopes	2	2
Afforested / deforested peatland	Considered within Forestry (F), see below	0	0

Table 4.6 Peat geomorphology classes, association with instability and scores

The Site is afforested with planar peatland in rides and glades and few gullies. Planar areas receive a score of 2 to reflect that failures generally occur on planar slopes (where there is a greater propensity for pipe networks and where much of the water is therefore routed subsurface rather than in gullies or resident in pools). Scores are shown on **Figure 9.4.8** and **9.4.9**. Forestry is not scored as it is assessed within the forestry contributory factor.

4.3.6 Artificial Drainage (D)

Table 4.6 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	Bog burst
Drains aligned along contours (<15 °)	Drains aligned to contour create lines of weakness in slopes	3	2
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	2
Drains aligned downslope (<30° to slope)	Failures are rarely associated with artificial drains parallel to slope or adjacent to natural drainage lines	1	1
No / minimal artificial drainage	No influence on stability	0	0

Table 4.6 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 4.6**). Buffers are shown on **Figures 9.4.8** and **9.4.9**.

4.3.7 Slope Curvature (C)

Table 4.7 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	Bog burst
Rectilinear Slope	Peat slides are most frequently reported on rectilinear slopes, while bog bursts are often reported on rectilinear slopes	3	2
Convex Slope	Peat slides are often reported on or above convex slopes while bog bursts are most frequently associated with convex slopes	2	3
Concave Slope	Peat failures are occasionally reported in association with concave slopes	1	1

Table 4.7 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. Corresponding scores are shown on **Figures 9.4.8** and **9.4.9** in accordance with **Table 4.7** above.

4.3.8 Forestry (F)

Table 4.8 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	Bog burst
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	3
Deforested, rows aligned to slope	Deforested peat is less stable than afforested peat, but slope aligned inter ridge cracks have less impact	2	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	2
Afforested, rows aligned to slope	Afforested peat is more stable than deforested peat, but potentially less stable than unforested (never planted) peat	1	1
Windblown	Windblown trees have full disruption to the underlying peat and residual hydrology due to root plate disturbance	0	0
Not afforested	No influence on stability	0	0

Table 4.8 Forestry classes, association with instability and scores

Afforested coupes with rows oblique to slope attract the highest susceptibility scores. Most coupes have moderate scores based on their ridge and furrow alignments (**Figures 9.4.8** and **9.4.9**).

4.3.9 Land use (L)

Table 4.9 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	Bog burst
Machine cutting (deep slots)	Machine cutting may compartmentalise slopes, but has been reported primarily in association with peat slides	3	2
Quarrying	Quarrying may remove slope support from upslope materials, and has been observed with spreading failures (bog bursts)	2	3

Land Use	Association with instability	Peat slide	Bog burst
Hand cutting (turbary)	Hand cutting may remove slope support from upslope materials, and has been reported with raised bog failures	1	2
Burning (deep cracking to substrate)	Failures are rarely associated with burning, but deep desiccation cracking will have the most severe effects	2	2
Burning (shallow cracking)	Failures are rarely associated with burning, shallow desiccation cracking will have very limited effects	1	1
Grazing	Failures have not been associated with grazing, no influence on stability	0	0

Table 4.9 Land use classes, association with instability and scores

There are no land uses on the Site other than forestry and a small quarry at the Proposed Development entrance. A buffer of 25 m has been applied to the upslope side of the quarry (to reflect removal of support to the peat / soil upslope) and assigned a moderate score. The rest of the Site is scored 0 (**Figure 9.4.8** and **9.4.9**).

4.3.10 Generation of Slope Facets

The eight contributory factor layers shown on **Figures 9.4.8 and 9.4.9** were combined in ArcPro to produce approximately 1,738 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

Summed Score from Contributory Factors	Typical site conditions associated with score	Likelihood (Qualitative)	Landslide Likelihood Score
> 21	Modified peat with high scores for most contributory factors (unusual except in areas with evidence of incipient instability)	Very High	5

Table 4.10 Likelihood classes derived from the landslide susceptibility approach

Table 4.10 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

4.4.1 Peat slide

Figure 9.4.10 shows the outputs of the contributory factor approach for peat slides. Scores indicate Low to Very Low likelihood of instability as peat slides over almost all of the Site, the exception being a localised area of Moderate likelihood on the north facing slopes above a minor watercourse outside the Site boundary.

There are no areas of High or Very High likelihood.

4.4.2 Bog burst

Figure 9.4.11 shows the outputs of the contributory factor approach for bog bursts. Due to the nature of the Site (gentle slopes and deep peat depths), bog burst likelihoods are higher than peat slides. That being said the majority of the Site is still indicated as having Low likelihood of bog burst with only very localised areas of Moderate likelihood away from infrastructure locations.

There are no areas of High or Very High likelihood.

4.4.3 Combined Landslide Likelihood

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** below).

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.

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

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 (e.g. groundwater dependent terrestrial ecosystems or GWDTEs) and infrastructure, both that related to the Proposed Development and other infrastructure, e.g. roads and power lines. These are considered for the Proposed Development below.

5.2.1 Watercourses

The Proposed Development Site is drained by two minor watercourses, small in dimensions with limited downstream extents prior to their confluences with Swinzie Burn. Swinzie Burn is not designated and assessment in **Chapter 9: Hydrology, Hydrogeology, Geology and Peat** of the EIA Report indicates water quality to be ‘Medium’, with low flood risk and low morphological sensitivity.

As a result, none of these watercourses are regarded as of high sensitivity and watercourses are assigned a consequence score of 3 (‘Moderate’ consequence).

5.2.2 Habitats

While blanket bog habitats are valuable, they generally recover from instability events through revegetation over a matter of years to decades and therefore, a consequence score of 3 is assigned for all open bog habitats within the Proposed Development Site (**Table 5.1**).

5.2.3 Infrastructure

The Proposed Development is bounded to the east by the M77 which sits slightly downslope of the proposed access track. For a road with this frequency of use and speed of traffic, consequences would potentially be high (4 or 5) with potential for loss of life, however, no source zones have been identified within the Site and, as a result, there is not anticipated to be any risk to road users in this area. Neither would any ingress of debris into the watercourses within the Site affect the M77, since watercourses generally flow to the south-west.

The Proposed Development infrastructure and personnel working in vicinity to the infrastructure locations during construction are also receptors. While commercial losses would be important to the Applicant, risks to life can be mitigated through safe systems of working. These infrastructure risks are not considered to be ‘environmental’ risks and are considered separately in the consequence assessment below.

Receptor and type	Consequence	Score	Justification for Consequence Score
Watercourses - aquatic habitats	Short term increase in turbidity	3	Undesignated watercourse, recovery expected to be rapid following initial cleanup
Terrestrial habitats (open moorland)	Short to medium term loss of vegetation cover, disruption of peat hydrology, carbon release	3	Long term effects unlikely following revegetation
Road infrastructure	Short term disruption to road users prior to cleanup, moderate likelihood of injury	4	Possible disruption to local road users but effects very likely to be short term
Project infrastructure	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

5.3 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.

6 Risk Mitigation

6.1 Overview

Reducing risk can be achieved by identifying lower likelihood locations within which to site infrastructure or route construction traffic, reducing the compound effect of construction activities on this baseline likelihood, reducing the consequences in the event a landslide occurs, or combinations of all three. Section 6.2 considers location-specific risk reduction measures, while sections 6.3 to 6.5 consider general good practice prior to, during and subsequent to construction.

6.2 Location-specific Risk Mitigation

Risks have been calculated to be no higher than Low given current proposed construction methods. Nevertheless, risks can be further reduced in key locations by adopting the mitigation measures below:

- **Turbine 1** is positioned across a minor headwater channel , interaction with which is being mitigated through the detailed infrastructure design process to maintain at least a 10 m buffer between infrastructure and the channel, or where not possible the channel will be culverted under the hardstanding during construction (see **Chapter 9** of the EIA Report). Nevertheless, the degree of subsurface flow in this area (which was noted to be particularly wet during walkover) would merit pre-construction assessment with ground penetrating radar (GPR) to identify any substantive subsurface drainage pathways prior to groundworks. GPR surveys along contour at intervals across the full extent of proposed construction would aid in further de-risking this area.
- **Turbines 4 and 5** are positioned to the north of the Swinzie Burn but have relatively substantial felling works specified to support construction. Much of this felling, particularly to the south of the turbines, is unlikely to be required until the turbines are due to be assembled and therefore the natural protection offered by a retained treeline may merit retention until the hardstandings, tracks and ancillary infrastructure are constructed.

These site-specific measures are likely to be sufficient to retain risks at Low levels, or reduce them further. General good practice measures are described below.

6.3 Good Practice Prior to Construction

Prior to any excavations, 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 peat soils in the relevant areas.

These investigations should be sufficient to:

1. Determine the strength of free-standing bare peat excavations, and requirement for retention structures (e.g. cofferdams or equivalent).
2. Determine the strength of loaded peat (where excavators and plant are required to operate on temporary surfaces such as bog mats, 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.

6.4 Good Practice During Construction

The following good practice should be undertaken during construction, with all measures listed below included within a Construction Environmental Management Plan and / or Geotechnical Risk Register (as appropriate):

For excavations:

- Use of appropriate supporting structures around peat excavations 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, ensuring a banksman is specifically tasked with overseeing groundworks for the duration of peat excavation and for any period in which peat faces are left unsupported or unremediated.
- 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.
- 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.
- Awareness of peat instability and pre-failure indicators should be incorporated in site induction, training and monthly toolbox talks 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.
- An Emergency Response Plan (ERP) should be prepared to support site personnel in safely managing and mitigating the consequences of a peat instability event should it occur. The ERP should identify responsibilities for preparing for such an event and responding to it, ensure that short and medium term mitigations plans and procedures are in place and are implemented, and identify lessons learned to reduce the likelihood of subsequent occurrences once root cause has been identified.

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.

6.5 Good Practice Post-Construction (Operation)

Following cessation of construction activities, monitoring of any areas where peat has been disturbed should be undertaken to ensure stability within the first 12 months.

Specific signs of unexpected ground disturbance include:

- Ponding on the upslope side of infrastructure.
- Changes in the character of peat drainage within a 50 m buffer strip of track or access alignments and infrastructure (e.g. upwelling within the peat surface upslope of tracks, sudden changes in drainage behaviour downslope of tracks).
- Blockage or underperformance of any site drainage system.
- 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. In the event that unanticipated ground conditions arise during construction, the frequency of these intervals should be reviewed, revised and justified accordingly. Because slope movement in peatlands typically occur following later summer convective rainfall, site surveys are likely to be best undertaken in late September, also providing an opportunity to identify bare or drying peat that might require remedial works prior to winter.

In the event that further construction activities are required, e.g. track resurfacing, further ancillary works, remedial works or cable repairs, any activity that disturbs peat directly or indirectly should be subject to the same good practice as outlined in Section 6.4.

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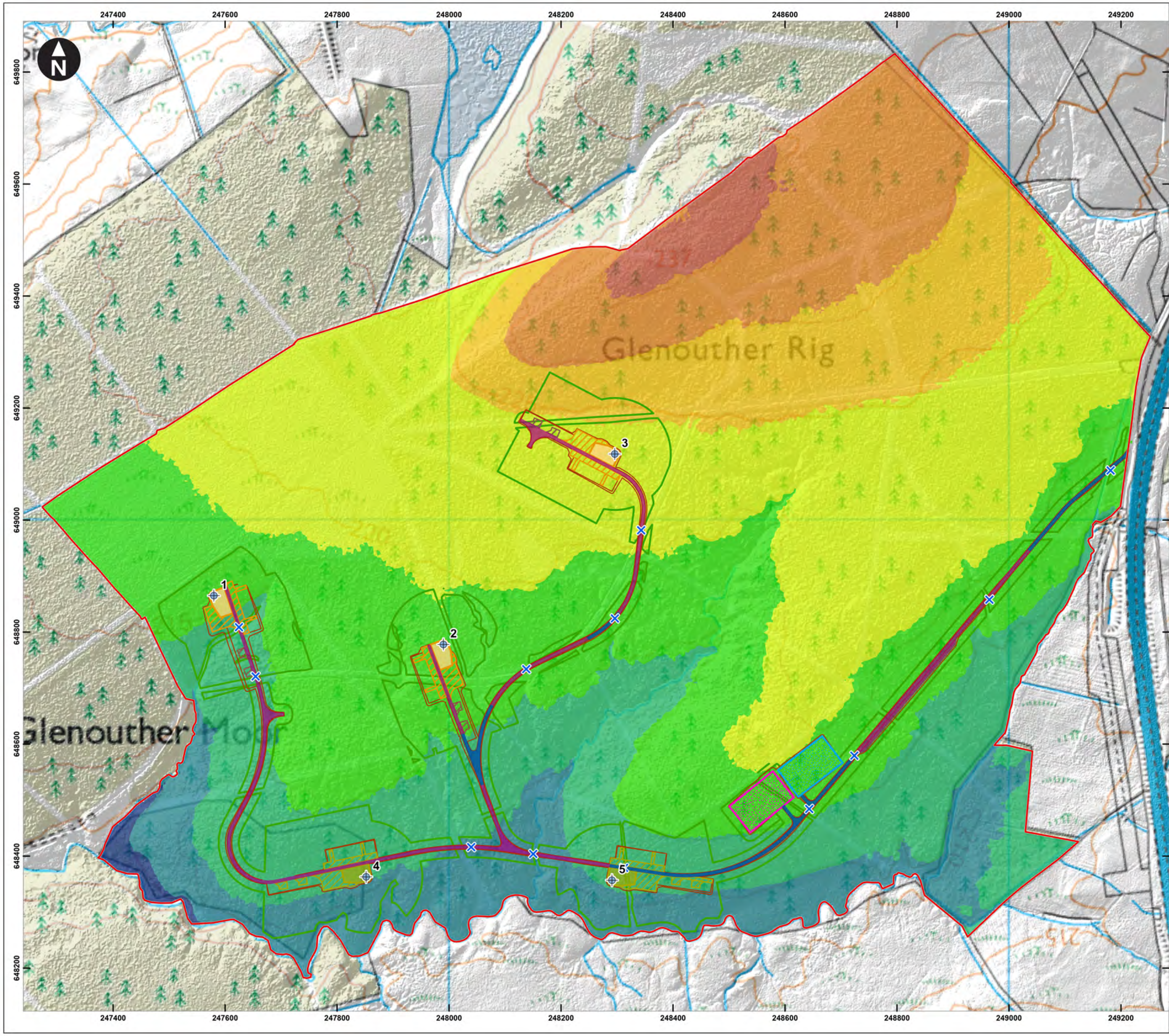

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
- Piled auxiliary crane pad (temporary) (T1, T2 and T3)
- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

- Piled turbine foundation/ hardstanding (permanent) (T1, T2 and T3)
- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Elevation (m)

- 200 - 205
- 205 - 210
- 210 - 215
- 215 - 220
- 220 - 225
- 225 - 230
- 230 - 235
- 235 - 240

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.1: Elevation

Drawn by: ST
Approved by: AM

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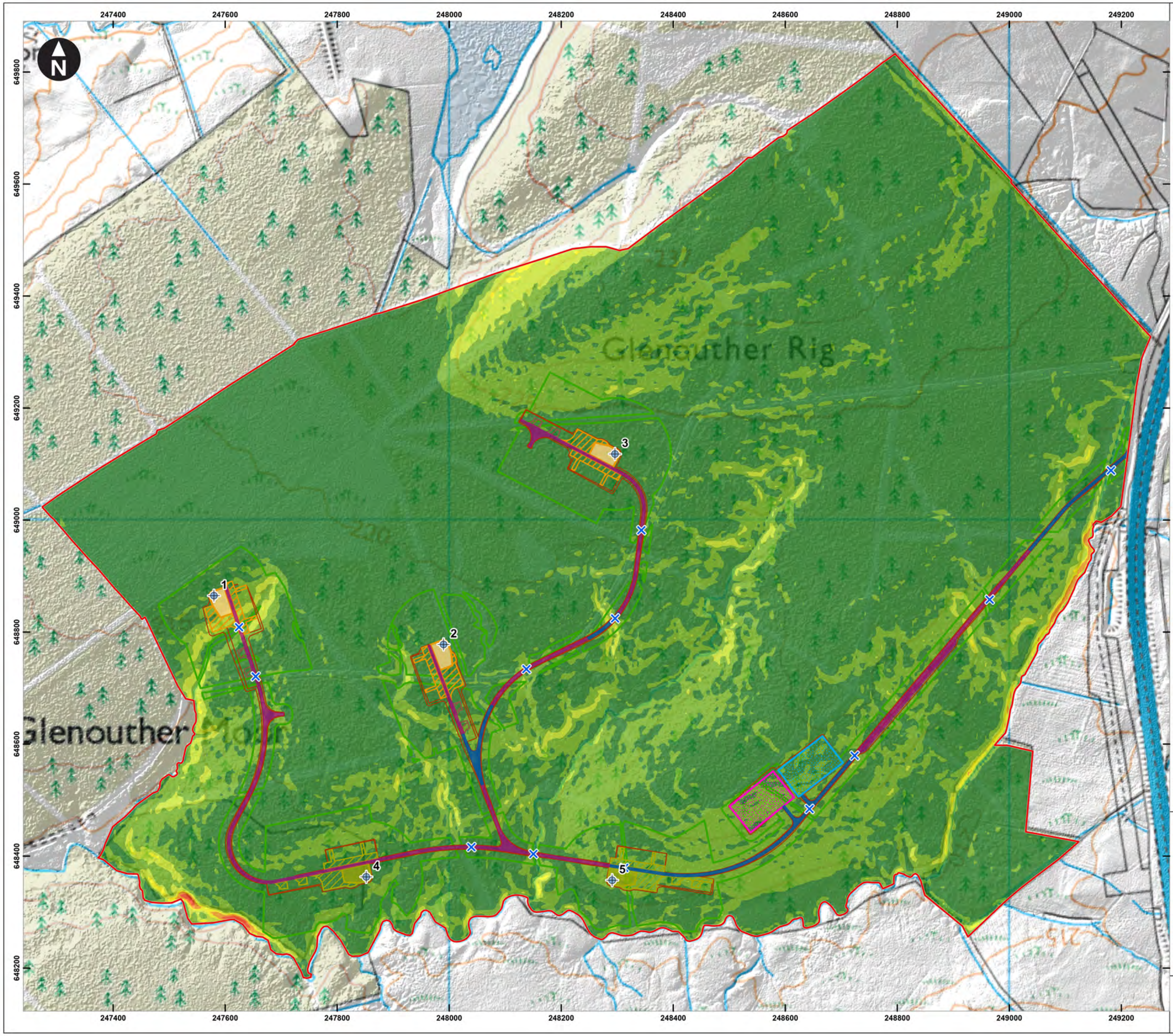

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
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- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

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- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Slope (°)

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

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.2: Slope

Drawn by: ST
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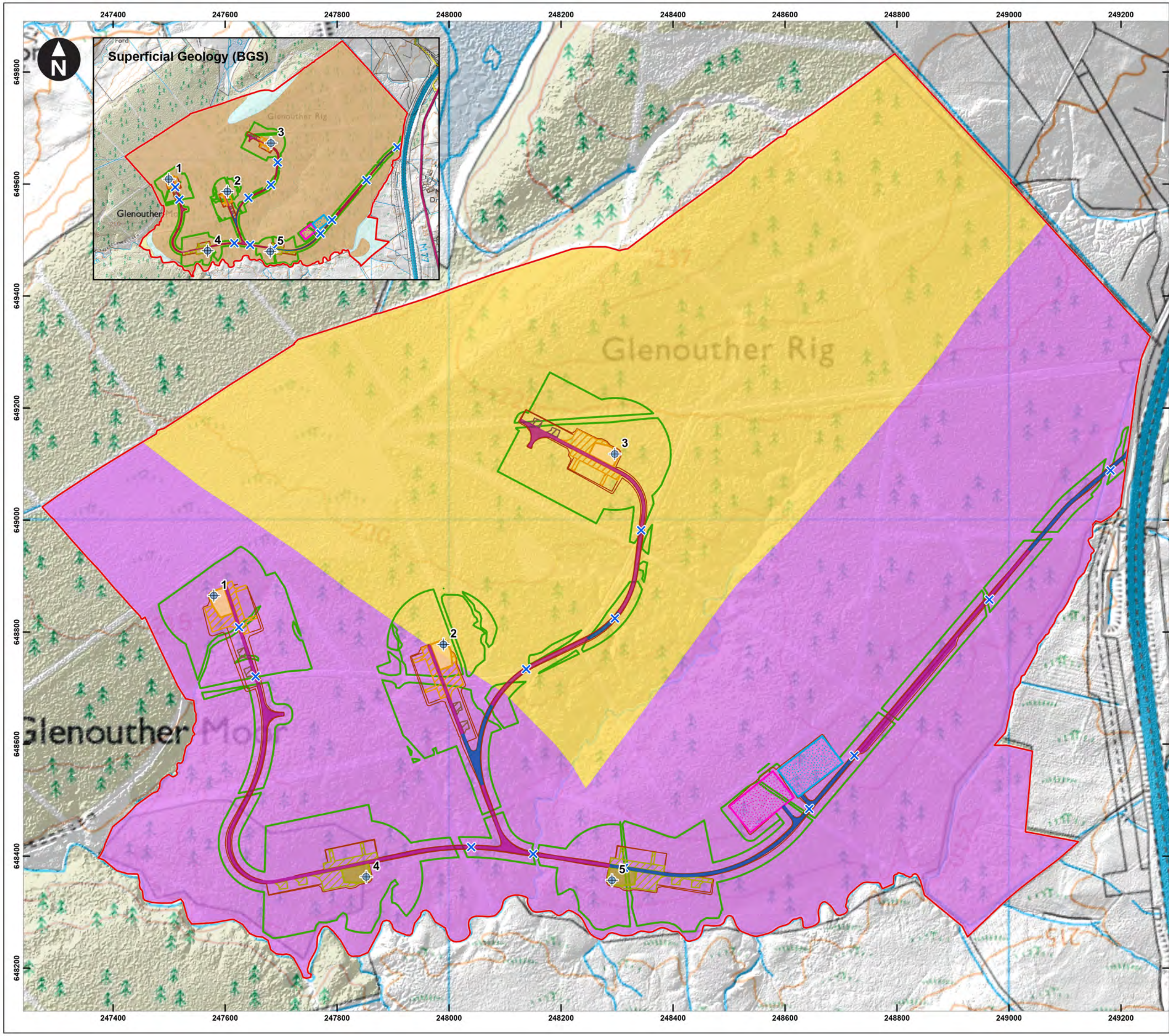

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
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- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

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- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Bedrock Geology (BGS)

- Harelaw Lava Member-Trachyte
- Flow Moss Lava Member

Superficial Geology (BGS) (Insert)

- Peat
- Devensian-Diamicton Till
- Alluvium – silt, sand and gravel

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Service Credits: BGS 50000 scale digital geology. Crown copyright and database rights 2026 Ordnance Survey AC0000808122

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.3: Geology

Drawn by: ST
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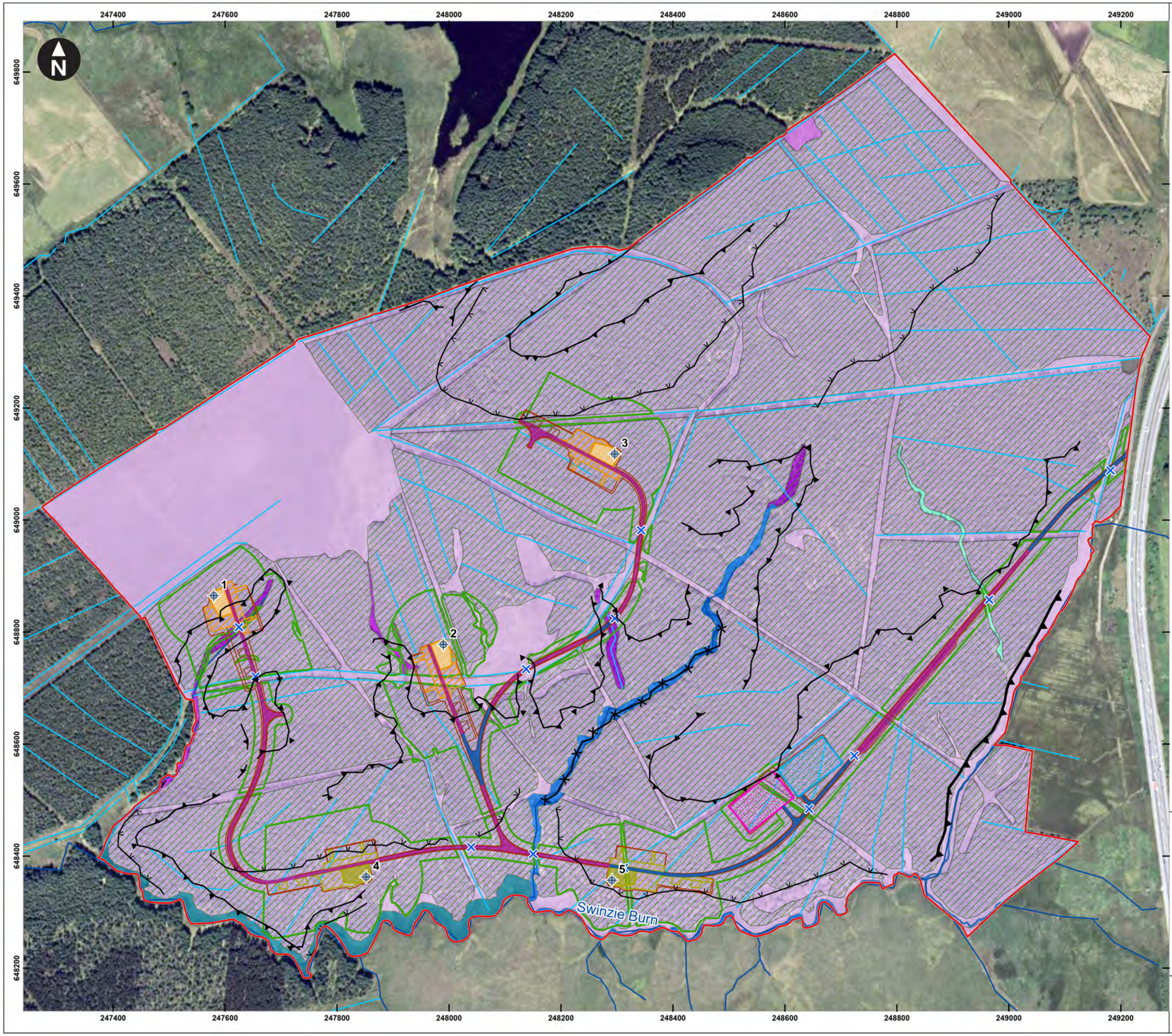

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

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- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

- Piled turbine foundation/hardstanding (permanent) (T1, T2 and T3)
- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing
- Natural Drainage
- Artificial Drainage
- Forestry
- Planar peatland (incl. rides / glades)
- Patterned ground
- Gully
- Afforested gully
- Diffuse water pathway
- River valley
- Watercourse
- Quarry
- Concave change of slope
- Convex change of slope

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Service Credits:
Azure Imagery

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.4: Geomorphology, Hydrology and Land Use

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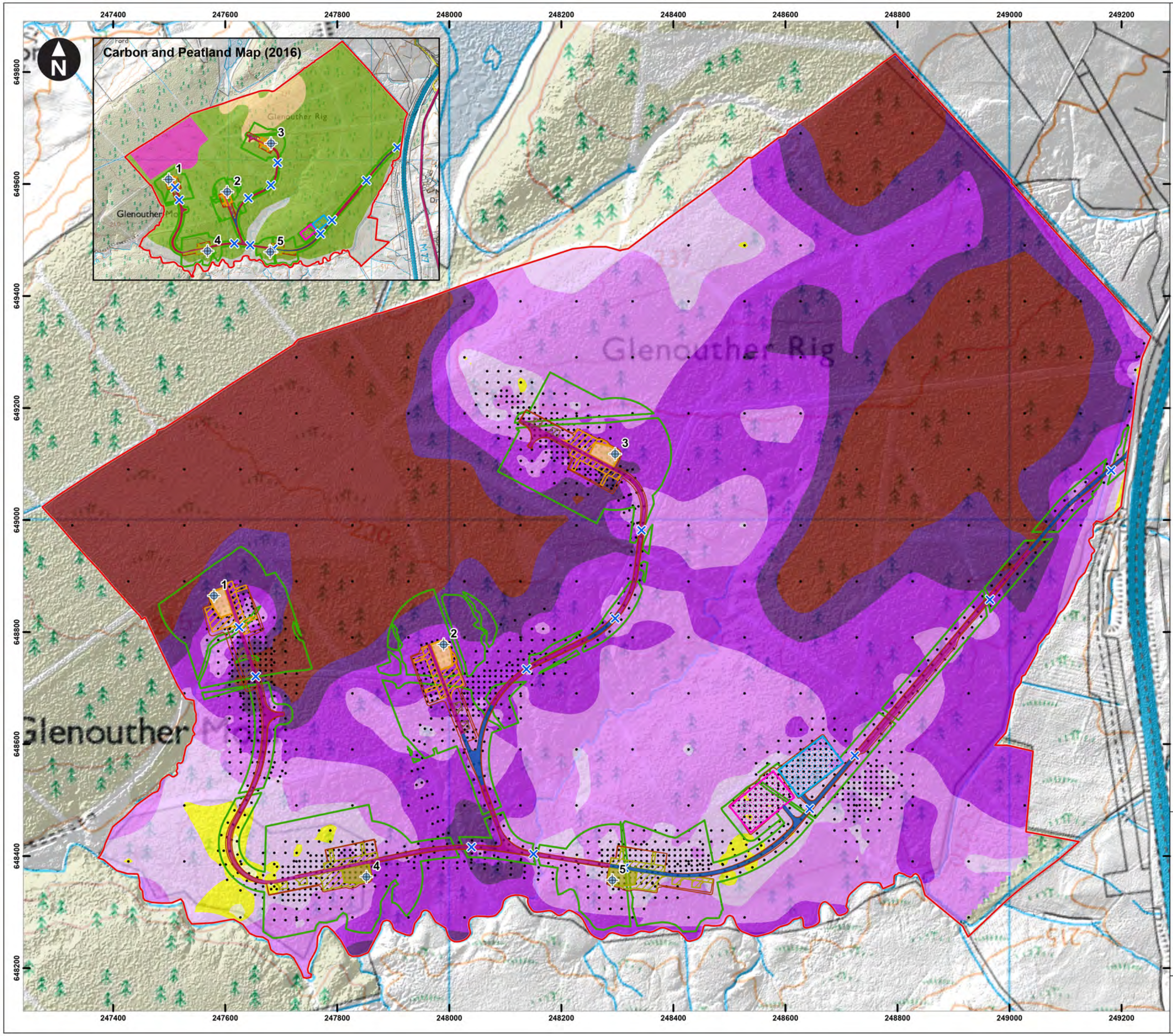

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
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- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

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- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Interpolated 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 - 5.0
- Probe Locations

Carbon and Peatland Map 2016 (Insert)

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

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.5: Peat Depth

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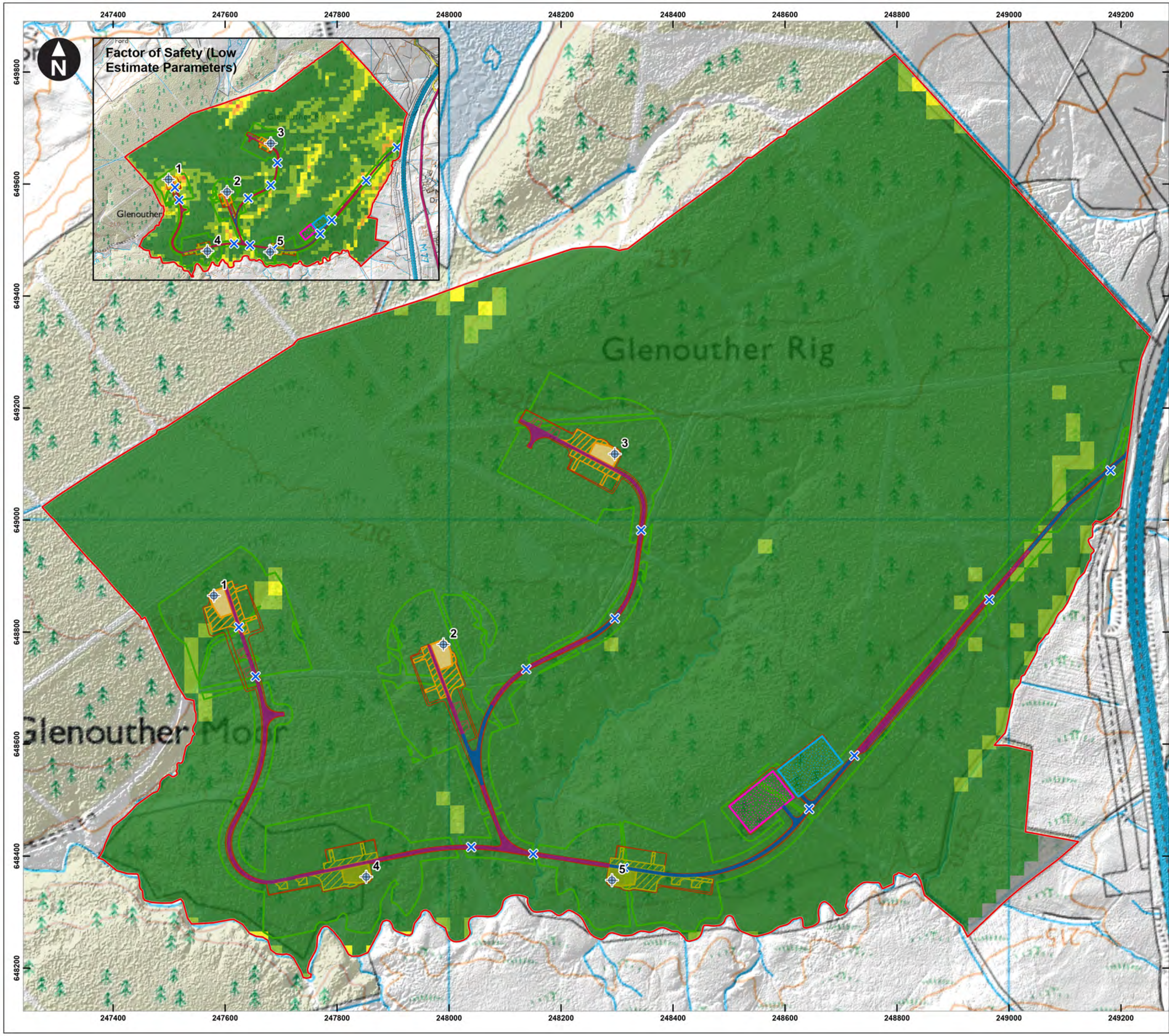

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
- Piled auxiliary crane pad (temporary) (T1, T2 and T3)
- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

- Piled turbine foundation/ hardstanding (permanent) (T1, T2 and T3)
- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Factor of Safety (Best Estimate Parameters)

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

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.6: Factor of Safety (Baseline)

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Approved by: AM

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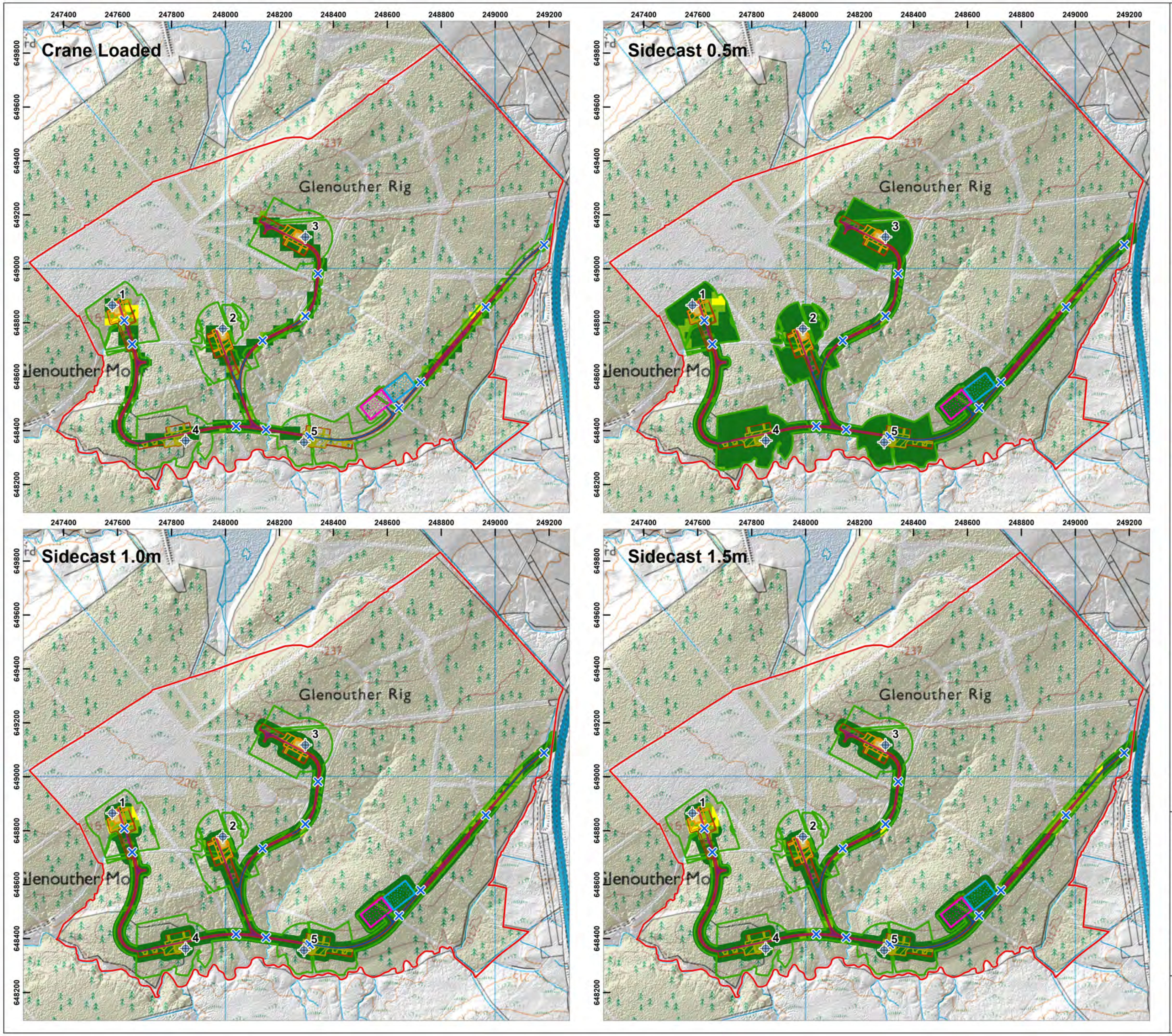

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
- Piled auxiliary crane pad (temporary) (T1, T2 and T3)
- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

- Piled turbine foundation/ hardstanding (permanent) (T1, T2 and T3)
- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Factor of Safety

- < 1.00 "Unstable" (None Calculated)
- 1.01 - 1.40 "Marginally Stable"
- 1.41 - 2.00 "Stable"
- 2.01 - 3.00 "Stable"
- > 3.01 "Stable"

0 125 250 375 500 Metres

Scale at A3: 1:13,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Service Credits:

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.7: Factor of Safety (Crane Loaded and Sidecast)

Drawn by: ST
Approved by: AM

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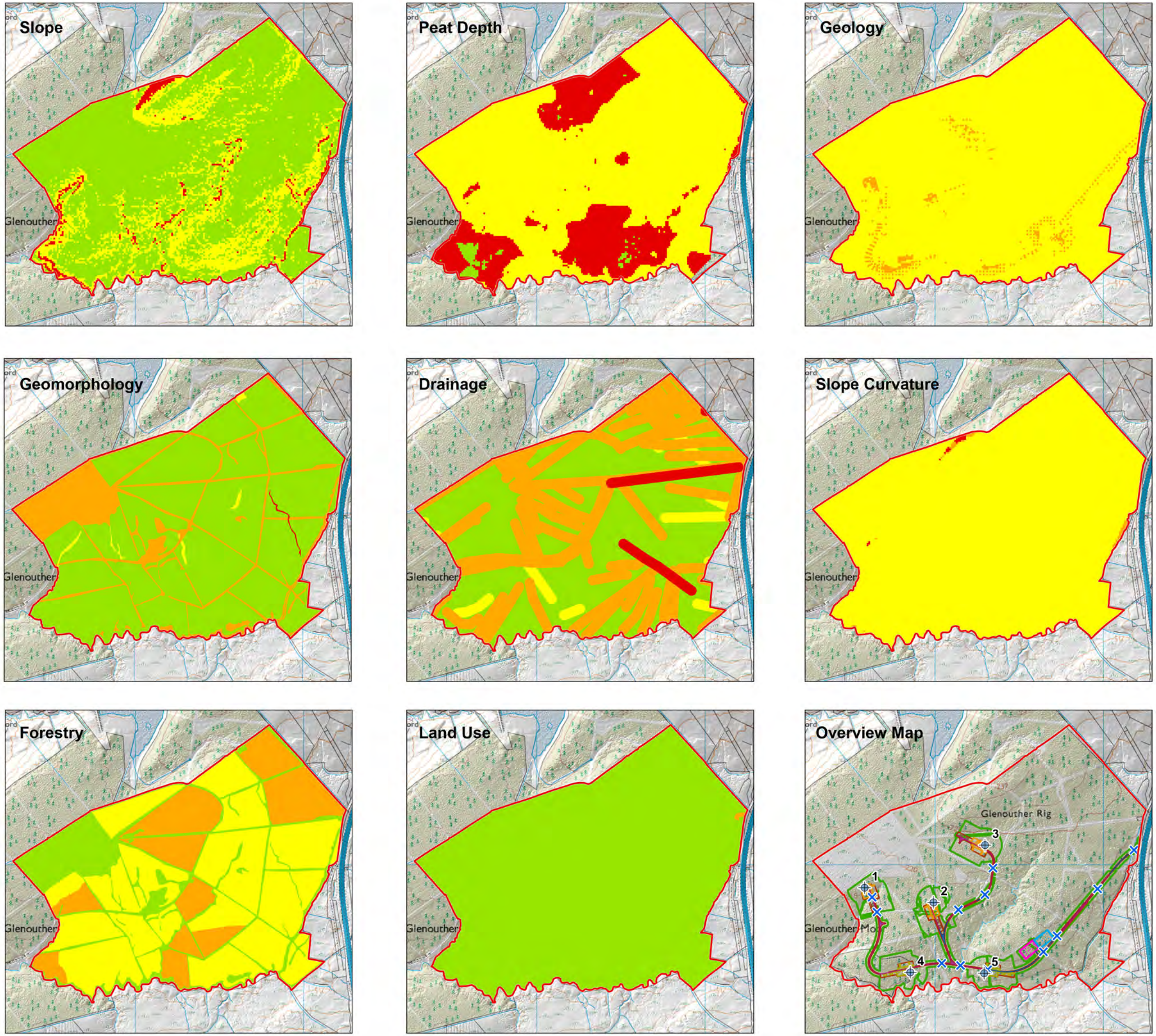

Legend

Site boundary

Contributory Factor Score

- 0
- 1
- 2
- 3

0 0.25 0.5 0.75 1 km

Scale at A3: 1:22,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.8: Contributory Factors (Peat Slide)

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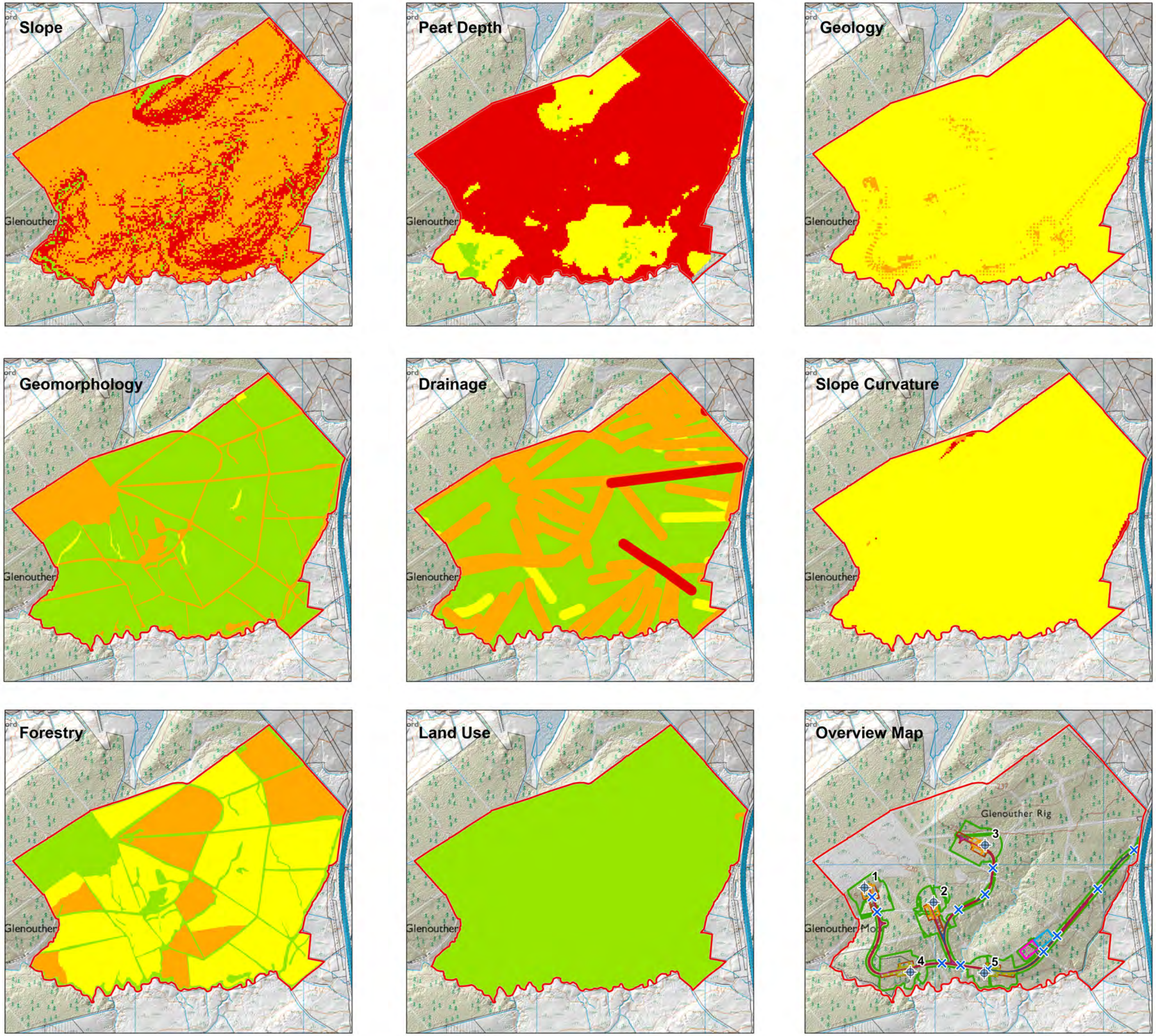

Legend

Site boundary

Contributory Factor Score

- 0
- 1
- 2
- 3

0 0.25 0.5 0.75 1 km

Scale at A3: 1:22,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.9: Contributory Factors (Bog Burst)

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Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.10: Landslide Likelihood (Peat Slide)

Drawn by: ST
Approved by: AM

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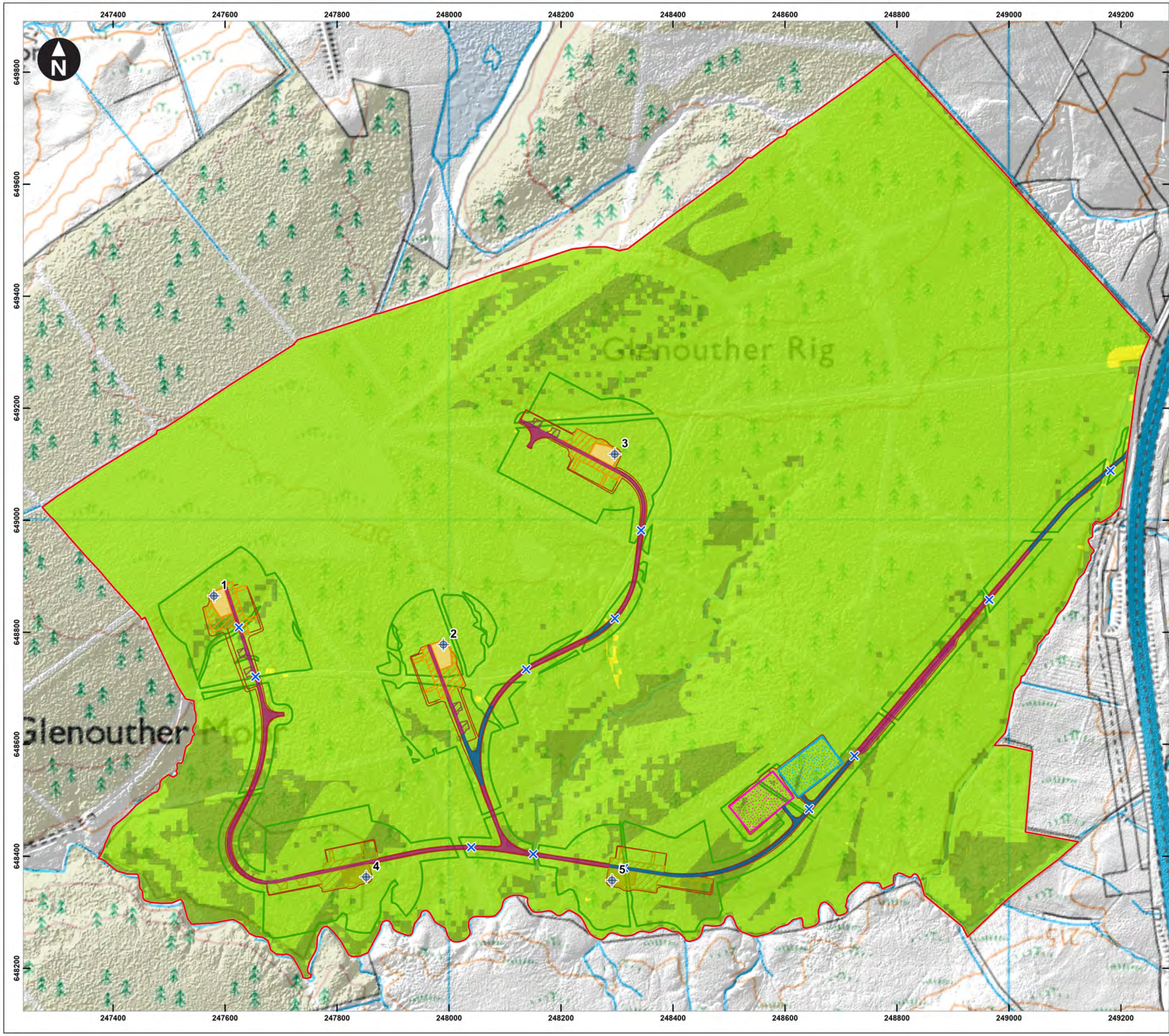

Legend

- Site boundary
- Turbine
- Construction compound (temporary)
- Substation compound
- New access track/ turning head (floated)
- New access track (excavated)

Hardstanding (Temporary)

- Floating hardstanding (temporary) (T1, T2 and T3)
- Piled auxiliary crane pad (temporary) (T1, T2 and T3)
- Excavated hardstanding (temporary) (T4 and T5)

Hardstanding (Permanent)

- Piled turbine foundation/ hardstanding (permanent) (T1, T2 and T3)
- Excavated turbine foundation/ hardstanding (permanent) (T4 and T5)
- Earthworks
- Felling Area for Construction
- Watercourse crossing

Landslide susceptibility

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

0 50 100 150 200 Metres

Scale at A3: 1:6,500

Spatial Reference
Name: British National Grid
Projection: Transverse Mercator

Glenouther Wind Farm
Peat Landslide Hazard and Risk Assessment (PLHRA)

Figure 9.4.11: Landslide Likelihood (Bog Burst)

Drawn by: ST
Approved by: AM

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June 2026

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