Appendix 7.4: Peat Landslide Hazard and Risk Assessment

Consulting Report

Appendix 7.4 - Peat Landslide Hazard and Risk Assessment Loch Liath Wind Farm

Highlands
Loch Liath Wind Farm Ltd

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1. INTRODUCTION

1.1. Background

Loch Liath Wind Farm Ltd (the Applicant) is seeking consent under Section 36 of the Electricity Act 1989 for construction of the Loch Liath Wind Farm, located in the Highlands (hereafter referred to as the 'Proposed Development').

The Proposed Development is predominantly located within the Balmacaan Estate, directly west of the Great Glen and Loch Ness, with the closest proposed turbine being located approximately 14km southwest of Drumnadrochit (Plate 1.1). The Site (shown as the red-line boundary) is in open moorland and is bordered to the south by the operational Bhlaraidh Wind Farm. In this report, 'main infrastructure area' refers to the southwest quarter of the Site in which infrastructure is concentrated.

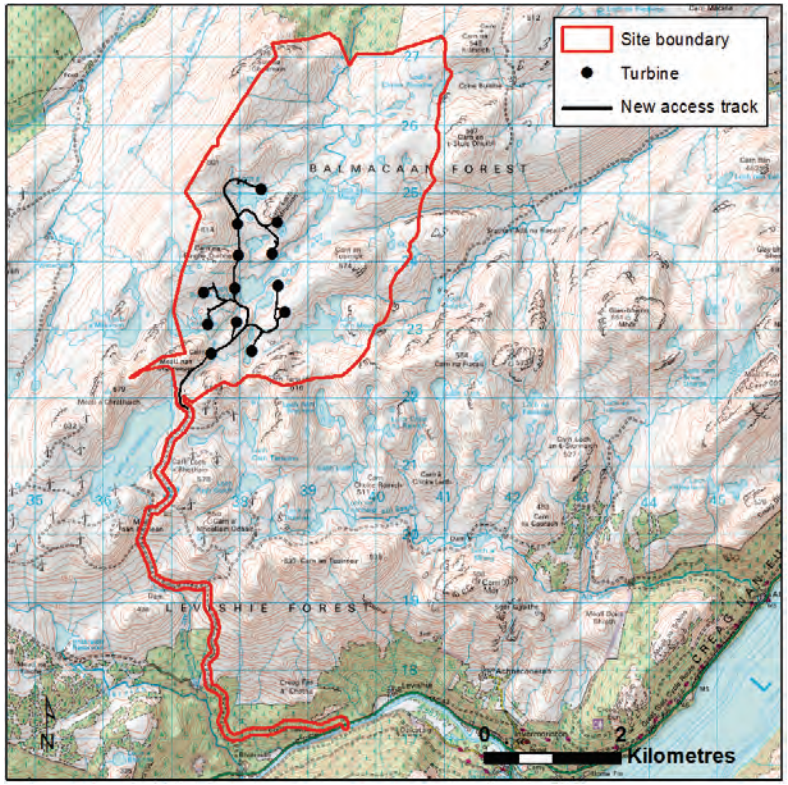

Plate 1.1 Proposed location of the Loch Liath wind farm

The Proposed Development will comprise up to 13 turbines (ten of which will have a maximum blade tip height of 200m and three of which will have a maximum blade tip height of 180m) and associated foundations, laydown areas and crane hardstandings. There will also be a permanent anemometer mast, control building and substation, a network of underground cables and approximately 26.6km of access tracks of which approximately 17.3km will be upgraded existing track and 9.3km will be new track. The Proposed Development is described in full in Chapter 4: Project Description of the EIA Report.

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 Development site and therefore a PLHRA is required. This PLHRA Report is provided as an Appendix to the Environmental Impact Assessment (EIA) Report for the Proposed Development.

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*" (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.

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 Peat Management Plan (PMP) (EIA Report Appendix 7.3) and have been informed by results from the Peat Survey (EIA Report Appendix 7.2). Where relevant information is available elsewhere in the EIA Report and associated figures and appendices, 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. Plate 1.2 shows the approach:

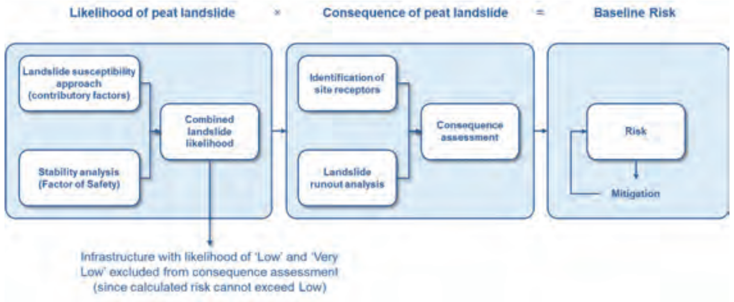

Plate 1.2 Risk assessment approach

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 Site 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 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. Peat landslides have also been reported within the site of the under-construction Viking Wind Farm on Shetland (Shetland News, 2022) in association with construction works. A pre-construction landslide was reported within the same site in 2015, but not in association with construction (The Shetland Times, 2015).

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 the one reported Scottish example occurring on the Shetland Islands, an area previously associated with peat instability.

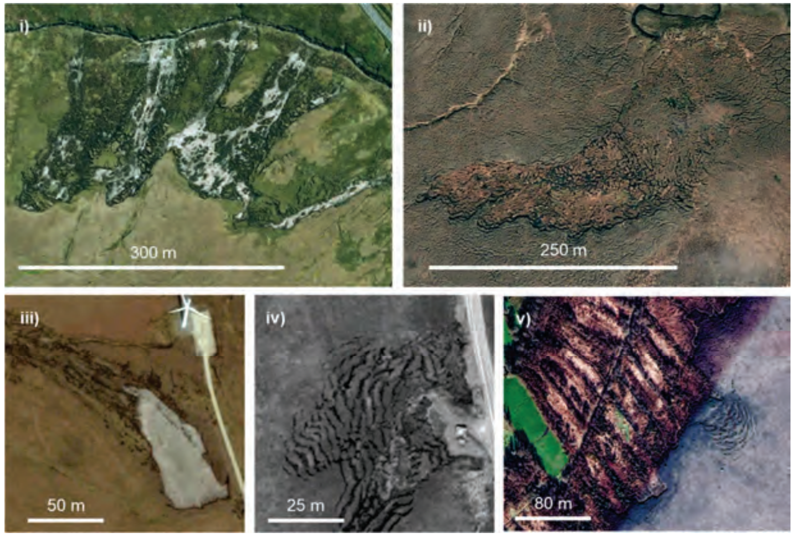

Plate 2.1 Characteristic peat landslide types in UK and Irish peat uplands: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: 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 2.2.1 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.

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- **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 0.5m and 1.5m) and on moderate slope angles (typically 5°-15°, see Plate 2.2).

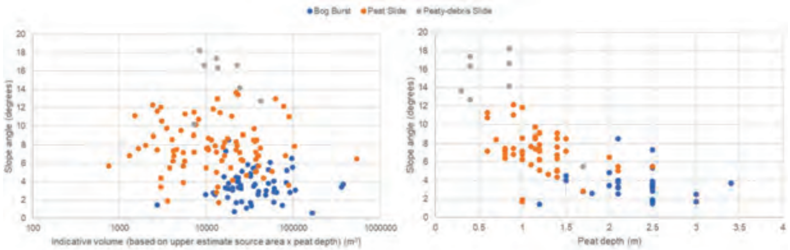

Plate 2.2 Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)

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.

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 <0.5m 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 (e.g. Bowes, 1960).

There are no published failures or news reports of landslides in proximity to the Proposed 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).
- 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 or impacts on public water supply that are the primary concern.

3. DESK STUDY

3.1. Topography

The Proposed Development straddles the hills between Meall nan Oighreagan (c. 610m) in the south and Carn Loch Mhuilinn (c. 560m) in the north, flanked to the west by Carn na Ruighe Duibhe (613m) and to the east by Carn an Tuairneir (c. 580m). The centre of the main infrastructure area hosts numerous large lochans at c. 500m AOD, and the overall setting for the infrastructure approximates that of a bowl surrounded by gently rounded peaks (see Plate 3.1 and Figure 7.4.1). Proposed access tracks typically run along contour on the lower slopes that fall from each summit, or are routed within the low undulating terrain in the basin floor.

Slope angles are relatively steep on the sideslopes below each summit, frequently exceeding 15° over large areas but rapidly reducing in the basin floors where the terrain undulates between the numerous lochans and smaller water bodies (Figure 7.4.2). In many cases, to maintain distance from these areas of standing water, tracks are cut into moderate to steep sideslopes. While this may involve cut and fill sections to enable a sufficient width of running surface, peat depths are generally much shallower in these areas.

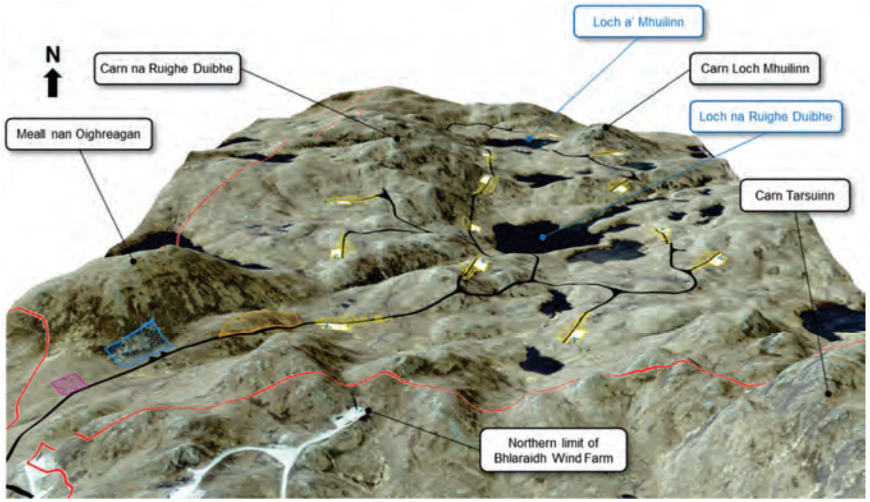

Plate 3.1 Perspective view of Proposed Development (note 2x vertical exaggeration)

3.2. Geology

Figure 7.4.3 shows the superficial and solid geology of the Site mapped from 1:50,000 scale publicly available BGS digital data and indicates the full infrastructure area to be underlain by psammites of the Tarvie Psammite Formation, with localised areas of psammites and semipelites of the Achnaconeran Striped Formation, these latter forming the higher ground. Information on superficial geology is very limited, with large pockets of peat shown in areas of lower ground or otherwise 'unknown/unclassified' or 'no deposits'. Observations undertaking during field survey indicate a fairly distinct contact onto granular bedrock beneath the peat deposits that mantle the rocky hillsides.

The Carbon and Peatland 2016 Map (shown as an inset on Figure 7.4.5) predicts the majority of the infrastructure area to lie in Class 1 nationally important carbon-rich soils, deep peat, and priority peatland habitat (i.e., land covered by peat-forming vegetation or vegetation associated with peat formation). Exceptions are the steeper rocky hillsides which are indicated to be Class 5 (no peatland habitat recorded, but soils are considered to be carbon-rich and deep peat is present). There are small areas of predicted Class 2 in the east and west of the Site.

There are no Sites of Special Scientific Interest (SSSIs) within the Site and therefore no Regionally Important Geological Sites (RIGS) or Local Geodiversity Sites (LDS).

3.3. Hydrology

The Site hosts a number of lochans of varying size (Figure 7.4.4) with interconnecting minor water bodies running along the undulating topography that runs south to north . The largest of these is Loch na Ruighe Duibhe, which approaches a kilometre in length from SW to NE, and which drains via a minor watercourse into the next un-named lochan to the north. Turbine 8 and the connecting track north to Turbine 10 run alongside Loch na Ruighe Duibhe, while Turbine 5 lies on the opposite side.

Loch a Chràthaich (to the southwest of the Site and to the west of the operational Bhlaraidh Wind Farm) and Loch nam Meur (to the east of Turbines 3 and 4) are classified as high sensitivity due to their high quality for migrating fish and trout fishing respectively.

Although there are numerous within-site watercourses, these are generally un-named and primarily flow from one water body to another over very gentle gradients. Turbines 1 to 8 and supporting infrastructure generally drain towards Loch na Ruighe Duibhe while Turbines 9 to 13 drain to a series of smaller lochs. Turbine 13 drains into Loch a' Mhuilinn, which itself drains north towards the Allt Seanabhaile, Turbines 9 and 10 drain towards a watercourse connecting Loch na Ruighe Duibhe to Loch a' Mhuilinn and Turbines 11 and 12 drain into watercourses or small lochans that ultimately drain into Loch nam Meur (a second loch of that name within the Site). All watercourses are of relatively limited capacity in the basin floor, due to their low gradients, and the presence of numerous water bodies means that any material conveyed along streams will likely strand within these water bodies rather than being transmitted further.

Further detail on the Site's hydrology is provided in Chapter 7 of the EIA Report. Site photographs of typical hydrological features are shown on Plate 3.2.

3.4. Land Use

The Site is relatively unmodified by human activity, unaffected by moor drainage, lacking muirburn, quarrying or strong evidence of grazing impacts. There are no peat cuttings on the Site and no major quarries.

3.5. Peat Depth and Character

Peat depth probing was undertaken in a number of phases in accordance with Scottish Government (2017) guidance:

- Phase 1 was undertaken between December 2019 and February 2020 and comprised an extensive 100m grid over a much larger area than the submitted design footprint, totalling 3,579 probe locations.

Plate 3.2 a) A typical low gradient watercourse between lochs in the centre of the Site, b) a moderate planar hillside falling towards a loch, c) arcuate bog pools indicating a possible former minor peat displacement on an area of negligible gradient

- Phase 2 was undertaken in August 2021 to support detailed design and comprised a series of transects oriented perpendicular to the prevailing geological structures to capture variations in depth from rocky highs to deep peat lows that might have been misrepresented by the 100m grid – transects were targeted at proposed infrastructure locations and 1,043 probes were collected.
- Phase 3 comprised the first phase of detailed infrastructure-specific probing, was undertaken in November 2021 and comprised 4,890 probes.
- Phase 4 was completed in June 2022 and comprised further detailed infrastructure-specific probing in order to accommodate layout changes informed by Phase 3. A further 1,267 probes were collected.
- A total of 10,779 probes were collected across the four phases, providing an extremely comprehensive representation of peat across the Site.
- 68.54% of probes recorded depths <50 cm and therefore recorded organic soils (rather than peat), although it should be noted that organic soils may still support priority peatland habitats.
- The vast majority (c. 30%) of the remaining probes recorded less than 2.0m of peat with one very deep peat deposit >5.0m (in an area which has been avoided).

- 52 cores were taken across the Site, 43% of which were in depths >0.5m. Substrate corresponding to bedrock or granular (weathered) bedrock was recorded at over 99.5% of locations (see Table 2, Appendix 7.2).

The peat survey report (Appendix 7.2) provides more detail on the peat surveys.

Figure 7.4.5 provides a peat depth map of the Proposed Development interpolated from the peat depth surveys, with probing locations superimposed. Interpolation of peat depths was undertaken in the ArcMap 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).

Figure 7.4.5 indicates that:

- Peat is relatively widespread across the Site, but generally most prevalent on the lower slopes and in the basin floor surrounding the various water bodies.
- Areas with strongly rocky topography generally have patchier peat coverage.

Comparison of the peat depth model with the layout demonstrates 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 or organic soils where possible. Typically, this process involved minimising the overlap of permanent excavation footprints with deeper deposits, mirroring hardstandings to further reduce overlap, and adjusting track alignments away from pockets of deep peat. Floating track has been specified in areas with the deepest peat deposits, including:

- West of Turbine 13.
- At and east of the junction north of Turbine 10.
- On three sections of track between Turbine 5 and 3.
- Between Turbine 1 and the junction to Turbine 2.

Although it would be preferrable to use floating track over larger areas, many of the tracks are on moderate slopes and use of floating tracks in these areas has not been proposed to avoid potential stability issues.

Further details on the iterative site design adopted for the Proposed Development (which took account of all constraints, not just peat) are provided in Chapter 3: Site Selection and Design Strategy of the EIA Report.

3.6. Peatland Geomorphology

Both Google Earth^{TM} and bing.com satellite imagery available as ArcGIS Basemap layers were used to characterise the Site. The resulting geomorphological map, shown on Figure 7.4.4, was subsequently verified during a site walkover undertaken in November 2021 by a Chartered Geologist / peatland geomorphologist with over 25 years' experience of assessing peat landslides. Plates 3.2 to 3.4 show typical features identified during the walkovers.

Figure 7.4.4 shows the key features of the main infrastructure area. The presence, characteristics and distribution of these features are 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.

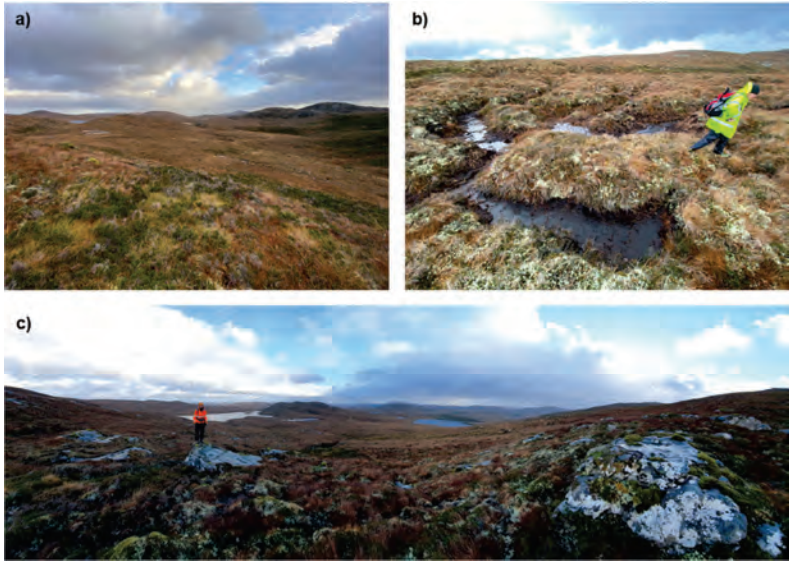

Plate 3.3 a) a typical area of open slope with local rocky outcrops, b) lightly degraded hagged terrain, c) an area of extensive rocky outcrops with shallow peat in-between

The geomorphology of the Site is relatively complex with numerous areas of patchy rock outcrop with thin peat or soil interspersed amongst wider areas of planar peat on sideslopes (see Plate 3.3 for typical ground conditions). Areas of steeper slope frequently exhibit soil terracing (indicative of creep, but not mass movement) and being drier are often heather covered.

Locally, the peatland shows anastomosing or dendritic drainage patterns, the latter converging on or feeding into numerous small watercourses. Rarely, particularly wet flushy areas are visible as lighter tones on satellite imagery. Locally, there are areas of bare ground in some of the more eroded areas of anastomosing drainage. Some of these areas have the potential for peatland restoration, and this is considered further in Appendix 7.3.

Four minor instability features were observed during site walkover, although only one of these is located in proximity to the infrastructure (to the southeast of the floating track section between the track linking the spurs to Turbines 3 and 4). This feature appeared as minor cracking only. The others features are shown on Plate 3.4 and correspond to peaty-soil slides, with marginal peat depths at or just under 0.5m. They occur on locally moderate slopes, typically where bedrock is immediately beneath the peat and the contact between the peat soil and bedrock is particularly smooth. They lack the large-scale morphology of bona-fide peat landslides (e.g. rafting, blocks, etc) and are more indicative of minor instability than true large-scale peat landslide morphology.

Plate 3.4 a) a shallow peaty-soil slide on a moderate slope (c. 300 m east of Turbine 13, b) a larger but shallower failure (on north-facing slope south of the southern Loch nam Meur) c. 30 m in length with little residual evidence of landslide debris (therefore it is possibly older than the failure shown in a), c) another small peaty-soil slide with peat depth <0.5m at the headscarp (c. 250 m southwest of Turbine 3)

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 the 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 7.4.2 and 7.4.5).

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 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 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 ArcMap 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. 11,500 grid cells were analysed within the main infrastructure area although a wider area was initially assessed during early layout planning. A 25 m x 25 m cell size was chosen as it is sufficiently small to define a credible landslide size and avoid 'smoothing' of important topographic irregularities.

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).

4.2.3. Results

The outputs of the drained analysis (effective stress) are shown for the best estimate parameter combinations in Figure 7.4.6. This parameter combination gives credible results, with only localised areas of marginal stability (F < 1.4) on the moderate to steep sideslopes below rocky summits, but otherwise indicating widespread stability across the site. The more conservative combination (minimum c' and ϕ', not shown on the figure) suggests that a significant proportion of the site is either unstable (F < 1) or of marginal stability (F < 1.4) which is not consistent with site observations nor 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.

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 main infrastructure area to another according to the complexity of ground conditions. In total, c. 16,040 facets were considered in the main infrastructure area, with an average area of c. 430 m^2 (or an average footprint of c. 20 m x 20 m), consistent with the small scale peaty soil slides observed at the Site or smaller peat slides reported in the published literature.

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
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

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 4.2 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 Figures 7.4.1 and 7.4.2 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' (e.g. Plate 2.2).

Note that the slope model is a TIN (interpolated from irregularly spaced measures of elevation) and these types of slope model tend to simplify slopes into triangular surfaces – this can have the effect of steepening or shallowing slopes relative to their actual gradients.

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 – 15.0		3
>15.0		3

Table 4.2 Slope classes, association with instability and scores

Figure 7.4.7 shows the distribution of slope angle scores. Other than in the gently undulating basin and some of the more gentle summits, much of the main infrastructure area receives the maximum score for the slope factor.

4.3.3. Peat Depth (P)

Table 4.3 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 7.4.5 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 4.3 Peat depth classes, association with instability and scores

The distribution of peat depth scores is shown on Figure 7.4.7. Much of the main infrastructure area is between 0.5 and 1.5m in depth, and therefore receives the maximum score.

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
Cohesive (clay) or iron pan	Failures are often associated with sticky clay substrates and/or iron pans	3
Unknown / gravelly clay	Failures are occasionally associated with clay with a granular component	2
Granular or bedrock	Failures are less frequently associated with bedrock or granular (silt / sand / gravel) substrates	1

Table 4.4 Substrate geology classes, association with instability and scores

Coring undertaken at turbine locations and elsewhere (and documented in EIA Report Appendix 7.2) indicates granular substrate or bedrock over 99.5% of the main infrastructure area and therefore the lowest score is assigned to the full site extent. Figure 7.4.7 shows the distribution of scores.

4.3.5. Peat Geomorphology (M)

Table 4.5 shows the geomorphological features typical of peatland environments, their association with instability and related scores. Being an open moorland site (rather than afforested), there is a strong degree of confidence in the identification and mapping of these features, where present.

Geomorphology	Association with instability	Peat slide
Incipient instability (cracks, ridges, bulging)	Failures are likely to occur where pre-failure indicators are present – existing peaty-soils slides are buffered with a 25m zone and included in this class	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	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 / dendritic drainage / anastomosing drainage / minor gullies	Failures are rarely reported in areas with gullying, strong patterned ground or bare peat	1
Patchy rock outcrop / non-peat terrain	Failures do not occur where peat is absent	0
Heavily eroded /hagged peat / extensive gullies / bare peat	Failures are not reported in areas that are heavily eroded or bare	0
Afforested / deforested peatland / made ground	Considered within Forestry (F) or Land Use (L), see below	0

Table 4.5 Peat geomorphology classes, association with instability and scores

Figure 7.4.7 shows the geomorphological classes from Figure 7.4.4 re-coloured to correspond with Table 4.5. Much of the main infrastructure area comprises patchy rock outcrop or dendritic / anastomosing drainage (with low scores) however areas of planar peat slopes and flushes have moderate to high scores.

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
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 4.6 Drainage feature classes, association with instability and scores

There were no artificial drains observed at the Site, and therefore the full extent of the main infrastructure area has a minimum score.

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
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

Profile Curvature	Association with instability	Peat slide
Concave Slope	Peat failures are occasionally reported in association with concave slopes	1
Compartmentalised	Peat failures are very rarely reported on undulating slopes with short slope lengths	0

Table 4.7 Slope curvature classes, association with instability and scores

The Site has a particularly complex topography, with numerous areas of rectilinear slopes falling from the rocky summits. Given the complexity in defining curvature for this site, a decision was made to apply a conservative worst case score for the entire area under consideration, as shown on Figure 7.4.7.

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
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 4.8 Forestry classes, association with instability and scores

None of the Site is forested and therefore the Site receives a zero score for this factor (see Figure 7.4.7).

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). While it is hypothesised that burning may cause desiccation cracking in peat and facilitate water flows to basal peat (and potential shear surfaces), there is little evidence directly relating burnt ground to peat landslide events.

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

Land Use	Association with instability	Peat slide
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 4.9 Land use classes, association with instability and scores

There was no evidence of typical peatland land use practices within the main infrastructure area, and therefore the lowest score was assigned (see Figure 7.4.7).

4.3.10. Generation of Slope Facets

The eight contributory factor layers shown on Figure 7.4.7 were combined in ArcMap to produce approximately 16,040 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 4.10 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.

4.3.11. Results

Figure 7.4.8 shows the outputs of the landslide susceptibility approach. The results indicate that the majority of the main infrastructure area has a ‘Low’ or ‘Very Low’ likelihood of instability, with isolated areas of ‘Moderate’ likelihood in the deeper peat areas in the main infrastructure area, around Turbine 11 and Turbine 12. Areas of ‘Moderate’ likelihood are typically located on moderate slopes with moderate peat depths and where drains are present. There are no areas identified with ‘High’ or ‘Very High’ landslide likelihood. When compared with the stability analysis approach, the outputs of this approach indicate slightly more of the main infrastructure area to be at lower stability under natural conditions.

4.3.12. Combined Landslide Likelihood

Figure 7.4.9 shows in purple any proposed areas of infrastructure of greater than 25 m in length intersecting with areas of moderate or higher landslide likelihood (from the contributory factor approach) or Factor of Safety of 1.4 or less (from the limit equilibrium approach). A 25 m overlap has been selected as this is considered the minimum size of a potentially environmentally significant landslide. For there to be a “Medium” or “High” risk (Scottish Government, 2017), likelihoods must be “Moderate” or higher (see Plate 4.1 below) and hence this provides a screening basis for the likelihood results. Only 1 infrastructure location meets these criteria, and this location is considered in Section 5.

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

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 Ground Water Dependant Terrestrial Ecosystems [GWDTEs]) 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 Development below.

5.2.1. Watercourses and water bodies

The Site is characterised by numerous large lochs and smaller lochans with interconnecting watercourses, all of which are fed by steeper minor watercourses and tributaries draining from the moderate slopes and peaty summits above. There are no main rivers within the main infrastructure area and no watercourses below infrastructure that do not first drain into water bodies prior to a further interconnecting watercourse conveying outside the Site boundary.

Loch a Chràthaich (to the southwest of the Site and to the west of the operational Bhlaraidh Wind Farm) and the southern of the two Loch nam Meurs (to the east of Turbines 3 and 4) are classified as high sensitivity due to their high quality for migrating fish and trout fishing respectively. A consequence score of 4 is assigned for short term increases in acidity and turbidity for these water bodies, whose fish populations might be affected were a landslide to occur. Other water bodies and watercourses are assigned a score of 3.

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 these terrestrial habitats (See Table 5.1).

Receptor and type	Consequence	Score	Justification for Consequence Score
Water bodies (Loch nam Meur (South), Loch a Chrathaich)	Short term increase in turbidity and acidification, potential fish kill	4	Potential effects on sensitive fish populations.
Watercourses (aquatic habitats)	Short term increase in turbidity and acidification, potential fish kill	3	Undesignated watercourses, no specific sensitivities noted.
Terrestrial habitats	Short to medium term loss of vegetation cover, disruption of peat hydrology, carbon release	3	Long term effects unlikely following revegetation.
Infrastructure	Potential blocking or undermining of tracks,	2	Minimal likelihood of impact on site personnel, minor remedial works

Receptor and type	Consequence	Score	Justification for Consequence Score
	disruption to construction programme		required that would not likely affect construction programme

Table 5.1 Receptors considered in the consequence analysis

5.2.3. Infrastructure

The Proposed Development site is isolated, with no existing infrastructure located where new wind farm infrastructure is proposed. The adjacent Bhlaraidh Wind Farm is the nearest infrastructure that might be affected by site activities. A consequence score of 2 is assigned for short term remedial works (e.g. track or hardstanding clearance) were they to be required in the event of a landslide occurring.

5.3. Consequences

5.3.1. Overview

A consequence assessment has been undertaken by determining the potential for a landslide sourced at the infrastructure location with a Moderate natural likelihood of peat instability to affect the receptors identified above. As an example, if a turbine is located in a Moderate (likelihood score of 3) area of open slope and is located 50 m from a watercourse (with a consequence score of 5), it is probable that a landslide triggered during construction would reach that watercourse. The calculated risk would be a product of the likelihood and consequence scores (likelihood: 3 x consequence: 5 = risk: 15, see Plate 4.1) and be equivalent to a "Medium" risk.

To determine the likelihood of impact on watercourses and infrastructure, 'runout pathways' have been defined that show the estimated maximum footprint of the landslide. Runout pathways are divided in a downslope direction into 50m, 100m, 250m and 500m zones on the basis of typical runout distances detailed in Mills (2002). The likelihood of runout passing from one runout zone to the next (e.g. from the 50m zone into the 100 m zone) is based on the proportion of the published peat landslide population that reaches each runout distance shown on Plate 5.1 (0-50m: 100%, 50-100m: 87%, 100-250m: 56%, 250-500m: 44%). The first 50m includes the landslide source area.

Figure 7.4.9 shows in purple the one infrastructure location that overlaps with an area of moderate likelihood based on the combined Factor of Safety and landslide susceptibility results. The location is on the main spur of the Proposed Development, adjacent to the junction with the spur track to Turbine 2. Approximately half of the source length falls within organic soil (<0.5m deep) and half on deeper peat (the average depth is 0.45m across the two halves of the source zone).

5.3.2. Local limits on runout (watercourses / water bodies)

The source zone is linked to a lochan at the base of the slope, which is connected to a second lochan to the north by c. 300m of small watercourse, and then ultimately to Loch na Duibhe. None of the water bodies are noted to be especially sensitive, and it is considered very likely that any material entering the first of the three lochans / lochs would strand immediately rather than be conveyed a further 300m into the second or even third loch. As a result, even were a landslide to occur, impacts would be relatively localised.

5.3.3. Local limits on runout (slope curvature)

Plate 5.1 shows runout distances based on published literature. Typically, runout distances would be expected to be less where slope angles decline with distance from the source zone (i.e. on concave

slopes) whereas the full runout lengths shown on Plate 5.1 may be achievable on steepening (convex) slopes or rectilinear slopes. The slope below the source zone down to the minor watercourse is relatively continuous and no restrictions on runout from topography are expected. Runout will likely be arrested by the lochan rather than slope distance.

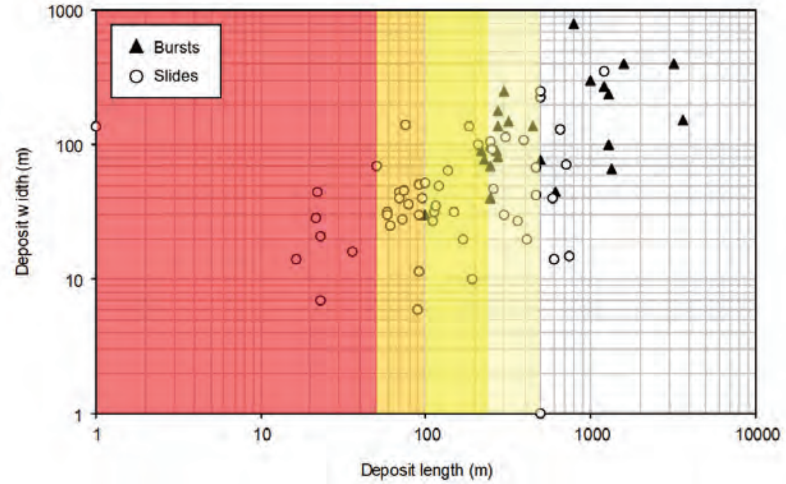

Plate 5.1 Runout distances for published peat landslides (after Mills, 2002), colours on the plot correspond to runout pathway zones on Figure 7.4.9

5.3.4. Local limits on runout (peat thickness in source zone)

Landslide runout may be "supply-limited" by the availability of peat material generated in the failure or source zone. Typically, mobilised material thins with increasing distance from the source zone as rafts of landslide material break down into blocks, and blocks become abraded and roll, breaking down further into a blocky slurry (Plate 5.1).

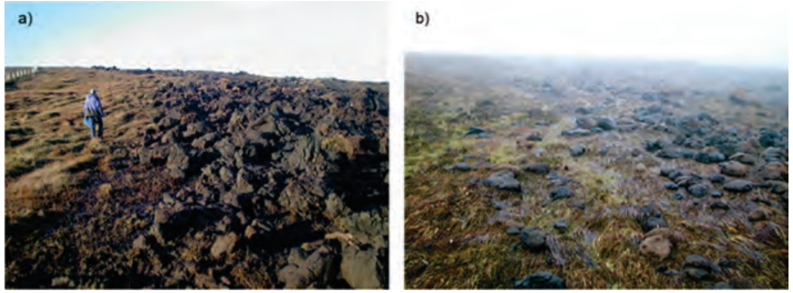

Plate 5.1 Examples of landslide runout (Dooncarton, Co. Mayo): a) blocky debris mid-slope, b) abraded and rolled blocks in lower slope

Following identification of the runout zone for the single identified source zone, additional analysis has been undertaken to approximate this effect. The analysis assumes a source volume equivalent to the source footprint (0m - 50m zone) multiplied by the average peat depth in this source zone (0.45m) (from the peat depth model). This volume is then distributed over the full runout pathway (i.e. mobilised volume / runout area) to generate an average thickness of deposit. As the runout length and area increases, the volume thins, in keeping with observed peat landslide deposits. Where deposits fall below 0.2m in thickness, it is assumed that runout will stall due to the roughness of surface vegetation relative to the thickness of landslide material. If the thickness is calculated to be 0.2m or less in the zone adjoining a watercourse, then it is judged that there will be no significant impact on that watercourse (even if a landslide occurs).

5.3.5. Results of runout analysis

Runout from the one source location identified would thin from 0.45m below the source zone to c. 0.15m in the 100-250m runout zone and may not enter the first of the three lochans described above.

5.4. Calculated Risk

The risk level associated with the source zone has been calculated as a product of likelihood and consequence and is shown as a zoomed inset on Figure 7.4.9 for the runout pathway. The runout zones within the runout pathway are colour coded to match the risk rankings shown on Plate 4.1. For each zone, the score for the most sensitive environmental receptor has been chosen for the risk calculation (i.e. a conservative approach). Both the waterbody receptor and habitat receptor result in risks calculated to be “Low” within the runout pathway. There are no areas with “Medium” or “High” calculated risks.

Based on the calculated risks shown on Figure 7.4.9, site-wide good practice measures should be sufficient to manage and mitigate any construction induced instability risks. This is considered in the next section.

5.5. Restoration Activities

As part of the peat management proposals for the Proposed Development, a number of hagged areas have been recommended for restoration using peat excavated primarily from turbine foundations and hardstandings. As part of the assessment for this restoration work, all Moderate likelihood and areas with Factors of Safety <1.4 were compared with potential restoration areas, and if present, those hagged areas were excluded from the restoration proposals. Further information on managing the relocated materials is provided in Appendix 7.3 of the EIA Report.

6. RISK MITIGATION

6.1. Overview

A number of mitigation opportunities exist to further reduce the risk levels identified at the Proposed 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; examples include tension cracks along the peat escarpment and 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” for 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 LOW or greater risk. 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 second 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.
- Avoid temporary storage of peat on slope gradients >3° where possible, and preferably store on ground with neutral slopes and natural downslope barriers to peat movement.
- For permanent restoration areas, undertake pre-construction UAV or topographic surveys to determine i) gradients of eroded floors of hagged areas (to inform/refine infill depths), and ii) position and integrity of intact peat haggs into which berms and retaining structures may be keyed.
- Undertake regular monitoring of emplaced peat in restoration areas to identify evidence of creep or pressure on retaining structures (dams and berms).
- Monitor effects of wetting / re-wetting stored peat on surrounding peat areas, and prevent water build up on the upslope side of peat mounds.

- 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 the 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 50m 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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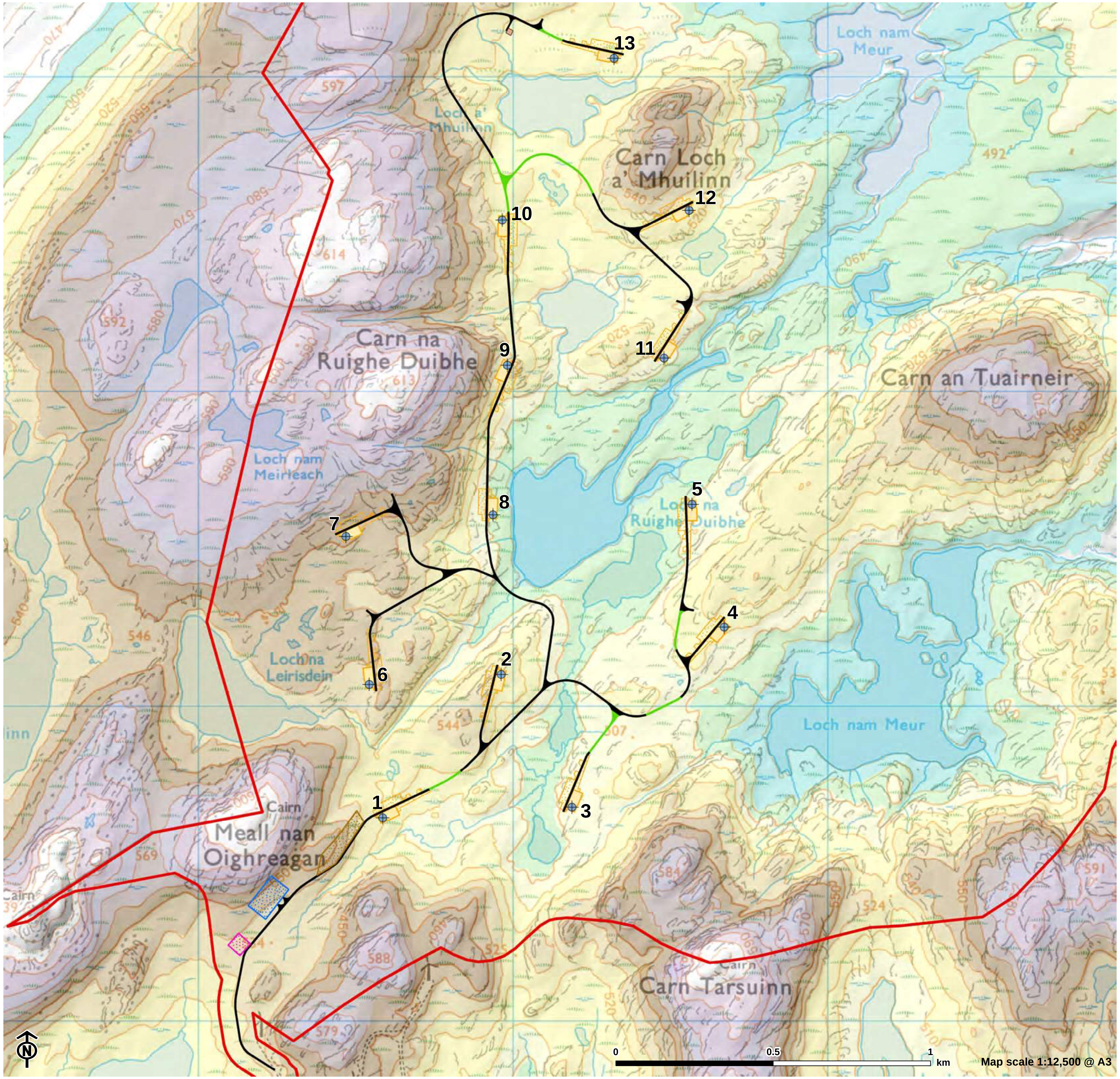
Figure 7.4.1 - Elevation



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Elevation (m)

- 480 - 490
- 491 - 500
- 501 - 510
- 511 - 520
- 521 - 530
- 531 - 540
- 541 - 550
- 551 - 560
- 561 - 570
- 571 - 580
- 581 - 590
- 591 - 600
- > 610

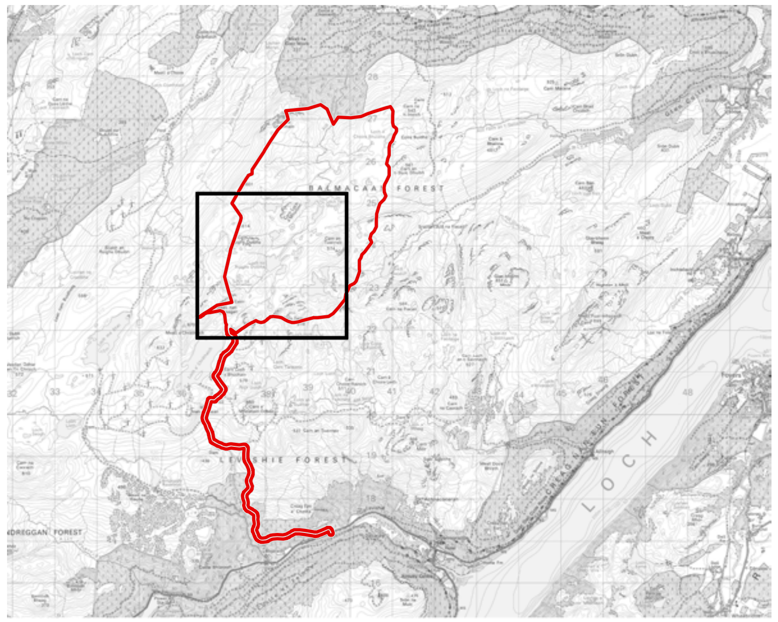


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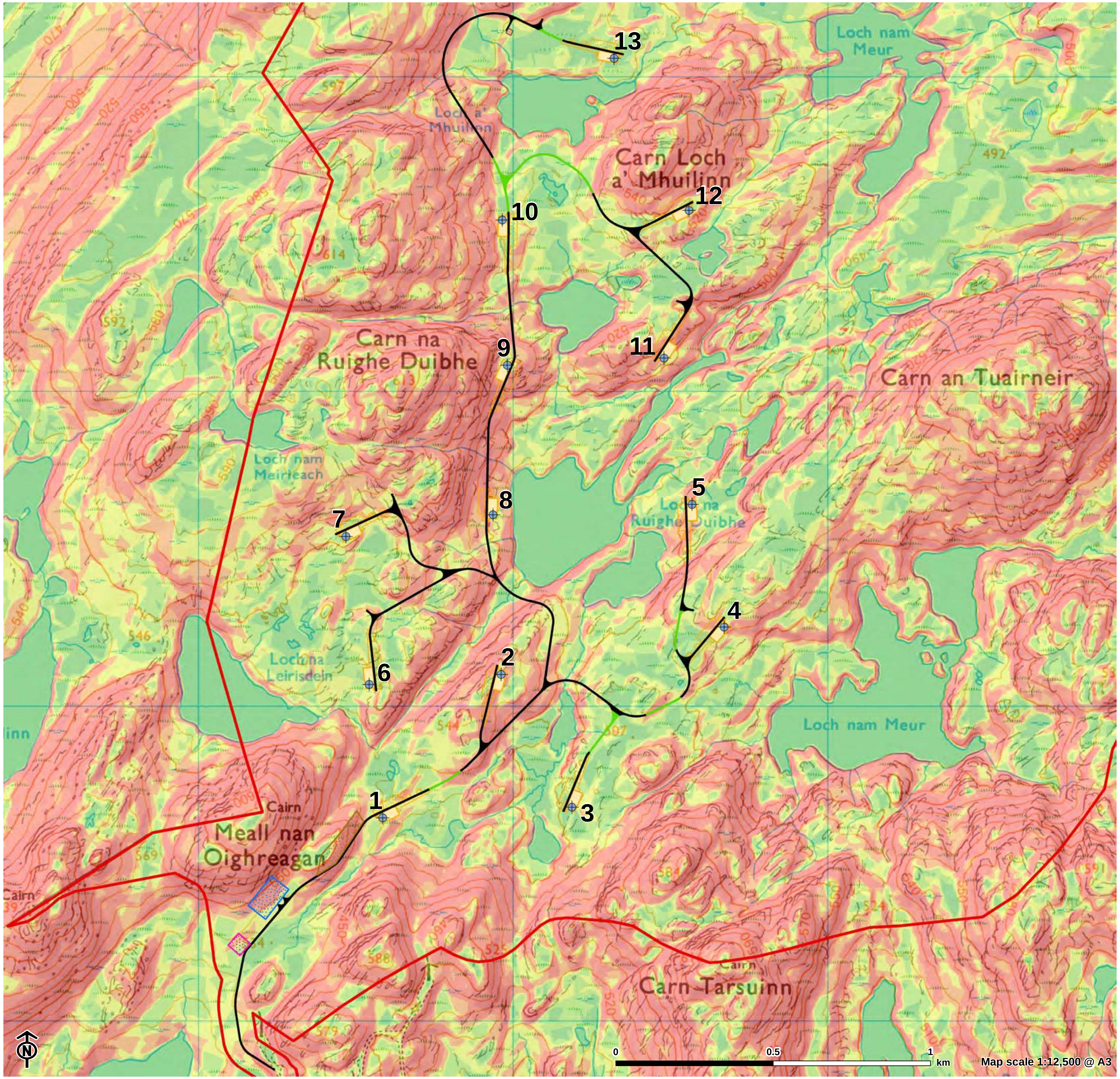
Figure 7.4.2 - Slope



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Slope (in degrees)

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

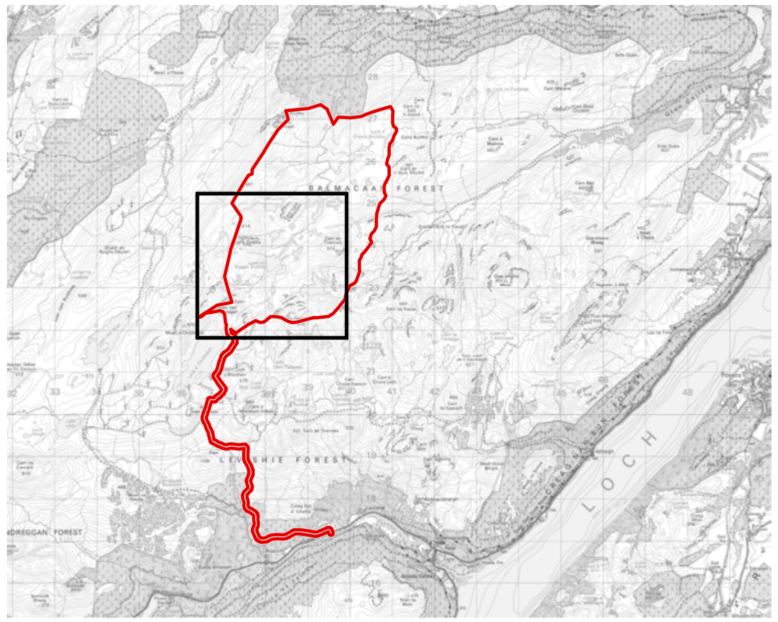


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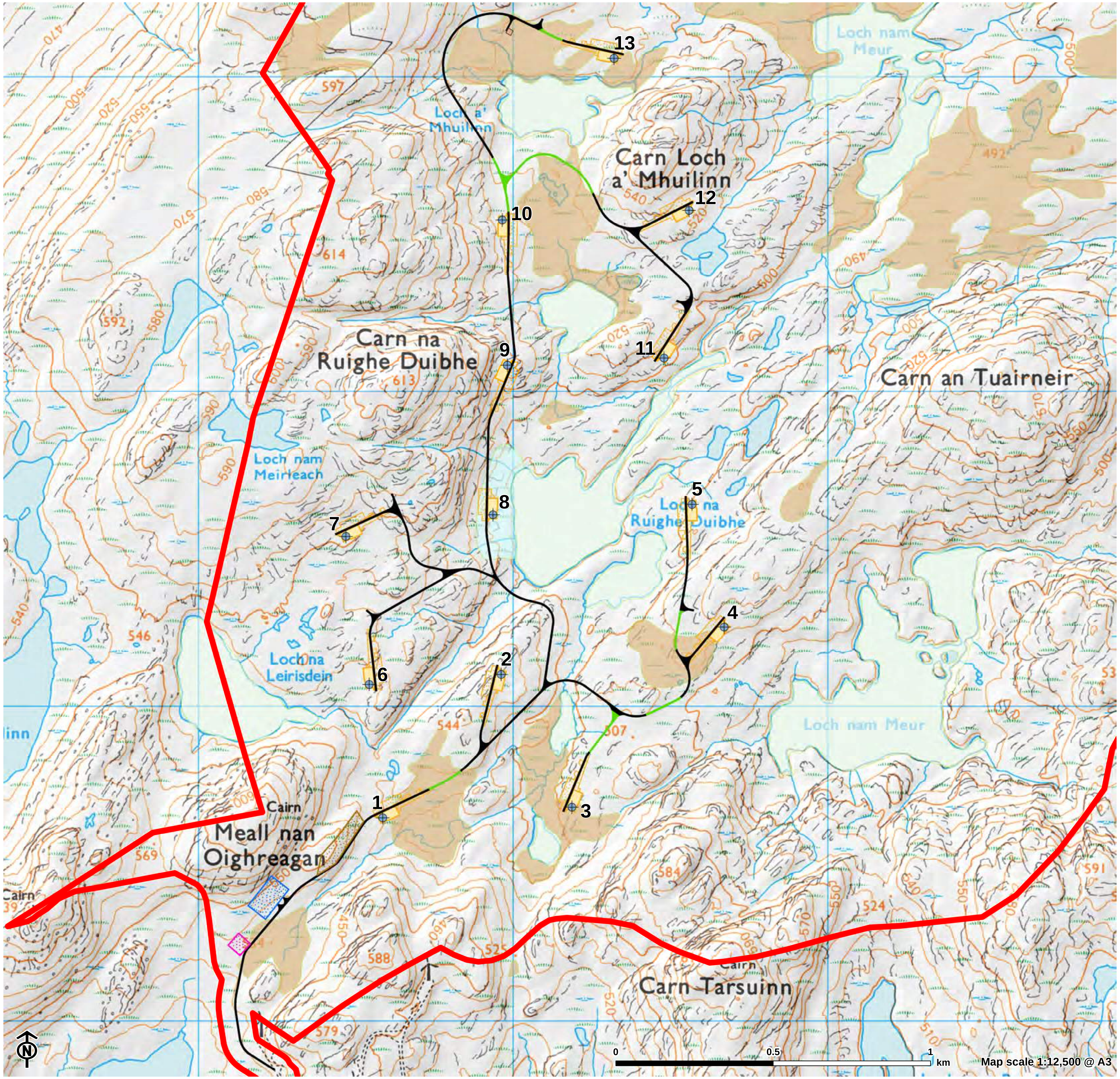
Figure 7.4.3 - Geology and Superficial Geology



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Superficial Geology

- Peat - Peat
- Till, Devensian - Diamicton
- Unknown/Unclassified Entry

Bedrock Geology (inset map)

- Achnaconeran Striped Formation - Psammite and Semipelite
- Tarvie Psammite Formation - Psammite
- Tarvie Psammite Formation - Semipelite

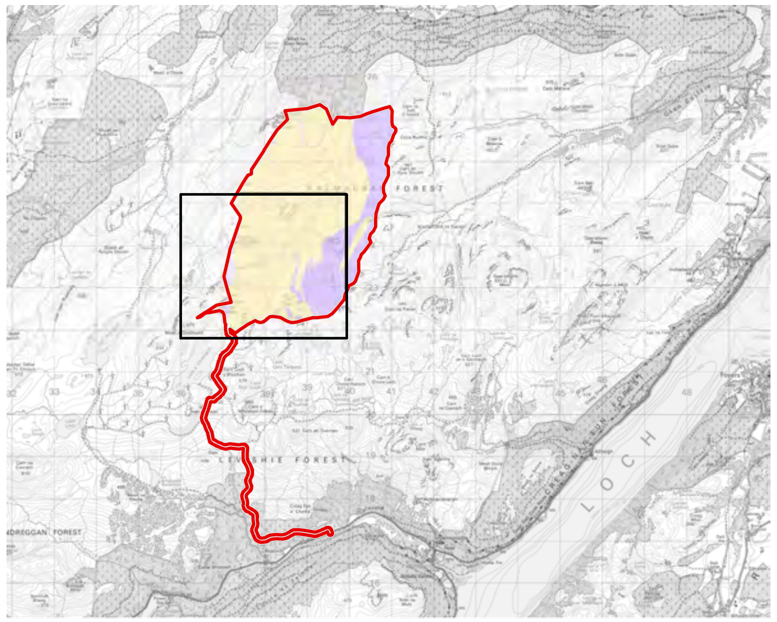


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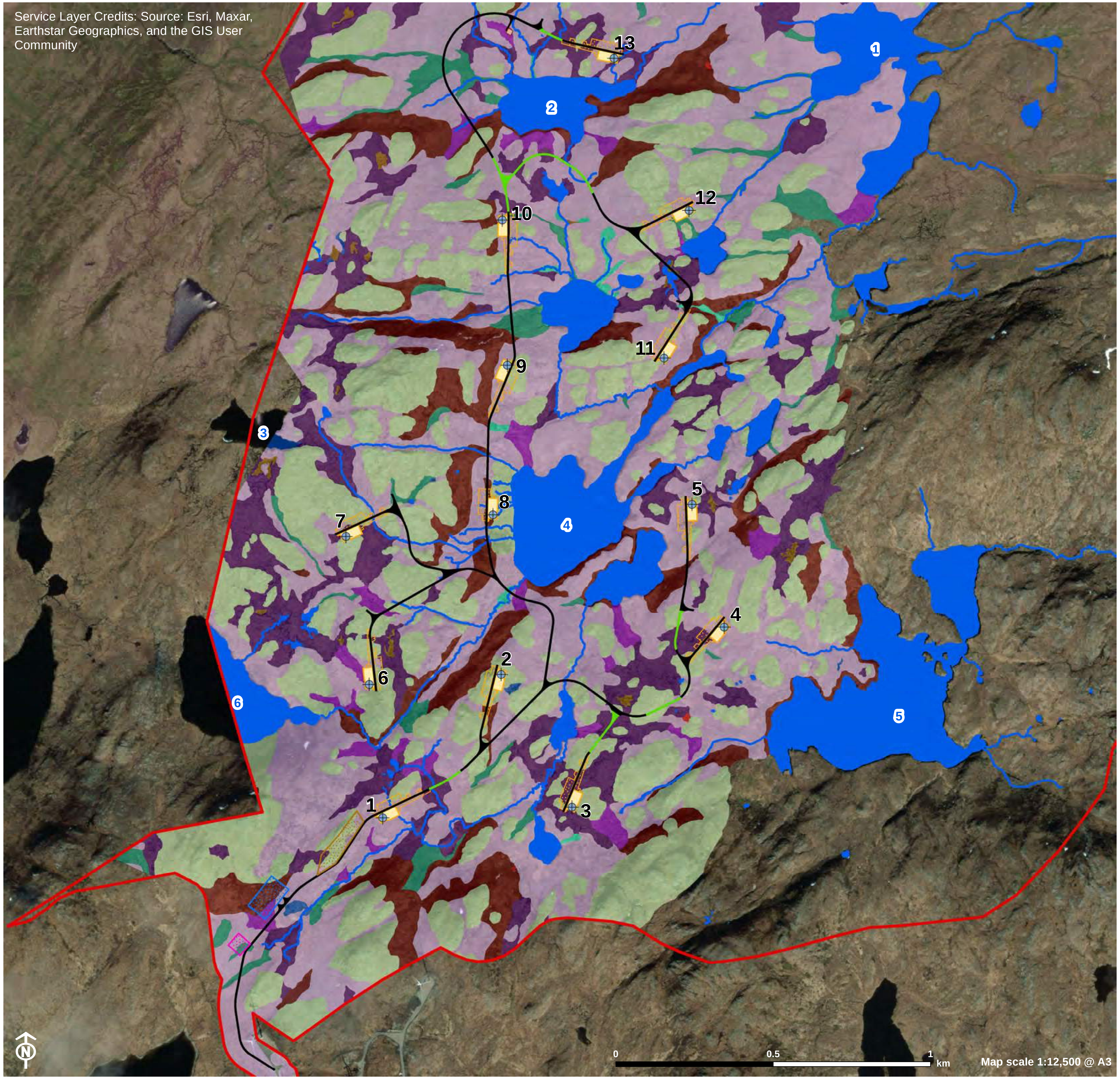
Figure 7.4.4 - Geomorphology, hydrology and land use



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Hydrology

- Watercourses
- Waterbodies

Geomorphology / Land Use

- Flush
- Anastomosing drainage
- Dendritic drainage
- Linear drainage
- Planar peat
- Bare / eroded peat
- Instability
- Steep slopes (with heather / local terracettes)
- Pool
- Patchy rock outcrop / thin peat or soil

Loch Names

1. Loch nam Meur
2. Loch a' Mhuilinn
3. Loch nam Meirleach
4. Loch na Ruighe Duibhe
5. Loch nam Meur
6. Loch na Leirisdein

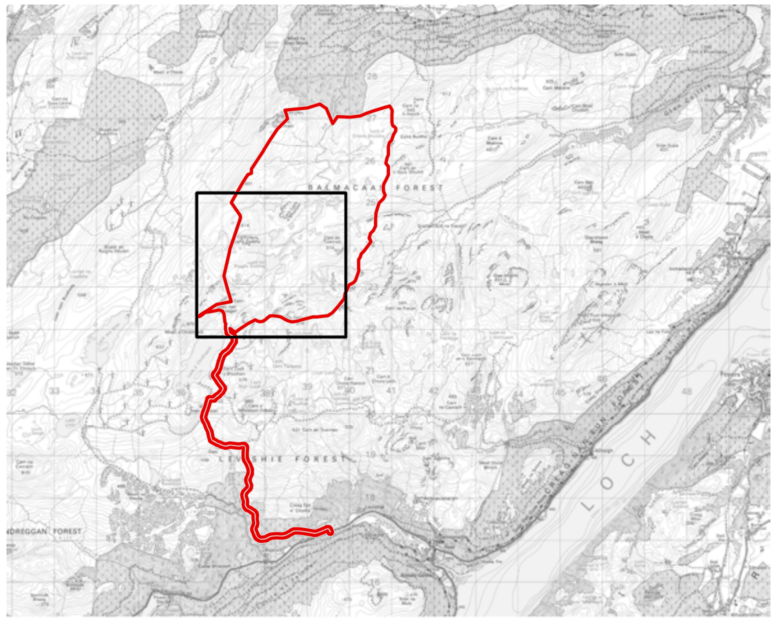


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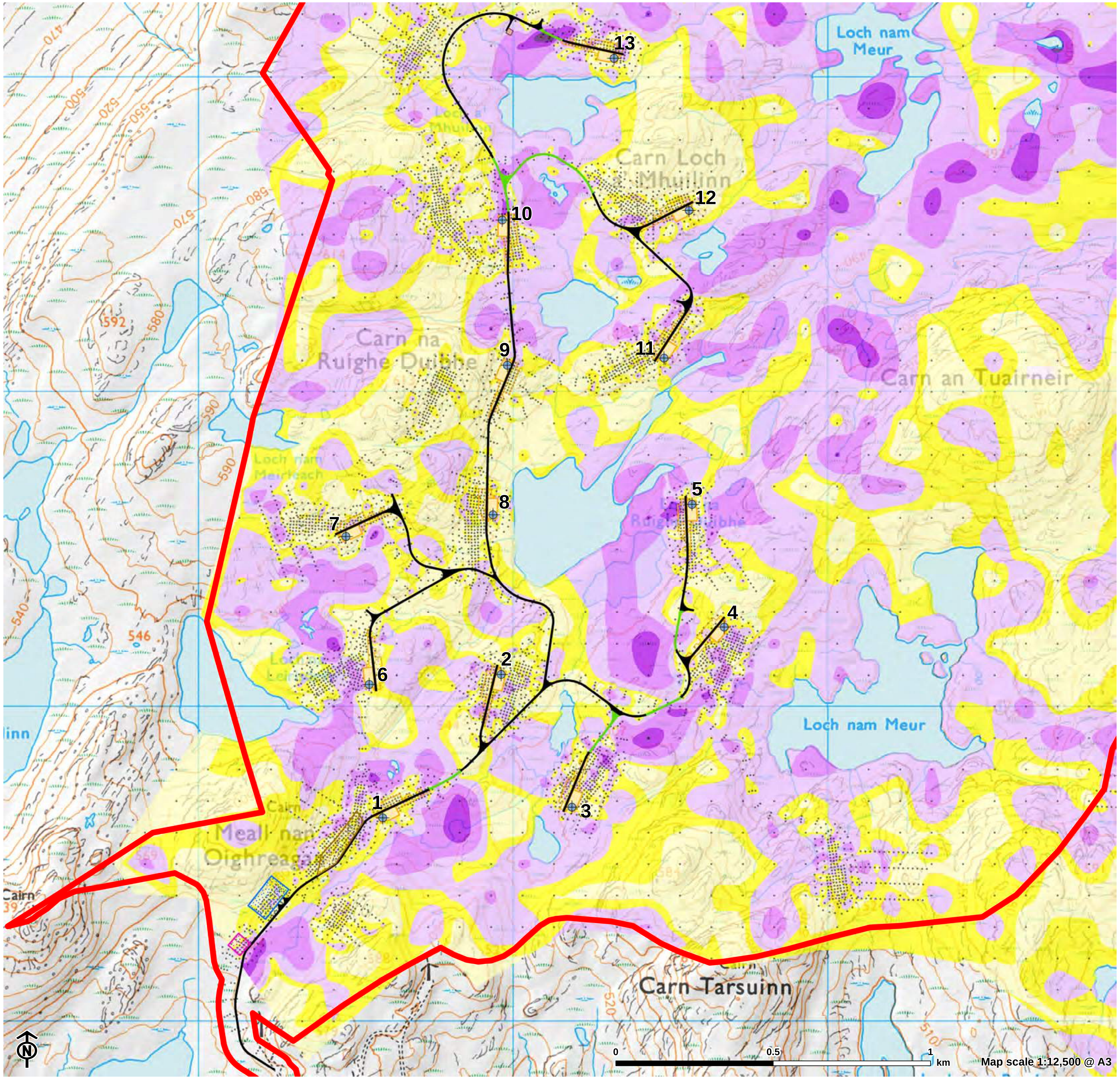
Figure 7.4.5 - Peat Depth



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track
- Probe Locations

Interpolated 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 - 5.0
- > 5.0

Carbon and Peatland Map (2016) classification (inset map)

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

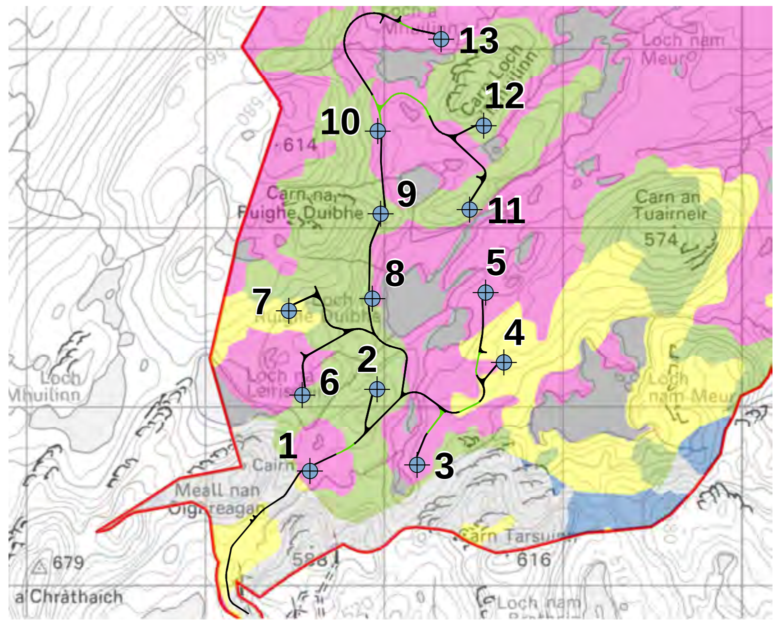


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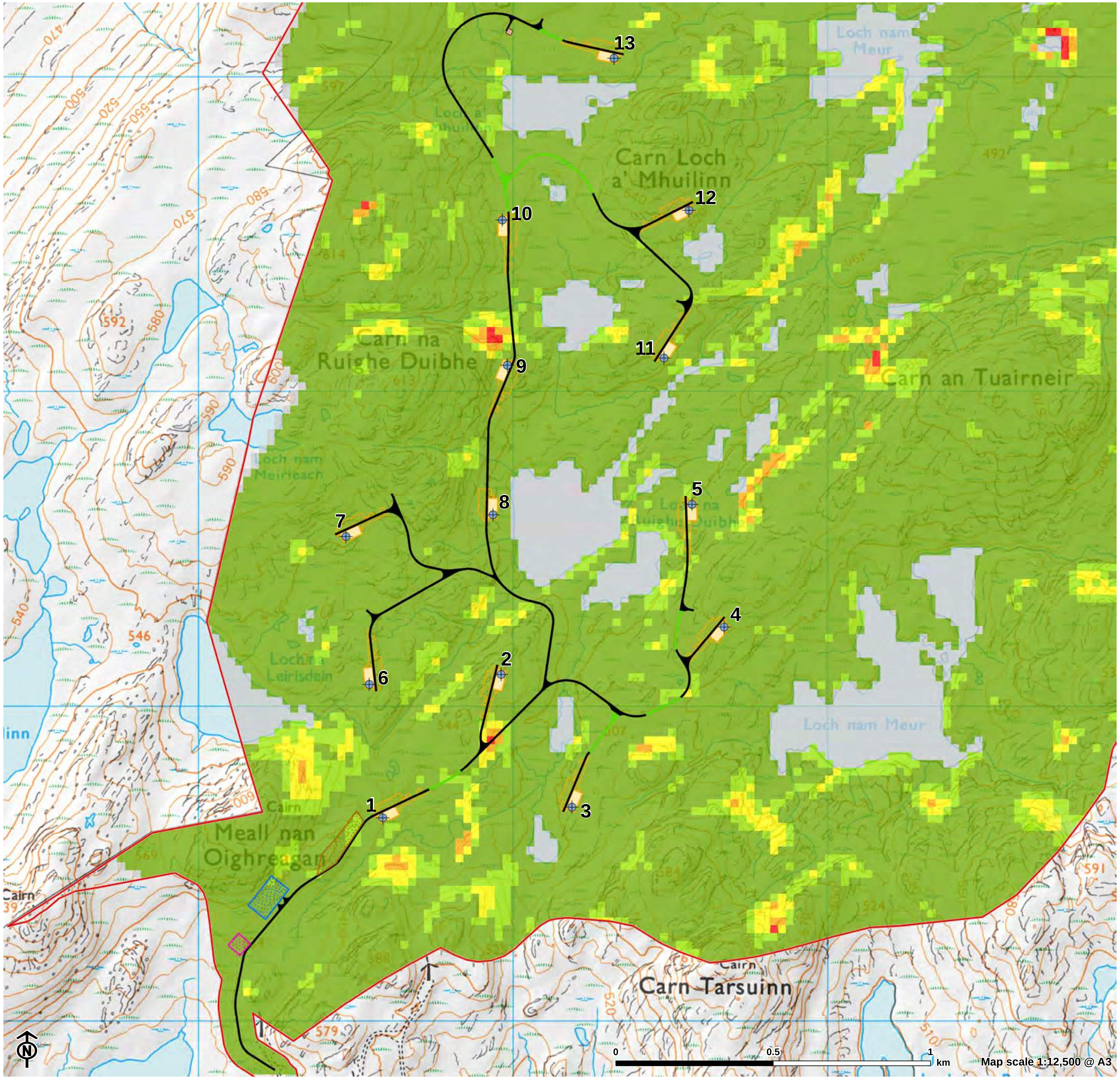
Figure 7.4.6 - Factor of Safety (Best Estimate Parameters)



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access
- New standard access

Factor of Safety (Best estimate parameters)

- No calculation
- < 1.0 (Unstable)
- 1.0 - 1.4 (Marginally Stable)
- 1.41 - 2.00 (Stable)
- 2.01 - 3.00 (Stable)
- > 3.01 (Stable)

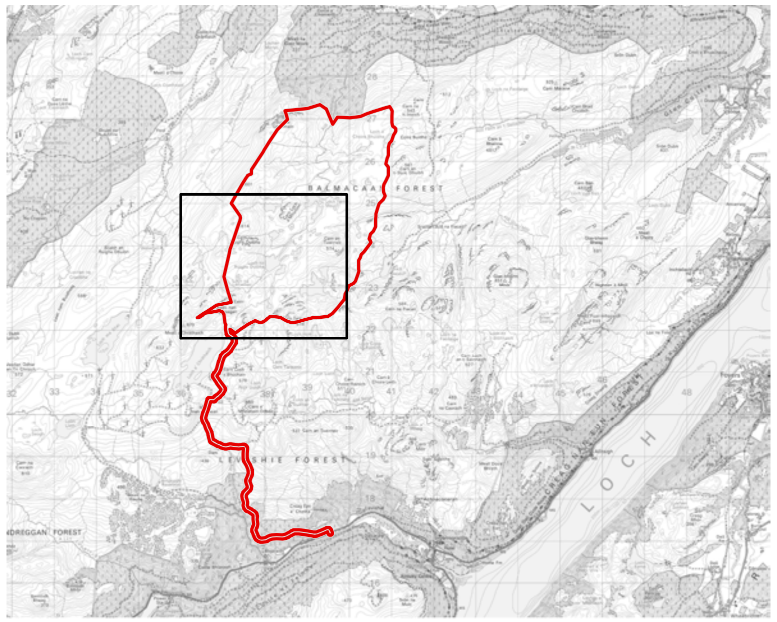


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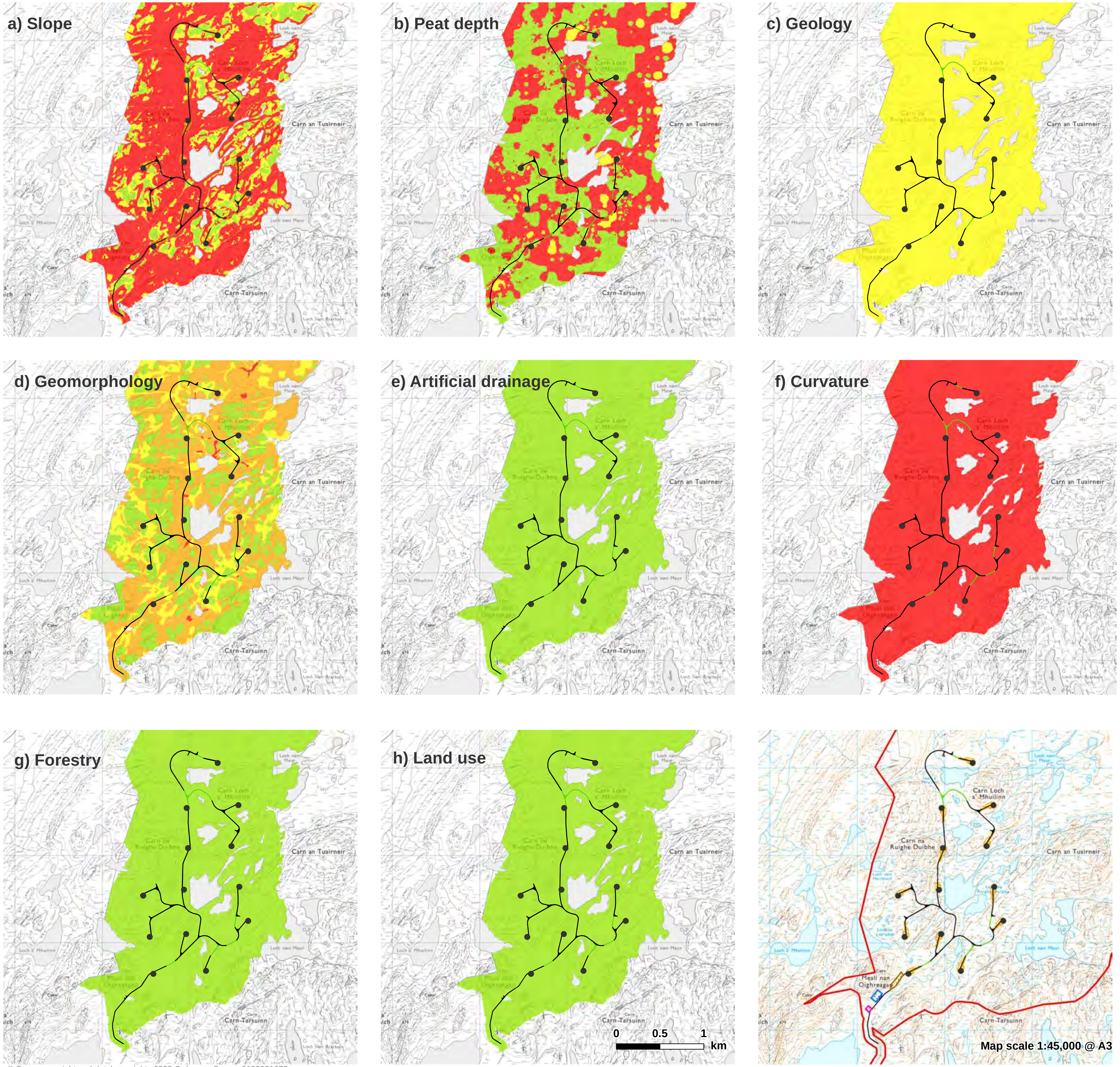
Figure 7.4.7 - Contributary Factors



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Contributory Factor Scores

- 0
- 1
- 2
- 3

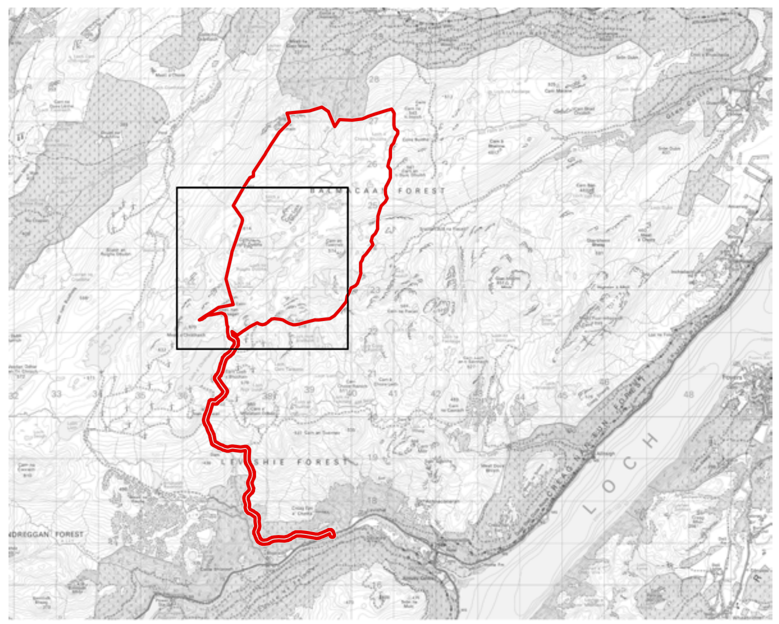


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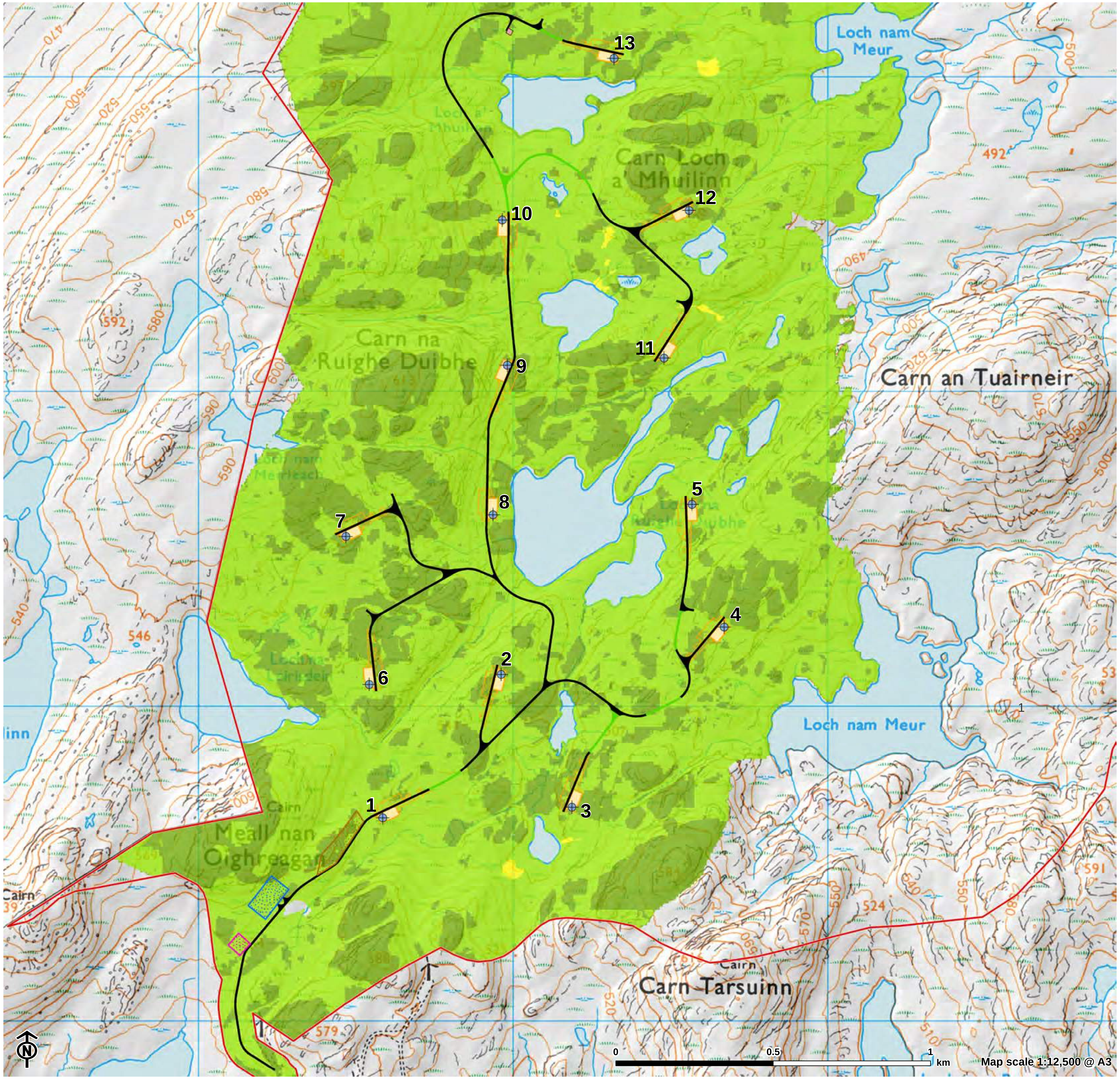
Figure 7.4.8 - Peat Landslide Likelihood



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Landslide Susceptibility Score

- Very Low
- Low
- Moderate
- High
- Very High

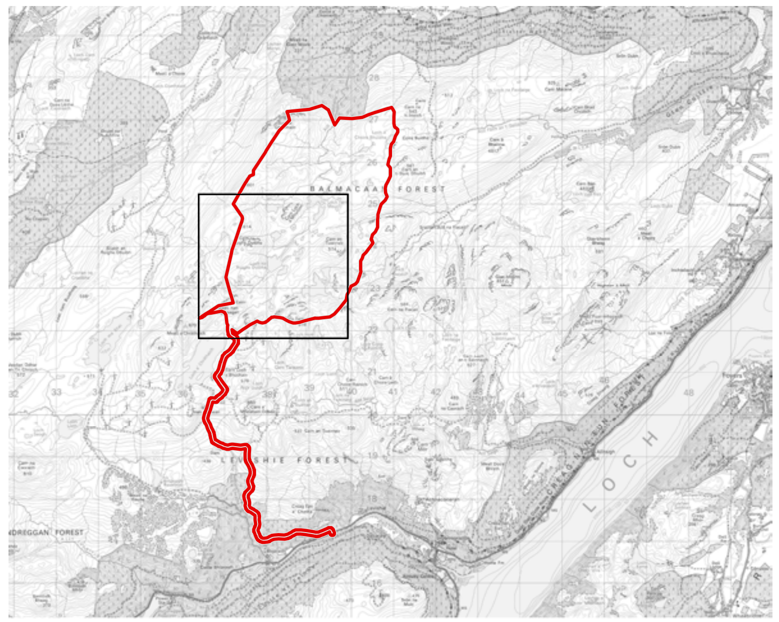


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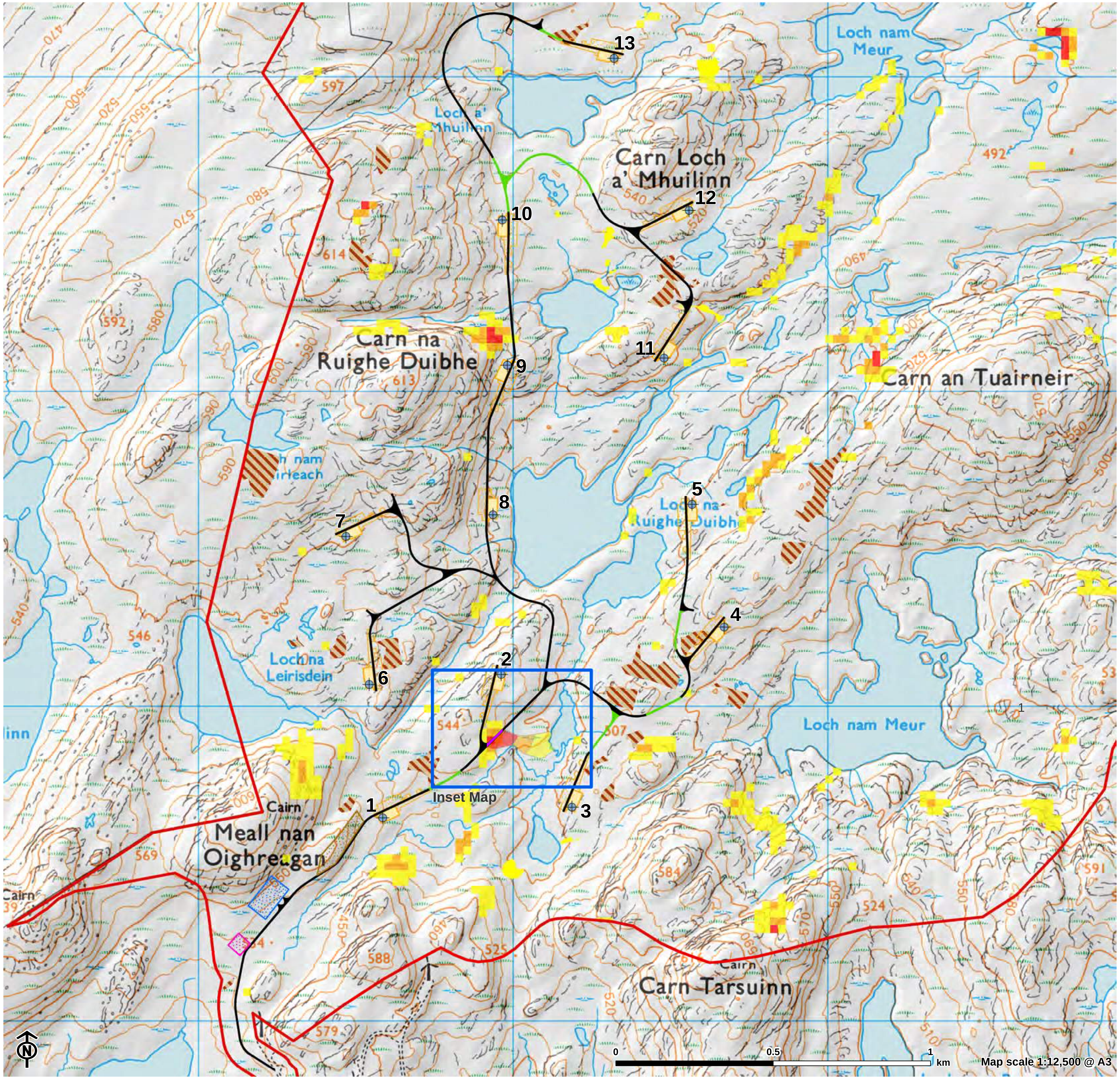
Figure 7.4.9 - Runout zones and calculated risk



Legend

Infrastructure

- Turbine
- Site boundary
- Borrow pit
- Construction compound
- Substation
- Met mast
- Hardstanding
- Permanent hardstanding
- New floating access track
- New standard access track

Factor of Safety (Best Estimate Parameters)

- < 1.0 (Unstable)
- 1.0 - 1.4 (Marginally Stable)
- 1.41 - 2.00 (Stable)

Calculated Risk (inset)

- Negligible (green)
- Low (Yellow)
- Medium (Orange)
- High (Red)

Peat Landslide Likelihood

- Moderate

Source Zones

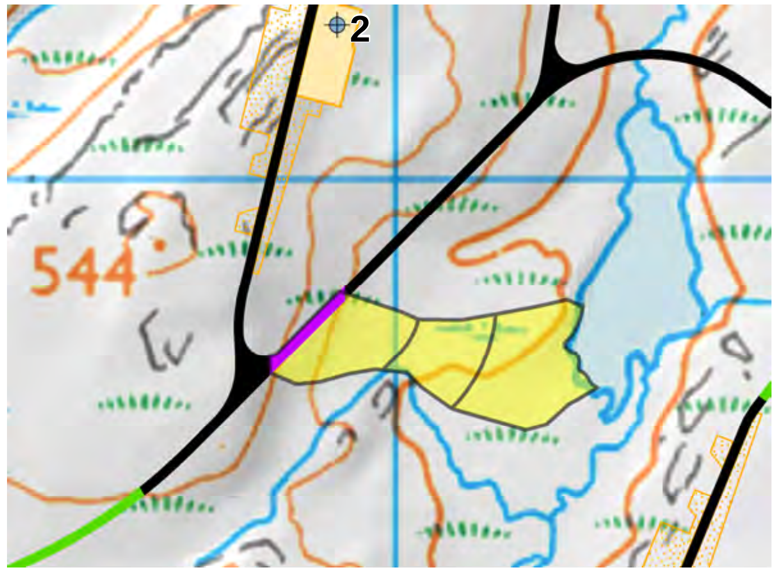
- Source Zones

Runout Zones

- 0 - 50 m
- 50 - 100 m
- 100 - 250 m
- 250 - 500 m (none present)

Restoration Areas (see Appendix 7.3)

- Restoration areas



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