Bhlaraidh Wind Farm Extension

Appendix 10.2: Peat Stability Risk Assessment Report

June 2021

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Contents

Executive summary

Mott MacDonald has been commissioned by SSE Generation Limited (the Applicant) to prepare a Peat Stability Risk Assessment Report to inform the design and layout of the proposed Bhlaraidh Wind Farm Extension (Proposed Development), located north west of Invermoriston in the Great Glen, Highlands.

The purpose of the report is to assess the risk of a peat slide occurring such that suitable controls and appropriate methodologies can be employed during construction and commissioning to mitigate these risks. The report provides an assessment of the peat stability conditions based on a Desk Study and subsequent Site Reconnaissance, including phased peat probing surveys to identify ground conditions that may influence the stability of the peat based on the current infrastructure layout.

Peat covers the majority of the terrain within the Proposed Development. Peat is underlain in the west of the Site by Psammite of the Upper Garry Psammite Formation and in the east of the site by interbedded Psammite and Semipelite of the Achnaconeran Striped Formation. A small number of localised igneous intrusions are recorded across the Proposed Development. A number of faults are inferred across the western half of the Proposed Development, generally trending northeast to southwest.

A Qualitative Risk Assessment (Q_LRA) was undertaken to determine the baseline peat stability conditions in areas of proposed infrastructure within the Site. The Q_LRA approach is based on a system where factors of influence and impact are multiplied together to generate Risk Rating Scores and corresponding qualitative relative risks. The Q_LRA was undertaken at each probe location using the data from the previous 2012 PSRA for the Operational Development, the Phase 1 (2019) and Phase 2 (2020) probing undertaken by Mott MacDonald across the Proposed Development. The baseline assessment found the risk of peat slide events occurring was classified as generally Very Low to Medium risk, prior to undertaking further quantitative analysis.

Given the Medium risk identified at some locations in the baseline assessment, a Quantitative Risk Assessment (Q_NRA), via a slope stability analysis was carried out. The slope stability analysis was based on the infinite slope model (model which uses failure mechanisms similar to translational slips), and determined that areas of 'Medium' risk would have an overall Very Low to Low risk to the Site, provided appropriate mitigation measures are taken.

Using professional engineering judgement with respect to construction impact, the risk from the construction phase of the Proposed Development will remain Very Low to Low, provided the recommendations and mitigation measures described in this report are followed. The report also identifies mitigation measures and sets out recommendations for both syn-construction (during construction) and post-construction stages of the Proposed Development, including a preliminary Geotechnical Risk Register for consideration and further development prior to construction.

1 Introduction

1.1 Background

Mott MacDonald (MML) has been commissioned by SSE Generation Limited (the Applicant) to carry out a Peat Stability Risk Assessment to inform the design and layout of the proposed Bhlaraidh Wind Farm Extension (herein referred to as the 'Proposed Development').

As part of this task, a Desk Study comprising a review of available information (Section 3) was undertaken. Site Reconnaissance comprising walkovers and phased peat probing surveys were carried out to collect information on peat depth, stratification and localised hydrological and geomorphological conditions.

The importance of assessing the stability of peat deposits in relation to wind farm development came to the fore as a result of peat failures during the construction of Derrybrien Wind Farm in Ireland in 2003 (Ref. [1]). As wind farms tend to be constructed in high moorland areas, which are commonly associated with significant peat deposits (typically blanket bogs), there is a potential for peat instability to occur, particularly where deposits are in excess of 1 m deep. Peat instability is a natural occurrence which is influenced by many factors including, but not limited to, peat thickness, slope gradient and subsurface hydrology.

The methodologies used as part of the peat stability risk assessment are based on guidance from the Scottish Government – 'Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments' (Ref. [2]). It is recommended within the guidance that a peat stability risk assessment is carried out as part of the Environmental Impact Assessment process.

The Proposed Development comprises 18. No. wind turbines and associated infrastructure, including but not limited to; associated underground cabling, access tracks and turning points, crane hardstandings, temporary construction compounds, control building and substation compound, LiDAR and borrow pits. Reference should be made to Figure 1.1, Figure 1.2 and Figure 1.3 in Chapter 1 of the EIA for the Site Location, Site Layout and Wider Layout Plan.

The report assesses the stability of peat at the Site based on peat probing surveys undertaken for the current Bhlaraidh Wind Farm Extension infrastructure layout.

1.2 Scope of Report

This report summarises the findings of the Desk Study and Site Reconnaissance, and provides an assessment of the prevailing ground conditions as they relate to peat stability issues. This report comprises:

- A summary of the methodology adopted for the Desk Study and Site Reconnaissance (Section 2);
- The findings from the Desk Study and Site Reconnaissance (Section 3);
- An outline of the geology and ground conditions at the Site (Section 3);
- A description of the factors that are generally considered to influence peat stability (Section 4.2);
- A Qualitative Risk Assessment (Q_LRA) of each peat probe location within the Q_LRA assessment area, and a subsequent Quantitative Risk Assessment (Q_NRA) if required, using the peat data gathered during the Site Reconnaissance (Section 4);

- A summary of the recommended controls to be adopted during construction to minimise the risk of peat instability occurring at Bhlaraidh Wind Farm Extension (Section 5);
- Conclusions and recommendations for further work, if required (Section 6).

1.3 Description of the Proposed Development

The Proposed Development is located approximately 5.5km to the north west of the village of Invermoriston, in the Great Glen, Highlands. The Proposed Development covers approximately 9.7km^2 and comprises predominantly open upland moorland crossed by rivers and lochans.

Access to the Proposed Development during construction is proposed via the Operational Development access track, which is located off the A887 (refer to Figure 1.1, Figure 1.2 and Figure 1.3 in Chapter 1 of the EIA for the Site Location, Site Layout and Wider Layout Plan).

The terrain is varied, with turbines proposed on a number of slopes across the Site, predominantly in areas of open moorland.

Peat thicknesses vary across the Site but are generally between 0.5m and 1.0m, with localised thicker peat accumulations (> 1.5m). Thick peat accumulations have developed in areas where the terrain is relatively flatter around lower lying areas of the Site between the topographical highs. The thickest peat encountered during the Site Reconnaissance survey was 3.3m.

The Proposed Development includes approximately 11.4km of infrequent and minor upgrade of existing Operational Development track and 2.4km of fully upgraded track to the existing Hydro Scheme to the east of the Proposed Development, and total new track length of 10.2km. The track will typically consist of a 4.5m wide running surface with 0.5m wide verge shoulders on each side and incorporate passing places [3].

1.4 Proposed Geotechnical and Construction Works

In assessing the potential for peat instability, and subsequent construction methodologies and controls, the following activities and construction elements were considered (refer to Section 4.8):

- Access tracks, leading to turbines, a control building and substation compound, including:
  - infrequent and minor upgrade of existing Operational Development tracks (11.4km);
  - full upgrade of existing Hydro Scheme track (existing access tracks 2.4km);
  - construction of 10.2km of new access tracks and turning heads, (4.5m wide running surface with 0.5m wide shoulders) incorporating passing places (18 No., each with an area of approximately 60m^2) and watercourse crossings;
- Construction of temporary access tracks, a temporary construction compound, lay down area and borrow pits;
- Excavation for turbine bases (18 No.) to a suitable bearing stratum;
- Construction (permanent) of:
  - turbine foundations and adjacent hardstandings (with an area of approximately 1875m^2);
  - foundations for the substation compound;
  - on site underground cabling, connecting the wind turbines to the substation;
  - substation compound containing substation buildings;
- Construction (temporary) of:
  - Temporary turbine hardstandings;
  - construction compound and lay down area;

  - concrete batching plant;
- 8 No. borrow pits of varying dimensions (5 plus 3 hydro borrow pit search areas).

It should be noted that temporary tracks to borrow pits have not been identified at this stage. The preferred access points will be identified following further detailed site investigation.

1.5 Terminology and Abbreviations

The 'Proposed Development' is used in reference to the proposed 18 turbine Bhlaraidh Wind Farm Extension in the Highland region of Scotland, as identified on Figure 1.1, Figure 1.2 and Figure 1.3 in Chapter 1 of the EIA for the Site Location, Site Layout and Wider Layout Plan.

The 'Operational Development' is used in reference to the existing Bhlaraidh Wind Farm, located to the west of the proposed development.

The 'scoping boundary' refers to the area considered during the initial scoping assessment for the location of the proposed wind farm. The scoping boundary is based on the land ownership extents of the Glenmoriston Estate, and constraints including ornithology, ecology, hydrology and cultural heritage.

The term 'the Site' is used to denote the area within the red line boundary which forms the application boundary.

The 'turbine development area' refers to the area where turbines are to be positioned and where the majority of the peat probing was concentrated.

The term 'works' is used to describe the construction of infrastructure elements.

The term 'sensitivity' is defined as "the relative potential for instability" and is derived from a combination of several factors including, but not limited to, peat thickness, slope gradient and groundwater conditions that may affect the likelihood of a peat failure.

Factor of Safety (FoS) is used to assess the stability of a slope (for total stress), which is a ratio sum of resisting forces (soil strength) and the sum of destabilising forces (weight of soil mass).

Acronyms

- mAOD – metres Above Ordnance Datum
- mbgl – metres below ground level
- BGS – British Geological Survey
- DTM – Digital Terrain Model
- FoS – Factor of Safety
- GIS – Geographical Information System
- HMSO – Her Majesty's Stationery Office
- OS – Ordnance Survey
- PSRA – Peat Stability Risk Assessment
- Q_LRA – Qualitative Risk Assessment
- Q_NRA – Quantitative Risk Assessment
- SNH – Scottish Natural Heritage
- SEPA – Scottish Environment Protection Agency

2 Methodology

2.1 Desk Study

A desk study has been undertaken to gain a thorough understanding of site conditions including geology, topography, hydrology, and site history. The materials consulted during the Desk Study are referenced below with the findings given in Section 3 of this report:

- BGS Onshore GeoIndex Viewer (Ref. [4]);
- BGS Onshore GeoIndex - Hydrogeology Viewer (Ref. [5]).

2.2 Site Reconnaissance and Peat Depth Probing

Site Reconnaissance surveys with peat depth probing were undertaken between July and August 2019, and August and September 2020. Peat depth probing was also completed in 2011 for the Operational Development, and pertinent records from this data set have also been utilised.

The purpose of the survey work was to confirm Desk Study findings and provide information on the nature of peat depth and hydrological conditions. The results of the peat depth probing are shown on Figure A.1 in Appendix A.

Three phases of peat depth probing were carried out within the Site, with a total of 2,909 peat depth probes undertaken. Details of the various phases of probing are as follows:

- Previous 2012 Bhlaraidh PSRA: Peat depth probing undertaken by Mott MacDonald between September and November 2011 (821 of 2,432 probes within current site boundary).
- Phase 1: Peat depth probing (599 probes) was undertaken by Mott MacDonald in July to August 2019 based on a 100m grid across the Proposed Development area;
- Phase 2: Additional probing (1,489 probes) was undertaken by Mott MacDonald in August to September 2020, targeting the proposed locations of the 18 No. turbines and associated infrastructure.

A visual assessment of peat conditions and estimated peat extents across the Proposed Development were carried out during the surveys, with pertinent features such as active, incipient or relict instability recorded. Peat probing was undertaken using a gouge auger to identify the thickness of peat deposits, as well as providing an indication of peat stratification and localised surface hydrological conditions.

At each probing location, the following information was recorded:

- an indication of the nature of the peat; described as fibrous, semi-fibrous or amorphous. These descriptions were determined with reference to Section 5.12 and Table 5 of BS EN ISO 14688-1:2002+A1:2013 (Ref. [6]) with the exception that the term ‘pseudo-fibrous’ is replaced with ‘semi-fibrous’ in this report;
- a qualitative visual observation of the apparent moisture content of the peat samples collected using the descriptions in Table 2.1;
- an indication of the substrate below the peat, with categories including:
  - hard at base (probable bedrock);
  - weathered rock;
  - glacial till;

- glacial sands and gravels; and
- silt/clay.

Table 2.1: Subjective Moisture Content Descriptions

Moisture Content Descriptor	Appearance	Squeeze Test
Dry	Peat may appear shrivelled or cracked	Crumbles, no moisture content and feels dry
Moist	Peat damp to touch	Pliable with little or no excess water when squeezed
Wet	Peat appears saturated but remains intact	Pliable with excess water when squeezed
Very wet	Peat appears watery. Peat sample may be partially lost on retrieval of auger.	Liquefies to slurry when squeezed.

2.3 Peat Stability Risk Assessment

The peat stability risk assessment is undertaken in three phases:-

- Baseline (pre-construction) – carried out using a Qualitative Risk Assessment Method (Q_LRA).
- Syn-construction (or during construction) – assessment of impacts of construction using engineering judgement and Quantitative Risk Assessment (Q_NRA) via numerical modelling where appropriate.
- Post-construction – assessment comprising a subjective assessment of anticipated long-term impacts of the wind farm on peat stability.

2.3.1 Baseline Assessment

The baseline assessment uses a deterministic approach, where the outcome/risk ranking is calculated using inputs into a peat stability risk ranking system. This method has been described as a Qualitative Risk Assessment (Q_LRA) or Semi-quantitative Risk Assessment by Lee & Jones (Ref. [7]), and is derived from rating factors that are considered to influence stability. The relative scoring for each factor in the risk ranking system has been estimated using a combination of field observations and engineering judgement, including reference to literature to reflect the importance of each factor. It should be noted that the risk ranking is specific to the proposed wind farm.

With regards to the deterministic methodology, information gathered from the Site Reconnaissance has been used to undertake an evaluation of the 'sensitivity' of peat deposits, the likelihood of a peat slide and the consequences of a peat slide. The factors that contribute to these parameters are detailed in Section 4 of this report.

Slope gradients have been derived using a GIS slope angle analysis tool on OS Terrain 5 digital terrain model (DTM) data for the Site.

The peat depths recorded across the Site are presented on Figure A.1 in Appendix A.

2.3.2 Syn-Construction Assessment

Following identification of the baseline conditions of the peat, determined using the qualitative approach described above, an assessment is carried out (where appropriate) using quantitative analysis to determine the impacts of construction activities (syn-construction state). The stability of the peat at the proposed Site may be affected by the following construction activities:

- construction of temporary and permanent tracks (floating and cut/at grade);
- excavation for turbine bases and substation compound;
- construction of crane hardstandings, construction compound and laydown area, concrete batching plant, control building and substation compound;
- temporary storage of peat and soils; and
- excavation of borrow pits.

All these activities may result in increasing the likelihood of peat instability, e.g. by increasing surface loads on peat areas.

2.3.3 Post-Construction Assessments

The medium to long-term impacts of the construction and operation/commissioning of the Proposed Development on peat are likely to comprise the following:

- consolidation caused by settlement of floating tracks (not currently anticipated);
- changes to the surface and sub-surface hydrology.

Design and construction mitigation measures can minimise these impacts in the medium to long-term operation of the Proposed Development, and are discussed in Section 4.8.

3 Desk Study and Site Constraints Review

3.1 Study Area

The area within the Red Line Boundary is approximately 1107ha in area, which includes the Proposed Development area and the Operational Development.

3.2 Topography

Based on a review of available Ordnance Survey maps for the Proposed Development, altitudes vary from approximately 600mAOD in the north, to approximately 400mAOD in the south.

Topographic highs in the Proposed Development include:

- Meall a' Chrathaich (679 mAOD) in the west;
- Carn Tarsuinn (616 mAOD) in the north; and
- Carn Loch a' Bhothain (578 mAOD), in the south west.

Topographic lows include:

- The land adjacent to Loch a' Mheig in the east.

3.3 Land Use

The current land use within the Proposed Development is predominately open moorland. The Operational Development is present adjacent to, and extends onto, the south west of the Proposed Development.

3.4 Aerial Photography Interpretation

A review of the digital aerial photographs was carried out as part of the desk study review. The findings and main observations summarised from the interpretation of the aerial photographs are provided below:-

- Exposed/broken peat is visible in the form of peat hags.
- Dendritic drainage patterns are evident across the Proposed Development, indicating relatively shallow temporary drainage conditions on gently sloping ground. These dendritic drainage patterns feed into tributaries of the Allt Saigh.
- Blocked drainage is visible in the east of the Proposed Development at tributaries of the Allt Chaltuinn, this appears to be natural.
- North east to south west trending linear subsurface features, potentially expressions of the bedrock geology, are present to south west of the Proposed Development.
- A large number of minor and major rock outcrops visible across the Proposed Development.
- There is evidence of active / incipient peat instability across the Proposed Development.

3.4.1 Geomorphology

The geomorphological characteristics of the Proposed Development are typical of upland peat areas in this part of Scotland. The elevated terrain comprises relatively steep hills, numerous outcrops of exposed rock and generally flat areas covered in blanket bog, wet modified bog and wet heath. Exposed rock covers the majority of the landscape, whilst basin peat has developed locally in topographic depressions and flats within the terrain. Large and small ponds of standing water can be found scattered around the relatively flat areas within boggy ground, particularly in the northern area of the Proposed Development. Numerous peat hags are throughout the Proposed Development, generally up to 1m in height.

Geomorphological features that are evident from aerial photographs and site reconnaissance surveys include the following:

- Majority of landscape shows exposed or near surface rock.
- Frequent immature and mature peat hags and hummocks throughout the Site;
- Gully erosion of steepened watercourses;
- Peat pipes (some of which collapsed leaving sunken depressions) in localised areas;
- Dendritic drainage paths are across the Site, indicating relatively shallow temporary drainage conditions on gently sloping ground. These dendritic drainage patterns generally feed into tributaries of the Allt Saigh;
- South west to north east trending linear subsurface feature, potentially an expression of the bedrock geology, present to the south west of the Site, likely to represent a fault line; and
- Numerous watercourses including small streams and lochans.

An interpretation of aerial photography for exposed rock, peat hags and dendritic drainage is shown on Figure A.4 in Appendix A.

3.5 Hydrology and Hydrogeology

3.5.1 Hydrology

The MM desk study identified two surface water catchment areas for the Site using the SEPA RBMP Interactive Map (Ref. [8]):

- Allt Saigh, located along the southern boundary of the Proposed Development, flowing to the east towards Loch Ness;
- Allt Bhlaraidh; and
- River Moriston

There are a number of watercourses within the Site boundary which are small tributaries to the above detailed rivers.

The SEPA Flood Maps Viewer (Ref. [9]) indicates that the Allt Saigh river channel is classified as high river flood potential. The flood maps also indicate that a small number of localised areas on site are at a medium and high risk of flooding from surface water.

For further details please refer to Chapter 9 – Hydrology and Hydrogeology of the EIA.

3.5.2 Hydrogeology

The BGS Onshore GeoIndex Hydrogeology Viewer (Ref. [5]) indicates that the Proposed Development is underlain by rocks of the following aquifer groups:

- Loch Eil Group – recorded as a low productivity aquifer with small amounts of groundwater in near surface weathered zones and secondary fractures.
- Glenfinnian Group – recorded as a low productivity aquifer with small amounts of groundwater in near surface weathered zones and secondary fractures.

According to the BGS Hydrogeology Map of Scotland (Ref. [5]) the lithologies beneath the Proposed Development are described as regions underlain by impermeable rocks, generally without groundwater except at shallow depth.

A review of the SEPA RBMP Interactive Map (Ref. [8]) indicates that the Proposed Development is within a ground 'drinking water protection zone' but is not within a surface 'drinking water protection zone'. The Site is underlain by the Northern Highlands waterbody which is classified as 'good' in terms of groundwater quality.

For further details please refer to Chapter 9 – Hydrology and Hydrogeology of the EIA.

Based on the Site Reconnaissance, peat of varying thickness covers large areas of the Proposed Development. Peat is also known to typically comprise 90% water (Ref. [10]). Groundwater flow within peat is commonly considered as a diffusive process. As a result, peat may store water and release it continuously within a catchment long after periods of rainfall. Notwithstanding these generic conceptions of how groundwater moves within peat, runoffs from peatlands are known to be typically flashy, with short lag times following storm events.

The hydraulic conductivity of peat is highly variable, where hydraulic conductivity is found to typically decrease with increasing degree of peat humification and depth (e.g. decreasing permeability from fibrous to semi-fibrous and amorphous peat). This decrease in hydraulic conductivity can be attributed to decomposition of plant remains within the peat, resulting in a reduction of average pore sizes. Hydraulic conductivity of peat is also known to decrease where the water table falls, resulting in the collapse of large pores within the peat due to the loss of the buoyancy effects of pore water pressure. In contrast, peat pipes present significant focused hydraulic flows within the peat deposits, their collapse resulting in peat hags which themselves can present significant surface flows, particularly following heavy rain and snow melt.

It was noted during the Site Reconnaissance that exposed peat was visible alongside existing access tracks. As noted in Section 4.2.4, this can impact the subsurface hydrology by redefining drainage paths (dewatering the acrotelm leading to desiccation), which could lead to a potential for increased peat instability.

3.6 Superficial Geology

The 1:50,000 BGS Superficial Geology Map (Ref. [11]) indicates that superficial cover is absent across the majority of the Proposed Development, suggesting that bedrock is at or close to the surface. Peat is indicated to be present in a number of localised areas across the Proposed Development, predominantly within topographical depressions or adjacent to waterbodies.

Peat probing across the Site indicates peat depths are typically between 0.5m and 1.0m thick, with the thickest deposits recorded being >2.5m thick. This is detailed further in Section 4.5.

Historical ground investigation records are available for the Operational Development [12], in the west of the Site, however this only partially over laps the western extent of the Proposed Development to the east of the Site. Boreholes along the western extent of the Proposed Development (BHT26, BHT31 and BHT32) recorded the superficial deposits to comprise peat to a depth of between 0.4 to 0.9mbgl, underlain by a thin layer of sand (0.9 to 1.2mbgl) at BHT32 in the south west.

3.7 Solid Geology

The 1:50,000 BGS Bedrock Geology Map from the BGS Onshore GeoIndex Viewer (Ref. [4]) and BSG Solid Geology Map Sheet 73W (Ref. [12]) indicates that the solid geology underlying the Proposed Development comprises Psammite with micaceous layers and calc-silicate pods of the Upper Garry Psammite Formation in the west of the Proposed Development, and interbedded Psammite and Semipelite of the Achnaconeran Striped Formation in the east of the Site. Note that the Upper Gary Formation has been renamed to the Tarvie Psammite Formation on the more recent GeoIndex Viewer.

On the western boundary, proposed turbine location T02 is underlain by semipelite with relic kyanite porphyroplasts of the Tarvie Psammite Formation, which were originally sedimentary rocks formed in shallow seas and later altered by low-grade metamorphism

A small number of localised and minor unnamed igneous intrusions are recorded across the Proposed Development, recorded to be comprise Amphibolite and Hornblende Schist of Pre Cambrian age.

During the site reconnaissance, outcrops were visible across the majority of the Proposed Development.

Historical ground investigation records are available for the Operational Development [12], in the west of the Site, however this only partially over laps the western extent of the Proposed Development to the east of the Site. Boreholes along the western extent of the Proposed Development (BHT26, BHT31 and BHT32) recorded the solid geology to comprise Psammite to a depth of between 0.5 to 7.2mbgl.

3.8 Structural Geology

A number of faults are inferred across the western half of the Proposed Development, as shown on the BGS GeoIndex viewer [4] , generally trending north east to south west. The axial plane of a major synform is indicated to underly turbine location T02 in the west of the Proposed Development.

An axial plane trace of antiform and an axial plane trace of a synform are indicated to the west the Proposed Development, located generally parallel, and trending north to south.

4 Peat Stability Risk Assessment

It is considered important that the presence of significant peat deposits (greater than 1.0m thickness), as well as any active, incipient or relict peat instability is determined prior to construction, such that the ‘baseline’ peat conditions for the Site can be established; following which, any implications for proposed construction methodologies can be incorporated into the design and construction process. It is intended that the information provided in this report be used by the Contractor to assess the risk of future peat slides (if any) and will be developed further to assist with construction management for the proposed development.

The qualitative assessment applies to the baseline peat stability conditions at the Site as determined for each peat probe location undertaken by Mott MacDonald within the Site boundary.

Assessments for the change to the peat stability baseline condition due to the effects caused by the construction of the wind farm are provided in the syn-construction and post-construction sections for each area.

Within Sections 4.6 and 4.7, the risk is described for baseline, syn-construction and post construction conditions. Syn-construction conditions describe specific construction elements, with associated changes in overall risk rating due to these construction activities. Post-construction conditions describe anticipated changes to the peat condition within specific areas depending on what has been constructed.

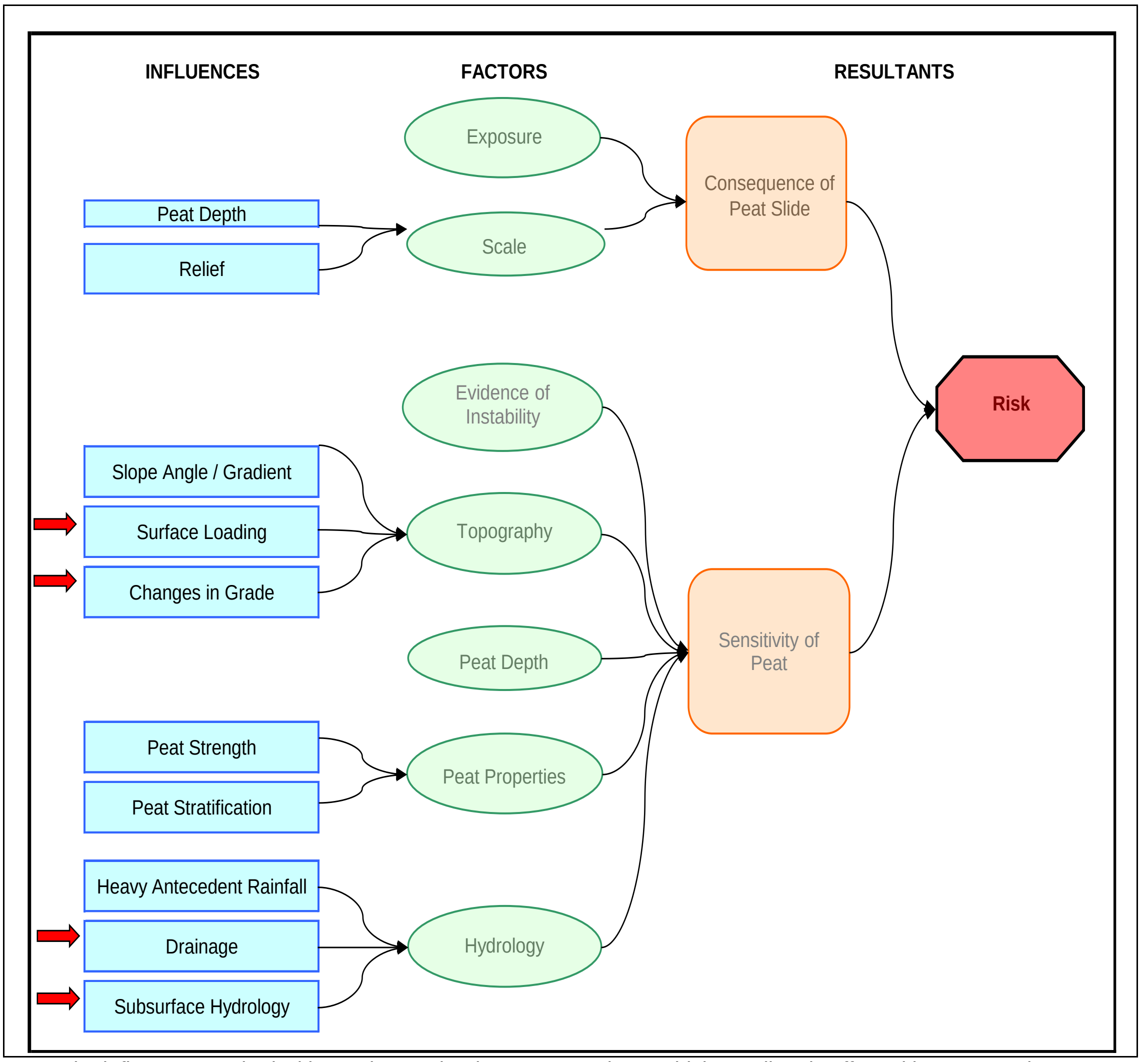
4.1 Qualitative Risk Assessment (Q_LRA)

In this report, the risk of ‘peat instability’ is deemed to include bog flows, bog bursts and translational slides (see Section 4.2.3), and hence peat slides. The risk of peat instability is therefore a function of the sensitivity to a peat failure occurring and the consequence(s) of the failure.

It is widely accepted that the main contributing factors and influences governing peat instability are peat depth, slope angle and subsurface hydrological conditions. However, several other factors and influences are involved in determining potential stability, or otherwise, of peat deposits. These are outlined in Figure 4.1, which is a non-exhaustive list of the commonly perceived causes and mechanisms that have been noted as significant in incidents of peat instability and how they relate to risk identification (see Refs. [10], [13], [14], [15], [16], [17], [18] and [19]). Nonetheless, it should also be noted that “… *although peat slides occur due to the stability threshold being exceeded, the factors responsible for creating instability, where and when they did, are difficult to establish with certainty* …” (Ref. [16].)

The qualitative methodology used to determine the baseline conditions is based on a scoring system, where factors and influences are multiplied together to produce Risk Rating Scores, and corresponding Qualitative Relative Risk values (which range from Very Low to Very High). The weighting for the parameters used in this qualitative assessment are derived with reference to literature (Section 4.5) and engineering judgement.

Figure 4.1: Qualitative Risk Assessment Process



Note: The influences marked with a red arrow in Figure 4.1 are those which are directly affected by construction activities on site. Section 4.2 discusses these factors and their influence on peat stability.

The numerical value used for each peat stability factor/parameter in the Q_LRA represents the probability that each factor will detrimentally influence peat stability. The relationship between the influencing parameter value and probability is shown in the example in Table 4.1.

Table 4.1: Example of Peat Instability Influencing Factor and Probability of Detrimentally Affecting the Overall Risk Score

Peat Depth Description	Parameter Value	Description	Probability (P Value)
No peat evident	0	Negligible	<10
Thin (0.1 – 0.5 m)	0.5	Unlikely	10–25%
Medium Thin	1	Probable	25–50%
Medium Thick	1.5	Likely	50–75%
Thick (> 2.0 m)	2	Very Likely	>75%

The probability (P-value) represents the probability that a particular parameter value will affect the risk score. For parameter conditions that have an overriding influence on risk, e.g. potential impact on nearby dwellings, a value of greater than two will be allocated to reflect their significance.

The rationale for the numerical values used in the qualitative assessment is described in detail in Section 4.2 and Section 4.3.

4.2 Q_LRA Factors Affecting Instability

This section of the report presents the influences and factors that can affect the occurrence of peat instability within the proposed wind farm, with a brief explanation of the Q_LRA scoring system.

4.2.1 Evidence of Instability

Peat instability can be grouped into one of three categories, as follows:

- active peat instability is identified as that which has recently occurred, or is presently occurring (i.e. a recent failure);
- incipient peat instability is identified by such factors as tension cracks and evidence of creep, indicating that progressive failure is occurring, which may lead to instantaneous peat failure with time;
- relict peat instability is defined as the remains of past failures being recognised in landforms, indicating that conditions were once such that failure of the material occurred, and as such could occur again.

Evidence of previous or recent peat instability may provide an indication that a particular area may be prone to further instability.

Table 4.2 shows the relationship between the Q_LRA numerical value assigned to the factor 'Signs of Instability' and increasing probability that this factor will affect the overall peat stability Risk Rating score.

Table 4.2: Signs of Instability QRA Parameter Value and Probability of Detrimentally Affecting the Overall Risk Score

Evidence of Active, Incipient or Relict Instability Description	Factor Value	Description	Probability (P Value)
No evidence of instability	1	Unlikely	10–50%
Surface erosion and creep	2	Likely	50–75%
Localised evidence of instability	3	Very Likely	75–95%
Extensive evidence of instability	5	Almost Certain	>95%

4.2.2 Topography

4.2.2.1 Slope Angle/Gradient

Whilst peat is known to have failed on relatively gentle slope angles, areas of level soil materials are considered to have a reduced likelihood of failure, since there is no gravitational driver to facilitate instability. As such, areas of flat peat deposits are not considered to be as susceptible to failure. The 'Slope Angle/Gradient' parameter has a value between 0.05 and 2.0, from flat terrain to terrain sloping greater than 15° respectively. Increasing values of this parameter relate to more onerous conditions and increasing probability that slope angles will have significant influence on peat stability and the overall relative Risk Rating score.

Table 4.3 shows the relationship between the 'Slope Angle/Gradient' numerical values (used in the Q_LRA) and the probability of slope angle influencing the overall peat stability Risk Rating score.

Table 4.3: Slope Angle QRA Parameter Value and Probability of Detrimentally Affecting the Overall Risk Score

Slope Angle Description	Parameter Value	Description	Probability (P Value)
Flat/plateau	0.05	Negligible	<1%
Low slope angle, < 3º	0.2	Very Unlikely	<10%
Gentle slope angle, 3 – 6º	0.5	Unlikely	10–25%
Moderate slope angle, 6 – 10º	1	Probable	25–50%
Moderate slope angle, 10 – 15º	1.5	Likely	50–75%
Steep slope angle, > 15º	2	Very Likely	>75%

The allocation of slope angle within the assessment has been categorised with reference to the predominant slope angle at each probe location. However, there may be very localised areas of steeper or shallower slope which are considered not to represent a significant influence.

4.2.2.2 Surface Loading

Analysis of the failure at Derrybrien Wind Farm (Ref. [1]) reported that one of the principal factors influencing the likelihood of failure was "the thickness of the extra material placed on the slope". This refers to the placement of excavated spoil from construction of turbine bases and access tracks being placed on the crest of the hill slope which then led to failure in the peat mass. Therefore, increased surface loading on peat deposits can lower the factor of safety leading to previously stable conditions becoming unstable.

In this report, the relative risk scoring for 'Surface Loading' assumes no significant loading, therefore, a constant numerical value of 1 (multiplier) has been used in the Q_LRA to represent baseline conditions with regards to peat stability. It should be noted that loading of peat by excess spoil during excavations should be avoided as a matter of good construction practice. Where there is the potential or requirement for significant loading (i.e. stockpiling peat) it will be recommended that a quantitative slope stability analysis is undertaken, with sensitivity analyses of potential variations in peat strength. Surface loading is addressed by quantitative analysis undertaken as part of the risk assessment of the syn-construction ground conditions. In this case, a quantitative analysis has not been undertaken as part of the risk assessment.

4.2.2.3 Changes in Grade

It has been observed that marked 'Changes in Grade' can be considered a causative factor in peat mass movement, with historical peat slides having been reported at sites with concave breaks of slope, convex breaks of slope and on convex-concave slopes (Ref. [16]). The impact of 'Changes in Grade' on drainage and stress development within the peat mass is deemed to influence peat sliding.

In the case of a convex change in grade, frontal and lateral resistance is lowered which could facilitate translational failure. For example, excavation of turbine bases and cuttings for access tracks could instigate instability, especially through deeper peat where frontal support to a peat mass is removed. As well as reduction in confinement, a track cutting on sidelong ground may temporarily result in a stable batter due to the favourable downslope conditions allowing drainage of the peat mass and reducing pore pressures. However, in certain circumstances, this frontal mound of peat can subsequently fail due to loss of constraint and/or due to the development of excessive pore water pressure in the peat mass upslope (c.f. Ref. [16]; discussed further in Section 4.2.4).

The term 'cutting' in this report means both peat cuttings (found in some areas of Scotland) and cuttings into the peat caused by construction activities such as track construction and excavation for turbine bases.

The 'Changes in Grade' parameter in the Q_LRA has a value between 1.0 and 2.0, from no change to cutting respectively. However, for the purposes of the Q_LRA for the peat stability baseline conditions, cuttings (in peat during construction) have been omitted. These are assessed separately. Increasing values for concave to convex changes in grade (1.4 and 1.7 respectively) reflect increasingly onerous conditions, as a consequence of both changes in sub-surface hydrology and changes in ground stresses. These are represented in Table 4.4 below.

Table 4.4: Changes in Grade QRA Parameter Value and Probability of Detrimentally Affecting the Overall Risk Score

Changes in Grade Description	Parameter Value	Description	Probability (P Value)
Negligible change	1.0	Negligible	<1%
Concave change in slope	1.4	Unlikely to probable	1–40%
Convex change in slope	1.7	Probably to Very Likely	>40–75%
Cutting (or sharp break in slope)	2.0	Very Likely	>75%

4.2.2.4 Relief

The 'Relief' parameter is used to describe and score the type of terrain in determining the potential scale of a peat slide. A description of the terms used in Figure 4.2 is as follows:

Figure 4.2: 'Relief' Parameters

Numerous mounds and depressions (Score 1.0)

Terrain that is predominantly undulating and topographically confined, limiting the scale of peat slide and debris run-out distances. Typically occurs on very broad upland ridges and peaks and on glaciofluvial terrain with broad valley floors.

Rolling terrain (Score 1.5)

Terrain that has a general slope direction and comprises both sloping sections and relatively flat stretches. Defined separately due to the flat areas where peat slides may lose energy and deposition is likely to occur.

Long straight uninterrupted slopes (Score 2.0)

Terrain that is sloping in one direction with little to no change in gradient. Peat slides are likely to remain erosional along the whole slope until reaching the toe of the hill.

The relationship between the 'Relief' parameter value and increasing probability that relief will influence the scale of a potential peat slide is shown in Table 4.5.

Table 4.5: Relief QRA Parameter Value and Probability of Detrimentally Affecting the Overall Risk Score

Relief Description	Parameter Value	Description	Probability (P Value)
Numerous mounds and depressions	1.0	Unlikely	<40%
Rolling terrain	1.5	Likely	40–75%
Long, straight uninterrupted slopes	2.0	Very Likely	>75%

4.2.3 Peat Properties

4.2.3.1 Peat Depth

Failures in peat masses have been reported to occur in deposits that are less than 1.0 m in thickness (Ref. [14]). Therefore, on these grounds alone, peat instability should be considered possible at the Site. The depth of peat present affects the potential scale of a peat slide, but is also a major factor in the potential for failure. This is due, to some extent, to the relationships between the thickness, stratification, strength, and hydrology of peat masses, as discussed below.

It has been reported that peat slides occur most frequently in peat masses ranging between 0.5 and 1.5 m in thickness (Ref. [15]), while bog bursts commonly occur in peat ranging between 1.0 and 5.0 m deep. Peat slides are defined as "*slab-like, shallow translational failures with a shear failure mechanism operating at, or just below, the peat and underlying substrate interface*" (Ref. [17]), whilst bog bursts "*involve large quantities of water and peat debris that flows downslope*…" (Ref. [18]) following 'eruption' of liquefied basal peat through tears in the surface layers as a result of subsurface creep or swelling (Ref. [17]).

4.2.3.2 Peat Stratification

Peat failure may be facilitated through the development of weak layers within the peat mass which may either form naturally or be created by 'hydrological factors'. Peat has a natural anisotropic strength due to the process by which it is formed. In particular, the nature of the interface between the distinct layers within a peat mass is defined by hydrology. These distinct layers are:

- top mat, consisting of the living vegetation of herbaceous plants, grasses and mosses;
- acrotelm, which comprises decomposing peat (organic matter), which is periodically saturated (i.e. lies above the average water table, creating aerobic conditions), and is of relatively high permeability. It is typical of 'fibrous' peat (Ref. [6]) and generally ranges between 0.2m and 1.0m in thickness; although this varies with saturation depth (i.e. is thicker when drier);
- catotelm, which consists of dense peat that is permanently saturated (i.e. lies below the water table, in anaerobic conditions), and is of relatively low permeability. It is typically 1.0m to 2.0m deep, with its base defining the bottom of the peat mass. In terms of identification and description (Ref. [6]), this layer corresponds with the 'semi-fibrous' through to 'pseudo-amorphous' and 'amorphous' descriptors.

In broad terms, plant remains are recognisable in fibrous peat (which allows it to retain some strength), however are unrecognisable in amorphous. It is considered that the nature of the interfaces between the acrotelm and catotelm (whether a sharp or a diffuse boundary), and between the catotelm and the underlying deposits (e.g. mineral soil, weathered rock) influence the strength of the peat mass (Ref. [17]).

Peat stratification and peat depth are intrinsically linked. This is due to the fact that thin deposits of peat are unlikely to have a catotelm and may mainly be composed of a top mat and immature acrotelm. As such, with inherent strength as a consequence of fibres, peat thicknesses of less than 0.5m are not reported to fail catastrophically.

Of the 2909 peat probes undertaken at the Site, 40% of peat deposits on site were recorded as fibrous, 59% as semi-fibrous and only 1% as amorphous material.

4.2.3.3 Peat Strength

It has been recognised that an appreciation of the shear strength of peat is essential to assess the stability of peat masses. However, it is difficult to apply traditional soil mechanics methods due to the presence and inherent variability in the fabric and stratification of peat deposits (Refs. [18] and [19]). Given the variable nature of the peat at the Site, the influence of shear strength has not been included within the weighting parameter of 'Peat Thickness' within the qualitative risk assessment. It has, however, been taken into account during the further quantitative analysis (Q_NRA).

4.2.3.4 Rationale for Numerical Value of Peat Depth

For the purposes of qualitative risk assessment, this parameter has a value between 0.0 and 2.0, and its weighting includes peat stratification, where increasing values relate to more onerous conditions, reflecting the tendency for 'weaker' peat to be present as thickness increases in addition to the presence of a greater disturbing force as a consequence of the increasing thickness. The values relate to increasing probability that the 'Peat Depth' parameter may influence the Risk Rating Score and this is shown in Table 4.1 in Section 4.1.

4.2.4 Hydrology

4.2.4.1 Heavy Antecedent Rainfall

An increase in pore water pressures generated by intense rainfall is a significant 'trigger mechanism' for many peat slides. However, prolonged periods of heavy rainfall are not necessarily related to instability. Both the distribution and intensity of precipitation have a complex influence on the mass movement of peat (Ref. [15]).

In many cases of peat failures, a relatively dry period has been followed by intense rainfall. Hence, it appears it is how, and where, the water resulting from heavy rainfall events is distributed within the peat that is significant. Although intense rainfall appears to be an important factor, it is fundamental to recognise that the occurrence of an extreme event does not necessarily directly result in peat instability; this being a function of many factors and a combination of climatic preparatory events. For the purpose of the Q_LRA, 'Rainfall' has been considered to be a constant for the entire Site.

4.2.5 Surface Hydrology

It has been noted that peat slides have been initiated along natural drainage lines or in association with artificial drainage (Ref. [15]). Blocking of pre-existing drainage during construction could reduce the natural strength of a peat mass and create a buoyancy effect or cause liquefaction due to raised pore water pressures at the base of the peat.

Areas of limited drainage (either natural or man-made), i.e. blanket bog, are considered to be more susceptible to significant instability due to higher groundwater tables than adjacent better-drained zones, i.e. hagged formations. It is anticipated that ditches and cuttings will be created as part of the works. Longitudinal and transverse ditches (or cuttings) can cause water to build up in particular areas of a peat mass leading to increased potential instability. Should these ditches be partly infilled and vegetated, they may act as a store of water from upslope areas rather than facilitating the rapid removal of it. When initially created, these ditches or cuttings may result in more stable slopes by facilitating removal of excess water during periods of heavy rain, and hence lowering pore water pressures. However, with degradation over time, their ability to achieve this may decline, allowing pore water pressures in the upslope peat mass to exceed critical levels during intense rainfall (Ref. [16]).

In the Q_LRA, the relative risk scoring for 'Surface Hydrology' is based on visual observations carried out during the Site Reconnaissance survey. The parameter 'Surface Hydrology' has been given a value between 0.5 and 3.0. Increasing values relate to relatively poorer ground conditions that will directly increase the probability of instability occurring. For example, peat slides are less likely to occur on well drained terrain (typically not forming thick accumulations), while thick peat tends to accumulate in areas of poorly drained ground on sloping terrain resulting in increased risk of peat instability.

The relationship between the Q_LRA numerical value and increasing probability of this parameter influencing the overall peat stability Risk Rating score is shown in Table 4.6.

Table 4.6: Surface Hydrology QRA Parameter Value and Probability of Detrimentally Affecting the Overall Risk

Surface Hydrology Description	Parameter Value	Description	Probability (P Value)
Well drained, good network of drainage paths and streams	0.5	Unlikely	10–25%

Surface Hydrology Description	Parameter Value	Description	Probability (P Value)
Boggy, stream heads, diffused drainage	1.0	Probable	25–50%
Saturated with standing water	1.5	Likely	50–85%
Blocked drainage paths	3.0	Very Likely	>85%

4.2.5.1 Subsurface Hydrology

In peat masses, groundwater is considered to actively flow through the high permeability acrotelm, and to be more static within the lower permeability catotelm, although the presence of peat pipes within either horizon could greatly increase the potential for localised water transfer. Peat pipes present significant focused hydraulic flows within the peat deposits, their collapse resulting in peat hags which themselves can present significant surface flows, particularly following heavy rain and snow melt.

Any construction on peat (e.g. floating tracks), or excavations through peat, will influence the existing hydrology by altering permeability and/or redefining drainage paths. Consequently, new areas of hydrological sensitivity will run parallel to access tracks, and be concentrated around turbine bases and crane hardstandings. During construction, consideration should be given to how drainage paths may be affected, as this could potentially lead to significant changes in groundwater levels, either through drainage (e.g. dewatering) or saturation (e.g. pooling/damming). Of specific concern, in general, is the possibility of dewatering the acrotelm leading to desiccation, or pooling / damming leading to increased pore water pressures in the catotelm.

In the medium-term (possibly two to five years post-construction), a new hydrological regime will become established in the peat in response to the permanent construction elements of the Site. Were significant changes to take place between the pre- and post- construction hydrological regimes (e.g. desiccation, or increased pore water pressures), at locations where substantial peat deposits are present across the proposed wind farm, then the potential for increased peat instability exists. Application of appropriate construction methodologies and mitigation measures, as outlined in Section 4.8 of this report, should ensure that the differences between the pre- and post-construction hydrological regimes within the peat are minimised.

The potential for the rapid transfer of surface waters to a failure zone within the peat mass (e.g. the interface between the acrotelm and catotelm, or the interface between the catotelm and mineral soil) by peat pipes, or by prior cracking of the peat due to desiccation or slow mass movement has been considered significant in previous published peat studies (Ref. [20]).

In terms of the Q_LRA, ‘Subsurface Hydrology’ is considered to be constant for the entire Site due to practical limitations in determining this parameter. Although there has been no clear evidence on the relationship of sub-surface hydrology and changes in slope, it is thought that convex or concave changes in slope may focus groundwater flows, increasing the probability of peat sliding (Ref. [16]).

4.3 Factors Controlling Consequence of Peat Stability

During the Q_LRA, factors that control the consequences of peat instability are considered to include the Scale of the peat failure (i.e. the volume of peat mass translating), and the Exposure of sensitive receptors to the risk. These factors are discussed below.

4.3.1 Scale

Failures of peat masses can be divided into two distinct forms – peat slides and bog bursts, as defined in Section 4.2.3. Peat slides are typically localised and limited in volume, usually moving over a relatively short distance with the peat mass generally remaining intact, whilst bog bursts are larger and more catastrophic in nature as they usually occur in deeper peats and therefore redistribute a higher volume of peat mass. However, peat slides could affect adjacent or downslope peat deposits sensitive to disturbance resulting in the instigation of larger volume debris type flows of material. Bog bursts usually occur where there are raised bogs within the terrain; these conditions are not present within the Site.

As well as the failure mechanism, the 'Scale' of peat instability is also linked to the volume of peat with the potential for failure, and the relief of the Site. For example, at Derrybrien (Ref. [1]), the downward movement of one of the peat slide failures was halted by a slight topographic rise that occurred perpendicular to the toe of the slide. In addition to confining peat masses, irregular ground is less likely to generate large volumes of peat flow as the size of the peat mass with the potential for movement is restricted by topography.

4.3.2 Exposure

There are a number of elements potentially exposed to the risk of peat instability including:

- construction works, including temporary and permanent access tracks, crane hardstandings, control building and substation compound, and construction compound;
- environmentally sensitive areas, i.e. watercourses;

The consequences of these elements being exposed to the risk include, but are not limited to, the following:

- contamination of watercourses or private water supplies;
- injury to or death of construction personnel or remote persons;
- disruption to the construction process;
- damage to construction works or plant
- damage to remote infrastructure/habitation etc.;
- blockage of temporary drainage;
- injury or death of wildlife;
- degradation and erosion of peat habitats;
- damage to cultural heritage assets;
- visual landscape changes.

Furthermore, the determination of 'Exposure' needs to take account of 'Scale', i.e. where a large volume of peat initiated into movement has the potential to affect a larger area, and therefore affect more receptors, than a smaller mass of peat.

The relationship between the numerical value for the 'Exposure' factor and the increasing probability of this factor affecting the overall Q_LRA Risk Rating score is shown in the Table 4.7.

Table 4.7: Exposure QRA Factor Value and Probability of Detrimentally Affecting the Overall Risk Score

Exposure Description	Factor Value	Description	Probability (P Value)
Potential to disrupt construction	0.2	Unlikely	10–25%
Potential to impact on minor watercourses	1.0	Probable	25–50%

Exposure Description	Factor Value	Description	Probability (P Value)
Potential to interfere with environmentally sensitive areas	2.0	Likely	50–85%
Potential to interfere with dwellings	3.0	Very Likely	>85%

4.4 Approach to Peat Stability Rating

A Qualitative Risk Assessment (Q_LRA) was used in this report to assign Relative Risk Rating Scores to peat deposits which have the potential to be susceptible to peat sliding based on factors and influences, as shown in the worked example on Figure 4.3 in Section 4.5. The Relative Risk Rating Scores are assigned Risk Rating Values (ranging from Negligible to Very High) as shown on Figure 4.3 and Table 4.8, and plotted on Figure A.2 in Appendix A, which allows, for example, reconfiguration of the layout of wind farm infrastructure to avoid potential areas of higher risk of peat slides (i.e. particularly those deemed to be Medium, High or Very High), or the understanding that particular care is required in certain areas.

Table 4.8: Baseline Risk Rating Values

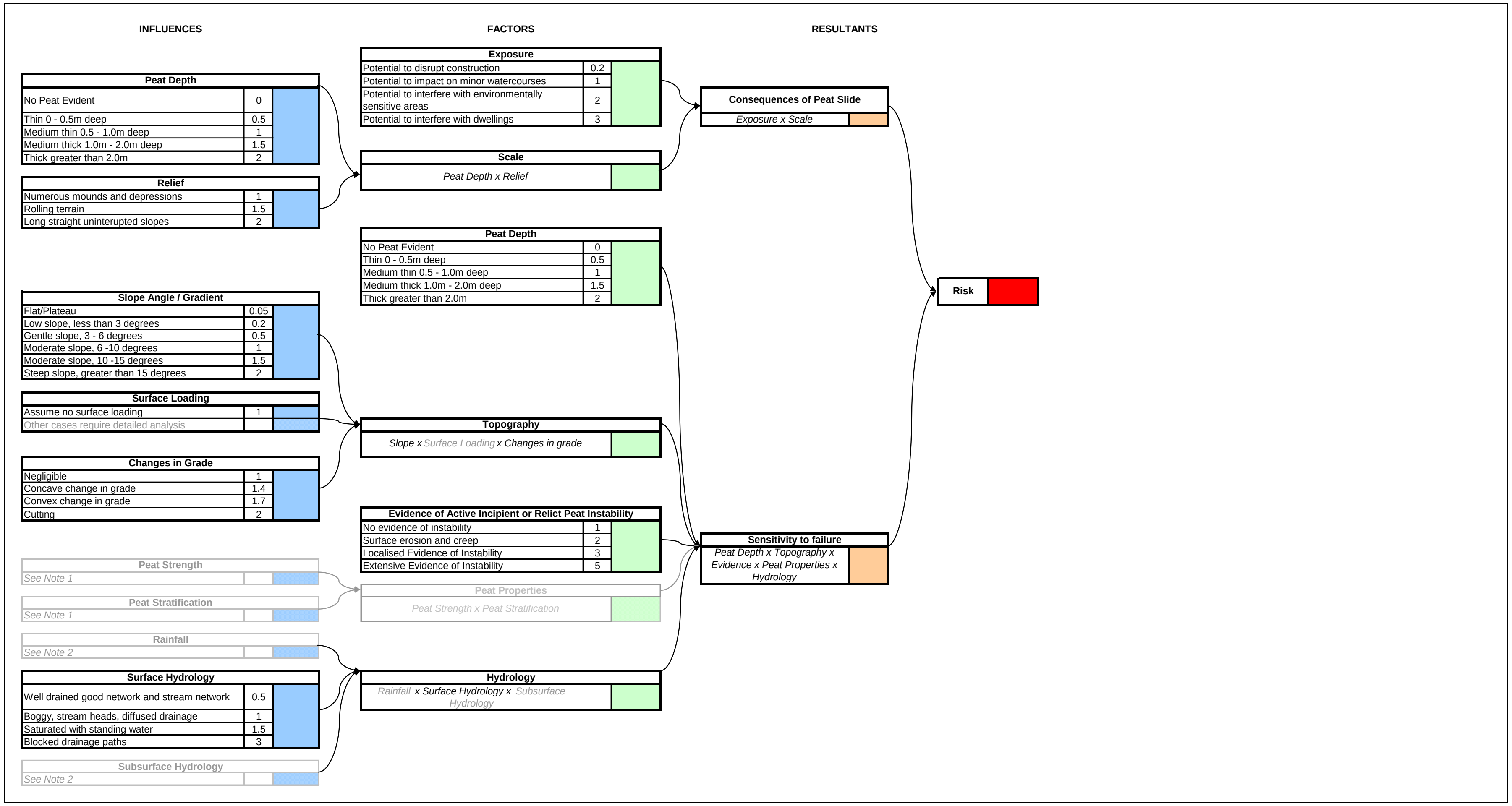
Risk Scoring	Risk Category	Equivalent Hazard Ranking
>90	Very High	Serious
40–90	High	Substantial
8–40	Medium	Significant
0.6–8	Low	Insignificant
0–0.6	Very Low	
0	Negligible (i.e. no significant depths of peat present)	Negligible

Source: Scottish Executive Best Practice Guide for Proposed Electricity Generation Developments, Ref. [2]

As discussed in Sections 4.2.3 and 4.2.4, four factors – ‘Peat Strength’, ‘Peat Stratification, ‘Rainfall’ and ‘Subsurface Hydrology’ – have not been scored in the Q_LRA.

It should be noted that the Surface Loading factor is considered to be constant across the Site. No significant surface loading anticipated as it is recommended that appropriate construction methodologies be employed, and as such, excavated spoil from such activities shall not be placed on peat areas without first undertaking a stability risk assessment.

Figure 4.3: Relative Risk Rating Scoring



Source: 1. The influence of ‘Peat Strength’ and ‘Peat Stratification’ are included in the parameter ‘Peat Depth’.

2. For the purpose of the Q_LRA, ‘Rainfall’ and ‘Subsurface Hydrology’ are considered to be a constant for the entire site

4.5 Scoring the Qualitative Risk Assessment Area and Peat Conditions

This section of the report describes the results of the Qualitative Risk Assessment, using the peat probe measurements for within the Site boundary. Slope gradients have been derived from the OS Terrain 5 DTM elevation data for the Site and were verified using a compass clinometer during the Site Reconnaissance.

A worked example showing how the scores are calculated is shown in Figure 4.4. The peat probes are represented in terms of their Baseline conditions, as follows:

- Baseline: The baseline condition for each peat probe describes the pre-construction factors and influences that are used for the preliminary assessment of peat stability. These are primarily slope gradient, slope morphology, peat depth, and hydrological conditions, described in the Q_LRA in Section 4.1. The results of the Baseline assessment for all probes, including all factors used, are included in Figure A.1 in Appendix A.

Recommended mitigation measures have been provided for the syn-construction and post-construction phases of the proposed wind farm and can be referenced to the pre-construction geotechnical risk register for peat stability in Appendix B.

Figure 4.4: Worked Example of Qualitative Risk Assessment

Peat Depth, *Evidence of Instability*, *Surface Hydrology (Drainage)* and *Exposure* are scored as a result of observations made on-site.

The *Topography* score is worked out as follows:

Topography **= Slope Angle** x **Surface Loading** x **Changes in Grade**

= (Gentle slope angles (3to 6°)) x **(no surface loading)**

x **(negligible changes in grade)**

= (0.5) x **(1.0)** x **(1.0)**

= 0.5

Scale is calculated by multiplying *Peat Depth* by *Relief*:

Scale **= Peat Depth** x **Relief**

= (Peat 0.5-1.0m deep) x **(numerous mounds and depressions)**

= 1.0 x **1.0**

= 1.0

Consequence is worked out by multiplying *Scale* by *Exposure*:

Consequence **= Scale x Exposure**

= 1.0 x **(Potential to impact on minor watercourses)**

= 1.0 x **1.0**

= 1.0

Sensitivity is calculated as follows:

Sensitivity **= Peat Depth** x **Topography** x **Evidence** x **Hydrology**

= (Peat between 0.5 and 1.0 deep) x (0.5) x (evidence of surface erosion and creep observed) x (slightly boggy)

= (1.0) x (0.5) x (2.0) x (1.0)

= 1.0

Therefore, ***Risk Score*** is *Sensitivity* multiplied by *Consequence*:

Risk Score **= Sensitivity** x **Consequence**

= 1.0 x 1.0

= 1.0 (Low)

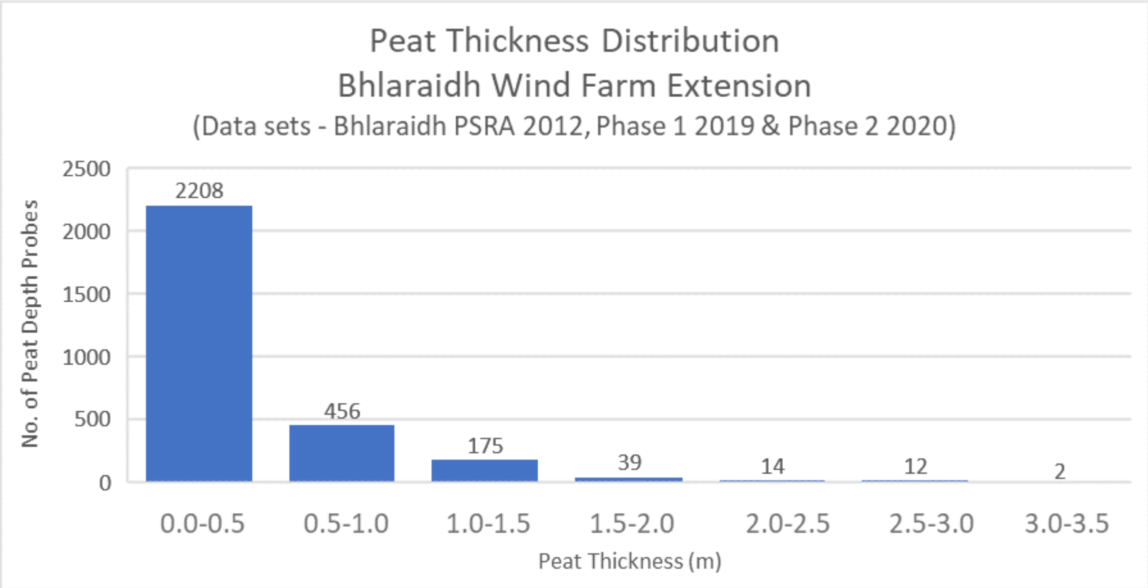
All 2909 peat depth probes undertaken by Mott MacDonald were within the Site boundary and have therefore been assessed. A histogram showing the distribution of peat thicknesses encountered is presented in Figure 4.5.

The peat probe survey of the Q_LRA assessment area recorded peat depths >3.0m in 2 peat depth probes (>0.1% of the 2909 total peat depth probes). However, the majority of probes ,2208 (76%) recorded peat up to 0.5m thick, and 456 probes (15%) recorded peat depths between 0.5 to 1.0m thickness.

Thicker peat (>2.0 m) was not recorded within 15m of the centre of proposed turbines locations. Thick peat was recorded at localised areas near the access tracks, near proposed turbine locations T04, T05, T06, T10, T15 and T18, and near the proposed substation in the centre of the Proposed Development.

Peat depth across the Site is variable, and is primarily driven by local topography, with pockets of deeper peat found on the relatively flat ground between hills.

Figure 4.5: Peat Thickness Distribution within Q_LRA Assessment Area



4.6 Baseline Risk Assessment Results

The baseline qualitative assessment has been undertaken for all peat depth probes. The results, as shown on Figure A.2 in Appendix A, categorise the risk of peat instability across the majority of the turbine development area to be Very Low to Low. This is due in part to the thickest peat deposits being generally encountered in topographic lows or on slopes of angles generally 0–3°.

The baseline qualitative assessment uses values for each factor at each peat probe location as discussed in Section 4.3, rather than adopting a conservative 'worst case' blanket approach for a whole area, and is believed to be more representative.

A total of 12. No. localised Medium risk probe locations were identified, with none identified in the vicinity (within 25m) of proposed turbine locations, and two identified within the vicinity (within 25m) of proposed site infrastructure as follows:

- Access track between turbine location T18 and T13 (Phase 1 probe ID P1-140);
- Main access track to the east of the proposed substation compound, after the junction to proposed turbine T10 (Phase 2 probe ID P2-843).

4.7 Quantitative Risk Assessment (Q_NRA) Results

A total of 12 No. probe locations were identified as Medium risk in the qualitative risk assessment outlining the baseline conditions; with two locations within 25m of proposed infrastructure. Therefore, it was considered necessary to carry out a Q_NRA on those Medium risk probe locations in order to assess the effects of construction activities on each of those locations. A slope stability analysis has been carried out using the infinite slope stability model.

The analysis assumed total stress (undrained) analysis with no surface loading (section of cut track/upgrade to existing track). It is understood that all tracks will be cut, with no floating roads to be constructed as part of the Proposed Development.

A conservative undrained shear strength value of 10kN/m^2 was assumed for the peat, based on the lowest average results of shear vane tests undertaken across the Site.

A full description of the methodology of the analysis and the results is included in Appendix C, and the results of the assessment are discussed in the following section.

4.8 Construction Impacts

Syn-construction

It is proposed to construct 18 No. wind turbine generators with associated hardstands/crane pads, cabling routes, a temporary construction compound and laydown area, a control building and substation compound, borrow pits and a concrete batching plant, and approximately 10.2km of new access tracks, anticipated to be 'cut'.

For the use of FoS for peat slopes a factor of 1.3 is considered appropriate when adopting conservative parameters. The results of the Q_NRA for the 2 No. Medium risk areas identified within 25m of infrastructure indicate the following:

- Both locations returned resultant FoS values above 1.3 for unloaded 'cut track' conditions

The results show that each Medium Risk location maintains a satisfactory FoS in the unloaded case ('cut track' conditions), provided the peat is not loaded in these areas. Therefore, following the Q_NRA, the overall risk of a peat slide is considered to be Very Low to Low for the Site. It is considered that this is due to the thickest peat deposits being encountered in topographic lows or on slopes of angles less than 6º. Locations where the slope angle is greater than 6º generally encounter thinner peat deposits.

Figure A.4 in Appendix A shows the Overall Peat Slide Risk Rating based on the above.

As part of the Proposed Development, it is also proposed to excavate up to 8 No. borrow pits at the Site. The formation of a borrow pit at the Site can have the following impacts:

- It can reduce peat stability due to temporary stock piling of excavated materials (including peat) on the downslope side of the excavations;
- It can potentially affect the groundwater and hydrology conditions of the peat in the immediate vicinity of the extraction area, resulting in either an increase or decrease in peat stability.

The design of the borrow pit and methods of extraction will be determined after further intrusive ground investigation and blasting assessment trials, carried out by specialist contractors. This report will be made available to the contractors to assess the likely impacts of their activities on the overall peat stability.

Post-construction

The presence of turbine bases, compounds, crane hardstandings, cabling routes, access tracks, compound and laydown areas, and restored borrow pits at the Site are likely to affect drainage conditions. Preferential drainage of surface run off may occur along the tracks affecting the subsurface hydrological regime, creating increased surface erosion which will lead to the risk of instability. However, if suitable drainage measures are constructed and maintained then the general risk of ground instability will remain Very Low to Low.

5 Construction Methodologies and Control Measures

It is understood that access tracks will be 'cut' due to the shallow peat depths anticipated. Track design will require further consideration during the pre-construction/detailed design and construction phase, particularly during the excavation and temporary storage of excavated materials for reuse. However, based on the information presented in this report, the peat depths encountered are not considered to present any significant risk of instability during construction.

Considerations for construction methodologies and mitigation measures are presented in this section of the report.

5.1 Construction Methodologies

The following is a list of controls that should be considered for incorporation into the development of construction methodologies for the works in all areas of peat during detailed design stage:

- A robust design of drainage systems and associated measures (i.e. silt traps, etc.) to minimise sedimentation into natural watercourses. Method statements should be prepared in advance to mitigate against a slide occurring and should include, but not be limited to, the use of check dams and erosion protection to limit flows and prevent contamination of watercourses;
- Measures shall be put in place to ensure drainage systems are well maintained, to include the identification and demarcation of zones of sensitive drainage or hydrology in areas of construction, e.g. inclusion of maintenance regimes for drainage systems into a construction management plan or similar;
- A minimisation of 'undercutting' of peat slopes, but where this cannot be avoided, a more detailed assessment of the area of concern by a geotechnical engineer would be required;
- Careful micro-siting of turbine bases, crane hardstandings and access track alignments to minimise impacts on the prevailing hydrology;
- Although the overall risk of a peat slide is considered to be Very Low to Low for the Site (after quantitative analysis), it is recommended that methodologies should be developed as a contingency to minimise the impacts to watercourses in the unlikely event of peat instability;
- The use of floating track or in areas of deeper peat, i.e. >1.0m. However, floating tracks should not be constructed on slopes greater than 10º (floating road are not anticipated as part of the Proposed Development);
- The stripping of superficial deposits (peat, topsoil and subsoil) to expose a suitable formation level such as glacial till or rock, where necessary. The storage of material stripped or removed for future reinstatement.

Notwithstanding any of the above comments, detailed design and construction practices will need to take into account the particular ground conditions and the specific works at each location throughout the construction period. It is recommended that an appropriately experienced and qualified engineering geologist/geotechnical engineer is appointed during the construction phase, to provide advice during the setting out, micro-siting and construction phases of the works.

The findings presented following the Derrybrien landslide (Ref. [1]), made the key recommendation that concentrated loads, such as excavated material from turbine foundation excavations, shall not be placed on marginally-stable ground. However, it is considered that such conditions do not occur at the Proposed Development.

5.2 Mitigation Measures

Based on previous experience and good practice for the development of wind farm layouts, the findings of the peat probing survey works and preliminary baseline peat stability risks have been considered and incorporated throughout the development of the infrastructure layout.

Wind farm tracks and other construction elements have been designed to avoid areas of deeper peat and areas of unsuitably steep sloping ground where practicable; minimising the generation of excavated soil and peat volumes.

The following list of mitigation measures is provided in an attempt to minimise the risk of potentially inducing peat landslides during construction of the Proposed Development:

General

- Raise Health and Safety awareness of the peat environment at the Proposed Development for construction staff by incorporating the issue into the Site Induction. Include peat slide risk assessment information (e.g. peat instability indicators, best practice and emergency procedures) in tool box talks with relevant operatives e.g. plant drivers;
- Introduce a 'Peat Hazard Emergency Plan' to provide instructions for site staff in the event of a peat slide or discovery of peat instability indicators;
- For sections of track that require track side cuttings into peat, suitable support measures will need to be designed to maintain the stability of the adjacent peat terrain;
- Refine/optimise the design through the pre-construction phase following completion of a detailed ground investigation;
- Develop methodologies to ensure that accelerated degradation and erosion of exposed peat deposits does not occur. The breakup of the peat top mat has significant implications for the morphology, and thus hydrology, of the peat (e.g. minimise off-track plant movements within areas of peat).

Drainage Measures

Drainage design for the proposed wind farm is a critical mitigation measure in maintaining the hydrological conditions. In order to maintain hydrological conditions the following requirements of the drainage measures should be met:

- Development of drainage systems that will not create areas of concentrated flow or cause over-, or under-, saturation of peat habitats;
- Development of robust drainage systems that will require minimal maintenance;
- Development of drainage systems that will minimise increased sedimentation into natural watercourses (e.g. by use of silt traps, silt fences or settlement ponds).

It is recommended that a Geotechnical Risk Register be compiled prior to construction to include risks relating to peat instability, as this will be beneficial to both the Developer and the Contractor in identifying potential risks that may be involved during construction. A Preliminary Geotechnical Risk Register is provided in Appendix B.

6 Conclusions and Recommendations

6.1 Conclusions

From the information obtained during the peat probing , it was identified that peat deposits ranged predominantly from <0.5m to 1.0m, with some localised areas of deeper peat >2.0m thick generally observed within flat plateau or low angle slope areas. Where deeper areas of peat were identified, the infrastructure of the Proposed Development has been located to be outwith these areas.

The bedrock underlying the west of the Proposed Development consists predominantly of psammite and pelite of the Tarvie Psammite Formation. The east of the Site is underlain psammite and semipelite of the Achaconeran Striped Formation. A number of localised minor unnamed igneous intrusions comprising amphibole and hornblende schists of Pre Cambrian age are also recorded across the Site. There are a number of faults within the Proposed Development boundary, mainly to the west of the Proposed Development, trending south west to north east and also north to south.

A total of 2909 peat depth probes were carried out to inform the Qualitative Risk Assessment (Q_LRA) assessment within the Site boundary. It was noted that >0.1% (2) of the peat probes undertaken within the Q_LRA assessment area recorded peat depths greater than 3.0m, with the maximum thickness of peat recorded being 3.3m. However, peat depths >3.0 m were only recorded in 2 probes (>0.1% of the 2909 total peat depth probes). The majority of probes ,2208 (76%) recorded peat up to 0.5 m thick, and 456 probes (15%) recorded peat depths between 0.5 to 1.0m thickness.

Of the 2909 peat probes undertaken at the Site, 40% of peat deposits on site were recorded as fibrous, 59% as semi-fibrous and only 1% as amorphous material.

Shear strength tests were undertaken on the peat deposits encountered in areas of proposed new access tracks. From data specific to the Proposed Development (in-situ Hand Shear Vane Testing data collected by Mott MacDonald), undrained shear strengths for the peat ranges between 0kN/m^2 and 43kN/m^2, though readings were generally between 10kN/m^2 and 20kN/m^2.

The design process has taken cognisance of the above distribution of peat thicknesses through consultation with the EIA team, whereby efforts have been made to ensure that areas of deep peat are avoided where practicable.

A Q_LRA was undertaken to determine the baseline peat stability conditions in areas of proposed infrastructure. The Q_LRA approach is based on a system where factors and influence are multiplied together to generate Risk Rating Scores and corresponding qualitative relative risks. Each probe within the Q_LRA assessment area, i.e. with the Site boundary, was assessed to determine the baseline risks from peat landslide hazards. The results of this assessment categorised the baseline risk rating of the proposed wind farm to be Very Low to Low, locally Medium. Due to the presence of Medium risk locations, a Quantitative Risk Assessment (Q_NRA) was carried out to determine the potential effect of syn-construction activities on the level of risk. This indicated that the risk of instability at these locations is Low, providing suitable construction methodologies are established.

Some recommendations on construction methodologies and mitigation measures are provided within this report (Section 4.8) and a Preliminary Geotechnical Risk Register is provided in Appendix B that will assist in minimising the increased risk of potential peat landslides within the Site during construction and post construction of the Proposed Development. Whilst it is not possible to categorically state that peat failure will not occur at the Site, it is considered that the overall risk is Very Low to Low once quantitative analysis has been considered and that with judicious planning and an appreciation of the risks, suitable working practices and mitigation measures can be established to prevent increased risk.

6.2 Recommendations for Further Work

With regards to peat stability and notwithstanding the construction methodologies and mitigation measures outlined in Section 4.8, further recommendations, relating to the proposed construction elements, for the consideration of the Developer and their Contractor(s) are listed below:

- Prepare method statements for mitigation measures including, but not limited to, the use of check dams and erosion protection to limit flow and prevent contamination of watercourses;
- Input into the Geotechnical Risk Register and pre-construction information pack for the project, including references to this report and the identified area of peat slide risk;
- Appoint an appropriately qualified and experienced engineering geologist or geotechnical engineer to advise during the setting out, micro-siting and construction phases of the works.

7 References

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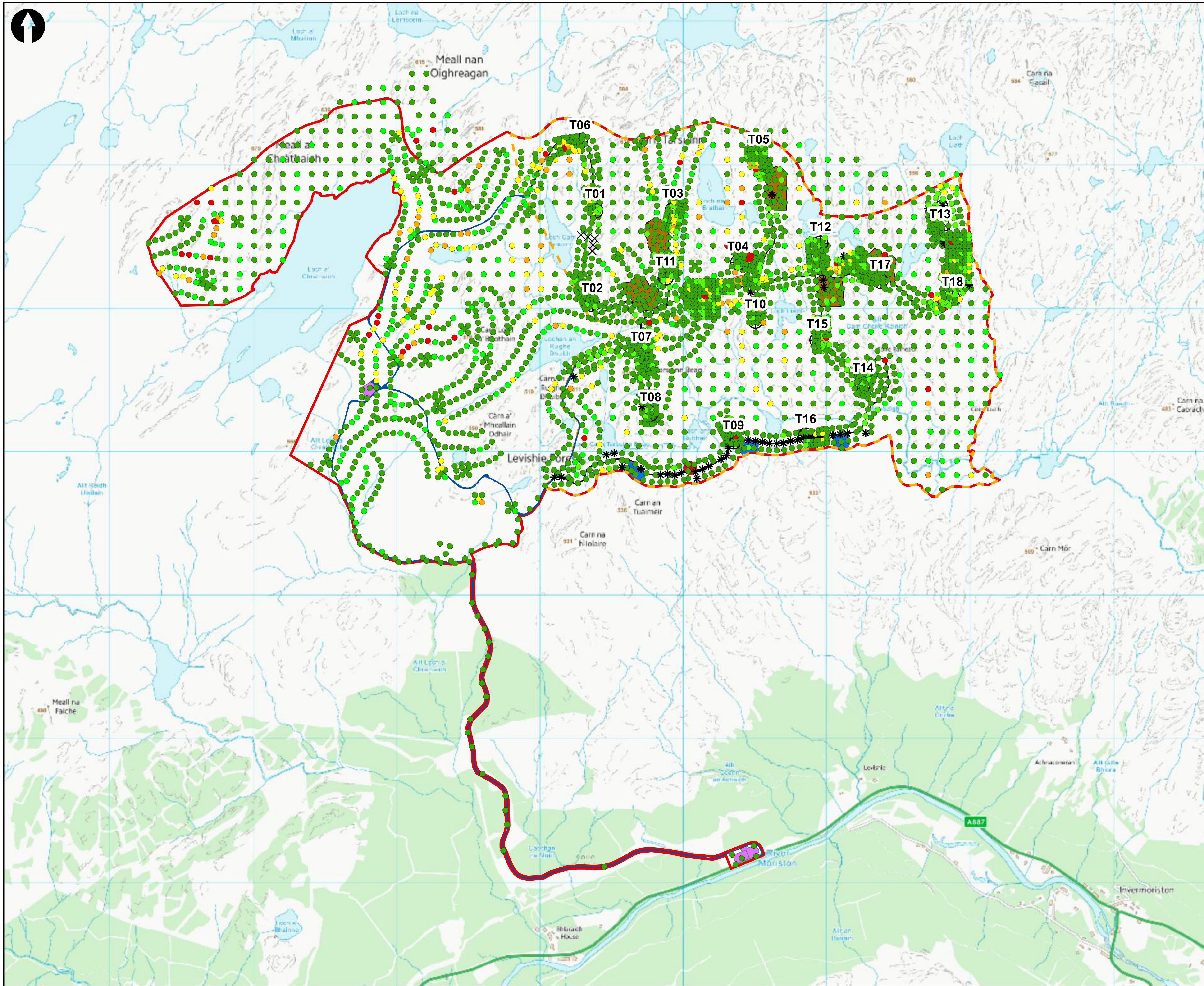
A. Figures

A.1 Peat Thickness (MMD-100410845-DR-PSRA-GIS-002)

A.2 Qualitative Risk Assessment (MMD-100410845-DR-PSRA-GIS-003)

A.3 Overall Peat Slide Risk Rating (MMD-100410845-DR-PSRA-GIS-004)

A.4 Geomorphology (MMD-100410845-DR-PSRA-GIS-005)



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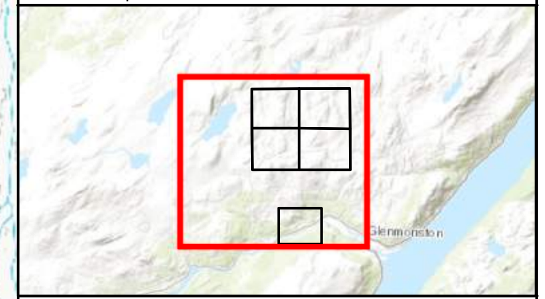

Key to Symbols

- 18Turbine Layout
- Peat Depth (m)
  - 0 - 0.5
  - 0.51 - 1.0
  - 1.01 - 1.5
  - 1.51 - 2.0
  - >2.0
- No Recovery
- Inaccessible
- BHLX LiDAR
- BHLX Cross Country Cable Route
- Proposed Track
- Access Route via Existing Wind Farm Track
- BHLX Batching Plant Search Area
- BHLX Borrowpit Search Area
- BHLX Hydro Borrowpit Search Area
- BHLX Compound
- BHLX Hardstanding
- BHLX Substation
- BHLX TurningHead
- Turbine Development Area
- Site Boundary

Rev	Date	Drawn	Description	Ch'k'd	App'd
02	17/08/21	JL	For Information	AT	GMcP

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Bhlaraidh Wind Farm Extension
Peat Stability Risk Assessment (PSRA)
Figure A.1 Peat Thickness
Overview

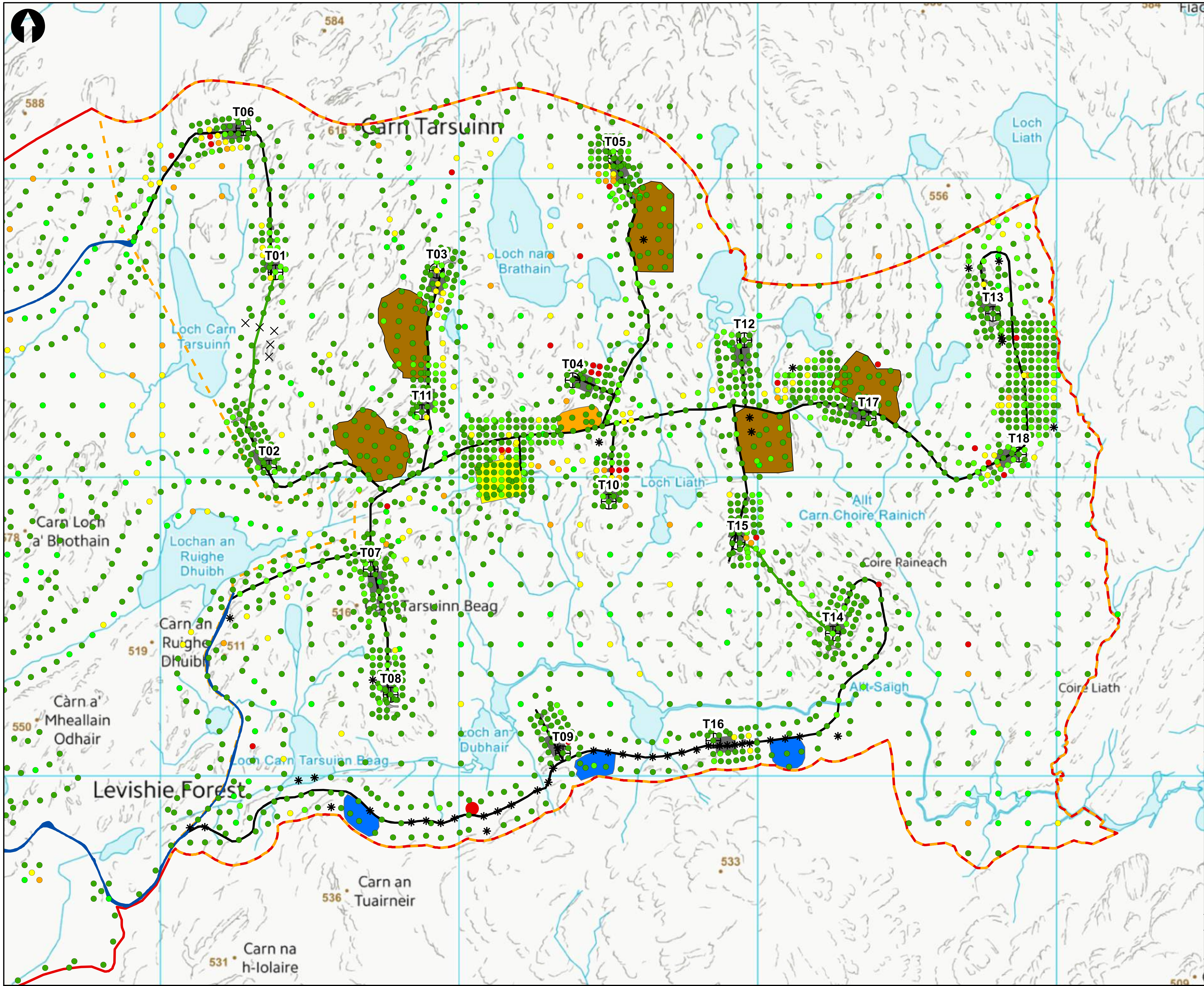
Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

Scale at A3	Status	Rev	Security
1:25,000	FI	01	STD

0 200 400 m

Drawing Number

MMD-100410845-DR-PSRA-GIS-002



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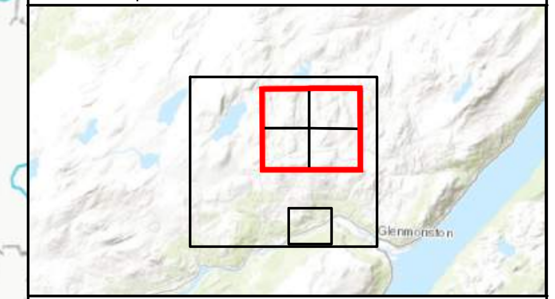

Key to Symbols

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Bhlaraidh Wind Farm Extension
Peat Stability Risk Assessment (PSRA)
Figure A.1 Peat Thickness
Turbine Development Area

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GIS Check	K.Young	Approved	G.McPake

Scale at A3	Status	Rev	Security
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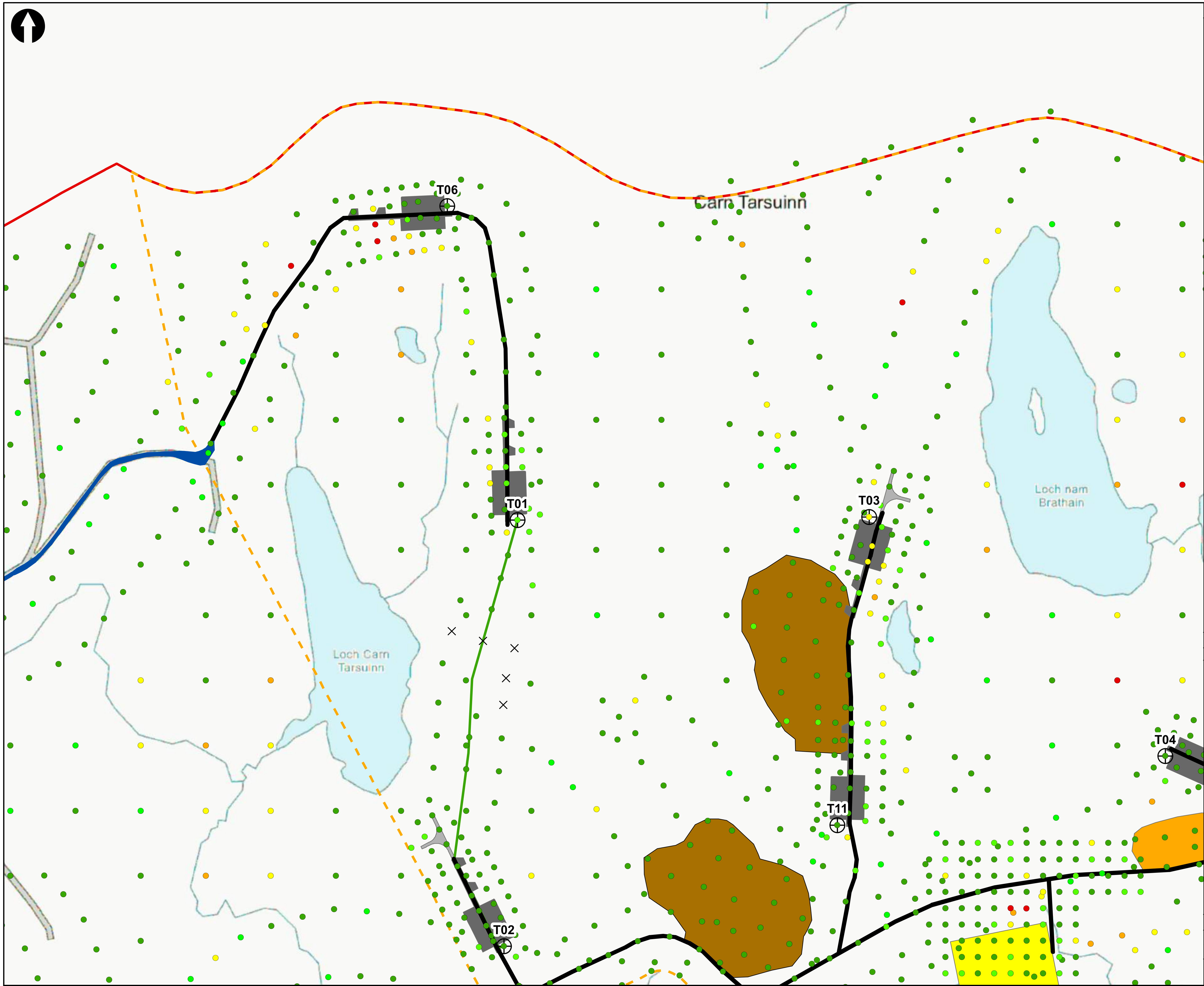

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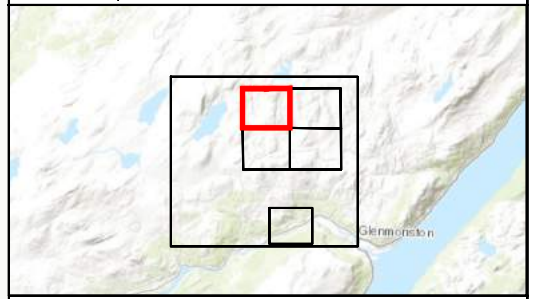

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Peat Stability Risk Assessment (PSRA)
Figure A.1 Peat Thickness
Page 1

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GIS Check	K.Young	Approved	G.McPake

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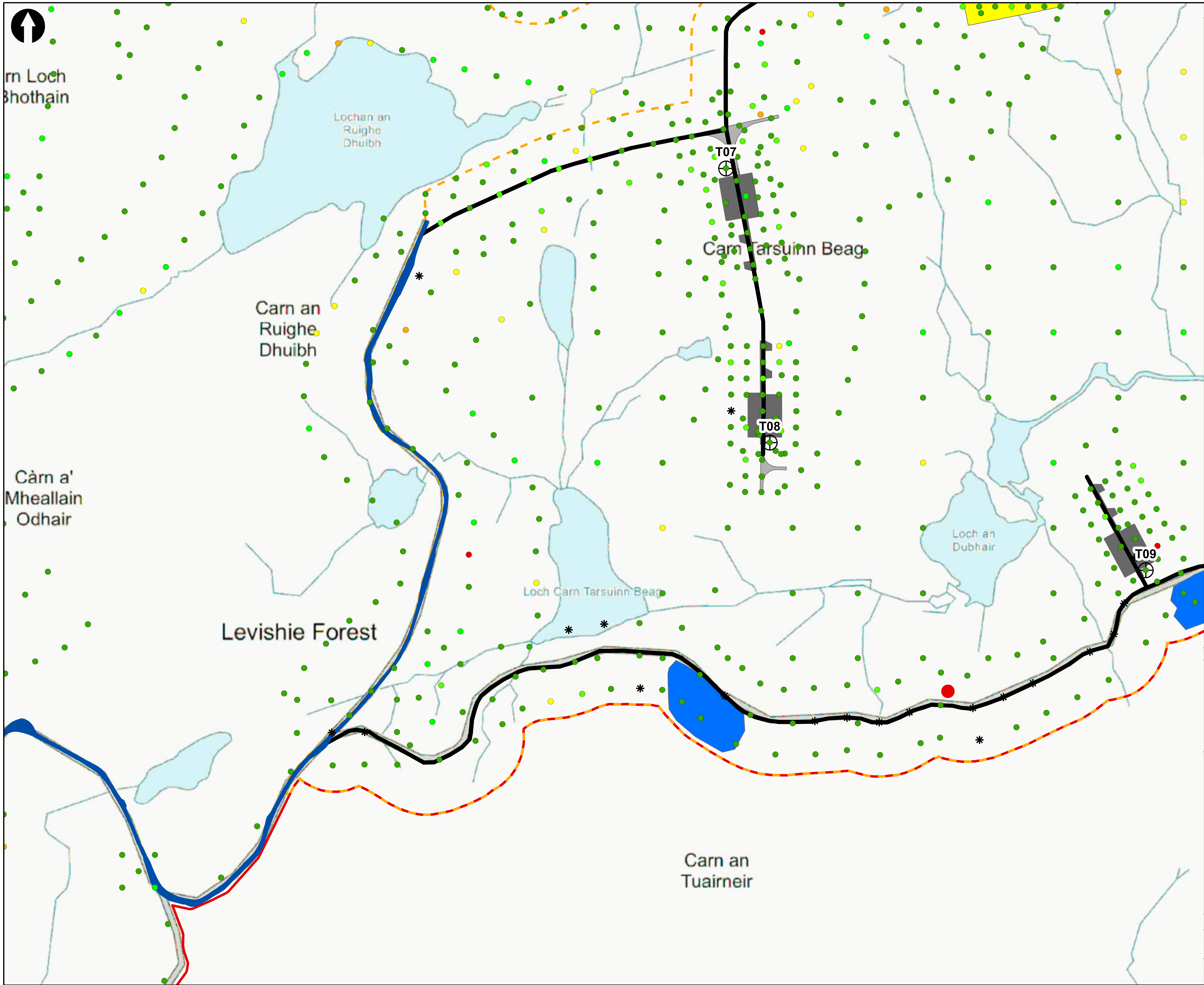

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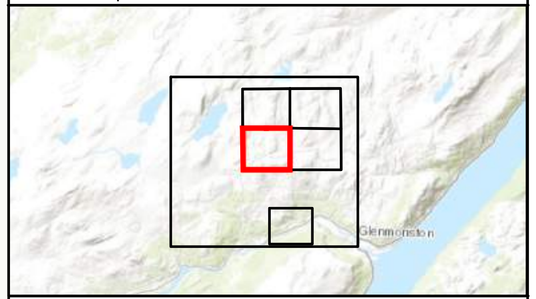

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Figure A.1 Peat Thickness
Page 2

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GIS Check	K.Young	Approved	G.McPake

Scale at A3	Status	Rev	Security
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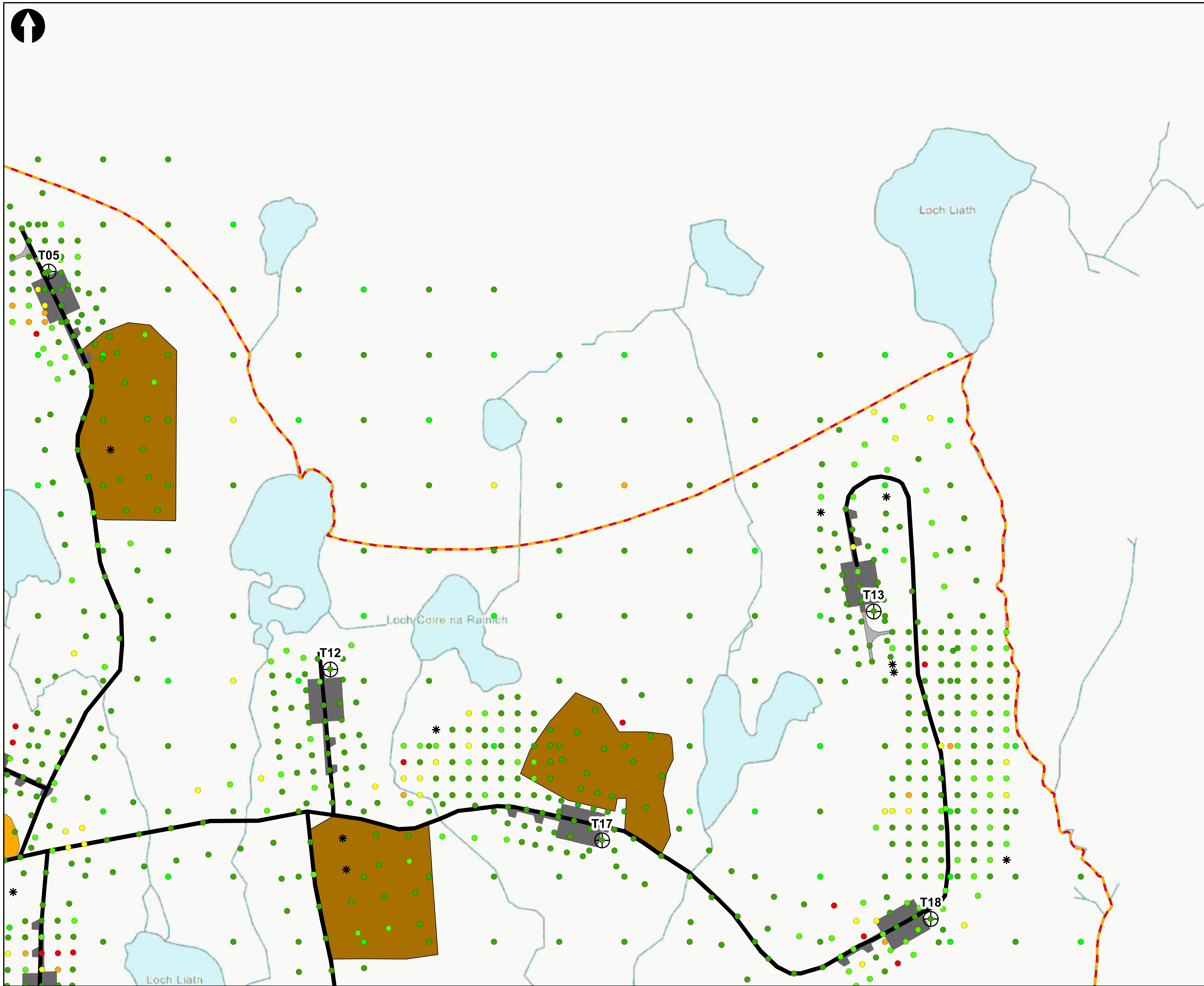

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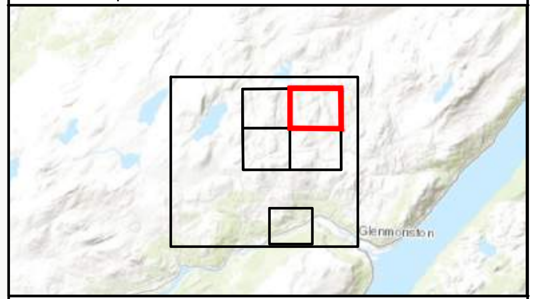

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Bhlaraidh Wind Farm Extension
Peat Stability Risk Assessment (PSRA)
Figure A.1 Peat Thickness
Page 3

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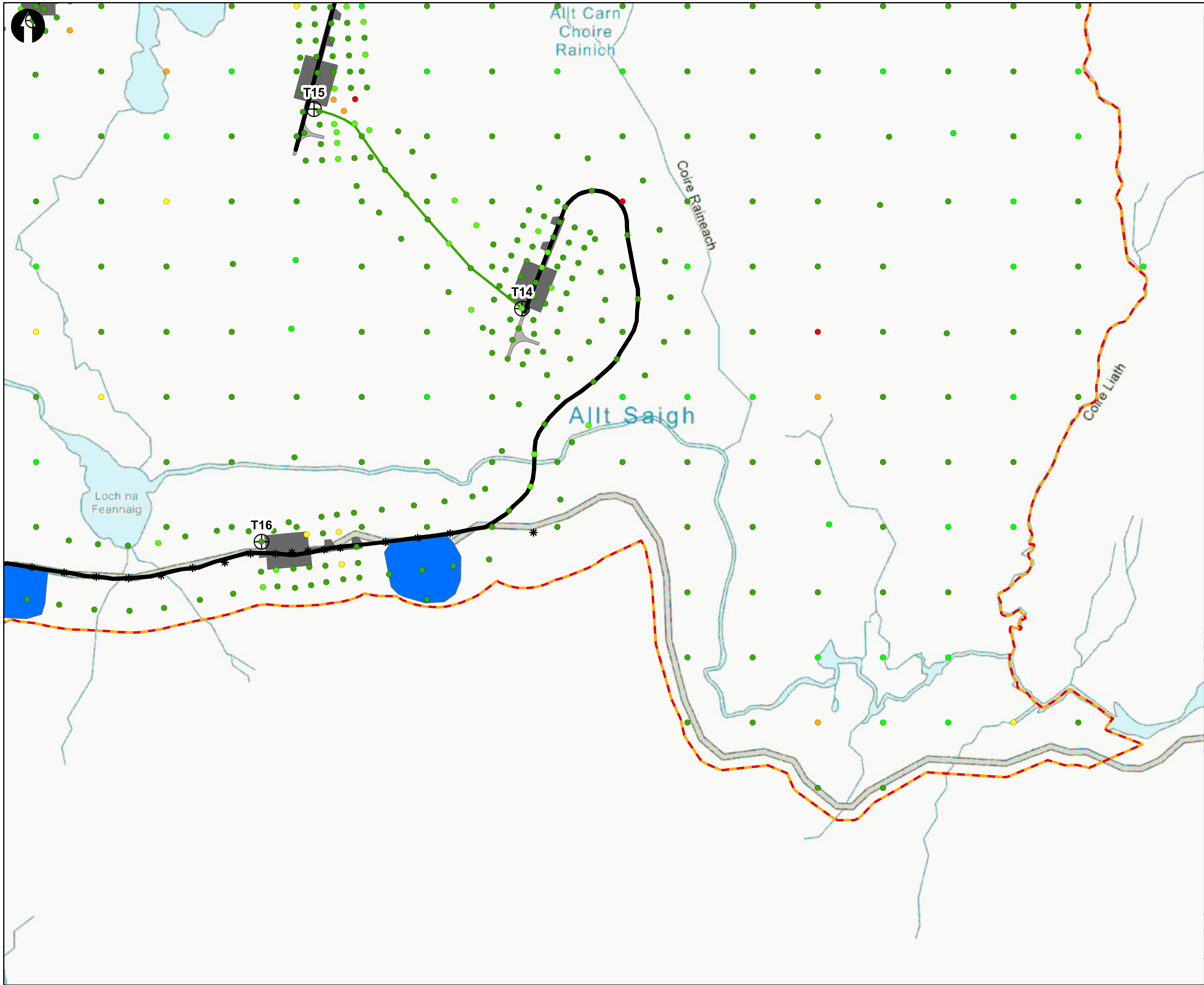

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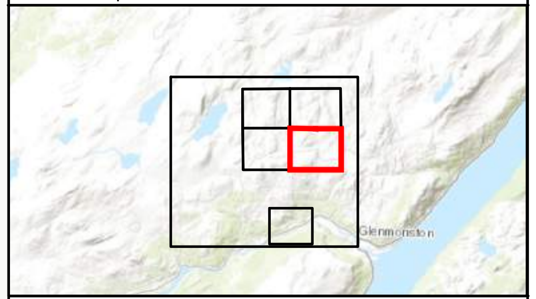

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Bhlaraidh Wind Farm Extension
Peat Stability Risk Assessment (PSRA)
Figure A.1 Peat Thickness
Page 4

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Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

Scale at A3	Status	Rev	Security
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0 200 400 m

Drawing Number
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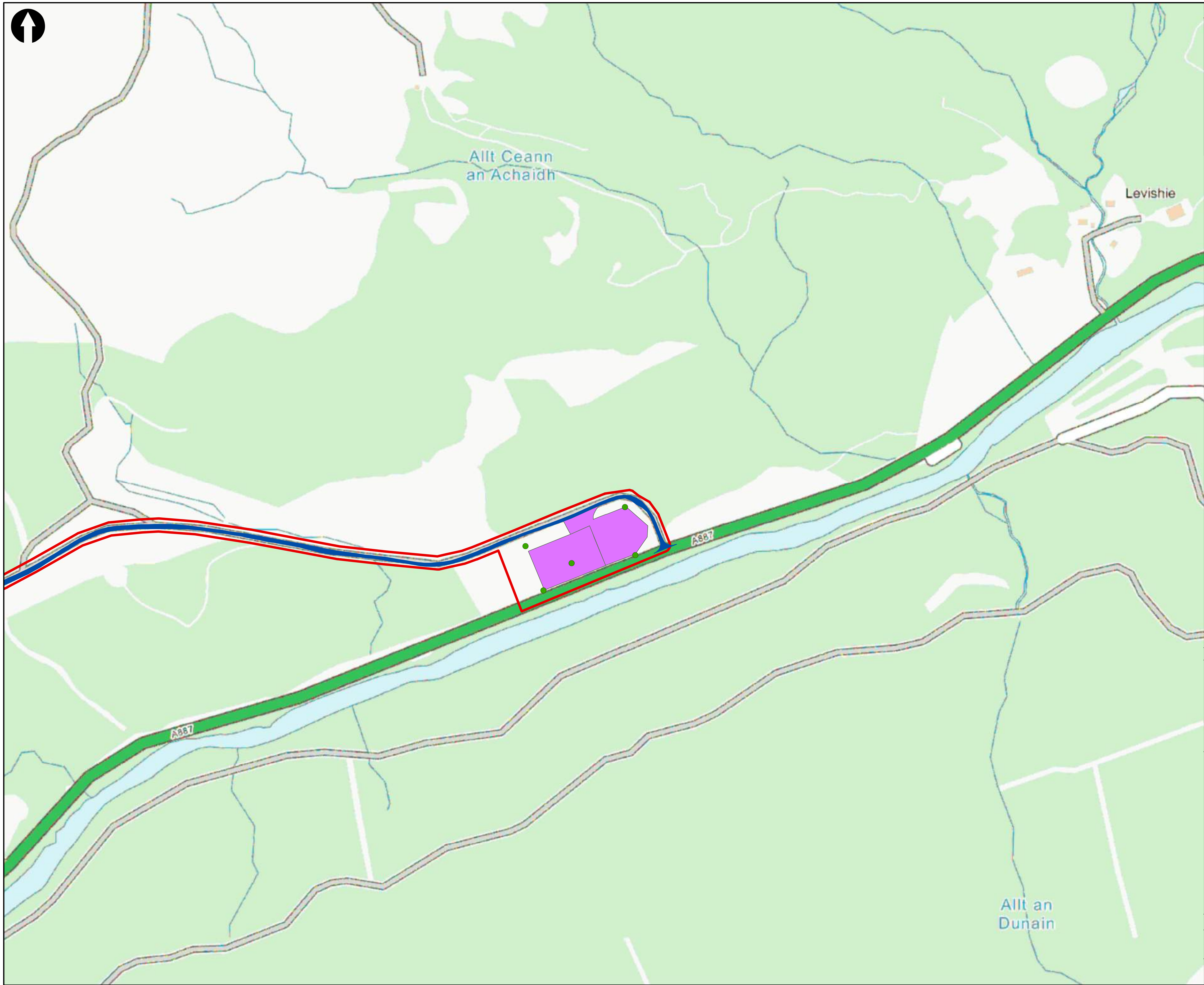

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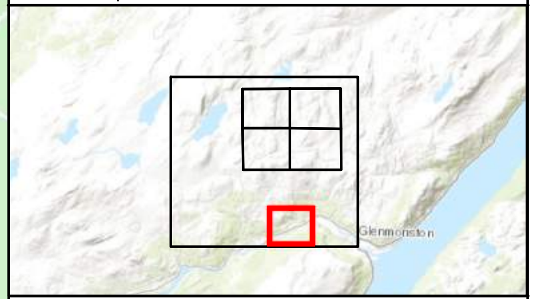

Key to Symbols

- 18Turbine Layout
- Peat Depth (m)
- 0 - 0.5
- 0.51 - 1.0
- 1.01 - 1.5
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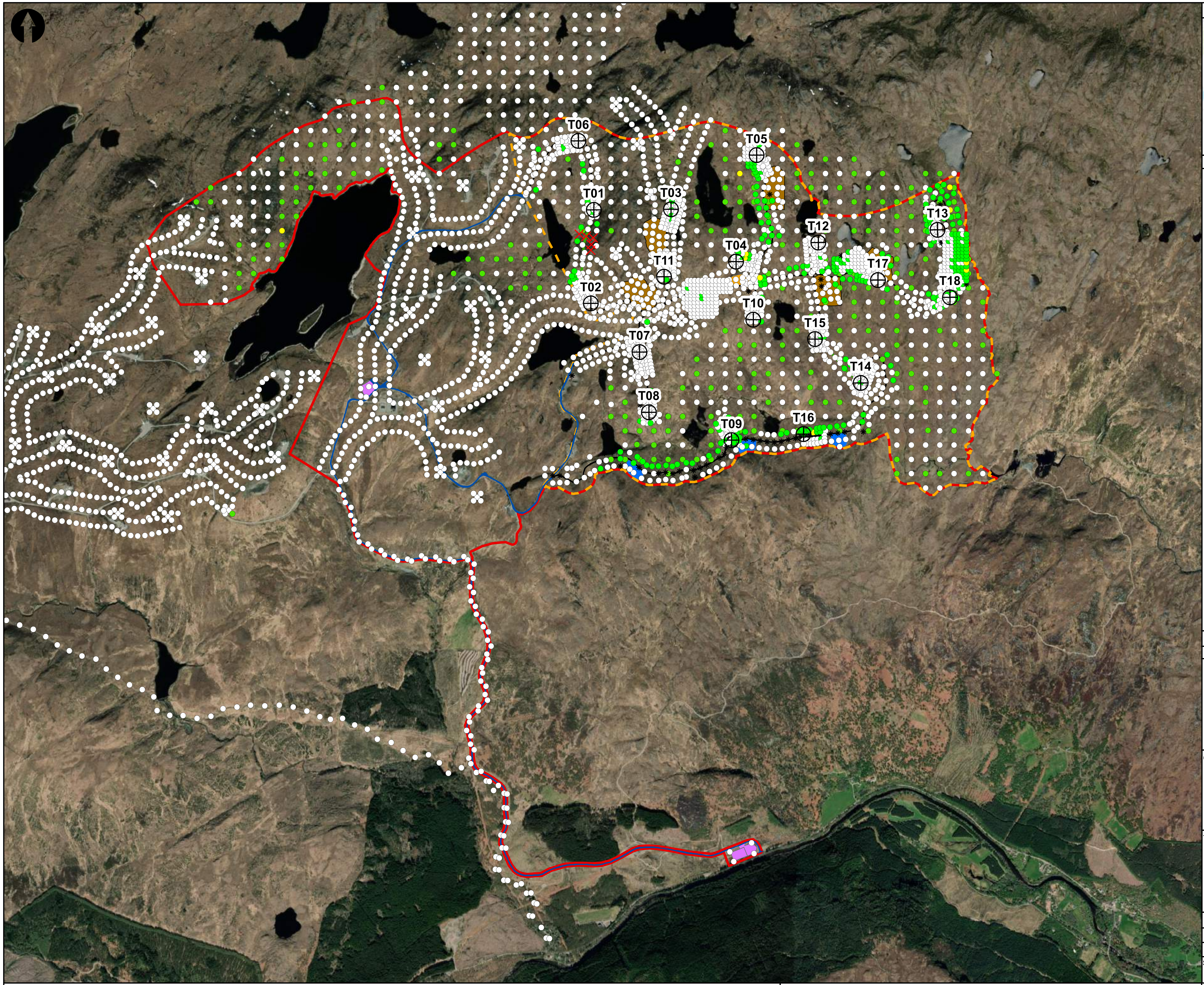
Bhlaraidh Wind Farm Extension
Peat Stability Risk Assessment (PSRA)
Figure A.1 Peat Thickness
Page 5

Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

Scale at A3	Status	Rev	Security
1:5,500	FI	01	STD

0 200 400 m

Drawing Number
MMD-100410845-DR-PSRA-GIS-002



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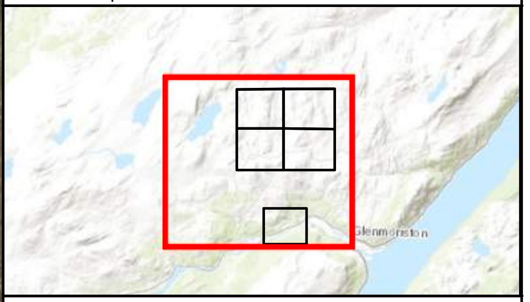

Key to Symbols

- 18Turbine Layout

Risk Rating

- Very Low
- Low
- Medium
- High
- Very High
- No Recovery
- Inaccessible
- Access Route via Existing Wind Farm Track
- Turbine Development Area
- Proposed Track
- BHLX Compound
- BHLX Batching Plant Search Area
- BHLX Substation
- BHLX Cross Country Cable Route
- BHLX TurningHead
- BHLX Hardstanding
- BHLX Hydro Borrowpit Search Area
- BHLX Borrowpit Search Area
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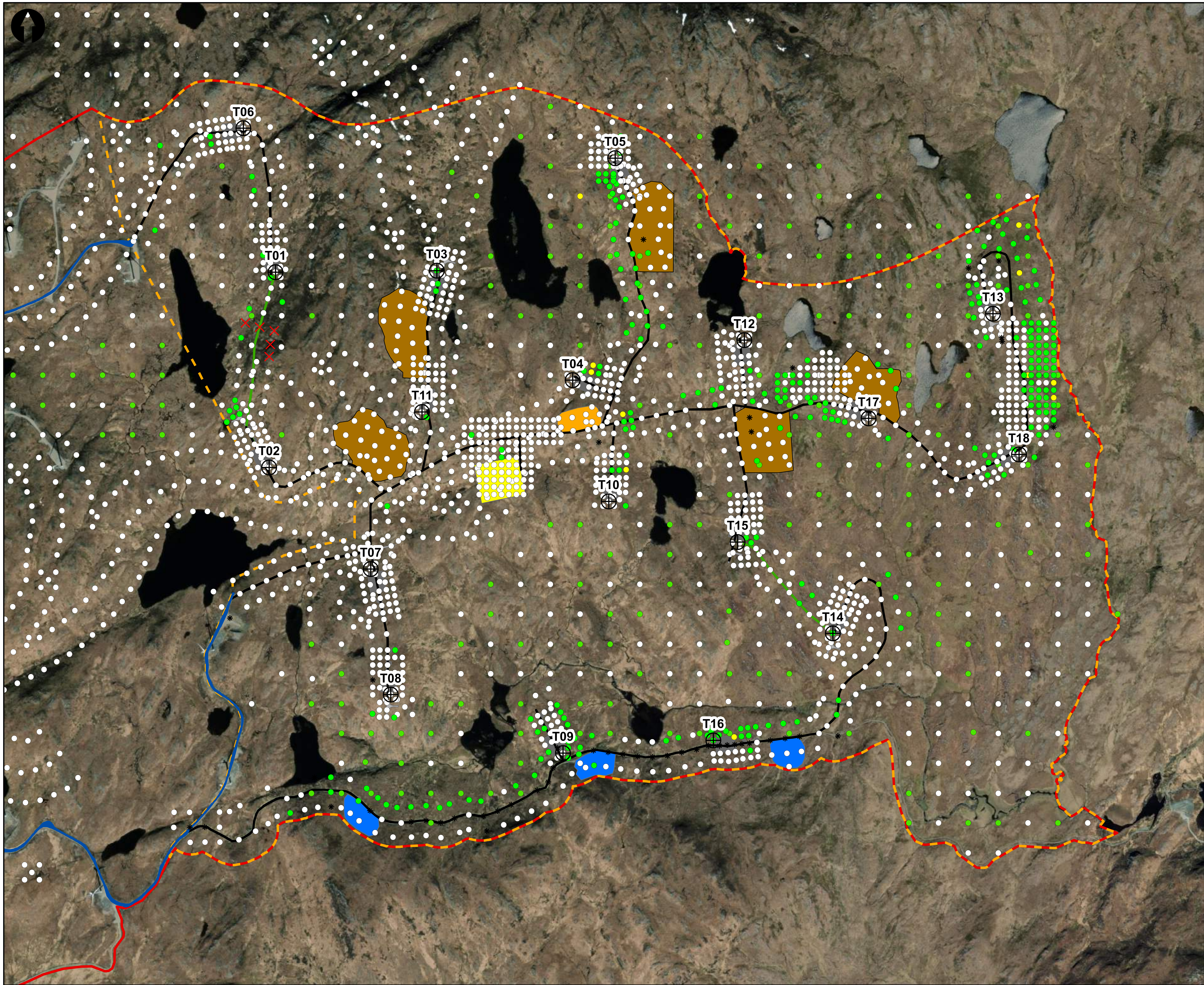
Title

Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)
Overview

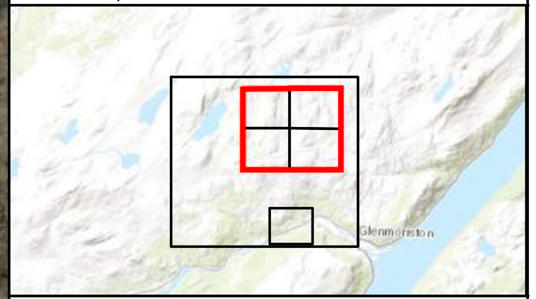
Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

Scale at A3	Status	Rev	Security
1:25,000	FI	02	STD

Drawing Number
MMD-100410845-DR-XX-GIS-003



Location Map



Key to Symbols

- 18Turbine Layout

Risk Rating

- Very Low
- Low
- Medium
- High
- Very High
- No Recovery
- Inaccessible
- Access Route via Existing Wind Farm Track
- Turbine Development Area
- Proposed Track
- BHLX Compound
- BHLX Batching Plant Search Area
- BHLX Substation
- BHLX Cross Country Cable Route
- BHLX TurningHead
- BHLX Hardstanding
- BHLX Hydro Borrowpit Search Area
- BHLX Borrowpit Search Area
- Site Boundary

Rev	Date	Drawn	Description	Ch'k'd	App'd
02	17/08/21	JL	For Information	AT	GMcP

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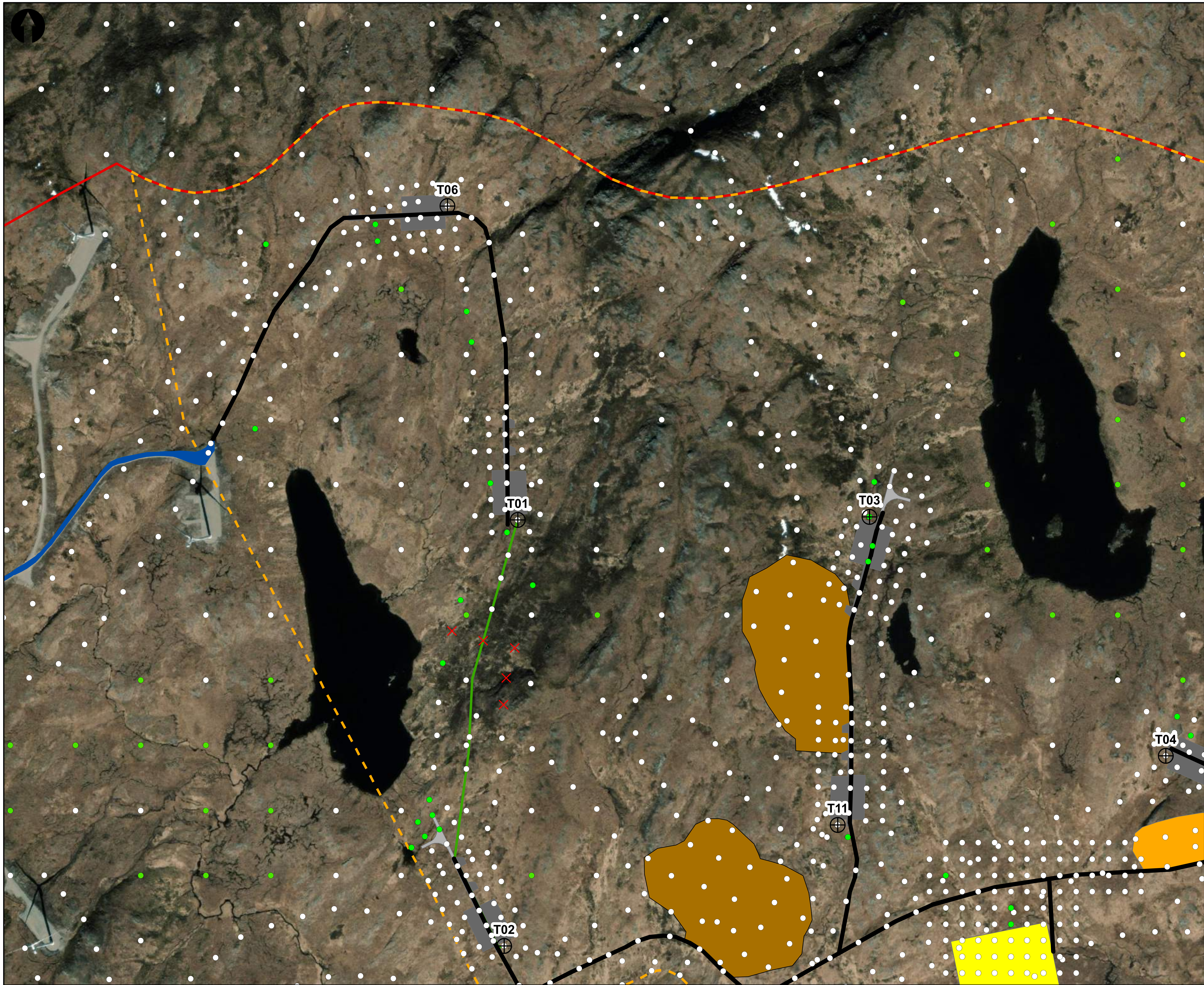
Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)
Turbine Development Area

Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

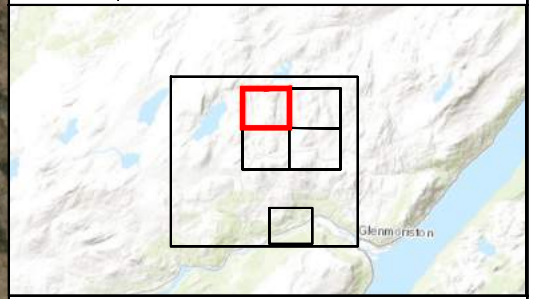
Scale at A3	Status	Rev	Security
1:12,000	FI	02	STD

Drawing Number
MMD-100410845-DR-XX-GIS-003

0 200 400 m



Location Map



Key to Symbols

- 18Turbine Layout

Risk Rating

- Very Low
- Low
- Medium
- High
- Very High
- No Recovery
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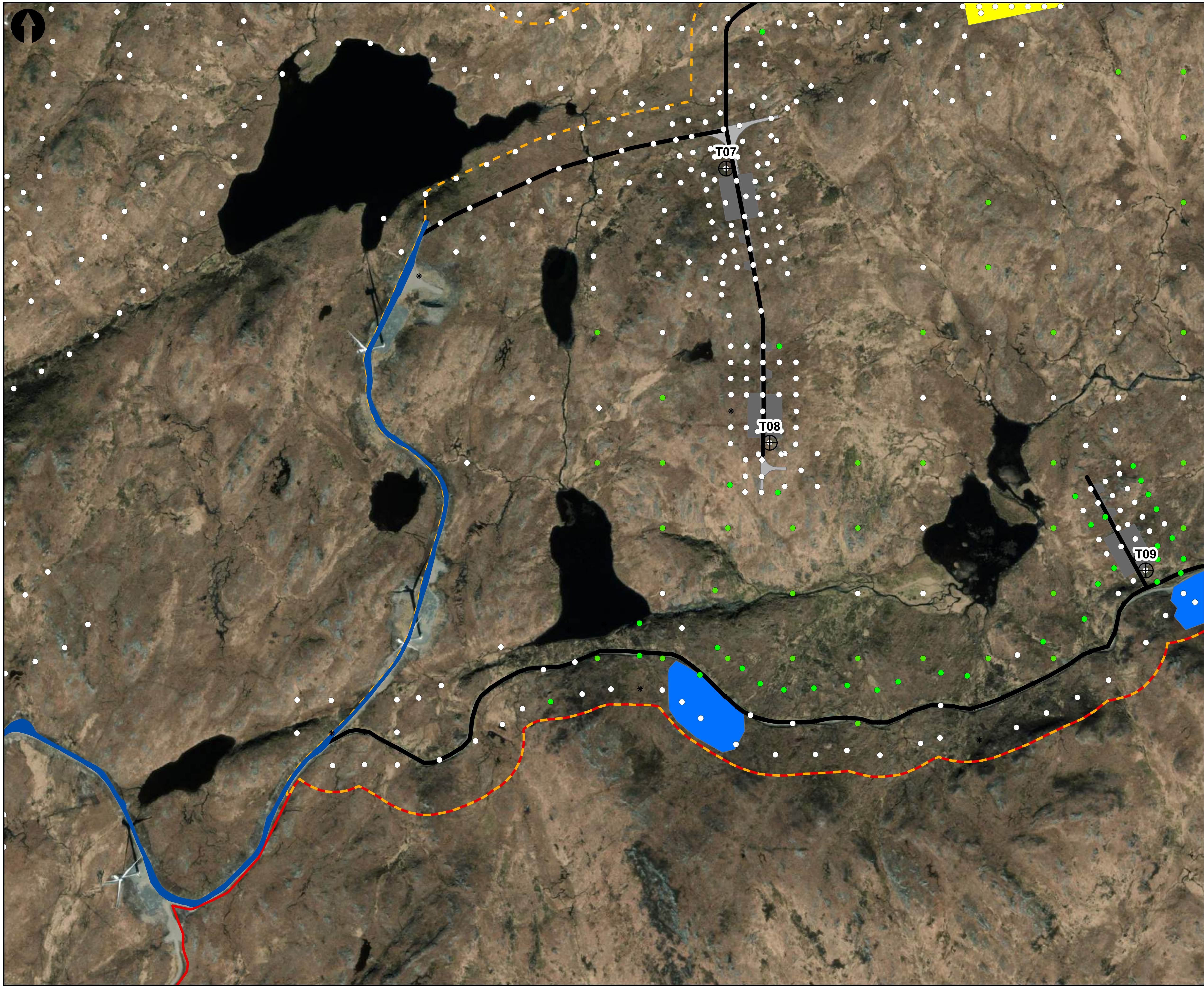
Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)
Page 1

Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

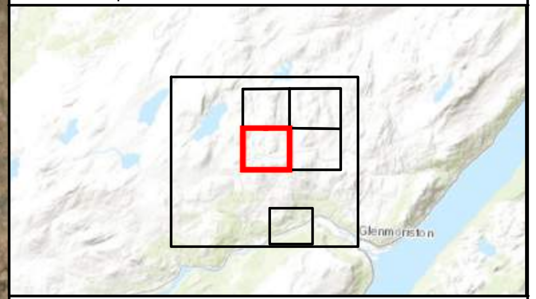
Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

0 200 400 m

Drawing Number
MMD-100410845-DR-XX-GIS-003



Location Map



Key to Symbols

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Risk Rating

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Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)

Page 2

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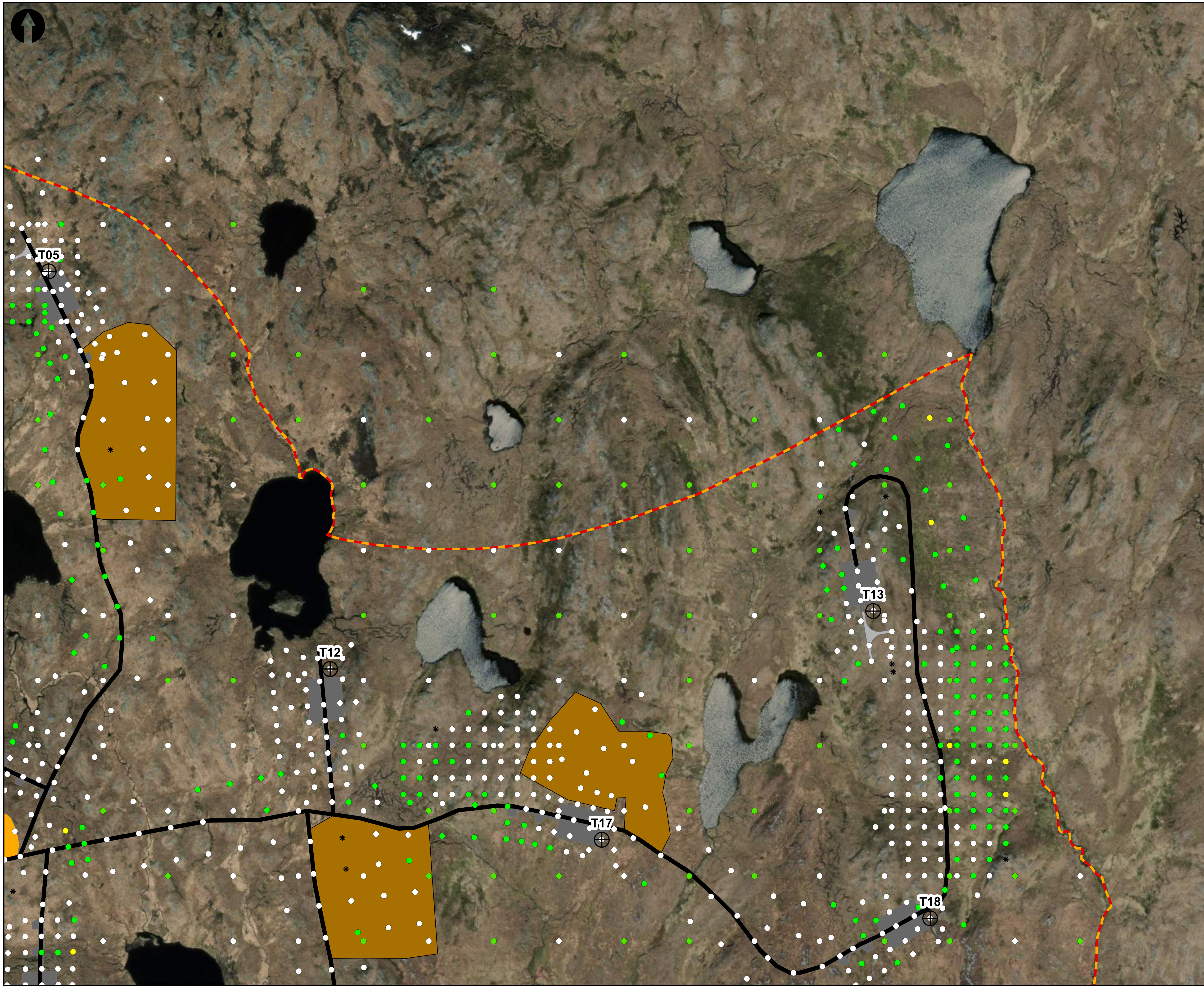
Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

Drawing Number
MMD-100410845-DR-XX-GIS-003



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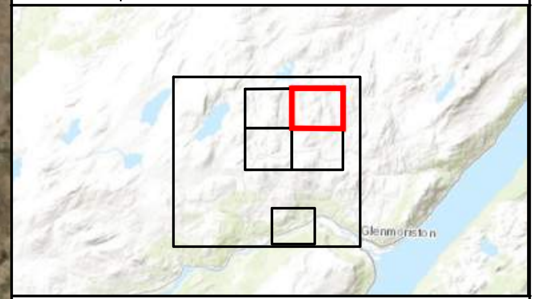

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Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)

Page 3

Designed	J.Lawrie	Eng Check	K.Young
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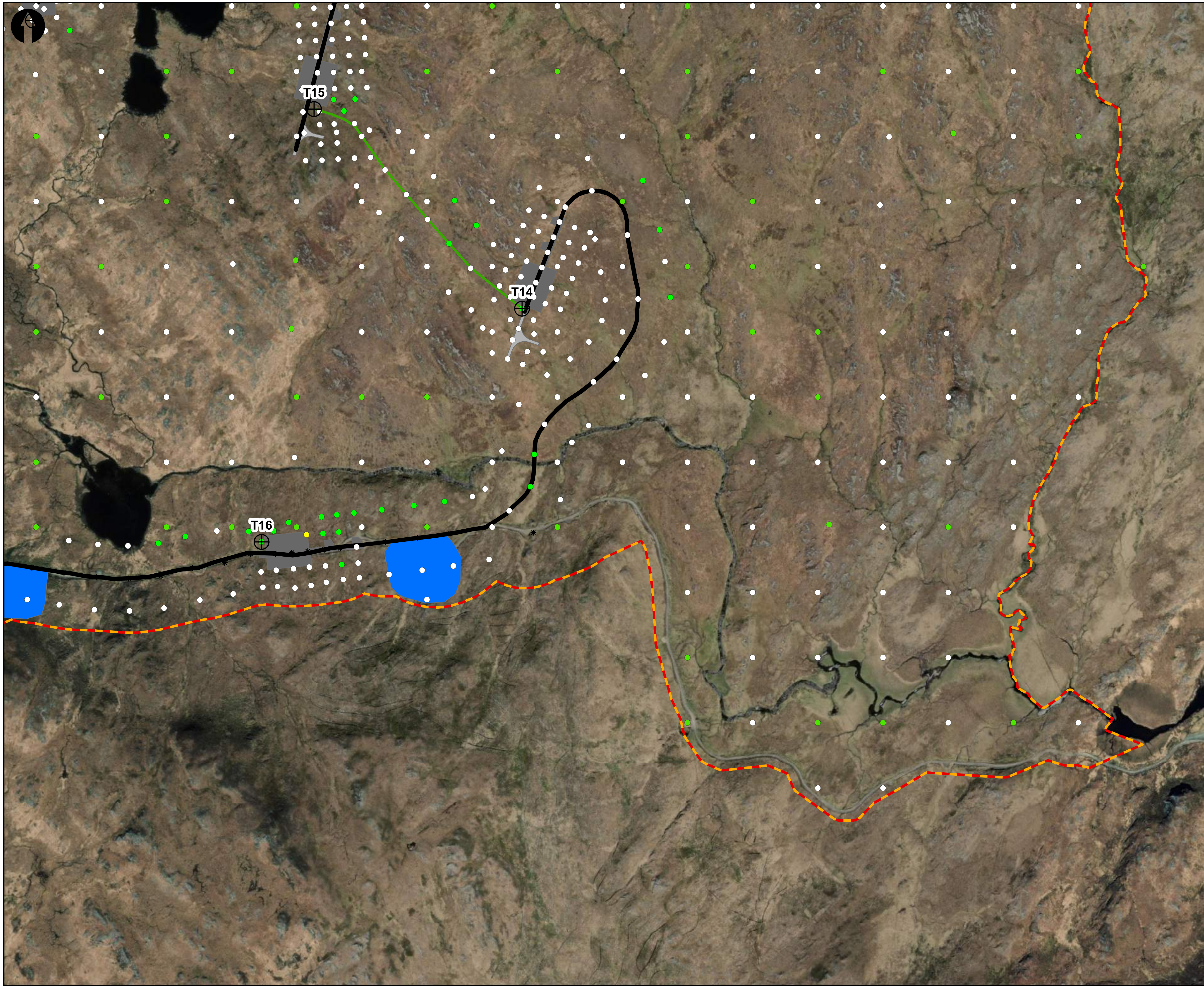
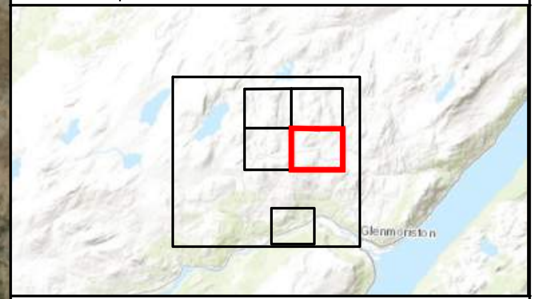
Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

Drawing Number

MMD-100410845-DR-XX-GIS-003



Location Map



Key to Symbols

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Risk Rating

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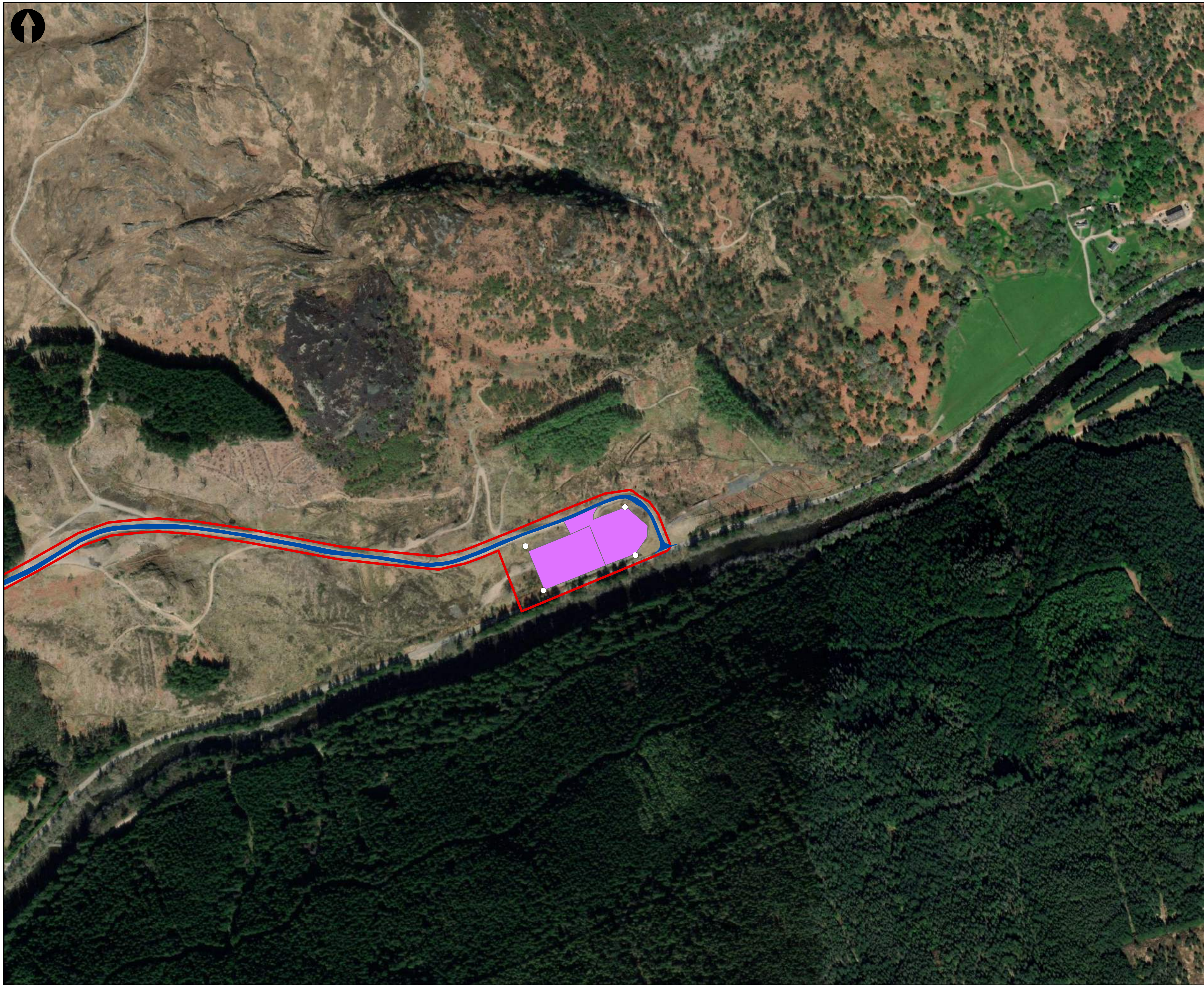
Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)
Page 4

Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

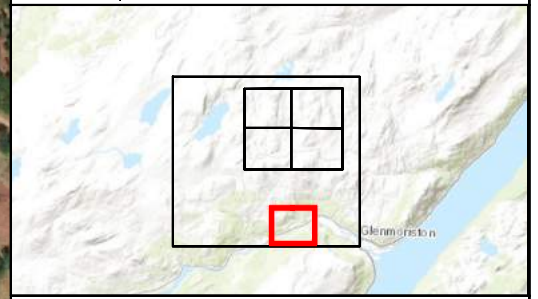
Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

0 200 400 m

Drawing Number
MMD-100410845-DR-XX-GIS-003



Location Map



Key to Symbols

- 18Turbine Layout

Risk Rating

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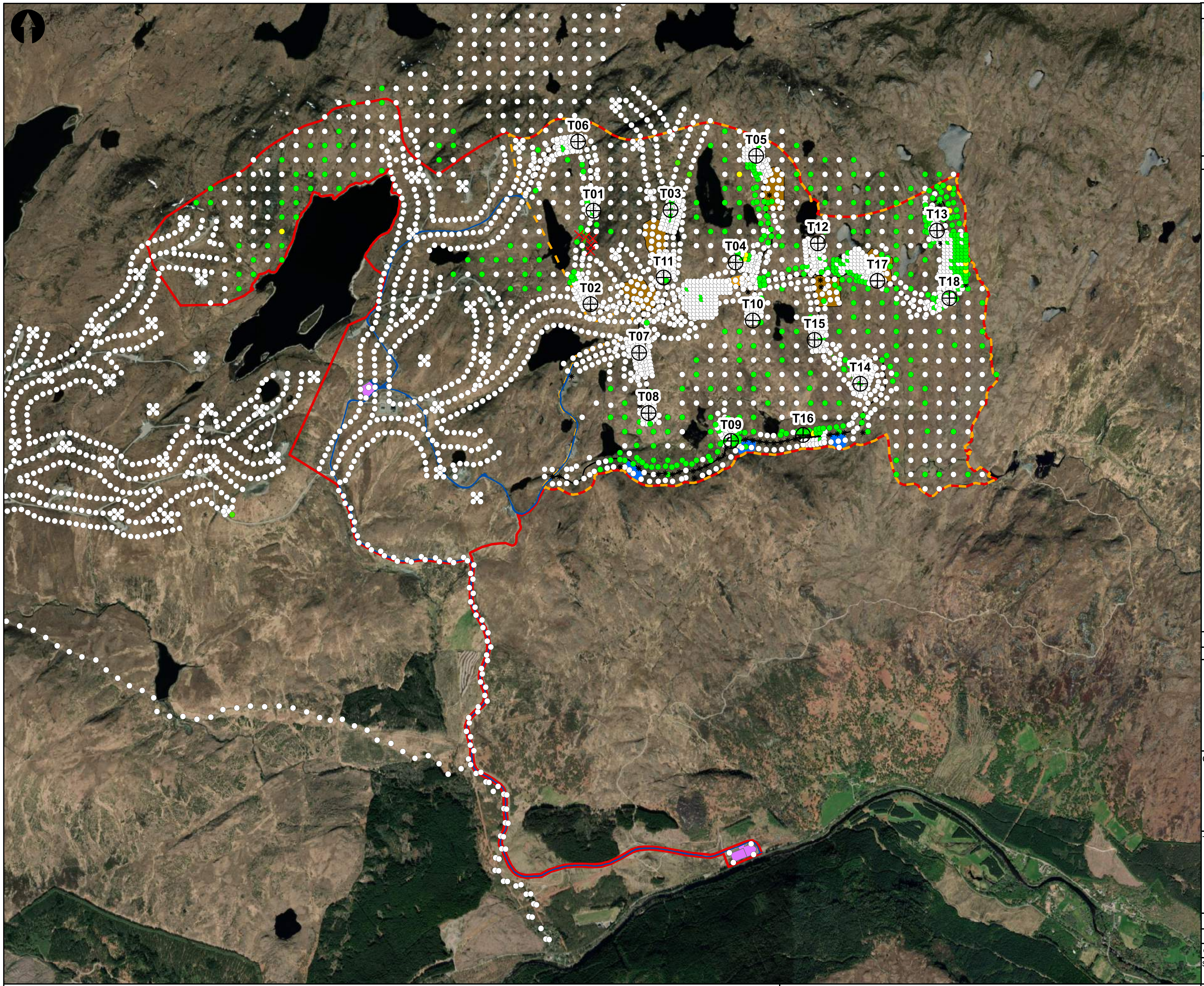
Bhlaraidh Wind Farm Extension
Figure A.2 Qualitative Risk Assessment
Peat Stability Risk Assessment (PSRA)
Page 5

Designed	J.Lawrie	Eng Check	K.Young
Drawn	J.Lawrie	Coordination	A.Tourish
GIS Check	K.Young	Approved	G.McPake

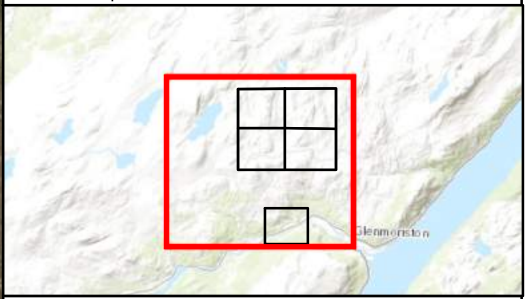
Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

0 200 400 m

Drawing Number
MMD-100410845-DR-XX-GIS-003



Location Map



Key to Symbols

- 18Turbine Layout

Risk

- Very Low
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Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Overview

Designed	S Eyers-Young	Eng Check	K Young
Drawn	S Eyers-Young	Coordination	A Tourish
GIS Check	J.Lawrie	Approved	G McPake

Scale at A3	Status	Rev	Security
1:25,000	FI	02	STD

Drawing Number
MMD-100410845-DR-PSRA-GIS-004

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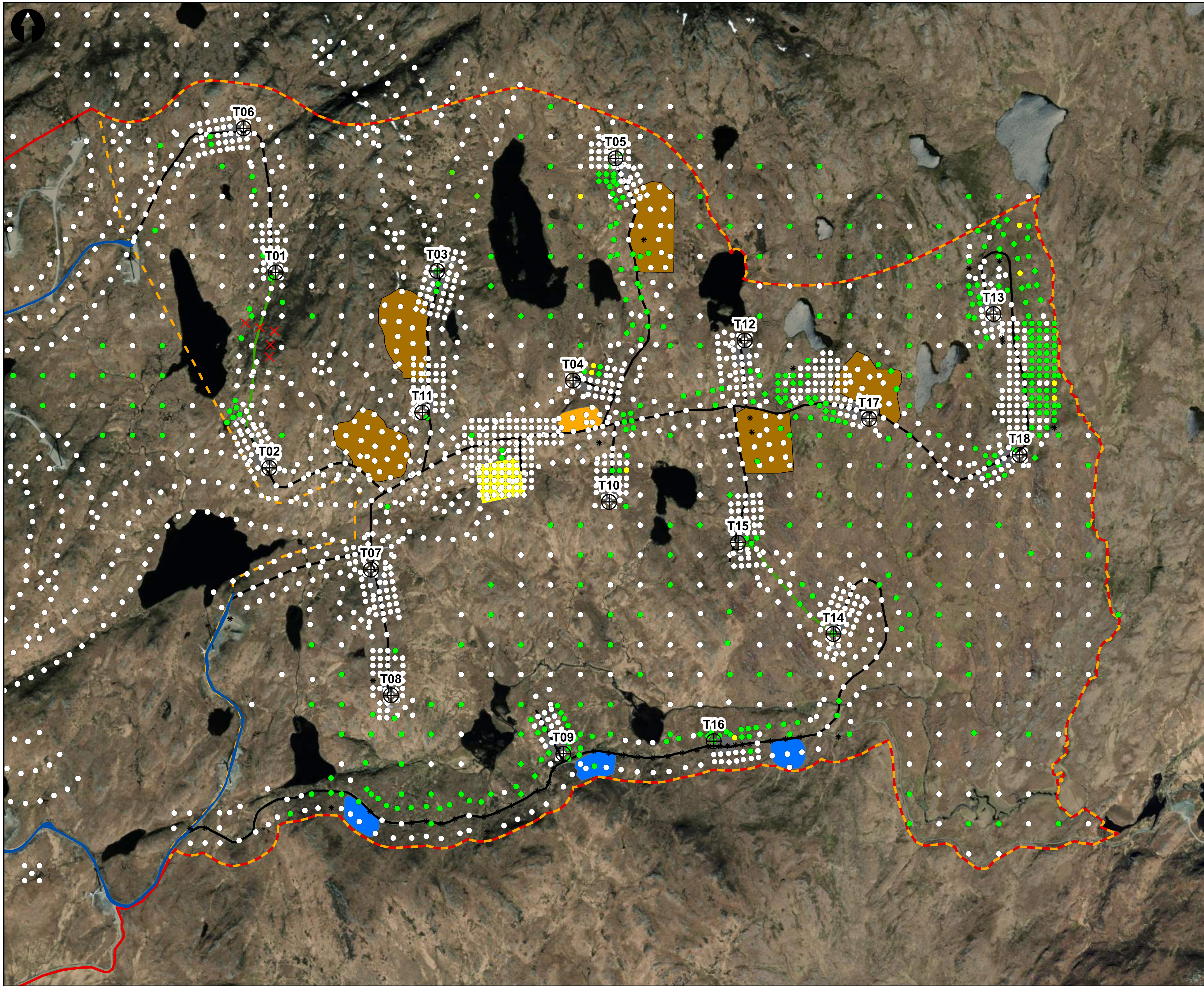
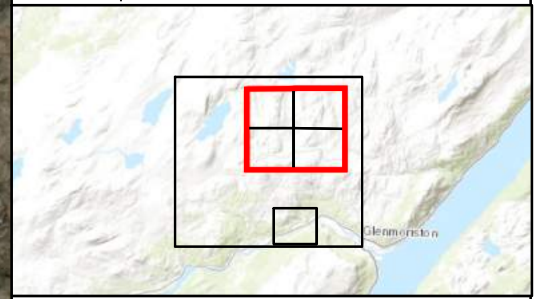


Location Map



Key to Symbols

- 18Turbine Layout

Risk

- Very Low
- Low
- Medium
- High
- Very High
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Title

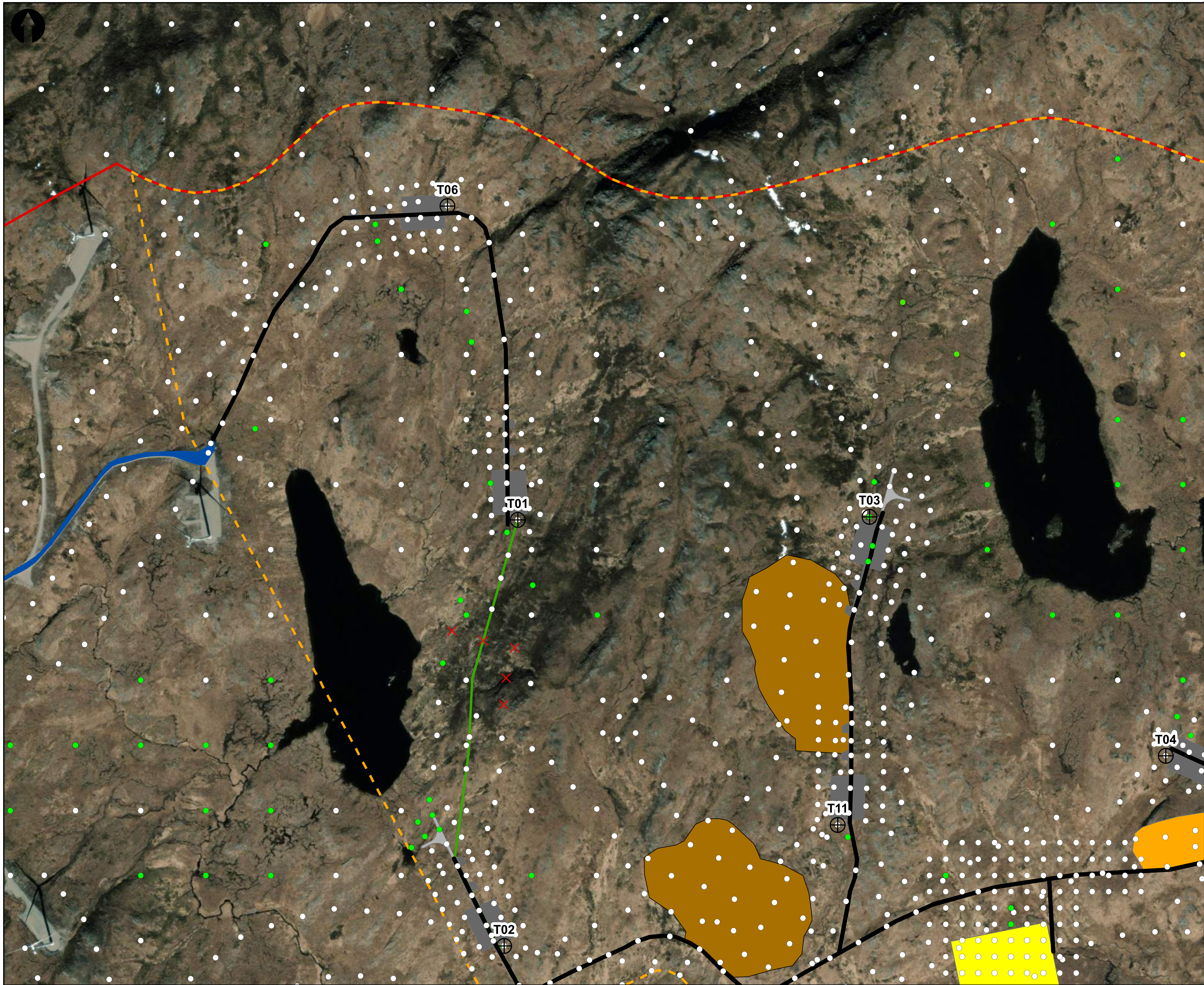
Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Turbine Development Area

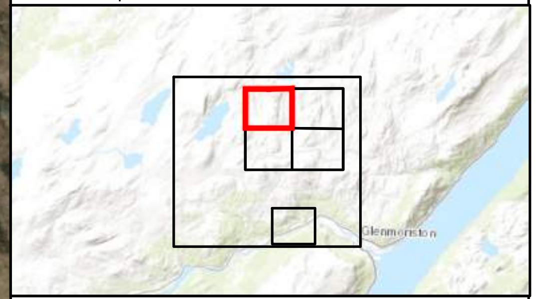
Designed	S Eyers-Young	Eng Check	K Young
Drawn	S Eyers-Young	Coordination	A Tourish
GIS Check	J.Lawrie	Approved	G McPake

Scale at A3	Status	Rev	Security
1:12,000	FI	02	STD

Drawing Number
MMD-100410845-DR-PSRA-GIS-004



Location Map



Key to Symbols

- 18Turbine Layout

Risk

- Very Low
- Low
- Medium
- High
- Very High
- No Recovery
- Access Route via Existing Wind Farm Track
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Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Page 1

Designed	S Eyers-Young	Eng Check	K Young
Drawn	S Eyers-Young	Coordination	A Tourish
GIS Check	J.Lawrie	Approved	G McPake

Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

Drawing Number
MMD-100410845-DR-PSRA-GIS-004

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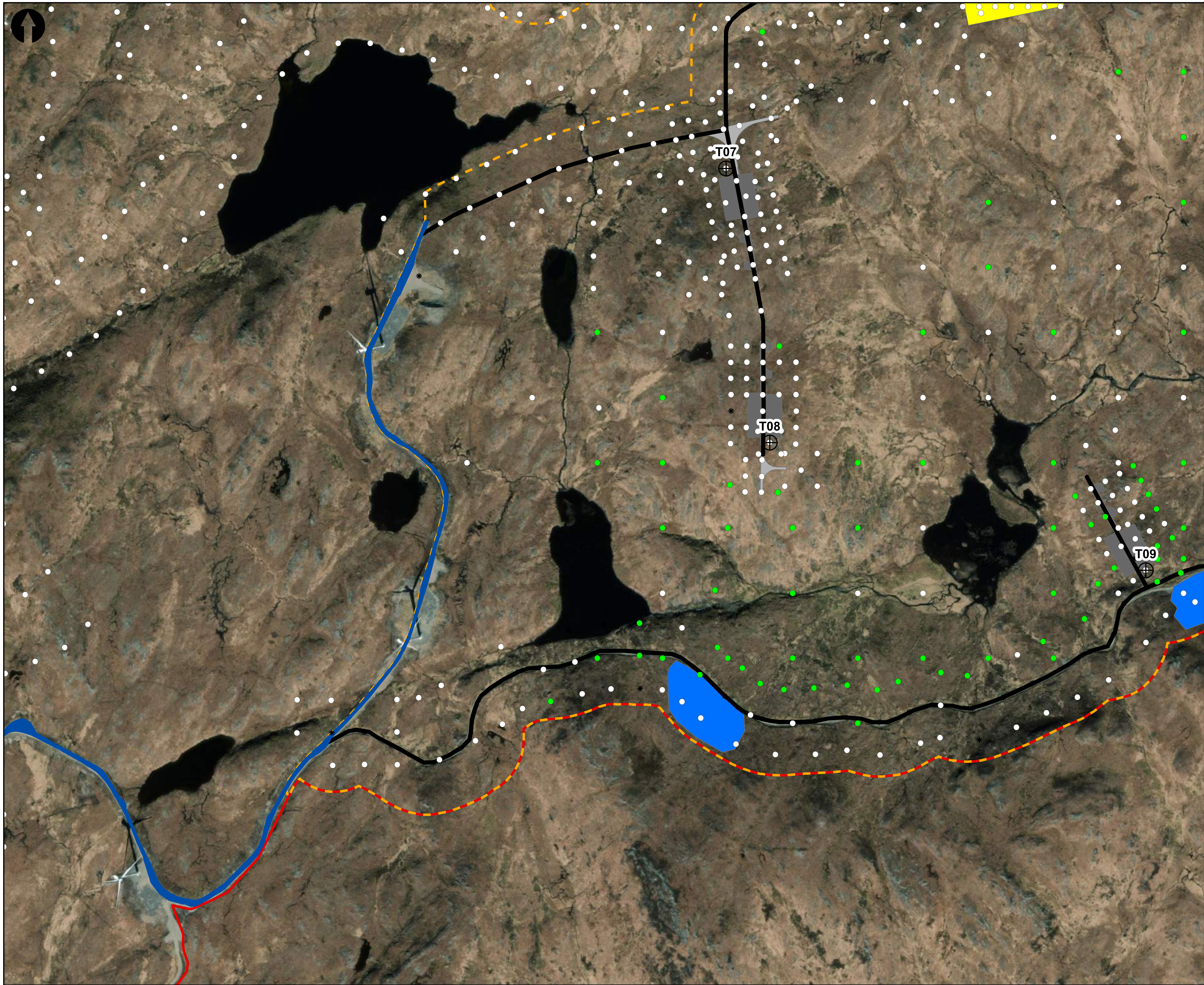
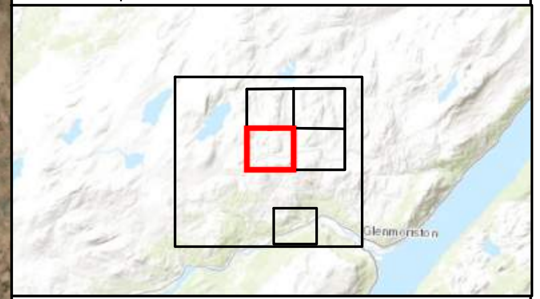


Location Map



Key to Symbols

- 18Turbine Layout

Risk

- Very Low
- Low
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- High
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Title

Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Page 2

Designed	S Eyers-Young	Eng Check	K Young
Drawn	S Eyers-Young	Coordination	A Tourish
GIS Check	J.Lawrie	Approved	G McPake

Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

0 100 200 m

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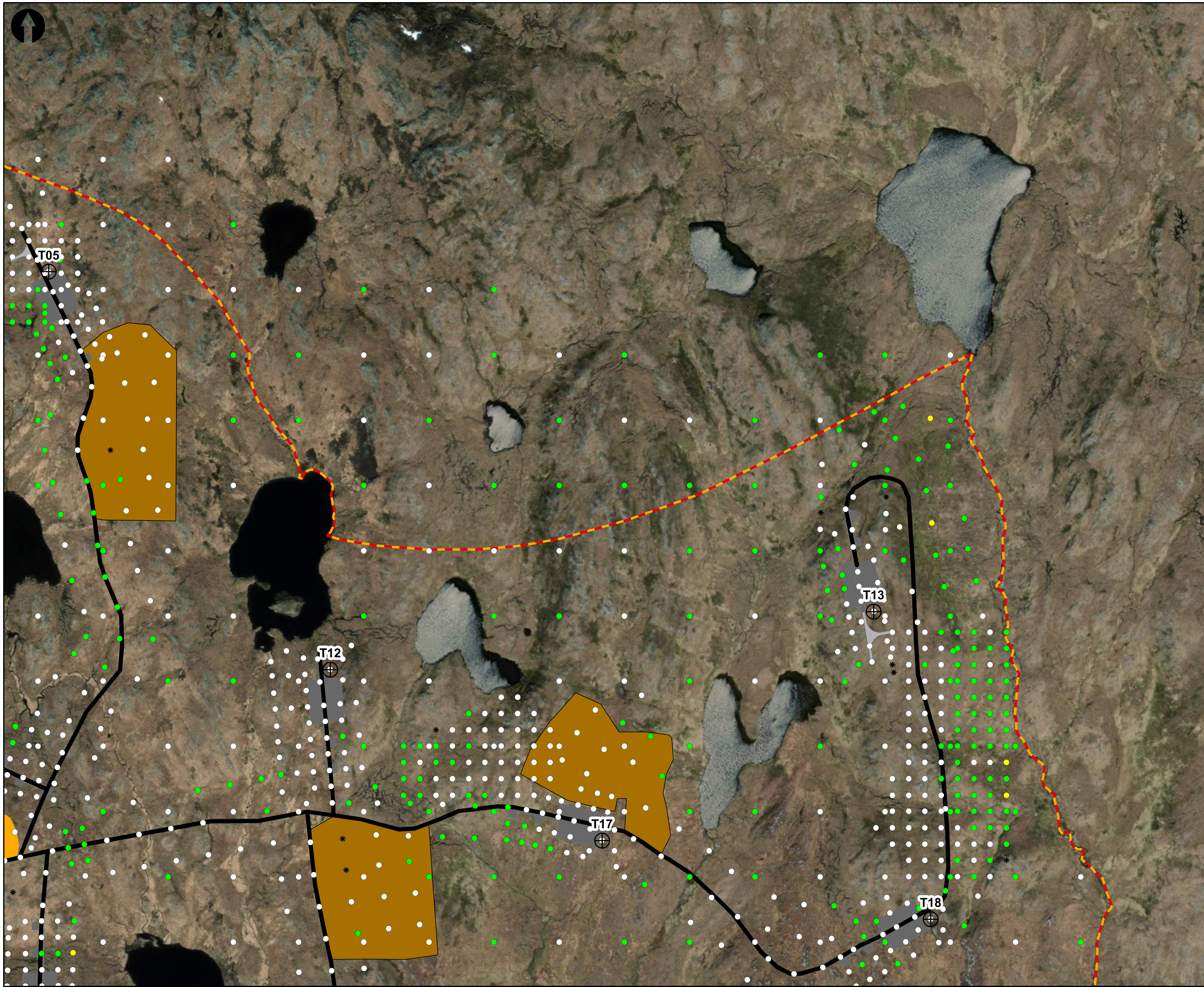
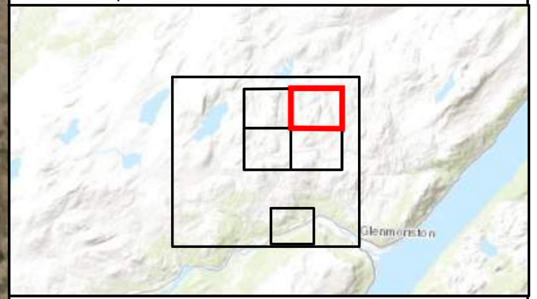


Location Map



Key to Symbols

- 18Turbine Layout

Risk

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Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Page 3

Designed	S Eyers-Young	Eng Check	K Young
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Scale at A3	Status	Rev	Security
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0 100 200 m

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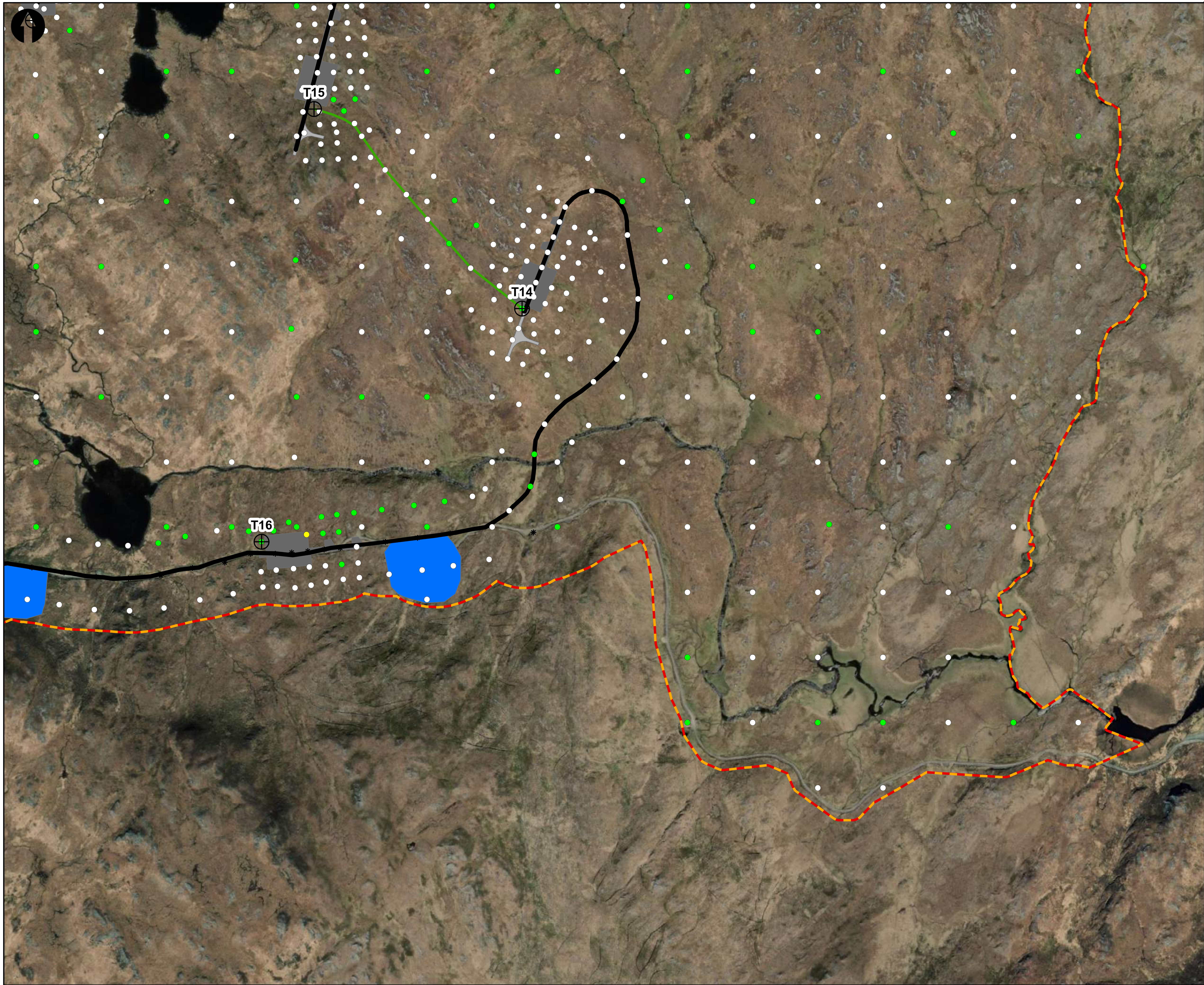

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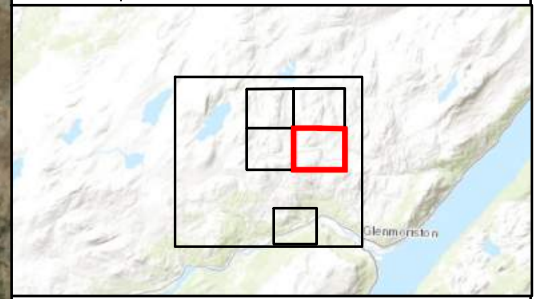

Key to Symbols

- 18Turbine Layout
- **Risk**
- Very Low
- Low
- Medium
- High
- Very High
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Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Page 4

Designed	S Eyers-Young	Eng Check	K Young
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Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

Drawing Number
MMD-100410845-DR-PSRA-GIS-004

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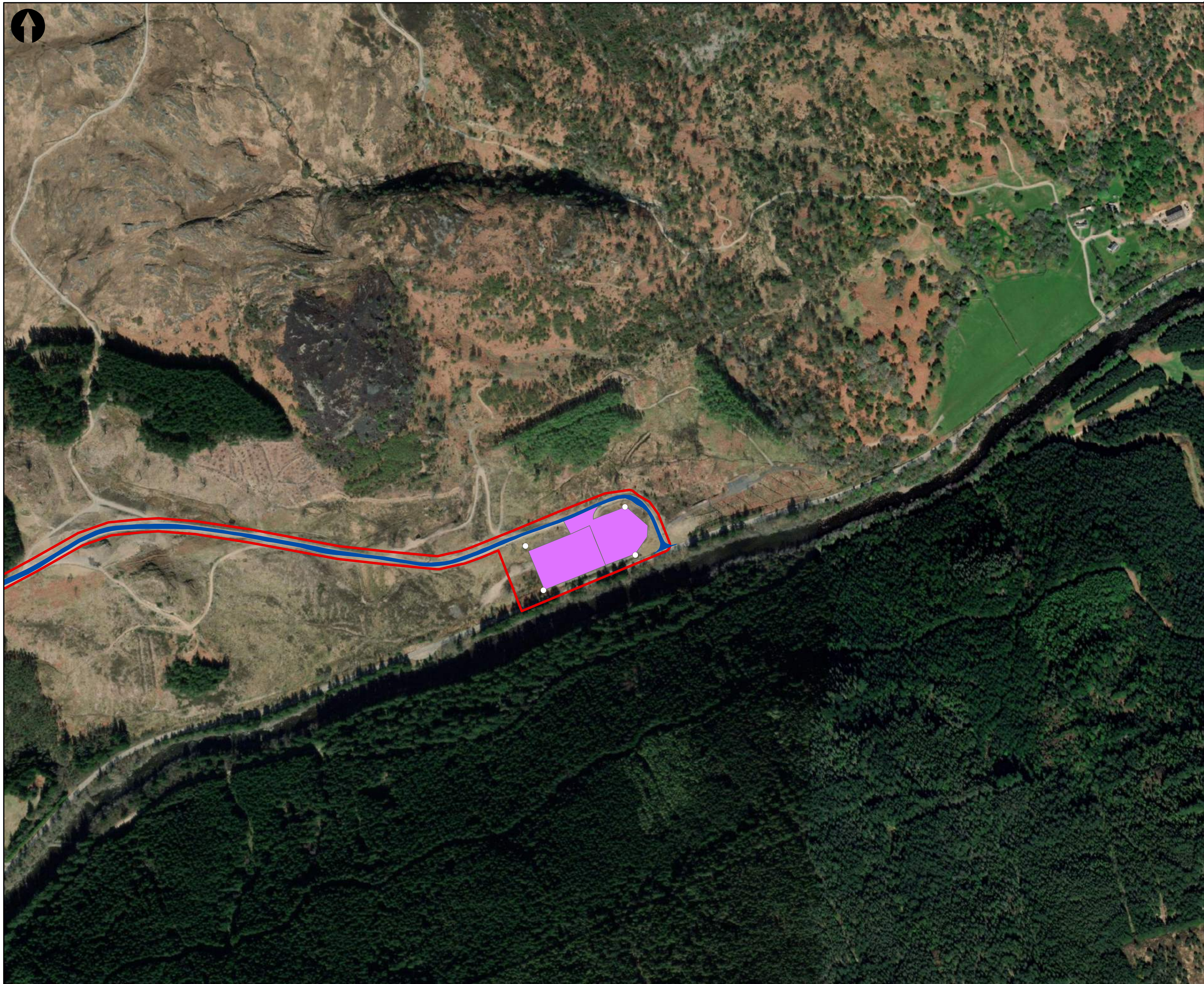
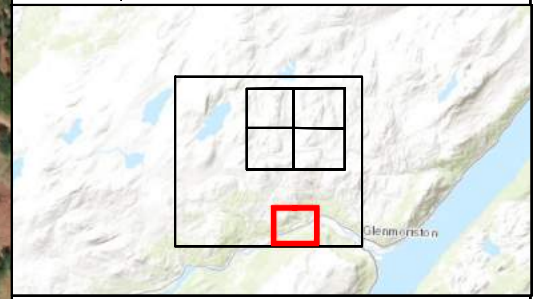


Location Map



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Bhlaraidh Wind Farm Extension
Figure A.4 Overall Peat Slide Risk Rating
Peat Stability Risk Assessment (PSRA)

Page 5

Designed	S Eyers-Young	Eng Check	K Young
Drawn	S Eyers-Young	Coordination	A Tourish
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Scale at A3	Status	Rev	Security
1:5,500	FI	02	STD

Drawing Number
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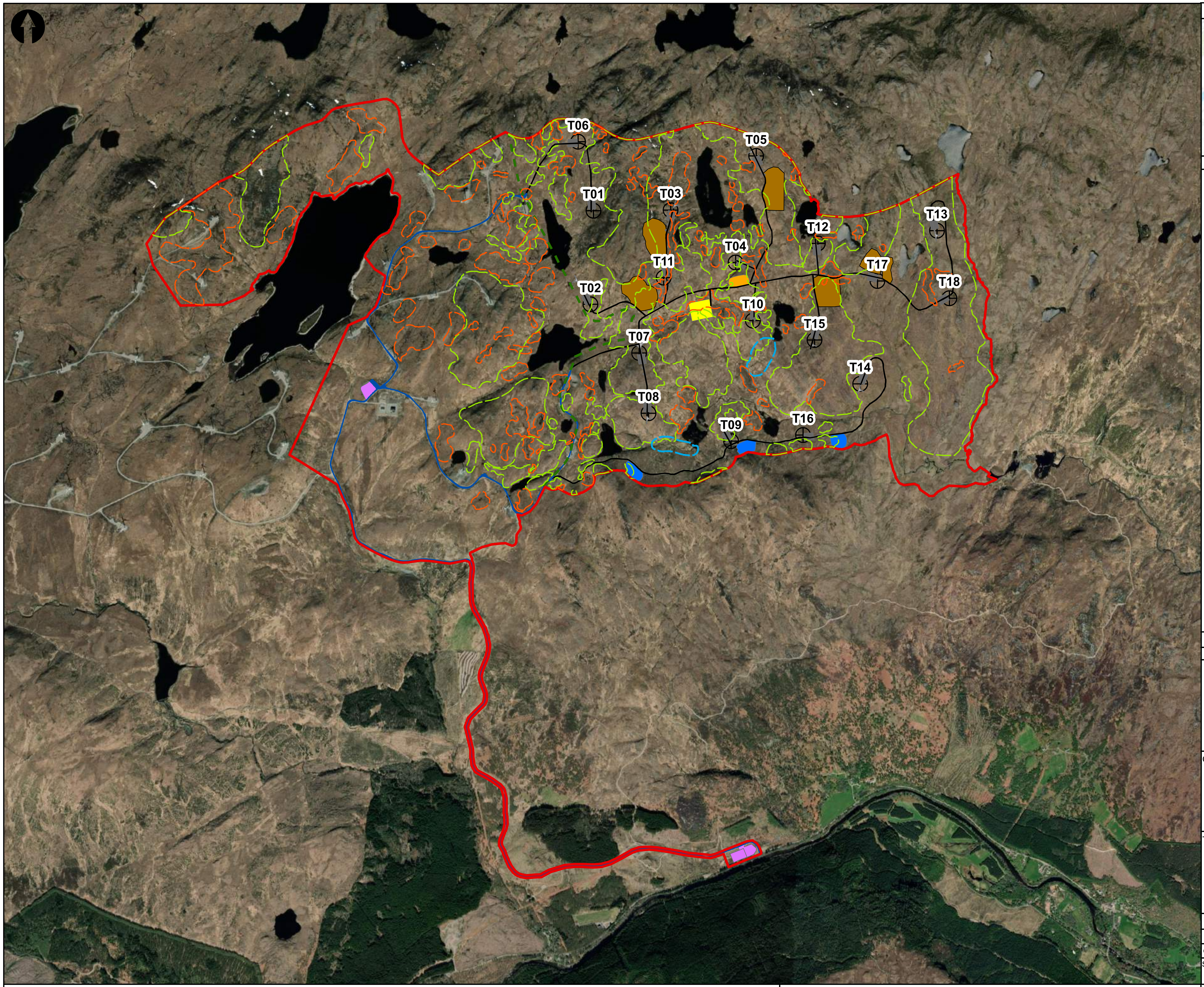
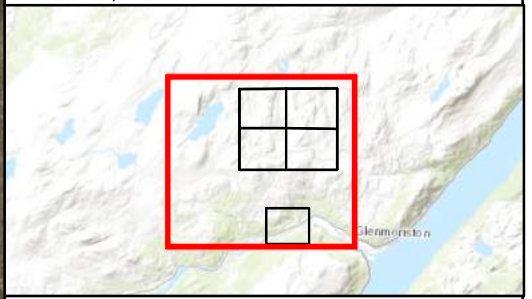
0 100 200 m



Location Map



Key to Symbols

- Peat Hags
- Dendritic Drainage
- Bedrock Exposed
- Site Boundary
- Turbine Development Area
- Access Route via Existing Wind Farm Track
- Proposed Track
- BHLX Compound
- BHLX Batching Plant Search Area
- BHLX Substation
- BHLX TurningHead
- BHLX Hardstanding
- BHLX Hydro Borrowpit Search Area
- BHLX Borrowpit Search Area
- 18Turbine Layout
- Site Boundary

Rev	Date	Drawn	Description	Ch'k'd	App'd
02	17/08/21	SEY	For Information	KY	GMcP

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Bhlaraidh Wind Farm Extension
Figure A.4 Geomorphology
Peat Stability Risk Assessment (PSRA)

Overview

Designed	S Eyers-Young	Eng Check	A Tourish
Drawn	S Eyers-Young	Coordination	S Eyers-Young
GIS Check	J.Lawrie	Approved	G McPake

Scale at A3	Status	Rev	Security
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Drawing Number
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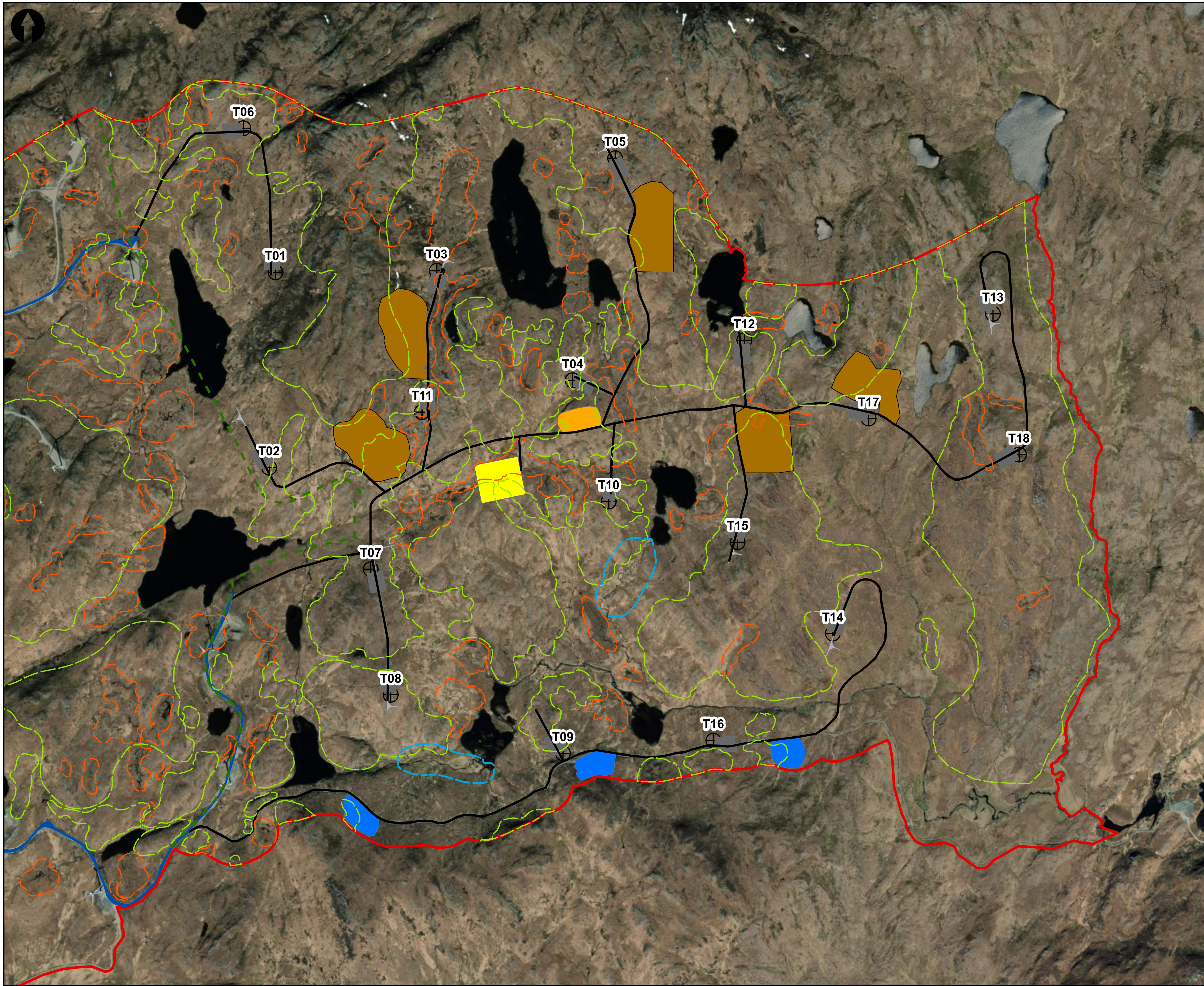

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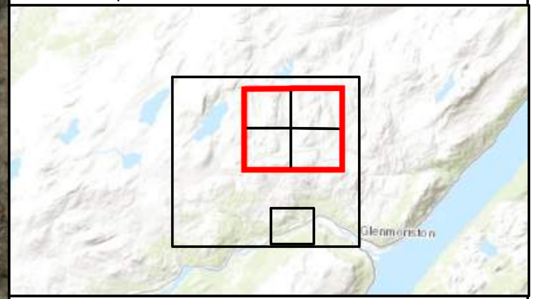

Key to Symbols

- Peat Hags
- Dendritic Drainage
- Bedrock Exposed
- Site Boundary
- Turbine Development Area
- Access Route via Existing Wind Farm Track
- Proposed Track
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Bhlaraidh Wind Farm Extension
Figure A.4 Geomorphology
Peat Stability Risk Assessment (PSRA)
Turbine Development Area

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Scale at A3	Status	Rev	Security
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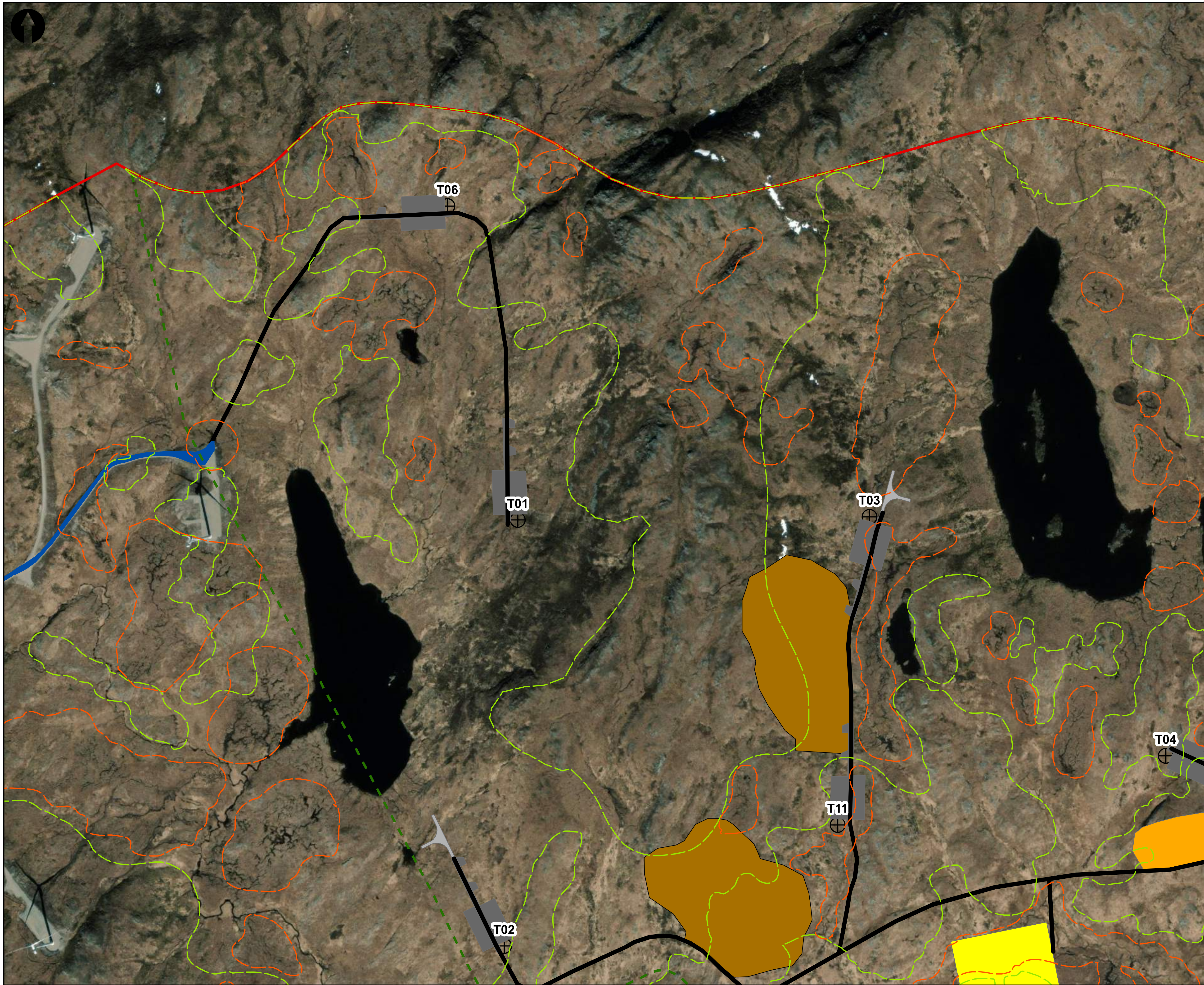

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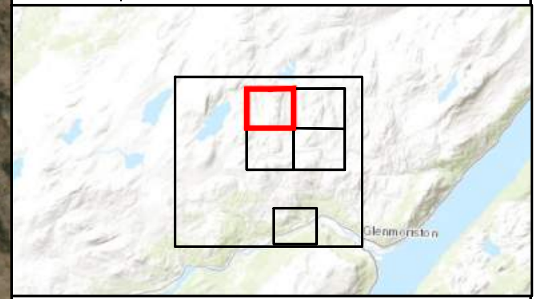

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Peat Stability Risk Assessment (PSRA)
Page 1

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Drawing Number
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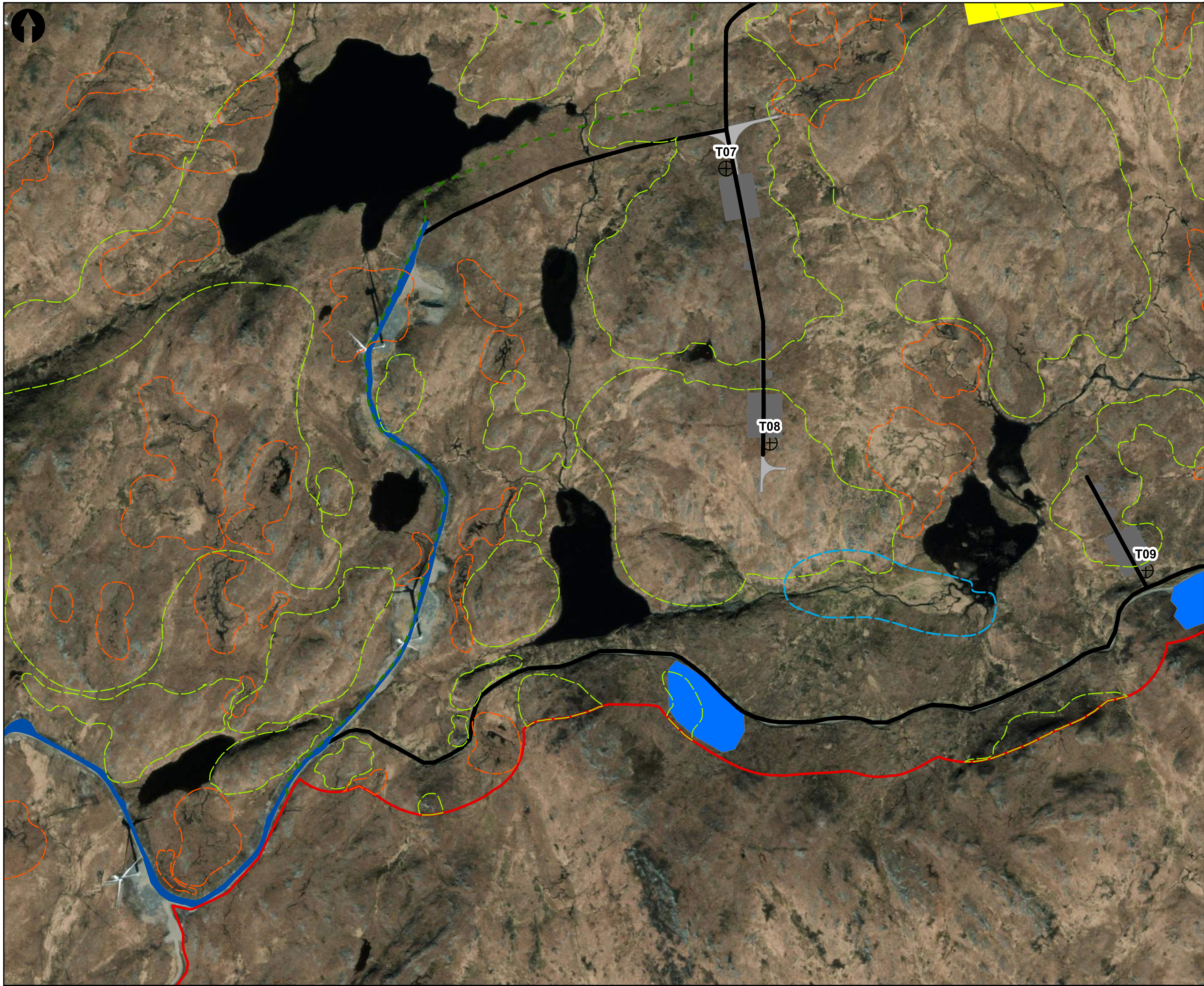

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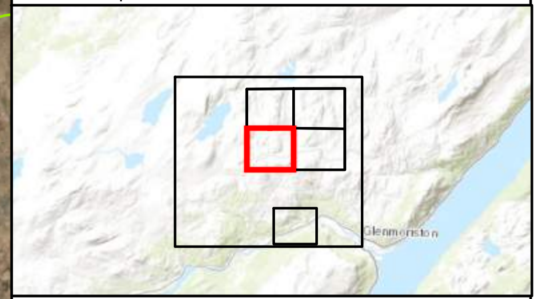

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Figure A.4 Geomorphology
Peat Stability Risk Assessment (PSRA)

Page 2

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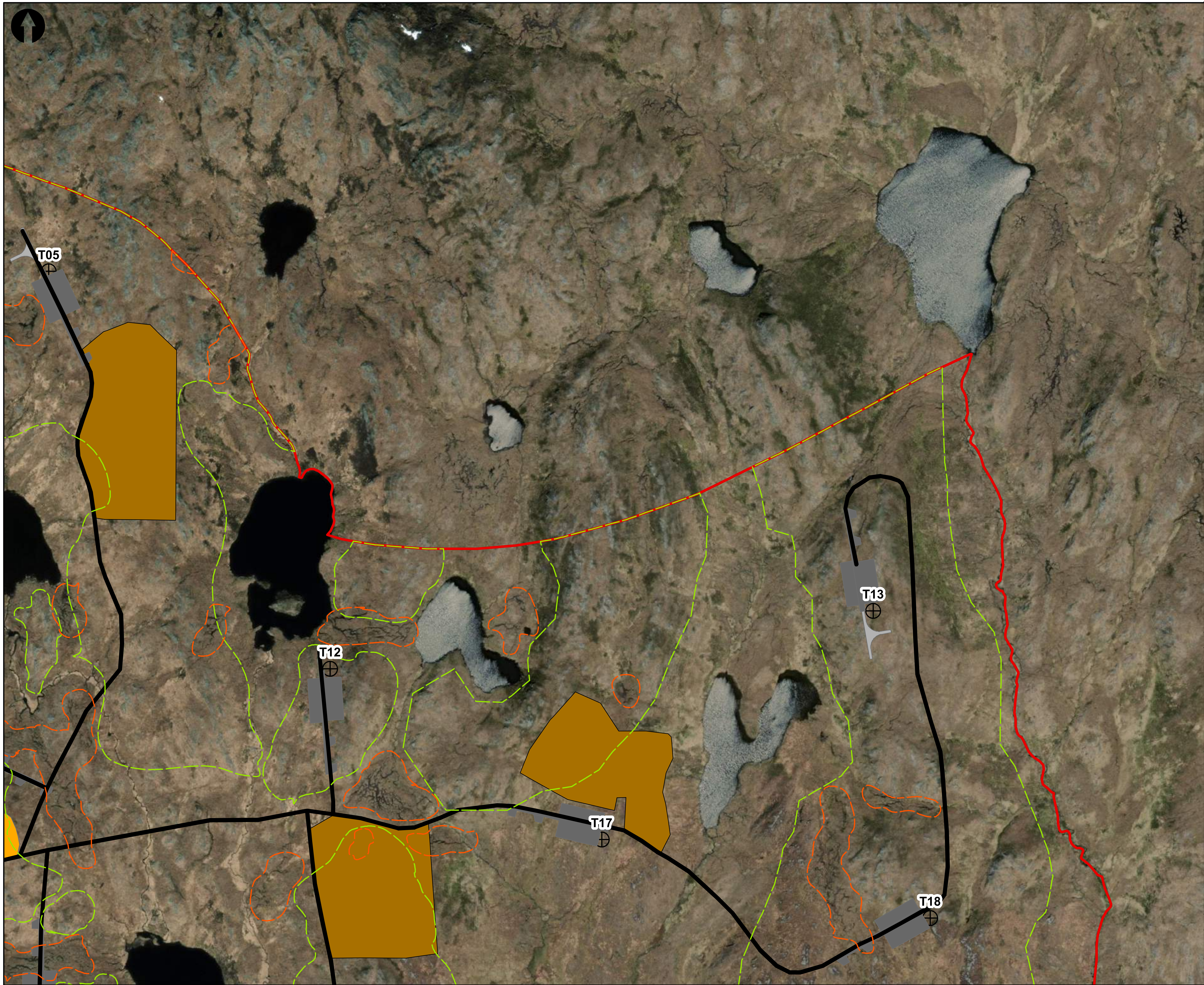
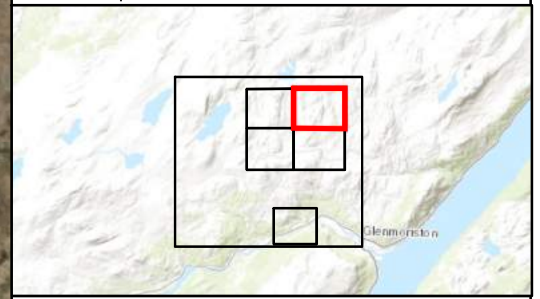


Location Map



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Page 3

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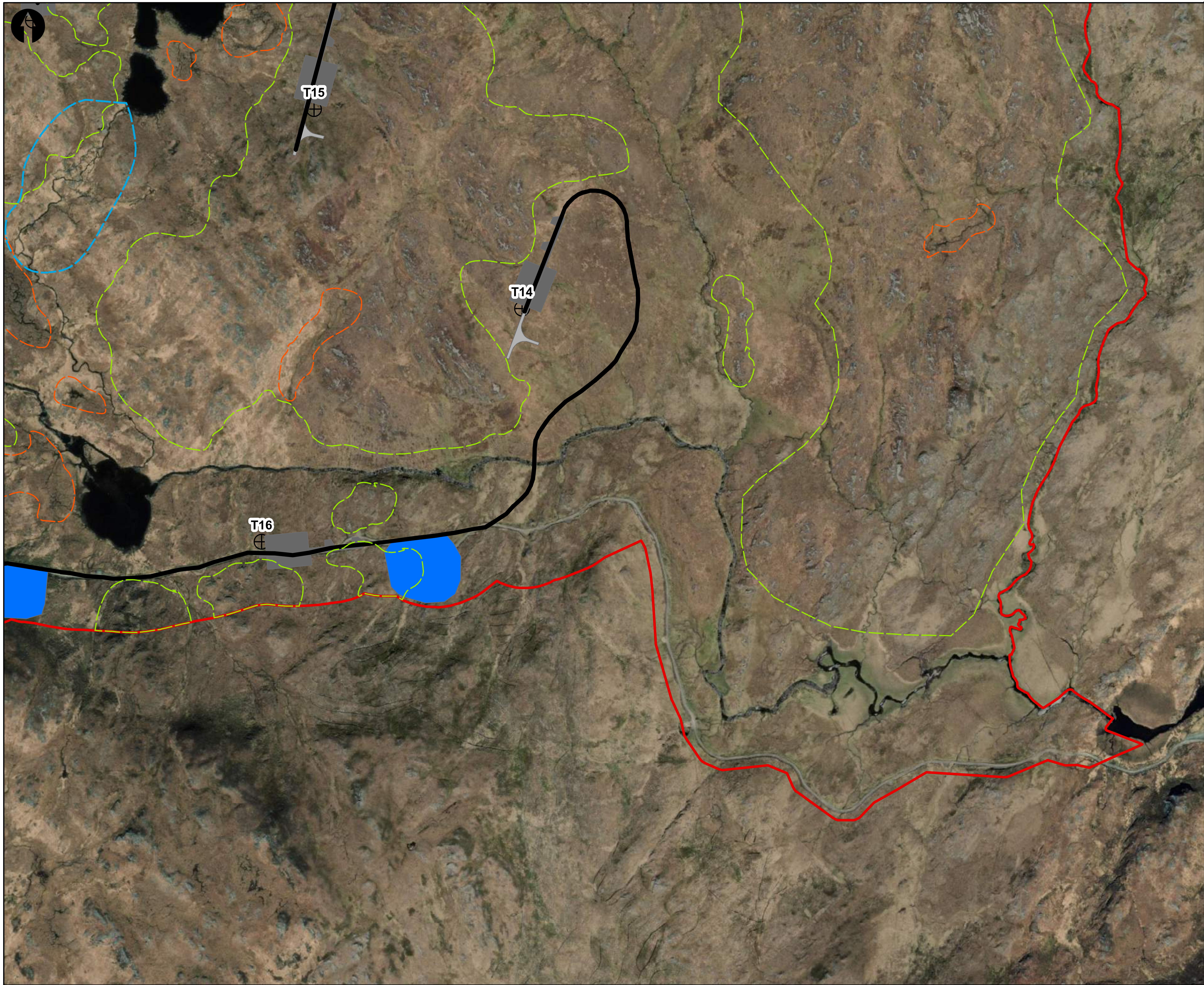

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Page 4

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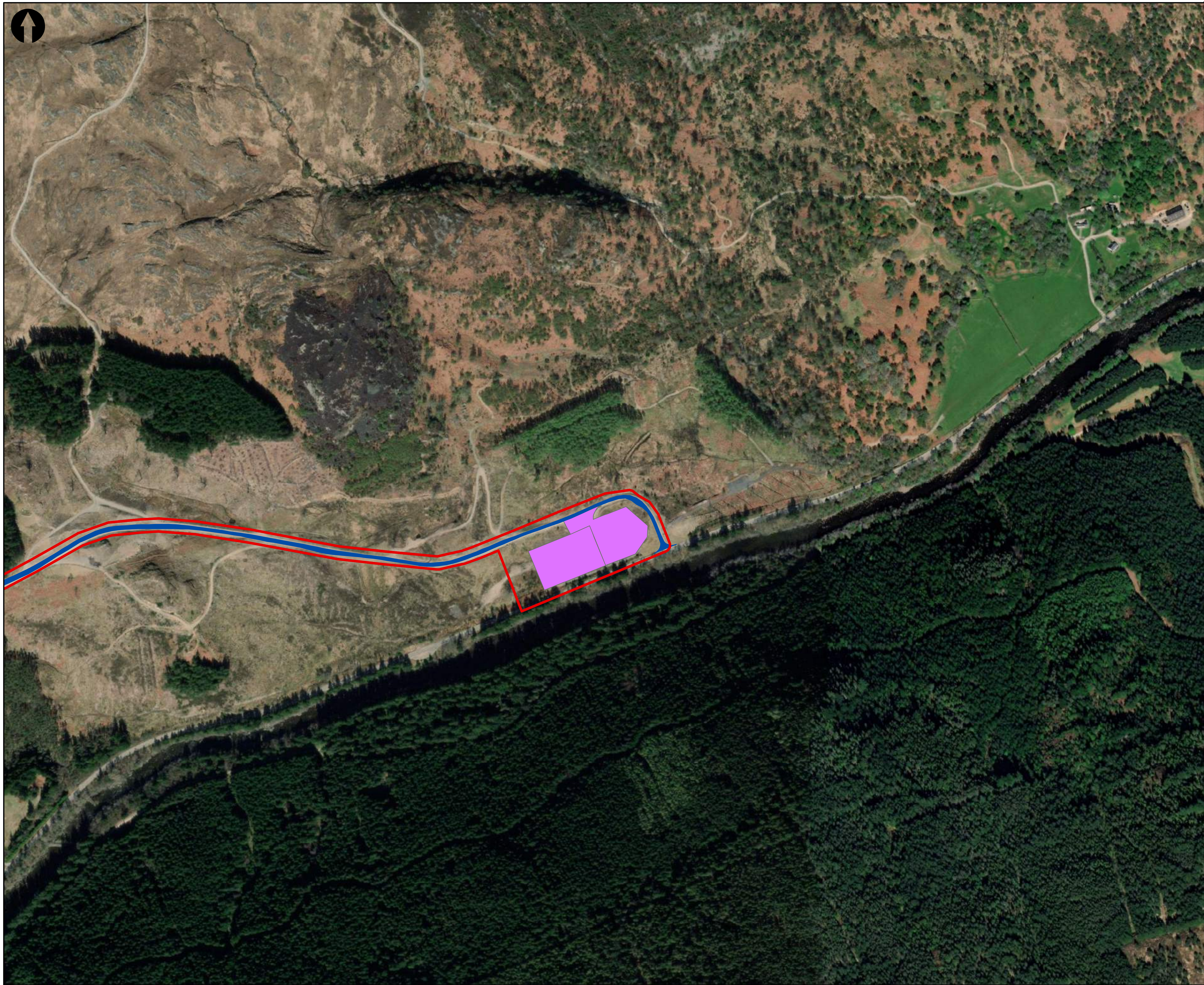
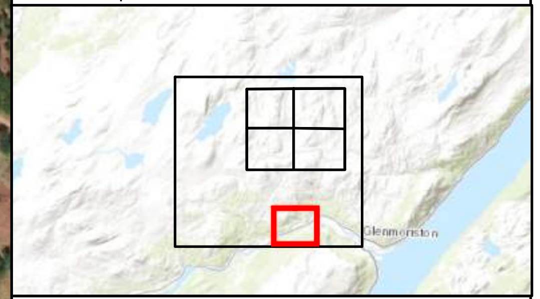


Location Map



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Page 5

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1:5,500	FI	02	STD

0 100 200 m

Drawing Number
MMD-100410845-DR-PSRA-GIS-005

B. Pre-construction Geotechnical Risk Register

<table>
<tr><td colspan="3">RISK REGISTER:</td><td colspan="9">Bhlaraidh Wind Farm Extension
Pre-construction Geotechnical Risk Register (Peat Stability)</td></tr>
<tr><td colspan="3">DATE OF ASSESSMENT:</td><td colspan="7">March 2021</td><td>Rev:</td><td>A</td></tr>
<tr><td rowspan="2">RISK ID</td><td rowspan="2">Description</td><td rowspan="2">Hazard</td><td rowspan="2">Mechanism</td><td rowspan="2">Potential Consequence</td><td rowspan="2">Potential Risk Control Measures / Actions to Mitigate</td><td colspan="2">Impact</td><td colspan="2">Likelihood</td><td rowspan="2">Residual Risk</td><td rowspan="2">Further Work to Reduce Risk</td></tr>
<tr><td>No Mitigation</td><td>With Mitigation</td><td>No Mitigation</td><td>With Mitigation</td></tr>
<tr><td>A1.1</td><td>Excavation at substation</td><td>Soft ground</td><td>Movement/tracking of plant within and around the substation location.</td><td>Time lost by plant sinking into soft ground and potential damage to habitat and instability.</td><td>Delineate areas acceptable for tracking plant and avoid unnecessary tracking on soft ground.</td><td>M</td><td>L</td><td>M</td><td>L</td><td>L</td><td></td></tr>
<tr><td>A1.2</td><td>Cut Track Construction</td><td>Slope failure</td><td>Excavation of peat mass leads to pooling / damming of water which removes frontal resistance to translational sliding.</td><td>Translational peat mass slide as a result of build-up of water increasing pore water pressures in peat, and lowering resistance to failure.</td><td>Minimise excavations in peat >1.0 m deep across slopes without further analysis at detailed design stage.
Ensure that robust drainage management systems are in place.</td><td>M</td><td>M</td><td>L</td><td>VL</td><td>L</td><td></td></tr>
<tr><td>A1.3</td><td>Cut Track Construction</td><td>Slope failure</td><td>Stockpiling of peat spoil adjacent to full depth pavement design increases load onto peat mass.</td><td>Both slope and peat spoil become unstable.</td><td>No stockpiling of excavated peat adjacent to tracks in locations where peat has been identified.</td><td>M</td><td>L</td><td>L</td><td>VL</td><td>L</td><td></td></tr>
</table>

RISK REGISTER:			Bhlaraidh Wind Farm Extension Pre-construction Geotechnical Risk Register (Peat Stability)								
DATE OF ASSESSMENT:			March 2021							**Rev:**	A
RISK ID	**Description**	**Hazard**	**Mechanism**	**Potential Consequence**	**Potential Risk Control Measures / Actions to Mitigate**	**Impact**		**Likelihood**		**Residual Risk**	**Further Work to Reduce Risk**
						No Mitigation	**With Mitigation**	**No Mitigation**	**With Mitigation**		
A1.4	Turbine and Crane Hardstanding Excavations	Slope failure	Excavation of peat leading to removal of frontal resistance to translational sliding.	Translational peat mass slide.	Consider constructing bunds around turbine base excavation to support upslope faces if peat depth >2.0 m or if peat is particularly weak/wet; seek geotechnical advice. Avoid long term excavations, exposure to wet weather and cut back slopes at a suitable angle.	M	L	M	VL	L	
A1.5	Turbine and Crane Hardstanding Excavations	Slope failure	Turbine base excavation in localised saturated deep peat >1.5 m (e.g. potentially at turbines T2, T6, T8, T9, T10, T11 and T13) with water inflow from sides of excavation.	Slumping of sides and loss of frontal resistance.	Install drainage upslope of excavation to divert water flows, therefore minimising the amount of water that can enter the excavation. Excavation to remain open for as little time as possible.	M	M	M	L	L	
A1.6	Turbine and Crane Hardstanding Excavations	Slope failure	Stockpiling of peat spoil adjacent to turbine excavation increases load onto peat mass.	Both slope and peat spoil become unstable.	No stockpiling of excavated peat >2.5 m thick or spoil >1.5 m thick on areas where peat has been identified, unless detailed assessment is undertaken.	M	L	M	L	L	

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						No Mitigation	**With Mitigation**	**No Mitigation**	**With Mitigation**		
A1.7	Access Track (Cutting)	Soil and Rock Slope Instability (Flooding)	Intense or prolonged precipitation causing significant overland surface water flow.	Erosion of slope surface and instability.	Ensure maintenance programme in place for slope and drainage structures, visual inspection of slopes within windfarm site following heavy precipitation event.	M	L	M	L	L	
A1.8	Access Track (Cutting)	Soil and Rock Slope Instability	Slopes cut at a steep angle.	Instability as slope angle returns to equilibrium state through mass wasting.	Ensure maintenance programme in place for slope and drainage structures, visual inspection of slopes within windfarm site following heavy precipitation event.	M	L	M	L	L	
A1.9	Access Track	Excessive/ Differential Settlement	Differing thicknesses of compressible strata/ embankment thicknesses.	break up of in pavement of access track, instability in embankment slopes.	Visually monitor access tracks for damage to running surface indicating excessive settlement. Ensure maintenance programme in place for slope and drainage structures.	M	L	L	VL	L	
A1.10	Access Track (embankment)	Embankment slope instability	Embankment side slopes formed at angles too steep to ensure long term stability of fill material.	Instability in embankment sideslope, damage to access track/ infrastructure sited on embankment.	Embankments visually monitored to warn of potential instability.	M	L	L	VL	L	
A1.11	Access Track (embankment)	Embankment slope instability (Flooding)	Intense or prolonged precipitation can lead to oversaturation of fill mass, increase in porewater pressures, then failure.	Instability in embankment sideslope, damage to access track/ infrastructure sited on embankment.	Ensure maintenance programme in place for slope and drainage structures, visual inspection of slopes within windfarm site following heavy precipitation event.	M	L	L	VL	L	

RISK REGISTER:			Bhlaraidh Wind Farm Extension Pre-construction Geotechnical Risk Register (Peat Stability)								
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A1.12	Drainage Structures (maintenance)	Slope failure	Excavation of drainage ditches in peat mass removes frontal resistance to translational sliding.	Translational failure of peat mass.	Ensure that no excavations are made parallel to contour lines within peat areas, without further risk assessment.	M	M	M	L	L	
A1.13	Drainage Structures (maintenance)	Slope failure; Flooding	Excavation of drainage ditches in peat mass creates saturated zones in previously dry peats i.e. cutting of the peat top mat.	Increased saturation moisture content levels causing localised translational failure of peat mass.	Ensure that no excavations are made parallel to contour lines within peat areas, without further risk assessment.	M	M	M	L	L	
A1.14	Drainage Structures	Slope failure; Flooding	Blockage of drainage structures leading to oversaturation of peat upslope.	Increased porewater pressure resulting in translational failure of peat mass.	Ensure maintenance programme in place to rapidly clear blockages with minimum impact should any occur.	M	M	M	VL	L	
A1.15	Entire Site	Slope failure; Flooding	Intense or prolonged precipitation can lead to oversaturation of peat mass, increase in porewater pressures, then failure.	Translational failure of peat mass.	Ensure drainage maintenance programme in place to rapidly clear blockages with minimum impact should any occur.	M	M	L	L	L	
A1.16	Entire Site	Slope failure; Flooding	Desiccation cracks in peat mass can assist rapid transfer of surface waters towards peat base (as a result of an intense rainfall event following a prolonged period of dry weather).	Translational failure of peat mass.	Ensure drainage maintenance programme in place.	M	M	L	L	L	

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						No Mitigation	**With Mitigation**	**No Mitigation**	**With Mitigation**		
A1.17	Entire Site (maintenance)	Peat slide	Excavation of drainage ditches in peat mass removes frontal resistance to translational sliding.	Translational failure of peat mass.	Ensure that no excavations are made parallel to contour lines within peat areas, without further risk assessment.	M	M	L	VL	L	
A1.18	Entire Site (maintenance)	Peat slide	Excavation of peat mass leads to pooling / damming of water which removes frontal resistance to translational sliding.	Translational failure of peat mass.	Ensure that no excavations are made parallel to contour lines within peat areas, without further risk assessment.	M	M	L	VL	L	
A1.19	Peat Spoil Storage (if required)	Ground instability at peat storage area	Failure of stockpile due to loading.	Failure of walls leading to escape of stockpiled peat material.	Stockpile to be designed by competent engineering geologist / geotechnical engineer with an understanding of ground conditions, slope stability and hydrology of peat.	M	L	L	VL	L	
A1.20	Borrow Pit Excavation	Shear failure of peat surface	Blasting rock from borrow pits causes ground vibrations, which exceeds peat shear strength locally, leading to failure.	Damage to borrow pit construction. Initiation of peat mass movement, which could lead to downstream sedimentation and damage to infrastructure.	Alternative excavation methods should be considered. Blasting shall be designed and controlled by an appropriate competent person.	M	M	L	VL	L	

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RISK ID	Description	Hazard	Mechanism	Potential Consequence	Potential Risk Control Measures / Actions to Mitigate	No Mitigation	With Mitigation	No Mitigation	With Mitigation	Residual Risk	Further Work to Reduce Risk
A1.21	Entire Site	Slope failure; Flooding	Intense or prolonged precipitation can lead to oversaturation of peat mass, increase in pore water pressures, then failure.	Translational failure of peat mass.	Frequently monitor weather forecast for area. Phase works to ensure no works to be carried out during intense/prolonged rainfall events.	M	M	M	L	L	
A1.22	Entire Site	Slope failure; Flooding	Desiccation cracks in peat mass can assist rapid transfer of surface waters towards peat base (as a result of an intense rainfall event following a prolonged period of dry weather).	Translational failure of peat mass.	Frequently monitor weather forecast for area. Phase works to ensure that no works are carried out during intense / prolonged rainfall events.	M	M	M	L	L	
A1.23	Culvert construction	Slope failure	Excavation of culvert in peat mass removes frontal resistance to translational sliding.	Translational failure of peat mass.	Ensure that no significant excavations are made parallel to contour lines within peat areas, without further analysis at detailed design stage.	M	VL	L	VL	VL	
A1.24	Culvert construction	Slope failure; Flooding	Excavation of culverts in peat mass creates saturated zones in previously dry peats i.e. cutting of the peat top mat.	Increased pore water pressure causing translational failure of peat mass.	Ensure that no significant excavations are made parallel to contour lines within peat areas, without further analysis at detailed design stage.	M	VL	L	VL	L	

C. Infinite Slope Stability Analysis

C.1 Infinite Slope Stability Analysis

Peat slides can be modelled using a failure mechanism similar to translational slips. According to Craig (Ref. [20]) '*translational slips' tend to occur where the adjacent stratum is at a relatively shallow depth below the surface of the slope: the failure tends to be plane and roughly parallel to the slope.*

The infinite slope analysis method is suitable for translational slip analysis and assumes that the peat failure will be a planar translational failure where failure occurs parallel to the slope surface, and close to the base of the peat.

The stability of a slope (for total stress) can be assessed by calculating a Factor of Safety (FoS), which is a ratio sum of resisting forces (soil strength) and the sum of destabilising forces (weight of soil mass):

$$FoS = \frac{s_u}{\gamma \cdot z \cdot sin\beta \cdot cos\beta}$$

Where,

s_u = undrained shear strength
γ = bulk unit weight of saturated peat
γ_w= unit weight of water
m = height of water table as a fraction of the peat depth
z = peat depth
β = angle of the slope to the horizontal

C.1.1 Parameters for Slope Stability Analysis

The following parameters were used in the analysis:-

Undrained shear strength (s_u) – From data specific to this site (in-situ Hand Shear Vane Testing data collected by Mott MacDonald), undrained shear strengths for the peat ranges between 0 kN/m^2 and 43 kN/m^2, please see Figure D.1. The infrastructure layout of the Site has been designed to avoid areas of deep peat; hence areas of amorphous peat have been avoided. For the purposes of the analysis in this report, a shear strength of 10 kN/m^2 has been used to represent a conservative value for undrained shear strength of the peat across the entire Site.

Peat Depth (z) – The peat depths used in the analysis have been obtained from fieldwork, and have been supplemented with in-situ Hand Shear Vane Testing data collected by Mott MacDonald. The depth and Hand Shear Vane data are included within the associated GIS geodatabase.

Bulk Unit Weight (γ) – Based on a review of literature (Ref. [18]) regarding peat properties, a unit weight for saturated peat has been assumed to be approximately 1.05 Mg/m^3.

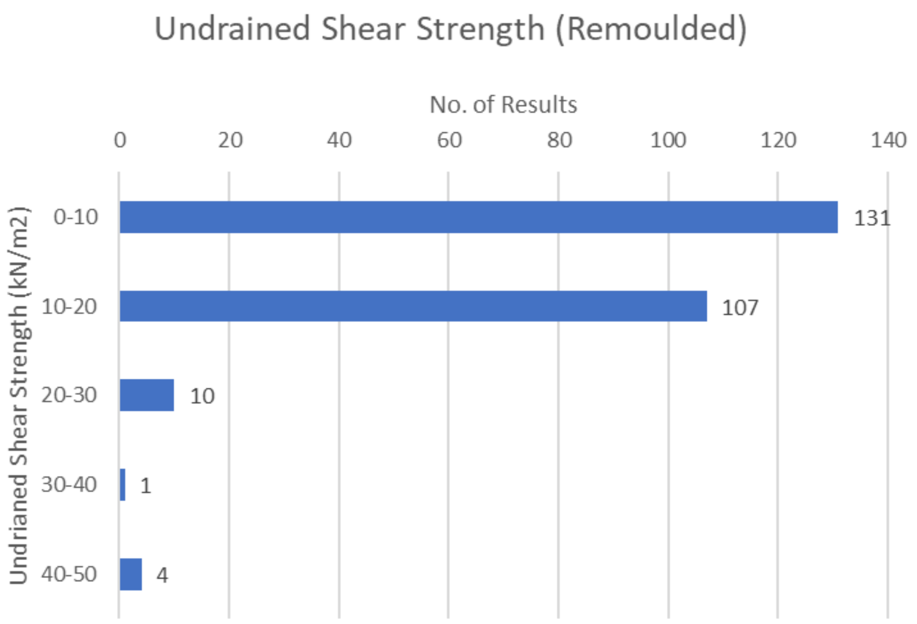
Slope Angle on basal surface (β) – The slope angle of the basal surface has been derived from available surface slope angles. Surface slope angles have been determined using 5 m (xyz) grid data (providing a DTM). Since a translational slip model is being used, it can be assumed that the slope angle of the planar slip surface is roughly parallel to the surface slope angle from the DTM.

Water table (m) – The depth of water table has been assumed to be 0.3m below the surface.

Factor of Safety (FoS) – Approach using BS 6031:1981 (Ref. [21], "suggest that a safety factor between 1.3 and 1.4 should be designed for. For a slide involving entirely pre-existing slip surfaces, but otherwise of similar status, a safety factor of about 1.2 should be provided". For the use of FoS for peat slopes a factor of 1.3 is considered appropriate, when adopting conservative parameters.

Surface Loading – Analysis of the failure at the Derrybrien Wind Farm (Ref. [1]) reported that one of the principal factors influencing the likelihood of failure was "the thickness of the extra material placed on the slope", which refers to the placement of excavated spoil from construction of turbine bases and access tracks being placed on the crest of the slope, which then led to failure in the peat mass. Therefore, increased surface loading on peat deposits can lower the factor of safety leading to a previously stable conditions becoming unstable. For the purposes of this analysis, a conservative peat thickness of 2 m and 3 m of peat spoil placed on peat deposits has been assumed

Figure D.1: Undrained Shear Strength Site Results



Source: Mott MacDoanld

C.1.2 The Analysis

It is recognised that the definition of single representative values for peat is difficult due to variable and relatively complex geotechnical nature of the peat material, however, with regards to reporting, the results of the analysis for value of s_u = 10 kPa are described.

- Total stress (undrained) analysis with no surface loading (section of cut track/upgrade to existing track).

The Factor of Safety for the unloaded 'cut' track case have been calculated using peat thickness at each location and slope angle to the horizontal. The results of the calculations are presented in Table D.1. Results in bold are within 25m of infrastructure.

Table D.1: FoS Analysis Results at Medium Risk Locations

Peat Depth Probe Ref.	Peat Thickness (m)	Slope (º)	Undrained Shear Strength used in FoS Calculation (kPa)	FoS (Unloaded) Undrained
P1-140	**1.90**	**10 to 15**	**10**	**2.01**
P1-172	0.90	>15	10	3.29
P1-309	1.40	10 to 15	10	2.72
P2-198	0.65	>15	10	4.56
P2-343	2.8	6 to 10	10	1.99
P2-352	3.2	6 to 10	10	1.74
P2-427	2.8	3 to 6	10	3.27
P2-580	1.5	10 to 15	10	2.54
P2-672	1.2	6 to 10	10	4.64
P2-843	**1.2**	**6 to 10**	**10**	**4.64**
P2-1333	1.3	10 to 15	10	2.93
P2-1368	1.3	10 to 15	10	2.93

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