Volume 5: Appendix 13.6 – Peat Landslide Hazard Risk Assessment (PLHRA)

CONTENTS

LIST OF ABBREVIATIONS

AOD: Above Ordnance Datum

BPG: Best Practice Guidance

C: Slope Curvature (contributory factor)

D: Drainage (contributory factor)

DTM: Digital Terrain Model

ECU: Energy Consents Unit

EIA: Environmental Impact Assessment

F: Forestry (contributory factor)

FoS: Factor of Safety

G: Substrate Geology (contributory factor)

GIS: Geographic Information System

kV: Kilovolt

L: Land Use (contributory factor)

LOD: Limit of Deviation

M: Peat Geomorphology (contributory factor)

OHL: Overhead Line

OPMP: Outline Peat Management Plan

P: Peat Depth (contributory factor)

PLHRA: Peat Landslide Hazard and Risk Assessment

S: Slope Angle (contributory factor)

SPL: Peat Landslide Likelihood Score

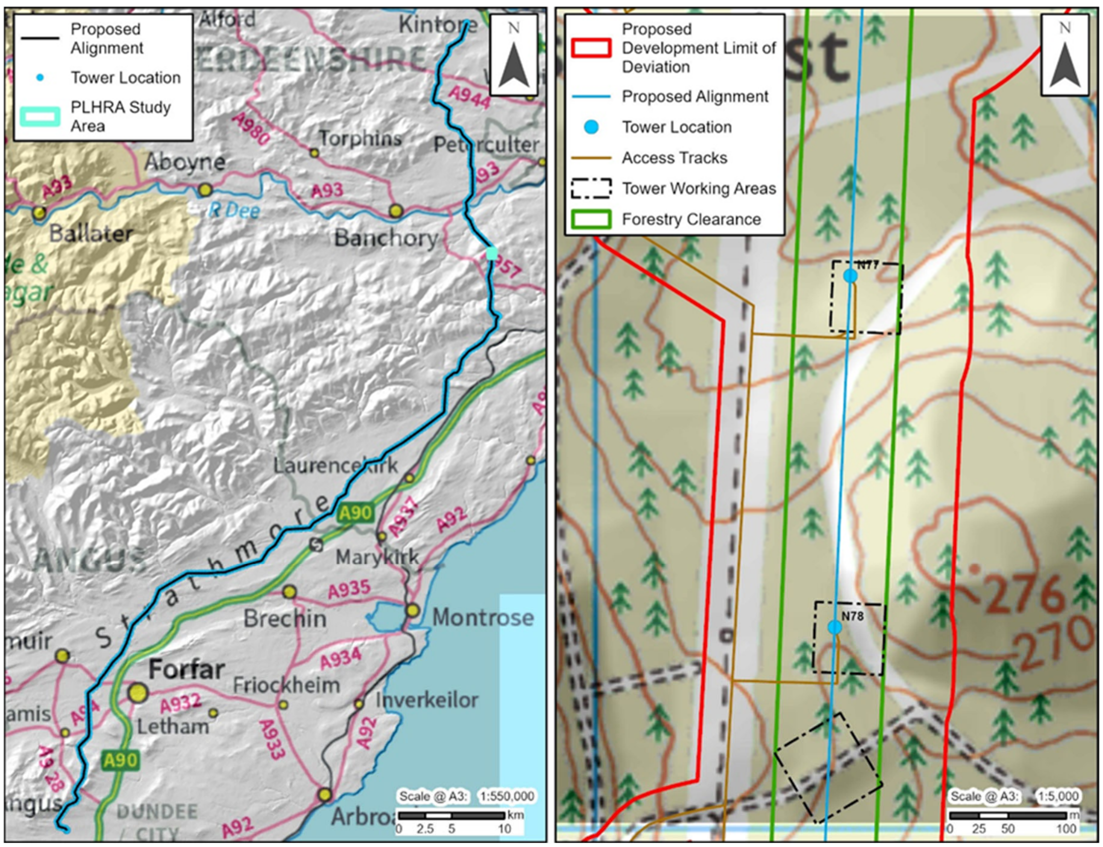
1 INTRODUCTION

1.1 Background

1.1.1 Scottish & Southern Electricity Networks Transmission (SSEN Transmission, the Applicant) is seeking Consent under Section 37 of the *Electricity Act 1989* and deemed planning permission under the *Town and Country Planning (Scotland) Act 1997* for construction of the Kintore to Tealing 400 kilovolt (kV) Overhead Transmission Line (OHL) from Aberdeenshire to Angus (hereafter the 'Proposed Development').

1.1.2 The Proposed Development comprises six sections (A to F) from a new proposed 400 kV substation known as Emmock, near Tealing in the south, to the existing Kintore Substation in the north. The Proposed Development is approximately 105.2 km in length, comprising double circuit 400 kV OHL supported by a combination of suspension and tension towers with associated temporary workings to enable construction and access. Permanent realignment of existing OHLs, a crossing of an existing OHL and temporary OHL diversions are also required. A broad overview of the route is shown on the left panel of **Plate 13.6.1: Proposed Location of Kintore to Tealing 400 kV OHL (left) and the PLHRA Study Area (right)**.

Plate 13.6.1: Proposed Location of Kintore to Tealing 400 kV OHL (left) and the PLHRA Study Area (right)



1.1.3 The *Scottish Government Best Practice Guidance* (BPG) provides a screening tool to determine whether a peat landslide hazard and risk assessment (PLHRA) is required (Scottish Government, 2017)[1]. This is in the form of a flowchart, which indicates that where blanket peat is present, slopes exceed 2° and proposed infrastructure is located on peat, a PLHRA should be prepared. These conditions exist at Towers N77 and N78 and therefore a PLHRA is required for these towers only (see PLHRA Study Area, right panel of **Plate 13.6.1:** Proposed Location of Kintore to Tealing 400 kV OHL (left) and the PLHRA Study Area (right).

[1] Scottish Government, 2017. Peat Landslide Hazard and Risk Assessments, Best Practice Guide for Proposed Electricity Generation Developments (Second Edition). Scottish Government, 84p. [Online] Available at: https://www.gov.scot/binaries/content/documents/govscot/publications/advice-and-guidance/2017/04/peat-landslide-hazard-risk-assessments-best-practice-guide-proposed-electricity/documents/00517176-pdf/00517176-pdf/govscot%3Adocument/00517176.pdf

1.2 Scope of Work

1.2.1 The scope of the PLHRA is as follows:

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

1.2.2 The contents of this PLHRA have been prepared in accordance with the BPG, noting that the guidance "*should not be taken as prescriptive or used as a substitute for the developer's [consultant's] preferred methodology*" (Scottish Government, 2017)[1]. The first edition of the BPG was issued in 2007 and provided an outline of expectations for approaches to be taken in assessing peat landslide risks on wind farm sites. After ten years of practice and industry experience, the BPG was reissued in 2017, though without fundamental changes to the core expectations. A key change was to provide clearer steer on the format and outcome of reviews undertaken by the Energy Consents Unit (ECU) checking authority and related expectations of report revisions, should they be required.

1.2.3 In Section 4.1 of the BPG, the key elements of a PLHRA are highlighted, as follows (Scottish Government, 2017)[1]:

i. an assessment of the character of the peatland within the application boundary including thickness and extent of peat, and a demonstrable understanding of site hydrology and geomorphology;
ii. an assessment of evidence for past landslide activity and present-day instability eg pre-failure indicators;
iii. a qualitative or quantitative assessment of the potential for or likelihood of future peat landslide activity (or a landslide susceptibility or hazard assessment);
iv. identification of receptors (eg habitats, watercourses, infrastructure, human life) exposed to peat landslide hazards; and
v. a site-wide qualitative or quantitative risk assessment that considers the potential consequences of peat landslides for the identified receptors.

1.2.4 Section 3 of **Volume 5, Appendix 13.4: Outline Peat Management Plan (PMP)** details how the spatial scope of the OPMP and this PLHRA was refined to the Tower N77 and N78 area due to widespread absence of peat over the vast majority of the route. A combination of the Carbon and Peatland (2016) Map, 1:50,000 Scale BGS superficial geology data and interpretation of textures on satellite imagery was used to undertake an initial screening exercise for Phase 1 peat depth probing. Where probing confirmed the presence of peat in the vicinity of infrastructure, detailed probing was subsequently undertaken to support the OPMP and PLHRA. Of Sections A to F of the proposed route, only sections E and F evidenced peat, and only section E in the vicinity of infrastructure - that area being assessed in this report.

1.3 Report Structure

1.3.1 This report is structured as follows:

- **Section 2** gives context to the landslide risk assessment methodology through a literature based account of peat landslide types and contributory factors, including review of any published or anecdotal information available concerning previous instability at or adjacent to the Site.
- **Section 3** provides a site description based on desk study and site observations, including consideration of aerial or satellite imagery, digital elevation data, geology and peat depth data.
- **Section 4** describes the approach to and results of an assessment of peat landslide likelihood under both natural conditions and in association with construction of the Proposed Development.

- **Section 5** provides mitigation and control measures to reduce or minimise risks prior to, during and after construction.

1.3.2 Assessments within the PLHRA have been undertaken alongside assessments for **Volume 5, Appendix 13.4: Outline Peat Management Plan (PMP)** and have been informed by results from **Volume 5, Appendix 13.3: Peat Depth Survey Report**. Where relevant information is available elsewhere in the Environmental Impact Assessment Report (EIAR), this is referenced in the text rather than repeated in this report.

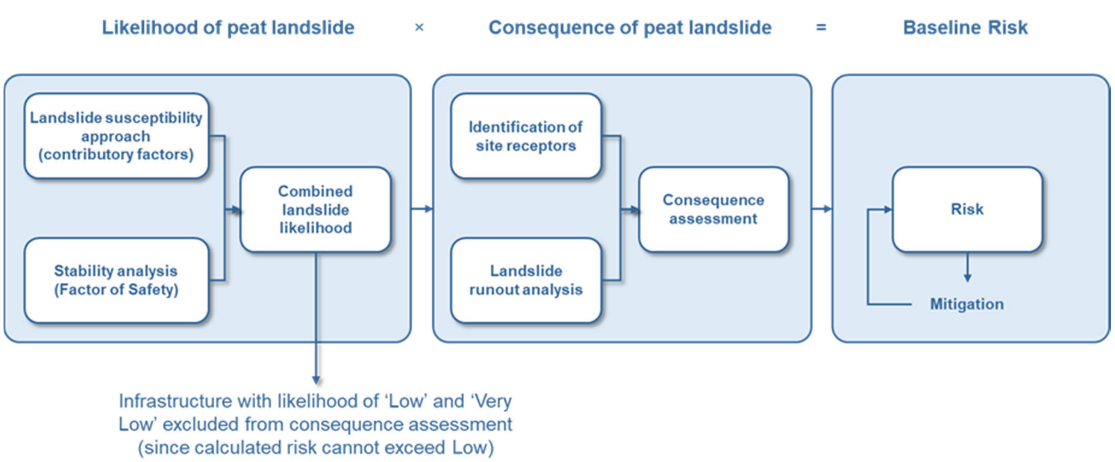
1.4 Approaches to Assessing Peat Instability for the Proposed Development

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

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

1.4.3 To reflect these limitations, both approaches are adopted and outputs from each approach integrated in the assessment of landslide likelihood. **Plate 13.6.2: Risk Assessment Approach** shows the approach:

Plate 13.6.2: Risk Assessment Approach



1.5 Statement of Qualifications

1.5.1 The PLHRA has been undertaken by a Chartered Geologist (CGeol) and peatland geomorphologist with 27+ years experience of mapping and interpreting peatlands and peat landslides. Peat depth probing has been undertaken by an experienced peatland survey team (Kaya Consulting).

2 BACKGROUND TO PEAT INSTABILITY

2.1 Peat Instability in the UK and Ireland

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

2.1.2 Peat instability, or peat landslides, are a widely documented but relatively rare mechanism of peatland degradation that may result in damage to peatland habitats, potential losses in biodiversity and depletion of peatland carbon stores (Evans & Warburton, 2007)[2]. Public awareness of peat landslide hazards increased significantly following three major peat landslide events in 2003, two of which had natural causes and one occurring in association with a wind farm.

2.1.3 On 19 September 2003, multiple peat landslide events occurred in Pollatomish (Co. Mayo, Ireland; Creighton and Verbruggen, 2003)[3] and in Channerwick in the Southern Shetland Islands (Mills et al, 2007)[4]. Both events occurred in response to intense rainfall, possibly as part of the same large-scale weather system moving northeast from Ireland across Scotland. The former event damaged several houses, a main road and washed away part of a graveyard. Some of the landslides were sourced from areas of turbary (peat cutting) with slabs of peat detaching along the cuttings. The landslides in Channerwick blocked the main road to the airport and narrowly missed traffic using the road. Watercourses were inundated with peat, killing fish inland and shellfish offshore (Henderson, 2005)[5].

2.1.4 In October 2003, a peat failure occurred on an afforested wind farm site in Derrybrien, County Galway, Ireland, causing disruption to the site and large-scale fish kill in the adjoining watercourses (Lindsay and Bragg, 2004)[6].

2.1.5 The Derrybrien event triggered interest in the influence of wind farm construction and operation on peatlands, particularly in relation to potential risks arising from construction induced peat instability. In 2007, the (then) Scottish Executive published guidelines on peat landslide hazard and risk assessment in support of planning applications for wind farms on peatland sites. While the production of PLHRA reports is required for all Section 37 energy projects on peat, they are now also regarded as best practice for smaller wind farm applications. The guidance was updated in 2017 (Scottish Government, 2017)[1].

2.1.6 Since then, a number of peat landslide events have occurred both naturally and in association with wind farms (eg **Plate 13.6.3: Characteristic Peat Landslide Types in UK and Irish Peat Uplands**: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: iii) peat slide adjacent to turbine foundation, iv) spreading around foundation, v) spreading upslope of cutting). In the case of wind farm sites, these have rarely been reported, however landslide scars of varying age are visible in association with wind farm infrastructure on Corry Mountain, Co. Leitrim, at Sonnagh Old Wind Farm, Co. Galway (near Derrybrien; Cullen, 2011)[7], and at Corkey Wind Farm, Co. Antrim. In December 2016, a plant operator was killed during excavation works in peat at the

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[2] Evans MG & Warburton J, 2007. *Geomorphology of Upland Peat: Erosion, Form and Landscape Change*. Blackwell Publishing, 262p. Available at: https://content.e-bookshelf.de/media/reading/L-579345-060d79140b.pdf

[3] Creighton R and Verbruggen K, 2003. G*eological Report on the Pollatomish Landslide Area, Co. Mayo*. Geological Survey of Ireland, 13p.

[4] Mills AJ, Moore R, Carey JM and Trinder SK, 2007. *Recent landslide impacts in Scotland: possible evidence of climate change? In. McInnes, R. et al (Eds) Landslides and climate change: challenges and solutions*, Proceedings of Conference, Isle of Wight, 2007.

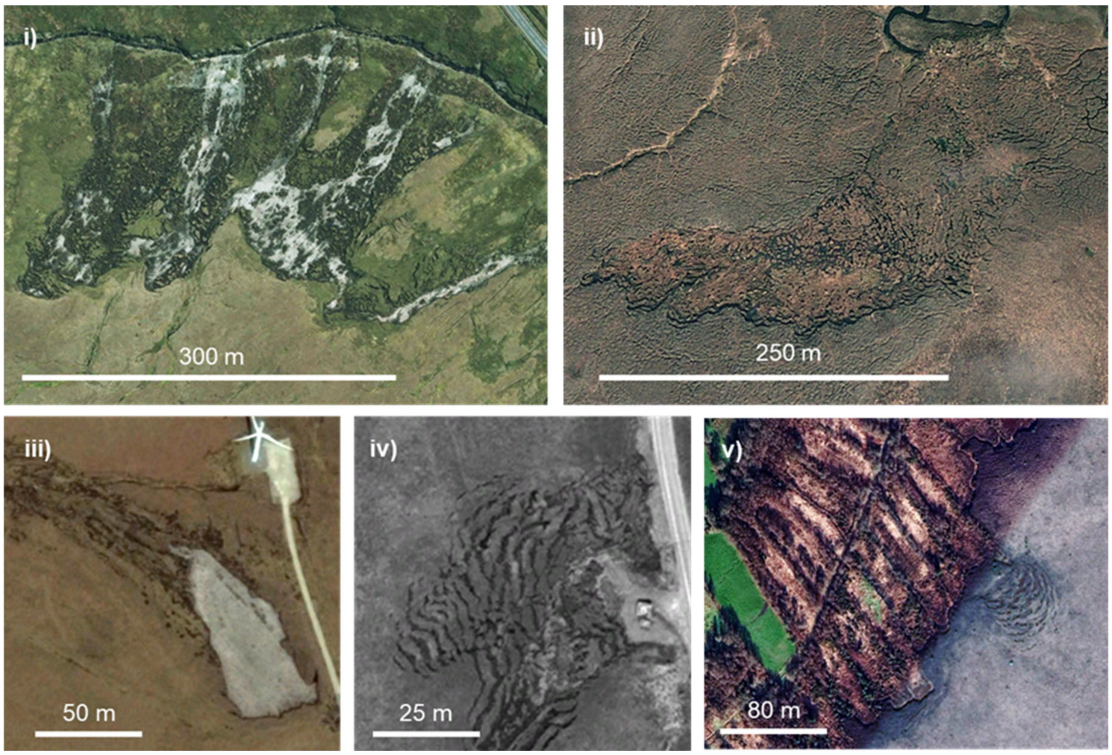
[5] Henderson S, 2005. *Effects of a landslide on the shellfish catches and water quality in Shetland*. Fisheries Development Note No. 19, North Atlantic Fisheries College.

[6] Lindsay RA and Bragg OM, 2004. *Wind farms and blanket peat*. A report on the Derrybrien bog slide. Derrybrien Development Cooperative Ltd, Galway, 149p.

[7] Cullen C, 2011. *Peat stability – minimising risks by design*. Presentation at SEAI Wind Energy Conference 2011, 45p.

Derrysallagh wind farm site in Co. Leitrim (Flaherty, 2016)[8] on a plateau in which several published examples of instability had been previously reported. A peat landslide was also reported in 2015 near the site of a proposed road for the Viking Wind Farm on Shetland (The Shetland Times, 2015)[9] though this was not in association with construction works.

Plate 13.6.3: Characteristic Peat Landslide Types in UK and Irish Peat Uplands: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: iii) peat slide adjacent to turbine foundation, iv) spreading around foundation, v) spreading upslope of cutting



2.1.7 Other recent natural events include another failure in Galway at Clifden in 2016 (Irish News, 2016)[10], Cushendall, Co. Antrim (BBC, 2014)[11], in the Glenelly Valley, Co. Tyrone in 2017 (BBC, 2018)[12], Drumkeeran in Co. Leitrim in July 2020 (Irish Mirror, 2020)[13] and Benbrack in Co Cavan in July 2021 (The Anglo-Celt, 2021)[14]. Noticeably, the vast majority of reported failures since 2003 have occurred in Ireland and Northern Ireland, with one reported Scottish example occurring on the Shetland Islands (Mid Kame), an area previously associated with peat instability. Two

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[8] Flaherty R, 2016. *Man dies in suspected landslide at wind farm in Co Sligo*. Irish Times, 13/12/2013,. [Online] Available at: https://www.irishtimes.com/news/crime-and-law/man-dies-in-suspected-landslide-at-wind-farm-in-co-sligo-1.2903750. Accessed 19 July 2018.

[9] The Shetland Times, 2015. *Mid Kame landslip on proposed windfarm site*. [Online] Available at: http://www.shetlandtimes.co.uk/2015/10/30/mid-kame-landslip-on-proposed-windfarm-site. Accessed 19 July 2018.

[10] Irish News, 2016. *Major landslide sees 4,000 tonnes of bog close popular Galway tourist route*. [Online] Available at: https://www.independent.ie/irish-news/major-landslide-sees-4000-tonnes-of-bog-close-popular-galway-tourist-route-34830435.html. Accessed 19 July 2018.

[11] BBC, 2014. *Torrential rain leads to landslides in County Antrim*. [Online] Available at: https://www.bbc.co.uk/news/uk-northern-ireland-28637481. Accessed 19 July 2018.

[12] BBC, 2018. *Glenelly Valley landslides were 'one-in-3,000 year event'*. [Online] Available at: https://www.bbc.co.uk/news/uk-northern-ireland-43166964. Accessed 19 July 2018.

[13] Irish Mirror, 2020. *Photos show massive mudslides in Leitrim after heavy flooding*. [Online] Available at: https://www.irishmirror.ie/news/irish-news/mudslides-drumkeeran-leitrim-flooding-photos-22281581. Accessed 01 September 2021.

[14] The Anglo-Celt, 2021. *Hillwalker captures aftermath of landslide*. [Online] Available at: https://www.anglocelt.ie/2021/07/22/hillwalker-captures-aftermath-of-landslide/. Accessed 23 July 2021.

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

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

2.2 Types of Peat Instability

2.2.1 Peat instability is manifested in a number of ways (Dykes and Warburton, 2007)[15] all of which can potentially be observed on site either through site walkover or remotely from high resolution aerial photography:

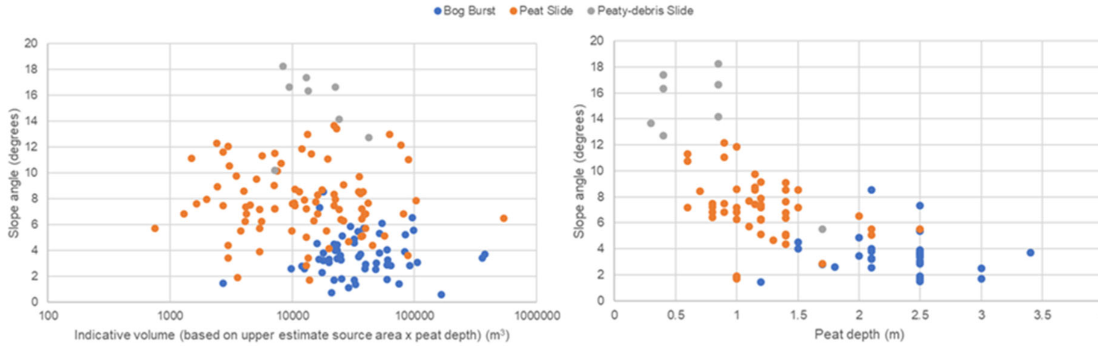
- **minor instability**: localised and small-scale features that are not generally precursors to major slope failure and including gully sidewall collapses, pipe ceiling collapses, minor slumping along diffuse drainage pathways (eg along flushes); indicators of incipient instability including development of tension cracks, tears in the acrotelm (upper vegetation mat), compression ridges, or bulges/thrusts (Scottish Government, 2017)[1]; these latter features may be warning signs of larger scale major instability (such as landsliding) or may simply represent a longer term response of the hillslope to drainage and gravity, ie creep.
- **major instability**: comprising various forms of peat landslide, ranging from small scale collapse and outflow of peat filled drainage lines/gullies (occupying a few-10s cubic metres), to medium scale peaty-debris slides in organic soils (10s to 100s cubic metres) to large scale peat slides and bog bursts (1,000s to 100,000s cubic metres).

2.2.2 Evans and Warburton (2007)[2] present useful contextual data in a series of charts for two types of large-scale peat instability – peat slides and bog bursts. The data are based on a peat landslide database compiled by Mills (2002)[16] which collates site information for reported peat failures in the UK and Ireland. Separately, Dykes and Warburton (2007)[15] provide a more detailed classification scheme for landslides in peat based on the type of peat deposit (raised bog, blanket bog, or fen bog), location of the failure shear surface or zone (within the peat, at the peat-substrate interface, or below), indicative failure volumes, estimated velocity and residual morphology (or features) left after occurrence.

2.2.3 For the purposes of this assessment, landslide classification is simplified and split into three main types, typical examples of which are shown in **Plate 13.6.3: Characteristic Peat Landslide Types in UK and Irish Peat Uplands**: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: iii) peat slide adjacent to turbine foundation, iv) spreading around foundation, v) spreading upslope of cutting. Dimensions, slope angles and peat depths are drawn from charts presented in Evans and Warburton (2007)[2]. The term "peat slide" is used to refer to large-scale (typically less than 10,000 of cubic metres) landslides in which failure initiates as large rafts of material which subsequently break down into smaller blocks and slurry. Peat slides occur 'top-down' from the point of initiation on a slope in thinner peats (between 0.5 m and 1.5 m) and on moderate slope angles (typically 5°-15°, see **Plate 13.6.4: Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)[16]**).

[15] Dykes A and Warburton J, 2007. *Mass movements in peat: A formal classification scheme*. Geomorphology 86, pp. 73–93.

Plate 13.6.4: Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)[16]



2.2.4 The term "bog burst" is used to refer to very large-scale (usually greater than 10,000 of cubic metres) spreading failures in which the landslide retrogresses (cuts) upslope from the point of failure while flowing downslope. Peat is typically deeper (greater than 1.0 m and up to 10 m) and more amorphous than sites experiencing peat slides, with shallower slope angles (typically 2°-5°). Much of the peat displaced during the event may remain within the initial failure zone. Bog bursts are rarely (if ever) reported in Scotland other than in the Western Isles (eg Bowes, 1960)[17].

2.2.5 The term "peaty soil slide" is used to refer to small-scale (1,000s of cubic metres) slab-like slides in organic soils (ie they are <0.5 m thick). These are similar to peat slides in form, but far smaller and occur commonly in UK uplands across a range of slope angles (Dykes and Warburton, 2007)[15]. Their small size means that they often do not affect watercourses and their effect on habitats is minimal.

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

2.3 Factors Contributing to Peat Instability

2.3.1 Peat landslides are caused by a combination of factors – triggering factors and reconditioning factors (Dykes and Warburton, 2007[15]; Scottish Government, 2017[1]). Triggering factors have an immediate or rapid effect on the stability of a peat deposit whereas preconditioning factors influence peat stability over a much longer period. Only some of these factors can be addressed by site characterisation.

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

- impeded drainage caused by a peat layer overlying an impervious clay or mineral base (hydrological discontinuity);
- a convex slope or a slope with a break of slope at its head (concentration of subsurface flow);
- proximity to local drainage, either from flushes, pipes or streams (supply of water);
- connectivity between surface drainage and the peat/impervious interface (mechanism for generation of excess pore pressures);
- artificially cut transverse drainage ditches, or grips (elevating pore water pressures in the basal peat-mineral matrix between cuts, and causing fragmentation of the peat mass);
- increase in mass of the peat slope through peat formation, increases in water content or afforestation;

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[16] Mills AJ, 2002. *Peat slides: Morphology, Mechanisms and Recovery*, unpublished PhD thesis, University of Durham. Available at: https://etheses.dur.ac.uk/1075/1/1075.pdf?EThOS%20(BL)

[17] Bowes DR, 1960. *A bog-burst in the Isle of Lewis*. Scottish Geographical Journal. 76, pp. 21-23.

- reduction in shear strength of peat or substrate from changes in physical structure caused by progressive creep and vertical fracturing (tension cracking or desiccation cracking), chemical or physical weathering or clay dispersal in the substrate;
- loss of surface vegetation and associated tensile strength (eg by burning or pollution induced vegetation change);
- increase in buoyancy of the peat slope through formation of sub-surface pools or water-filled pipe networks or wetting up of desiccated areas; and
- afforestation of peat areas, reducing water held in the peat body, and increasing potential for formation of desiccation cracks which are exploited by rainfall on forest harvesting.

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

- intense rainfall or snowmelt causing high pore pressures along pre-existing or potential rupture surfaces (eg between the peat and substrate);
- rapid ground accelerations (eg from earthquakes or blasting);
- unloading of the peat mass by fluvial incision or by artificial excavations (eg cutting);
- focusing of drainage in a susceptible part of a slope by alterations to natural drainage patterns (eg by pipe blocking or drainage diversion); and
- loading by plant, spoil or infrastructure.

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

2.4 Consequences of Peat Instability

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

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

- the development infrastructure (damage to towers, tracks, substation, etc);
- site workers and plant (risk of injury/death or damage to plant);
- wildlife (disruption of habitat) and aquatic fauna;
- watercourses and lochs (particularly associated with public water supply);
- site drainage (blocked drains/ditches leading to localised flooding/erosion); and
- visual amenity (scarring of landscape).

2.4.3 While peat failures may cause visual scarring of the peat landscape, most peat failures revegetate fully within 50 to 100 years and are often difficult to identify on the ground after this period of time (Feldmeyer-Christe and Küchler, 2002[18]; Mills, 2002[16]). Typically, it is short-term (seasonal) effects on watercourses that are the primary concern or impacts on public water supply. Internet searches using the term ‘landslip’ and Durris Forest (the local placename) indicated no reports of landslides in this area. The Topic Paper (Soils)[19] for the emerging Aberdeenshire Local Development Plan (2027) which summarised key findings in relation to landslides in Aberdeenshire noted that “*Landslip and soil erosion are not thought to be significant issues across Aberdeenshire*.”

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[18] Feldmeyer-Christe E and Küchler M, 2002. *Onze ans de dynamique de la vegetation dans une tourbiere soumise a un glissement de terrain*. Botanica Helvetica 112, 103-120.

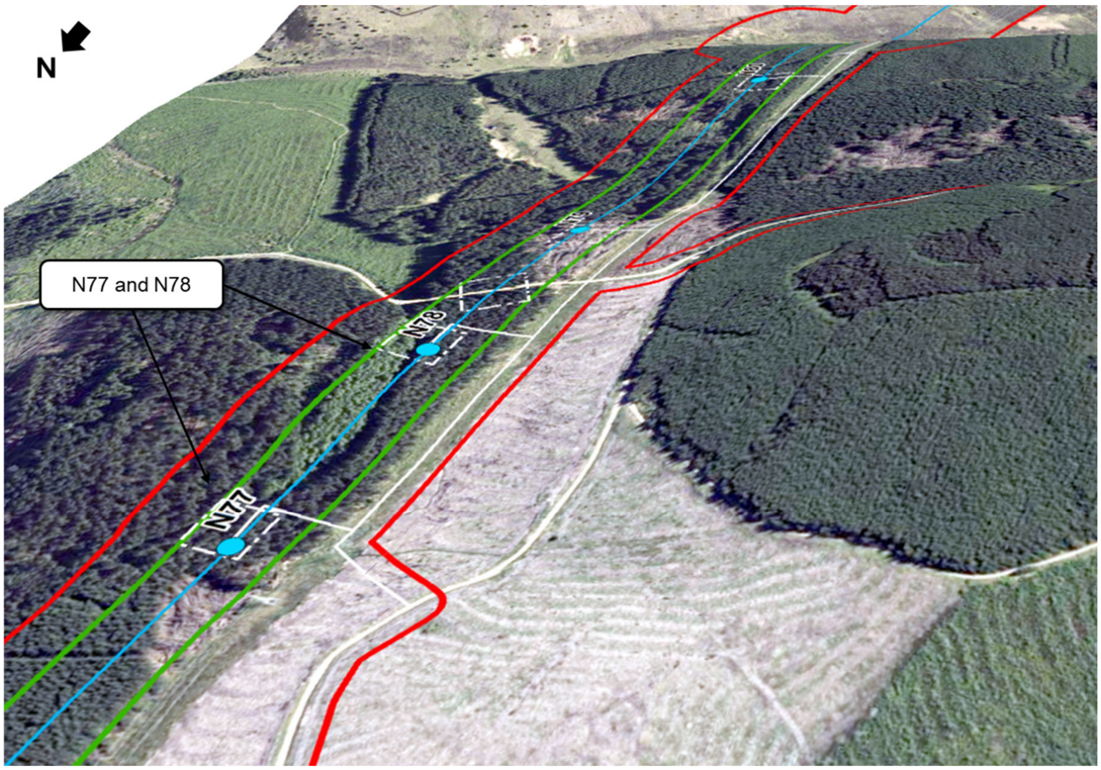
[19] Aberdeenshire Council, 2024. *Local Development Plan Topic Paper (Soils)*, 28p Available at: https://engage.aberdeenshire.gov.uk/ldp-evidence-report-soils-topic-paper

3 BASELINE CONDITIONS

3.1 Topography

3.1.1 The route for the OHL between Towers N77 and N78 passes an unnamed hillside of low relief (276 m above ordnance datum (AOD), **Annex 1, Figure A13.6.1: Site Characteristics**) situated between Cairn-mon-earn (378 m AOD c. 1 km to the west) and Strathgyle (297 m AOD, c. 1 km to the east). Towers N77 and N78 sit at approximately 257 m and 266 m elevation respectively (**Annex 1, Figure A13.6.1: Site Characteristics,** 'Elevation' panel). The general ground conditions are shown on **Plate 13.6.5: Ground Conditions in the Vicinity of Towers N77 and N78** below.

Plate 13.6.5: Ground Conditions in the Vicinity of Towers N77 and N78



3.1.2 A 5m digital terrain model (DTM) was used to identify slopes within the Site (**Annex 1, Figure A13.6.1: Site Characteristics, '**Slope' panel). Slopes are generally gentle (< 5°) within the Site, locally steeper (up to 15°) on the eastern side of the Limit of Deviation on the sideslopes of a localised unnamed summit.

3.2 Geology

3.2.1 **Annex 1, Figure A13.6.1: Site Characteristics,** 'Superficial Geology' panel (top centre panel) shows the superficial geology of the study area mapped from 1:50,000 scale publicly available BGS digital data and indicates the Site to be underlain by peat, till diamicton (glacial deposits) or bedrock. The bedrock underlying peat and superficial deposits is indicated to be Water of Dye Granite (Mount Battock Pluton).

3.2.2 The Carbon and Peatland 2016 Map (**Annex 1, Figure A13.6.1: Site Characteristics,** 'Carbon and Peatland (2016) Map' panel), which provides a high-level estimate of habitat quality and presence / absence of peat soil shows the entire study area to be Class 5, corresponding to peat soil with no peatland vegetation (and therefore not of high habitat value).

3.3 Hydrology

3.3.1 The nearest watercourses are Strans Burn, the source of which is approximately 250 m northeast of Tower N77, and Clash Burn, c. 1 km to the north.

3.3.2 Strans Burn is < 50 cm wide and therefore unlikely to be able to convey any peat material.

3.3.3 There is an artificial drain on the edge of the limit of deviation (LOD) in the west, at the edge of a deforested area, and another feeding into the source of Strans Burn approximately 250 m northeast of tower N77.

3.4 Land Use

3.4.1 The predominant land use at the Site is commercial forestry, including both afforested and deforested areas. There are also sections of planar ground, including areas between forest stands to the east and west and a corridor containing an existing OHL. Additionally, some made ground is present, in the form of access tracks (**Annex 1, Figure A13.6.1: Site Characteristics,** 'Geomorphology, Hydrology and Land Use**'** panel).

3.5 Peat Depth and Character

3.5.1 A peat depth survey report (**Volume 5, Appendix 13.3: Peat Depth Survey Report**) summarises peat deposits across the full probed extent of the OHL route. Probing was undertaken on a 10 m grid within tower working areas and on a coarser modified Phase 1 grid of 100 m along the centreline axis with 50 m intervals from the centreline out to the LOD. **Volume 5, Appendix 13.4: Outline Peat Management Plan (PMP)** details how the spatial scope of the PMP (and this PLHRA) was reduced to the Tower N77 and N78 area. The Peat Survey Report indicates that 2,826 probes were collected within peat survey areas, with c. 2,581 being on non-peat soils (<0.5 m) and <10% on peat.

3.5.2 Within Section E:

- peat is generally thin to absent over much of this section of the OHL;
- locally, immediately to the north and partially overlapping the N77 working area, peat reaches up to 2.0 m in depth within a topographic hollow facing east towards Strans Burn;
- a second isolated pocket of peat is present to the west of the unnamed summit adjacent to Tower N78 – peat is up to 2.0 m in depth at the margin of the tower and working area; and
- Towers N79 to N82 are not located in peat.

3.5.3 The peat depth model is shown on **Annex 1, Figure A13.6.1: Site Characteristics,** 'Peat Depth' panel with probing locations superimposed. The tower working area for N77 is located at the periphery of a deep peat deposit, while N78 overlaps an area that deepens to the west. The peat at N77 varies between approximately 0.25 m and 2.1 m and the peat at N78 varies between 0.25 m (soil) and 2.0 m (peat). Given the relatively shallow depths, peat slides are modelled as the mode of failure within this PLHRA (see section 2.3).

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

3.6 Peatland Geomorphology

3.6.1 Multi-epoch satellite imagery was used to map ground conditions at the Site. LIDAR data were not available to review under-canopy conditions (although had been collected for prior alignments away from this section of the Proposed Development.

3.6.2 Review of the satellite imagery indicated an absence of typical peatland features within the study area due to the dominance of forestry and associated ground disturbance. Open ground is mapped as planar terrain (featureless vegetated peatland with no ground patterning or erosion features such as haggs). Observations undertaken during probing indicated ground conditions under forestry to be typical for plantation, with drier elevated ridges and lower furrows which carry surface water downslope. Neither on the ground observations nor observations from satellite imagery showed evidence of past landslide events or incipient instability features (such as tension cracks, pipe collapses or ground heave).

4 ASSESSMENT OF PEAT LANDSLIDE LIKELIHOOD

4.1 Introduction

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

Risk = Probability of a Peat Landslide x Adverse Consequences

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

4.1.3 Due to the combination of moderate slopes and thinner peat at this site, the most likely mode of failure is peat slides, and this is the failure mechanism considered in this report. This is in keeping with the most likely mode of failure for the peat depths and slope angles present at the Site (see **Plate 13.6.4: Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)** and **Annex 1, Figure A13.6.1: Site Characteristics**).

4.2 Limit Equilibrium Approach

<u>Overview</u>

4.2.1 Stability analysis has been undertaken using the infinite slope model to determine the Factor of Safety (FoS) for a series of 25 x 25 m grid cells within the Site. This is the most frequently cited approach to quantitatively assessing the stability of peat slopes (eg Scottish Government, 2017[1]; Boylan et al, 2008[20]; Evans and Warburton, 2007[2]; Dykes and Warburton, 2007[15]; Creighton, 2006[21]; Warburton et al, 2003[22]; Carling, 1986[23]). The approach assumes that failure occurs by shallow translational landsliding, which is the mechanism usually interpreted for peat slides. Due to the relative length of the slope and depth to the failure surface, end effects are considered Negligible and the safety of the slope against sliding may be determined from analysis of a 'slice' of the material within the slope.

4.2.2 The stability of a peat slope is assessed by calculating a Factor of Safety, F, which is the ratio of the sum of resisting forces (shear strength) and the sum of driving forces (shear stress) (Scottish Government, 2017)[1]:

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

4.2.3 In this formula c' is the effective cohesion (kPa), γ is the bulk unit weight of saturated peat (kN/m3), γw is the unit weight of water (kN/m3), z is the vertical peat depth (m), h is the height of the water table as a proportion of the peat depth, β is the angle of the substrate interface (°) and ϕ' is the angle of internal friction of the peat (°). This form of the infinite slope equation uses effective stress parameters, and assumes that there are no excess pore pressures, ie that the soil is in its natural, unloaded condition. The choice of water table height reflects the full saturation of the soils that would be expected under the most likely trigger conditions, ie heavy rain.

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

4.2.5 There are numerous uncertainties involved in applying geotechnical approaches to peat, not least because of its high

[20] Boylan N, Jennings P and Long M, 2008. *Peat slope failure in Ireland*. Quarterly Journal of Engineering Geology, 41, pp. 93–108.

[21] Creighton R (Ed), 2006. *Landslides in Ireland*. Geological Society of Ireland, Irish Landslides Working Group, 125p.

[22] Warburton J, Higgitt D and Mills AJ, 2003. *Anatomy of a Pennine peat slide, Northern England*. Earth Surface Processes and Landforms, 28, pp. 457-473.

[23] Carling PA, 1986. *Peat slides in Teesdale and Weardale, Northern Pennines, July 1983: description and failure mechanisms.* Earth Surface Processes and Landforms, 11, pp. 193-206.

water content, compressibility and organic composition (Hobbs, 1986[24]; Boylan and Long, 2014[25]). Peat comprises organic matter in various states of decomposition with both pore water and water within plant constituents, and the frictional particle-to-particle contacts that are modelled in standard geotechnical approaches are different in peats. There is also a tensile strength component to peat which is assumed to be dominant in the acrotelm, declining with increasing decomposition and depth. As a result, analysis utilising geotechnical approaches is often primarily of value in showing relative stability across a site given credible and representative input parameters rather than in providing an absolute estimate of stability. Representative data inputs have been derived from published literature for drained analyses considering natural site conditions.

Data Inputs

4.2.6 Stability analysis was undertaken in ArcMap GIS software. A 25 m x 25 m grid was superimposed on the Site and key input parameters derived for each grid cell. In total, c. 580 grid cells were analysed. A 25 m x 25 m cell size was chosen because it is sufficiently small to define a credible landslide size and avoid ‘smoothing’ of important topographic irregularities.

4.2.7 Two forms of analysis have been undertaken:

- **baseline stability**: input parameters correspond to undisturbed peat, prior to construction, and under water table conditions typically associated with instability (ie full saturation). Effective stress parameters are used in a drained analysis; and
- **modified (loaded) stability**: input parameters correspond to disturbed peat, subsequent to construction, with peat loaded by floating track and typical vehicle loads. Total stress parameters are used in this undrained analysis.

4.2.8 Areas where peat has been excavated (eg the excavated peat itself and the peat upslope of the excavation) have not been modelled since it is assumed that safe systems of work will include buttressing of/support to excavations.

4.2.9 **Table 13.6.1: Geotechnical Parameters for Drained Infinite Slope Analysis** shows the input parameters and assumptions for the baseline stability analysis. The shear strength parameters c' and ϕ’ are usually derived in the laboratory using undisturbed samples of peat collected in the field and therefore site specific values are often not available ahead of detailed site investigation for a development. Therefore, for this assessment, a literature search was undertaken to identify a range of credible but conservative values for c' and ϕ’ quoted in fibrous and humified peats. FoS analysis was undertaken with conservative ϕ’ of 20° and values of 2 kPa and 5 kPa for c’. These values fall at the low end of a large range of relatively low values (when compared to other soils).

4.2.10 **Table 13.6.2: Geotechnical Parameters and Assumptions for Undrained Infinite Slope Analysis** shows the input parameters and assumptions for the modified stability analysis. The analysis employs a 5 m wide floating track, and assumes representative loads for a multi-axle crane with maximum axle load of c. 16 t moving over the floated surface.

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

Results

4.2.12 The outputs of the drained analysis (effective stress) are shown for the best estimate parameters in **Annex 1, Figure A13.6.2: PLHRA Results,** ‘Factor of Safety – Best Estimate’ panel, which shows the entire study area to be “Stable” (F > 1.4).

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[24] Hobbs NB, 1986. *Mire morphology and the properties and behaviour of some British and foreign peats*. Quarterly Journal of Engineering Geology, London, 1986, 19, pp. 7–80.

[25] Boylan N and Long M, 2014. *Evaluation of peat strength for stability assessments*. Geotechnical Engineering, 167, pp422-430.

Table 13.6.1: Geotechnical Parameters for Drained Infinite Slope Analysis

Parameter	Values	Rationale	Source
Effective cohesion (c')	2, 5	Credible conservative cohesion values for humified peat based on literature review	5, basal peat (Warburton et al., 2003[22]) 8.74, fibrous peat (Carling, 1986[23]) 7 - 12, H8 peat (Huat et al, 2014[26]) 5.5 - 6.1, type not stated (Long, 2005[27]) 3, 4, type not stated (Long, 2005[27]) 4, type not stated (Dykes and Kirk, 2001[28])
Bulk unit weight (γ)	10.5	Credible mid-range value for humified catotelmic peat	10.8, catotelm peat (Mills, 2002[16]) 10.1, Irish bog peat (Boylan et al 2008[20])
Effective angle of internal friction (ϕ')	20, 30	Credible conservative friction angles for humified peat based on literature review (only 20° used in analysis)	40 - 65, fibrous peat (Huat et al, 2014[26]) 50 - 60, amorphous peat (Huat et al, 2014[26]) 36.6 - 43.5, type not stated (Long, 2005[27]) 31 - 55, Irish bog peat (Hebib, 2001[29]) 34 - 48, fibrous sedge peat (Farrell & Hebib, 1998[30]) 32 - 58, type not stated (Long, 2005[27]) 23, basal peat (Warburton et al, 2003[22]) 21, fibrous peat (Carling, 1986[23])
Slope angle from horizontal (β)	Various	Mean slope angle per 25 m x 25 m grid cell	5 m digital terrain model of site
Peat depth (z)	Various	Mean peat depth per 25 x 25 m grid cell	Interpolated peat depth model of site
Height of water table as a proportion of peat depth (h)	1	Assumes peat mass is fully saturated (normal conditions during intense rainfall events or snowmelt, which are the most likely natural hydrological conditions at failure)	

Table 13.6.2: Geotechnical Parameters and Assumptions for Undrained Infinite Slope Analysis

Parameter	Values	Rationale	Source
Undrained shear strength (Su)	5	Published values show undrained shear strength is typically very similar to effective cohesion (c')	4-30, medium and highly humified (Boylan et al, 2008[20]) 4, more humified (Boylan et al, 2008[20]) 5.2, peat type not stated (Long et al, 2005[27]) 5, Irish bog peat (Farrell and Hebib, 1998[30])
Bulk unit weight (γ)	10.5	Reduction in volume under floating road is balanced by increased density, so pre-load parameters are used	See **Table 13.6.1: Geotechnical Parameters for Drained Infinite Slope Analysis**
Slope angle from horizontal (β)	Various	Credible slope angles for which floating tracks are proposed	See **Table 13.6.1: Geotechnical Parameters for Drained Infinite Slope Analysis**

[26] Huat BBK, Prasad A, Asadi A and Kazemian S, 2014. *Geotechnics of organic soils and peat*. Balkema, 269p.

[27] Long M, 2005. *Review of peat strength, peat characterisation and constitutive modelling of peat with reference to landslides*. Studia Geotechnica et Mechanica, XXVII, 3-4, pp. 67–88.

[28] Dykes AP and Kirk KJ, 2001. *Initiation of a multiple peat slide on Cuilcagh Mountain, Northern Ireland*. Earth Surface Processes and Landforms, 26, 395-408.

[29] Hebib S, 2001. *Experimental investigation of the stabilisation of Irish peat*, unpublished PhD thesis, Trinity College Dublin.

[30] Farrell ER and Hebib S, 1998. *The determination of the geotechnical parameters of organic soils*, Proceedings of International Symposium on Problematic Soils, IS-TOHOKU 98, Sendai, 1998, Japan, pp. 33–36.

Parameter	Values	Rationale	Source
Peat depth (z)	Various	Reduction in volume (ie depth) under floating road is balanced by increased density, so pre-load parameters are used	See **Table 13.6.1: Geotechnical Parameters for Drained Infinite Slope Analysis**
Crane axle load (t)	16 t	Typical axle load corresponding to an "abnormal load" for a multi-axle crane used in tower erection.	

4.2.13 The outputs of the undrained analysis incorporating crane loads on floating track are shown on the centre panel of **Annex 1 Figure A13.6.2: PLHRA Results, Factor of Safety – Crane Loaded** panel which indicates stability in proposed floating track areas.

4.3 Landslide Susceptibility Approach

<u>Overview</u>

4.3.1 The landslide susceptibility approach is based on the layering of contributory factors to produce unique 'slope facets' that define areas of similar susceptibility to failure. These slope facets vary in size and are different to the regular grid used for the FoS approach. The number and size of slope facets varies from one part of the Site to another according to the complexity of ground conditions. In total, 438 facets were considered in the analysis, with an average area of c. 792 m^2 (c. 28 m x 28 m), consistent with smaller to medium scale peaty soil or peat slides reported in the published literature.

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

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

$$SPL = SS + SP + SG + SM + SD + SC + SF + SL$$

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

<u>Slope Angle (S)</u>

4.3.5 **Table 13.6.3: Slope Classes, Association with Instability and Scores** shows the slope ranges, their association with instability and related scores for the slope angle contributory factor. Slope angles were derived from the 5 m digital terrain model (shown on the bottom left panel of **Annex 1 Figure A13.6.1: Site Characteristics, Slope** panel) and scores assigned based on reported slope angles associated with peat landslides rather than a simplistic assumption that 'the steeper a slope, the more likely it is to fail' (eg **Plate 13.6.4: Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)**).

Table 13.6.3: Slope Classes, Association with Instability and Scores

Slope range (°)	Association with instability	Peat slide
≤2.5	Slope angle ranges for peat slides and bog bursts are based on lower and upper limiting angles for observations of occurrence (see Plate 2.2 and increase with increasing slope angle until the upper limiting angle eg peat slides are not observed on slopes <2.5°, while bog bursts are not observed on slopes > 7.5°). It is assumed that beyond 7.5° the mode of failure will be peat slides.	0
2.5 - 5.0		1
5.0 – 7.5		3
7.5 - 10.0		3
10 – 15.0		3
>15.0		3

4.3.6 The steeper slopes around the unnamed hill in the east of the study area receives the highest scores for peat slides, with the rest of the moderate slopes receiving either 0 or a 1.

Peat Depth (P)

4.3.7 **Table 13.6.4: Peat Depth Classes, Association with Instability and Scores** shows the peat depths, their association with instability and related scores for the peat depth contributory factor. Peat depths were derived from the peat depth model shown on **Annex 1, Figure A13.6.1: Site Characteristics,** 'Peat Depth' (upper right panel) and reflect the peat depth ranges most frequently associated with peat landslides (see **Plate 13.6.4: Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)**).

Table 13.6.4: Peat Depth Classes, Association with Instability and Scores

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

4.3.8 The lowest scores are in areas of thin or absent peat between the two towers. The towers themselves sit in deeper peat (>1.5 m) and therefore receive a score of 1 for peat slide, with the surrounding, more moderate peat depths receiving the highest score.

Substrate Geology (G)

4.3.9 **Table 13.6.5: Substrate Geology Classes, Association with Instability and Scores** shows substrate type, association with instability and related scores for the substrate geology contributory factor. The shear surface or failure zone of reported peat failures typically overlies an impervious clay or mineral (bedrock) base giving rise to impeded drainage. This, in part, is responsible for the presence of peat, but also precludes free drainage of water from the base of the peat mass, particularly under extreme conditions (such as after heavy rainfall, or snowmelt).

4.3.10 Peat failures are frequently cited in association with glacial till deposits in which an iron pan is observed in the upper few centimetres (Dykes and Warburton, 2007)[15]. They have also been observed over glacial till without an obvious iron pan, or over impermeable bedrock. They are rarely cited over permeable bedrock, probably due to the reduced likelihood of peat formation.

Table 13.6.5: Substrate Geology Classes, Association with Instability and Scores

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

4.3.11 Probing undertaken across the study area indicated primarily bedrock or granular substrates using the refusal method, and therefore most of the study area receives a score of 1 or 2. There are some very small areas of clay which were assigned the highest score.

Peat Geomorphology (M)

4.3.12 **Table 13.6.6: Peat Geomorphology Classes, Association with Instability and Scores** shows the geomorphological features typical of peatland environments, their association with instability and related scores.

Table 13.6.6: Peat Geomorphology Classes, Association with Instability and Scores

Geomorphology	Association with instability	Peat slide
Incipient instability (cracks, ridges, bulging)	Failures are likely to occur where pre-failure indicators are present	3
Planar with pipes	Failures generally occur on planar slopes, and are often reported in areas of piping	3
Planar with pools/ quaking bog	Bog bursts are more likely in areas of perched water (pools) or subsurface water bodies (quaking bog)	2
Flush/Sphagnum lawn (diffuse drainage)	Peat slides are often reported in association with areas of flushed peat or diffuse drainage	3
Planar (no other features)	Failures generally occur on planar slopes rather than dissected or undulating slopes	2
Peat between rock outcrops	Failures are rarely reported in areas of peat with frequent rock outcrops	1
Slightly eroded (minor gullies)	Failures are rarely reported in areas with gullying or bare peat	1
Heavily eroded (extensive gullies)/bare peat	Failures are not reported in areas that are heavily eroded or bare	0
Afforested/deforested peatland	Considered within Forestry (F), see below	0

4.3.13 The majority of the study area is afforested/deforested peatland and therefore receives the lowest score. The planar area in between the forestry receives a score of 2.

Artificial Drainage (D)

4.3.14 **Table 13.6.7: Drainage Feature Classes, Association with Instability and Scores** shows artificial drainage feature classes, their association with instability and related scores. Transverse (or contour aligned)/oblique artificial drainage lines may reduce peat stability by creating lines of weakness in the peat slope and encouraging the formation of peat pipes. A number of peat failures have been identified in published literature which have failed over moorland grips (Warburton et al, 2004)[31]. The influence of changes in hydrology becomes more pronounced the more transverse the orientation of the drainage lines relative to the overall slope.

Table 13.6.7: Drainage Feature Classes, Association with Instability and Scores

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

4.3.15 The effect of drainage lines is captured through the use of a 30 m buffer on each artificial drainage line (producing a 60 m wide zone of influence) present within the peat soils at the Site. Each buffer is assigned a drainage feature class based on comparison of the drainage axis with elevation contours (transverse, oblique or aligned, as shown in **Table 13.6.7: Drainage Feature Classes, Association with Instability and Scores**). The drains in the west are predominantly oblique to the contour and therefore receive a score of 2, and the drain in the northeast is aligned along the contours and therefore receives the highest score of 3.

[31] Warburton J, Holden J and Mills AJ, 2004. *Hydrological controls of surficial mass movements in peat*. Earth Science Reviews, 67, pp. 139-156.

Slope Curvature (C)

4.3.16 **Table 13.6.8: Slope Curvature Classes, Association with Instability and Scores** shows slope (profile) curvature classes, association with instability and related scores. Convex and concave slopes (ie positions in a slope profile where slope gradient changes by a few degrees) have frequently been reported as the initiation points of peat landslides by a number of authors. The geomechanical reason for this is that convexities are often associated with thinning of peat, such that thicker peat upslope applies stresses to thinner 'retaining' peat downslope. Conversely, buckling and tearing of peat may trigger failure at concavities (eg Dykes & Warburton, 2007[15]; Boylan and Long, 2011[32]). However, review of reported peat landslide locations against Google Earth elevation data indicates that the majority of peat slides occur on rectilinear (straight) slopes and that the reporting of convexity as a key driver may be misleading. Accordingly, rectilinear slopes are assigned the highest score.

Table 13.6.8: Slope Curvature Classes, Association with Instability and Scores

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

4.3.17 The 5 m digital terrain model and OS contours were used to identify areas of noticeable slope convexity across the Site. Slope curvature was modelled using the 5 m DTM and slope rasters and assigned scores in accordance with **Table 13.6.8: Slope Curvature Classes, Association with Instability and Scores** above.

Forestry (F)

4.3.18 **Table 13.6.9: Forestry Classes, Association with Instability and Scores** shows forestry classes, their association with instability and related scores. A report by Lindsay and Bragg (2004)[6] on Derrybrien suggested that row alignments, desiccation cracking and loading (by trees) could all influence peat stability.

Table 13.6.9: Forestry Classes, Association with Instability and Scores

Forestry Class	Association with instability	Peat slide
Deforested, rows oblique to slope	Deforested peat is less stable than afforested peat, and inter ridge cracks oblique to slope may be lines of weakness	3
Deforested, rows aligned to slope	Deforested peat is less stable than afforested peat, but slope aligned inter ridge cracks have less impact	2
Afforested, rows oblique to slope	Afforested peat is more stable than deforested peat, but inter ridge cracks oblique to slope may be lines of weakness	2
Afforested, rows aligned to slope	Afforested peat is more stable than deforested peat, but potentially less stable than unforested (never planted) peat	1
Not afforested	No influence on stability	0
Wind damaged oblique	The peat in the wind damaged sites is typically disrupted by fallen trees which would also constrain peat movement	1
Wind damaged aligned to slope	The peat in the wind damaged sites is typically disrupted by fallen trees which would also constrain peat movement	0
Reafforested oblique	Reforested sites once trees are established will behave similarly to afforested sites	2
Reafforested aligned to slope	Reforested sites once trees are established will behave similarly to afforested sites	1

[32] Boylan N and Long M, 2011. *In situ strength characterisation of peat and organic soil using full-flow penetrometers*. Canadian Geotechnical Journal, 48(7), pp1085-1099.

4.3.19 The majority of the Site is forestry, including afforested, deforested and windblown areas. These areas were categorised and assigned scores from **Table 13.6.9: Forestry Classes, Association with Instability and Scores**.

Land use (L)

4.3.20 **Table 13.6.10: Land Use Classes, Association with Instability and Scores** shows land use classes, association with instability and related scores. A variety of land uses have been associated with peat failures (see **Section 2.1**). While it is hypothesised that burning may cause desiccation cracking in peat and facilitate water flows to basal peat (and potential shear surfaces), there is little evidence directly relating burnt ground to peat landslide events.

Table 13.6.10: Land Use Classes, Association with Instability and Scores

Land Use	Association with instability	Peat slide
Machine cutting	Machine cutting may compartmentalise slopes, but has been reported primarily in association with peat slides	3
Quarrying	Quarrying may remove slope support from upslope materials, and has been observed with spreading failures (bog bursts)	2
Hand cutting (turbary)	Hand cutting may remove slope support from upslope materials, and has been reported with raised bog failures	1
Burning (deep cracking to substrate)	Failures are rarely associated with burning, but deep desiccation cracking will have the most severe effects	2
Burning (shallow cracking)	Failures are rarely associated with burning, shallow desiccation cracking will have very limited effects	1
Grazing	Failures have not been associated with grazing, no influence on stability	0

4.3.21 There are no land uses present in the study area which contribute to peatland instability (other than forestry, scored previously) and therefore the entire study area receives the lowest score, equivalent to 'grazing'.

Generation of Slope Facets

4.3.22 The eight contributory factor layers were combined in ArcMap to produce approximately 438 slope facets. Scores for each facet were then summed to produce a peat landslide likelihood score. These likelihood scores were then converted into descriptive 'likelihood classes' from 'Very Low' to 'Very High' with a corresponding numerical range of 1 to 5 (in a similar format to the *Scottish Government BPG*).

Table 13.6.11: Likelihood Classes Derived from the Landslide Susceptibility Approach

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

4.3.23 **Table 13.6.11: Likelihood Classes Derived from the Landslide Susceptibility Approach** describes the basis for the likelihood classes. A judgement was made that for a facet to have a moderate or higher likelihood of a peat landslide, a likelihood score would be required exceeding both the worst case peat depth and slope angle scores summed (3 in each case, ie 3 x 2 classes) alongside three intermediate scores (of 2, ie 2 x 3 classes) for other contributory factors. This means that any likelihood score of 13 or greater would be equivalent to at least a moderate likelihood of a peat landslide. Given that the maximum score attainable is 24, this seems reasonable.

Results

4.3.24 The right panel of **Annex 1, Figure A13.6.2: PLHRA Results, '**Peat Landslide Likelihood' panel, shows the outputs of the landslide susceptibility (likelihood) approach for peat slides. The results indicate that the majority of the study area has a 'Very Low' or 'Low' likelihood with only one facet being of a 'Moderate' likelihood of a peat slide under natural conditions. This applies to the construction and working areas of both towers, and to the intervening section of land over which the access track is proposed.

4.3.25 The one facet of 'Moderate' likelihood is located on a moderate rectilinear slope, adjacent to a drain and in moderately deep peat. The facet is sufficiently small (c. 15 m in length and c. 5 m wide) that it would not be expected to propagate into a larger area of instability even if it were to fall within the construction envelope.

4.3.26 There are no areas identified with 'High' or 'Very High' landslide susceptibility. When compared with the stability analysis approach (the left panel of **Annex 1, Figure A13.6.2: PLHRA Results,** 'Factor of Safety – Best Estimate**'** panel), the outputs of the landslide susceptibility approach indicate more of the study area to be at a slightly lower stability under natural conditions.

Combined Landslide Likelihood

4.3.27 **Annex 1, Figure A13.6.2: PLHRA Results** indicates the Site to be stable in areas where infrastructure is proposed. In order for there to be a "Medium" or "High" risk (Scottish Government, 2017)[1], likelihoods must be "Moderate" or higher (see **Plate 13.6.6: Top: Risk Ranking as a Product of Likelihood and Consequence; Bottom: Suggested Action Given Each Level of Calculated Risk** below).

4.3.28 There are no areas where Factor of Safety (using Best Estimate or crane-loaded parameters) is < 2.0, nor where the landslide susceptibility approach has calculated Moderate likelihood or greater, and therefore risks cannot exceed Low. This provides a screening basis for the likelihood results such that a consequence assessment is not required, and good practice construction methods should be sufficient to manage and minimise landslide risks.

4.3.29 This is considered further in **Section 5**.

Plate 13.6.6: Top: Risk Ranking as a Product of Likelihood and Consequence; Bottom: Suggested Action Given Each Level of Calculated Risk

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

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

5 RISK MITIGATION

5.1 Overview

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

5.1.2 Based on the analysis presented in this report, risks are calculated to be "Low" or "Negligible" across the Site, and site-specific mitigation is not required to reduce risks pre-consent. **Sections 5.2 to 5.4** provide information on good practice pre-construction, during construction and post-construction (ie during operation).

5.2 Good Practice Prior to Construction

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

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

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

5.3 Good Practice During Construction

5.3.1 The following good practice should be undertaken during construction:

5.3.2 For excavations:

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

5.3.3 For cut tracks:

- assess all areas onto which materials will be sidecast to ensure they will be stable under temporary loads of excavated material;

- where possible, place sidecast material on the upslope side of tracks to allow the track and drain to act as a retention structure;
- maintain drainage pathways through tracks to avoid ponding of water upslope;
- monitor the top line of excavated peat deposits for deformation post-excavation; and
- monitor the effectiveness of cross-track drainage to ensure water remains free-flowing and that no blockages have occurred.

5.3.4 For floating tracks:

- allow peat to undergo primary consolidation by adopting rates of road construction appropriate to weather conditions;
- identify ‘stop’ rules, ie weather dependent criteria for cessation of track construction based on local meteorological data;
- run vehicles at 50% load capacity until the tracks have entered the secondary compression phase; and
- prior to construction, setting out the centreline of the proposed track to identify any ground instability concerns or particularly wet zones.

5.3.5 For storage of peat and for restoration activities:

- ensure stored peat is not located upslope of working areas or adjacent to drains or watercourses;
- undertake site specific stability analysis for all areas of peat storage (if on sloping ground) to ensure the likelihood of destabilisation of underlying peat is minimised;
- avoid storing peat on slope gradients >3° and preferably store on ground with neutral slopes and natural downslope barriers to peat movement;
- monitor effects of wetting/re-wetting stored peat on surrounding peat areas, and prevent water build up on the upslope side of peat mounds;
- undertake regular monitoring of emplaced peat in restoration areas to identify evidence of creep or pressure on retaining structures (dams and berms); and
- maximise the interval between material deliveries over newly constructed tracks that are still observed to be within the primary consolidation phase.

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

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

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

5.4 Good Practice Post-Construction

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

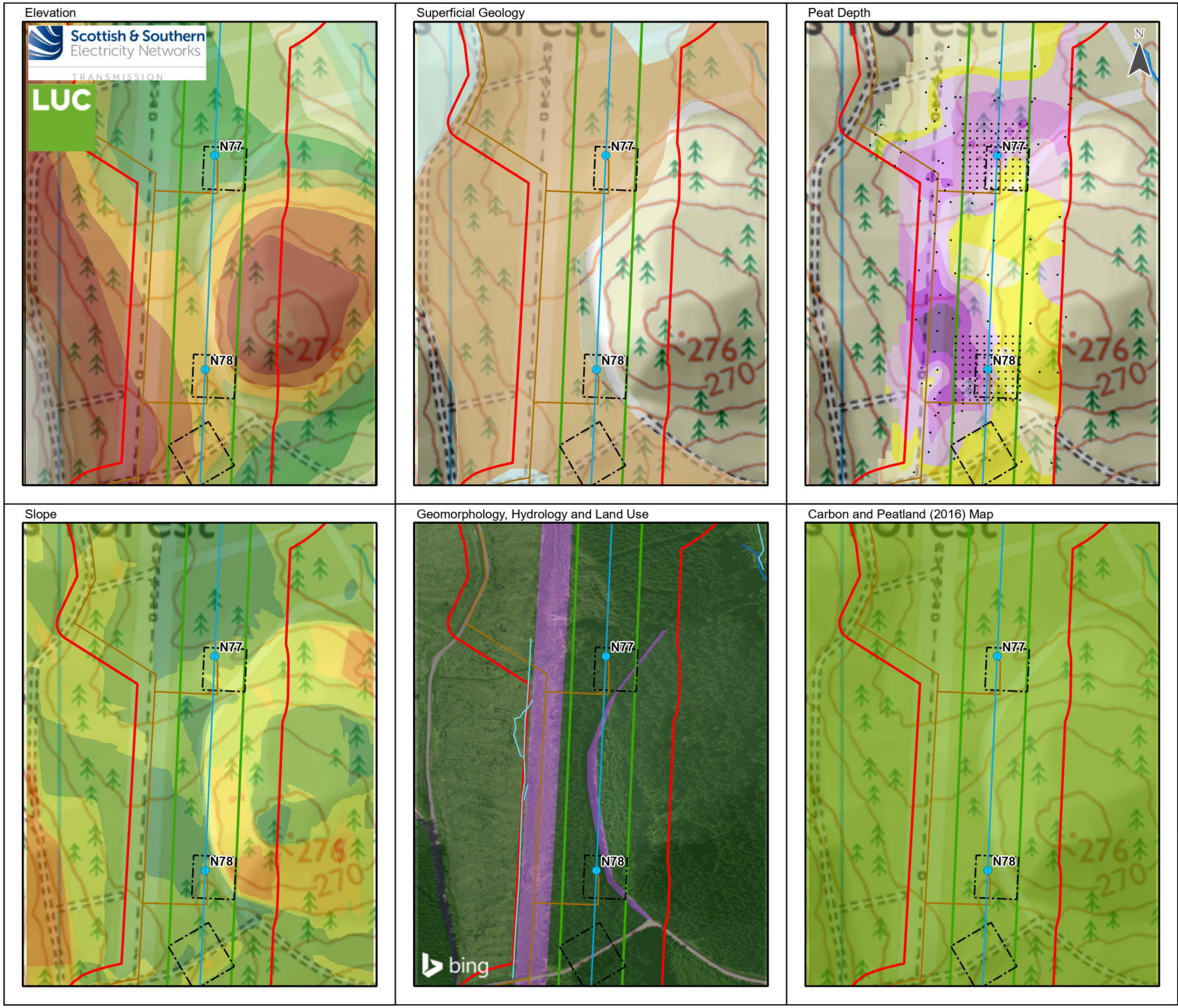
- ponding on the upslope side of infrastructure sites and on the upslope side of access tracks;
- changes in the character of peat drainage within a 50 m buffer strip of tracks and infrastructure (eg upwelling within the peat surface upslope of tracks, sudden changes in drainage behaviour downslope of tracks);
- blockage or underperformance of the installed site drainage system;
- slippage or creep of stored peat deposits; and
- development of tension cracks, compression features, bulging or quaking bog anywhere in a 50 m corridor surrounding the Site of any construction activities or site works.

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

ANNEX 13.6.1: FIGURES A13.6.1 AND A13.6.2

Figure A13.6.1: Site Characteristics

Figure A13.6.2: PLHRA Results



Elevation [m] (Top Left Panel)
- 246 - 246
- 247 - 249
- 250 - 252
- 253 - 255
- 256 - 258
- 259 - 261
- 262 - 264
- 265 - 267
- 268 - 270
- 271 - 273
- 274 - 276
- 277 - 279
- 280 - 282
- 283 - 285
- 286 - 288
- 289 - 291
- 292 - 294

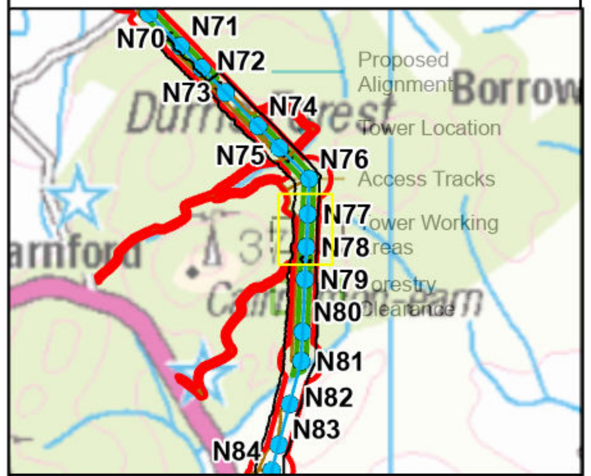
Carbon and Peatland (2016) Map (Bottom Left Panel)
- Class 1
- Class 2
- Class 3
- Class 4
- Class 5
- Mineral Soil
- Unknown Soil
- Non Soil
- Proposed Development Limit of Deviation
- Proposed Alignment
- Tower Location
- Access Tracks
- Tower Working Areas
- Forestry Clearance

Slope [°] (Bottom Left Panel)
- 0.0 - 2.5
- 2.5 - 5.0
- 5.0- 7.5
- 7.5 - 10.0
- 10.0- 15.0
- > 15.0

Superficial Geology (Top Centre Panel)
- Peat
- Banchory Till Formation - Diamicton
- Hummocky Glacial Deposits - Diamicton, Sand and Gravel
- No Deposits

Geomorphology, Hydrology and Land Use (Bottom Centre Panel)
- Forestry
- Made Ground
- Planar (peat / soil)
- Watercourses
- Drains

Peat Depth [cm] (Top Right Panel)
- <= 30
- 31 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- Peat Probe Locations



Scale @ A3: 1:5,000

0 0.03 0.06 0.12 0.18 0.24 0.3 km

Project No: LT455
Project: Kintore to Tealing 400kV Overhead Line

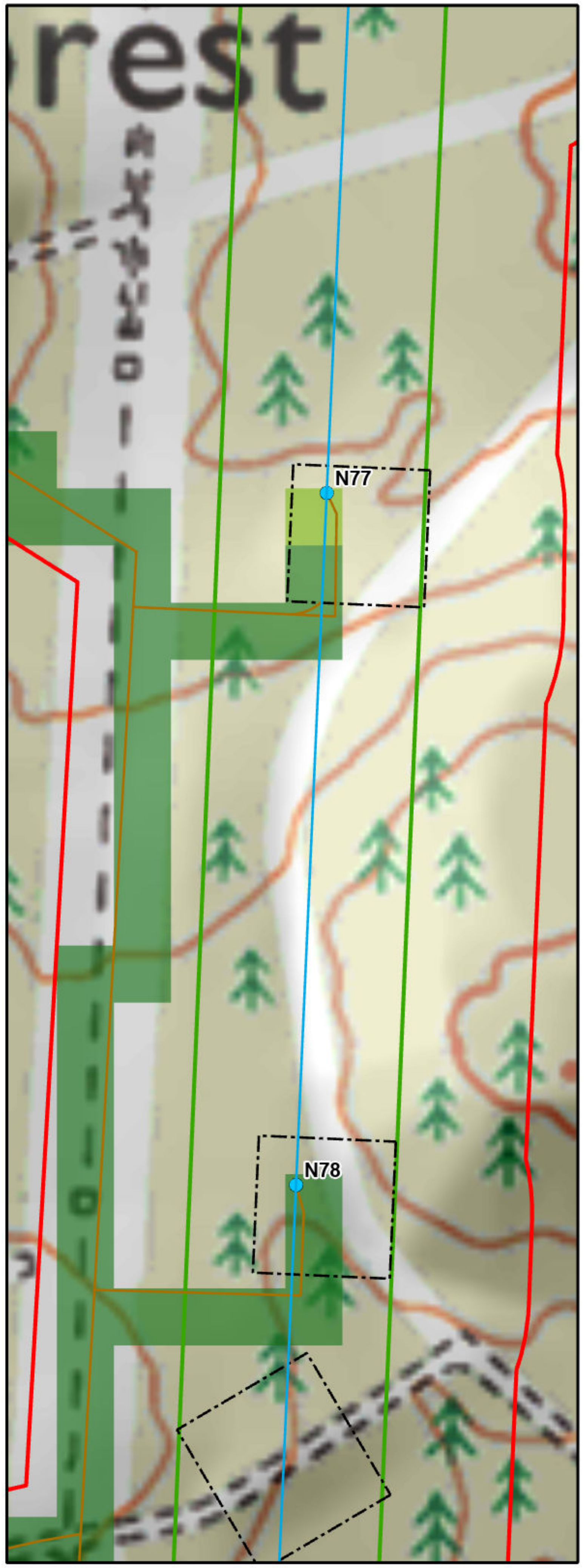
Title: Figure A13.6.1 Site Characteristics

Drawn by: RH Date: 01/07/2025

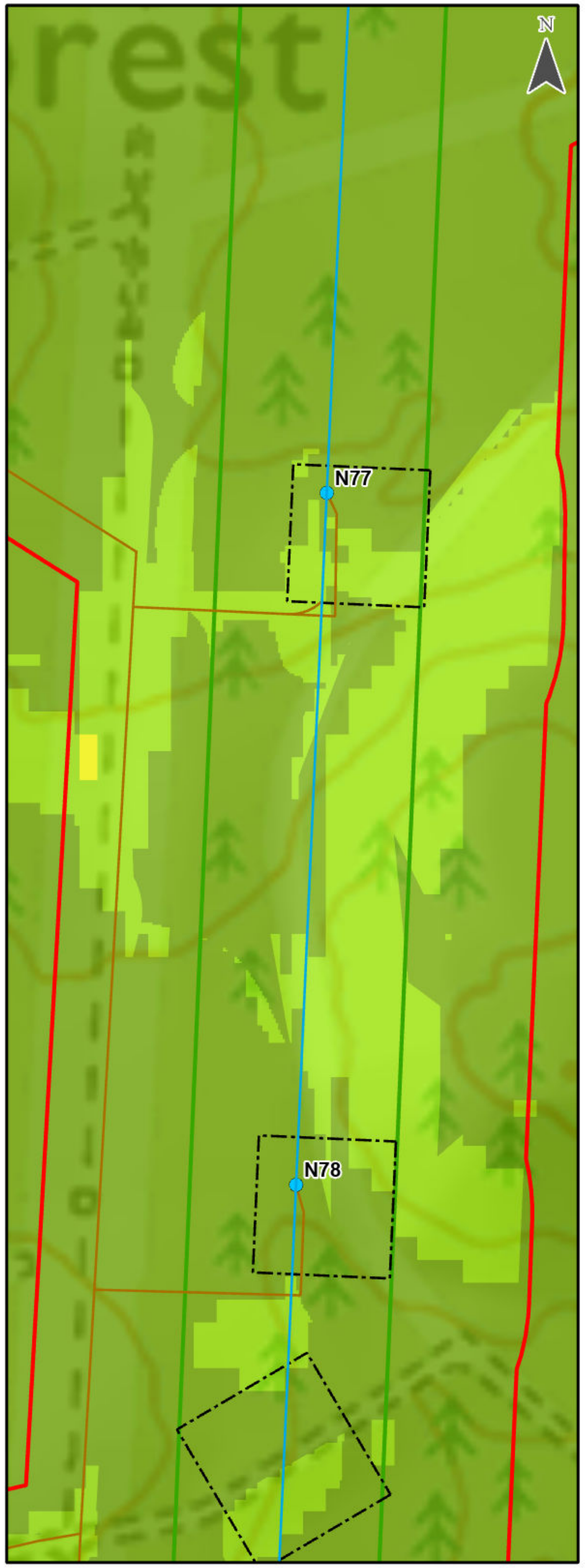
Drawing: 01

Factor of Safety - Best Estimate

Factor of Safety - Crane Loaded



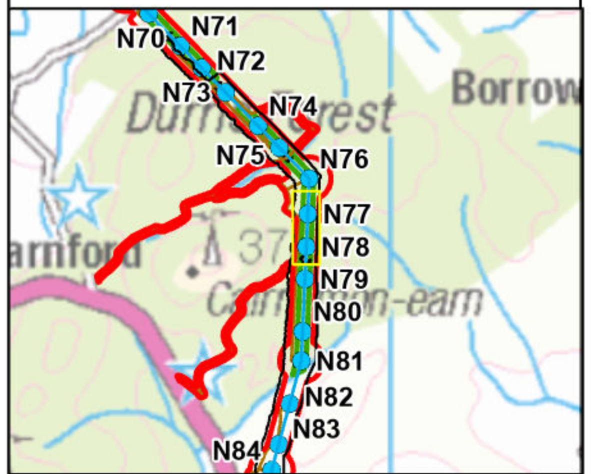
Peat Landslide Likelihood



Proposed Development Limit of Deviation
Proposed Alignment
Tower Location
Access Tracks
Tower Working Areas
Forestry Clearance

Factor of Safety
- < 1.00 "Unstable"
- 1.01 - 1.40 "Marginally Stable"
- 1.41 - 2.00 "Stable"
- 2.01 - 3.00 "Stable"
- > 3.01 "Stable"

Peat Landslide Likelihood
- Very Low
- Low
- Moderate
- High (none calculated)
- Very High (none calculated)



Scale @ A3: 1:2,500

0 0.015 0.03 0.06 0.09 0.12 0.15 km

Project No: LT455
Project: Kintore to Tealing 400kV Overhead Line

Title: Figure A13.6.2 PLHRA Results

Drawn by: RH Date: 01/07/2025

Drawing: 01