

**Beauly to Blackhillock to New Deer to
Peterhead 400 kV Project
Environmental Impact Assessment Report
Volume 5 | Appendices**

**Appendix 10.3 – Peat Landslide Hazard and Risk
Assessment**



APPENDIX 10.3 – PEAT LANDSLIDE HAZARD AND RISK ASSESSMENT

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1 Introduction

1.1 Background

- 1.1.1 Scottish Hydro Electric Transmission PLC (the Applicant) is seeking consent under Section 37 of the Electricity Act 1989 for construction of the Beauly to Blackhill to New Deer to Peterhead 400 kV Overhead Line (OHL) in Highland, Moray and Aberdeenshire, hereafter referred to as the 'Proposed Development'. The Proposed Development is described in detail in **Chapter 3: Project Description** of the Environmental Impact Assessment Report (EIA Report) and shown on **Figure 3.1: Site Layout**. Given the length and complexity of the Proposed Development, descriptions within this technical appendix are limited to those of relevance to the peat landslide hazard and risk assessment.
- 1.1.2 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 various locations along the route of the Proposed Development and therefore a PLHRA that assesses these areas is required.

1.2 Scope of work

- 1.2.1 The scope of the PLHRA is as follows:
- characterise the peatland geomorphology of the Proposed Development to determine whether prior incidences of instability have occurred and whether contributory factors that might lead to instability in the future are present;
 - 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 Scottish Government Best Practice Guidance (BPG) was issued in 2007 and provided an outline of expectations for approaches to be taken in assessing peat landslide risks on windfarm 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)¹:
- i. an assessment of the character of the peatland within the application boundary including thickness and extent of peat, and a demonstrable understanding of site hydrology and geomorphology;
 - ii. an assessment of evidence for past landslide activity and present-day instability e.g. pre-failure indicators;

¹ Scottish Government (2017). Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments. 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>

- iii. a qualitative or quantitative assessment of the potential for or likelihood of future peat landslide activity (or a landslide susceptibility or hazard assessment);
- iv. identification of receptors (e.g. habitats, watercourses, infrastructure, human life) exposed to peat landslide hazards; and
- v. a site-wide qualitative or quantitative risk assessment that considers the potential consequences of peat landslides for the identified receptors.

1.2.4 The Proposed Development is extensive, c. 185 km in length, and peat would not be expected over its full extent. Accordingly, the spatial scope of this assessment has been limited to those sections of the Proposed Development that contain peat. This is considered further in the next section.

1.3 Spatial Scope

- 1.3.1 Due to the length of the Proposed Development, the Applicant undertook consultation with SEPA and NatureScot to agree a suitable basis for focusing peat depth probing on the areas most likely to overlap with peat and which would therefore be subject to peat survey and assessment through the peat landslide hazard and risk assessment (PLHRA) and outline peat management plan (**Appendix 10.2: Peat Management Plan**). The approach is documented in **Section 4.1** of **Appendix 10.1: Peat Depth Survey Report** (PDSR) and relies on a combination of the James Hutton Institute (JHI) predictive peat model, the Carbon and Peatland (2016) Map, BGS superficial geology layers and interpretation of satellite imagery to produce an initial survey scope, the extent of which was iteratively refined on the ground during survey if peat was found beyond the predicted peat extents.
- 1.3.2 The full extent of the peat surveys is described in the PDSR, see **Section 3.5** of this report, and **Figure 10.3.3: Spatial Scope**. The spatial scope of this assessment is informed by the PSR, but is confined to areas of the Proposed Development within which peat was proven, not the full extent of the survey area (which demonstrated peat to be absent in many areas).
- 1.3.3 At a local level, the spatial scope of the assessment focuses on proposed infrastructure, since it is only groundworks in association with infrastructure that has the potential to trigger instability as part of the Proposed Development. However, a Limit of Deviation ('LoD') forms part of the Proposed Development and describes the area over which infrastructure *could* be located in the event that post-consent detailed ground investigation requires minor adjustments to layout. Therefore the spatial scope comprises the full extent of the LoD in areas where peat has been proven. All infrastructure within the peat survey area where the presence of peat was proven have been assessed in this report. Infrastructure for which survey has not been undertaken (e.g. ATV / Trackway) has not. **Figures 10.3.4 to 10.3.11** in this report present only these surveyed areas with peat in order to preclude the need for extensive and superfluous reporting.

1.4 Report Structure

- 1.4.1 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 along the Proposed Development.
 - **Section 3** provides a description of the Proposed Development area based on desk study and observations during site visits, including consideration of aerial or satellite imagery, digital elevation data, geology and peat depth data.
 - **Section 4** describes the approach to and results of an assessment of peat landslide likelihood under both natural conditions and in association with construction of the Proposed Development.
 - **Section 5** describes the approach to and results of a consequence assessment that determines potential impacts on-site receptors and the associated calculated risks.

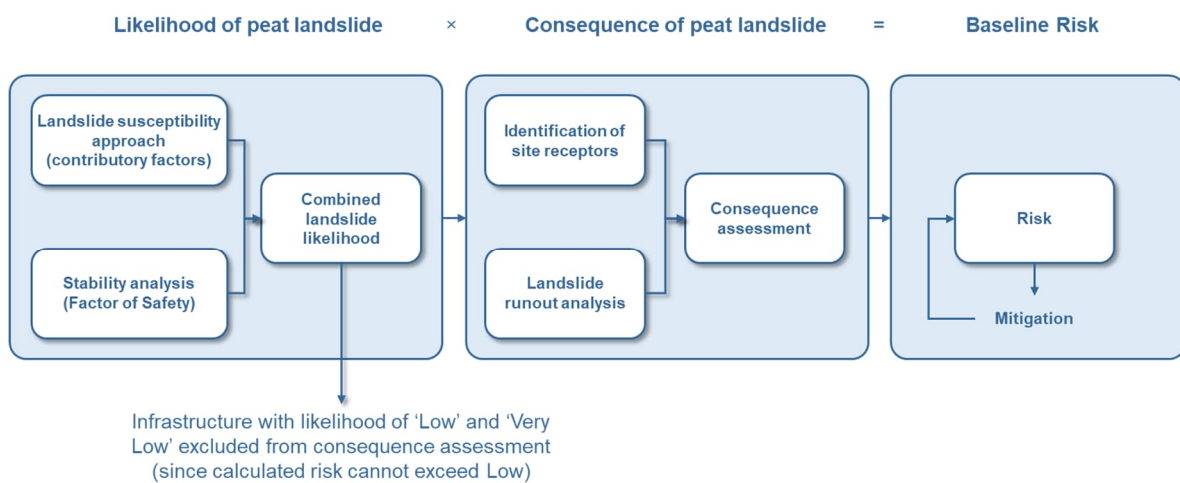
- **Section 6** provides mitigation and control measures to reduce or minimise these risks prior to, during and after construction.

1.4.2 Assessments within the PLHRA have been undertaken alongside assessments for the Outline Peat Management Plan (**Appendix 10.2: Peat Management Plan**) and have been informed by results from the Peat Survey Report (**Appendix 10.1: Peat Depth Survey Report**). Where relevant information is available elsewhere in the EIA Report, this is referenced in the text rather than repeated in this report.

1.5 Approaches to assessing peat instability for Proposed Development

- 1.5.1 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.
- 1.5.2 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.
- 1.5.3 To reflect these limitations, both approaches are adopted and outputs from each approach integrated in the assessment of landslide likelihood. **Plate 1.1** shows the approach.

Plate 1.1: Risk assessment approach



1.6 Team competencies

- 1.6.1 This PLHRA has been undertaken by a chartered geologist with 27+ years experience of mapping and interpreting peatland terrains and peat instability features. Geomorphological walkover survey was undertaken by Fluid Environmental Consulting during peat depth probing, a highly experienced peatland survey team, and additional site observations and photographs were made available from these surveys to the PLHRA team.

2 Background to Peat Instability

2.1 Peat Instability in the UK and Ireland

- 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 and 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 windfarm. To-date, there have been no publicly reported peat landslides in association with overhead line projects.
- 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 machined 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 windfarm 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. The Derrybrien event triggered interest in the influence of windfarm 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 windfarms on peatland sites. While the production of PLHRA reports is required for all Section 36 energy projects on peat, they are now also regarded as best practice for smaller windfarm applications. The guidance was updated in 2017 (Scottish Government, 2017)¹ and is now generally applied to all forms of energy generation and grid infrastructure in peatland areas.
- 2.1.5 A number of peat landslide events have occurred both naturally and in association with built infrastructure (e.g. **Plate 2.1**). In the case of windfarm sites, these have rarely been reported, however landslide scars of varying age are visible in association with windfarm 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 Derrysallagh windfarm site in Co. Leitrim (Flaherty, 2016)⁸ on a plateau in which several published examples of instability had been previously reported. In 2020, a bog burst occurred at the Meenbog wind farm, Co. Donegal, on land undergoing construction (Morton et al, 2024)⁹. Two occurrences of instability in association with construction works on the Viking Wind Farm (Shetland) have been reported (July 2022 and May 2024), though in both cases, these have involved failure of peat or

² Evans, M.G. and Warburton, J. (2007). *Geomorphology of Upland Peat: Erosion, Form and Landscape Change*. UK: Blackwell Publishing.

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

⁴ Mills, A.J., Moore, R., Carey, J.M. and Trinder, S.K. (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, R.A. and Bragg, O.M. (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.

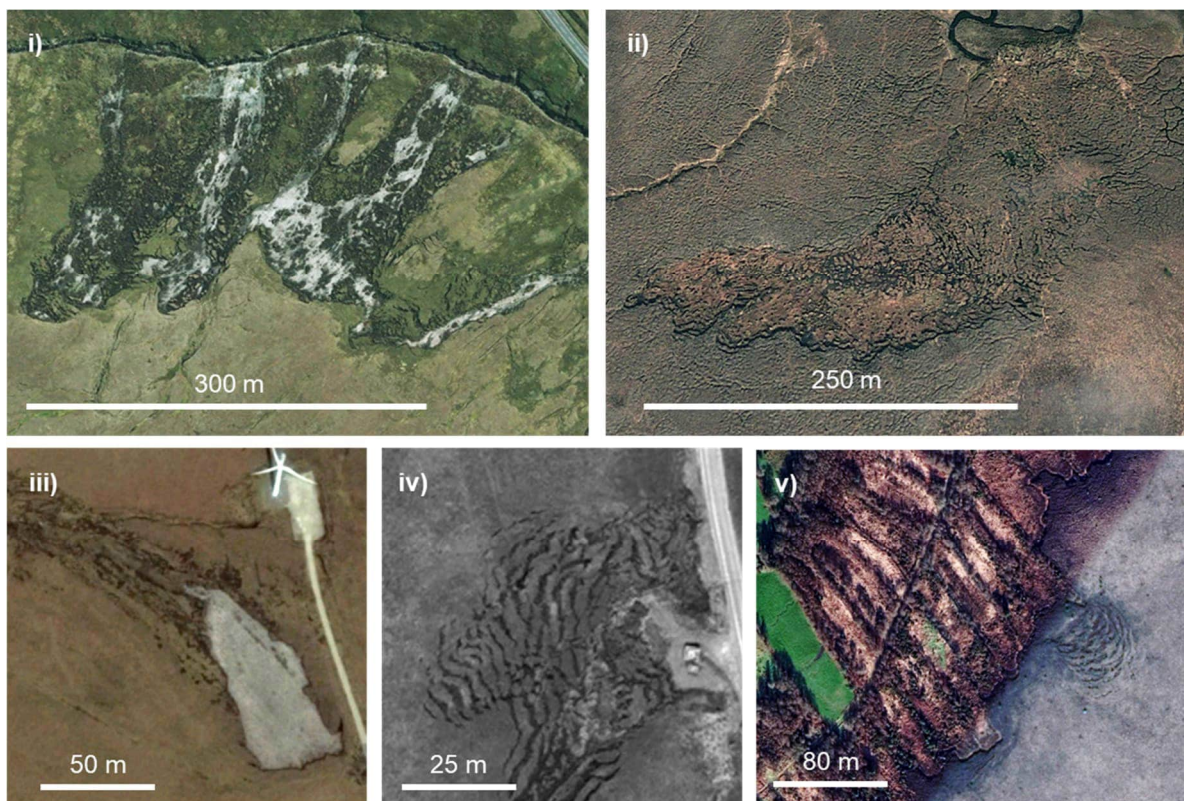
⁸ Flaherty, R. (2016). Man dies in suspected landslide at wind farm in Co Sligo. Irish Times, 13/12/2013. Available at: <https://www.irishtimes.com/news/crime-and-law/man-dies-in-suspected-landslide-at-wind-farm-in-co-sligo-1.2903750>

⁹ Morton, P.A., Hunter, W.R., Cassidy, R., Doody, D., Atcheson, K. and Jordan, P. (2024). Muddying the waters: impacts of a bogflow on carbon transport and water quality. *Catena*, 238.

mineral spoil at track margins rather than the triggering of a new 'peat slide' by groundworks. An earlier failure in 2015 (The Shetland Times, 2015)¹⁰ pre-dated construction of the windfarm and was not associated with construction works.

- 2.1.6 Other relatively recent natural events include another failure in Galway at Clifden in 2016 (Irish News, 2016)¹¹, Cushendall, Co. Antrim (BBC, 2014)¹² (Comment) in the Glenelly Valley, Co. Tyrone in 2017 (BBC, 2018)¹³, Drumkeeran in Co. Leitrim in July 2020 (Irish Mirror, 2020)¹⁴ and Benbrack in Co Cavan in July 2021 (The Anglo-Celt, 2021)¹⁵. 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.

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



- 2.1.7 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.

¹⁰ The Shetland Times (2015). Mid Kame landslip on proposed windfarm site. Available at: <https://www.shetlandtimes.co.uk/2015/10/30/mid-kame-landslip-on-proposed-windfarm-site>

¹¹ Irish News (2016). Major landslide sees 4,000 tonnes of bog close popular Galway tourist route. Available at: <https://www.independent.ie/irish-news/major-landslide-sees-4000-tonnes-of-bog-close-popular-galway-tourist-route-34830435.html>

¹² BBC (2014). Torrential rain leads to landslides in County Antrim. Available at: <https://www.bbc.co.uk/news/uk-northern-ireland-28637481>

¹³ BBC (2018). Glenelly Valley landslides were 'one-in-3,000 year event'. Available at: <https://www.bbc.co.uk/news/uk-northern-ireland-43166964>

¹⁴ Irish Mirror (2020). Photos show massive mudslides in Leitrim after heavy flooding. Available at: <https://www.irishmirror.ie/news/irish-news/mudslides-drumkeeran-leitrim-flooding-photos-22281581>

¹⁵ The Anglo-Celt (2021). Hillwalker captures aftermath of landslide. Available at: <https://www.anglocelt.ie/2021/07/22/hillwalker-captures-aftermath-of-landslide/>

2.2 Types of Peat Instability

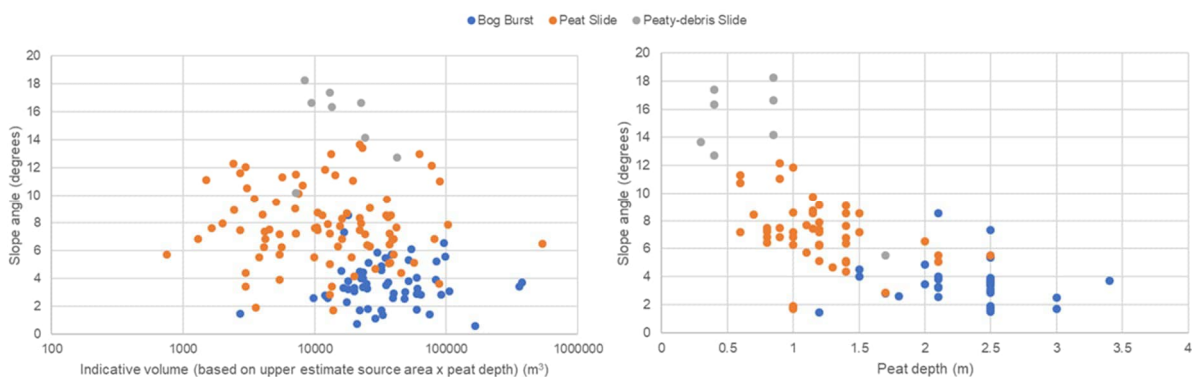
2.2.1 Peat instability is manifested in a number of ways (Dykes and Warburton, 2007)¹⁶ all of which can potentially be observed on-site either through site walkover or remotely from high resolution aerial photography:

- **minor instability:** localised and small-scale features that are not generally precursors to major slope failure and including gully sidewall collapses, pipe ceiling collapses, minor slumping along diffuse drainage pathways (e.g. along flushes); indicators of incipient instability including development of tension cracks, tears in the acrotelm (upper vegetation mat), compression ridges, or bulges / thrusts (Scottish Government, 2017)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, i.e. creep;
- **major instability:** comprising various forms of peat landslide, ranging from small scale collapse and outflow of peat filled drainage lines / gullies (occupying a few-10s cubic metres), to medium scale peaty-debris slides in organic soils (10s to 100s cubic metres) to large scale peat slides and bog bursts (1,000s to 100,000s cubic metres).

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)¹⁷* which collates site information for reported peat failures in the UK and Ireland. Separately, *Dykes and Warburton (2007)¹⁶* 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 2.1**. 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 2.2**).

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



¹⁶ Dykes, A. and Warburton, J. (2007) Mass movements in peat: A formal classification scheme. *Geomorphology* 86, pp. 73–93.

¹⁷ Mills, A.J. (2002). Peat slides: Morphology, Mechanisms and Recovery, unpublished PhD thesis. University of Durham.

- 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 (e.g. *Bowes, 1960¹⁸*).
- 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 (i.e. they are <0.5 m thick). These are similar to peat slides in form, but far smaller and occur commonly in UK uplands across a range of slope angles¹⁶. 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 (i.e. bog bursts) have been reported in Scotland, with only one or two unpublished examples in evidence on the Isle of Lewis and Caithness.

Factors Contributing to Peat Instability

- 2.2.7 Peat landslides are caused by a combination of factors – triggering factors and preconditioning factors (Dykes and Warburton, 2007; Scottish Government, 2017)^{16,1}. 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.
- 2.2.8 Preconditioning factors may influence peat stability over long periods of time (years to hundreds of years), and include:
- i. impeded drainage caused by a peat layer overlying an impervious clay or mineral base (hydrological discontinuity);
 - ii. a convex slope or a slope with a break of slope at its head (concentration of subsurface flow);
 - iii. proximity to local drainage, either from flushes, pipes or streams (supply of water);
 - iv. connectivity between surface drainage and the peat / impervious interface (mechanism for generation of excess pore pressures);
 - v. artificially cut transverse drainage ditches, or grips (elevating pore water pressures in the basal peat-mineral matrix between cuts, and causing fragmentation of the peat mass);
 - vi. increase in mass of the peat slope through peat formation, increases in water content or afforestation;
 - vii. reduction in shear strength of peat or substrate from changes in physical structure caused by progressive creep and vertical fracturing (tension cracking or desiccation cracking), chemical or physical weathering or clay dispersal in the substrate;
 - viii. loss of surface vegetation and associated tensile strength (e.g. by burning or pollution induced vegetation change);
 - ix. increase in buoyancy of the peat slope through formation of sub-surface pools or water-filled pipe networks or wetting up of desiccated areas;
 - x. afforestation of peat areas, reducing water held in the peat body, and increasing potential for formation of desiccation cracks which are exploited by rainfall on forest harvesting.
- 2.2.9 Triggering factors are typically of short duration (minutes to hours) and any individual trigger event can be considered as the ‘straw that broke the camel’s back’:
- i. intense rainfall or snowmelt causing high pore pressures along pre-existing or potential rupture surfaces (e.g. between the peat and substrate);
 - ii. rapid ground accelerations (e.g. from earthquakes or blasting);

¹⁸ Bowes, D.R. (1960). A bog-burst in the Isle of Lewis. *Scottish Geographical Journal*. 76, pp. 21-23.

- iii. unloading of the peat mass by fluvial incision or by artificial excavations (e.g. cutting);
- iv. focusing of drainage in a susceptible part of a slope by alterations to natural drainage patterns (e.g. by pipe blocking or drainage diversion);
- v. loading by plant, spoil or infrastructure.

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

Consequences of Peat Instability

- 2.2.11 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.
- 2.2.12 A key part of the risk assessment process is to identify the potential scale of peat instability should it occur and identify the receptors of the consequences. Potential sensitive receptors of peat failure are:
- the development infrastructure and towers (damage to tower bases, tracks, 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).
- 2.2.13 While peat failures may cause visual scarring of the peat landscape, most peat failures revegetate fully within 50 to 100 years and are often difficult to identify on the ground after this period of time (Feldmeyer-Christe and Küchler, 2002; Mills, 2002)^{19, 17}. Typically, it is short-term (seasonal) effects on watercourses that are the primary concern or impacts on public water supply.

¹⁹ Feldmeyer-Christe, E., & Küchler, M. (2002). Eleven years of vegetation dynamics in a peat bog affected by a landslide. *Botanica Helvetica*, 112(2), 103–120.

3 Baseline conditions

3.1 Topography

- 3.1.1 **Figure 10.3.1: Elevation** shows the Proposed Development from Beauly in the Highlands to Peterhead in Aberdeenshire based on a 5 m digital terrain model (DTM). The Proposed Development is situated within lowlands until Newtonhill, rising into low hills of The Aird, before descending to the Caledonian Canal and then running along the northern flanks of a hill complex of which Càrn nan Tri-tighearnan forms the central peak. It then crosses undulating lowland and uplands until Orbliston before being at low elevations until Peterhead. Where peat is present, it is typically in the form of blanket peat or saddle mires in the uplands, and valley mires and fens in the lowland areas.
- 3.1.2 Slope angles vary considerably along the Proposed Development, though there are few areas of very steep ground (where peat would be expected to be absent). **Figure 10.3.2** shows slope angles for the Proposed Development.
- 3.1.3 The spatial scope of the assessment is limited by the presence of peat, this being partially informed by topography. **Section 1.3** details the rationale behind the spatial scope of this PLHRA assessment, which focuses on four key sections of the Proposed Development where peat is present, shown on **Figure 10.3.3: Spatial Scope** as hashed black boxes. The spatial scope is determined by the peat depth surveys, not by the Carbon and Peatland (2016) Map layers on **Figure 10.3.3**, which are provided for context only. The spatial scope is as follows, with each section below shown on one of four panels on **Figures 10.3.4 to 10.3.9**:
- Castledown to Bruachmary;
 - Bruachmary to Tomdow;
 - Beachans to west of Carn na Cailliche (summit); and
 - North of Carn na Cailliche (summit) to south of Fogwatt.
- 3.1.4 Importantly, any peat within areas outside these focus areas has still been fully assessed using the methodology described in **Section 4** of this report, but if present, it is usually highly localised and therefore has not been included in the figure set.

3.2 Geology

- 3.2.1 **Figure 10.3.4: Geology Bedrock** shows the bedrock geology for the spatial scope of the Proposed Development, mapped from 1:50,000 scale publicly available BGS digital data. The Castledown to Bruachmary section is Saddle Hill Granite, before crossing an extensive area of gneissose psammite, semipelite and subordinate quartzite (Dava Subgroup) broken by a section of Ardclach Granite through Bruachmary to Tomdow. From Beachans to Fogwatt, the majority of the Proposed Development is underlain by Nethybridge Psammite.
- 3.2.2 **Figure 10.3.5: Geology Superficial** shows the superficial geology for the spatial scope of the Proposed Development, also mapped from 1:50,000 scale BGS data. The Castledown to Bruachmary section (first panel) lies primarily over Devensian glacial till, with localised peat deposits, and alluvium in the valley floors.
- 3.2.3 The Bruachmary to Tomdow section is primarily over glaciofluvial deposits, again with peat indicated to be present in the east, while peat is more widespread in the east nearer Tomdow (second panel). Hummocky glacial till deposits, peat and alluvium are present over much of the section from Beachans to north of Carn na Cailliche (third panel), while there Devensian till is the primary substrate from Carn na Cailliche (fourth panel).
- 3.2.4 There are no geological designations within the area covered by the spatial scope.

3.3 Peat Depth and Character

- 3.3.1 Extensive peat depth probing has been undertaken to support design of the Proposed Development. The PDSR (**Appendix 10.1: Peat Depth Survey Report**) details probing phases undertaken by a variety of contractors and consultants in support of an early JHI peat model (see **Section 2 of Appendix 10.1: Peat Depth Survey Report**) and then detailed probing to *Scottish Government (2017)¹* specifications. Variations from this guidance are documented in **Table 3.1 of Appendix 10.1: Peat Depth Survey Report**, and occurred in response to the level of evidence derived from the JHI peat model. The approach to varying probing density was agreed with key stakeholders prior to undertaking of the infrastructure-specific probing programme.
- 3.3.2 In total, 21,203 probes and 40 cores (focused in peat areas) were collected by Fluid Environmental Consulting, with 11,662 probes recording no peat. Cores were used to validate the probing in key areas, particularly where there was over-representation of depth was suspected due to underlying soft substrate.
- 3.3.3 Records of the underlying substrate character were collected using the 'feel' method for all probe locations, in which the rate and mode of refusal was used to estimate underlying conditions, e.g. a sudden change in stiffness but with continuing penetration might indicate clay (particularly if present on the probe tip after withdrawal), a grinding sound might indicate a mineral rich / gritty substrate and a sudden refusal might indicate bedrock.
- 3.3.4 **Figure 10.3.6: Peat Depth** shows the peat depth model interpolated from the peat depth data collected along the Proposed Development. Probing locations and depths are provided in the PDSR and are not repeated in this report, however the broad summary of peat distribution is provided below.

Coverage

- Depth of penetration probing, considered equivalent to peat depth, has been completed across the Proposed Development where either the JHI model predicted peat or where priority peatland habitats have been mapped.
- Probing was completed at 50 m intervals with 10 m offsets along proposed new and upgraded access tracks and on a 50 m grid at other infrastructure (tower working areas and conductor pulling zones) where the JHI model recorded scores of 1 or 2, and / or priority peatland was present.
- Probing was completed at 25 m intervals with 10 m, 30 m and 50 m offsets along proposed access tracks and on a 10 m grid at other infrastructure where the JHI model recorded scores of between 2 and 5, or where peat was encountered in the coarser grid and therefore probing on the denser grid was required.
- No probing was completed where the JHI model scores were 0 or where no priority peatland habitat was mapped.

Depth and distribution

- Peat has been determined to be present up to a depth of 8.1 m based on 21,203 depth of penetration probes and 40 cores.
- A peat depth contour model has been developed across the survey area based on the probing results which indicates that there is no peat across 83.26% of the survey area, peat up to 1 m depth across 7.65% of the survey area and peat >1 m depth across 9.1% of the survey area (see **Table 4.2, Appendix 10.2: Peat Management Plan**).
- Peat is almost entirely absent for the section of the Proposed Development from Beauly to about 7 km east of Inverness and from south of Elgin to Peterhead. From approximately 7 km east of Inverness to directly south of Elgin peat occurrence and depth is variable along with peat generally present in pockets which can extend up to 8 m in depth.
- Peat depth does not always correspond to areas mapped as priority peatland habitat as peat is also present in forestry and open moorland, and there is also an absence of peat in some of the areas mapped as priority peatland habitat.

Peat character

- A distinct acrotelm layer was identified in 35 of the 40 coring locations that ranged between 0.05 m and 0.20 m thick and averaged 0.11 m where present.
- Coring for peat depth verification and assessment of peat characteristics was completed at 40 locations. The coring verified the peat probing depths in 38 of the 40 locations where the probe depths were the same or within 0.1 m of difference. Two of the cores overestimated the peat depth by between 0.55 m and 0.70 m. This difference was due to soft and penetrable layers consisting of silty topsoil, clayey silt and degraded peat / peaty soils that were indistinguishable from peat using the probe and would indicate that there may be some areas of the site where the depth of peat is over estimated.
- No amorphous peat was identified at site.

3.3.5 Interpolation of peat depths was undertaken in the ArcMap GIS environment using a natural neighbour approach. This approach was selected because it preserves recorded depths at each probe location, unlike some other approaches (e.g. kriging), is computationally simple, and minimises 'bullseye' effects. The approach was selected after comparison of outputs with three other methods (inverse distance weighted, kriging and TIN (triangulated irregular network)). The peat depth model is shown for the spatial scope of the PLHRA on **Figure 10.3.6: Peat Depth**.

3.3.6 Peat avoidance is relatively limited by the span lengths permissible from one tower to the next, the requirement to maintain straight alignments across sub-sections of towers (to limit tension effects) and the need to gain access to the base of each tower for access and construction. While the LoD provides opportunity (post-consent) to adjust the layout to minimise impacts, the submitted alignment enables a credible assessment of potential environmental impacts, including peat landslide risk.

3.4 Hydrology

- 3.4.1 The Proposed Development intersects with numerous catchments and watercourses. The hydrological baseline is described in **Chapter 10: Water and Geological Environment**.
- 3.4.2 The potential impacts of a peat landslide occurring in association with construction would be limited to those watercourses within credible landslide runout distances of landslide source zones. These watercourses are only defined once the source zones have been identified (see **Section 5**) and it is not intended to provide an overview of hydrological receptors in this section.
- 3.4.3 Key considerations in determining the likelihood of impacts are:
- the distance of the watercourse from the potential origin of a landslide (calculated based on infrastructure locations relative to areas of higher landslide susceptibility / lower factor of safety);
 - the rate of breakdown and thinning of debris between the source zone and watercourse receptor;
 - the degree of topographic (or other) obstruction between the source zone and watercourse receptor; and
 - the size of the watercourse and its ability to convey material.
- 3.4.4 All of these factors are considered in **Section 5** of this report along with the value of watercourse receptors (as a function of their ecological sensitivity or importance for water supply).
- 3.4.5 Additional hydrological considerations include the influence of artificial drainage on stability and the influence of seepage zones / diffuse flow pathways (e.g. flushes) on stability. These features have been characterised as part of the geomorphological mapping exercise undertaken in support of the PLHRA (see **Section 3.6**).

3.5 Land Use

3.5.1 As with hydrology, land use varies considerably over the Proposed OHL Alignment from agriculture in the lowlands to forestry and managed moorland in the uplands, the latter being where much of the peat is found. Key land uses of relevance to peat instability mapped during geomorphological / terrain appraisal of the peat covered sections of the Proposed Development are as follows:

- presence of forestry, both growing coupes and felled coupes (with plantation ridge & furrow alignment used to inform forestry scores for landslide susceptibility (see **Section 4** of this report); forestry is present extensively over peat areas, in particular between the slopes north of Creag an Daimh (Tower CB4-11) and Ferness (Tower CB6-8), from the River Dorbrac (Tower CB7-7) to the Burn of Yellowbog (Tower CB9-5A) and between Cold Burn (Tower CB9-9A) and the summit of Mill Buie (Tower CB9-15);
- presence of moor drains (or grips) in both open ground and within forestry, including orientation relative to prevailing slope; moor drainage typically occurs within open areas set within wider afforested peatland or in lowland valley mires; areas of drainage outwith forestry are most prevalent east of Ferness (between Towers CB6-12 and CB7-4) and on the open ground between Mill Buie and Glen Latterach (in the Kellas alternative alignment from Tower CB9C-14 to Tower CB10-8);
- presence of quarries and made ground, the former being buffered on their upslope sides but all made ground exempted from stability calculations (due to the absence of peat);
- presence of muirburn, including consideration of potential for shallow or deeper surface cracking and potential for ingress of water to deeper layers; the main area of burnt ground occurs between Saddle Hill and Creag an Daimh (Tower CB3-15 and CB4-7A); and
- presence of peat cuttings, either informal or mechanised – these occur locally in a handful of locations, notably near Tower CB4-16 and between Towers CB6-9 and CB6-12.

3.5.2 The land use factor that considers the various ground conditions above forms one of eight contributory factors used in the landslide susceptibility analysis described in **Section 4**.

3.6 Peatland Geomorphology

3.6.1 Satellite imagery available as an ArcGIS Basemap layer was used to interpret and map features. Additional imagery from different epochs available on both Google Earth™ and Bing was also referred to in order to validate the satellite imagery interpretation. The resulting geomorphological map is shown on **Figure 10.3.7:**

Geomorphology, hydrology and land use. Site walkovers undertaken during peat depth survey were used to verify identified features and provide an opportunity to record any instability features visible only on the ground (none were recorded). The presence, characteristics and distribution of geomorphological features are helpful in understanding potential precursors to instability across the Proposed Development.

3.6.2 Peatlands within the Site are dominated by either forestry, in which geomorphological features are absent, or by open ground in which an array of typical geomorphological features are present and have been mapped. These features comprise:

- dendritic and linear gullies, natural drainage features typically found in eroding uplands;
- patterned ground, i.e. terrain comprising either pool and hummock morphology or complex ground patterning driven chiefly by macro-scale vegetation;
- bog pools, typically discrete and isolated rather than extensive bog pool systems;
- flush / diffuse surface flow pathways, within which water flows are concentrated near the ground surface;
- eroded ground / damaged ground, where peat vegetation has been sufficiently degraded that bare peat is visible, either in hags or as bare patches; and

- planar peatland generally absent of features, so lacking signs of gullying or erosion, unmodified by land management, more likely than other terrain types to exhibit subsurface drainage (generally assumed to be associated with instability).

3.6.3 **Figure 10.3.7: Geomorphology, hydrology and land use** shows the distribution of these features within the spatial scope of the PLHRA.

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:

$$\text{Risk} = \text{Probability of a Peat Landslide} \times \text{Adverse Consequences}$$

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

4.2 Limit Equilibrium Approach

Overview

- 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 m x 25 m grid cells within the area defined by the Limit of Deviation. This is the most frequently cited approach to quantitatively assessing the stability of peat slopes (e.g. Scottish Government, 2017; Boylan et al, 2008; Evans and Warburton, 2007; Dykes and Warburton, 2007; Creighton, 2006; Warburton et al, 2003; Carling, 1986)^{1,20,2;16,21,22,23}. 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), γ_w 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, i.e. that the soil is in its natural, unloaded condition. The use of cut and fill for foundations and tracks across almost much of the construction footprint suggest this is an appropriate approach. The choice of water table height reflects the full saturation of the soils that would be expected under the most likely trigger conditions, i.e. heavy rain.

- 4.2.4 Where the driving forces exceed the shear strength (i.e. where the bottom half of the equation is larger than the top), F is < 1 , indicating instability. A factor of safety between 1.0 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

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, A.J. (2003). Anatomy of a Pennine peat slide, Northern England. Earth Surface Processes and Landforms, 28, pp. 457–473.

²³ Carling, P.A. (1986). Peat slides in Teesdale and Weardale, Northern Pennines, July 1983: description and failure mechanisms. Earth Surface Processes and Landforms, 11, pp. 193–206.

high water content, compressibility and organic composition (Hobbs, 1986; Boylan and Long, 2014)^{24;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 full extent of the Limit of Deviation and key input parameters derived for each grid cell. Cells without peat were excluded from the analysis. In total, c. 11,770 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 (i.e. full saturation). Effective stress parameters are used in a drained analysis.
 - 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 (e.g. 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 4.1** shows the input parameters and assumptions for the baseline stability analysis. The shear strength parameters c' and ϕ' are usually derived in the laboratory using undisturbed samples of peat collected in the field and therefore site specific values are often not available ahead of detailed site investigation for a development. Therefore, for this assessment, a literature search has been undertaken to identify a range of credible but conservative values for c' and ϕ' quoted in fibrous and humified peats. FoS analysis was undertaken with conservative ϕ' of 20° and values of 2 kPa and 5 kPa for c' . These values fall at the low end of a large range of relatively low values (when compared to other soils).

Table 4.1: 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) ¹⁷ 10.1, Irish bog peat (Boylan et al 2008) ²⁰

²⁴ Hobbs, N.B. (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.

²⁶ Huat, B.B.K., 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, A.P. and Kirk, K.J. (2001). Initiation of a multiple peat slide on Cuilcagh Mountain, Northern Ireland. Earth Surface Processes and Landforms, 26, 395-408.

Parameter	Values	Rationale	Source
Effective angle of internal friction (ϕ')	20 degrees	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 (Farrell, 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 m x 25 m grid cell	Interpolated peat depth model of site
Height of water table as a proportion of peat depth (h)	1	Assumes peat mass is fully saturated (normal conditions during intense rainfall events or snowmelt, which are the most likely natural hydrological conditions at failure)	

4.2.10 **Table 4.2** shows the input parameters and assumptions for the modified stability analysis. The analysis employs a 5 m wide floating track, and assumes representative loads for a multi-axle crane with maximum axle load of 12 t moving over the floated surface. The analysis assumes pre-loading of the peat by floating track during which the track is built in layers and pore pressures are allowed to dissipate. The combined weight of the track and peat are then modelled in an undrained analysis utilising the heaviest vehicle loads likely to use the access the track.

Table 4.2: 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 4.1
Slope angle from horizontal (β)	Various	Credible slope angles for which floating tracks are proposed	See Table 4.1
Peat depth (z)	Various	Reduction in volume (i.e. depth) under floating road is balanced by increased density, so pre-load parameters are used	See Table 4.1
Crane axle load (t)	16 t	Axle load corresponding to Abnormal load vehicle.	

Results

4.2.11 The outputs of the drained analysis (effective stress) are shown for the best estimate parameter combination in **Figure 10.3.8: Factor of Safety**. This parameter combination (minimum c' and ϕ') indicates the vast majority of peat within the Proposed Development to be stable, consistent with site observations and reports of peat instability in general.

²⁹ Hebib, S. (2001). Experimental investigation of the stabilisation of Irish peat, unpublished PhD thesis, Trinity College Dublin.

³⁰ Farrell, E.R. 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.

4.2.12 The outputs of the modified loaded (undrained analysis) incorporating crane loads on floating track are shown as black outlined grid cells on **Figure 10.3.8: Factor of Safety** for cells that overlap with floating track and which indicate $FoS < 1.4$. In order for a section of floating track to be considered a potential source zone, two or more contiguous 25 m cells must have Factors of Safety of < 1.4 . This reflects the tendency of regularised grids to produce single cell outliers in results whereas two contiguous cells of similar value would indicate a consistent trend more reflective of the local ground conditions and also of a size more typically associated with instability features. There are several instances of contiguous cells that satisfy this criterion, and a majority of the potential landslide initiation locations ('source zones') identified in this PLHRA are associated with floating track, rather than towers or ancillary infrastructure.

4.3 Landslide Susceptibility Approach

Overview

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, c. 132,000 facets were considered in the analysis, with an average area of c. 3,500 m² (or an average footprint of c. 59 m x 59 m, consistent with medium scale 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. The contributory scores for each factor are shown in the 'Peat slide' column in **Tables 4.3 to 4.10** below.

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

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

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.

Slope Angle (S)

4.3.5 **Table 4.3** shows the slope ranges, their association with instability and related scores for the slope angle contributory factor. Slope angles were derived from the 5 m digital terrain model shown on **Figure 10.3.2: Slope** and scores assigned based on reported slope angles associated with peat landslides rather than a simplistic assumption that 'the steeper a slope, the more likely it is to fail' (e.g. **Plate 2.2**). A differentiation in scores is applied for peat slides and bog bursts reflecting the shallower slopes on which the latter are most frequently observed.

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

Table 4.3: 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	0
2.5 - 5.0		1

Slope range (°)	Association with instability	Peat slide
5.0 – 7.5	2.2 and increase with increasing slope angle until the upper limiting angle e.g. peat slides are not observed on slopes <2.5°, while bog bursts are not observed on slopes > 7.5°).	3
7.5 - 10.0		3
10 – 15.0		3
>15.0		3

Peat depth (P)

- 4.3.7 **Table 4.4** shows the peat depths, their association with instability and related scores for the peat depth contributory factor. Peat depths were derived from the peat depth model shown on **Figure 10.3.6: Peat Depth** and reflect the peat depth ranges most frequently associated with peat landslides (see **Plate 2.2**).

Table 4.4: 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

Substrate Geology (G)

- 4.3.8 **Table 4.5** shows substrate type, association with instability and related scores for the substrate geology contributory factor. The shear surface or failure zone of reported peat failures typically overlies an impervious clay or mineral (bedrock) base giving rise to impeded drainage. This, in part, is responsible for the presence of peat, but also precludes free drainage of water from the base of the peat mass, particularly under extreme conditions (such as after heavy rainfall, or snowmelt).
- 4.3.9 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)¹⁶. 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 4.5: 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

- 4.3.10 Probing undertaken across the site indicated primarily bedrock or granular substrates using the refusal method, and coring at 40 locations confirmed this. No iron pans were observed (see **Appendix 10.3.1**).

Peat Geomorphology (M)

- 4.3.11 **Table 4.6** shows the geomorphological features typical of peatland environments, their association with instability and related scores.

Table 4.6: 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
Eroded / damaged peat (minor gullies) or linear / dendritic drainage	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

- 4.3.12 The geomorphological classes on **Figure 10.3.7: Geomorphology, hydrology and land use** have been scored in accordance with **Table 4.6**, with the exception of afforested peatland, which is considered in a specific forestry category (see below).

Artificial Drainage (D)

- 4.3.13 **Table 4.7** shows artificial drainage feature classes, their association with instability and related scores. Transverse (or contour aligned) / oblique artificial drainage lines may reduce peat stability by creating lines of weakness in the peat slope and encouraging the formation of peat pipes. A number of peat failures have been identified in published literature which have failed over moorland grips (Warburton et al, 2004)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 4.7: 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

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

- 4.3.14 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).

Slope curvature (C)

- 4.3.15 **Table 4.8** shows slope (profile) curvature classes, association with instability and related scores. Convex and concave slopes (i.e. positions in a slope profile where slope gradient changes by a few degrees) have frequently been reported as the initiation points of peat landslides by a number of authors. The geomechanical reason for this is that convexities are often associated with thinning of peat, such that thicker peat upslope applies stresses to thinner 'retaining' peat downslope. Conversely, buckling and tearing of peat may trigger failure at concavities (e.g. Dykes & Warburton, 2007; Boylan and Long, 2011)^{16;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 4.8: 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

- 4.3.16 The 5 m digital terrain model and OS contours were used to identify areas of noticeable slope convexity and concavity across the site. An ArcGIS geoprocessing model was used to calculate slope curvature and subdivide slopes into concave, convex and rectilinear slopes, and 'flat' areas, i.e. those with minimal rate of gradient change on subdued terrain.

Forestry (F)

- 4.3.17 **Table 4.9** 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 and the scores shown reflect this.

Table 4.9: 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
Windblown	Windblown trees have full disruption to the underlying peat and residual hydrology due to root plate disturbance	0
Not afforested	No influence on stability	0

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.

4.3.18 Much of the Proposed Development where peat is present includes forestry and hence scores tend to be higher in this category than for other categories.

Land use (L)

4.3.19 **Table 4.10** shows land use classes, association with instability and related scores. A variety of land uses have been associated with peat failures (see **Section 2.2.1**). While it is hypothesised that burning may cause desiccation cracking in peat and facilitate water flows to basal peat (and potential shear surfaces), there is little evidence directly relating burnt ground to peat landslide events.

Table 4.10: 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	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

4.3.20 Forestry is the primary land use on-site (and considered separately above). Small areas of cutting and burning are scored as shown.

Generation of Slope Facets

4.3.21 The eight contributory factor layers were combined in ArcMap to produce approximately 132,000 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).

4.3.22 **Table 4.11** describes the basis for the likelihood classes. A judgement was made that for a facet to have a moderate or higher likelihood of a peat landslide, a likelihood score would be required exceeding both the worst case peat depth and slope angle scores summed (3 in each case, i.e. 3 x 2 classes) alongside three intermediate scores (of 2, i.e. 2 x 3 classes) for other contributory factors. This means that any likelihood score of 13 or greater would be equivalent to at least a moderate likelihood of a peat landslide. Given that the maximum score attainable is 24, this seems reasonable.

Table 4.11: 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

Summed Score from Contributory Factors	Typical site conditions associated with score	Likelihood (Qualitative)	Landslide Likelihood Score
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

4.4 Results

4.4.1 **Figure 10.3.9: Landslide Likelihood** shows the outputs of the landslide susceptibility approach for peat slides. The results indicate that the majority of the site has a 'Low' likelihood and much of the remainder a 'Moderate' likelihood of a peat slide under natural conditions.

4.4.2 Areas of 'Moderate' likelihood are typically located on moderate slopes, adjacent to drains or in association with felled plantation forestry with adverse ridge and furrow alignment. There are no areas identified with 'High' or 'Very High' landslide susceptibility and only localised areas of 'Very Low' likelihood.

Combined Landslide Likelihood

4.4.3 **Figure 10.3.9: Landslide Likelihood** highlights 14 source zones that have been identified based on the outputs of the landslide susceptibility approach and the factor of safety approach (both best estimate and crane-loaded undrained assessment). The locations are shown as purple lines and labels with individual source zones ('SZ') numbers indicated. Source Zones have been identified wherever infrastructure of greater than 25 m in length intersects with areas of moderate or higher landslide susceptibility (from the landslide susceptibility approach) or Factor of Safety of 1.4 or less (from the limit equilibrium approach). A minimum 25 m overlap has been selected as this is considered the minimum size of a potentially environmentally significant landslide. In order for there to be a "Medium" or "High" risk (Scottish Government, 2017), likelihoods must be "Moderate" or higher (see **Plate 4.1** below) and hence this provides a screening basis for the likelihood results. The SZs are numbered from 1 to 19, however only 14 have been carried into the analysis following adjustments to layout to relocate infrastructure in the most critical locations in a previous layout iteration. Source Zones 2, 3, 4, 7 and 14 are not included in the analysis.

4.4.4 The source locations are summarised as follows:

- **Source zones 1:** a source zones originating within the piling pad footprint of CB3-11 adjacent to the Allt Tarsuinn.
- **Source zones 5 and 6:** two source zones adjacent to the Allt Glac a' Bhealaich, originating along a length of floating track.
- **Source zones 8 and 9:** two source zones originating adjacent to a narrow valley floor, within which there is no environmental receptor and which by its topography would preclude runout of any appreciable distance. Runout would be extremely limited or stalled immediately by the negligible slope (i.e. equivalent to an small embankment failure rather than a large-scale peat landslide) and while illustrated on subsequent figures there are not anticipated to be any risks associated with these source zones.
- **Source zone 10:** a small valley head source zone south of Achneim Wood originating within the piling pad footprint of Tower CB5-3.
- **Source zone 11:** a source zone in a small gully head within a forestry ride below the Hill of Tomechole originating along floating track east of Tower CB8-3.

- **Source zone 12:** a source zone originating within forestry east of Tomechale and to the southwest of Lone Hill in association with floating track on the approach to Tower CB8-8A.
- **Source zone 13:** another source zone originating within forestry to the southeast of Lone Hill along a section of floating track to the west of Tower CB8-11A.
- **Source zone 15:** a small source zone at the head of a linear gully above Cachy Du in association with floating track east of Tower CB8-19.
- **Source zone 16:** a source zone within forestry within the Lochs of Bogmussach in association with floating track adjacent to CB8-26A, runout is very likely to be constrained by the gentle topography (and forestry) in this location.
- **Source zones 17 and 18:** two nearby source zones, the first associated with the piling pad for Tower CB9C-16 and the second with floating track on the approach to the same tower.
- **Source zone 19:** a source zone associated with floating track on the approach to Tower CB9-15 to the southeast of Mill Buie.

4.4.5 **Section 5** of this report describes the consequence assessment and risk calculation for all areas where infrastructure intersects "Moderate" likelihood of a peat landslide.

Plate 4.1: 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 Assessment of Consequence and Risk

5.1 Introduction

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

5.2 Receptors

5.2.1 Peat uplands are typically host to the following receptors: watercourses and associated water supplies (both private and public), terrestrial habitats (e.g. groundwater dependent terrestrial ecosystems or GWDTEs) and infrastructure, both those that are related Proposed Development and other infrastructure, e.g. roads and power lines. These are considered for the Proposed Development below in areas relevant to the ten source zone locations described previously.

5.3 Watercourses

5.3.1 Source zones identified as part of this assessment have the potential to runout into the following watercourse receptors:

- Allt Tarsuinn;
- Allt Glac a' Bhealaich;
- Souters Stripe;
- Lone Burn;
- Burn of Auchness;
- Cachy Du; and
- Allt Creach

5.3.2 All of these watercourses have been assigned a high sensitivity in **Chapter 10: Water and Geological Environment** of the EIA Report based on good ecological status of the watercourse, good ecological status of the watercourse with which they are confluent, or the presence downstream of a public water supply (Glenlatterach reservoir for Allt Creach). Accordingly, they receive a consequence score of 4 (as shown in **Plate 4.1**).

5.4 Habitats

5.4.1 While blanket bog habitats are valuable, they generally recover from instability events through revegetation over a matter of years to decades and therefore a consequence score of 3 is assigned for all open blanket bog and other semi-natural habitats within runout distance of the Proposed Development. A consequence score of 2 is assigned for afforested peatland, given the degraded state of habitats in these areas.

5.5 Infrastructure

5.5.1 Source zone 13 has the potential to impact an upland track with occasional use, with this being assigned a consequence score of 3. The most likely infrastructure to be affected by instability is that associated with the overhead line works, including piling locations and track locations with potential risks to personnel working in these areas. While commercial losses would be important to the Applicant, loss of life / injury would be of greater

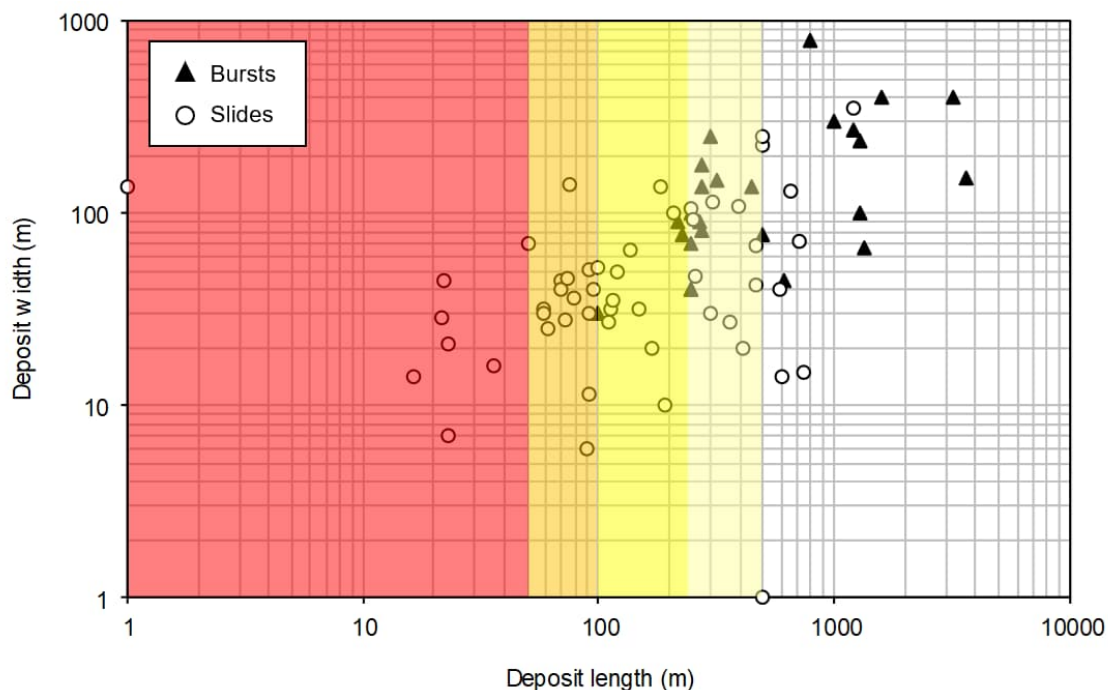
concern, and a consequence score of 5 is assigned for any infrastructure locations subject to potential peat landslides. However, risks to life can be mitigated through safe systems of working, these infrastructure risks are not considered to be 'environmental' risks, and therefore they are not explicitly considered in the consequence assessment below.

5.6 Consequences

Overview

- 5.6.1 A consequence assessment has been undertaken by determining the potential for landslides sourced at infrastructure locations with a Moderate natural likelihood of peat instability to impact the receptors identified above. For example, if a tower is located in a Moderate (likelihood score of 3) area of open slope and is located 50 m from a watercourse (with a consequence score of 5), it is probable that a landslide triggered during construction would reach that watercourse. The calculated risk would be a product of the likelihood and consequence scores (likelihood: 3 x consequence: 5 = risk: 15, see **Plate 4.1**) and be equivalent to a "Medium" risk.
- 5.6.2 In order to determine the likelihood of impact on watercourses and infrastructure, 'runout pathways' have been defined that show the estimated maximum footprint of the landslide. Runout pathways are divided in a downslope direction into 50 m, 100 m, 250 m and 500 m zones on the basis of typical runout distances detailed in *Mills (2002)*²⁷. The likelihood of runout passing from one runout zone to the next (e.g. from the 50 m zone into the 100 m zone) is based on the proportion of the published peat landslide population that reaches each runout distance shown on **Plate 5.1** (0-50 m: 100%, 50-100 m: 87%, 100-250 m: 56%, 250-500 m: 44%). The source zone area is either the footprint of hardstandings or non-linear infrastructure or where an access track is the source, the track length overlapping the source multiplied by an upslope length of up to 50 m (or the track length affected, if less than 50 m).
- 5.6.3 **Figure 10.3.10: Source and Runout Zones** shows in purple all infrastructure locations that overlap with moderate likelihoods or factors of safety <1.4, based on the combined landslide likelihood scores described in **Section 4**.

Plate 5.1: Runout distances for published peat landslides (after Mills, 2002), colours on the plot correspond to runout pathway zones on Figure 10.3.10



Local limits on runout (Watercourses)

- 5.6.4 Runout pathways defined on **Figure 10.3.10: Source and runout zones** terminate at watercourses if within 500 m of the source zone, reflecting the position of watercourses at valley floors / within topographic lows. At this point, debris is regarded as entering the watercourse and risk is calculated as the product of consequence (dependent on the watercourse consequence score) and likelihood (from **Section 4**). If watercourses contain physical barriers (e.g. weirs), are highly sinuous within low floodplains and may encourage stranding of debris, or if streams are too small to convey material, then runout may also be considered to stall where these restrictions come into effect.

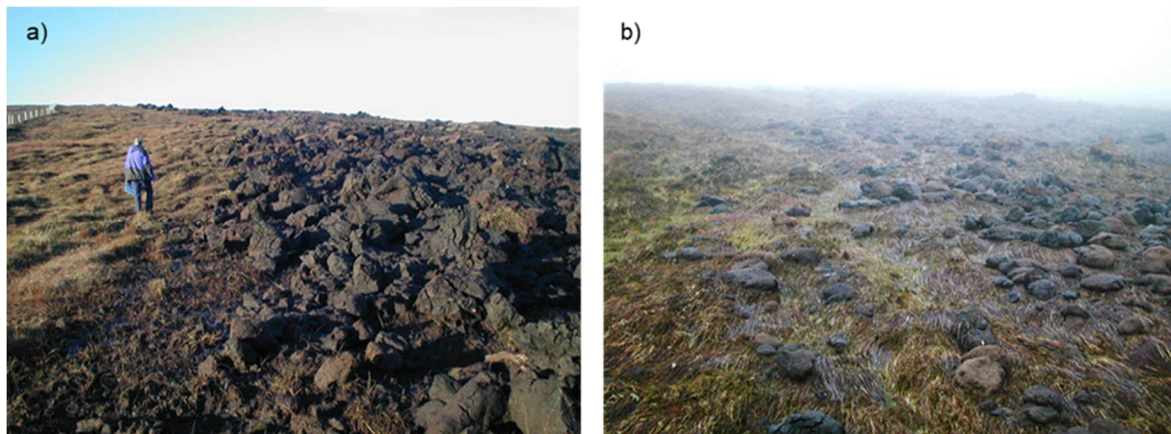
Local limits on runout (slope curvature)

- 5.6.5 **Plate 5.1** shows runout distances based on published literature. Typically, runout distances would be expected to be less where slope angles decline with distance from the source zone (i.e. on concave slopes) whereas the full runout lengths shown on **Plate 5.1** may be achievable on steepening (convex) slopes or rectilinear slopes. The convexity or concavity of slopes along the runout pathway have been assessed for each runout zone.

Local limits on runout (peat thickness in source zones)

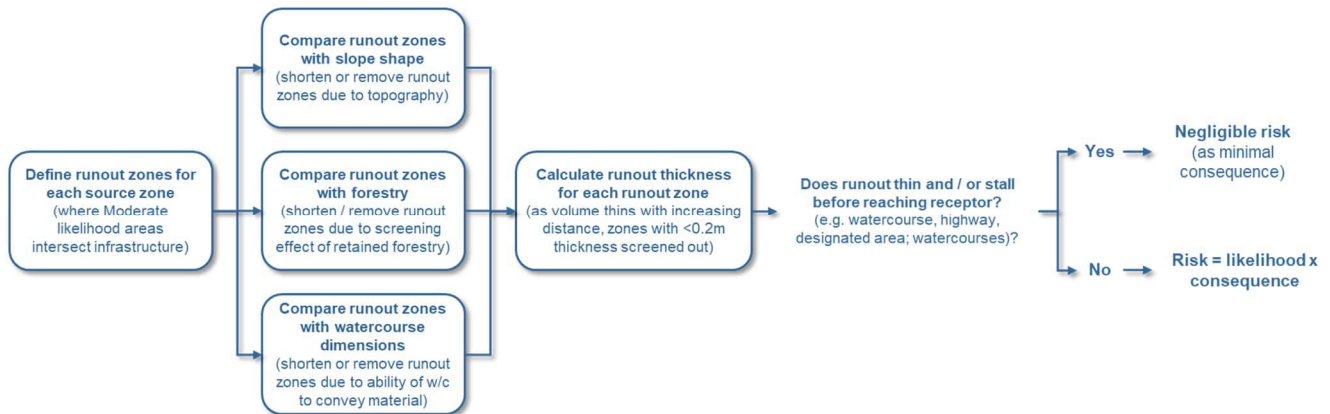
- 5.6.6 Landslide runout may be “supply-limited” by the availability of peat material generated in the failure or source zone. Typically, mobilised material thins with increasing distance from the source zone as rafts of landslide material break down into blocks, and blocks become abraded and roll, breaking down further into a blocky slurry (**Plate 5.2**).

Plate 5.2 Examples of landslide runout (Dooncarton, Co. Mayo): a) blocky debris mid-slope, b) abraded and rolled blocks in lower slope



- 5.6.7 Following identification of runout zones, additional analysis has been undertaken to approximate this effect. The analysis assumes a source volume equivalent to the source footprint (if not a track, then the polygon shown as the Source Zone on **Figure 10.3.10: Source and Runout Zones**, or if a track section, then the track length x (up to) 50 m. This source footprint is multiplied by the average peat depth in the source zone (from the peat depth model) to calculate a volume, and this volume is then distributed over the full runout pathway (i.e. mobilised volume / runout area) to generate an average thickness of deposit.
- 5.6.8 As the runout length and area increases, the volume thins, in keeping with observed peat landslide deposits. Where deposits fall below 0.2 m in thickness, it is assumed that runout will stall due to the roughness of surface vegetation relative to the thickness of landslide material. If the thickness is calculated to be 0.2 m or less in the zone adjoining a watercourse, then it is judged that the runout will stall prior to reaching it or be negligible in volume on entry and there will be no significant impact on that watercourse (even if a landslide occurs).
- 5.6.9 **Plate 5.3** shows a schematic of the full runout approach to assessing consequences.

Plate 5.3 Runout approach to assessing consequences



Results of runout analysis

5.6.10 Of the 19 source locations identified, 12 have been taken forward into runout analysis (see **Section 4.4**) and 7 have the potential for runout to reach watercourses:

- Source zone 1 (Allt Tarsuinn);
- Source zones 5 & 6 (Allt Glac a' Bhealaich);
- Source zone 10 (no receptor);
- Source zone 11 (unnamed track);
- Source zone 12 (Souters Stripe);
- Source zone 13 (Lone Burn);
- Source zone 15 (Cachy Du);
- Source zone 16 (no receptor);
- Source zone 17 (no receptor);
- Source zone 18 (unnamed watercourse); and
- Source zone 19 (Allt Creach).

5.6.11 Source zones 1, 10, 12, 13 and 19 are constrained by forestry, with runout likely to stall once it hits the treeline beyond the felling corridor required to construct and operate infrastructure. Runout zones affected by this constraint are shown with hashed shading on **Figure 10.3.11: Calculated Risk**.

5.6.12 Source zones 6, 17 and 18 are constrained by their source volumes such that debris would thin before reaching the watercourse receptors (for 6 and 18), with only open habitat of moderate sensitivity being affected by runout from source zone 17. Again, the affected runout zones are shown with hashed shading.

5.6.13 Source zone 15 occurs above a large sink hole within the peatland above the head of the Cachy Du watercourse, and therefore runout would stall due to topographic constraints before reaching this receptor. All runout zones are affected and are shown with hashed shading.

5.6.14 Runout from the remaining source zones is unconstrained, i.e. from source zones 5, 11 and 16. Although runout from source zone 5 is unconstrained, the reduction in likelihood of progress from one runout zone to the next (see 5.6.2) is sufficient for risks to be calculated as Low in this runout pathway.

5.7 Calculated Risk

5.7.1 Calculated risks for all zones are Low or Negligible based on the analysis above and therefore manageable

through the application of good practice measures.

- 5.7.2 The calculated risks for all source zones after the consideration of constraints (forestry, curvature, debris thinning) and are shown on **Figure 10.3.11: Calculated Risk**. This figure indicates that risks are calculated to be "Low" to "Negligible" across the site. No source locations have a "Medium" or "High" calculated risk.
- 5.7.3 Based on the calculated risks shown on **Figure 10.3.11: Calculated Risk**, site-wide good practice measures should be sufficient to manage and mitigate any construction induced instability risks. This is considered in the next section.

6 Risk Mitigation

6.1 Overview

- 6.1.1 A number of mitigation opportunities exist to further reduce the risk levels identified at the Proposed Development site. These range from infrastructure specific measures (which may act to reduce peat landslide likelihood, and, in turn, risk) to general good practice that should be applied across the site to engender awareness of peat instability and enable early identification of potential displacement and opportunities for mitigation.
- 6.1.2 Based on the analysis presented in this report, risks are calculated to be “Low” or “Negligible” across the site, subject to minor changes to track design and / or micro-siting detailed below. **Sections 6.2 to 6.4** provide information on good practice pre-construction, during construction and post-construction (i.e. during operation).

6.2 Good Practice Prior to Construction

- 6.2.1 The alignment of all tracks and placement of ancillary infrastructure should be reviewed against information derived from detailed intrusive site investigation and laboratory analysis post-consent, this being 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.
- 6.2.2 These investigations should be sufficient to:
1. Determine the strength of free-standing bare peat excavations.
 2. Determine the strength of loaded peat (where excavators and plant are required to operate on floating hardstandings or track, or where operating directly on the bog surface).
 3. Identify sub-surface water-filled voids or natural pipes delivering water to the excavation zone, e.g. through the use of ground penetrating radar or careful pre-excavation site observations.
- 6.2.3 A comprehensive Geotechnical Risk Register should be prepared post-consent, but pre-construction, detailing sequence of working for excavations, measures to minimise peat slippage, design of retaining structures for the duration of open hole works, monitoring requirements in and around the excavation and remedial measures in the event of unanticipated ground movement. The risk register should be considered a live document and updated with site experience as infrastructure is constructed. Ideally, a contractor with experience of working in deep peat should be engaged to undertake the works.

6.3 Good Practice During Construction

- 6.3.1 The following good practice should be undertaken during construction.
- 6.3.2 For excavations:
- use of appropriate supporting structures around peat excavations (e.g. for tower foundations and compounds) to prevent collapse and the development of tension cracks;
 - avoid cutting trenches or aligning excavations across slopes (which may act as incipient back scars for peat failures) unless appropriate mitigation has been put in place;
 - implement methods of working that minimise the cutting of the toes of slope, e.g. working up-to-downslope during excavation works;
 - monitor the ground upslope of excavation works for creep, heave, displacement, tension cracks, subsidence or changes in surface water content;
 - monitor cut faces for changes in water discharge, particularly at the peat-substrate contact;

- minimise the effects of construction on natural drainage by ensuring that natural drainage pathways are maintained or diverted such that 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).

6.3.3 For cut tracks:

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

6.3.4 For floating tracks:

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

6.3.5 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 $>3^\circ$ and preferably store on ground with neutral slopes and natural downslope barriers to peat movement;
- monitor effects of wetting / re-wetting stored peat on surrounding peat areas, and prevent water build up on the upslope side of peat mounds;
- undertake regular monitoring of emplaced peat in restoration areas to identify evidence of creep or pressure on retaining structures (dams and berms);
- maximise the interval between material deliveries over newly constructed tracks that are still observed to be within the primary consolidation phase.

6.3.6 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 and relevant regulators to identify any unusual or unexpected changes to ground conditions (which may be associated with construction or which may occur independently of construction);
- all construction activities and operational decisions that involve disturbance to peat deposits should be overseen by an appropriately qualified geotechnical engineer with experience of construction on peat sites;
- awareness of peat instability and pre-failure indicators should be incorporated in site induction and training to enable all site personnel to recognise ground disturbances and features indicative of incipient instability;
- a weather policy should be agreed and implemented during works, e.g. identifying 'stop' rules (i.e. weather dependent criteria) for cessation of track construction or trafficking;
- monitoring checklists should be prepared with respect to peat instability addressing all construction activities proposed for site.

- 6.3.7 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 (i.e. Moderate consequences) with a Very Low likelihood of occurrence.

6.4 Good Practice Post-Construction

- 6.4.1 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 (e.g. upwelling within the peat surface upslope of tracks, sudden changes in drainage behaviour downslope of tracks;
 - blockage or underperformance of the installed site drainage system;
 - slippage or creep of stored peat deposits;
 - development of tension cracks, compression features, bulging or quaking bog anywhere in a 50 m corridor surrounding the site of any construction activities or site works.
- 6.4.2 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.