Appendix 9.6: Peat **Landslide Hazard and Risk Assessment**

east point geo

Kendoon to Tongland 132kV Reinforcement Project

Appendix 9.6 Peat Landslide Hazard and Risk Assessment

June 2020

Client	SPEN
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Contents

1. Introduction

1.1. Background

1.1.1 Scottish Power Energy Networks (SPEN) is seeking consents under Section 37 of the Electricity Act 1989 to modernise and reinforce the 132 kV electricity network between Kendoon and Tongland in Dumfries and Galloway. The proposed works comprise five new connections, each of which is being progressed as a single application:

- A new 132 kV double circuit steel tower overhead line, of approximately 10.6 km in length between Polquhanity (approximately 3 km north of the existing Kendoon substation) and Glenlee substation, via the existing Kendoon substation (P-G via K).
- A new 132 kV single circuit wood pole overhead line, of approximately 2.6 km in length, between Carsfad and Kendoon (C-K).
- A new 132 kV single circuit wood pole overhead line, of approximately 1.6 km in length, between Earlstoun and Glenlee (E-G) (together with a short section of underground cable).
- A new 132 kV double circuit steel tower overhead line deviation of the existing BG route, at Glenlee substation approximately 1 km in length (BG Deviation).
- A new 132 kV double circuit steel tower overhead line, of approximately 32.5 km in length, between Glenlee and Tongland (G-T).

1.1.2 In addition, 43km of existing overhead lines (OHL) known as N and R routes will be removed. The existing substation at Glenlee will be extended to accommodate changes to the lines and a planning application for the extension has already been submitted to Dumfries and Galloway Council. Collectively, these works are referred to as 'the KTR Project'. A full description of the scheme is provided in Chapter 4 ('**Project Description**') of the Environmental Impact Assessment (EIA) Report.

1.1.3 The KTR Project is situated within Dumfries and Galloway and is located within the Glenkens Valley and Galloway Hills within the Southern Uplands. The linear route runs north to south from Polquhanity (c. 3 km north of the Kendoon substation) to a substation at Tongland (1.5 km east of Kirkcudbright). The study areas for environmental assessment within the EIA vary according to the likely extent of effects (see EIA **Chapter 1: Introduction**).

1.1.4 This is a Peat Landslide Hazard and Risk Assessment (PLHRA) in respect of the KTR Project. 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) for applications under Section 36 and Section 37 of the Electricity Act 1989. 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 within parts of the KTR Project study area and therefore a PLHRA is required. To focus this assessment on areas of potential impact, an initial screening exercise has been undertaken to determine the study area (see section 1.2 below).

1.2. Scope of Work

1.1.5 The scope of this PLHRA is as follows:

- Identify a refined study area within which peat landslide risks may be present (as a function of presence of continuous peat deposits, and slope angle where peat is present).
- Characterise the peatland geomorphology to determine whether prior incidences of instability have occurred and whether contributory factors that might lead to instability in future are present across the site.
- Determine the likelihood of a future peat landslide under natural conditions and in association with construction activities associated with the KTR Project.
- Identify potential receptors that might be affected by peat landslides, should they occur, and quantify the associated risks.
- Provide appropriate mitigation and control measures to reduce risks to acceptable levels such that the KTR Project is developed safely and with minimal risks to the environment.

1.1.6 Based on detailed peat probing undertaken for the five connections as part of the routeing, design and EIA process, four of the connections were screened out of the assessment due to a lack of continuous deep peat. Removal of the existing overhead lines has also been screened out due to the minimal groundworks associated with decommissioning. **Table 1** summarises the findings of the screening assessment. On this basis, only the Glenlee to Tongland connection ("the GT connection") is subject to PLHRA. The locations of these areas considered as part of the PLHRA are shown (as yellow 100m wide corridors) on **Figure 1**.

Table 1: Screening outcomes for assessment of peat instability

Infrastructure	Area	Reason for inclusion in PLHRA
Access 40	From the A712 onto Darsalloch Hill rising to join the OHL at Tower 17	Low to moderate depth peat present in midslopes over c. 300 m length of access track
Tower 17 to 18	Saddle between Peal Hill and Benbrack	Moderate to deep peat present over c. 600 m length of access track and at tower locations
Tower 23 to 24	Afforested moorland on Tannoch Flow	Moderate to deep peat present over c. 600 m length of access track and at tower locations
Tower 30	Over Mid Burn to the southwest of Cairn Edward Hill	Low to moderate depth peat present around Tower 30
Tower 48 to Tower 51	Either side of the River Dee falling from Airds Craig and rising towards Bennan Hill to the west	Pockets of deep peat present along c. 800m length of track and at tower locations
Tower 54 to 56	East flank of Slogarie Hill	Isolated pockets (up to 100 m in length) of low peat depth present along access track
Tower 67 to 72	Undulating low ground south of Kenick Wood	Isolated pockets of locally deep peat present over c. 1 km of access track
Tower 78 to 79	Lowland north of Edgarton Loch	Locally deep peat present between Towers 78 and 79
Tower 82 to 91	Undulating ground to the west of Bargatton Loch	Deep peat present over sizeable areas for c. 2 km

1.1.7 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).

1.3. Report Structure

1.2.1 This report is structured as follows:

- Section 2 provides a site description based on desk study and site observations, including consideration of aerial imagery, digital elevation data, geology and peat depth data.
- Section 3 gives context to the landslide risk assessment methodology through an account of peat landslide types and contributory factors before providing an overview of the approach taken for the KTR Project.
- 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 KTR Project.
- 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.

1.2.2 Where relevant information is available elsewhere in the EIA Report, this is referenced in the text rather than repeated here.

2. Desk Study

2.1. Study Area

2.1.1 Following the initial PLHRA screening exercise, the Glenlee to Tongland connection was subdivided into nine subsections for which assessment of peat landslide risks has been undertaken (see **Figure 1**). The sections are as follows:

- **Access 40:** a new access track from the A712 onto Darsalloch Hill rising to join the OHL at Tower 17.
- **Tower 17 to Tower 18:** new access track and towers in the saddle between Peal Hill and Benbrack.
- **Tower 23 to Tower 24:** new access track and towers over afforested moorland on Tannoch Flow.
- **Tower 30:** new access track and towers over Mid Burn to the southwest of Cairn Edward Hill.
- **Tower 48 to Tower 51:** new access track and towers to either side of the River Dee falling from Airds Craig and rising towards Bennan Hill to the west.
- **Tower 54 to Tower 56:** new access track and towers passing the east flank of Slogarie Hill.
- **Tower 67 to Tower 72:** new access track and towers following undulating low ground south of Kenick Wood.
- **Tower 78 to 79:** new access track and towers on lowland north of Edgarton Loch.
- **Tower 82 to Tower 91:** new access track and towers running along undulating ground to the west of Bargatton Loch.

2.1.2 Although there are other isolated instances of peat, these are either too small to experience large scale failure of the type typically assessed in PLHRAs or are not coincident with infrastructure and therefore no impacts are anticipated from the KTR Project. The remainder of this section of the report considers site characteristics of relevance to peat instability for these nine subsections.

2.2. Topography

2.2.1 The topography of the GT connection is shown for each of the nine subsections assessed in **Figure 2** ('Elevation) and indicated by a hillshaded digital terrain model underlying the satellite imagery on **Figure 1** for the full route of the GT connection. The proposed OHL rises from a low point of 52 m AOD at Glenlee in the north, close to the Water of Ken, up to around 240 m AOD in the upland area of Galloway Forestry Park. For the most part, the OHL route stays at low elevations below various hill summits, hugging the valley sides or passing through saddles between summits (e.g. between Cairn Edward Hill and Benbrack).

2.2.2 Close to Mossdale, the connection falls to around 75 m AOD adjacent to the River Dee crossing before rising again to the south as it passes through the hills of Galloway Forest Park, again reaching elevations of 240 m AOD. Further south, as the OHL leaves the upland forest park, the elevation falls towards the Water of Ken, with ground levels of around 37 m AOD at Tongland.

2.2.3 Slope angles are shown for the nine subsections on **Figure 3** ('Slope Angle'). Slopes are typically minor (less than 5°) over the majority of the subsections, with the exceptions of:

- **Access 40:** moderate north-facing slopes of 5-10° on the rise to Darsalloch Hill.
- **Tower 30:** moderate southwest facing slopes of 5-15° below Cairn Edward Hill.
- **Tower 50 to Tower 51:** locally moderate to steep slopes of 5-20° rising from the River Dee crossing to Bennan Hill.

2.2.4 The steeper topography and slope ranges would most likely be associated with peat slide morphology, while the more gentle gradients (<5°) on plateau or in the lowlands would typically be associated with bog bursts.

2.3. Geology and Soils

Superficial and Bedrock Geology

2.3.1 British Geological Survey solid geology layers viewed as an ArcGIS™ basemap layer show solid geology as follows for the nine subsections:

- **Access 40:** Gala 1 Formation (Silurian) - Medium to thick bedded turbidites: Sandstones are mainly quartzose and coarse grained. Mostly within the thermal aureole of the Cairnsmore of Fleet granite, where metamorphosed and foliated.
- **Subsections between Tower 17 and Tower 31:** Cairnharrow Granite pluton (Cairnsmore of Fleet granite) (Late Silurian to Early Devonian) - Course grained granite formed as an igneous intrusion.
- **Subsections between Tower 48 and Tower 72:** Gala 4, Gala 5, Gala 7, Cairnharrow Formation, Kirkmaiden Formation, Carghidown Formation all comprising metamorphosed turbidite greywacke deposits. The Kirkmaiden formation is more calcareous in composition and the Carghidown Formation contains minor intrusion of porphyritic microdiorite.
- **Subsections between Tower 78 and Tower 84:** Cairnharrow Formation (as above).
- **Subsection Tower 85 to Tower 91:** Kirkmaiden Formation (as above).

2.3.2 Superficial geology is shown to be as follows (see **Figure 4** 'Superficial Geology'):

- **Access 40, Tower 52 to Tower 70:** Devensian tills and diamictons comprised of gravels and muds formed from glacially reworked sandstones.
- **Tower 23 to Tower 24, locally between Tower 47 and Tower 51, Tower 78 and Tower 79 and Tower 82 to Tower 90:** Peat, primarily lacustrine and palustrine in origin.
- **Locally from Tower 47 to Tower 51:** Hummocky glacial deposits and diamicton of sand and gravel, again formed by glacial reworking.
- **Locally from Tower 78 to Tower 84:** Glaciofluvial deposits of gravel, sand and silt associated with glacial meltwater channels.

2.3.3 Elsewhere, superficial deposits are shown to be largely absent. Peat is relatively limited in extent based on these data. The presence of tills, particularly where very fine grained (i.e. clay) has been associated with peat instability in the published literature. There are no known geological designated areas within the GT connection (or the rest of the KTR Project).

2.3.4 Substrate characteristics are reported within **Appendix 9.4: Peat Survey Report**, based on resistance and feel during probing. All locations are recorded as either bedrock, silt, gritty silt or grit. There are no reports of clay (which would normally coat the probe tip and be easily observable on recovery).

Soils

2.3.5 Scottish Soil mapping (see EIA Report **Chapter 9: Geology, Hydrology, Water Resources and Peat**) shows the majority of the GT connection to be underlain by brown soils with some areas of peaty gleys, peaty podzols and peat. Peaty gleys are shown in areas of forestry and moorland between the west of

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Cairn Edward Hill and Bennan Hill. Peaty podzols are shown in the Laurieston forestry area between Slogarie Hill, Tormollan Hill and to the south. The majority of the rest of the OHL is located on Brown Earths down to Tongland.

2.3.6 Reference to the SNH Carbon and Peatlands Map 2016 shows the majority of the GT connection to be located on minerals soils with local potential for peat soils. None of the nine subsections considered in this report are on nationally important Class 1 or Class 2 carbon-rich soils and are either on Class 4 (predominantly mineral soils) or Class 5 soils which may have peat, but exhibit no peatland habitat. The exception is a small area between Tower 81 and 85 (Beoch Moor) which is shown as Class 3 (carbon rich soils with some areas of deep peat).

Peat

2.3.7 Site specific data is more reliable than desk-based sources and for large infrastructure projects, such as the KTR Project, is acquired through peat survey. Peat depth probing was undertaken between 2017 to 2019 over several phases in areas where peat was shown as potentially present on a combination of SNH, Scottish Soils and BGS mapping. These peat surveys were undertaken to inform the design of the new OHL and provide a baseline for assessment of impacts on peat. A very high density of probing has been achieved, with centrelines and two parallel offsets at 15 m and 30 m on both sides of the centreline. Dense grids have been taken at infrastructure footprints (such as at towers and temporary construction compounds). The results of the peat survey are shown on **Figure 5** along with superimposed probe locations.

2.3.8 **Figure 5** ('Peat Depth') shows peat to be largely absent from the GT connection other than in the subsections of the route taken forward for this assessment (see **Table 1**). Otherwise, peat is present as minor pockets, typically less than 1.0 m in depth and less than 50 m in lateral extent. These pockets are surrounded by areas of soil. Exceptions are as follows:

- A short section between Towers 41 and 43 accessed via a spur from the existing track that largely avoids the peat deposits.
- A short section between Towers 57 and 58 which has been avoided by re-routing to the west.
- A short section on the existing access track up to Towers 73 and 74 (this is excluded as track is already present).

2.3.9 Iterative design of the OHL layout was undertaken where possible to avoid deep peat deposits (e.g. between Towers 57 and 58). Full details of the peat surveys for the GT and other connections are presented within **Appendix 9.4: Peat Survey Report**.

2.3.10 Of the subsections taken forward for this assessment, peat is generally shallow or discontinuous for Access 40 and Tower 54 to 56, and locally deep for all subsections from Tower 17 to Tower 51 and from Tower 67 to Tower 79. Extensive deep peat is present at low elevation adjacent to Bargatton Loch. Given the discontinuous peat present in most of the subsections, peat depths are considered most conducive to 'peat slides' rather than bog bursts (which usually occur in larger extents of peat). The one exception is the continuous deep peat adjacent to Bargatton Loch, where 'bog bursts' rather than peat slides are considered.

2.4. Hydrology

2.4.1 A full description of the catchments and watercourses of the KTR Project is provided in **Chapter 9: Geology, Hydrology, Water Resources and Peat**. Salient points are summarised below.

2.4.2 The majority of the GT connection is located within subcatchments of the Water of Ken and River Dee, which flows in a southerly direction to the east of the OHL route. The Water of Ken is known as the River Dee downstream of Loch Ken at the confluence with the Black Water of Dee. The distance between the OHL and Water of Ken/River Dee watercourses is at its greatest in the central part of the GT connection where it is up to 6 km west of the river.

2.4.3 A number of burns flow east or southeast towards the Water of Ken / River Dee. Those present within or close to the subsections considered in this report are listed below:

- **Knocknairling Burn:** below Access 40.
- **Darsalloch Burn and Pultarson Burn:** Towers 17 to 18.
- **Mid Burn:** Tower 30.
- **The River Dee:** at the crossing between Towers 49 and 50.
- **Kenick Burn:** Towers 68 to 69.
- **Bargatton Loch:** Towers 85 to 86.

2.4.4 In addition, some lowland field drains are crossed in the lowland area south of the Laurieston Forest. Where possible, areas of wet, boggy ground or marshland were avoided during alignment of the OHL.

2.4.5 **Chapter 9** of the EIA Report details protected sites within or close to the GT connection. Those in proximity to the subsections assessed in this report are as follows:

- **Water of Ken Woods Site of Special Scientific Interest (SSSI):** located approximately 5 km downstream of the Access 40 junction with the A712 and comprising woodland sites along the Water of Ken valley.
- **Loch Ken and River Dee Marshes Special Protection Area (SPA) and Wetlands of International Importance (RAMSAR) site:** located on Loch Ken and the River Dee approximately 5 km downstream of Access 40.
- **Laughenghie and Airie Hills SSSI:** which includes Stroan Loch and is located near the River Dee crossing.

2.4.6 Water bodies are typically considered as receptors within PLHRAs since mobilised peat generated during peat landslides has the potential to enter watercourses and be transmitted downstream.

2.4.7 **Figure 7** of **Chapter 9** of the EIA Report shows two private water supplies (PWS) alongside Knocknairling Burn (Waulkill and The Brough). No other PWS are shown near to or adjoining the subsections of the OHL considered in this report.

2.5. Land Use

2.5.1 The study area is relatively sparsely populated and primarily comprises areas of upland commercial forestry and lowland agriculture.

2.5.2 Two large afforested areas are present; the Bennan Forest between Towers 13 and 67, and the Laurieston Forest south of the B795 between Towers 68 and 74. The orientation of rows of trees and the presence of isolated forest drains are clearly visible on aerial imagery (**Figure 6**). No pre-forestry satellite imagery was available on Google Earth™. A smaller area of forestry is present adjacent to Bargatton Loch.

2.5.3 There are no areas of cutting visible within the peat areas shown on **Figure 5**, and what little peat there is, is largely forested.

2.5.4 There are no other land uses visible that might have an effect on peat instability.

2.6. Geomorphology

Peat geomorphology and character

2.6.1 Satellite imagery available on Google Earth™ dating from 2011 and digital aerial photography was used to interpret and map peatland geomorphological features within 100 m corridors centred on the nine subsections along the GT connection. Additional imagery from later dates available on both Google Earth™ and bing.com/maps was also referred to in order to validate the air photo interpretation (in particular forestry status). Site walkover undertaken during peat probing provided an opportunity to identify instability features along the full route, though none were identified.

2.6.2 **Figure 6** ('Geomorphology, hydrology and land use') shows the key features and peatland geomorphology of the site. The presence, characteristics and distribution of these features are helpful in understanding the hydrological function of a peatland, the balance of erosion and peat accumulation (or condition), and the sensitivity of a peatland to potential land-use changes.

2.6.3 The majority of the peat areas within the nine subsections are concealed by mature or semi-mature forest plantation. No imagery was available prior to afforestation to determine peatland condition prior to tree planting. Aerial imagery indicates the presence of forest drains in some parts of the site, but no evidence of geomorphological features typical of upland blanket peat (e.g. gullies, pools and hummocks, pipes, flushes, etc.). Such features, although often concealed by forestry, may still be preserved if the original ground preparations were limited in particularly wet areas or if subsurface drainage lines persist following ploughing. However, it is likely that any such features, had they been present prior to afforestation, were removed during ground preparation for planting. For similar reasons, no features indicative of instability are observed on satellite imagery. There are no published reports of landslides in peat in this part of Scotland, and in general across Scotland, published landslide examples in peat are extremely rare.

2.6.4 As part of the peat surveys undertaken to collect depth data for the OHL route, 43 locations were cored using a gouge auger (see **Appendix 9.4: Peat Survey Report**). The cores were logged using the von Post technique. The firmness of the ground underfoot was also reported for all core locations (providing a qualitative measure of wetness and bearing capacity). Together, the coring and probing indicated the following:

- No amorphous peat was identified at the site (typically basal peat is H7 to H8, which still retains some fibrous component).
- Locally, in one location adjacent to Bargatton Loch, peat exceeded 6.7 m in depth.
- Most of the site has no 'peat' (i.e. probed depths are less than 0.5 m).
- The ground surface was generally firm underfoot for all probe locations.

2.6.5 Photographs of typical ground conditions under forestry, at the bog surface and in open ground are provided in Appendix I of **Appendix 9.4**.

3. Background to Peat Instability

3.1. Peat Instability in the UK and Ireland

3.1.1 This section reviews published literature to highlight commonly identified landscape features associated with recorded peat landslides in the UK and Ireland. This review, alongside professional judgement gained over twenty years of experience in assessing peat landslides and peatland geomorphology, forms the basis for identifying similar features at the KTR Project site and using them to understand the susceptibility of the site to naturally occurring and human induced peat landslides.

3.1.2 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. Three significant peat landslide events occurred in 2003, raising public awareness of peatland hazards (Evans and Warburton, 2007), two of which had natural causes and one occurring in association with a wind farm.

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

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

3.1.5 The Derrybrien event triggered interest in the influence of wind farm construction and operation on peatlands, particularly in relation to potential risks arising from construction induced peat instability. In 2007, the (then) Scottish Executive published guidelines on peat landslide hazard and risk assessment in support of planning applications for peatland sites. The guidance was updated in 2017 (Scottish Government, 2017).

3.1.6 Since then, a number of peat landslide events have occurred both naturally and in association with wind farms. In the case of wind farm sites, these have rarely been reported, however landslide scars of varying age are visible in association with wind farm infrastructure on Corry Mountain, Co. Leitrim, at Sonnagh Old Wind Farm, Co. Galway (near Derrybrien; Cullen, 2011), and at Corkey Wind Farm, Co. Antrim. In December 2016, a plant operator was killed during excavation works in peat at the Derrysallagh wind farm site in Co. Leitrim (Flaherty, 2016) on a plateau in which several published examples of instability had been previously reported. A peat landslide was also reported in 2015 near the site of a proposed road for the Viking wind farm on Shetland (The Shetland Times, 2015) though this was not in association with construction works. No peat landslides have been reported in association with groundworks for OHL infrastructure.

3.1.7 Other recent natural events include another failure in Galway at Clifden in 2016 (Irish News, 2016), Cushendall, Co. Antrim (BBC, 2014) and in the Glenelly Valley, Co. Tyrone in 2017 (BBC, 2018). Noticeably, the vast majority of reported failures since 2003 have occurred in Ireland and Northern Ireland, with the one reported Scottish example occurring on the Shetland Islands, an area previously associated with peat instability.

3.1.8 This section of the report provides an overview of peat instability as a precursor to the hazard and risk assessment provided in Sections 4 and 5. Section 3.2 outlines the different types of peat instability documented in the UK and Ireland and Section 3.3 provides an overview of factors known to contribute to peat instability based on published literature.

3.2. Types of peat instability

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

- **minor instability:** localised and small-scale features that are not generally precursors to major slope failure and including gully sidewall collapses, pipe ceiling collapses, minor slumping along diffuse drainage pathways (e.g. along flushes); indicators of incipient instability including development of tension cracks, tears in the acrotelm (upper vegetation mat), compression ridges, or bulges / thrusts (Scottish Government, 2017); these latter features may be warning signs of larger scale major instability (such as landsliding) or may simply represent a longer term response of the hillslope to drainage and gravity, i.e. creep.

- **major instability:** comprising various forms of peat landslide, ranging from small scale collapse and outflow of peat filled drainage lines/gullies (occupying a few-10s cubic metres), to medium scale peaty-debris slides in organic soils (10s to 100s cubic metres) to large scale peat slides and bog bursts (1,000s to 100,000s cubic metres).

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

3.2.3 For the purposes of this assessment, landslide classification is simplified and split into three main types, typical examples of which are shown in **Plate 1**. Dimensions, slope angles and peat depths are drawn from charts presented in Evans and Warburton (2007). The term “peat slide” is used to refer to large-scale (typically less than 10,000 of cubic metres) landslides in which failure initiates as large rafts of material which subsequently break down into smaller blocks and slurry. Peat slides occur ‘top-down’ from the point of initiation on a slope in thinner peats (between 0.5 m and 1.5 m) and on moderate slope angles (typically 5-15°).

Plate 1: Characteristics landslide types in UK uplands: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area, iii) multiple peaty soil slides in a headwater area with displacement of thin soils exposing substrate (all images are at a similar scale and approximately 400m in width)

3.2.4 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, 1960).

3.2.5 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 angles (Dykes and Warburton, 2007). Their small size means that they often do not affect watercourses and their effect on habitats is minimal.

3.2.6 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. Reports of peat slides are also rare in Scotland in comparison to Ireland, Northern Ireland and England, either because they rarely occur or have not been reported. It is considered that peat slides would be the most likely landslide mechanism in the upland areas and bog bursts adjacent to Bargattan Loch.

3.3. Factors contributing to peat instability

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

3.3.2 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.

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

i) Intense rainfall or snowmelt causing high pore pressures along pre-existing or potential rupture surfaces (e.g. between the peat and substrate).
ii) Rapid ground accelerations (e.g. from earthquakes or blasting).
iii) Unloading of the peat mass by fluvial incision or by artificial excavations (e.g. cutting).
iv) Focusing of drainage in a susceptible part of a slope by alterations to natural drainage patterns (e.g. by pipe blocking or drainage diversion).
v) Loading by plant, spoil or infrastructure.

3.3.4 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.

3.4. Consequences of peat instability

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

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

- Site workers and plant (risk of injury / death or damage to plant).
- The development infrastructure (damage to towers and tracks).
- Wildlife (disruption of habitat) and aquatic fauna.
- Watercourses and lochs (particularly if associated with public water supply).
- Site drainage (blocked drains / ditches leading to localised flooding / erosion).
- Visual amenity (scarring of landscape).

3.4.3 While peat failures may cause visual scarring of the peat landscape, most peat failures revegetate fully within 50 to 100 years and are often difficult to identify on the ground after this period of time (Feldmeyer-Christe and Küchler, 2002; Mills, 2002). Typically, it is short-term (seasonal) effects on watercourses that are the primary concern or impacts on public or private water supply.

3.5. Good Practice

Scottish Government Guidance

3.5.1 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 for energy infrastructure (including wind farms, pumped storage, hydroelectric schemes and supporting infrastructure such as overhead lines and substations). 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.

3.5.2 In section 4.1 of the BPG, the key elements of a PLHRA are highlighted, as follows (Scottish Government, 2017):

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

Section 2 of this report responded to elements i) and ii) and sections 4 and 5 address elements iii)-v).

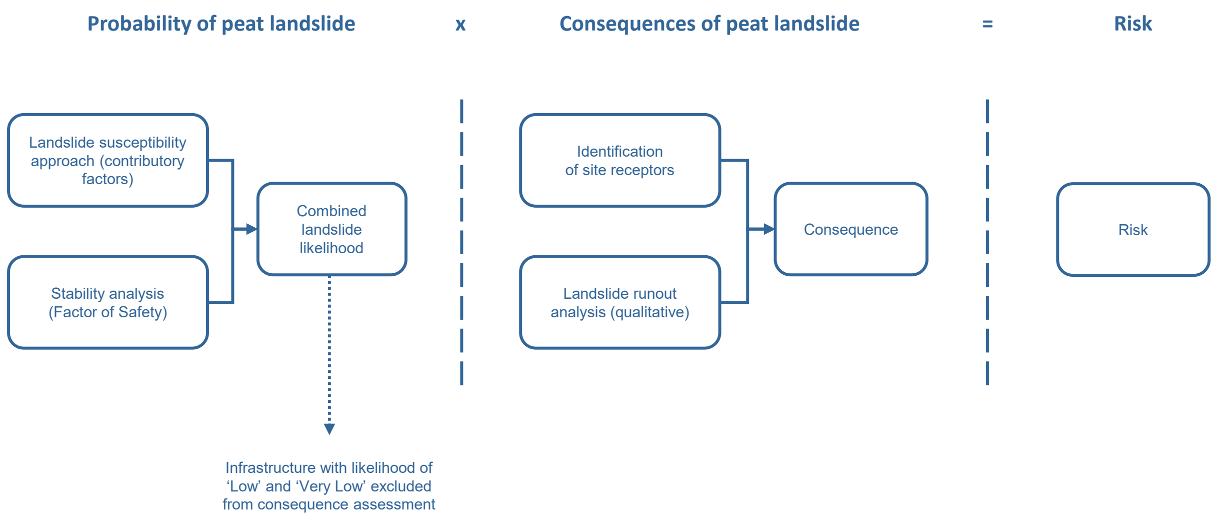
Approaches to assessing peat instability

3.5.3 This report approaches elements iii) – v) through both a qualitative contributory factor-based approach and via more conventional stability analysis (through limit equilibrium or Factor of Safety (*F*) analysis). The advantage of the former is that many observed relationships between reported peat landslides and ground conditions can be considered together where *F* 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.

3.5.4 The advantage of the *F* 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.

3.5.5 To reflect these limitations, both approaches are adopted and outputs from each approach integrated in the assessment of landslide likelihood. In line with the reasoning in paragraph 3.2.6, peat slides are only considered in the upland parts of the route and bog bursts adjacent to Bargatton Loch. **Plate 2** shows the approach.

Plate 2: Schematic representation of risk assessment approach



4. Assessment of Peat Landslide Likelihood

4.1. Introduction

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

Risk = Probability of a Peat Landslide x Adverse Consequences

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

4.2. Limit equilibrium approach

4.2.1 Stability analysis has been undertaken using the infinite slope model to determine the factor of safety for a series of 25 m x 25 m cells within the nine subsections defined for the GT connection. This is the most frequently cited approach to quantitatively assessing the stability of peat slopes (e.g. Scottish Government, 2017; Boylan et al, 2008; Evans and Warburton, 2007; Dykes and Warburton, 2007; Creighton, 2006; Warburton et al, 2003; Carling, 1986). The approach assumes that failure occurs by shallow translational landsliding, which is the mechanism usually interpreted for peat slides. Due to the relative length of the slope and depth to the failure surface, end effects are considered negligible and the safety of the slope against sliding may be determined from analysis of a 'slice' of the material within the slope.

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):

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

4.2.3 In this formula c' is the effective cohesion (kPa), γ is the bulk unit weight of saturated peat (kN/m^3), γ_w is the unit weight of water (kN/m^3), *z* is the vertical peat depth (m), *h* is the height of the water table as a proportion of the peat depth, β is the angle of the substrate interface (°) and ϕ' is the angle of internal friction of the peat (°). This form of the infinite slope equation uses effective stress parameters, and assumes that there are no excess pore pressures, i.e. that the soil is in its natural, unloaded condition. The choice of water table height reflects the full saturation of the soils that would be expected under the most likely trigger conditions, i.e. heavy rain.

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 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 Where peat is loaded, for example by movement of plant over the bog surface, a total stress approach utilising undrained shear strength can be used. This approach reflects the effects of rapid loading in generating excess pore pressures in the peat (which are unable to drain, reducing frictional resistance between particles).

4.2.6 In this case, the equation is:

$$F = \frac{S_u}{(\gamma z + \gamma_{ct})\sin\beta\cos\beta}$$

S_u is the undrained shear strength and γ_{ct} is the unit weight of construction traffic. EIA Report **Chapter 5: Felling, Construction, Operational Maintenance and Decommissioning** indicates that where temporary tracks are used, they will only be of floating construction where peat exceeds 1.0m in depth (either through conventional geotextile / geogrid and stone, or using wood / steel matting), with very limited cut and fill used where crossing slopes. Many tracks are already present and require minor upgrades, and some parts of the site may be passable by low pressure vehicles (requiring no track construction or upgrade).

4.2.7 There are numerous uncertainties involved in applying geotechnical approaches to peat, not least because of its high water content, compressibility and organic composition (Hobbs, 1986; Boylan and Long, 2014). Peat comprises organic matter in various states of decomposition with both pore water and water within plant constituents, and the frictional particle-to-particle contacts that are modelled in standard geotechnical approaches are different in peats. There is also a tensile strength component to peat which is assumed to be dominant in the acrotelm, declining with increasing decomposition and depth. As a result, analysis utilising geotechnical approaches is often primarily of value in showing relative stability across a site given credible and representative input parameters rather than in providing an absolute estimate of stability. With this in mind, representative data inputs have been derived from published literature and used in both drained and undrained analyses.

Data inputs

4.2.8 Stability analysis was undertaken in ArcMap GIS software. A 25 m x 25 m grid was superimposed on the full site extent and key input parameters derived for each grid cell. In total, 1,815 grid cells were analysed. A 25 m x 25 m cell size was chosen because it is sufficiently small to define a minimum credible landslide size and avoid 'smoothing' of important topographic irregularities. Given the cell size of the input DTM, which provides a key input parameter, any smaller cell size would be unlikely to provide significant benefits.

4.2.9 **Table 2** shows the input parameters and assumptions for the stability analyses undertaken. 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. *F* analysis was undertaken with conservative ϕ' of 20° and values of 2 kPa and 5 kPa for c'.

4.2.10 Preliminary stability analysis was also undertaken for a 5 m wide floating track, assuming representative loads for a 60 t multi-axle crane moving over floating road (which is proposed where new tracks are needed, see paragraph 4.2.6). For this analysis, input data corresponded to two representative cases – a 5° slope with 2.5 m deep peat and a 10° slope with 1.0 m deep peat. The peat depth was assumed to reduce by 20% due to primary consolidation and the unit weight was assumed to increase by the same proportion. The weight of the track was assumed to contribute to both the downslope destabilising load and the normal force into the slope and was estimated to be 0.75 m thick with a unit weight of 25 kN/m3. The resulting vehicle loaded analysis was then checked against the non-loaded and drained analysis described above. Assumptions are detailed in **Table 3**.

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

Table 3: Geotechnical parameters and assumptions for undrained infinite slope analysis

Parameter	Values	Rationale	Source
Undrained shear strength (Su)	5 kPa	Rounded conservative end of published values	4-30, medium and highly humified (Boylan et al, 2008) 4, more humified (Boylan et al, 2008) 5.2, peat type not stated (Long et al, 2005) 5, Irish bog peat (Farrell and Hebib, 1998)
Bulk unit weight (γ)	12.6 kN/m³ after primary consolidation	Reduction in volume under floating road is balanced by increased density, so pre-loaded parameters are used	See Table 2
Bulk unit weight of track (γ_t)	25.0 kN/m³	Typical value for hard rock used for aggregate	Assumed
Slope angle from horizontal (β)	5° 10°	Credible slope angles for which floating tracks are proposed	See Table 2
Peat depth (z)	2.5 m 1.0 m	Reduction in volume (i.e. depth) under floating road is balanced by increased density, so pre-loaded parameters are used	See Table 2
Crane axle load (t)	20 t	Maximum haul weight that is not considered an "abnormal load"	Assumed, based on a typical 3 axle 60 t crane

Results

4.2.11 The outputs of the drained analysis (effective stress) are shown for the less conservative combination in **Figure 7** ('Factor of Safety Results (Limit Equilibrium'). The more conservative combination, not shown, suggests that a considerable proportion of the site is either unstable (F < 1) or of marginal stability (F < 1.4) which is not consistent with site observations nor with the stability of peat in general – peat landslides are very rare occurrences given the wide distribution of peat soils in England, Scotland and Wales. The less conservative combination therefore results in more credible results, with only the steepest valley sideslopes showing marginal stability (F < 1.4).

4.2.12 Relative to the natural case for the same peat depths and slope angles under drained conditions, the calculated factor of safety declines from 3.6 to 2.8 for the 2.5 m / 5° case and from 2.5 to 1.8 for the 1.0 m / 10° case under undrained (loaded) conditions. This demonstrates that while there is a reduction in stability from loading, it falls within acceptable bounds for representative ground conditions on site.

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 (**Figure 8** 'Likelihood of Peat Landslide'). In contrast to the regular grid cells used for the limit equilibrium approach, the number and size of slope facets will vary from one part of the site to another according to the complexity of ground conditions. In total, c. 1,100 facets were considered in the analysis, with an average area of c. 750 m³ (or an average footprint of c. 27 m x 27 m, consistent with small scale peaty soil or peat slides reported in the published literature in afforested areas (e.g. with rides or glades).

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), forestry (F), slope convexity (C) and land use (L). For each factor, a series of numerical scores between 0 and 3 are assigned to factor 'classes', the significance of which is tabulated for each factor. The higher a score, the greater the contribution of that factor to instability for any particular slope facet. Scores of 0 imply neutral / negligible influence on instability.

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

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

In practice, a maximum score is unlikely, as the chance of all contributory factors having their highest scores in one location is very small.

Slope angle (S)

4.3.4 **Table 4** shows the slope ranges, their significance and related scores for the slope angle contributory factor. Slope angles were derived from the 5 m digital terrain model shown on **Figure 3** and scores assigned based on reported slope angles associated with peat landslides rather than a simplistic assumption that 'the steeper a slope, the more likely it is to fail'. A differentiation in scores is applied for peat slides and bog bursts reflecting the shallower slopes on which the latter are most frequently observed.

4.3.5 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: Slope classes, significance and scores

Slope range (°)	Significance	Score (Peat Slide)	Score (Bog Burst)
>20.0	Failure typically occurs as peaty-debris slides due to low thickness of peat	1	1
15.1 - 20.0	Failure typically occurs as peaty-debris slides due to low thickness of peat	2	1
10.1 - 15.0	Failure typically occurs as peat slides, bog slides or peaty-debris slides, a key slope range for reported population of peat failures	3	1
5.1 - 10.0	Failure typically occurs as peat slides, bog slides or peaty-debris slides, a key slope range for reported population of peat failures	3	2
2.1 - 5.0	Failure typically occurs as bog bursts, bog flows or peat flows; peat slides and peaty debris slides rare due to low slope angles	2	3
≤2.0	Failure is very rarely associated with flat ground (unless as bog bursts in raised bog settings), neutral influence on stability	0	1

Peat depth (P)

4.3.6 **Table 5** shows the peat depths, their significance and related scores for the peat depth contributory factor. Peat depths were derived from the peat depth model shown on **Figure 5** and reflect the peat depth ranges most frequently associated with peat slides and bog bursts (Evans and Warburton, 2007). A differentiation in scores is applied for peat slides and bog bursts reflecting the deeper peats in which bog bursts are observed.

Table 5: Peat depth classes, significance and scores

Depth range (m)	Significance	Score (Peat Slide)	Score (Bog Burst)
>1.5	Sufficient thickness for any type of peat failure	2	3
1.0 - 1.5	Sufficient thickness for peat slide or bog slide	3	2
0.5 - 1.0	Sufficient thickness for peat or bog slide and peaty-debris slide but not for bog burst	3	2
<0.5	Organic soil rather than peat, failures would be peaty-debris slides	1	1
No organic soil	No organic soil and therefore failures cannot be interpreted as peat slides, neutral influence on stability	0	0

4.3.7 Slope facets identified as having 'organic soils', i.e. comprising <0.5 m thickness of peat, are still included in the peat landslide susceptibility analysis since landslides with a significant organic soil content are often misinterpreted as peat failures by stakeholders.

Substrate geology (G)

4.3.8 **Table 6** shows substrate type, significance and related scores for the substrate geology contributory factor. The shear surface or failure zone of 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 sometimes cited in association with glacial till deposits in which an iron pan is observed in the upper few centimetres (Dykes and Warburton, 2007). They have also been observed over glacial till without an obvious iron pan, or over impermeable bedrock. They are rarely cited over permeable bedrock, probably due to the reduced likelihood of peat formation.

4.3.10 Probing undertaken across the site indicated primarily bedrock or granular substrates using the refusal method, and coring at 43 locations confirmed this. No iron pans were observed. Accordingly, the full site is treated as if underlain by impermeable bedrock or granular glacial till (see **Figure 4**).

Table 6: Substrate geology classes, significance and scores

Substrate Geology	Significance	Score
Cohesive (clay) glacial till with iron pan	Failures often associated with underlying till, particularly where impermeable iron pan provides polished shear surface	3
Cohesive (clay) glacial till	Failures often associated with underlying till	2
Impermeable bedrock / granular till	Failures sometimes associated with bedrock, particularly if smooth top surface	1
Permeable bedrock	Failures rarely associated with permeable bedrock (peat is often thin or absent), neutral influence on stability	0

Peat geomorphology (M)

4.3.11 **Table 7** shows geomorphological features typical of upland and lowland peat terrain, their significance and related scores. A variety of terrains are observed over the site, but the majority of those where peat is present comprise planar slopes or plateau under forest cover.

Table 7: Peat geomorphology classes, significance and scores

Geomorphology	Significance	Score (Peat Slide)
Adjacent/upslope (<50m) to existing instability (peat slide, peaty-debris slide, bank failure)	Failures often occur in close proximity to previous failures	3
Incipient instability (tension crack, compression ridge, bulging, quaking bog)	Failures are likely to occur where incipient failure morphology is observed	3
Intact planar peat	Failures are most frequently recorded in intact planar peat	2
Flush / diffuse surface drainage / pool	Failures are often associated with areas of diffuse subsurface drainage (such as flushes)	2
Pipe / collapsed pipe	Failures are often associated with areas of soil piping	2
Existing peat slide	Failures typically stabilise and do not reactivate after the initial event	1
Gullied / dissected / hagged / eroded peat / bare peat / bare ground	Failures are rarely recorded in peat fragmented by erosion	1

4.3.12 **Figure 6** shows the geomorphological classes corresponding with **Table 7**. Note that the list of features in the table may be greater than the range of features present on site.

Drainage (D)

4.3.13 **Table 8** shows artificial and natural drainage feature classes, their significance and related scores. Transverse / oblique drainage lines, both natural and artificial, 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 which have failed over moorland grips (Warburton et al, 2004). The influence of changes in hydrology becomes more pronounced the more transverse the orientation of the drainage lines relative to the overall slope.

Table 8: Drainage feature classes, significance and scores

Drainage Feature	Significance	Score
Artificial drain or natural drainage line oblique to slope	Failures are sometimes reported in association with artificial drains oblique/transverse to slope (leading to loss of toe suppoer) or where undercut by natural drainage lines	3
Artificial drain or natural drainage line aligned to slope	Failures are rarely associated with artificial drains parallel to slope or adjacent to natural drainage lines	1
No artificial or natural drainage lines	Neutral influence on stability	0

4.3.14 The effect of drainage lines is captured through the use of a 50 m buffer on each natural or artificial drainage line present within peat deposits. Where oblique to slope, only the upslope portion of each buffer is retained (as this is the portion of slope for which support has been removed by the cutting of the drain) and the drainage axis is then compared with elevation contours (oblique or aligned) to assign a score.

Forestry (F)

4.3.15 **Table 9** shows forestry classes, their significance and related scores. A report by Lindsay and Bragg (2004) on Derrybrien suggested that row alignments, desiccation cracking and loading (by trees) could all influence peat stability. Row alignment was determined from review of aerial imagery and mapped areas scored as shown in **Table 9**.

Table 9: Forestry classes, significance and scores

Forestry Class	Significance	Score
Afforested area (with mature trees), ridge and furrows oblique to slope	Peat underlying forestry stands with rows aligned oblique to slope has inter ridge cracks which are conducive to slope instability	2
Afforested area (with mature trees), ridge and furrows aligned to slope	Peat underlying forestry stands with rows aligned with slope is conducive to slope instability, but less so than where rows are aligned oblique to slope	1
Deforested area (few or no trees), ridge and furrows oblique to slope	Peat underlying deforested stands has a higher water table and more neutral buoyancy, but retains inter ridge cracks (lines of weakness) conducive to instability; alignment of cracks oblique to slope is most conducive to instability	3
Deforested area (few or no trees), ridge and furrows aligned to slope	Peat underlying deforested stands has a higher water table and more neutral buoyancy, but retains inter ridge cracks (lines of weakness), however, orientation of these cracks is less critical when aligned to slope	2
Not afforested	Neutral influence on stability	0

Slope convexity (C)

4.3.16 **Table 10** shows profile convexity classes, significance and related scores. Convex and concave slopes (i.e. positions in a slope profile where slope gradient changes by a few degrees) have been associated with the initiation point of peat landslides by a number of authors. 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).

Table 10: Profile convexity classes, significance and scores

Profile Convexity	Significance	Score
Convex Slope	Peat failures are often reported on or above convex slopes	3
Concave Slope	Peat failures are occasionally reported in association with concave slopes	2
Rectilinear Slope	Rectilinear slopes show no particular predisposition to failure, neutral influence on stability	0

4.3.17 The 5m digital terrain model and OS contours were reviewed to identify areas of noticeable slope convexity across the site, however no significant convexities or concavities (in slope profile) were present within the nine subsections under consideration.

Land use (L)

4.3.18 Error! Reference source not found. shows land use classes, significance and related scores. A variety of land uses have been associated with peat failures (see Section 3.3). 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. There is no cutting, quarrying or other relevant land use in the nine subsections considered (see **Figure 6**).

Table 11: Land use classes, significance and scores

Land Use	Significance	Score
Cutting / turbary	Failures are often associated with peat cuttings / turbary	3
Adjacent quarrying	Failures are occasionally reported adjacent to quarries (usually as bog bursts, bog flows or peat flows)	2
Burning	Failures are rarely associated with burning though this activity may create pathways for water to the base of peat	1
Other land use	Failures are rarely associated with other forms of land use	0

Generation of slope facets

4.3.19 The eight contributory factor layers were combined in ArcMap to produce 1,100 slope facets. Scores for each facet were then summed to produce likelihood scores for peat landslides. 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 (see Table 12)).

4.3.20 **Table 12** 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 equivalent to both the worst case peat depth and slope angle scores (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 12 or greater would be equivalent to at least a moderate likelihood of a peat landslide. Given that the maximum score attainable is 24, this seems reasonable.

Results

4.3.21 **Figure 8** shows the outputs of the landslide susceptibility approach for peat landslides. The results indicate that the majority of the site has a ‘Low’ to ‘Very Low’ likelihood of a peat landslide under natural conditions. Areas of ‘Moderate’ likelihood are typically located on moderate slopes. There are no areas identified with ‘High’ or ‘Very High’ landslide susceptibility. In common with the stability analysis approach, the outputs of this approach indicate the majority of the site to be stable under natural conditions, which is in accordance with site observations.

Table 12: Likelihood classes derived from the landslide susceptibility approach

Summed Score from Contributory Factors	Typical site conditions associated with score	Likelihood (qualitative)	Peat landslide likelihood score
≤ 6	Unmodified peat with no more than low weightings for peat depth, slope angle, underlying geology and peat morphology	Very Low	1
7 - 11	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
12 - 16	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
17 - 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

Combined landslide likelihood

4.3.22 **Figure 9** (‘Landslide Source Areas and Runout Zones’) shows in purple any proposed areas of infrastructure intersecting with areas of Moderate or higher landslide likelihood (from the contributory factor approach) or Factor of Safety of 1.4 or less (from the limit equilibrium approach). In order for there to be a “Medium” or “High” risk (Scottish Government, 2017), likelihoods must be “Moderate” or higher (see **Plate 3**, below) and hence this provides a screening basis for the likelihood results. In all, 6 infrastructure locations overlap with areas of “Moderate” landslide likelihood. No areas are calculated to have “High” or “Very High” likelihoods.

4.3.23 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 3 Top: Risk ranking as a product of likelihood and consequence; Bottom: suggested action given each level of calculated risk (after Scottish Government, 2017)

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

Score	Risk Level	Action suggested for each zone
17 - 25	High	Avoid project development at these locations
11 - 16	Medium	Project should not proceed 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 investigation to refine assessment and mitigate hazard through relocation or re-design at these locations
1 - 4	Negligible	Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate

5. Assessment of Consequence and Risk

5.1. Introduction

5.1.1 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 (as described in paragraph 4.1.1).

5.2. Receptors

5.2.1 At the KTR Project site there are five primary receptors: watercourses, designated sites, private water supplies, non-riverine habitats (e.g. groundwater dependent terrestrial ecosystems or GWDTEs) and infrastructure. These are considered below and the consequence and consequence score associated with a peat landslide for each receptor type are summarised in **Table 13**.

Watercourses, designated sites and private water supplies

5.2.2 A number of watercourses are close to the nine subsections of the GT connection considered in this report (see paragraph 2.4.3). However, of these, only the following watercourses are close to areas of Moderate landslide likelihood:

- **Knocknairling Burn:** c.100 m below Access 40.
- **Darsalloch Burn:** c. 100 m below Tower 17.
- **An un-named watercourse on the east flank of Slogarie Hill:** c. 30 m south of Tower 56.

In all other cases, watercourses are not likely to be hydrologically connected to potential peat landslide source zones.

5.2.3 Knocknairling Burn flows through the Water of Ken Woods SSSI, which has its upstream limit some 5 km downstream of Access 40. Although peaty debris from peat landslides does have the potential to be transmitted some distance downstream (if entering Knocknairling Burn), the watercourse is highly sinuous between Access 40 and the SSSI with numerous potential stranding locations for floating peat blocks, and it is considered that impacts on the defining characteristics of the SSSI (lichen and ancient oak woodland) would be minimal (as these are out of water features). Therefore, no consequence score is assigned for the SSSI.

5.2.4 Similarly, the Loch Ken and River Dee Marshes SPA and Wetlands of International Importance RAMSAR sites are located in excess of 5 km downstream. In contrast to mobilised material that may strand overbank, there is some possibility that solute load from peaty debris could be transmitted over 5 km into the SPA and RAMSAR sites and deposited within the loch bed. A moderate consequence score of 3 is applied for the SPA and RAMSAR sites since effects on the qualifying characteristics (breeding and wintering birds) is likely to be limited from this impact (due to minimal volumes and impacts on water quality).

5.2.5 Two potential private water supplies are also located along the Knocknairling Burn (see paragraph 2.4.7, although it is expected that any impacts on these would be very short term (hours to days rather than weeks), i.e. the passage of time required for mobilised material to move through the river system. A moderate consequence score of 3 is applied for private water supplies.

Non-riverine habitats

5.2.6 While blanket bog habitats are valuable, they generally recover from instability events through revegetation in two to three decades. However, bog habitats are limited in the nine subsections of the GT connection, since where peat is present, bog habitat has largely been replaced with understorey habitats typical of afforested upland. **Chapter 10: Ecology** does note some areas of heath and mire habitat near Bargatton Loch. No GWDTE's are present within this connection (see **Chapter** 9). Accordingly, a moderate consequence score of 3 is assigned for non-riverine habitats.

Infrastructure

5.2.7 The primary infrastructure components within the subsections considered for the GT connection are existing forest tracks, the B795 (west of Laurieston), and the A762 south of Laurieston. None of this infrastructure is in areas of Moderate or higher landslide likelihood, and therefore risks to these routes cannot exceed "Low". Given the application of good practice construction techniques (referred to as 'embedded mitigation' in the assessment of effects presented in the EIA Report and which is assumed to be in place) and monitoring, risks would likely be reduced to Negligible.

5.2.8 Other infrastructure that might be affected in the event of a peat landslide would be KTR Project infrastructure. These effects would be most likely during construction, at which time personnel would be using the access track network or be present at infrastructure locations for long periods. While commercial losses would be important to SPEN, loss of life / injury would be of greater concern, and a consequence a score of 5 is assigned for any infrastructure locations subject to potential peat landslides, reflecting the potential for loss of life or injury.

Table 9.6.13: Receptors considered in the consequence analysis

Receptor	Consequence	Score	Justification for Consequence Score
Watercourses	Short term increase in turbidity and acidification, potential fish kill	3	Watercourses ultimately connect to the Water of Ken / River Dee
Designated Sites (Loch Ken and River Dee Marshes SPA)	Minor siltation from organic solute load with effects on turbidity	3	Distance from source means minor impacts, SPA based on breeding and wintering birds rather than aquatic habitat
Infrastructure (Private Water Supply)	Short term increase in turbidity, acidification and changes to water colour	3	Distance from source, watercourse will self clean after a short period, alternative sources of water likely to be available if required.
Non-riverine habitats	Short to medium term loss of vegetation cover, disruption of peat hydrology, carbon release	3	Not high quality habitat (no GWDTEs), effects of peat landslides on habitats are generally short-lived.
Infrastructure and site workers	Damage to infrastructure, possible injury, loss of life	5	Loss of life, though very unlikely, is a severe consequence; financial implications of damage and re-work are less significant

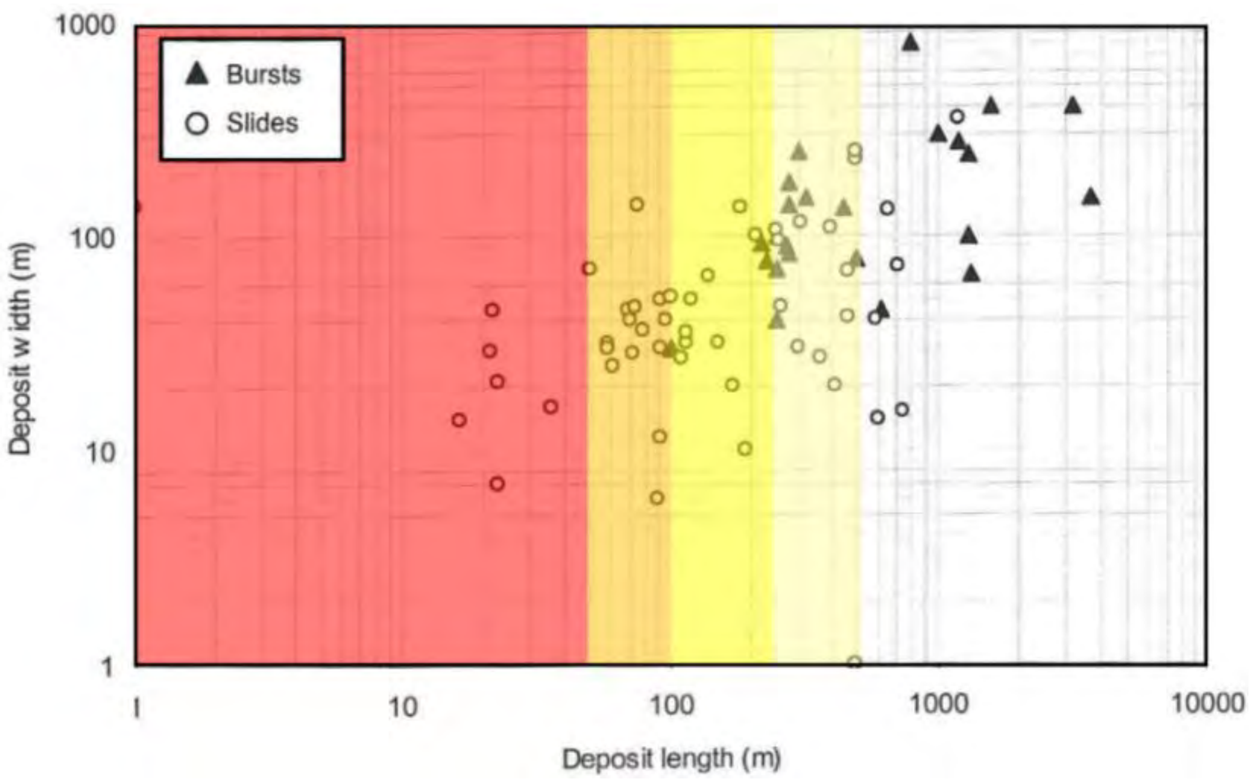
5.3. Consequences

5.3.1 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 section of access track is located in a Moderate area (likelihood score of 3) and is less than 50 m upslope of a watercourse (with a consequence score of 3), it is possible 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: 3 = risk: 9, see **Plate 3**) and be equivalent to a "Low" risk (scores of 5-10 being "Low").

5.3.2 **Figure 9** shows all infrastructure locations that overlap with Moderate likelihoods, based on the combined landslide likelihood scores described in Section 4. In order to determine the likelihood of impact on watercourses and infrastructure, 'runout pathways' have been defined that show the estimated maximum footprint of a landslide initiating at the source zone (i.e. infrastructure location). The footprint is taken to be the first 50 m downslope of the infrastructure. This is considered to be a conservative approach given the size of landslides in afforested settings (which are typically small).

5.3.3 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). The likelihood of runout passing from one runout zone to the next (e.g. from the 50m zone into the 100m zone) is based on the proportion of the published peat landslide population that reaches each runout distance on **Plate 4** (0-50 m: 100%, 50-100 m: 87%, 100-250 m: 56%, 250-500 m: 44%). The first 50 m includes the landslide source area. These statistics assume failure occurs on open slopes with ground level vegetation (i.e. with no significant barrier to runout). Where forestry is present or slopes are neutral or very shallow (e.g. <5°) adjacent to the source zone, runout may be significantly reduced and this is judged on a case-by-case basis according to observed ground conditions.

Plate 4: Runout distances for published peat landslides (after Mills, 2002), colours on plot correspond to runout pathways on Figure 9



5.3.4 Additional analysis was also performed to determine whether a landslide, once initiated, would become exhausted of material as it thinned downslope. The analysis assumed a source volume equivalent to the source footprint multiplied by the average peat depth in the source area (from the peat depth model). This volume was then distributed over the full runout pathway (i.e. mobilised volume / runout area) to generate an average thickness of deposit. As the runout length increases, the volume thins, in keeping with observed peat landslide deposits. Deposits less than 0.20 m thick are assumed to stall on the vegetated ground surface within that runout zone due to surface roughness.

5.3.5 This analysis indicates the following:

- **At Access 40:** due to the proximity of the source zone to Knocknairling Burn, runout from the lower part of the source area would (if on open slopes) be expected to reach the Burn. However, the presence of continuous tree cover, other than for the 20 m felling width along the track, would in likelihood stall the majority of moving material against the treeline, limiting its downslope movement. The minor peat depths in this area (0.5-1.0 m, see **Figure 5**) make this more likely still.
- **At the track north of Tower 17:** as for Access 40, the limited felling width along a sinuous section of access track would notably impede the movement of materials downslope towards Darsalloch Burn, and it is therefore likely that peat would not enter the burn in any notable quantity.
- **At the track adjacent to Tower 18:** the track in this section lies within a saddle between Benbrack to the southwest and Peal Hill to the northeast. There is no accommodation space for runout to either side of the track and the nearest downslope area is over 75 m to the southeast. Therefore instability would be confined to this location and likely be in the form of ground collapse rather than large-scale landsliding.
- **At the track adjacent to Tower 30:** runout would in likelihood stall against the felled treeline for wayleave to the west of the OHL.
- **At the track adjacent between Tower 55 and 56:** runout would likely stall rapidly on entry to the treeline and be very limited in extent along the track axis due to the gentle slopes immediately to the south of the source zone. There is a small possibility that some material may enter a minor un-named watercourse which descends the east flank of Slogarie Hill. On inspection, the watercourse has the appearance of a forest drain in its upper reaches and is likely to be too small (<1.0 m in width) to transmit material any notable distance from the track, particularly given the gentle slope along its axis (<4° over a distance of 0.5 km).
- **At Tower 86:** while there is no likelihood of runout at this location (due to the minimal slopes), Tower 86 is due to be founded in very deep peat adjacent to Bargatton Loch. There is a possibility that ground collapse may occur into any excavations in this area, and alternative construction techniques may be required to protect site personnel and plant working the site. Impacts on the Loch itself are likely to be minimal.

5.3.6 Based on the calculation of runout thicknesses as a function of runout area, all of the source zones close to watercourses would generate sufficient volumes of material to reach their respective watercourse receptors *if* the ground surface was clear of forest. However, the presence of forest acts as a notable constraint to landslide runout, and therefore watercourse impacts are expected to be minimal.

5.4. Calculated risk

5.4.1 The primary receptors for landslide impacts at all six locations are site personnel undertaking groundworks in areas of Moderate landslide likelihood (see **Table 14**). In summary:

- Risks to site personnel and infrastructure are **Medium** (see **Plate 3**) for all 6 locations.
- Risks to 'named' watercourses, designates sites and private water supplies are **Negligible** due to the likelihood of material entering watercourses being reduced from Moderate to Very Low (following runout assessment).
- Risk to the upper reaches of the un-named watercourse on Slogarie Hill is **Low**. Risk to the lower reaches of the watercourse (which appears to have been recut to be a forest drain) is considered to be **Negligible** due to very limited capacity of the drain to carry runout any notable distance (i.e. a Very Low likelihood of transmission of peaty material to the lower reaches of the drain / watercourse).

- Risks to non-riverine habitats remain **Low**.

5.4.2 The Medium risks relate to injury to site personnel. These risks will be mitigated to Low or Negligible through good engineering practice. Section 6 considers how these risks will be reduced post-consent.

6. Risk Mitigation

6.1. Overview

6.1.1 A number of mitigation opportunities exist to reduce the risk levels identified for the KTR Project. 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. General good practice measures are referred to as 'embedded mitigation' in the assessment presented in the EIA Report and are assumed to be in place for the purposes of the assessment.

6.1.2 Risks may be mitigated by:

i) Undertaking site specific stability analysis using better quality geotechnical data, final design loads for infrastructure and detailed ground models in areas of specific concern (e.g. at Tower 18).
ii) Precautionary construction measures - use of monitoring, good practice (i.e. 'embedded mitigation') and a geotechnical risk register in all locations.

6.1.3 Mitigation measures are provided below specific to each area of "Medium" risk. These mitigation measures will also help further reduce "Low" and "Negligible" risks to watercourses, non-riverine habitats, private water supplies and designated sites. General good practice (i.e. 'embedded mitigation') is outlined in sections 6.3 and 6.4.

6.2. Proposed mitigation

6.2.1 **Table 14** lists the 6 locations (labelled by source infrastructure area), the key receptor(s) identified in the consequence assessment, location specific mitigation measures and their anticipated effect in risk reduction relative to the calculated risk.

6.2.2 A variety of mitigation measures are recommended, some of which involve reducing conservatism in the risk assessment e.g. by de-risking drains through site specific analysis. In other cases, on-site measures could be implemented, such as installation of catch fences as a precaution against runout into watercourses (e.g. above Knocknairling Burn and/or Darsalloch Burn).

6.2.3 Finally, preparation of a geotechnical risk register (GRR) providing explicit mitigation measures tailored to each "Medium" or "Low" risk location will enable risks to be further minimised. The GRR will provide a series of measures detailing additional site investigation and assessment needs, indicating site specific features that may require active management during construction (e.g. pool complexes, drains), provide monitoring protocols to identify any early signs of reduced stability during construction works, and control measures to address unanticipated ground displacement.

6.2.4 For most locations, detailed site specific stability analysis has been recommended to determine whether the current level of analysis is overly conservative. The primary sources of uncertainty in relation to current inputs is the slope model used in both the qualitative and quantitative likelihood approaches and the likely conservatism in geotechnical parameters for peat (noting that **Appendix 9.4** reports nearly all peat cored on site as firm underfoot). The TIN model used for the slope map tends to oversimplify the slope geometry, steepening and softening slopes (dependent on the locations and separation of elevation data used in the model, see paragraph 4.3.4). It is unlikely that a better DTM will become available (given the degree of forest cover) and therefore site specific slope measurements may improve the characterisation of slope in the six locations.

Table 14: Mitigation measures for areas with "Medium" and "Low" risks

Infrastructure	Key Receptor	Runout thickness at watercourses*	Calculated Risk Level	Location Specific Mitigation	Residual Risk
Access 39	Site personnel / Knocknairling Burn (and downstream PWS / designated sites)	0.3 m	Medium	• Close monitoring of track construction works, including use of stop rules in adverse weather • Site specific stability analysis based on local peat strength data • Investigate and manage drains in source zone • Install catch fencing and gate on approach to Knocknairling Burn during construction	Low
Track north of Tower 17	Darsalloch Burn	0.86 m	Medium	• Site specific stability analysis based on local peat strength data • Investigate and manage drains in source zone • Install catch fencing above Darsalloch Burn if slope stability analysis suggests necessary and retain during construction • Close monitoring of track construction works, including use of stop rules in adverse weather	Low
Track adjacent to Tower 18	Site personnel	n/a	Medium	• Close monitoring of track construction works, including use of stop rules in adverse weather	Negligible
Track adjacent to Tower 30	Site personnel	0.18 m	Medium	• Close monitoring of track construction works, including use of stop rules in adverse weather	Negligible
Track between Towers 55 and 56	Site personnel / unnamed watercourse entering ponds at foot of hill	0.75 m	Medium	• Site specific stability analysis based on local peat strength data • Install catch fencing below watercourse crossing c. 150 m downstream of source zone to mitigate impacts during construction • Close monitoring of track construction works, including use of stop rules in adverse weather	Low
Tower 86	Site personnel	n/a	Medium	• Site specific stability analysis based on local peat strength data • If possible, pile foundations for Tower 86 to minimise excavation and prevent ground collapse • Float access tracks to minimise excavation • Close monitoring of track construction works, including use of stop rules in adverse weather	Low

* depths are based on runout volume distributed over all runout zones up to the point of entry into a watercourse, and assume that hillsides are open and non-forested (in practice, the presence of dense tree cover means these thicknesses are very unlikely to occur)

6.2.5 A third area where the analysis may be over-conservative is in the estimate of drainage effects on the surrounding peat slopes. As noted in paragraph 4.3.14, buffers were applied to each artificial drainage line, and these areas are often associated with areas of higher landslide likelihood (and, in turn, risk). Post-consent, site-based review of the areas surrounding these drains may aid in reducing the assessed risks at some locations.

6.2.6 Close monitoring of track alignments during and following installation and areas upslope of excavations (i.e. tower foundations and any sections of cut track) will be of value in identifying unanticipated ground displacements before they represent a risk to receptors.

6.3. Good practice during construction

6.3.1 The paragraphs below detail good practice that will be undertaken during construction. These measures are considered 'embedded mitigation' for the purposes of the assessment, and have been assumed to be in place for the purposes of the assessment presented in the EIA Report:

6.3.2 For excavated groundworks (e.g. tower foundations):

- Use of appropriate supporting structures around peat excavations to prevent collapse and the development of tension cracks.

- Avoid cutting trenches or aligning excavations across slopes (which may act as incipient headscarps for peat failures) unless appropriate mitigation has been put in place.
- Implement methods of working that minimise the cutting of the toes of slopes, 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 ensures natural drainage pathways are maintained or diverted such that there is no significant alteration of the hydrological regime of the site; 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 it water remains free-flowing and that no blockages have occurred.

6.3.4 For floating tracks:

- Prior to the construction, setting out the centre-line of the proposed track should include a walk over performed by the site manager or general foreman, along with the suitably qualified Geotechnical Engineer, and appropriate Clerk of Works. This should be carried out to check that the ground conditions/drainage paths are as expected, and “fine-tuning/micrositing” of the alignment if required.
- 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 (e.g. allowing tracks to thaw following periods of hard frost).
- Allow peat to undergo primary consolidation by adopting rates of road construction appropriate to weather conditions.

6.3.5 For storage of peat:

- Ensure stored peat is not located in areas identified with ‘Moderate’ or higher peat landslide likelihoods or within areas identified as at Medium (pre-mitigation) risk (see **Table 14**).
- Undertake site specific stability analysis for all areas of peat storage to ensure the likelihood of destabilisation of underlying peat is minimised. Analysis should consider the slope angle of the storage location, the thickness of peat being stored and being loaded and use representative parameters for both the stored and underlying peat.
- Avoid storage of peat in areas of peat >1.5m in depth.
- Minimise haul distances for peat, storing as near to excavation as possible.
- Monitor effects of wetting / re-wetting stored peat on surrounding peat areas, and prevent water build up on the upslope side of peat mounds. Mitigate any run-off.

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

- A geotechnical risk register (GRR) should be prepared for the site following intrusive investigations post-consent and location specific stability analyses – the risk register should be considered a live document and updated with site experience as infrastructure is constructed.
- 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.
- Monitoring checklists should be prepared with respect to peat instability addressing all construction activities proposed for site.

6.4. Good practice post-construction

6.4.1 Following cessation of construction activities, the following activities will be built into any monitoring of groundworks undertaken for the development:

- Ponding on the upslope side of infrastructure sites and on the upslope side of access tracks.
- Subsidence and lateral displacement 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.

7. References

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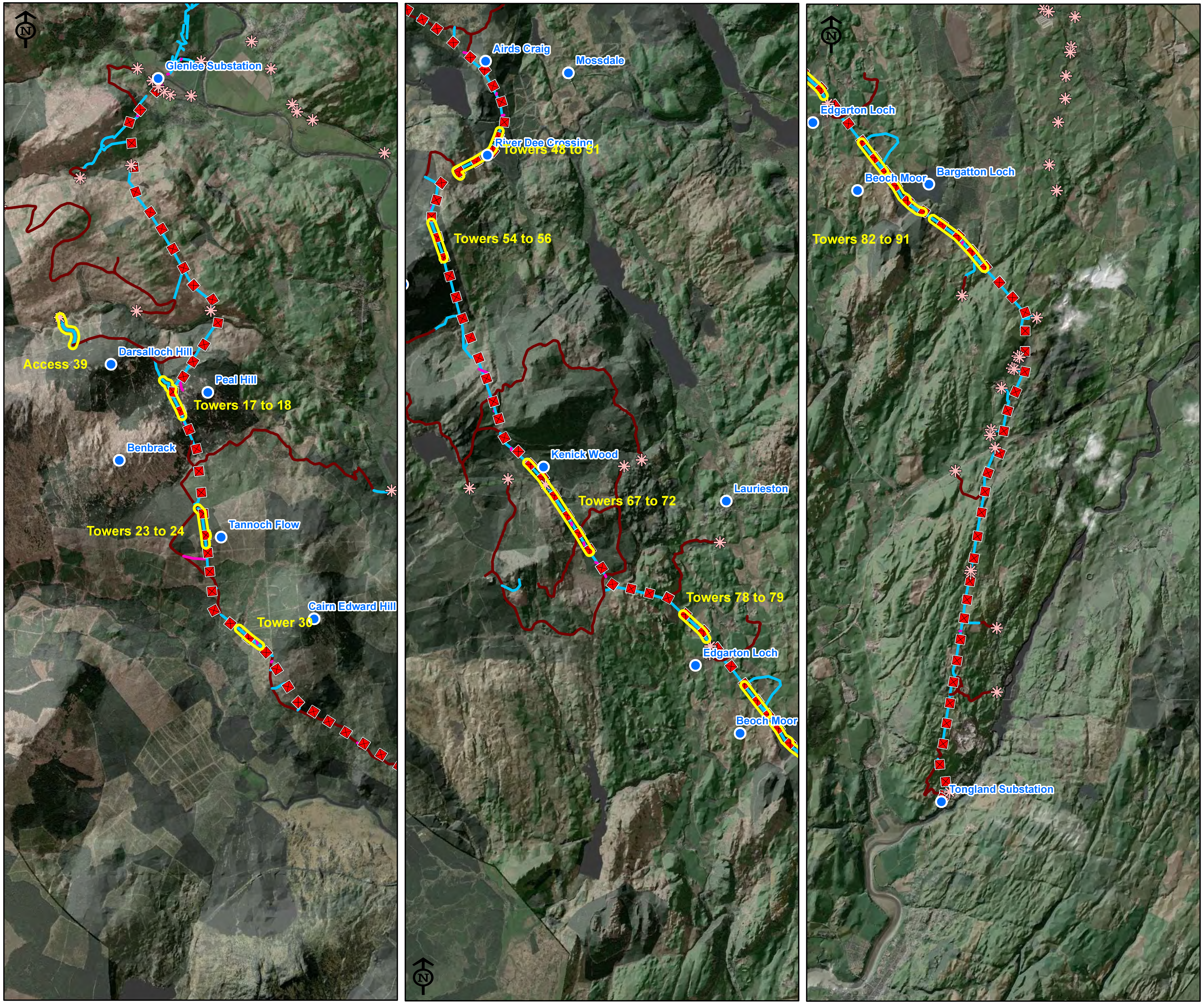
Figures



KTR Project
Peal Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Corridors

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

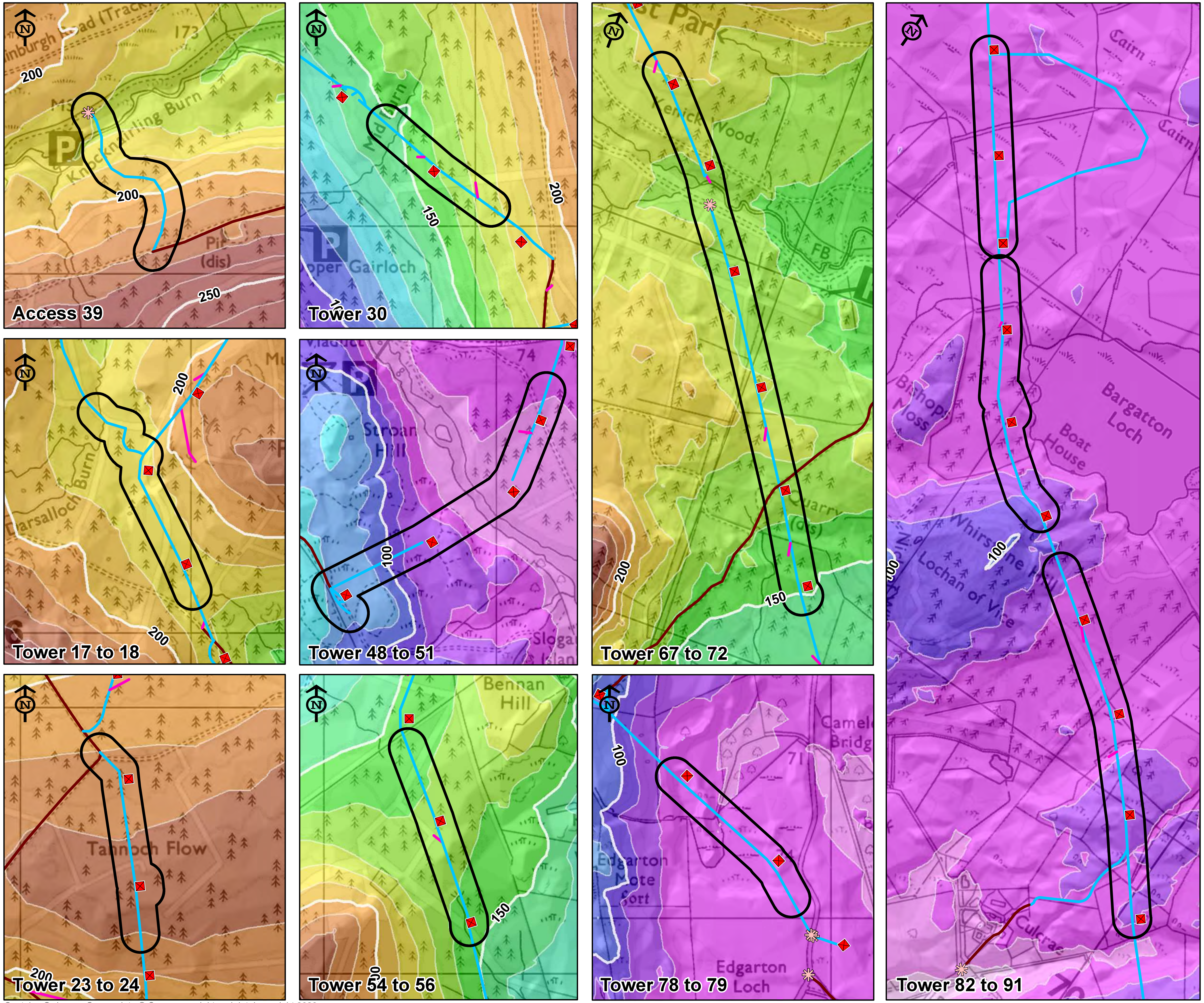
Appendix 9.6
Figure 1: KTR Overview

0 500 1,000 2,000 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Elevation (m)

Up to 50	>140 - 150
>50 - 60	>150 - 160
>60 - 70	>160 - 170
>70 - 80	>170 - 180
>80 - 90	>180 - 190
>90 - 100	>190 - 200
>100 - 110	>200 - 210
>110 - 120	>210 - 220
>120 - 130	>220 - 230
>130 - 140	>230 - 240

Contours are shown at 10m intervals and labelled at 50m intervals.

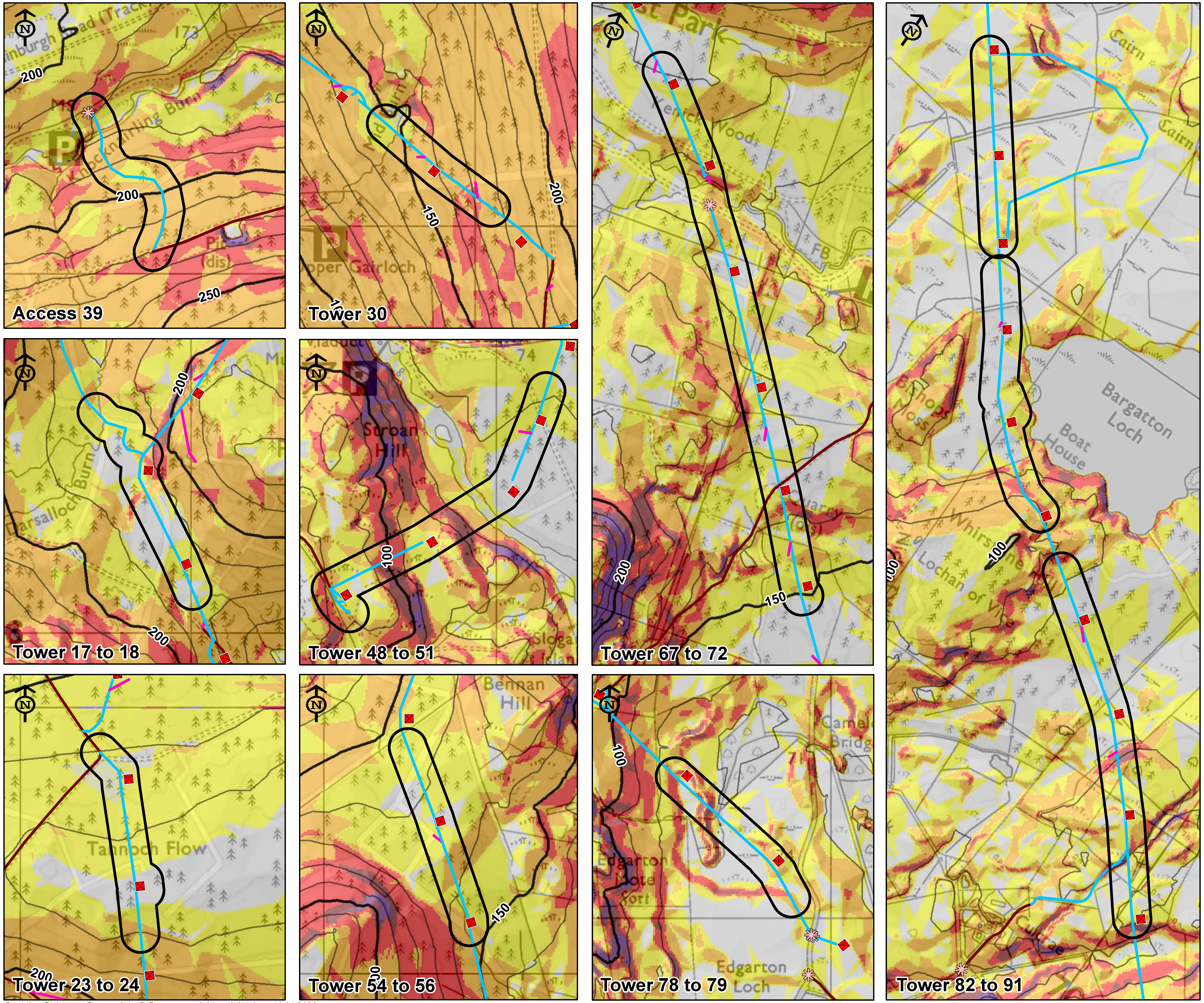
Appendix 9.6
Figure 2: Elevation

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Slope (degrees)

- 0 - 2
- >2 - 5
- >5 - 10
- >10 - 15
- >15 - 20
- >20

Contours are shown at 10m intervals and labelled at 50m intervals.

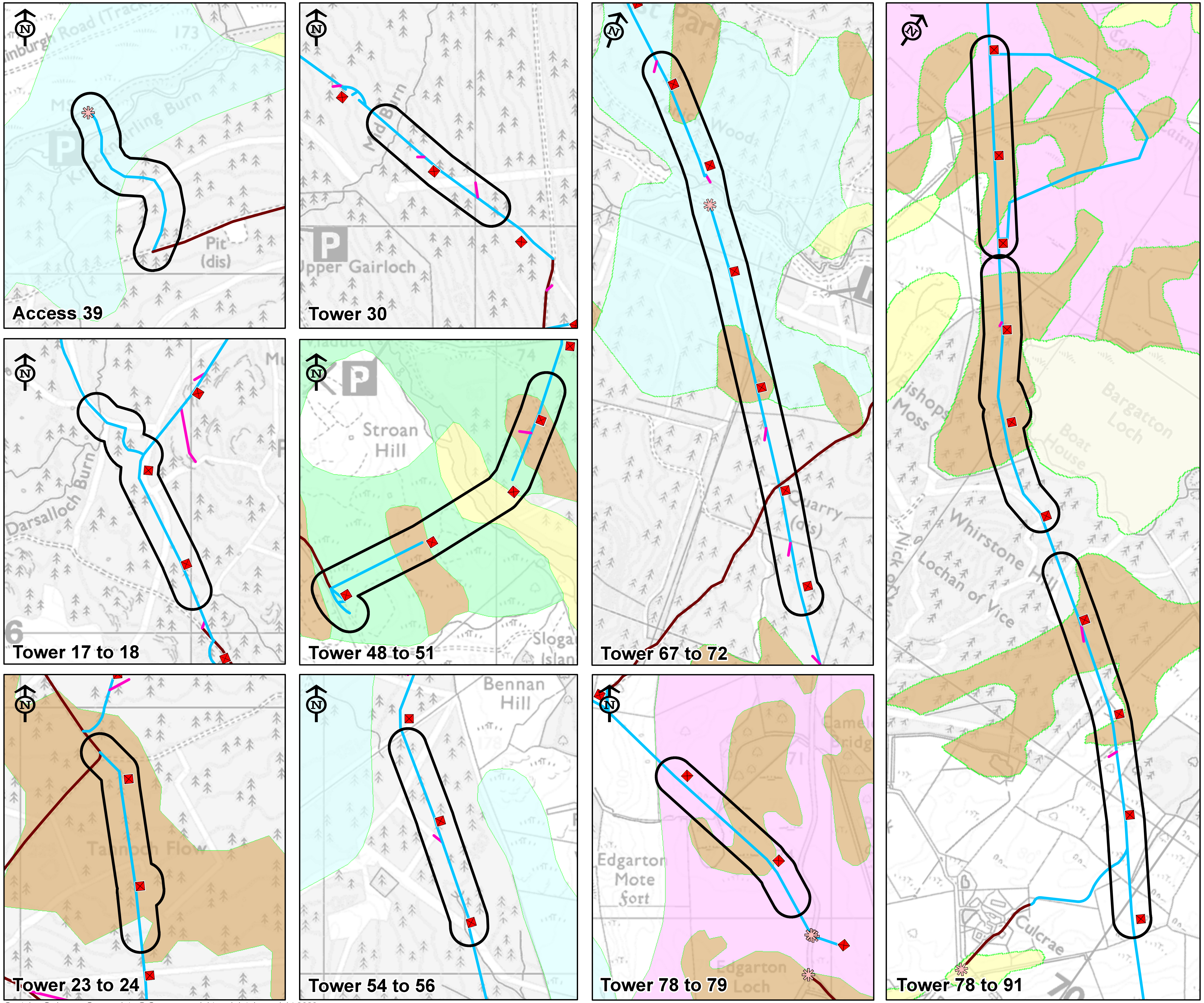
Appendix 9.6
Figure 3: Slope Angle

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Superficial Geology

- Hummocky glacial deposits
- Devensian till / diamicton
- Alluvium
- Glaciofluvial
- Peat

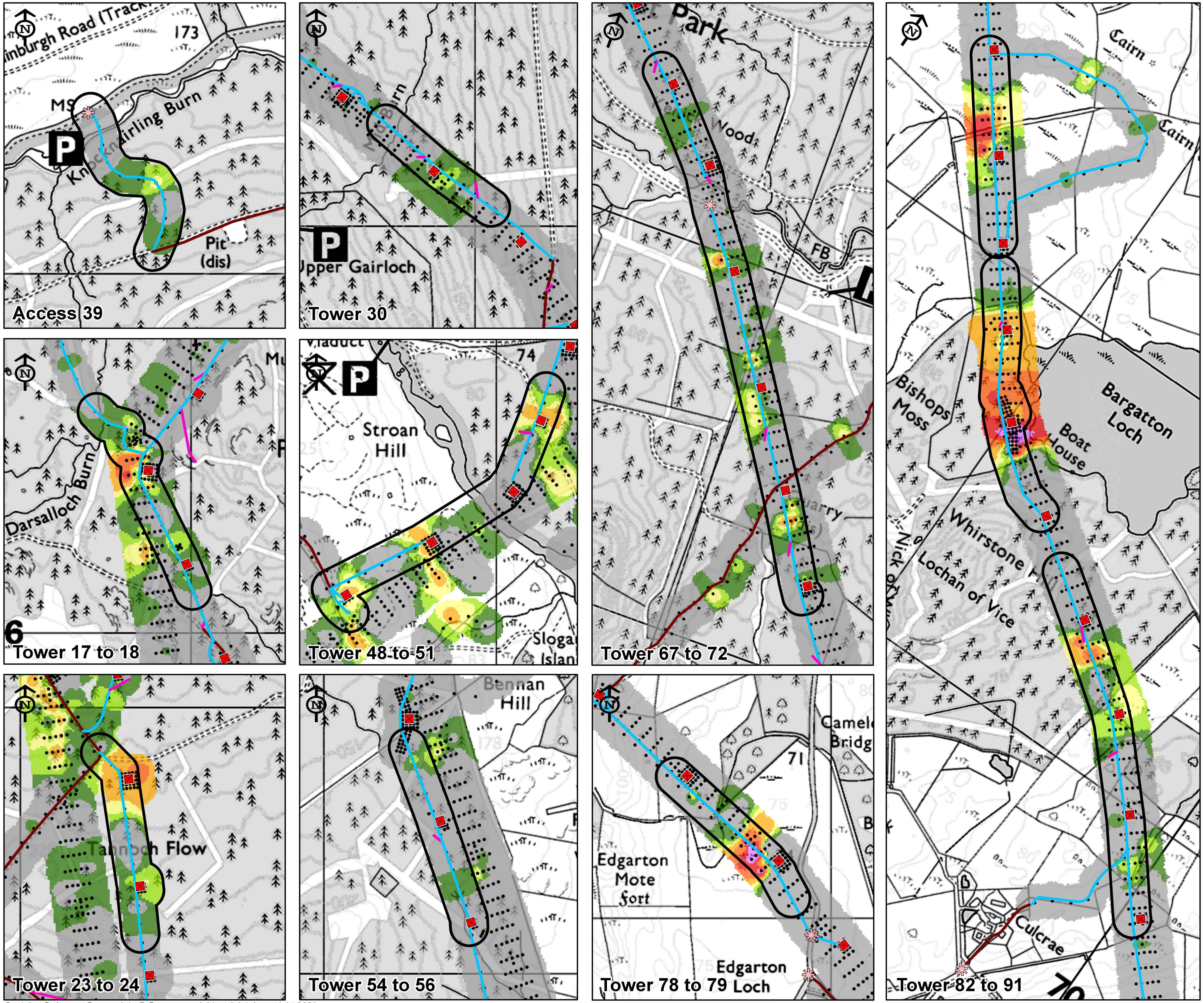
Appendix 9.6
Figure 4: Superficial geology

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



**KTR Project
Peat Landslide Hazard
and Risk Assessment**

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Peat Depth (m)

- 0.0 - 0.5 m
- > 0.5 - 1.0 m
- > 1.0 - 1.5 m
- > 1.5 - 2.0 m
- > 2.0 - 3.0 m
- > 3.0 - 4.0 m
- > 4.0 - 5.0 m
- > 5.0 - 6.0 m
- > 6.0 m
- Peat depth probe location

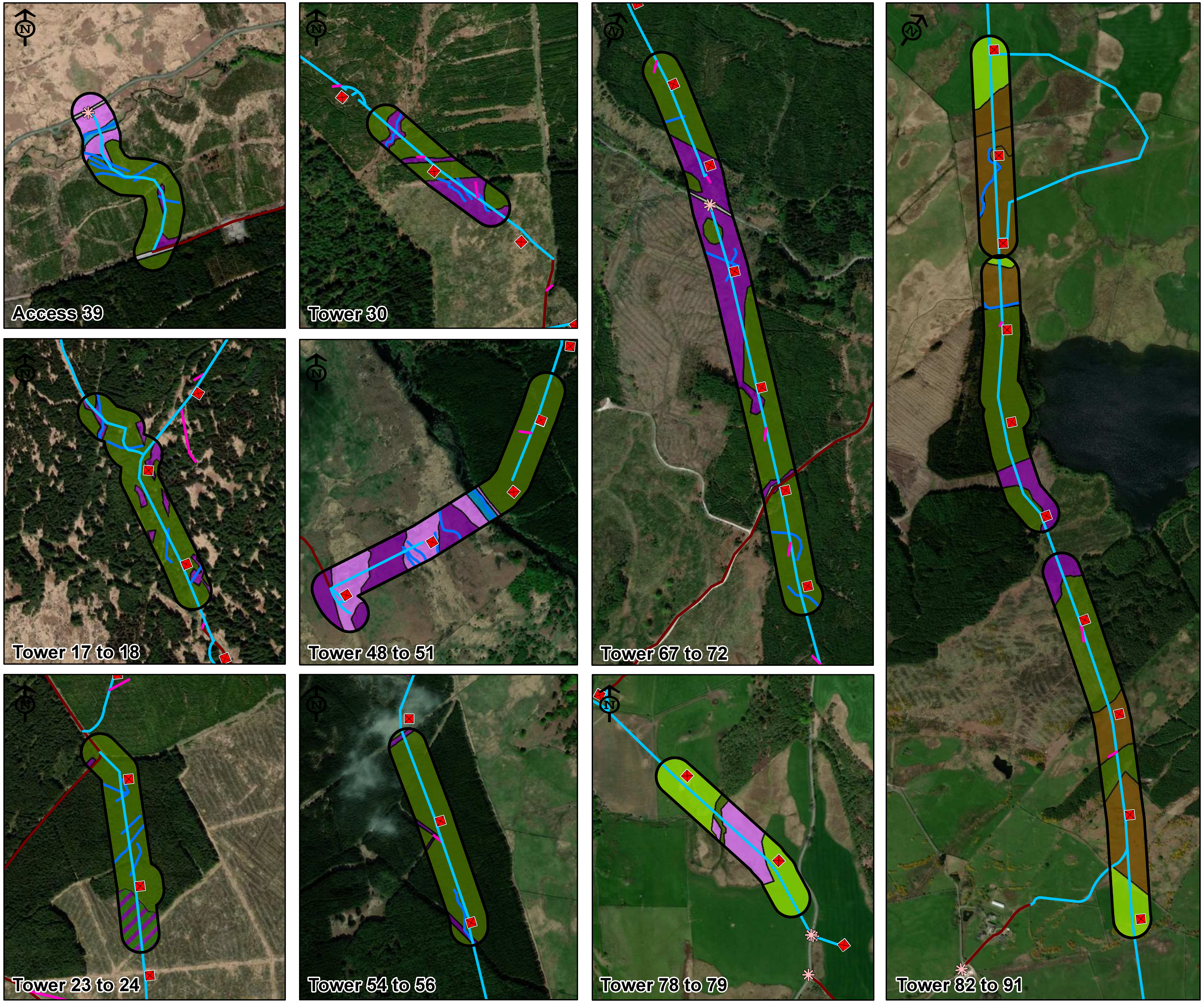
**Appendix 9.6
Figure 5: Peat Depth**

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Geomorphology / Land Use

- Afforested planar peat
- Deforested planar peat
- Planar peat (dark)
- Planar peat (light)
- Lowland marsh
- Planar non-peat soils
- Road
- Floodplain / river
- Forest drain /

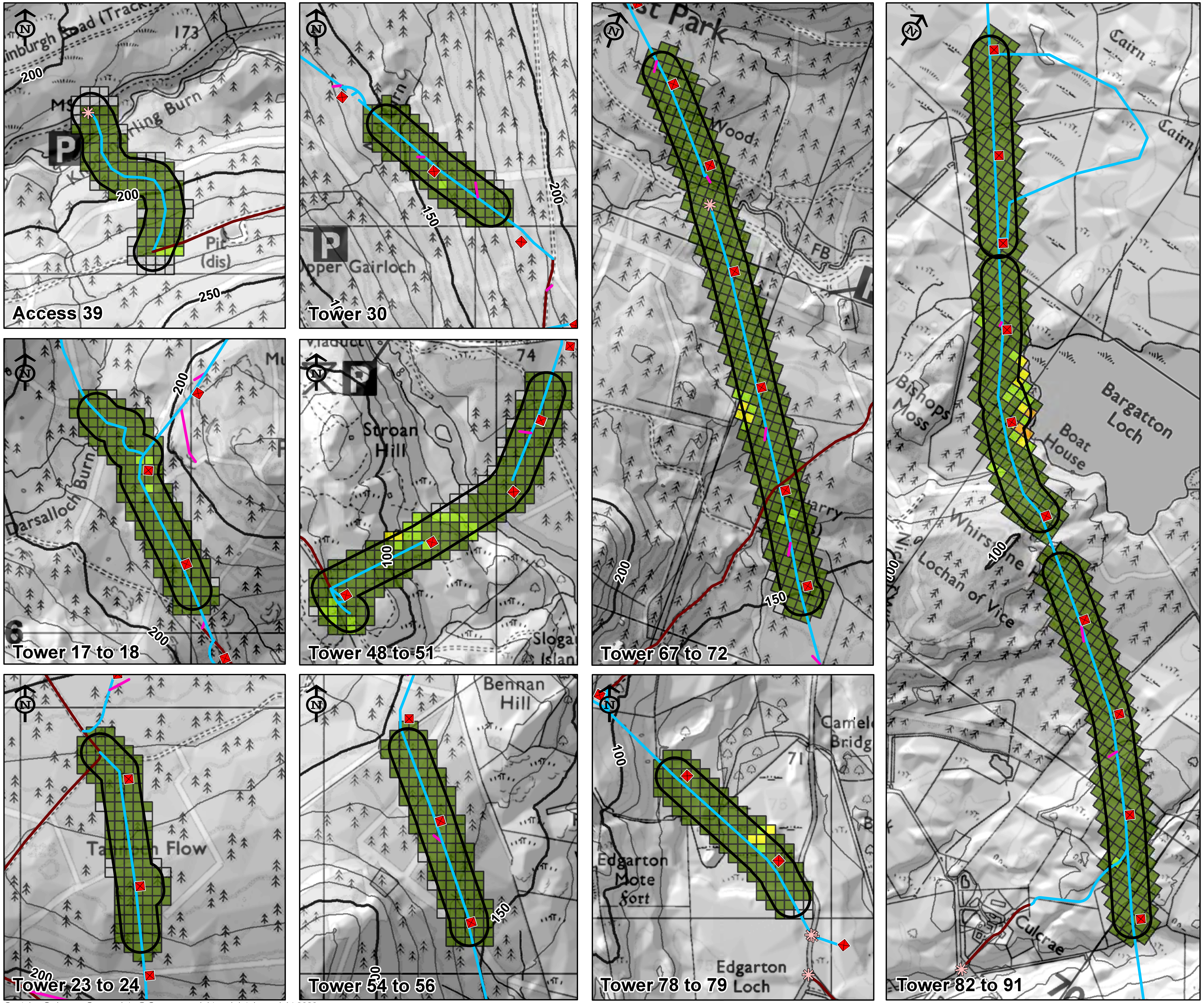
Appendix 9.6
Figure 6: Geomorphology, hydrology and land use

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Factor of Safety

<= 1.0	Unstable
> 1.0 to 1.4	Marginally Stable
> 1.4 to 2.0	Stable
> 2.0 to 3.0	Stable
> 3.0	Stable
No results	

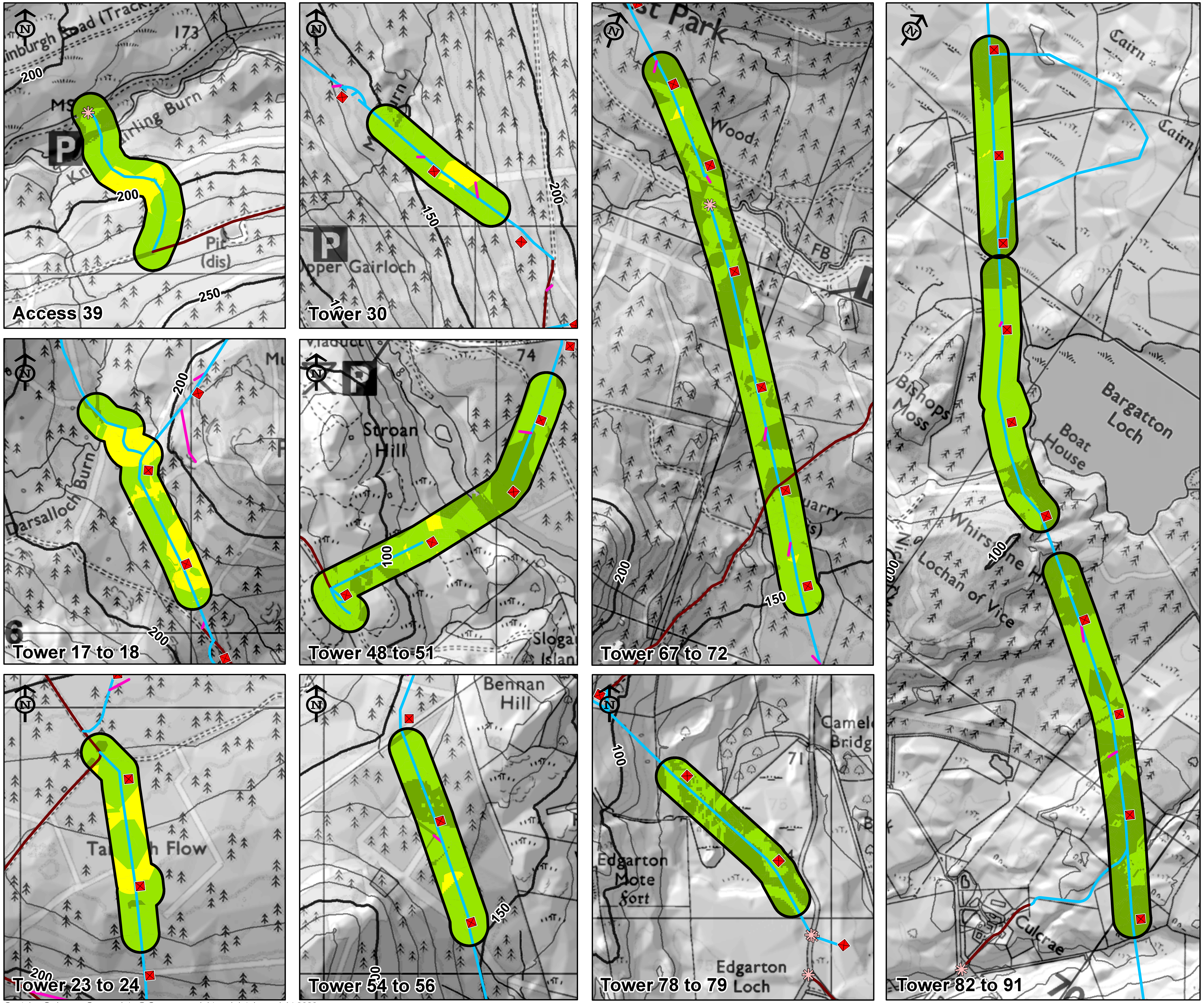
Appendix 9.6
Figure 7: Factor of Safety Results (Limit Equilibrium)

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Summed Likelihood Score

- Very Low (<= 6)
- Low (7-11)
- Moderate (12-16)
- High (17-21)
- Very High (>21)

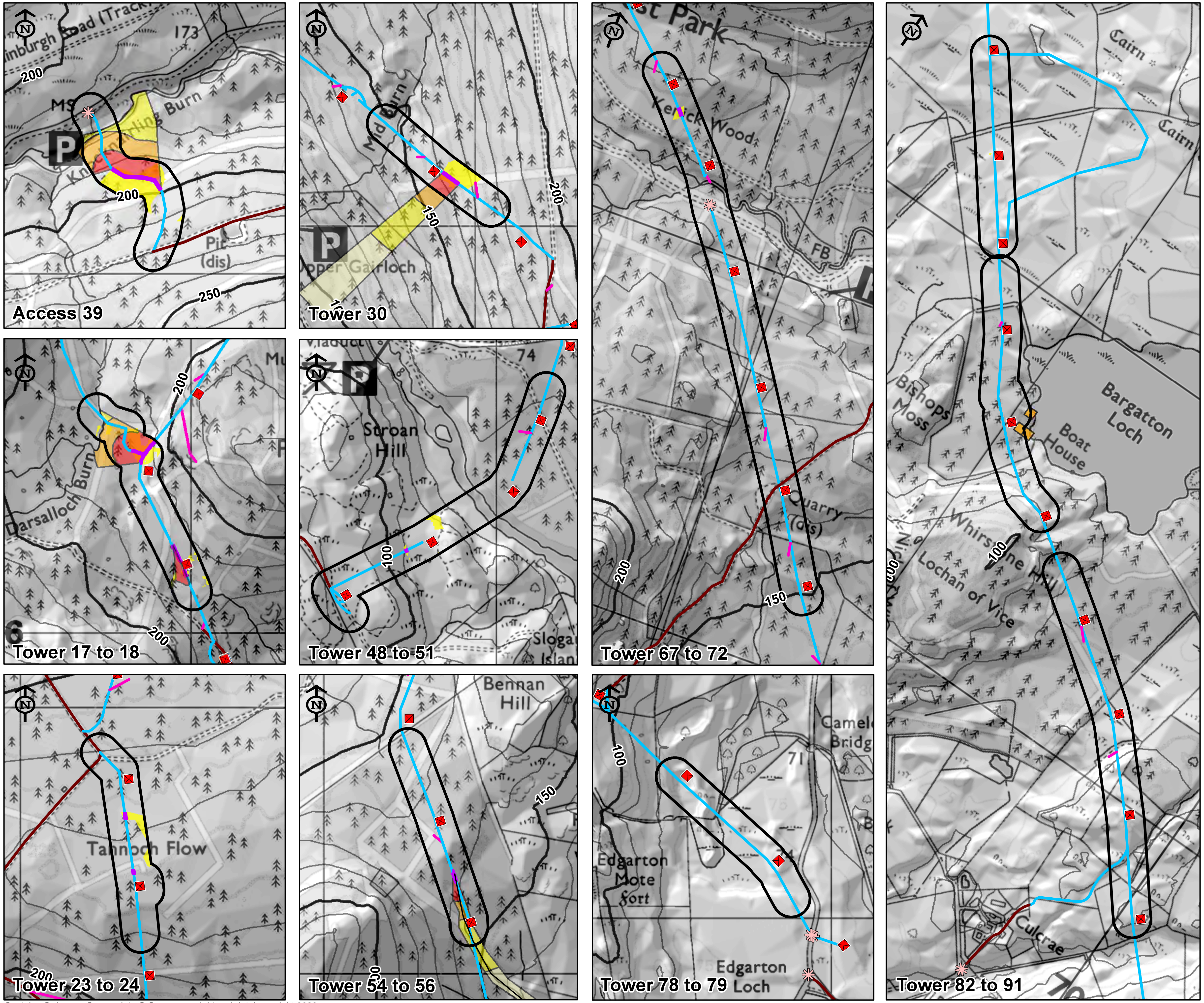
Appendix 9.6
Figure 8: Likelihood of Peat Landslide

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS



KTR Project
Peat Landslide Hazard and Risk Assessment

Legend

- Access Entrance
- Glenlee to Tongland (Steel Lattice Tower)
- Existing Access
- New Access
- Timber Extraction Spur
- 100m Subsections

Runout Zones

Cumulative runout distance (m):

- 50
- 100
- 250
- 500

- Moderate likelihood (12-16)
- Factor of Safety <=1.0
- Factor of Safety >1.0 - 1.4
- Source area (infrastructure)

Appendix 9.6
Figure 9: Source Areas and Runout Zones

0 100 200 400 Metres

1:10,000 scale at A3

east point geo

SP ENERGY NETWORKS

Appendix 9.7 Groundwater Dependent Terrestrial Ecosystem (GWDTE) Assessment

Contents

Figures

Appendix 9.7: GWDTE Assessment

Introduction

9.7.1 Groundwater Dependent Terrestrial Ecosystems (GWDTEs) are types of wetland that are specifically protected under the Water Framework Directive. GWDTEs should be considered in terms of their hydrology and their ecology. This Appendix has been provided to 'bridge the gap' between the two disciplines of Ecology and Hydrology by providing information from both disciplines to complete the assessment of potential effects of the proposed Kendoon to Tongland 132kV Reinforcement project ('the KTR Project') on GWDTEs.

9.7.2 This Appendix should be read in conjunction with Chapter 9: Geology, Hydrology, Hydrogeology, Water Resources and Peat and Chapter 10: Ecology and Appendix 10.2: Phase 1 Habitat and NVC Survey of the EIA Report. The assessment draws together detailed information from both chapters, summarising where applicable.

9.7.3 The Scottish Environmental Protection Agency (SEPA) has produced detailed guidance[i] on how to assess impacts of proposed development on GWDTEs and the following assessment is based on the SEPA guidance.

9.7.4 For the purposes of the EIA, the KTR Study Area encompasses five new overhead line (OHL) connections, the associated removal of the existing N and R routes and undergrounding of existing 11kV OHLs. To maintain consistency with the EIA, the description and assessment of GWDTEs is set out for each connection.

Identification of GWDTE

GWDTE and NVC Surveys

9.7.5 Phase 1 habitat surveys were undertaken during the accepted ecological survey seasons of 2017 and 2019 and the survey extent and results are described in Appendix 10.2. Where Phase 1 habitat types had potential to support GWDTE vegetation communities[i], further investigation was undertaken. Phase 1 habitat types that have potential to support GWDTE communities include:

- B5 Marshy Grassland;
- D1 – D6 Heathland;
- E1 – D4 Bog; and
- F1 – F2 Swamp.

9.7.6 Where appropriate, within habitats coded as above, the NVC method[ii] was used to identify potential GWDTE communities. However, to avoid unnecessary extensive botanical study, where Phase 1 habitat types were obviously attributable to surface water movement, rather than groundwater movement, no NVC was completed. This included stands of marshy grassland in hollows on steep slopes, obviously ombrogenous bogs etc.

9.7.7 However, where water influence was less clear, NVC was completed. As above, NVC data was also considered in light of wider influencing factors. Upon determining the NVC community, a decision tool was used to establish the level of dependency of each community on groundwater. Table 1 below shows the decision-making tool used in determining GWDTE presence.

Table 1: GWDTE Decision Tool. Determining the Level of Ground Water Dependency

Criteria	Yes	No
A. Is the GWDTE vegetation evidently influenced by groundwater? (i.e. base-enriched (M10, M11, M37 and/or M38) and/or discharging from an evident point source such as a spring head (M31, M32, M33).		
If the answer to A is 'Yes' then field assessment ends at this stage and the GWDTE is treated as 'high', as per the guidance. If 'No', continue to B.		
B. Is the GWDTE polygon associated with an evident surface water feature? i.e. is the vegetation located within one of the following topographic locations:		
Watershed/ridge		
Watercourse		
Floodplain		
Ponding location, pond, loch, etc (localised depression)		
Surface water conveyance (drain, gully, rill, etc.)		
If the answer to B is 'Yes' then the GWDTE polygon is no more than 'moderate' and very likely to be 'low'. Additional floristic and environmental data should be collected, including photographs to allow for further, desk-based determination of the groundwater dependency. If 'No', continue to C.		
C. Is the GWDTE polygon associated with an ombrogenous system? i.e. with blanket bog or wet heath habitat. This is especially relevant to M6 and M25:		
Presence/persistence of distinctive bog habitat, species and/or associations.		
Deep peat not confined to depressions/valleys (>0.5 m visible in drains or hagged areas).		
If the answer to C is 'Yes' then the GWDTE is no more than 'moderate' and very likely to be 'low'. Additional floristic and environmental data should be collected, including photographs to allow for further, desk-based determination of the groundwater dependency.		

GWDTE Baseline

9.7.8 Figure 2 of Appendix 10.2 presents the Phase 1 habitat survey results and Figure 3 of Appendix 10.2 presents the GWDTE (NVC) survey results. The habitat survey results are discussed in detail in Appendix 10.2 and are not repeated here. The GWDTE baseline is presented below.

Polquhanity to Glenlee (via Kendoon) (P-G via K)

9.7.9 Within the study area for this connection, the many areas of marshy grassland could suggest some level of groundwater dependency; however visual observations noted that topographical factors were key in influencing these vegetation communities.

9.7.10 For example, marshy grassland predominantly sits below steep slopes or has formed in hollows or shallower slopes on otherwise steep ground. The habitat type is also common in areas where surface water collects and flows towards the Water of Deugh, or Carsfad or Earlston Loch. Commonly, marshy grassland is located on the margins of small watercourses and more closely associated with running water than groundwater. Occasionally marshy grassland communities sit in areas of very deep peat, on the margins of ombrogenous bog habitats. While many of these marshy grasslands can be categorised as NVC MG10, and therefore potentially of low - moderate groundwater dependence, the majority of marshy grassland within the P-G via K study area is not considered to be groundwater dependent.

9.7.11 However, three areas of marshy grassland that accord with NVC M23 *Juncus effusus/acutiflorus - Galium palustre* rush-pasture, a mire community, were identified in the north of the study area, near towers 1 and 2 (refer to Figure 1 and Figure 3 of Appendix 10.2). According to best practice[i], M23 is considered to be potentially highly groundwater dependent.

9.7.12 These communities were much more species diverse than other marshy grasslands in the study area and included small *Sphagnum fallax* hummocks, tormentil and heath bedstraw. Although a small number of watercourses were identified within these vegetation communities, their reliance on groundwater could not be ruled out, however it is considered that their potential groundwater dependency is no greater than moderate.

Carsfad-Kendoon (C-K)

9.7.13 The marshy grassland components within the C-K study area could suggest a degree of groundwater dependency, however field studies identified that these features are predominantly small stands of *Juncus* and *Molinea* in low-lying areas of improved or semi-improved grassland features. The marshy grasslands have developed as a consequence of surface water flow and topography and are unlikely to be groundwater dependent. Hence, there are no GWDTE within the C-K study area.

Earlstoun to Glenlee (E-G)

9.7.14 The marshy grassland components within the E-G study area could reflect a degree of groundwater dependency, however field studies identified that these features are predominantly small stands of *Juncus* and *Molinia* in low-lying areas of improved or semi-improved grassland features. The marshy grasslands have developed as a consequence of surface water flow and topography and are unlikely to be groundwater dependent. Hence, there are no GWDTE within the E-G study area.

BG Deviation

9.7.15 The marshy grassland components within the BG Deviation study area could reflect a degree of groundwater dependency, however field studies identified that these features are predominantly small stands of *Juncus* and *Molinea* in low-lying areas of improved or semi-improved grassland features. The marshy grasslands have developed as a consequence of surface water flow and topography and are unlikely to be groundwater dependent. Hence, there are no GWDTE within the BG Deviation study area.

Glenlee to Tongland (G-T) Including Removal of R Route

9.7.16 Within the study area for this connection, the many areas of marshy grassland suggest some level of groundwater dependency; however visual observations noted that topographical factors were key in influencing these vegetation communities.

9.7.17 Modified bog habitats are ostensibly groundwater dependent. However, where these are present within the study area, they generally correlate with areas of deep peat (over 1m deep) on level or gently sloping ground, suggesting ombrogenous systems highly dependent on rainwater. No bog systems within the study area are considered to be groundwater dependent.

9.7.18 The G-T connection study area supports many small areas of marshy grassland. However, the majority of these are small pockets of *Juncus* in depressions or low-lying areas within heavily improved grassland. Their species composition is a function of topography and surface water flow and do not suggest a groundwater dependency.

9.7.19 Two areas of marshy grassland that accords with NVC M23 *Juncus effusus/acutiflorus* - *Galium palustre* rush-pasture, a mire community, were identified in the north of the study area, near Maggot Plantation, towers 8-10 (refer to Figure 2 and Figure 3 in Appendix 10.2). According to best practice[i], M23 is considered to be potentially highly groundwater dependent.

9.7.20 These communities were much more species diverse than other marshy grasslands in the study area. While still dominated by *Molinia* and *juncus effusus,* the habitat also supported a wide range of neutral grasses, including *Anthoxanthum odoratum*. Acidic and mire conditions were represented by the presence of sphagnum, although rare, tormentil, deer grass *Trichophorum cespitosum* and butterwort *Pinguicula vulgaris.* Bog myrtle was abundant throughout these communities.

9.7.21 Topographically, the communities are located downhill of an ombrogenous bog system, with a number of small watercourses flowing to a small loch to the north east. While it is likely that these communities, therefore, rely on surface water flows to some degree, it is not possible to entirely rule out a level of groundwater dependency. While M23 communities can be considered highly groundwater dependent, at these locations they are considered to have a dependency no greater than moderate.

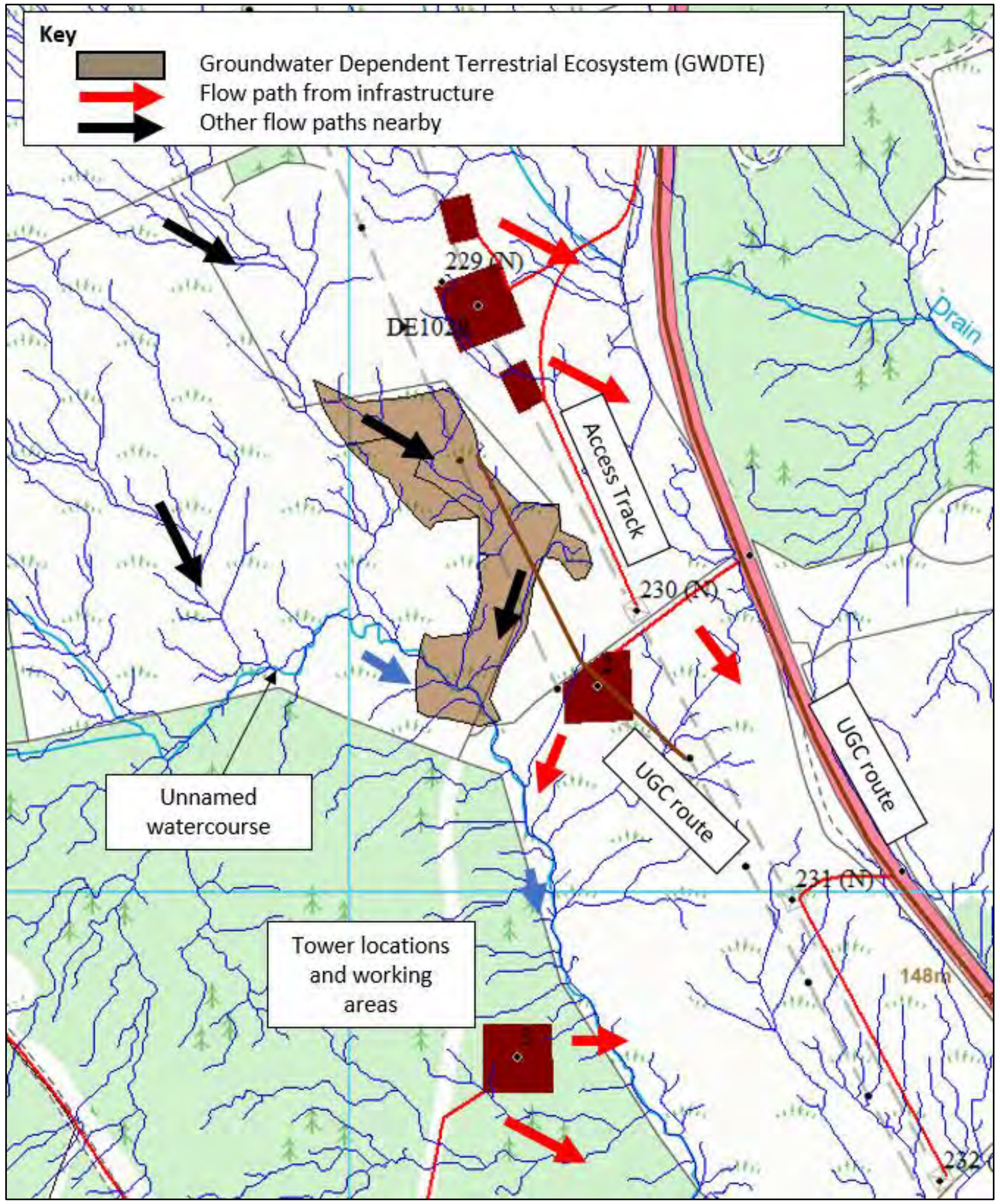
Effects Assessment

9.7.22 Following ecological identification of groundwater dependent habitats and an assessment of the levels of groundwater dependency of the specific habitats (above), this section provides an assessment of the potential effects of the KTR Project infrastructure upon groundwater flow to each of the identified areas of GWDTE. A site-specific qualitative risk assessment of each GWDTE was carried out based on the available data on local geology, hydrology, ecology and hydrogeological regime at each location. There is no available data on sub-surface flows and in the absence of data, it is considered that the movement of sub-surface water is primarily driven by topography.

Polquhanity to Glenlee (via Kendoon) (P-G via K)

9.7.23 The GWDTE communities identified within this connection's study area are considered to have a potential groundwater dependency of no greater than moderate and are associated with NVC M23 *Juncus effusus/acutiflorus* - *Galium palustre* rush-pasture, a mire community. The location of the moderately dependent GWDTE is shown on Figure 1 and is described in context with available geological, peat and hydrological information. A site-specific assessment of the GWDTE follows.

Figure 1: Location of moderately dependent GWDTE in hydrological setting, showing indicative surface water flow paths (P-G connection)



9.7.24 BGS solid geology maps indicate that the geology at the GWDTE site is Portpatrick Formation Greywackes (Figure 9.6.1 in the EIA Report). Greywacke metamorphic rocks are classified as a non-aquifers or low productivity aquifers that are generally without groundwater, except at shallow depths within the weathered zone or fractures.

9.7.25 BGS maps indicate that the superficial drift geology at the GWDTE site comprises a combination of glacial till deposits and hummocky glacial deposits (Figure 9.5.1).

9.7.26 The SNH Carbon and Peatlands Map 2016 (Figure 9.4.1) shows that most of the GWDTE site corresponds a Class 3 area: *"Dominant vegetation cover is not priority peatland habitat but is associated with wet and acidic type. Occasional peatland habitats. Most soils are carbon-rich soils, with some areas of deep peat"*. A small part of the GWDTE is in a class 5 area: *"Soil information takes precedence over vegetation data. No peatland habitat recorded, may also include areas of bare soil. Soils are carbon-rich and deep peat"*.

9.7.27 The peat depth survey (Figure 9.7.1) undertaken for the EIA did not extend to the GWDTE site, however the peat depth survey of the area around tower 2 shows that no peat was present around the proposed tower to the south of the site.

9.7.28 An unnamed surface watercourse flows in a south-easterly direction through the southern part of the GWDTE habitat, indicating that the GWDTE is likely to be driven partially by surface water flows from the watercourse (rather than dependent only on groundwater).

9.7.29 The movement of sub-surface water on the site is primarily driven by topography and hence are similar to surface water flow paths. The underlying bedrock is classed as generally impermeable, although it may provide some local groundwater.

9.7.30 Flow routing analysis was carried out in Global Mapper GIS software using 1m Light Detection and Ranging (LiDAR) terrain data of the GWDTE site and surrounds. In the absence of data on ground water levels and flow paths, analysis of topography and surface water flows paths was used to infer hydrological and hydrogeological connectivity to the KTR project infrastructure. Surface water flow paths indicate that the GWTDE drains towards the unnamed watercourse to the south of the site (Figure 1) and the source catchment for the GWDTE is discrete, local and small.

9.7.31 The GWDTE site is marshy and the water table is considered to sit close to, or at the ground surface, although will fluctuate with weather conditions (i.e. rapidly rising during storms).

9.7.32 The assessment of impact on a flow path for the KTR Project is made with reference to distance, slope, aspect, typical water table levels and features such as watercourses. This assessment is made with imperfect knowledge of the exact extent that a particular impact may have and imperfect knowledge of specific sub-surface flow paths. As such, it takes a precautionary approach using the best available information.

9.7.33 Two specific aspects are considered in the assessment. One is the likelihood of an impact upon a flow path feeding an area of groundwater. The second aspect is the likelihood that an area of groundwater may be drained at an un-naturally fast rate following the introduction of drainage for infrastructure / access tracks / tower bases.

9.7.34 The SEPA Guidance[i] for assessing impacts of development on GWDTEs recommends a 250m buffer zone from all excavations deeper than 1m and a 100m buffer for excavations less than 1m deep. The two buffers are shown on Figure 9.2.1 in the EIA report. While towers 1 and 2 and the new temporary access track for the removal of R towers do not directly impinge on the GWDTE and are located on higher ground to the west, they are within 100m of the moderately groundwater dependent GWDTE. Tower 3 is 205m south of the GWDTE (see Figure 9.2.1 and Figure 1). At the time of writing the proposed route for undergrounding of the existing 11kV cable is shown to pass directly through the GWDTE. However, SPEN have noted that the final UGC route design will aim to avoid the GWDTE area during construction, but no route has been agreed at present. For the purposes of the assessment, the UGC route is assumed to pass directly through the GWDTE as shown in Figure 1, as a conservative (worst-case) scenario.

9.7.35 Based on the project description and construction methods outlined in Chapters 4 and 5 of the EIA Report, excavation for the tower foundations will be deeper than 1m. and There is not anticipated to be any excavation of the temporary access track for the removal of the existing N tower however there is a risk the access track could block sub-surface flow paths to the GWDTE or runoff from the tracks could result in increased sediment/pollution draining towards the habitat. Installation of the UGC will involve trenching with the cable laid at a depth of ~1m and the trench backfilled with sand and native material and the surface reinstated. The UGC route passes through the GWDTE for a length of ~100m (see Figure 1) and the typical trench width is 30cm with a 3m temporary working width adjacent to the trench. Excavation and trenching could affect the GWDTE habitat, although the works will be temporary, as typical cable installation rates are ~160-200m per week, indicating that the installation works in the vicinity of the GWDTE will take less than one week.

9.7.36 The GWDTE sits in an area of lower ground approximately 2m lower than ground levels at proposed tower 1 and the temporary access track Ground levels at proposed tower 2 are at approximately the same level as the GWDTE site, although there is a local low point between the GWDTE and the tower location. The working areas for towers 1 and 2 are approximately 30m north and 45m west of the GWDTE habitat and are not hydrologically connected to the GWDTE. Tower 3 is 205m south of the GWDTE and separated hydrologically by the unnamed watercourse; flow path analysis indicates that the location of tower 3 is not hydrologically linked to the GWDTE (Figure 1). However, given the proximity of the excavations for towers 1 and 2, there is a risk that excavations during construction of the tower bases may temporarily affect sub-surface flows to the habitat. Installation of the UGC route will result in some temporary loss of habitat along the working area of the trench (approximately 300m^2 of habitat) and a temporary effect on subsurface flows during construction. However, as the native material will be replaced in the trench and the surface re-instated immediately after installation, the effects will be short-lived and there is not considered to be any significant effects on the GWDTE during operation.

9.7.37 Surface water flow paths based on topography (Figure 1) indicate that the flow paths feeding the GWDTE are in different sub-catchments to towers 1 and 2. However, given the uncertainty regarding sub-surface flow paths and the proximity of the excavations (including the trenching for the underground cable installation) to the GWDTE and the moderate groundwater dependence of the GWDTE, the effect on the GWDTE is considered to be of moderate magnitude, but temporary, resulting in an effect of moderate significance during construction. There is not expected to be any long-term effect on hydrology and sub-surface flows to the GWDTE, although monitoring will be put in place to confirm this.

9.7.38 Embedded mitigation measures (e.g. SUDS and best practise construction techniques) will minimise the risk of pollution/sediment to the GWDTE. Best practice construction techniques as set out in the guidance document "Good Practice during Wind Farm Construction" (2019[iii]) will be employed to ensure that the infrastructure does not affect groundwater flow or chemistry to sensitive receptors. Additional mitigation measures will be put in place during construction to maintain the baseline subsurface flows towards the GWDTE and ensure that any proposed drainage does not alter the natural drainage conditions of the site Specific measures will be implemented on a case by case basis as directed by the Ecological Clerk of Works during construction. In addition, the final design of the UGC route will aim to avoid the GWDTE habitat as far as possible during construction.

9.7.39 The additional mitigation will include excavated material during tower base and trench construction to be replaced without compaction. In addition, the new temporary access track will be designed with suitable drainage under the track to ensure subsurface flows are maintained. Monitoring will be put in place to assess the quantitative and chemical effect of the infrastructure to ensure that the groundwater flow and quality to the GWDTE are not statistically significantly changed post construction. Monitoring will be carried out based on SEPA guidance[i] and will comprise a representative number of hand-driven groundwater monitoring wells. Pre-construction monitoring will commence at least six months before construction commences. Monitoring reports will be prepared, and remedial actions identified if statistically significant changes to the groundwater flow or chemistries to sensitive receptors are identified.

9.7.40 Additional mitigation and monitoring will reduce the likelihood of any significant effects on the GWDTE and the residual effect is considered to be minor.

Glenlee to Tongland (G-T) Including Removal of R Route

9.7.41 There are two area of moderately dependent GWDTE communities identified within this connection's study area (Figure 2) which are associated with NVC M23 *Juncus effusus/acutiflorus - Galium palustre* rush-pasture, a mire community. The GWDTEs are described below in context with available geological, peat and hydrological information. A site-specific assessment of the GWDTEs follow.

9.7.42 BGS solid geology maps indicate that the geology at the site is Gala 1 Formation (Silurian) greywacke, which comprises medium to thick bedded turbidites. Sandstones are mainly quartzose and coarse grained. (Figure 9.6.2 in the EIA Report). The rocks are classified as non-aquifers or low productivity aquifers that are generally without groundwater, except at shallow depths within the weathered zone or fractures.

9.7.43 BGS superficial or drift geology mapping maps indicate that both areas of GWDTE sites are not underlain by superficial or drift deposits (Figure 9.5.2).

9.7.44 The SNH Carbon and Peatlands Map 2016 (Figure 9.4.2) shows that the GWDTE sites are either Class 4: *"Unlikely to be associated with peatland habitats or include carbon-rich soils"* or un-classed mineral soils.

9.7.45 The peat depth survey (Figure 9.7.1) undertaken for the EIA around tower 8 shows that no peat was present close to the northern GWDTE habitat. There is an area of deeper peat associated with the southern GWDTE site in an area to the east of tower 10, where peat depths range from 1.5 - 2m, with a small part of the site with peat depths >2m.

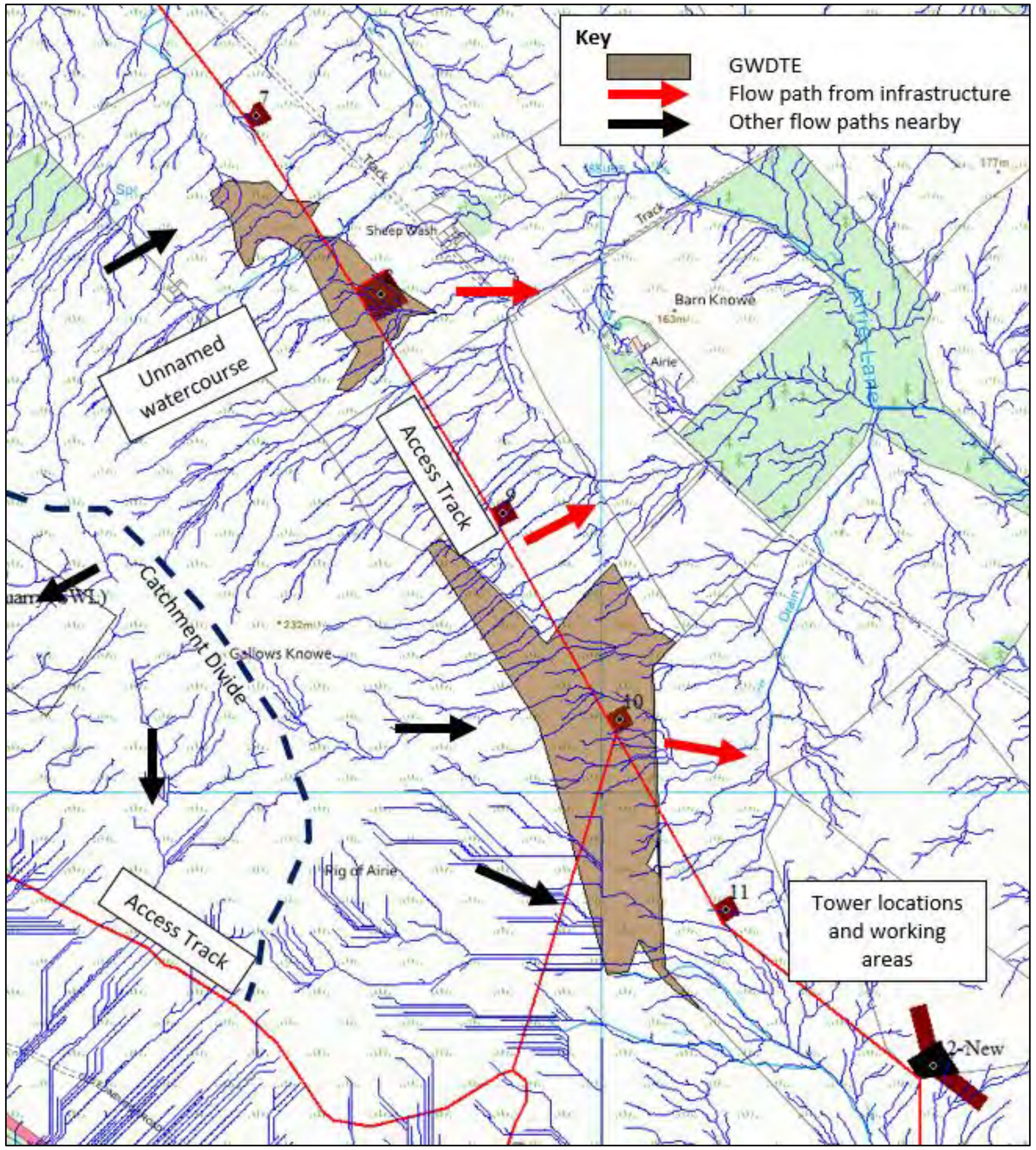
9.7.46 Topographically, both GWDTE communities are located downhill of an ombrogenous bog system, with a number of small watercourses flowing to a small loch to the north east, indicating that they rely on surface water flows to some degree (rather than dependent only on groundwater).

9.7.47 The movement of sub-surface water on the site is primarily driven by topography and hence are similar to surface water flow paths. The underlying bedrock is classed as generally impermeable, although it may provide some local groundwater.

9.7.48 Flow routing analysis was carried out in Global Mapper GIS software using the best available topographic data. 1m Light Detection and Ranging (LiDAR) terrain data is available for the GWDTE sites and the areas to the east. The area west of the GWDTE is not covered by LiDAR data, so 5m Ordnance Survey Terrain Data was used.

9.7.49 In the absence of data on ground water levels and flow paths, analysis of topography and surface water flows paths was used to infer hydrological and hydrogeological connectivity to the KTR project infrastructure. Surface water flow paths indicate that the northern GWTDE, close to tower 8, drains towards an unnamed watercourse which drains mainly to the north-east (Figure 2) and the source catchment for the GWDTE is discrete, local and small. The southern GWDTE drains in a south-easterly direction to a number of unnamed watercourses (Figure 2) and again the source catchment is local and small. Both GWDTE area on the eastern slopes of Gallows Knowe hill, which forms a catchment divide to the west (Figure 2).

Figure 2: Location of moderately dependent GWDTE in hydrological setting, showing indicative surface water flow paths (G-T connection)



9.7.50 The GWDTE sites are marshy and the water table is considered to sit close to, or at the ground surface, although will fluctuate with weather conditions (i.e. rapidly rising during storms).

9.7.51 The assessment of impact on a flow path for the KTR Project is made with reference to distance, slope, aspect, typical water table levels and features such as watercourses. This assessment is made with imperfect knowledge of the exact extent that a particular impact may have and imperfect knowledge of specific sub-surface flow paths. As such, it takes a precautionary approach using the best available information.

9.7.52 Two specific aspects are considered in the assessment. One is the likelihood of an impact upon a flow path feeding an area of groundwater. The second aspect is the likelihood that an area of groundwater may be drained at an un-naturally fast rate following the introduction of drainage for infrastructure / access tracks / tower bases.

9.7.53 The SEPA Guidance[i] for assessing impacts of development on GWDTEs recommends a 250m buffer zone from all excavations deeper than 1m and a 100m buffer for excavations less than 1m deep. The two buffers are shown on Figure 9.2.5 in the EIA report. Towers 8 and 10 are located within the GWDTEs and construction of the tower bases will result in direct loss of the habitat. The new access track also passes directly through the GWDTEs, which again will result in direct loss of habitat (see Figure 9.2.5 and Figure 2).

9.7.54 Based on the project description and construction methods outlined in Chapters 4 and 5 of the EIA Report, excavation for the tower foundations will be deeper than 1m, and there may be some excavation associated with the construction of the new access track, although this is likely to be less than 1m deep. There is also a risk that the access track could block sub-surface flow paths to the GWDTE or runoff from the tracks could result in increased sediment/pollution draining towards the habitat.

9.7.55 Given the proximity of the excavations for towers 8, 9, 10 and 11 there is a risk that excavations during construction of the tower bases may temporarily affect sub-surface flows to the habitat. The hydrological data indicates that the GWDTE may be partially fed by surface water and the dependency on groundwater is considered to be no greater than moderate. Given the direct loss of a small area of GWDTE habitat, the effect on both GWDTEs is considered to be of moderate magnitude, resulting in an effect of moderate significance during construction.

9.7.56 Embedded mitigation measures (e.g. SUDS and best practise construction techniques) will minimise the risk of pollution/sediment to the GWDTE. Best practice construction techniques as set out in the guidance document "Good Practice during Wind Farm Construction" (2019[iii]) will be employed to ensure that the infrastructure does not affect groundwater flow or chemistry to sensitive receptors. Additional mitigation measures will be put in place during construction to maintain the baseline subsurface flows towards the GWDTE and ensure that any proposed drainage does not alter the natural drainage conditions of the site. Specific measures will be implemented on a case by case basis as directed by the Ecological Clerk of Works during construction.

9.7.57 The additional mitigation will include excavated material during tower base construction to be replaced without compaction. In addition, the new temporary access track will be designed with suitable drainage under the track to ensure subsurface flows are maintained. Monitoring will be put in place to assess the quantitative and chemical effect of the infrastructure to ensure that the groundwater flow and quality to the GWDTEs are not statistically significantly changed post construction. Monitoring will be carried out based on SEPA guidance[i] and will comprise a representative number of hand-driven groundwater monitoring wells. Pre-construction monitoring will commence at least six months before construction commences. Monitoring reports will be prepared, and remedial actions identified if statistically significant changes to the groundwater flow or chemistries to sensitive receptors are identified.

9.7.58 Additional mitigation measures will reduce the significant effects on the GWDTE however given the direct loss of the habitat, the residual effect is moderate.

Summary

9.7.59 There are three areas of GWDTE habitats that have been assessed to have some dependence on groundwater; based on the GWDTE Decision Tool (Table 1) they all have no more than a moderate dependency on groundwater and surface water will feed the GWDTE to some extent.

9.7.60 Further site-specific desk-based analysis confirms that they are all partially fed by surface water and have small, discrete, localised catchments.

9.7.61 The effects on the GWDTE (assuming embedded mitigation measures, such as construction SUDS, are in place) are summarised below:

- P-G (via K) connection – the GWDTE habitat is close to the working areas for towers 1 and 2 and a temporary access track and the proposed UGC route passes through the GWDTE (Figure 1). Analysis of surface water flow paths indicate that the flow paths feeding the GWDTE are in different sub-catchments to the KTR towers and access tracks. However, given the proximity of the excavations to the GWDTE, the temporary loss of a small area of GWDTE habitat during trench excavation for the UGC and the moderate groundwater dependence of the GWDTE, the effect on the GWDTE is considered to be of moderate magnitude, but temporary, resulting in an effect of moderate significance during construction. There is not expected to be any long-term effect on hydrology and sub-surface flows to the GWDTE.
- G-T connection – a new access track and two towers are directly within the GWDTE and will result in direct loss of a small area of the habitat (Figure 2). In addition, given the proximity of the excavations for towers 8, 9, 10 and 11 there is a risk that excavations during construction of the tower bases may temporarily affect sub-surface flows to the habitat. The hydrological data indicates that the GWDTE may be partially fed by surface water and the dependency on groundwater is no greater than moderate. Given the permanent direct loss of a small area of GWDTE habitat, the effect on both GWDTEs is considered to be of moderate magnitude, resulting in an effect of moderate significance during construction.

9.7.62 Embedded mitigation measures (e.g. SUDS and use of best practice construction techniques) will minimise the risk of pollution/sediment to the GWDTEs. Additional mitigation measures will be put in place during construction to maintain the baseline subsurface flows towards the GWDTEs and ensure that any proposed drainage does not alter the natural drainage conditions of the site. Mitigation measures primarily aim to ensure that the water supply to a GWDTE is not interrupted and that any proposed drainage does not alter the natural drainage conditions of the site. Specific measures will be implemented on a case by case basis as directed by the Ecological Clerk of Works during construction.

9.7.63 The additional mitigation will include excavated material during tower base construction and UGC trench construction to be replaced without compaction and the final design of the UGC route will aim to avoid the GWDTE habitat as far as possible during construction. In addition, the new temporary access track will be designed with suitable drainage under the track to ensure subsurface flows are maintained.

9.7.64 Monitoring of the three identified GWDTEs will be carried out to assess the quantitative and chemical effect of the infrastructure to ensure that the groundwater flow and quality are not significantly changed, which would put the sensitive receptors at risk. Monitoring will be carried out before and after construction and will follow SEPA guidance[i]; this will include the installation and sampling of several hand driven groundwater monitoring wells, upgradient and downgradient of the infrastructure. Details of the proposed monitoring programme will be set out in the Construction and Decommissioning Environmental Management Plan (CDEMP) that will be agreed with SEPA and DGC in advance of the works.

9.7.65 With additional mitigation, the residual effects on the GWDTE areas in the P-G (via K) and G-T connections are assessed to be of minor and moderate significance, respectively.

References

[i] SEPA (2017). Land Use Planning System SEPA Guidance Note 31. Guidance on Assessing the Impacts of Development Proposals on Groundwater Abstractions and Groundwater Dependent Terrestrial Ecosystems.
[ii] Rodwell, J.S. 1991-2000. British plant communities. 5 Volumes. Cambridge University Press.
[iii] Scottish Renewables, SNH, SEPA & Forestry Commission Scotland (2019) Good Practice during Windfarm Construction, 4th Edition 2019.