Technical Appendix 6.4: Peat Landslide Hazard and Risk Assessment

Statkraft

This page is intentionally blank.

Consulting Report

Technical Appendix 6.4 - Peat Landslide Hazard and Risk Assessment Appin Wind Farm

Dumfries and Galloway, Scotland
Statkraft

O-NR-R14-0045-D-001v01

28/04/2025

CONTENTS

1. INTRODUCTION

1.1. Background

Appin Wind Farm Ltd (the Applicant) is seeking consent under Section 36 of the Electricity Act 1989 for construction of the Appin Wind Farm (hereafter the 'Proposed Development'), located in Dumfries and Galloway.

The Site for the Proposed Development lies approximately 6.2 km north of Moniaive and 14.8 km east of Carsphairn and is approximately 3.5 km^2 (c. 350 ha) in area (see Figure 3.1 of EIAR). The Site is set within and surrounded by relatively steep sided rolling hills that are largely planted with commercial plantation forestry.

The Proposed Development will comprise:

- Up to nine turbines of up to maximum blade tip height of 200 m.
- Turbine foundations and hardstandings for blade, tower and nacelle storage.
- A network of on-site access tracks of which 14.8 km will be upgraded existing track and 12.9 km will be new track with turning heads and passing places.
- An on-site substation compound (70 m x 150 m) including a control building for the Scottish Power Energy Networks (SPEN) substation and wind farm substation.
- One SPEN construction compound (50 m x 100 m).
- One temporary construction compound for the wind farm (50 m x 100 m).
- Three borrow pit search areas.

The Scottish Government Best Practice Guidance (BPG) provides a screening tool to determine whether a Peat Landslide Hazard and Risk Assessment (PLHRA) is required (Scottish Government, 2017). This is in the form of a flowchart, which indicates that where blanket peat is present, slopes exceed 2° and proposed infrastructure is located on peat, a PLHRA should be prepared. These conditions exist at the Proposed Development and therefore a PLHRA is required.

1.2. Scope of Work

The scope of the PLHRA is as follows:

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

The contents of this PLHRA have been prepared in accordance with the BPG, noting that the guidance "*should not be taken as prescriptive or used as a substitute for the developer's [consultant's] preferred methodology*" (Scottish Government, 2017). The first edition of the Scottish

Government Best Practice Guidance (BPG) was issued in 2007 and provided an outline of expectations for approaches to be taken in assessing peat landslide risks on wind farm sites. After ten years of practice and industry experience, the BPG was reissued in 2017, though without fundamental changes to the core expectations. A key change was to provide clearer steer on the format and outcome of reviews undertaken by the Energy Consents Unit (ECU) checking authority and related expectations of report revisions, should they be required.

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

i. An assessment of the character of the peatland within the application boundary including thickness and extent of peat, and a demonstrable understanding of site hydrology and geomorphology.

ii. An assessment of evidence for past landslide activity and present-day instability e.g. pre-failure indicators.

iii. A qualitative or quantitative assessment of the potential for or likelihood of future peat landslide activity (or a landslide susceptibility or hazard assessment).

iv. Identification of receptors (e.g. habitats, watercourses, infrastructure, human life) exposed to peat landslide hazards; and

v. A site-wide qualitative or quantitative risk assessment that considers the potential consequences of peat landslides for the identified receptors.

Section 1.3 below describes how this report addresses this indicative scope.

The spatial scope of the PLHRA is limited to the main infrastructure area within which wind turbines and ancillary infrastructure are located. This is because probing (see Section 3.5) indicates peat to be absent along the main access track, except where the already high quality forest road is to be subject to minor upgrades. The upgrading of the access is not anticipated to extend beyond the existing footprint of disturbance and primarily comprises resurfacing or reprofiling of existing track.

1.3. Report Structure

This report is structured as follows:

- Section 2 gives context to the landslide risk assessment methodology through a literature based account of peat landslide types and contributory factors, including review of any published or anecdotal information available concerning previous instability at or adjacent to the Site.
- Section 3 provides a Site description based on desk study and Site observations, including consideration of aerial or satellite imagery, digital elevation data, geology and peat depth data.
- Section 4 describes the approach to, and results, of an assessment of peat landslide likelihood under both natural conditions and in association with construction of the Proposed Development.
- Section 5 describes the approach to and results of a consequence assessment that determines potential impacts on Site receptors and the associated calculated risks.
- Section 6 provides mitigation and control measures to reduce or minimise these risks prior to, during and after construction.

Assessments within the PLHRA have been undertaken alongside assessments for the Outline Peat Management Plan (**Technical Appendix 6.3**) and have been informed by results from the Peat Survey (**Technical Appendix 6.2**). Where relevant information is available elsewhere in the Environmental Impact Assessment (EIA) Report, this is referenced in the text rather than repeated in this report.

1.4. Approaches to assessing peat instability for the Proposed Development

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

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

To reflect these limitations, both approaches are adopted and outputs from each approach integrated in the assessment of landslide likelihood. Error! Reference source not found.Plate 1.1 shows the approach:

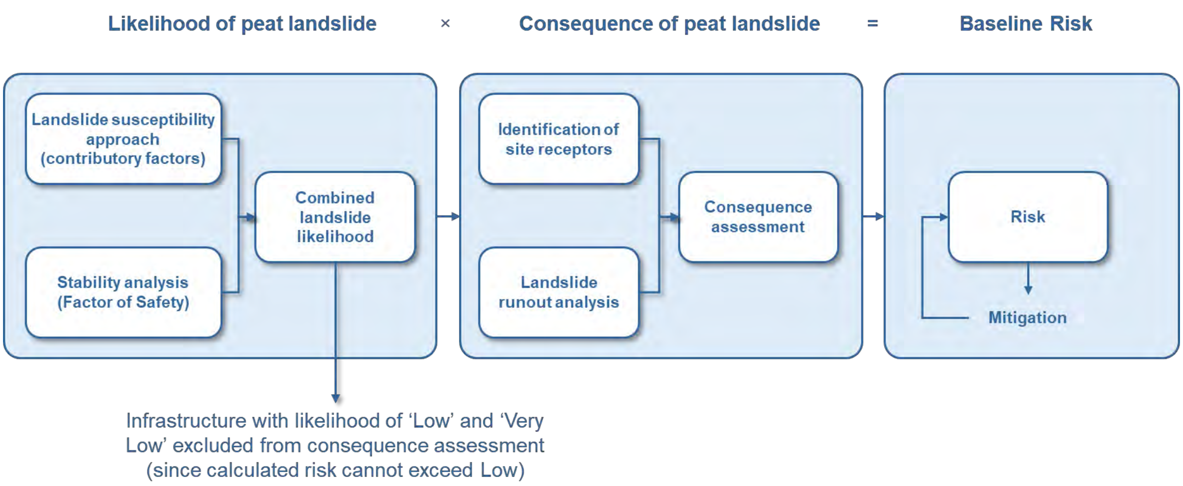


Plate 1.1 Risk assessment approach

1.5. Team competencies

This PLHRA has been undertaken by Dr Andy Mills (BSc MSc PhD CGeol), a chartered geologist with 27+ years experience of mapping and interpreting peatland terrains and peat instability features. Geomorphological walkover survey was undertaken in October 2021 by the same individual. Peat depth probing was undertaken by Kaya Consulting, a highly experienced peatland survey team, and additional Site observations and photographs were made available from these surveys to the PLHRA team.

2. BACKGROUND TO PEAT INSTABILITY

2.1. Peat Instability in the UK and Ireland

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

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

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

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

The Derrybrien event triggered interest in the influence of wind farm construction and operation on peatlands, particularly in relation to potential risks arising from construction induced peat instability. In 2007, the (then) Scottish Executive published guidelines on peat landslide hazard and risk assessment in support of planning applications for wind farms on peatland sites. While the production of PLHRA reports is required for all Section 36 energy projects on peat, they are now also regarded as best practice for smaller wind farm applications. The guidance was updated in 2017 (Scottish Government, 2017).

Since then, a number of peat landslide events have occurred both naturally and in association with wind farms (e.g. **Plate 2.1**). In the case of wind farm sites, these have rarely been reported, however landslide scars of varying age are visible in association with wind farm infrastructure on Corry Mountain, Co. Leitrim, at Sonnagh Old Wind Farm, Co. Galway (near Derrybrien; Cullen, 2011), and at Corkey Wind Farm, Co. Antrim. In December 2016, a plant operator was killed during excavation works in peat at the Derrysallagh wind farm site in Co. Leitrim (Flaherty, 2016) on a plateau in which several published examples of instability had been previously reported. 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.

Other recent natural events include another failure in Galway at Clifden in 2016 (Irish News, 2016), Cushendall, Co. Antrim (BBC, 2014), in the Glenelly Valley, Co. Tyrone in 2017 (BBC, 2018), Drumkeeran in Co. Leitrim in July 2020 (Irish Mirror, 2020) and Benbrack in Co Cavan in July 2021 (The Anglo-Celt, 2021). Noticeably, the vast majority of reported failures since 2003 have occurred in Ireland and Northern Ireland, with one reported Scottish example occurring on the Shetland Islands

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

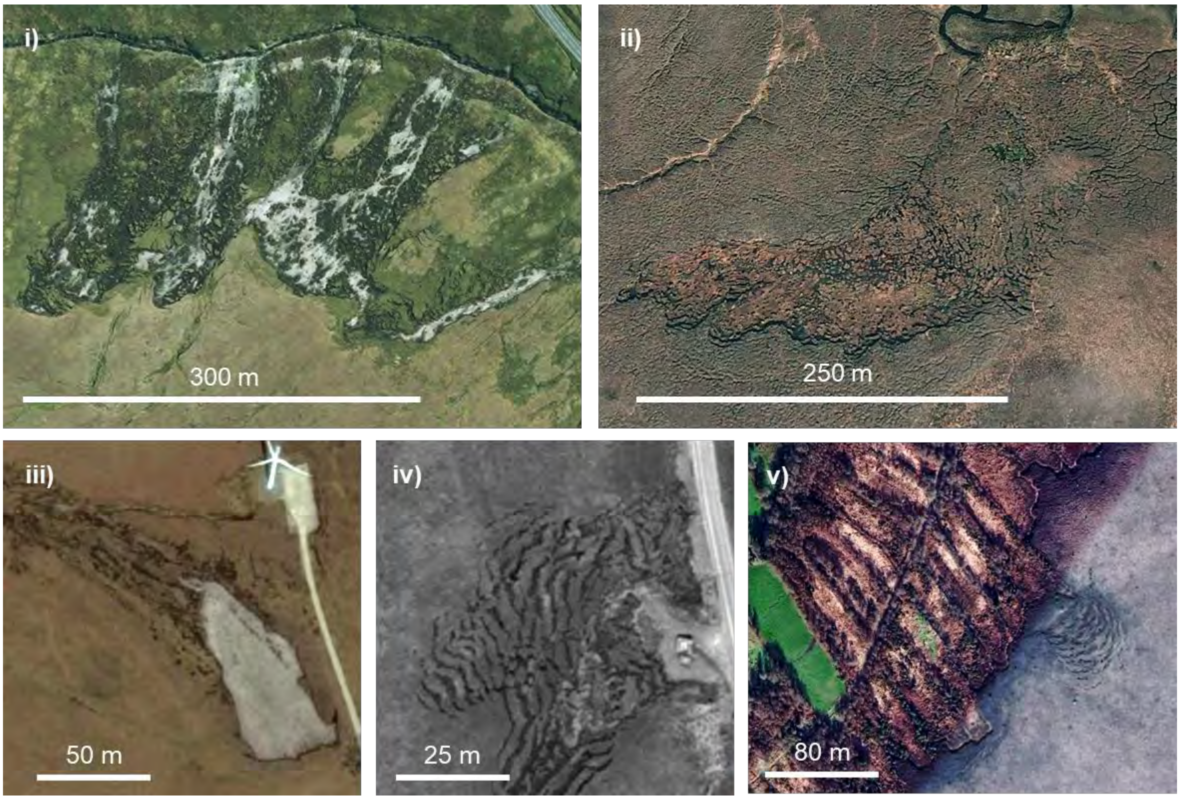


Plate 2.1 Characteristic peat landslide types in UK and Irish peat uplands: Top row - natural failures: i) multiple peat slides with displaced slabs and exposed substrate, ii) retrogressive bog burst with peat retained within the failed area; Bottom row - failures possibly induced by human activity: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

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

2.2. Types of Peat Instability

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

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

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

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

For the purposes of this assessment, landslide classification is simplified and split into three main types, typical examples of which are shown in **Plate 2.1**. Dimensions, slope angles and peat depths are drawn from charts presented in Evans and Warburton (2007). The term “peat slide” is used to refer to large-scale (typically less than 10,000 of cubic metres) landslides in which failure initiates as large rafts of material which subsequently break down into smaller blocks and slurry. Peat slides occur ‘top-down’ from the point of initiation on a slope in thinner peats (between 0.5 m and 1.5 m) and on moderate slope angles (typically 5°-15°, see **Plate 2.2**).

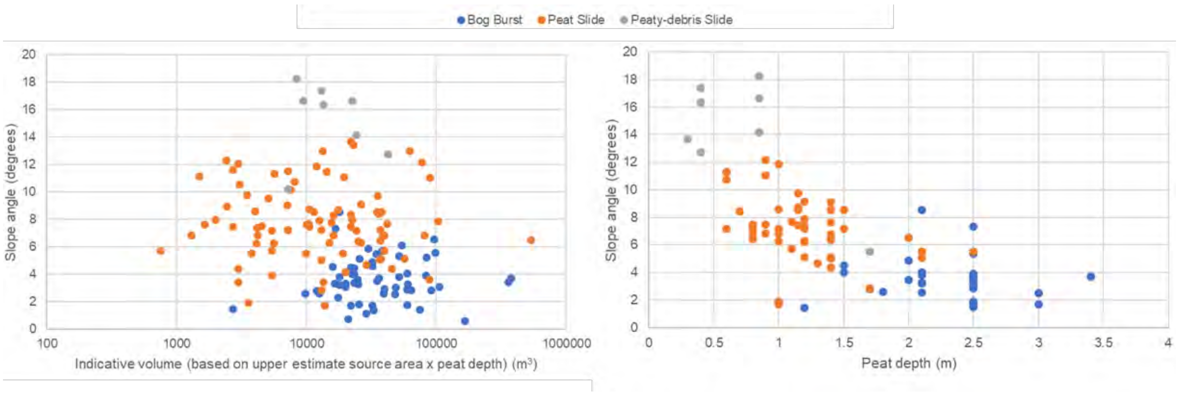


Plate 2.2 Reported slope angles and peat depths associated with peat slides and bog bursts (from literature review of locations, depths and slope angles, after Mills, 2002)

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).

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.

Few if any spreading failures in peat (i.e. bog bursts) have been reported in Scotland, with only one or two unpublished examples in evidence on the Isle of Lewis and Caithness.

2.2.1. Factors Contributing to Peat Instability

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

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

i. Impeded drainage caused by a peat layer overlying an impervious clay or mineral base (hydrological discontinuity).

ii. A convex slope or a slope with a break of slope at its head (concentration of subsurface flow).

iii. Proximity to local drainage, either from flushes, pipes or streams (supply of water).

iv. Connectivity between surface drainage and the peat/impervious interface (mechanism for generation of excess pore pressures).

v. Artificially cut transverse drainage ditches, or grips (elevating pore water pressures in the basal peat-mineral matrix between cuts, and causing fragmentation of the peat mass).

vi. Increase in mass of the peat slope through peat formation, increases in water content or afforestation.

vii. Reduction in shear strength of peat or substrate from changes in physical structure caused by progressive creep and vertical fracturing (tension cracking or desiccation cracking), chemical or physical weathering or clay dispersal in the substrate.

viii. Loss of surface vegetation and associated tensile strength (e.g. by burning or pollution induced vegetation change).

ix. Increase in buoyancy of the peat slope through formation of sub-surface pools or water-filled pipe networks or wetting up of desiccated areas.

x. Afforestation of peat areas, reducing water held in the peat body, and increasing potential for formation of desiccation cracks which are exploited by rainfall on forest harvesting.

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

i. Intense rainfall or snowmelt causing high pore pressures along pre-existing or potential rupture surfaces (e.g. between the peat and substrate).

ii. Rapid ground accelerations (e.g. from earthquakes or blasting).

iii. Unloading of the peat mass by fluvial incision or by artificial excavations (e.g. cutting).

iv. Focusing of drainage in a susceptible part of a slope by alterations to natural drainage patterns (e.g. by pipe blocking or drainage diversion).

v. Loading by plant, spoil or infrastructure.

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

2.2.2. Consequences of Peat Instability

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

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

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

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

3. BASELINE CONDITIONS

3.1. Topography

The Site is distributed around the summit slopes of a horseshoe-shaped east-facing valley drained by the Appin Burn. The highest point is Colt Hill (598 m Above Ordnance Datum (AOD)) at the western limit of the Proposed Development . On the northern valley side, an access track sits just south of the catchment divide to Shinnel Water in the next valley, Turbine 1 just short of Lamgarroch (573 m AOD). Turbine 2 sits between Turbine 1 and Colt Hill, with the track broadly following the contour around to the southern valley side. Turbine 3 sits just north of Blackcraig Hill (555 m AOD) while Turbines 5 and 6 are located on twin peaks at Mullwhanny (535 m and 520 m AOD), with Turbine 4 in the saddle between Blackcraig and Mullwhanny's western slopes. Turbines 7 and 8 are on the north side of Transparra / Wether Hill and Turbine 9 just north of Green Hill (540 m AOD). There is a sharp drop in elevation to the valley floor of 250-300 m (**Figure 6.4.1**). Key geographical features are shown on the perspective view on **Plate 3.1**.

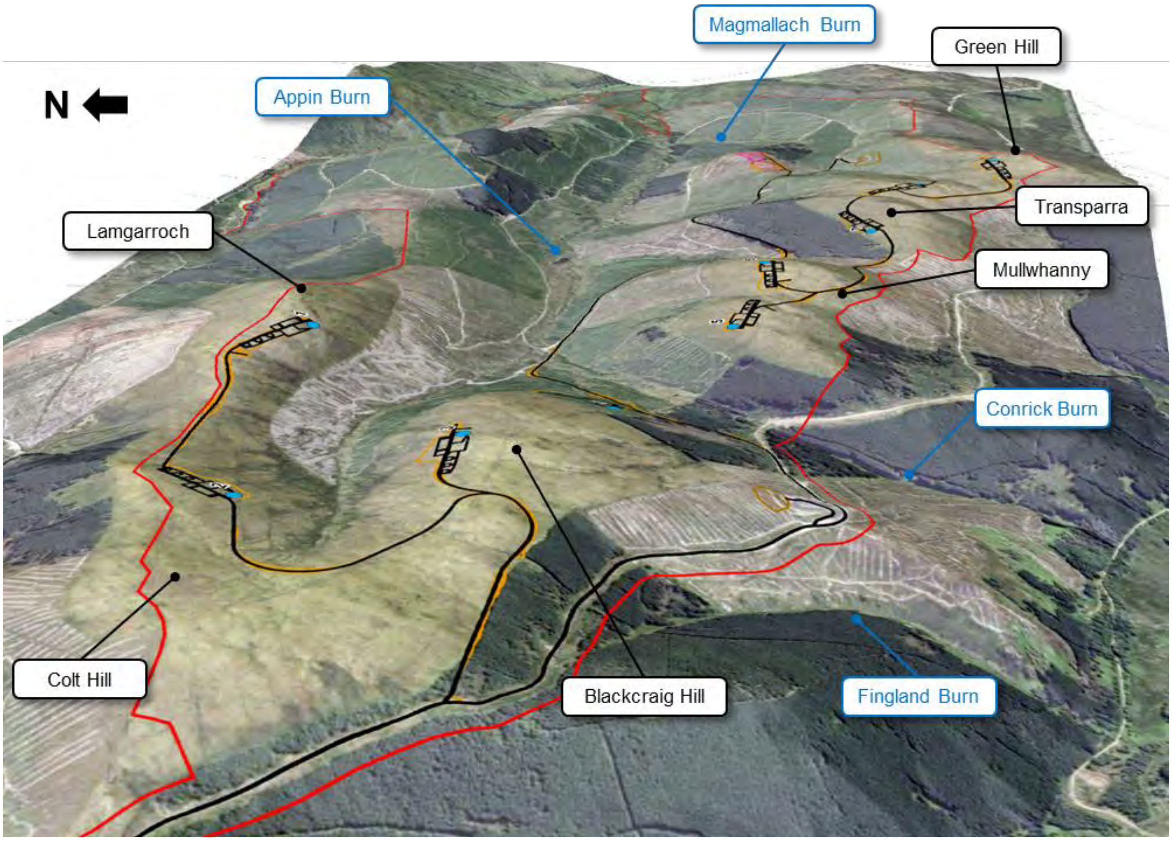


Plate 3.1 Perspective view of Site showing key geographical features

Figure 6.4.2 shows slope angles to be steep over much of the Site, with the majority of sideslopes exceeding 15° and relatively large areas >25°, particularly on south facing slopes on the north side of the valley. Generally, slope shapes are convex from the summits and ridgelines over onto the sideslopes and then rectilinear down to the valley floor.

3.2. Geology

The inset panel of **Figure 6.4.3** shows the solid geology of the Site mapped from 1:50,000 scale publicly available BGS digital data and indicates the Site to be underlain by sedimentary rock (wacke) of the Portpatrick Formation. A small area in the southeast of the Site around Turbine 9 is underlain by greywacke of the Shinnel Formation. The main panel of **Figure 6.4.3** shows the superficial geology of the Site to comprise Devensian till and diamicton on lower ground in the valley floor and around watercourses, with very limited areas of peat on the upper slopes (or otherwise no deposits). Probing indicated sporadic clay deposits at Turbine 2 (< 10% of probes) and isolated probes with clay present at Turbines 1 and 3 (<5% of probes). Further detail on the geology and its implications for hydrology are provided in **Chapter 6** of the EIA Report.

There are no geological designations within the Site boundary.

3.3. Hydrology

There are numerous watercourses draining the Site. Minor watercourses fall from the summit ridge to the main west-to-east flowing watercourses in the valley floor (see **Figure 6.4.4**). **Plate 3.2** shows typical hydrological features at the Site.

Plate 3.2 Typical hydrological features: a) an active artificial drain on the northern valley side, b) the eroding floor of a widening active drain, c) the Appin Burn in its upper reaches, d) the Appin Burn in the wider valley floor

Outside the Site to the north lies the Shinnel Water. Although none of the infrastructure on the northern valley side in the Site is within the Shinnel Water catchment, the Appin Burn flows into the Shinnel Water at the edge of the eastern Site boundary.

Within the main infrastructure area and central valley, the Appin Burn is a highly sinuous watercourse in the eastern half of the Site, but has more upland characteristics in the west, including small waterfalls and chutes. On both valley sides, a small number of unnamed watercourses fall towards the Appin Burn. Only Magmallach Burn is named, descending from Green Hill near Turbine 9.

To the south of the Appin Burn valley, the Dalwhat Water drains east, and is joined by a number of named minor watercourses. Those in proximity to infrastructure are Fingland Burn Lagdubh Burn, Conrick Burn and Benbuie Burn.

Chapter 6 of the EIA Report notes that all of the watercourses within the study area are of Medium water quality and morphological character (Table 6.6). The hydrology chapter (**Chapter 6: Geology, Hydrology and Peat** of the EIA Report) has scoped effects on fisheries out of the EIA Report.

In addition to natural watercourses, the Site has been relatively widely drained, both on the upper slopes above the forestry and within the planted areas (see **Figure 6.4.4**). In total over 32 km have been cut into the slopes within the main infrastructure area.

The Site does not lie within a surface water Drinking Water Protected Area (DWPA), noting that the effects of peat instability are generally on surface water features (and not groundwater).

3.4. Land Use

The primary land use at the Site is commercial forestry plantation, which is widespread on the valley sideslopes but generally absent on the summits. There is little evidence of peat cutting or burning.

3.5. Peat Depth and Character

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

- Phase 1 probing on a 100 m grid was undertaken from September to October 2021 and in November 2022 – in total, 740 probes were taken in Phase 1.
- Phase 2 probing was undertaken in December 2024 and February 2025 on a 10 m grid within infrastructure footprints and at 50 m intervals with 10 m offsets along access tracks – in total, a further 3,509 probes were taken in Phase 2 taking the total number to 4,249.
- Cores were acquired at all turbine locations, construction compounds, the substation and borrow pits.

A Peat Survey Report (**Technical Appendix 6.2**) documents the findings of these site investigations and summarises peat depth variation over the Site. Peat depth data was used to generate a peat depth model. Interpolation of peat depths was undertaken in the ArcMap GIS environment using a natural neighbour approach. This approach was selected because it preserves recorded depths at each probe location, unlike some other approaches (e.g. kriging), is computationally simple, and minimises 'bullseye' effects. The approach was selected after comparison of outputs with three other methods (inverse distance weighted, kriging and TIN).

Taken together the peat depth probing and model indicate the following:

- Peat is generally shallow or absent across much of the Proposed Development area, 86.8% of probes returning depths of <0.5 m, 10.7% of probes depths of 0.5 – 1.0 m and only 2.5% of probes >1.0 m.
- Peat is almost entirely absent from the sideslopes and valley floor, with the majority of deposits present at altitude on the gently sloping summits and moderate sideslopes above the forest – these locations are also the most practicable for wind infrastructure (from both a resource and constructability perspective).
- The deepest deposits within the main infrastructure area lie in the saddle between Blackcraig Hill and Mullwhanny and are centred on the unnamed watercourse that flows north to Appin Burn; here, peat depths reach between 2.0 and 3.0 m.
- Pockets of peat of up to 2.0 m are present elsewhere, but largely avoided by infrastructure.

The peat depth model is shown on **Figure 6.4.5** with probing locations superimposed. The average depths of peat within the permanent hardstanding footprints for Turbines 1 to 9 are shown in **Table 3.1.** Overlap with peat >1.0 m occurs in five locations:

- At the tip of the turning head east of Turbine 3.
- In earthworks on the approach to Turbine 8 and in the corner of the main hardstanding area.
- At the tip of the turning head east of Turbine 9.
- Adjacent to the substation compound.

Comparison of the peat depth model with the layout indicates that significant efforts have been made during layout design to move infrastructure out of the deepest peat areas and to route access tracks onto shallower peat.

Infrastructure	Mean Depth (m)	Max Depth (m)
Turbine 1	0.28	0.63
Turbine 2	0.36	0.64
Turbine 3	0.45	0.87
Turbine 4	0.27	0.64
Turbine 5	0.35	0.71
Turbine 6	0.31	0.55
Turbine 7	0.26	0.43
Turbine 8	0.50	1.73
Turbine 9	0.47	1.08

Table 3.1 Average peat depths within hardstanding area (including clearance, excluding earthworks)

The Carbon and Peatland (2016) Map shows Class 1 carbon-rich soils, deep peat and priority peatland habitat around much of the head of the valley, however, peat depth data and habitat data do not support this classification, nor the extent of peat on Mullwhanny on the south side of the valley.

Due to the relatively localised distribution of peat across the Site and moderate to steep slopes away from the summits, floating track is not specified as a mitigation design for the Proposed Development.

3.6. Peatland Geomorphology

Satellite imagery available as an ArcGIS Basemap layer was used to interpret and map features within the Site boundary. Additional imagery from different epochs available on both Google Earth™ and bing.com/maps was also referred to in order to validate the satellite imagery interpretation. The resulting geomorphological map (**Figure 6.4.6**) was subsequently verified during a site walkover undertaken in October 2021 by a Chartered Geologist / peatland geomorphologist with over 27 years' experience of assessing peat landslides. **Plates 3.2** and **3.3** show typical features identified during the walkovers.

Figure 6.4.6 shows the key features of the Proposed Development. 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.

The Proposed Development Site is relatively featureless over the majority of the Site footprint, comprising open summits with very little evidence of erosion or gullying. Where erosion is present, it is usually in association with drain floors that have started to cut into the underlying substrate due to steepening slopes (e.g. Plate 3.2b). Elsewhere, the most frequent features are diffuse drainage zones, or flushes, within which rushes tend to dominate and surface water flow is more noticeable. There are isolated pipes present on the northern valley side, though not in proximity to infrastructure. No evidence of peat instability was observed during walkover, with no tension cracks, compression ridges, quaking ground or collapsed pipes. Isolated bog pools are present on the south-east side of Transparra and on Communnoch Hill in the southeast of the Site.

Within the afforested areas, which are largely mutually exclusive with peat covered areas, the terrain is rough, with felling and new crop creating a challenging surface to walkover and creating numerous topographic barriers to potential landslide debris.

Plate 3.3 Typical terrain features: a) Better quality habitat within forest rides east of Turbine 1 (and away from infrastructure), b) typical exposed and featureless planar summit, c) dense forest on moderate sideslopes, d) flush zone with flattened grasses amongst rushes on moderate slope

4. ASSESSMENT OF PEAT LANDSLIDE LIKELIHOOD

4.1. Introduction

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

Risk = Probability of a Peat Landslide x Adverse Consequences

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

Due to the combination of moderate slopes and thinner peat at this Site, the most likely mode of failure is peat slides, and this is the failure mechanism considered in this report. This is in keeping with the most likely mode of failure for the peat depths and slope angles present at the Site (see **Plate 2.2** and **Figures 6.4.2** and **6.4.5**).

4.2. Limit Equilibrium Approach

4.2.1. Overview

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

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

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

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

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 FoS 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 FoS greater than 1.4 are generally considered to be stable.

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

4.2.2. Data Inputs

Stability analysis was undertaken in ArcMap GIS software. A 25 m x 25 m grid was superimposed on the full Site extent and key input parameters derived for each grid cell. In total, c. 10,290 grid cells were analysed. A 25 m x 25 m cell size was chosen because it is sufficiently small to define a credible landslide size and avoid ‘smoothing’ of important topographic irregularities.

Stability analysis was undertaken using input parameters correspond to undisturbed peat, prior to construction, and under water table conditions typically associated with instability (i.e. full saturation). Effective stress parameters are used in a drained analysis.

Table 4.1 shows the input parameters and assumptions for the baseline stability analysis. The shear strength parameters c' and ϕ’ are usually derived in the laboratory using undisturbed samples of peat collected in the field and therefore site specific values are often not available ahead of detailed site investigation for a development. Therefore, for this assessment, a literature search has been undertaken to identify a range of credible but conservative values for c' and ϕ’ quoted in fibrous and humified peats. FoS analysis was undertaken with conservative ϕ’ of 20° and values of 2 kPa and 5 kPa for c’. These values fall at the low end of a large range of relatively low values (when compared to other soils).

4.2.3. Results

The outputs of the drained analysis (effective stress) are shown for both parameter combinations in **Figure 6.4.7**. The more conservative combination (minimum c’ and ϕ’, inset panel) suggests localised areas of low factor of safety on the steeper sideslopes below infrastructure, while the best estimate parameters (main panel) indicate a similar pattern, albeit it with a smaller number of lower stability areas, with these having higher (more stable) results. The primary reason for the relatively low incidence of low stability is the absence of peat on moderate slopes.

This is consistent with Site observations and 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.

Parameter	Values	Rationale	Source
Effective cohesion (c')	2, 5	Credible conservative cohesion values for humified peat based on literature review	5, basal peat (Warburton et al., 2003) 8.74, fibrous peat (Carling, 1986) 7 - 12, H8 peat (Huat et al, 2014) 5.5 - 6.1, type not stated (Long, 2005)

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

Table 4-1 Geotechnical parameters for drained infinite slope analysis

4.3. Landslide Susceptibility Approach

4.3.1. Overview

The landslide susceptibility approach is based on the layering of contributory factors to produce unique ‘slope facets’ that define areas of similar susceptibility to failure. These slope facets vary in size and are different to the regular grid used for the FoS approach. The number and size of slope facets varies from one part of the Site to another according to the complexity of ground conditions. In total, c. 21,330 facets were considered in the analysis, with an average area of c. 333 m^2 (or an average footprint of c. 18 m x 18 m), consistent with smaller scale peaty soil or peat slides reported in the published literature.

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

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

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

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

4.3.2. Slope Angle (S)

Table 4-2 shows the slope ranges, their association with instability and related scores for the slope angle contributory factor. Slope angles were derived from the 5 m digital terrain model shown on **Figure 6.4.2** and scores assigned based on reported slope angles associated with peat landslides rather than a simplistic assumption that 'the steeper a slope, the more likely it is to fail' (e.g. **Plate 2.2**).

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

Table 4-2 Slope classes, association with instability and scores

Figure 6.4.8 shows the distribution of slope angle scores across the Site. Given the severity of slopes on Site, the vast majority of the study area has the highest slope score.

4.3.3. Peat Depth (P)

Table 4-33 shows the peat depths, their association with instability and related scores for the peat depth contributory factor. Peat depths were derived from the peat depth model shown on **Figure 6.4.5** and reflect the peat depth ranges most frequently associated with peat landslides (see **Plate 2.2**).

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

Table 4-3 Peat depth classes, association with instability and scores

The distribution of peat depth scores is shown on Figure 6.4.8. Due to the absence of peat over most of the Site, much of the study area scores 0. Where peat is present, it is typically of shallow to moderate depth (0.5 1.5 m) and therefore scores the maximum score.

4.3.4. Substrate Geology (G)

Table 4-4 shows substrate type, association with instability and related scores for the substrate geology contributory factor. The shear surface or failure zone of reported peat failures typically overlies an impervious clay or mineral (bedrock) base giving rise to impeded drainage. This, in part, is responsible for the presence of peat, but also precludes free drainage of water from the base of the peat mass, particularly under extreme conditions (such as after heavy rainfall, or snowmelt).

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

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

Table 4-4 Substrate geology classes, association with instability and scores

Probing undertaken across the Site indicated primarily bedrock or granular substrates using the refusal method. While clay was locally present at Turbines 1, 2 and 3, the proportion of probes were identified was small. Accordingly, the full Site is treated as if underlain by impermeable bedrock or granular glacial till (**Figure 6.4.8**).

4.3.5. Peat Geomorphology (M)

Table 4-5 shows the geomorphological features typical of peatland environments, their association with instability and related scores. Being an open moorland site (rather than afforested), there is a strong degree of confidence in the identification and mapping of these features, where present.

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

Table 4-5 Peat geomorphology classes, association with instability and scores

Figure 6.4.8 shows the geomorphological classes from **Figure 6.4.6** re-coloured to correspond with **Table 4-5**. Much of the Site comprises planar slopes with the exception of flushes on the steeper slopes above the forestry (which are assigned the highest score).

4.3.6. Artificial Drainage (D)

Table 4-6 shows artificial drainage feature classes, their association with instability and related scores. Transverse (or contour aligned) / oblique artificial drainage lines may reduce peat stability by creating lines of weakness in the peat slope and encouraging the formation of peat pipes. A number of peat failures have been identified in published literature which have failed over moorland grips (Warburton et al, 2004). The influence of changes in hydrology becomes more pronounced the more transverse the orientation of the drainage lines relative to the overall slope.

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

Table 4-6 Drainage feature classes, association with instability and scores

The effect of drainage lines is captured through the use of a 30 m buffer on each artificial drainage line (producing a 60 m wide zone of influence) present within the peat soils at the Site. Each buffer is assigned a drainage feature class based on comparison of the drainage axis with elevation contours (transverse, oblique or aligned, as shown in **Table 4-6).** Buffers are shown on **Figure 6.4.8**.

4.3.7. Slope Curvature (C)

Table 4-7 shows slope (profile) curvature classes, association with instability and related scores. Convex and concave slopes (i.e. positions in a slope profile where slope gradient changes by a few degrees) have frequently been reported as the initiation points of peat landslides by a number of authors. The geomechanical reason for this is that convexities are often associated with thinning of peat, such that thicker peat upslope applies stresses to thinner 'retaining' peat downslope. Conversely, buckling and tearing of peat may trigger failure at concavities (e.g. Dykes & Warburton, 2007; Boylan and Long, 2011). However, review of reported peat landslide locations against Google Earth elevation data indicates that the majority of peat slides occur on rectilinear (straight) slopes and that the reporting of convexity as a key driver may be misleading. Accordingly, rectilinear slopes are assigned the highest score.

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

Profile Curvature	Association with instability	Peat slide
Concave Slope	Peat failures are occasionally reported in association with concave slopes	1

Table 4-7 Slope curvature classes, association with instability and scores

The 5 m digital terrain model was used to identify areas of noticeable slope convexity across the Site. An ArcGIS geoprocessing model was used to calculate slope curvature into concave, convex and rectilinear slopes and 'flat' areas, i.e. those with minimal rate of gradient change on subdued terrain. Curvature scores are shown on **Figure 6.4.8** in accordance with **Table 4-7** above.

4.3.8. Forestry (F)

Table 4-8 shows forestry classes, their association with instability and related scores. A report by Lindsay and Bragg (2004) on Derrybrien suggested that row alignments, desiccation cracking and loading (by trees) could all influence peat stability.

Forestry Class	Association with instability	Peat slide
Deforested, rows oblique to slope	Deforested peat is less stable than afforested peat, and inter ridge cracks oblique to slope may be lines of weakness	3
Deforested, rows aligned to slope	Deforested peat is less stable than afforested peat, but slope aligned inter ridge cracks have less impact	2
Afforested, rows oblique to slope	Afforested peat is more stable than deforested peat, but inter ridge cracks oblique to slope may be lines of weakness	2
Afforested, rows aligned to slope	Afforested peat is more stable than deforested peat, but potentially less stable than unforested (never planted) peat	1
Windblown	Windblown trees have full disruption to the underlying peat and residual hydrology due to root plate disturbance	0
Not afforested	No influence on stability	0

Table 4-8 Forestry classes, association with instability and scores

Much of the Site is afforested, though little of the infrastructure is located in areas of forestry. Scores are shown on **Figure 6.4.8**.

4.3.9. Land use (L)

Table 4-9 shows land use classes, association with instability and related scores. A variety of land uses have been associated with peat failures (see section 2.2.1). While it is hypothesised that burning may cause desiccation cracking in peat and facilitate water flows to basal peat (and potential shear surfaces), there is little evidence directly relating burnt ground to peat landslide events.

Land Use	Association with instability	Peat slide
Machine cutting	Machine cutting may compartmentalise slopes, but has been reported primarily in association with peat slides	3
Quarrying	Quarrying may remove slope support from upslope materials, and has been observed with spreading failures (bog bursts)	2

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

Table 4-9 Land use classes, association with instability and scores

Forestry is the primary land use on Site and considered separately in the forestry category. Where existing borrow pits are present, the upslope sides have been buffered to reflect possible loss of support to the soils above. Scores for land use are shown on **Figure 6.4.8.**

4.3.10. Generation of Slope Facets

The eight contributory factor layers shown on **Figure 6.4.8** were combined in ArcMap to produce approximately 21,330 slope facets. Scores for each facet were then summed to produce a peat landslide likelihood score. These likelihood scores were then converted into descriptive 'likelihood classes' from 'Very Low' to 'Very High' with a corresponding numerical range of 1 to 5 (in a similar format to the Scottish Government BPG).

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

Table 4-10 Likelihood classes derived from the landslide susceptibility approach

Table 4-10 describes the basis for the likelihood classes. A judgement was made that for a facet to have a moderate or higher likelihood of a peat landslide, a likelihood score would be required exceeding both the worst case peat depth and slope angle scores summed (3 in each case, i.e. 3 x 2 classes) alongside three intermediate scores (of 2, i.e. 2 x 3 classes) for other contributory factors.

This means that any likelihood score of 13 or greater would be equivalent to at least a moderate likelihood of a peat landslide. Given that the maximum score attainable is 24, this seems reasonable.

4.3.11. Results

Figure 6.4.9 shows the outputs of the landslide susceptibility approach for peat slides. The results indicate that the majority of the Site has a 'Low' or 'Very Low' likelihood with some summit areas having a 'Moderate' likelihood of a peat slide under natural conditions.

Areas of 'Moderate' likelihood are typically located on moderate slopes, adjacent to drains and along the peat escarpment. There are no areas identified with 'High' or 'Very High' landslide susceptibility and only localised areas of 'Very Low' likelihood. When compared with the stability analysis approach, the outputs of this approach indicate slightly more of the Site to be at lower stability under natural conditions.

4.3.12. Combined Landslide Likelihood

Figure 6.4.10 shows in purple any proposed areas of infrastructure of greater than 25 m in length intersecting with areas of moderate or higher landslide susceptibility (from the contributory factor approach) or FoS of 1.4 or less (from the limit equilibrium approach). A 25 m overlap has been selected as this is considered the minimum size of a potentially environmentally significant landslide. In order for there to be a "Medium" or "High" risk (Scottish Government, 2017), likelihoods must be "Moderate" or higher (see **Plate 4.1** below) and hence this provides a screening basis for the likelihood results.

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

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

Plate 4.1 Top: risk ranking as a product of likelihood and consequence; Bottom: suggested action given each level of calculated risk

In all, 14 infrastructure locations overlap with areas of “Moderate” landslide likelihood.

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

5. ASSESSMENT OF CONSEQUENCE AND RISK

5.1. Introduction

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

5.2. Receptors

Peat uplands are typically host to the following receptors: watercourses and associated water supplies (both private and public), terrestrial habitats (e.g. groundwater dependent terrestrial ecosystems or GWDTEs) and infrastructure, both those that are related to the wind farm and other infrastructure, e.g. roads and power lines. These are considered for the Proposed Development below.

5.2.1. Watercourses

The Proposed Development Site is drained by numerous watercourses, a majority of which in the main infrastructure area drain into the Appin Burn. One source zone is situated in the catchment of the Dalwhat Water (Source Zone 8). The watercourses on the sideslopes are very small in cross-section, and while steep, have limited potential to convey debris to the lower slopes, however, the Appin Burn in its lower reaches would likely be able to convey material a number of kilometres downstream. The watercourses are of Medium quality and sensitivity and therefore are assigned consequence scores of 3. The Site does not lie within a surface water DWPA.

5.2.2. Habitats

While blanket bog habitats are valuable, they generally recover from instability events through revegetation over a matter of years to decades and therefore a consequence score of 3 is assigned for all open blanket bog habitats within the Proposed Development (**Table 5-1**). Habitats at the Proposed Development are not typical of higher quality priority peatland habitats, and impacts are unlikely to raise issues of National Interest.

Receptor and type	Consequence	Score	Justification for Consequence Score
Watercourses (aquatic habitats)	Short term increase in turbidity and acidification, potential fish kill	3	Undesignated watercourse, no sensitive species noted
Terrestrial habitats	Short to medium term loss of vegetation cover, disruption of peat hydrology, carbon release	3	Best habitats noted to be lower quality blanket bog, long term effects unlikely following revegetation
Wind farm infrastructure (Project)	Damage to infrastructure, injury to site personnel, possible loss of life	5	Loss of life, though very unlikely, is a severe consequence; financial implications of damage and re-work are less significant

Table 5-1 Receptors considered in the consequence analysis

5.2.3. Infrastructure

The Proposed Development Site is relatively isolated, with the primary non-wind farm infrastructure limited to forest roads and quarries.

Infrastructure that would be most affected in the event of a peat landslide would be the Proposed Development 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 the Applicant, loss of life / injury would be of greater concern, and a consequence score of 5 is assigned for any infrastructure locations subject to potential peat landslides (**Table 5-1**). However, risks to life can be mitigated through safe systems of working. These infrastructure risks are not considered to be 'environmental' risks and are not explicitly considered in the consequence assessment below.

5.3. Consequences

5.3.1. Overview

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 turbine is located in a Moderate (likelihood score of 3) area of open slope and is located 50 m from a watercourse (with a consequence score of 5), it is probable that a landslide triggered during construction would reach that watercourse. The calculated risk would be a product of the likelihood and consequence scores (likelihood: 3 x consequence: 5 = risk: 15, see **Plate 4.1)** and be equivalent to a "Medium" risk.

In order to determine the likelihood of impact on watercourses and infrastructure, 'runout pathways' have been defined that show the estimated maximum footprint of the landslide. Runout pathways are divided in a downslope direction into 50 m, 100 m, 250 m and 500 m zones on the basis of typical runout distances detailed in Mills (2002). The likelihood of runout passing from one runout zone to the next (e.g. from the 50 m zone into the 100 m zone) is based on the proportion of the published peat landslide population that reaches each runout distance shown on **Plate 5.1** (0-50 m: 100%, 50-100 m: 87%, 100-250 m: 56%, 250-500 m: 44%). The source zone area is either footprint of hardstandings or non-linear infrastructure or where an access track is the source, the track length multiplied by a typical landslide downslope length of 25 m.

Figure 6.4.10 shows in purple all infrastructure locations that overlap with moderate likelihoods, based on the combined landslide likelihood scores described in Section 4. In total, 14 source and runout zones have been identified.

5.3.2. Local limits on runout (Watercourses)

All runout pathways defined on **Figure 6.4.10** terminate at watercourses if within 500 m of the source zone, reflecting the position of watercourses at valley floors / within topographic lows. At this point, debris is regarded as entering the watercourse and risk is calculated as the product of consequence (dependent on the watercourse consequence score) and likelihood (from Section 4). If watercourses contain physical barriers (e.g. weirs), are highly sinuous within low floodplains and may encourage stranding of debris, or if streams are too small to convey material, then runout may also be considered to stall where these restrictions come into effect.

5.3.3. Local limits on runout (slope curvature)

Plate 5.1 shows runout distances based on published literature. Typically, runout distances would be expected to be less where slope angles decline with distance from the source zone (i.e. on concave slopes) whereas the full runout lengths shown on **Plate 5.1** may be achievable on steepening (convex) slopes or rectilinear slopes. At the Proposed Development, slopes are steep and convex / rectilinear, and therefore slope is unlikely to limit runout.

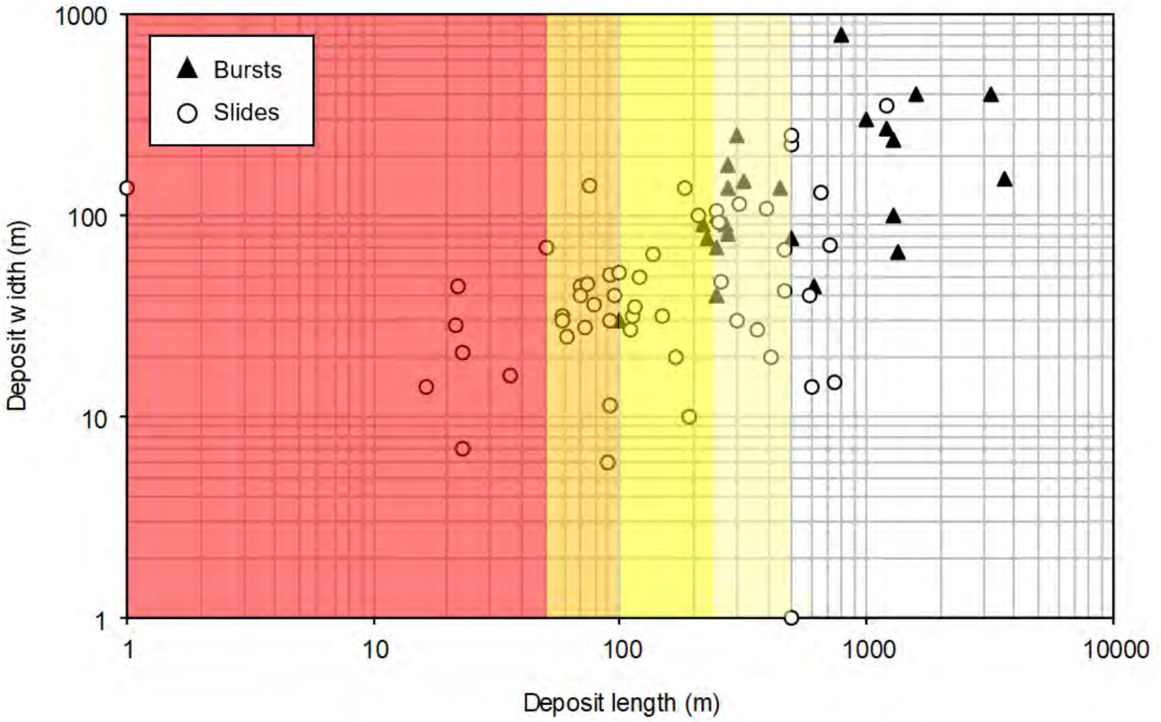


Plate 5.1 Runout distances for published peat landslides (after Mills, 2002), colours on the plot correspond to runout pathway zones on Figure 6.4.10

5.3.4. Local limits on runout (forestry)

The lower slopes below the source zones are largely afforested, in various states of stocking, with mature crop, second rotation and brash covered areas. All of these ground covers would provide substantial impediment to movement of debris over the ground surface. Where runout zones intersect with forestry, it is assumed that debris would stall within the first zone encountering a forest coupe.

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

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

Following identification of runout zones, additional analysis has been undertaken to approximate this effect. The analysis assumes a source volume based on the source footprint (if *not* a track), or if a track section, then the track length x 50 m. This source footprint is multiplied by the average peat depth in the source zone (from the peat depth model) to calculate a volume, and this volume is then distributed over the full runout pathway (i.e. mobilised volume / runout area) to generate an average thickness of deposit.

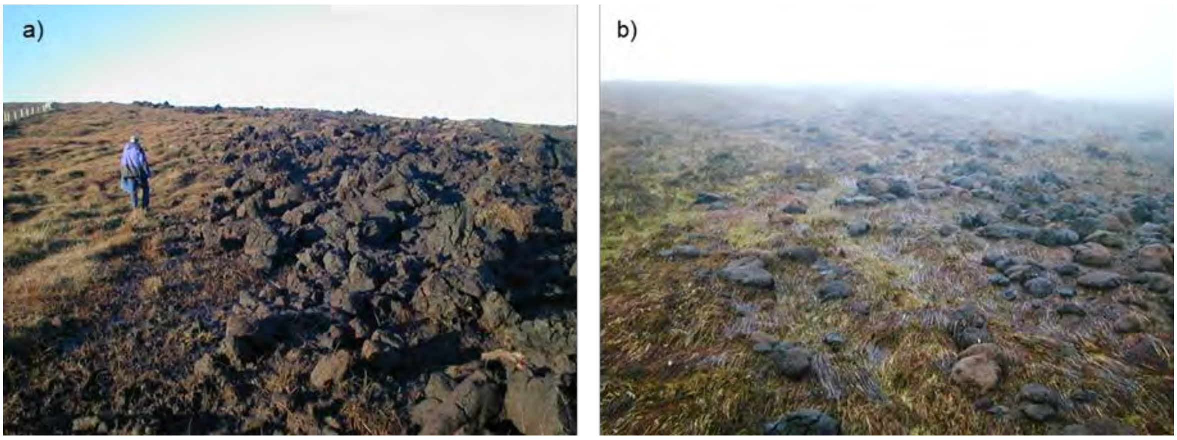


Plate 5.2 Examples of landslide runout (Dooncarton, Co. Mayo): a) blocky debris mid-slope, b) abraded and rolled blocks in lower slope

As the runout length and area increases, the volume thins, in keeping with observed peat landslide deposits. Where deposits fall below 0.2 m in thickness, it is assumed that runout will stall due to the roughness of surface vegetation relative to the thickness of landslide material. If the thickness is calculated to be 0.2 m or less in the zone adjoining a watercourse, then it is judged that the runout will stall prior to reaching it or be negligible in volume on entry and there will be no significant impact on that watercourse (even if a landslide occurs).

Plate 5.3 shows a schematic of the full runout approach to assessing consequences.

.

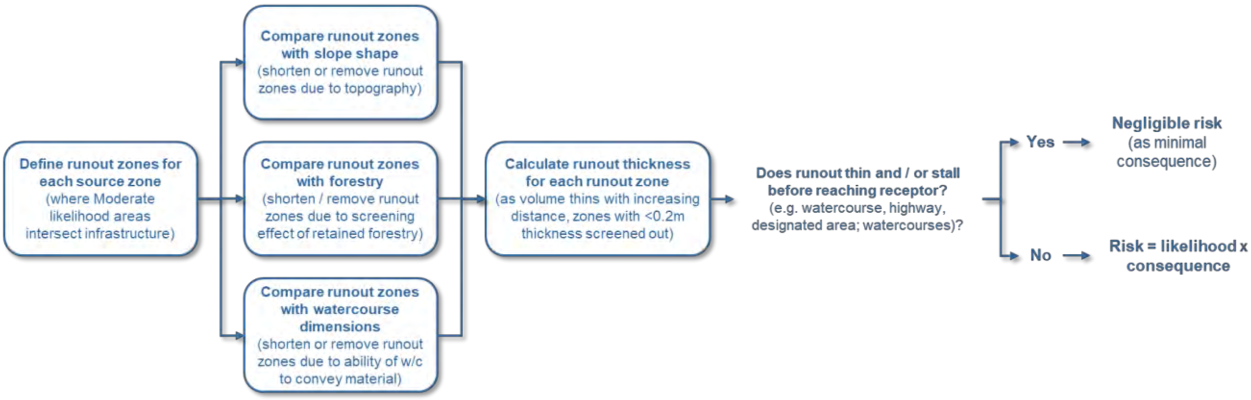


Plate 5.3 Runout approach to assessing consequences

5.3.6. Results of runout analysis

All 14 source locations have the potential for runout to reach named watercourses, with watercourses located within 500 m in all case:

- **Source zone 1 (track to Turbine 1):** upper reaches of Appin Burn.
- **Source zone 2 (track to Turbine 3):** upper reaches of Appin Burn.
- **Source zone 3 (secondary crane hardstanding at Turbine 3):** upper reaches of Appin Burn.
- **Source zone 4 (turning head at Turbine 3):** upper reaches of Appin Burn.
- **Source zone 5 (track from summit towards substation):** Magmallach Burn.

- **Source zone 6 (track from summit towards substation):** upper reaches of Magmallach Burn.
- **Source zone 7 (track from summit towards substation):** no runout assigned due to orientation of source zone directly downslope.
- **Source zone 8 (track to Turbine 9):** upper reaches of Magmallach Burn.
- **Source zone 9 (main hardstanding at Turbine 8):** upper reaches of Magmallach Burn.
- **Source zone 10 (T-junction adjacent to Turbine 8):** upper reaches of Magmallach Burn.
- **Source zone 11 (track to Turbine 8):** upper reaches of minor tributary within Dun Cleuch.
- **Source zone 12 (track to Turbine 8):** upper reaches of unnamed tributary within Dun Cleuch.
- **Source zone 13 (track to Turbine 7):** upper reaches of unnamed tributary within Shiel Cleuch.
- **Source zone 14 (hardstanding at Turbine 9):** upper reaches of Magmallach Burn.

However, due to the presence of forestry coupes between their source zones and respective watercourse receptors, all of the runout zones are limited by forestry acting as a roughness constraint between the source zone and primary receptor. In addition to passage of debris being restricted by intact forest (new or old) or rough terrain associated with felling, source volumes are sufficiently small that runout from source zones 1, 3, 4, 5, 8, 9, 10, 13 and 15 would thin to below 0.2 m in depth within the first 100 m of runout. Runout from source zones 5 and 13 would not reach the existing forestry tracks below them for the same reasons.

5.4. Calculated Risk

Risk levels have been calculated as a product of likelihood and consequence and are shown on **Figure 6.4.11** for each runout pathway. Each runout zone is colour coded to match the risk rankings shown on **Plate 5.1**. For each zone, the score for the most sensitive environmental receptor has been chosen for the risk calculation (i.e. a conservative approach). Where runout becomes constrained by forestry or depth, the runout zone is shown as hashed fill instead of solid fill, indicating that debris is not expected to advance beyond a treeline or beyond the end of the uppermost hashed zone.

Figure 6.4.11 indicates that risks are calculated to be “Low” to “Negligible” across the Site. No source locations have a “Medium” or “High” calculated risk.

Based on the calculated risks shown on **Figure 6.4.11** site-wide good practice measures should be sufficient to manage and mitigate any construction induced instability risks. This is considered in Section 6 below.

6. RISK MITIGATION

6.1. Overview

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

Risks may be mitigated by:

i. Post-consent site specific review of the ground conditions contributing to Moderate likelihoods which may result in a reduced likelihood, and in turn, further reduction in risk.

ii. Precautionary construction measures – including use of monitoring, good practice and a geotechnical risk register relevant to all locations.

Based on the analysis presented in this report, risks are calculated to be “Low” or “Negligible” across the site, and site-specific mitigation is not required to reduce risks pre-consent. **Sections 6.2** to **6.4** provide information on good practice pre-construction, during construction and post-construction (i.e. during operation).

6.2. Good Practice Prior to Construction

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

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

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

6.3. Good Practice During Construction

The following good practice should be undertaken during construction:

For excavations:

- Use of appropriate supporting structures around peat excavations (e.g. for turbines, crane pads and compounds) to prevent collapse and the development of tension cracks.

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

For cut tracks:

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

For floating tracks:

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

For storage of peat and for restoration activities:

- Ensure stored peat is not located upslope of working areas or adjacent to drains or watercourses.
- Undertake site specific stability analysis for all areas of peat storage (if on sloping ground) to ensure the likelihood of destabilisation of underlying peat is minimised.
- Where possible, avoid storing peat on slope gradients >3° and preferably store on ground with neutral slopes and natural downslope barriers to peat movement; if steeper slopes are required, construct temporary retaining structures.
- Monitor effects of wetting / re-wetting stored peat on surrounding peat areas, and prevent water build up on the upslope side of peat mounds.
- Undertake regular monitoring of emplaced peat in restoration areas to identify evidence of creep or pressure on retaining structures (dams and berms).

- Maximise the interval between material deliveries over newly constructed tracks that are still observed to be within the primary consolidation phase.

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

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

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

6.4. Good Practice Post-Construction

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

- Ponding on the upslope side of infrastructure sites and on the upslope side of access tracks.
- Changes in the character of peat drainage within a 50 m buffer strip of tracks and infrastructure (e.g. upwelling within the peat surface upslope of tracks, sudden changes in drainage behaviour downslope of tracks).
- Blockage or underperformance of the installed site drainage system.
- Slippage or creep of stored peat deposits.
- Development of tension cracks, compression features, bulging or quaking bog anywhere in a 50 m corridor surrounding the site of any construction activities or site works.

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

REFERENCES

The Anglo-Celt (2021) Hillwalker captures aftermath of landslide. https://www.anglocelt.ie/2021/07/22/hillwalker-captures-aftermath-of-landslide/ accessed 23/07/2021

BBC (2014) Torrential rain leads to landslides in County Antrim. https://www.bbc.co.uk/news/uk-northern-ireland-28637481 accessed 19/07/2018

BBC (2018) Glenelly Valley landslides were 'one-in-3,000 year event'. https://www.bbc.co.uk/news/uk-northern-ireland-43166964 accessed 19/07/2018

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

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

Boylan N and Long M (2014) Evaluation of peat strength for stability assessments. Geotechnical Engineering, 167, pp422-430

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

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

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

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

Cullen C (2011) Peat stability – minimising risks by design. Presentation at SEAI Wind Energy Conference 2011, 45p

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

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

Evans MG & Warburton J (2007) Geomorphology of Upland Peat: Erosion, Form and Landscape Change, Blackwell Publishing, 262p

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

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

Flaherty R (2016) Man dies in suspected landslide at wind farm in Co Sligo. Irish Times, 13/12/2013, https://www.irishtimes.com/news/crime-and-law/man-dies-in-suspected-landslide-at-wind-farm-in-co-sligo-1.2903750, accessed 19/07/2018

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

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

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

Huat BBK, Prasad A, Asadi A and Kazemian S (2014) Geotechnics of organic soils and peat. Balkema, 269p

Irish News (2016) Major landslide sees 4,000 tonnes of bog close popular Galway tourist route. https://www.independent.ie/irish-news/major-landslide-sees-4000-tonnes-of-bog-close-popular-galway-tourist-route-34830435.html accessed 19/07/2018

Irish Mirror (2020) Photos show massive mudslides in Leitrim after heavy flooding. https://www.irishmirror.ie/news/irish-news/mudslides-drumkeeran-leitrim-flooding-photos-22281581 accessed 01/09/2021

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

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

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

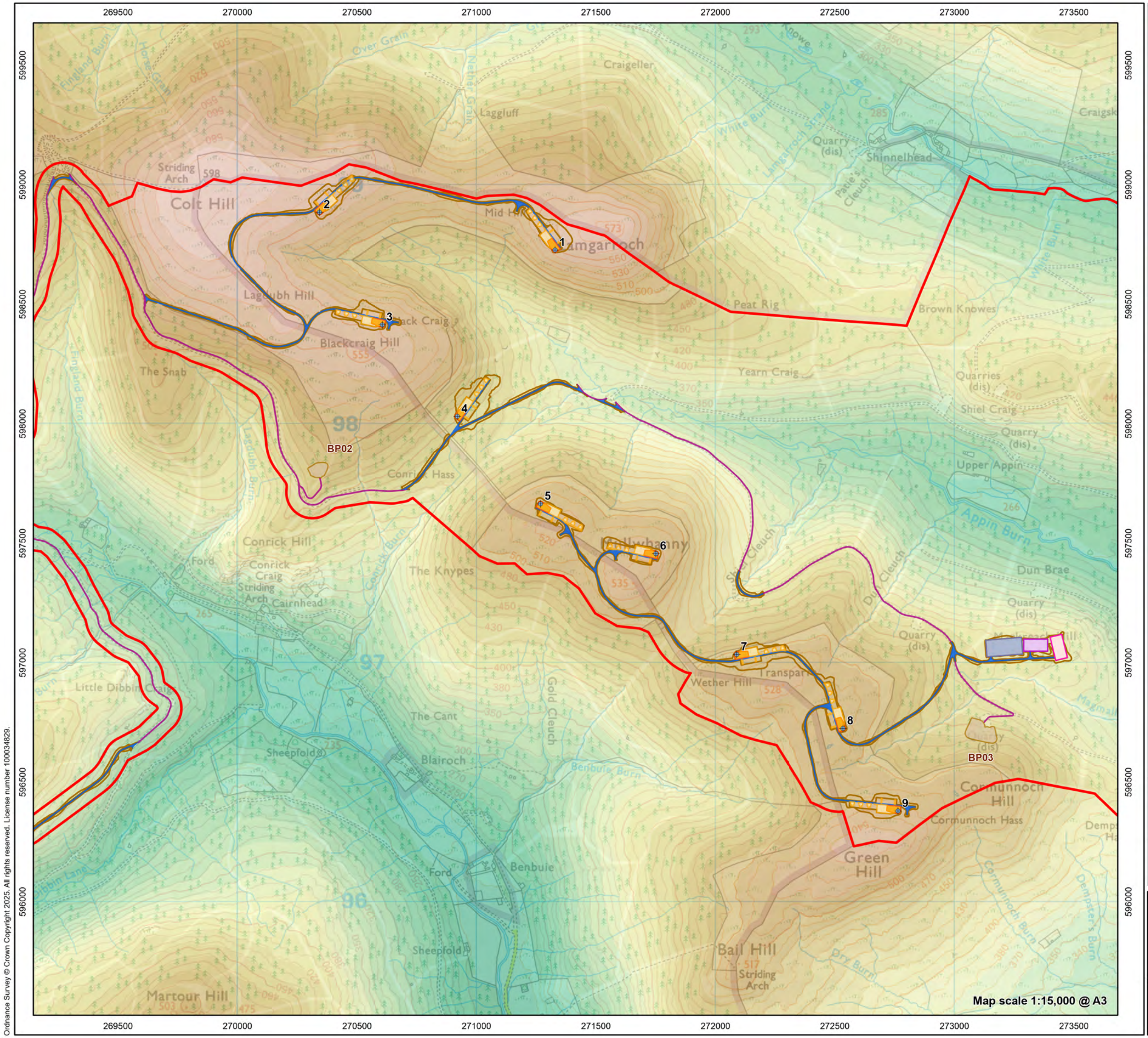
Mills AJ (2002) Peat slides: Morphology, Mechanisms and Recovery, unpublished PhD thesis, University of Durham

Scottish Government (2017) Peat Landslide Hazard and Risk Assessments, Best Practice Guide for Proposed Electricity Generation Developments (Second Edition). Scottish Government, 84p

The Shetland Times (2015) Mid Kame landslip on proposed windfarm site. http://www.shetlandtimes.co.uk/2015/10/30/mid-kame-landslip-on-proposed-windfarm-site accessed 19/07/2018

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

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



Statkraft

N

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks

Elevation [m]

- 201 - 220
- 221 - 240
- 241 - 260
- 261 - 280
- 281 - 300
- 301 - 320
- 321 - 340
- 341 - 360
- 361 - 380
- 381 - 400
- 401 - 420
- 421 - 440
- 441 - 460
- 461 - 480
- 481 - 500
- 501 - 520
- 521 - 540
- 541 - 560
- 561 - 580
- 581 - 600

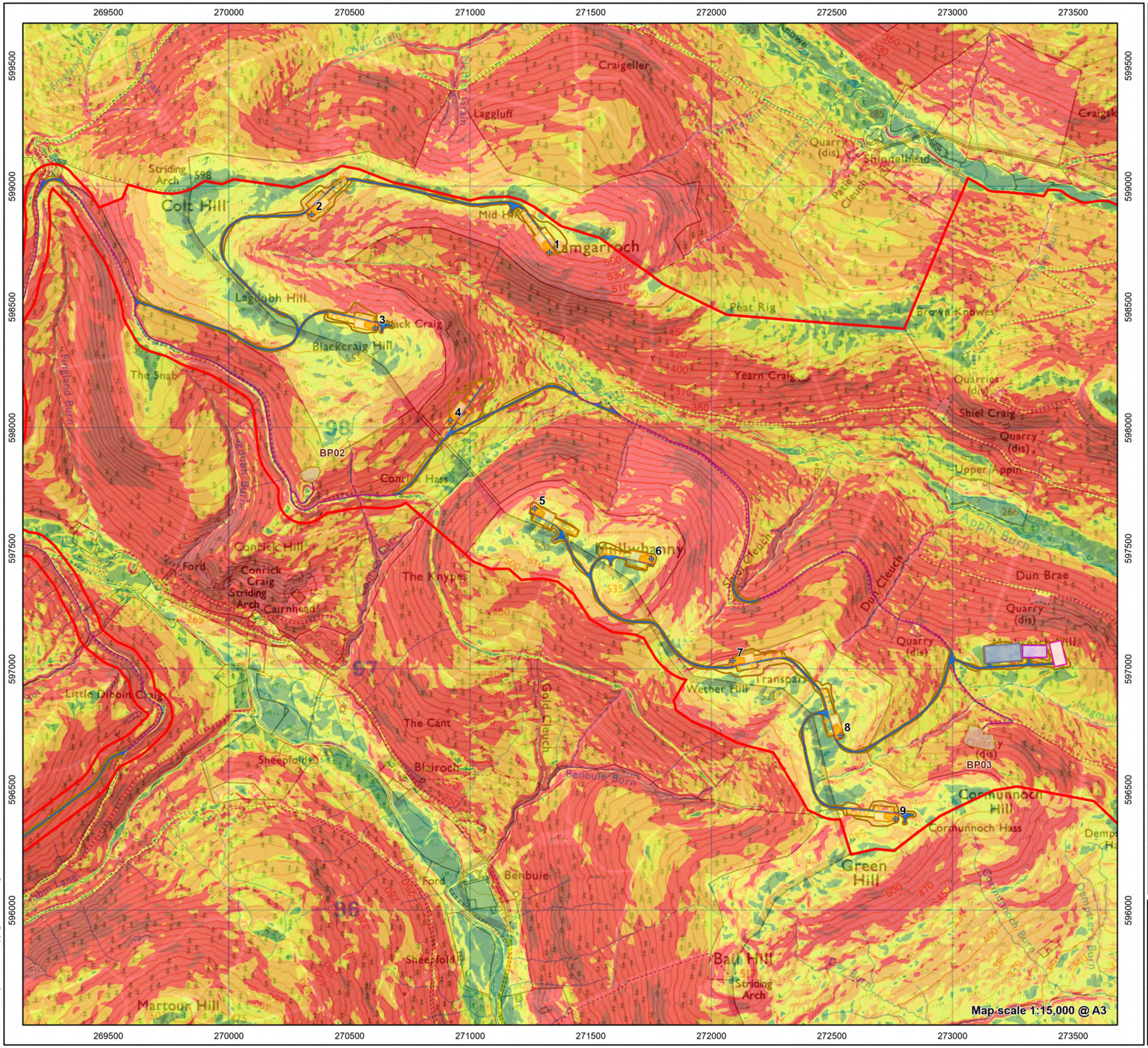
0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01

Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.1 Elevation

Appin Wind Farm
EIA Report



Statkraft

N

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks

Slope [°]

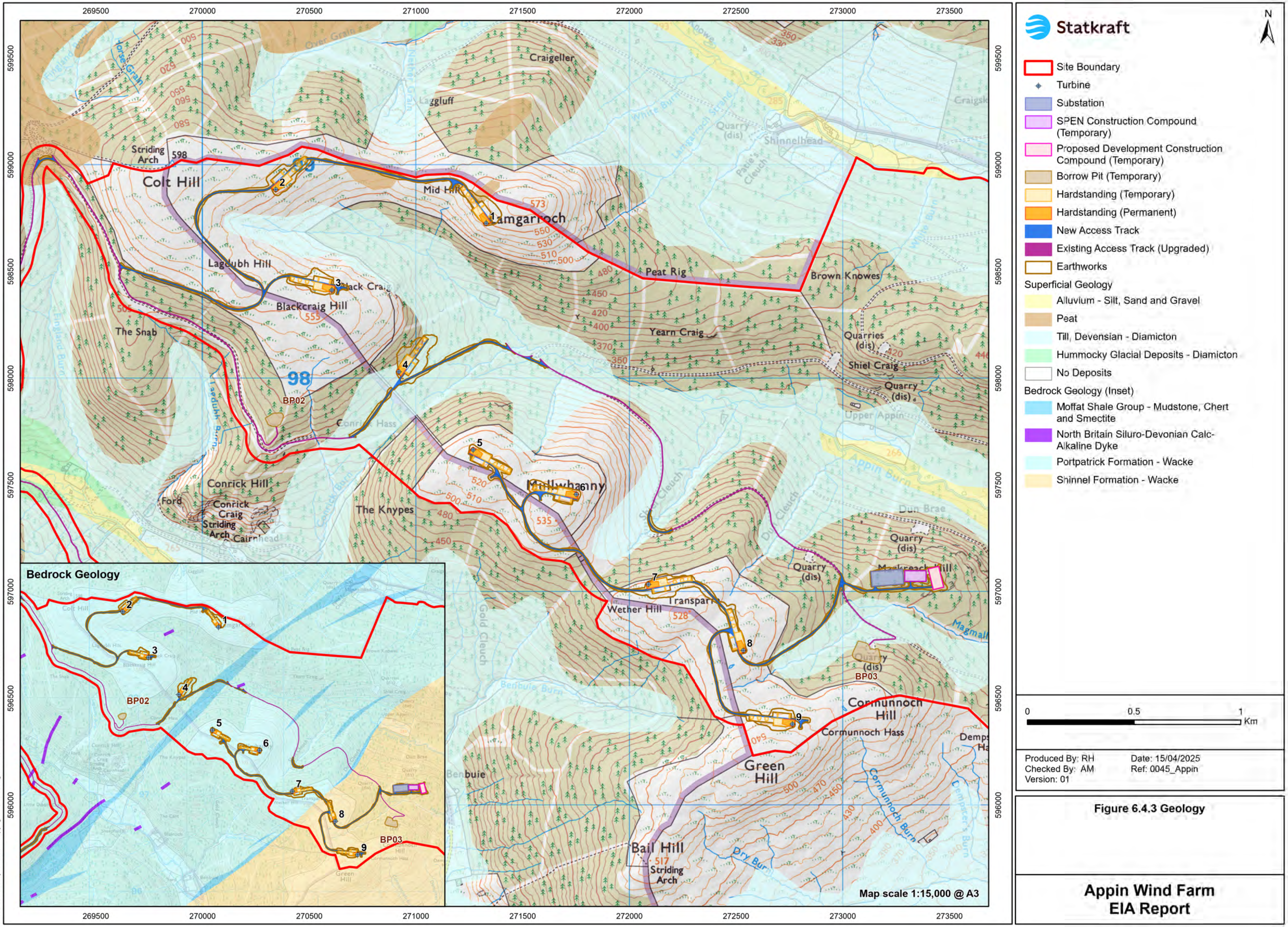
- 0.0 - 2.5
- 2.5 - 5.0
- 5.0 - 7.5
- 7.50 - 10
- 10.0 - 15.0
- 15.0 - 25.0
- > 25.0

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.2 Slope

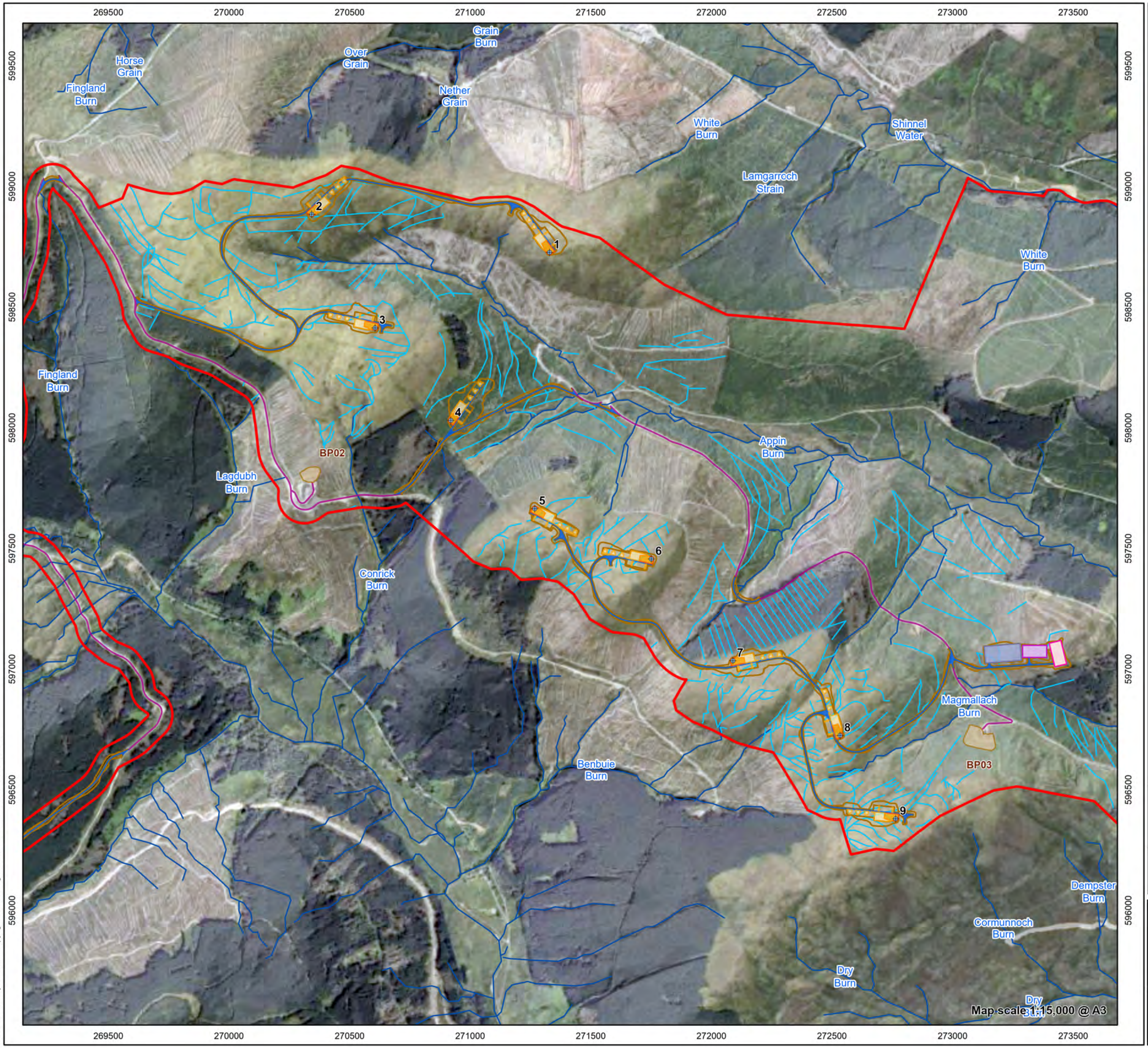
Appin Wind Farm EIA Report



Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.3 Geology

Appin Wind Farm EIA Report



Statkraft

N

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks

Hydrology

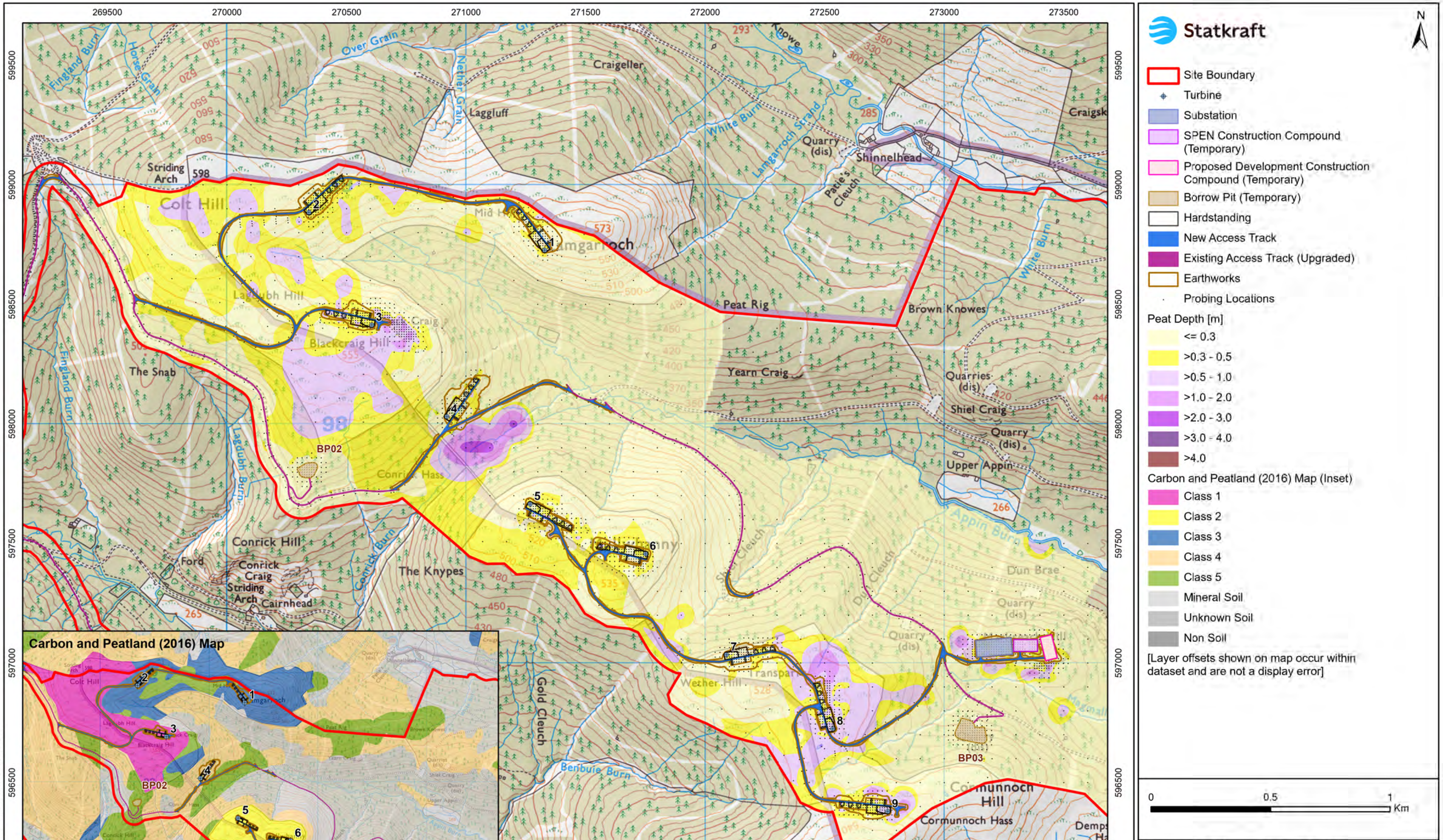
- Drains
- Watercourses

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.4 Hydrology

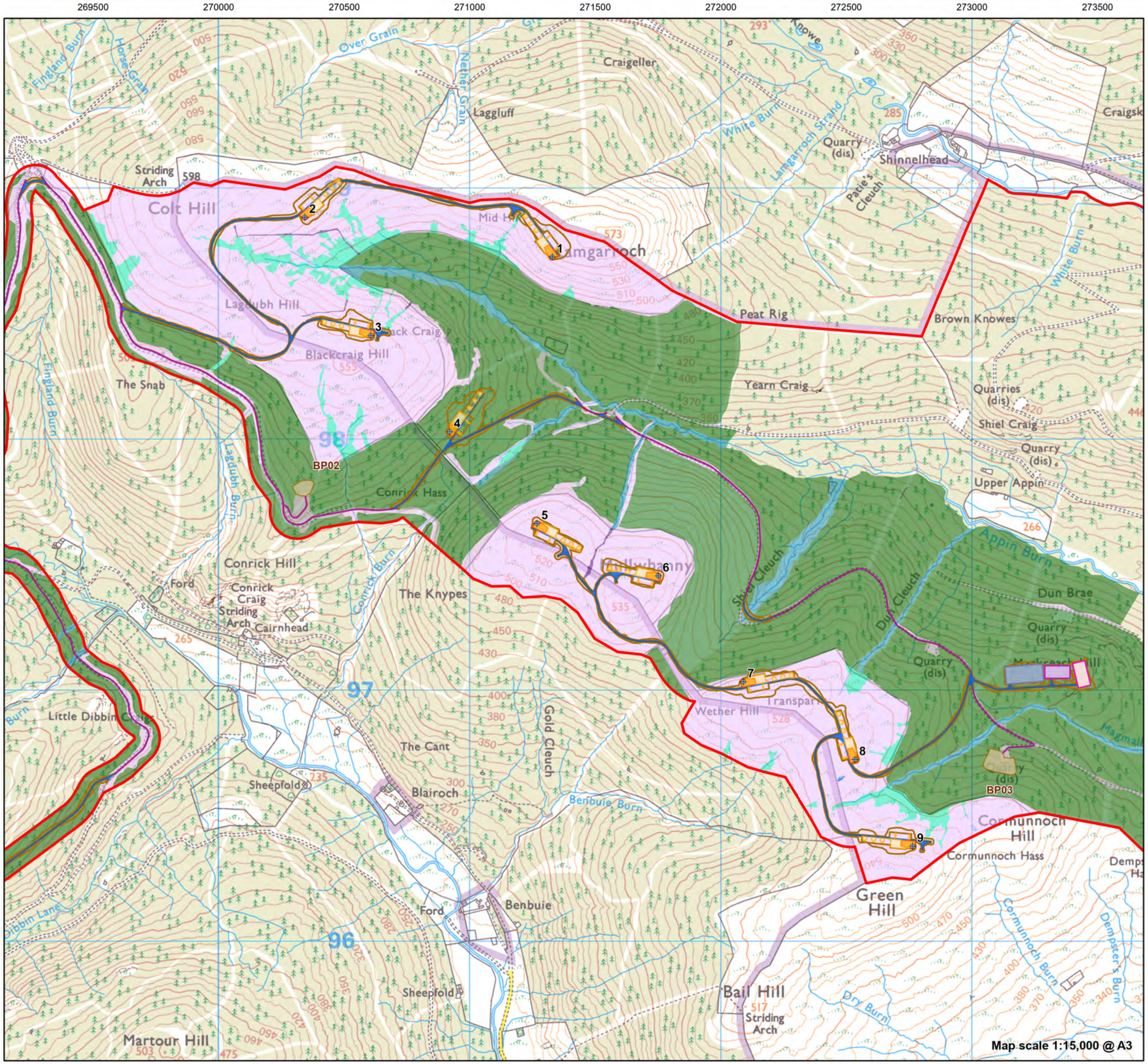
Appin Wind Farm EIA Report



Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.5 Peat Depth

Appin Wind Farm
EIA Report



Statkraft

N

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks

Geomorphology and Land Use

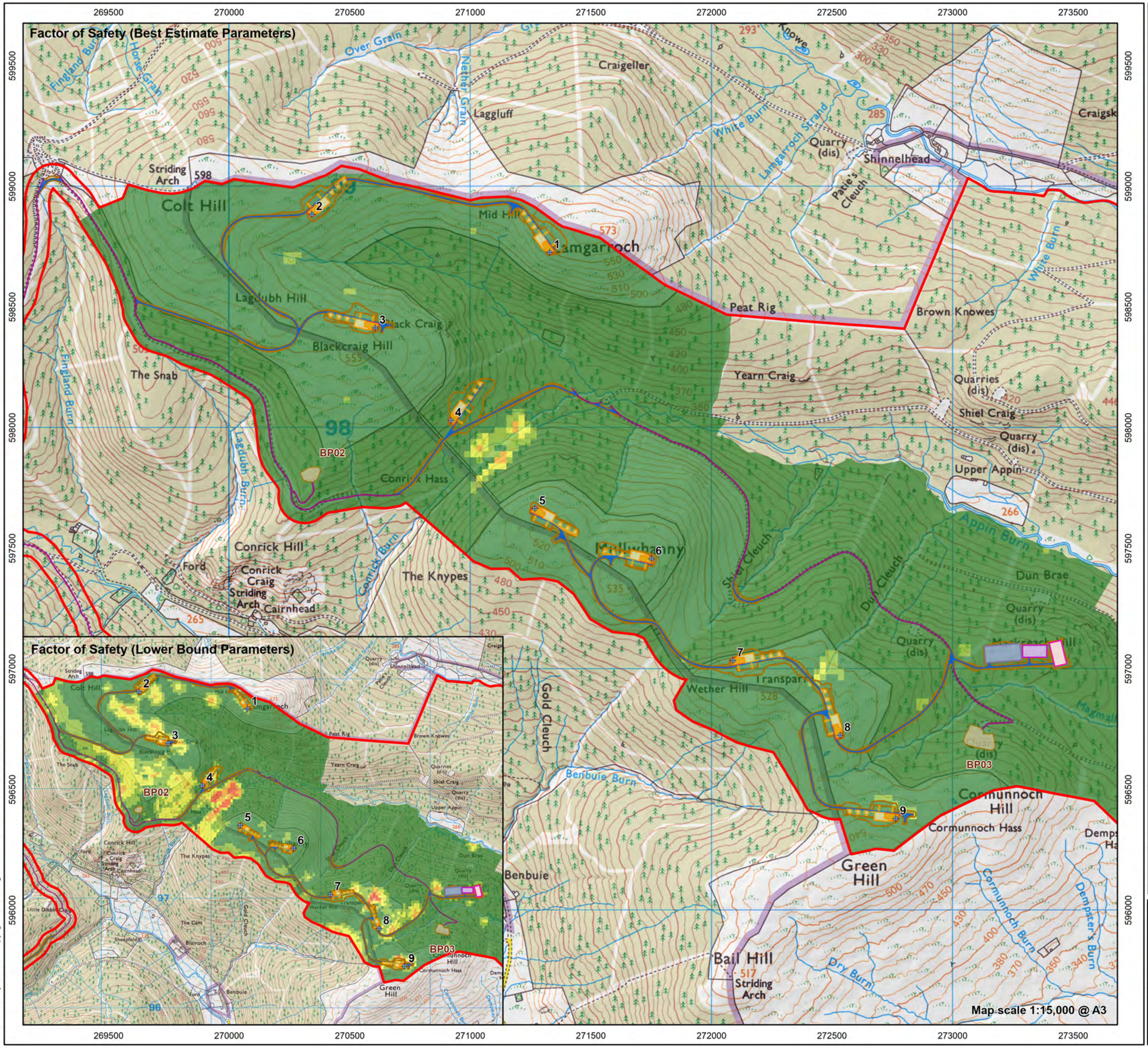
- Flush
- Forestry
- Gully
- Planar peat
- Pool
- Quarry
- Valley side

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.6 Geomorphology and Land Use

Appin Wind Farm
EIA Report



Statkraft

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks

Factor of Safety

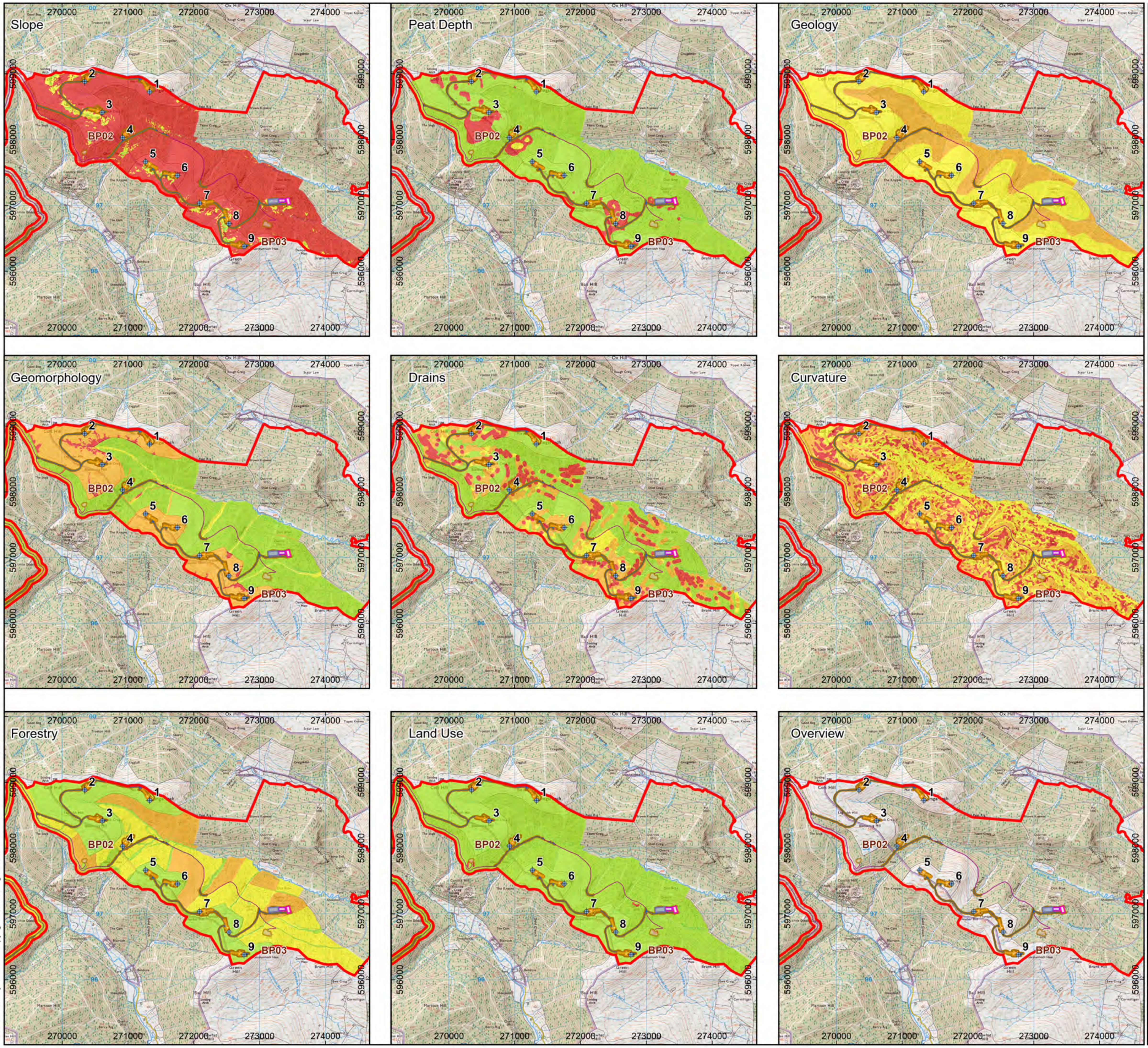
- < 1.00 "Unstable"
- 1.01 - 1.40 "Marginally Stable"
- 1.41 - 2.00 "Stable"
- 2.01 - 3.00 "Stable"
- > 3.01 "Stable"
- No Calculation

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.7 Factor of Safety

Appin Wind Farm
EIA Report



Statkraft

N

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks

Contributory Factor Score

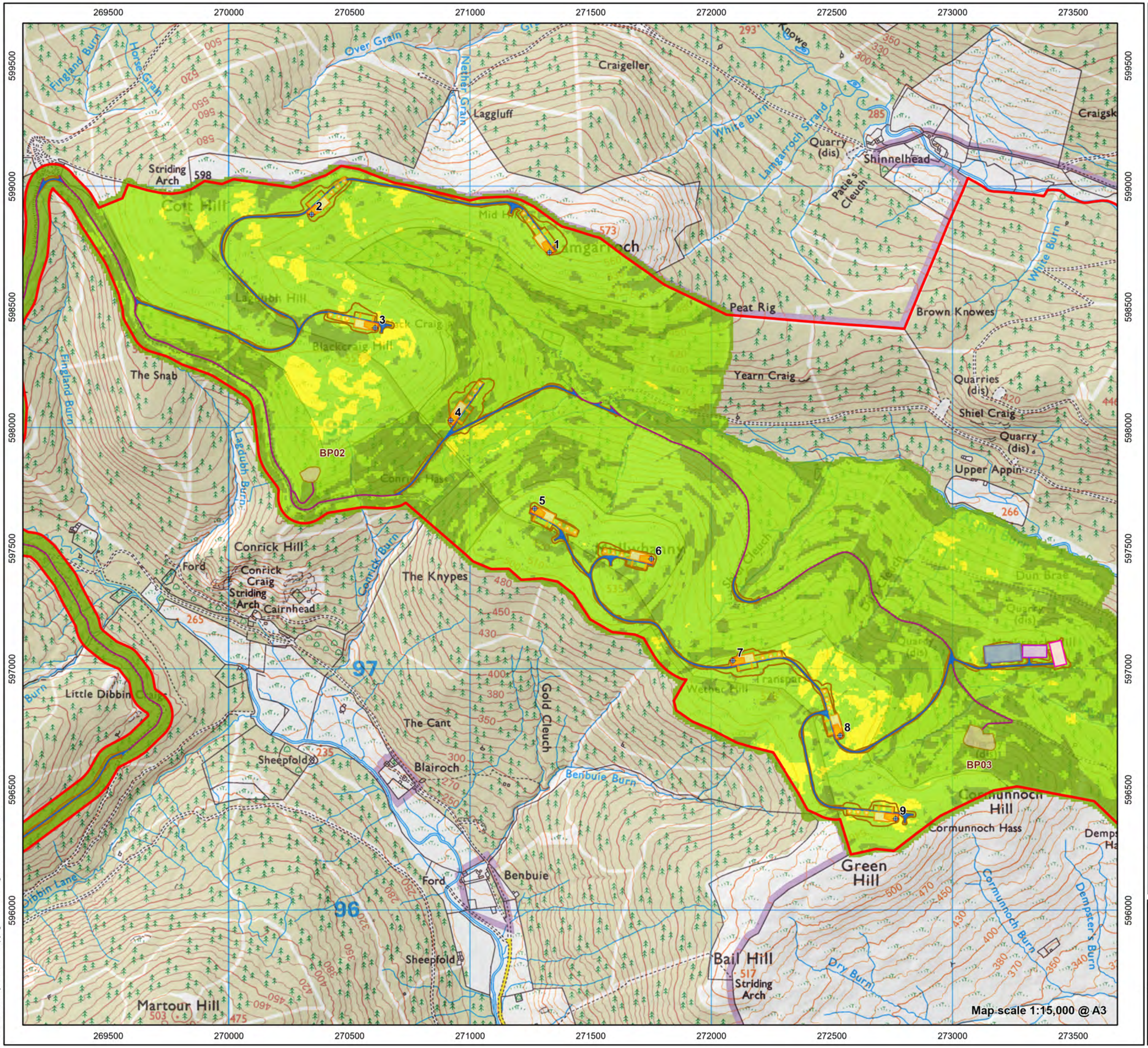
- 0
- 1
- 2
- 3

0 0.5 1 2 3 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.8 Contributory Factors

Appin Wind Farm
EIA Report



Statkraft

N

Legend	
Site Boundary	
Turbine	
Substation	
SPEN Construction Compound (Temporary)	
Proposed Development Construction Compound (Temporary)	
Borrow Pit (Temporary)	
Hardstanding (Temporary)	
Hardstanding (Permanent)	
New Access Track	
Existing Access Track (Upgraded)	
Earthworks	

Landslide Likelihood

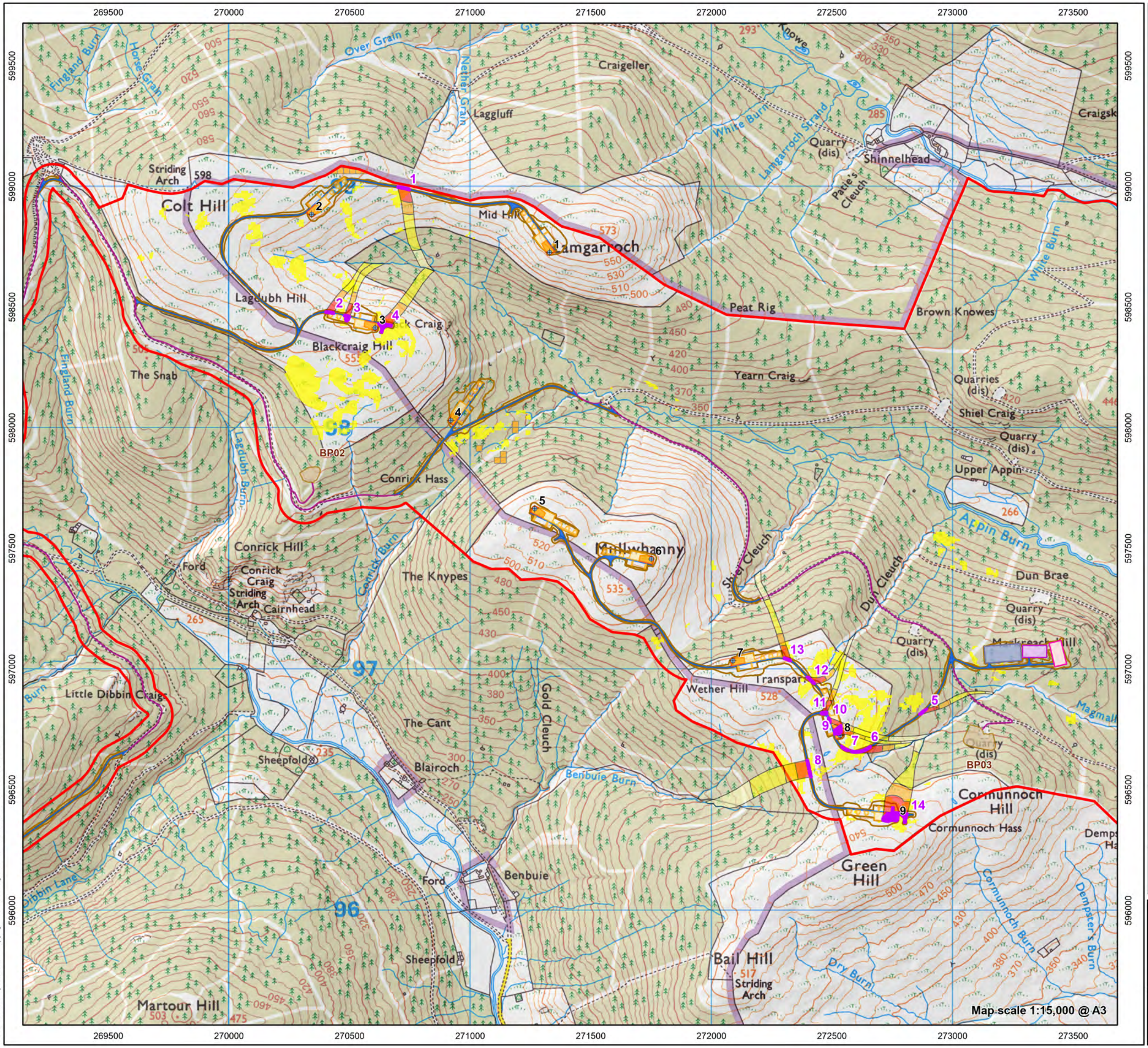
- Very Low
- Low
- Moderate
- High (none calculated)
- Very High (none calculated)

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.9 Landslide Likelihood

Appin Wind Farm EIA Report



Statkraft

N

Site Boundary
Turbine
Substation
SPEN Construction Compound (Temporary)
Proposed Development Construction Compound (Temporary)
Borrow Pit (Temporary)
Hardstanding (Temporary)
Hardstanding (Permanent)
New Access Track
Existing Access Track (Upgraded)
Earthworks
Source Zones

Runout Zones
Distance [m]
50
100
250
500

Factor of Safety
>1.0 - 1.4 (Marginally Stable)

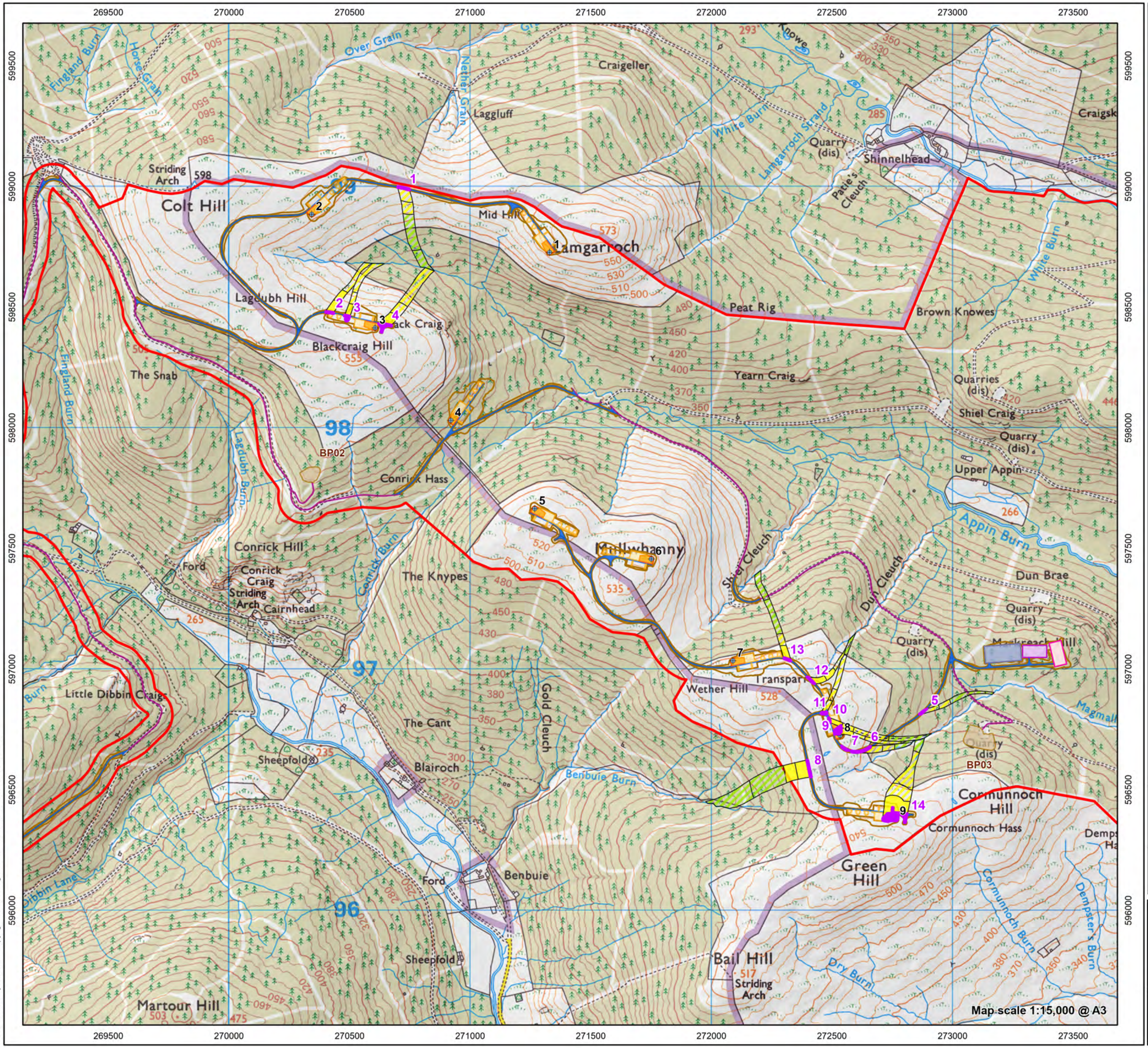
Landslide Likelihood
Moderate
High (none calculated)
Very High (none calculated)

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.10 Source and Runout Zones

Appin Wind Farm EIA Report



Statkraft

N

- Site Boundary
- Turbine
- Substation
- SPEN Construction Compound (Temporary)
- Proposed Development Construction Compound (Temporary)
- Borrow Pit (Temporary)
- Hardstanding (Temporary)
- Hardstanding (Permanent)
- New Access Track
- Existing Access Track (Upgraded)
- Earthworks
- Source Zones

Calculated Risk
- Low
- Low (Limited)
- Negligible
- Negligible (Limited)

0 0.5 1 Km

Produced By: RH
Checked By: AM
Version: 01
Date: 15/04/2025
Ref: 0045_Appin

Figure 6.4.11 Calculated Risk

Appin Wind Farm EIA Report