Appendix 10.5

Preliminary Peat Landslide Risk Assessment

Contents

Tables

Annexes

1 Introduction

1.1.1 In support of **Chapter 10** (**Volume 1**) of the Design Manual for Roads and Bridges (DMRB) Stage 3 Environmental Impact Assessment (EIA) report, this technical appendix presents a Preliminary Peat Landslide Risk Assessment for Project 7 – Glen Garry to Dalwhinnie of the A9 Dualling Programme, hereafter referred to as the Proposed Scheme.

1.1.2 The purpose of the appendix is to present a review of available information from desk studies, field surveys, walkovers and ground investigations (GI), characterise the study area conditions and peat characteristics in relation to peat instability hazard and undertake a preliminary peatslide risk assessment to identify areas of the Proposed Scheme likely to be affected. Based on the results, strategies for risk mitigation are provided with recommendations on risk management plans.

1.1.3 The risk assessment has been undertaken using both quantitative and qualitative methods. The quantitative approach has used a standard stability model supported by site-specific data or published literature values on peat properties. The qualitative analysis has then been based on the geomorphological and hydrogeological factors that contribute to peat slide hazard and their distribution across the study area. Conclusions are drawn based on the results of both.

1.1.4 The information presented herein supports the impacts assessed in **Chapter 10** (**Volume 1**) and has been prepared utilising available information as described in **Appendix 10.1** (**Volume 2**). This and other relevant aspects of the DMRB Stage 3 EIA should therefore be referred to as necessary.

2 Peat Landslide Risk Assessment

2.1 Importance

2.1.1 Blanket bog is the most widespread peatland type in Scotland. It is particularly common in the uplands and therefore likely to be affected by development. However, raised bogs, intermediate bogs and fens are also sometimes affected. Each of these habitats are of high value for nature conservation due to their rarity and vulnerability to the direct and indirect effects of construction and climate change.

2.1.2 Peat landslides are a characteristic landscape, most commonly in response to intense rainfall events in peat uplands but may also occur as a response to activities such as peat cutting for fuel or construction. Failures usually initiate by sliding and may develop into peaty flows of debris before becoming incorporated in stream channels as peaty debris floods. The importance of understanding peat landslide mechanisms and the potential for their occurrence has increased as pressure for development sites in peatlands has risen.

2.1.3 Infrastructure within and adjacent to peatlands may be affected by, or cause, peat landslides and other infrastructure, such as road networks, flood defences, drainage, power lines, residential areas and farmland, may also be affected by peat landslides occurring during construction. Terrestrial habitats in the path of a peat landslide may be damaged by ground displacement or by burial by debris, and aquatic habitats may be damaged by input of landslide debris to watercourses (McCahon *et al.*, 1987). In addition, the displacement and break-up of peaty debris after a landslide event will ultimately result in small scale depletion of the terrestrial carbon store (Nayak *et al.*, 2008).

2.1.4 Peat landslides have occurred close to (but not necessarily in association with) other road developments and road infrastructure, such as the multiple Channerwick peat landslides in

Shetland in 2003, which led to the temporary closure of the A970 (Halcrow, 2009) and at Llyn Ogwen North Wales; where a peatslide of $250m^3$ obstructed the London to Holyhead (A5) trunk road in 2005 (Nichol *et al*., 2007). Assessment of peat landslide hazard is therefore an important element of EIA for infrastructure in peatland environments.

2.2 Scope and Guidance

2.2.1 As the Proposed Scheme passes through areas of peat, its presence and potential impacts are a key environmental and engineering consideration. *'Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments Guidance'* (Scottish Executive, 2006) recommends that a peat landslide risk assessment be undertaken where peat is present in the development area and where there may be existing or induced peat stability risks. Further details on the nature of peat instability that were used to inform this stability assessment are provided in **Annex 10.5.1**.

2.2.2 In the absence of specific guidance on approaches to peat landslide risk assessment for road infrastructure; the assessment for the Proposed Scheme has been undertaken in accordance with relevant aspects of '*Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments'* (Scottish Executive, 2006), which includes:

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

2.2.3 In doing so, desk-based assessment and peat probing, sampling and walkover surveys and GI have been undertaken as described in **Appendix 10.1** (**Volume 2**). The available findings from these have been used to generate a detailed map of peat and peaty soil depth for the Proposed Scheme as shown in **Drawing 10.17** to **10.23** (**Volume 3**), and then used to undertake the hazard and risk analysis. It should be noted that the resulting hazard and risk assessment is only valid for the extent of the data collected and no inferences should be made about the levels of peat landslide hazard and risk beyond the extent of the resulting analyses.

2.3 Quantitative Analysis

2.3.1 In the first instance, a preliminary quantitative analysis of stability using the infinite slope model to determine a Factor of Safety (FoS) has been undertaken, as follows:

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

Where:

- F is the Factor of Safety (greater than 1.4 is stable, between 1 and 1.4 is considered marginally stable and less than 1 is unstable)
- *c′* is the effective cohesion of the soil (where 'soil' is an engineering term for unconsolidated material, peat in this case)
- γ is the unit weight of the soil
- *h* is the height of the water table relative to the depth of soil
- γ_w is the unit weight of water
- *z* is the vertical depth of the soil
- β is the slope angle
- φ' is the effective angle of internal friction of the soil

2.3.2 Site-specific geotechnical input parameters for peat soils within and surrounding the Proposed Scheme are limited to unit weight at the time of writing. The quantitative analysis therefore additionally relies on data from published literature and other recent assessments for effective cohesion and angle of internal friction parameters. Sensitivity testing has been applied to assess the impact of varying those parameters where site-specific data is unavailable, to provide a guide to the likely stability of peat slopes. The parameters chosen are nevertheless considered conservative and likely to overstate the hazard, rather than understate it.

2.3.3 Due to the special geotechnical characteristics of peat, which make modelling it as a geotechnical 'soil' problematic, difficulties in geotechnical testing of peat and limited site-specific data; results of the quantitative analysis should be treated cautiously and only be used as an indication of the relative stability across the study area, under varying geotechnical conditions. The results of the stability modelling have however, also been compared to semi-quantitative analysis to identify areas where the two methods generated similar results, and where they diverge.

2.3.4 It is also important to note that the quantitative analysis best replicates stability on slopes where the failure surface is parallel to the slope surface, and the length of the failure is long in comparison to its width. It is therefore most suited to assessment of peat slide (as opposed to bog burst) hazard. In should also be noted that the quantitative analysis equations can generate spurious results (negative FoS'), where low unit weights and low slope angles are present, particularly where peat depth is great and the simulated water table is high.

2.4 Semi-quantitative Analysis

2.4.1 Given the limitations on the preliminary quantitative assessment, this has been followed by a semi-quantitative analysis for the Proposed Scheme, which is described in detail within **Annex 10.5.2**. This also allows the study area conditions relevant to peat landside risk to be considered.

2.4.2 There are various semi-quantitative approaches to hazard and risk assessment in relation to peat landslide, with examples including the *'Peatslide Hazard Rating System'* (Nichol, 2006) and '*Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments'* (Scottish Executive, 2006). Both approaches have merits and their methodologies share consideration of key contributors to instability risk; including peat depth, slope angle, geomorphological features, presence of water on the slope and indicators of previous instability.

2.4.3 The Scottish Executive (2006) method has been adopted for the Proposed Scheme, because:

- It lends itself better to using GIS to interpolate levels of hazard between points. On a scheme of this size, where design changes occur and new data becomes available throughout the assessment process (not necessarily at the same points data has previously been captured), this allows more flexibility in a project
- It also allows a greater consideration of the consequences of peat instability occurring, but at the same time, still requires separate evaluation of the peat instability hazard
- It is compatible with recognised approaches to semi-quantitative assessment of risk, such as those put forward in Lee and Jones (2014), as it allows the risk to be assessed as:

Risk = Probability of a hazard occurring x Adverse consequence

2.4.4 There are also varying approaches which can be used to assess the consequences of a peat landslide occurring. Such consequences could include:

- The potential for harm to life during construction
- The potential economic costs associated with lost infrastructure, or delay in programme
- The potential for reputational loss associated with occurrence of a peat landslide in association with construction activities
- The potential for permanent, irreparable damage to the peat resource (both carbon stock and habitat) associated with mobilisation (and ultimately loss) of peat in a landslide
- The potential for ecological damage to watercourses subject to inundation by peat debris.

2.4.5 In this assessment, the severity of a consequence has been qualitatively assigned, giving the highest severity to a consequence which could result in a loss of life (such as a peat landslide event hitting a railway line and derailing a train, or hitting a building that is likely to be occupied), with lower severity consequences assigned to economic and ecological receptors.

2.4.6 For this assessment, the severity of a peat landslide event reduces as receptors become more distant. This is for two reasons, as follows:

- Firstly, without specific data on the distance a specific landslide is likely to travel from its source, the likelihood of an impact on that receptor will reduce the further it is from the event source (Mills, 2002); because the mass movement may come to a stop before reaching the receptor, and the mass movement is more likely to miss the receptor if it has greater opportunity to take a different path to that containing the receptor.
- Secondly, the magnitude of the consequence (i.e. the severity of the damage caused) if a hit occurs is likely to reduce the further the receptor is from the landslide. This is not an infallible rule, as mass movements may gather additional material or water, particularly if channelised, and increase their destructive power away from their sources. However, the channelisation of an event and the potential for watercourses to transfer material significant distances from landslide events is accounted for by their relatively high consequence severity.

2.4.7 To incorporate the consequence severities into the assessment, the severity of the consequence of a peat landslide occurring from a particular location has been given both a qualitative descriptor and a value from one to five, to represent the relative severity of the consequence. The final risk score has then been established by multiplying the final value derived from the contributory factors for hazard by the value derived for risk, giving an indication of the degree of risk associated with a peat landslide occurring from a particular point within or near to the Proposed Scheme.

3 Peat Landslide Potential

3.1 Study Area

3.1.1 As shown in **Drawings 10.1**, **10.4** and **10.5** (**Volume 3**), BGS mapping indicates two areas of peat within the study area – located adjacent to the west of the existing A9 at approximate chainage (ch.) 6,200 and ch. 7,600 near Balsporran and Drumochter, while published soil mapping shows complex peaty soils with peat throughout.

3.1.2 While no direct indicators of peat landslide occurrence in the vicinity of the Proposed Scheme have been identified through desk study, surveys or GI; various evidence suggests there is the potential for first-time peat instability failures to occur. This includes the presence of slopes ranging from <1° to 40° in the catchments through which the Proposed Scheme passes, and the presence of indirect indicators of potential instability such as small water bodies (bog pools), springs, flushes and cross-slope artificial drainage.

3.1.3 There are also a range of sensitive receptors in the Proposed Scheme corridor, including the existing A9 carriageway, watercourses and water bodies that provide habitat for sensitive species, the Highland Main Line railway, residential properties, geodiversity features and other existing infrastructure. These receptors mean that should a peat landslide occur, the hazard could have adverse consequences via injury or economic impact, and there would be a risk.

3.1.4 Beyond the immediate vicinity of the Proposed Scheme, there are also several areas where peat is recorded in BGS mapping as noted above, or through recognition in aerial and satellite imagery (Google Earth). The nature of the topography and the fact that many of these areas are upslope or upstream, presents an additional limited possibility that peat landslides occurring well beyond the Proposed Scheme may impact upon it.

3.2 Land Use

3.2.1 Different land uses and human activities can affect the stability of peat; including cutting, burning, grazing and construction activity. Afforestation is a particular concern because it can increase the mass of the peat slope as trees grow in it; and can also reduce the volumes of water held in the peat, which increases the potential for desiccation crack formation which can create a direct route for water to reach peat-substrate contact, locally increasing pore water pressures during rainfall events.

3.2.2 Plantation woodland is present and proposed at points within the permanent and temporary works boundaries, adjacent to the Proposed Scheme, often in the form of a winter resilience shelter belt to reduce the risks of drifting snow. There is therefore the potential for forestry to impact on the peat landslide hazard.

3.3 Geomorphology and Hydrology

3.3.1 The distribution of geomorphological and hydrological features of note across the study area are shown in **Drawings 10.5.5** and **10.5.6** (**Volume 3**). The general nature of the peatland present is blanket bog (in some instances degraded) on the hillslopes, often occurring in mosaic with wet heath environments. Areas of blanket bog, fen and transition mire occur in the valley bottoms. At the northernmost extent of the Proposed Scheme, there is also a small area located to the west of the existing A9 which has been interpreted to be raised bog, albeit with a low dome perched on a low terrace above the River Truim floodplain. This indicates a range of conditions which may give rise to peat landsliding; in the form of flows, slides or bog bursts.

3.3.2 No direct indicators of peat instability, such as tension cracks, compression ridges or revegetating failure scars have been observed within the study area based on aerial and satellite imagery (Google Earth). Several areas of possible revegetated peat slides or bog burst scars were identified and then inspected during site walkover visits (CFJV, 2016 and 2017), but no geomorphological indicators of on-going peat instability were observed.

3.3.3 Nevertheless, there are several geomorphological and hydrological features which indicate the potential for indirect peat instability within the study area, including bog pools, flushes and springs. No other features that might be related to an elevated level of potential peat instability, such as peat haggs, gullies or pipes, were identified through review of satellite or aerial imagery (Google Earth), site surveys or walkovers.

3.4 Slope

3.4.1 The existing slopes across the Proposed Scheme and catchments upslope are shown in **Drawings 10.5.1** and **10.5.2** (**Volume 3**). Slopes within the permanent and temporary works boundaries range from <1° to approximately 75°, but with the majority being less than 26° and practically all being less than 40°. Nonetheless, this represents the full range of slope angles in which peat instability most commonly occurs.

3.4.2 Beyond the boundaries, slopes fall within similar ranges albeit with a greater prevalence of steeper slopes, as elevation increases rapidly to the east. The presence of slopes within this range indicates the presence of slope angles which could contribute to peat landslide occurrence.

3.5 Peat Conditions

3.5.1 The peat depth model generated for the Proposed Scheme is based on a substantial dataset acquired in the field, as described in **Appendix 10.1** (**Volume 2**), and is considered to be of sufficient quality to underpin the hazard and risk assessment. The interpolation methods used have been shown to be suitable for this kind of assessment in other peat-related assessments (RWE, 2013). However, as with any interpolated model there remains the possibility that actual peat depths may be different to the modelled depth in areas between real field data points.

3.5.2 Although approximately 7% of the permanent and temporary works boundaries of the Proposed Scheme do not presently have peat depth data; desk-based information and ecological surveys indicate that peat greater than 0.50m is unlikely to be present in these areas. It is therefore considered that the peat depth model is a fair representation of the Proposed Scheme extents. However, localised variations could exist, particularly where the topography of the substrate geology is complex; for example, in areas of hummocky glacial sediment that may include kettle holes and elevated kame terraces.

Peat Depth

3.5.3 The peat depth model indicates that recorded peat and peaty soil depth across the areas investigated varies from 0.00m to 8.40m, as illustrated in **Drawings 10.17** to **10.23** (**Volume 3**). Most areas (approximately 65%) in the permanent and temporary works boundaries are underlain by peaty soil or topsoil less than 0.50m thickness, and approximately 10% is underlain by no peat. Shallow peat, between 0.50 and 1.00m in thickness, is present in approximately 12% of the areas and only 6% is underlain by peat greater than 1.00m in thickness.

3.5.4 When compared to **Table 1** in **Annex 10.5.2** the range of depths present indicate that there is the possibility for a range of failure types which could occur within the Proposed Scheme and its surroundings.

Peat Characteristics

3.5.5 The true depth of the acrotelm is often difficult to determine in the field, and may be deeper than suggested by indicators such as living mosses and poorly decomposed plant material. However, where identifiable from available investigation and survey information and against the von Post Scale (Hobbs, 1986); the acrotelm across the Proposed Scheme has been recorded to predominantly comprise thin (0.05m to 0.30m) undecomposed to moderately decomposed (H1 to H5) layers and variably distinct semi-natural vegetation. Some decomposition ratings are higher than would be expected for acrotelm that is healthy, and actively peat-forming; but thicker (0.10 to 0.40m) layers showing no or only very slight decomposition (H1 to H3) and distinct vegetation were observed in larger blanket bog, mire and swamp areas to the west of the Proposed Scheme through the Pass of Drumochter and beyond the Highland Main Line railway.

3.5.6 The acrotelm is underlain by catotelm layers varying between spongy, plastic and firm condition. The type of peats also varied from reddish to dark brown and black fibrous to pseudo-fibrous, and amorphous peat; with highly variable root and wood content. Pseudo-fibrous peat was typically described as H4 to H5 on the von Post scale (slight to moderate decomposition), fibrous peat was typically H3 to H6 (very slight to moderate decomposition), while more amorphous peat or amorphous content within it was described as H7 to H8 (strong to very strong decomposition).

3.5.7 Evidence of H9 to H10 peat (nearly complete to completely decomposed) has been observed at locations in blanket bog, transition mire and swamp to the west of the Proposed Scheme in the Pass of Drumochter and beyond the Highland Main Line railway. These correspond to the deepest peat areas encountered, and were observed at depths greater than 5.00m within the profiles.

3.5.8 Estimated water contents in samples have covered the full range of possible values on the Von Post scale, from B1 (dry) to B5 (very high).

Laboratory Testing

3.5.9 Laboratory testing of peaty soil and peat samples for all, or a selection of, organic matter, loss on ignition, moisture content, bulk density, pH, total carbon and total organic carbon from selected trial pit/ borehole and peat core locations was undertaken as part of GI works for the Proposed Scheme, as described in **Chapter 10** (**Volume 1**) and **Appendix 10.1** (**Volume 2**).

3.5.10 Peaty soil/ topsoil samples were recovered across a range of habitat types, including dry and wet heath, grassland transitions and mire/ heath mosaics. The testing results indicate bulk densities for these ranging between 0.2 and 0.78 Mg/m^3, dry densities between 0.08 and 0.27 Mg/m^3 and moisture contents of between 8 and 1481%. Results for total organic carbon ranged from 0.3 to 48%, from 0.3 to 57% for total carbon content and from 16 to 92.6% for mass loss on ignition. pH values ranged from 3 to 6.7.

3.5.11 Shallow peat samples were recovered across a similar range of habitat types, with bulk densities ranging between 0.57 and 0.98 Mg/m^3, dry densities ranging from 0.08 to 0.48 Mg/m^3 and moisture contents of between 64 and 994%. Results for total organic carbon ranged from 3.4 to 54%, from 4.8 to 62% for total carbon content and from 26.8 to 96.6% for mass loss on ignition. pH values ranged from 3.3 to 5.7.

3.5.12 Within deeper peat profiles in areas of mire, wet heath, mosaics of these or swamp, bulk densities ranged between 0.2 and 0.94 Mg/m^3, dry densities ranged from 0.02 to 0.44 Mg/m^3 and moisture contents were recorded between 106 and 4912%. Results for total organic carbon varied between 1 and 63%, between 2.2 and 64% for total carbon content and from 12.3 to 98.6% for mass loss on ignition. pH values ranged from 3.2 to 6.3.

3.6 Substrate

3.6.1 Available sampling and GI information indicates that the nature of the substrate throughout the study area is predominantly granular. As shown in **Drawing 10.1** (**Volume 3**), BGS mapping indicates that superficial deposits are widespread and predominantly granular, including till, hummocky and planar glacial sands and gravels, and alluvial fans. A limited number of trial pits, boreholes and peat coring locations did identify the presence of clay or silt substrate beneath the peat profiles. However, in all instances, these had notable amounts of sand as a secondary component and are therefore likely to be fine-grained tills.

3.6.2 Poorly draining fine-grained till and impermeable bedrock are most likely to adversely influence peat stability, with more granular and freely draining material and permeable bedrock benefiting it. Given this potential influence, substrate as a contributory factor to peat landsliding has been incorporated into the assessment.

3.7 Peat Instability

Potential Occurrence of Peat Instability Upslope and Upstream

3.7.2 The primary focus of the hazard assessment is the Proposed Scheme and its immediate environs. This is driven by, 1) the much higher likelihood of a peat landslide being generated by construction work associated with the Proposed Scheme and its immediate vicinity, 2) the higher likelihood that a peat landslide occurring near to the Proposed Scheme will impact upon it, and 3) the practical limit to the extent of detailed data that can be acquired and considered (within budget and time constraints) for the Proposed Scheme. However, the nature of slopes, the presence of peat and other instability features in areas upslope and upstream of the Proposed Scheme indicate that it may be affected by instability occurring some distance away.

Expected Nature of the Peat Landslide Hazard

3.7.3 Based on the available data, site observations and the nature of the hazard in relation to peat landsliding (particularly the topography, peat depths and slope angles); it is anticipated that the potential for peat instability is low (given a lack of features directly indicative of this). However, there is potential for peat instability in the form of peat slides (where relatively shallow peat slides at or just below its contact with the substrate), or a bog burst (more likely to occur in deeper peats through the break-out and evacuation of a semi-liquid basal mass). Consequently, both are taken into consideration in the risk assessment.

Potential Receptors of Peat Landslide Hazard

3.7.4 The Proposed Scheme is located within an existing transport corridor, passes through the Cairngorms National Park and is located within, adjacent to or nearby areas of environmental designation – including the River Spey Special Area of Conservation (SAC) (River Truim) and the Drumochter Hills Special Protection Area (SPA), SAC and Site of Special Scientific Interest (SSSI) (including the Allt Dubhaig Geological Conservation Review (GCR) site). Other land uses in the vicinity include the Highland Main Line railway, the National Cycle Network Route 7 (NCN7), local residential properties and the Scottish and Southern Energy (SSE) Beauly-Denny Power Line.

3.7.5 There is therefore the potential for peatslide hazards to have real consequences on various receptors, which are further detailed within **Annex 10.5.2**.

4 Quantitative Analysis

4.1 Approach

4.1.1 A preliminary quantitative analysis of stability across the Proposed Scheme has been undertaken using GIS, to inform the overall hazard and risk assessment. To do so, an infinite slope analysis has been used to calculate a FoS for the slope, in accordance with '*Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments'* (Scottish Executive, 2006). This analysis requires the following input parameters:

- Unit weight of soil (kN/m^3)
- Unit weight of water (kN/m^3)
- Effective cohesion *c'* (kPa)
- Effective angle of internal friction *φ'* (°)
- Slope angle (°)
- Vertical depth of peat (m)
- The vertical height of the water table above the slide plane (taken to be the base of the peat), expressed as fraction of the soil thickness above the slide plane.

4.1.2 Two broad scenarios have been tested in the analysis, a 'worst case' and a 'moderately conservative case'. The values selected for each parameter, and the source of those values are summarised in **Table 1**.

Table 1: Quantitative Stability Analysis Parameters

Parameter	'Worst case'	'Moderately conservative case'
Unit weight of soil (kN/m^3)	14.52 (measured maximum)	8.76 (measured average)
Unit weight of water (kN/m^3)	9.81	9.81
Effective cohesion c' (kPa)	2 (Halcrow, 2012)	5 (Mouchel, 2013)
Effective angle of internal friction φ' (°)	5 (Mouchel, 2013)	20 (Halcrow, 2012) (lowest value in scenario testing, less than φ' in most fibrous peats)
Slope angle (°)	Location-specific (Engineering Digital Terrain Model (DTM))	Location-specific (Engineering DTM)
Vertical depth of peat (m)	Location-specific (Peat depth model)	Location-specific (Peat depth model)

4.1.3 The scenarios tested have also been varied according to groundwater conditions; with each scenario having the following values applied for height of the water table relative to the depth of the peat profile:

- 0.80 – to represent dryer than normal conditions where the water depth is at the base of the acrotelm.
- 1.00 – to represent 'normal' conditions where the water table is at or near ground level.
- 1.50 – to represent an extreme and unlikely scenario where the piezometric surface exceeds the ground level due to high water pressures at the base of the peat, such as in a peat pipe.

4.1.4 The scenarios have been further varied to represent the application of the following surcharges:

- In the 'worst case' scenario, a surcharge of 14.52 kPa (based on the site maximum unit weight of peat) has been applied to represent an overburden of peat stored to a height of 1.00m.
- In the 'moderately conservative' scenario, a surcharge of 10 kPa has been applied to represent overburden from construction plant, in accordance with BS6031:2009 *'Code of Practice for Earthworks'* (BSI, 2009).

4.1.5 Taken together, these variations produce twelve possible scenarios that have been tested, as summarised in **Table 2**.

Table 2: Quantitative Stability Analysis Scenarios

	Low Water Table	Normal Water Table	High Water Table
Moderately conservative (no surcharge)	**Scenario 1** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m3) = 8.76 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 2** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m3) = 8.76 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 3** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m3) = 8.76 Water table = 1.50 Surcharge (kPa) = 0
Moderately conservative (with surcharge)	**Scenario 4** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m3) = 8.76 Water table = 0.80 Surcharge (kPa) = 10	**Scenario 5** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m3) = 8.76 Water table = 1.00 Surcharge (kPa) = 10	**Scenario 6** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m3) = 8.76 Water table = 1.50 Surcharge (kPa) = 10
Worst case (no surcharge)	**Scenario 7** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m3) = 14.52 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 8** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m3) = 14.52 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 9** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m3) = 14.52 Water table = 1.50 Surcharge (kPa) = 0
Worst case (with surcharge)	**Scenario 10** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m3) = 14.52 Water table = 0.80 Surcharge (kPa) = 14.52	**Scenario 11** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m3) = 8.76 Water table = 1.00 Surcharge (kPa) = 14.52	**Scenario 12** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m3) = 14.52 Water table = 1.50 Surcharge (kPa) = 14.52

4.2 Scenario-Modelling Results

4.2.1 To assess the results of the quantitative stability analysis, the resulting GIS outputs for each scenario have been categorised into the following zones:

- Factor of Safety less than 1.00, indicating instability.
- Factor of Safety between 1.00 and 1.40, indicating marginal stability.
- Factor of Safety greater than 1.40, indicating stability.

4.2.2 The outcomes of the analysis are summarised in the following sections.

Scenario 1: Moderately Conservative Case, Low Water Table, No surcharge

4.2.3 The majority of the site is indicated to be stable in this scenario, but with several areas of limited extent which are indicated to be unstable. These are likely to be 'false positives' however, where the interpolated peat depth model indicates very deep peat (greater than 3.00m) to be present, but where in reality, this space is occupied by an existing embankment or cutting slope, or is on a natural slope which delimits the edge of a basin, where the presence of deep peat on the slope is an artefact of the interpolated peat model.

4.2.4 Areas of notable extent likely to be false positives include:

- ch. 3,650, immediately adjacent to the existing A9.
- Between ch. 3,900 and ch. 4,100.
- Between ch. 4,000 and ch. 4,100 in the footprint of a proposed compensatory flood storage area.
- Between ch. 4,250 and ch. 4,300, west of the existing A9.
- ch. 4,450, approximately 55m west of the existing A9.
- Between ch. 6,050 and ch. 6,150, immediately east of the existing A9.
- Between ch. 7,150 and ch. 7,250, immediately west of the existing A9.
- Between ch. 9,250 and ch. 9,300, immediately east of the existing A9.

4.2.5 Other areas indicated to be unstable in this scenario and less likely to be 'false positives' of instability are found on steeper slopes (greater than 20°), where the peat depth model indicates peat greater than 1.50m in depth. Each of these areas are of limited spatial extent, as follows:

- ch. 50, approximately 20m upslope of the existing A9 to the east and adjacent to a proposed cutting slope for Dalnaspidal Junction.
- ch. 450, approximately 55m of the existing A9 to the east, on the right bank of Allt Coire Mhic-Sith and adjacent to the footprint for Dalnaspidal Junction.
- ch. 600, approximately 70m upslope of the existing A9 to the east, falling within the footprint of the cutting slopes for Dalnaspidal Junction.
- Between ch. 1,050 and ch. 1,100, immediately downslope of the existing A9 to the west, falling within the footprint of a proposed embankment for the mainline.
- ch. 2,300 to ch. 2,400, approximately 30m upslope of the existing A9 to the east, there are several areas of marginal stability falling within an existing cutting.
- Between ch. 6,050 and ch. 6,150, immediately west of the existing A9, there are areas at the boundary of natural slopes and the existing road footprint, where survey information indicates relatively deep peat (2.00 to 3.00m in depth) to be present and slopes are greater than 20°. These areas fall within the footprint of the proposed mainline and access track.
- Between ch. 6,050 and ch. 6,150, immediately east of the existing A9, there is an area of relatively deep peat situated on a slope greater than 20° that falls within the footprint of a proposed access track.
- Approximately 165m north of ch. 9,741, immediately east of the Drumochter Estate access track. This may be a 'false positive' generated by the slope around the construction pad for a Beauly-Denny pylon base, coinciding with an interpolated area of deep peat. A real data point is present within the footprint of this pad so is highlighted here rather than specifically as a false positive. However, the data point pre-dates construction of the pad and therefore the data point on which the interpolation relies may no longer be valid, if all peat in the area has been removed for construction.

Scenario 2: Moderately Conservative Case, Normal Water Table, No Surcharge

4.2.6 In general terms, most areas classed as unstable in this scenario mirror those in Scenario 1, although their extent increases slightly. Notable areas of potential instability, or where the extent has significantly expanded, include between ch. 3,900 and ch. 4,100 – where the areas identified as being potentially unstable under Scenario 1 now extend further between the proposed mainline and a proposed compensatory flood storage area. These are predominantly outwith the permanent and temporary works boundaries, but are notably across the extent of a watercourse diversion immediately west of the proposed mainline at ch. 3,950.

Scenario 3: Moderately Conservative Case, High Water Table, No Surcharge

4.2.7 Many of the areas identified as potentially unstable in Scenario 3 are comparable to those identified in Scenario 2, but with slightly greater spatial extents. New areas of potential instability, and where the extent of potentially unstable areas has expanded substantially, include the following:

- ch. 200, approximately 60m south west and downslope of the existing A9. This is an area of peat interpolated to be deeper than 1.00m on a natural slope exceeding 20° and coincides with the toe of a proposed embankment and two cut-off drains.
- ch. 450, approximately 190m east of the existing A9 adjacent to the Allt Coire Mhic-Sith, downslope of the proposed works and outside of the permanent and temporary works areas.
- ch. 400 at proposed SuDS 004, there is an area of peat deeper than 1.50m on slopes of between 5° and 10° within the footprint of the proposed basin.
- ch. 500, approximately 60m north east and upslope of the existing A9 within the footprint of Dalnaspidal Junction.
- Between ch. 550 and ch. 600, approximately 130m north east and upslope of the existing A9 within the footprint of Dalnaspidal Junction.
- Between ch. 650 and ch. 750, approximately 80m north east of the existing A9, immediately outside the permanent and temporary works boundaries on slopes between 8 and 15° in peat greater than 1.50m deep.
- Between ch. 1,100 and ch. 1,050, approximately 100m north east and upslope of the existing A9. Small areas of instability are indicated within a larger area of marginal stability. These are approximately 30m from the permanent and temporary works boundaries on slopes of approximately 10° and in peat between 1.00 and 1.50m deep.
- Between ch. 1,050 and ch. 1,000, immediately adjacent and south west of the existing A9. This area is highlighted in Scenario 1, but is of substantially greater extent away from the road across an area identified as greater than 1.00m deep peat, on a slope of approximately 15°.
- ch. 1,200, approximately 45m south east and downslope of the existing A9. This area is very small in extent and coincides with an area of deep peat within the footprint of a proposed cutting for the mainline alignment.
- ch. 1,800, located immediately adjacent to the east of the existing A9. This is a very small area of deeper peat within the extent of the proposed mainline earthworks.
- ch. 2,050, approximately 30m east of the existing A9. This is a very small area of deeper peat, partially within the footprint of the proposed mainline earthworks.
- Between ch. 2,250 and ch. 2,400, approximately 30m east and upslope of the existing A9. This area is highlighted in Scenario 1 as several small pockets of marginal instability. In this scenario, those areas have coalesced and form a more extensive area of potential instability.

- Between ch. 2,550 and ch. 2,650, approximately 100m east and upslope of the existing A9. This area is approximately 50m from the permanent and temporary works boundaries.
- Between ch. 2,950 and ch. 3,000, approximately 65m west and downslope of the existing A9. This is an area of peat greater than 1.00m deep on slopes of approximately 20°, within and adjacent to the permanent and temporary works boundaries.
- Between ch. 3,050 and ch. 4,500, there are extensive areas of deep peat between the existing A9 and the Highland Main Line railway to the west. These all appear as unstable under the conditions modelled in this scenario. However, these are likely to be either generating spurious or extremely unrealistic results, as analysis of the data indicates the infinite slope analysis performs poorly under the conditions found here.
- Between ch. 3,600 and ch. 4,500, several areas of potential instability are indicated on the east side of the carriageway where steep slopes (greater than 20°) and interpolated peat depths greater than 1.00m converge. These fall within the footprint of the proposed mainline earthworks.
- ch. 4,900, immediately west and downslope of the existing A9 on a slope of approximately 7°, where peat depths exceed 2.00m. This area falls within the footprint of the proposed mainline earthworks and a small compensatory flood storage area.
- ch. 5,050, approximately 10m west and downslope of the existing A9 where peat depths are up to 1.00m and slopes are greater than approximately 20°.
- Between ch. 5,900 and ch. 6,200, several areas of potential instability of limited extent occur either side of the existing carriageway, mostly within the proposed mainline earthworks footprint.
- Between ch. 6,450 and ch. 6,650, several areas of potential instability of limited extent are located upslope of the carriageway, most notably at ch. 6,550; where the area of instability falls partially within and above a proposed cutting, and at ch. 6,550, where the area of potential instability occurs approximately 50m from the permanent and temporary works boundaries, due to a combination of slopes between 10 and 20° and peat depths up to 1.50m.
- Between ch. 7,050 and ch. 7,100, there is an area of potential instability approximately 45m west of the existing A9, but which falls outwith the permanent and temporary works boundaries.
- Between ch. 7,150 and ch. 7,250, an extensive area of potential instability is indicated, but which are basins of very deep peat and very low slope angles; where the application of the infinite slope analysis is likely to be generating either spurious or extremely unrealistic results.
- ch. 7,250, within an area of interpolated peat depths up to 1.80m immediately to the west of the existing A9 on a range of slope angles. This area falls wholly within the footprint of the proposed mainline earthworks.
- ch. 7,550, an area of potential instability exists approximately 100m east of the existing A9 coincident with the footprint of a proposed cutting for the Balsporran/ Drumochter Junction north-east loop. This is an area of peat greater than 2.00m deep on low slope angles.
- ch. 7,550, an area of potential instability exists approximately 112m west of the existing A9 adjacent to the River Truim. The north-eastern part of this area coincides with a basin of deep peat and very low slope angles, where application of the infinite slope analysis is not appropriate. However, closer to the river, slope angles are steeper and the potential instability more realistic, albeit only in the extreme conditions indicated by this scenario.

- Between ch. 9,250 and ch. 9,300, a potential instability occurs approximately 120m south east and upslope of the existing A9. This is likely to be a false positive, as the areas indicated as potentially unstable due to steeper slopes in deep peat are actually formed in material generated from construction of the Beauly-Denny Power Line.
- Approximately 165m north of ch. 9,741, immediately east of the Drumochter Estate access track. The area of deep peat around a Beauly-Denny pylon is indicated to be much greater in extent than in Scenario 1 and Scenario 2, beyond the slopes which form the edges of the pad on which the pylon is founded. In this scenario, this is therefore considered to be a potential area of instability rather than a false positive.

4.2.8 The much higher number of areas indicated to be unstable in this scenario, combined with the lack of field evidence for instability, indicate that the parameters used are extremely unlikely. However, they potentially indicate areas where mitigation measures (particularly those which control the application of excess water to slopes) are most important, and areas that are more likely to be vulnerable to instability in very wet conditions.

Scenario 4: Moderately Conservative Case, Low Water Table, With Surcharge

4.2.9 The notable difference between this scenario and Scenario 1 (the equivalent scenario without surcharge) is the substantially increased number and extent of areas of marginal stability and a more limited increase in areas indicated as being unstable. The common element linking the areas, is that they are on steeper slopes – embankments, cuttings, steeper natural hillside slopes and channel (natural and artificial) banks.

4.2.10 Analysis of statistics extracted from the quantitative GIS outputs indicate that the minimum slope angle in which instability occurs in this scenario is 26° and the minimum slope angle on which marginal stability occurs is 18°. Peat depths, the only other variable across the Proposed Scheme in this scenario, show no such threshold depths. As such, the conclusion from this scenario is that the placement of surcharges on embankments, cuttings, steeper natural hillside slopes and channel should be avoided in all weather conditions.

Scenario 5: Moderately Conservative Case, Normal Water Table, With Surcharge

4.2.11 The change in the simulated water table between Scenario 4 and Scenario 5 results in only incremental differences to the extent and severity of the instability areas indicated. Again, no discernible trend in the impact of peat depth is visible and threshold slope angles for instability and marginal stability appear to be 22° and 16°, respectively.

Scenario 6: Moderately Conservative Case, High Water Table, With Surcharge

4.2.12 As with Scenario 4 and Scenario 5, the change in simulated water table between Scenario 5 and Scenario 6 results in only incremental changes in the extent and severity of areas of instability and marginal stability, with areas within those categories being almost exclusively embankments, cuttings, steeper natural hillside slopes and channel banks. No discernible trend in the peat depth threshold is evident, but threshold angles for instability and marginal stability in this scenario are 12° and 9°, respectively.

Scenario 7 to Scenario 12: Worst Case, Variable Water Table, With and Without Surcharge

4.2.13 In each of the worst case scenarios applied, large expanses within and outwith the permanent and temporary works boundaries for the Proposed Scheme are indicated to be unstable, or of marginal stability. Given the lack of evidence of peat instability indicated within the study area, this indicates that the parameters used are unlikely to be realistic. Notwithstanding, the following should be noted:

- There are few instances, even in these unrealistic scenarios where areas with peat depths of <1.00m and slope angles are less than approximately 5° either with or without surcharge in place, where instability is indicated. As such and as a rule of thumb, it is sensible to select locations that meet these criteria for the permanent and temporary storage of materials (including excavated peat) and avoid surcharges on slopes not meeting these criteria wherever possible. This rule of thumb may be useful in planning but should not replace appropriate assessment of the stability of chosen storage locations and earthworks during detailed design.
- The areas of potential instability and marginal instability significantly increase under very high water table conditions, highlighting the importance of monitoring groundwater conditions and having appropriate rules in place to stop working when conditions are particularly wet.

4.2.14 The analysis of the worst case scenarios also indicates that stability will increase with the addition of surcharge in areas of very low slope and very deep peat. However, the infinite slope analysis is known not to behave particularly well in such circumstances and therefore this apparent increase in stability should not be relied upon.

4.3 Summary

4.3.1 In summary, the preliminary quantitative analysis undertaken has limitations on the input parameters. The moderately conservative scenarios modelled are more likely to be realistic, given the more limited extent of areas of instability indicated (which more closely concurs with site observations) but are still likely to overstate the actual levels of hazard.

4.3.2 Numerous areas of potential instability have been identified in the moderately conservative scenarios. Whilst these may be overstated, it is in these areas where the peat instability hazard is most likely greatest and therefore construction should proceed with caution as result.

4.3.3 The analysis also indicates the increasing hazard of peat instability with elevated water tables and therefore reinforces the importance of monitoring groundwater conditions prior to and during construction, with appropriate rules in place to stop work when conditions are particularly wet; as identified and described in **Appendix 10.6** (**Volume 2**).

5 Semi-Quantitative Analysis

5.1 Approach

5.1.1 Given the limitations on the preliminary quantitative assessment, this has been followed with a semi-quantitative approach; which is effectively one of expert judgement regarding the degree of contribution a particular factor makes to the peat landslide risk at a particular location. The application of numerical values to these judgements allows a consistent assessment of hazard, consequence and risk to be undertaken.

5.1.2 The risk calculation moderates the peat instability hazard by the sensitivity of, and proximity to, receptors located in the vicinity of the Proposed Scheme. This can be expressed as:

Risk = Probability of a hazard occurring x Adverse consequence

5.1.3 The evaluation of peat landslide hazard and its contributory factors, the assessment of the consequence of peat landslide hazards occurring, including how this is reduced with increasing distance from the source of instability, and the method for combining hazard and consequence components to derive risk levels for the Proposed Scheme is detailed in **Annex 10.5.2.**

5.1.4 The distribution of contributory factors to peat landslide hazard, overall peat landslide hazard, consequence and risk are also shown in **Drawings 10.5.1** to **10.5.18** (**Volume 3**).

5.2 Hazard

5.2.1 The hazard outcomes are presented as separate sections for peat slides and bog bursts; due to the differing nature of these peat landslide types, the hazard level for each can differ with the same contributory factor values. As such, different areas can be identified as a peat slide hazard to those being identified as a bog burst hazard.

Peat Slide Hazard

5.2.2 **Drawing 10.5.11** (**Volume 3**) shows the peat slide hazard across the study area, which has been assessed as 'Unlikely' or lower for 98% of the area within the temporary and permanent works boundaries. However, there are areas where the peat slide hazard has been assessed as 'Possible' occur throughout the Proposed Scheme, most predominantly towards the south – these tending to be where steeper slopes, peat over 0.50m deep, oblique artificial drainage and forestry are present. The areas of 'Possible' peat slide hazard can be characterised as follows:

- Between ch. 300 and ch. 550 – around Dalnaspidal Junction, particularly to the east of the existing A9 on the right bank of the Allt Coire Mhic-Sith, but also elsewhere within the footprint of the junction and associated infrastructure.
- ch. 700 and ch. 800 – very small areas near proposed watercourse diversion, wholly within the footprint of the proposed works.
- Between ch. 1,200 and ch. 1,250 – very small area near the top of the proposed cutting, approximately 35m west of the existing A9.
- Between ch. 1,600 and ch. 1,750 two small areas parallel to the existing A9, approximately 20m to the east and all within proposed cuttings.
- ch. 1,650 – discontinuous areas west of the existing A9 adjacent to a small drain.
- Between ch. 1,950 and ch. 2,000 – small discontinuous areas approximately 35m east of the existing A9.
- Between ch. 2,050 and ch. 2,100, approximately 15 to 20m east of the existing A9.
- Between ch. 2,200 and 2,900 – small discontinuous areas at varying distance to both sides of the existing A9.
- Between ch. 2,850 and ch. 3,000 – either side of drainage channel approximately 26m west of existing A9.
- Between ch. 3,100 and ch. 3,700 – discontinuous areas to both sides of the existing A9.
- Between ch. 3,900 and ch. 4,150 – extensive area to the west of existing A9. Low slope angles but hazard driven by presence of deep peat and artificial drainage. Track, temporary works and watercourse diversions are proposed in this area. East of existing A9, smaller less continuous areas of 'Probable' level hazard are present.
- Between ch. 4,450 and ch. 4,700 – small, discontinuous areas east of the existing A9 situated beyond or at the end of proposed earthworks.

- Between ch. 5,000 to ch. 6,000 – very small, very discontinuous areas mostly within the footprint of the proposed new carriageway. Occasionally others further upslope to the east of the existing A9.
- Between ch. 6,050 and 6,150 – discontinuous, moderately sized areas associated with gentle slopes and deep peat. Both sides of the existing A9.
- ch. 6,150 to ch. 9,147 – very small, discontinuous areas which only coincide with the earthworks footprints at ch. 6,550 and ch. 7,450 (Balsporran/ Drumochter Junction).

5.2.3 Areas where the peat slide hazard has been assessed as 'Probable' are extremely limited in number and mostly small in extent, but include:

- Between ch. 450 and ch. 500 on the right bank of the Allt Coire Mhic-Sith, where a drainage channel runs through this area.
- Between ch. 3,950 and ch. 4,050, immediately west of the existing A9. These areas are very small in extent and discontinuous at the toe of a proposed embankment.
- Between ch. 6.100 and ch. 6,150 – very small, discontinuous areas within the footprint of the proposed new carriageway.

5.2.4 There are no areas where the peat slide hazard is assessed as being 'Almost Certain'.

Bog Burst Hazard

5.2.5 **Drawing 10.5.12** (**Volume 3**) shows the resulting bog burst hazard across the study area, which has been assessed as 'Unlikely' or lower across 98% of the area within the temporary and permanent works boundaries. However, there are numerous areas where the bog burst hazard has been assessed as 'Possible' – focused principally on areas of peat deeper than 0.50m in the following locations:

- Between ch. 300 and ch. 550 – around the proposed Dalnaspidal Junction, particularly to the east of the existing A9 on the right bank of the Allt Coire Mhic-Sith, but also elsewhere within the footprint of the Junction and associated infrastructure.
- Between ch. 1,600 and ch. 1,650 – approximately 20m east of the existing A9.
- Between ch. 2,300 and ch. 2,400 – approximately 20m east of the existing A9.
- Between ch. 2,800 and ch. 2,950 – between the existing A9 and Highland Main Line railway.
- Between ch. 3,050 and ch. 3,550 – semi-continuous areas between the existing A9 and the Highland Main Line railway, mostly beyond the footprint of the proposed works.
- Between 3,600 and ch. 3,700 – west of, and within the footprint of the proposed works.
- Between 3,700 and ch. 3,950 – discontinuous areas west of the proposed works, crossed by proposed access tracks, drainage and watercourse diversions.
- Between ch. 3,950 and ch. 4,150 – extensive, continuous area focused in an area of deep peat
- Between ch. 6,000 and ch. 6,150 – discontinuous areas within the footprint of and to the west of the proposed earthworks.
- Between ch. 7,400 and ch. 7,650 – discontinuous areas within and around the proposed Balsporran/ Drumochter Junction.

5.2.6 Areas where the bog burst hazard has been assessed as 'Probable' are, as for peat slides, extremely limited. The only locations where these areas occur are:

- Between ch. 3,950 and ch. 4,050 – very small discontinuous areas extending west from the existing A9.

5.2.7 No areas of 'Almost Certain' bog burst hazard have been identified.

5.3 Consequence Severity

5.3.1 The consequence severity describes the potential impact of a peatslide or bog burst on sensitive ecology or infrastructure receptors. **Drawings 10.5.13** and **10.5.14** (**Volume 3**) show the consequence severities across the study area for peat slides and bog bursts, respectively.

5.3.2 Due to the statistical difference in likely run-out distance between the two types of peat landslide (**Annex 10.5.2**), the spatial distribution of consequence severity varies slightly between the two. However, both follow the same general pattern of a north-south aligned 'Very High' consequence severity corridor through the centre of the study area, which widens and diverges at various points, relating to convergences and divergences between the Highland Main Line railway and existing road infrastructure.

5.4 Risk

5.4.1 ArcGIS has been used to multiply the final scores for hazard and consequence, to produce a Peat Landslide Risk map for the Proposed Scheme, as shown in **Drawings 10.5.15** to **10.5.18** (**Volume 3**). In order to incorporate the consequence severities into the assessment, the output of the risk calculation has been classed into five categories, each with a qualitative descriptor of the degree of risk at a given location.

5.4.2 The majority of the study area in this respect has been assessed as having 'Negligible' or 'Slight' for peat landslide risk. Areas assessed as being at 'Moderate' risk are considerably less extensive. In these areas and those identified as being 'Substantial' risk, it is recommended that additional quantitative stability analysis is undertaken prior to construction or precautionary mitigation measures implemented as detailed in the preliminary risk register in **Section 6.**

5.5 Summary

Comparison with Quantitative Analysis

5.5.2 Comparison between the semi-quantitative analysis and quantitative analysis is difficult due to the uncertainty around the parameters for the quantitative analysis, the additional factors considered in the semi-quantitative analysis (other than peat depth and slope) and the consideration of consequence in the semi-quantitative analysis.

5.5.3 However, comparison between the 'Moderately Conservative Case' without surcharge and the semi-quantitative hazard stage of the semi-quantitative analysis is probably the most logical, given the, most likely, unrealistic results generated by the 'Worst Case' and the lack of a mechanism for considering surcharge in the semi-quantitative analysis. Of the three variants of the 'Moderately Conservative Case' without surcharge, the high water table variant generates the most extensive areas of potential instability and is therefore considered most comparable.

5.5.4 Many areas in both this quantitative scenario and the semi-quantitative hazard analysis coincide, and the evidence from both assessments is included in the preliminary risk register in **Section 6**. Additional potential areas of instability identified by the quantitative analysis (Moderately Conservative Case, High Water Table, No Surcharge scenario) are incorporated in this for completeness. However, it should be noted that these areas represent elevated hazard, rather than the elevated risk, as identified through the semi-quantitative analysis.

Site Observations of High Hazard and Risk Areas

5.5.5 Field walkovers of the areas identified as at 'Substantial' risk of peat landsliding in the semi-quantitative analysis or as 'Unstable' in Scenario 3 from the quantitative assessment were undertaken by CFJV in June 2017. During these, observations of instability were only identified at one location within the Proposed Scheme extents – on the steep southern (left) bank of the Allt Coire Mhic-Sith. However, the failures in this location are most likely related to downcutting of the river and over steepening of the banks causing other superficial deposits to fail, rather than due to the peat landsliding mechanisms described in **Annex 10.5.1**.

6 Mitigation Measures

6.1 Avoidance

6.1.1 Throughout the DMRB Stage 3 iterative design development process for the Proposed Scheme described in **Chapter 4** (**Volume 1**); significant consideration was afforded to peat and efforts made to develop a layout that avoided and/ or minimised encroachment into areas of it. However, for a narrow, linear corridor with a large number of other environmental receptors; it is inevitable that the Proposed Scheme will affect or be affected by peat instability to some degree.

6.1.2 Wherever possible therefore, opportunities to further reduce risk by avoidance of areas of peat landslide hazard, or areas where sensitive receptors are likely to be impacted, should be sought and identified during detailed design and construction.

6.2 Further Assessment

6.2.1 No geotechnical data relating to the angle of internal friction, cohesion or strength of the peat is available at the time of writing. Should such data become available, it should be utilised to update the quantitative assessment of peat stability prior to construction. Modelling using geotechnical software should also be undertaken, with a specific focus on peat stability in those areas identified as 'Moderate' risk or above where infrastructure is proposed.

6.2.2 Monitoring of groundwater levels, including shallow groundwater in peat, should also be undertaken for a twelve-month period prior to construction in order to understand the expected annual cycle of fluctuation in groundwater levels and therefore, the levels that might be deemed exceptionally high and indicate a higher peat landslide hazard. Threshold levels above which groundwater is considered exceptionally high should be included in any 'stop criteria' to temporarily halt construction until levels have fallen again.

6.3 Good Practice during Construction

6.3.1 Assuming that detailed design has confirmed the suitability of the Proposed Scheme layout, the following good practice should be undertaken during construction:

- Use of appropriate supporting structures around peat excavations to prevent collapse and the development of tension cracks
- Wherever possible, avoid cutting trenches or aligning excavations across slopes (which may act as incipient back scars for peat failures)
- A series of weather dependent 'stop rules' should be identified under which construction in areas of moderate or higher peat landslide risk should cease when local meteorological data indicate threshold conditions have been exceeded. Either relevant meteorological data

(including, but not exhaustively, weather warnings) could be analysed to identify rainfall conditions that would be considered as abnormally high. Better still, analysis of groundwater fluctuation in installed piezometers could be compared to rainfall conditions to identify the rainfall conditions which are likely to generate abnormally high groundwater levels on site.

- To minimise the effects of construction on the natural drainage regime of the site, site design and construction should proceed with the adoption of temporary SuDS infrastructure which ensures free drainage is maintained and that there is no adverse alteration of the hydrological regime. Drainage plans should avoid creating drainage or infiltration areas or settlement ponds towards the tops of slopes (where they may act to both load the slope and elevate pore pressures)
- Supervision of all construction activities and operational decisions should be undertaken by an appropriately qualified and experienced geotechnical engineer, with experience of construction on peat
- Monitoring checklists should be established with respect to peat instability addressing all construction activities, such as:
  - (i) Monitoring for tension cracks, subsidence, ponding and ground heave in proximity to cut faces associated with excavations
  - (ii) Installation of displacement markers and monitoring for subsidence, lateral heave and upslope ponding along floating roads
  - (iii) Monitoring of groundwater levels in association with excavation and proposed construction works
  - (iv) Monitoring of daily, weekly and 2-weekly rainfall averages across the site to identify potential peaks for rainfall induced instability
  - (v) Full site walkovers at scheduled intervals by an appropriately qualified and experienced engineering geologist, geotechnical engineer or geomorphologist to identify changes to ground conditions, which may be associated with construction or occur independently of it.
- Incorporation of awareness of peat instability into site inductions and training to enable all site personnel to recognise ground disturbances and features indicative of incipient peat instability
- Where floated roads are constructed:
  - (i) Peat should be allowed to undergo primary consolidation (which takes place in a matter of days), by adhering to a rate of construction of 50m/day in good weather and 25m/day in poor weather (SNH/FCS, 2010)
  - (ii) The effects of secondary compression on track integrity should be monitored, and should be continued throughout the period for which the tracks are in use
  - (iii) Intervals between material deliveries over newly constructed tracks that are still observed to be within the primary consolidation phase, and running vehicles at 50% load capacity until the tracks have entered the secondary compression phase
  - (iv) The centreline of the proposed track should be identified prior to construction and inspected by an appropriately qualified and experienced geotechnical engineer, engineering geologist or geomorphologist to identify any ground instability concerns.

6.4 Good Practice following Construction

6.4.1 Following construction, monitoring of the Proposed Scheme should continue through a series of full site walkovers by appropriately qualified and experienced geotechnical engineers, engineering geologists or geomorphologists; to inspect for signs of unexpected ground disturbance in both Proposed Scheme earthworks in peat and areas on natural slopes in the vicinity of and beyond these.

6.4.2 Practically, this could form part of a scheduled earthworks asset inspection regime and such unexpected ground disturbances may, but not exhaustively, include:

- Ponding on the upslope side of constructed scheme elements (including earthworks and built infrastructure)
- Subsidence and lateral displacement of tracks
- Changes in the character of natural peat drainage within the permanent and temporary works boundaries and a 50m corridor either side of the Proposed Scheme (e.g. formation of new bog pools, development of quaking bog)
- Blockage or under-performance of installed site drainage
- Slippage or creep of peat where it has been stored or re-used
- Development of tension cracks, compression features, bulging or quaking bog anywhere within the permanent and temporary works boundaries and 50m either side.

6.4.3 Monitoring such as this should be undertaken on a quarterly basis for the first year after construction and annually thereafter. In the event of unforeseen ground conditions encountered during scheduled inspections; additional, targeted inspections may be required.

6.5 Engineering Measures

Engineering Mitigations to Minimise Landslide Occurrence

6.5.2 The Scottish Executive (2006) identify a limited number of engineering mitigation measures which may be employed to minimise the risks associated with potential triggers of peat instability, such as short term peaks in hydrogeological activity. These include:

- **Installation of drainage measures:** Targeted drainage measures would aim to isolate areas of susceptible peat from upslope water supply, re-routing surface (flushes/ gullies) and sub-surface (pipes) drainage around critical areas. Surface water drainage plans should be considered as a useful way of accounting for modified flows created by construction, which in turn may affect peat stability, pollution and wildlife interests. Drainage measures need to be carefully planned to minimise any negative impacts.
- **Construction management:** This would include site specific procedures aimed at minimising construction-induced peat landslide hazards, which should be identified, implemented and followed rigorously by site construction personnel. These may include work method statements subject to an environmental check to monitor compliance. These checklists should incorporate a weather forecast to minimise peat working during heavy rain and to allow mitigation measures to be put in place where construction work is ongoing. Weather forecasts can be obtained using data available from numerous websites or provided at a cost by commercial organisations or the Met Office.

Particular care should also be taken in relation to storage of excavated peat deposits on site, with loading of intact peat by excavated deposits avoided wherever possible. Further guidance in relation to the construction of tracks on peatlands, and the management of peat on construction sites is provided by SNH and SEPA (SNH, 2005; SEPA, 2010) and the Outline Peat Management Plan for the Proposed Scheme, presented in **Appendix 10.6** (**Volume 2**).

Engineering Mitigations to Control Landslide Impacts

6.5.3 The Scottish Executive (2006) also identifies engineering measures available for reducing the consequences in the event of a peat landslide hazard occurring. These include:

- **Catch wall fences:** Where the potential for peat landslides has been identified, catch fences positioned downslope of the suspected or known landslide prone area can slow or halt run-out (Tobin, 2003). Catch fences should be engineered into the peat substrate and fencing may require periodic inspection for removal of debris.
- **Catch ditches:** Ditches may slow or halt runout, although it is preferable that they are cut in non-peat material. Simple earthwork ditches can form a useful low-cost defence. Paired ditches and fences have been observed (Tobin, 2003) to slow peat landslide run-out at failure sites.

6.6 Preliminary Risk Register

6.6.1 The peat landslide risk, and the general mitigation measures described to limit such risk, should be included in any risk register related to construction of the Proposed Scheme, such as that which may accompany the Construction Environment Management Plan (CEMP). The locations of concern and suggested mitigations should also form part of any such risk register. However, they should not be treated as exhaustive and should be added to if additional specific locations of concern are identified as further data becomes available.

6.6.2 **Table 3** presents a preliminary risk register for the Proposed Scheme, summarising general mitigations for ‘Negligible’ and ‘Slight’ risk areas. The locations identified as ‘Moderate’ or ‘Substantial’ risk from either peat slide or bog burst are also detailed, with suggested mitigations intended to reduce the residual risk to ‘Slight’ or ‘Negligible’, which should be considered in addition to quantitative assessment of stability at these locations. Further locations identified as being at higher potential for peat instability through the preliminary quantitative analysis of stability are also included in the risk register.

Table 3: Preliminary Peat Landslide Risk Register

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
-	Negligible	-	-	-	-	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks.
-	Slight	-	-	-	-	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks.
-	Moderate	Smaller areas of moderate risk	-	-	-	Undertake additional quantitative stability analysis prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce landslide risks.
ch.-450 to ch. -400	-	-	Very small area of potential instability between existing A9 and Highland Main Line railway.		Direct access not possible due to restrictions. However, this is a steep area with flush vegetation indicating presence of water. Do not consider as 'false positive'	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, take measures (catch fences etc.) to protect railway from minor run out.
ch. -200	-	-	Very small area of potential instability between existing A9 and Highland Main Line railway.		-	-
ch. 0 to ch. 100	-	-	Relatively large area of instability.	-	Not directly observed.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, take measures (catch fences etc.) to protect existing dualled section of the A9 from minor run out during construction of pre-earthworks drainage.
ch. 350 to ch. 650	Moderate	Multiple areas within/ adjacent to proposed Dalnaspidal Junction, partly within earthworks footprint, permanent and temporary works and partly outwith. Driven by peat depth on steep slopes and presence of Allt Coire Mhic-Sith.	Areas of potential instability and marginal stability indicated around the Dalnaspidal Junction and Allt Coire Mhic-Sith.		Area identified in quantitative analysis below mast likely to be false positive – steep slope but no peat cover.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, mitigation measures against potential impact such as temporary catch ditches or fences to catch run-out from any potential failure should be considered to protect the Allt Coire Mhic-Sith and Private Water Supply infrastructure present in this area, which supplies the Old Schoolhouse, Station Cottage and other properties at Dalnaspidal.
					Area identified in quantitative analysis underlying eastern junction loop – likely false positive.	
					Area of up to 1.75m deep peat on sloping ground within footprint of proposed cutting – unlikely to be false positive. Peat will be removed by the cutting but recommend protection of works below from possible run out.	

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
ch. 350 to ch. 650	Moderate	Multiple areas within/ adjacent to proposed Dalnaspidal Junction, partly within earthworks footprint, permanent and temporary works and partly outwith. Driven by peat depth on steep slopes and presence of Allt Coire Mhic-Sith.	Areas of potential instability and marginal stability indicated around the Dalnaspidal Junction and Allt Coire Mhic-Sith.		Likely false positive within footprint of proposed cutting for eastern loop (near top). Slope visible in area photographs has an apparent overlap with an area interpolated as deep peat in the peat depth model. However, additional on-site measurements indicate peaty soil only.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, mitigation measures against potential impact such as temporary catch ditches or fences to catch run-out from any potential failure should be considered to protect the Allt Coire Mhic-Sith and Private Water Supply infrastructure present in this area, which supplies the Old Schoolhouse, Station Cottage and other properties at Dalnaspidal.
	Moderate				Slope visible in area photograph has an apparent overlap with area of interpolated deep peat, from measurements in basin to right. However, additional on-site measurements indicate peaty soil only therefore	
ch. 450 to ch. 500	Substantial	Approximately 120m east of existing A9 carriageway on right bank of Allt Coire Mhic-Sith, within a more extensive area of moderate risk. Risk driven by presence of shallow and deep peat, steep slopes and proximity to Allt Coire Mhic-Sith.	-	  	Limited peat cover, but very wet and located upstream of Private Water Supply infrastructure for The Old Schoolhouse, Station Cottages and other properties at Dalnaspidal. Instability due to over steepened slopes caused by fluvial cutting on far bank indicate possibility of failures into channel in area of construction.	The location is mostly within the permanent and temporary works boundaries but mostly outwith the footprint of the proposed earthworks, except for a drainage channel which crosses the area. The slope falls away from the proposed earthworks, so the risk is primarily related to Allt Coire Mhic-Sith. Either the drainage channel should be re-routed around the highest risk area or Allt Coire Mhic-Sith protected with catch fences. However, mitigation measures from potential failure should be considered and re-assessment may be required if forestry is removed. No materials should be stored in this area.
ch. 650 to ch. 850	Moderate	East of existing A9, wholly within footprint of proposed earthworks (therefore will be removed) and driven by slope, proximity of artificial drainage and forestry.	-	-	Not directly observed.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect existing A9 carriageway from possible minor runouts with temporary catch ditch or fence.
ch. 650 to ch. 1,050	-	-	Multiple discontinuous areas upslope of permanent and temporary works boundaries, approximately 75 to 100m north east of the existing A9.		Relatively steep sloping ground around ch. 650 to ch. 700. Likely false positive as probing during site observations indicated max peat depth of 0.30m.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks and protect working areas with catch fences.
					Small area around ch. 800 with water present on slope – unlikely to be false positive.	

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
ch. 650 to ch. 1,050	-	-	Multiple discontinuous areas upslope of permanent and temporary works boundaries, approximately 75 to 100m north east of the existing A9.		Extensive area between ch. 950 and ch. 1,050. Probing during walkover indicated peat up to 1.65m deep on sloping ground, therefore not a false positive.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks and protect working areas with catch fences.
ch.1,050 to ch.1,100	-	-	Between existing and NCN7 route, falling within footprints of proposed earthworks so will be removed.	 	Variable peat depths from 0 to 0.88m – treat with caution during construction.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks and consider protection of NCN7 route and watercourse with catch fences during construction.
ch. 1,200 to ch. 1,250	-	-	Between mainline and NCN7, falling within footprint of proposed earthworks so will be removed.		Likely false positive, with only peaty soil present.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks.
ch. 1,600 to ch. 1,750	Moderate	Approximately 30m east of existing A9, two areas within cutting footprints associated with convexity at top of existing cutting. Also discontinuous area west of A9 associated with drainage channel, partially within and partially outwith permanent and temporary works boundaries.	Areas of potential instability and marginal stability indicated east of the existing mainline around the convexity at top of existing cutting.	-	Not directly observed.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect existing A9 carriageway from possible minor runouts with temporary catch ditch or fence. Also protect channel from minor runouts during construction of nearby watercourse diversion.
ch. 1,950 to ch. 2,100	Moderate	Three separate areas to east and west of existing A9, almost entirely within permanent and temporary works boundaries and partly in footprint of cutting. Partly associated with presence of drainage and partly with convexity (as well as peat and slope).	-	-	Not directly observed.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect existing A9 and natural channels during construction with temporary catch ditches or fences.
ch. 2,000 to ch. 2,050.	-	-	Between existing and NMU route, falling within footprints of proposed earthworks so will be removed.	-	Not directly observed.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Consider protection of NCN7 route and natural watercourse with catch fences during construction.

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
ch. 2,250 to ch. 2,400	Moderate	Road-parallel associated with convexity at top of existing cut slope for A9. Wholly in footprint of proposed cutting.	Road-parallel area of potential instability and marginal stability on upper slope.		Peat present as indicated in peat model above cutting slope, but none present on cutting slope. As such careful removal of peat at top of cut slope would be recommended during construction along with protection of the existing A9.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect existing A9 and natural channels during construction with temporary catch ditches or fences.
ch. 2,500 to ch. 3,000	Moderate	Multiple small linear areas associated with existing drainage or deeper peat, both sides of existing A9. Partially within and outwith the proposed earthworks footprint.	Multiple small and discontinuous areas of potential instability and marginal stability either side of the existing A9 associated with deeper peat and slopes around artificial drainage.		Smaller more southerly areas not directly observed, with photograph taken between ch. 2,850 and ch. 2,900. Steeply sloping with only peaty soil and shallow peat, small scar present at base of slope, possibly from slumping after cutting of drain.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, use catch ditches or silt fences to prevent minor incursions of failed material into artificial drainage.
ch. 3,050 to ch. 3,900	Moderate	Multiple discontinuous areas between the existing A9 and Highland Main Line railway, partially overlapping with proposed compensatory flood storage area. Driven by deeper peat and slightly elevated slopes. Partly within and outwith permanent and temporary works boundaries.	Multiple discontinuous areas between the existing A9 and Highland Main Line railway. Driven by deeper peat and slightly elevated slopes. Partly within and outwith permanent and temporary works boundaries.		Deep peat, very low slope angles interspersed with hummocks of glacially derived material. Peat concentrated in hollows and basins.	Undertake quantitative stability analysis prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Carefully plan and microsite temporary works activities in area of deep peat.
ch. 3,350 to ch.4,150	Moderate	Multiple discontinuous areas associated with drainage, forestry, convexity, steeper slopes and greater peat depths, upslope (east) of existing A9.	Multiple small and discontinuous areas of potential instability associated with steeper slopes and greater peat depths, upslope (east) of existing A9.	-	Not directly observed.	Undertake quantitative stability analysis prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect existing A9 from minor runouts during construction through catch ditches and catch fences.
ch. 4,000 to 4,100	Substantial	Small areas immediately west of the existing A9 between ch. 4,000 and ch. 4,050, extending to ca. 60m west of the existing A9. This is an area of deep peat with slightly elevated slopes, though may be a result of interpolated depths and overlap with steep slopes at the edge of a deep peat basin.	Within continuous area of potential instability west of the existing A9 and partially within and outwith the footprint of the earthworks and permanent and temporary works boundaries. Associated with deep peat, slightly elevated slopes and the presence of the existing A9 and drainage.		Area of deep peat and very low slope angles, with increased hazard and risk due to presence of watercourse.	This area is wholly within the permanent and temporary works boundary, but with limited overlap with the earthworks footprint. The proximity of the existing A9 partly drives the risk, however this is upslope of the area identified. A proposed access track passes through this area; excavation should be avoided (use of floating tracks and piles or bridging instead) to avoid disturbance of the deep peat and the suitability of the ground to take the floating road should be assessed at detailed design. Slopes where the peat is situated are low, but watercourses should be protected whilst still active to prevent ingress and transportation of any disturbed peat.
ch.3,900 to ch.4,150	Moderate	Continuous area west of existing A9 partially within the footprint of the proposed earthworks and permanent and temporary works boundary, partly outwith all. Associated with deep peat, slightly elevated slopes, the existing A9 and drainage.	Continuous area of potential instability west of the existing A9 and partially within the footprint of the proposed earthworks and permanent and temporary works boundaries and partially outwith all. Associated with deep peat, and very low slopes.		Very low slope angles and deep peat. However, bog burst risk could be realised if excavation takes place and excavation should therefore be avoided and watercourses protected.	Undertake quantitative stability analysis, particularly to assess the stability of excavations, prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Downslope of the existing A9 so unlikely to create runout onto this, but drainage from runout should be protected and careful planning and micrositing of temporary works activities away from deep peat and moderate risk areas considered where possible.

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
ch.4,150 to ch. 4,500	-	-	Northwards extension of area identified between ch. 3,900 and ch. 4,150, associated with areas of deep peat. Possible 'false positive' due to behaviour of infinite slope equation where peat is deep, slope angles are shallow and unit weight of material is low.	  	Very low slope angles but very deep peat. The area of potential in stability picks out basins between elevated ground. Excavation in these areas best avoided/ minimised and watercourses protected from any runout or debris laden run-off.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Quantitatively assess stability of specific Proposed Scheme elements in this area for peat stability during detailed design.
ch. 4,450 to ch. 6,000	Moderate	Multiple discontinuous areas very small in extent.	-	-	Not directly observed.	Undertake quantitative stability analysis prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow guidance measures in **Section 6** on how to reduce landslide risks. Where risk proven, consider temporary catch ditches or fences.
ch. 4,900	-	-	Immediately east of existing A9, upslope of drainage channel. Completely within footprint of infrastructure so peat will be removed during construction.	-	Not directly observed.	Protect drainage channel and Highland Main Line railway from minor failures with catch fence during construction.
ch. 6,000 to ch. 6,150	Moderate	Multiple extensive areas east and west of the existing A9 associated with deeper peat and elevated slopes.	Multiple extensive areas of potential instability and marginal stability east and west of the existing A9 associated with deeper peat and elevated slopes.		No signs of instability in area shown in photograph to west of existing A9 and NCN7.	Undertake quantitative stability analysis prior to construction. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect existing A9 and River Truim from potential run-out during construction through catch ditches and catch fences.
ch. 6,100 to ch. 6,150	Substantial	Immediately east of the existing A9, around a road-parallel large artificial drain in an area identified as deep peat.			No sign of instability in area to east of existing A9. Probably false positive indicated by presence of steeper slopes around road drain and presence of road drain itself.	The location is wholly within the footprint of the proposed earthworks and therefore peat will be removed during construction. Despite being east of the existing A9, the road here is on embankment so there is unlikely to be a risk to the road presented. However, an existing culvert is present which discharges almost directly into the River Truim, so it is recommended measures are taken to prevent the debris from any minor failures during construction passing through the culvert and entering the River Truim.
ch. 6,150 to ch. 7,050	-	-	Multiple areas of small extent east of A9.	-	Not directly observed.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Quantitatively assess stability of specific Proposed Scheme elements for peat stability in this area during detailed design.
ch. 7,050 to ch. 7,300	-	-	Multiple areas immediately west of existing A9 associated with deep peat.		This area is likely to be a false positive as the quantitative analysis appears to be picking out the hummock slopes, which have little peat on them.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Quantitatively assess stability of specific Proposed Scheme elements for peat stability in this area during detailed design.

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
ch. 7,050 to ch. 7,300	-	-	Multiple areas immediately west of existing A9 associated with deep peat.	 	Area of very low slope angles but deep peat. Area of potential instability picks out basins between elevated ground. Excavation in these areas would be best avoided/ minimised and watercourses protected from any runout or debris laden run-off. The area of potential instability shown around ch. 7,250 is most likely a false positive. The area identified in the quantitative assessment crosses the NCN7 and the road embankment and is likely created due to interpolation between points of deep peat to both the east and west of the existing carriageway.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Quantitatively assess stability of specific Proposed Scheme elements for peat stability in this area during detailed design.
ch. 7,400 to ch. 7,600	Moderate	Multiple, very small in extent areas in the vicinity of the proposed Balsporran-Drumochter Junction. More extensive area nearer to the River Truim, mostly outside of permanent and temporary works.	Multiple, very small areas of potential instability and marginal stability in the vicinity of the proposed Balsporran-Drumochter Junction. More extensive area adjacent to River Truim, mostly outside of the permanent and temporary works boundaries.	 	Most areas not directly observed. However, photographs show area adjacent to River Truim where erosion on the outside of the meander apex has caused undercutting and toppling of peat blocks. Gullying has also occurred on the upper surface.	Undertake quantitative stability analysis prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks. If risk proven, protect River Truim from potential runout and topples of peat blocks at river edge when constructing drainage channels west of the existing A9.
ch. 7,550	-	-	Moderately extensive area around north-eastern loop of Balsporran-Drumochter Junction associated with an area of deep peat.		Very wet area that is mostly flat at the top of proposed cutting. Recommend works protected from potential failure during construction and additional measures to prevent failure once cut. Area of potential instability identified by quantitative analysis extends into the trees shown in the right of the photograph.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Quantitatively assess stability of specific Scheme elements for peat stability in this area during detailed design. May require additional stabilisation measures at top of cutting to protect against failure.
ch. 7,650 to ch. 9,741	-	-	Multiple areas of very small extent associated with pockets of deeper peat between existing A9 and Drumochter Estate access track. Outwith permanent and temporary works boundaries.	-	Not directly observed.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks, particularly avoiding discharge of additional water into this area.
130m north of ch. 9,741	Moderate	West (downslope) of the existing A9	West (downslope) of the existing A9		Outfall for drainage is planned in this area. Area highlighted by quantitative assessment is the embankment of the NCN7. Area highlighted by semi-quantitative assessment is just flat area of deeper peat at base of embankment.	Undertake quantitative stability analysis prior to construction and mitigate as required if risk confirmed. If risk is disproved, follow general guidance measures in Section 6 on how to reduce peat landslide risks, Excavation should be avoided here if possible and measures taken to prevent material entering the small watercourse which runs through here.

Approx. Chainage	Pre-Mitigation Risk	Semi-Quantitative Assessment	Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation
Drumochter Estate Access Track	-	-	Deep peat area around Beauly Denny pylon at grid reference 264062, 782003.		Boggy below area grubbed up for pylon construction, though the hazard here is likely exaggerated by overlap between an area of interpolated deep peat and slopes around the pylon. Outside of permanent and temporary works boundaries.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks.

7 Conclusions and Recommendations

7.1.1 In conclusion, there is potential for peat instability in the corridor through which the Proposed Scheme passes. The range of peat depths, slopes and the features (indirectly) indicative of peat instability present suggest that there is the potential for either peat slide or bog burst. The nature of the corridor also means it contains a range of receptors which could be affected by the occurrence of a peat slide or bog burst should one occur, to differing levels of severity.

7.1.2 The Proposed Scheme and adjacent areas have been investigated through desk studies, field surveys and GI. This information was utilised to complete a quantitative assessment using a range of conservative parameter values selected from literature and GI data available at the time of writing. A semi-quantitative assessment of peat stability was also conducted – by assessing hazard through a series of factors likely to contribute to peat landsliding, combining this with an assessment of severity of the potential consequences, and considering the distance of receptors from the potential sources of peat landslide events.

7.1.3 Through the semi-quantitative analysis, most of the study area has been assessed as having only a 'Negligible' or 'Slight' risk arising from peat landsliding (either peat slide or bog burst). However, reasonably extensive areas of 'Moderate' risk exist throughout the study area and further quantitative assessment should be undertaken in these areas prior to construction, with appropriate mitigation measures implemented to reduce any risks which are confirmed.

7.1.4 A very limited number of areas (of limited spatial extent) have been assessed as being at 'Substantial' risk from a peat slide or bog burst hazard. Mitigation measures have been suggested for these areas, but re-design or micrositing infrastructure elements to avoid these during detailed design and construction should be considered, taking account of detailed location-specific stability analysis.

7.1.5 The risk presented by peat landsliding for the Proposed Scheme should be included in the construction risk register and areas identified as being 'Substantial' risk should form line items in the project risk register. The good practice procedures identified for during and following construction should be followed as a minimum and be preceded by additional quantitative assessment where suggested.

7.1.6 It is difficult to directly compare the results of the quantitative and semi-quantitative assessments undertaken here, due to the different approaches and uncertainties. However, the 'moderately conservative scenario without surcharge' scenario assessed quantitatively, is most comparable to the outcomes of the semi-quantitative analysis. Analysis of the conservative high water table assessment indicates similarities in the results. However, some areas of difference have been highlighted and these are included in the preliminary risk register.

8 References

Boylan, N., Jennings, P., Long, M. (2008). Peat Slope Failure in Ireland. Quarterly Journal of Engineering Geology and Hydrogeology, 41, pp93-108.

British Standards Institute (2009). BS 6031 – Code of Practice for Earthworks, 2009.

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

Department of Environment (1996). Landslide Investigation and Management in Great Britain: A Guide for Planners and Developers, HMSO, London.

Dykes A. P., Kirk, K. J. (2000). Morphology and interpretation for a recent multiple peat slide even on Cuilcagh Mountain, Northern Ireland. In Landslides in Research, Theory and Practice (Volume 1), Bromhead E, Dixon N, Ibsen M-L (eds). Thomas Telford: London; 495-500.

Dykes A. P. Warburton J., (2007). Mass Movements in Peat: A Formal Classification Scheme, Geomorphology, 86.

Evans, M.G. and Warburton, J. (2007). Geomorphology of Upland Peat: Erosion, Form and Landscape Change. Blackwell Publishers Limited, Oxford.

Feldmeyer-Christe, E. and Küchler, M. (2002). Onze ans de dynamique de la vegetation dans une tourbière soumise à un glissement de terrain. Botanica Helvetica, 112, pp103-120.

Halcrow Group Ltd (2009). Peat Landslide Hazard Assessment: Summary Report. Report for Shetland Island Council, March 2009.

Halcrow Group Ltd (2012). Stornoway Wind Farm: Peat Stability Assessment. Report for Lewis Wind Power Limited. 24 January, 2012.

Hobbs, N.B. (1986). Mire morphology and the properties and behaviour of some British and Foreign peats. Quarterly Journal of Engineering Geology, 19, pp7-80.

Lee, E.M. and Jones, D.K.C. (2014). Landslide risk assessment, 2nd Edition. Thomas Telford, London.

Lindsay, R.A. and Bragg, O.M. (2004). Windfarms and blanket peat. A report on the Derrybrien bog slide. Derrybrien Development Cooperative Ltd, Galway.

McCahon, C.P., Carling, P.A. and Pascoe, D. (1987). Chemical and Ecological Effects of a Pennine Peat-slide. Environmental Pollution, 45(4), p275-289.

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

Mouchel (2013). Creag Riabhach Wind Farm: Technical Appendix 9.1 Peat Stability Assessment. Report for Creag Riabhach Wind Farm.

Nayak, D.R., Miller, D., Nolan, A., Smith, P. and Smith, J. (2008) Calculating Carbon Savings from Wind Farms on Scottish Peat Lands – A New Approach.

Norbury, D. (2010). Soil and Rock Description in Engineering Practice. Whittles, Dunbeath.

Nichol, D. (2006). Peatslide hazard rating system for wind farm development purposes. Proceedings of the 28th Annual Conference of the British Wind Energy Association (BWEA28).

Nichol, D. Doherty, G.K. Scott, M.J. (2007). A5 Llyn Ogwen Peatslide, Capel Curig, North Wales. Quarterly Journal of Engineering Geology and Hydrogeology, 40, pp293-299.

Raeburn Drilling and Geotechnical Ltd (2017). A9 Dualling – Glen Garry to Dalraddy, Project 7 Glen Garry to Dalwhinnie – Final Report on Ground Investigation, Raeburn Drilling and Geotechnical Ltd, issued on 31 March 2017

Raeburn Drilling and Geotechnical Ltd (2017). A9 Dualling – Glen Garry to Dalraddy, Project 7 Glen Garry to Dalwhinnie – Draft Final Report on Preliminary Ground Investigation, Raeburn Drilling and Geotechnical Ltd, issued on 22 June 2017

RWE (2013). Carnedd Wen Peat Model. Report for Carnedd Wen Windfarm and Habitat Restoration Project. April 2013.

Scottish Environmental Protection Agency (2010). SEPA Regulatory Position Statement – Developments on Peat.

Scottish Executive (2006). Peat Landslide Hazard and Risk Assessments Best Practice Guide for Proposed Electricity Generation Developments.

Scottish Government, Scottish Environment Protection Agency, Scottish Natural Heritage and The James Hutton Institute (2014). Guidance on Developments on Peatland – Site Surveys 7p.

Scottish Government, Scottish Natural Heritage and Scottish Environment Protection Agency (2017). Peatland Survey – Guidance on Developments on Peatland.

Scottish Natural Heritage and Forestry Commission Scotland (2010). Floating Roads on Peat - A Report into Good Practice in Design, Construction and Use of Floating Roads on Peat with particular reference to Wind Farm Developments in Scotland.

Scottish Natural Heritage (2013). Constructed tracks in the Scottish Uplands, Second Edition (updated September 2015)

Scottish Natural Heritage, Scottish Environment Protection Agency, The James Hutton Institute (2014). Guidance on Developments on Peatland - Site Surveys

Scottish Natural Heritage (2016). Peatland Condition Assessment.

Tobin (2003). Report on the Landslides at Dooncarton, Barnachuille and Pollathomais, County Mayo. Mayo County Council

Troels-Smith, J. (1955). Karakterisering af lose jordater (Characterisation of Unconsolidated Sediments). Danm. Geol. Unders. IV, 3, pp1-73.

Annex 10.5.1

The Nature of Peat Instability

Nature of Peat Instability

Peat instability manifests itself in a number of ways (Dykes and Warburton, 2007) all of which can be observed on site or remotely from high resolution aerial photography:

- **Minor instability:** such as localised, small scale development of tension cracks, tears in the upper vegetation mat (acrotelm), compression ridges, or bulges of thrusts; these 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 (10s to 100s cubic metres) to large scale peat slides and bog bursts (1,000s to 100,000s cubic metres).

Dykes and Warburton (2007) provide a classification scheme for landslides in peat based on a comprehensive database of examples collated from literature and field studies.

Peat Landslide Types

Classes of peat landslide reflect:

- 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
- Residual morphology (or features) left after occurrence.

Table 1 shows the indicative slope angles and peat thicknesses associated with each type.

Table 1: Peat Landslide Types and Key Controlling Parameters (after Dykes and Warburton, 2007a)

Peat landslide type	Definition	Typical slope range	Typical peat thickness
Bog burst	Failure of a raised bog (i.e. bog peat) involving the break-out and evacuation of (semi-) liquid basal peat	2 – 5˚	2 – 5m
Bog flow	Failure of a blanket bog involving the break-out and evacuation of semi-liquid highly humified basal peat from a clearly defined source area	2 – 5˚	2 – 5m
Bog slide	Failure of a blanket bog involving sliding of intact peat on a shearing surface within the basal peat	5 – 8˚	1 – 3m
Peat slide	Failure of a blanket bog involving sliding of intact peat on a shearing surface at the interface between the peat and the mineral substrate material or immediately adjacent to the underlying substrate	5 – 8˚ (inferred)	1 – 3m (inferred)
Peaty debris slide	Shallow translational failure of a hillslope with a mantle of blanket peat in which failure occurs by shearing wholly within the mineral substrate and at a depth below the interface with the base of the peat such that the peat is only a secondary influence on the failure	4.5 – 32˚	< 1.5m

Peat landslide type	Definition	Typical slope range	Typical peat thickness
Peat flow	Failure of any other type of peat deposit (fen, transitional mire, basin bog) by any mechanism, including flow failure in any type of peat caused by head-loading	Any of the above	Any of the above

With time, the features associated with these types of landslide will re-vegetate, leaving only subtle scars in the landscape (Feldmeyer-Christe and Küchler, 2002; Mills, 2002). A study of vegetation recovery for several UK peat slide sites indicated that typical features were clearly visible in the field and on aerial photographs for 20-30 years post-failure. Thereafter, failure morphology degraded and vegetation growth made scars increasingly difficult to identify (Mills, 2002).

Controls on Peat Instability

Several preparatory factors operate in peatlands which act to make peat slopes increasingly susceptible to failure without necessarily initiating failure. Triggering factors change the state of the slope from marginally stable to unstable and can be considered as the 'cause' of failure (DoE, 1996). There are also inherent characteristics (or preconditions) of some peat covered slopes which predispose them to failure. These preparatory and triggering factors are detailed in the following sections. Where relevant to the Proposed Scheme and identifiable, evidence of these has been mapped and their presence incorporated into the assessment.

Preparatory Factors

The following are some of the transient factors which operate to reduce the stability of peat slopes in the short to medium term (tens to hundreds of years):

i. Increase in mass of the peat slope through progressive accumulation (peat formation)

ii. Increase in mass of the peat slope through increases in water content

iii. Increase in mass of the peat slope through growth of trees planted within the peat deposit (afforestation)

iv. 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

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

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

vii. 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.

The impacts of factors (i) and (ii) are poorly understood, but the formation of tension cracks, desiccation cracks and pipe networks have been noted in association with many recorded failures. Long-term reductions in slope stability contribute to slope failure when triggering factors operate on susceptible slopes.

Triggering Factors

Peat landslides may be triggered by natural events and human activities. Natural triggers include:

i. Intense rainfall causing development of transient high pore-water pressures along pre-existing or potential rupture surfaces (e.g. at the discontinuity between peat and substrate)

ii. Snow melt causing development of high pore-water pressures, as above

iii. Rapid ground accelerations (earthquakes) causing a decrease in shear strength

iv. Unloading of the peat mass by fluvial incision of a peat slope at its toe, reducing support to the upslope material

v. Loading of the peat mass by landslide debris causing an increase in shear stress.

Factors (i) and (ii) are the most frequently reported triggers for peat mass movements in the UK. The increasing incidence of multiple peat landslide events may be associated with increased storm frequency (Evans and Warburton, 2007), a climatic trigger considered to be more likely under climate change scenarios.

Triggers associated with human activities include:

i. Alteration to natural drainage patterns focussing drainage and generating high pore-water pressures along pre-existing or potential rupture surfaces (e.g. at the discontinuity between peat and substrate)

ii. Rapid ground accelerations (blasting or mechanical vibrations) causing an increase in shear stresses

iii. Unloading of the peat mass by cutting of peat at the toe of a slope reducing support to the upslope material (e.g. during track construction)

iv. Loading of the peat mass by heavy plant, structures or overburden causing an increase in shear stress

v. Digging and tipping, which may be associated with building, engineering, farming or mining (including subsidence).

Natural factors are difficult to control, and while some human factors can be mitigated, some cannot. For these reasons, it is essential to identify and select locations for development infrastructure that avoid the deepest peat areas and minimise the impact on peatlands.

Lindsay and Bragg (2004) provide a review of the potential destabilising effects of forestry activities on a peatland in Ireland associated with the Derrybrien failure, including discussion of some of the anthropogenic triggers listed above. In preparing peat landslide risk assessments, developers should therefore give afforested peatlands (which are often hydrologically disrupted and physically degraded) the same scrutiny as peatlands without forest.

Preconditions

The following static or inherited factors may act as preconditions to slope instability in peatlands (Evans and Warburton, 2007; Dykes and Warburton, 2007a):

- Impeded drainage caused by a peat layer overlying an impervious clay or mineral base (hydrological discontinuity, especially an iron pan at the base of the peat deposit)
- A convex slope or a slope with a break of slope at its head (concentration of subsurface flow)
- Proximity to local drainage, either from flushes, pipes or streams (supply of water)
- Connectivity between surface drainage and the peat/impervious interface (mechanism for generation of excess pore pressures).

Dykes and Warburton (2007b) note that "…areas of peat subjected to tine cutting, peat upslope of transverse ditches and thin upland peat on convex mountain slopes should be identified as potentially unstable where not obviously disrupted by previous failures or surface erosion".

Pre-failure Indicators

The presence of preparatory or precondition factors prior to failure are often indicated by ground conditions that can be mapped or measured remotely, or through site visits. In many cases, sites that have experienced landslides apparently without warning could often have been identified as susceptible to failure by a suitably trained person or through relatively inexpensive monitoring strategies. The nature and signs of instability often differ depending on the type and scale of failure.

The following critical features are indicative of potential failure in peat environments:

- Presence of historical and recent failure scars and debris
- Presence of features indicative of tension
- Presence of features indicative of compression
- Evidence of 'peat creep'
- Presence of subsurface drainage networks or water bodies
- Presence of seeps and springs
- Presence of artificial drains or cuts down to substrate
- Concentration of surface drainage networks
- Presence of soft clay with organic staining at the peat and (weathered) bedrock interface
- Presence of an iron pan within a mineral substrate.

Any of the indicators listed above may in isolation indicate future potential for peat landslides to occur and combinations of these features may indicate a greater susceptibility to failure. Greater peat thickness and steeper angles are rarely cited as the drivers of peat instability alone. Evans and Warburton (2007) and Boylan et al. (2008) note that the majority of recorded failures are on relatively low gradients (typically 4-8°) and in thin to moderate thickness peats (typically 0.5 – 2.0m deep in blanket peat, but thicker in raised bogs; Boylan et al., 2008).

Annex 10.5.2

Semi-Quantitative Hazard and Risk Analysis Methods

Evaluation of Peat Landslide Hazard

Peat landslide hazard for the Proposed Scheme has been assessed through consideration of a series of contributory factors. In the case of peat depth and slope (the primary controls on peat landslides), different values have been assigned for peat slides and bog bursts. These contributory factors, and the weighting applied to them, are explored in more detail below.

A GIS approach has been used to undertake the assessment, which involved the establishment of a $1m^2$ raster grid, with specific values on each of the contributory factors assigned to each grid cell. The values in the rasters themselves were derived from mapping of the contributory factors or from remotely sensed data.

To derive the overall hazard score for each $1m^2$ cell the values of each layer are added together. The approach to development of the model has been iterative and initial runs of the model indicated that secondary factors contributing to peatslide hazard were having an overly large influence on resulting hazard scores, generating high hazard scores where site observations and knowledge of the literature would indicate hazard to be lower.

Once the totals of the scores have been derived, these have been categorised into a five-point scale for ease of incorporation with the consequence assessment to evaluate the level of peat landside (either peat slide or bog burst) risk.

In summary, hazard has been calculated using the following approach:

Hazard = (Slope angle score * 2) + (Peat depth score * 2) + Artificial drainage score + Slope curvature score + Geomorphological/Hydrological indicator score + Substrate score + Land use score + Upslope/Upstream landslide potential score

Contributory Factors to Peat Landslide Hazard

Slope Angle

The range of slope angles and peat depths in which peat instability is more likely to occur are well documented (Evans and Warburton, 2007) and measurable across the site.

Slope has been determined from a 1m-resolution raster Digital Terrain Model (DTM) created from the Proposed Scheme's 'engineering DTM' used in the design. **Table 1** indicates the typical slope ranges associated with peat landslides of various types based on data collected by Mills (2002; in Evans and Warburton, 2007).

The scores assigned to each class reflect the proportion of recorded failures in published literature (Evans and Warburton, 2007). **Table 1** shows the classes, significance for peat instability, scores and associated rationale for scoring of each slope class and **Drawing 10.5.1** (**Volume 3**) presents an overview of the distribution of slope angles over the study area.

The steeper slope classes have lower scores because they are associated with thinner and better-drained peat deposits. In the case of bog bursts, these are generally concentrated on lower angle slopes (less than 10^{o}) and very rarely reported on slopes exceeding these ranges (Evans and Warburton, 2007).

Table 1: Classes, Significance of Peat Instability and Scores for Each Slope Class

Slope Range	Significance	Score (peat slide)	Score (bog burst)
0 - 2°	Peat instability generally not associated with flat ground	1	2
2 - 5°	Peat instability generally manifest as bog bursts, bog flows or peat flows; bog slides, peat slides and peaty-debris slides rare	2	4
5 - 10°	Peat instability generally manifest as bog slides, peat slides and peaty-debris slides; a key slope range for reported population of peat failures	3	3
10 - 15°	Peat instability generally manifest as bog slides, peat slides and peaty-debris slides; a key slope range for reported population of peat failures	4	1
15 - 20°	Peat instability generally manifest as peaty debris slides due to low thicknesses of true peat in this slope range	3	1
>20°	Peat instability generally manifest as peaty- debris slides due to low thicknesses of true peat in this slope range	1	1

Peat Depth

Slope has been determined from a 1m-resolution raster Digital Terrain Model (DTM) created from the Proposed Scheme's 'engineering DTM' used in the design. **Table 1** indicates the typical slope ranges associated with peat landslides of various types based on data collected by Mills (2002; in Evans and Warburton, 2007).

Peat thickness is one of the key factors associated with peat stability. Typically, the deeper the peat the more humified and potentially weaker and unstable it is. **Table 2** shows scores assigned to peat thickness, reflecting the recorded association of peat landslides with peat thickness (Evans and Warburton, 2007). **Drawings 10.17** to **10.23** (**Volume 3**) illustrate the peat depths recorded across the Proposed Scheme area.

Table 2: Classes, Significance of Peat Instability and Scores for Each Peat Depth Class

Peat Depth	Significance	Score (peat slide)	Score (bog burst)
0	No peat present	0	0
<0.50m	No true 'peat' cover, any failure would be classed as 'peaty debris slide' and not a peat slide.	1	0
0.50 - 1.0m	Sufficient peat thickness for peaty debris slide, not thick enough for peat or bog slide	2	1
1.0 – 1.5m	Sufficient peat thickness for peat or bog slide, or bog flow over low slopes	4	3
1.5 – 2.0m	Sufficient thickness for the occurrence of a bog burst, fewer peat slides occur within this range	3	4
>2.0m	Few peat slides occur in peat of this depth, a proportionately high number of bog bursts occur in this range.	3	4

Artificial Drainage

Artificial ditches reduce peat stability by disrupting the hydrology of the peat blanket, and fragmenting the peat mass. Drains in open peatlands (grips), may weaken a peat covered slope by creating vertical discontinuity, removing tensile strength in the upper layers and enabling ponding of water and thus also elevating pore water pressures in the basal peat-mineral matrix between cuts and potentially instigating instability.

The influence of changes in hydrology becomes more pronounced the more transverse the orientation of the drainage lines relative to the overall slope. This is also the case with regards to fragmentation of the peat. Accordingly, transverse ditches are considered to have greater effect than drains aligned parallel or sub-parallel to slope. IUCN (2014) state that whilst the influence of drainage on conveying surface and acrotelmic flows is significant, the low hydraulic conductivity of catotelmic peat means that the influence of drains at anything but very shallow depths is likely to be limited to the 5m immediately adjacent to the drain.

Table 3 indicates artificial drainage features typically observed over the peatland and their significance for peat instability, associated scores and rationale for each drainage feature class. The area of influence of the artificial drainage has been conservatively estimated to be 5m either side of the drain and **Drawing 10.5.8** (**Volume 3**) shows the artificial drainage scores across the study area.

Table 3: Classes, Significance of Peat Instability and Scores for Each Artificial Drainage Class

Drainage feature	Description	Significance	Score
Drained (oblique to slope)	Artificial drainage lines where alignment is generally oblique to dominant dip of slope	Artificial drainage cuts aligned oblique / transverse to slope are frequently associated with peat instability	3
Drained (aligned to slope)	Artificial drainage lines where alignment is generally aligned with dominant dip of slope	Artificial drainage cuts aligned parallel to slope are sometimes associated with peat instability	2
No drainage	Surface single thread drainage line	Neutral influence on slope stability	0

Slope Curvature

Slope curvature can affect the peat instability hazard in two principal ways. Convex slopes or those with a convex break of slope at their head can be a precondition to failure, possibly due to potential for concentration of subsurface flows or the stresses placed on blanket peat by the change in slope. Slope concavities may also concentrate flows from elsewhere on a hillslope, leading to the propensity for higher pore-water pressures than in less concave areas. Given the uncertainty around the mechanisms through which slope convexity and slope concavity exert an influence on peat landsliding, but the observational and empirical evidence for both being influences on peat landsliding an approach which allocates higher scores to both the extreme convexities and extreme concavities across the Proposed Scheme.

Curvature has been determined through analysis of a DTM in GIS. To smooth the model and generate a realistic representation of the ground, the 1m resolution raster has been aggregated to 50m resolution. This resolution was chosen based on a visual assessment of the best representation of major concavities and convexities visible in the DTM, and knowledge of the scale of feature most likely to generate major concentrations of flow on the slope.

In the absence of research specifying the degree of convexity or concavity that is likely to have the greatest influence on peat instability, a statistical approach to the degree of influence has been adopted, based on standard deviations from the mean curvature. **Table 4** details the scoring system applied. **Drawing 10.5.7** (**Volume 3**) shows the curvature scores across the site.

Table 4: Classes, Significance of Peat Instability and Scores for Each Curvature Class

Degree of Curvature	Description and Significance	Score
Less than 1 standard deviation from the mean	Very low convexity or concavity; unlikely to influence peat landsliding	1
Between 1 and 2 standard deviations from the mean	Limited concavity or convexity; low likelihood of significant influence on peat landsliding	2
Between 2 and 3 standard deviations from the mean	Moderate concavity or convexity; moderate to high likelihood of influence on peat landsliding	3
Greater than 3 standard deviations from the mean	Extreme concavity or convexity; high to very high likelihood of influencing peat instability	4

Geomorphological and Hydrological Indicators

No direct indicators such as tension cracks, compression ridges or peat landslide failure scars were identified within the Proposed Scheme boundaries through desk study investigations or site reconnaissance. Potential peat landslide features beyond the Scheme boundary, but within 500m of the permanent and temporary works boundary, were also visited and shown to be changes in vegetation, or outcrops of bedrock. These features suggest that peat instability hazard is low.

However, various natural slope drainage features, which are indirect indicators of peat instability, were identified across the site including bog pools, flushes and springs. Evans and Warburton (2007) state that at most peat failure sites, point and diffuse drainage is present in both the peat and the substrate, and seepage pressures in frequently ponded flush zones may act to destabilise a slope. **Table 5** shows the scoring system for these features. **Drawing 10.5.5** (**Volume 3**) shows the geomorphological and hydrological indicators, and the associated hazard scores, associated with peat slides, and **Drawing 10.5.6** (**Volume 3**) shows the same for bog burst hazard.

Table 5: Geomorphological and Hydrological Indicators of Peat Instability

Features	Significance	Score (peat slides)	Score (bog bursts)
Bedrock exposures	Indicative of no peat or shallow peat depth	0	0
Natural watercourses	Likely to provide drainage counter to peat instability, but may also bring additional water to an area during flood conditions or destabilise surrounding ground through incision.	1	1
Bog pools	High water contents likely to contribute to peat landsliding hazard	2	3
Flushes, springs and upland fens	High water contents highly likely to contribute significantly to peat landslide hazard; strong potential indicators of subsurface drainage.	4	4
Direct indicators of peat instability	Geomorphological indicators (tension cracks, compression ridges, rafts, blocks of failed peat) which pertain to recent or imminent peat instability	5	5

Substrate

The influence of substrate on peat landsliding is illustrated by Carling (1986) and Dykes & Kirk (2000). Poorly draining fine-grained soils and impermeable bedrock are most likely to adversely influence peat stability, with more granular and freely draining soils and permeable bedrock benefiting peat stability. Given this potential influence, substrate as a contributory factor to peat landsliding has been incorporated into the assessment.

Available survey and GI information have identified that the substrate is predominantly granular, where it could be identified, confirming the nature of the substrate as indicated by the BGS data. However, fine-grained substrate (clay or silt) was identified in a limited number of locations.

In order to account for this contributory factor, where granular or clay substrate has been identified an area with a radius of 50m around each of these points has been assumed to be underlain by that substrate type. To adopt a conservative approach to the assessment, where there is overlap between the two substrate types the higher score has been allocated to the overlapping area. Remaining areas have been allocated an intermediate score, to reflect both that the likelihood is that these areas are underlain by granular substrate or bedrock, but that there is a level of uncertainty in this assumption and fine-grained substrate may be present, albeit it less likely.

Table 6 shows the scores allocated each substrate category and **Drawing 10.5.9** (**Volume 3**) shows the substrate derived hazard scores across the study area.

Table 6: Substrate Contributory Scores to Peat Landslide Hazard Assessment

Substrate Type	Description and significance	Score
Fine-grained	Less than 50m from a point positively identified as having substrate of predominantly silts or clays; likely to drain poorly and be more prone to failure.	2
Granular	Less than 50m from a point positively identified as having substrate of sand, gravel, cobbles or boulder; likely to be freely draining and less prone to failure.	0
Unidentified	Areas further than 50m from a point at which substrate has been positively identified. Substrate is likely to be granular but lesser possibility that the substrate is fine grained.	1

Land Use

The land use assessed as likely to have the most influence on peat instability across the site is plantation forestry, due to its desiccating effect on underlying peat, the disturbance to the peat required to afforest an area and the impacts afforestation can have on the effective weight of the peat slope.

To recognise this contributory factor, a straightforward approach to assessing the influence of forestry the peat landslide hazard across the Proposed Scheme has been adopted, which involves allocating a score of zero to areas with no forest cover, or where forest has recently been felled, and one to afforested areas. Recent deforestation was assessed using aerial imagery dating from 2010.

Table 7 shows the scores allocated to this contributory factor and **Drawing 10.5.8** (**Volume 3**) shows the associated scores.

Table 7: Land Use Contributory Scores to Peat Landslide Hazard Assessment

Land use	Description and significance	Score
Afforested or recently deforested	Woodland or forestry present; higher propensity for ground disturbance from planting and maintenance and for desiccation cracking.	2
No forest	No woodland or forestry present.	0

Landslide Potential Upslope and Upstream of the Proposed Scheme

Whilst the focus of the assessment is on the Proposed Scheme boundary and its immediate environs, it is acknowledged that it is possible that the area covered by the Proposed Scheme could be affected by a peat landslide event generated some distance from it. Therefore, a simple assessment of the peat landslide hazard on a catchment-scale has been undertaken and included as a contributory factor for the Proposed Scheme.

The approach taken has been to make a simple assessment of the peat landslide potential in each of the catchments already defined by hydrological studies (**Appendix 11.4** (**Volume 2**)). These catchments extend from the top of the slope to the river and encompasses the whole of the Proposed Scheme area. If a peat landslide event occurred within a catchment, debris runout will follow existing watercourses. Therefore, the impacted area of the Proposed Scheme is most likely to be around existing watercourses.

The contributory factors to peatslide hazard within each catchment that have been considered include:

- Presence of peat
- Instability features (peat or otherwise) mapped from Google Earth
- Average slope angle (from an OS 50m resolution DTM).

The resulting scores for each catchment or other upslope areas are shown in **Table 8** and **Drawing 10.5.10** (**Volume 3**) shows the associated scores across the wider area.

Table 8: Contributory Scores to Peat Landslide Hazard Assessment for Upslope Instability

Criteria	Score
No peat present, irrespective of other factors	0
Peat present	1
Peat present; either instability features present or average slope greater than 5°	2
Peat present; instability features present and average slope greater than 5°	3

Evaluation of Overall Hazard

The overall hazard has been determined by adding together the scores for the individual contributory factors. Due to the more marginal influence of the other contributory factors and the more reliable data relating to these factors, peat depth and slope have been allocated a weighting of two. This also prevents areas of very shallow peat and very low slope, where there is a negligible chance of a peat landslide of any nature occurring from being determined as a high hazard area, due to the presence of other less influential contributory factors.

Once total scores have been established across the Proposed Scheme, these are categorised into a five-point hazard scale. The maximum possible score if the top score was met for each category is 26. This allows simple incorporation into an assessment of risk, but provides a degree of mitigation against uncertainty in such a semi-quantitative scoring system. **Table 9** shows the five-point hazard scale.

Table 9: Five-Point Hazard Scale

Scores	Likelihood of Occurrence	Score
21-26	Almost Certain	5
17-21	Probable	4
12-16	Possible	3
7-11	Unlikely	2
0-6	Negligible	1

Table 10 provides a worked example of how a score for a particular location in the assessment derives its hazard score for peat slide hazard.

Table 10: Worked Example of Hazard Score and Score on Five-Point Hazard Scale (Peat Slide)

Contributory Factor	Value/Criteria	Score
Slope Angle	6°	3
Peat Depth	0.75m	2
Artificial Drainage	Drained (Oblique to slope)	3
Slope Curvature	Less than 1 standard deviation from the mean	1
Geomorphological and Hydrological Features	Bog Pools	2
Substrate	Fine-grained	2
Land use	Not afforested	0
Instability Potential Upslope and Upstream of the Scheme	Peat present, no instability features, average slope angle >5°	2
	Total	15
	Score on Five-Point Scale	3 - Possible

Evaluation of Consequence

The consequence of the occurrence of a peat landslide (either peat slide or bog burst) has been evaluated through the assessment of the potential impact on a series of sensitive receptors. Broadly, these receptors can be classified either as ecology or infrastructure.

Infrastructure receptors include the existing road network (including both the existing A9 carriageway and A889), the SSE-operated Beauly-Denny Power Line pylons, inhabited buildings, the SSE Aqueduct, weirs, dams, filter beds, tracks and major paths (including the NCN7 cycleway), the Highland Main Line railway, cultural heritage assets and private water supplies.

It should be noted that the consequence of a peat landslide has been assessed only for the infrastructure receptors that already exist. The Proposed Scheme itself has not been included as a receptor of the peat landslide hazard because wherever the infrastructure is located, it will, by definition, increase the severity of consequence in that area. This work therefore gives a baseline definition of peat landslide risk.

This does not detract from the fact that the Proposed Scheme and people working on it are potential receptors of the peat landslide hazard. However, the hazard mapping (**Drawings 10.5.11** and **10.5.12** (**Volume 3**)) shows where the peat landslide hazards are greatest throughout the study area. This can therefore be used to understand risk to personnel and temporary infrastructure during construction and to support construction of any temporary mitigation measures.

Potential ecological receptors include watercourses, waterbodies, sensitive terrestrial habitats and high value or sensitive fauna. For the purposes of this assessment, only watercourses and waterbodies have been included as ecological receptors for the following reasons:

- Data available at the time of writing only identifies potential Annex 1 habitats on the basis of vegetation species present. These potential Annex 1 habitats are therefore very widespread and may include many false positives (potential misidentified Annex 1 habitats) which could in turn misleadingly inflate the assessed consequence associated with a peat landslide impacting on a given area.

- The high value and sensitive fauna in the area are mostly water dwellers (otter, water vole, water pearl mussel, salmonids and lampreys) and due to the dispersive behaviour of sediment from mass movements once incorporated into a watercourse or waterbody, are much more likely to be affected by peat landslide impacting on their habitat.

The relative severity of a consequence of a receptor being hit by a peat landslide has been assessed according to the nature of the consequence should a receptor be hit.

A 'Very High' severity of consequence has been allocated to receptors where there is a chance that a peat landslide event could result in loss of life or injury. Such receptors would include the road network (e.g. resulting in road traffic collision), Highland Main Line railway line (e.g. derailment) or an occupied building.

'High' severity of consequence has been allocated to receptors in which there is likely to be a substantial economic or environmental consequence, but a lower probability of loss of life. Such receptors include watercourses and waterbodies (which are sensitive habitats and may convey peat landslide debris much further than on land) and the SSE Beauly-Denny Power Line.

'Moderate' consequence severities are reserved for those infrastructure elements which if hit by a peat landslide event are likely to suffer a more limited economic consequence or result in the loss or damage of a cultural heritage or recreation asset, with much more limited likelihoods of injury or death. **Table 11** summarises this approach to the assessment of consequence and **Table 12** presents the assessed consequence severities for the receptors identified.

Table 11: Definitions of Consequence and Severity

Consequence		Definition	
Qualitative	Score	Environmental receptors	Infrastructure receptors
Very High	5	Blocking/filling of water bodies Debris dispersal throughout water body Death of large numbers of fauna	Injury equivalent to or exceeding loss of a human life Infrastructure out of operation for >48 hours
High	4	Significant input of debris to water bodies Probable death of fauna	Potential for human injury Infrastructure out of operation for 24-48 hours
Moderate	3	Potentially significant input of debris to water bodies Possible death of fauna	Some potential for human injury Infrastructure out of operation for up to 24 hours
Low	2	Minor inputs of debris to water bodies Unlikely to kill fauna	Limited potential for human injury Delays to operation of infrastructure
Very Low	1	Insignificant inputs of debris to water bodies No death of fauna	No potential for human injury No delays to operation of infrastructure

Table 12: Assessed Consequence Severities for Identified Receptors

Receptor	Receptor type	Consequence at source	
		Peat slides	Bog bursts
Watercourses	Environmental	High	High
Water bodies	Environmental	High	High
Road network	Infrastructure	Very High	Very High
Pylon	Infrastructure	High	High
Building	Infrastructure	Very High	Very High
Weirs	Infrastructure	Moderate	Moderate
Dams	Infrastructure	High	High
Tracks, major paths	Infrastructure	High	High
Railway	Infrastructure	Very High	Very High
Cultural heritage	Environmental	Moderate	Moderate
Private water supplies	Infrastructure	High	High

The consequences are assessed as the 'worst case' severity for a receptor being hit. Overall, severity of a consequence and the likelihood of a receptor being hit decrease with distance away from the source for all peat landslide mechanisms. However, variations in the volume and nature of the material involved and the gradient of slope associated with peat slides and bog bursts means the likelihoods of a receptor being hit under these mechanisms are slightly different (Mills, 2002).

Furthermore, the severity of the destruction caused by a peat landslide event, with exception of one that becomes channelised is likely to reduce over long distances, due to the loss of energy as the event runs out. As such a scheme has been applied based on the statistics to vary the severity of the likely consequence.

This assessment applies the approach shown in **Table 13** and **Table 14** to vary the consequence severity depending on the distance of the receptor from the source of the peat landslide event. 'At source consequence' assumes that the peat landslide event is sourced within the footprint of the receptor.

Table 13: Reduction in Consequence Severity with Distance of Receptor from Peat Slide Source

Peat slide consequence at distance from source (m), relative to evaluated 'at source' consequence						
At-Source Consequence	Distance from source (m)	0 to 50	50 to 100	100 to 250	250 to 500	500 to 750
	Probability of a hit	1.00	0.87	0.56	0.33	0.11
		⇩	⇩	⇩	⇩	⇩
Very High	⇨	Very High	High	Moderate	Low	Very Low
High	⇨	High	Moderate	Low	Very Low	Very Low
Moderate	⇨	Moderate	Low	Very Low	Very Low	Very Low
Low	⇨	Low	Very Low	Very Low	Very Low	Very Low
Very Low	⇨	Very Low	Very Low	Very Low	Very Low	Very Low

Table 14: Reduction in Consequence Severity with Distance of Receptor from Bog Burst Source

Bog burst consequence at distance from source (m), relative to evaluated 'at source' consequence						
At-Source Consequence	Distance from source (m)	0 to 50	50 to 100	100 to 250	250 to 500	500 to 750
	Probability of a hit	1.00	1.00	0.94	0.63	0.06
Very High		Very High	Very High	High	Moderate	Very Low
High		High	High	Moderate	Low	Very Low
Moderate		Moderate	Moderate	Low	Very Low	Very Low
Low		Low	Low	Very Low	Very Low	Very Low
Very Low		Very Low	Very Low	Very Low	Very Low	Very Low

The 'At Source' consequence severity has been applied to the footprint of each feature. These features have then been 'buffered' to identify zones of reducing consequence severity around the receptor, should a peat landslide occur within each of those zones.

As expected for infrastructure corridors, there is overlap between the buffers created for the various receptors. Where overlap occurs, the highest score has been adopted. **Table 15** and **Table 16** present the receptors and consequence severity across the site for peat slides and bog bursts respectively, based on the definitions supplied in **Table 11**.

Table 15: Consequence Severity for Specific Receptor Types at Varying Distances from Peat Slide

Failure type	Runout distance (m)	Water-courses	Water bodies	Road network	Pylon	Building	Weirs	Dams	Tracks, major paths	Railway	Cultural heritage	Camp (Cultural Heritage Asset)	Private water supplies
Peat slide	At Source	H	H	VH	H	VH	M	H	H	VH	M	H	H
	0 to 50	H	H	VH	H	VH	M	H	H	VH	M	H	H
	50 to 100	M	M	H	M	H	L	M	M	H	L	M	M
	100 to 250	L	L	M	L	M	VL	L	L	M	VL	L	L
	250 to 500	VL	VL	L	VL	L	VL	VL	VL	L	VL	VL	VL
	500 to 750	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

Table 16: Consequence Severity for Specific Receptor Types at Varying Distances from Bog Burst

Failure type	Runout distance (m)	Water-courses	Water bodies	Road network	Pylon	Building	Weirs	Dams	Tracks, major paths	Railway	Cultural heritage	Camp (Cultural Heritage Asset)	Private water supplies
Bog burst	At Source	H	H	VH	H	VH	M	H	H	VH	M	H	H
	0 to 50	H	H	VH	H	VH	M	H	H	VH	M	H	H
	50 to 100	H	H	VH	H	VH	M	H	H	VH	M	H	H
	100 to 250	M	M	H	M	H	L	M	M	H	L	M	M
	250 to 500	L	L	M	L	M	VL	L	L	M	VL	L	L
	500 to 750	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

Evaluation of Risk

Risk in this assessment is defined as the product of the hazard and the consequence. This has been achieved using GIS to multiply the final scores for hazard and consequence together to result in a Peat Landslide Risk map (**Drawings 10.5.15** to **10.5.19** (**Volume 3**)). In order to incorporate the consequence severities into the assessment, the output of the risk calculation has been classed into five categories, each with a qualitative descriptor of the degree of risk at a given location.

The highest risk areas are therefore those where there is a high hazard (i.e. probability of a peat landslide occurring) and a high value receptor (i.e. there is a high risk that the peat landslide event would have its source at or near the location of the receptor). In some instances, reasonably high risk can be generated in low hazard areas if the consequence of that receptor being hit is severe. It is also feasible for a risk to be registered some distance from the landslide hazard because of the effects of debris runout.

Table 17 below shows the resulting risks when the hazard and consequence scores are multiplied together and **Table 18** presents the suggested implications for the Scheme construction in each instance.

Table 17: Risk Score Ranges and Implications for Construction

		Hazard (likelihood)				
		Almost Certain (5)	Probable (4)	Possible (3)	Unlikely (2)	Negligible (1)
Consequence Severity	Very High (5)	25	20	15	10	5
	High (4)	20	16	12	8	4
	Moderate (3)	15	12	9	6	3
	Low (2)	10	8	6	4	2
	Very Low (1)	5	4	3	2	1

Table 18: Risk Scores Generated by Various Hazard and Consequence Scores

Risk Descriptor	Risk Score Range	Implication
Serious	21 - 25	Avoid construction in these areas
Substantial	16 - 20	Consider relocation or redesign of infrastructure to avoid construction in area of risk. Where relocation is not possible undertake detailed assessment of peat stability and receptors likely to be affected and develop specific mitigation measures prior to construction commencing.
Moderate	11 -15	Undertake detailed assessment of peat stability and receptors likely to be affected and develop specific mitigation measures to reduce hazard or protect receptors prior to construction commencing.
Slight	6 - 10	Proceed with construction adhering to generic mitigation measures to reduce peat landsliding risks and protect sensitive receptors
Negligible	1 - 5	Proceed with construction adhering to generic mitigation measures to reduce peat landsliding risks and protect sensitive receptors

Annex 10.5.3

Quantitative Hazard Analysis Figures

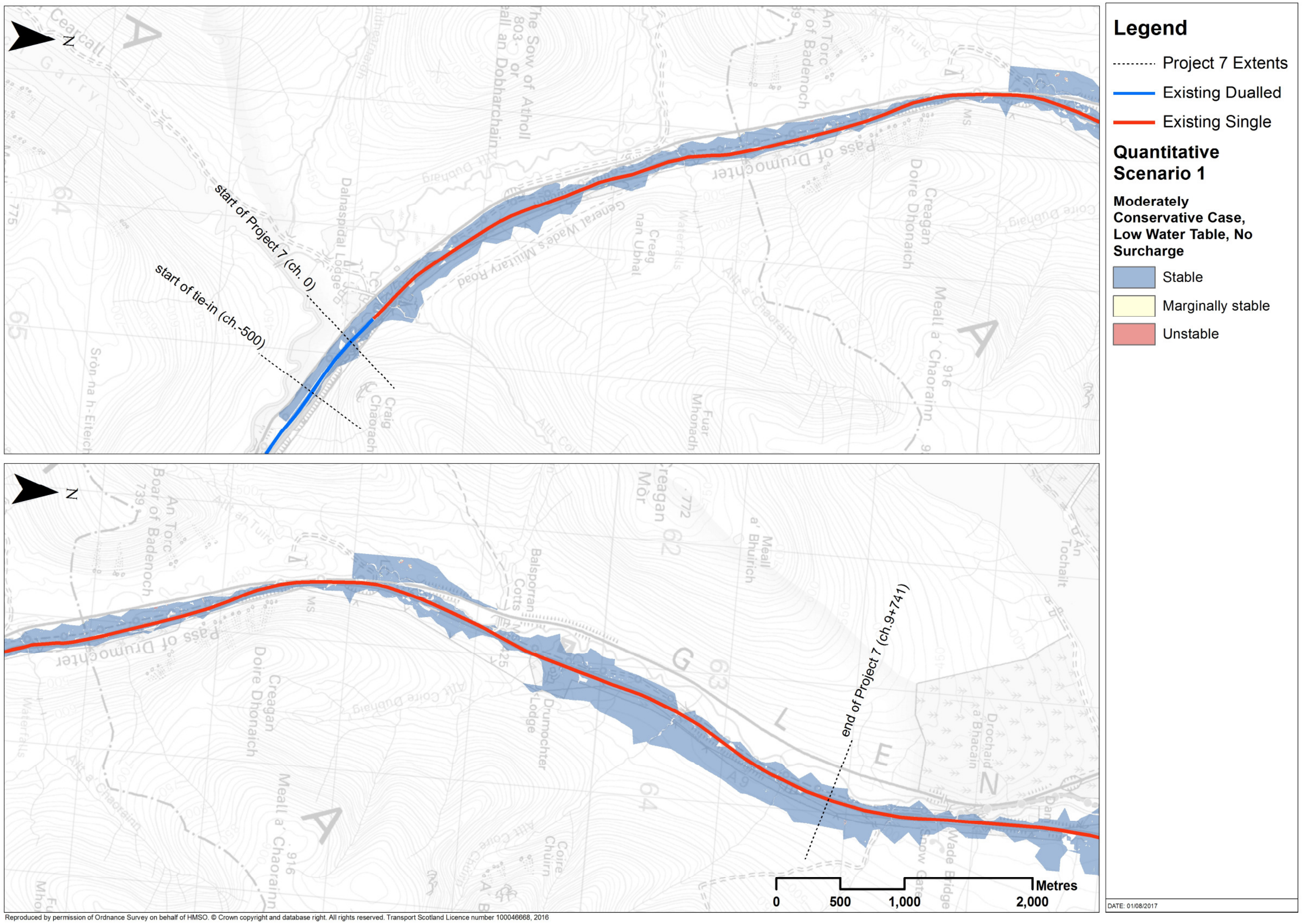

Figure 1: Quantitative Stability Assessment Scenario 1; Moderately Conservative Case, Low Water Table, No Surcharge

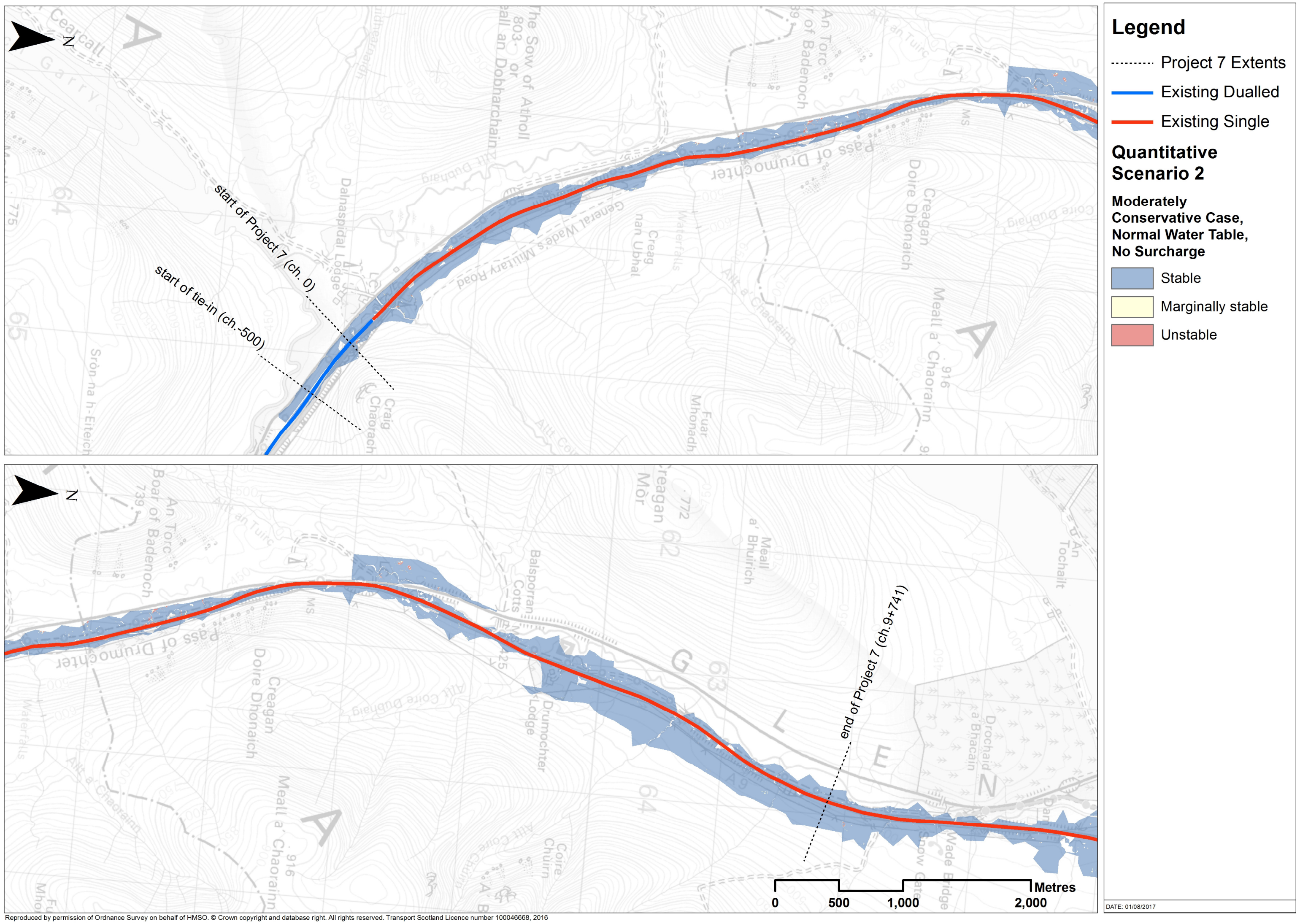

Figure 2: Quantitative Stability Assessment Scenario 2; Moderately Conservative Case, Normal Water Table, No Surcharge

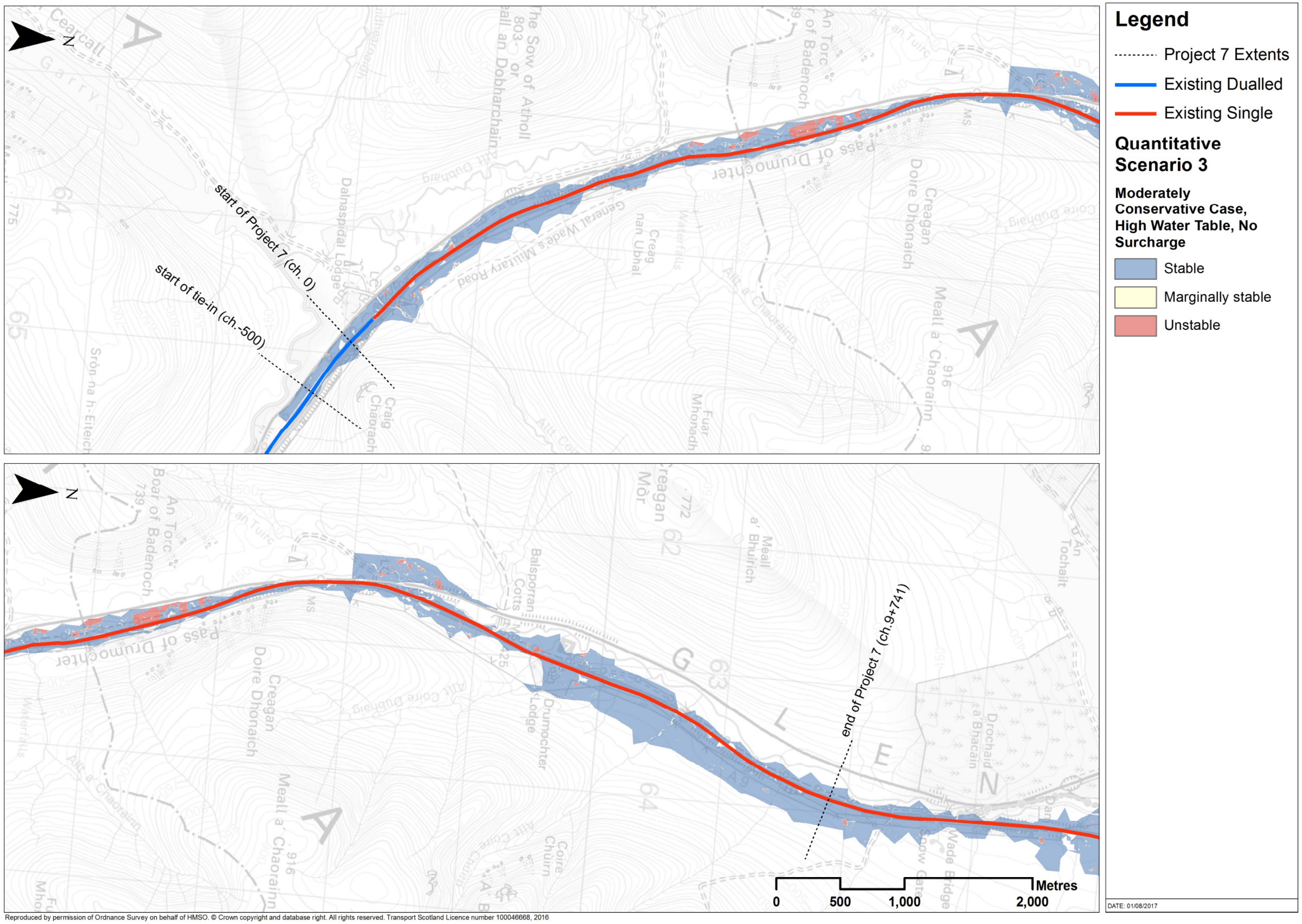

Figure 3: Quantitative Stability Assessment Scenario 2; Moderately Conservative Case, High Water Table, No Surcharge

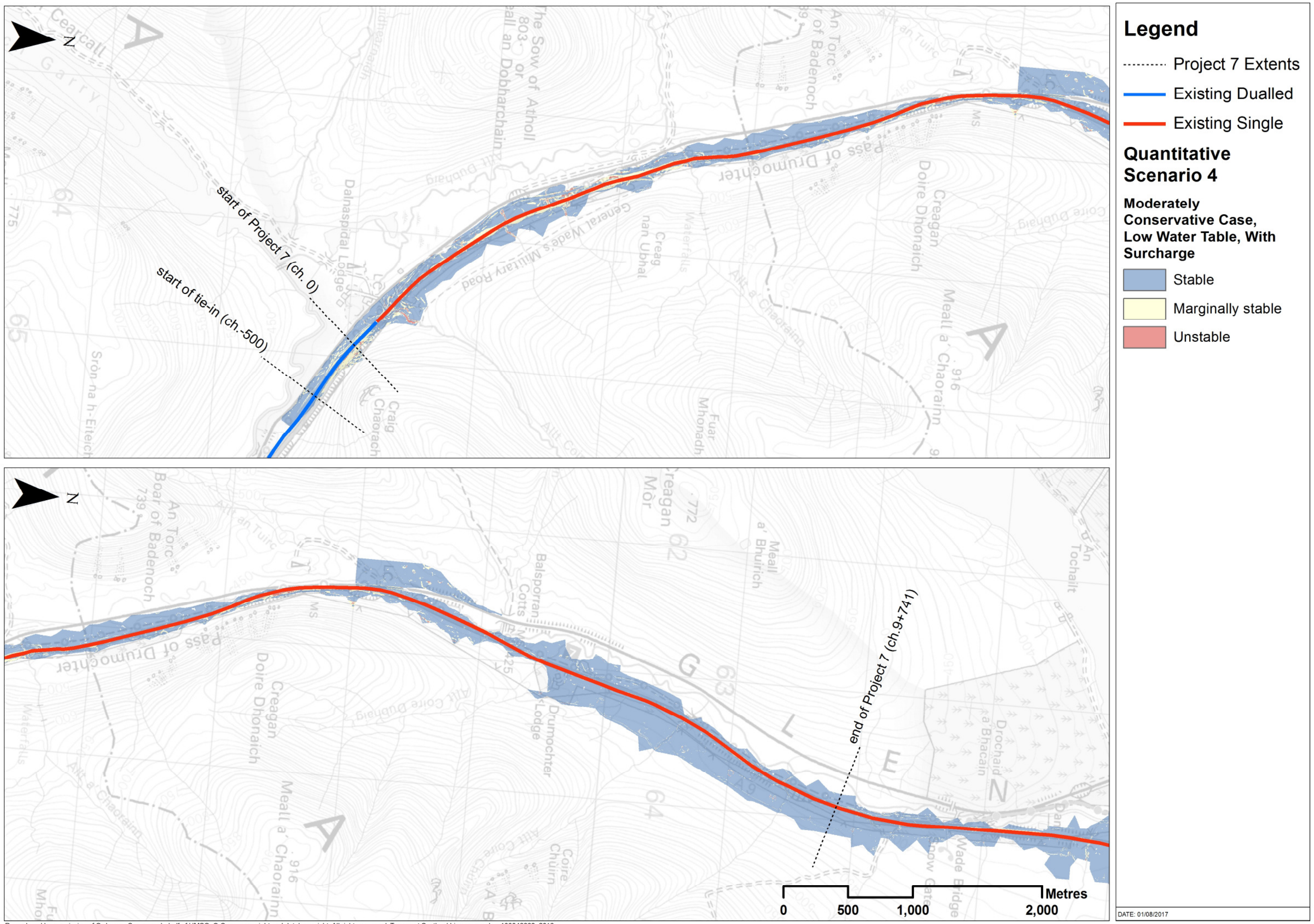

Figure 4: Quantitative Stability Assessment Scenario 4; Moderately Conservative Case, Low Water Table, With Surcharge

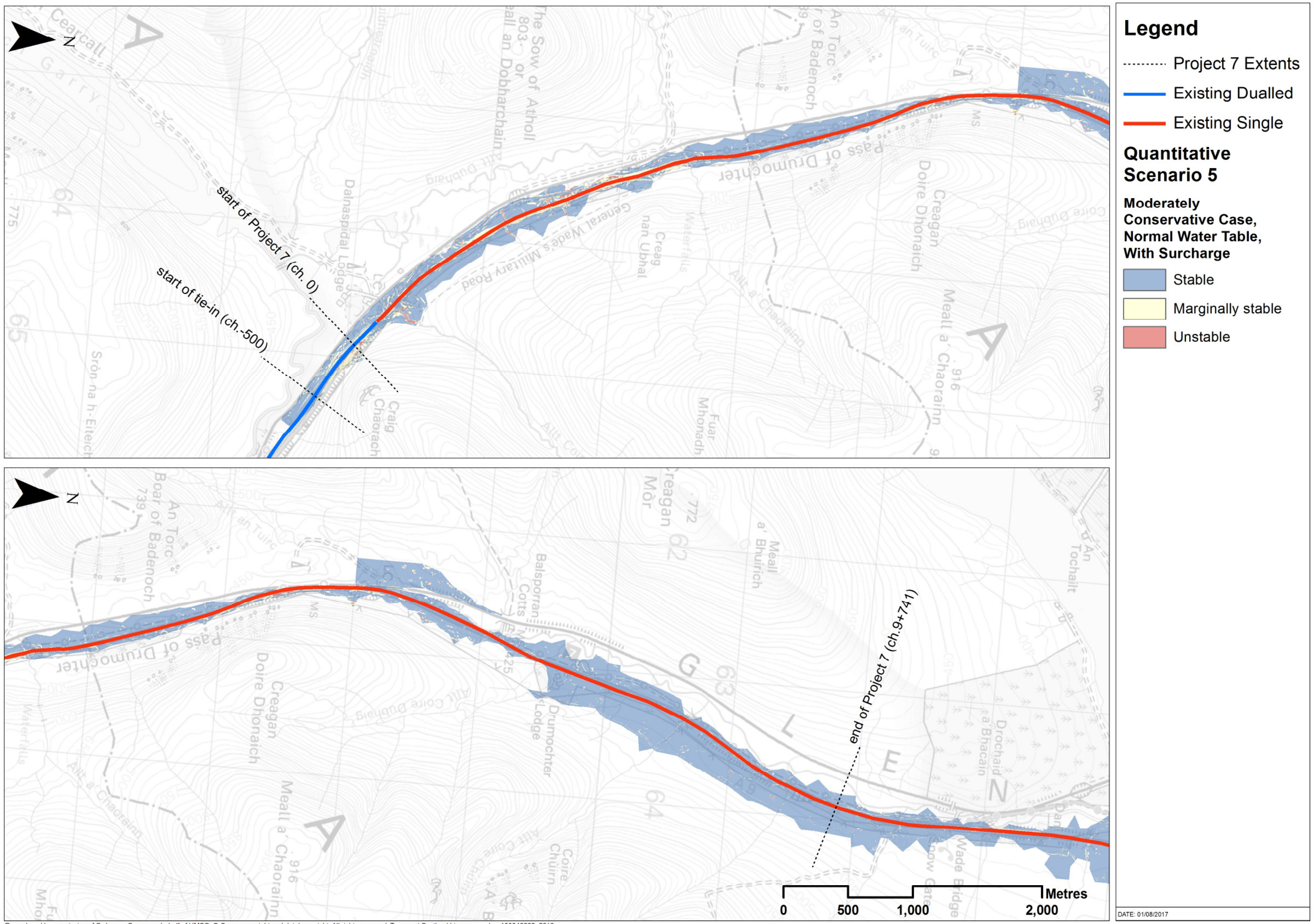

Figure 5: Quantitative Stability Assessment Scenario 5; Moderately Conservative Case, Normal Water Table, With Surcharge

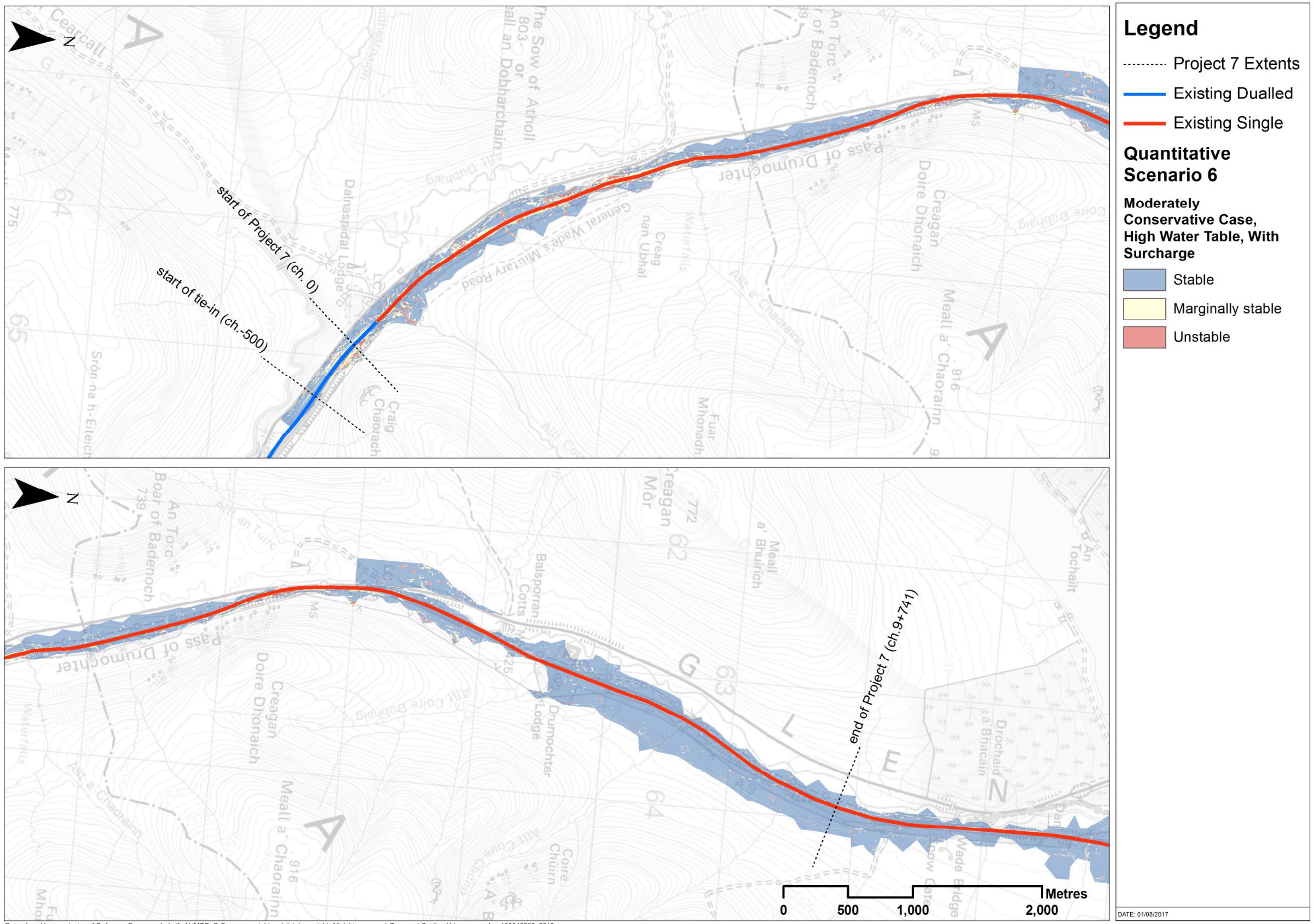

Figure 6: Quantitative Stability Assessment Scenario 6; Moderately Conservative Case, High Water Table, With Surcharge

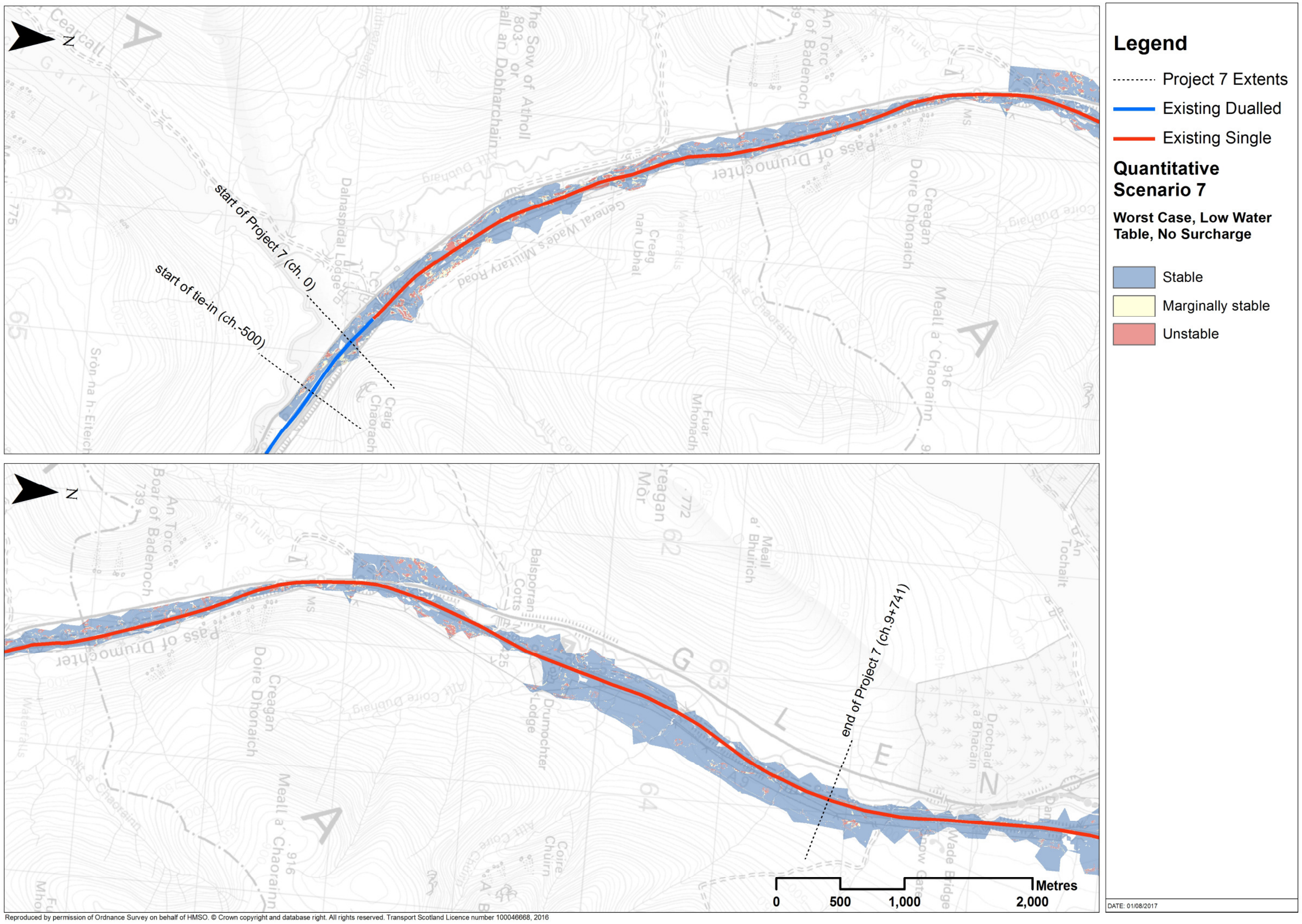

Figure 7: Quantitative Stability Assessment Scenario 7; Worst Case, Low Water Table, No Surcharge

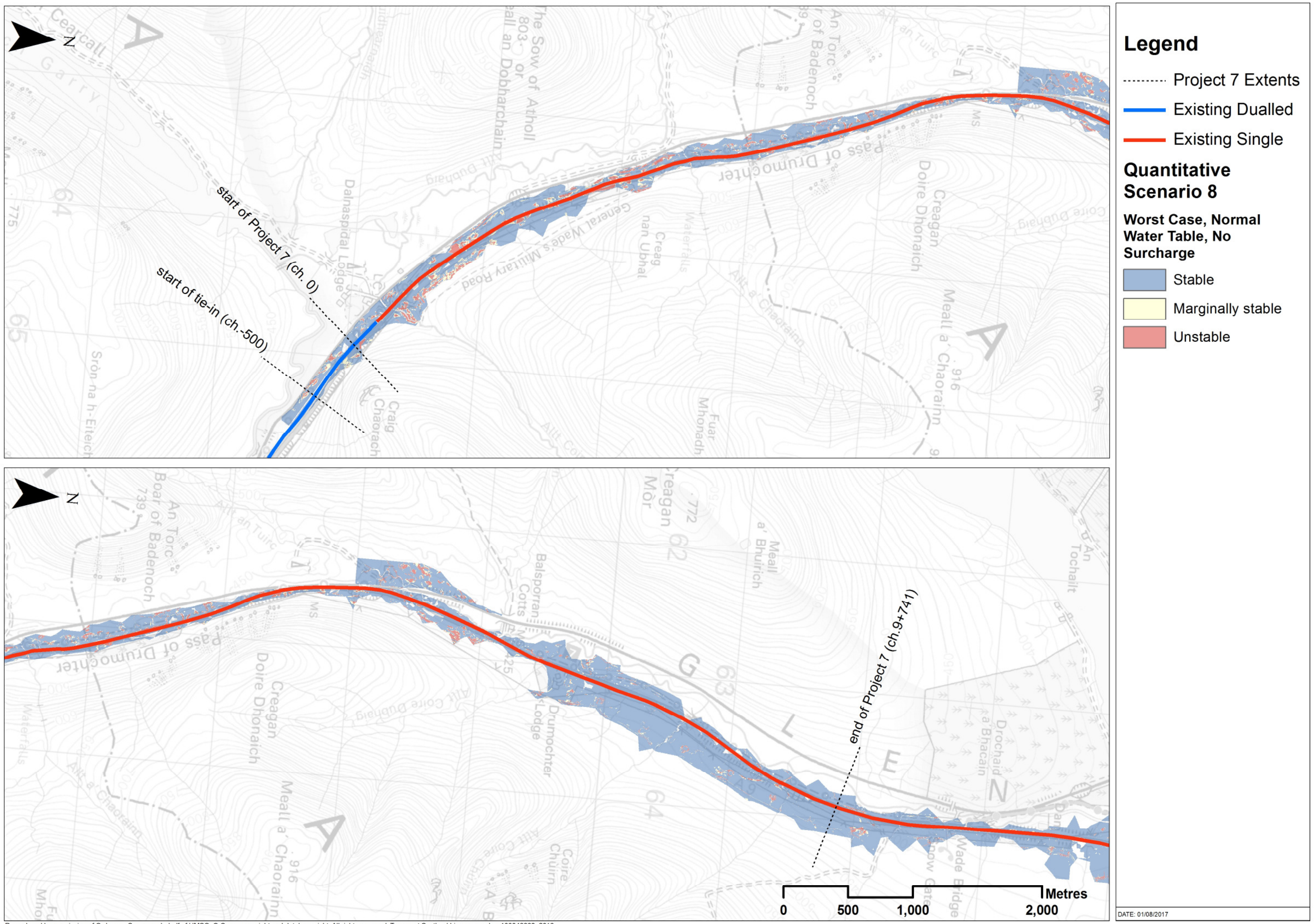

Figure 8: Quantitative Stability Assessment Scenario 8; Worst Case, Normal Water Table, No Surcharge

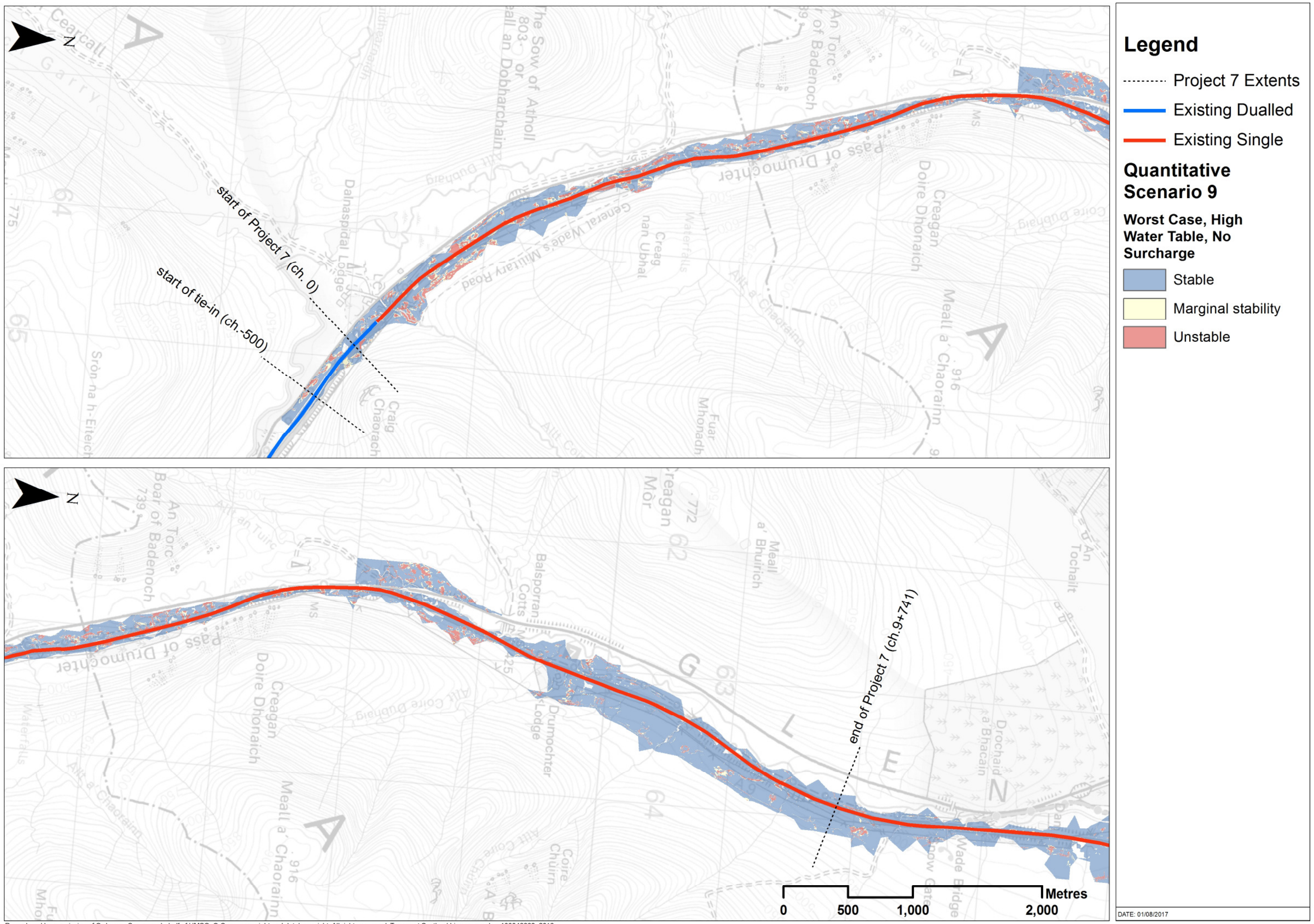

Figure 9: Quantitative Stability Assessment Scenario 9; Worst Case, High Water Table, No Surcharge

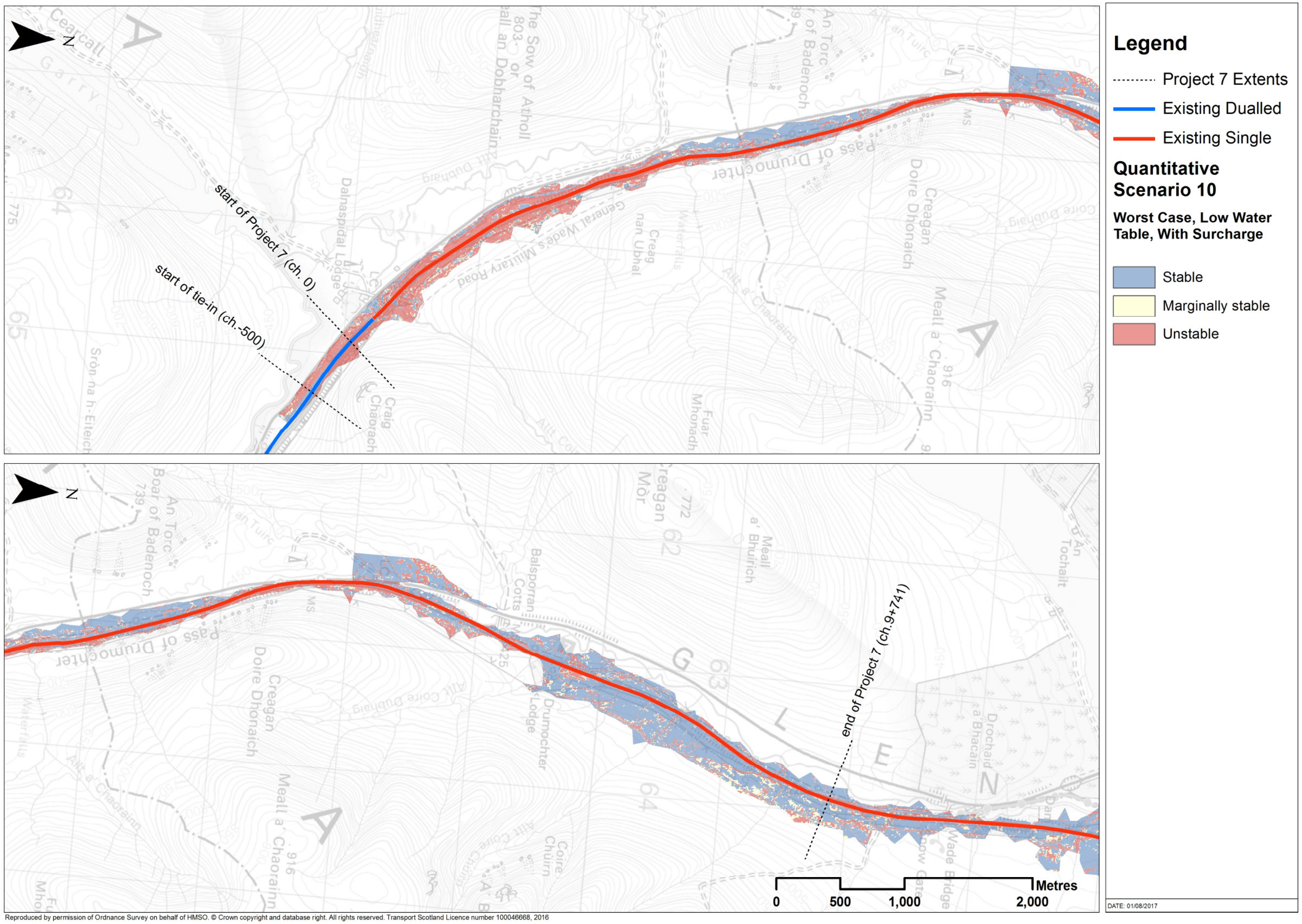

Figure 10: Quantitative Stability Assessment Scenario 10; Worst Case, Low Water Table, With Surcharge

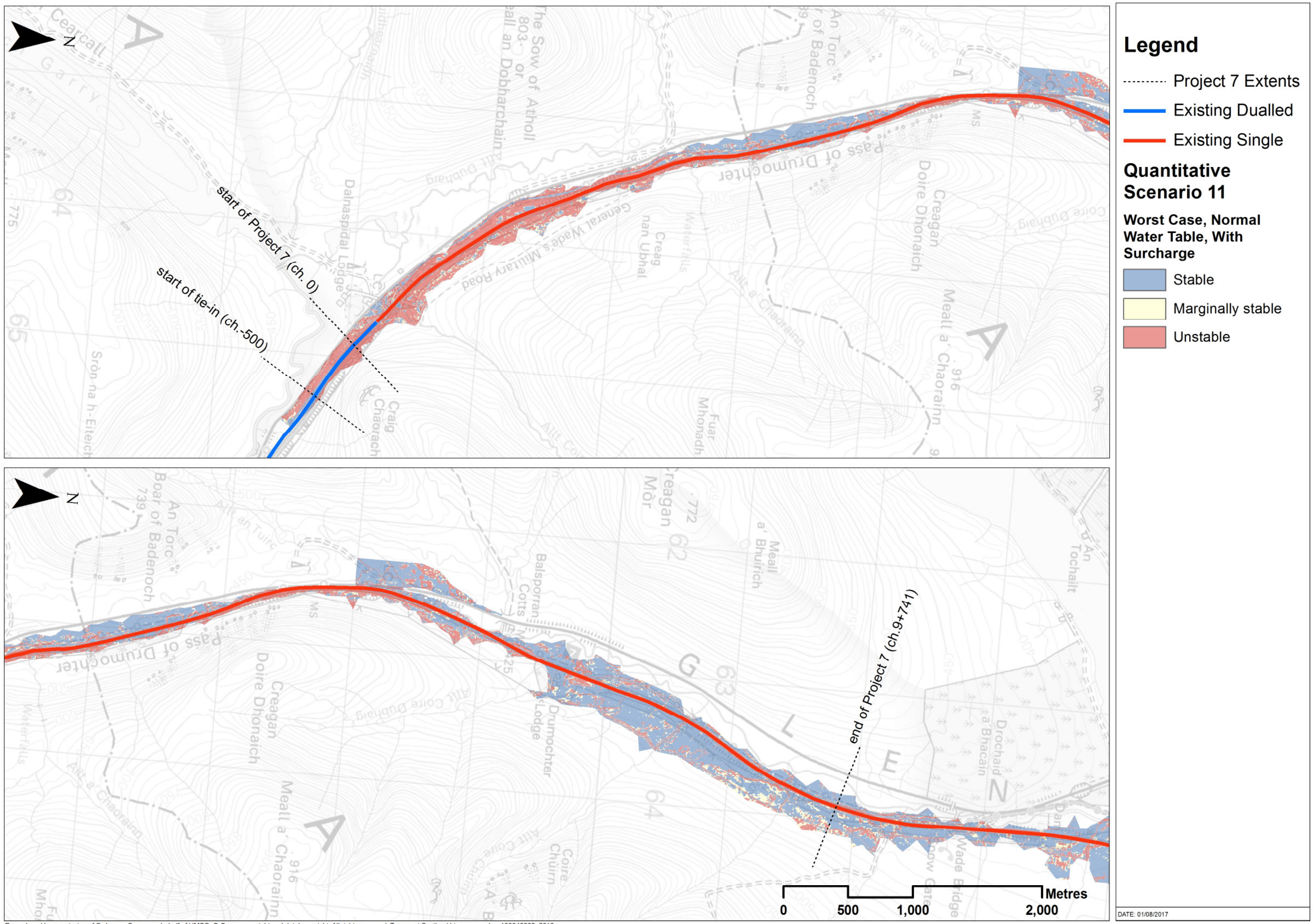

Figure 11: Quantitative Stability Assessment Scenario 11; Worst Case, Normal Water Table, With Surcharge

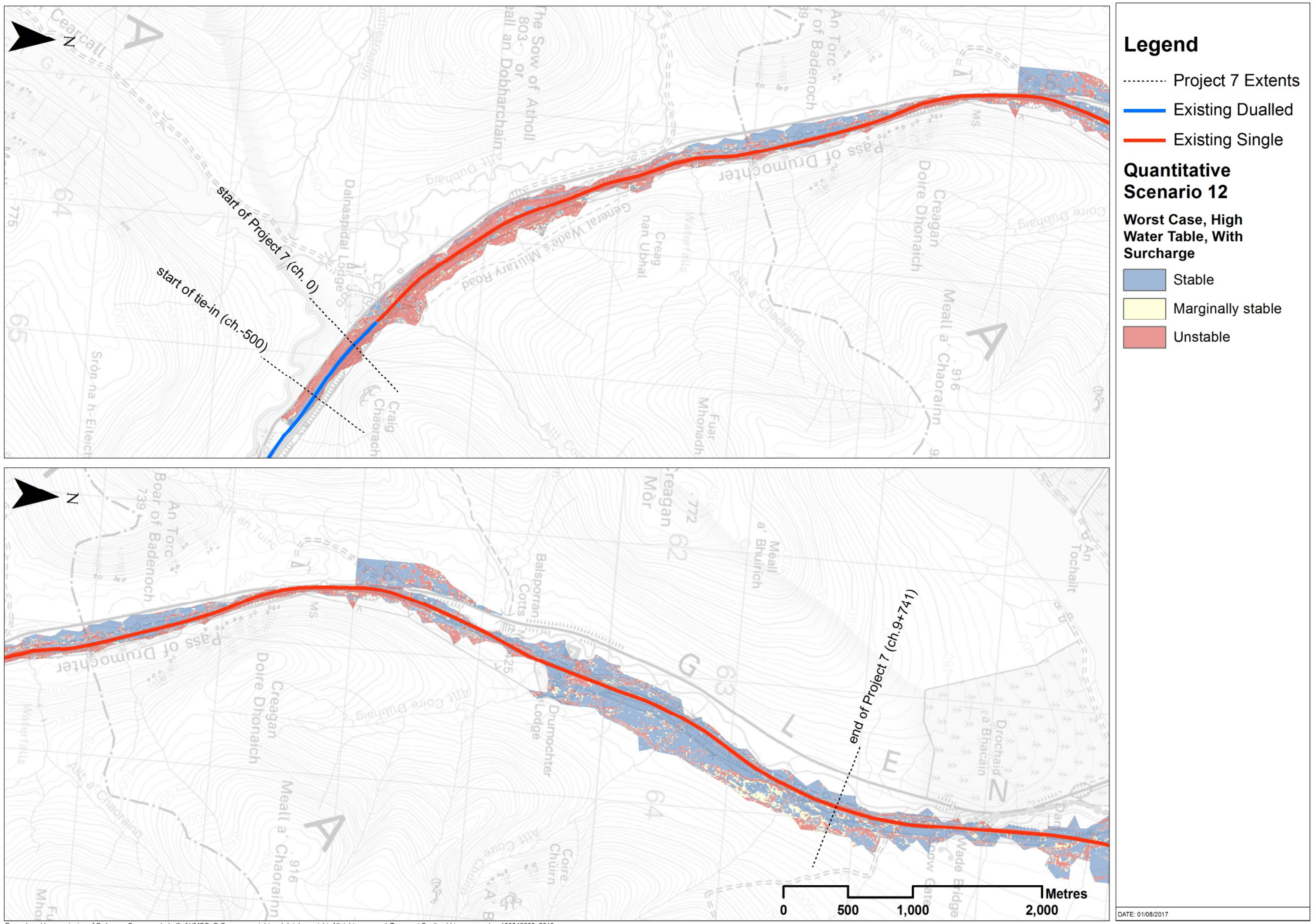

Figure 12: Quantitative Stability Assessment Scenario 12; Worst Case, High Water Table, With Surcharge