Appendix 10.5

Preliminary Peat Landslide Risk Assessment

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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 8 – Dalwhinnie to Crubenmore 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 and ground investigations (GI), characterise the study area conditions and peat characteristics in relation to peat instability hazard and undertake a preliminary peat slide 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 slope stability model supported by site-specific data or values for geotechnical properties of peat from published literature. The qualitative analysis is based on an understanding of the geomorphological and hydrological factors that contribute to peat slide hazard and their distribution across the study area. Conclusions are drawn based on the results of both methods.

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 and is particularly common in the uplands. It is therefore likely to be affected by the Proposed Scheme. However, raised bogs, intermediate bogs and fens are also sometimes affected. All 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 feature of peat upland landscapes, most commonly occurring in response to intense rainfall events but also as a response to 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 during construction. Terrestrial habitats in the path of a peat landslide may also be damaged by ground displacement and by burial by debris, and aquatic habitats damaged by incorporation of landslide debris in 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 peat slide of 250m^3 obstructed the London to Holyhead (A5) trunk road in 2005 (Nichol *et al*., 2007).

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** of this appendix.

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 the Scottish Executive (2006) guidance for electricity developments, 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 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 soil (where 'soil' is an engineering term for unconsolidated material, in this case peat)
- 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. 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 the limited site-specific data, results of the quantitative analysis should be treated cautiously and only bused 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 the 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. Furthermore, the quantitative analysis equations can also generate spurious results (e.g. 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 a quantitative analysis, a semi-quantitative analysis has also been adopted for the Proposed Scheme assessment and is described in detail within **Annex 10.5.2**. This also allows the study area conditions relevant to peat landside risk (which are not taken into account in a quantitative deterministic assessment) to be taken into account.

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 more to using GIS to interpolate levels of hazard between particular points. On a Proposed 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 a greater degree of flexibility.
- 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 approaches to assessing 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 further a receptor is from the source of a peat landslide event, the more the severity of the consequence of impact on that receptor reduces. This is for two reasons.

2.4.7 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 the receptor is away from the event source (Mills, 2002) because a) the mass movement may come to a stop before reaching the receptor and b) the mass movement is more likely to miss the receptor if it takes a different path to that containing the receptor.

2.4.8 Secondly, in general, 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.

2.4.9 In order 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 an according value (from one to five), representing the relative severity of the consequence.

2.4.10 Following the Lee and Jones (2014) calculation above, the final risk score has then been derived 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 **Drawing 10.1** (**Volume 3**), British Geological Survey (BGS) mapping identifies two areas of peat within the study area, one 130m east of the existing A9 at ch. 24,800, and the other adjacent to the west at Chainage (ch.) 25,600 near Cuaich. Published soil mapping (James Hutton Institute, 2013) shown in **Drawings 10.4** and **10.5** (**Volume 3**) also indicates complex peaty soils and peat in several parts of the study area, and dystrophic (acidic and nutrient-poor) basin and valley peat to the east of Dalwhinnie.

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, the presence of slopes ranging from flat to 75° in the catchments through which the Proposed Scheme passes, and the presence of indirect indicators of potential peat instability such as the presence of small water bodies (bog pools), springs, flushes and cross-slope artificial drainage suggest there is the potential for peat instability to occur in the form of first-time failures.

3.1.3 There are a range of existing sensitive receptors within the Proposed Scheme corridor, including the existing A9 carriageway, watercourses and water bodies that provide habitat for sensitive species, the Highland Mainline railway, various commercial and residential buildings and other infrastructure. The presence of these receptors introduces the possibility that the occurrence of a peat landslide could have a real consequence in terms of injury or economic impact and therefore, there is a *risk* associated with that as well as just the peat landslide hazard itself.

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

3.2 Land Use

3.2.1 Several land uses or human activities can affect the stability of peat including peat cutting, burning, grazing and construction activity. Afforestation has a particular influence as it can increase the mass of the peat slope through the growth of trees planted within the peat deposit, apply additional mass to the slope and can also reduce the volumes of water held in the peat, which increases the potential for formation of desiccation cracks which can form a direct route for water to reach the peat-substrate contact, increasing pore water pressures at this point during rainfall events.

3.2.2 Plantation woodland is present at numerous points throughout the permanent and temporary works boundaries, or is adjacent to the Proposed Scheme, often in the form of winter resilience shelter belt to reduce the risks presented to road users by snow drift. 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, with areas of fen and transition mire occurring locally in the valley bottoms. At the southernmost extent of the Proposed Scheme to the west of the existing A9, there is also a small area 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 either in the form of flows, slides or bursts.

3.3.2 There are no direct and conclusive indicators of peat instability, such as tension cracks, compression ridges or revegetating failure scars. Several areas of possible revegetated peat slides or bog burst scars identified during reviews of Google Earth imagery were inspected during site walkover visits (CFJV, 2016 and 2017), but no geomorphological indicators of ongoing peat instability were observed.

3.3.3 There are, however, geomorphological and hydrological features which indicate an elevated potential for peat instability to be present around the study area. These are principally bog pools, flushes and springs. No other features, which might be related to an elevated level of potential peat instability such as peat haggs or gullies or pipes were identified through review of satellite or aerial imagery, surveys or site walkovers.

3.4 Slope

3.4.1 Existing slopes across the Proposed Scheme and catchments upstream and upslope of it are shown in **Drawings 10.5.1** and **10.5.2** (**Volume 3**). Slopes within the permanent and temporary works boundaries range from flat to approximately 75°, but with the vast 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 Proposed Scheme boundaries, slopes are likely to fall within similar ranges albeit with a greater prevalence of steeper slopes, as elevation increases rapidly to the east in some areas. The presence of slopes within this range indicates that slope angles are present which could contribute to the occurrence of peat landsliding.

3.5 Peat Conditions

3.5.1 Approximately 5% of the permanent and temporary works boundaries of the Proposed Scheme do not presently have peat depth data coverage. However, desk-based information and ecological surveys indicate that peat in these areas is unlikely to be greater than 0.50m thick.

Peat Depth

3.5.2 The peat depth model and data indicate that the full range of recorded peat and peaty soil depths across areas investigated varies from 0.00 to 4.95m, as illustrated in **Drawings 10.12** to **10.20** (**Volume 3**). The majority of areas (approximately 70%) within the permanent and temporary works boundaries are underlain by peaty soil or topsoil less than 0.50m thickness, and at least 10% is underlain by no peat. Shallow peat (between 0.50 and 1.00m in thickness) is present underlying around 11% of the areas and only around 3% is underlain by deep peat (greater than 1.00m in thickness).

3.5.3 When compared to **Table 1** in **Annex 10.5.1**, the range of depths present indicates there is a possibility for a range of failure types which could occur within the Proposed Scheme and its environs.

3.5.4 The peat depth model is based on a substantial dataset acquired in the field and is therefore thought to be of sufficiently high 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 where there are limited field data.

Peat Characteristics

3.5.5 It has frequently been the case from investigation information available for the Proposed Scheme that no true acrotelm (i.e. that part of the peat profile which experiences fluctuations in water table) has been identifiable, with this frequently considered to be impacted or degraded.

3.5.6 Where identifiable however and against the von Post scale (Hobbs, 1986), the acrotelm across the Proposed Scheme has been recorded to predominantly comprise thin (0.05 to 0.11m) moderately decomposed (H3 to H5) layers and variably distinct semi-natural vegetation. Such decomposition is higher than would be expected for acrotelm that is healthy, and actively peat-forming – which was only locally observed adjacent to the Proposed Scheme at Dalwhinnie, where thicker (0.20m) layers showing no or only very slight decomposition (H1 to H3) and distinct vegetation were observed.

3.5.7 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 locally 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 was described as H7 to H8 (strong to very strong decomposition).

3.5.8 No evidence of H9 to H10 peat (nearly complete to completely decomposed) has been observed and humification of the peat appears to increase with depth as would be expected. In this respect, the implication is that deeper peat is likely to have a lower strength than that at shallow depth. However, where recorded, it is noted that samples have generally been classified highly in terms of fibre content or are described as fibrous and pseudo-fibrous, which may indicate that the peat has some degree of tensile strength and structure.

3.5.9 Estimated water contents in samples have covered the full range of possible values on the Von Post scale, with a general trend for water content to increase with depth.

Laboratory Testing

3.5.10 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** and **Appendix 10.1** (**Volume 2**).

3.5.11 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 1.04 and 1.48 Mg/m^3, dry densities between 0.14 and 0.68 Mg/m^3 and moisture contents of between 4.4 and 963%. Results for total organic carbon ranged from 1.5 to 62%, from 2.2 to 57% for total carbon content and from 6.9 to 93.2% for mass loss on ignition. pH values ranged from 3.6 to 6.7.

3.5.12 Shallow peat samples were recovered across a similar range of habitat types, with bulk densities ranging between 0.65 and 1.31 Mg/m^3, dry densities ranging from 0.07 to 0.27 Mg/m^3 and moisture contents of between 53 and 972%. Results for total organic carbon ranged from 3.6 to

57%, from 3.5 to 69% for total carbon content and from 18.5 to 97% for mass loss on ignition. pH values ranged from 3.8 to 6.3.

3.5.13 Within deeper peat profiles in areas of mire, wet heath, mosaics of these or swamp, bulk densities ranged between 0.27 and 1.67 Mg/m^3, dry densities ranged from 0.08 to 1.16 Mg/m^3 and moisture contents were recorded between 11 and 1,324%. Results for total organic carbon varied between 0.9 and 58%, between 1 and 59% for total carbon content and from 22.6 to 96.9% for mass loss on ignition. pH values ranged from 3.3 to 5.9.

3.6 Substrate

3.6.1 Available sampling and GI information has indicated that the nature of the substrate throughout the study area is predominantly granular. This corresponds well with BGS mapping, which indicates predominantly granular superficial deposits; including till, hummocky glacial deposits, alluvial fans and glaciofluvial deposits. However, a limited number of trial pits, boreholes and peat coring locations also identified the presence of clay.

3.6.2 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.

3.7 Peat Instability

Potential Occurrence of Peat Instability Upslope and Upstream

3.7.1 The primary focus of the hazard is the Proposed Scheme itself and its immediate environs. This is driven by, 1) the much higher likelihood of a peat landslide being generated by construction work for the Proposed Scheme itself and in the immediate vicinity rather than distant from it, 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 (with 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

3.7.2 Based on the data gathered, 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 peat mass). Consequently, both are taken into consideration in the risk assessment.

Potential Receptors of Peat Landslide Hazard

3.7.3 The Proposed Scheme is located within an existing transport corridor, passes through the Cairngorms National Park for its entire length and is close to environmentally designated areas including Special Protection Areas (SPA), Special Areas of Conservation (SAC) and Sites of Special Scientific Interest (SSSI). It is also close to other infrastructure including the Scottish Southern Energy (SSE)-operated Beauly to Denny Powerline and Aqueduct. There is therefore potential for peatslide hazards to have real consequences on various receptors, which are further detailed in terms of their consideration in the assessment in **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 scenarios have been tested in the analysis: 'worst case', which uses the worst possible values for each parameter; and a 'moderately conservative case', which uses more credible, but still pessimistic, values. The values for each of the parameters, 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 having the following values applied for water table height relative to 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 (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 results of the quantitative analysis are presented as figures in **Annex 10.5.3** and 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, with a limited number of areas of limited extent indicated to be unstable. However, these are likely to be 'false positives', 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 Examples of an area likely to be a false positive can be found in the footprint of a proposed embankment west of the mainline alignment at ch. 30,350, and between ch. 20,400 and ch. 20,450, to the west of the access road; where the analysis picks out the slopes at the edges of the Beauly-Denny powerline construction pad, where peat is likely to be have been removed since the data was collected prior to construction.

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

4.2.5 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 the area mentioned above (Paragraph 4.2.4) near ch. 30,350. The areas identified as being marginally unstable under Scenario 1 also now extend further, and in some cases, contain small areas which may be classified as unstable. An example of this lies to the east and upslope of the existing A9, near a proposed watercourse diversion at ch. 29,900.

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

4.2.6 Many of the areas identified as potentially unstable in Scenario 3 are coincident with those identified in Scenario 2 but have greater spatial extents, in some cases substantially. New areas of potential instability and areas where the extent of the potentially unstable area has expanded substantially include the following:

- Upslope and east of the mainline alignment between ch. 20,400 and ch. 20,500
- In the vicinity of the proposed Dalwhinnie junction
- West of the existing A9 (and mostly outside of the proposed permanent and temporary works boundaries) between ch. 24,000 and ch. 24,350
- East of the existing A9 under the footprint of the proposed access road for Cuaich, between ch. 25,700 and ch. 25,700.
- East of the existing A9 near the eastern edge of the proposed permanent and temporary works area between ch. 26,800 and ch. 26,950.
- East of the existing A9 between ch. 27,400 and ch. 27,450, within the footprint of the proposed works.
- Within the footprint of the earthworks for the Proposed Scheme at ch. 28,300
- In the vicinity of the watercourse diversions to the east of the existing A9 between ch. 29,800 and ch. 30,000.

4.2.7 The 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

4.2.8 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 similar increase in areas of indicated as being unstable. The common theme linking the areas is that they are on steeper slopes – embankments, cuttings, steeper natural hillside slopes and channel (natural and artificial) banks.

4.2.9 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

4.2.10 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

4.2.11 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

4.2.12 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. Nevertheless, 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 less than approximately 5° either with or without surcharges 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 proper assessment of the stability of chosen storage locations and earthworks during detailed design.
- The areas of potential instability and marginal instability vastly 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.

4.2.13 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 had limitations on the input parameters available. 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 considered likely to overstate the actual levels of hazard. Numerous areas of potential instability have been identified in the moderately conservative scenarios. Whilst these may be overstated, it is these areas where the peat instability hazard is most likely greatest and construction should proceed with caution as result.

4.3.2 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 assessment, which is effectively one of expert judgement about the degree of contribution a particular factor makes to the peat landslide risk at a particular location. The application of numerical values to the 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 **Drawing 10.5.1** to **10.5.19** (**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 'Negligible' or 'Unlikely' for the clear majority of areas within the temporary and permanent works boundaries. However, there are several areas where the peat slide hazard has been assessed as 'Possible'; these tending to be where steeper slopes, peat over 0.50m deep, oblique artificial drainage and forestry are present. General areas of note in this respect are:

- Small, fragmented areas to the east of the existing A9 between ch. 21,400 and the proposed Dalwhinnie Junction.
- To the east of the Proposed Scheme around the Dalwhinnie Junction and northwards towards the SSE aqueduct crossing, along lines of artificial drainage and deeper peat coincident with sloping ground.
- Within and to the east of the footprint of proposed cutting east of the mainline, between ch. 25,000 and ch. 25,500, principally along the convexity at the top of the existing cutting and artificial drainage lines.
- West of the proposed permanent and temporary works boundaries between ch. 25,450 and 25,550 within Lechden Woods.
- To the east of the proposed mainline at ch. 25,750, at the location of the proposed Cuaich access road, and SuDS basins 258 and 259.
- To the east of the proposed mainline between ch. 26,600 and ch. 26,800 along existing artificial drainage and along the convexity at the top of the existing cutting.
- West of the mainline between the existing A9 carriageway and the Highland Mainline railway, between ch. 29,400 and ch. 29,700, and between ch. 30,150 and ch. 30,200.
- East of the mainline around ch. 29,350 and between ch. 29,550 and ch. 30,250 along the convexity at the top of the existing cutting and on the sloping ground above.

5.2.3 There are no areas where the peat slide hazard is assessed as being ‘Probable’ or ‘Almost Certain’.

Bog Burst Hazard

5.2.4 **Drawing 10.5.12** (**Volume 3**) shows the resulting bog burst hazard across the study area, which has been assessed as below ‘Negligible’ for the vast majority of areas within the temporary and permanent works boundaries. This is because the depth of the peat is considered too low to be significant for this mode of peat instability. However, there are numerous and reasonably extensive 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:

- Around the proposed Dalwhinnie Junction, particularly northwards in the vicinity of the SSE Aqueduct crossing.
- East of the mainline at Cuaich.

5.2.5 Other areas identified include in the vicinity of Lechden Woods and on steeper slopes north of the Allt Garbh (ch. 29,200) as far as ch. 30,200, and in an area of access track to the east of the mainline between ch. 30,700 and ch. 30,850. However, in some of these areas, peat is shallow, indicating that contributors other than peat depth and slope are driving the bog burst hazard and therefore, the model is leading to a somewhat conservative conclusion.

5.2.6 No areas of ‘Probable’ or ‘Almost Certain’ bog burst hazard have been identified.

5.3 Consequence Severity

5.3.1 The consequence severity describes the potential impact 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 differences in consequence severity at specific distances between bog bursts and peat slides, 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 around Dalwhinnie, where there is an increased number of occupied buildings, infrastructure and the River Truim.

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 **10.5.19** (**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.

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 less extensive, but still reasonably common. 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 **Table 3**.

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**; 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 scheme corridor with many other environmental receptors, it is inevitable that the Proposed Scheme will potentially affect, or potentially 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. 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 incorporated during construction:

- Use of appropriate supporting structures around peat excavations to prevent collapse and the development of tension cracks
- Avoid, wherever possible, cutting trenches or aligning excavations across slopes (which may act as incipient back scars for peat failures)
- A series of 'stop rules' (weather dependent criteria) should be identified under which construction in areas of moderate or higher peat landslide risk should cease, using local meteorological data to monitor whether the 'stop rules' are met
- In order 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 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 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
  (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 geotechnical engineer, engineering geologist or geomorphologist to identify any ground instability concerns.

6.4 Good Practice following Construction

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

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 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 quarterly basis for the first year after construction and annually thereafter. In the event that unanticipated ground conditions are discovered during scheduled inspections, additional more frequent and 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:** Installation of 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 environmental 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 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:

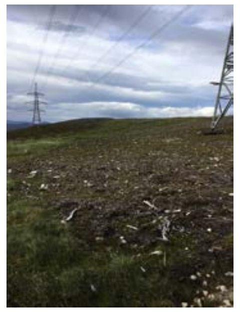
- **Catch wall fences:** Where the potential for peat landslides has been identified, catch fences positioned downslope of the suspected or known landslide prone area can slow or halt run-out (Tobin, 2003). Catch fences should be engineered into the peat substrate. Fencing may require periodic inspection for removal of debris
- **Catch ditches:** Ditches may also 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

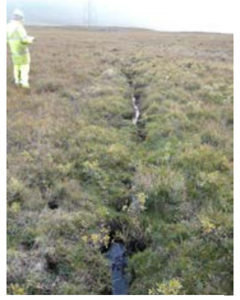
6.6.1 The peat landslide risk, and the general mitigation measures described to limit such risk, should be included in any risk register related to construction of the Proposed Scheme, such as that which may accompany the Construction Environment Management Plan (CEMP). The locations of concern and suggested 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’ 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.

Table 3: Preliminary Peat Stability Risk Register

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation Guidance
-	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 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.
ch. 20,350 to ch. 20,400	Moderate	Area of both marginal stability and instability located on both sides of the mainline	West (downslope) of the existing A9		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.
ch. 20,400 to ch. 20,450		-	Deep peat area around Beauly Denny pylon at grid reference 264,062 782,003. East (upslope) of the mainline.		Boggy below area grubbed up for pylon construction. Hazard here likely exaggerated by presence overlap between an area of interpolated deep peat and slopes around the pylon. Outside of permanent and temporary works boundary.	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.
ch. 20,550 to ch. 20,600	-	Small areas of marginal stability and instability upslope (east) of the proposed mainline. Associated with track cutting. Likely false positive.	-	-	Not directly observed.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Protect working areas with catch fences.
ch. 20,700 to ch. 21,500	Moderate	Area of marginal stability, verging into instability, directly underneath proposed mainline footprint	Relatively small, fragmented areas east of the mainline		Not all directly observed. No evidence of instability where observed at between ch. 21,000 and 21,050. Potential instability in models created by steeper cutting slope.	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.
ch. 21,950	Moderate	Relatively extensive areas of indicated instability throughout the Dalwhinnie junction on both sides of the proposed infrastructure	Relatively extensive area ca. 70m upslope (east of the existing A9)	 	No instability 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. Trees to remain. Sheep pen to be added in this area. Recommend no additional water is introduced into this area from construction of the pen.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation Guidance
ch. 22,150 to 22,400	Moderate	Small area ca. 100m west of the existing A9 at ch. 22,300	Multiple areas mostly on the north (right bank) side of the Allt Coire Bhathaich, picking out slightly elevated slopes, deeper peat and proximity to the Bhathaich and artificial drainage. Partly within construction footprint, partly outwith construction footprint but within permanent and temporary works boundaries and partly completely outside		Photo shows area highlighted by quantitative assessment. Quantitative assessment has picked up steeper slope of hummock of granular material. Deeper peat is present in adjacent basin but not on the slopes.	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. Protect Allt Coire Bhathaich from minor run-out with catch fences. Note the presence of the offtake (dam) for a pipe which runs to the SSE aqueduct where the Allt Coire Bhathaich crosses the eastern edge of the permanent and temporary works boundary.
ch. 22,450 to ch. 22,500	-	Area of indicated instability indicated south of the access road linking the existing A889 to the Dalwhinnie Junction. Overlaps at northern end with proposed embankment and in south with temporary works area.	-		Area of deep peat, but generally very flat with no evidence of instability so likely false positive.	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. Excavations should be avoided if possible and appropriately supported where not.
ch. 22,550 to 22,850	-	Multiple small areas of indicated instability indicated predominantly east of existing A9 (with two small areas to west). Predominantly within the footprint of the proposed works, and all within the proposed temporary and permanent works boundaries	-	  	No evidence of instability observed. These areas are unlikely to be problematic. Area within proposed eastern junction loop has slight slope and natural drainage line. Area to west of existing A9 at ch. 22,700 is likely a false positive.	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.
ch. 22,650 to ch. 22,800	-	Extensive areas of indicated instability ca. 160m east of the existing A9 Dalwhinnie predominantly outside of the permanent and temporary works boundaries.	-	 	No evidence of instability. Deeper peat and slight slope in west, steeper slope in east (but with less peat) likely generating possibility of instability in model in extreme conditions in quantitative model.	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. Avoid surcharges and excavation in the identified area.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation Guidance
ch. 22,850 to ch. 23,500	Moderate	One very extensive area of indicated instability between ch. 22,850 and ch. 23,100. wholly outside of permanent and temporary works boundaries Smaller discontinuous areas between ch. 23,050 and ch. 23,500.	Extensive semi continuous area to east of the junction, predominantly outwith the permanent and temporary works boundaries, driven by deep peat and slight slopes, but focused on artificial and natural drainage lines.	   	Slightly sloping low angle area crossed with artificial drainage. Deep peat.	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. Avoid surcharges and excavation in the identified areas. Protect drainage channels to prevent minor runouts into watercourses.
ch. 23,650 to ch. 23,800	Moderate	-	Very small areas between existing A9 and existing aqueduct.	-	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.
ch. 23,950 and ch. 24,350	Moderate	Areas of indicated instability located to the west (downslope) of the route alignment. Picks out steeper slopes at edge of terrace. Well outside permanent and temporary works boundaries.	West (downslope) of the mainline and east (upslope) of the aqueduct. Appears to pick out artificial drainage lines in areas of deeper peat. Well outside of permanent and temporary works boundaries	-	Not directly observed.	Where within the permanent and temporary works boundaries, 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.
ch. 24,900 and ch. 25,500	Moderate	Small area of marginal instability under footprint of cutting at ch. 24,950	Fragmented areas east (upslope) of the proposed mainline. Mostly following the line of the top of the existing cutting. (i.e. the steeper slope with an associated convexity)	-	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. Protect existing A9 from minor runouts during construction.
ch. 25,450 to ch. 25,600	Moderate	-	Area of moderate risk driven by presence of forestry and proximity of deep peat. Predominantly outwith permanent and temporary work boundaries, but some limited overlap with proposed watercourse diversions and drains.	-	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. Protect existing watercourses and drains from minor runouts during construction.
ch. 25,700 to 25.750	-	Small areas of indicated marginal stability and instability underneath junction to the east. Sits fully within proposed access track alignment and likely to be removed.	-		Area of deeper peat at base of steeper slope (not formed in peat). Likely arises due to slightly steeper slope.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Protect working areas with catch fences.
ch. 26,200 to 26,250	-	Small area of indicated marginal stability underneath mainline footprint	-	-	Not directly observed	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Protect existing A9
ch. 26,600 and ch. 27,000	Moderate	Sections of indicated marginal stability, verging into instability, located to the east of the mainline following the approximate line of proposed watercourses	Fragmented areas east (upslope) of the proposed mainline	-	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. Consider protection of watercourses and existing A9 from minor runouts during construction.
ch. 27,400 to ch. 27,450	-	Small area of indicated marginal stability underneath mainline footprint. Picks out steeper (cutting) slope.	-	-	Not directly observed.	Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Protect working areas with catch fences.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation Guidance
ch. 27,450 to ch. 27,600	Moderate	Small area of indicated marginal stability lying underneath watercourse footprint.	West (downslope) of the mainline, following the line of artificial drainage	-	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. Consider protection of existing A9 and natural watercourse with catch fences during construction.
ch. 28,250 to ch. 28,300	Moderate	Discrete area of indicated instability located under the footprint of a proposed cutting/ watercourse diversion	East (upslope) of the proposed mainline, close to the edge of the permanent works boundary	-	Not directly observed.	Undertake quantitative stability analysis prior to construction and mitigate as required if risk confirmed. Follow general guidance measures in **Section 6** on how to reduce peat landslide risks. Consider protection of existing A9 natural watercourse with catch fences during construction.
ch. 29,300 to ch. 29,400	Moderate	Small area of indicated marginal instability underneath proposed embankment slope at ch. 29,350	Fragmented areas east (upslope) of the proposed mainline driven by proximity of watercourse and existing A9		Falls at southern end of proposed mitigation area. Unlikely to be problematic, provided any peat placed is tapered towards watercourse and watercourses is protected from minor runouts during construction. Note only foreground of photo (bare area) is within area identified as moderated risk. Slight or negligible risk beyond.	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.
ch. 29,400 to ch. 29,700	Moderate	-	West (downslope) of the mainline. Predominantly outwith the permanent and temporary works boundary, but relatively extensive overlap with proposed embankment and watercourse diversions.	-	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.
ch. 29,550 to ch. 29,850	Moderate	Small area of indicated instability ca. 55m east of the existing A9 on sloping ground above existing cutting (see photo). Within footprint of proposed cutting.	East (upslope) of the existing A9. Associated either small watercourses or the convexity at the top of the existing cutting.		No instability evident.	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. Consider protection of existing A9 and natural watercourse with catch fences during construction.
ch. 29,850 to ch. 30,000	Moderate	Two large areas of indicated instability located ca. 80m east of the existing A9 above the existing cutting. These intersect with proposed watercourse diversions and temporary works areas.	East (upslope) of the existing A9. Linear areas associated with existing cut off drains above the existing cutting and further upslope partly intersecting with a proposed watercourse and temporary works area.	   	No obvious evidence of recent instability and slopes are gentle. However, surface water is plentiful and there is an area of exposed substrate at the margins of the area of deeper peat. Topography is also undulating. Unlikely to indicate major peat instability but advise treat area with caution, protecting existing A9 and works below from possible runouts during construction.	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. Consider protection of existing A9 and natural watercourse with catch fences during construction.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, 2017)	Area Observations (CFJV, 2017)	Risk Mitigation Guidance
ch. 30,100 to ch. 30,150	Moderate	-	West of the existing A9 adjacent within the footprint of a proposed embankment and adjacent to a proposed watercourse diversion.		No signs of instability on this slope. Additional probing during reconnaissance in June 2017 indicated only very shallow peaty topsoil.	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.
ch. 30,100 and ch. 30,350	Moderate	-	East (upslope) of the existing A9 above existing cutting and associated with artificial drainage.	-	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. Consider protection of watercourse diversion being constructed to prevent minor runouts entering the channel during construction.
ch. 30,300 to ch. 30,350	-	Discrete area of indicated instability fringed by moderate instability between ch. 30,300 and 30,400, intersecting with proposed embankment slope	-	 	No peat present on the slope. Mineral soil present. Probably false positive.	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.
ch. 30,650 to ch. 31,850	Moderate	-	East (upslope) and west (downslope) of the existing A9, partly within the footprint of proposed scheme, picking out areas of forestry, drainage and steeper slopes.	-	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.

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 indicate 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 available GI data. 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 The majority 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 specific mitigation measures implemented to reduce any risks which are confirmed. No areas have been assessed as being above ‘Moderate’ risk from a peat slide or bog burst hazard.

7.1.4 The risk presented by peat landsliding for the Proposed Scheme should be included as a risk in the appropriate risk registers during construction. 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.

7.1.5 It is difficult to directly compare the results of the quantitative and semi-quantitative assessments undertaken, 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.

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Annex 10.5.1

The Nature of Peat Instability

Nature of Peat Instability

Peat instability manifests itself in several 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 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

A number of 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.

Whilst peat depth and slope alone (particularly simply increasing peat depth and slope alone) are not the only controls on peat instability, 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. As such, peat depth and slope have been weighted by a factor of two, resulting in a model more consistent with site observations.

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 + Peat depth score + 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

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 10.12** to **10.20** (**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)
0.0m	No peat present	0	0
<0.5m	No true 'peat' cover, any failure would be classed as 'peaty debris slide' and not a peat slide.	1	0
0.5 - 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 burst 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 subparallel 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 concavity exert an influence on peat landsliding, but the observational and empirical evidence for both being so; an approach which allocates higher scores to both the extreme convexities and concavities across the Proposed Scheme has been adopted.

Curvature has been determined through analysis of a DTM in GIS. In order 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

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 the likelihood 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 this is considered 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 has been to make a simple assessment of the peat landslide potential in each of the catchments already defined by hydrological studies in **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 in the area of 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. 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 hit for each category, taking into account the weighting for peat depth and slope, is 36. 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

Weighted Scores	Likelihood of Occurrence	Score
21-26	Almost Certain	5
17-21	Probable	4
12-16	Possible	3
7-11	Unlikely	2
1-6	Negligible	1
0	Practically none	0

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 powerline pylons, inhabited buildings, the SSE Aqueduct, weirs, dams, filter beds, tracks and major paths (including the NCN7 cycleway), the Highland Mainline railway, cultural heritage assets and private water supplies.

It should be noted that the consequence of a peat landslide has been assessed 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 (**Drawing 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 nature of 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 Mainline 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 or serious injury. Such receptors include watercourses and waterbodies (which are sensitive habitats and may convey peat landslide debris much further than on land), SSE Beauly-Denny powerline pylons and the SSE Aqueduct.

'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 in 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

Receptor	Receptor type	Consequence at source	
		Peat slides	Bog bursts
Pylon	Infrastructure	High	High
Building	Infrastructure	Very High	Very High
Aqueduct	Infrastructure	High	High
Weirs	Infrastructure	Moderate	Moderate
Dams	Infrastructure	High	High
Filter beds	Infrastructure	Moderate	Moderate
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, except for one that becomes channelised, is likely to reduce over long distances due to the loss of energy as the event runs out. As such an adjustment 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	Aqueduct	Weirs	Dams	Filter beds	Tracks, major paths	Railway	Cultural heritage	Camp	Private water supplies
Peat slide	At Source	H	H	VH	H	VH	H	M	H	M	H	VH	M	H	H
	0 to 50	H	H	VH	H	VH	H	M	H	M	H	VH	M	H	H
	50 to 100	M	M	H	M	H	M	L	M	L	M	H	L	M	M
	100 to 250	L	L	M	L	M	L	VL	L	VL	L	M	VL	L	L
	250 to 500	VL	VL	L	VL	L	VL	VL	VL	VL	VL	L	VL	VL	VL
	500 to 750	VL	VL	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	Aqueduct	Weirs	Dams	Filter beds	Tracks, major paths	Railway	Cultural heritage	Camp	Private water supplies
Bog burst	At Source	H	H	VH	H	VH	H	M	H	M	H	VH	M	H	H
	0 to 50	H	H	VH	H	VH	H	M	H	M	H	VH	M	H	H
	50 to 100	H	H	VH	H	VH	H	M	H	M	H	VH	M	H	H
	100 to 250	M	M	H	M	H	M	L	M	L	M	H	L	M	M
	250 to 500	L	L	M	L	M	L	VL	L	VL	L	M	VL	L	L
	500 to 750	VL	VL	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 16: 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 17: 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
Practically none	0	Proceed with construction adhering to generic mitigation measures to reduce peat landsliding risks and protect sensitive receptors

Annex 10.5.3

Quantitative Hazard and Risk Analysis Figures

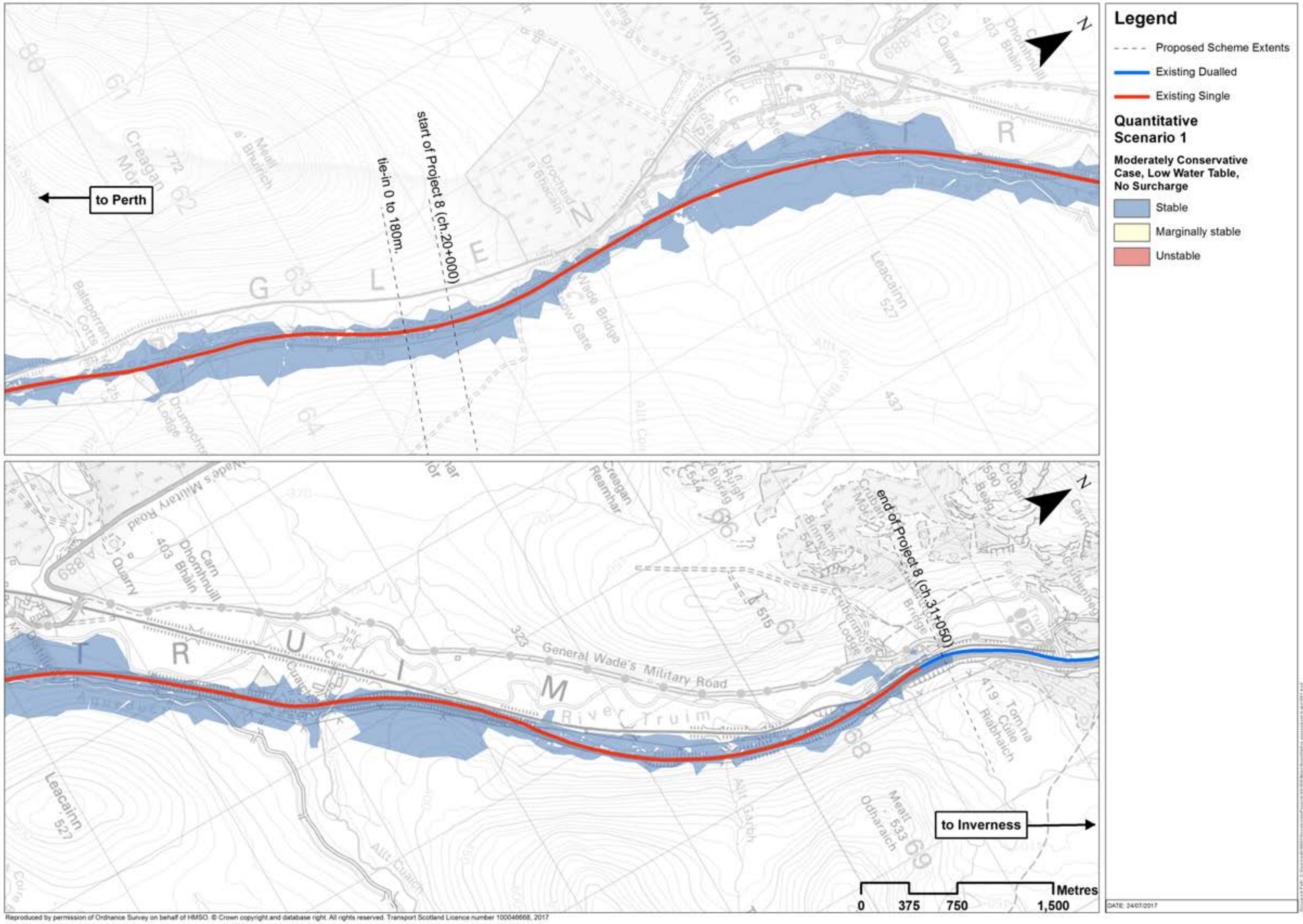

Figure 1: Quantitative Stability Assessment Scenario 1; Moderately Conservative Case, Low Water Table, No Surcharge

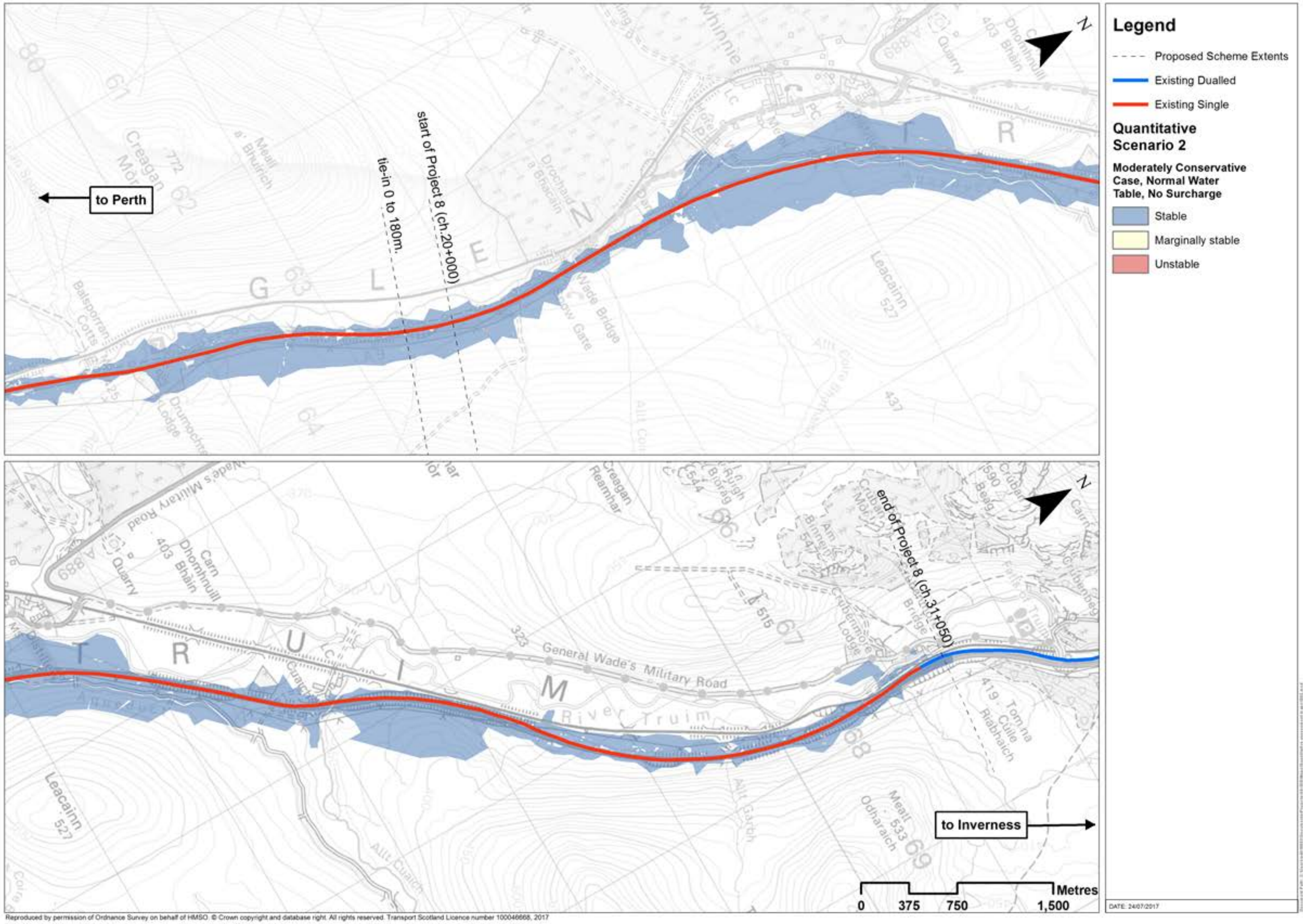

Figure 2: Quantitative Stability Assessment Scenario 2; Moderately Conservative Case, Normal Water Table, No Surcharge

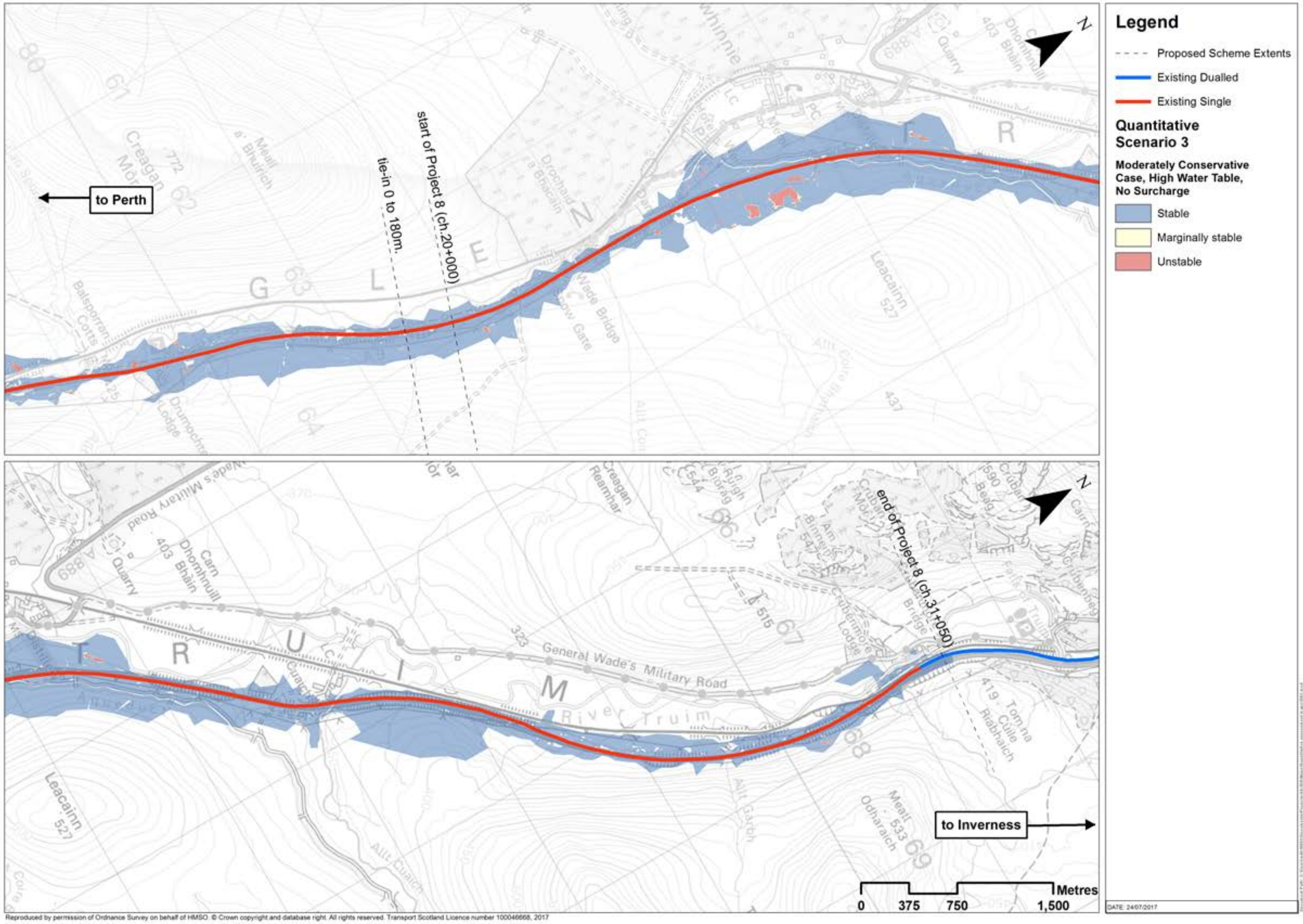

Figure 3: Quantitative Stability Assessment Scenario 2; Moderately Conservative Case, High Water Table, No Surcharge

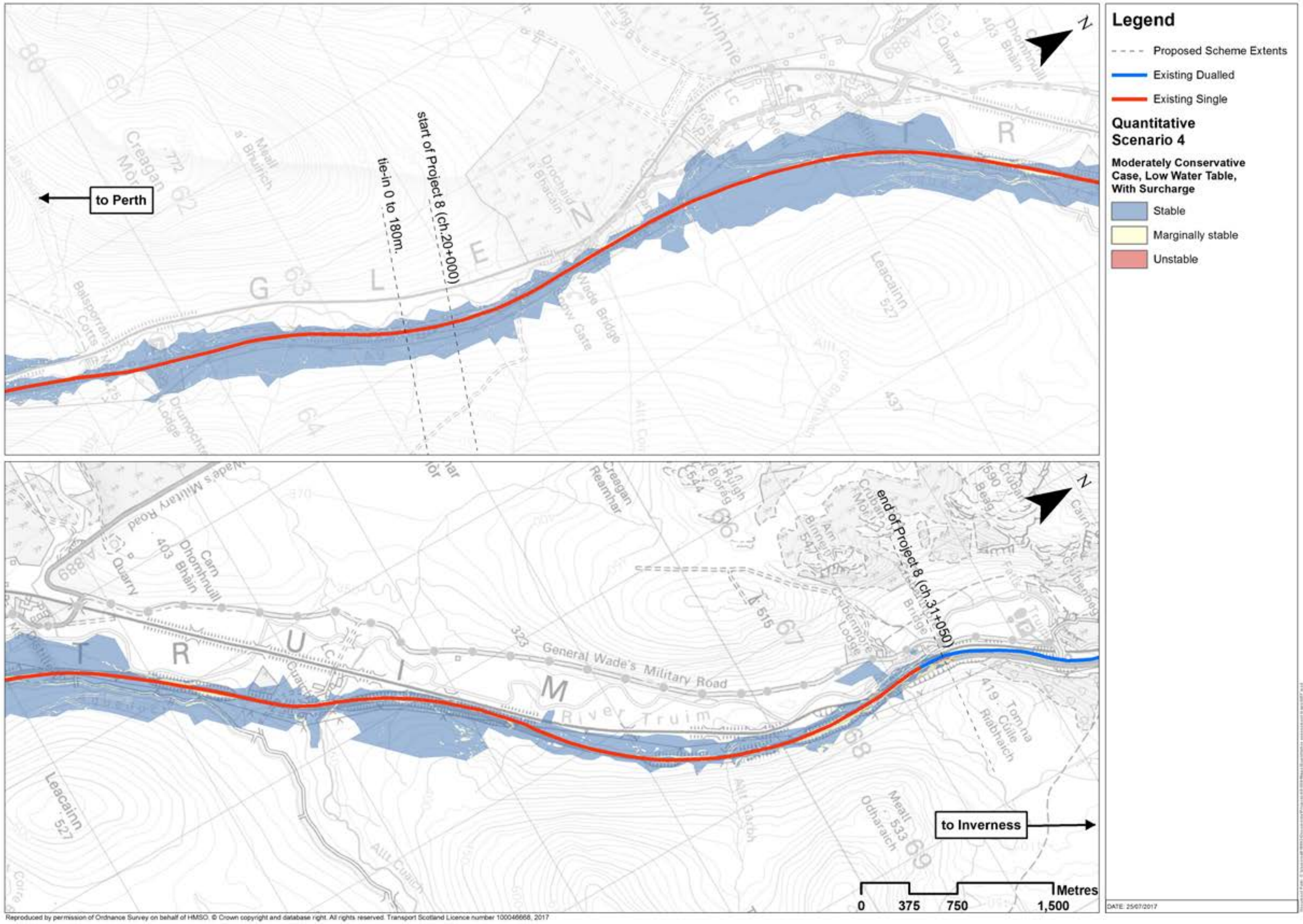

Figure 4: Quantitative Stability Assessment Scenario 4; Moderately Conservative Case, Low Water Table, With Surcharge

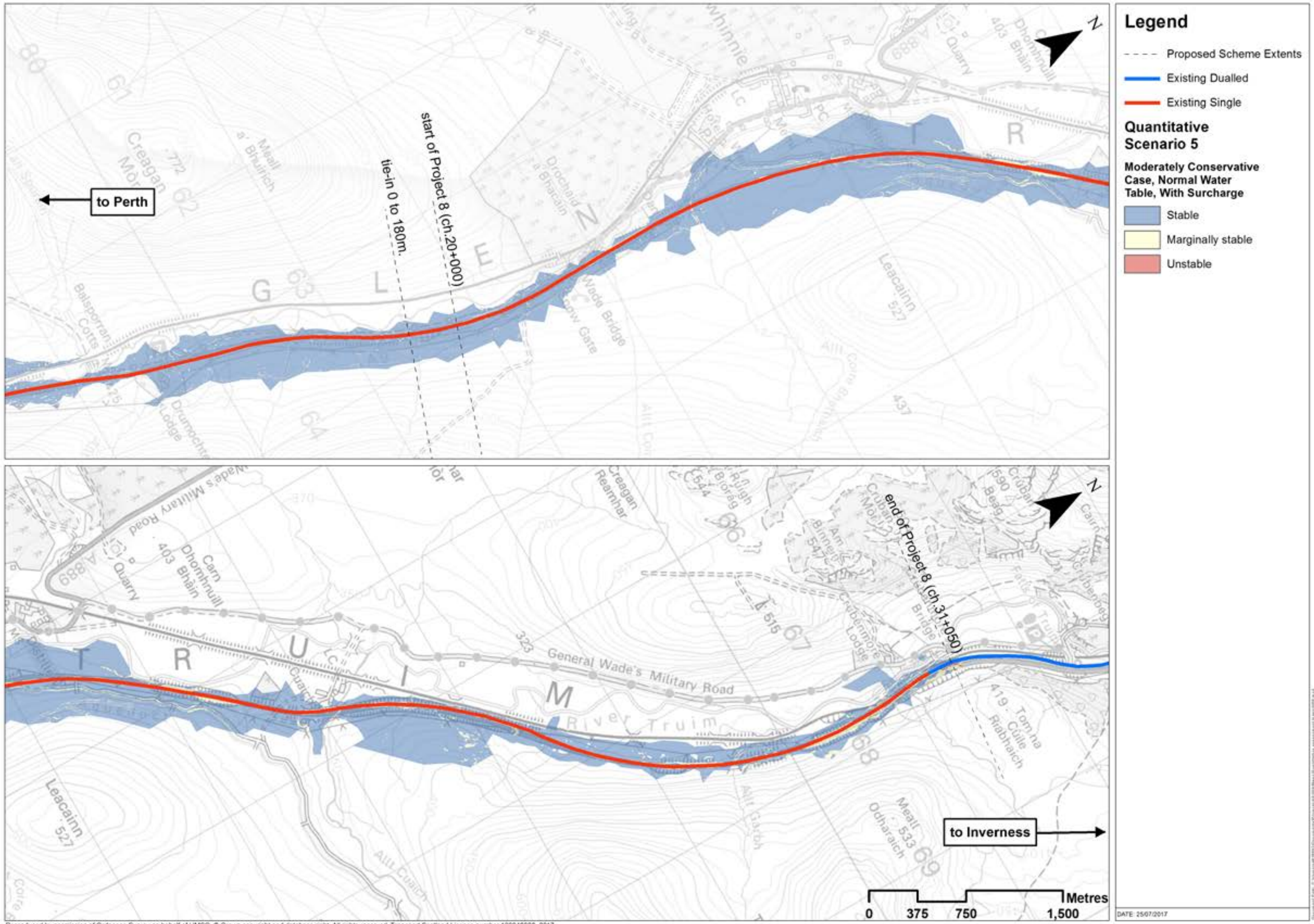

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Figure 5: Quantitative Stability Assessment Scenario 5; Moderately Conservative Case, Normal Water Table, With Surcharge

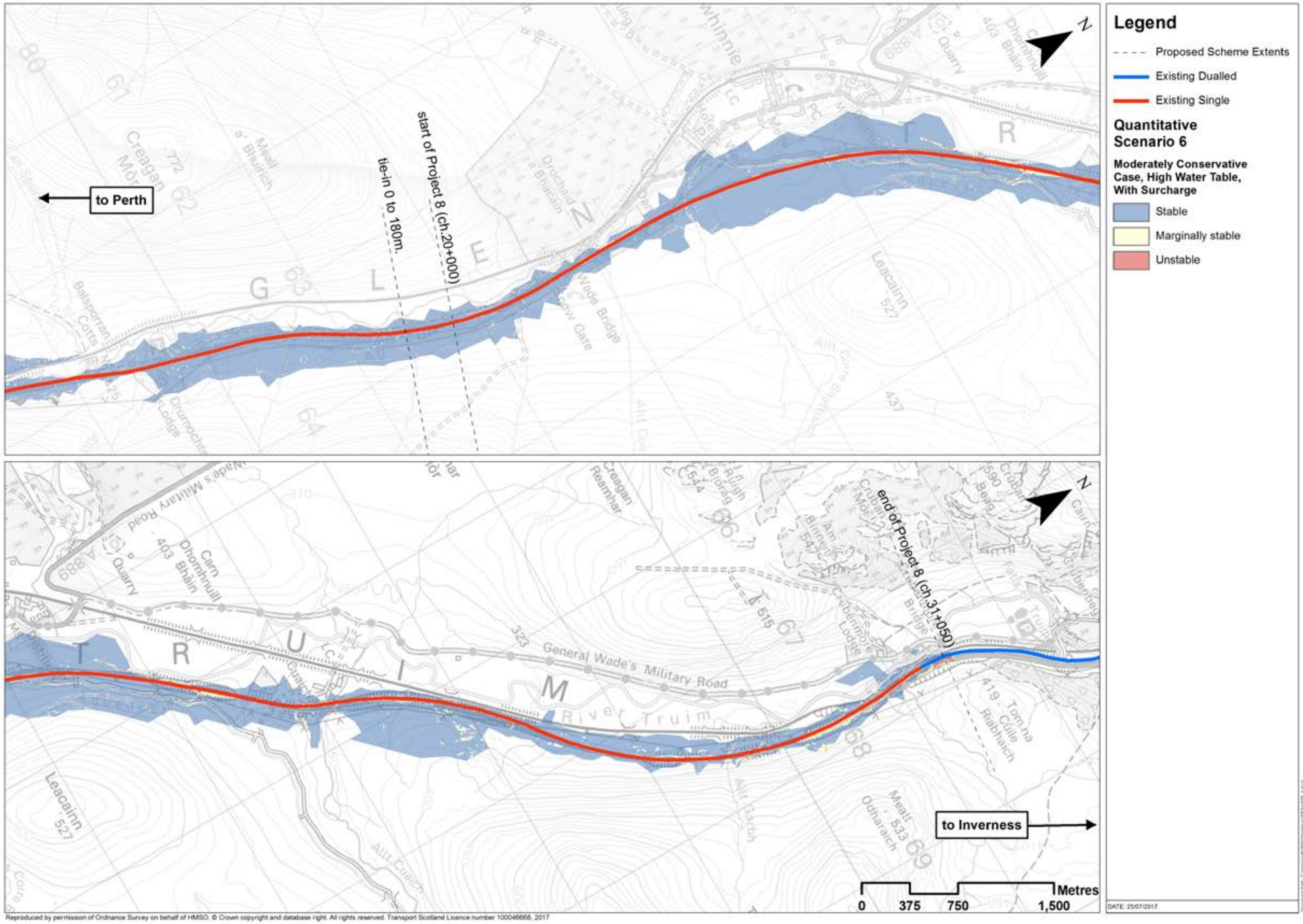

Figure 6: Quantitative Stability Assessment Scenario 6; Moderately Conservative Case, High Water Table, With Surcharge

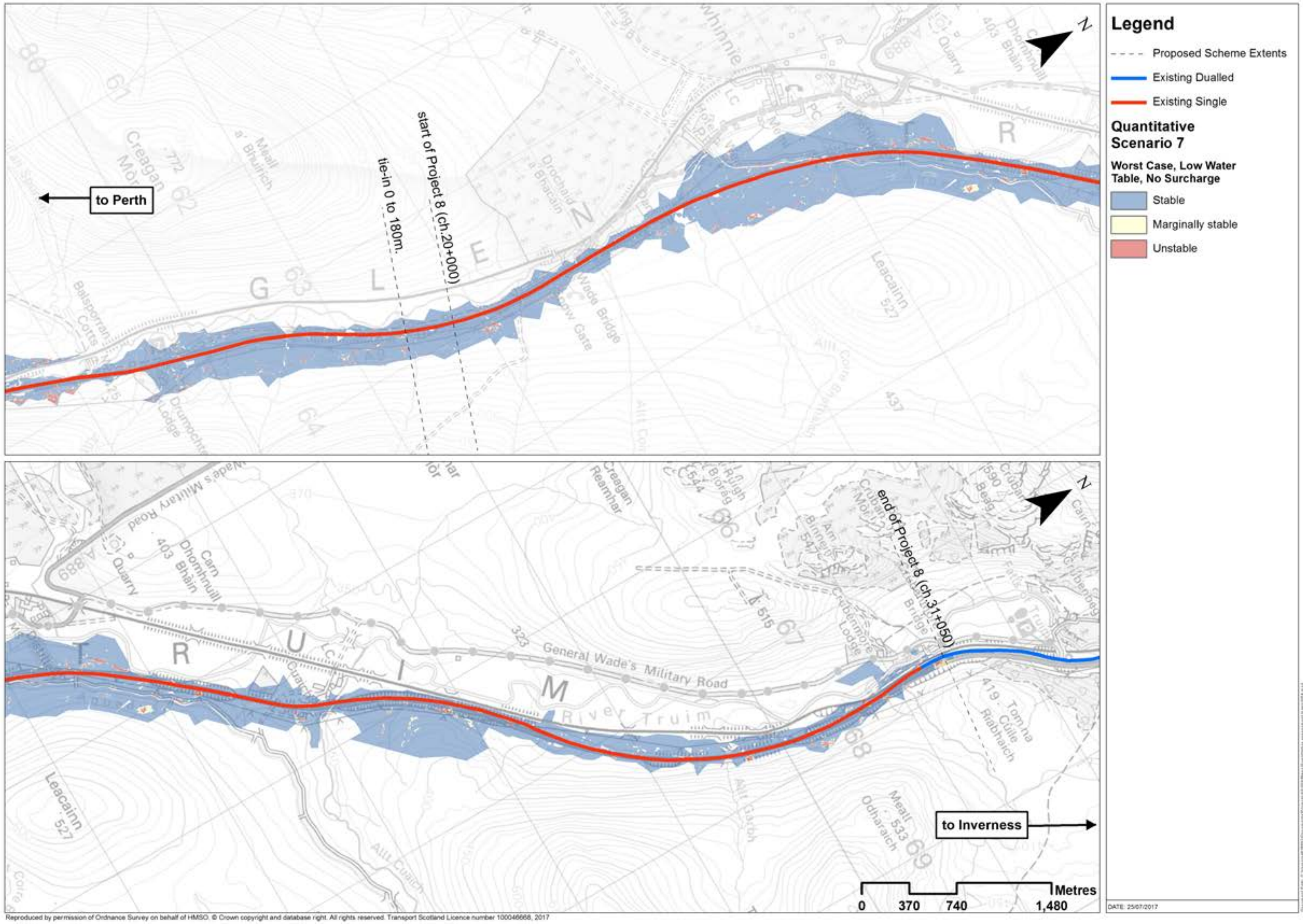

Figure 7: Quantitative Stability Assessment Scenario 7; Worst Case, Low Water Table, No Surcharge

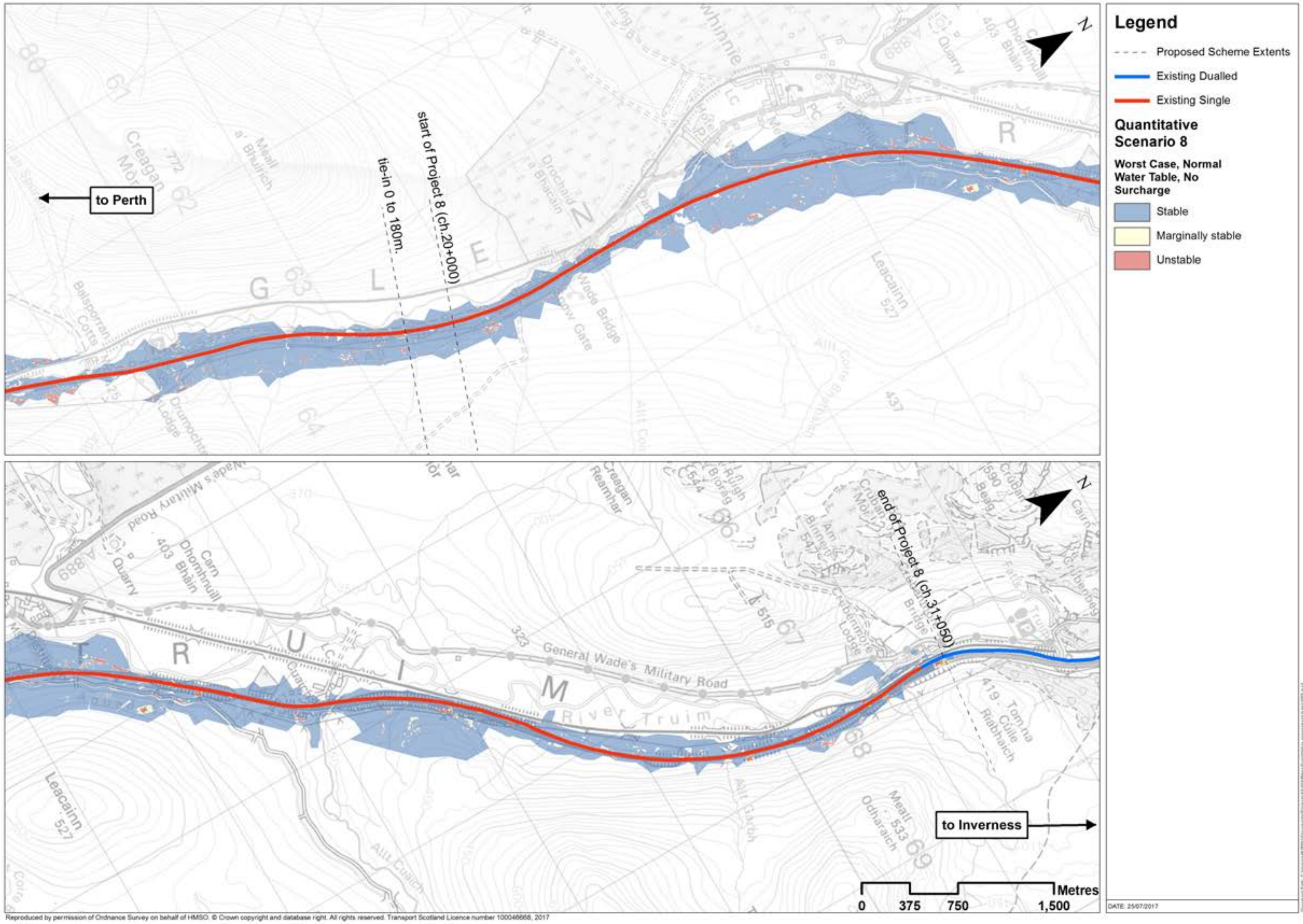

Figure 8: Quantitative Stability Assessment Scenario 8; Worst Case, Normal Water Table, No Surcharge

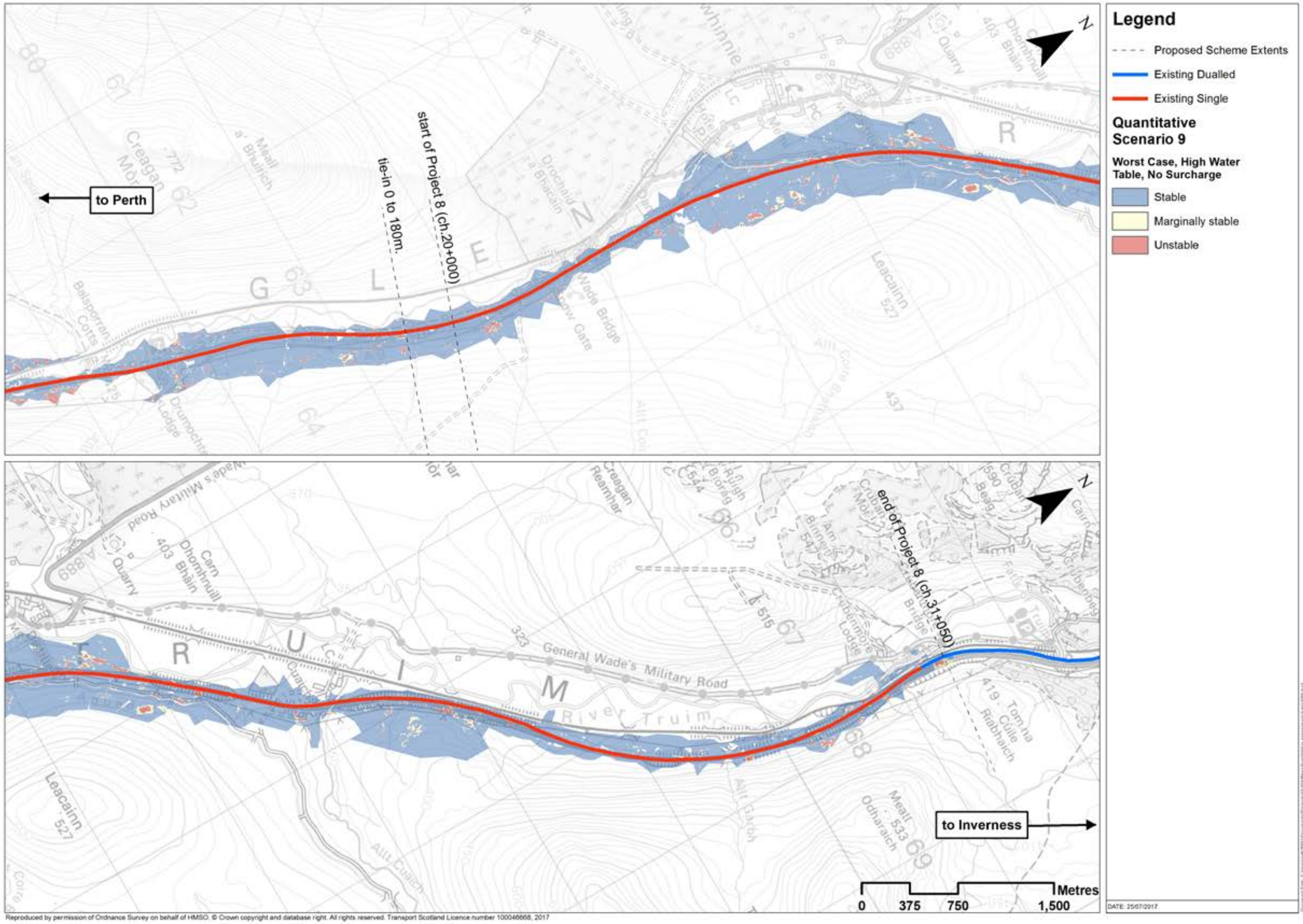

Figure 9: Quantitative Stability Assessment Scenario 9; Worst Case, High Water Table, No Surcharge

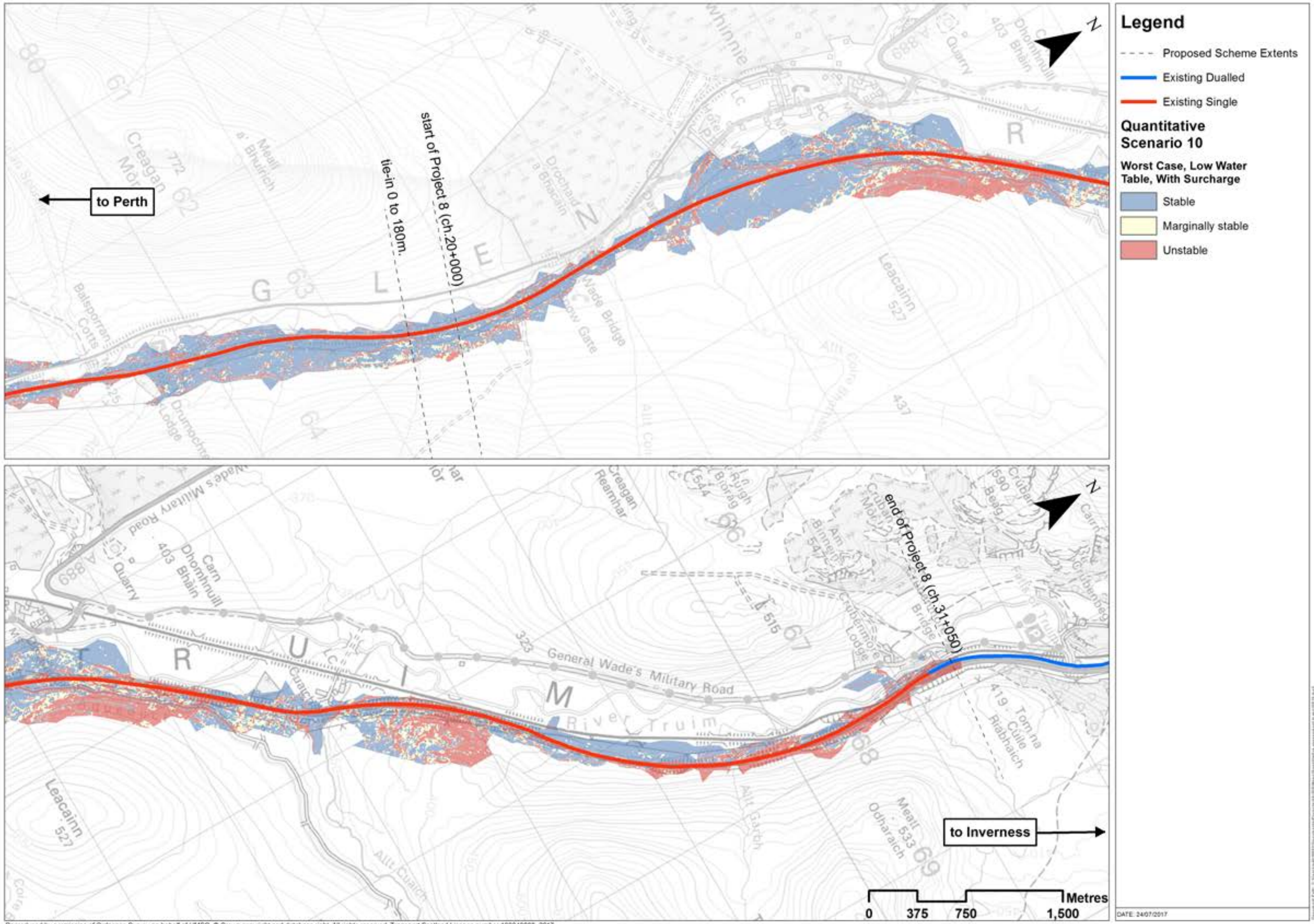

Figure 10: Quantitative Stability Assessment Scenario 10; Worst Case, Low Water Table, With Surcharge

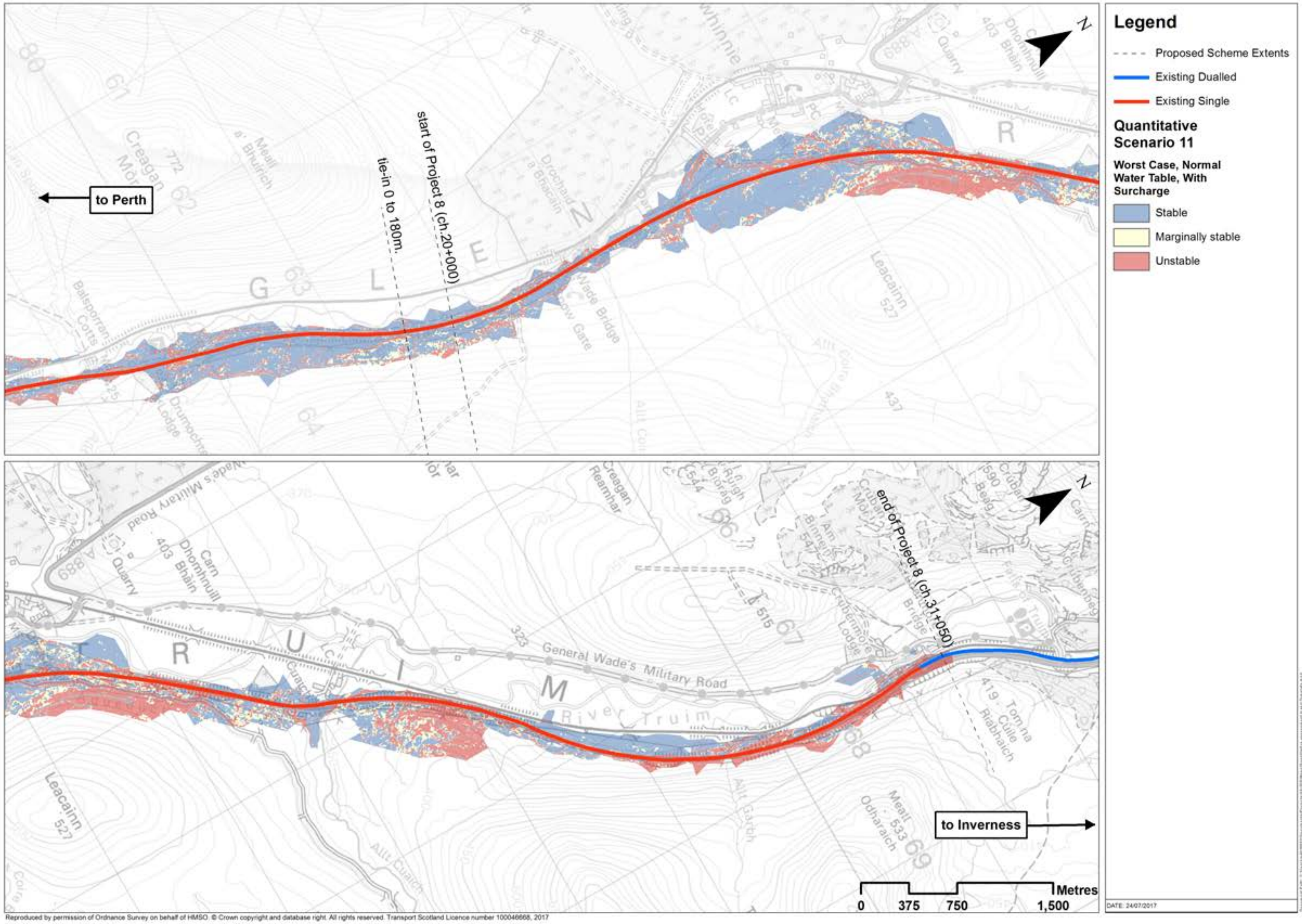

Figure 11: Quantitative Stability Assessment Scenario 11; Worst Case, Normal Water Table, With Surcharge

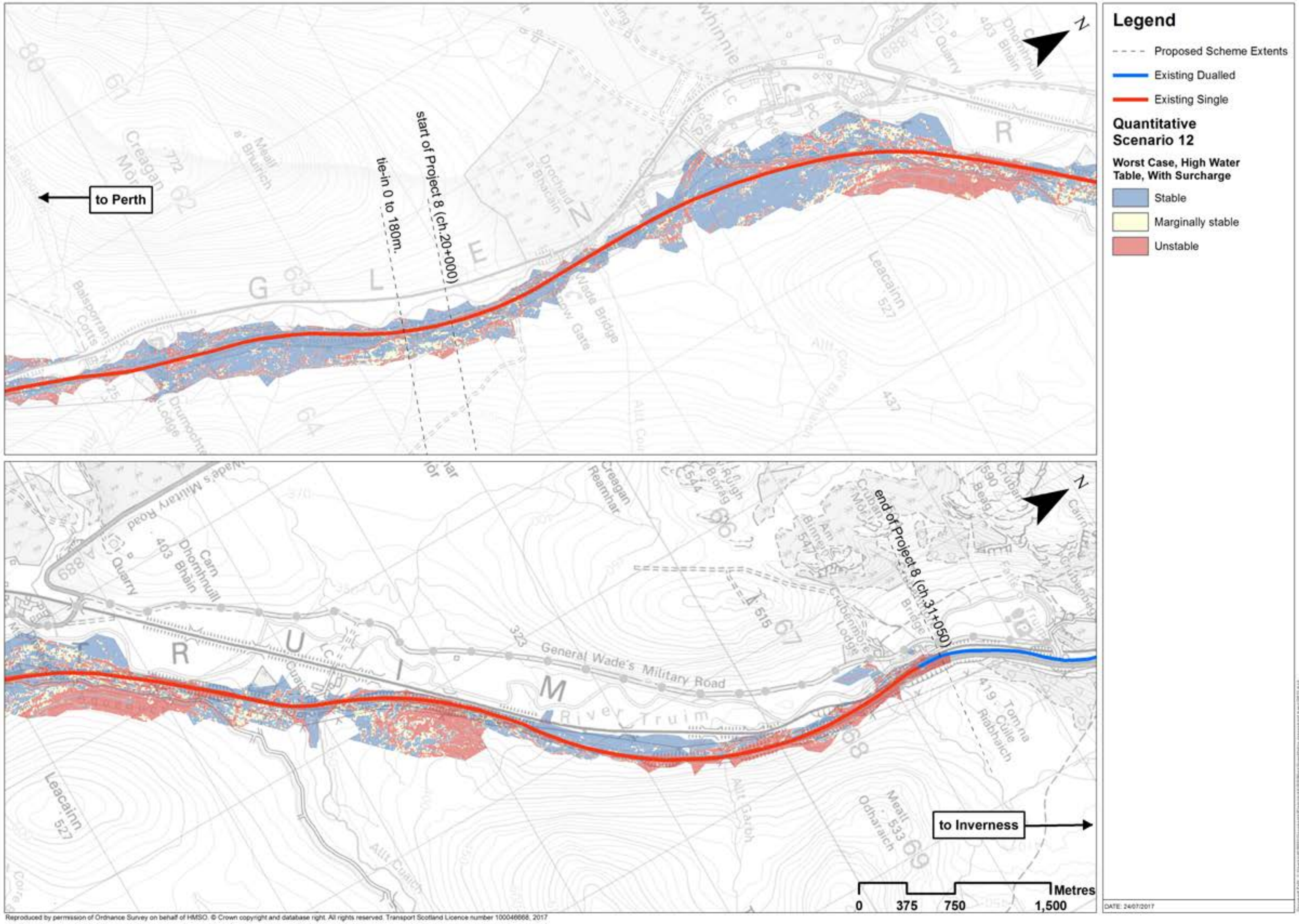

Figure 12: Quantitative Stability Assessment Scenario 12; Worst Case, High Water Table, With Surcharge