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 9 – Crubenmore to Kincraig 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 landslide hazard and undertake a preliminary peat landslide risk assessment to identify areas of the Proposed Scheme that may be affected. Based on the results, strategies for risk mitigation are provided with recommendations on risk management plans.

1.1.3 The assessment has been undertaken using both quantitative and semi-quantitative methods. The quantitative approach has used a standard slope stability calculation supported by site-specific data or values for geotechnical properties of peat from published literature. The semi-quantitative 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 using available information as described in **Appendix 10.1** (**Volume 2**). Some elements of the Proposed Scheme fall outside of the extent of data available and therefore no assessment of the peat landslide risk has been undertaken in these areas.

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 locally 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 by peat landslides during construction. Terrestrial habitats in the path of a peat landslide may also be damaged by ground displacement and by burial under 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 as a result of) 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 and adjacent to 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 Government, 2017) recommends that a peat landslide risk assessment be undertaken where peat is present in the development area and where there may be existing or induced peat stability risks. Further details on the nature of peat instability that were used to inform this stability assessment are provided in **Annex 10.5.1**.

2.2.2 In the absence of specific guidance on approaches to peat landslide risk assessment for road infrastructure, the assessment for the Proposed Scheme has been undertaken in accordance with relevant aspects of the Scottish Government (2017) 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 10.11** to **10.22** (**Volume 3**), and then used to undertake the hazard and risk analysis. The general approach used is consistent with that adopted for Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) of the A9 Dualling Programme, located to the south of the Proposed Scheme.

2.2.4 It should be noted however, 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. In particular, at the time of undertaking this assessment, no Digital Terrain Model (DTM) was available for the northern tie-in, where dualling of Project 10 (Kincraig to Dalraddy) of the A9 Dualling Programme is now complete. Therefore, no assessment of the peat landslide risk in this area has been undertaken, and this should be given additional consideration in later stages of design as necessary.

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 or 'FoS' (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, and due to the timing at which GI laboratory testing results became available, data from Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) of the A9 Dualling Programme, located to the south of the Proposed Scheme, was initially used in the quantitative analysis. This was then supplemented with quantitative analysis using the laboratory testing results specific to the Proposed Scheme, but which are again, limited to unit weight.

2.3.3 The quantitative analysis therefore also 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 existing slopes where peat is present. The parameters chosen are nevertheless considered conservative and are likely to overstate the hazard, rather than understate it.

2.3.4 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 be used as an indication of the relative stability across the study area, under varying geotechnical conditions. The results of the stability modelling have, however, also been compared to the semi-quantitative analysis to identify areas where the two methods generated similar results, and where they diverge.

2.3.5 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, unit weights of soil are low 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 methodology 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 considered in a 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 Government, 2017). 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 Government (2017) 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 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 in a project.
- It also allows a greater consideration of the consequences of peat instability occurring, but at the same time, still requires separate evaluation of the peat instability hazard.
- It is compatible with recognised 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, which are likely to be short-lived or manageable.

2.4.6 For this assessment, it is assumed that severity of the consequence of impact reduces with distance from the source of a peat landslide. 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). This is 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) risk 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 consequence, 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.

2.5 Limitations

2.5.1 Every effort has been made to make both the quantitative and semi-quantitative assessments robust. However, it should be recognised that limitations in the assessments exist, due to:

- the spatial extent of data (such as peat depth and DTM data), which is in part determined on the spatial extent of the Proposed Scheme, which has evolved throughout the assessment
- the availability of site-specific data and lack of historical data, such as historical aerial photographs, although historical Ordnance Survey mapping has been referred to where publicly available
- limitations in the techniques used to undertake the assessment. For the quantitative analysis, this includes the nature of slopes and potential failures to which the quantitative analysis is applicable and the impracticality of modelling every possible combination of parameters. For the semi-quantitative assessment, the necessity that an element of professional judgement is used to identify appropriate values for each of the factors considered.

2.5.2 These limitations are also further explored in the following sections, where necessary.

3 Peat Landslide Potential

3.1 Study Area

3.1.1 As shown in **Drawing 10.1** (**Volume 3**), BGS mapping identifies scattered areas of peat throughout the study area. The majority of these are located south and east of the existing A9 starting at ch. 40,000 and continuing to ch. 44,000, along with two smaller areas to the north near Raliabeag. The remaining areas are located north and west of Kingussie, between ch. 50,200 and ch. 56,645, with the largest of these lying directly south of the existing A9 carriageway between ch. 51,600 and ch. 52,200. Published soil mapping shown in **Drawings 10.4** and **10.5**

(**Volume 3**) also identifies areas of peaty soils, including peaty gleys, peaty podzols, peaty gleyed podzols and peaty alluvial soils.

3.1.2 While few direct indicators of peat landslide occurrence in the vicinity of the Proposed Scheme have been identified through desk study, surveys or available GI, the presence of slopes ranging from flat to 34° 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 hazards to occur in the form of first-time failures.

3.1.3 There are also a range of 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, other infrastructure, cultural heritage assets and environmental designations. The presence of these receptors introduces the possibility that the occurrence of a peat landslide hazard could have a consequence in terms of injury or economic impact and therefore, there is a credible peat instability risk.

3.1.4 Beyond the immediate vicinity of the Proposed Scheme, there are also several areas where peat is recorded in BGS mapping, or is recognisable 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 originating beyond the Proposed Scheme may have an 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 and other woodland is present or proposed at numerous points throughout the permanent and temporary works boundaries, or adjacent to the Proposed Scheme. 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 other mires occurring flatter-lying valley bottoms and 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 or conclusive indicators of peat instability, such as tension cracks, compression ridges or revegetating failure scars. However, a lobate feature (as shown in **Photograph 1**) was identified 350m east of ch. 41,000, as was a possible area of historical peat cutting around 450m southeast of ch. 40,000 (as shown in **Photograph 2**).

Photograph 1: Lobate feature approximately 350m east of ch. 41,000

3.3.3 Further inspection of the lobate feature during site walkovers (CFJV, November 2017) identified that it was located at the end of an approximate 450m long tongue of variably deep peat, which appears to have developed in a valley without an obvious surface watercourse. Semi-quantitative risk assessment indicates that this is an area creating a 'substantial' risk and the downslope portion is identified as unstable in most quantitative assessment scenarios. The lobate nature of the feature may result from slow creep of its downslope end. However, no construction or mitigation activities are planned here, there was no evidence of rapid movement during the site walkovers, and the feature is separated from the Proposed Scheme by over 450m of relatively flat, open, unchannelised ground.

Photograph 2: Area of possible former peat cutting approximately 450m south east of ch. 40,000

3.3.4 The area of possible peat cutting is even further from the Proposed Scheme, and site walkovers (CFJV, November 2017) did not identify any direct indicators of instability, as the area has almost completely revegetated. As it is located beyond the extent of the available topographic elevation data, it is not possible to fully assess the risk in either the quantitative or semi-quantitative assessments. However, its distance from the Proposed Scheme and lack of direct indicators of instability suggests it is likely to present little of any potential risk.

3.3.5 In addition to these two features, there are some geomorphological and hydrological features which indicate an elevated potential for peat instability to be present around the study area – including 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, site walkover or available GI information.

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 78°, but the majority of the study area is less than 27°, and very little is steeper than 40°. Nonetheless, this represents the full range of slope angles in which peat instability most commonly occurs.

3.4.2 Slopes beyond the Proposed Scheme boundaries are likely to fall within similar ranges, albeit the maximum slope indicated beyond the Proposed Scheme (34°) is lower, probably due to smoothing effects of the available low-resolution elevation model. Nonetheless as noted above, the presence of slopes within this range indicates slope angles are present which could contribute to the occurrence of peat landsliding.

3.5 Peat Conditions

3.5.1 Approximately 7% of the permanent and temporary works boundaries of the Proposed Scheme do not presently have peat depth data coverage at the time of writing. However, desk-based and ecological surveys indicate that peat greater than 0.50m thickness is unlikely to be present in most of these areas, particularly as they are situated on superficial deposits of glaciofluvial origin.

Peat Depth

3.5.2 The peat depth model and available data indicate that the full range of recorded peat and peaty soil depths across areas investigated varies from 0.00 to 4.85m, as illustrated in **Drawings 10.11** to **10.22** (**Volume 3**). The vast majority of areas (approximately 77%) within the permanent and temporary works boundaries are indicated to be underlain by peaty soil or topsoil less than 0.50m thickness, and approximately 11% is underlain by no peat. Shallow peat (between 0.50 and 1.00m in thickness) is present underlying less than 4% of the areas and less than 1% is underlain by deep peat (greater than 1.00m in thickness). Available GI has also identified peat strata, between 0.10 and 3.30m thickness, buried beneath granular horizons of made ground and/ or sands and gravels at several locations. 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.

3.5.3 The peat depth model is based on a substantial dataset, as described in **Chapter 10** (**Volume 1**) and **Appendix 10.1** (**Volume 2**) and it is considered 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

3.5.4 The true depth of the acrotelm is often difficult to determine in the field and may be deeper than suggested by indicators such as living mosses and poorly decomposed plant material. Indeed, it has frequently been the case from investigation information available for the Proposed Scheme that the acrotelm (i.e. that part of the peat profile which experiences fluctuations in water table) was recorded to be impacted or degraded.

3.5.5 In this respect, the acrotelm across the Proposed Scheme has been observed to predominantly comprise thin (0.05 to 0.30m) variably decomposed (H1 to H6, locally greater) layers and variably distinct semi-natural vegetation. The decomposition varied throughout, with several areas with decomposition ratings higher than would be expected for an acrotelm that is healthy and actively peat-forming. However, areas showing no or only very slight decomposition (H1 to H3) with distinct vegetation indicating good condition were also observed locally – around the proposed Newtonmore junction (ch. 42,700 to ch. 43,600) and an area of mire located at Nuide (ch. 46,000). In areas conducive to flooding, within the River Spey floodplain and Insh Marshes, high proportions of mineral content (sand, gravel and silt) were observed in the acrotelm layers.

3.5.6 The catotelm layers underlying the acrotelm were recorded to vary between spongy, plastic and firm condition. The type of peats also varied from dark brown and black fibrous to pseudo-fibrous, and locally amorphous; with highly variable root, wood, sand and silt content. Pseudo-fibrous peat was typically described as H3 to H7 on the von Post scale (very slight to strong decomposition), fibrous peat was typically described as H1 to H5 (no decomposition to moderate decomposition), while locally more amorphous peat or amorphous content within it was described as H8, H9 or H10 (very strong, nearly complete or complete decomposition).

3.5.7 The recorded humification ratings show a very weak trend for humification to increase with depth as identified in **Appendix 10.1** (**Volume 2**), due to some instances of strong decomposition (H8 or greater) observed at relatively shallow depths less than 0.50 or 1.00m. This may reflect the modified nature of the peatland environments in the vicinity of the Proposed Scheme.

3.5.8 Estimated water contents in samples have covered the full range of possible values on the von Post scale, but with practically no correlation between water content and depth.

Laboratory Testing

3.5.9 Laboratory testing of peaty soil and peat samples for all, or a selection of the following; 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 noted in **Chapter 10** (**Volume 1**) and **Appendix 10.1** (**Volume 2**).

3.5.10 Peaty soil/ topsoil samples were recovered across a range of habitat types, including wet heath, mire, mosaics of these, dry heath, grasslands and woodland. The testing results indicate bulk densities for these ranging between 0.07 and 0.29 Mg/m^3, dry densities between 0.02 and 0.05 Mg/m^3 and moisture contents of between 98 and 1443%. Results for total organic carbon ranged from 6.8 to 46%, from 5.5 to 44% for total carbon content and from 19 to 97% for mass loss on ignition. pH values ranged from 3.6 to 5.9.

3.5.11 Shallow peat samples were recovered across wet heath, blanket mire, swamp/ mire mosaic and woodland habitats, with bulk densities ranging between 0.33 and 0.49 Mg/m^3, dry densities ranging from 0.03 to 0.09 Mg/m^3 and moisture contents of between 272 and 1423%. Results for total organic carbon ranged from 4.9 to 51%, from 5.4 to 43% for total carbon content and from 15 to 94% for mass loss on ignition. pH values ranged from 3.5 to 5.3.

3.5.12 Within local deeper peat profiles in areas of mire, blanket mire, wet heath, mosaics of these or swamp, bulk densities ranged between 0.14 to 0.58 Mg/m^3, dry densities ranged from 0.02 to 0.22 Mg/m^3 and moisture contents were recorded between 98 and 1372%. Results for total organic carbon varied between 15 and 54%, between 11 and 55% for total carbon content and from 30 to 100% for mass loss on ignition. pH values ranged from 3.7 to 6.6.

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, alluvial fans, river terrace deposits, alluvium and glaciofluvial deposits.

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 assessment 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 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). Furthermore, the Scottish Road Network Landslides Study (Transport Scotland, 2009) does not identify this section as being high risk for landslides of any type or further detailed study. 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 developed areas, cultural heritage asset areas and environmentally designated sites, including Special Protection Areas (SPA), Special Areas of Conservation (SAC), Sites of Special Scientific Interest (SSSI) Ramsar and National Nature Reserves (NNR). There is therefore potential for peat landslide hazards to have real consequences on various receptors, which are further detailed 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 Government, 2017). 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 types of scenario have were initially tested in the analysis using data from Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) of the A9 Dualling Programme, located to the south of the Proposed Scheme: a '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**.

4.1.3 To take account of the testing data specific to the Proposed Scheme however, variations on the unit weight of soil used in each scenario have been modelled, noted in **Table 1** as a), b) and c). These variations include the maximum and average unit weights from the site-specific data, equivalent to the unit weights considered from the Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) data. In addition, due to the generally lower unit weights present within the Proposed Scheme extents, the impact of the site-specific minimum unit weight has been assessed against both the other 'worst case' and 'moderately conservative case' parameters, to understand the possible impact of extremely low unit weight peats.

Table 1: Quantitative Stability Analysis Parameters

Parameter	'Worst case'	'Moderately conservative case'
Unit weight of soil (kN/m^3)	a) 14.52 (measured maximum from Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore)) b) 5.69 (measured site-specific maximum) c) 0.69 (minimum site-specific unit weight)	a) 8.76 (measured average from Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore)) b) 3.60 (measured site-specific average) c) 0.69 (minimum site-specific unit weight)
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 DTM)	Location-specific (Engineering DTM)

Parameter	'Worst case'	'Moderately conservative case'
Vertical depth of peat (m)	Location-specific (Peat depth model)	Location-specific (Peat depth model)

4.1.4 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.

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

- In the 'worst case' scenarios using the Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) unit weight data, a surcharge of 14.52 kPa (maximum measured unit weight of peat) has been applied to represent an overburden of peat stored to a height of 1.00m.
- In the 'moderately conservative' scenarios using the Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) unit weight data, a surcharge of 10 kPa has been applied to represent overburden from construction plant, in accordance with BS 6031: 2009 (BSI, 2009).
- In the 'worst case' scenarios using site-specific unit weight data, a surcharge of 10 kPa has been applied to represent overburden from construction plant, in accordance with BS 6031: 2009 (BSI, 2009). This was selected in preference to an overburden of the highest unit weight peat stored to a height of 1.00m, as given the lower unit weights of the peat in the Proposed Scheme extents, such a value would be lower than 10 kPa.
- In the 'moderately conservative' scenarios using site-specific unit weight data, a surcharge of 3.6 kPa has been applied to represent an overburden of average unit weight peat stored to a height of 1.00m.
- In the 'minimum unit weight' scenarios using site-specific unit weight data, in both the 'moderately conservative case' and the 'worst case' scenarios, a 'low' surcharge of 0.69 kPa representing the storage of this extremely low unit weight peat to a height of 1.00m **and** a 'high' surcharge of 10 kPa representing the overburden from construction plant have been applied, in accordance with BS 6031: 2009 (BSI, 2009).

4.1.6 Taken together, these variations produce 42 possible scenarios that have been tested, as summarised in **Table 2**.

Table 2: Quantitative Stability Analysis Scenarios

Scenario	Low Water Table	Normal Water Table	High Water Table
Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) Unit Weight Data Scenarios			
Moderately conservative (no surcharge)	**Scenario 1** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m^3) = 8.76 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 2** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m^3) = 8.76 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 3** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m^3) = 8.76 Water table = 1.50 Surcharge (kPa) = 0

Scenario	Low Water Table	Normal Water Table	High Water Table
Moderately conservative (with surcharge)	**Scenario 4** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m^3) = 8.76 Water table = 0.80 Surcharge (kPa) = 10	**Scenario 5** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m^3) = 8.76 Water table = 1.00 Surcharge (kPa) = 10	**Scenario 6** φ' (°) = 20 c' (kPa) = 5 Unit Weight (kN/m^3) = 8.76 Water table = 1.50 Surcharge (kPa) = 10
Worst case (no surcharge)	**Scenario 7** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m^3) = 14.52 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 8** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m^3) = 14.52 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 9** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m^3) = 14.52 Water table = 1.50 Surcharge (kPa) = 0
Worst case (with surcharge)	**Scenario 10** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m^3) = 14.52 Water table = 0.80 Surcharge (kPa) = 14.52	**Scenario 11** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m^3) = 8.76 Water table = 1.00 Surcharge (kPa) = 14.52	**Scenario 12** φ' (°) = 5 c' (kPa) = 2 Unit Weight (kN/m^3) = 14.52 Water table = 1.50 Surcharge (kPa) = 14.52
Site-specific Unit Weight Data Scenarios			
Moderately conservative (no surcharge)	**Scenario 13** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 3.6 Water table = 0.8 Surcharge (kPa) = 0	**Scenario 14** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 3.6 Water table = 1 Surcharge (kPa) = 0	**Scenario 15** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 3.6 Water table = 1.5 Surcharge (kPa) = 0
Moderately conservative (with surcharge)	**Scenario 16** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 3.6 Water table = 0.80 Surcharge (kPa) = 3.6	**Scenario 17** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 3.6 Water table = 1.00 Surcharge (kPa) = 3.6	**Scenario 18** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 3.6 Water table = 1.50 Surcharge (kPa) = 3.6
Worst case (no surcharge)	**Scenario 19** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 5.69 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 20** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 5.69 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 21** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 5.69 Water table = 1.50 Surcharge (kPa) = 0
Worst case (with surcharge)	**Scenario 22** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 5.69 Water table = 0.80 Surcharge (kPa) = 10	**Scenario 23** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 5.69 Water table = 1.00 Surcharge (kPa) = 10	**Scenario 24** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 5.69 Water table = 1.50 Surcharge (kPa) = 10
Site-specific Minimum Unit Weight Data Scenarios			
Moderately Conservative Case (no surcharge)	**Scenario 25** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 26** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 27** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 1.50 Surcharge (kPa) = 0
Moderately Conservative Case (low surcharge)	**Scenario 28** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 0.80 Surcharge (kPa) = 0.69	**Scenario 29** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 1.00 Surcharge (kPa) = 0.69	**Scenario 30** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 1.50 Surcharge (kPa) = 0.69

Scenario	Low Water Table	Normal Water Table	High Water Table
Moderately Conservative Case (high surcharge)	**Scenario 31** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 0.80 Surcharge (kPa) = 10	**Scenario 32** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 1.00 Surcharge (kPa) = 10	**Scenario 33** φ' (°) = 20 c' (kPa) = 5 Bulk Weight (kN/m^3) = 0.69 Water table = 1.50 Surcharge (kPa) = 10
Worst Case (no surcharge)	**Scenario 34** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 0.80 Surcharge (kPa) = 0	**Scenario 35** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 1.00 Surcharge (kPa) = 0	**Scenario 36** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 1.50 Surcharge (kPa) = 0
Worst Case (low surcharge)	**Scenario 37** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 0.80 Surcharge (kPa) = 0.69	**Scenario 38** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 1.00 Surcharge (kPa) = 0.69	**Scenario 39** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 1.50 Surcharge (kPa) = 0.69
Worst Case (high surcharge)	**Scenario 40** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 0.80 Surcharge (kPa) = 10	**Scenario 41** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 1.00 Surcharge (kPa) = 10	**Scenario 42** φ' (°) = 5 c' (kPa) = 2 Bulk Weight (kN/m^3) = 0.69 Water table = 1.50 Surcharge (kPa) = 10

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 1.0, indicating instability
- Factor of Safety between 1.0 and 1.4, indicating marginal stability
- Factor of Safety greater than 1.4, 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 study area 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, and where the presence of deep peat on the slope is an artefact of the interpolated peat model.

4.2.4 There are few cases where an area of modelled instability falls within the permanent and temporary boundaries of the Proposed Scheme. One such example includes the A9 around ch. 48,500, where deeper peat apparently overlies a steep slope, but from investigation of similar ground nearby, this material is likely to be granular. Nonetheless, caution should still be applied in this area and further analysis undertaken before construction be undertaken.

4.2.5 Other, small areas where peat instability is indicated in this scenario are clustered in the far south (between the southern end of the Proposed Scheme and ch. 41,000) and upslope of it around ch. 45,500. These areas are generally associated with steeper slopes at the edges of deep peat areas, where the peat model interpolates deep peat incorrectly onto steeper slopes. These instances are therefore also likely to be false positives, but caution should be taken in these areas nonetheless.

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

4.2.6 In general terms, most areas classed as unstable in this scenario mirror those in Scenario 1, although their extent increases slightly. Some areas of small extent appear north of ch. 54,100, immediately upslope or downslope of the B9152, on steep cut or embankment slopes. These areas are likely to be false positives, where an overlap with areas of adjacent deep peat has been incorrectly interpolated by the peat model.

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

4.2.7 Many of the areas identified as potentially unstable in Scenario 3 are 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:

- Approximately 150m to the east of the existing A9, between ch. 40,200 and ch. 40,300
- Approximately 200m south of the existing A9 from ch. 42,500 to 42,700
- Approximately 130m south of the existing A9 and within the permanent and temporary works boundaries at ch. 43,100
- Approximately 80m south of the existing A9 and overlapping the proposed Newtonmore junction, between ch. 43,300 and ch. 43,500
- In between the proposed mainline alignment and the access road to the north at ch. 45,900
- Within the earthworks extents to the north of the proposed mainline alignment, between ch. 47,200 and ch. 47,300
- Approximately 130m north of the existing A9 between ch. 47,500 and 47,600
- To the north of the Proposed Scheme between ch. 48,100 and ch. 48,300, outside of the permanent and temporary works boundaries
- Immediately outside (north west) of the Proposed Scheme boundaries between ch. 48,800 and ch. 49,000
- On the banks of various natural watercourses, including the River Spey, to the west of the Proposed Scheme between ch. 49,200 and 50,200
- South of the existing A9 carriageway, partially within but principally outwith the Proposed Scheme boundaries between ch. 51,600 and ch. 52,200
- To the south of the existing A9 between ch. 53,900 and ch. 55,600.

4.2.8 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

4.2.9 The notable difference between Scenario 4 and Scenario 1 (i.e. with and without surcharge) is the substantially increased number and extent of areas of marginal stability and a similar increase in areas indicated as being unstable. The common theme linking the areas is that they are on steeper slopes – embankments, cuttings, steeper natural hillsides and channel (natural and artificial) banks.

4.2.10 Analysis of the statistics extracted from the quantitative GIS outputs indicate that the minimum slope angle in which instability occurs in this scenario is 28° and the minimum slope angle on which marginal stability occurs is 19°. Peat depth, which is the only other variable across the Proposed Scheme in this scenario, show no such threshold depths. As such, the conclusion from this scenario is that the placement of surcharges on embankments, cuttings, steeper natural hillside slopes and channel should be avoided in all weather conditions.

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

4.2.11 The change in the simulated water table between Scenario 4 and Scenario 5 results in only incremental differences to the extent and severity of the instability areas indicated. Again, no discernible trend in the impact of peat depth is visible and threshold slope angles for instability and marginal stability appear to be 23° and 16°, respectively.

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

4.2.12 As with Scenario 4 and Scenario 5, the change in simulated water table between Scenario 5 and Scenario 6 results in only incremental changes in the extent and severity of areas of instability and marginal stability, with areas within those categories being almost exclusively embankments, cuttings, steeper natural hillside slopes and channel banks. No discernible trend in the peat depth threshold is evident, but threshold angles for instability and marginal stability in this scenario are 14° and 10°, respectively.

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

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

- There are few instances, even in these unrealistic scenarios, where areas with peat depths of less than 1.00m and slope angles less than approximately 5°, either with or without surcharges in place, where instability or marginal stability is indicated. As such and as a rule of thumb, it is sensible to select locations that meet both 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 full assessment of the stability of possible storage locations and earthworks to the appropriate standards 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.

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

Scenario 13 to Scenario 18: Moderately Conservative Case, Variable Water Table, With and Without Surcharge

4.2.15 In those scenarios without surcharge, areas identified as unstable or marginally stable differ somewhat from those identified in the equivalent moderately conservative case scenarios which use Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) data. They are often in areas adjacent to those identified in using the Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) data, but pick out areas of peat deeper than 1.00m, as opposed to areas where shallow or deep peat overlap with steeper slopes. This indicates that instability is more sensitive to peat depth than slope where low unit weight peats are concerned. However, it is also important to note that in such flatter areas of deeper peat, the infinite slope analysis is most representative of peat slides (as opposed to other types of peat landslide) which are unlikely to occur in these areas.

4.2.16 The addition of a moderate surcharge in these scenarios gives an apparent increase in stability in many of the flatter, deeper areas of peat in which instability is indicated in the scenarios without surcharge. However, as noted above, this should be interpreted with caution due to the infinite slope analysis's poor performance in such areas. It should also be noted that extensive areas of peat deeper than 1.00m, irrespective of slope, remain apparently unstable even with the addition of the surcharge in the high water table scenario. In comparison to the equivalent scenarios which use the Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) data, in which many steeper slopes (embankments, cutting slopes, steeper natural hillsides and channel banks) were identified as being unstable or of marginal stability, the use of a lower surcharge (due to the lower unit weight of the peat) results in a substantial reduction in the extent of the unstable slopes. Due to the inherent issues with the infinite slope analysis in areas of deeper, flatter peat though, only limited conclusions can be drawn. However, comparing the 'with surcharge' scenarios to the equivalent Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) results, where unit weights of peat are proven to be lower, there is likely to be scope to place such store peat temporarily on steeper slopes than the minimum 5° indicated above. However, each individual area chosen should be assessed to appropriate standards before use.

Scenarios 19 to Scenario 24: Worst Case, Variable Water Table, With and Without Surcharge

4.2.17 In the scenarios without surcharge, the predominance of deeper peat as a control on instability diminishes relative to the equivalent moderately conservative case parameters. Whether this is specifically because of the less favourable values of *c*' and *φ*' used in these scenarios or the increased unit weight of peat, is not possible to say, but it is likely to be a combination of both. In comparison to the equivalent scenarios using the Project 7 (Glen Garry to Dalwhinnie) and Project 8 (Dalwhinnie to Crubenmore) data, the reduced unit weight of peat in the site-specific data scenarios substantially reduces the extent of the areas of sloping ground identified as unstable or marginally stable. However, particularly in the high water table scenario, areas of peat deeper than 1.00m are frequently identified as unstable or marginally stable. This is consistent with findings in Scenarios 13 to 18, specifically that the storage of lower unit weight peats on sloping ground is less problematic than the storage of those of higher unit weight.

4.2.18 In the scenarios with surcharge, the worst case scenarios indicate the potential for widespread instability focused on all but the most gently sloping ground. This is in part likely to be due to unrealistically conservative parameters, but shows that on such very low slopes (less than around 4°), the use of construction plant and the storage of peats of the unit weights specified is unlikely to be problematic, but should nonetheless be subject to assessment according to appropriate standards at the relevant stage prior to construction.

Scenario 25 to Scenario 33: Moderately Conservative Case, Variable Water Table, With and Without Surcharge

4.2.19 In the scenarios without surcharge, further reducing the minimum unit weights of peat increases the sensitivity of the analysis to peat depth, and reduces the relative sensitivity to slope. As such, all areas where peat is deeper than 0.97m are indicated to be unstable, irrespective of slope in the high water table scenario.

4.2.20 In the scenarios with low surcharge, there is little difference in the distribution of areas of indicated instability (focused on those where peat is deeper than 1.00m). However, the extent of these areas reduces slightly; a similar effect to that seen in other scenarios where areas of deep peat are indicated to be unstable without surcharge.

4.2.21 In the scenarios with a higher (10 kPa) surcharge, the addition of that surcharge has the apparent effect of increasing stability in the flatter areas of deeper peat, but pushing areas of steeper slopes (embankments, cuttings, steeper natural hillslopes and channel banks) into the category of marginal stability in the low and medium water table scenarios, and into marginal instability and unstable categories in the high water table scenario.

Scenario 34 to Scenario 42: Worst Case, Variable Water Table, With and Without Surcharge

4.2.22 In the scenarios without surcharge, the change in parameters has the unexpected effect of reducing the extent of instability in areas of deep peat, relative to the moderately conservative case which uses ostensibly more favourable parameters. This is likely due to the poor applicability of the infinite slope equation in such areas, and from using such extreme values of unit weight. The addition of the low surcharge produces similar results, albeit further reducing the extent of the areas of deep peat identified as unstable. However, with the addition of the higher surcharge, as would be expected from previous scenarios, instability across the site becomes more sensitive to slope rather than peat depth with embankments, cutting slopes, steeper natural hillsides and channel banks being identified as unstable or marginally stable; reinforcing the point that irrespective of peat depth or antecedent weather conditions, the loading of such peat or peaty soil slopes with additional peat or plant should be avoided.

4.3 Summary

4.3.1 In summary, the preliminary quantitative analysis undertaken has limitations associated with the input parameters available, and inherent limitations on its applicability where the mode of failure, should one occur, is unlikely to be a peat slide. 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.

4.3.2 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.

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

4.3.4 Consideration of the impact of the lower unit weight peats within the Proposed Scheme extents indicates that peat depth is likely to be a stronger influence on instability than slope angle, relative to when peats with higher unit weight are present. Indeed, the presence of lower unit weight peats appears likely to mitigate the extent of marginally stable and unstable areas in scenarios where values of effective cohesion and effective friction angles are lower. However, the analysis using the lower unit weight values obtained also indicates that particular caution should be exercised when construction in areas where peat is greater than 1.00m deep and unit weights of soil are low.

5 Semi-Quantitative Analysis

5.1 Approach

5.1.1 Given the limitations on the preliminary quantitative assessment, it 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 **10.5.20** (**Volume 3**).

5.2 Hazard

5.2.1 The hazard outcomes are presented as separate sections for peat slides and bog bursts; as 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 majority of areas within the permanent and temporary works boundaries. However, there are several areas where the peat slide hazard has been assessed as 'Possible'. These tend to be steeper slopes with peat over 0.50m deep, with oblique artificial drainage and where forestry is present. General areas of note in this respect are:

- Discontinuous sections on both sides of the Proposed Scheme between ch. 40,000 and ch. 41,900
- An extensive, continuous area between ch. 40,600 and ch. 41,000 approximately 250m east of the existing A9 which coincides with the infilled valley and lobate feature shown in **Photograph 1**
- A larger, more continuous area between ch. 42,000 and ch. 42,300 on both sides of the Proposed Scheme, but particularly to the east
- North and south of the Proposed Scheme, but predominantly beyond its boundaries between ch. 42,500 and ch. 43,100
- Small and discontinuous areas north and south of the existing A9, both within and outwith the Proposed Scheme boundaries, between ch. 43,100 and ch. 44,300
- South of the existing A9 carriageway in existing woodland between ch. 44,300 and ch. 45,000
- Mostly small discontinuous areas between ch. 45,400 and ch. 46,300, with a more extensive area between the existing A9 and parallel minor road to the north between ch. 45,900 and 46,000. More extensive (but still discontinuous) in woodland stretching southwards from the A9
- Continuous linear area immediately north of the existing A9 between ch. 46,300 and ch. 47,100
- A large continuous area between ch. 46,700 and ch. 47,300, immediately south of the existing A9, then a small, mostly discontinuous areas north and south of the existing A9 between ch. 47,300 and ch. 48,200
- Very small discontinuous areas between ch. 49,200 and ch. 51,200, located on both sides of the existing A9
- Discontinuous larger areas between ch. 51,200 and ch. 52,200 south of the existing A9, with smaller small discontinuous areas northward of this between ch. 52,400 and the end of the Proposed Scheme on either side
- Small, discontinuous areas both sides of the B9152 between ch. 52,900 and the end of the Proposed Scheme.

5.2.3 There are a few small areas where the peat slide hazard is assessed as being 'Probable' and these are located as follows:

- East of the Proposed Scheme between ch. 40,600 and ch. 41,000, in the small valley infilled with peat, where the lobate feature shown in **Photograph 1** is located
- Very small area east of the existing mainline between ch. 42,000 and ch. 42,100
- Predominantly south of the existing A9 between ch. 46,800 and ch. 47,400, where artificial drains pass through areas of deep peat

- North of the Proposed Scheme between ch. 47,500 and ch. 47,600, where a small steep slope is in close proximity to a deep peat area within woodland.

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

Bog Burst Hazard

5.2.5 **Drawing 10.5.12** (**Volume 3**) shows the resulting bog burst hazard across the study area, which has been assessed as below 'Negligible' for the majority of it. 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' and a very limited number of areas of limited extent where the bog burst hazard has been assessed as 'Probable' – focused exclusively on areas of peat deeper than 0.50m. These areas are almost all concurrent with the location of the areas of elevated peat slide hazard, but with slightly different extents.

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

5.3 Consequence Severity

5.3.1 The consequence severity describes the potential impact on sensitive ecology, infrastructure or other 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, with a greater extent of the study area assessed as having a higher consequence should a bog burst occur, principally due to the propensity of bog bursts to travel further. However, both follow the same general pattern of a southwest to northeast aligned 'Very High' consequence severity corridor through the centre of the study area, following the existing A9 carriageway and the River Spey, with multiple branches where watercourses flow. Other areas of increased severity include where there are waterbodies present (predominantly lochans) and in the Kingussie area, where there the concentration of occupied buildings is relatively dense.

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 **10.5.20** (**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 and 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** (**Volume 3**); 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 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 for the Proposed Scheme. 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 selected areas of peat, should also be undertaken for a twelve-month period prior to construction 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, as described in the Outline Peat Management Plan in **Appendix 10.6** (**Volume 2**).

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, or if, 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 and 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 a 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 Government (2017) 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 where 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 Government (2017) also identifies engineering measures available for reducing the consequences in the event of a peat landslide hazard occurring. These include:

- **Catch 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

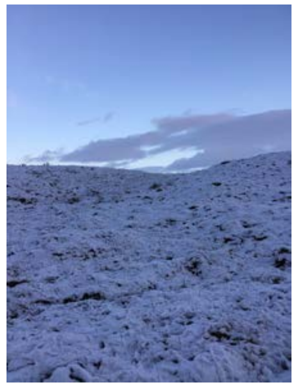
6.6.1 The peat landslide risk, and the general mitigation measures described to limit such risk, should be included in any risk register related to construction of the Proposed Scheme, such as that which may accompany the Construction Environment Management Plan (CEMP). The locations of concern and suggested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

Table 3 presents a preliminary risk register for the Proposed Scheme, summarising general mitigations for 'Negligible' and 'Slight' risk areas. The locations identified as 'Moderate' or higher risk from either peat slide or bog burst are also detailed. The suggested mitigations intended to reduce the residual risk to 'Slight' or 'Negligible' should be considered, in addition to further quantitative assessment of stability at these locations. Where appropriate, additional commentary has also been included from the quantitative assessment, with a focus on the moderately conservative case, high water table, no surcharge scenarios. Although still likely to be very conservative, these are considered most likely to be representative of the site in extremely wet conditions.

Table 3: Preliminary Peat Stability Risk Register

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 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. 40,000 to ch. 40,600	Moderate	Small areas of marginal stability and instability within Proposed Scheme boundaries immediately east of existing A9.	Small discontinuous areas of moderate risk within Proposed Scheme boundaries, immediately east of existing A9.	 	Hazard and risk models have highlighted road drain and embankment. Very limited risk at this location.	Around ch. 40,500, a proposed watercourse diversion is in close proximity to the areas of risk and modelled instability. Consideration should be given to protecting this watercourse diversion using a catch fence or bund if risk proven at detailed design. 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. 40,200 to ch. 40,400		Small areas of modelled instability on sloping ground approximately 190m east of the existing A9. In lower unit weight scenarios, this extends on to flatter ground below where deep peat is present (closer to road but still outwith the permanent and temporary works boundaries).	Small area of deep peat at base of sloping ground approximately 150m east of the existing A9.		Small, steep cliff at top of slope. Exposed boulders in the slope and limited peat cover. Plenty of flat ground at base to accommodate runout if failure occurs.	Presently well outside permanent and temporary works boundaries of the Proposed Scheme. No additional mitigation required unless works footprint changes to encompass this area.
ch. 40,200 to ch. 40,900	Moderate	Discontinuous areas of sloping ground up to 130m west of the existing A9.	Discontinuous areas of sloping ground up to 130m west of the existing A9.	-	Not directly observed	Overlaps with permanent and temporary works boundary. Possibly results from interpolated overlap of deep peat and steeper 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.
ch. 40,600 to ch. 41,100	Moderate	Mostly continuous area of modelled instability focused on small peat filled valley approximately 200 to 450m east of existing A9.	Mostly continuous area of risk focused on small peat filled valley approximately 200 to 450m east of existing A9.	 	Valley infilled with peat and very wet in places. Access road appears to impound water on its upstream side. Down valley direction is away from stream. No signs of movement other than lobate feature at downslope end (see **Photograph 1**). Slow movement has possibly created lobate form. Separated from the Proposed Scheme by extensive relatively low gradient open land.	Avoid any disturbance to this area. Should construction footprint change sufficiently to encroach into this area, 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.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 2017)	Risk Mitigation Guidance
ch. 40,600 to ch. 41,100	Substantial	Mostly continuous area of modelled instability focused on small peat filled valley approximately 200 to 450m east of existing A9.	Mostly continuous area of risk focused on small peat filled valley approximately 200 to 450m east of existing A9.	   	Valley infilled with peat and very wet in places. Access road appears to impound water on its upstream side. Down valley direction is away from stream. No signs of movement other than lobate feature at downslope end (see **Photograph 1**). Slow movement has possibly created lobate form. Separated from the Proposed Scheme by extensive relatively low gradient open land.	Avoid any disturbance to this area. Should construction footprint change sufficiently to encroach into this area, 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. 40,900 to ch. 41,200	Moderate	-	Small areas either side of existing A9 within Proposed Scheme boundaries and existing woodland		West side: False positive; assessment has identified top and bottom of cutting slope where peat is not present. Photograph taken on the west side of the existing A9, looking south. The east side was not observed directly but similar terrain.	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. No additional mitigation required.
ch. 41,900 to ch. 42,300	Moderate	-	Relatively continuous area immediately east of the existing Newtonmore junction, associated with existing woodland	 	East side comprises a steep slope in granular (cobble and gravel) material, with little to no peat development. The west side comprises granular made ground. Both are therefore likely to be false positives, with the moderate risk level overstated	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. No additional mitigation required.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 2017)	Risk Mitigation Guidance
ch. 41,900 to ch. 42,300	Moderate	-	Relatively continuous area immediately east of the existing Newtonmore junction, associated with existing woodland	 	East side comprises a steep slope in granular (cobble and gravel) material, with little to no peat development. The west side comprises granular made ground. Both are therefore likely to be false positives, with the moderate risk level overstated	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. No additional mitigation required.
ch. 42,000 to 42,100	Substantial	-	Very small area of substantial risk flanking small watercourse		Likely false positive, but watercourse may be vulnerable to small inputs of peat before it is diverted.	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. This is likely to be a false positive, but if the watercourse is not diverted before mainline construction starts, it would be prudent to protect the watercourse with catch fences.
ch. 42,500 to ch. 43,300	Moderate	Extensive area of modelled instability approximately 220m from the existing A9, between ch. 42,500 and ch. 42,800 and smaller area approximately 150m south of the existing A9 within Proposed Scheme permanent works boundary.	Fragmented but reasonably extensive areas north and south of the existing A9, within and outwith the Proposed Scheme boundaries where deeper peat is present.	 	North side of the A9 between Ralia Beag and the Highland Mainline railway was not directly observed due to access constraints, therefore unable to ground truth the risk for this area. Access to areas of moderate risk and modelled instability south of the A9 were also constrained by access and conditions at the time of the site walkovers. However, most of the moderate risk is well outside the Proposed Scheme boundaries, with only some encroachment into areas identified for landscaping re-use of excavated material. The areas of moderate risk appear to coincide with drainage lines and peat probing during site walkovers indicated peat depths to be limited to 0.30 and 0.40m.	Undertake additional site walkovers to areas identified as moderate to serious risk between Ralia Beag and the Highland Mainline railway. Avoid loading peat in areas intended for landscaping material re-use, consideration may need to be given to excavation of existing peat and appropriate re-use if placing materials in such areas is deemed necessary. Additional quantitative stability analysis should also be undertaken prior to construction, with mitigation as required if risk is confirmed. If risk is disproved, follow general guidance measures in **Section 6** on how to reduce peat landslide risks.
ch. 43,300 to ch. 44,300	Moderate	Small areas of modelled instability on steep slope within and adjacent to permanent and temporary works boundaries. More extensive areas of modelled instability up to 220m upslope in quantitative analyses using lower unit weights and high water tables.	Small, fragmented areas within the Proposed Scheme boundaries, immediately north and south of the existing A9.	-	Not directly observed	Consider enhancing the cut off drain at the top of the cutting around ch. 43,600 to ch. 43,800 in case of instability upslope. 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. 44,300 to ch. 44,900	Moderate	-	Fragmented areas within existing woodland to the north and south of the existing A9, partially within the boundaries of the Proposed Scheme.	-	Not directly observed due to access constraints	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. 45,400 to ch. 45,600	Moderate	-	Very small areas north and south of the Proposed Scheme, around watercourses and woodland.	-	Not directly observed due to access constraints	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.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 2017)	Risk Mitigation Guidance
ch. 45,700 to ch. 46,100	Moderate	Very small areas of instability indicated at end of a drain approximately 65m north of the existing A9, and around margins of peat basin.	Multiple fragmented areas north of the existing A9 with the Proposed Scheme permanent and temporary works boundaries, spatially co-incident with proposed drains and compensatory flood storage areas.		These areas are focused on drains or small watercourses and boggy areas. The most significant is a flat boggy area with standing water north of the existing A9, partially within but completely surrounded by the Proposed Scheme boundaries. Two proposed drains will feed water into this area. Other areas identified are steeper slopes of sand and gravel.	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. Particular attention should be given to the effects of the additional water the area will receive via drainage and any impacts that may have on the minor road which cuts across the downstream end of this boggy area.
ch. 46,100 to ch. 46,400	Moderate	-	Small, fragmented areas south of an existing access track parallel to the A9, extending southwards where woodland is present.	-	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. 46,300 to ch. 47,100	Moderate	-	Linear strip north of the existing A9, within the Proposed Scheme boundaries.		The linear feature being picked out is a cut off drain and small cut slope further south. Very limited risk as peat is very shallow.	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. 46,700 to ch. 47,400	Moderate	Reasonably extensive areas of modelled instability in minimum unit weight scenarios, but wholly within the extent of the area identified by the semi-quantitative analysis as at moderate risk from peat landsliding.	Extensive continuous area south of the existing A9, predominantly outwith, but partially within the Proposed Scheme boundaries.		Low lying area of deep peat and area of moderate risk is extensive. Area of elevated (substantial) risk follows the watercourses in the area.	Avoid excavation and storage where possible, and protect drainage and watercourse features from failures during works. However, it is noted that the watercourse in the area will require diversion to accommodate the proposed embankment. The new watercourse should therefore be protected or constructed to prevent the ingress of peat from the area to the south. 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. 46,800 to ch. 47,300	Substantial		Linear strips of limited extent south of the existing A9, partially within the Proposed Scheme boundaries.			
ch. 47,100 to ch. 47,800	Moderate	Very small area of modelled instability between ch. 47,200 and ch. 47,300 and north of the Proposed Scheme around ch. 47,500.	Fragmented areas associated with slightly steeper slopes and existing woodland partially within the Proposed Scheme boundaries to north and south of the existing A9		Between ch. 47,100 and ch. 47,400 assessment has in part, picked out the wooded embankment, which overlaps with deeper peat in the peat model. This apparently deeper peat is an interpolation error in the DTM. However, buried peat horizons have also been indicated by the ground investigation in this area. Between ch. 47,400 and ch. 47,800 slightly steeper slopes and the presence of woodland have increased the level of risk. Peat is generally not present on the slopes, but there is an area of relatively deep peat at the base of the slopes which fall on the north side of the proposed access track around ch. 47,500 to ch. 47,600 which may create a bog burst risk, or be difficult to handle if excavated.	Avoid encroachment into deeper peat north of proposed access track around ch. 47,500. Undertake additional probing to establish extent of this peat deposit. 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. No additional mitigation required.
ch. 47,500 to ch. 47,600	Substantial	Small area of modelled instability in pocket of deep within woodland peat around ch. 47,500, becomes more extensive in lower unit weight peat scenarios.	Very small area of substantial risk where deep peat present.			

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 2017)	Risk Mitigation Guidance
ch. 48,000 to ch. 48,300	Moderate	Area of indicated instability on steep right bank of the River Spey, outwith Proposed Scheme boundaries.	Relatively continuous area of moderate risk on palaeo river cliff of River Spey between ch. 47,900 and ch. 48,100.	  	Very high and very steep abandoned river cliff which becomes active beyond ch. 48,100. No peat present (probe depths were around 0.15m) but should be avoided nevertheless.	Avoid construction on or near to this slope. If construction much take place, undertake quantitative stability analysis prior to this 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. 48,400 to ch. 49,100	Moderate	Areas of indicated instability on steep active and palaeo river cliffs of the River Spey. Also area of modelled instability on flatter flood plain in lower unit weight peat scenarios.	-	 	No peat present at this location on the steep slopes, indicating it is likely over-interpolation of deeper probe points on the floodplain causing overlap with steep slopes. This area likely will be removed from list of risks once updated model run. Granular material recovered on probe. Low risk but caution advised as outfall proposed here. Flood plain area not visited.	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. 49,200 to ch. 50,200	Moderate	Small fragmented areas of instability along small natural watercourse and slightly steeper slopes and deeper peats on the River Spey floodplain, upstream and downstream of the River Spey crossing.	Small fragmented areas of indicated instability along small natural watercourse and slightly steeper slopes on the River Spey floodplain, upstream of the River Spey crossing.	-	Not directly observed due to access constraints (active ground investigation and livestock). Most areas of identified risk are outwith the Proposed Scheme permanent and temporary works boundaries. However, at ch. 49,300 small area north/west of the existing A9 falls within the proposed boundaries. Ground investigation indicates the possibility of buried peat horizons in this area.	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. 49,700 to ch. 49,900	Moderate	Discontinuous areas of modelled instability, focused on pockets of deep peat.	Discontinuous areas on east side of the existing A9, on the River Spey floodplain associated with deep peat. Partially within Proposed Scheme permanent and temporary works boundaries.		Standing water present in this area during site visit, indicating excavations may prove difficult due to high groundwater levels and high water contents in any peat present. Peat model coverage is not comprehensive in this area due to access restrictions (flooding). The areas of modelled risk may therefore well extend into the area outside of the risk model to its immediate south and east.	Ensure geotechnical input to the design of excavations in this area is sought and ensure the Construction-stage Peat Management Plan specifically considers excavation methods, storage and re-use options of material from this area. 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. 50,400 to ch. 50,600	Moderate	-	Very small areas around Kingussie recreation area. Likely false positives driven by the presence of a water body.	-	Not directly observed, but noted to be outwith Proposed Scheme 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.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 2017)	Risk Mitigation Guidance
ch. 51,200 to ch. 52,200	Moderate	Areas of indicated instability of variable size and continuity to the south of the existing A9 carriageway, which partially overlap with proposed works. Extent of modelled instability very large in minimum unit weight scenarios.	Several, relatively large areas of moderate risk, predominantly south of the existing A9 but with one small area to the north, between ch. 51,600 and 51,800.	 	The area north of A9 was not directly observed due to access constraints. However, it was noted that most of the area is outwith the permanent and temporary works boundaries in low lying, very wet, marshy ground. Other areas immediately south of the A9 between ch. 51,900 and ch. 52,000 are on higher ground covered by woodland, which is likely to be driving up the risk score. Risks are likely to be low, but advise proceeding with caution as disturbed ground in the locality indicated peaty deposits, despite being partially obscured by snow.	Avoid encroachment into low lying, flat, very wet marshy areas wherever possible. Peats excavated here are likely to be difficult to handle. 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. 53,000 to ch. 53,300	Moderate	-	Fragmented areas of moderate risk, predominantly to south of the existing A9, driven by elevated slope, the presence of existing woodland and proximity to the A9.		Not observed directly due to access restrictions, However, the woodland on the slope is likely to be elevating the risk scores. There is unlikely to be peat present on the slope in this area, and the risk indication is likely to be an overinterpolation of deeper peat data from adjacent lower-lying boggy ground.	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. 53,800 to ch. 54,500	-	Extensive area of indicated instability, situated between the B9152 and Highland Mainline railway, associated with deeper peat.	-		Low lying marshy area, distant from the Proposed Scheme works areas, meaning it is highly unlikely to be affected.	Avoid design or construction of infrastructure here as excavations are likely to be difficult due to high groundwater levels and high water content of any peat present. 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. 54,100 to ch. ch. 54,200	Moderate	Small areas of instability and more extensive areas of marginal stability on slopes either side of the B9152. Predominantly outwith the boundaries of the proposed scheme.	Small areas on either side of the B9152 associated with steeper slopes.	   	Elongated area downslope (south) of B9152 proved to be gravel embankment with no peat (probe depth 0.35m). Peat has been overinterpolated from lowlying marshy flood plain area located to the south-east. Upslope of the B9152, deep peat also appears to have been overinterpolated onto the embankment of the existing A9. In general, the risks are likely to be low in this area. However, an area of ponded water was noticed between the B9152 and the existing A9.	Additional caution to design and construction may be required around the area of ponded water. Suggest the B9152 is protected from minor failures with catch fence 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.

Approximate Chainage	Pre-Mitigation Risk	Quantitative Assessment	Semi-Quantitative Assessment	Area Photographs (CFJV, November 2017)	Area Observations (CFJV, November 2017)	Risk Mitigation Guidance
ch. 54,400 to ch. 54,600	Moderate	Fragmented areas of marginal stability on slopes either side of the B9152. Outwith the boundaries of the proposed scheme.	Fragmented areas on either side of the B9152 associated with steeper slopes.		Bedrock slope located between the existing A9 and the B9152, representing a possible location of former borrow pit, with no peat present. Downslope of the B9152, small gravel embankment and likely, very limited 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. 54,700 to ch. 55,200	Moderate	Fragmented areas of instability and more extensive areas of marginal stability on slopes either side of the B9152. Outwith the boundaries of the proposed scheme. Also more extensive area of modelled instability in lower unit weight peat scenarios on flatter, deeper peats between B9152 and Highland Mainline Railway.	Fragmented areas on either side of the B9152 associated with steeper slopes.	 	Area of overinterpolated peat between low marshy ground downslope of the B9152 and a point to north of the existing A9. Probes undertaken at the base of embankment and on slope above the B9152 proved no peat to be present at this location. Very limited risk. Flatter area not visited.	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. 55,100 to ch. 55,200	Moderate	Fragmented areas of marginal stability on slopes either side of the B9152.	Fragmented areas on either side of the B9152 associated with steeper slopes.		Embankment of the B9152 and slope above being picked out are due overinterpolation of a deep peat measurement downslope/ south-east of the area. Very limited 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. 55,300 to ch. 55, 600	Moderate	Fragmented areas of instability and more extensive areas of marginal stability on slopes either side of the B9152. Overlaps with watercourse diversion works within the proposed boundaries.	Fragmented areas on either side of the B9152 associated with steeper slopes.	   	Overinterpolation of deep peat has picked out the small embankment on the south side of the B9152 and some areas of the slope between the B9152 and the existing A9. Probes show that no or very little peat is present and risks are therefore very limited.	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. 55,600 to ch. 56,500	Moderate	-	Small fragmented areas north and south of the existing A9 carriageway, partially overlapping with permanent and temporary works boundaries.	-	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 This assessment shows there is potential for peat instability risks in the corridor through which the Proposed Scheme passes. The range of peat depths, slopes and features (indirectly) indicative of peat instability present suggest that there is the potential for either peat slide or bog burst. The nature of the corridor also means it contains a range of receptors which could be affected by the occurrence of a peat slide or bog burst should one occur, to differing levels of severity.

7.1.2 The Proposed Scheme and adjacent areas have been investigated through desk studies, field surveys and GI. This information was utilised to complete a quantitative assessment using a range of conservative parameter values selected from literature and available GI and laboratory testing results. 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, numerous and in some instances reasonably extensive areas of 'Moderate' risk have been identified and further quantitative assessment should be undertaken in these areas prior to construction as part of the detailed design process, with appropriate specific mitigation measures implemented to reduce any risks which are confirmed. Only localised areas of limited extent and number have been assessed as 'Substantial' 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, with the local areas identified as being 'Substantial' risk to form specifically identified sub-sets of the overall risk. 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 as necessary.

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

With time, the features associated with these types of landslide will re-vegetate, leaving only subtle scars in the landscape (Feldmeyer-Christe and Küchler, 2002; Mills, 2002). A study of vegetation recovery for several UK peat slide sites indicated that typical features were clearly visible in the field and on aerial photographs for 20 to 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 to 8°) and in thin to moderate thickness peats (typically 0.50 to 2.00m 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 peat landslide hazard were having an overly large influence on resulting hazard scores, generating high hazard scores where site observations and knowledge of the literature would indicate hazard to be lower.

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

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

Hazard = Slope angle score + 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°) 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

Slope Range	Significance	Score (peat slide)	Score (bog burst)
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

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 10.11** to **10.22** (**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

Degree of Curvature	Description and Significance	Score
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

Geomorphological mapping using aerial photography, and ground truthing of features of interest identified during site visits in March and November 2017 identified no direct indicators such as tension cracks, compression ridges or peat landslide failure scars within the Proposed Scheme boundaries through desk study investigations or site reconnaissance. Potential peat landslide features beyond the Proposed Scheme boundary, but within 500m of the permanent and temporary works boundary, were also visited. One lobate feature was indicative of a slow-moving mass of peat, but its distance from the Proposed Scheme (approximately 350m from the permanent and temporary works boundaries) deems it more sensible to be accounted for under 'Landslide Potential Upslope of the Proposed Scheme'.

Overall therefore, the lack of direct indicators suggest that peat instability hazard is low. However, various natural slope drainage features, which are indirect indicators of peat instability, were identified across the Proposed Scheme area, 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 BGS mapping. 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 on 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 Truim or River Spey and encompass the whole of the Proposed Scheme area, other than the relatively flat area immediately around the existing River Spey bridge crossing which is outside any tributary catchments. 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 peat landslide 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 is 26. This allows simple incorporation into an assessment of risk, but provides a degree of mitigation against uncertainty in such a semi-quantitative scoring system. **Table 9** shows the five-point hazard scale.

Table 9: Five-Point Hazard Scale

Weighted Scores	Likelihood of Occurrence	Score
22-26	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, overhead powerlines, inhabited buildings, sewage works, tracks and major paths, 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 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) and overhead powerlines.

'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
Pylon/ powerline	Infrastructure	High	High
Building	Infrastructure	Very High	Very High
Filter beds and sewage works	Infrastructure	Moderate	Moderate
Tracks, major paths	Infrastructure	High	High

Receptor	Receptor type	Consequence at source	
		Peat slides	Bog bursts
Railway	Infrastructure	Very High	Very High
Cultural heritage	Environmental	Moderate	Moderate
Private water supplies	Infrastructure	High	High
Quarry	Infrastructure	Very High	Very 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	Filter beds, sewage works	Tracks, major paths	Railway	Cultural heritage	Quarry	Private water supplies
Peat slide	At Source	H	H	VH	H	VH	M	H	VH	M	VH	H
	0 to 50	H	H	VH	H	VH	M	H	VH	M	VH	H
	50 to 100	M	M	H	M	H	L	M	H	L	H	M
	100 to 250	L	L	M	L	M	VL	L	M	VL	M	L
	250 to 500	VL	VL	L	VL	L	VL	VL	L	VL	L	VL
	500 to 750	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	Filter beds, sewage works	Tracks, major paths	Railway	Cultural heritage	Quarry	Private water supplies
Bog burst	At Source	H	H	VH	H	VH	M	H	VH	M	VH	H
	0 to 50	H	H	VH	H	VH	M	H	VH	M	VH	H
	50 to 100	H	H	VH	H	VH	M	H	VH	M	VH	H
	100 to 250	M	M	H	M	H	L	M	H	L	M	M
	250 to 500	L	L	M	L	M	VL	L	M	VL	L	L
	500 to 750	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 calculated 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 **10.5.20** (**Volume 3**)). In order to incorporate the consequence severities into the assessment, the output of the risk calculation has been classed into five categories, each with a qualitative descriptor of the degree of risk at a given location.

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

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

Table 17: Risk Score Ranges and Implications for Construction

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

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

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

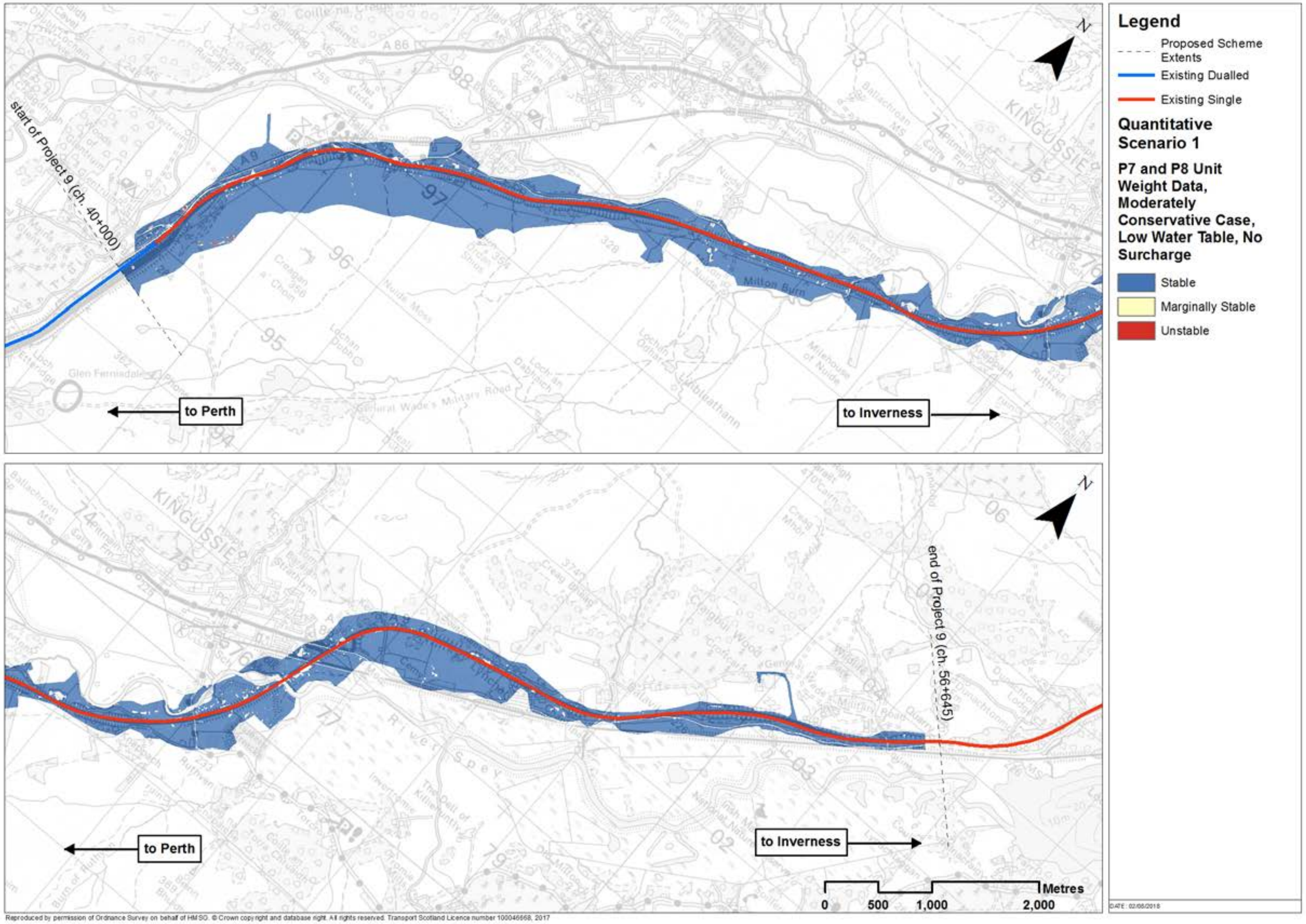

Figure 1: Quantitative Stability Assessment Scenario 1; Moderately Conservative Case, Low Water Table, No Surcharge

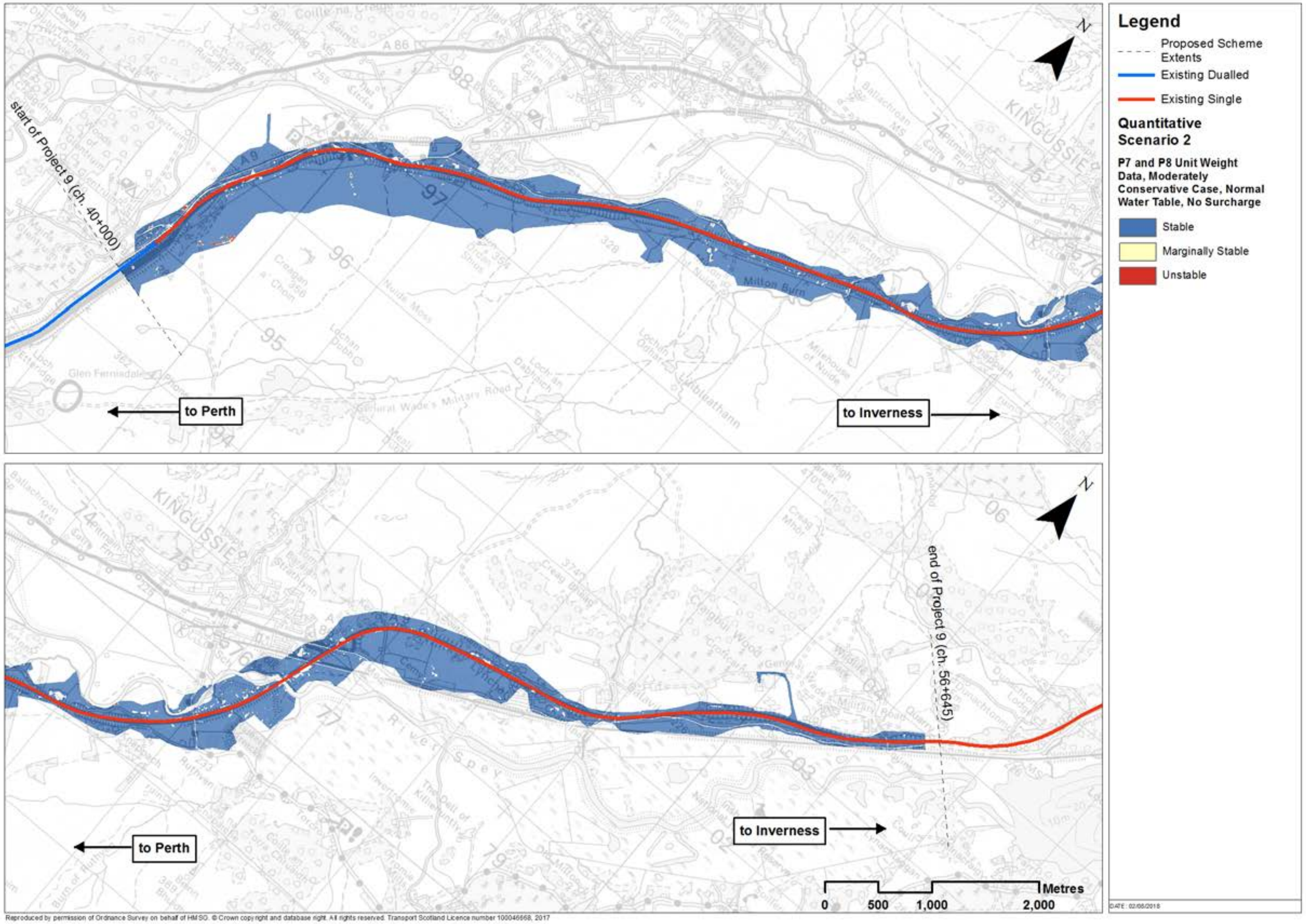

Figure 2: Quantitative Stability Assessment Scenario 2; Moderately Conservative Case, Normal Water Table, No Surcharge

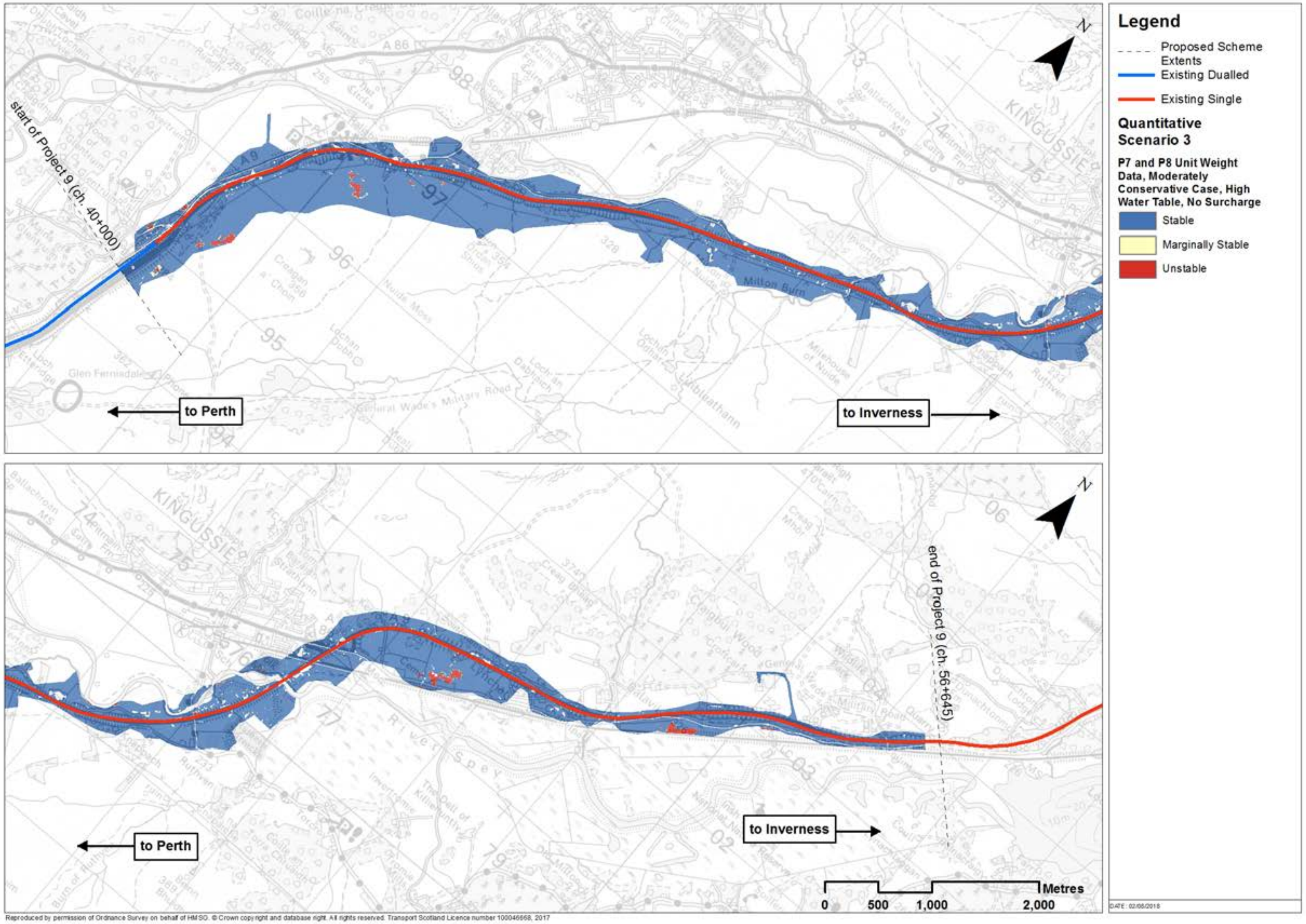

Figure 3: Quantitative Stability Assessment Scenario 3; Moderately Conservative Case, High Water Table, No Surcharge

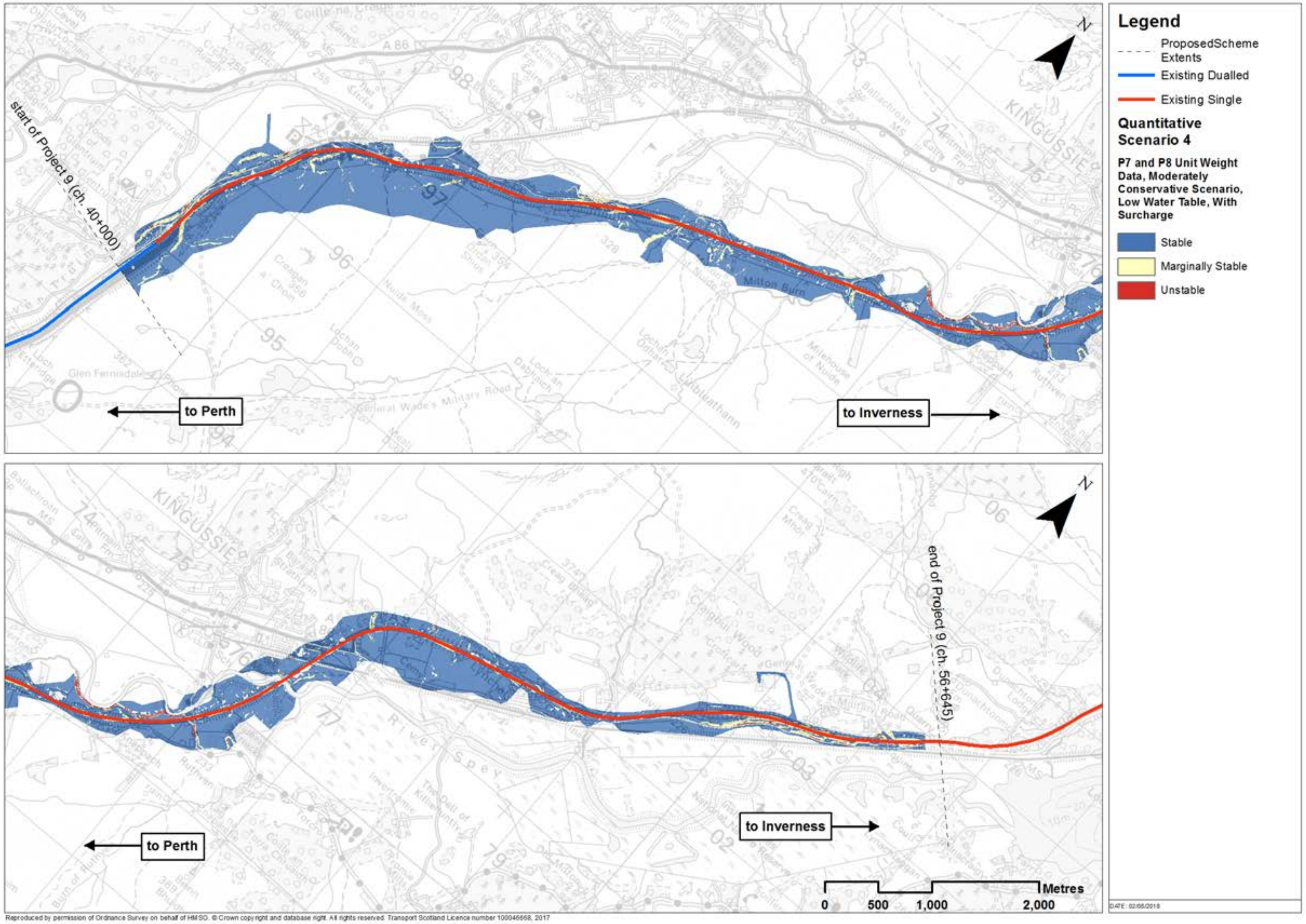

Figure 4: Quantitative Stability Assessment Scenario 4; Moderately Conservative Case, Low Water Table, With Surcharge

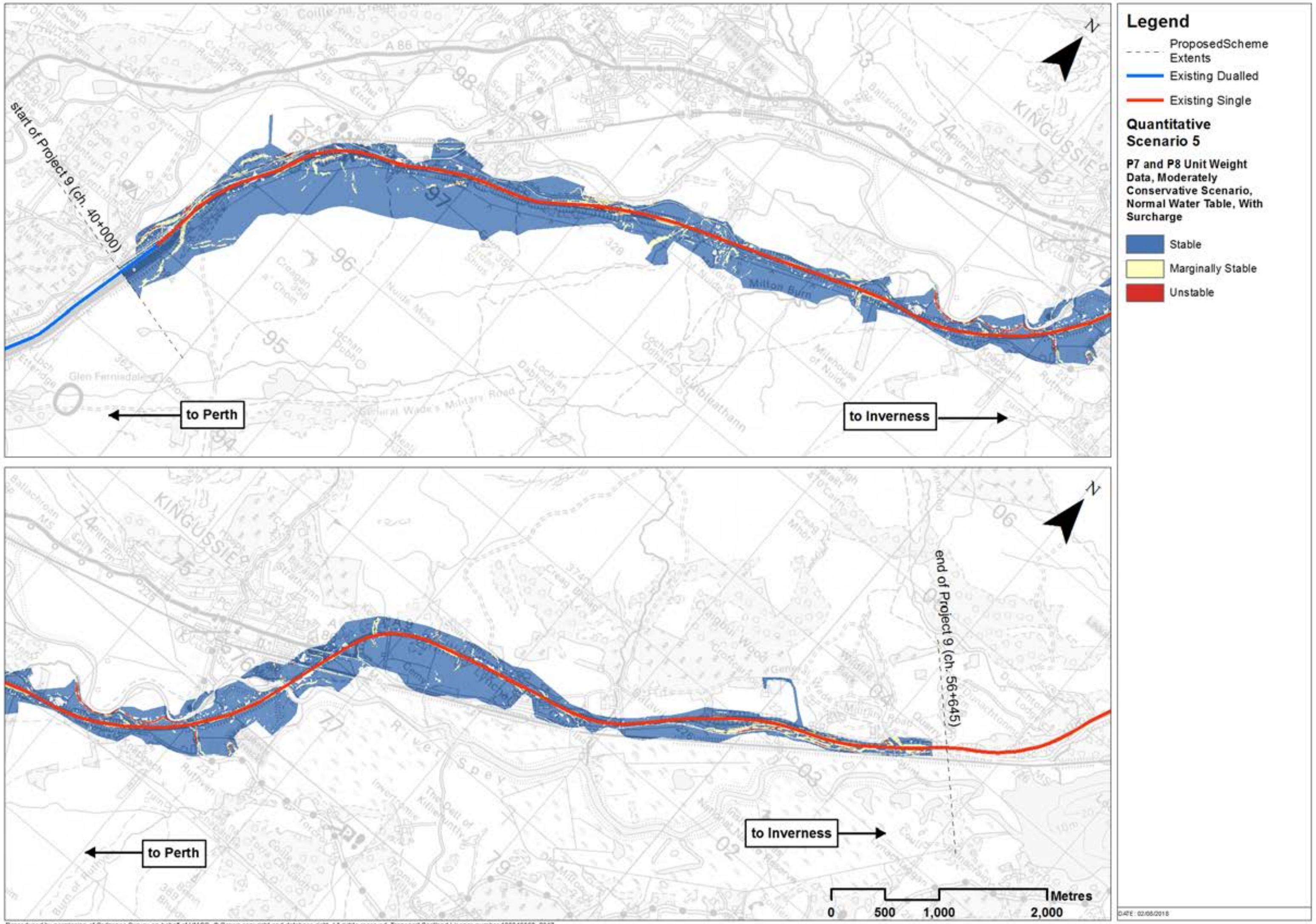

Figure 5: Quantitative Stability Assessment Scenario 5; Moderately Conservative Case, Normal Water Table, With Surcharge

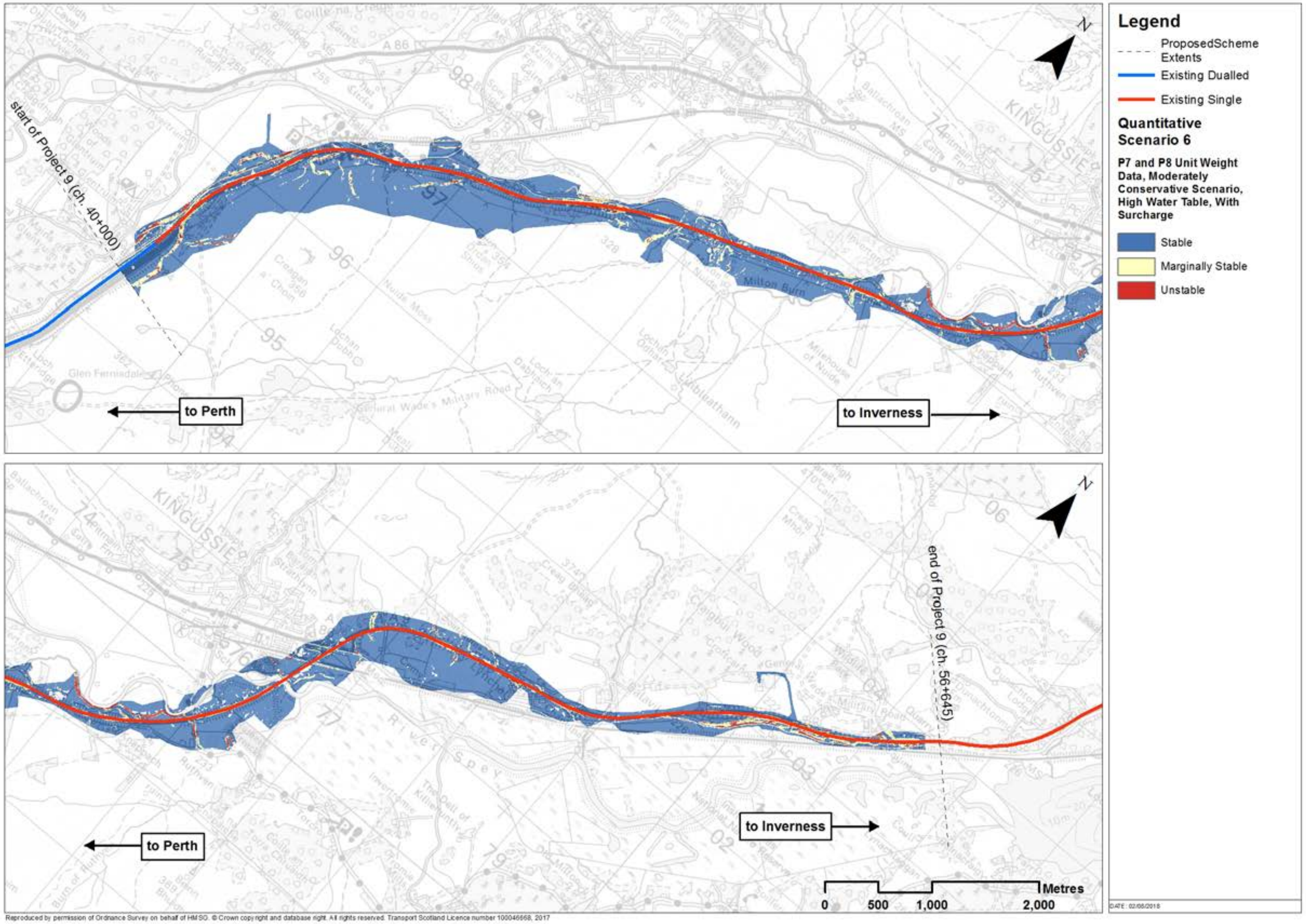

Figure 6: Quantitative Stability Assessment Scenario 6; Moderately Conservative Case, High Water Table, With Surcharge

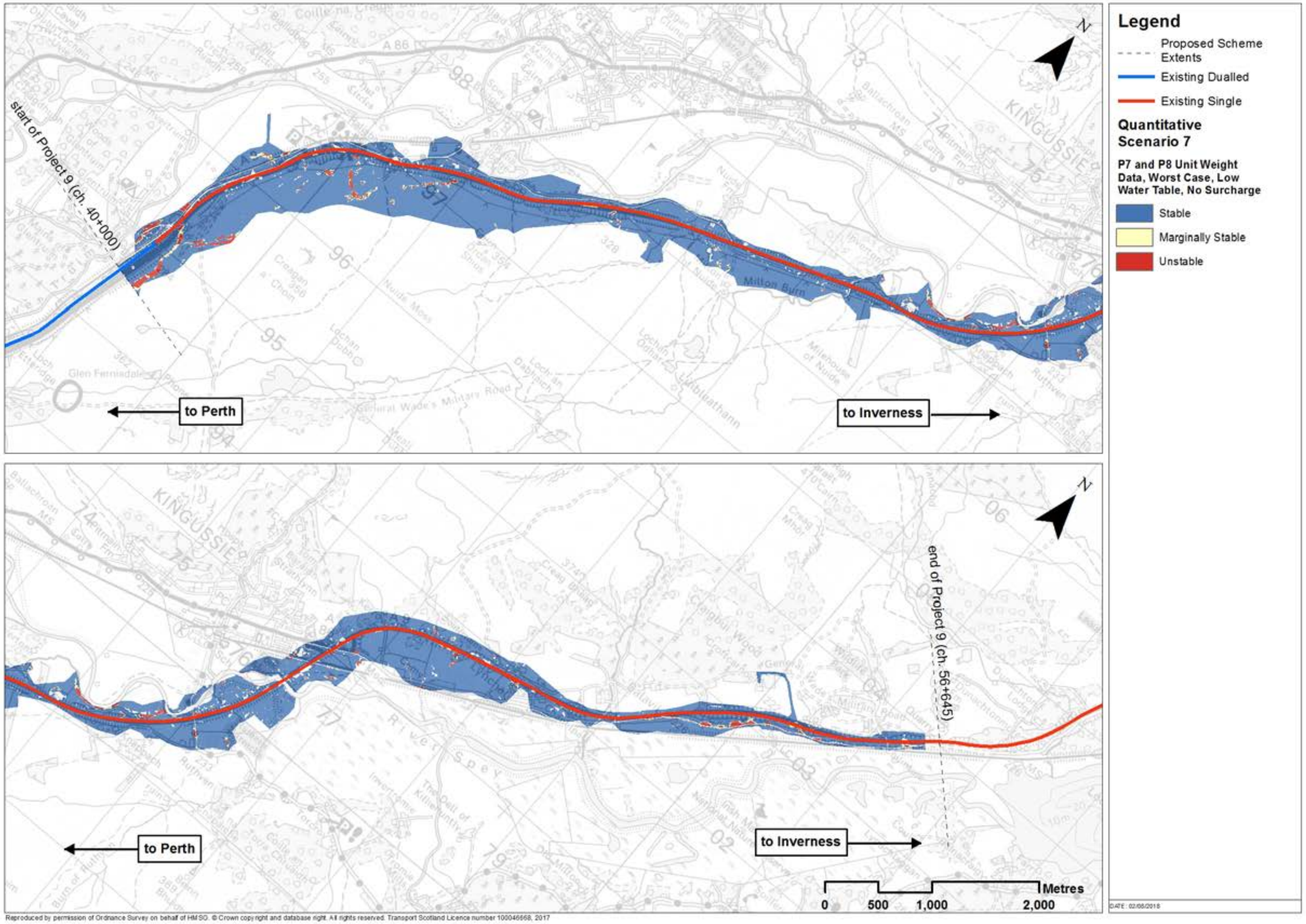

Figure 7: Quantitative Stability Assessment Scenario 7; Worst Case, Low Water Table, No Surcharge

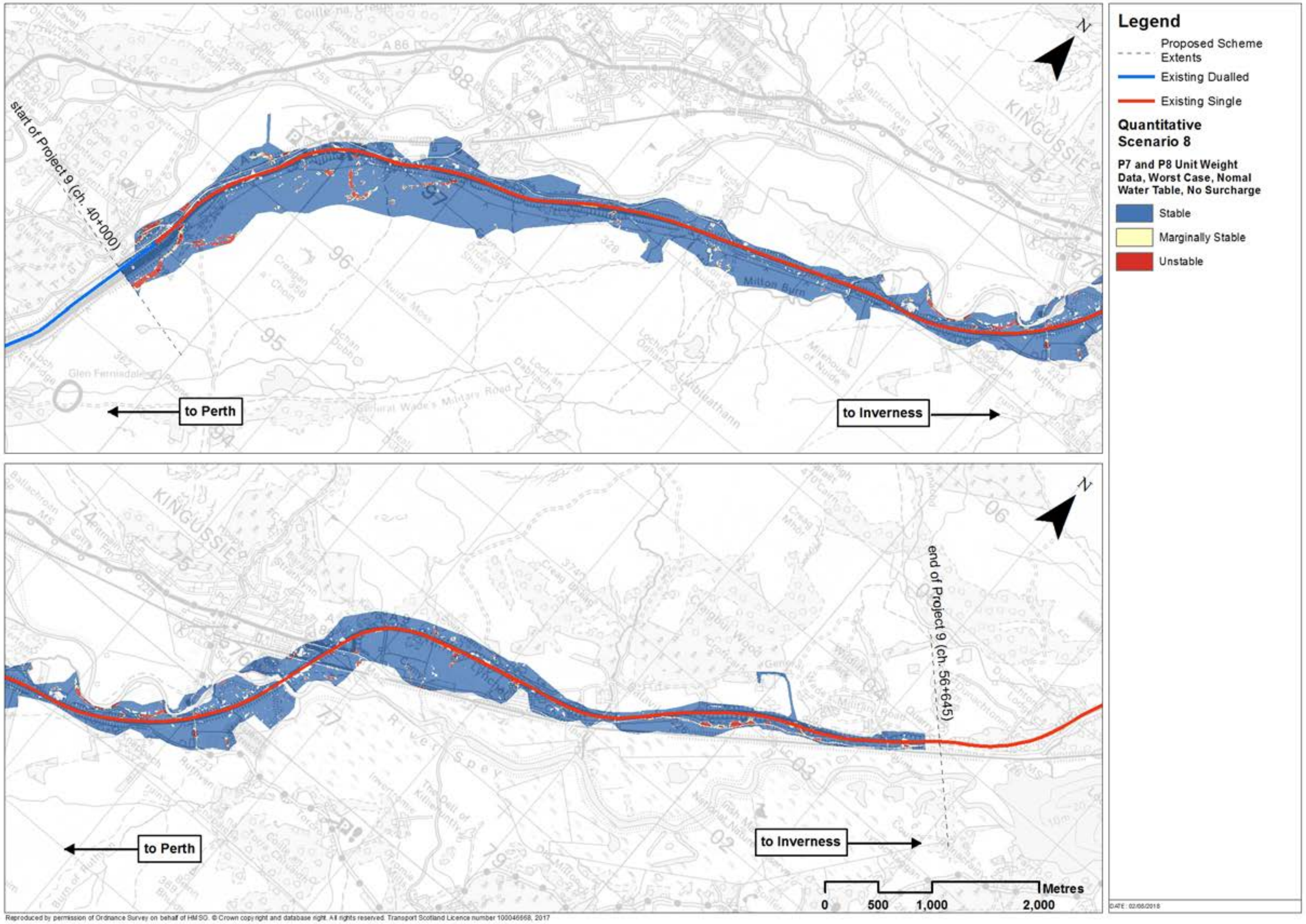

Figure 8: Quantitative Stability Assessment Scenario 8; Worst Case, Normal Water Table, No Surcharge

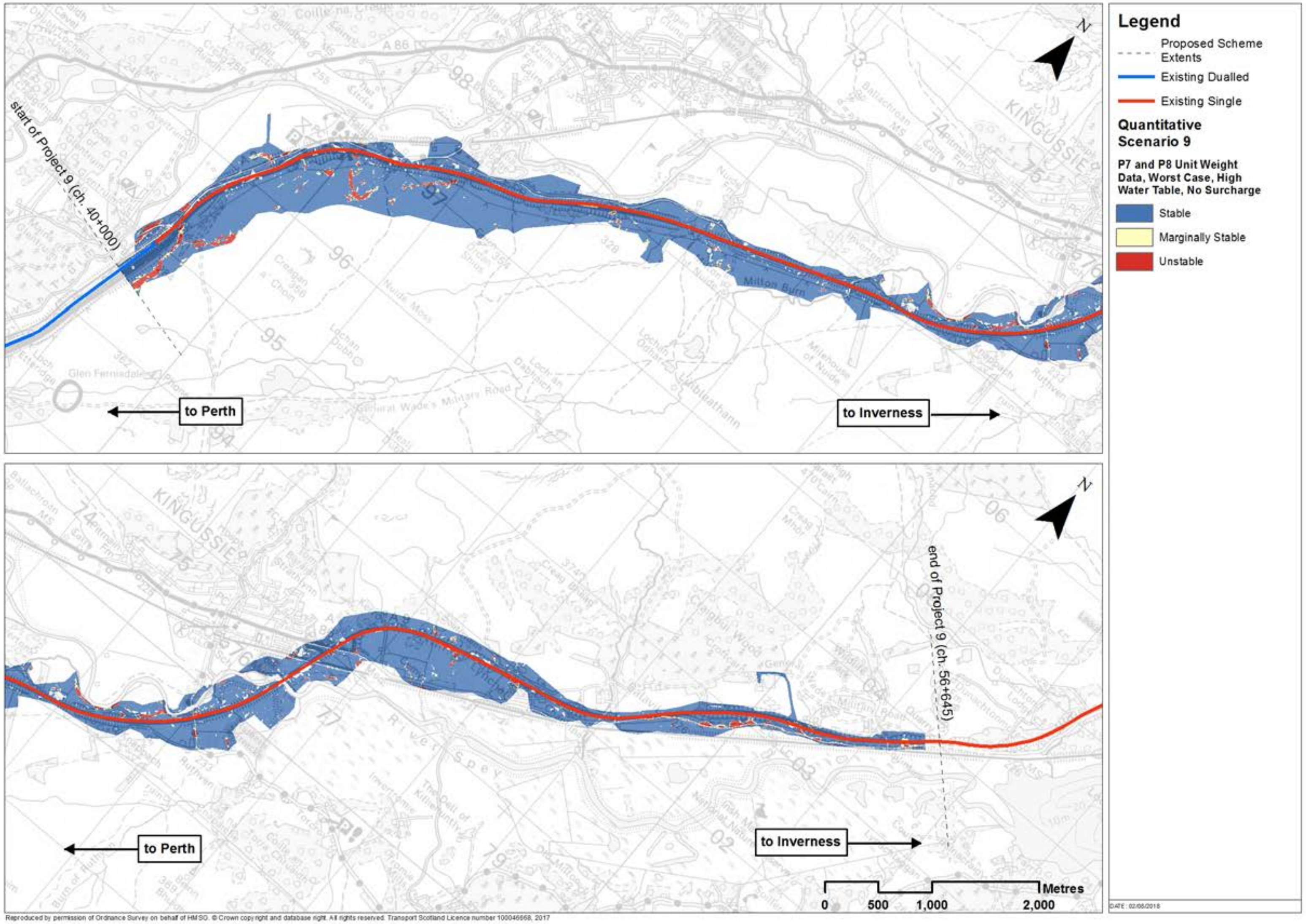

Figure 9: Quantitative Stability Assessment Scenario 9; Worst Case, High Water Table, No Surcharge

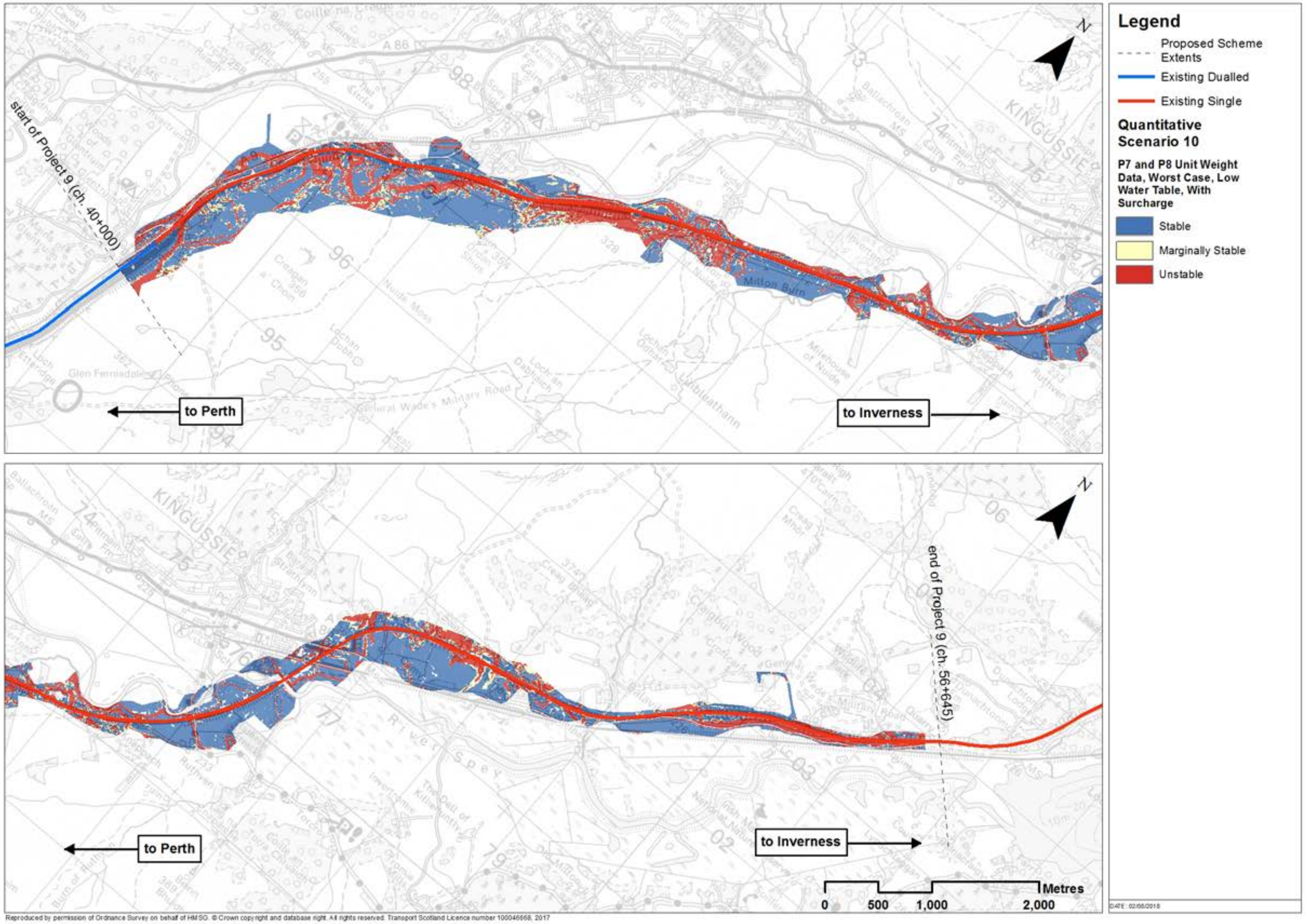

Figure 10: Quantitative Stability Assessment Scenario 10; Worst Case, Low Water Table, With Surcharge

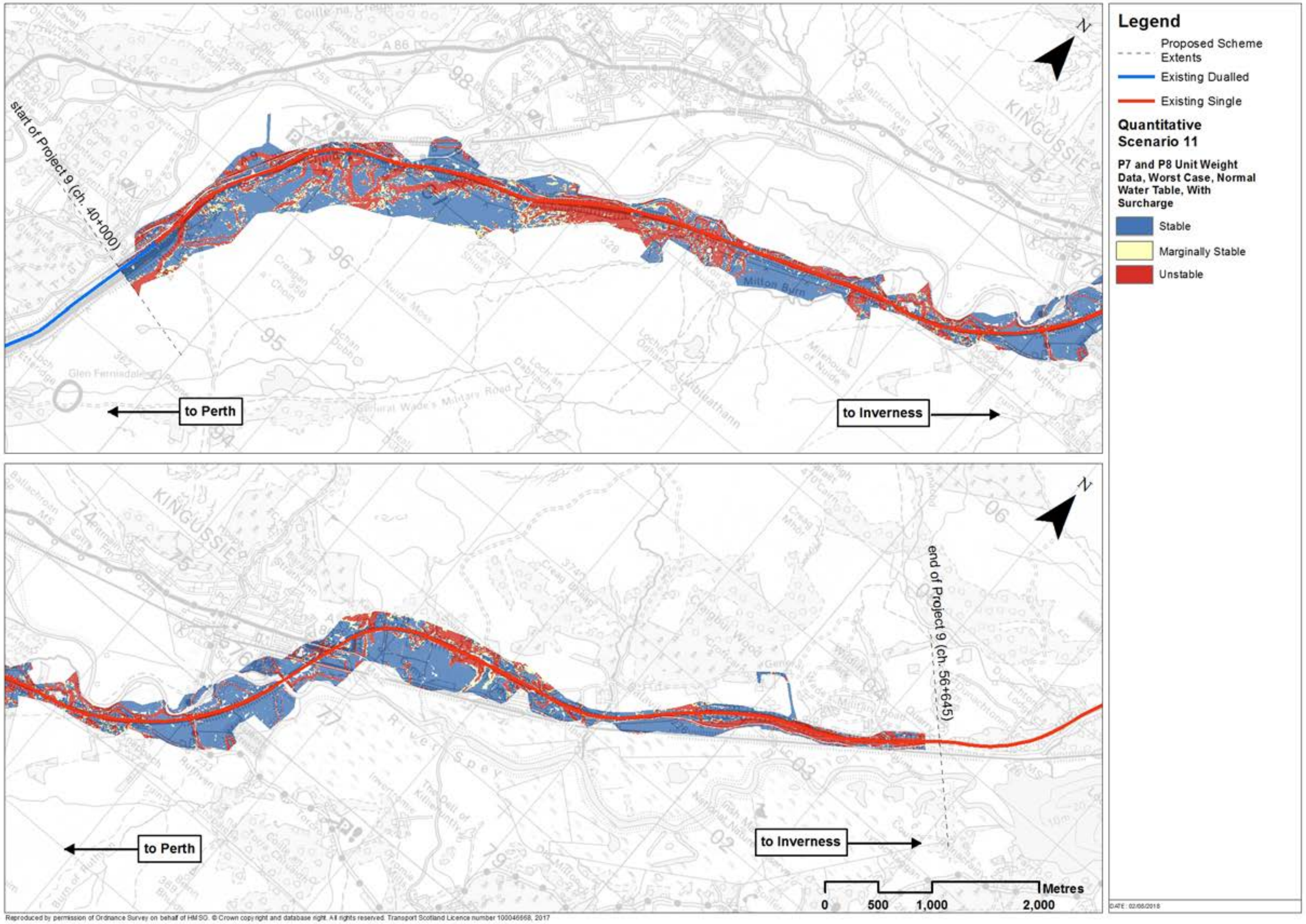

Figure 11: Quantitative Stability Assessment Scenario 11; Worst Case, Normal Water Table, With Surcharge

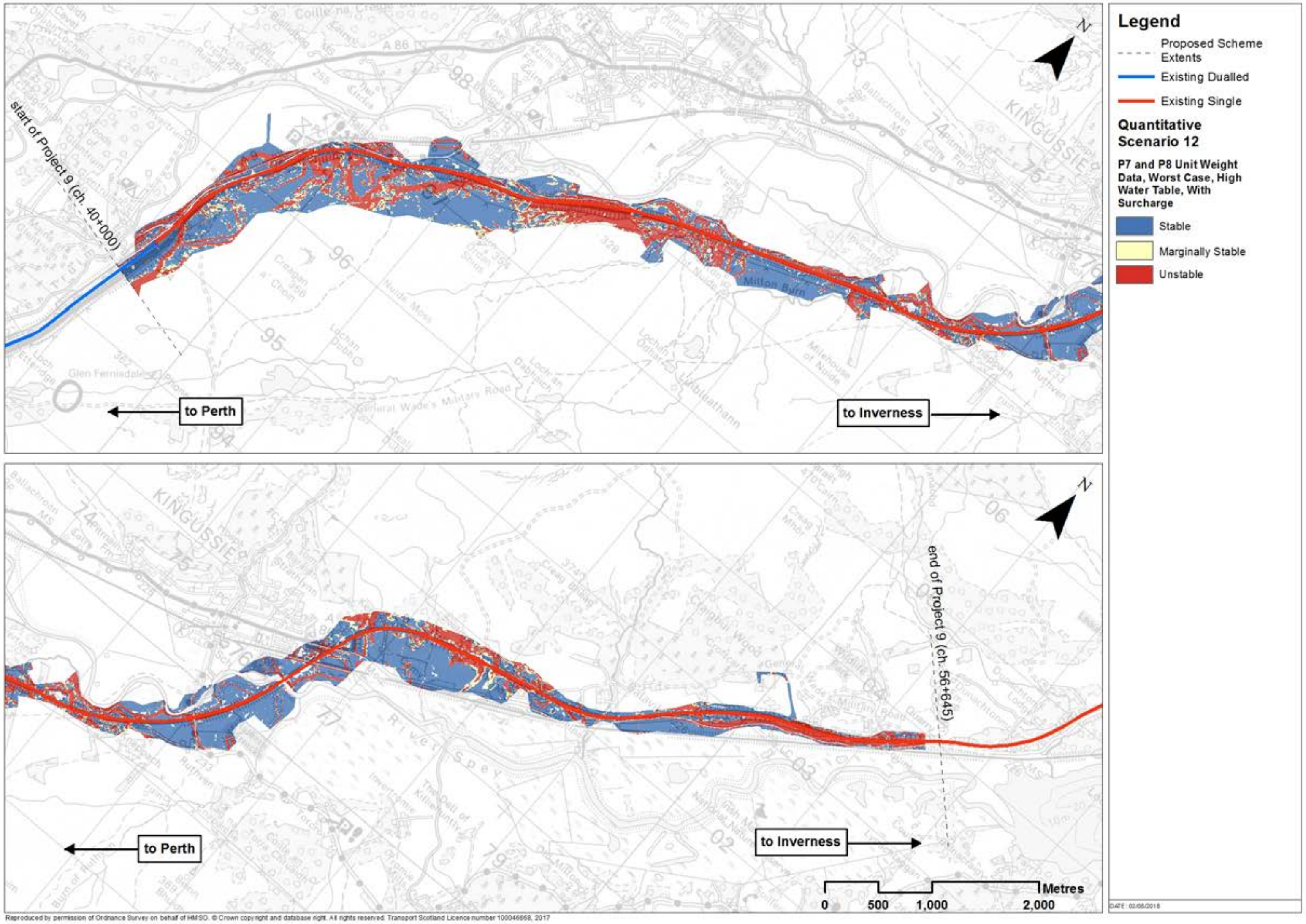

Figure 12: Quantitative Stability Assessment Scenario 12; Worst Case, High Water Table, With Surcharge

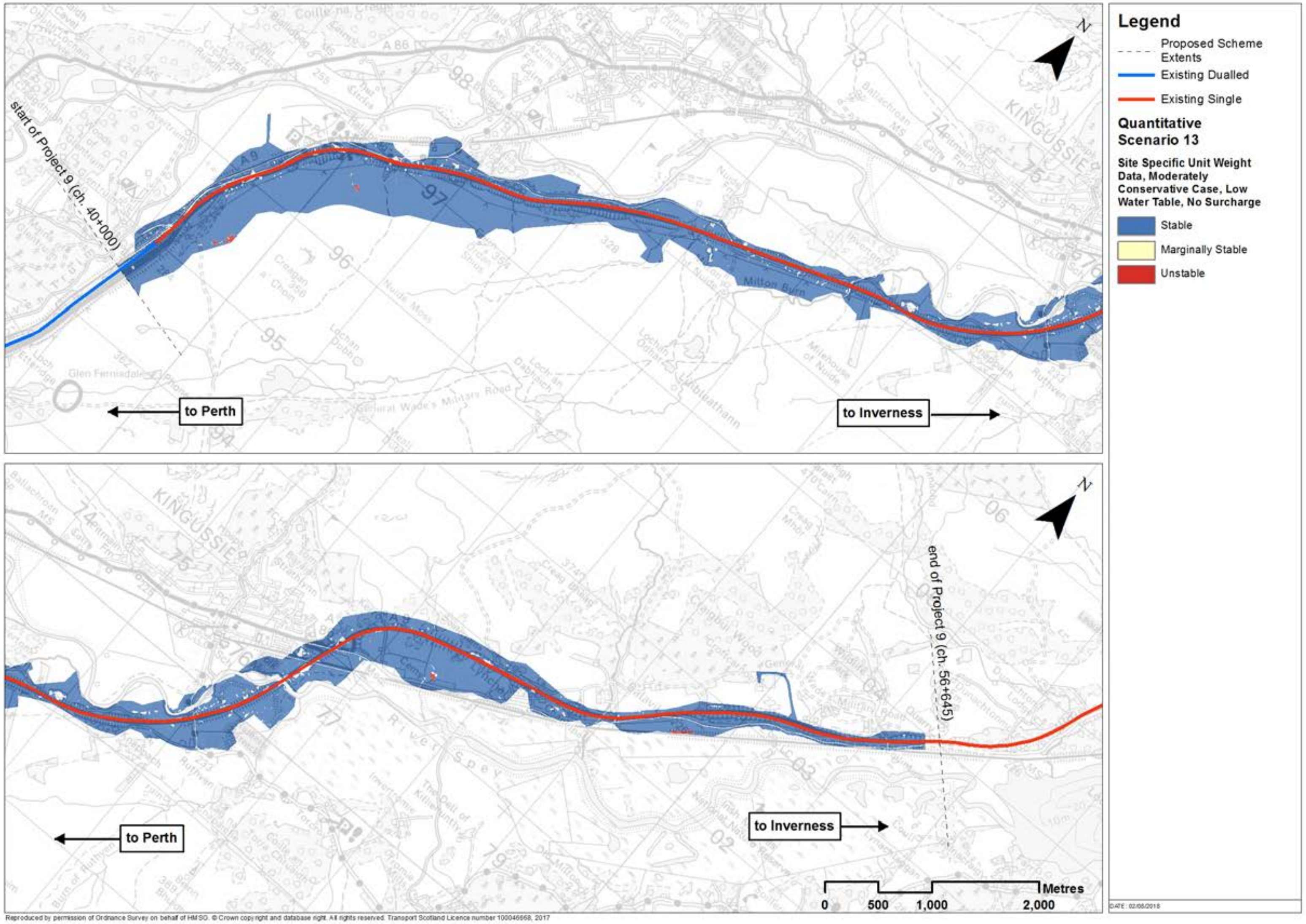

Figure 13: Quantitative Stability Assessment Scenario 13; Moderately Conservative Case, Low Water Table, No Surcharge

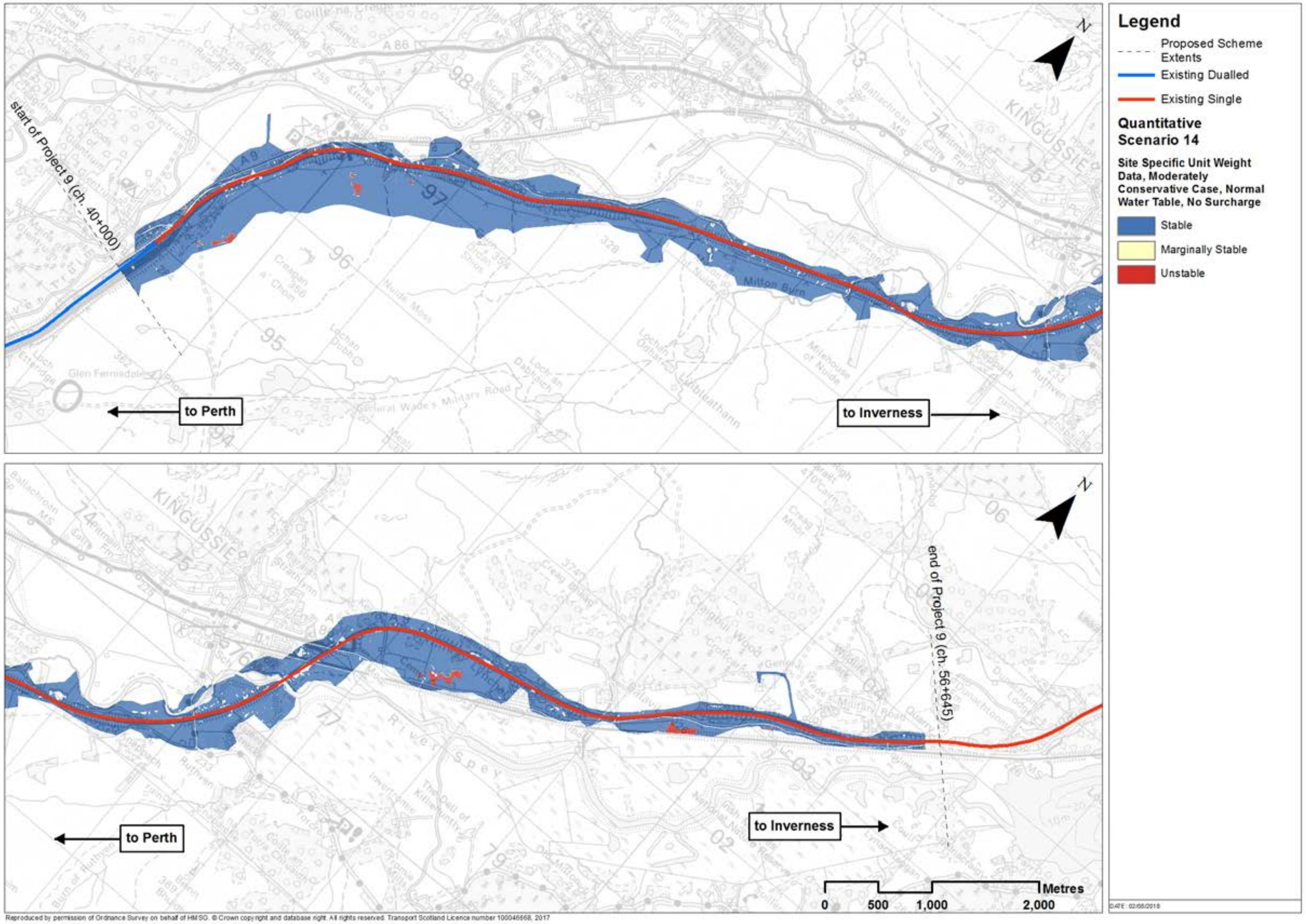

Figure 14: Quantitative Stability Assessment Scenario 14; Moderately Conservative Case, Normal Water Table, No Surcharge

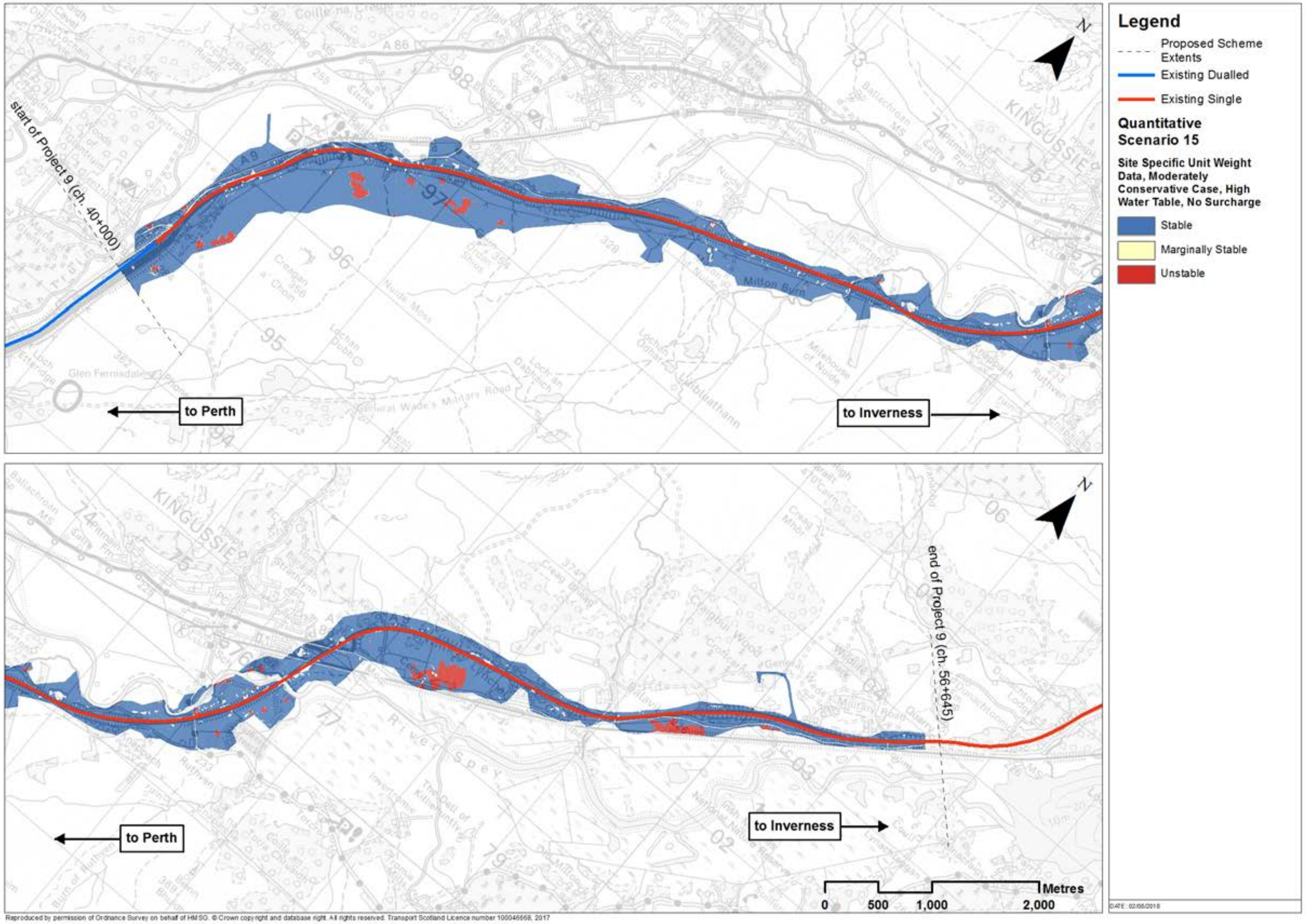

Figure 15: Quantitative Stability Assessment Scenario 15; Moderately Conservative Case, High Water Table, No Surcharge

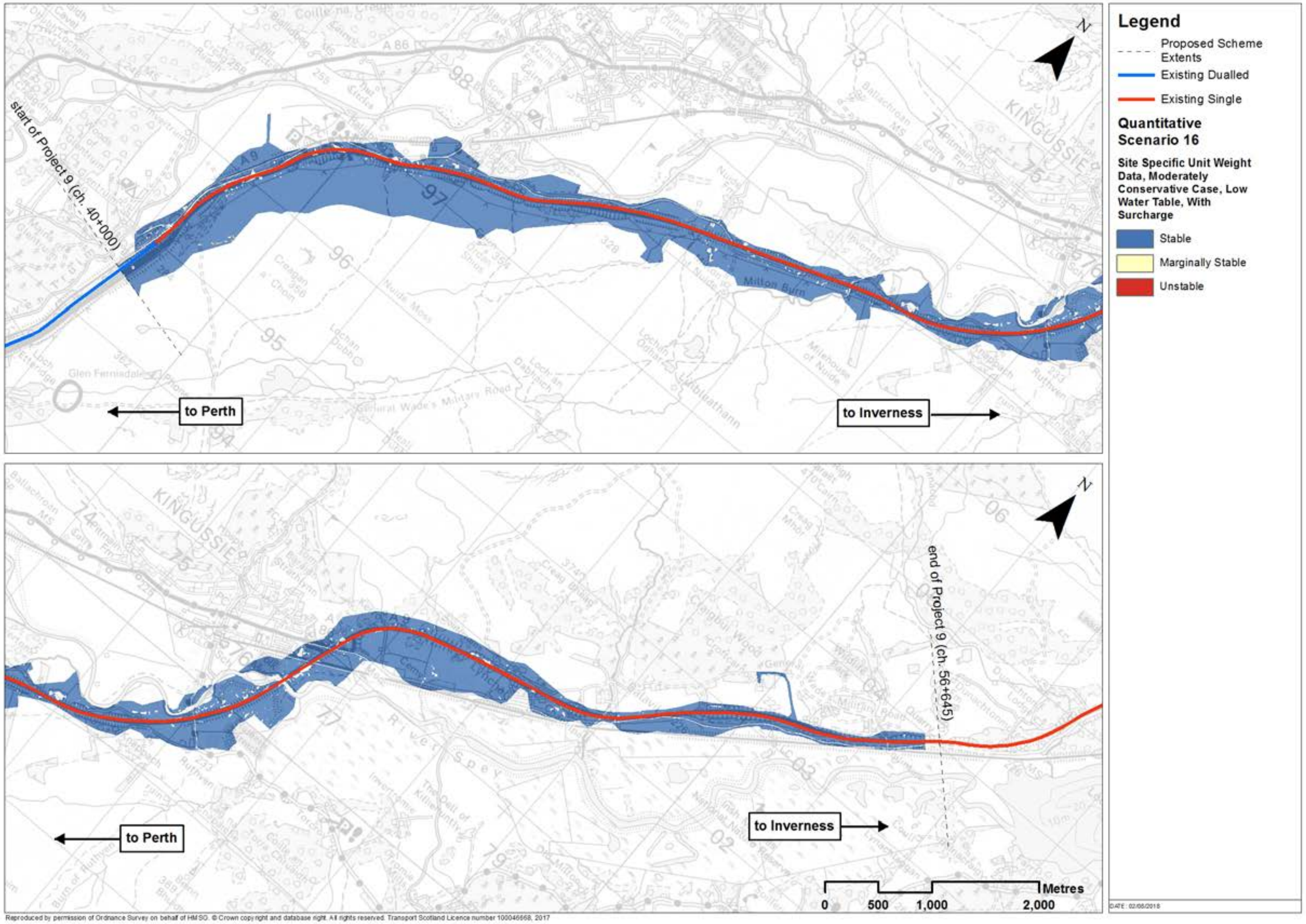

Figure 16: Quantitative Stability Assessment Scenario 16; Moderately Conservative Case, Low Water Table, With Surcharge

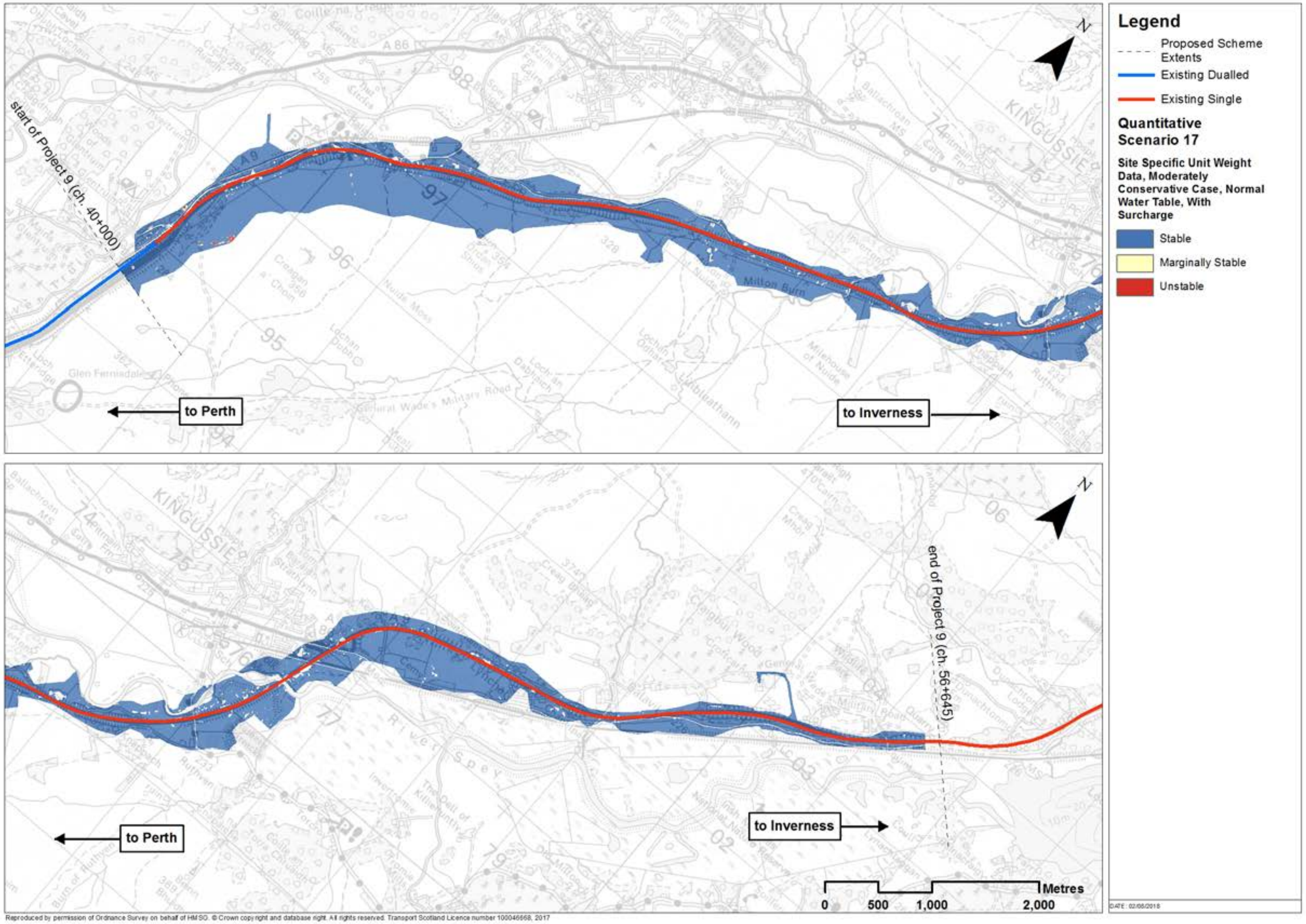

Figure 17: Quantitative Stability Assessment Scenario 17; Moderately Conservative Case, Normal Water Table, With Surcharge

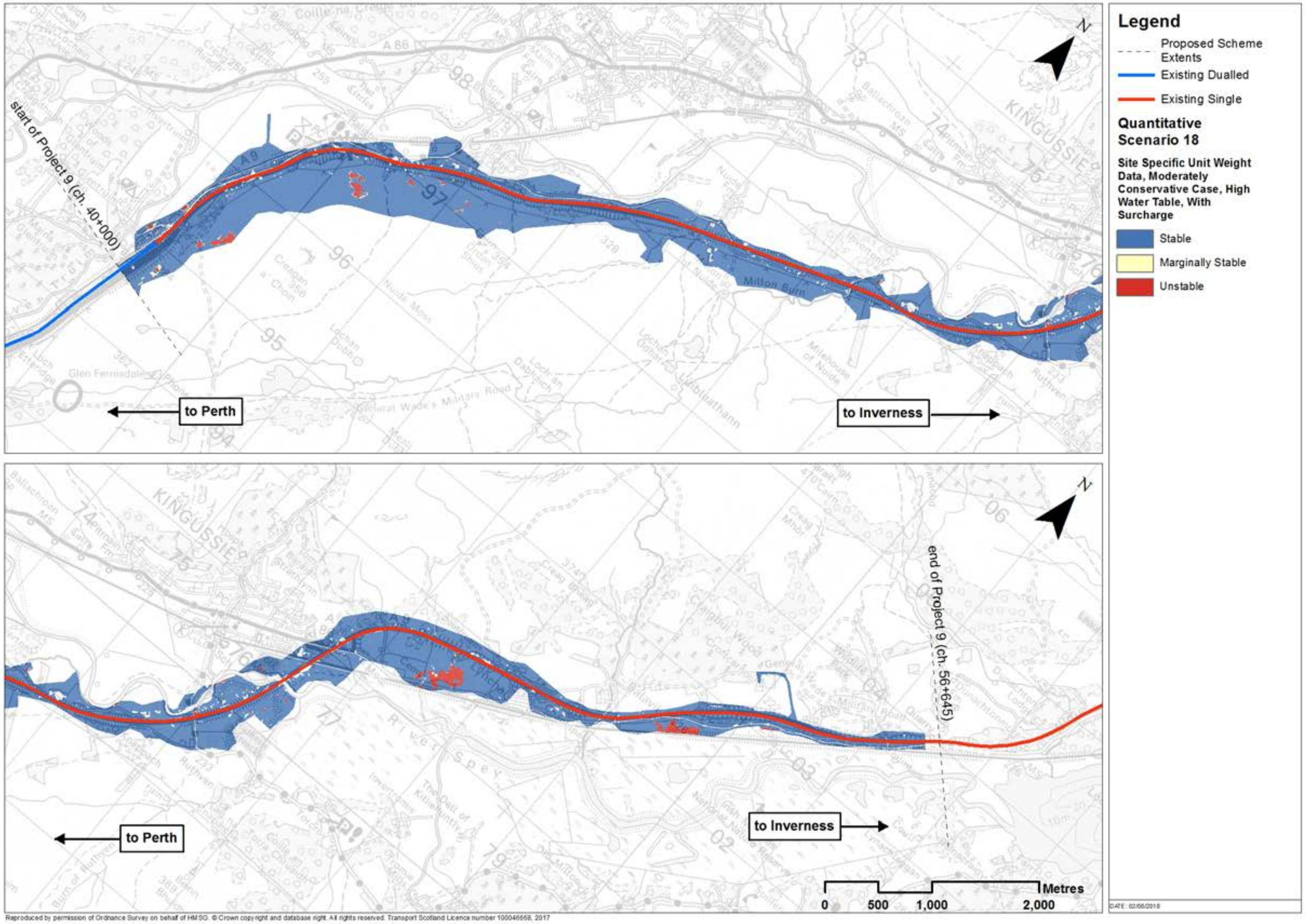

Figure 18: Quantitative Stability Assessment Scenario 18; Moderately Conservative Case, High Water Table, With Surcharge

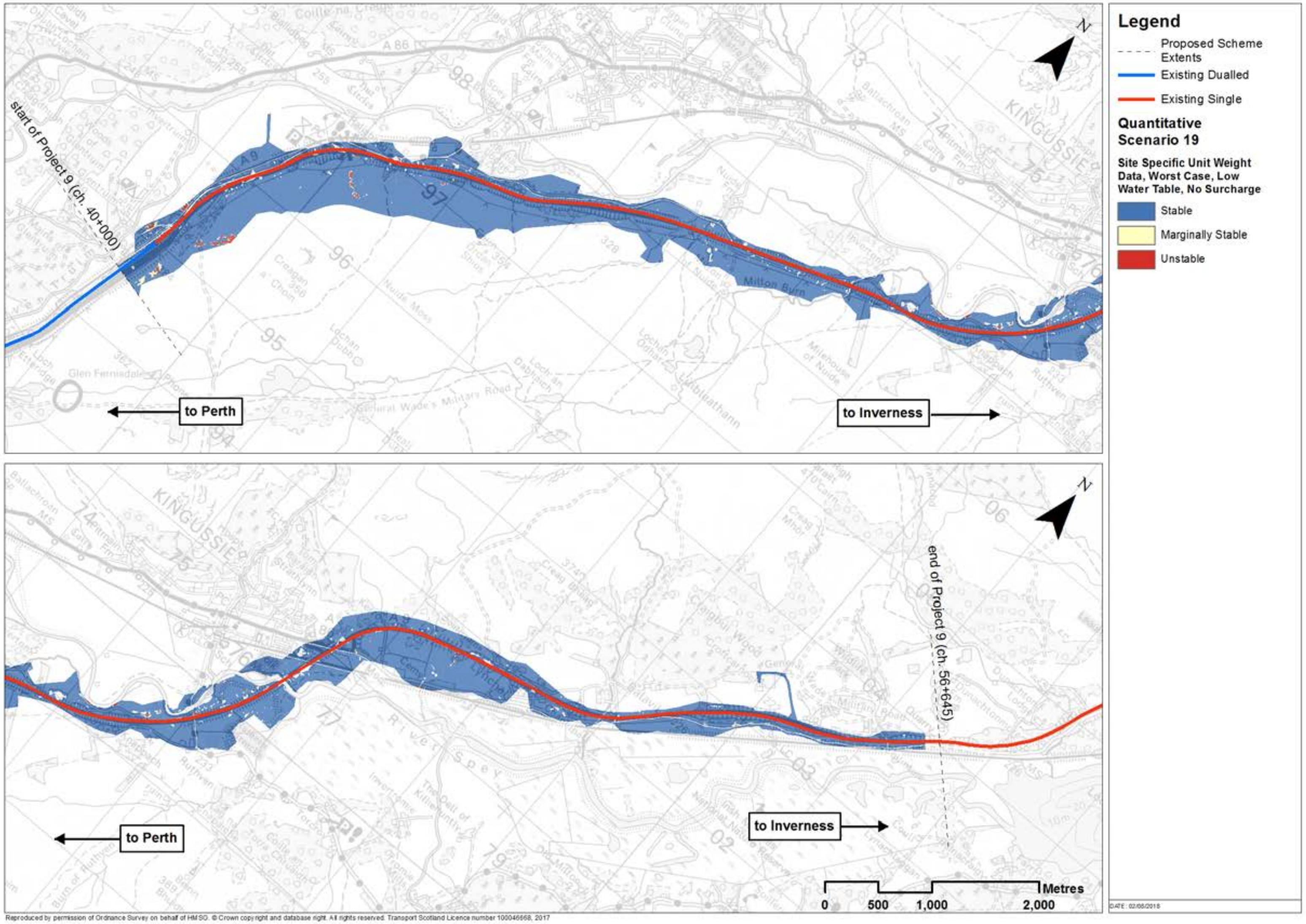

Figure 19: Quantitative Stability Assessment Scenario 19; Worst Case, Low Water Table, No Surcharge

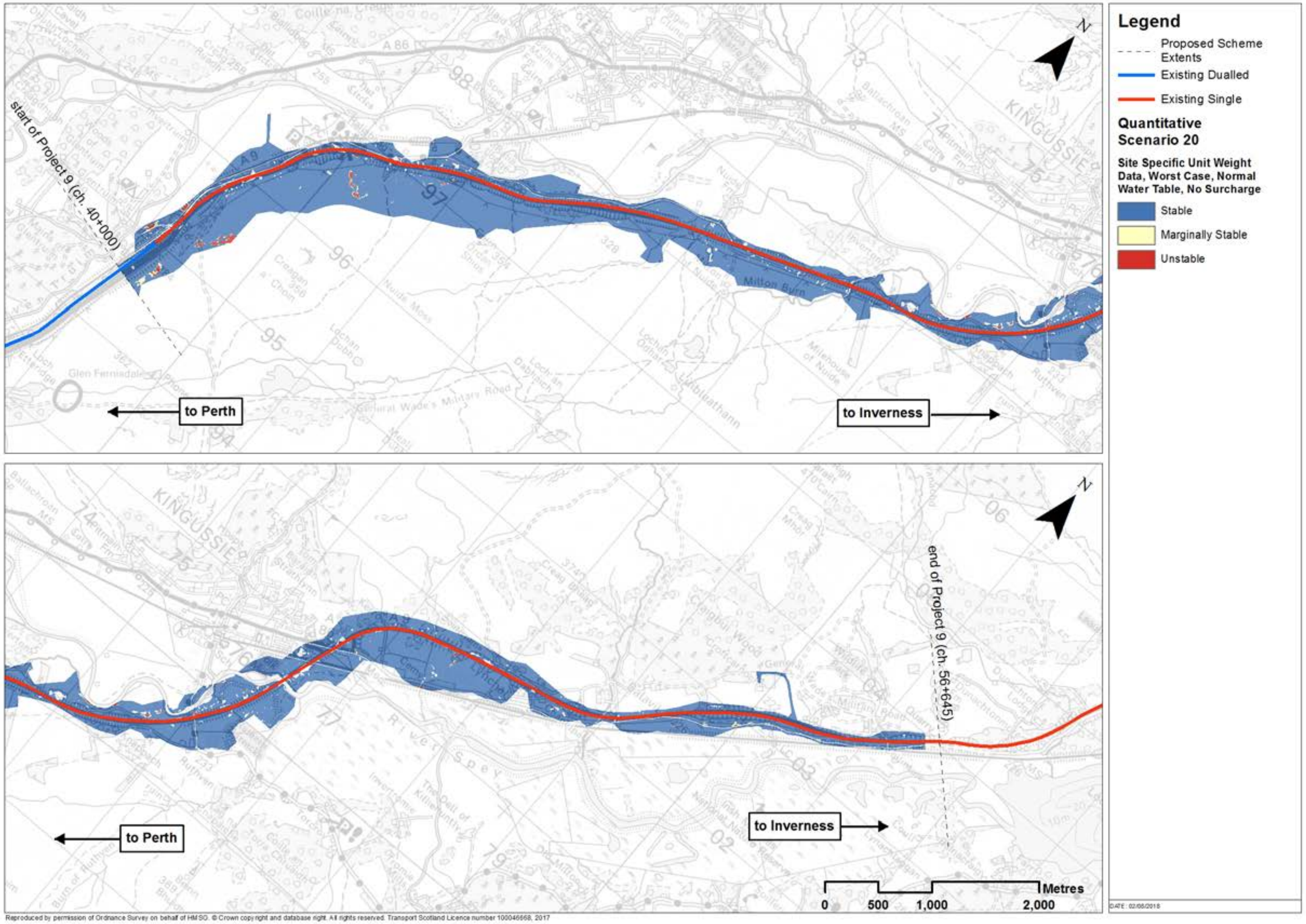

Figure 20: Quantitative Stability Assessment Scenario 20; Worst Case, Normal Water Table, No Surcharge

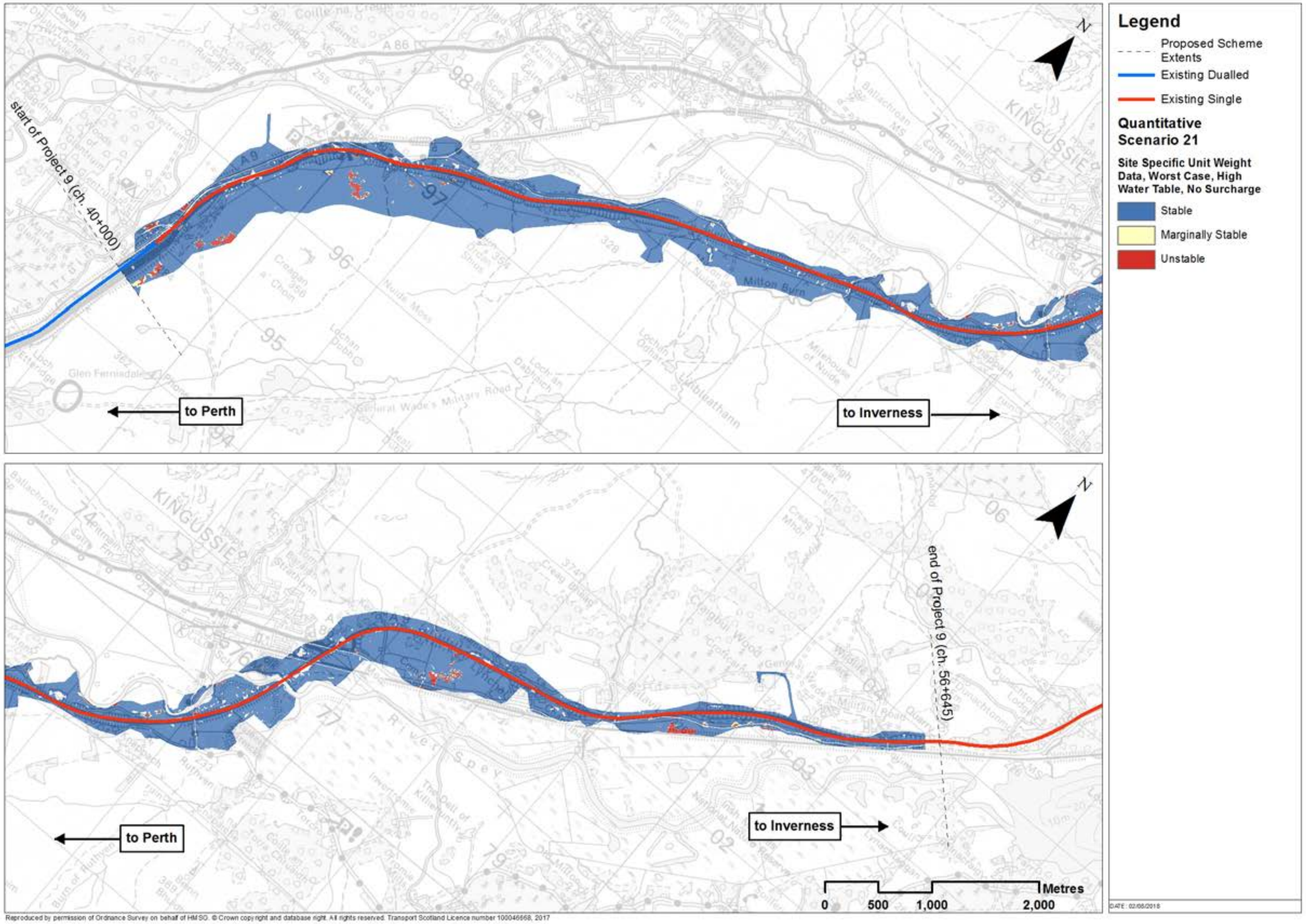

Figure 21: Quantitative Stability Assessment Scenario 21; Worst Case, High Water Table, No Surcharge

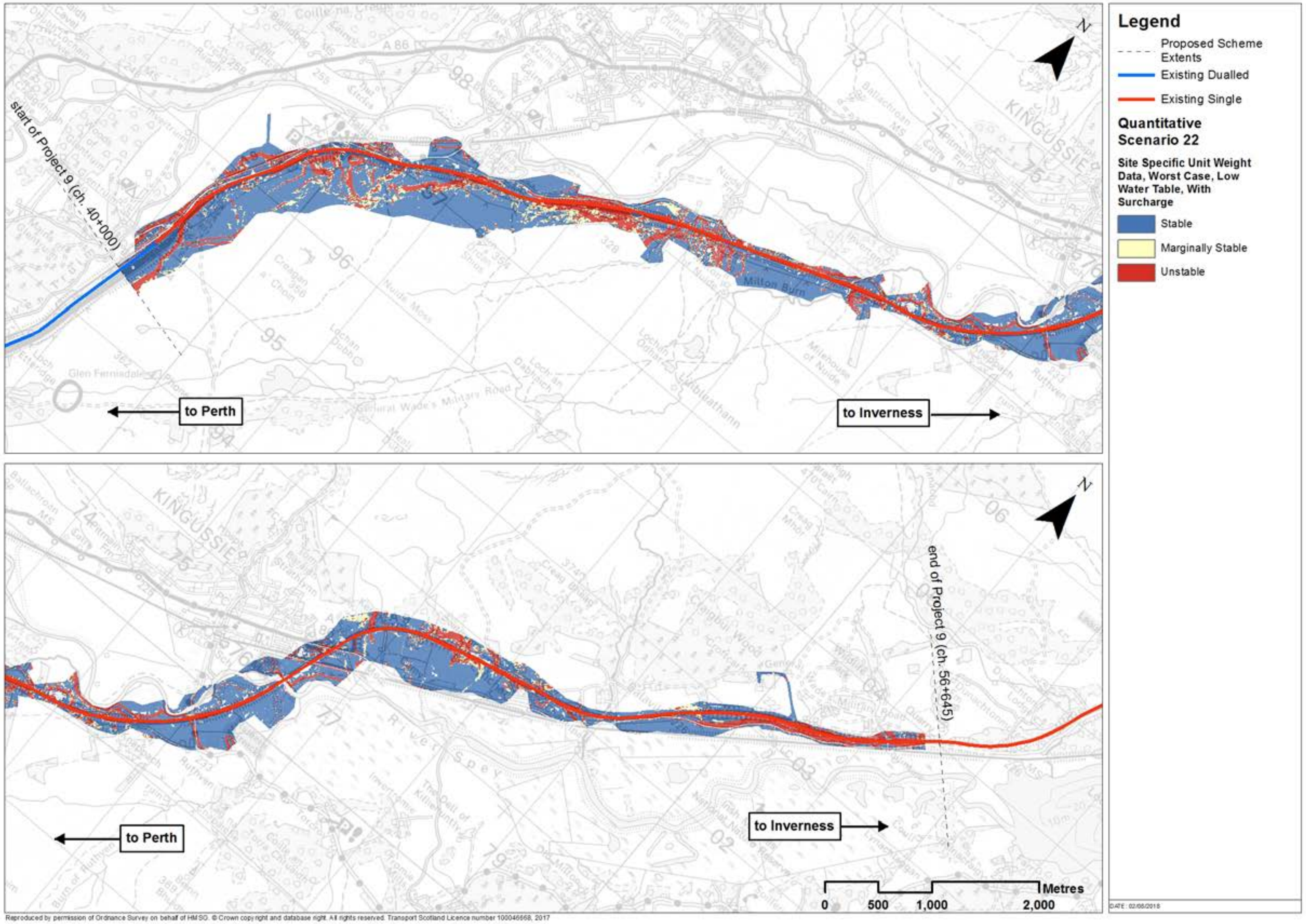

Figure 22: Quantitative Stability Assessment Scenario 22; Worst Case, Low Water Table, With Surcharge

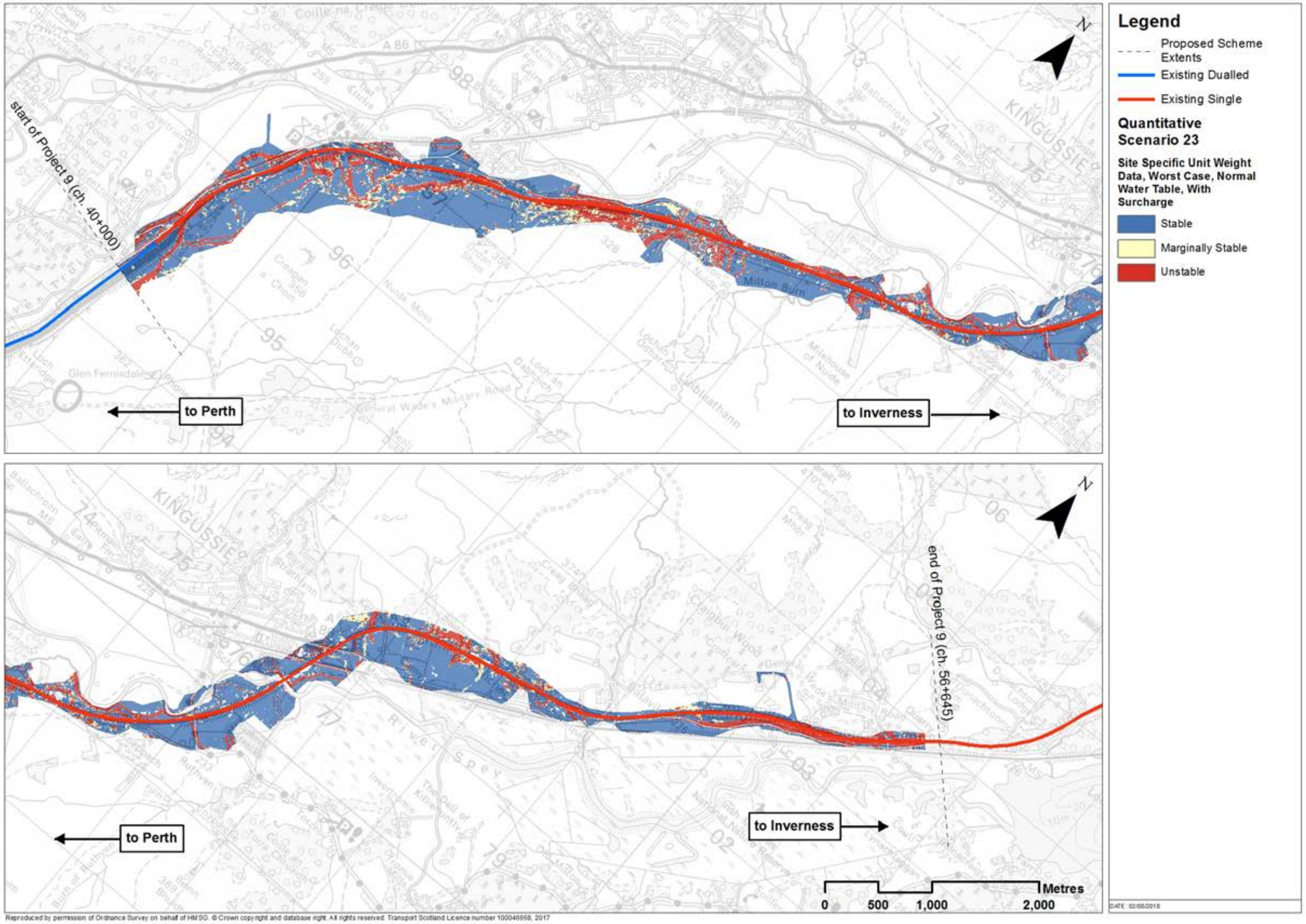

Figure 23: Quantitative Stability Assessment Scenario 23; Worst Case, Normal Water Table, With Surcharge

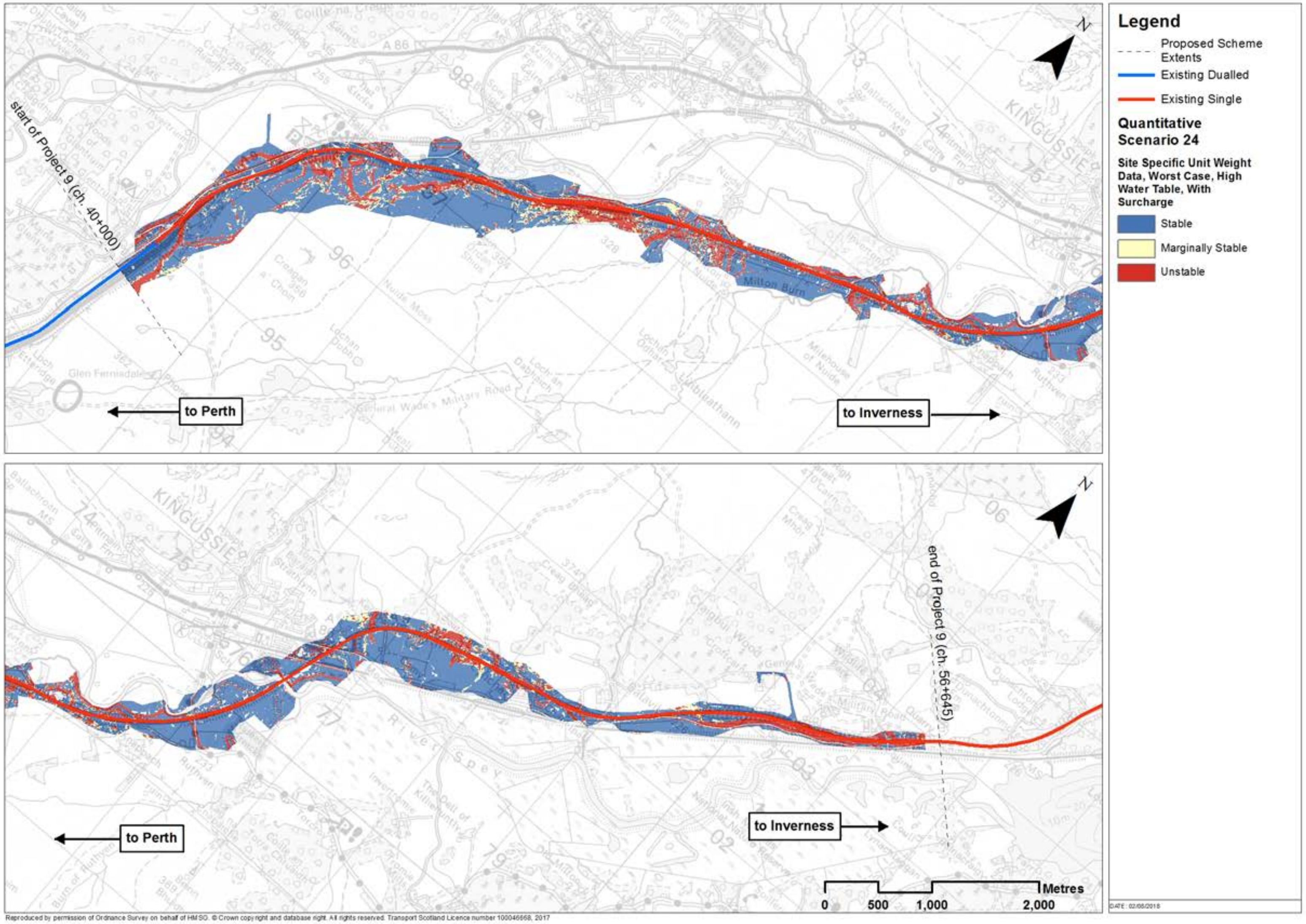

Figure 24: Quantitative Stability Assessment Scenario 24; Worst Case, High Water Table, With Surcharge

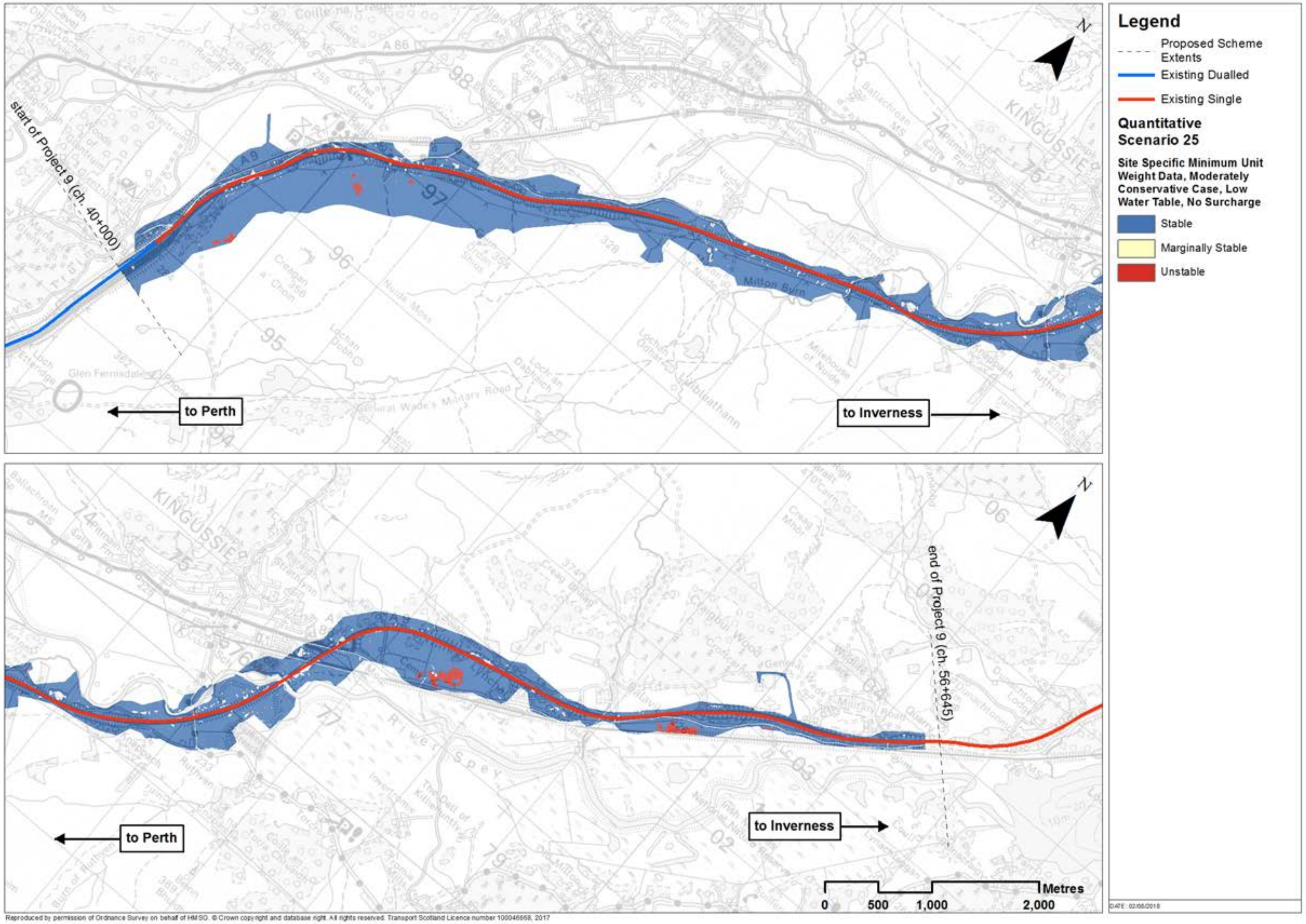

Figure 25: Quantitative Stability Assessment Scenario 25; Moderately Conservative Case, Low Water Table, No Surcharge

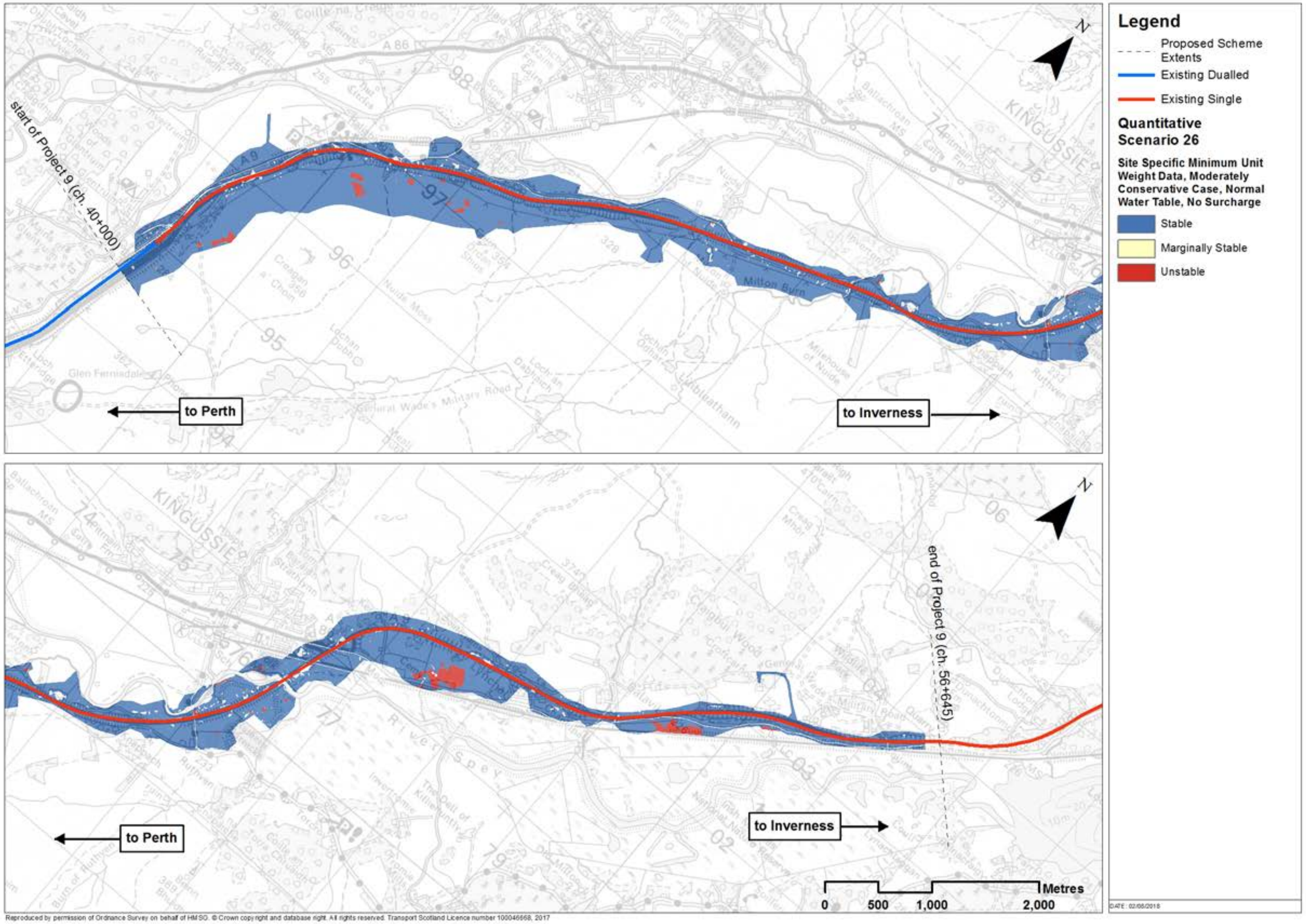

Figure 26: Quantitative Stability Assessment Scenario 26; Moderately Conservative Case, Normal Water Table, No Surcharge

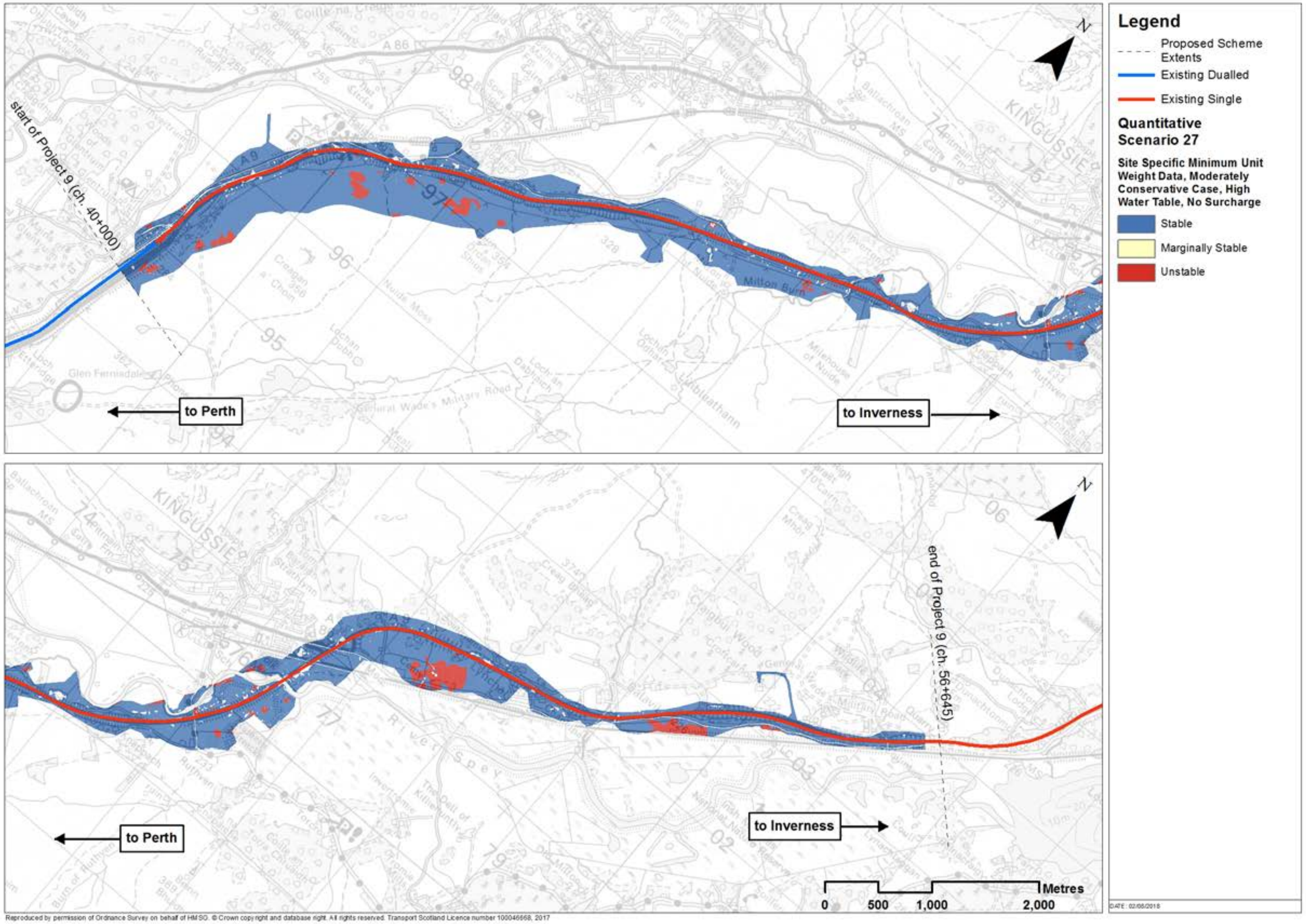

Figure 27: Quantitative Stability Assessment Scenario 27; Moderately Conservative Case, High Water Table, No Surcharge

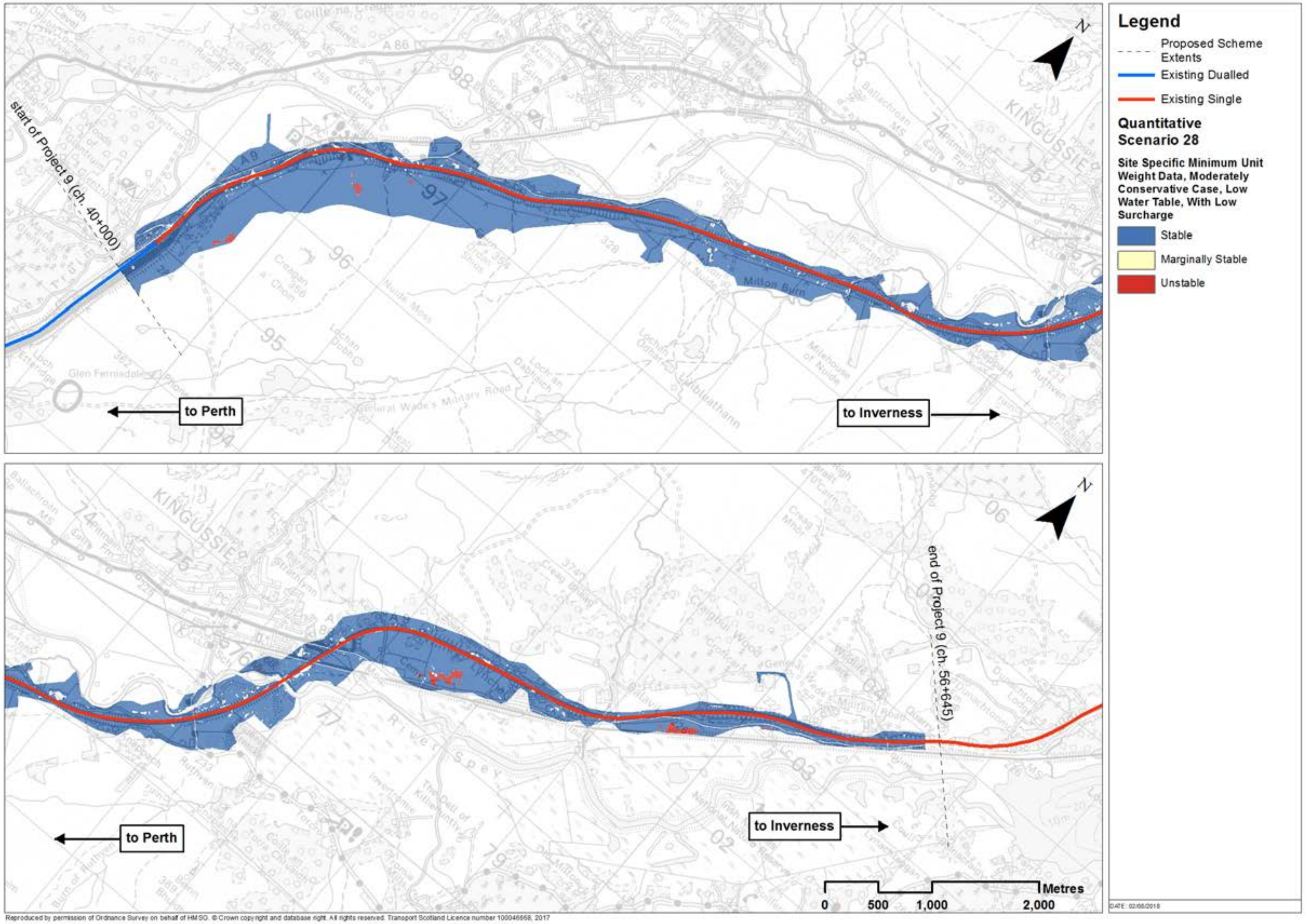

Figure 28: Quantitative Stability Assessment Scenario 28; Moderately Conservative Case, Low Water Table, With Low Surcharge

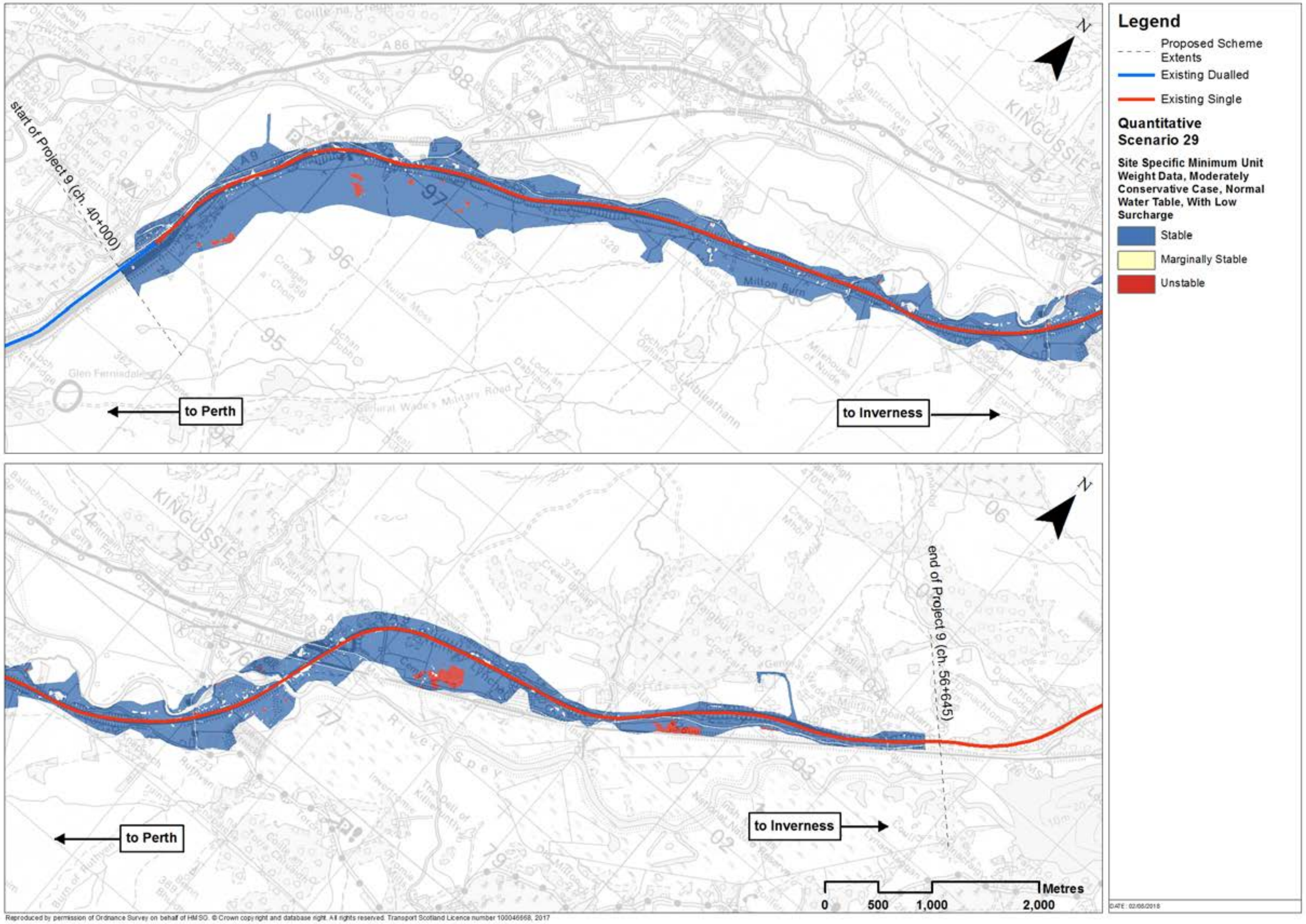

Figure 29: Quantitative Stability Assessment Scenario 29; Moderately Conservative Case, Normal Water Table, With Low Surcharge

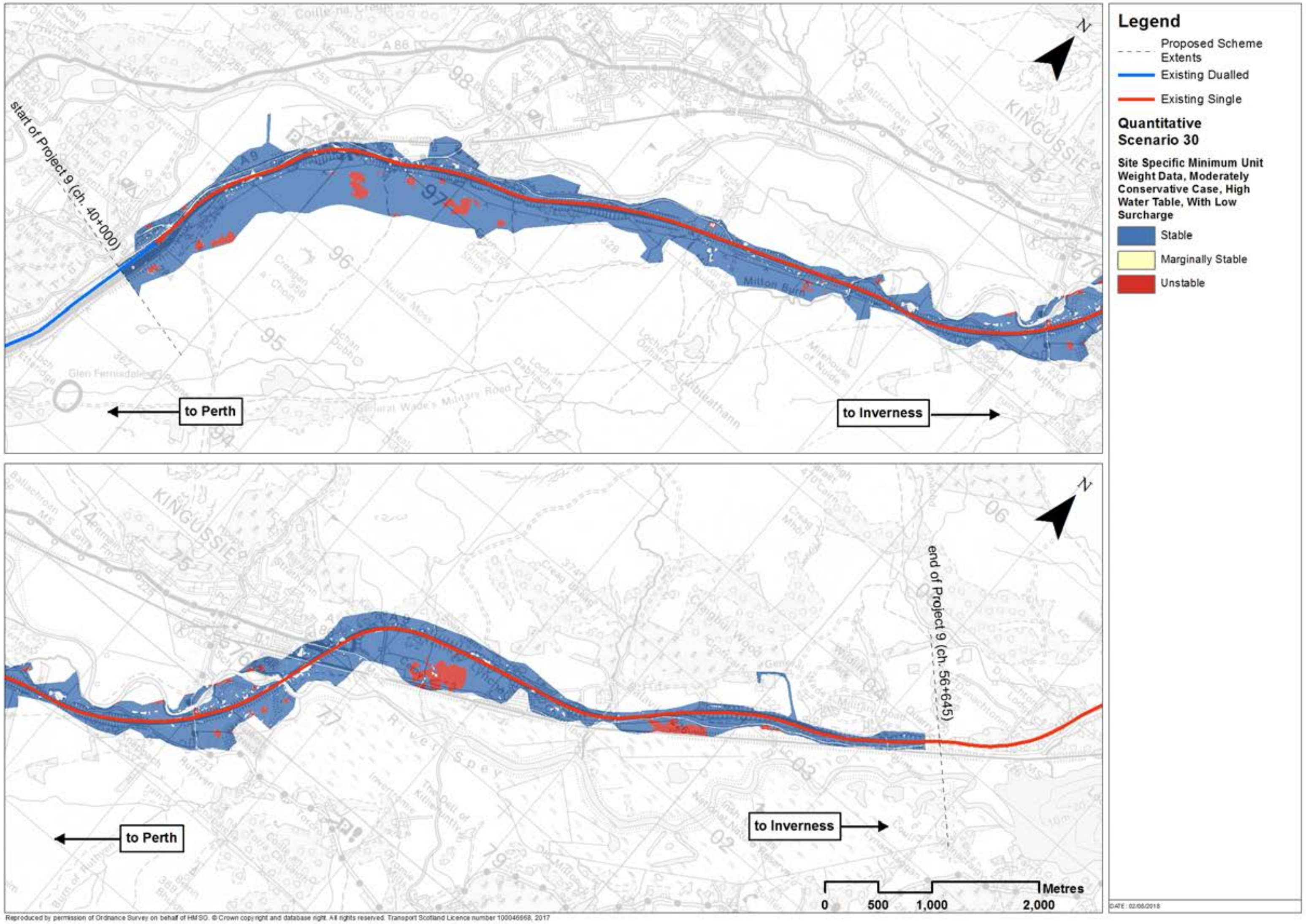

Figure 30: Quantitative Stability Assessment Scenario 30; Moderately Conservative Case, High Water Table, With Low Surcharge

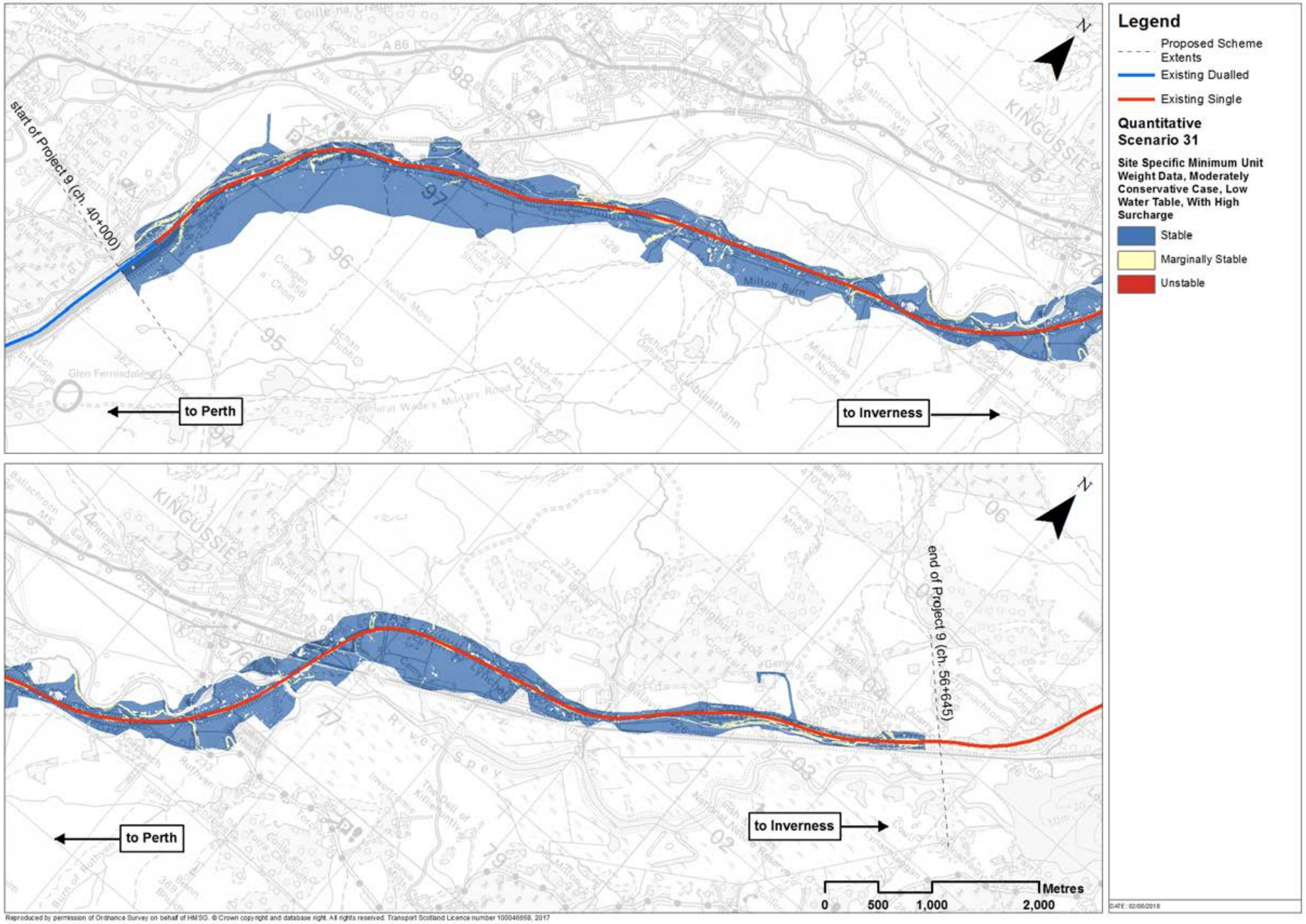

Figure 31: Quantitative Stability Assessment Scenario 31; Moderately Conservative Case, Low Water Table, With High Surcharge

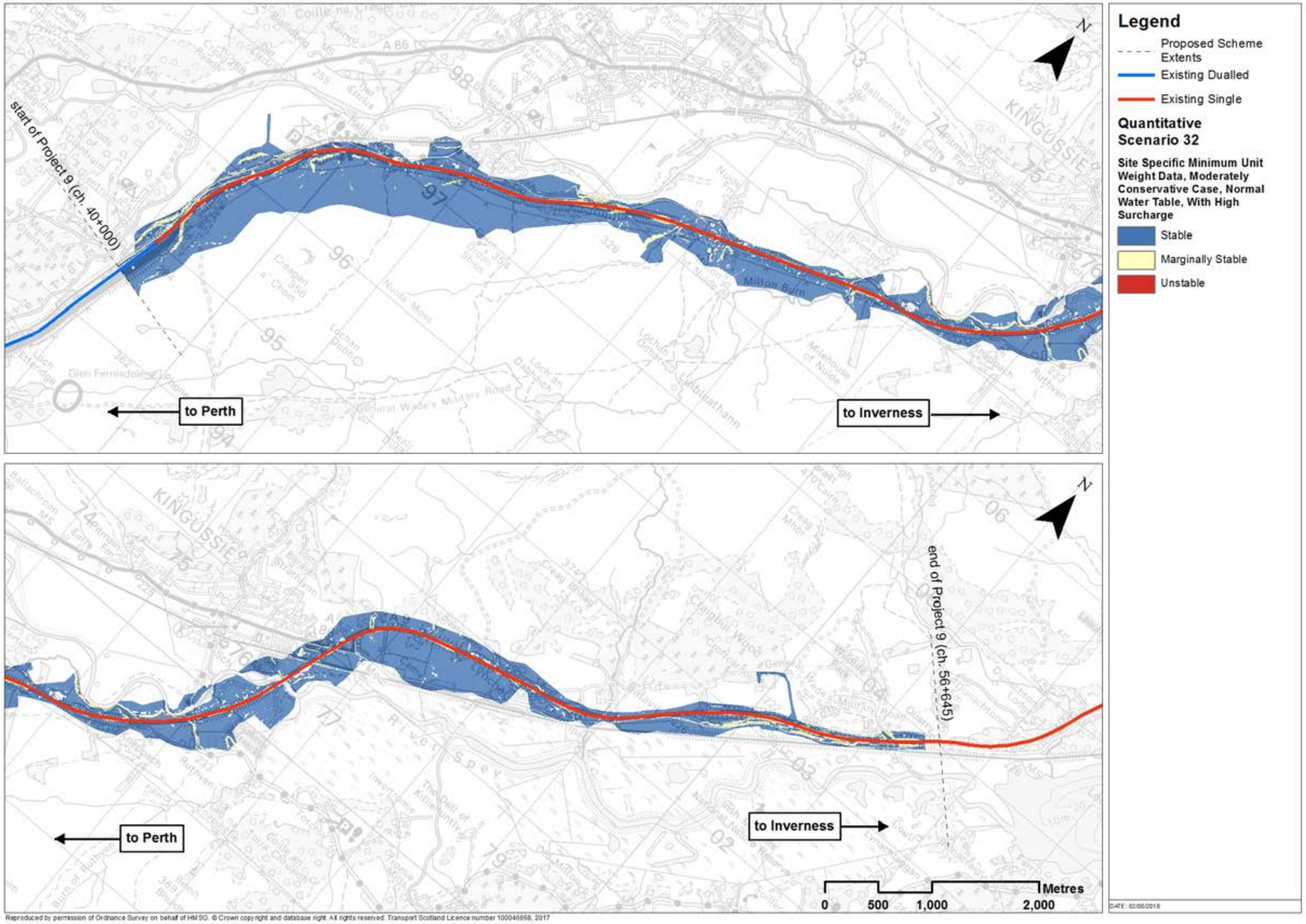

Figure 32: Quantitative Stability Assessment Scenario 32; Moderately Conservative Case, Normal Water Table, With High Surcharge

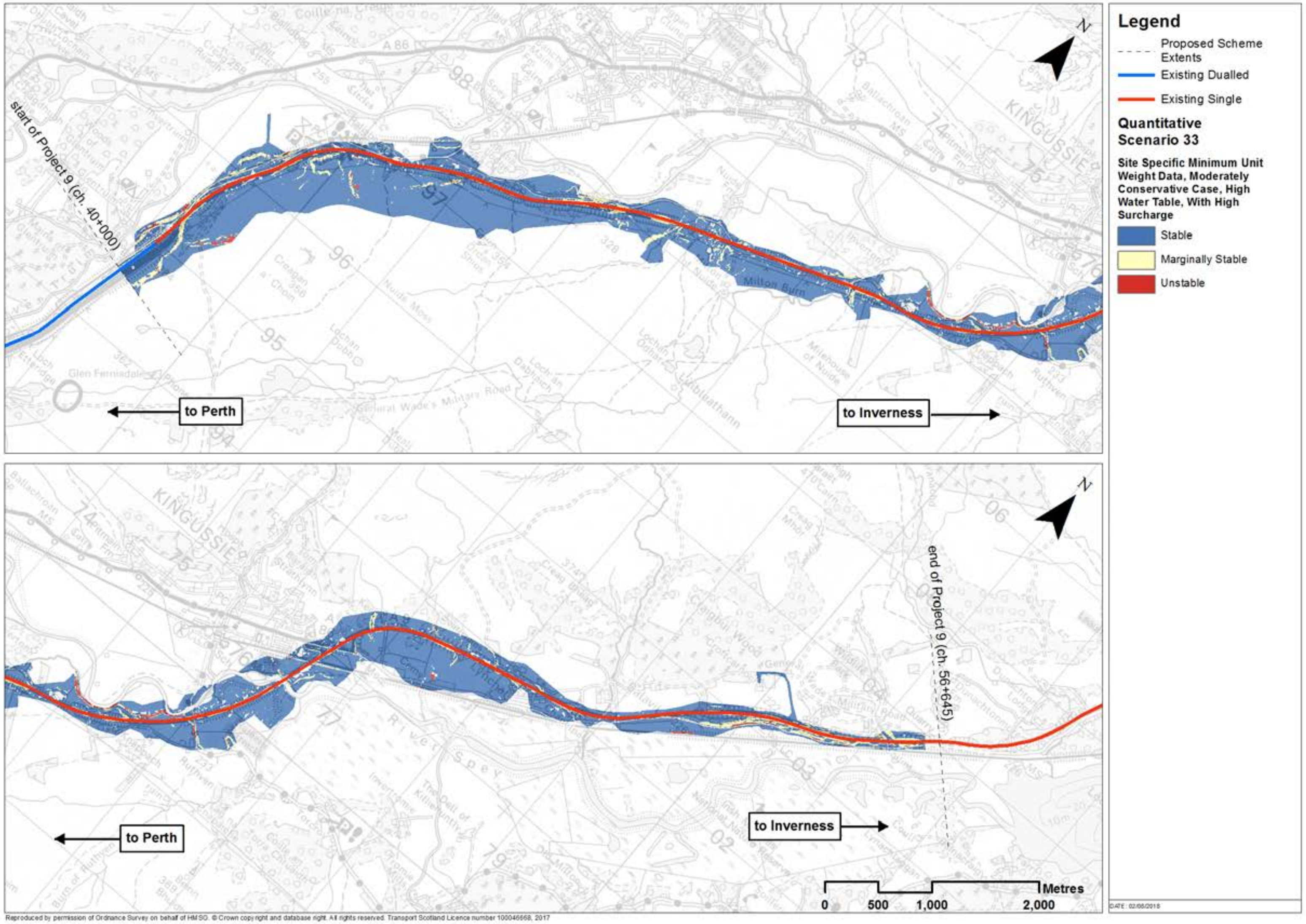

Figure 33: Quantitative Stability Assessment Scenario 33; Moderately Conservative Case, High Water Table, With High Surcharge

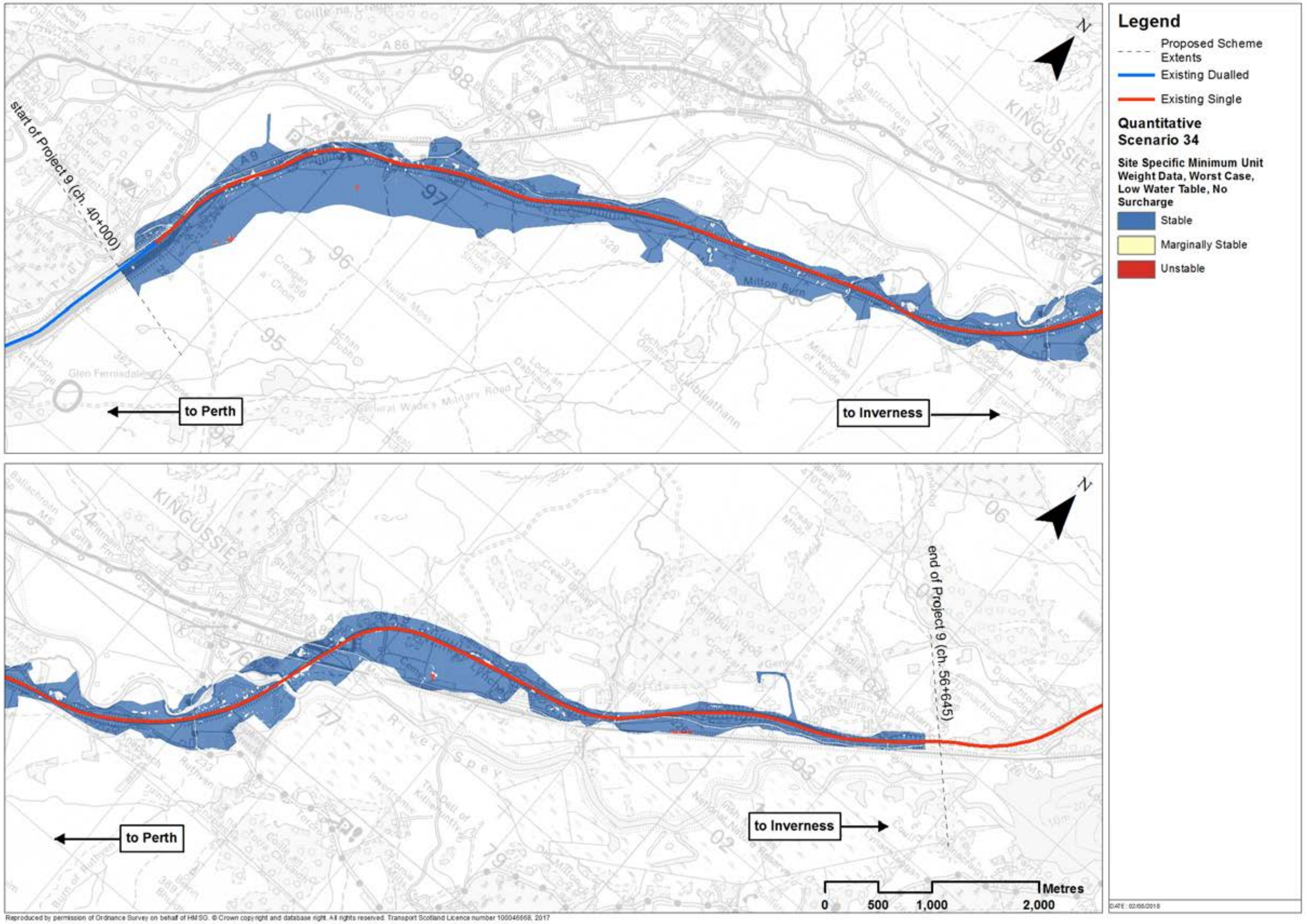

Figure 34: Quantitative Stability Assessment Scenario 34; Worst Case, Low Water Table, No Surcharge

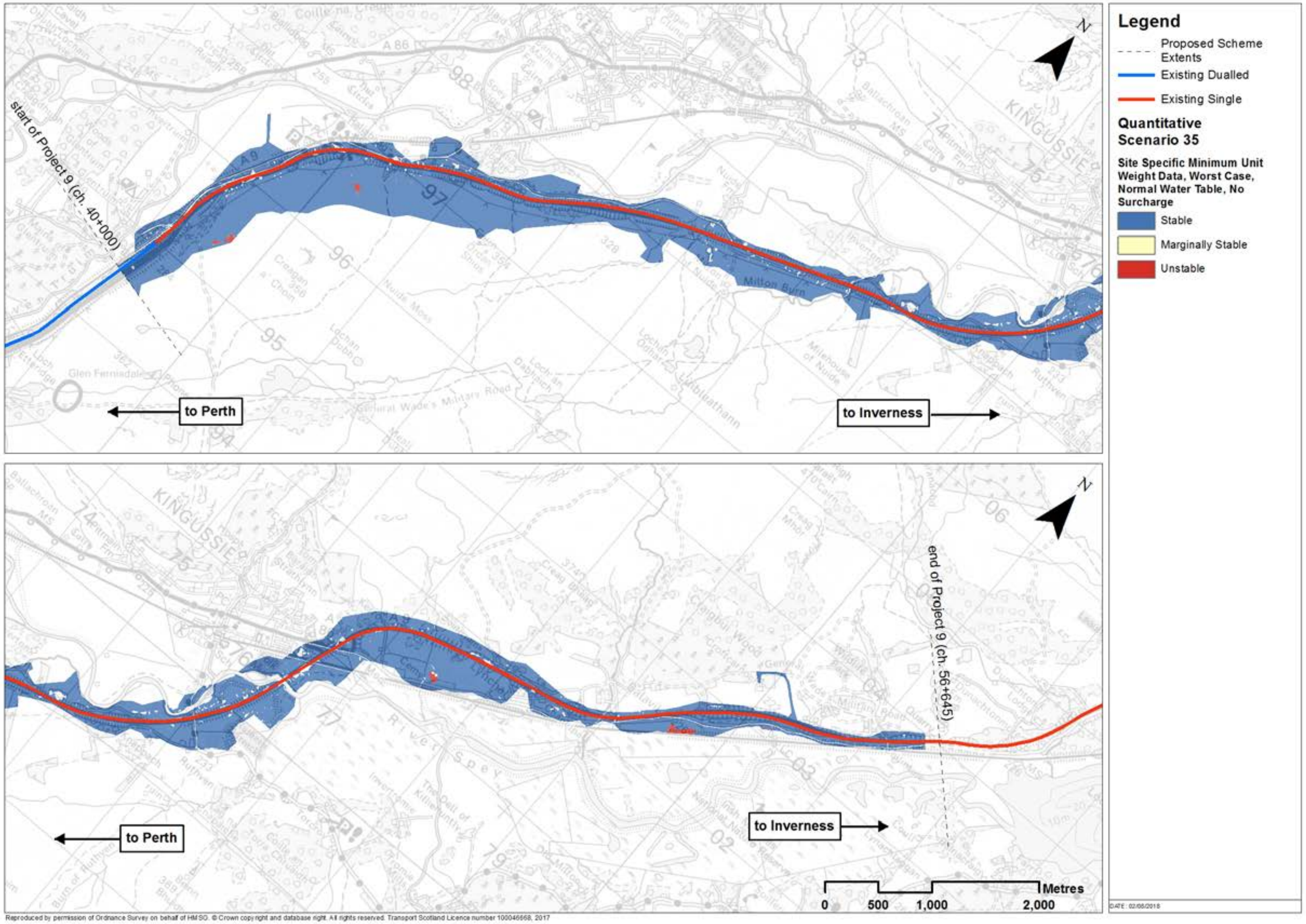

Figure 35: Quantitative Stability Assessment Scenario 35; Worst Case, Normal Water Table, No Surcharge

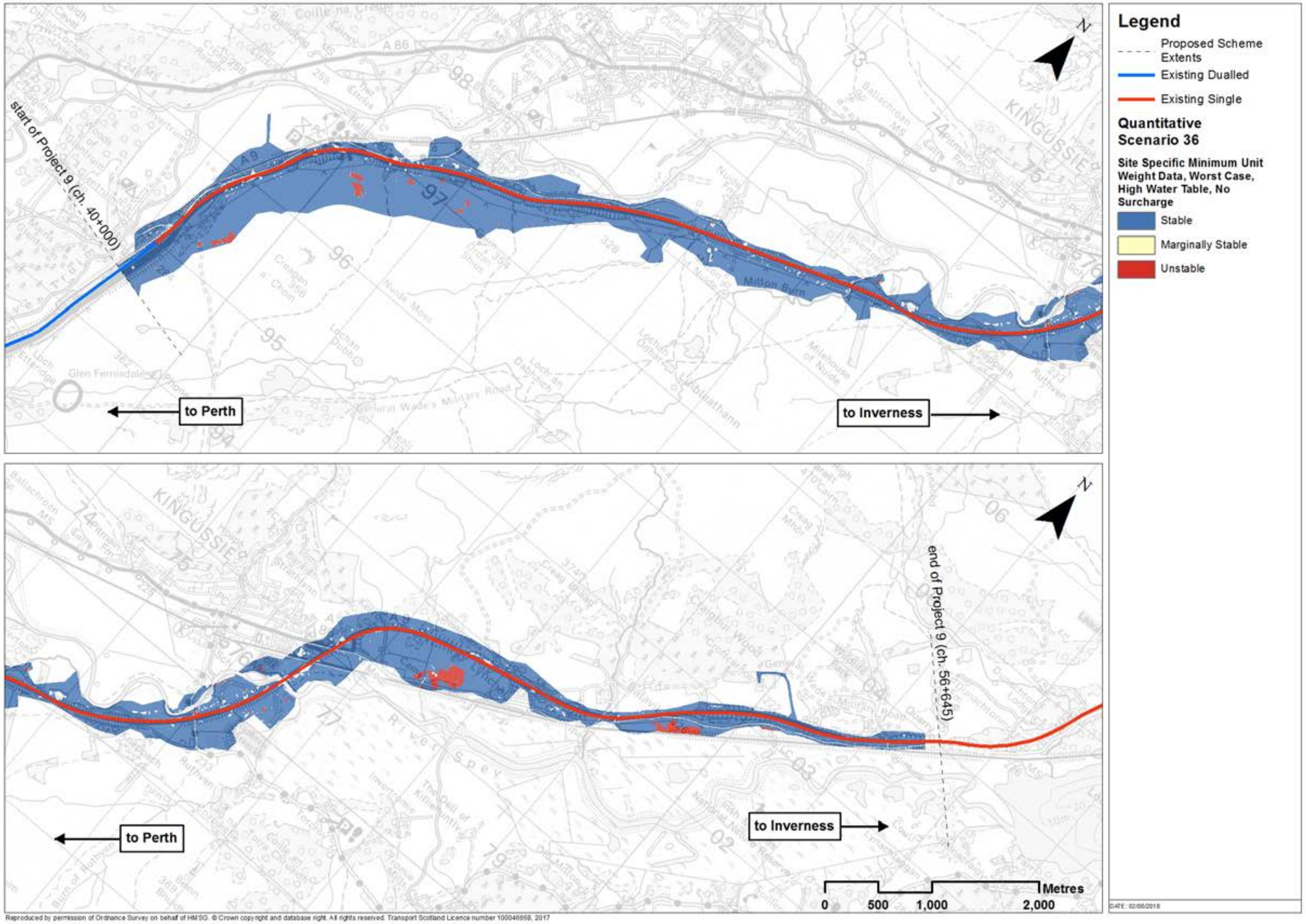

Figure 36: Quantitative Stability Assessment Scenario 36; Worst Case, High Water Table, No Surcharge

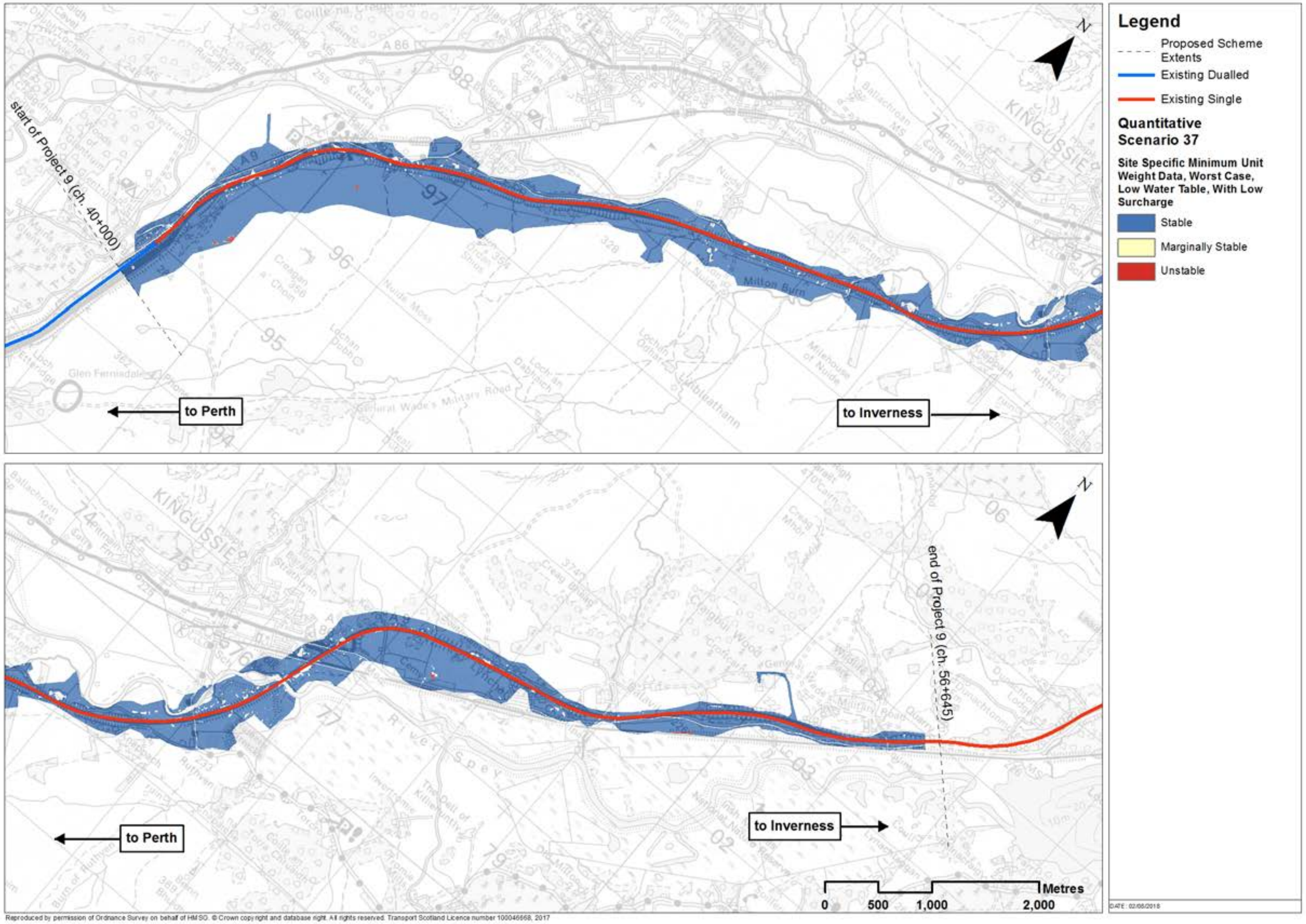

Figure 37: Quantitative Stability Assessment Scenario 37; Worst Case, Low Water Table, With Low Surcharge

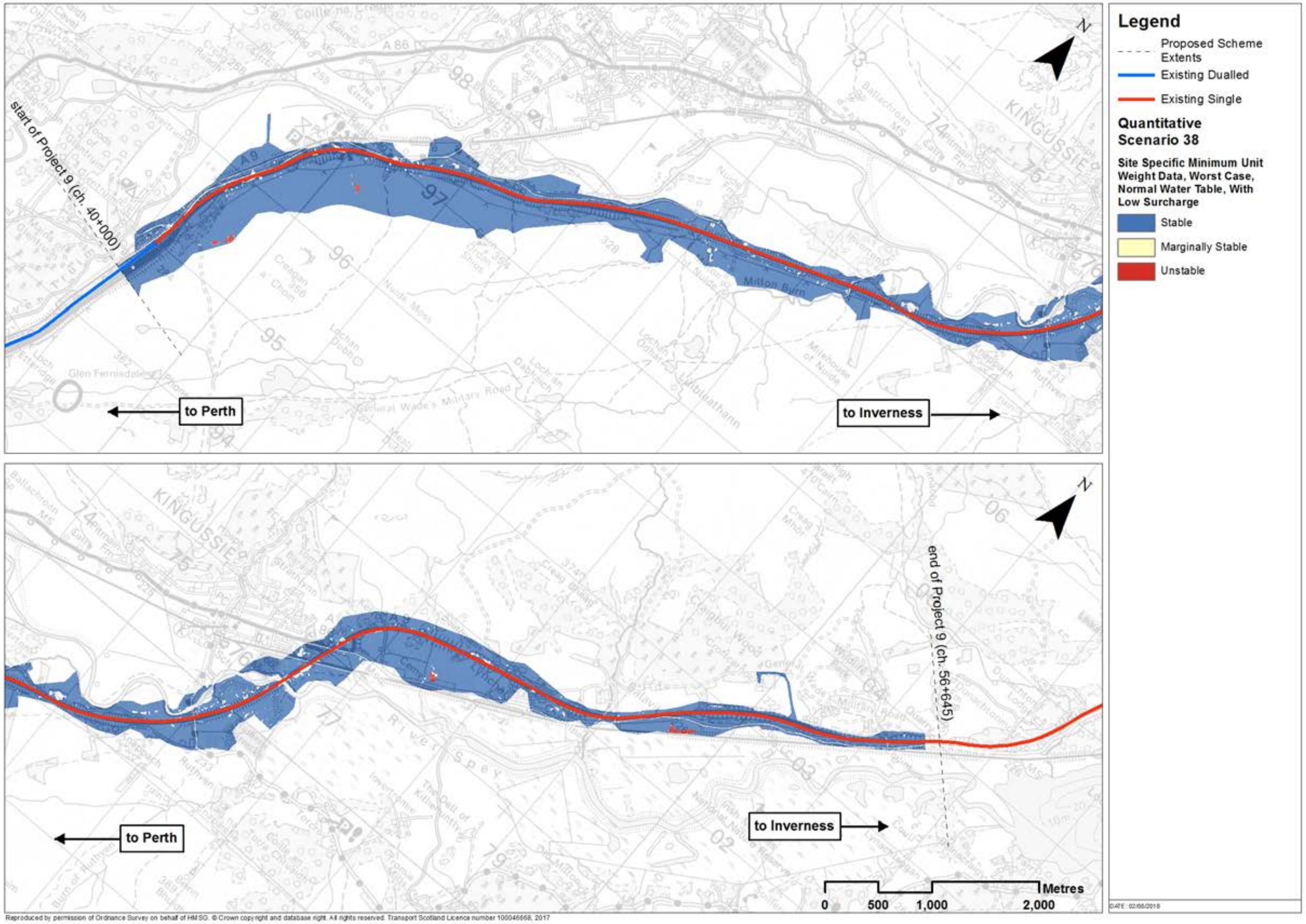

Figure 38: Quantitative Stability Assessment Scenario 38; Worst Case, Normal Water Table, With Low Surcharge

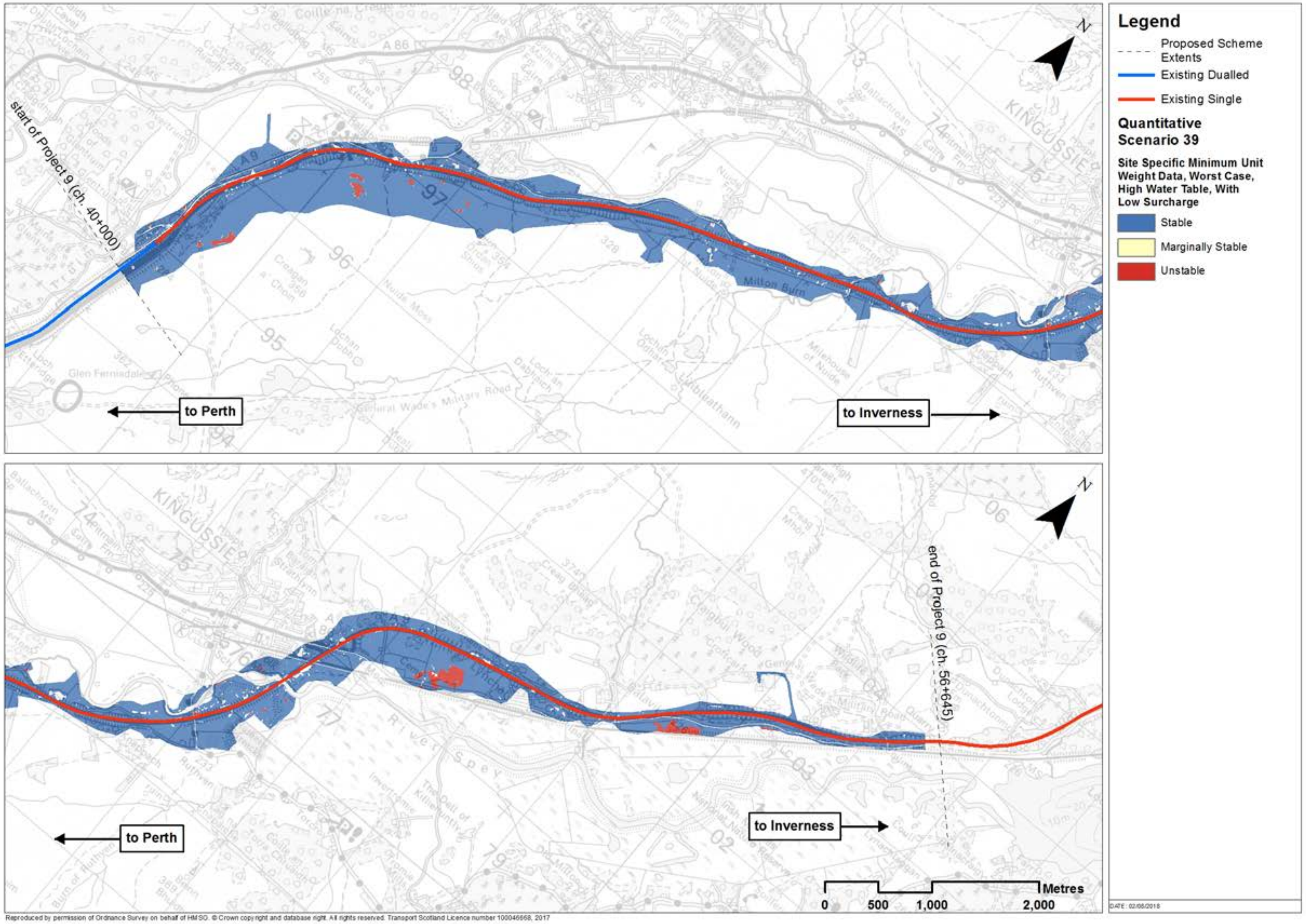

Figure 39: Quantitative Stability Assessment Scenario 39; Worst Case, High Water Table, With Low Surcharge

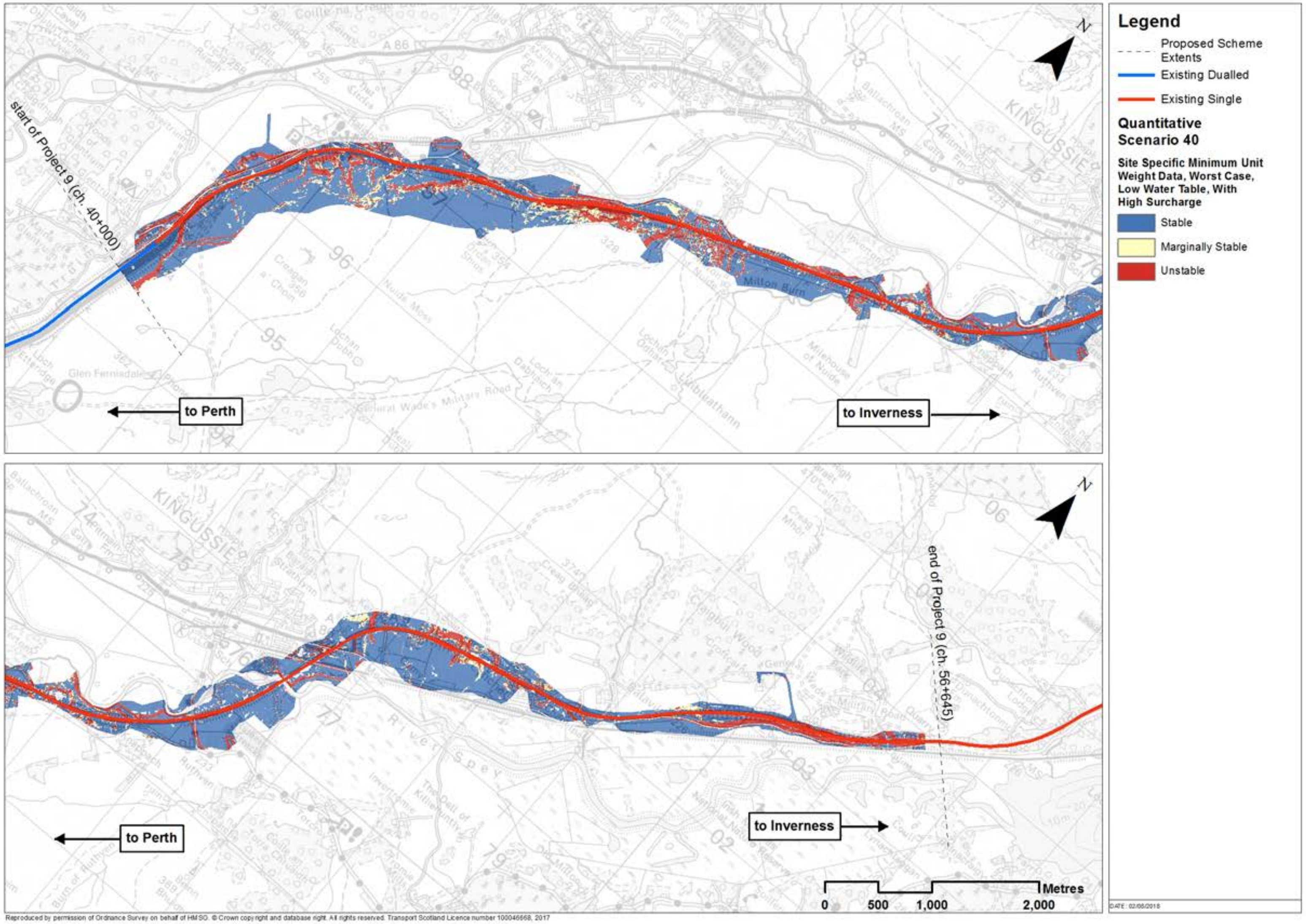

Figure 40: Quantitative Stability Assessment Scenario 40; Worst Case, Low Water Table, With High Surcharge

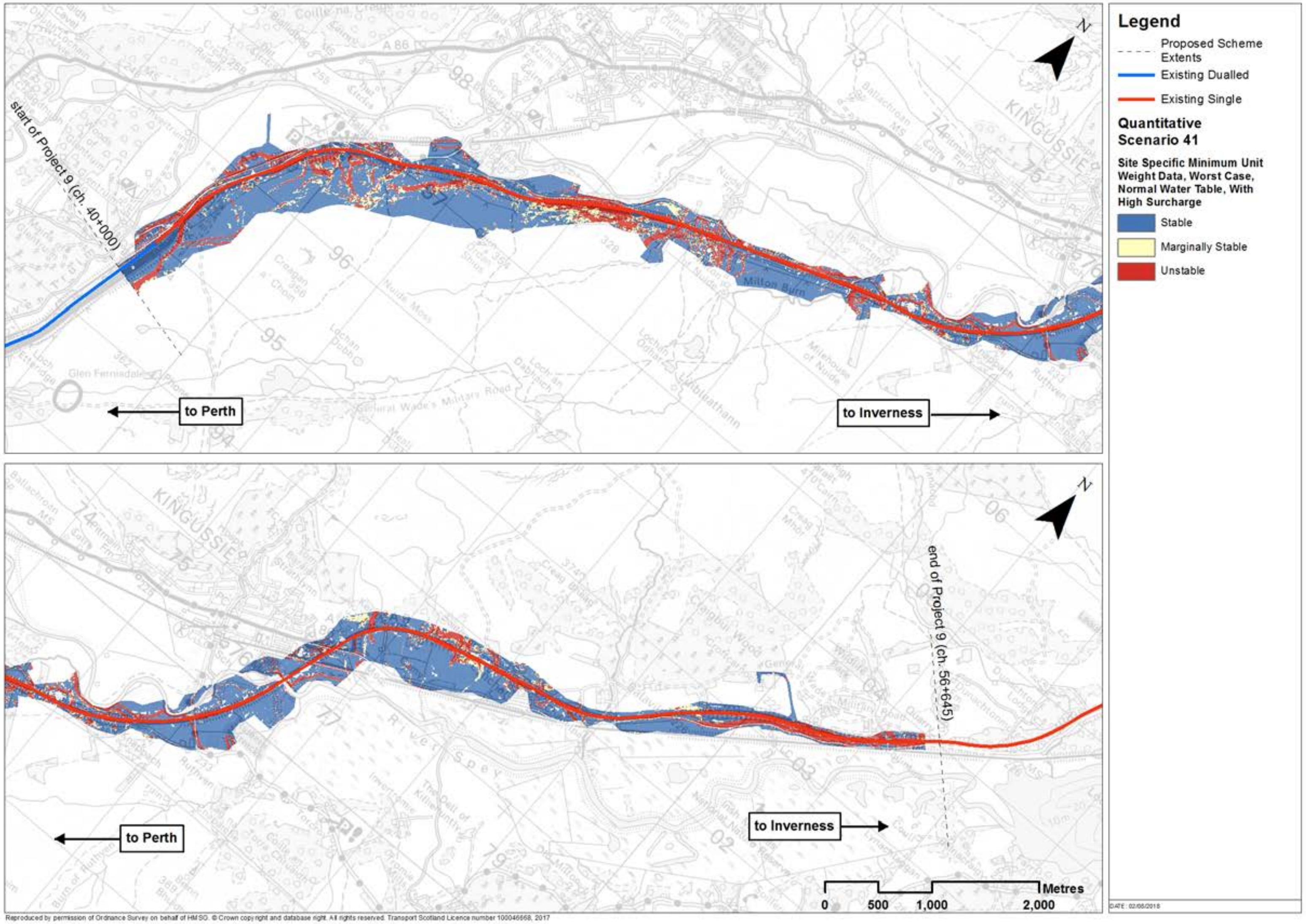

Figure 41: Quantitative Stability Assessment Scenario 41; Worst Case, Normal Water Table, With High Surcharge

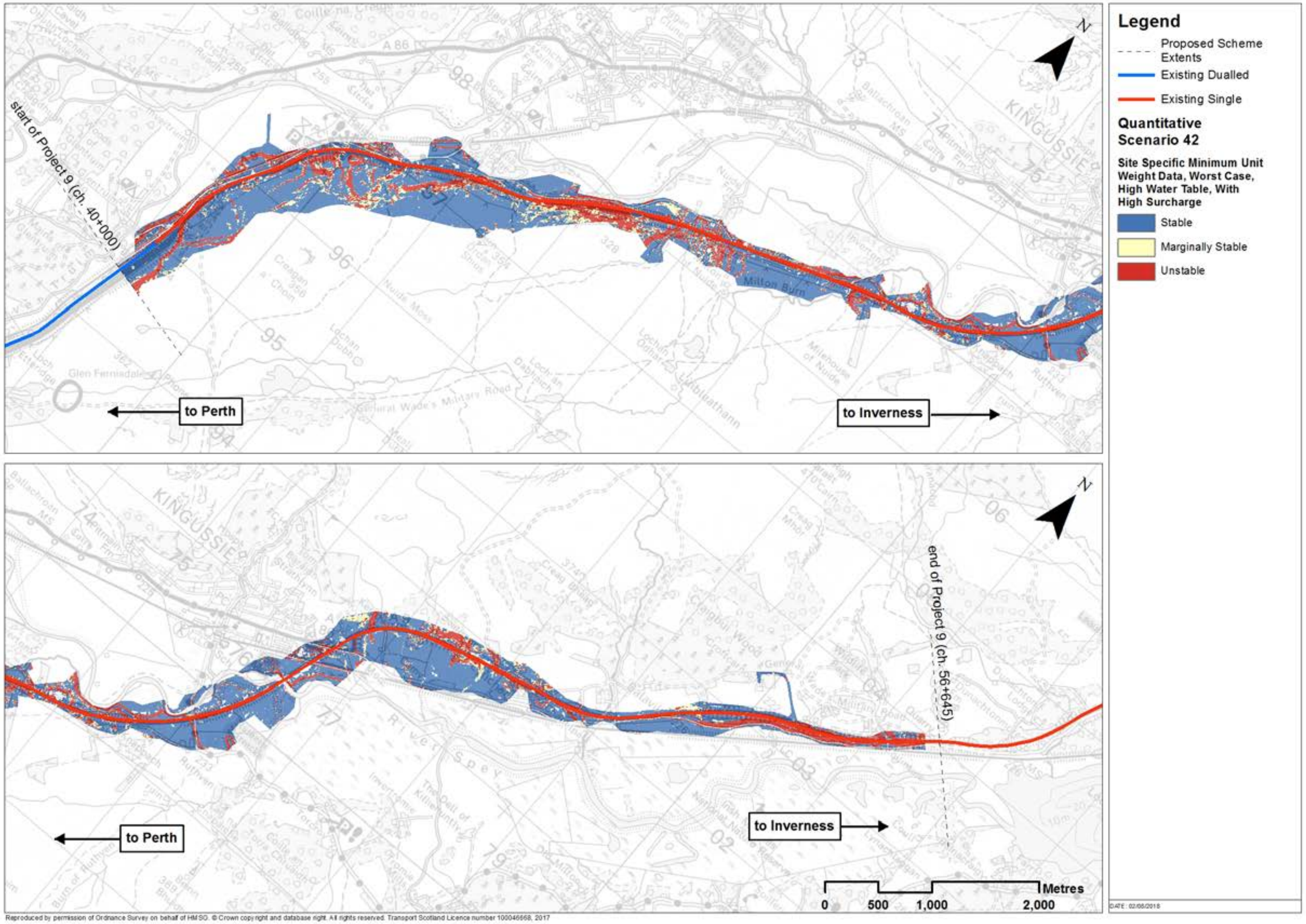

Figure 42: Quantitative Stability Assessment Scenario 42; Worst Case, High Water Table, With High Surcharge