Appendix A11.5: Fluvial Geomorphology

1 Introduction

General Background

1.1.1 This technical appendix informs Chapter 11 (Road Drainage and the Water Environment) of the Environmental Statement (ES). It focuses on the fluvial geomorphology aspects of the study, providing a detailed understanding of the baseline environment and the assessment of impacts of the proposed scheme. The appendix focuses only on those water features that have been given a medium, high or very high sensitivity. Low sensitivity water features are not included in the appendix; these are discussed in Appendix A11.1 (Baseline conditions) and Appendix A11.7 (Impact Assessment).

1.1.2 For the purposes of the assessment, the term water feature includes all rivers, streams and ditches. The water features range in size from ephemeral field drains to large rivers. A glossary of terms is provided in Section 8 (Glossary).

1.1.3 Fluvial geomorphology has been included in the Environmental Impact Assessment primarily as a result of the EU Water Framework Directive (WFD, 2000/60/EC), transposed into Scottish Law by the Water Environment and Water Services (Scotland) Act 2003 (WEWS Act). The legislation aims to classify rivers according to their ecological and chemical status and sets targets for improvements through River Basin Management Plans (Scottish Government, 2015). Ecological status is split into three quality elements: biological; hydromorphological; and physio-chemical quality. For High Status water bodies, the WFD requires that there is no more than very minor human alteration to the hydromorphology quality elements including:

- the quantity, dynamics and velocities of flow;
- the continuity of the river: allowing sediment transport and migration of aquatic organisms; and
- the morphology of the river: channel patterns, width and depth variations, substrate conditions and both the structure and condition of the riparian zone (river corridor).

What is Fluvial Geomorphology?

1.1.4 Fluvial geomorphology is the study of the landforms and physical features associated with river systems (including their channels and floodplains); and the sediment supply and transport processes that create them. Fluvial processes create a wide range of morphological forms that provide a variety of habitats within and around river channels. As a result, geomorphology is integral to river management.

1.1.5 Fluvial geomorphology considers the processes of sediment transfer (erosion, transport and deposition) in river systems and also the relationships between channel forms and processes.

1.1.6 The geomorphological form of a river channel and valley floor is influenced by many different factors and complex inter-related processes. Controls influencing river systems are both external (including catchment geology, topography, soil type, climatic trends and land management practices) and internal (including bed and bank materials, vegetation characteristics, gradient and flow conditions). These variable controls and their interactions determine the character of fluvial processes, which in turn, influence individual channel forms and features.

1.1.7 As an unmodified system, a river evolves in response to natural influences. However, rivers are often affected by human activities. Channel modifications including artificial structures alter flow and sediment movement, typically resulting in changes to river morphology (form), laterally (channel width, floodplain connectivity) and/or longitudinally (planform, bed gradient or depth). Changes in one part of the river catchment either through natural or human activity can result not only in geomorphological adjustment over time at that point, but also in changes upstream and downstream.

1.1.8 An understanding of fluvial geomorphology adds value to the design of river modifications and structures (such as culverts, scour/bank protection and channel realignment) by identifying areas at risk of erosion and/or deposition. This leads to a potential reduction of maintenance costs by embedding mitigation to both protect assets and reduce/eliminate impacts on natural fluvial processes.

1.1.9 In support of statutory requirements to protect biodiversity, fluvial geomorphology also contributes to the understanding of habitat requirements, their sustainable management and mitigation of impacts resulting from development works.

Assessment Aims

1.1.10 The specific objectives of this assessment to are to:

- understand the baseline characteristics for each water feature;
- assess the potential impacts on each water feature affected by the proposed scheme against the baseline (with consideration of the sediment regime, channel morphology and natural fluvial processes);
- recommend mitigation measures to minimise potential impacts resulting from the proposed scheme; and
- understand and outline any residual impacts following the application of recommended mitigations.

1.1.11 The assessment also takes into consideration the potential impacts on the current status of the WFD water bodies which may be affected by the proposed scheme, including any WFD measures proposed upon that water body and the ability of the water body to meet its overall objective to achieve Good Status.

1.1.12 Where required, mitigation measures would be developed to prevent deterioration in status of the WFD water body quality elements (see paragraph 1.1.3) and/or overall status of the WFD water body. Furthermore, the assessment would investigate whether the proposed scheme would prevent the WFD water body from achieving/maintaining Good Status.

Study Area

1.1.13 The study area for the fluvial geomorphology assessment included a 500m reach of the water features upstream and downstream of the proposed scheme. For some more sensitive water features, the study area was extended to 1km to allow for a more detailed assessment of the baseline characteristics and processes.

2 Approach and Methods

General Approach

2.1.1 Geomorphological impacts are assessed in terms of potential disturbance to the existing channel morphology; sediment regime; and fluvial processes.

2.1.2 The forms and processes occurring within river systems provide and sustain physical habitat for aquatic species, and may also influence water quality, the stability of infrastructure and flood risk, with implications for local communities and businesses. Potential receptors, sensitive to geomorphological change, are therefore both environmental and socio-economic.

2.1.3 To inform the impact assessment process, both desk-based and field data were collected and analysed. Given the dynamic nature of the main rivers in the study area, in particular those of high or very high sensitivity, additional investigations were undertaken. This included an assessment of bank erosion risk (to inform optioneering and engineering design) and a specific geomorphological assessment for the Habitat Regulations Assessment report.

2.1.4 The methodology for the fluvial geomorphology assessment follows best practice guidance including:

- The Fluvial Design Guide (Environment Agency, 2010);
- Guidebook of Applied Fluvial Geomorphology (Sear et al., 2010); and

- Supporting Guidance (WAT-SG-21) Environmental Standards for River Morphology (SEPA, 2012).

2.1.5 Section 11.2 (Chapter 11: Road Drainage and Water Environment) provides a description of how the baseline information has been gathered, as well as the criteria for assigning sensitivity, determining the magnitude of potential impacts and the significance of impact.

Additional Assessment

2.1.6 As part of the geomorphological assessment for the southern section of the A9 Dualling Programme (Pass of Birnam to Glen Garry), an additional assessment has been undertaken on potential erosion risk at locations along the River Tay. The assessment focused on locations where the existing A9 infrastructure is currently at risk and/or the proposed scheme could be at risk from fluvial erosion in the future, considering both short and longer term timescales. A rapid erosion risk prioritisation tool (developed by Jacobs) was used to identify sites at risk of erosion. The tool considered the link between the hazard (erosion) and receptor (the scheme). The magnitude of impact was then assessed, along with the likelihood of erosion, and an assessment of the effectiveness of any existing management (if applicable). The potential erosion risk was then ranked using a risk matrix and a risk rating assigned (from Risk Rating 1 – no risk to Risk Rating 9 – high risk).

2.1.7 Site work was then undertaken for those sites rated as medium to high risk (Risk Rating 5-9) to further develop the assessment and verify the results. Stream power and sediment transport calculations were also undertaken to inform the detailed assessment of these higher risk sites providing an understanding of the capacity of the channel to erode and transport sediment. The sites were then reassessed and a new risk rating given (if deemed necessary). Bathymetric survey data was also collected to determine the extent of channel incision and potential undercutting of the bank toe between ch1300 and 1900. For those still considered high risk (Risk Rating 7-9) mitigation proposals were developed ranging from monitoring, to soft engineering and hard engineering.

2.1.8 An additional geomorphological baseline and impact assessment has also been undertaken to inform the Habitat Regulations Assessment. This focused on the potential impacts of structures, outfalls and discharges to designated habitats and species as part of the River Tay Special Area of Conservation (SAC) as well as fresh water pearl mussel. The assessment considers the significance of changes in geomorphological processes to SAC habitat characteristics both within the channel and floodplain, extending 1km upstream and downstream of the proposed scheme. Relevant results are provided in Chapter 12 (Ecology and Conservation).

Limitations to Assessment

2.1.9 Baseline conditions reported in this study are informed by site walkover information, gathered at specified time periods and the coinciding water levels. Although these data allow assessment of in-channel features and provide an understanding of the nature of the channel at varying levels, it should be noted that most water features have only been visited on one occasion.

2.1.10 Weather conditions during site walkovers determined that some water features were surveyed during high flows, thereby limiting the visibility of some bed substrate and/or morphological features being recorded. During the February, March and June 2015 surveys, above average flow was observed in most catchments following recent rainfall. During the April 2015 surveys, conditions in advance of and during the surveys were dry and warm, leading to observed low flow conditions in small catchments, dry soils and limited runoff to water features.

2.1.11 This assessment has been based on the DMRB guidance, standard good practice and guidance notes from SEPA, supported and further developed using professional judgement.

2.1.12 The numerical modelling of sediment input, transfer or deposition during road operation or construction, was beyond the scope of this assessment and was not undertaken due to the lack of available data (flow, channel morphology, sediment load) around which to build the models, and, with the exception of the River Tummel (WF70) and Tay (WF6), due to the small size of most water features. However, the approach taken is considered appropriate for the level of detail required to determine impacts for the purposes of this DMRB Stage 3 Environmental Impact Assessment.

2.1.13 The upstream and downstream assessment boundaries were determined by the extent of likely impacts caused by the proposed scheme and access constraints. The extent of the site walkovers also varied according to these constraints. However, all site walkovers considered the channel upstream and downstream of the proposed scheme over a distance of 500m to 1km. The distance of survey was proportional to the size of the water feature.

2.1.14 It is not possible to fully assess the potential impacts of construction before the construction programme of works is developed, including the location of temporary access roads and timing of construction. However, an assessment was made of the likely potential impacts during construction upon each water feature affected, based upon best available data at the time of writing.

3 Baseline

Summary of Baseline Conditions

3.1.1 The following sections describe the details of the baseline conditions for the fluvial geomorphology attributes of each medium, high or very high sensitivity water feature potentially impacted by the proposed scheme. An assessment of the baseline condition of all water features including those with low sensitivity can be found in Appendix A11.1 (Baseline Conditions).

Water Feature Descriptions

<u>River Tay (WF6)</u>

3.1.2 The River Tay within the study area has a meandering planform and a predominantly single-thread channel. The channel exhibits signs of a previously wandering gravel-bed system with palaeochannels and side-arms present within the floodplain, and active erosion and deposition at several locations. The channel has numerous large pebble/cobble deposits throughout the study area including point bars, side bars and mid-channel bars (both vegetated and unvegetated) (Photograph 1). A combination of flow regulation and river training, such as embankments, river realignment and localised bank protection, has resulted in the river being confined primarily within a single-thread channel. Given the discharge and energy of this river system, it retains the power to re-activate former river channels and adjust its course during high flow events.

3.1.3 The riparian corridor mainly consists of agricultural fields (both pasture and arable) with localised patches of scrub and forestry.

3.1.4 Historical maps from 1867 indicate active channel change at the confluence with River Tummel (Richard’s Island) (NN 977 511) and at Kindallachan (Lamb Island and Big Island) (NN 988 502). At these locations, channel avulsion occurred, along with a shifting mosaic of fluvial landforms and features (such as point bars, side bars and mid-channel bars). The map from 1867 also shows a multi-thread channel at both Lamb Island and Big Island. These features are typical of the river’s previous wandering gravel-bed planform.

3.1.5 Assessment of bank erosion risk along the River Tay identified a zone of potential bank instability between ch3600 and ch3800. Following site investigation, the risk of fluvial erosion was re-assessed as low due to tree fall (likely by windthrow) being considered the primary cause of bank destabilisation. The river banks are composed of sand and gravel with cobbles, thus when tree fall occurs, the loosely bound soil is easily eroded. This has caused patches of bare banks; however, the bankface along this reach is predominantly vegetated with trees, grasses and shrubs. In addition, the fallen trees provide natural bank protection at the bank toe.

3.1.6 Between ch1650 and ch1900, the risk of fluvial erosion and undercutting has been assessed, and, due to the proximity of the existing A9, bank stabilisation measures are deemed necessary to protect the infrastructure. Undercutting of the bank toe was observed with vertical undercut bank toe profiles. The bank face is reprofiled with a steep gradient up to the bank top and evidence of some slip planes. The bank face is well vegetated with grasses, scrub and trees. This bank was formed during the construction of the existing A9 and erosion of the bank toe has occurred over the past 40 years as the river adjusts to the modification. Bathymetric data collected along this reach reveals a deeply incised channel, as would be expected, along the outside of this meander bend. The channel bed forms a shallow shelf adjacent to the eroded bank toe, thus there is no evidence of severe bank toe undercutting with hollowing out of the lower bank. There remains the risk of future erosion of the bank toe, in particular due to the rock armour protection along the bank toe having partially collapsed since construction of the existing A9. In addition, due to the steep engineered gradient of the existing bank face, along with slip planes being present, there is the risk of bank slumping, which could undermine the bank profile and compromise the integrity of the infrastructure. The bank face could be particularly prone to slumping should the bank material become saturated. Any future fluvial action against the bank toe could exacerbate this risk.

3.1.7 The River Tay within the study area is currently achieving Good Ecological Potential. Table 1 provides a summary of the classification status of the key quality elements applicable to the fluvial geomorphology assessment.

Table 1: River Tay Water Framework Directive classification

WFD Quality Element	River Tay (R Tummel to R Isla Confluences)
Water body ID	6499
Overall classification	Good Ecological Potential
Designation as Artificial or Heavily Modified Water Body (A/HMWB)	HMWB
Pressures on water body	Physical alterations
Water flows and levels	Good
Physical condition	Good
Water quality	Good

Photograph 1a: The River Tay looking downstream at Dowally

Photograph 1b: The River Tay looking upstream at Kindallachan

WF23

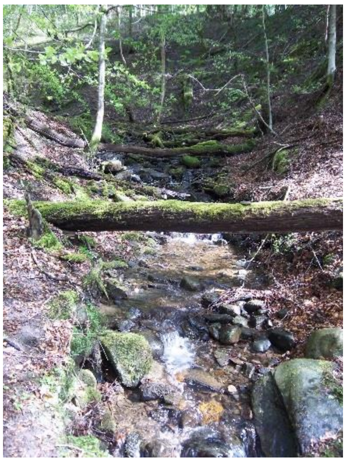
3.1.8 WF23 is a medium watercourse which has its source in Rotmell Wood approximately 350m east of General Wade's Military Road. The channel has a steep gradient and is confined at the base of two steep valley sides, with an average width of approximately 1m upstream of Rotmell Wood forestry track and approximately 2m downstream of the road. The catchment land use consists predominantly of coniferous woodland with a small section of marshland in the centre of the catchment area.

3.1.9 Upstream of the forestry track, the channel predominantly consists of bedrock cascades and small waterfalls. WF23 has a reinforced bed for approximately 15m as it passes under the forestry track and has gabion basket reinforcement on the left bank for approximately 10m downstream of the crossing. The right bank consists of bedrock at this location. Downstream of the crossing, the channel has a step-pool sequence with pebble and cobble substrate. The water feature is crossed by a bridge for General Wade's Military Road and a culvert under the existing A9.

3.1.10 Historical map analysis shows minimal change in the watercourse, with the planform remaining consistent since 1967.

Photograph 2a: Bedrock cascade looking upstream of Rotmell Wood forestry track

Photograph 2b: Step-pool sequence upstream of General Wade's Military Road



WF24

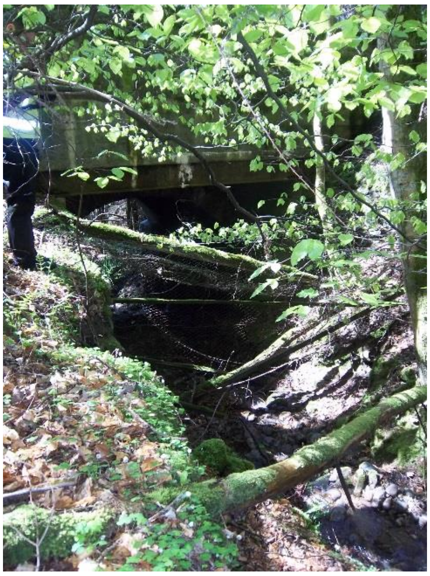
3.1.11 WF24 is a medium watercourse which has its source in a clearing of Rotmell Wood. The water feature flows west for approximately 630m before flowing into the River Tay north west of Warren Lodge. The channel has a steep gradient and is confined within the valley sides. Catchment land use consists of open moorland in the upper section and coniferous woodland in the downstream section.

3.1.12 The channel predominantly has a step-pool sequence with cobble and sand substrate. The water feature is crossed by a bridge structure for the forestry track and General Wade's Military Road, and is culverted under the existing A9.

3.1.13 Historical map analysis shows minimal change with the planform remaining consistent since 1867. The water feature was culverted under the existing A9 between 1900 and 1977.

Photograph 3a: Downstream of forestry track (looking downstream)

Photograph 3b: Riffle-pool sequence upstream of existing A9 (looking upstream)



WF25

3.1.14 WF25 is a medium watercourse which has its source in Rotmell Wood and flows south west for approximately 550m before flowing into the River Tay. Catchment land use consists of coniferous woodland upstream of the existing A9 and establishing coniferous woodland downstream of the existing A9. The water feature is culverted under General Wade's Military Road and the existing A9.

3.1.15 WF25 has a predominantly straight planform with a step-pool sequence and cobble and sand substrate, measuring approximately 0.7m in width upstream of the existing A9 and 1.5m downstream of the road. The channel appeared to be incised along several reaches and woody material (including fallen trees and broken branches) created a variety of flow types in several locations, particularly upstream of General Wade's Military Road.

3.1.16 Historical map analysis shows minimal change with the planform remaining consistent since 1867. The water feature was culverted under the existing A9 between 1900 and 1977.

Photograph 4a: WF25 upstream of General Wade's Military Road (looking upstream)

Photograph 4b: Looking downstream of the existing A9 crossing towards the Tay

WF32

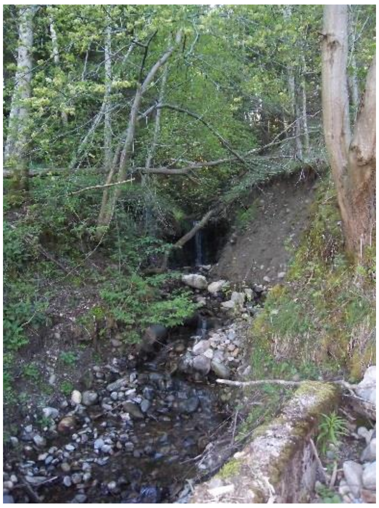
3.1.17 WF32 is a medium watercourse which has its source in Rotmell Wood. The water feature flows north-west for approximately 1.65km before flowing into the River Tay west of Cottage No 2. Rotmell Farm. Catchment land use consists of coniferous woodland in the upstream reach and open moorland and pastoral agricultural land in the downstream reach. The channel has a steep gradient and, from available mapping, appears to be culverted under several access roads, forestry tracks and for approximately 100m under Rotmell Farm and Farmhouse. The water feature is also culverted under General Wade's Military Road and the existing A9.

3.1.18 The channel has a relatively straight planform measuring approximately 0.3m wide in the upper catchment. At this location the channel appeared to be laterally adjusting and narrowing with several localised areas of vegetated deposition, particularly upstream of Rotmell Farm and Farmhouse. Immediately upstream of the farm, the channel has a sluice structure crossing the channel. Downstream of the farm, the channel measures approximately 1.2m in width and has a step-pool sequence with cobble and gravel substrate. Upstream of General Wade's Military Road, a large knickpoint (erosion of the channel bed migrating upstream) is present, measuring approximately 1.3m in height.

3.1.19 Historical map analysis shows minimal change with the planform remaining consistent since 1867. The water feature was culverted under the existing A9 between 1900 and 1977.

Photograph 5a: Step-pool sequence (looking upstream)

Photograph 5b: Knickpoint migration immediately upstream of General Wade's Military Road (looking upstream)



WF36 (Dowally Burn)

3.1.20 Dowally burn is a large watercourse which flows from Lochan Oisinneach Beag (approx. NGR NO 038 557) for 0.9km to Lochan Oisinneach Mor. The water feature continues south for 5km to Loch Ordie before flowing south-east for a further 5km (drop in elevation of 230m) to the River Tay west of Dowally. Catchment land use consists predominantly of open moorland in the upstream section and mixed coniferous and deciduous woodland in the downstream section (west of Raor Lodge) with a small section of pastoral agricultural land downstream of the existing A9.

3.1.21 The channel has an irregular meandering planform upstream of Dowally and an artificially straightened planform immediately upstream of the existing A9 and downstream to the confluence with the River Tay. Upstream of Dowally, the channel has extensive step-pool sequences with several bedrock cascades. Through Dowally, the channel gradient decreases and the channel becomes more uniform with riffle-pool sequences. Channel substrate consists predominantly of cobbles and pebbles and the channel width is approximately 3m wide. Downstream of the existing A9, the channel is embanked on both sides (approximately 1.5m in height) to its confluence with the River Tay. The water feature is culverted under several access roads, forestry tracks and the existing A9. The water feature is also crossed by an access bridge to Dowally Farm to the West of the existing A9.

3.1.22 Analysis of historical mapping shows that Dowally Burn historically has a sinuous planform downstream of Dowally with woodland land use and mid channel bars. Between 1900 and 1977 the channel was modified to become straightened at this location. With the exception of this, the channel is largely unchanged since 1867.

3.1.23 WF36 is classified as a WFD water body (referred to as Dowally Burn/Pitrannoch Burn), which is currently achieving Moderate overall status and Moderate hydromorphology status.

Photograph 6a: Typical channel character upstream of Dowally (looking upstream)

Photograph 6b: Channel downstream of Dowally, immediately upstream of the existing A9 (looking upstream)

WF38

3.1.24 WF38 comprises of three sinuous channels and one straight uniform drainage channel (historically modified). All four watercourses join east of General Wade's Military Road to form one channel under the road and the existing A9.

3.1.25 The channels upstream of the A9 have step-pool sequences with cobble and pebble substrate and large woody dams creating a variety of flow types. The channels at this location measure approximately 0.8m wide and are incised with bank full heights measuring up to 2m. Downstream of the existing A9, the channel is straightened and enters a soak-away approximately 220m to the east of the River Tay. There is no channel to the west of the railway. The channel downstream of the existing A9 is straightened and uniform with fine gravel substrate. Embankments measuring approximately 0.3m high are present on both banks.

3.1.26 Historical mapping shows that the planform of the water feature has not changed significantly since first records in 1867.

Photograph 7a: Typical channel cross-section with step-pool sequence upstream of General Wade's Military Road (looking upstream)

Photograph 7b: Straight planform and embankment downstream of the existing A9 (looking downstream)

WF39 (Sloggan Burn)

3.1.27 Sloggan Burn (WF39) has its source approximately 2km east of Guay. The channel has a sinuous planform upstream of the existing A9 and is culverted under the field to the west of the A9 where it discharges into the River Tay. Approximately 300m from the source the channel is impounded, creating a surface water feature measuring approximately 50m in length and 10m wide. The water feature is culverted under several forest and access tracks and roads. Catchment land use consists of open moorland in the upper section and a mixture of deciduous woodland and pastoral agricultural land in the downstream section. The watercourse also flows through the village of Guay.

3.1.28 Within the upstream sections, the channel measures approximately 1.2m wide and has step-pool sequences with cobble and gravel substrate. Downstream of the existing A9, Sloggan Burn appeared to be overwidened (approximately 4m wide) and the river had deposited material to create a low flow channel of approximately 0.7m wide, which split into two channels west of the railway.

3.1.29 Historical mapping from 1867 shows that the channel was slightly more sinuous in planform near Guay, than the current channel. The channel also appears to have been straightened in the lower reach, most likely due to the construction of the railway.

Photograph 8a: Typical channel cross-section upstream of the existing A9 (looking downstream)

Photograph 8b: Section of bank reinforcement immediately downstream of the highland railway (looking upstream)

WF40 (Kindallachan Burn)

3.1.30 Kindallachan Burn (WF40) has its source north of Baledmund Farm, approximately 2km north-east of Kindallachan village. The water feature flows south for 2km to West Balnald and west for a further 1.35km to its confluence with the River Tay. The channel has a sinuous planform within the upper sections and a straightened, more modified planform in the downstream section, particularly downstream of the existing A9 crossing. The water feature is crossed by several access tracks and roads, including General Wade's Military Road and the existing A9. Catchment land use consists of pastoral agricultural land in the upper catchment and mixed deciduous and coniferous woodland in the downstream section. The water feature has a continuous tree lining which is likely to provide channel shading and bank stability.

3.1.31 Upstream of Kindallachan, the watercourse has a number of waterfalls suggesting a relatively laterally stable channel, which is bedrock controlled with a steep gradient. The channel substrate consists predominantly of cobble, pebble and gravel substrate. As the watercourse flows through Kindallachan, the channel gradient decreases and forms riffle-pool sequences with some cobble side bars present. Downstream of General Wade's Military Road, the channel has an embankment on the right bank measuring up to 0.5m high. Downstream of the existing A9, the channel is straightened and uniform with reinforced banks. The channel at this location measures approximately 3.5m wide.

3.1.32 Analysis of historical maps shows that the planform of WF40 has remained relatively consistent since first records in 1867. The burn flowed into a secondary channel of the River Tay prior to 1980, however, currently flows into a palaeochannel feature that drains via a straightened channel to the River Tay.

3.1.33 WF40 is classified as a WFD water body (referred to as Tulliemet Burn), which is currently achieving Good overall status and Good hydromorphology status.

Photograph 9a: Typical channel downstream of General Wade's Military Road (looking downstream)

Photograph 9b: Typical channel cross-section downstream of the existing A9 (looking downstream)

WF50

3.1.34 WF50 has its source south of Cuil-an-Duin and flows south for approximately 250m before flowing under the existing A9. Downstream of the road, the burn is shown to 'sink' a further 200m downstream, potentially via a culvert. The watercourse has an irregularly meandering planform in the upper catchment and the channel is incised consisting of a step-pool sequence with predominantly cobble and pebble substrate. The channel measures approximately 0.8m in width and is relatively active with areas of erosion (mass failure and undercutting) and deposition (cobble bars). The channel downstream of the existing A9 is artificially straightened with fine gravel and silt substrates.

3.1.35 Analysis of historical maps shows that the channel is only visible on maps after 1977. After this date the channel appears to have the same planform currently shown on contemporary OS maps.

Photograph 10a: Looking upstream south of the existing A9

Photograph 10b: Looking upstream north of the existing A9

WF70 (River Tummel)

3.1.36 The River Tummel (WF70) is a wandering gravel-bed river, with the localised planform from Ballinluig crossing to the confluence with the River Tay being relatively straight. Large cobble/pebble depositional features are characteristic of the Tummel in the form of point bars, side bars and mid-channel bars. Both unvegetated and vegetated depositional features are present; the latter providing an indicator of stability. A riparian zone, consisting of established trees and shrubs, is present on both banks. The river channel is approximately 50m wide, with a variety of geomorphological features, including large riffle sequences, secondary channels and palaeochannels.

3.1.37 Existing pressures include morphological alterations due to the production of renewable electricity and the resulting flow regulation and sediment starvation as a result of the Pitlochry Dam. This has reduced the natural flow and sediment regime of the river, and consequently, has impacted on the spatial extent, pattern of fluvial landforms, and the resulting species rich biological communities that colonise the shingle islands. The reduced disturbance regime has enabled vegetation succession to occur and the encroachment of scrub on the shingle islands.

3.1.38 Historical map analysis shows that the River Tummel has a long history of channel change over the past 275 years. Historical records, dating back to 1747, reveal the River Tummel to have had a braided planform between Tomdachoille (upstream of the study area) and the confluence with the River Tay, with six to seven historical channel threads and approximately 21 mid-channel islands. In 1837, the then Duke of Atholl authorised flood protection along the banks of the Tummel, resulting in the construction of flood embankments between 1838 and 1850 (Parsons, 2000). This resulted in a predominantly single-thread channel. However, embankment breaches were common due to the high stream power and volumes of sediment movement during flood events. In 1903, following an extensive flood event, the landowner took the decision to allow the embankments to fall into disrepair along the most active reaches of the River Tummel due to the frequency of costly repairs (Parsons, 2000). The river then adjusted to a more natural planform, with channel instability, including channel avulsion, being characteristic of the River Tummel. Since the construction of Pitlochry Dam for hydro-electric power between 1950 and 1955, the river has been further adjusting to both flow regulation and the loss of sediment supply. At present, significant channel change and instability appears to be the result of high magnitude flood events with a return period of greater than 10 years (Parsons, 2000). The River Tummel flood event of 1993 caused extensive channel adjustment and re-working of the gravels; at the time, this event was the second highest flood event on record with a peak discharge of 1048m3s-1 and an estimated return period of 40 years (Parsons, 2000). The River Tummel maintains a wandering gravel-bed river planform downstream of Loch Faskally reservoir, with notable channel change, in particular around Tomdachoille Island, Ballinluig Island and Richard’s Island during the 20th Century since the abandonment of embankment maintenance in 1903.

3.1.39 The dynamic nature of the River Tummel has created a diverse mosaic of fluvial morphological units resulting in high species and habitat diversity. The River Tummel forms part of the River Tay SAC and is sensitive to changes in the fluvial conditions and processes operating within the channel.

3.1.40 The River Tummel at the study area is currently achieving Good Ecological Potential. Table 2 provides a summary of the classification and status of the key quality elements applicable to the fluvial geomorphology assessment.

Table 2: River Tummel Water Framework Directive classification

WFD Quality Element	River Tummel (L Faskally to R Tay)
Water body ID	6828
Overall classification	Good Ecological Potential
Designation as Artificial or Heavily Modified Water Body (A/HMWB)	HMWB
Pressures on water body	Physical alterations
Water flows and levels	Good
Physical condition	Good
Water quality	Good

Photograph 11a: Typical channel cross-section south of the existing A9 (looking downstream)

Photograph 11b: Large gravel deposit observed north of the existing A9 (looking upstream)

Summary

3.1.41 Following the assessment of the baseline condition for each water feature, a sensitivity level has been assigned based on the methodology outlined in Section 11.2 (Approach and Methods) of Chapter 11 (Road Drainage and the Water Environment) of the ES. Table 3 below provides a summary of the medium and high sensitivity water features. No water features with a very high sensitivity are present within the study area.

Table 3: Overview of fluvial geomorphology sensitivities of Medium and above

Water Feature ID	Qualifying criteria for sensitivity of water features	Sensitivity
WF6, WF40, WF70	Water feature sediment regime provides habitats suitable for species sensitive to changes in sediment concentration and turbidity. Water feature exhibiting a natural range of morphological features, with limited signs of artificial modifications or morphological pressures. Predominantly natural water feature with a diverse range of fluvial processes that is highly vulnerable to change as a result of modification.	High
WF23, WF24, WF25, WF32 WF36, WF38, WF39, WF50	Water feature sediment regime provides some habitat suitable for species sensitive to change in suspended sediment concentrations or turbidity. Water feature exhibiting some natural morphological features. Water feature with some natural fluvial processes, including varied flow types.	Medium

4 Potential Impacts

4.1.1 The potential impacts of the proposed scheme on fluvial geomorphology have been divided into construction and operational impacts. The construction impacts are those associated with activities undertaken during the construction phase and are therefore considered to have shorter-term effects. The operational impacts are considered to be longer-term impacts.

4.1.2 The following assessment of potential impacts is based on the proposed scheme without considering mitigation. Where embedded mitigation has been included within the design, this is accounted for in the potential impacts assessment. This includes (but is not limited to):

- geomorphology design input to outfall locations;
- geomorphology input to channel realignments (consideration of optimum lengths, gradients, alternative routing etc.);
- geomorphology input to culvert extensions and new culverts on minor water features to ensure appropriate channel gradients and continuity (upstream and downstream);
- recommendations for optimal bridge designs e.g. clear span, set back abutments; and

- flood risk input to sizing of culverts.

4.1.3 The most significant risks of potential impacts on the fluvial geomorphology of water features are associated with:

- Increases in fine sediment delivery to water features with potentially detrimental effects on sensitive species. These could result during construction and operation of the proposed scheme.
- Reductions in the morphological diversity of river channels, for example due to culverting, bank and bed protection, and realignment works.
- Alteration of the natural functioning of the river channel (natural fluvial processes), for example prevention of channel migration due to bank protection or culverting. The interruption of natural fluvial processes may have negative consequences on WFD targets due to detrimental effects on habitat diversity.
- Accelerated fluvial activity such as an increase in the rate of bank erosion in response to channel engineering, such as unsympathetic channel realignment. Accelerated bank erosion leading to an increase in fine sediment delivery can have impacts where sites of importance for freshwater ecology are located downstream.

General Impacts

4.1.4 An outline of the potential general impacts on the fluvial geomorphology elements (sediment regime, channel morphology and natural fluvial processes) of the water features during both construction and operation are provided in Chapter 11 (Road Drainage and the Water Environment). The following provides a summary of the potential impacts likely to occur:

Construction

- vegetation clearance and topsoil stripping;
- in-channel construction (including structures such as culverts, outfalls and bridges);
- channel realignments and diversions (including release of flow into new channels); and
- construction within the floodplain (including drainage and embankments).

Operation

- culverting (including culvert extensions);
- outfall structures and associated discharges;
- bridge structures;
- permanent realignment (or diversions); and
- changes to flow paths and catchment areas.

Site Specific Impacts

4.1.5 An impact assessment for both the construction and operation of the proposed scheme has been undertaken for all water features and is provided in Appendix A11.7 (Impact Assessment). Table 4 provides a more detailed understanding of the impacts on fluvial geomorphology for the medium, high and very high sensitivity water features. The assessment has considered the existing baseline (as outlined in Section 3: Baseline) and the key fluvial geomorphology elements (sediment regime, channel morphology and natural fluvial processes).

Table 4: Specific impact assessment for construction and operation on fluvial geomorphology

Source of Impact	Construction impacts	Magnitude of effect	Operational impacts	Magnitude of effect
WF06 (River Tay)	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction activities within the channel and indirectly from works within the tributaries and surrounding earthworks and construction activities (including construction of drainage, embankments and side roads in the floodplain). This could lead to changes of the morphological features present, including smothering of bed substrate and depositional features. **Works within the vicinity of the water feature** Works within the vicinity and along the banks of the River Tay altering channel banks and reducing floodplain area. This could alter the lateral connectivity of the water feature. **Outfalls (six in total)** Permanent removal of a length of natural bank and bed at each outfall, with localised changes to flow dynamics and the potential for alterations in sediment processes. Lateral connectivity with the floodplain altered as a result of new headwalls. Permanent removal of riparian vegetation. Potential for localised erosion of bed and banks around headwall structures. **River Tay bank stabilisation** Works along the banktop and/or bankface to install a contiguous bore piled wall bank stabilisation solution between approximate ch1600-1900 has the potential for the release of fine sediment into the River Tay from direct construction activities. This could lead to changes to the existing baseline conditions, including smothering of bed substrate and depositional features, and potential for alteration to flow patterns.	moderate adverse	**Outfalls (six in total)** There are six proposed outfall structures located along the River Tay (WF6). This would lead to the permanent removal of the natural bed, banks and vegetated riparian corridor. Subsequently this could lead to changes in flow processes and sediment movement. **River Tay bank stabilisation** Post-construction of the bank stabilisation works, including the reinstatement of a vegetated earth bank, there is likely to be a period of fluvial adjustment. This could result in erosion of the bank material, which could expose the contiguous piled wall solution. Should the design solution become exposed, the artificial material would potentially prevent lateral adjustment locally. The bank reinforcement could alter flow patterns both locally and downstream, thus altering erosion and deposition processes. The bank reinforcement may trigger bank erosion and/or channel incision downstream. **Works on tributaries of the water feature** Potential for cumulative change in flow and sediment regime from affected tributaries.	moderate adverse
WF23	**Release of suspended sediments** Potential for fine sediment input from culvert extension activities, including removal of riparian tree lining. Temporary works and alteration to steep river banks leading to the potential for erosion of bank substrates. **Culvert extension** Alteration to the gradient of the steep water feature as well as the banks and natural bedrock bed as a result of the culvert extension. There would be disturbance of the existing morphological features within the channel (notably the natural step-pool sequence and pebble and cobble substrate). **Channel realignment** Disturbance to the existing morphological features during construction of the realignment and potential infilling of existing channel to link with the proposed new culvert.	minor adverse	**Culvert extension** The new culvert would alter the existing channel cross-section and remove existing riparian vegetation (including established trees). The extended culvert bed and apron would remove the natural cobble and pebble bed substrate. The culvert would also change the gradient of the channel by slackening it upstream of the existing culvert. This could alter existing flow processes, subsequently leading to changes in the potential for sediment deposition upstream. **Channel realignment** Potential changes to the localised channel gradient where channel is lengthened. However, proposed works are minimal and unlikely to have a significant impact.	minor adverse
WF24	**Release of suspended sediments**	minor adverse	**Culvert extension**	minor adverse

JACOBS

Source of Impact	Construction impacts	Magnitude of effect	Operational impacts	Magnitude of effect
	Potential fine sediment input to water feature from direct construction activities within the channel. This could lead to changes of the morphological features present, including smothering of bed substrate and depositional features. **Culvert extension** Works within the water feature for culvert extension, leading to removal of earth banks and cobble and sand bed. The culvert works would also lead to the removal of the vegetated riparian corridor, including established trees.		The culvert extension would remove a long length of bed and banks, including existing step-pool sequence. The culvert gradient would also be decreased as a result, altering the flow and sediment transport and deposition processes locally.	
WF25	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction of culvert extension. This could lead to changes in the morphological features present, including smothering of cobble substrate and depositional features. **Culvert extension** Disturbance of banks and cobble bed, as well as natural morphological features such as the step/pool sequence. Potential for channel adjustment upstream as a result of in-channel working.	minor adverse	**Culvert extension** Culvert extension leading to removal of a length of natural cobble bed and gravel banks. Extended length of culvert would lead to changes in the bed roughness, flow processes and sediment transfer through the system. As a result, erosion could occur at the upstream of the inlet in response to the channel modification. The extension could also alter lateral connectivity with the floodplain.	minor adverse
WF32	**Release of suspended sediments** Potential fine sediment input to water feature from construction activities within the channel. This could lead to changes in the morphological features present, including smothering of cobble and gravel substrate and depositional features. **Culvert extension** Removal of banks and bed during construction works.	minor adverse	**New side road** The new side road would alter floodplain connectivity potentially leading to changes in flow and sediment processes during high flow. **Culvert extension** The culvert extension would remove a length of bed and banks, including existing step-pool sequence and natural cobble and gravel bed substrate. The new culvert would also alter the lateral and longitudinal connectivity within the water feature. **Channel realignment** Potential changes to the localised channel gradient where channel is lengthened. However, proposed works are minimal and unlikely to have a significant impact.	minor adverse
WF 36 (Dowally Burn)	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction activities within the channel and earthworks and construction activities within the surrounding floodplain. This could lead to changes of the morphological features present, including smothering of bed substrate and depositional features. **Culvert extension** Disturbance of banks and cobble and pebble bed, as well as natural morphological features such as the riffle-pool sequence. Potential for channel adjustment both upstream and downstream as a result of in-channel working. **Outfalls (three in total)**	moderate adverse	**New side road** The new side roads could alter floodplain connectivity leading to changes in runoff and potential flow and sediment processes, particularly during high flow. However, due to the existing presence of embankments on both banks, this is unlikely to cause a significant impact. **Culvert extension** Extending the existing culvert both upstream and downstream under side roads, leading to permanent removal of a length of existing bed and banks both upstream and downstream. There would also be the potential for alteration to the channel downstream of culvert (including erosion or deposition) as a result of channel adjustment in response to the modifications. **Outfalls (three in total)**	moderate adverse

Source of Impact	Construction impacts	Magnitude of effect	Operational impacts	Magnitude of effect
	Permanent removal of a length of natural bank and bed at each outfall, with localised changes to flow dynamics and the potential for alterations in sediment processes. Lateral connectivity with the floodplain altered as a result of new headwalls. Permanent removal of riparian vegetation. Potential for localised erosion of bed and banks around headwall structure.		There are three proposed outfall structures located along Dowally Burn. This would lead to the permanent removal of the natural bed, banks and vegetated riparian corridor. Subsequently this could lead to changes in flow processes and sediment movement.	
WF38	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction activities within the channel and disturbance of soils due to associated earthworks for substantial construction activities in this location near to the channel, which may be washed into the water feature. This could lead to changes of the morphological features present, including smothering of bed substrate. **Culvert replacement and extension** Works within the water feature for culvert extension and construction of new culvert, leading to removal of earth banks and cobble and pebble bed. The culvert works would also lead to the removal of the vegetated riparian corridor, including established trees. **Channel re-grading/realignment** Modification to existing channel planform. Potential for alteration to downstream movement of sediment when constructed realigned channel connected, with water passing down the channel entraining newly exposed sediment. **Flood Compensation Area** Construction of compensatory flood storage area would cause significant delivery of fine sediment to downstream section of water feature caused by large area of exposed soil following excavation. **Outfall (two in total)** Permanent removal of a length of natural bank and bed at the outfalls, with localised changes to flow dynamics and the potential for alterations in sediment processes. Lateral connectivity with the floodplain altered as a result of new headwalls. Permanent removal of riparian vegetation. Potential for localised erosion of bed and banks around headwalls structure.	moderate adverse	**Culvert replacement and extension** The new culvert would lead to the removal of a length of natural bed and banks, including step-pool sequence and cobble and pebble bed. This could alter the flow and sediment processes and potentially lead to scour around the banks and inlet of the culvert. However, due to the low energy nature of the water feature, this is unlikely to be a significant impact. **Channel re-grading/realignment** Changes in the channel gradient within the vicinity of the new culverts leading to changes in flow and sediment processes. Loss of natural morphological features in new channel. **Flood Compensation Area** Flood compensation area would reduce the height of water feature banks downstream of the A9. Potential for change in flow and sediment processes within the channel at this location, particularly during high flow events. **Outfall (two in total)** The proposed outfall structures would lead to the permanent removal of the natural bed, bank and vegetated riparian corridor. Subsequently this could lead to changes in flow processes and sediment movement.	minor adverse
WF39 (Sloggan Burn)	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction activities within the channel and due to earthworks and construction activities in close proximity to the channel. This could lead to changes of the morphological features present, including smothering of cobble and gravel substrate and depositional features downstream of the existing A9. **Culvert extension and new culvert (for side road and access track)** Works within the water feature for culvert extension and new culvert, leading to removal of earth banks, gravel and cobble bed and step-pool	moderate adverse	**New side road and access track** The new access track could alter floodplain connectivity leading to changes in runoff and potential flow and sediment processes, particularly during high flow. Alteration to morphological conditions due to culvert installation. **Culvert extension and new culvert (for side road and access track)** Culvert extension leading to removal of a length of natural cobble and gravel bed and vegetated earth banks. Extended length of culvert could lead to changes in the bed roughness, flow processes and sediment transfer through the system. As a	moderate adverse

Source of Impact	Construction impacts	Magnitude of effect	Operational impacts	Magnitude of effect
	sequence. Removal of vegetated riparian zone, including established trees, shrubs and grasses. **Outfall** Permanent removal of a length of natural bank and bed at the outfall, with localised changes to flow dynamics and the potential for alterations in sediment processes. Lateral connectivity with the floodplain altered as a result of a new headwall. Permanent removal of riparian vegetation. Potential for localised erosion of bed and banks around the headwall structure.		result, erosion could occur at the upstream of the inlet in response to the channel modification. The extension could also alter lateral connectivity with the floodplain. The new culvert would lead to the removal of a length of natural bed and banks. This could alter the flow and sediment processes and potentially lead to scour around the banks and the culvert inlet and outlet. **Outfall** The proposed outfall structure would lead to the permanent removal of the natural bed, bank and vegetated riparian corridor. Subsequently this could lead to changes in flow processes and sediment movement.	
WF40 (Kindallachan Burn)	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction activities within the channel. This could lead to changes of the morphological features present, including smothering of bed substrate. **Bridge extension** Works within the vicinity and at the top of the river banks associated with the bridge extension. Potential for the disturbance of the adjacent riparian vegetation (particularly trees).	moderate adverse	**Bridge extension and new bridge (and side road)** Potential for loss of existing riparian zone through the extension of the bridge over the watercourse. Loss of lateral connectivity with the floodplain at this location and potential for changed flow and sediment processes during high flows. New side road potentially alters runoff entering the water feature. The changes to runoff reaching the water feature could consequently alter flow and sediment processes particularly during high flows.	minor adverse
WF50	**Release of suspended sediments** Potential fine sediment input to water feature from direct construction activities within the channel. This could lead to changes of the morphological features present, including smothering of bed substrate. **New culvert** Works within the water feature for new culvert, leading to removal of earth banks, gravel and cobble bed and step-pool sequence. Removal of vegetated riparian zone, including established trees, shrubs and grasses. **Channel Re-alignment** Disturbance to and removal of the existing morphological features during construction of the realignment and potential infilling of existing channel to link with the proposed new culvert.	moderate adverse	**New culvert** New culvert leading to permanent removal of a length of existing bed and banks. There would also be the potential for alteration to the channel downstream of culvert (including erosion or deposition) as a result of channel adjustment in response to the modifications. **Channel Re-alignment** Potential changes to the localised channel gradient where channel realigned and lengthened. Changes to flows and sediment movement downstream of the realignment. Realignment would be designed to include geomorphological improvements to channel downstream of the A9 crossing. Changed flow regime associated with channel realignment into WF49. This has the potential to alter sediment processes and geomorphological features within the new realigned downstream reach.	moderate adverse

Significance of Impacts

4.1.6 The specific impact assessment has identified that there would likely be significant potential impacts (i.e. **Moderate** or above), without considering mitigation, on the following water features:

Construction

- WF06 (River Tay) – **Moderate** significance: as a result of fine sediment input from works within the channel and all tributaries in the catchment. The six outfalls would also require works within the channel and floodplain, altering morphological processes and features. Bank stabilisation works between approximately ch1600-1900 would impact upon fine sediment delivery during construction, as well as impacting upon fluvial processes locally and immediately downstream.
- WF36 (Dowally Burn), WF38, WF39 (Sloggan Burn), WF40 (Kindallachan Burn), and WF50 – **Moderate** significance: as a result of fine sediment input from works within the channel and removal of morphological features during construction.

Operation

- WF06 (River Tay) – **Moderate** significance: as a result of six additional outfalls removing the natural bank and changing flow and sediment patterns locally. Bank stabilisation works between approximately ch1600-1900 would result in a permanent barrier to natural lateral migration of the river eastwards. Whilst the design of the contiguous bore piled wall solution would be set-back from the bank face, over time the structure may become exposed by erosion processes operating on the bank. This may result in localised alteration to flow patterns and bankside flow velocities which may transfer erosive energy downstream, resulting in the potential for bed scour and/or bank erosion and an alteration in the pattern of sediment deposition.
- WF36 (Dowally Burn) – **Moderate** significance: as a result of the proposed bridge extension and three new outfalls completely removing an existing bank, as well as the potential for removal of other morphological features and riparian zone.
- WF39 (Sloggan Burn), WF40 (Kindallachan Burn), and WF50 – **Moderate** significance: due to the removal of natural river bed and banks. The structures would alter geomorphological features (including bed substrate and associated flow types), flow patterns, constrict flow, confine the channel and remove/alter of lateral and longitudinal connectivity.

5 Mitigation

Specific Mitigation

5.1.1 A number of standard mitigation measures would be implemented to reduce the impact of the construction and operation of the proposed scheme. An overview of the standard mitigation identified for reducing the potential impacts on the fluvial geomorphology of the water features can be found in Section 11.5 of Chapter 11 (Road Drainage and Water Environment) and Table 21.5 (Chapter 21: Schedule of Environmental Commitments).

5.1.2 Taking into account the standard mitigation, it is considered that for the majority of the water features, the impacts are reduced to non-significant and no further mitigation is required. However, there are a number of water features where additional specific mitigation is required for the construction phase, detailed design and operation of the proposed scheme to further mitigate for the fluvial geomorphology impacts. The medium and high sensitivity water features requiring specific mitigation are outlined in Table 5. The low sensitivity water features requiring specific mitigation can be found in Appendix A11.7 (Impact Assessment). There are no water features within the study area of very high sensitivity.

Table 5: Site specific mitigation for construction and operation (for medium and high sensitivity water features)

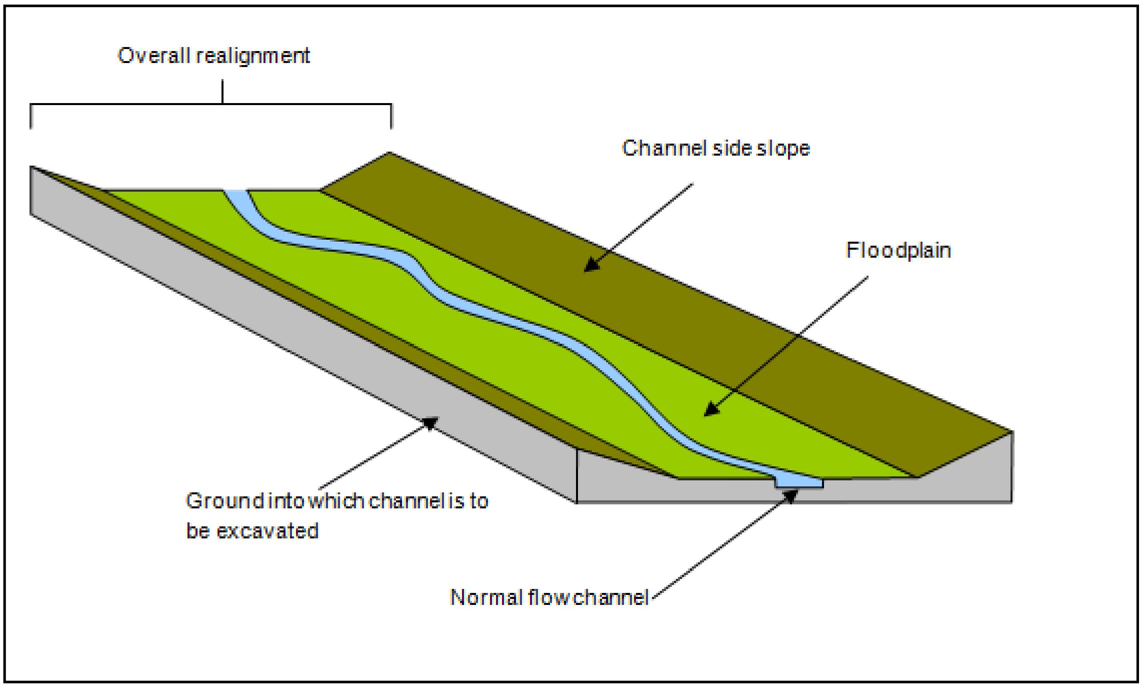
Water feature	Mitigation details
Construction	
All Water Features	• Construction: implement Construction Environmental Management Plan (CEMP) (or similar) to minimise impacts to the channel and surrounding riparian area. Fine sediment control methods recommended to minimise delivery of silt to watercourse. Retain trees on banks and bank top as far as practicable during construction. Retain fallen trees and large wood on banks and in channel margins where practicable. • Training to be provided by a suitably qualified geomorphologist to ensure that natural features/structures are installed as intended by design • Any proposed channel realignment works or other morphological features would be supervised by a suitably qualified geomorphologist who could also provide on-site advice to resolve unexpected issues or constrains that might emerge during their construction.
Operation	
All Water Features	• Additional sediment or flow calculations might be required during the detailed design stage of channel realignments, culverts or channel re-grading. This will be determined as the designs progress. Geomorphological input to engineering designs will be provided on a case-by-case basis.
All Water Features	• Geomorphological input into detailed design of culvert (including depressed invert to allow natural channel bed formation and minimising impact on existing channel bed and bank, and the use of energy dissipation measures within the culvert, at the inlet and outlet on a site by site basis). Energy dissipation measures will be used where the channel gradient would be steepened due to the works, such as an energy dissipation pool (e.g. stilling pool) at the culvert outlet.
WF06	• Geomorphological input into detailed design of outfall headwalls and associated drainage channels where outfalls are set-back, and location of outfalls to minimise risk of erosion/scour. Outfalls should be angled in the downstream direction of flow. Avoid outfall placement in zones of erosion or deposition where practicable. • At approximate ch1600-1900, geomorphological input into the detailed design of bank stabilisation works. • Re-planting of vegetation around outfall structures, tying in with natural vegetation. Of particular importance is planting of trees if removed. • At ch3870 the outfall should be orientated in line with the direction of flow. Re-grading of the slope around the outfall structure. Maintain fallen trees in situ where possible as they provide natural bank protection. Plant bank face around the outfall structure with a native mix of grasses, shrubs and trees (avoiding the use of shallow rooting trees). Green bank engineering techniques are recommended around the outfall structure, such as seeded coir matting, willow spilling, root wads and brash. CPO of the field at the bank top and plant with a native mix of trees to provide a wind screen to trees lining the bank top to reduce further windthrow. Planting should avoid casting shade in the vicinity of the SuDS pond and embankments for basking areas.
WF16 WF18-WF25 WF30-WF42 WF47 WF49 WF50 WF52 WF53	• Geomorphological led design, construction supervision and post project appraisal of cascades and channel realignments/re-gradings. Incorporation of appropriate geomorphological features and suitable design of cross-section and planform to ensure movement of water downstream is not compromised.
WF38	• Geomorphological input into detailed design of outfall headwall and associated drainage channels. Ensure outfalls are set-back, and location of outfall is determined to minimise risk of erosion/scour. Outfall should be angled in the downstream direction of flow.
WF16-WF39 WF41-WF53	• Geomorphological input into detailed design, construction supervision and post-project appraisal of culverts. Measures to include use of depressed invert culverts, enabling the formation of a natural bed and minimising impact on existing channel bed and bank.
WF40	• Reinstate riparian vegetation where possible. • Set-back bridge abutments for new extended bridge as far back as practicable from back top.

Conceptual Design

5.1.3 The mitigation detailed above outlines some design recommendations for the water features to mitigate against the operational impacts of the proposed scheme. These primarily relate to the realignment of the water features and the use of cascades to grade the channel into the new culverts. The following provides some indicative designs to be taken forward to detailed design for these features.

5.1.4 Diagram 1 provides a conceptual design for a water feature realignment, where the channel cross-section is varied to create a more naturalised channel. The design would allow for low flows (within the centre channel), deposition and potential channel adjustment without losing surrounding land.

Diagram 1: Conceptual illustration of a two-stage channel with a straight overall form by sinuous low flow channel (not drawn to scale)



5.1.5 Diagrams 2, 3 and 4 provide an indicative conceptual design illustrating the potential design and layout of the proposed natural cascade (step-pool sequence) detailed above. The design replicates the natural bed (i.e. gravel or cobble) and uses large boulders to form the steps that check the gradient in a steepened length that requires a cascade. Between each step, a pool is created, proportional to channel geometry, acting to slow flows and dissipate energy. The conceptual design provides a cascade that would be closer to mimicking existing channel characteristics and would therefore, would provide benefits for the morphology of the water features. The design would need to be developed during detailed design and made specific to each water feature to ensure it functions effectively.

Diagram 2: Conceptual diagram illustrating, in profile, plan view and cross-section, the constituents of a step-pool bed morphology for bedrock channel.

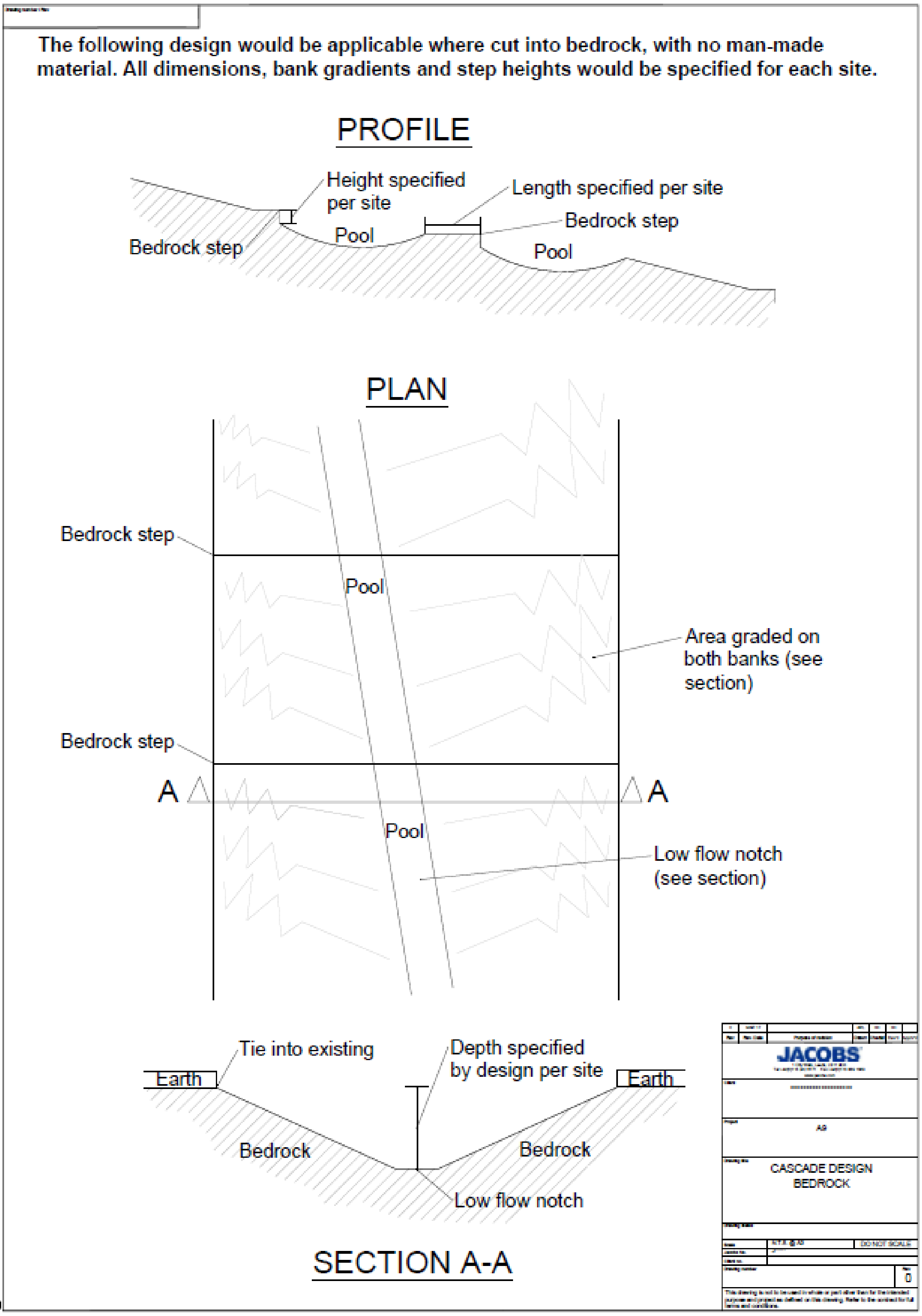


Diagram 3: Conceptual diagram illustrating, in profile, plan view and cross-section, the constituents of a step-pool bed morphology for 'naturalised' design

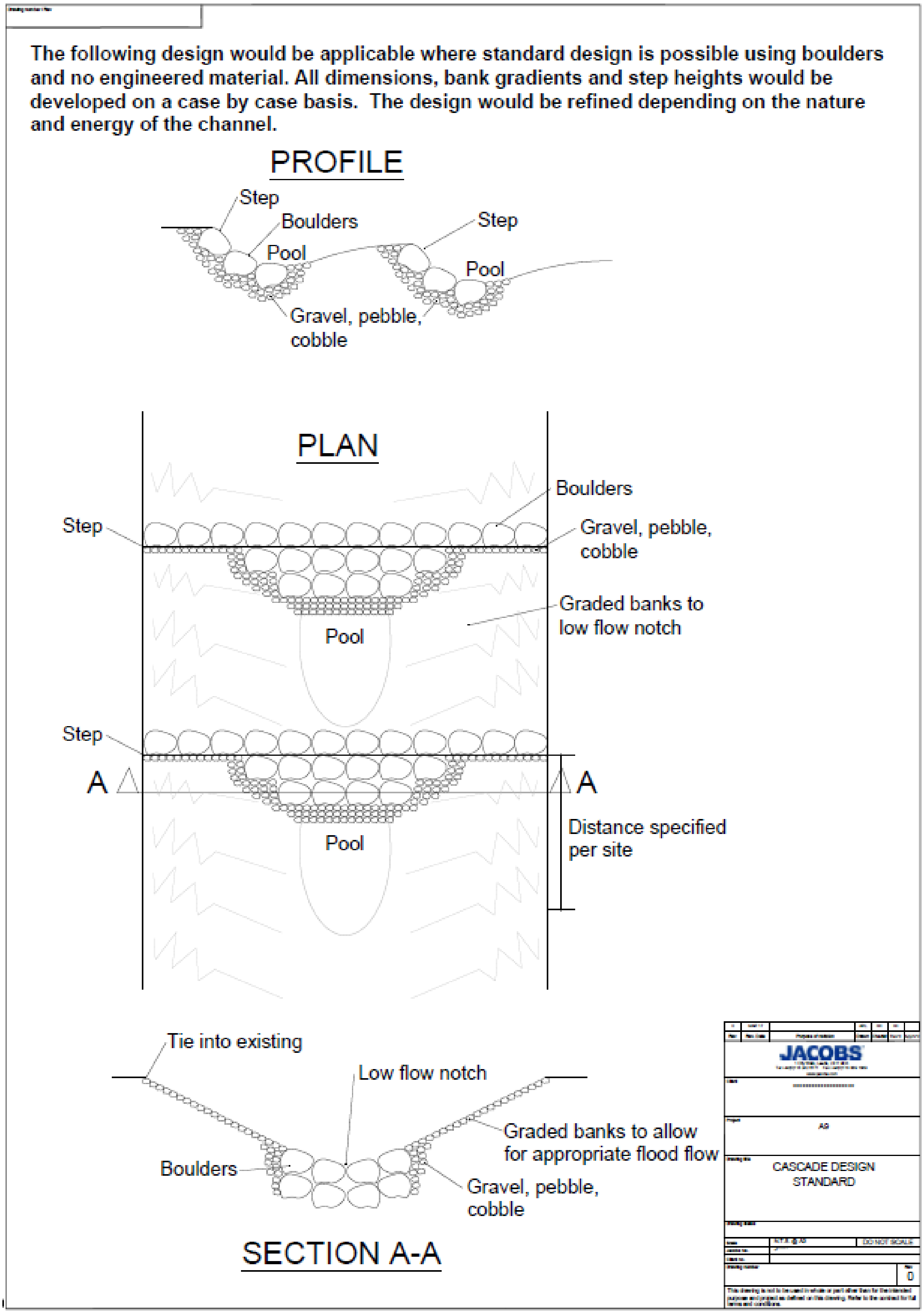
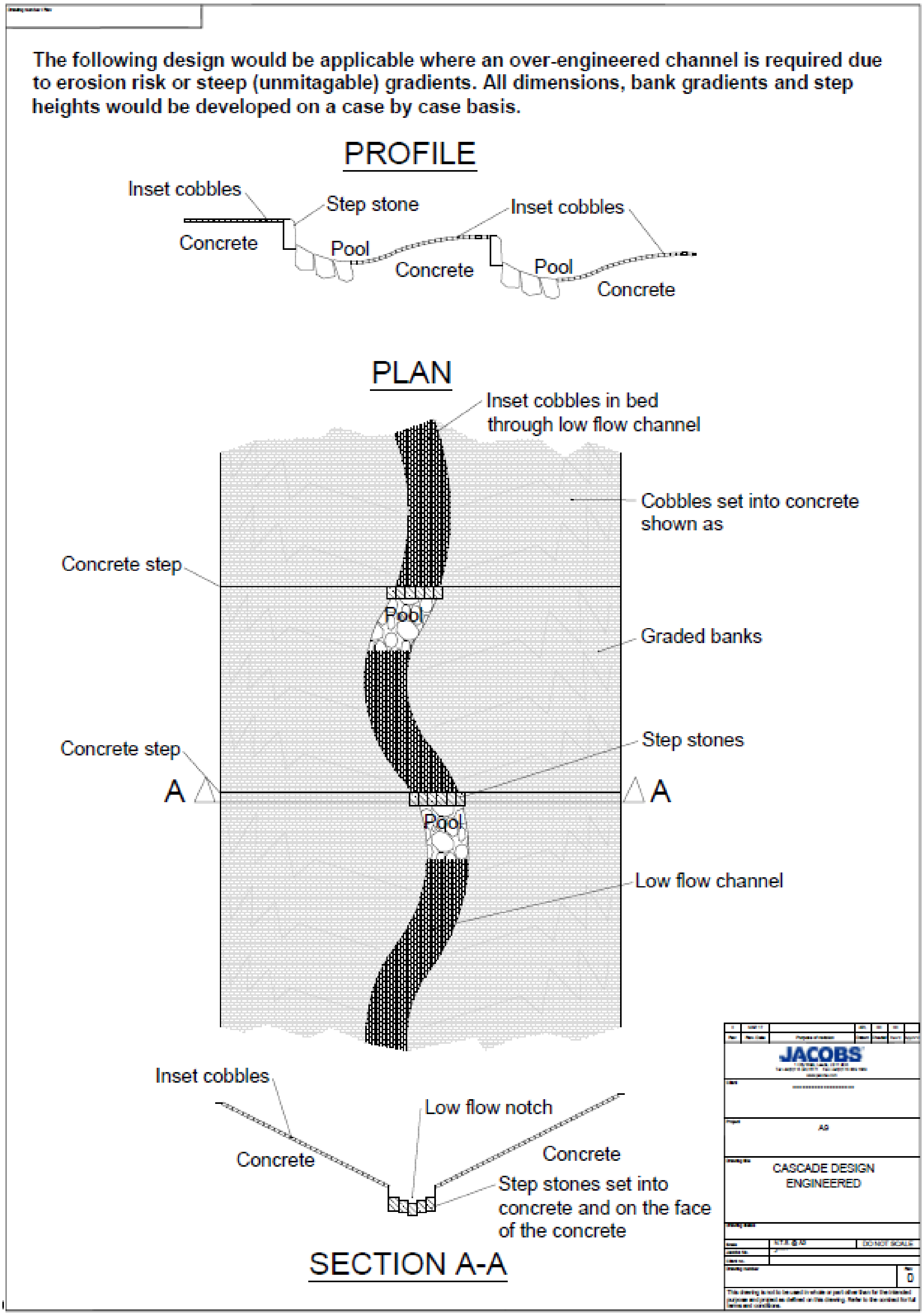


Diagram 4: Conceptual diagram illustrating, in profile, plan view and cross-section, the constituents of a step-pool bed morphology for an engineered design for high erosion risk sites



6 Residual Impacts

6.1.1 The significant residual impacts likely to occur during either the construction and/or operational phases following the application of mitigation measures are set out in the following paragraphs. Non-significant fluvial geomorphological residual impacts identified for each surface water feature are set out in Appendix A11.7 (Impact Assessment).

Construction Residual Impacts

6.1.2 Following the assessment of all of the construction activities likely to impact the water features along the proposed scheme, it has been concluded that there are no residual impacts of **Moderate** significance or above expected, provided all mitigation is adhered to.

Operational Residual Impacts

6.1.3 Following the assessment of all of the operational activities likely to impact the water features along the proposed scheme, it has been concluded that there are no residual impacts of **Moderate** significance or above expected, provided all mitigation is adhered to.

7 References

Environment Agency (2010). The Fluvial Design Guide. Available online at: http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide.aspx.

Parsons, H., (2000). Analyses of Landscape Diversity on a Wandering Gravel-Bed River, Scotland. PhD Thesis, University of Stirling

Scottish Government (2003). Water Environment Water Services (WEWS) Act 2003. Available online at: http://www.legislation.gov.uk/asp/2003/3/contents.

Scottish Government (2015). The River Basin Management Plan for the Scotland River Basin District: 2015–2027. Available online at: http://www.sepa.org.uk/media/163445/the-river-basin-management-plan-for-the-scotland-river-basin-district-2015-2027.pdf

Sear, D.A., Newson, M.D. and Thorne, C.R. (2010) Guide Book of Applied Fluvial Geomorphology. Defra/Environment Agency R&D Technical Report FD1914, pp. 233

SEPA (2012) SEPA Supporting Guidance (WAT-SG-21) Environmental Standards for River Morphology, v2.1. Available online at: https://www.sepa.org.uk/media/152194/wat_sg_21.pdf [Accessed 25 May 2016

8 Glossary

Term	Definition
Adjustment	The modification of river channel morphology, both vertically and in planform, through erosion and deposition, which occurs in response to a modification to a channel caused by external factors such as human interference, climate or land use.
Avulsion	Avulsion is the rapid abandonment of a river channel and the formation of a new river channel
Bar	A general term referring to a depositional feature, usually formed of gravel deposited in a river.
Berm	Permanent deposits that have developed on the margin of the channel consisting of bench like features which effectively create a two-stage channel.
Channel capacity	The volume of water that can be contained within a given section of river channel.
Catchment	The total area of land that drains into any given river.
Channel	The course of a river including the bed and banks.
Cobble	Particle of diameter 64mm to 256mm, approximately "fist" sized.
Continuity	Relates to how continuous the flow or sediment transfer is within a particular water feature. Culverts often break the continuity through promoting deposition. Lateral connectivity refers to the connection between the channel and the floodplain at either bank. Longitudinal connectivity refers to the upstream and downstream connection throughout a channel.
Culvert	Artificial structure, often concrete, for carrying water underground or under bridges.
Discharge	The volume of water flow per unit time usually expressed in cubic metres per second (m3 s-1)
Dynamic (active) rivers	Rivers with high energy levels; which are prone to change their channel characteristics relatively rapidly.
Embankment	Artificial flood bank built for flood defence purposes, which can be flush with the channel or set back on the floodplain.
Ephemeral stream	Usually low order, water only during and immediately after heavy rainfall.
Erosion	The process by which sediments are mobilised and transported by rivers.
Equilibrium	Where erosion and deposition are balanced. This is achieved through morphological adjustment which maintains sediment transport continuity.
Fine sediment	Sediment of grain diameter finer than 2mm.
Floodplain	Area of the valley bottom inundated by water when a river floods
Flow processes	Description of how the flow in a river varies over time and how frequently and for how long high flows (floods) and low flows (during droughts) occur.
Fluvial	The branch of geomorphology that describes the characteristics of river systems and examines the processes sustaining geomorphology them.
Geomorphology	The study of features and processes operating upon the surface of the Earth.
Gravel	Particle of diameter between 2mm and 64mm.
Hydrological	Referring to the flow of water, specifically its routeing and speed.
Incised channel	Where the riverbed is well below the floodplain due to downwards erosion (incision).
In-channel	That part of the channel covered by water in normal flow conditions.
Large wood	Large wood accumulations creating a dam across part or the whole of the channel and causing water to pond back.
Meander	A bend in the river formed by natural river processes e.g. erosion and deposition.
Mid-channel bars	Gravel or other shallow deposits in the middle of straight sections of water feature.
Migration	Lateral movement of channel across floodplain through bank erosion and deposition.
Modification	Channel features that have been created by management interventions and often involve river engineering.
Poaching	Trampling by livestock.
Point bar	Gravel or other shallow sediment deposition on the inside of bends.
Pool	Discrete areas of deep water typically formed on the outside of meanders.
Reach	A length of an individual river which shows broadly similar physical characteristics.
Realignment	Alteration of the planform channel (often by straightening) to speed up flows and reduce flood risk.
Riffle	A shallow, fast flowing section of water with a distinctly disturbed surface forming upstream-facing unbroken standing waves, usually over a gravel substrate.
Riparian	Land on the side of the river channel.

Term	Definition
River corridor	Land to either side of the main river channel, including associated floodplain(s).
Runoff	Water entering a channel via overland flows following rainfall events, flowing down the slope to the channel.
Sedimentation	The accumulation of sediment (fine or/and coarse) which was formerly being transported.
Scour	Erosion caused resulting from hydraulic action.
Sediment transport	The movement of solid particles (i.e. sediment), typically due to a combination of gravity acting on the sediment and/or the movement of the fluid in which the sediment is entrained.
Stream Power	A measure of the specific energy acting in a channel to determine the river's capacity to transport sediment and perform geomorphic work, e.g. erosion.
Side bars	Gravel or other shallow deposits along the edges of straight sections of river channels.
Siltation	Deposition of fine sediment (comprising mainly silt) on the channel bed often promoting vegetation growth if it is not flushed downstream regularly.
Sinuous	A channel displaying a meandering course. High sinuosity relates to a channel with many bends over a short distance; low sinuosity is often used to describe a fairly straight channel.
Toe (of the riverbank)	Where the riverbed meets the bank.
Water Framework Directive	Under this Directive, Member States must achieve good ecological status/potential and prevent deterioration in the status of surface waters. Ecological status is to be assessed using a number of parameters, including hydromorphological (or fluvial geomorphological and hydrological) quality elements: • Hydrological regime – the quality and connection to groundwater reflect totally or neat totally undisturbed conditions. • River continuity – the continuity of the river is not disturbed by human activities and allows the undisturbed migration of aquatic organisms and sediment transport. • Morphological conditions – channel patterns and dimensions, flow velocities, substrate conditions and the structure and condition of the riparian zone correspond totally or nearly totally to undisturbed conditions.

Annex A: Technical Note - Outline approach to mitigate erosion risk

Technical Note

Outline approach to mitigate erosion risk

Client	Transport Scotland	**Date**	27 February 2018
Project	A9 Tay Crossing to Ballinluig	**Project No.**	B2140003
Subject	Outline approach to mitigate erosion risk		
Reference	A9P03-JAC-ZZZ-A_ML016_ZZ-TN-ZZ-0001		
Prepared by	Matthew Sullivan		
Copies to	Transport Scotland		
Checked by: Mark Preston	**Reviewed by:** Keith Sheridan	**Approved by:** Alan Gillies	

1. Introduction

As part of the DMRB Stage 3 assessment, the risk posed by river bank erosion to the proposed alignment has been considered along the entire length of the Southern Section of the A9 Dualling Programme, for which Jacobs is responsible. This assessment identified an erosion risk on the eastern bank within the extents of Project 3: Tay Crossing and Ballinluig between Chainage (Ch.) 1600m and 1900m (see Figure 1). This technical note summarises the work undertaken to assess the risk, options considered, preferred mitigation approach and the associated potential environmental impacts.

Figure 1. Aerial view of erosion risk site.

2. Background

2.1 Site description

In the reach of interest, the channel is approximately 80m to 90m wide at bank full, with a wetted width of between 65m and 75m at base flow. The floodplain extends some distance to the west with approximately 1.5m high flood embankments set back around 30m from the river bank. On the east bank, the historical island forms a more extensive area of floodplain between the existing A9. Along the majority of the area of erosion, the embankment rises from the river to the existing A9.

The general flow character is that of a large meandering river with run-pool-run sequences transitioning from bank to bank as the river meanders, with limited or localised areas of shallow riffle in depositional zones. The main gravel exposures are limited to the east bank bar on the inside of the meander bend, with sub-surface deposition upstream evident from photography towards the east bank at the northern and southern extents of the area of erosion.

River engineering works during the construction of the existing A9 are likely to have confined the channel within its existing planform south of Woodinch and north of Tom Ban. Review of historical maps indicates that the entirety of the left bank in this reach of the river is man-made. Maps pre-dating the construction of the A9 dated 1900 show the course of the River Tay to overlie the existing route of the A9. The 1977 edition, dating from during or post-construction, shows the existing A9 in its current alignment and the east bank of the river re-aligned to the west. Within the reach of interest, the bank toe is thought to comprise of non-cohesive material (sand, gravel and cobbles) with large boulders also noted. Archive video footage from the website of the National Library of Scotland[1] suggests these boulders were placed along the toe to form a rock armour protection feature.

Inspection has been made from both the western and eastern banks of the river. Erosion of the east river bank was observed along its toe with gravel, cobbles and boulders exposed up to an estimated 2m above the water line at the time of inspection.

The river bank ranges in height between around 6m and 9m with slope angles generally between 25^0 and 30^0, although considered to be much steeper at the toe of the bank where influenced by erosion. The existing A9 carriageway is adjacent to the top of the bank, with a distance of between 2m and 3m between the top of bank and the carriageway edge. The proposed alignment requires southbound widening at this location; therefore, the northbound carriageway edge is likely to be at the same location post construction.

2.2 Surveys

Bathymetric survey of the bed and laser scanning of the bank have been undertaken to understand the extent of bed scour and erosion of the bank toe.

As expected, the bathymetric survey of the bed has identified a depositional gravel bar to the west bank and deeper water on the outside of the meander bend.

Although the vegetation cover at the time of the laser scanning has reduced the effectiveness of the survey in examining the condition of the bank accurately, the information provided has allowed an initial assessment to be undertaken.

The analysis of the laser survey illustrates that the bank is in various states of failure, with some undercut areas close to collapse and others already having retreated along the length of the reach. In some locations, the bank toe is less than 5m from the road embankment toe and the stability of the embankment may potentially be threatened in some of the areas if this was to progress much further.

There is limited GI information within this area; however, a phase of Detailed GI incorporating seven boreholes and surface geophysics surveys in proximity to the erosion location is being undertaken in

[1] http://movingimage.nls.uk/film/1962

February and March 2018 to provide information on the ground and groundwater conditions. This will allow more detailed assessment and development of accurate ground models.

2.3 Erosion

Since the construction of the existing A9, spatial analysis of OS mapping and current toe geometry suggests approximately 5m of bank retreat being evident over a period of approximately 40 years. With failure of the rock armour protection, erosion has been observed along the bank toe along with signs of other erosion processes operating on the bank face (mass failure and sub-aerial weathering and weakening).

Whilst rates of toe erosion are estimated to be low (0.125m per annum average), erosion may occur rapidly under high flow conditions. There is a risk of mass failure and weathering of the bank face due to the loss of toe material supporting the river bank, which poses a significant risk to both the existing A9 and the proposed scheme. A stream power assessment revealed that the average reach stream power is 93 ω (Wm-2), using an average gradient of 1 in 1000. This figure equates to a medium energy river channel type and indicates that the river has the ability to erode.

The process of fluvial erosion is thought to be both abrasion of the river bank surface and erosion of the river bed. Erosion of the river bed and toe will lead to the river bank being over steepened and then failing and slumping into the river. As the banks are non-cohesive, mass failure and slumps would not remain at the toe of the bank and limit further erosion, as the material is then transported away during high flows.

The reach is sub-divided into sections as follows:

- Ch.1600m south; downstream of the rock outcrop at approximate Ch.1600m, the river is more depositional in nature with a gravel bar evident between Ch.1600m and Ch.1400m on the left bank and with the energy transferring to the right bank.
- Ch.1600m to Ch.1680m; the bank appears to be relatively intact, is well vegetated and relatively unimpacted by erosion processes.
- Ch.1680m to Ch.1800m; bank erosion is more severe due to the steep upper slopes making erosion of the toe and bed more likely to result in mass failure of the upper slope.
- Ch.1800m to Ch.1850m; bank erosion is evident but although erosion and bank undercutting is apparent, there is a relatively wide flatter area on the bank top extending to the road embankment toe that limits significant mass failure.

The review of survey data obtained confirms an over steepening of the bank toe and has allowed an estimate of erosion rates. This indicates that erosion is resulting in undermining of the highway embankment and that further erosion will ultimately compromise the existing and proposed A9 alignment.

2.4 Conclusion

In recognition of the observed erosion to-date, bank geometry and the close proximity of the existing and proposed carriageway alignment, there is potential for instability to the road embankment, and therefore also the carriageway, should erosion continue un-mitigated. The potential severity to road infrastructure and road users should this occur is very high. Based on the bank erosion assessment, the section between Ch.1600m and Ch.1900m is considered to be at high to very high risk of further bank erosion and potential for embankment failure or instability. Details on the erosion risk assessment and assessment criteria can be found in Appendix B.

It is considered that if the A9 Dualling scheme was not being progressed, the risk posed by river erosion to the existing A9 would have to be addressed, most probably as emergency works. However, it is considered highly unlikely in the near future that a single event would result in a mass failure of the bank impacting the existing A9.

3. Option Development and Sifting

3.1 Long List of Options

Given the risk to the existing and proposed A9 infrastructure, the following options were considered and assessed against various criteria including technical, economic, environmental, health and safety, and residual risk. These options are listed below with a brief narrative for each.

- Do minimum (monitoring and emergency maintenance):- Erosion is allowed to continue unmitigated but is monitored. A monitoring regime would be designed and implemented. In addition, a contingency for maintenance may be required to place rock armour (riprap) along the toe as necessary in the event of further erosion of the bank.

- Move proposed road alignment:- The proposed alignment could be shifted to the east to increase the distance between the river and the road embankment thus reducing the risk of erosion impacting the road.

- River training (rock revetment):- The existing river bank and river bed could be protected with a rock armour (riprap) revetment system offering protection against fluvial scour.

- Steepen existing road embankment:- Following construction of the new southbound lanes, the northbound embankment could be re-constructed and engineered at a steep gradient to increase the distance between the toe of the road embankment and the river bank. This distance would be sacrificial with some erosion between the river and the road embankment toe permitted (acceptable limits would need to be considered).

- Retaining wall (steel sheet pile):- Installation of steel sheet piles close to the river edge to limit the extent of future erosion. Works would require a temporary platform at approximate river level, i.e. following construction of new southbound lanes, excavate to form piling platform, install piles and construct new northbound embankment (piling from road level is not viable due to retained height). A revetment detail would be required on the slope above the sheet piles, up to the 1:200-year flood level.

- Retaining wall (contiguous bored pile wall):- Installation of bored concrete piles close to the river edge to limit the extent of future erosion. As above, appropriate construction phasing required to allow formation of temporary platform for necessary plant to install piles along the river bank. Installation level of the piles would require careful design to ensure their constructability and effectiveness, and ideally this level would be as far down the river bank as possible. A revetment detail would be required on the slope above the contiguous bored pile wall, up to the 1:200-year flood level.

- Construct caissons:- Caissons installed along the toe of the river bank (within the river) to provide protection to the bank from further erosion. Installation depth could be up to 6m depth suggesting a minimum diameter of 3m (based on general rule of caisson diameter equal to half the length). The caisson itself would likely be constructed of concrete and infilled with concrete or rock fill.

- Ground improvement:- Compaction grouting of the existing bank to form a gravity block which would be resistant to erosion between the existing and proposed alignment, and the river. The existing embankment above the maximum river level could be excavated to form a temporary platform for grouting operations.

- Buried viaduct:- Construct new dualled A9 on viaduct supported by buried piers/columns (formed from bored piles). Further natural erosion is permitted, potentially exposing buried viaduct elements over time.

3.2 Preferred Option

Initial sifting ruled out a number of the options on various grounds, which is summarised in the table below:

Option	Assessment Summary
Do minimum (monitoring and emergency maintenance	The risk of erosion impacting on the A9 would remain. Furthermore, erosion over the lifespan of the road is likely to require emergency protection works, potentially within the aquatic habitat with the potential for direct impacts on QIs and terrestrial habitat of the River Tay SAC. This has the potential to alter the structure and functioning of the SAC by changing hydrological flows, scour and deposition. Therefore, this option was removed from further consideration.
Move proposed road alignment	Although this option increases the separation between the River Tay and the dualled A9, the long-term risk of erosion impacting the A9 would remain and have an impact on a property to the east of the existing A9. Furthermore, erosion over the lifespan of the road is likely to require emergency protection works, potentially within the aquatic habitat with the potential for direct impacts on QIs and terrestrial habitat of the River Tay SAC. This has the potential to alter the structure and functioning of the SAC by changing hydrological flows, scour and deposition. Therefore, this option was removed from further consideration.
River training (rock revetment)	There would be extensive works required within the river channel, resulting in potential direct impacts on QI and in a permanent change in aquatic and terrestrial habitat of the River Tay SAC. This would impact the hydrological flows, scour and deposition within the SAC. Therefore, this option was removed from further consideration due to the associated impact on the SAC.
Steepen existing road embankment	Although this option increases the separation between the River Tay and the dualled A9, the long-term risk of erosion impacting the A9 would remain. Furthermore, erosion over the lifespan of the road is likely to require emergency protection works, potentially within the aquatic and terrestrial habitat of the River Tay SAC. This has the potential for direct impacts on QI in the river channel and to alter the structure and functioning of the SAC by changing hydrological flows, scour and deposition. Therefore, this option was removed from further consideration.
Retaining wall (steel sheet pile)	In recognition of the limited information on ground conditions but on the understanding that the river bank contains a significant quantity of coarse material including large boulders, the installation of sheet piles was not considered a

Option	Assessment Summary
	viable option at this stage, therefore, this option was removed from further consideration.
Retaining wall (contiguous bored pile wall)	This option was identified as the preferred solution although acknowledging that this resulted in a significant cost (approx. £5 million). There would be no in channel work required although works would be undertaken in the terrestrial SAC habitat. Should the contiguous bored pile wall become exposed over time, this may have the potential to alter the hydrological flows and scour and deposition over the lifespan of the scheme.
Construct caissons	Extensive works required within the river channel, resulting in a permanent change in aquatic habitat with the potential for direct impacts on QIs and terrestrial habitat of the River Tay SAC and impacting the hydrological flows, scour and deposition within the SAC. Therefore, this option was removed from further consideration due to the associated impact on the SAC.
Ground improvement	Compaction grouting of the river bank may result in a permanent change to terrestrial habitat and alter the structure and functioning of the River Tay SAC by changing hydrological flows and scour. Due to the potential impact on the SAC and the difficulty in predicting how effective the solution would be in offering protection from erosion, this option was removed from further consideration.
Buried viaduct	This option provided a robust solution although, should the piers become exposed during the lifespan of the scheme, the exposed piers may alter the structure and functioning of the SAC by changing hydrological flows and scour. However, the related cost (>£20 million) is significantly greater than the contiguous bored piled wall. Therefore, this option was removed from further consideration.

4. Outline Design and Constructability

4.1 Outline Design

The outline design requires the construction of a contiguous bored pile wall, formed with piles of the order of 1200 mm diameter, with a revetment detail on the slope above (see Drawing A9P03-JAC-HGT-A_ML016_RW-DR-GE-0001 found in Appendix A). The proposed wall will be designed to protect the river bank from fluvial erosion and scour. The revetment is also required to maintain the integrity of the road embankment during flood events above the retaining wall and up to the 1:200-year flood level.

The line of the wall shown in Drawing A9P03-JAC-HGT-A_ML016_RW-DR-GE-0001 has been determined in order to strike a balance between efficient design and constructability of the wall, and protection of the environment. It is proposed that the piles along the river bank are to be installed at the Q_{MED} level[2] of 52.6mAOD. Installation of the piles at the Q_{MED} level is required so as to reduce the retained height as far as reasonably possible. This provides technical advantages in ensuring the constructability of the wall and also reduces the height of wall which may become visible in the future but comes at the cost of a higher risk of water inundation of the works during construction.

An offset of at least 4m will be maintained between the current river edge and the centre of the pile so as to reduce the likelihood of instability and collapse of the lower bank during pile installation. Both the line of the wall and the allowed offset also take into account the required plant movements on the working platform (i.e. the piling rig(s) and an attendant crane) and other construction operations, laydown areas, etc.

The groundwater conditions are unknown at this stage, although it is considered reasonable to assume that groundwater is controlled by the River Tay. Accordingly, the pile bores are likely to be wet and given the probability of boring through granular materials, support of the pile bore will be required. Support could be provided by fully casing the pile bore; however, given the likely depth of the pile bore, the handling of casings will be challenging and slow with associated impact on construction programme and cost. Alternatively, a biodegradable polymer support fluid could be used to stabilise the pile bore. The drilling fluid is continually recirculated thus limiting the loss of fluid and is not discharged into watercourses. Products include SlurryPro CDB (manufactured by KB International) and SuperMud (manufactured by PDS) have been used previously in similar environments.

A capping beam will be required, likely to be approximately 2m wide and installed along the top of the piles. The wall may also need to be anchored as shown on the cross section in Drawing A9P03-JAC-HGT-A_ML016_RW-DR-GE-0001. These works can both be completed from the working platform. Where anchoring of the wall is required it is envisaged that this would be at capping beam level.

Upon completion of the wall construction, the earthworks for the northbound carriageway will be constructed. These works will also include the construction of a revetment detail on the embankment face to protect the A9 infrastructure from events up to the 1:200-year flood event.

4.2 Constructability

In order to construct the wall, a temporary working platform must be constructed. This will allow access for the required plant to install piles at the Q_{MED} level. It is estimated that the works could take up to 18 months to construct. The envisaged outline construction sequence is described below:

1. Construction of the new southbound embankment and carriageway.

2. Transfer of two-way traffic from the existing A9 carriageway on to the new southbound lanes (as two-way traffic).

3. Excavation of the existing A9 carriageway to form a temporary working platform at the Q_{MED} level. The working platform would be constructed with a slight fall back into the slope which would help in preventing surface run-off from entering the River Tay. In addition, a low height bund could be provided between the pile bores and the river. A temporary 40° slope is envisaged between the A9 and the platform with a small filter drain along the toe to collect run-off from the working platform. An access ramp on to the platform will be required at the northern end. These works require vegetation clearance, construction of a piling platform and temporary drainage.

4. Construct piles (potentially sleeved/sacrificial casing over the section above the waterline).

[2] *Q_{MED} is the Median of the annual maximum flow series – the flow that has an annual exceedance probability of 50% or a return period of two years. This is approximate to bank full flow.*

5. Construct restraint system if required (potential for drilled anchors/deadman anchors/barrette piles, etc. (i.e. passive mechanisms).

6. Construct capping beam arrangement.

7. Construct earthworks to form new northbound carriageway including revetment on face of embankment as required.

The management of surface water run-off is considered to be critical to the construction of the proposed approach. Potential run-off volumes from the exposed banks over a range of durations and magnitudes have been considered and determined that a mobile tank could be used as a reservoir for managing and pumping surface water (collected from the filter drain) to a treatment facility on the northern extents of the works. Alternatively, a mobile package plant treatment system could be used that discharges treated runoff directly to the River Tay. The contractor would need to ensure effective attenuation and treatment is maintained at all times by their chosen method. In addition to the surface water management mitigation measures, the contractor will need to ensure adequate protection of FWPM populations downstream of the proposed works. A temporary sediment barrier will be available on site to be deployed across the mouth of the downstream side channel containing FWPM in the event of significant sediment release (i.e. if a section of the bank face collapses) during installation of the bored piled wall.

5. Potential Environmental Impacts

5.1 Ecology

5.1.1 Baseline Data

The River Tay in this location is within the River Tay Special Area of Conservation (SAC), designated for otter (*Lutra, lutra*), Atlantic salmon (*Salmo salar*), sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*) and brook lamprey (*L. planeri*). In addition, oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea* is a qualifying habitat of the SAC but was not recorded within the Tay Crossing to Ballinluig area.

The River Tay in the erosion risk site provides mainly habitat for juvenile salmonids (Atlantic salmon and also brown/sea trout (*Salmo trutta*)), adult lamprey and European eel (*Anguilla anguilla*). Few substrates suitable for spawning salmonids were recorded and adult salmonids are likely to use the area as passage habitat. Little suitable habitat was recorded in the area for spawning or juvenile lamprey (Figure 3).

Freshwater pearl mussels (FWPM) (*Margaritifera margaritifera*) (124 adults and 2 juveniles) were recorded in a side channel immediately downstream (Ch.1300m to Ch.1600m) of the erosion risk site in June 2017 (Figure 3). A single FWPM was also recorded at the upstream extent of the proposed works. No other FWPM were recorded within the erosion risk site and while some suitable substrates are available, strong flows in this section make the main channel predominantly unsuitable for this species.

Two otter holts have been identified south of the works area (Ch.1500m and Ch.1580m). However, both are below the high water line and likely to be submerged at times. Monitoring has shown only occasional use (Figure 3).

The bank between the existing A9 carriageway and the River Tay consists of a thin strip of broadleaved woodland in this area (see Figure 1).

5.1.2 Consenting

Habitats Regulations Appraisal (HRA)

The Habitats Directive was transposed into British legislation via the Conservation (Natural Habitats &c.) Regulations 1994 (as amended), referred to as the Habitats Regulations. The Habitats

Regulations require that an Appropriate Assessment (AA) be undertaken by a Competent Authority where any plan or project not directly connected with or necessary to the management of the European/Ramsar site (i.e. a SAC or Special Protection Area (SPA), or candidate or potential SAC/SPA, or a Ramsar site), is likely to have a significant effect either individually or in combination with other plans or projects. HRA is the process, which includes an AA, whereby a Competent Authority comes to a conclusion as to whether there is no adverse effect on site integrity from a plan or project.

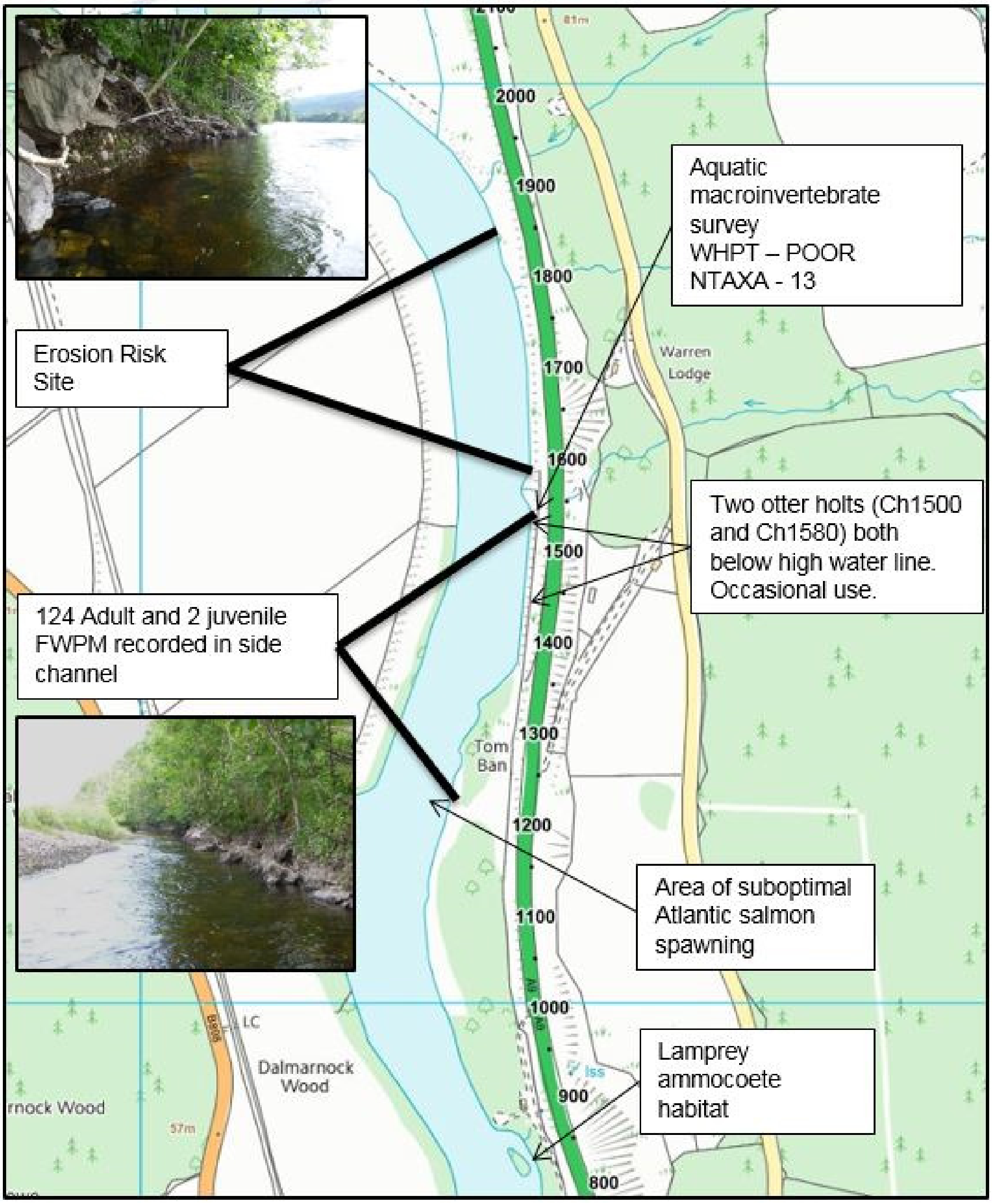


Figure 3. Ecological features in the vicinity of the erosion risk site

As mentioned previously, otter, Atlantic salmon, and brook, river and sea lamprey are the qualifying interests of the River Tay SAC. The following conservation objectives are applicable to these species within the site:

- To avoid deterioration of the habitats of the qualifying species (listed below) or significant disturbance to the qualifying species, thus ensuring that the integrity of the site is maintained and the site makes an appropriate contribution to achieving favourable conservation status for each of the qualifying features.
- To ensure for the qualifying species that the following are maintained in the long term:

- population of the species, including range of genetic types for salmon, as a viable component of the site;
- distribution of the species within site;
- distribution and extent of habitats supporting the species;
- structure, function and supporting processes of habitats supporting the species; and
- no significant disturbance of the species.

Likely impacts, principally noise/vibration and pollution sediment release and mitigation for these impacts, are described in Section 5.1.3 below.

Environmental Statement

The Environmental Statement considers all of the potential environmental impacts of the proposed works and is not restricted to the SAC's qualifying interests. In terms of ecology, the main concern of relevance to the erosion site that is not covered in the HRA is FWPM. FWPM are listed as Critically Endangered in Europe on the IUCN Red List (Moorkens, 2011) and are protected under Schedule 5 of the Wildlife and Countryside Act 1981, making it an offence to intentionally or recklessly:

- kill, injure or take a wild animal;
- damage, destroy or obstruct access to any structure or place which such an animal uses for shelter or protection; or
- disturb such an animal when it is occupying a structure or place for shelter or protection.

FWPM are particularly sensitive to changes in water quality and therefore strict mitigation must be in place to prevent pollution or sediment release. In addition, FWPM rely on salmonid hosts for completion of their lifecycle and as such any activities which affect salmonids may indirectly affect FWPM.

European Protected Species Licences

Due to the status of otter as a European Protected Species and the proximity of the works to an otter holt (less than 30m), a European Protected Species Licence may be required. Consultation with SNH will determine whether this licence is required.

5.1.3 Likely Impacts and Mitigation

Noise, Vibration and Lighting

Noise, vibration and lighting during construction have the potential to disturb salmonids, lamprey species and European eel in the River Tay. Avoidance of the area subjected to noise, vibration and lighting may effectively result in habitat fragmentation, with migrating fish reluctant to pass the construction area to reach areas that they use upstream or downstream. At high levels, noise and vibration have the potential to cause injury to fish.

Noise, vibration and lighting also have the potential to disturb otter causing them to avoid the area. This could effectively result in habitat fragmentation if otter are reluctant to pass the works area to other habitats that they use, and disturbance also runs the risk of an offence being committed without appropriate mitigation and licensing.

Soft-start drilling/piling will be employed to encourage species to evacuate the area prior to the commencement of works. The use of bored piles rather than driven piles reduces the level of noise and vibration, and therefore reduces the impact on fish and otters.

As the area contains few substrates suitable for spawning and no in-stream works are required, seasonal restrictions to avoid the spawning and emergence period for salmonids and lamprey are not thought to be necessary at this location. However, no works would be conducted during night time.

This removes the requirement for lighting and avoids the periods during which fish and otter are most active, allowing them regular, undisturbed use of the habitat adjacent to the works. Underwater noise monitoring would be undertaken during drilling or piling activities at this location. If noise levels mid-channel are above 50dBht (Atlantic salmon) works would only continue with agreement from SNH.

Habitat Loss

Vegetation clearance will result in the temporary loss of a thin strip of woodland habitat between Ch.1600m and Ch.1900m, a small amount of which may fall within the SAC boundary. This woodland is not listed on the Ancient Woodland Inventory or on the Native Woodland Survey of Scotland. The habitat was either planted when this section of the existing A9 was constructed, or may have developed through natural regeneration. Riparian woodland provides lying-up opportunities for otter. However, this habitat is widespread along the River Tay and the loss of woodland in this area is not predicted to have a significant effect on otter. The loss of woodland will be replaced through landscape and ecological planting throughout the Tay Crossing to Ballinluig scheme.

Pollution/Sediment Release

The release of sediments or pollution during construction has the potential to affect water quality in the River Tay. Significant pollution or sediment release could result in mortality of fish species or changes in habitat use, due to habitats becoming unsuitable.

In addition, any changes in water quality and sediment load may negatively affect FWPM. This species is critically endangered and particularly sensitive to changes in water quality. FWPM have been recorded immediately downstream of the works and are susceptible to smothering and mortality in the event of sediment release or pollution.

Pollution has the potential to affect otter both directly and indirectly through effects on prey species – fish – as described above.

Mitigation in the form of construction drainage preventing any run-off entering the River Tay and silt fencing around the works area would reduce the potential for any impacts from sediment laden run-off. Adherence to best practice guidance including, but not limited to, *Guidance for Pollution Prevention (GPP) 5: works and maintenance in or near water* (SEPA, 2017) and *Engineering in the Water Environment Good Practice Guide: Temporary construction methods* (SEPA, 2009) would further reduce the potential for impacts from sediment release and pollution. Further details of measures to protect water quality are given in Section 4.2.

A temporary sediment barrier will be available on site to be deployed across the mouth of the downstream side channel containing FWPM in the event of significant sediment release (i.e. if a section of bank face collapses).

If a pile bore support fluid is utilised, a water-soluble and biodegradable polymer, would be used during boring (see Section 4 for details). This fluid would be used in a recirculating system and would not be pressurised, therefore reducing the risk of the fluid seeping through the bank substrates. In addition to the pollution mitigation above, this method of use means that neither impacts on fish nor FWPM, or indirect impacts on otter are predicted from use of this biodegradable polymer material.

5.1.4 Ecology Summary

All of the qualifying species of the River Tay SAC, in addition to brown/sea trout, European eel and FWPM are present in the vicinity of and potentially affected by the proposed works. However, with the implementation of the mitigation detailed above it is predicted that there will be no significant residual impacts on these species and no adverse effect on the integrity of the River Tay SAC due to works at the erosion site. These works and their assessment of potential impacts would be included in the ES and HRA.

5.2 Landscape

5.2.1 Baseline

The proposed erosion protection works would be located within the River Tay (Dunkeld) National Scenic Area (NSA) which is characterised by natural and semi-natural scenery and cultural influences, where the highland features of rivers, straths and haughlands are balanced with farmland, settlements and managed woodland over hills and across policies and designed landscapes. 'Characterful rivers' (The Tay and the Braan) are included amongst the nine Special Qualities of the NSA (The Special Qualities of the National Scenic Areas. Scottish Natural Heritage Commissioned Report No.374 (2010)). For the majority of the length of the proposed contiguous bored pile wall, the existing bank slopes down to the water level of the river and comprises a mix of scrub and riparian woodland, which has over time become established on the original embankment constructed at the time of the existing A9. North of Ch.1800m, where the land strip between the A9 and the River Tay becomes wider, the scrub and woodland on the original embankment gradually peters out along a more level area next to the river, to become scrubby grassland. There is also a small area of wider wooded embankment at Ch.1600m.

5.2.2 Construction

The key landscape and visual impacts that would occur during construction would arise from:

- the ongoing presence of construction machinery;
- site clearance (including tree and scrub removal), excavation and regrading;
- increased visibility of traffic on the A9 due to vegetation clearance; and
- potential visibility of the restraint system (e.g. anchors), pile wall and rock revetment/road embankment during construction.

These would have localised impacts on landscape elements and character within the NSA, and visual impacts on people at the following receptor locations, from which there are views across the strath floor and the River Tay towards the existing A9, filtered through the riparian scrub and woodland:

- the cluster of properties at Dalmarnock Farm;
- the B898/NCR 77; and
- the Highland Mainline Railway.

It is assumed that much of the existing riverside vegetation would be lost during construction.

5.2.3 Operation

The following impacts would remain during the operational phase:

- loss of existing well-established riverside scrub and woodland;
- the engineered appearance of the new rock revetment, pile wall and capping beam; and
- increased visibility of traffic on the A9.

Once the proposed scheme becomes operational, some natural regeneration may gradually occur along the riverbank. However, as a worst-case scenario the current bank erosion is anticipated to continue and lead to washing away of the original A9 embankment and existing vegetation next to the river, exposing the piled retaining wall and capping beam above the waterline. The c.300m long section of rock revetment will be the most prominent and widely visible element of the proposed erosion control works. Its prominence would be further increased by the loss of existing riverbank vegetation. Given the large size of the rocks (circa 900mm diameter) making up the revetment, and the interstices between them, it is unlikely that organic material would naturally accumulate to allow natural establishment of vegetation. Therefore, although some screening may be provided by remaining/regenerated riverside vegetation, the revetment would remain visually prominent.

5.2.4 Mitigation Options

Where possible, the protection and retention of scrub and woodland next to the River Tay should be a considered throughout the detailed design and construction, especially in the two areas where the land widens slightly.

Consideration should be given to establishment of vegetation on the revetment, for example through grading down the rock size towards the surface of the revetment to allow soil to be added and seeded/vegetated, using coir matting/bags or other soil retention measures as necessary.

Mitigation of the appearance of any exposed piling by appropriate facing would be difficult to achieve (due to working in/above water issues).

The most effective mitigation measures along the riverbank (which would also assist greatly in integration of the pile cap and rock revetment over time) would depend upon the possibility of stabilising the existing riverside embankment and its graded tie-in with the lower edge of the piling cap. A stable rock substrate covered by soiled/seeded matting would allow much quicker establishment of vegetation which would reduce adverse landscape and visual impacts and avoid exposure of the piling wall along the river's edge.

5.3 Water Environment

5.3.1 Water Quality

Construction

The construction of the engineered solution has the potential to impact the water quality via the following processes:

- Slippage of the bank toe into the channel;
- Run-off from the exposed earth banks entering the channel;
- Pollution from machinery or engineering works.

It is considered that the risk of water quality being affected by any of these occurring can be mitigated by adoption of the proposals outlined in Section 4 and 5.1.3. Standard construction mitigation measures proposed will be included within the Environmental Statement and presented in Appendix C.

Operation (and exposure)

It is considered that the sediment inputs from bank erosion and exposure pose a limited risk to the water environment as erosion of the bank will occur over a relatively long period. The eroding material is unknown but likely to be formed of local excavation material. The processes of failure are discussed in the subsequent geomorphology section.

5.3.2 Geomorphology

The proposed approach has been chosen as it allows for natural processes to continue in the reach until the point where the wall is exposed and the embankment and road is protected from further erosion and potential instability and failure. The bored pile wall has been set back from the bank toe and should have no impact on hydraulics unless it becomes exposed. It is anticipated that river bank erosion processes have the potential to expose sections of the wall during the design life of the proposed scheme.

There is the potential for the bored pile wall to become exposed through further bank erosion. Exposure of the wall is likely to be a gradual process and may be localised initially but propagate out from the weaker sections of the bank. It is anticipated that this process would take around 20-60 years based on current migration rates and there are considerable uncertainties in the process and timescales of exposure with potential for acceleration and large flow events causing more rapid erosion.

Should there be complete erosion the area this would release a sediment volume of approximately 3,000 - 4.000m^3 with a proportion of the larger granular bank materials remaining in situ. This volume is relatively insignificant over the likely period of time it will take to expose the wall and would be considered to be natural process.

It is therefore concluded that the impact on fluvial geomorphology is considered to be low as natural process is maintained for as long as possible; adjustment is likely to be slow and event driven.

5.3.3 Monitoring

Prior to commencing construction of the proposed scheme, a monitoring programme is recommended due to the proximity of the existing A9 to the river channel. A monitoring programme should consist of:

- Collection of a detailed baseline of the existing bank condition and position including a photographic record, site notes, further bathymetry data, detailed geomorphological survey of the study reach.
- Annual inspections of the river bank by a geomorphologist and a geotechnical engineer, with additional surveys conducted following high flow events.
- Estimates of rates of bank erosion from the present to the commencement of construction activities. This should be in the form of:
    - fixed point photography along with field observations and a record of flow conditions at the time of survey; and
    - annual bathymetric survey data and additional surveys following high flow events.
- During each survey, records should be taken of the following:
    - weather conditions both on the day and a summary of weather conditions leading up to the survey including any notable precipitation events higher up in the catchment, including any periods of snowmelt;
    - data on flow levels at the time of the survey;
    - when surveying following a high flow event, a record of the maximum flood level should be recorded along with other relevant flow data and notes on the extent of flooding/whether flows were retained within bank; and
    - detailed description of the bank along with fixed-point photography as listed above.

Analyses of data from a monitoring programme should then be used to inform the detailed design of bank stabilisation works and the length of bank requiring protection.

5.3.4 Flooding

Risk during construction

The monthly probability of the river exceeding threshold flood levels is considered based on available flow records.

To provide a seasonal perspective upon the likelihood of river levels reaching or exceeding a certain flood level at the Dowally site the following approach was used. The available 15-minute flow data from the SEPA Tay at Caputh gauging station (catchment area 3,210 km^2) was transposed upstream to Dowally (catchment area 2,954 km^2). Since the issue relates to flood events the transposition was based upon the ratio of Flood Estimation Handbook (FEH) catchment descriptor estimates of Q_{MED}. Twenty-five years (1 January 1991 to 31 December 2015) of continuous 15-minute flow data was available and was used in the analysis.

Independent events were classified as having at least 24 hours separating the falling limb of the previous event from that of the following event at the threshold being investigated. This prevents double counting of events where small rises and falls in the hydrograph close to the threshold value can suggest numerous events when in fact they are all related to a single flood. It was considered that

24 hours was appropriate since: i) it equates to the design length of the Tay flood hydrograph in these reaches, ii) large scale Atlantic depressions that tend to trigger individual floods on the Tay are typically separated by at least a day, and iii) site work patterns will tend to assess the river level on a daily basis.

The number of flood events equalling or exceeding the threshold value were counted for each month in the record. This enabled the probability of experiencing a certain number of floods calculated for each month of the year. The monthly probability of encountering at least one flood event for flow values of 630 m3/s and 710 m^3/s flood events was highest between August and March.

Limitations

The analysis only provides the probability of experiencing a flood greater or equal to a certain threshold. It gives no indication of the duration of time that that flow is exceeded. It also gives no indication of how much the threshold is likely to be exceeded in each month. The dataset used is reasonably long (25 years); however, it does not enable a precisely accurate probability to be calculated since it is only a finite proportion of the true population. For example, although the analysis of the 25 years suggests that no floods exceeding the thresholds occurred in the month of June, it is not true to say that there is no possibility that such a flood could happen. There does remain a chance (albeit a very small chance) of a June flood occurring; and had there been an infinitely long record then this event would almost certainly be present. The given probabilities should therefore be interpreted as indicative, but they do not guarantee an event could not occur in the months where during the last 25 years there has been none.

Operational impacts on flood risk

The bank profile post-construction would change and has the potential to impact on flood risk. The change in geometry of the bank will slightly increase the cross-sectional area above the Q_{MED} level up to the 0.5%AEP (200-year) plus CC event stage level. The Q_{MED} level corresponds with bank-full conditions and the river is beginning to expand into the floodplain. Based on the slight increase in overall floodplain volume it is considered that there would be no change in local or downstream flood risk from the engineering works during the operational phase.

6. Risk

An assessment has been undertaken to estimate the rate and extent of erosion; however, this has not been based on long term monitoring of the bank and river bed therefore a risk remains that the rate or erosion differs from the assessment. In order to reduce the uncertainty on erosion rates, an ongoing monitoring regime will be undertaken to confirm the required extent of the proposed solution.

In addition, the development of the proposed approach of constructing a contiguous bored pile retaining wall solution is based on limited information on the ground conditions, therefore assumptions on ground conditions have been made from the information available to allow this approach to be progressed. In the coming months, additional ground investigations will be undertaken which will seek to further determine the existing ground conditions in the vicinity of the erosion area prior to construction.

Although a conservative approach has been undertaken to progress this proposal, there is a risk that the ground conditions and rate of erosion differ significantly from that which is currently assumed that may lead to necessitate a change to the outline approach proposed in this note.

This document presents possible approaches and the preferred solution for discussion with SNH. Although it is currently considered that there would be no adverse effect on site integrity of the River Tay SAC, this document will inform the consenting process in relation to the HRA through dialogue with SNH.

7. Summary

The assessment undertaken to date, has identified that the bank erosion presents a considerable risk to the existing and proposed A9 alignment, specifically between approximate Ch.1600m and Ch.1900m, and that a solution is required to mitigate this risk.

The preferred approach of constructing a contiguous bored pile wall requires significant works to the river bank and careful consideration of the construction methodology has avoided the need to undertake works within the River Tay. However, works would be required within the River Tay SAC boundary and terrestrial SAC habitat would be lost.

There are environmental impacts associated with the proposed approach; however, these are relatively minor when compared against other potential options which include works within the channel of the River Tay. Nevertheless, these impacts will require specific mitigation as discussed within the note to reduce the effect of the proposed works on the environment.

It is proposed that further monitoring is undertaken in the coming years up to construction to determine whether the outline approach put forward in this note is appropriate in terms of dealing with the risk posed by bank erosion.

8. References

Historical maps:

- Perthshire 05000, 1:10,560 (1867).
- Perthshire 06100, 1:10,560 (1867).
- Perthshire 050SE, 1:10,560 (1900-1901).
- Perthshire 061NE, 1:10,560 (1900-1901).
- Ordnance Survey Plan, NO04NW, 1:10,000 (1977, 2006 & 2012).
- Perthshire 050_16, 1:2,500 (1867, 1898 & 1900).
- Perthshire 061_04, 1:2,500 (1867, 1898 & 1900).
- Ordnance Survey Plan, NO0045, 1:2,500 (1977 & 1995).

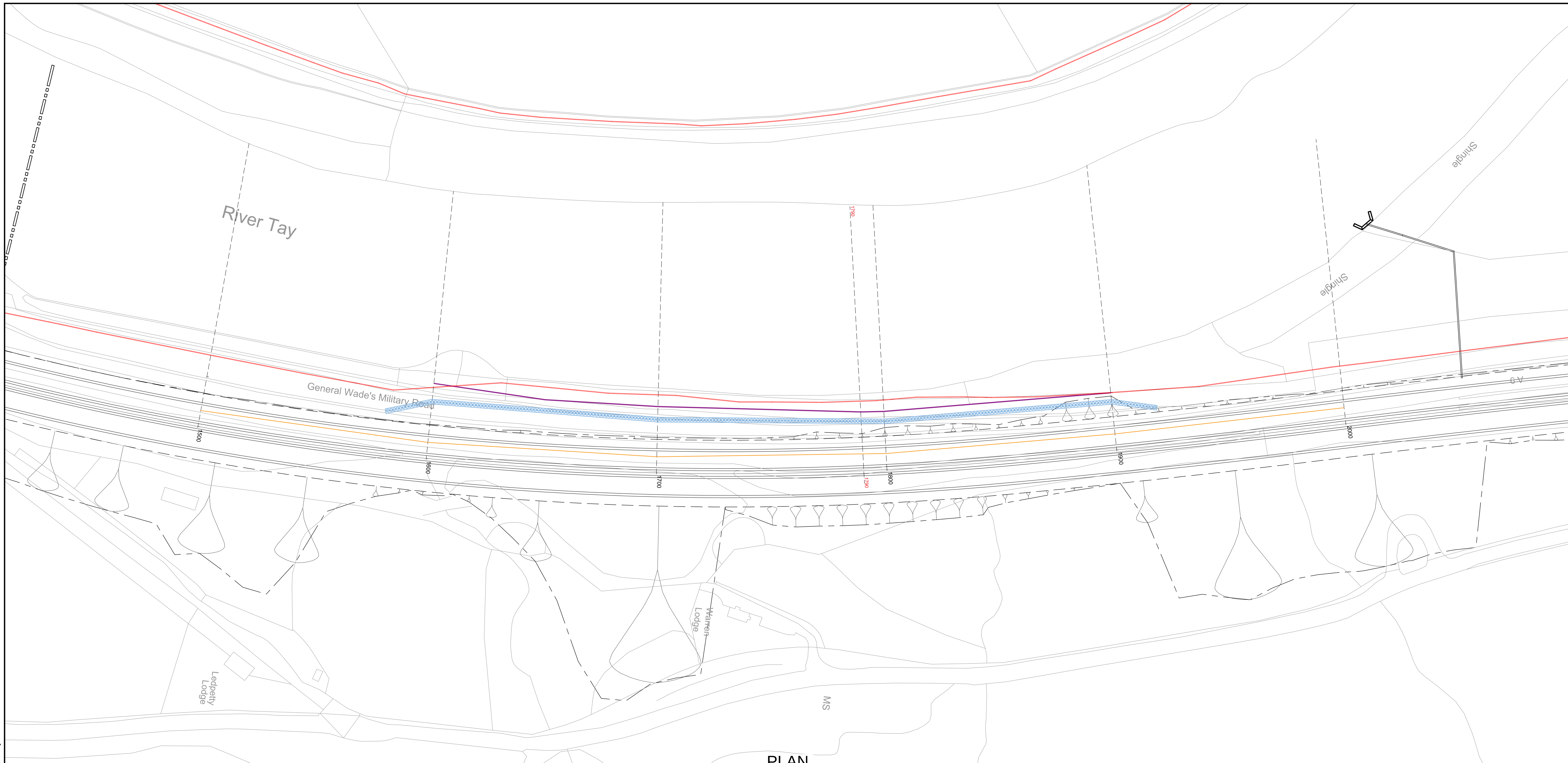
Moorkens, E. (2011). *Margaritifera margaritifera*. The IUCN Red List of Threatened Species 2011: e.T12799A3382660. Downloaded on 12 February 2018. Available online at http://www.iucnredlist.org/details/12799/1.

National Library of Scotland, *A9 Highland Highway*, documentary film (1982).
Available at: http://movingimage.nls.uk/film/1962

SEPA (2009). Engineering in the Water Environment Good Practice Guide: Temporary construction methods. Available online at https://www.sepa.org.uk/media/150997/wat_sg_29.pdf.

SEPA (2017). Guidance for Pollution Prevention. Works and maintenance in or near water: GPP 5. Available online at http://www.netregs.org.uk/media/1418/gpp-5-works-and-maintenance-in-or-near-water.pdf?utm_source=website&utm_medium=social&utm_campaign=GPP5%2027112017.

Appendix A Drawing: A9P03-JAC-HGT-A_ML016_RW-DR-GE-0001

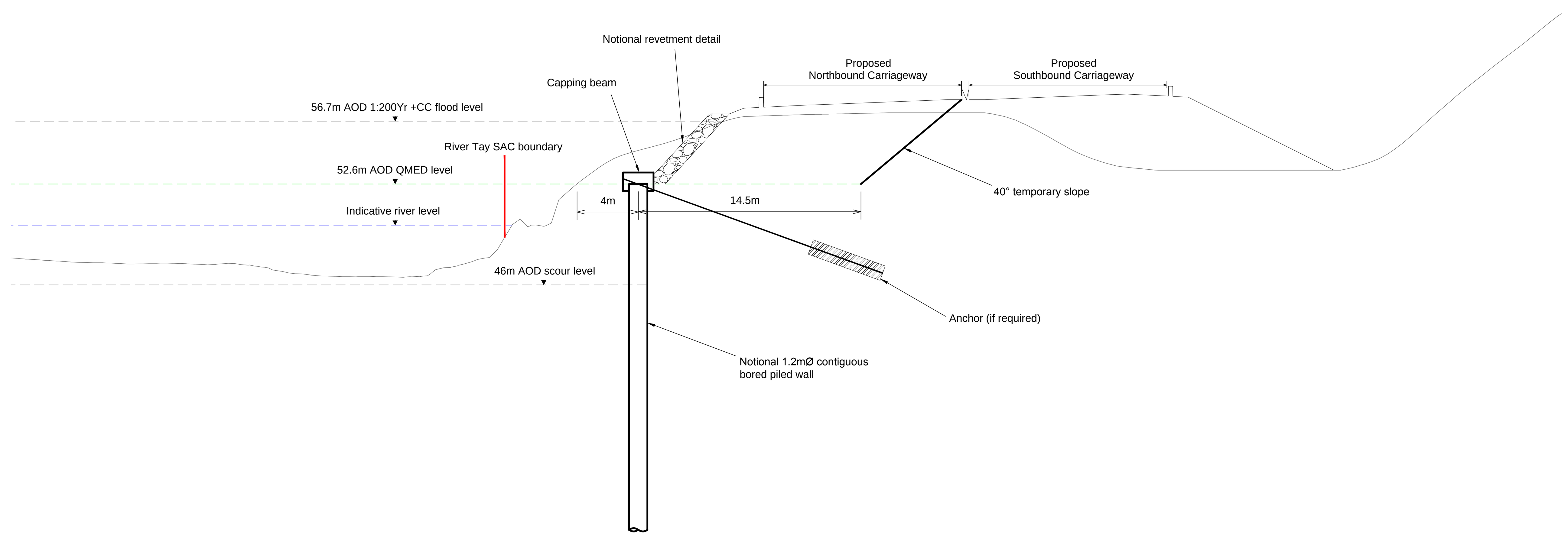


Reproduced by permission of Ordnance Survey on behalf of HMSO.

Ordnance Survey Licence number 100046668.

PLAN

Scale 1:1000



SECTION
Chainage 1790

Scale 1:250

Legend:

- Natural earthwork slope (1:2 or shallower)
- Graded earthwork slope between verges
- Drainage outfall
- Proposed retaining wall structure
- QMED level
- Proposed toe of temporary cut slope
- River Tay SAC boundary

Notes:

1. This drawing is a preliminary sketch for an outline approach to mitigate the risk of river erosion to the proposed A9 alignment. It does not represent an engineering detail for a proposed solution.
2. This drawing should be read in conjunction with the technical note titled *An outline approach to mitigate erosion risk* .
3. The QMED level is 52.6m AOD.
4. The centre-line of the proposed wall has been offset at least 4m from QMED level on the bank.
5. The proposal allows for at least 14m of working space between the centre-line of the wall and the toe of the temporary slope.
6. It is proposed that the temporary slope be formed at 40°.
7. The proposed revetment detail may require rock armour of at least Dn50=0.63m, Wn50=650kg.
8. The critical section is considered to be CH.1790.

P1	Feb 2018	For information	CSS	MDS	FNM	
Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd

JACOBS
95 Bothwell St, Glasgow, G2 7HX
Tel:+44(0)141 243 8000 Fax:+44(0)141 226 3109
www.jacobs.com

Client

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

Project

A9 DUALLING
PERTH TO INVERNESS
Tay Crossing to Ballinluig

Drawing title

SKETCH FOR PROPOSED BORED PILED RETAINING WALL (LAYOUT AND SECTIONS)

Drawing status

FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE
Jacobs No.	B2140003	
Drawing number	A9P03-JAC-HGT-X_ML016_RW-DR-GE-0001	Rev P1

File: C:\Users\sullivmd\appdata\local\temp\AcPublish_8180\A9P03-JAC-HGT-A_ML016_RW-DR-GE-0001.dwg Date: Feb 26, 2018 - 10:02am Plotted by: sullivmd

[Page intentionally left blank]

Appendix B Erosion risk assessment

Based on the assessments undertaken, it is evident that there is the potential for continued erosion leading to embankment instability within the design life of the proposed scheme. The following assessment sets out the likelihood of erosion and the level of severity to the road infrastructure and gives a risk rating. The following design criteria have been used in the risk classification:

- DMRB requires that bridge elements located on the floodplain are designed as if the bridge element is in the channel, if there is a likelihood that the channel will shift its location into the floodplain over the life of the bridge. This approach is applicable to other road features such as a road embankment in this case.
- DMRB provides no further guidance to determine the likelihood of channel shift, which will depend on many factors including the rate of bank erosion, channel shape/alignment, flood magnitude, type of soil and vegetation coverage.
- The Rail Safety and Standards Board's *Safe Management of Railway Structures – Flooding and Scour Risk* (July 2005) refers to an assessment method presented in HR Wallingford's report *Hydraulic Aspects of Bridges – Assessment of the Risk of Scour* (1993) (EX2502), which categorises features located on the floodplain. Features 'set well back' are considered to be at lower scour risk and EX2502 defines 'set well back' from the river as elements located further than a distance equivalent to 20% of the channel width from the river bank.

The probability of erosion is simply based on position within or close to the channel and proximity to the bank based on channel width. Being 'set well back' from the river does not necessarily mean that scour risk is negated and consideration should be given to 'local' scour at the road embankment. Further assessment will be required in this respect but the use of vegetation and geotextiles may be sufficient to offer protection to the road embankment surface.

The risk of road failure due to fluvial scour, taking into consideration the likelihood of fluvial erosion as well as the resultant severity level to the road, is shown below in Table A1.

Based on the criteria detailed above, the entire reach of interest between Ch.1900m and Ch.1400m has less than the prescribed offset and the likelihood of fluvial erosion is possible. On the basis of the road type, the entire reach would be considered to be at 'high to very high' risk of failure due to fluvial erosion.

It is considered that the risk of fluvial erosion diminishes south of Ch.1600m due to the depositional nature of the river bed and which is transferring energy towards the opposite bank, although there is potential for this to change should the river planform adjust in the future.

Table A1. Risk of road failure due to bank erosion processes.

Likelihood of bank erosion	**Improbable** *i.e. Feature at edge of floodplain*	**Low** Accept but monitor erosion.	**Medium** DMRB design as on floodplain and monitor erosion.	**Medium** DMRB design as on floodplain and monitor.	**High** DMRB design as though in river channel and monitor erosion.
	Possible *i.e. Feature offset <20% river width*	**Low** Accept but monitor erosion.	**Medium** DMRB design as on floodplain and monitor erosion.	**High** DMRB design as though in river channel and monitor erosion.	**Very High** DMRB design as though in river channel and monitor erosion.
	Probable *Feature is within river*	**Medium** DMRB design as on floodplain and monitor erosion.	**High** DMRB design as though in river channel and monitor erosion.	**High** DMRB design as though in river channel and monitor erosion.	**Very High** DMRB design as though in river and monitor erosion.
Type of Road (Importance Factor, V[3])		*B/other class road* *(0.7)*	*A/B class road* *(0.8)*	*Motorway/A road* *(0.9)*	*Motorway/A road* *(1.0)*
		Acceptable	**Tolerable**	**Undesirable**	**Intolerable**
		Level of Severity to the Road			

[3] Road Importance Factors obtained from DMRB Vol 3 Sect 4 Part 21 BD 97/12

Appendix C Standard construction mitigation measures

<table>
<tr><th>Mitigation Item</th><th>Description</th></tr>
<tr><td colspan="2">Standard Construction Mitigation</td></tr>
<tr><td>SMC-W3</td><td>The Contractor will implement appropriate controls for construction site runoff and sedimentation including:
• avoiding unnecessary stockpiling of materials and exposure of bare surfaces, limiting topsoil stripping and phasing stripping to areas where bulk earthworks are immediately programmed;
• installation of temporary drainage systems/SuDS (or equivalent) including pre-earthworks drainage;
• pre-earthworks drainage/SuDS with appropriate outfalls to be in place prior to any earthworks activities;
• treatment facilities to be scheduled prior to any works which may generate site run-off and sedimentation, to allow settlement and treatment of any pollutants contained in site runoff and to control the rate of flow before water is discharged into a receiving watercourse;
• the adoption of silt fences, check dams, settlement lagoons, soakaways and other sediment trap structures as appropriate;
• the maintenance and regrading of haulage route surfaces where issues are encountered with the breakdown of the existing surface and generation of fine sediment;
• provision of wheel washes at appropriate locations (in terms of proposed construction activities) and >10m from water features;
• protecting soil stockpiles using bunds, silt fencing and peripheral cut-off ditches, and location of stockpiles at distances of >10m; and
• restoration of bare surfaces (seeding and planting) throughout the construction period as soon as possible after the work has been completed.</td></tr>
<tr><td>SMC-W4</td><td>In relation to in-channel working, the Contractor will adhere to PPGs (SEPA, 2006-2017) and other good practice guidance (Table 11.1), and implement appropriate measures which will include, but may not be limited to:
• undertaking in-channel works during low flow periods (i.e. when flows are at or below the mean average) as far as reasonably practicable to reduce the potential for sediment release and scour;
• no in-channel working during the salmonid spawning seasons, unless permitted within any CAR license;
• minimise the length of channel disturbed and size of working corridor, with the use of silt fences or bunds where appropriate to prevent sediment being washed into the water feature;
• limit the removal of vegetation from the riparian corridor, and retaining vegetated buffer zone wherever reasonably practicable; and
• limit the amount of tracking adjacent to watercourses and avoid creation of new flow paths between exposed areas and new or existing channels.</td></tr>
<tr><td>SMC-W6</td><td>In relation to refuelling and storage of fuels the Contractor will adhere to GPP/PPGs (SEPA, 2006-2017) and other good practice guidance (Table 11.1), and implement appropriate measures which will include, but may not be limited to:
• only designated trained and competent operatives will be authorised to refuel plant;
• refuelling will be undertaken at designated refuelling areas (e.g. on hardstanding, with spill kits available, and >10m from water features) where practicable;
• appropriate measures will be adopted to avoid spillages (refer to Mitigation Item SMC-W7); and
• compliance with the Pollution Incident Control Plan (refer to Mitigation Item SMC-S1).</td></tr>
<tr><td>SMC-W7</td><td>In relation to oil/fuel leaks and spillages, the Contractor will adhere to GPP/PPGs (SEPA, 2006-2017) and other good practice guidance (Table 11.1), and implement appropriate measures which will include, but may not be limited to:
• stationary plant will be fitted with drip trays and emptied regularly;
• plant machinery will be regularly inspected for leaks with maintenance as required;
• spillage kits will be stored at key locations on-site and detailed within the Construction Environmental Management Plan (CEMP) (refer to Mitigation Item SMC-S1); and
• construction activities will comply with the Pollution Incident Control Plan (refer to Mitigation Item SMC-S1).</td></tr>
<tr><td>SMC-W8</td><td>In relation to chemical storage, handling and reuse the Contractor will adhere to GPP/PPGs (SEPA, 2006-2017) and other good practice guidance (Table 11.1), and implement appropriate measures which will include, but may not be limited to:
• chemical, fuel and oil storage will be undertaken within a site compound, which will be located on stable ground at a low risk of flooding and >10m from any watercourse;
• chemical, fuel and oil stores will be locked and sited on an impervious base within a secured bund with 110% of the storage capacity; and
• pesticides, including herbicides, will only be used if there are no alternative practicable measures, and will be used in accordance with CAR requirements, the manufacturer’s instructions and application rates.</td></tr>
</table>

Mitigation Item	Description
SMC-W9	In relation to concrete, cement and grout the Contractor will adhere to GPP/PPGs (SEPA, 2006-2017) and other good practice guidance (Table 11.1), and implement appropriate measures which will include, but may not be limited to: • concrete mixing and washing areas will be: ➢ be located more than 10m from any water bodies; ➢ have settlement and re-circulation systems for water reuse; and ➢ have a contained area for washing out and cleaning of concrete batching plant or ready-mix lorries. • wash-water will not be discharged to the water environment and will be disposed of appropriately either to the foul sewer (with permission from Scottish Water), or through containment and disposal to an authorised site; • where concrete pouring is required within a channel, a dry working area will be created; • where concrete pouring is required within 10m of a water feature or over a water feature, appropriate protection will be put in place to prevent spills entering the channel (e.g. isolation of working area, protective sheeting); and • quick setting products (cement, concrete and grout) will be used for structures that are in or near to watercourses.
SMC-W10	Sewage from site facilities will be either disposed appropriately either to foul sewer (with the permission of Scottish Water) or appropriate treatment and discharge agreed with SEPA in advance of construction in accordance with 'PPG04 Treatment and Disposal of Sewage' (SEPA, 2003 – 2013).
SMC-W12	For works within areas identified as potentially containing contaminated land and sediment the Contractor will reduce the risk of surface water pollution to an acceptably low level through: • further site investigation to determine the level of contamination prior to construction beginning; • the installation of temporary treatment facilities to enable removal of pollutants from surface waters; and • adoption of mitigation measures relating to contaminated land as outlined in Chapter 10 (Geology, Soils, Contaminated Land and Groundwater).