# Appendix A11.5: Fluvial Geomorphology

## 1 Introduction

### 1.1 General Background

1.1.1 This technical appendix informs Chapter 11 (Road Drainage and the Water Environment) of the 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 and those that were scoped out of the assessment are not included here; these are discussed in Appendix A11.1 (Baseline Conditions) and Appendix A11.7 (Impact Assessment). Three other water features have also been scoped out of the appendix due to the distance from the scheme and the lack of pathways to the receptors with respect to potential impacts occurring on the fluvial geomorphology. These include WF180, WF181, WF182, WF183 and WF184.

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 small ephemeral field drains to larger 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 physico-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).

### 1.2 What is Fluvial Geomorphology?

1.2.1 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.

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

1.2.3 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.

1.2.4 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.

1.2.5 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.

1.2.6 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.

## 1.3 Assessment Aims

1.3.1 The specific objectives of this assessment 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.

1.3.2 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.

1.3.3 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.

## 1.4 Study Area

1.4.1 The study area for the fluvial geomorphology assessment included a 500m length 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

## 2.1 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 Appraisal 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., 2003); and
- Supporting Guidance (WAT-SG-21) Environmental Standards for River Morphology (SEPA, 2012a).

2.1.5 Section 11.2 in 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.

## 2.2 Additional Assessments

2.2.1 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 by geomorphologists on potential erosion risk at locations along the River Garry and River Tummel. 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).

2.2.2 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 was given (if deemed necessary). For those still considered high risk (Risk Rating 7-9), mitigation proposals were developed ranging from monitoring to soft engineering and hard engineering.

2.2.3 An additional geomorphological baseline and impact assessment has also been undertaken to inform the Habitat Regulations Appraisal. This focused on the potential impacts of structures, outfalls and discharges to River Tay Special Area of Conservation (SAC) habitats and species, 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).

## 2.3 Limitations to Assessment

2.3.1 Baseline conditions reported in this study are informed by site walkover information, gathered at specified time periods, and the coinciding water levels. Although this data allows assessment of in-channel features and provides 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.

2.3.2 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 overland flow to water features.

2.3.3 Some surveys were undertaken prior to the flood events of winter 2015-2016, and therefore changes may have occurred on the more dynamic rivers since the surveys. However, updates on the condition of watercourses have been acquired from other survey teams who have been out on site throughout the preparation of the ES, such as the Ecology teams. For some of their site visits, we have specifically requested that they record information on channel bed and banks and report back any evidence of erosion, including taking a photographic record.

2.3.4 This assessment has been based on the DMRB guidance (Volume 11, Section 3, Part 10 (HD 45/09): Road Drainage and the Water Environment) (Highways Agency et al, 2009), standard good practice and guidance notes from SEPA (see SEPA, 2008a; 2008b; 2010; and 2012a), supported and further developed using professional judgement.

2.3.5 The mathematical 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 Garry (WF100) and River Tummel (WF70), 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.

2.3.6 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 a survey was proportional to the size of the water feature.

2.3.7 It is not possible to fully assess the potential impacts of construction before the construction programme of works details 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 on best available data at the time of writing.

# 3 Baseline

## 3.1 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).

## 3.2 Water Feature Descriptions

**WF60**

3.2.1 WF60 originates approximately 450m upstream of the existing A9. At the upstream extent, the channel flows adjacent to the road through a residential area and is then culverted under a local access road. The water feature then runs in an open channel through the wooded area towards General Wade's Military Road. This reach had a sinuous planform and a semi-continuous riparian corridor. The substrate consisted of gravels and cobbles and there were some depositional features within the channel.

3.2.2 The channel is culverted under General Wade's Military Road and emerges again to flow parallel to the north east of the existing A9. The water feature then turns 90 degrees to flow towards the A9, adjacent to residential properties. At this location, the channel had a sinuous planform, and the substrate consisted of gravel and cobbles. The channel is culverted again under the existing A9 and the Highland Main Line Railway.

3.2.3 Historical map analysis shows that there is no significant change in the channel planform upstream of the existing A9 since 1867 (National Library of Scotland, 2016). The maps do show, however, that in 1978 (and maps pre-dating this) the water feature flows in open channel between the existing A9 and the confluence with the River Tummel.

**Photograph 1: View of WF60 upstream from General Wade's Military Road**

**Photograph 2: View of WF60 downstream from General Wade's Military Road**

**WF64**

3.2.4 WF64 originates approximately 2.8km upstream of the existing A9. The channel has its source in an upland landscape where the channel planform was sinuous. Further downstream, the channel flows through woodland and is joined by another channel from the south west, approximately 600m upstream of the existing A9. The channel then continues to flow through woodland and agricultural land until it reaches the existing A9, where it is culverted. Upstream of the A9, the channel had a naturally sinuous planform, and the substrate consisted of boulder, cobble and gravel. A step/pool sequence was observed within this length of channel.

3.2.5 Downstream of the existing A9 the channel continues a short distance through agricultural and residential land before it is culverted under a local access road, Foss Road. It then flows northeast, parallel to the existing A9 road, before having a sharp 90-degree bend through a caravan park towards its confluence with the River Tummel. Downstream of the existing A9, the channel planform was straight with some evidence of modification, particularly on the left bank. The channel had a semi-continuous riparian corridor.

3.2.6 Historical map analysis shows that from 1948 (and maps that pre-date this) the water feature appears to continue flowing north downstream of the existing A9 towards a mill pond, before discharging into the River Tummel. Upstream of the existing A9, some lateral migration can be seen between 1867 and 1948. From 1978 onwards, the channel appears to have less noticeable meander bends with a typically straighter planform (National Library of Scotland, 2016).

**Photograph 3: View of WF64 upstream immediately upstream of the existing A9.**

**Photograph 4: View of WF64 downstream of the existing A9 and local access road.**

### WF65

3.2.7 WF65 originates approximately 950m upstream of the existing A9. The channel has a sinuous planform and flows through woodland and agricultural land, in close proximity to a residential area. The upstream channel lies within a deep 'natural' v-shaped valley with a continuous vegetated riparian corridor. The channel has a sinuous planform with cobble and gravel substrate present. Large woody material was also observed. Immediately upstream and downstream of the existing A9, the channel is modified with an artificially straightened planform with some artificial bank and bed material observed. The channel is culverted under the existing A9 and again under Foss Road. WF64 eventually discharges into WF64 to the north of Foss Road.

3.2.8 Historical map analysis shows that there is no significant change in the channel planform throughout the length of the water feature since 1867 (National Library of Scotland, 2016).

**Photograph 5: View of WF65 downstream towards the existing A9 (stepped profile).**

**Photograph 6: View of WF65 at the western channel upstream of the existing A9.**

### WF66

3.2.9 WF66 originates approximately 750m upstream of the existing A9. The channel had a natural sinuous planform, flowing through a wooded v-shaped valley. The water feature flows through a pond before being culverted under a local access road upstream of the existing A9. The water feature then flows in an open channel for a short distance before being culverted again under the existing A9. Where open, the channel had a step/pool sequence with cobble and gravel substrate. Large woody material was also observed within the channel. In the immediate vicinity of the culvert under the existing A9, the channel was artificial, composed of reinforced bed and banks.

3.2.10 Downstream of the existing A9, the channel had a sinuous planform through a wooded area. It is culverted under several small access roads and then under Port-na-Craig Road before discharging into the River Tummel. The channel appeared to be modified with concrete embankments immediately downstream of the final culvert before its confluence with the River Tummel.

3.2.11 Historical map analysis shows that there is no significant change in the channel planform throughout the length of the water feature since 1867 (National Library of Scotland, 2016).

**Photograph 7: View of WF66 upstream away from existing A9 culvert (step/pool sequence visible).**

**Photograph 8: View of WF66 immediately upstream of the existing A9 (stepped profile).**

**WF68**

3.2.12 WF68 originates approximately 1.4km upstream of the existing A9. The channel has its source in a moorland landscape. The water feature then flows through woodland and grassland and is culverted several times under local access roads. The channel was observed to be natural with a sinuous planform, situated within a deep v-shaped valley with a diverse range of morphological features noted throughout the length walked. A step/pool sequence and boulder, cobble and gravel substrate was observed.

3.2.13 Downstream of the existing A9, the channel was modified with a uniform cross-section. A knickpoint was observed, located near to the confluence with Loch Faskally, where the concrete reinforcement was observed to be undermined.

3.2.14 Historical map analysis shows that at the upstream extent (north of the existing A9), the channel appeared to have a more meandering planform in maps from 1948 and earlier. Some reaches appear to have been straightened to follow field boundaries between 1867 and 1900 (National Library of Scotland, 2016).

**Photograph 9: View of WF68 looking upstream away from the existing A9.**

**Photograph 10: View of WF68 upstream towards existing A9 culvert.**

**WF69**

3.2.15 WF69 originates approximately 1.3km upstream of the existing A9. The channel has its source in an area of moorland. The water feature then flows through woodland and grassland and is culverted several times under local access roads. The water feature was sinuous with some step/pool sequences. The channel substrate was observed to consist of cobble and gravels. Erosion and deposition were evident; however, the channel primarily functioned as a sediment store. Upstream of the culvert under the existing A9, the channel was artificial and composed of a reinforced bed and banks.

3.2.16 Immediately upstream of the existing A9, an artificially straightened drain meets the water feature before going into a culvert under the existing A9. Within the existing A9 culvert, it is thought that an additional drain enters into the water feature before it discharges into Loch Faskally.

3.2.17 Historical map analysis shows that the artificially straightened branch of the channel has not changed since the first available map in 1867. However, in the sinuous branch, there has been some lateral migration resulting in movement of the channel planform (National Library of Scotland, 2016).

**Photograph 11: View of WF69 looking upstream away from the existing A9 and confluence with additional channels.**

**Photograph 12: View of WF69 immediately upstream of existing A9 culvert and confluence with additional channels (straightened planform).**

**WF74**

3.2.18 WF74 originates approximately 150m upstream of the existing A9. There are two branches of the channel that meet before going into a culvert under the existing A9 and the Highland Mainline Railway. The northern branch flows through plantation and was observed to be modified with a uniform cross-section and a straight planform. The channel substrate was composed of silt where large woody material was also noted.

3.2.19 The eastern branch was sinuous with a step/pool sequence and cobble and gravel substrate both upstream and downstream of the existing A9. The water feature flows through woodland and is culverted under several local access routes downstream of the A9 and B8019, before discharging into Loch Faskally. Channel incision was noted and the reach was operating as a sediment exchange (i.e. eroding and depositing).

3.2.20 Historical map analysis shows that there has been no significant change in the channel planform since 1989. The water feature is not visible on historical maps prior to this date (National Library of Scotland, 2016).

**Photograph 13: View of WF74 upstream and modified section.**

**Photograph 14: Upstream view of WF74 in Faskally Woods.**

**WF76 (Allt an Aghastair)**

3.2.21 Allt an Aghastair (WF76) originates approximately 1.6km upstream of the existing A9. The channel has its source in an area of forestry and is split into two channels that converge about 600m downstream of the source. The channel is sinuous and flows through woodland and plantation. It is culverted under several local access routes before reaching the existing A9.

3.2.22 Immediately upstream of the existing A9 the channel bed consisted of bedrock and cobbles, and, the channel was embanked on both sides. Downstream of the culverted section under the existing A9 and General Wade’s Military Road, the channel had a natural bedrock cascade with some silt substrate observed. Minimal flows were observed downstream of the existing A9 culvert, with moss growth on rocks in the channel. The riparian corridor was observed to be continuous on both banks. The water feature joins with WF74 and runs through woodland before discharging into Loch Faskally.

3.2.23 Historical map analysis shows that there have been minor changes to the channel planform through lateral migration of meanders since 1863, particularly upstream of the existing A9 (National Library of Scotland, 2016).

**Photograph 15: View of WF76 (Allt an Aghastair) downstream towards existing A9 culvert.**

**Photograph 16: Upstream view of WF76 immediately downstream of General Wade's Military Road culvert.**

**WF70 (River Tummel – Loch Faskally to River Tay)**

3.2.24 The River Tummel flows alongside the existing A9 between Loch Faskally and its confluence with the River Tay. The channel flows through several land use types, including woodland, grassland, agricultural fields and urban areas. The River Tummel flows through Loch Faskally reservoir, a hydropower dam and is crossed by several bridge structures.

3.2.25 Overall, the water feature has a wandering gravel bed planform down to the confluence with the River Tay. Immediately downstream of the dam at Pitlochry to the Tummel crossing, the river was straightened with some localised bank reinforcement. This reinforcement includes riprap, concrete and wooden boards.

3.2.26 The channel was observed to be approximately 40m wide in some locations, with a semi-continuous vegetated riparian corridor. The channel was observed to have varied, high-energy flow types, which led to a range of distinct morphological features. This included a pool/riffle sequence, large deposits, both vegetated and unvegetated point bars and side bars, and erosion of the banks. Large, shifting deposits in the form of bars are characteristic of this river. Bed substrate primarily consisted of coarse material, including large cobbles and gravels. The Tummel Shingle Islands SSSI, formed by extensive deposits, primarily consisted of cobble and coarse gravels. Due to a reduced disturbance regime as a result of the Pitlochry Dam and river regulation, these shingle islands have become well vegetated and more stabilised during the latter half of the twentieth century.

3.2.27 The bank erosion observed along the River Tummel was not considered to pose a risk to either the existing A9 infrastructure or the proposed scheme, thus the erosion risk sites were scoped out of further assessment.

3.2.28 The WFD hydromorphology status of the water feature is classified as moderate based on SEPA mapping (SEPA, 2016a). The river is a heavily modified water body due to Loch Faskally and Pitlochry Dam which are both used for hydropower generation.

3.2.29 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 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 1048 $m^3 s^{-1}$ and an estimated return period of 40 years (Parsons, 2000).

3.2.30 The dynamic nature of the River Tummel has created a diverse mosaic of fluvial morphological units resulting in high species and habitat diversity. Consequently, the River Tummel Shingle Island SSSI has been designated near Tomdachoille. In addition, the River Tummel forms part of the River Tay SAC. This reach of the River Tummel, at the downstream extent of the study area, is sensitive to changes in the fluvial conditions and processes operating within the channel.

**Photograph 17: Downstream view of WF70 (River Tummel) towards Tummel underbridge.**

**Photograph 18: View of WF70 (River Tummel) immediately downstream of Tummel underbridge.**

**WF75 (Loch Faskally)**

3.2.31 Loch Faskally is an online loch of the River Tummel. There is a natural riparian buffer, measuring over 50m wide, around the margins of the loch.

3.2.32 Along the shores of the loch, there are cobble beaches mixed with some sand. The substrate forming the rest of the marginal area of the loch was observed to also consist of cobble, sand and silt. Bank modifications were present in some locations. The surrounding land use includes plantation, woodland, grassland, and the urban area of Pitlochry. There are several structures associated with the loch including: a dam, power station, fish ladder and Clunie Underbridge.

3.2.33 The WFD hydromorphology status of the water feature is classified as moderate based on SEPA mapping (SEPA, 2016a). The loch is a heavily modified water body due to hydropower generation.

3.2.34 Loch Faskally was constructed between 1947 and 1950. Historical map analysis shows that prior to this, the River Tummel flowed through the centre of the loch footprint with a meandering planform. At this time the surrounding land use was primarily woodland (National Library of Scotland, 2016).

**Photograph 19: Downstream view of WF75 (Loch Faskally) from Clunie footbridge.**

**Photograph 20: Upstream view of WF75 (Loch Faskally) from Clunie footbridge.**

**WF100 (River Garry - Errochty Water Confluence to Loch Faskally)**

3.2.35 WF100 (River Garry from Errochty Water to Loch Faskally) is a naturally active meandering, predominantly single thread gravel and cobble bed river. Within the study area, the river flows through woodland, plantation and grassland. The River Garry is crossed by several bridges along its length.

3.2.36 River terraces were observed in the floodplain and the channel has steep valley sides. Throughout the length observed within the study area, large depositional features were present and are known to be characteristic of this river. The flows within the channel are regulated by upstream dams and as a result a defined low flow channel has formed controlled by shifting deposits. Bed substrate was typically observed to be coarse material, primarily cobbles.

3.2.37 Historical map analysis shows that the planform within the study area has remained consistent since 1867. It does show, however, that there has been active formation and loss of depositional features throughout the length of the water feature over time (National Library of Scotland, 2016).

3.2.38 The WFD hydromorphology status of the water feature is classified as moderate according to SEPA mapping (SEPA, 2016a). The river is a heavily modified water body due to hydropower generation.

## 3.3 Summary

3.3.1 Following the assessment of the baseline condition for each water feature, a sensitivity level has been assigned (based on the methodology set out in Section 11.2 (Approach and Methods) of Chapter 11 (Road Drainage and the Water Environment) of the ES. Table 3.1 below provides a summary of the medium, high and very high sensitivity water features.

**Table 3.1: Overview of fluvial geomorphology sensitivities of Medium and above**

| Water Feature ID | Summary | Sensitivity |
|---|---|---|
| 68, 70 (River Tummel – Loch Faskally to River Tay), 100 (River Garry – Errochty Water Confluence to Loch Faskally) | 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, despite river regulation and hydropower dam. Predominantly a dynamic water feature with a diverse range of fluvial processes that is highly vulnerable to change as a result of modification. | high |
| 60, 64, 65, 66, 69, 74, 76 (Allt an Aghastair), 75 (Loch Faskally) | Water feature sediment regime provides some habitat suitable for species sensitive to change in suspended sediment concentrations or turbidity. Water feature exhibiting some 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, bridge pier installation or culverting. The interruption of natural fluvial processes may have negative consequences upon 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.

## 4.2 General Impacts

4.2.1 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 with the floodplain.

**Operation**

- culverting (including culvert extensions);
- outfall structure and associated discharges;
- bridge structure;

- permanent realignment (or diversions); and
- changes to flow paths and catchment areas.

## 4.3 Site Specific Impacts

4.3.1 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 4.1 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 4.1: Specific impact assessment for construction and operation on fluvial geomorphology**

| Source of Impact | Construction impacts | Magnitude of Impact | Operation impacts | Magnitude of effect |
|---|---|---|---|---|
| WF60 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and works within the water feature. Potential for fine sediment to be transferred downstream to the River Tummel.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to construct culvert. | minor adverse | **Culvert extension**<br>Culvert extension removing earth bed and banks. However, the channel being removed is modified and is a small length of day lighted channel prior to a long culvert under agricultural land to the south of the existing A9. The water feature would be diverted downstream of the existing A9 via an open channel to the River Tummel and, therefore, there will be a slight improvement over the existing conditions. | minor adverse |
| WF64 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and in-channel works. Potential for sediment to be transferred to the River Tummel.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to construct culvert. | minor adverse | **Culvert extension**<br>The extended culvert would remove a length of natural bed and realignment of the main channel upstream and downstream of the carriageway. This would have a particular impact upstream where a natural boulder cascade would be removed. Realignment would remove existing dense riparian vegetation, including continuous lining of trees. Potential for natural channel adjustment post-construction both upstream and downstream as the watercourse establishes a new equilibrium.<br>**Re-alignments**<br>Realignment of pre-earthworks drainage adjacent to the existing A9 (east and west). Potential for change in flow and sediment processes. | moderate adverse |
| WF65 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and in-channel works in east and west branch of water feature.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to construct culvert. | minor adverse | **Culvert extension**<br>The western branch of the water feature is a drainage channel that was dry at the time of the survey. The extended culvert would lead to the removal of riparian vegetation and alter lateral connectivity with the floodplain and the other branch of the drain.<br>**New culvert**<br>The new culvert on the eastern branch of the water feature would require a new inlet, removing a length of modified channel. The channel gradient would be further slackened downstream, where the channel is heavily modified and artificial. | minor adverse |
| WF66 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and in-channel works and potential for this to be transferred to the River Tummel.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to construct culvert. | minor adverse | **New structures**<br>Channel is modified and man-made where the culvert inlet would be lowered; therefore, works are likely to have an insignificant impact. However, regrading upstream would remove a length of natural step-pool sequence and natural riparian vegetation. Potential for natural channel adjustment post construction both upstream and downstream as the watercourse establishes a new equilibrium. | moderate adverse |

| Source of Impact | Construction impacts | Magnitude of Impact | Operation impacts | Magnitude of effect |
|---|---|---|---|---|
| WF68 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and in-channel works. Potential for sediment to be transferred to the Loch Faskally. Potential for disturbance of man-made materials in the channel bed and for these to enter the water feature or Loch Faskally.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to construct culvert. Potential for altered flow processes during construction leading to changes in existing knickpoint. | minor adverse | **Culvert extension**<br>The extended culvert would be close to an existing knickpoint (area of instability) located downstream where the man-made reinforcement stops. Potential for natural channel adjustment post construction as the watercourse establishes a new equilibrium.<br>Culvert extension upstream would replace an existing track crossing making it wider. Removal of natural bed and banks and step/pool sequence. Potential for natural channel adjustment post construction downstream as the watercourse establishes a new equilibrium. | minor adverse |
| WF69 | **Release of suspended sediments**<br>Increase in fine sediment delivery due to runoff from bare earth surfaces, in-channel works and extensive earthworks to fill in water feature gorge. Potential for sediment to be transferred to Loch Faskally. | moderate adverse | **Culvert extension**<br>The culvert extension would remove a length of steeper channel with a step-pool sequence, natural bed and banks and vegetated riparian corridor. The extension would also reduce the existing channel gradient and lead to potential channel adjustment downstream as the watercourse establishes a new equilibrium. | moderate adverse |
| WF74 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and extensive in-channel works disturbing channel bed and banks.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to enable construction of culvert. | moderate adverse | **New culvert**<br>Complete removal of the majority of the water feature upstream of the existing A9. The new culvert would also lead to removal of an extensive area of riparian vegetation including trees. | major adverse |
| WF76 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces and extensive in-channel works disturbing channel bed and banks.<br>**Culvert extension**<br>Diversion/damming of flow during in-channel works to enable construction of culvert. | moderate adverse | **New side road**<br>Extensive removal of natural channel under the mainline widening and the new side road. Permanent removal of natural bed and banks and natural step-pool sequence.<br>**New culvert**<br>Lateral connectivity removed as a result of the new culvert; although the natural valley is steep. Extensive removal of riparian vegetation. Change in the gradient of the water feature by straightening through a culvert, potentially altering flow processes downstream of the existing A9.<br>**Re-alignment**<br>Change to channel morphology and the sediment and flow processes due to channel realignment in a small tributary of main channel. | major adverse |

| Source of Impact | Construction impacts | Magnitude of Impact | Operation impacts | Magnitude of effect |
|---|---|---|---|---|
| WF70 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery due to runoff from bare earth surfaces, works within the water feature and from works within the tributaries feeding in to the water feature. Works to existing structures with potential for man-made material to enter the water feature.<br>**New bridge**<br>Diversion/damming of flow during in-channel works to construct outfalls and remove old bridge. A temporary in-channel pier may be required during the construction of the new Tummel Underbridge. This would cause localised alteration to flows, erosion and deposition processes. These impacts would be temporary. | moderate adverse | **New bridge**<br>The Tummel Underbridge abutments are set back in the floodplain, with some potential minor alterations to lateral connectivity.<br>**New outfalls**<br>Outfalls from SuDS basins D and B would discharge into the Tummel via an existing outfall. Potential for localised changes to flow dynamics with potential for alterations in sediment processes. This length of the River Tummel has large bars that have adjusted over time. This would mean that the outfall discharge is not always directly connected to the Tummel, but instead flows over a depositional feature. Potential to exacerbate erosion or cause more undermining.<br>**Water feature diversion**<br>The diversion of three water features into and open channel to the Tummel will increase flow into the river at this location. However, this reach of the Tummel is stable and no significant impacts are anticipated. | moderate adverse |
| WF75 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery from works in close proximity to the water feature, along the loch margins and from works within the tributaries feeding in to the water feature. | minor adverse | **Bridge replacement**<br>Proposed piers to be set back into Loch Faskally margins, meaning no modification is needed to the loch bed. However, a length of the dense established riparian corridor would need to be permanently removed.<br>**New outfalls**<br>Permanent removal of lengths of the natural bank and bed for the new outfalls. Localised changes to flow processes with potential for alterations in sediment movement through interrupting longshore processes. | minor adverse |
| WF100 | **Release of suspended sediments**<br>Temporary increase in fine sediment delivery from construction of the mainline carriageway and new side road along tributaries feeding into the River Garry. | negligible | No activities. | negligible |

## 4.4 Significance of Impacts

4.4.1 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

- WF69 – due to potential for increase in fine sediment delivery and extensive earthworks to fill in water feature gorge.
- WF74, WF76 – due to potential for a temporary increase in fine sediment delivery and extensive in-channel works disturbing channel bed and banks.
- WF70 – due to potential temporary increase in fine sediment delivery, including from works within the tributaries feeding in to the water feature.

Operation

- WF64 – due to extended culvert removing a length of natural bed and banks, removal of a natural boulder cascade and realignment removing existing dense riparian vegetation.
- WF66 – due to regrading upstream of the existing A9 removing a length of natural step-pool sequence and natural riparian vegetation.
- WF68 – due to the extended culvert and potential for an existing knickpoint (area of instability) to undermine the culvert as a result of channel adjustment.
- WF69 – due to the culvert extension removing a length of steeper channel with a step-pool sequence, natural bed and banks and vegetated riparian corridor.
- WF74 – due to complete removal of the majority of the water feature upstream of the existing A9.
- WF76 – due to extensive removal of natural channel and riparian corridor under the mainline widening and the new side road.
- WF70 – due to the presence of new abutments in the floodplain, as well as additional discharge via an existing outfall potentially altering flow and sediment processes, and the diversion of three water features into an open channel to the River Tummel.

# 5 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, high and very high sensitivity water features requiring specific mitigation are outlined in Table 5.1. The low sensitivity water features requiring specific mitigation can be found in Appendix A11.7 (Impact Assessment).

**Table 5.1: Site specific mitigation for construction and operation (for medium, high and very high sensitivity water features)**

| Water feature | Mitigation details |
|---|---|
| **Construction** | |
| 63 | Divert flow from the existing culvert during extensive construction works to prevent fine sediment and man-made materials entering the water column. |
| **Operation** | |

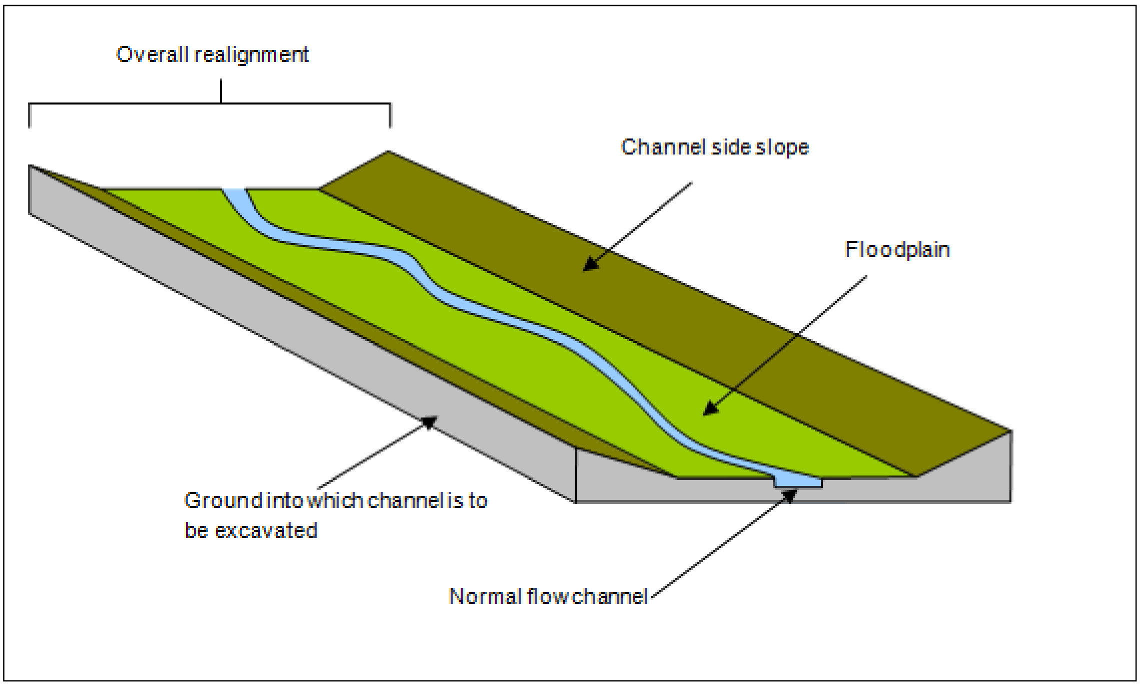
| Water feature | Mitigation details |
|---|---|
| 64 | Cascade design to be formed of natural boulder step-pools with the extent of reinforcement minimised as far as practicable, as well as re-using existing channel substrate, where practicable. |
| 66 | Natural design of channel re-grading and replanting mimicking existing riparian vegetation. |
| 68 | Re-grade channel downstream to tie in with the culvert outlet and remove existing knickpoint. A scour pool or naturalised step-pool design should be adopted. |
| 69 | Grade culvert under the mainline to remove drop at the outlet; this may require a step-pool sequence within the culvert or re-grading downstream to tie in with the existing channel. |
| 71 | Additional planting along retained water feature channel (west of mainline widening) to mitigate for loss of vegetated riparian corridor. |
| 74 | Management of surface water through collection of water runoff and channelling the flow into the culvert to ensure the downstream channel is not deprived of flow. |
| 76 | Incorporate a stepped sequence into the culvert or a low flow channel to mimic the existing gradient change and cross-section.<br>Appropriate re-grading of the upstream and downstream channel at the inlet and outlet to protect against scour and change in gradients (natural cascade design). |
| 70 | Discharge outfall SuDS basin D into small water feature already present or create a new channel to the River Tummel to avoid structure on being located on the right bank of the River Tummel. |

## 5.2 Conceptual Design

5.2.1 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.

5.2.2 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)**




5.2.3 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 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 a bedrock channel 'naturalised' design; and an over-engineered design for high erosion risk sites**

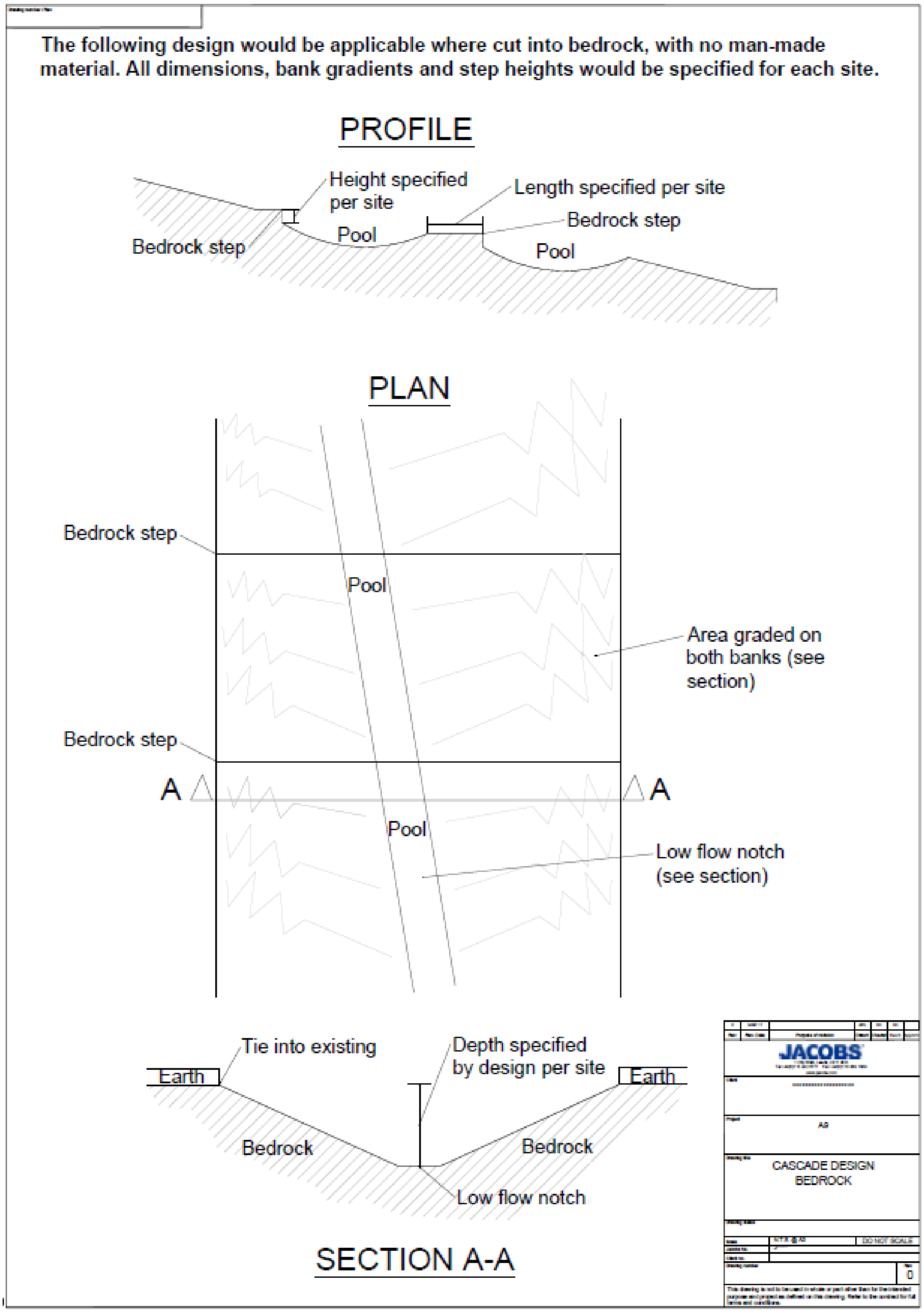


**Diagram 3: Conceptual diagram illustrating, in profile, plan view and cross-section, the constituents of a step-pool bed morphology for 'naturalised' design**

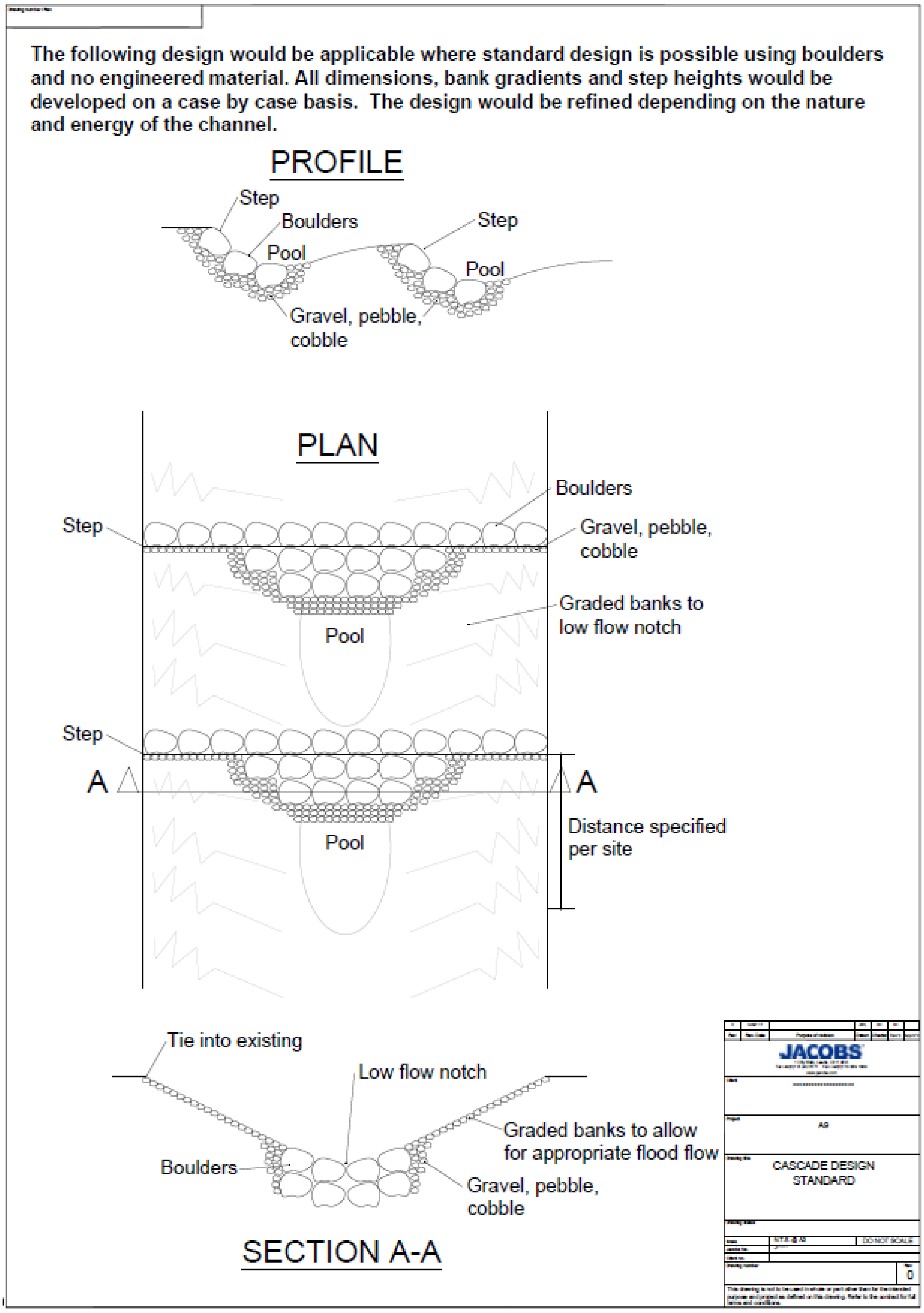
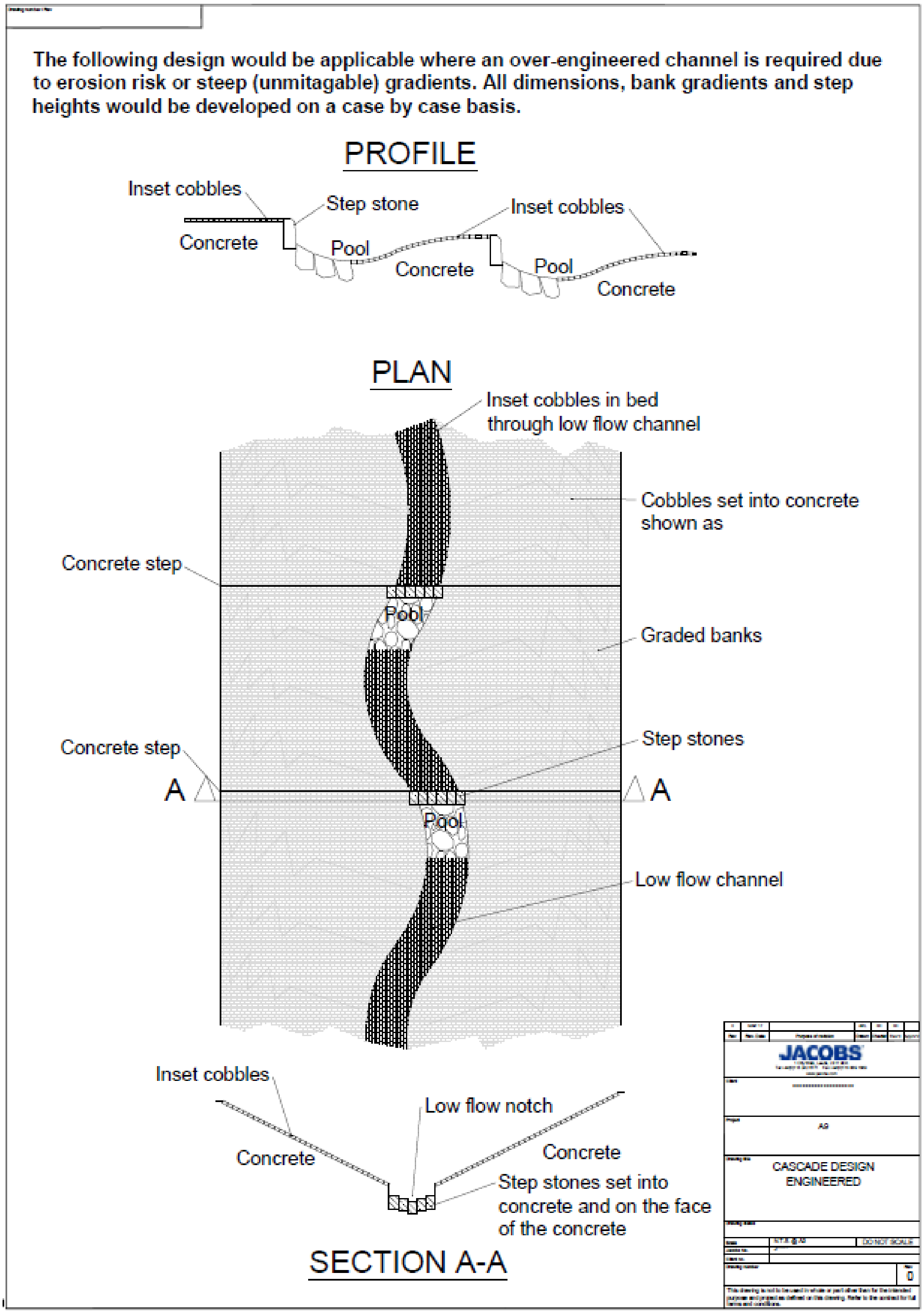


**Diagram 4: Conceptual diagram illustrating, in profile, plan view and cross-section, the constituents of a step-pool bed morphology for an over-engineered design for high erosion risk sites**



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# 6 Residual Impacts

## 6.1 Construction Residual Impacts

6.1.1 Following the assessment 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.

## 6.2 Operational Residual Impacts

6.2.1 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.

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# 8 Glossary

| Term | Definition |
|---|---|
| Adjustment | The modification of river channel morphology, both vertically and in platform, 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. |
| 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. |
| Coarse sediment | Sediment of grain diameter greater than 2 mm. |
| Cobble | Particle of diameter 64mm to 256mm, approximately “fist” sized. |
| Continuity | Relates to how continuous the flow or sediment transfer is within a particular watercourse. 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. |
| Debris dam | Coarse woody debris blocking the channel and causing water to pond back. |
| 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 2 mm. |
| 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. |
| Geotextile | Fabric membrane used for bank stabilisation, usually to aid re-vegetation. |
| Gravel | Particle of diameter between 2 mm and 64 mm. |
| 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. |
| 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 watercourse. |
| 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. |
| Re-naturalising | A formally modified channel that is adjusting to represent a more natural channel in terms of geometry and vegetation. |

| Term | Definition |
|---|---|
| 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. |
| 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:<br>Hydrological regime – the quality and connection to groundwater reflect totally or neat totally undisturbed conditions.<br>River continuity – the continuity of the river is not disturbed by human activities and allows the undisturbed migration of aquatic organisms and sediment transport.<br>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. |