# A83 Rest and Be Thankful

## LTS EIAR VOLUME 4, APPENDIX 19.4 - HYDROMORPHOLOGY ASSESSMENT

Transport Scotland

A83AAB-AWJ-EAC-LTS_GEN-RP-LE-000295

# A19-4. Hydromorphology Assessment

## A19-4.1. Introduction

A19-4.1.1. This document is a technical appendix to Volume 2, Chapter 19: Road Drainage and the Water Environment (RDWE). This assessment has been carried out in line with Volume 4, Appendix 19.1: Road Drainage and the Water Environment Legislation, Policy and Guidance and Volume 4, Appendix 19.2: Road Drainage and the Water Environment Methodology. The watercourse receptors, to which this assessment considers impacts, are identified, characterised and attributed a level of importance/sensitivity in Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline.

A19-4.1.2. The Proposed Scheme comprises the construction of new infrastructure to provide a sustainable Long Term Solution (LTS) to improve the resilience of the A83 to debris flows, in proximity to the Rest and Be Thankful (RaBT) in Glen Croe; consisting of works to approximately 2.4km of the A83. It also includes upgrading works to existing infrastructure, including the RaBT car park, B828 junction, watercourse crossings and drainage infrastructure. TS has also committed to delivering improvements to the Old Military Road (OMR) running parallel further downslope towards the glen floor, to deliver a safe, proportional and more resilient diversion route during the period when the A83 is closed until the permanent LTS is constructed and becomes operational.

A19-4.1.3. The Red Line Boundary (RLB) covers the entire area within which the Proposed Scheme would take place, including temporary access roads, laydown areas, the new debris flow shelter (DFS), debris flow wall (DFW) and any upgrade works to the existing infrastructure. These are anticipated as the maximum extent of land in which the Proposed Scheme may take place. A more detailed description of the Proposed Scheme design and construction methodology can be found in Volume 2, Chapter 4: The Proposed Scheme.

## A19-4.2. Proposed Scheme

A19-4.2.1. This section presents a summary of the design principles and activities associated with the Proposed Scheme that have the potential to affect the water environment.

A19-4.2.2. A number of water environment design principles have been adopted in developing the Proposed Scheme. The aim is to provide long term resilience to the A83 by minimising the impacts to the hydromorphological form and function of the watercourses and minimising the maintenance requirements (e.g. sediment clearance, erosion control) as far as possible.

A19-4.2.3. Key objectives for the watercourse crossing and realignments include:

- retain and convey flow through the existing and natural watercourse channels where possible, minimising length of realignment (vertical and lateral change)
- avoid exposure or heightening of flood risk to new or existing assets
- use clear span bridges to cross watercourses where possible
- accommodate both low and high flows (0.5% Annual Exceedance Probability (AEP) + Climate Change) through the A83 crossing structures
- promote natural fluvial processes and functions where possible and minimise the extent of hard modification in channel and on the banks
- provide sediment continuity (i.e. transfer of material through the crossing and downstream)
- promote stability of hillside and watercourse channels through natural measures where possible and
- treat road surface drainage separately to surface water flow.

A19-4.2.4. The Proposed Scheme involves upgrading the existing A83 road along a total length of 2.4km, which includes an extensive catch pit and a DFS/ DFW to protect the road and the users from falling debris and minimise blockage and road closures. These features and relevant water environment datasets are displayed on Volume 3, Figure 19.2: Water Feature References.

A19-4.2.5. Of the 22 existing watercourse crossings the A83, 15 are intercepted by the DFS (14) and DFW (1). The design of the catch pit allows flows from existing watercourses upslope of the structure to pass over the back wall (rock face), into the catch pit, then proceed through a horizontal grated drop structure, ultimately passing under the road via a culvert. The watercourses shall emerge from respective culverts and continue downslope towards the glen floor, crossing under the OMR on the lower slopes where the gradient is reduced. The individual tributary channels of the Croe Water converge on the glen floor in upper Glen Croe, flowing south to converge with the Croe Water, the main river in the base of the glen.

A19-4.2.6. The key elements of the Proposed Scheme that impact the hydromorphological functions of the watercourses include:

- rock debris catch pit
- culvert replacement, extension or modification (DFS / DFW culvert or other)
- new or replacement bridge
- watercourse realignment, both vertical and/or lateral
- concrete cascade (or similar)
- downslope bed and bank reinforcement
- bank / adjacent hillside reprofiling
- small sediment trap and
- localised bank protection.

A19-4.2.7. There is a single new culverted crossing associated with the extension of the HESCO barrier (a gravel-filled barricade), over watercourse A83_ML_024_000, which protects the OMR from debris flows. One culvert is to be reinstated, linking the upstream to the correct downstream watercourse, at the OMR that was made redundant due to the construction of the original HESCO barrier (watercourse A83_ML_023_000). The Proposed Scheme comprises multiple other replacements and / or extensions to the existing crossings, some of which require channel realignments to tie into the crossing inverts upstream and / or downstream. Watercourses within the Study Area are identified on Volume 3, Figure 19.3: The Proposed Scheme and Watercourses.

A19-4.2.8. Whilst the Proposed Scheme does not present a flood risk (Volume 4, Appendix 19.6: Flood Risk Assessment), the area enclosed by the Proposed Scheme Boundary does experience frequent heavy rainfall events and combined with the steep topography and geology is susceptible to watercourse/hillside channel change, debris flow events and landslips. Some slope reprofiling and bed and bank protection is required, but many of the channels already exhibit reinforcements upslope and downslope of the A83. The design of the Proposed Scheme aims to protect the critical infrastructure whilst maintaining as natural a flow and sediment regime as is practicable to minimise maintenance requirements. It is, however, recognised that there would be an ongoing need for catch pit clearance after heavy rain and adaptive management of the watercourses, for example after channel adjustment, overland flow erosion, protection remediation and sediment clearance.

A19-4.2.9. Some of these watercourse-related activities will require a Controlled Activities Regulations (CAR) licence from the Scottish Environment Protection Agency (SEPA), specifically watercourse realignments and any extensive channel bed or bank works. Preliminary CAR consultation was conducted with SEPA regarding the OMR improvement works (which will be conducted in advance of the LTS), on the 21 March 2024, with LTS design principles and constraints also being communicated to the SEPA representatives in attendance.

A19-4.2.10. Table 19-4.1 shows key elements of the Proposed Scheme requiring modifications to various watercourses, for both OMR improvements and LTS works. Individual channels are identified on Volume 3, Figure 19.3: The Proposed Scheme and Watercourses.

**Table 19-4.1 Watercourse receptors and key interventions required by the Proposed Scheme**

| Watercourse Id / Crossing Reference | Coincides with LTS works | OMR crossing | Rock debris catch pit | Culvert replacement \ extension | New / replacement bridge | Realignment (lateral or vertical) | Concrete cascade | Downslope bed and bank reinforcement | Bank/adjacent hillside reprofiling | Upstream sediment trap | Localised bank protection |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A83_ML_Z05_B01 | No | OMR_01 | No | Yes | No | Yes | No | No | Yes | Yes | Yes |
| A83_ML_Z05_B02 | No | OMR_02 | No | No | No | No | No | No | No | No | No |
| A83_ML_Z05_B03 | No | OMR_03 | No | No | No | No | No | No | No | No | No |
| A83_ML_Z05_B04 | No | OMR_04 | No | No | No | No | No | No | No | No | No |
| A83_ML_Z05_B05 | No | OMR_05 | No | No | No | No | No | No | No | No | No |
| A83_ML_Z05_B06 | No | OMR_06 | No | No | No | No | No | No | No | No | No |
| A83_ML_008_A01 | No | OMR_07 | No | No | No | No | No | No | No | No | No |
| A83_ML_010_B02 | No | OMR_08 | No | Yes | No | Yes | No | No | No | No | No |
| A83_ML_011_000 | No | OMR_09 | No | Yes | No | Yes | No | No | No | No | Yes |
| A83_ML_012_000 | No | OMR_10 | No | Yes | No | Yes | No | No | No | Yes | No |
| A83_ML_014_000 | Yes | OMR_11 | No | Yes | No | Yes | No | No | No | Yes | Yes |
| A83_ML_012_B03 | No | OMR_12 | No | Yes | No | Yes | No | No | No | No | Yes |
| A83_ML_015_000 | Yes | OMR_13 | No | No | Yes | No | No | No | No | No | No |
| A83_ML_016_000 | Yes | OMR_14 | Yes | Yes | No | Yes | Yes | Yes | No | Yes | Yes |
| A83_ML_017_000 | Yes | OMR_14 | Yes | Yes | No | No | No | No | No | No | No |
| A83_ML_017_B01 | No | OMR_15 | No | Yes | No | No | No | No | No | No | No |
| A83_ML_018_000 | Yes | OMR_16 | Yes | Yes | No | Yes | Yes | Yes | No | Yes | No |
| A83_ML_019_000 | Yes | OMR_17 | Yes | Yes | No | Yes | Yes | Yes | No | Yes | Yes |
| A83_ML_020_000 | Yes | n/a | Yes | No | No | No | No | No | No | No | No |
| A83_ML_021_000 | Yes | OMR_18 | Yes | Yes | No | No | No | No | No | No | Yes |
| A83_ML_022_000 | Yes | OMR_19 | Yes | No | No | No | No | No | No | No | No |
| A83_ML_023_000 | Yes | OMR_20/19 | Yes | Yes | No | Yes | Yes | Yes | Yes | No | Yes |
| A83_ML_024_000 | Yes | OMR_21 | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes |
| A83_ML_024_B01 | No | OMR_22 | No | Yes | No | No | No | No | No | No | Yes |
| A83_ML_025_000 | Yes | OMR_23 | Yes | Yes | No | Yes | Yes | Yes | Yes | No | No |
| A83_ML_026_B01 | No | OMR_24 | No | No | No | No | No | Yes | No | No | No |
| A83_ML_026_000 | Yes | OMR_25 | Yes | Yes | No | No | No | Yes | No | No | No |
| A83_ML_026_B02 | No | OMR_26 | No | Yes | No | No | No | No | No | No | Yes |
| A83_ML_027_000 | Yes | OMR_27 | Yes | Yes | No | No | No | Yes | Yes | No | Yes |
| A83_ML_028_000 | Yes | OMR_28 | Yes | Yes | No | Yes | Yes | Yes | Yes | No | No |
| A83_ML_029_000 | Yes | OMR_29 | Yes | Yes | No | No | No | Yes | No | Yes | Yes |
| A83_ML_030_000 | Yes | n/a | Yes | Yes | No | Yes | Yes | Yes | No | No | No |
| A83_ML_031_000 | Yes | OMR_30 | No | Yes | Yes | No | No | No | No | No | No |
| A83_ML_032_000 | Yes | OMR_31 | No | Yes | No | No | No | No | No | No | No |
| A83_ML_032_B01 | No | OMR_32 | No | No | No | No | No | No | No | No | No |
| A83_ML_032_B02 | No | OMR_33 | No | No | No | No | No | No | No | No | No |
| A83_ML_033_000 | Yes | OMR_34 | No | Yes | No | No | No | No | No | No | No |
| A83_ML_033_B02 | No | OMR_35 | No | Yes | No | No | No | No | No | No | No |
| A83_ML_033_B03 | No | OMR_36 | No | No | No | No | No | No | No | No | No |
| A83_ML_034_000 | Yes | n/a | No | Yes | No | No | No | No | No | No | No |
| A83_ML_035_000 | Yes | n/a | No | Yes | No | No | No | No | No | No | No |

| Watercourse Id / Crossing Reference | Coincides with LTS works | OMR crossing | Rock debris catch pit | Culvert replacement \ extension | New / replacement bridge | Realignment (lateral or vertical) | Concrete cascade | Downslope bed and bank reinforcement | Bank/adjacent hillside reprofiling | Upstream sediment trap | Localised bank protection |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A83_B8_001_000 | Yes | n/a | No | Yes | No | No | No | No | No | No | No |
| A83_B8_002_000 | Yes | n/a | No | Yes | No | No | No | No | No | No | Yes |
| A83_B8_003_000 | Yes | n/a | No | Yes | No | No | No | No | No | No | Yes |
| A83_B8_004_000 | Yes | n/a | No | Yes | No | No | No | No | No | No | No |

## A19-4.3. Construction Impacts

### Construction Activities and Risks

A19-4.3.1. Impacts during construction are typically temporary in nature but can have a longer term effect on the hydromorphology, and in turn, the ecological health of the watercourses.

A19-4.3.2. The Proposed Scheme shall be complex to construct and would directly interact with 45 watercourses over a duration of approximately five years.

A19-4.3.3. Construction activities such as rock blasting, piling, soil stripping and earthworks can have a detrimental impact if associated elevated sediment loading is allowed to enter watercourses. The steep slopes and flashy hydrological characteristics can lead to rapid surface runoff, slope erosion, sediment entrainment and subsequent siltation of downstream watercourses.

A19-4.3.4. To construct the DFS and OMR improvements, there would be a requirement for temporary diversions or convergence of watercourses and / or over pumping during the construction phase. There would be temporary disruption to flows and sediment downstream if the watercourses are temporarily conveyed through pipes (gravity fed or pumped). Temporary bunds would be required to pond the water at the upstream end (e.g. use of sandbags to pool the water).

A19-4.3.5. Watercourse realignments and channel reprofiling is required on some of the watercourses between the A83 and OMR to stabilise the slopes and improve the resilience of the OMR when being used by traffic during construction of the LTS upgrade to the A83.

A19-4.3.6. The majority of the headwater streams that are crossed by the A83 and OMR at the Proposed Scheme are tributaries of the Croe Water (including all crossed by the DFS structure). This major watercourse is a hydromorphologically diverse and ecologically sensitive watercourse as it travels south in the base of the glen, so would be impacted both directly and indirectly.

A19-4.3.7. More information on construction pollution and water quality impacts can be found in Volume 4, Appendix 19.5: Water Quality Assessment. For hydromorphological specific construction impacts refer to Table 19-4.2 below which outlines the risk of construction.

**Table 19-4.2 Construction activities and watercourse impacts prior to mitigation**

| Watercourse receptors | Construction elements directly impacting watercourse | Magnitude |
|---|---|---|
| A83_ML_015_000 (Croe Water) | Bailey bridge crossing, with new upstream rock armour bank protection.<br>Construction of drainage network crossing attached to the downstream parapet of the existing bridge crossing, not affecting flow or sediment conveyance. | Moderate Adverse |

| Watercourse receptors | Construction elements directly impacting watercourse | Magnitude |
|---|---|---|
| A83_ML_016_000, A83_ML_017_000, A83_ML_018_000, A83_ML_019_000, A83_ML_020_000, A83_ML_021_000, A83_ML_022_000, A83_ML_023_000, A83_ML_024_000, A83_ML_024_B01, A83_ML_025_000, A83_ML_026_B01, A83_ML_026_000, A83_ML_026_B02, A83_ML_027_000, A83_ML_028_000, A83_ML_029_000 & A83_ML_030_000 | Rock cutting for catch pit, piling for DFS and culvert.<br>Watercourse diversion/flume or overpump<br>Channel reprofiling and installation of cascades and downslope protection requiring extensive earthworks and silt management | Major Adverse |
| A83_ML_010_B02, A83_ML_011_000, A83_ML_012_000, A83_ML_014_000, A83_ML_012_B03 & A83_ML_024_000 | Watercourse diversion/flume or overpump.<br>Channel reprofiling requiring extensive earthworks and silt management<br>Installation of HESCO barrier. | Moderate Adverse |

| Watercourse receptors | Construction elements directly impacting watercourse | Magnitude |
|---|---|---|
| A83_ML_017_B01, A83_ML_032_000, A83_ML_033_000, A83_ML_033_B02, A83_ML_034_000, A83_ML_035_000, A83_B8_001_000, A83_B8_002_000, A83_B8_003_000 & A83_B8_004_000 | Watercourse diversion/flume or overpump.<br>Minor modifications to existing crossings involving earthworks and requiring silt management. | Moderate Adverse |
| A83_ML_031_000 | Construction of single span bridge, predominantly bed rock dominated with clearance of existing culvert and manmade embankment that supports the existing A83. | Moderate Adverse |
| A83_ML_Z05_B01, A83_ML_Z05_B02, A83_ML_Z05_B03, A83_ML_Z05_B04, A83_ML_Z05_B05, A83_ML_Z05_B06, A83_ML_008_A01, A83_ML_032_B01, A83_ML_032_B02 & A83_ML_033_B03 | No direct LTS or OMR improvement work impacts. | No Change |

Construction Specific Mitigation

A19-4.3.8. The Construction Environmental Management Plan (CEMP) will be developed and refined for the site, to include best practice measures to manage the potential environmental impacts of construction works, as recommended in the SEPA Good Practice Guide (Temporary Construction Methods - WAT-SG-29). The main risk identified is sediment-laden runoff into the watercourses from vegetation clearance, earth works, piling, excavations and vehicle movements. Mitigation measures to reduce these risks will be implemented within the construction process and will include:

- maintain a buffer area near watercourses if possible and avoid working/storing equipment or materials near a channel
- provide settlement ponds and cut off ditches to treat site runoff
- provide upstands or bunds where haul roads cross watercourses or/and across site to minimise runoff directly into watercourses
- fully isolate excavations and sections of watercourses that require works and use gravity fed flumes or pipes or over pump
- use sediment traps and filters (e.g. straw bales, aggregate or geotextiles) to limit fine sediment entering watercourses
- use single span structures to temporarily cross watercourses and minimise bed and bank disturbance/protection
- plan the works to avoid activities that would exacerbate runoff and sediment loading in wet weather
- plan the timing of work to avoid sensitive times of the year (e.g. fish spawning) wherever possible
- provide appropriate management /sequencing / monitoring of surface water flow during catch pit and DFS construction
- have emergency plans in place for heavy rain and or landslide events and

- monitor water quality throughout construction period and stop works if turbidity reaches trigger level thresholds (determined from baseline monitoring and agreed with SEPA).

### Construction Residual Effect

A19-4.3.9. As the works are intrusive to the watercourses there would be temporary disruption to flows and sediment downstream of the works, even with the above mitigation applied to the construction process. These mitigation measures would minimise the construction effects as far as is practicable. The residual effect to each watercourse is presented in Table 19-4.3.

**Table 19-4.3 Construction residual effects with mitigation**

| Watercourse Receptor ID | Sensitivity | Pre-Mitigation Impact | Post-Mitigation Impact | Residual Effect |
|---|---|---|---|---|
| A83_ML_Z05_B01 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B02 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B03 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B04 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B05 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B06 | Low | No Change | No Change | Neutral |
| A83_ML_008_A01 | Medium | No Change | No Change | Neutral |
| A83_ML_010_B02 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_011_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_012_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_014_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_012_B03 | Low | Moderate Adverse | Minor Adverse | Slight |

| Watercourse Receptor ID | Sensitivity | Pre-Mitigation Impact | Post-Mitigation Impact | Residual Effect |
|---|---|---|---|---|
| A83_ML_015_000 | High | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_016_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_017_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_017_B01 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_018_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_019_000 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_020_000 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_021_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_022_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_023_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_024_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_024_B01 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_025_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_026_B01 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_026_000 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_026_B02 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_027_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_028_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_029_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_030_000 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_031_000 | Medium | Moderate Adverse | Minor Adverse | Slight |

| Watercourse Receptor ID | Sensitivity | Pre-Mitigation Impact | Post-Mitigation Impact | Residual Effect |
|---|---|---|---|---|
| A83_ML_032_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_032_B01 | Low | No Change | No Change | Neutral |
| A83_ML_032_B02 | Low | No Change | No Change | Neutral |
| A83_ML_033_000 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_033_B02 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_033_B03 | Low | No Change | No Change | Neutral |
| A83_ML_034_000 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_035_000 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_B8_001_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_B8_002_000 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_B8_003_000 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_B8_004_000 | Low | Moderate Adverse | Minor Adverse | Slight |

## A19-4.4. Operational Impacts

A19-4.4.1. The hydromorphology team have worked with the engineers and geotechnical specialists to develop a design that protects the critical infrastructure, is viable to construct and that minimises operational phase impacts to the water environment.

A19-4.4.2. The Proposed Scheme is required to be resilient to extreme fluvial flows, debris flows and landslide events but operate as naturally as possible under more routine/regular flow conditions.

A19-4.4.3. A series of hydraulic modelling runs were undertaken to compare flows under the Proposed Scheme with the baseline. An iterative process helped test the sensitivity of each design parameter and informed the embedded mitigation necessary to maximise optimum operation.

A19-4.4.4. The modelling approach and results are within Annex 19-4-1. The Proposed Scheme reduces the velocities at the crossing location of the A83, primarily due to the larger culvert design. However, the steep slopes immediately downstream, together with the channel topography, mean that the potential velocities still remain high (>5m/s). This remained the case when the design of the culvert gradient was modified and dissipation measures were applied in the open channel (e.g. baffles). To summarise the model outcomes, the steep slope dominates the behaviour of the flow velocities, with various measures introduced to reduce the velocities through the culvert and immediately downstream dampened (to little benefit) within a very short distance.

### Operational Embedded Mitigation

A19-4.4.5. The following design elements have been included within the Proposed Scheme as embedded mitigation:

- catch pit longitudinal and lateral gradient (both 5%)
- culvert inlet of the A83 crossings positioned away from the back face of the rock cut to minimise blockage and damage
- culvert inlet grate to allow sediment <100mm to be transferred downstream
- culvert drop chamber to be angled to reduce deposition/accumulation of sediment
- low flow channel within a v-shaped culvert base to promote movement of sediment through the structure and reduce the need for maintenance
- dissipation measures within the open channel to slow the flow
- transition structures to accommodate vertical misalignments
- dissipation pools and bank and bed protection at the transition to minimise scour
- bank reprofiling to promote (geotechnical) stability

- fencing to prevent livestock and encourage hillside vegetation growth or/and planting of native shrubs to stabilise slopes adjacent to channels
- step-pool and bed check features proposed on some realignments to reduce risk of knick point/head-cut migration and
- small informal catch pit upstream of any OMR crossing where sediment deposition and potential blockage are assessed as a risk

A19-4.4.6. The following sections describe each of the design elements and the potential impact they have on the watercourses and hydromorphological processes and functioning.

### Rock debris catch pit

#### Description

A19-4.4.7. This catch pit will be cut out of the rock on the upslope side of the A83 to prevent large boulders and debris flow derived sediment from blocking the road. The catch pit will be circa 6m wide and 1.5km long and 15 watercourses will intersect with this rock cut catch pit. A 5% longitudinal gradient will be constructed southwards to allow for free drainage and a 5% lateral gradient directed towards the culvert inlet to encourage the capture of the natural flow, as far as is practicable. Whilst bedrock outcrops are evident upstream of the A83 it is not continuous. Ground investigation (GI) works will, when completed, confirm exposure or the depth of cover and will inform development of the specimen / detailed design.

#### Potential hydromorphological impact

A19-4.4.8. From a watercourse perspective, ideally the rock cut will vary to maximise the exposure and minimise the need for a retaining wall or spray concrete to protect the hillslope and back face of the catch pit. Where the watercourse flows over bedrock, the risk of scour or headcut (bed erosion migrating in an upstream direction) is negligible. There may be some instances where the adjoining channel slopes are too steep to ensure stability and may have to be reprofiled and/or protected. If unconsolidated material comprises the watercourse bed and cutting back to bedrock is not possible in the space available, then a vertical realignment design may be required, which could take the form of a rock or engineered cascade. A retaining wall creating a soft to hard transition point may promote scour and be outflanked. Hillslope drainage would also have to be managed.

A19-4.4.9. The catch pit would effectively trap any of the large material that is supplied from upstream of the A83 and this would be periodically cleared of debris. Each of the culvert inlets within the catch pit is aligned with a natural watercourse pathway and should capture the flow within the respective catchment areas. If a culvert inlet is blocked, flow would be directed south to the next culvert, following catch pit slope.

A19-4.4.10. Sediment continuity, by allowing material to be transferred from upstream to downstream, is important for both morphological (e.g. avoidance of sediment starvation and in turn, greater competence to erode rather than transport material) and ecological (e.g. gravels for fish habitat) reasons. Debris screens are necessary within the catch pit at the culvert inlet to minimise the risk of blockage from larger items entering the culvert, including dislodged boulders from the slope above or material entrained in a debris flow or landslide event.

A19-4.4.11. An interruption to sediment transfer would therefore create an impact with the construction of the catch pit, although existing modifications to channels largely disrupt flow and sediment movement as part of baseline.

A19-4.4.12. The disruption to flows would depend, in part, on the maintenance regime and frequency of sediment removal within the catch pit. Some flows may be transferred to the adjacent southerly culvert inlet if the corresponding area and culvert entrance is blocked, but this is also observed as an existing condition. It is not envisaged that there would be multiple blockages, out with a debris flow event, that could enable flow from all watercourses to travel to the most southerly culvert.

### Culvert replacement, extension or modification (DFS culvert or other)

#### Description

A19-4.4.13. The DFS and DFW culverts with the inlets embedded within the catch pit will be largely perpendicular to the road and 1.9 x 1.9m box culverts. These closed culverts will be approximately 20m in length and 5% gradient and are positioned to align with the receiving downstream watercourse.

A19-4.4.14. A concrete drop chamber with a grate (approximately 6m wide with 100mm spacings) will lead from the catch pit to these closed culverts. As determined in Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline, the assessment of sediment characteristic for the impacted watercourses found that more than 90% of the sediment in the watercourses was <100mm in diameter. This has been assessed as an appropriate size of sediment that the flows within the future proposed culverts will be competent to transport.

A19-4.4.15. An open channel at the downstream end of the culvert is proposed within the design which is shallower at 2.5% gradient and up to 8m in length.

A19-4.4.16. The other A83 and OMR watercourse crossings, not associated with the DFS, which have culvert modifications are in general on the same alignment as the existing watercourse crossings and are upsized or twinned pipe culverts and/or extensions. Those crossing the OMR are upgraded to pass the 2% AEP event. All crossings beneath the A83 and the B828 will convey at least the 0.5% AEP with an allowance for climate change (CC).

#### Potential hydromorphological impact

A19-4.4.17. The majority of the culverts are larger (with DFS culverts substantially larger) than those currently crossed by the A83 and OMR so will be able to accommodate higher flows (a greater discharge) through these proposed structures. Culverts have the potential to disrupt sediment transfer; oversized culverts have the potential to accumulate sediment, if flows are thinly spread and lose energy within the structure.

### New or replacement bridge

#### Description

A19-4.4.18. There will be two bridges installed as part of the Proposed Scheme. Volume 3, Figure 19.3 The Proposed Scheme and Watercourses, identifies the watercourse channels noted below.

A19-4.4.19. There will be a single new permanent bridge crossing of watercourse A83_ML_031_000, on the A83 alignment, which is required to improve the resilience of the A83 to debris flows to the north of the DFS. The A83 bridge crossing will replace an existing culvert crossing.

A19-4.4.20. A bailey bridge crossing of the Croe Water (watercourse A83_ML_015_000) is proposed as part of the improvements to the OMR. This bailey bridge is to be located approximately 5m upstream of the existing single lane OMR bridge crossing to allow two-way passage of vehicles across the watercourse.

#### Potential hydromorphological impacts

A19-4.4.21. Bridges can have several potential hydromorphological impacts on the rivers they span due to the potential constriction effect they can have on flows. Constricted flows can cause scour to the riverbed and banks due to a concentration in flow energy and also impact flood risk locally if they impede channel and floodplain conveyance. Constrictions and the scour effects can be exacerbated if they are prone to blockage from detritus, woody material or sediment. Both new bridges will be installed so that any hydraulic restriction under normal conditions would be located at the OMR. The permanent A83 crossing will be designed to convey flows greater than the 0.5% AEP event plus CC without any constriction.

### Watercourse realignment

#### Description

A19-4.4.22. Watercourse realignments are required at both the A83 and/or the OMR for some watercourses due to engineering restrictions on the vertical and/ or lateral alignments of culverts.

A19-4.4.23. Lateral misalignments have occurred both upstream and downstream of the A83.Upstream, the slope will be cut back to accommodate the DFS/DFW and catch pit resulting in misalignments where the watercourse flows into the catch pit north or south relative to the culvert inlet. Due to the spacing of the pile foundations required to support the DFS it is not possible to significantly skew (>10 degrees) the culvert beneath the A83. As the catch pit has a 5% longitudinal gradient, north to south, and from the bedrock backwall towards the closed wall of the DFS/DFW, those watercourses misaligned to the north would be directed to their corresponding culvert. However, there are two watercourses misaligned to the south, relative to the culvert entrance, would be transferred to the adjacent southerly culvert.

A19-4.4.24. Vertical misalignments have occurred at the A83 as the bed gradients of the closed culvert (5%) and open channel (2.5%) were agreed with the structures team as appropriate. The closed culvert is required to be steep enough to allow the sediment to be flushed through regularly (self-cleansing) but shallow enough to allow for access and maintenance. In accordance with Construction Design and Management (CDM) principles, as the culvert is a confined space, the requirements for access and maintenance will be designed to a minimum. There are also limitations as to how deep the culverts can be installed beneath the A83 as the bedrock is particularly hard, meaning any substantial lowering of a culvert may incur additional financial costs and programme delay to construct/install.

A19-4.4.25. Where culverts are being replaced/upsized at the OMR, it has been ensured that the downstream invert of all culverts tie-in to the natural channel. In locations where the OMR culvert is being lengthened in an upslope direction it has not always been possible to tie-in the culvert invert to the natural upstream channel, where this coincides with very steep upslope topography. Where this occurs, the upstream channel shall be steepened to meet the culvert invert and retain the existing OMR road level.

A19-4.4.26. At both the A83 and OMR where there is no space and/ or the upstream slope is too steep to make channel realignment feasible, a drop structure will be installed to link the upstream watercourse to the culvert inlet.

### Potential hydromorphological impacts

A19-4.4.27. Realigning channels can have impacts on both the flow and sediment due to changes in the energy regime compared to the baseline. A reduction in channel gradient would result in lower energy flows, with less competency to transport larger grades of sediment, leading to deposition. Steepening of a watercourse would result in higher energy flows that have the potential to erode and incise the channels in which they flow, both in upslope (head cutting) and downslope directions. To prevent channel erosion and incision, local bed and bank protection can be used.

A19-4.4.28. A drop chamber provides dissipation of energy relative to the upslope flow. This could be beneficial in terms of reducing pass forward flows, however, these features could potentially reduce the competence of the flows to transport entrained sediment, resulting in deposition which could impact the conveyance capacity of the culvert over time.

### Concrete cascade

### Description

A19-4.4.29. A concrete cascade is a series of concrete steps, generally installed on very steep watercourses to manage/dissipate energy within flows to mitigate the potential for erosion and channel incision.

### Potential hydromorphological impacts

A19-4.4.30. Concrete cascades are rigid structures that cannot adjust to the flow and sediment regime but are generally stable and adequately dissipate the flow. Engineered cascade features are used on slopes >15% gradient as more natural boulder cascade features have the potential to fail under extreme flows.

### Downslope bed and bank reinforcement

### Description

A19-4.4.31. Geo-engineering, slope reinforced/ stabilisation techniques, offer a means to protect the watercourses downstream of the A83 most at risk of erosion from fluvial and debris flows. These techniques take the form of rock roll/bags/cells made from high strength steel, anchored to the hillside. Similar in form to a gabion/reno mattress, these cells can be flexible in terms of width and depth, constructed from a range of sediment grades/boulder sizes to create the desired shape/profile of the channel, including steps to help dissipate energy. The coarse material within the cell absorbs the flow and dampens energy, reducing erosive power. They have been demonstrated to be highly effective at reducing coastal erosion, absorbing energy from breaking waves. This downstream protection measure may be used in combination with other measures (e.g. reprofiling, planting) to increase slope stability and will be informed by GI data.

### Potential hydromorphological impacts

A19-4.4.32. This type of bed and bank protection has the potential to impact the hydromorphological regime in several ways as during low/medium flow, water would pass through, within the cell, which may impact the competence to move sediment downstream. There is also the potential that fines and gravels may fill the voids within the cell, reducing energy dissipation efficiency. Although theoretically applicable, these products are untested on the slopes present at the Proposed Scheme and may not be effective in practice, plus may present buildability challenges.

A19-4.4.33. As was highlighted in Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline, several different protection and energy dissipation methods have historically been applied to watercourses downstream of the A83, with mixed success, with the transition between engineered measures and the natural channel highlighted as being particularly difficult to manage.

### Bank and hillside reprofiling

#### Description

A19-4.4.34. Historic debris flow events have resulted in several watercourses being over widened and deepened between the A83 and the OMR. Generally, the active channel in which fluvial flows travel have now naturally adjusted and stabilised, with natural features such as boulder cascades and step-pool sequences present. However, in several locations, the debris flows have eroded a substantial amount of the superficial deposits, leaving very tall (5-6m), steep banks, these could contribute a large influx of sediment to such channels if slumping occurs, potentially blocking OMR culverts. To improve channel and slope stability and increase the conveyance capacity of channels for both fluvial and debris flows, the banks of specific watercourses are to be widened and reprofiled to a reduced 1:2 gradient.

#### Potential hydromorphological impacts

A19-4.4.35. The reprofiling of slopes would require established vegetation to be removed. Vegetation offers protection from sediment erosion and transportation by intercepting rainfall and therefore shielding the superficial deposits from direct rain splash erosion. It also binds the soil within the subsurface root system, making particulates less mobile. Hillside erosion may, therefore, lead to exacerbated sediment entrainment and potential culvert blockages and/or aquatic habitat impacts.

A19-4.4.36. Though not a direct hydromorphological impact, there is the possibility that the regraded slopes become more accessible for livestock to graze, which could result in poaching of the slopes and areas adjacent to channels. This could potentially result in greater sediment mobilisation/input to these channels.

### Small sediment trap

#### Description

A19-4.4.37. A sediment trap is an over widened, over deepened reach of watercourse, often positioned immediately upstream of a culvert inlet, intended to reduce flow velocities and encourage sediment drop-out. Thus, maintaining culvert function/capacity by managing sedimentation in a controlled manner, with ease of clearance. Sediment traps are required for several of the OMR culverts, though not all, where the proposed culvert causes a reduction in channel gradient and competency of flow to transport sediment.

#### Potential hydromorphological impacts

A19-4.4.38. Sediment traps would reduce the amount of sediment within the watercourse downstream of the culvert. This has the potential to affect the watercourse in a number of ways, as any material eroded from the downstream watercourse may not be replaced due to restricted sediment transfer from upstream. Excessive erosion can lead to channel incision and changes to the in-stream habitats.

A19-4.4.39. If the sediment traps are not maintained, they would not effectively retain the culvert capacity and could ultimately blind the culvert, reducing flow capacity.

### Localised bed and bank protection

#### Description

A19-4.4.40. Where a watercourse has been assessed as being at risk from erosion, typically where modelled velocities are high and in particular at culvert exits or where a channel has been modified/realigned, there may be a requirement to protect the channel. This can include placing cobbles and boulders in key locations to provide protection and stability to the bed and banks of watercourses.

### Potential hydromorphological impacts

A19-4.4.41. Where channels are identified as at risk of scour erosion, if left unprotected, there is the long-term potential for culverts and roads to become undermined and left with reduced structural integrity.

### Operational impact assessment

A19-4.4.42. The magnitude of the operational impacts are summarised in Table 19-4.4 below, pre-mitigation.

**Table 19-4.4 Operational impacts to watercourse receptors**

| Watercourse Id / Crossing Reference | OMR crossing | Description and Embedded Mitigation (descriptions are based on the preliminary design and may ultimately change at detailed design but this will not result in more significant environmental impacts) | Magnitude |
|---|---|---|---|
| A83_ML_Z05_B01 | OMR_01 | This watercourse has been modified by works that have already been undertaken to increase the resilience of the OMR to flooding. This work has included the construction of a new access road, approximately 85m north of the existing access that links the A83 to the southern extent of the OMR. The watercourse has had to be realigned both in plan form and vertically to accommodate the new road and convey the water through a new culvert. These works are now complete. | No Change |
| A83_ML_Z05_B02 | OMR_02 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_Z05_B03 | OMR_03 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_Z05_B04 | OMR_04 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_Z05_B05 | OMR_05 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_Z05_B06 | OMR_06 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_008_A01 | OMR_07 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_010_B02 | OMR_08 | The OMR culvert is being extended upslope and downslope which requires minor realignment of the upstream watercourses, to maintain current culvert gradient and downstream invert. | Moderate Adverse |
| A83_ML_011_000 | OMR_09 | The OMR culvert is being extended upslope which requires a total of 48m of upstream watercourses/ditches (4) to be realigned both vertically and laterally (channel gradient up to 17%), to maintain current culvert gradient and downstream invert. | Moderate Adverse |
| A83_ML_012_000 | OMR_10 | The OMR culvert is being extended upslope which requires a total of 15m of upstream watercourse to be realigned both vertically and laterally (channel gradient up to 30%), to maintain current culvert gradient and downstream invert. An over widened sedimentation area is proposed upstream of the culvert entrance | Moderate Adverse |
| A83_ML_014_000 | OMR_11 | No LTS improvement works directly impact this watercourse. The OMR culvert is being extended upslope and downslope which requires a total of 17.5m of upstream watercourse to be realigned both vertically and laterally (channel gradient up to 20%), to maintain current culvert gradient and downstream invert. | Moderate Adverse |
| A83_ML_012_B03 | OMR_12 | The OMR culvert is being extended upslope and downslope which requires minor realignment of the upstream watercourses, to maintain current culvert gradient and downstream invert. | Moderate Adverse |
| A83_ML_015_000 | OMR_13 | No LTS improvement works directly impact this watercourse. A bailey bridge will be installed upstream of the existing bridge crossing, with set back abutments, as part of improvement works to the OMR. Upstream of the existing OMR crossing there are training walls on each bank, which are currently being eroded behind, that will be partially replaced by large boulders, placed in to the bank over a distance of approximately 10m. | Minor Adverse |

| Watercourse Id / Crossing Reference | OMR crossing | Description and Embedded Mitigation (descriptions are based on the preliminary design and may ultimately change at detailed design but this will not result in more significant environmental impacts) | Magnitude |
|---|---|---|---|
| A83_ML_016_000 | OMR_14 | This will be the southernmost watercourse that passes through the catch pit at the rear of the DFS. The culvert is to be upsized from the existing 0.6m pipe culvert that can only convey events less frequent than a 5% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. There is currently a disconnect between the upstream and downstream of this watercourse, at the A83, with flows routed south, along the upper edge of the A83 towards A83_ML_015_000. This disconnection would be removed. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (9.43m offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 20m total of channel protection will be required.<br>The OMR culvert is being upgraded to two, 0.9m diameter, barrels with extensions both upstream and downstream. The upslope extension will require an increase in channel gradient that will be mitigated with boulder bed checks to prevent headward cutting. There is an agricultural crossing of the watercourse 4m downstream of the OMR which will be replaced as part of the upgrade to OMR 14 with the twin culverts continued through. There is a lot of deposition upstream and downstream of the existing OMR culvert and through the culvert barrel. The gradient downstream of this culvert is substantially less than the majority of other culverts in the glen. The modelled culvert velocities are very high and would mean downstream protection of the channel is required. | Major Adverse |
| A83_ML_017_000 | OMR_14 | This watercourse passes through the catch pit at the rear of the DFS. The culvert is to be upsized from the existing 0.9m (W) x 1.0m (H) box culvert that can convey events up to the 0.5% AEP flow, to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. It is proposed that the existing concrete cascade features are kept at the downstream tie-in.<br>This watercourse converges with A83_ML_016_000 approximately 125m downslope from the A83 and approximately 115m upslope of the OMR. | Minor Adverse |
| A83_ML_017_B01 | OMR_15 | No LTS improvement works directly impact this watercourse.<br>The OMR culvert is being extended in the downslope direction to due to widening of the OMR. No additional watercourse works proposed. | Minor Adverse |
| A83_ML_018_000 | OMR_16 | The A83 culvert is to be upsized from the existing 0.6m pipe culvert that can only convey events less frequent than a 50% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (6.75m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 20m of channel protection will be required.<br>The OMR culvert is to be extended in a downslope direction. This culvert is approached by a natural upslope watercourse but also seems to accept flows from artificial drains parallel to the OMR. An upstream catch pit is required, with downstream erosion protection as the culvert is being upsized and extended and has a gradient of ~10%. | Major Adverse |

| Watercourse Id / Crossing Reference | OMR crossing | Description and Embedded Mitigation (descriptions are based on the preliminary design and may ultimately change at detailed design but this will not result in more significant environmental impacts) | Magnitude |
|---|---|---|---|
| A83_ML_019_000 | OMR_17 | The A83 culvert is to be upsized from the existing 0.45m pipe culvert that can convey events less frequent than a 5% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (4.17m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 20m of channel protection will be required. This culvert will receive additional flows as the culvert for watercourse A83_ML_020_000 will not be reinstated as part of the LTS, with flows passing south within the catch pit to this watercourse.<br>The OMR culvert is being extended upslope to pass beneath a new earth bund that is to be constructed to protect the OMR from debris flows. To link the upstream channel into the culvert and maintain the existing culvert gradient, a drop structure is required at the rear of the bund, with this designed as an alternative to extensive channel realignment due to the substantial elevation difference and steep upslope topography. Downstream, the channel is well vegetated and there is little evidence of erosion, however, as the culvert is being upsized there will be additional flow through the culvert increasing the potential for erosion, therefore scour protection shall be provided at the culvert exit. | Major Adverse |
| A83_ML_020_000 | Not applicable | The A83 culvert will not be reinstated as part of the LTS. Currently there is ~a 4m reach of this watercourse, downstream of the A83, before its confluence with A83_ML_021_000. The flows generated from this watercourse will flow south within the catch pit, behind the DFS, to combine with A83_ML_019_000. The catchment to the A83 is very small at only 0.033km$^2$, the downstream thalweg / watercourse will still receive surface runoff from the slopes between the A83 and OMR. | Minor Adverse |
| A83_ML_021_000 | OMR_18 | The A83 culvert is to be upsized from the existing 0.6m pipe culvert that can convey events less frequent than a 50% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. The existing step features are to be maintained.<br>The OMR culvert is being extended upslope to pass beneath a new earth bund that is to be constructed to protect the OMR from debris flows. To link the upstream channel into the culvert and maintain the existing culvert gradient, a drop structure is required at the rear of the bund as an alternative to channel realignment, due to the significant elevation difference and steep upslope topography. Downstream, the channel is well vegetated and there is little evidence of erosion, however, as the culvert is being upsized there will be additional flow through the culvert increasing the potential for erosion, therefore scour protection shall be provided at the culvert exit. | Moderate Adverse |
| A83_ML_022_000 | OMR_19 | The A83 culvert will not be reinstated as part of the LTS. The flows generated to this watercourse would flow south within the catch pit, behind the DFS, to combine with A83_ML_021_000. The catchment to the A83 is very small at only 0.005km$^2$, the downstream thalweg / watercourse would still receive surface runoff from the slopes between the A83 and OMR. | Moderate Adverse |

| Watercourse Id / Crossing Reference | OMR crossing | Description and Embedded Mitigation (descriptions are based on the preliminary design and may ultimately change at detailed design but this will not result in more significant environmental impacts) | Magnitude |
|---|---|---|---|
| A83_ML_023_000 | OMR_20/ 19 | The A83 culvert is to be upsized from the existing 0.9m pipe culvert that conveys events less frequent than a 3.33% AEP event, to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (3.14m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 50m of channel protection will be required.<br>The flows from this watercourse are currently diverted to the south due to the construction of the HESCO barrier at the OMR and pass through culvert OMR_19. As part of the OMR improvement works the connection with the rightful downstream watercourse will be made below the HESCO barrier. To maintain the current culvert gradient and sufficient cover to the road surface a 1.6m drop structure is required behind the HESCO as an alternative to channel realignment due to the significant elevation difference and steep upslope topography. Downstream scour protection will be required. 80m of both banks between the OMR and A83 will be reprofiled to a 1:2 slope to improve geotechnical stability as part of the OMR improvement works. | Major Adverse |
| A83_ML_024_000 | OMR_21 | The A83 culvert is to be upsized from the existing 1.2m (W) x 1.4m (H) box culvert that can convey flows up to the 0.5% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (5.56m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 50m of channel protection will be required<br>The OMR culvert is to be upsized from the existing 1.05m pipe culvert to a twin 0.9m pipe culvert, capable of conveying hydrological flows up to the 2% AEP event with a freeboard. An upstream sedimentation area and downstream scour protection will be required either side of the OMR. A new culverted crossing will be required to this watercourse between the A83 and OMR associated with the extension of the HESCO barrier (a gravel-filled barricade) to provide additional protection to the OMR from debris flows. The culvert through the HESCO barrier will be approximately 10m long and will have a greater conveyance capacity than the downstream OMR culvert (OMR_21). Any hydraulic restriction under normal conditions will be located at the OMR, as per the design, and not at the HESCO barrier. Immediately upstream of the new crossing, 20m of both the right and left bank will be reprofiled to a 1:2 slope to improve geotechnical stability as part of the OMR improvement works. | Major Adverse |
| A83_ML_024_B01 | OMR_22 | No LTS improvement works directly impact this watercourse.<br>The OMR culvert is being upsized from a single 0.375m pipe to a 0.6m culvert to convey the 2% AEP event with freeboard. Downstream scour protection is required (<10m). The upper 10m of this watercourse will be lost where the HESCO extension shall cross. | Moderate Adverse |
| A83_ML_025_000 | OMR_23 | The A83 culvert is to be upsized from the existing 0.9m pipe culvert that conveys events less frequent than a 3.33% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (6.77m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 50m of channel protection will be required.<br>No upgrades are proposed to the OMR culvert, however, 25m of the right bank between the OMR and A83 will be reprofiled to a 1:2 slope to improve geotechnical stability as part of the OMR improvement works. | Major Adverse |
| A83_ML_026_B01 | OMR_24 | No LTS works directly impact this watercourse.<br>No upgrades are proposed to the OMR culvert, however, 25m of both the right and left bank will be reprofiled to a 1:2 slope to improve geotechnical stability as part of the OMR improvement works; these works will affect a total of 50m of watercourse as they are offset and not directly opposite. | Minor Adverse |

| Watercourse Id / Crossing Reference | OMR crossing | Description and Embedded Mitigation (descriptions are based on the preliminary design and may ultimately change at detailed design but this will not result in more significant environmental impacts) | Magnitude |
|---|---|---|---|
| A83_ML_026_000 | OMR_25 | The A83 culvert is to be upsized from the existing 1.4m (W) x 1.5m (H) box culvert, capable of conveying hydrological flows in excess of the 0.5% AEP +CC event, to a standardised DFS 1.9m x 1.9m box culvert, with additional conveyance capacity. At the A83 culvert outlet up to 50m of channel protection will be required. This watercourse would receive greater flows than present due to the misalignment of A83_ML_027_000.<br>No OMR improvement works directly impact this watercourse. | Major Adverse |
| A83_ML_026_B02 | OMR_26 | No LTS improvement works directly impact this watercourse.<br>The OMR culvert is being upsized from a single 0.375m pipe to a twin 0.5m culvert to convey the 2% AEP event with freeboard. Downstream scour protection is required. | Moderate Adverse |
| A83_ML_027_000 | OMR_27 | The A83culvert is to be upsized from the existing 0.6m pipe culvert, capable of conveying hydrological flows less frequent than the 50% AEP event, to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83culvert outlet up to 20m of channel protection will be required. There would be an upstream misalignment between the watercourse and the culvert inlet; flows would be allowed to bypass to the south to A83_ML_026_000.<br>The OMR culvert is to be upsized from the existing 0.6m pipe culvert to a twin 0.9m pipe culvert, capable of conveying hydrological flows up to the 2% AEP event with a freeboard. Downstream scour protection will be required. 20m of the left bank between the OMR and A83 will be reprofiled to a 1:2 slope to improve geotechnical stability as part of the OMR improvement works. | Major Adverse |
| A83_ML_028_000 | OMR_28 | The A83 culvert is to be upsized from the existing 0.46m pipe culvert that conveys events less frequent than a 50% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (2.51m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 20m of channel protection will be required. This watercourse would receive greater flows due to the misalignment at A83_ML_029_000.<br>No upgrades are proposed to the OMR culvert, however, 60m of the left bank between the OMR and A83 will be reprofiled to a 1:2 slope to improve geotechnical stability as part of the OMR improvement works. | Major Adverse |
| A83_ML_029_000 | OMR_29 | This will be the northern most watercourse that passes through the rear of the DFS. The culvert is to be upsized from the existing 1.7m (W) x 1.3m (H) box culvert, capable of conveying hydrological flows in excess of the 0.5% AEP +CC event, to a standardised DFS 1.9m x 1.9m box culvert. At the A83 culvert outlet up to 20m of channel protection will be required. There would be an upstream misalignment between the watercourse and the culvert inlet; flows would be allowed to bypass to the south to A83_ML_028_000.<br>The OMR culvert is to be upsized from the existing 0.45m pipe culvert to a twin 0.6m pipe culvert, capable of conveying hydrological flows up to the 2% AEP event with a freeboard. An upstream sediment trap will be created and downstream scour protection will be required. | Major Adverse |
| A83_ML_030_000 | Not applicable | This will be the northern most watercourse that passes through the catch pit at the rear of the DFW. The culvert is to be upsized from the existing 0.5m pipe culvert that can convey events less frequent than a 50% AEP event to a 1.9m x 1.9m box culvert, capable of conveying hydrological flows well in excess of the 0.5% AEP +CC event. At the A83 culvert outlet it will be necessary to implement a diversion channel comprising concrete cascade (7.35m vertical offset) with transition mitigation including downstand, stilling feature and scour mitigation material. Up to 20m of channel protection will be required. This channel is already heavily modified, downstream of the cascade bank protection will be required to tie into the existing artificial, fibreglass lined channel, which may have to be widened to accommodate additional flow. | Minor Adverse |

| Watercourse Id / Crossing Reference | OMR crossing | Description and Embedded Mitigation (descriptions are based on the preliminary design and may ultimately change at detailed design but this will not result in more significant environmental impacts) | Magnitude |
|---|---|---|---|
| A83_ML_031_000 | OMR_30 | The current 1.2m (W) x 1.5m (H) box culvert crossing has a bedrock base and is capable of conveying hydrological flows in excess of the 0.5% AEP +CC event. It is being replaced by a clear span bridge, with a significantly greater conveyance capacity, due to the elevated risk of debris flow upslope of the A83 and as this location is not protected by the DFW or DFS. This bridge installation would open >25m of previously culverted channel.<br>The downslope side of the OMR bridge crossing is to be extended by 1.5m to accommodate a widened road. The extension would not impact the channel and would be capable of conveying the current channel capacity. | Minor Beneficial |
| A83_ML_032_000 | OMR_31 | The A83 culvert is to be upsized from the existing 0.9m pipe culvert that can convey events up to 10% AEP event to a culvert capable of conveying hydrological flows in excess of the 0.5% AEP +CC event.<br>No OMR improvement works directly impact this watercourse. | Minor Adverse |
| A83_ML_032_B01 | OMR_32 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_032_B02 | OMR_33 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_033_000 | OMR_34 | The A83 culvert is to be upsized from the existing 0.4m pipe culvert that can convey events up to a 0.5% AEP event to a culvert capable of conveying hydrological flows in excess of the 0.5% AEP +CC event.<br>The OMR culvert is to be upsized from the existing 0.375m pipe culvert to a 0.6m pipe culvert, capable of conveying hydrological flows up to the 2% AEP event with a freeboard. | Moderate Adverse |
| A83_ML_033_B02 | OMR_35 | No LTS improvement works directly impact this watercourse.<br>The OMR culvert is to be upsized from the existing 0.3m pipe culvert to a 0.6m pipe culvert, capable of conveying hydrological flows up to the 2% AEP event with a freeboard. | Minor Adverse |
| A83_ML_033_B03 | OMR_36 | No LTS or OMR improvement works directly impact this watercourse. | No Change |
| A83_ML_034_000 | Not applicable | The A83 culvert is to be upsized from the existing, partially collapsed, pipe culvert to a culvert capable of conveying hydrological flows in excess of the 0.5% AEP +CC event. The improved A83 drainage network (3A) would discharge via this A83 culvert. | Minor Adverse |
| A83_ML_035_000 | Not applicable | The A83 culvert is to be upsized to a culvert capable of conveying hydrological flows in excess of the 0.5% AEP +CC event. The improved A83 drainage network (3B) would discharge via this A83 culvert. | Minor Adverse |
| A83_B8_001_000 | Not applicable | B828 culvert to be extended and upsized to a culvert to convey the 0.5% AEP +CC event. | Minor Adverse |
| A83_B8_002_000 | Not applicable | B828 culvert to be extended and upsized to a culvert to convey the 0.5% AEP +CC event. | Minor Adverse |
| A83_B8_003_000 | Not applicable | B828 culvert to be extended and upsized to a culvert to convey the 0.5% AEP +CC event. | Minor Adverse |
| A83_B8_004_000 | Not applicable | B828 culvert to be extended and upsized to a culvert to convey the 0.5% AEP +CC event. | Minor Adverse |

### Operational Specific Mitigation

A19-4.4.43. Specific mitigation to minimise the impact on these watercourses will largely be related to the maintenance regime that will be adopted. It is understood that there will be frequent inspections and clearance of the catch pit to minimise the risk of blockage and accumulation of flow to the most southerly culvert. Maintenance to clear the sediment from culverts, should this be necessary, will also be conducted, with frequency to be determined and depending upon accumulations at various locations from routine and extreme events.

A19-4.4.44. Adaptive management of the watercourses will also be undertaken, as and when necessary. Channels inherently change, and continually adapt to their conditions; a maintenance and management strategy shall be developed to protect the critical infrastructure but with consideration for the hydromorphological functioning. Ultimately, working with natural processes, reduces the need for maintenance. Routine and ad-hoc maintenance currently occurs, although not all activities are beneficial for the hydromorphology of the channels. Previous management at the site has included diverting surface water flow paths, bed and bank protection, debris fences and traps and removal of sediment.

A19-4.4.45. Other specific mitigation measures that shall be introduced to all watercourses include:

- minimising the downslope protection, allowing the channel to naturally adjust to geomorphologically effective flows, where this does not introduce risk to the Proposed Scheme
- retaining the natural channel bed as far as is practicable
- reprofiling banks, if necessary, to accommodate a low flow and high flow channel (e.g. two stage channel)
- smoothing the transition between hard engineered features and the natural channel with boulders (e.g. creation of step-pool features) wherever possible

- fencing of the watercourses to prevent livestock access and promote vegetation growth, and associated improvements to slope and bank stability and
- Utilisation of coir matting, seeding or planting of native shrubs to accelerate hillside stability.

### Operational Residual Effect

A19-4.4.46. The operational residual effect to each watercourse is presented in Table 19-4.5, which is based on the implementation of the specific operational mitigation outlined in the previous sub-section.

**Table 19-4.5 Operational residual effects with mitigation**

| Watercourse Receptor ID | Sensitivity | Pre-Mitigation Impact | Post-Mitigation Impact | Residual Effect |
|---|---|---|---|---|
| A83_ML_Z05_B01 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B02 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B03 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B04 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B05 | Low | No Change | No Change | Neutral |
| A83_ML_Z05_B06 | Low | No Change | No Change | Neutral |
| A83_ML_008_A01 | Medium | No Change | No Change | Neutral |
| A83_ML_010_B02 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_011_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_012_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_014_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_012_B03 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_015_000 | High | Minor Adverse | Negligible | Slight |
| A83_ML_016_000 | Medium | Major Adverse | Moderate Adverse | Moderate |

| Watercourse Receptor ID | Sensitivity | Pre-Mitigation Impact | Post-Mitigation Impact | Residual Effect |
|---|---|---|---|---|
| A83_ML_017_000 | Medium | Minor Adverse | Negligible | Neutral |
| A83_ML_017_B01 | Low | Minor Adverse | Negligible | Neutral |
| A83_ML_018_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_019_000 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_020_000 | Low | Minor Adverse | Negligible | Neutral |
| A83_ML_021_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_022_000 | Medium | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_023_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_024_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_024_B01 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_025_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_026_B01 | Low | Minor Adverse | Negligible | Neutral |
| A83_ML_026_000 | Low | Major Adverse | Moderate Adverse | Slight |
| A83_ML_026_B02 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_027_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_028_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_029_000 | Medium | Major Adverse | Moderate Adverse | Moderate |
| A83_ML_030_000 | Low | Minor Adverse | Negligible | Neutral |
| A83_ML_031_000 | Medium | Minor Beneficial | Minor Beneficial | Slight Beneficial |
| A83_ML_032_000 | Medium | Minor Adverse | Negligible | Neutral |
| A83_ML_032_B01 | Low | No Change | No Change | Neutral |
| A83_ML_032_B02 | Low | No Change | No Change | Neutral |
| A83_ML_033_000 | Low | Moderate Adverse | Minor Adverse | Slight |
| A83_ML_033_B02 | Low | Minor Adverse | Negligible | Neutral |

| Watercourse Receptor ID | Sensitivity | Pre-Mitigation Impact | Post-Mitigation Impact | Residual Effect |
|---|---|---|---|---|
| A83_ML_033_B03 | Low | No Change | No Change | Neutral |
| A83_ML_034_000 | Low | Minor Adverse | Negligible | Neutral |
| A83_ML_035_000 | Low | Minor Adverse | Negligible | Neutral |
| A83_B8_001_000 | Medium | Minor Adverse | Negligible | Neutral |
| A83_B8_002_000 | Low | Minor Adverse | Negligible | Neutral |
| A83_B8_003_000 | Low | Minor Adverse | Negligible | Neutral |
| A83_B8_004_000 | Low | Minor Adverse | Negligible | Neutral |

## A19-4.5. Limitations and Further Assessment

A19-4.5.1. The assessment has been undertaken on the basis of data and design details available, applying the precautionary principle for uncertainties.

A19-4.5.2. The hillside is a dynamic system which responds to fluvial flows, debris flows and landslide events. These events in terms of magnitude and frequency are difficult to predict, and therefore design for. A considerable amount of geotechnical modelling has been undertaken, but with climate change and an evolving hillside, it is challenging to design sustainable, climate resilient infrastructure in this area. It is recognised that maintenance (e.g. sediment clearance) will continue to play an important role for ongoing performance of the A83.

A19-4.5.3. Ongoing monitoring of the slopes to evaluate movement and repeated Unmanned Aerial Vehicle (UAV) surveys should continue.

A19-4.5.4. There are geotechnical uncertainties as GI works have not been completed, therefore the design may be subject to change based on the GI results but also the viability to construct. The downslope structures (e.g. concrete cascades and stilling features) are based on hydraulic engineering principles and feasibility checks, however, the proposed downslope protection is innovative and untested in this steep environment.

A19-4.5.5. Test sites are recommended in this area to compare downslope protection at the transition zone between hard engineering feature and the more natural hillside.

A19-4.5.6. Slope stability would be improved by preventing livestock access and planting shrubs and trees. Following establishment of vegetation, this offers a sustainable method to reduce hillslope runoff (via altered interception and infiltration processes), associated erosion and sediment entrainment, as well as habitat and biodiversity benefits.

## A19-4.6. Summary and Conclusion

A19-4.6.1. Table 19-4.6 and Table 19-4.7 present the residual effects of construction and operation impacts onto watercourses after mitigation has been applied.

A19-4.6.2. There are 11 watercourses that are assessed with residual moderate adverse (significant) effects during construction, 24 slight adverse (not significant) and 10 assessed as neutral (not significant).

A19-4.6.3. During operation, 8 watercourses have been assessed as having residual moderate adverse (significant) effects, 13 slight adverse (not significant) and 23 assessed as neutral (not significant). One watercourse has been assessed with a residual slight beneficial (not significant) effect during the operational phase.

**Table 19-4.6 Summary of construction residual effects with specific mitigation**

| Watercourse Importance/ Effects | Moderate Adverse | Slight Adverse | Neutral |
|---|---|---|---|
| High | 0 | 1 | 0 |
| Medium | 11 | 6 | 1 |
| Low | 0 | 17 | 9 |

**Table 19-4.7 Summary of operational residual effects with specific mitigation**

| Watercourse Importance/ Effects | Moderate Adverse | Slight Adverse | Neutral | Slight Beneficial |
|---|---|---|---|---|
| High | 0 | 1 | 0 | 0 |
| Medium | 8 | 5 | 4 | 1 |
| Low | 0 | 7 | 19 | 0 |

A19-4.6.4. It is recognised that the watercourses in this area are already adversely impacted by existing physical modifications and maintenance regimes (e.g. sediment trapping and clearance), but the scale of the works to ensure that the A83 is appropriately protected are extensive and would further interrupt the flow and sediment regimes of these watercourses.

A19-4.6.5. Flow and sediment would ultimately reach the Croe Water, Water Framework Directive (WFD) water body, in the base of the glen, with a Slight Adverse effect to the supply of sediment, due to the DFS inlets being grated with 100mm spacings (impact would be negligible as significantly more than 90% of all sediment sampled in the tributaries was <100mm in diameter). The downstream stretch of the Croe Water is where the more valuable morphological features, and ecological habitat prevail.

A19-4.6.6. Enhancement of the Croe Water (riparian zone) is proposed as part of the Biodiversity Net Gain (BNG) strategy (Volume 4, Appendix 4.1 - Biodiversity

Net Gain / Natural Capital Assessment). This includes fencing and planting alongside the Croe Water to create buffer areas and reduce fine sediment and nutrient supply to the watercourse as well as shading and sheltering. These activities would improve water quality, hydromorphology and biological quality elements in this more sensitive area, which would aid in achieving WFD objectives and offset some of the modifications in the less ecologically sensitive headwaters.

# Annex 19-4-1 Sensitivity testing by hydraulic modelling

## A19-4.7. Introduction

A19-4.7.1. This Annex provides detailed explanation of the process undertaken to develop a good understanding of discharges and flow velocities at the crossing locations and downstream, including sensitivities from altering some of the design parameters on hydraulics.

A19-4.7.2. The hydrological and hydraulic modelling approach for this project is outlined in more detail within Volume 4, Appendix 19.6: RDWE Flood Risk Assessment. There are numerous limitations and assumptions made as it is a complex system to model. Caution should therefore be applied when analysing the absolute figures, with comparative values perhaps providing more utility, rather than the absolute values, both between the baseline and Proposed Scheme and between individual watercourses. These data have led to definition of the high risk watercourses (see Volume 4, Appendix 19.3: RDWE Baseline).

A19-4.7.3. The assessment has informed the design of the A83 culverts, passing beneath the DFS and DFW to help reduce flow velocities and scour potential at the inverts and to ensure that sufficient sediment is transferred from upslope to downslope.

A19-4.7.4. Section A19-4.8, of this Annex, compares the velocities at the closed culvert downstream invert between the Baseline and the Proposed Scheme. Section A19-4.10 describes the sensitivity testing to inform the embedded mitigation applied to reduce the velocities.

## A19-4.8. Baseline vs Proposed Scheme

A19-4.8.1. Not all the watercourses were modelled. To give a good indication of the relative change and maximum velocities that may be experienced, Watercourses A83_ML_023_000 to A83_ML_029_000 were modelled. These are identified on Volume 3 Figure 19.3, in the centre section of the Study Area.

A19-4.8.2. The flow path between the existing watercourses upslope of the DFS and where the watercourses would return to their existing alignment downslope of the DFS has been conceptualised as a series of sections, as set out in Plate A19-4.1 and Table 19-4.8.

**Plate 19-4.1 Hydraulic model schematic**

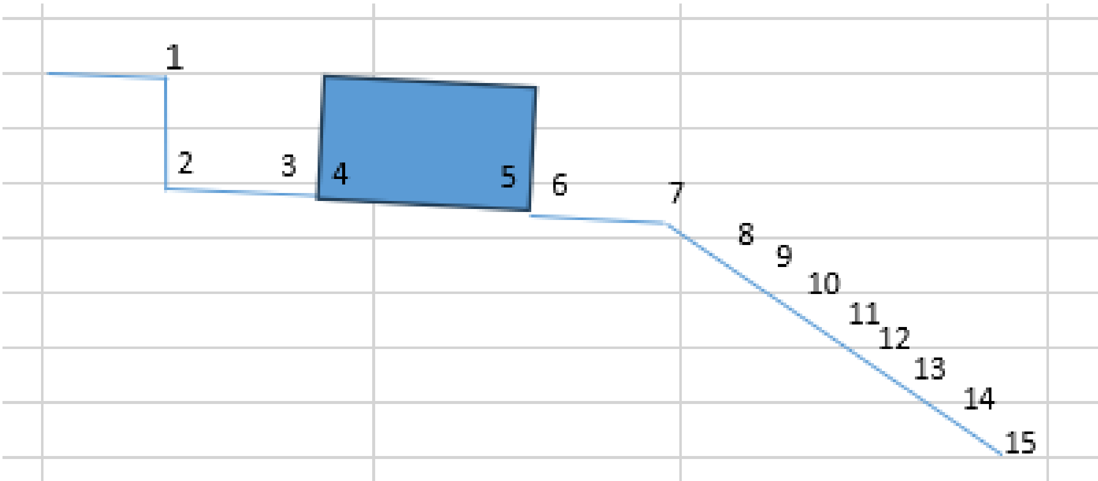



**Table 19-4.8 Summary Conceptualisation of the flow path from above the catch pit to the transition with the downstream watercourse**

| Section | Description | Assumptions |
|---|---|---|
| 1 | Existing watercourse upslope of the DFS | Cross sections can be taken from the DSM |
| 2 | The upslope face of the DFS | Flows would be allowed to freefall into the DFS where the DFS intersects the existing channel |
| 3 | Water in the DFS would flow to the next culvert inlet downslope | The bed of the DFS has a gradient of 5% towards the culvert inlet and the inlets are maintained unblocked |

| Section | Description | Assumptions |
|---|---|---|
| 4 | Flow passes through a 100mm horizontal grate, over a cascade and enters a closed channel upstream of the culvert inlet | The grate remains unblocked |
| 5 | The culverted section | The culvert bed gradient is 5%; the inlet type is assumed to be a square edge Type A – concrete |
| 6 | An open channel section to act as a transition between the culvert and the existing channel | The open channel bed gradient is 2.5% |
| 7 to 15 | The existing channel | Cross sections can be taken from the DSM |

A19-4.8.3. The length of the open channel (6 to 7) section that acts as a transition between the culverted section and the existing watercourse downslope of the DFS varies for each watercourse, dependent on the natural gradient of the existing channel and culvert outlet location.

A19-4.8.4. The hydraulic models have been run in steady state with checks undertaken using selective unsteady state runs, to ensure that steady state results can be used. Transcritical mode checks have also been carried out due to the occurrence of supercritical flow (rapid and/or unstable flow).

A19-4.8.5. It is acknowledged that the hydraulics of these watercourses is complex and that a 1D model is a relatively simple approach. However, it is considered sufficiently robust at this design stage to identify hydraulic controls and check the sensitivity of the design.

A19-4.8.6. The results have been summarised in Table 19-4.9 The Proposed Scheme provides a substantial reduction in velocities ranging from 29% to 65% compared to baseline with velocities ranging between 2 m/s and 5 m/s at the end of the closed culvert. The reduction in velocity is mainly related to the increased size of the culverts for the Proposed Scheme and would help to dissipate the energy of the flow as it transitions to the downslope channel. The velocities then pick up at Section 7 (Plate 19-4.1) because of the steep slope and the Proposed Scheme velocities are similar to that of the Baseline, generally between 6 m/s and 8 m/s.

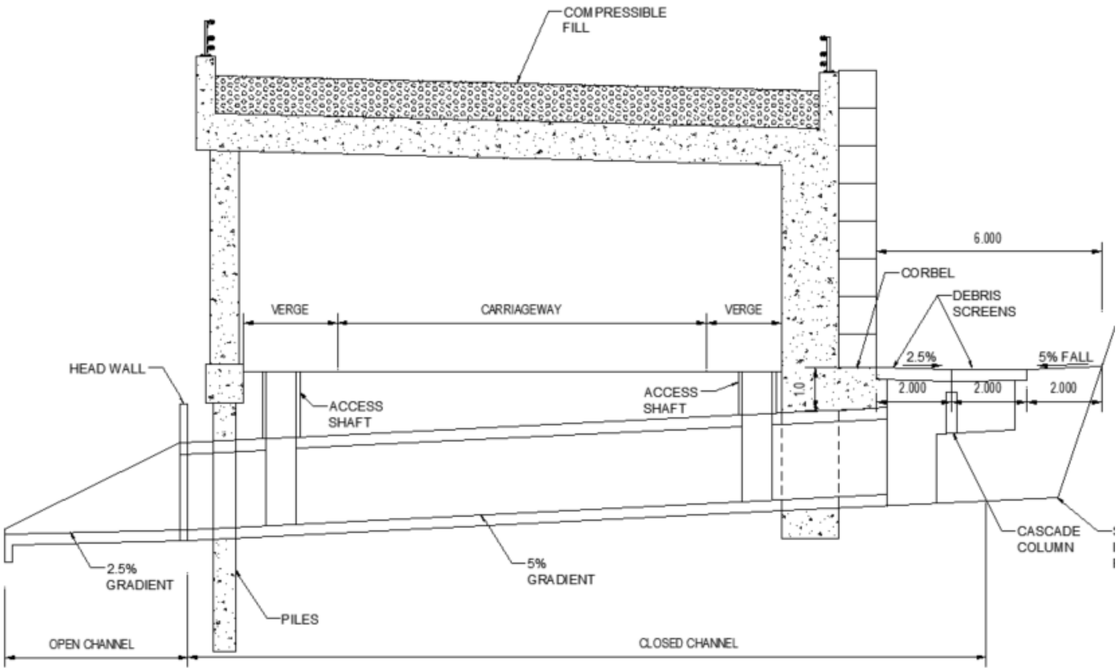
**Table 19-4.9 Baseline and Proposed Scheme comparison of modelled velocity of selected watercourses**

| Watercourse | 1:200-year flow + 46% Climate Change ($m^3/s$) | Relative velocity change between Baseline and Proposed Scheme at closed culvert downstream invert (%) | Velocity of Proposed Scheme at closed culvert downstream invert (m/s) |
|---|---|---|---|
| A83_ML_023_000 | 0.25 | -55% | 1.94 |
| A83_ML_024_000 | 3.64 | -42% | 5.16 |
| A83_ML_025_000 | 2.13 | -46% | 3.78 |
| A83_ML_026_000 | 1.02 | -57% | 2.86 |
| A83_ML_027_000 | 2.13 | -29% | 4.00 |
| A83_ML_028_000 | 2.13 | -37% | 2.82 |
| A83_ML_029_000 | 0.72 | -65% | 2.05 |

## A19-4.9. Options Identification

A19-4.9.1. The following sections will focus on the Debris Flow Shelter crossings which each comprise a 1.9m x 1.9m culvert. The design is work in progress but an indicative sketch for illustration purposes is shown in Plate A19-4.2.

**Plate 19-4.2 Indicative Drawing of Debris Flow Shelter Crossing**




A19-4.9.2. There are 3 main elements to the watercourse realignment design:

- upstream transition and culvert inlet including the catch pit
- culvert structure (5% gradient closed culvert, followed by 2.5% open channel) and
- downslope protection and transition.

### Upstream transition and catch pit

A19-4.9.3. The 6m wide catch pit would effectively trap any of the large material that is supplied from upstream of the A83 and this will be periodically cleared of debris. The catch pit has a 5% slope from north to south to allow for free drainage and provide hydraulic connectivity in the event of inlet blockage scenarios (resulting from debris flows and sediment build up). If a culvert inlet is blocked, flow would be directed to the next culvert, to the south.

A19-4.9.4. Sediment transport continuity to transfer from upstream to downstream is important for both morphological (avoidance of sediment starvation and greater competence to erode rather than transport material) and ecological (gravels for fish habitat in the shallower downstream rivers) reasons. Debris screens are necessary at the culvert inlet to minimise the risk of blockage due to a debris flow, landslide event, or large boulders entering the culvert. The grates will be set back from the toe of the rock cutting within the catchpit to reduce the risk of damage and blockage.

A19-4.9.5. The size of the debris screen grate spacing can vary but sediment transport analysis indicates that the energy within the culverts should be sufficient to transport sediment <100mm in diameter. This will enable the downslope channels to retain some natural functions and supply gravels to support the salmonid habitat in the Croe Water. This was based on empirical evidence (>90% of the sediment recorded in the watercourses was <100mm, see the detailed watercourse characterisations in Annex 19-3-1 of Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline) and the likely competence of the flows. Due to low flow rates and relatively shallow depths, it is unlikely that larger material would be entrained and transported through the culvert. The design of the inlet has been developed iteratively through multi-disciplinary discussions. One improvement which has been recommended is a sloping inlet to the closed culvert rather than a stepped approach to ensure sediment does not drop through the debris screen and accumulate on the ledge (Plate A19-4.2).

A19-4.9.6. Sediment entrainment calculations form part of the assessment to optimise the design through the culvert and downstream to enable <100mm sediment to be transported. With grate spacings of 100mm, any material greater than 100mm would be trapped within the catch pit and not pass through the inlet and culvert. Periodic maintenance (sediment clearance) of the catch pit will be required to ensure that the culvert inlets remain clear, including after heavy rainfall and high flow conditions (as well as following any debris flow / landslide events).

### Culvert

A19-4.9.7. It is proposed to utilise steep box culverts to convey flows under the A83, whilst avoiding overly steep gradients which will create difficulties for accessing to maintain and inspect. An initial longitudinal slope of 5% has been proposed for the box culvert. The engineered open channel downstream of the culvert is currently proposed at 2.5% longitudinal gradient to provide a length of channel which can be used for energy dissipation prior to the transition and tie-in with the existing channel downstream. Gradients for the proposed culverts and aprons will be subject to further analysis and revision at the specimen and detailed design phases. Site specific gradients will also be assessed. Criteria influencing the gradient of the proposed culverts are as follows:

- The culvert gradient should be sufficiently steep enough to transport sediment through the structure (self-cleansing).
- The gradient of the culvert and open channel should avoid excessively steep gradients to allow for access and maintenance. The design shall be such that the frequency of access for

maintenance and inspection will be minimised, however it is recognised that infrequent entry may be required and so suitable provision for doing so should be embedded within the design.

- The open channel needs to slow the flow and dissipate the energy before it outfalls onto the existing flow path down the steep hillside. This will require relatively shallow longitudinal gradients to make this feasible.

A19-4.9.8. The downslope transition point would be the most vulnerable to scour because of the marked change in gradient, and the transition from non-erodible to erodible material. Some sensitivity testing on the culvert gradient and dissipation measures are presented in Section A19-4.10. Table 19-4.10 and Table 19-4.11 describe the benefits and constraints of the options considered for managing energy through the culverts and open channels.

A19-4.9.9. The width of the open channel is not influenced by maintenance and inspection requirements, unlike the closed culvert. It may be preferable to therefore utilise a wider apron section to help spread the flow and lower the velocities during high flow events. Some reprofiling of the existing channel at the tie in will likely be required to achieve this. with this area immediately downstream of the outfall to be protected from erosion. The length of the open channels may vary, to integrate better with existing slope topography. Further consideration of energy dissipation and scour protection options at the channel transition are provided in Table 19-4.11 and Table 19-4.12.

**Table 19-4.10 Option appraisal for watercourse crossing design**

| Problem | Solution | Description | Benefits | Constraints | Other considerations (consenting, other risks) | Proceed for further assessment/design (justification, if no) |
|---|---|---|---|---|---|---|
| Culvert alignment | Downstream alignment | • Aligned to downstream channel – perpendicular to road | • Aligns channel to downstream flow direction helping to mitigate some bank scour risk<br>• Reduced number of culverts required across the scheme resulting in reduced cost and shorter construction programme<br>• No impact on current pile design | • Potential environmental impact as flow characteristic of the catchments is altered<br>• Some culverts will have their intended watercourse bypass the culvert<br>• Some culverts will have the flow of two watercourses which could result in channel widening/ increased scour<br>• Could require additional channel modifications upstream of the culvert to correct the watercourse alignment | • Bypassing culvert inlets will result in multiple catchments combining into a single culvert. Likely to increase scour in the downstream channel due to increased flow | Yes |
| Culvert Form | Upstream alignment | • Aligned to upstream channel – perpendicular to road | • Perpendicular culvert with no impact on the current pile design<br>• No works required to the upstream side, whereas the downstream side requires significant works anyway | • Requires downstream realignment - additional construction activity resulting in increased cost<br>• Difficult construction access<br>• Will require lining/ extensive stabilisation works to mitigate scour/ headcutting | • Ground conditions unknown meaning scour risks cannot be easily quantified<br>• Channel diversion will have a short-term and long-term stability risk (headcutting process can place road/structure at risk)<br>• Additional design activity could impact programme | Yes |
| Culvert Form | Aligned with existing | • Aligned to existing channel upstream and downstream of the A83, skewed to the road | • Reduces need for upstream channel modifications therefore more environmentally friendly<br>• Less costly as other solutions<br>• Maintains existing hydrology designs thus less work required<br>• Maintains natural channel alignment | • Requires change to foundation design<br>• Widening of the spacing of foundation piles locally would Increases the loading on the adjacent pile foundations | • Assumed maximum skew angle is 10 degrees<br>• Potentially requires redesigning pile foundations<br>• Increased risk of bank scour at transition | No -piles are spacing constraints |

| | | | | | | |
|---|---|---|---|---|---|---|
| Culvert Form | Bridge | • Open bottom culvert or bridge structure | • Allows existing channel gradient to be maintained | • Longer construction programme<br>• Uneven invert may be more difficult to walk one – inhibits person entry for maintenance and inspection<br>• Bed will require armouring to prevent scour, negating benefits of a portal frame culvert | • High risk of scour without additional armouring measures | Yes |
| Culvert Form | Box | • Closed box culvert structure | • Even surface on invert for maintenance and access | • May be prone to deposition without additional mitigating measures | • Sediment deposition risk to be given further consideration (i.e. maintain flows, limit sediment size entering culvert | Yes |
| Culvert Form | Pipe | • Pipe structure | • Curved invert provides improved low flow channel | • Typically comes in smaller sizes relative to box and portal – may inhibit access for maintenance and inspection | • Confined space entry is likely to be higher risk with a pipe | No –inaccessible for maintenance |
| Culvert Form | Flat concrete bed | • Full width of culvert base, smooth concrete. | • Easy to inspect and maintain (e.g. clear sediment). | • Spreads flow evenly across entire width which minimises velocities and promotes sediment deposition.<br>• May not be self- flushing at low and moderate flows. | • SEPA suggest culverts over 2% have a baffle arrangement to retain natural sediment for continuity and dissipate high energy flows, however these steep headwater streams are not aquatically sensitive and do not require a natural bed for ecology.<br>• Structure would be a confined space so design must minimise maintenance requirements due to deposition. | Yes |
| Sediment conveyance and energy management | Flat concrete bed with baffles | • Perpendicular baffles or sloping baffles | • Baffles would disrupt the higher flows and dissipate the energy, reducing the velocities/stream powers through the culvert and towards the open channel. | • Sediment transferred to the culvert barrel may be trapped behind the baffles, raising the bed level and promoting deposition across the width of the culvert.<br>• More difficult to maintain (e.g. clear sediment) with regular upstands in the culvert. | • Height of baffles could vary up to 300mm. HEC14 check confirms 300mm appropriate.<br>• Structure would be a confined space so design must minimise maintenance requirements due to deposition. | Yes |
| Sediment conveyance | Flat concrete bed with | • Perpendicular or sloping baffles with a lower narrow channel slot. | • Focuses low and moderate flows in the centre of the culvert to maximise sediment transfer through the culvert. | • Some sediment, especially the larger material may be trapped behind the baffles, potentially raising the bed level and promoting | • Optimum low flow channel dimensions to transfer sediment of agreed size to be estimated through sediment entrainment calculations. | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| and energy management | baffles and low flow channel | | • Baffles would dissipate energy during the higher flows.<br>• Alternate downstream sloping baffles would not trap as much sediment as perpendicular baffles. | aggradation along the channel margins. | • To minimise maintenance, regular self flushing (e.g. during a Q2, / 50% AEP event) is recommended.<br>• Structure would be a confined space so design must minimise maintenance requirements due to deposition. | |
| Sediment conveyance and energy management | V shaped concrete bed | • V shaped culvert bed to focus lower flows | • Easy to inspect and maintain (e.g clear sediment).<br>• Focuses flow toward the centre of the culvert.<br>• Minimises risk of sediment build up in the culvert barrel.<br>• Maximises sediment transfer potential over all flow events. | • High velocities likely to be experienced during high flow events. | • Roughness/dissipation could be introduced through other measures (e.g. gravel/cobble bed) or within the downstream open channel which is easier to maintain.<br>• Structure would be a confined space so design must minimise maintenance requirements due to deposition. | Yes |

**Table 19-4.11 Option appraisal for open channel design**

| Problem | Solution | Description | Benefits | Constraints | Other considerations (consenting, other risks) | Proceed for further assessment/design (justification, if no) |
|---|---|---|---|---|---|---|
| Scour mitigation/energy dissipation required at outlet of culvert | Baffles (e.g.300mm upstands) | • Perpendicular or sloping baffles with a lower narrow channel or v slot. | • Focuses low and moderate flows in the centre of the culvert to maximise sediment transfer through the culvert.<br>• Baffles would dissipate energy during the higher flows. | • Some sediment, especially the larger material may become trapped behind the baffles at the margins. | • Height of baffles could vary up to 300mm. HEC14 check confirms 300mm appropriate. | Yes |

| Problem | Solution | Description | Benefits | Constraints | Other considerations (consenting, other risks) | Proceed for further assessment/design (justification, if no) |
| --- | --- | --- | --- | --- | --- | --- |
| Scour mitigation/energy dissipation required at outlet of culvert | Roughened bed (embedded boulders) | • Buried boulders in the concrete bed. | • Protruding rocks would break up flow and reduce velocities and in turn the erosive force at the transition. Provides a natural looking surface compared to smooth concrete. | • Plucking force may be high so boulders would need to be adequately buried. • Maintenance (e.g. sediment clearance) may be difficult. | • Positioning boulders on the margins and accommodating a low flow channel or v slot would help with sediment conveyance. • Boulders could be positioned and act as baffles to promote some build up of natural sediment but allow easier maintenance (sediment clearance) if required. | Yes |
| Scour mitigation/energy dissipation required at outlet of culvert | Concrete flow breaker with orifice | • Wall of concrete with aperture. | • Allows the flow to back up behind and overtop as required. Allows a regulated flow through. | • Back up of flow would promote accelerated deposition / aggradation and potentially block the opening. • Sediment transfer would be adversely impacted. • Small opening would increase the jetting affect/velocity/erosive power as the flow outfalls. | • Different designs would have different hydraulic impacts but would essentially negate the benefits of a larger culvert minimising the jetting impact which currently exists. | No -Sediment deposition/ Maintenance |
| Scour mitigation/energy dissipation required at outlet of culvert | Weir structure | • Upstand that slows flows. | • Ponds the flow behind to reduce the velocity. | • Sediment would build up behind the weir aggrading the bed. Low flows may be impeded, as well as sediment continuity. | • Low flow slot could be considered. | No - Sediment deposition/ Maintenance |

### Downslope Protection

A19-4.9.10. The existing channels immediately downslope of the crossings clearly demonstrate the erosion potential of high flows in this area and would need to be adequately mitigated for. Whilst the larger proposed culverts would aid this to a certain degree (less "jetting" action), given the steep topography and the flashy nature of the system with a risk of debris flows, the area transition from the hydraulic structures to the existing channels will require protection to avoid the risk of downcutting and the culvert inverts being exposed. The downslope protection has been appraised based on whether the proposed culvert apron elevation ties in with the existing downstream channel. Where this is the case then downslope protection will be proposed in line with the options defined in Table 19-4.12. Additional engineering measures which are required to provide a tie-in between the hydraulic structures and the existing channel are appraised in Table 19-4.13. For these locations a transition feature will be required for scour mitigation, which will also be selected from the options defined in Table 19-4.12.

A19-4.9.11. In addition to the options appraisal tables, reference should be made to the baseline assessment of the watercourses in Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline. This helps inform the type and spatial extent of the downslope protection. An indicative length and likely features / modifications have been provided at this stage, but design for each of the watercourses immediately downslope of the DFS culverts are ongoing.

**Table 19-4.12 Option appraisal for scour mitigation measures at transitions**

| Problem | Solution | Description | Benefits | Constraints | Other considerations (consenting, other risks) | Proceed for further assessment/design (justification, if no) |
|---|---|---|---|---|---|---|
| Scour mitigation/energy dissipation required at transition from hydraulic structures to existing channel | Rock/boulder cascades | • Large boulder positioned to reflect a natural step/pool cascade feature. May require securing. | • Replicates a natural feature and watercourse function to slow flow and reduce velocities and scour potential. | • Unstable ground, weight of rock may exacerbate risk of landslip.<br>• Securing large boulders to a steep slope with unconsolidated material may be difficult and prone to failure.<br>• Risk to OMR (blockage and damage) if boulders are undermined or/and transported downstream in a debris flow. | • Engineered boulder cascades usually designed for slopes <15%. A83 has slopes >45%. | No - Very large rock would be required, which would be difficult to secure |
| Scour mitigation/energy dissipation required at transition from hydraulic structures to existing channel | Concrete drop structure | • Concrete drop structure and stilling basin to dissipate energy before flowing downstream. | • Controlled dissipation which can be sized appropriately to flow and velocity. | • May be prone to sedimentation and impede transfer of material downstream.<br>• Extends hard protection and transfers risk of erosion to transition with existing channel.<br>• Structure would require solid support; unconsolidated ground and bedrock depth variable across hillslope. | • Requires excavation at base of slopes with existing stability issues. | No - Sediment deposition/ Maintenance |
| Scour mitigation/energy dissipation required at transition from | Stilling basin | • Energy dissipation achieved through measures such as plunge pools, impact basins or induced hydraulic jump basins. | • Stilling basin helps regulate and control flow velocities at transition.<br>• Depending on solution, can be formed from materials with a more natural aesthetic. | • Spatial constraints may limit size, and thus effectiveness, of option. | • Stilling basins may accumulate sediment over time, reducing their effectiveness.<br>• Requires excavation at base of slopes with existing stability issues. | Yes |

| Problem | Solution | Description | Benefits | Constraints | Other considerations (consenting, other risks) | Proceed for further assessment/design (justification, if no) |
|---|---|---|---|---|---|---|
| hydraulic structures to existing channel | | | • Solution submerged (with exception of impact basin) resulting in reduced visual impact.<br>• Likely to be self-cleansing during high flows. | | | |
| Scour mitigation/energy dissipation required at transition from hydraulic structures to existing channel | Reprofiled slopes/banks | • Pull back banks to widen channel to better accommodate high flows. | • Sustainable measure which would allow for some adjustment and promote natural form and function.<br>• 2 stage channels can be designed to concentrate low flows. | • Not likely to be adequate to protect the channel from scour at the transition between the concrete open channel and hillside. Topography may restrict how the banks can be reprofiled | • Channel sized for each individual watercourse.<br>• To be used in combination with other measures.<br>• Fencing to reduce grazing pressures and planting to help stabilise the hillside also recommended. | Yes |
| Scour mitigation/energy dissipation required at transition from hydraulic structures to existing channel | Geo-engineered – scour mitigation | • Rock roll/bags/cells made from high strength steel and anchored to the channel invert or hillside banks. | • Can be flexible in terms of size and depth and constructed to the desired shape/profile of the channel including steps to help dissipate energy, using locally-won material.<br>• Coarse material within the cell absorbs the flow and dampens the energy reducing erosive power.<br>• Products can withstand high flow velocities and can be made of high strength steel to minimise the risk of damage/failure. | • Some flow would be lost through the rock until fines and gravels fill the voids and then the dissipation efficiency may be lost.<br>• Loss of flow may impact the competence to move sediment downstream.<br>• These products are untested on slopes of this magnitude and present a buildability challenge. | • Lateral and downstream tie ins to be anchored and tapered. | Yes |

**Table 19-4.13 Option appraisal for downslope tie-in measures**

| Problem | Solution | Description | Benefits | Constraints | Other considerations (consenting, other risks) | Proceed for further assessment |
|---|---|---|---|---|---|---|
| Tie-in channel required between proposed culvert apron and existing channel – Vertical alignment options | Linear bed profile | • Linear bed profile without integrated energy dissipation. | • Simple to construct and design.<br>• Highly efficient conveyance parameters.<br>• Utilises a single energy dissipator at transition. | • Does not provide effective energy dissipation.<br>• High flow velocities, increasing the risk of scour at transition necessitating more extensive dissipator/ scour mitigation. | • High scour risk at the transition - needs to be managed. | No – results in high velocity flows increasing scour risk |
| Tie-in channel required between proposed culvert apron and existing channel – Vertical alignment options | Baffled channel | • Linear bed profile with integrated energy dissipation. | • Baffles can effectively dissipate energy depending on unit discharge and slope angle.<br>• Baffles can facilitate the settling of suspended sediments.<br>• Can be affixed to a linear bed profile which may be simpler to construct than a cascade type structure.<br>• Reduces flow velocity reducing scale of transition energy dissipator/ scour mitigation. | • Baffles may require additional maintenance over time due to accumulation of debris and sediment.<br>• Baffles can be susceptible to creation of vortices which result in abrasion/cavitation along the channel invert. | • Risk of failure due to cavitation erosion effects.<br>• Risk of failure due to abrasion erosion effects.<br>• Risk of failure due to seepage and liquefication if the baffle fixings are drilled into the base of the channel.<br>• If not well installed flow can get underneath the baffle and uplift pressure can dislodge or overturn the baffle overtime.<br>• Energy dissipators would likely need to be affixed to a concrete invert. | No – channel gradients unlikely to work in conjunction with baffles |
| Tie-in channel required between proposed culvert apron and existing channel – Vertical alignment options | Cascade | • Stepped bed profile following existing gradient of hillside/A83 embankment | • Can provide effective energy dissipation in steep environments<br>• Reduces flow velocity reducing scale of transition energy dissipator/ scour mitigation<br>• The interaction between water and steps enhances aeration, improving water | • May be more difficult to construct and design than linear profile.<br>• Higher construction costs.<br>• Potential for debris accumulation.<br>• Non-natural appearance. | • Scour risk at the transition- needs to be managed.<br>• Risk of failure due to cavitation erosion effects.<br>• Risk of failure due to abrasion erosion effects.<br>• Risk of failure due to seepage and flow loss at construction joints. | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | quality by increasing oxygen levels<br>• More closely mimics flow regime for naturally (i.e. bedrock cascade) steep watercourses<br>• Existing cascades on A83 indicate this is a viable option, though is dependent on scale required | | • Risk of structural failure due to roll waves/shock waves acting on structure.<br>• Risk of structural failure due to stagnation pressures occurring at joints and drainage outlets, increasing uplift.<br>• Diversion likely to be too steep for natural bed forms therefore engineered cascade would be required. | |
| Tie-in channel required between proposed culvert apron and existing channel – Vertical alignment options | Drop structures/Check Dams | • Utilising a series of larger drops (compared to cascade) to dissipate energy and provide tie-in | • Reduces bed slope between structures.<br>• Reduces flow velocity reducing scale of transition energy dissipator/ scour mitigation.<br>• More likely to encourage sedimentation on drops which could improve aesthetics. | • Requires larger excavation volume to implement due to anticipated drop heights (i.e. >1m drops) and long basin lengths to accommodate hydraulic jumps. | • Risk of failure due to cavitation erosion effects.<br>• Risk of failure due to abrasion erosion effects.<br>• Risk of failure due to seepage and flow loss at construction joints.<br>• Risk of structural failure due to roll waves/shock waves acting on structure<br>• Drop structure wo.uld need to be constructed from concrete. | No – excavation requirements will be difficult to implement |
| Tie-in channel required between proposed culvert apron and existing channel – Channel form | Concrete channel | • Concrete lined channel or rectangular concrete channel | • Smooth surfaces and straight sides ensure efficient water flow<br>• Durable material requires minimal maintenance. Concrete channels have a long service life.<br>• Bed invert not susceptible to scour. | • Increased downstream scour risks due to increased velocities resulting from smooth surface.<br>• Non-natural aesthetic.<br>• High costs.<br>• Requires additional ancillary works (formwork reinforcement etc) to implement. | • Possible abrasion erosion risks due to high velocities and heavy sediment loads.<br>• Possible differential settlement risks due to non-flexible arrangement. | Yes |
| Tie-in channel required between proposed culvert apron and existing | Geo-engineered | • Rock mattress/high tensile steel mesh/rock bags/reno mattress type solution to | • Rock mattresses provide effective erosion control whilst maintaining a more natural appearance compared to concrete. | • Operational limits may be exceeded on A83 due to steep slopes, high velocities and heavy sediment loads. | • If mesh structure fails then unit will fail instantly due to small rock armour sizing contained within the unit. | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| channel – Channel form | | form channel bed and/or banks | • Rough surface helps to dissipate energy, reducing flow velocity.<br>• Plentiful supply of rock on site to fill gabions/reno/tecco.<br>• Flexible arrangement will better accommodate settlement and material loss compared to concrete. | • Presence of void spaces reduces effectiveness of energy dissipation when used in a cascade. | | |
| Tie-in channel required between proposed culvert apron and existing channel – Channel form | Composites | • Glass reinforced plastic/fibreglass channel | • Resistant to corrosion.<br>• Efficient conveyance due to low friction.<br>• Lightweight and therefore easier to transport and install compared to concrete.<br>• Can be manufactured to fit specific design requirements and more malleable during initial formation. | • Higher material costs compared to concrete.<br>• Degradation over time can lead to microplastic pollution.<br>• Production of GRP involves environmental impacts related to the use of resins and fibres.<br>• Specialized installation.<br>• Less resistant to heavy impacts compared to concrete.<br>• Can be affected by temperature changes, leading to potential deformation.<br>• Lightweight and therefore requires additional anchoring to mitigate uplift. | • May be susceptible to uplift, particularly when used in a stepped arrangement.<br>• Risk of microplastic pollution in watercourse downstream. | No – smooth surfaces encourage high velocities |
| Tie-in channel required between proposed culvert apron and existing channel – Channel form | Naturalised | • Utilising natural bedforms such as rocks and boulders to form channel bed and/or banks | • Maintains natural geomorphology.<br>• More natural aesthetic. | • Higher risk of material loss due to scour of fines which support the boulders. | • High risk of failure due to scouring of fines which are used to embed the boulders. | No – will be difficult to anchor and are likely to mobilise during debris flows |

## A19-4.10. Watercourse Sensitivity Analysis

### Crossing Structure

A19-4.10.1. A series of modelling exercises have been performed to inform the design of the A83 culverts, passing beneath the DFS and DFW, to reduce flow velocities/scour potential as the flows pass to the downstream watercourses and to ensure that sufficient sediment is transferred from upslope to downslope.

### Hydraulic modelling – sensitivity testing

A19-4.10.2. The schematic of the 1d model long profile is shown in Plate A19-4.1. The culvert 'barrel' beneath the A83 is located between cross-sections 4 and 5. Cross section 7 is the transition point at which the model changes from an open channel culvert apron to the natural watercourse at cross-section 8.

A19-4.10.3. For a general understanding of the impacts of specific changes to the culvert on flow velocity and depth the following scenarios were investigated:

- Baseline scenario consisting of a flat 1.9m width box culvert with a 5% culvert gradient from the catch pit drop structure to the culvert outlet.
- S1 - Increasing the depth of the step (cross section 1 to 2 in the schematic) by 500mm and maintain the gradient through the culvert from cross section 2 through to 5 at 5%.
- S2 - Increasing the gradient through the culvert from cross section 2 to 5 by 2% (from 5% to 7%). This would result in cross section 7 moving further downslope, closer to cross section 8 but reduce the difference in gradient from cross section 6 to 7 and 7 to 8.
- S3 - Increasing the culvert/barrel roughness to reflect internal baffles (Manning n from 0.02 to 0.04). Assuming baffles being approximately 200-300mm high, with an un-restricted central low flow channel, approximately 300-500mm wide (to be determined through comparison of modelled velocities and sediment entrainment calculations).

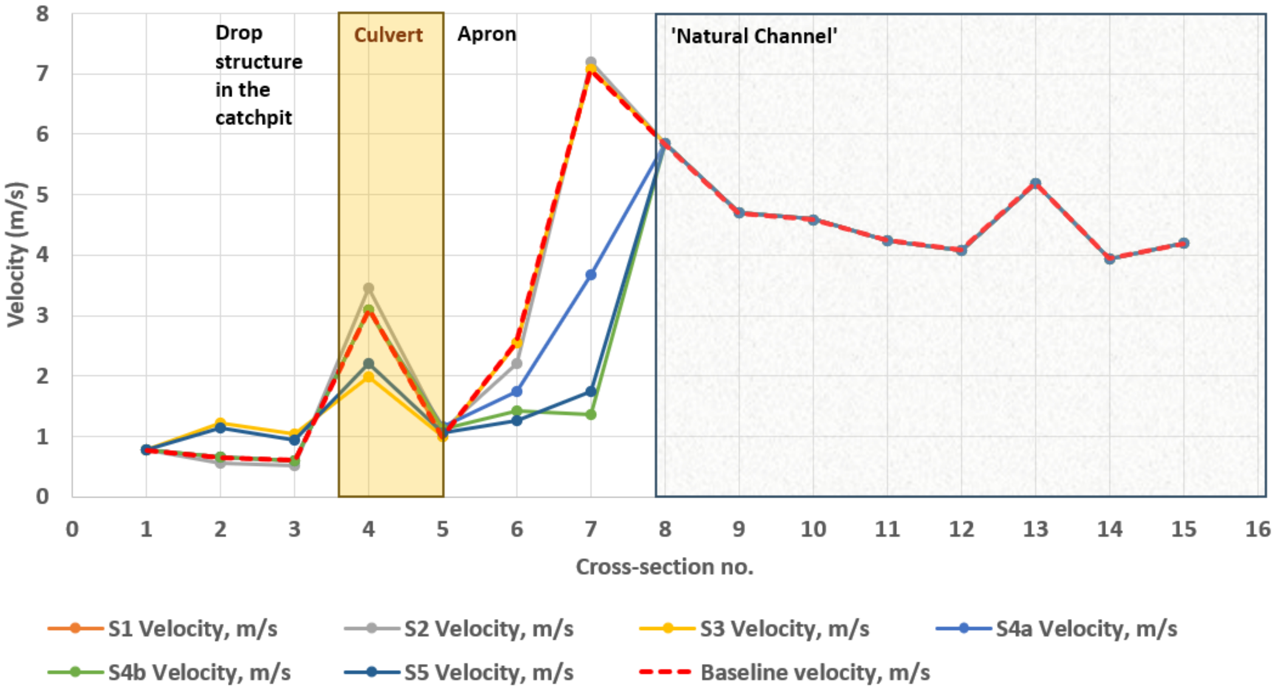
- S4 - Increasing the roughness between cross section 6 and 7 within the open channel to reflect the placement of some form of baffles (Manning n from 0.02 to 0.04).
- S5 - A combination of all 4 of the above scenarios.

### Preliminary sensitivity test results

A19-4.10.4. The modelling has used a 0.5% AEP +CC design event, with the initial focus being on watercourse A83_ML_026_000. This watercourse was selected for the sensitivity testing as it exhibits some of the greatest effects of ongoing erosion and the 0.5% AEP+CC design event flow of 1.02$m^3$/s is mid-range of flows passing through the affected culverts. Preliminary results of the model sensitivity testing, presented in Plate 19-4.3 demonstrates that in general there are measures that can be implemented to reduce velocities through the culvert and apron (to cross section 7), after which the velocities increase rapidly due to the naturally steep topography. From cross section 8 onward (downslope), the modelled velocities are independent of what is happening upstream of cross section 7, resulting in identical scenarios from cross section 8 across all scenarios.

A19-4.10.5. The outcome of the sensitivity test are shown in Table 19-4.14.

## Plate 19-4.3 Long section velocity profile




**Note on modelling results: The model results indicate that the velocity upstream of the culvert decreases when the velocity in the barrel increases and vice versa. There is a nonlinear relationship between velocity in the barrel and upstream at the inlet (outside the barrel at point 3) due to the presence of a head loss unit. Flood Modeller Pro calculates the head loss based on the barrel velocity for the outlet control condition (at the inlet) like scenario 3. As the velocity in the barrel has decreased in scenario 3, the head loss consequently would be less compared to the baseline scenario. This means that the water depth would be less at the inlet (outside the barrel). Since the water depth has decreased, the velocity then goes es higher than the baseline scenario to maintain the continuity equation ( Q = A x V).

**Table 19-4.14 Sensitivity test result summary and design consideration/decisions**

| Scenario | Modelling results summary and design recommendations |
|---|---|
| S1 - Increase step height of the cascade drop (by 0.5m) | No impact on baseline velocities.<br>This scenario will not be taken forward in culvert design proposals. |
| S2 - Increased gradient through the culvert from Point 2 to 5 (by additional 2%) | Increased velocities within the barrel, however, the upstream velocities are reduced. This is due to the way the head loss unit calculates the upstream velocities. Limited impact on downstream velocities.<br>This scenario will not be taken forward in culvert design proposals. |
| S3 - Increased culvert roughness (changed to 0.04 from existing 0.02 value) | Increased velocities upstream of the culvert but reduced within the barrel, apron velocities also reduced. A factor of the head loss calculations. This scenario likely better reflects the accumulation of some sediment within the base of the culvert.<br>This scenario will be taken forward in culvert design proposals. |
| S4a - Increased the roughness (to 0.04 from 0.02) between Point 6 and 7 to reflect the placement of baffle | Velocities on the apron are substantially reduced. The culvert velocities have increased, again a factor of the head loss calculations. The velocities have been reduced at the ideal location.<br>This scenario will be taken forward in culvert design proposals. |
| S4b - Increased the roughness (to 0.06 from 0.02) between Point 6 and 7 to reflect the placement of baffle | Velocities on the apron are substantially reduced. The culvert velocities have increased, again a factor of the head loss calculations. The velocities have been reduced in the location we wish them to have. The velocities pick up again after the apron.<br>Agreed to use scenario 4a in modelling rather than 4b as it provides the more conservative option. |

| Scenario | Modelling results summary and design recommendations |
|---|---|
| S5 - Combined Option = S1 + S2 + S3 + S4_b | This scenario will not be taken forward in the proposals for the culvert design. |

### Sediment entrainment modelling

A19-4.10.6. The design principle regarding sediment entrainment through the culvert is that the 2-year discharge (2 year event or 50% AEP) should be sufficient to transport the largest material. The upstream culvert entrance will be grated and limit the largest material that can pass as a 100mm cobble. Sediment entrainment calculations have been performed for the following scenarios for alternative culvert base configurations:

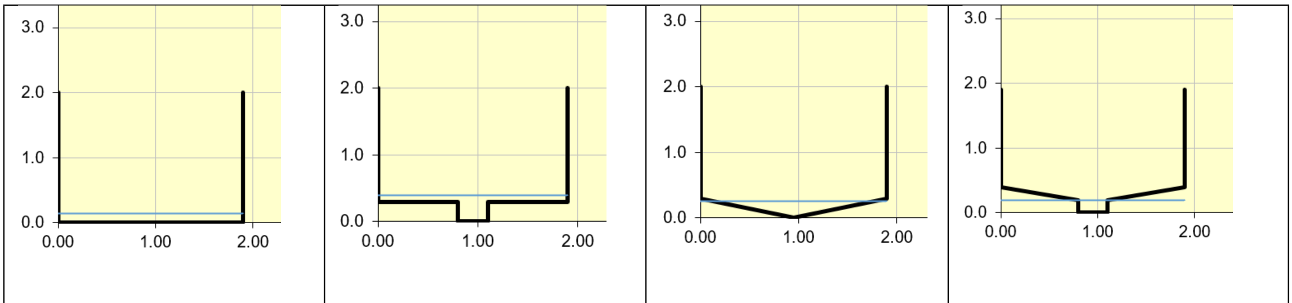
1. 1.9m width culvert with flat base
2. 1.9m width culvert with an internal low flow baffle; 0.3m width by 0.3m height
3. 1.9m width culvert with a low flow 'V' profile to 0.3m depth and
4. 1.9m width culvert with a low flow slot within 'V' that is 0.2m depth and 0.3m width.

A19-4.10.7. The results of the calculations for these four scenarios are presented in Table 19-4.15 and illustrations of the culvert base configurations are in Plate 19-4.4. The calculations have been performed using an AtkinsRéalis Geomorphology calculation template that is prepopulated with the commonly accepted approaches/formula for gravel bed streams/rivers in steep environments to estimate sediment that will be entrained by a critical discharge (Knighton 1998, Kirby et.al 2015, and Thorne et.al 1997). A caveat to these calculations is that an estimate is made for the discharge per unit width based on the slope and manning's roughness of the channel. The discharge per unit width is then multiplied across the full width of the channel to give an estimate of the total flow. Where the channel bed is variable, such as in Scenario 3, where the bed is profiled in to 'V' this results in an overestimate of the total flow in the channel. A professional judgement is that the velocities at the centre of the 'V', in the deepest part of the flow would be closer to the flow velocities that would be expected in Scenario 4 where calculations have been performed for a dedicated low flow channel.

**Table 19-4.15 Sediment entrainment results for different culvert base configurations**

| Scenario | Description | Channel width (m) | Flow depth (m) | Discharge (Q) ($m^3/s$) | Discharge (q) per unit width ($m^3/s$) | Min sed. entrainment (mm) |
|---|---|---|---|---|---|---|
| 1 | No low flow/baffle | 1.90 | 0.14 | 0.86 | 0.45 | 104 |
| 2 | Low flow/baffle | 1.90 | 0.40 | 0.80 | 0.42 | 100 |
| 3 | Low flow 'V' | 1.62 | 0.26 | 0.70 | 0.43 | 101 |
| 4 | Low flow slot within 'V' | 0.30 | 0.19 | 0.14 | 0.48 | 108 |

**Plate 19-4.4 Culvert base configurations tested**




| Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|

A19-4.10.8. Scenario 4 indicates that a 0.3m wide low flow baffle, with 0.19m depth of flow, should convey material up to 108mm with a flow of 0.14m$^3$/s. A 0.3m wide low flow channel was identified as the most suitable in Scenario 4 (above) by sensitivity testing the model. The flood peak hydrology for the 14 culverts that pass beneath the A83 set out in Table 19-4.16 with 3 culverts identified as having insufficient flows during a 2-year event to flush the largest material through. It should be noted that culverts A83_ML_020_000 and A83_ML_022_000 (Minor B watercourses) would be lost when the debris flow shelter is constructed with flows being routed south to flow through culverts A83_ML_019_000 and A83_ML_021_000, respectively. This means only A83_ML_023_000 would have flows that are insufficiently competent to transport material of 100mm. A83_ML_023_000 no longer drains the natural catchment however, as a channel diversion was constructed upstream of the A83 forcing water into the neighbouring catchment and watercourse (A83_ML_024_000). It was deemed important to retain a crossing here for future resilience.

A19-4.10.9. As highlighted above, the total discharge estimate for Scenario 3 is likely to be an overestimate. The low flow slot modelled in Scenario 4 has a flat base, therefore the same flow would be at a greater depth within a 'V' channel, meaning the flows in the centre of the 'V' would be more competent at transporting sediment than the flat bottomed low flow channel e.g. a 'V' within a 'V'.

**Table 19-4.16 Flood peaks for the culverts passing beneath the A83 (numbers followed by an asterisk (*) are highlighted as not achieving the 0.14m$^3$/s required to transport material up to 100mm)**

| Return interval event | 2 yr (m$^3$/s) | 5 yr (m$^3$/s) | 10 yr (m$^3$/s) | 50 yr (m$^3$/s) | 100 yr (m$^3$/s) | 200 yr (m$^3$/s) | 200+CC yr (m$^3$/s) |
|---|---|---|---|---|---|---|---|
| A83_ML_016_000 | 0.265 | 0.344 | 0.401 | 0.558 | 0.642 | 0.738 | 1.132 |

| Return interval event | 2 yr ($m^3/s$) | 5 yr ($m^3/s$) | 10 yr ($m^3/s$) | 50 yr ($m^3/s$) | 100 yr ($m^3/s$) | 200 yr ($m^3/s$) | 200+CC yr ($m^3/s$) |
|---|---|---|---|---|---|---|---|
| A83_ML_017_000 | 0.384 | 0.497 | 0.581 | 0.808 | 0.929 | 1.068 | 1.639 |
| A83_ML_018_000 | 0.299 | 0.388 | 0.453 | 0.631 | 0.725 | 0.833 | 1.279 |
| A83_ML_019_000 | 0.159 | 0.206 | 0.240 | 0.334 | 0.384 | 0.441 | 0.678 |
| A83_ML_020_000 | 0.136* | 0.177 | 0.207 | 0.288 | 0.330 | 0.380 | 0.583 |
| A83_ML_021_000 | 0.392 | 0.508 | 0.593 | 0.825 | 0.948 | 1.090 | 1.673 |
| A83_ML_022_000 | 0.020* | 0.027* | 0.031* | 0.043* | 0.050* | 0.057* | 0.087* |
| A83_ML_023_000 | 0.057* | 0.074* | 0.086* | 0.120* | 0.138* | 0.159 | 0.244 |
| A83_ML_024_000 | 0.847 | 1.099 | 1.283 | 1.786 | 2.053 | 2.359 | 3.621 |
| A83_ML_025_000 | 0.499 | 0.647 | 0.756 | 1.052 | 1.209 | 1.390 | 2.133 |
| A83_ML_026_000 | 0.239 | 0.310 | 0.362 | 0.503 | 0.578 | 0.665 | 1.020 |
| A83_ML_027_000 | 0.528 | 0.685 | 0.800 | 1.113 | 1.279 | 1.470 | 2.257 |
| A83_ML_028_000 | 0.231 | 0.299 | 0.349 | 0.486 | 0.559 | 0.642 | 0.986 |
| A83_ML_029_000 | 0.169 | 0.219 | 0.255 | 0.355 | 0.408 | 0.469 | 0.720 |

### Downstream Erosion Risk

A19-4.10.10. A high-level risk assessment of the erosion potential/stability for each of the 22 watercourses that pass beneath the A83 has been undertaken (Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline). The assessment has been performed using the latest (January 2024) aerial imagery, DTM, 3d model, geomorphology reports, site surveys and observations and available information relating to the existing A83 culverts.

A19-4.10.11. This part of the assessment helps inform the extent of downslope protection required for each of the watercourses. Based on the options assessment (Section A19-4.9), the most viable solution to provide scour mitigation at transitions form hydraulic structures to the existing channel is a protective rock cell/mattress. This measure in combination with reprofiling the channels (where possible) by reducing the gradient of the upper banks and widening the higher flow channel would help dissipate the flows and reduce the risk of scour. It is also expected that the watercourse channels shall be fenced off 10m either side of the watercourse centreline, to limit livestock and grazing pressures adjacent to the watercourses, enabling natural regeneration or planting of species to better anchor soil and aid slope stability over time.

A19-4.10.12. Some of the channels have a vertical misalignment and a concrete cascade is necessary to join the culvert outlet to the watercourse downstream, with no other viable options identified that were considered sufficiently robust for these steep and unstable slopes.

A19-4.10.13. Whilst it is important to protect the critical infrastructure, the watercourse, where possible, should be unprotected and function naturally, adjusting to its flow and sediment regime. These natural channels would be more sustainable in the long term, more resilient to climate change (during prolonged and intense periods of both dry and wet conditions) and require less management and maintenance. The impact assessment shows that at least 8 watercourses may require a concrete cascade and more extensive protection, with others of reduced concern.

## A19-4.11. Summary and Recommendations

### Summary

A19-4.11.1. This Annex has described the watercourses that are impacted by the proposed A83 scheme at the RaBT and the approach taken to better understand how the potential effects of the crossings could be mitigated within the design. It is clear that:

- the site is very steep with unstable slopes, varying flow pathways and erosion potential
- embedding mitigation within the design to minimise the impact to the water environment is essential to achieve a sustainable, climate resilient scheme
- the project requires a multi-discipline collaboration to optimise the design of the upstream transition, crossing structures and downslope protection
- many watercourses are likely to exhibit less excessive erosion during a range of flow events and the water environment would be improved because of the larger culverts proposed, but low flows would also need to be considered
- modification of the slope downstream of the crossings is required which is likely to be a combination of hard and soft measures
- some watercourses that are at higher risk of erosion (fluvial) and/or landslips (geotechnical) will require greater modification/stabilisation in terms of type of protection and length
- it is important to maximise natural processes and function as far as is practicable whilst having to consider construction constraints and operational maintenance/liability
- it is a fine balance between sediment transfer and a naturally self regulating (low maintenance) system and one that does not excessively scour where the erosion process dominates and

- if the watercourses are able to recover with no livestock grazing pressures the channels are likely to exhibit a betterment in terms of hydromorphology, water quality and ecology elements.

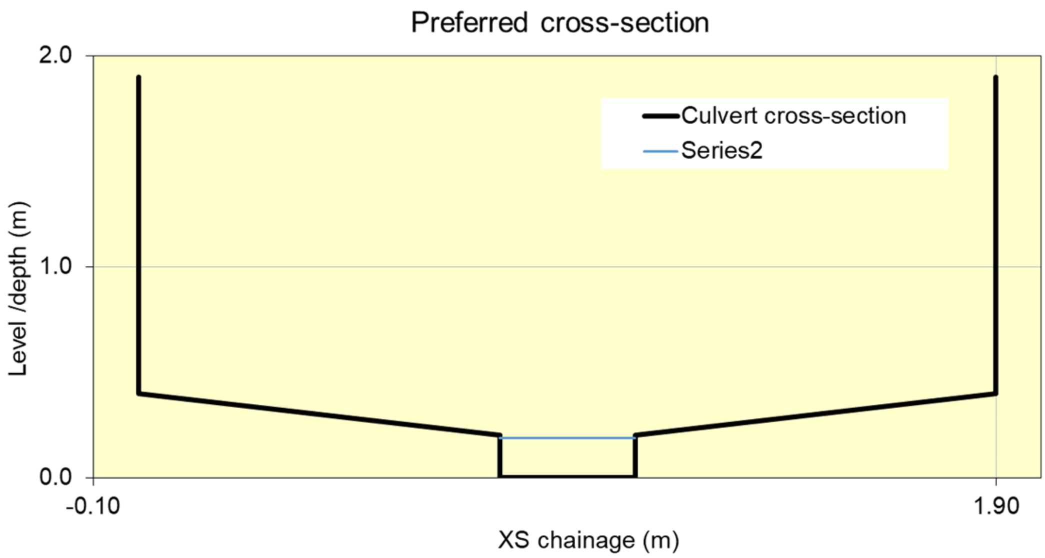
### Design agreements

A19-4.11.2. The assessment carried out to date to characterise the watercourses and the sensitivity to the proposed scheme and crossings has led to a number of design agreements, incorporated in to the preliminary design (for specimen design, CDF modelling should be explored as an approach to optimise the design), including:

- vary the rock cut to maximise the bedrock exposure at the upstream face of the crossing structure and catch pit to minimise the length of upslope channel realignment
- maintain an approximate 5% gradient on the longitudinal slope of the catch pit north to south to maintain flow (and sediment entrainment) to the culvert inlets
- Position the culvert inlets and debris screens road side of the catch pit to minimise damage and blockage by falling boulders and debris from the upstream hillside
- Allow the debris screens to have appropriately sized grates to permit sediment up to 100mm to pass
- Sloping, rather than stepped, culvert inlet to maximise the transfer of sediment into and through the culvert
- Maximise the size of the DFS culverts to 1.9m x 1.9m to accommodate extreme flows and reduce the erosive power and jetting action towards the downstream channel
- Maintain a 5% gradient through all the DFS culverts. Increasing or decreasing the gradient had no bearing on the velocity at the transition outfall where the main area of concern for scour lies. This gradient is also acceptable for safe entry for inspection and maintenance within the culvert

- Whilst increasing the roughness through the culvert helps slow the flow locally through the closed section, there is no positive impact at the outfall. In this regard, baffles can be discarded, which minimises the risk of sediment accumulation within the culvert and any associated maintenance requirements and
- Pre-fabricate a low flow channel into the culvert bed. Applying a low flow 300mm wide slot within a 'V' notch, is effective at entraining and transporting sediment, as shown on Plate 19-4.5. It is noted that a 'V' within a 'V' would be even more efficient.

**Plate 19-4.5 Culvert bed configuration for effective sediment transport**




- continue this culvert bed configuration through to the open channel section of the crossing to maintain low flows and sediment transfer
- reduce the gradient through the crossings to 2.5% for the open channel to reduce velocities (sediment management/maintenance is safer and easier within the open channel section)
- install other dissipation measures such as baffles or embed boulders on in the open culvert bed to break up the higher flows before outfall to the

downstream watercourse. Boulder features would appear more natural and be more aesthetically pleasing than a uniform concrete bed or baffles

- widen the open channel section from 1.9m at the upstream end to 2.0 - 3.0m (size to be determined through specimen design) to accommodate higher flows and reduce velocities and scouring potential at the outfall
- reprofile and protect the channel and banks to minimise scour potential immediately downstream of the crossings
- utilise engineered cascades downstream of the culvert apron where vertical offsets exist between the proposed culvert and existing channel;
- extend the protection downstream on the high risk watercourses
- reprofile watercourses, where appropriate, to maximise sustainability and natural form and function and
- fence watercourses (approximately up to 10m either side) to protect from livestock grazing pressures and promote vegetation growth to stabilise the hillside.