ACCESS ARGYLL & BUTE [A83]

AtkinsRéalis WSP

A83 Rest and Be Thankful

LTS EIAR VOLUME 4, APPENDIX 19.6 - FLOOD RISK ASSESSMENT

Transport Scotland

A83AAB-AWJ-EAC-LTS_GEN-RP-LE-000297

Event Severity

The severity of the events discussed in this document are as Annual Exceedance Probabilities (AEP), the table below provides a summary of AEP and corresponding return periods.

The AEP is the probability that there will be an event exceeding a particular severity in any one year. The return period is the average duration (in years) between events of a particular severity.

Table 19.1 Annual Exceedance Probability vs Return Period

Annual Exceedance Probability	Return Period
50%	1 in 2 years
20%	1 in 5 years
10%	1 in 10 years
4%	1 in 25 years
3.33%	1 in 30 years
2%	1 in 50 years
1.33%	1 in 75 years
1%	1 in 100 years
0.5%	1 in 200 years
0.5% with 46% increase allowance for climate change	1 in 200 years with 46% increase allowance for climate change

Glossary of Terms

Term	Definition
1D / 2D	1-Dimensional, 2-Dimensional. Used to describe hydraulic models.1D models represent channels using depth average velocity to represent each reach of the channel. 2D models represent floodplains as domains with depth averaged velocity. 1D / 2D models links the two approaches.
AEP	Annual Exceedance Probability of a specific flood event
Catchment	A catchment is an area where water is collected by the natural landscape. As the water flows over the landscape, it finds its way into streams and down into the soil, eventually feeding the river.
Catchpit	Channel at upstream side DFS.
Conveyance	The movement of water from one location to another.
Culvert	A primary culvert is defined as a buried conduit which carries, or is intended to carry, flow from a watercourse, and which does not form part of a larger pipe network. A connectivity culvert is defined as a buried conduit which is intended to carry flow from one side of an embankment or raised feature to another to ensure that hydraulic equilibrium is maintained.
DFS	Debris flow shelter
DFW	Debris flow wall
DMRB	The Design Manual for Roads and Bridges (DMRB) provides requirements which shall be applied to the appraisal, design, maintenance, operation and disposal of motorway and all-purpose trunk roads for which one of the Overseeing Organisations is highway or road authority.
DSM	Digital Surface Model
DTM	Digital Terrain Model

Term	Definition
Embankment	Flood embankments are earth filled structures designed to contain high river levels. They are commonly grass-covered but may need additional protection against erosion by swiftly flowing water, waves, or overtopping.
Erosion	A natural process leading to the removal of sediment from a riverbed, bank, floodplain, or coastline.
FEH	Flood Estimation Handbook and associated methods (https://www.ceh.ac.uk/services/flood-estimation-handbook)
Floodplain	The adjacent flat area next to the river that is associated with being flooded.
Fluvial flooding	Flooding caused by rivers.
FRA	Flood Risk Assessment
Freeboard	The difference between the flood defence level and the design flood level. The freeboard is to account for uncertainties involved in flood estimation, and other physical factors that vary between sites such as post-construction settlement or wave action.
Geomorphology	The study of landforms, their processes, form, and sediments at the surface of the Earth is known as Geomorphology.
LiDAR	Light Detecting and Ranging – technique used to gather terrain level data
Manning's n	Standard industry values for defining roughness within hydraulic models.
mAOD	Metres Above Ordnance Datum.
Meander	One of a series of regular sinuous curves in the channel of a river or other watercourse.
NRFA	National River Flow Archive (Search Data | National River Flow Archive (ceh.ac.uk))
QMED	The value of the annual maximum flood which may be expected to be equalled or exceeded once every two years on average.

Term	Definition
RaBT	Rest and Be Thankful
Riparian	The area related to or at the edge of a river.
ReFH2	Revitalised Flood Hydrograph Method 2 – ReFH2 software is used to derive peak flows and hydrographs as part of the FEH methods.
Return Period	A measure of the rarity of a flood event. It is the statistical average length of time separating flood events of a similar size. For example, the 100year return period does not mean this is the event that occurs every 100 years. It actually refers to the flood magnitude that has a probability of exceedance of 1/100 in any given year (i.e., a 1% chance).
Sedimentation	The process of settling or being deposited as a sediment.
SEPA	Scottish Environment Protection Agency
Small watercourses	The small watercourses flowing down the hillside.
Standard of Protection (SoP)	All flood protection structures are designed to be effective up to a specified flood likelihood (Standard of Protection). For events beyond this standard, flooding will occur. The chosen Standard of Protection will determine the required defence height and/ or capacity.
Surface water flooding	Flooding that occurs when rainwater does not drain away through the normal drainage systems or soak into the ground but lies on or flows over the ground instead.
SuDS	Sustainable Drainage System. SuDS are an approach to managing surface water (rainfall runoff) which mimic the natural processes of attenuation, infiltration and evapotranspiration. SuDS comprise a sequence of management practices, control structures and strategies which are designed to drain surface water efficiently and sustainably, whilst also minimising pollution and managing the impact on the water quality of local water bodies.

Term	Definition
TRN	Trunk Road Network
Watercourse	Any natural or artificial channel above or below ground through which water flows, such as a river, brook, beck, ditch, mill stream or culvert.
WINFAP-FEH	Software that enables you to estimate peak flows and flood frequency curves for gauged and ungauged catchments, using the latest Flood Estimation Handbook (FEH) methods.

A19-1.1. Introduction

A19-1.1.1. This document is a technical appendix to Volume 2, Chapter 19: Road Drainage and the Water Environment (RDWE). This Flood Risk Assessment (FRA) does not follow a traditional standalone document and information which would typically be included is provided in the following appendices:

- Volume 4, Appendix 19.1: Road Drainage and the Water Environment Legislation, Policy and Guidance and Volume 4 provides the context of the Proposed Scheme in terms of NPF4, local authority and SEPA legalisation and guidance.
- Appendix 19.2: Road Drainage and the Water Environment Methodology identifies and classifies the flood risk receptors used within this FRA in terms of the importance and sets out the method for defining impacts sensitivity applied from DMRB guidance.
- Volume 4, Appendix 19.3: Road Drainage and the Water Environment Baseline presents the baseline conditions and understanding of current flood risk to receptors in the area. Through use of site visit information and historic event flood records/ photos the understanding of area is provided which helps to facilitate conclusions within this FRA.
- Baseline flood map figures are available in Volume 3, Figures 19.9-19.12.

A19-1.1.2. 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 the Croe Valley; consisting of works to approximately 2.4km of the A83. It would also include upgrading works to existing infrastructure, including the RaBT car park, B828 junction, watercourse crossings and drainage infrastructure.

A19-1.1.3. The Proposed Scheme Boundary covers the entire area within which the Proposed Scheme would take place, including temporary access roads, construction compounds and laydown areas, as well as 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 of the Environmental Impact Assessment (EIA).

A19-1.1.4. TS has also committed to delivering improvements to the Old Military Road (OMR) running parallel further downslope towards the valley floor, to deliver a safe, proportional and more resilient diversion route for when the A83(T) is closed until the permanent LTS is constructed.

A19-1.1.5. The Proposed Scheme will be of flood risk benefit given the current road is liable to flooding from culvert blockage and undersized culverts. The Proposed Scheme would reduce this risk by managing flows, so they do not pass over the road during extreme events.

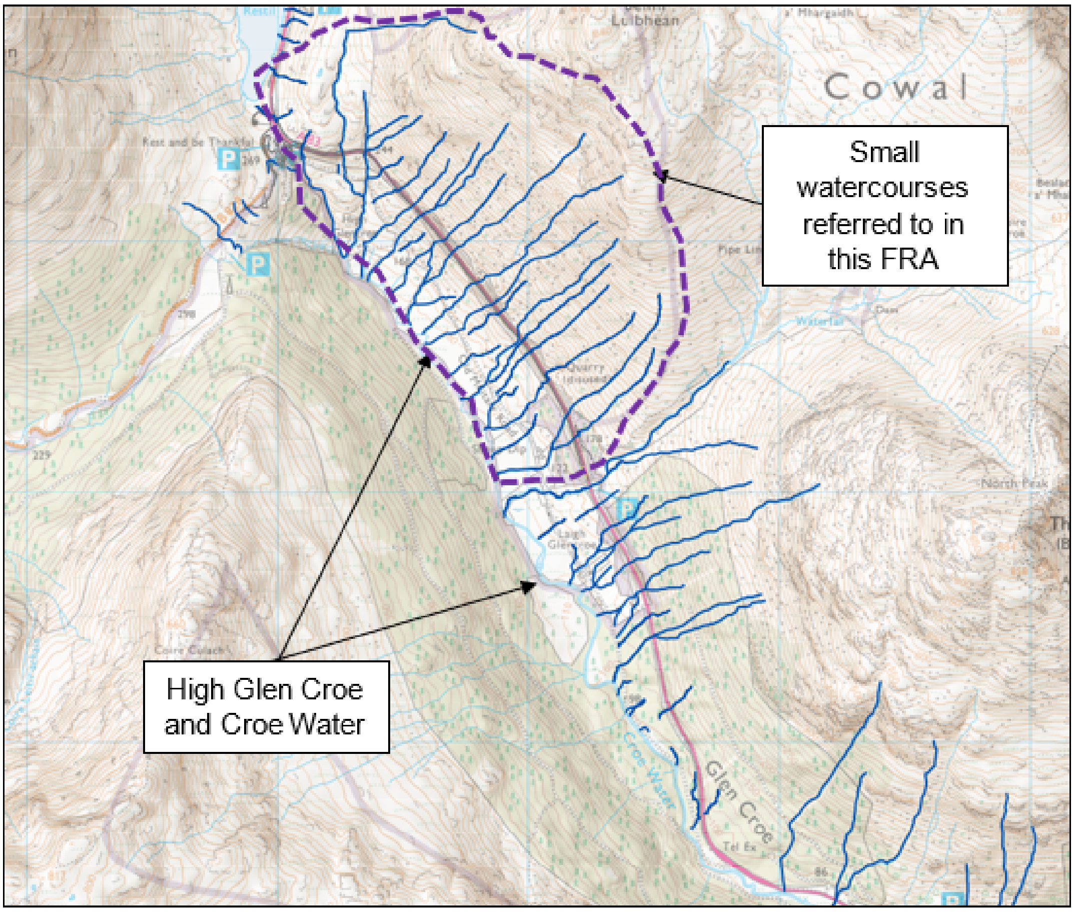
Approach to FRA

A19-1.1.6. The study area for the FRA presents challenging conditions to quantify baseline and Proposed Flood Risk hazard. Therefore, a pragmatic approach has been taken to understand the various mechanisms of flood risk and thus the potential impact of the Proposed Scheme.

A19-1.1.7. Principally the scheme could have an impact on the culvert capacity / debris and conveyance and there may be a minor catchment response to timing peaks. This FRA sets out to explore the impact this could have.

A19-1.1.8. For analysis the small watercourses and High Glen Croe / Croe water have been treated discretely as integrating multiple steep 1D watercourses into the 1D/2D model of the Croe would likely incur many instabilities. The rationale is that given all the small watercourses flow towards the High Glen Croe and Croe Water and the catchment is not being modified so any impacts would be reflected in the High Glen Croe and Croe Water respectively, consequently allowing for conclusions to be drawn about any potential impact on High Glen Croe/ Crow Water receptors.

Plate 19.1 - Flood Risk Areas of Interest



A19-1.1.9. Loch Restil was initially part of the original assessment when looking at multiple options of the Proposed Scheme however has subsequently been removed from this assessment as the loch and associated floodplain does not interact with the Scheme. The exception being a single culvert (Culvert A83_35 drains to Loch Restil and will be upsized to pass the 0.5%AEP+CC flow). However, its outlet invert level will be located above the 0.5%AEP+CC flood levels in the loch.

Purpose and Structure of this Report

A19-1.1.10. The purpose of this FRA is to report any flood risk to the Proposed Scheme in addition to any impacts as result of implementation of the Proposed Scheme. As previously mentioned, this FRA does not follow a traditional format whereby the legislation & policy, methodology and baseline discussion are included in this document. Therefore, these should be read in conjunction with this appendix.

A19-1.1.11. This appendix covers the specific details on flood risk to and from The Proposed Scheme and is set out as follows:

- A19 1.1 - Introduction - Background detail to The Proposed Scheme with the approach taken for the FRA. Information on consultation that has been undertaken to date and the limitations of the study.
- A19 1.2 Data collection - Information on the sources of data that have informed this study.
- A19 1.3 Description of key flood features of the Proposed Scheme - A description of specific features which are pertinent to the FRA in respect to the Proposed Scheme.
- A19 1.4 and 1.5 Flood Risk to the Proposed Scheme - Assessment of flood risk to The Proposed Scheme from all sources of flood risk.
- A19 1.6 Analysis of flood risk impact - Analysis of |The Proposed Scheme impact on the flood risk factors to inform the flood risk receptor impact assessment.
- A19 1.7 Flood risk impact assessment to receptors – Assessment of sensitivity of receptors using LA104 criteria (methodology in section 19.3).
- A19 1.8 Mitigation - Discussion of the embedded mitigation within the Proposed Scheme and mitigation proposed to alleviate impacts of The Proposed Scheme.
- A19 1.9 Residual flood risk - Any remaining flood risks after implementation of any mitigation.
- A19.10 - Flood Risk during construction – Any anticipated flood risk considerations during construction.
- A19 1.11 Conclusion - Conclusions of the study.

Consultation

SEPA and Argyll and Bute Council Historic flood records

A19-1.1.12. SEPA and Argyll and Bute Council were contacted as part of the FRA in relation to any flood records held within the study area.

A19-1.1.13. SEPA provided a response noting 10 records of pluvial flooding in the Rest and Be Thankful area since 2006, all concerning the A83 Trunk Road being closed due to landslips following heavy rain.

A19-1.1.14. Argyll and Bute Council did not hold any records of flood incidents within the study area.

SEPA engagement – FRA Approach

A19-1.1.15. The flood risk team presented to SEPA on the 27 June 2024. SEPA were taken through the current scheme and the approach taken with regards to hydrology, modelling of the hillside watercourses, modelling of the Croe Water and the proposed approach for understanding flood risk in the flood risk assessment.

A19-1.1.16. No concerns were raised about the discrete treatment of the small watercourses and High Glen Croe / Croe Water. The use of sensitivity to evaluate the realisation of the Proposed Scheme effects was also considered to be reasonable.

A19-1.1.17. Notes of the meeting are provided in Annex A.

Limitations

A19-1.1.18. The accuracy of the hydraulic models used in this assessment is influenced by the quality of available hydrological and topographical data. While the models provide valuable insights, it's important to note that their limitations stem from factors such as data resolution, survey accuracy, and the inherent assumptions of the modelling software. For further details on the specific limitations and uncertainties associated with the models, please refer to the annexes (B, C, D, and E).

A19-1.1.19. All the Proposed Scheme crossings drain small steep catchments, which are not accurately defined by the Flood Estimation Handbook website. Catchment boundaries have therefore been defined using topographic data and observations made during site visits. Freeboard allowances and model sensitivity have been used to include allowance for this uncertainty in the culvert design.

A19-1.1.20. Due to the rural and extreme nature of the watercourse terrain, no records of past flooding which would be of any value to calibrate the 1D and 1D/2D models are available.

A19-1.1.21. The current proposed design has made assumptions that are based on the most accurate data available at the time of writing. Only historic Ground Investigation (GI) has been completed at the time of writing this assessment however it is not expected that the results of the updated GI will have a large impact on these assumptions.

A19-1.2. Data Collection

A19-1.2.1. The following data sources have been used for this study are outlined in the table19.2.

Table 19.2 – Data sources

Data	Type	Description / Summary
Ordnance Survey (OS) 1:25,000 and 1:50,000 scale mapping	General	1:25,000 and 1:50,000 scale OS maps have been used for this assessment. Two resolutions have been considered to identify and compare the number of watercourses across the Study Area.
Rainfall data (as provided by SEPA)	General	Updated rain gauge data was not collected.
Site walkover findings, observations and photos	General	Two site walkovers were undertaken on the 7th December 2022 and the 17th February 2023 to observe the watercourse crossings in the Study Area and the Glen Croe valley floodplain. More recently, a site walkover was undertaken on the 23rd May 2024. Photos and videos were taken on this walkover that captured the Croe valley floor/floodplain area, culvert outlets in the vicinity of the A83 and a general sense of the watercourses.
Aerial photographs	General	Aerial photographs collected during drone flights dated 18th January 2024 and 24th April 2024.
AWJV drone photogrammetry	Topographic	Collected during drone flights dated 18th January 2024 and 24 April 2024 – 00mm RMSE in plan and height (absolute accuracy)
20cm LiDAR digital elevation model provided by Transport Scotland	Digital terrain model (LiDAR)	Taken at 100mm RMSE (Plan and Height).

Data	Type	Description / Summary
Flood Estimation Handbook (FEH)	Hydrology	FEH is the standard UK suit of methods to estimate design flows for gauged and ungauged catchments. The tools were applied together with SEPA and Environment Agency guidance to calculate design flows of for the annual exceedance probability (AEP) events listed above.
NRFA Peak Flow Dataset v12.1	Hydrology	The National River Flow Archive (NRFA) provides peak flow data (AMAX and POT data) for use in hydrological analysis. Version 12.1 of the NRFA Peak Flow Dataset files (released in Nov 2023) was used for all FEH calculations.

A19-1.3. Description of key flood features of the Proposed Scheme

A19-1.3.1. A full description of the Proposed Scheme is available in Volume 4 Chapter 2 – Proposed Scheme. The specific elements pertinent to flood risk, the catch pit and culverts are described in detail below.

Catch pit and culverts

A19-1.3.2. There are 22 existing watercourses that cross the A83 along the Proposed Scheme extent, 15 intercept the DFS (14) and DFW (1). The proposed design allows flows from watercourses upslope of the structure to pass over the back wall (hillside) into the catchpit below. This catchpit will have a 5% longitudinal slope to the south as well as a 5% transverse slope directing the flow towards the western side (roadside) of the catchpit. Along the western edge (roadside) of the catchpit, aligned with the path of the existing watercourses, will sit large, grated inlets.

A19-1.3.3. These grates will sit on top of a drop structure that will direct flows into the proposed culverts that will be orientated perpendicular to the A83. This grate will be designed to allow flow from a full range or return periods to pass into the drop structure, as well as granular material up to 100mm in diameter. This grate will also be able to alleviate some of the potential forces felt on the proposed structure, by passing the liquid portion of a debris flow event until it is blocked. If the grate does become blocked, flows will pass downslope to the next available grated inlet.

A19-1.3.4. After flow passes into the drop structure, it is directed into a large 1.9m x 1.9m box culvert that will convey flows under the A83 before discharging them to a short section of open channel downslope of the A83. From here, flows will pass via a section of scour mitigation, and then to an engineered channel that will converge with the existing natural channel upstream of the OMR. Further explanation of the proposed structure can be seen in the following table and plates.

Plate 19. 2 – An example of the proposed crossing.

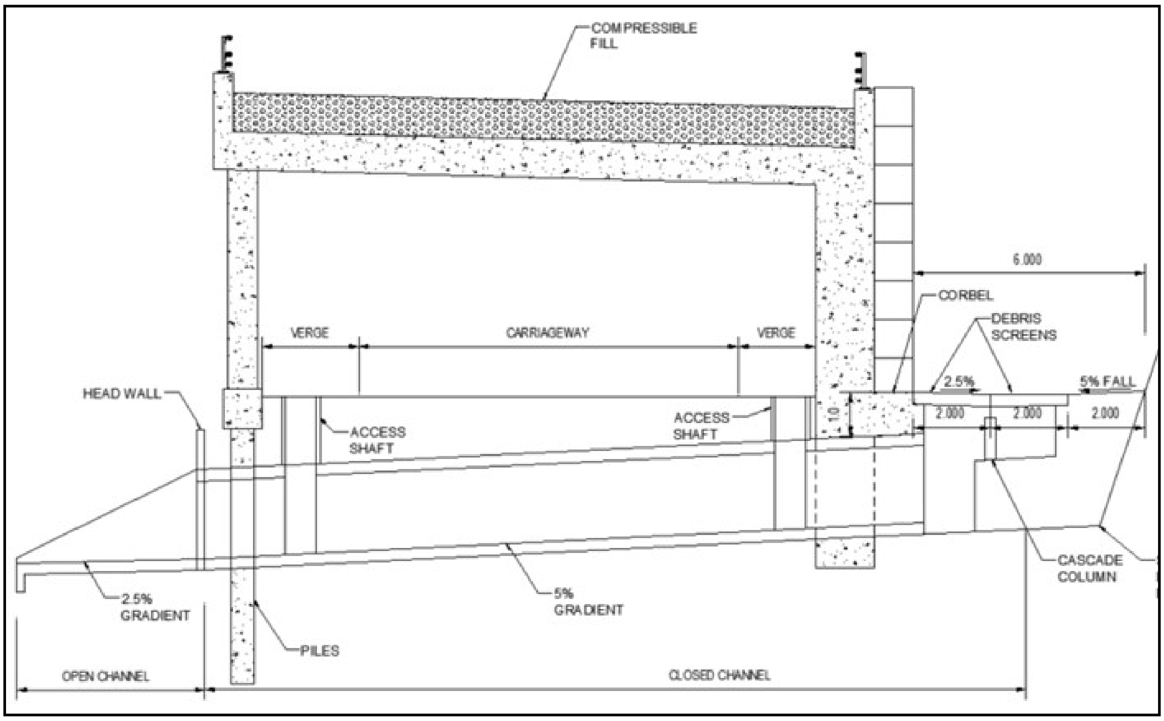


Plate 19. 3 – Sections of the proposed culvert crossing under the A83.

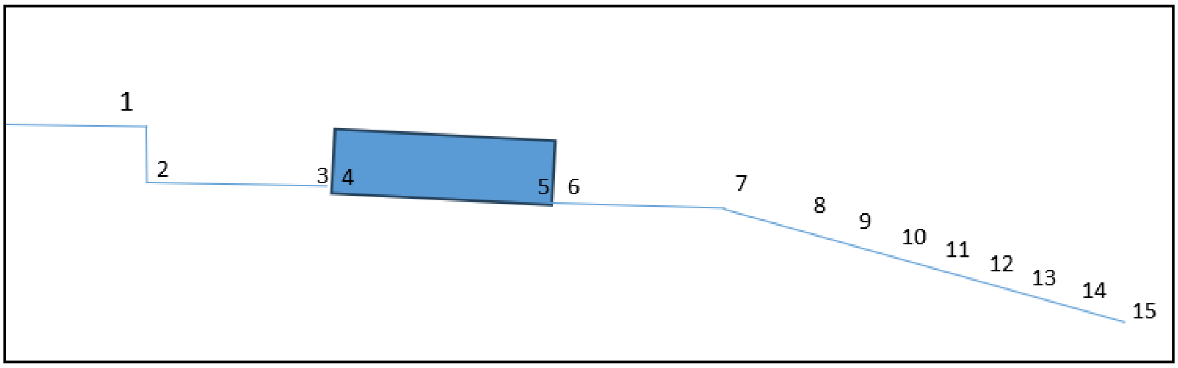


Table 19.3 - Catchpit/ culvert element assumptions

Section	Description	Assumptions
1	Existing watercourse upslope of the DFS	Cross sections can be taken from the Digital Surface Model (DSM)
2	The upslope face of the DFS	Flows will be allowed to freefall into the DFS where the DFS intersects the existing channel.
3	Water in the DFS will flow to the next culvert inlet downslope.	The bed of the DFS has a gradient of 5% and culvert inlets are maintained unblocked.
4	Flow passes through a 100mm grill, over a cascade and enters a closed channel upstream of the culvert inlet.	The grill remains unblocked for under everyday scenarios. During a debris flow event it may become blocked, and flow will pass to the next downslope culvert.
5	The culverted section	The 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 bed slope of the channel is 2.5%
7 - 15	The existing channel	Cross sections can be taken from the DSM

A19-1.4. The Proposed Scheme Flood Risk Assessment

A19-1.4.1. Flood Risk can be assessed in terms the impact of all sources of flood risk to the Proposed Scheme as well as the impact it could have elsewhere (one of the key considerations being to ensure flood risk is not exacerbated elsewhere as a result of the Proposed Scheme). Once this has been established any mitigation (as well as embedded mitigation to dealing with flood risk to the Proposed Scheme) and residual flood risk can be considered. The following section discuss this and are set out as follows:

- A19-1.5 - Flood Risk from other sources to the Proposed Scheme,
- A19-1.6 - Flood risk impact from the Proposed Scheme analysis,
- A19-1.7 - Based on the analysis assessment of the flood risk impact assessment to, the receptors from the Proposed Scheme,
- A19-1.8 - Mitigation;
- A19-1.9 - Residual flood risk, and;
- A19-1.10 - Flood risk during construction.

A19-1.5. Flood Risk Assessment to the Proposed Scheme Summary

A19-1.5.1. The flood risk to the Proposed Scheme from all sources has been summarised in Table 19.4. Surface water (the hillside watercourses) is the major source of flood risk to the Proposed Scheme. Whilst SEPA flood maps do not show this, photos of previous events highlight the surface water flood risk with water shown to come off the hillside and flood the A83.

Table 19.4 - Flood Risk to The Proposed Scheme summary

Source	Risk	Description and Comments	Information Source
Fluvial	Low Risk	There is a low risk to The Proposed Scheme from fluvial flooding. The Proposed Scheme is at a higher elevation than the main source of fluvial flooding (Croe Water).	Croe Water Flood Modelling SEPA Flood Maps (2024) Site visit (2023/2024)
Surface Water *	High Risk	There is a High Risk to The Proposed Scheme	Historic flood event photos

Source	Risk	Description and Comments	Information Source
		from surface water flooding.	
Groundwater	Low Risk	There is a low risk to The Proposed Scheme from groundwater given the topography of the land.	British Geological Survey Maps (2024) Site visit (2023) General OS mapping of the area (2023)
Sewer	None	Due to the nature of the scheme and location of the scheme with minimal sewer infrastructure present.	Scottish Water records / nature of The Proposed Scheme
Coastal	None	Due to the proximity from the closest coastal source (Loch Long).	OS mapping SEPA Flood maps (2024)
Other sources (Canals, reservoirs)	None	Due to The Proposed Schemes distance from other sources of flooding.	OS mapping

*Includes the highly dynamic small ephemeral watercourses that capture surface runoff and drain towards the A83

A19-1.6. The Proposed Scheme - Flood Risk Impact Analysis

A19-1.6.1. Based on the baseline information gathered analysis has been undertaken on the Proposed Scheme. The following sections details the analysis undertaken and discusses the following;

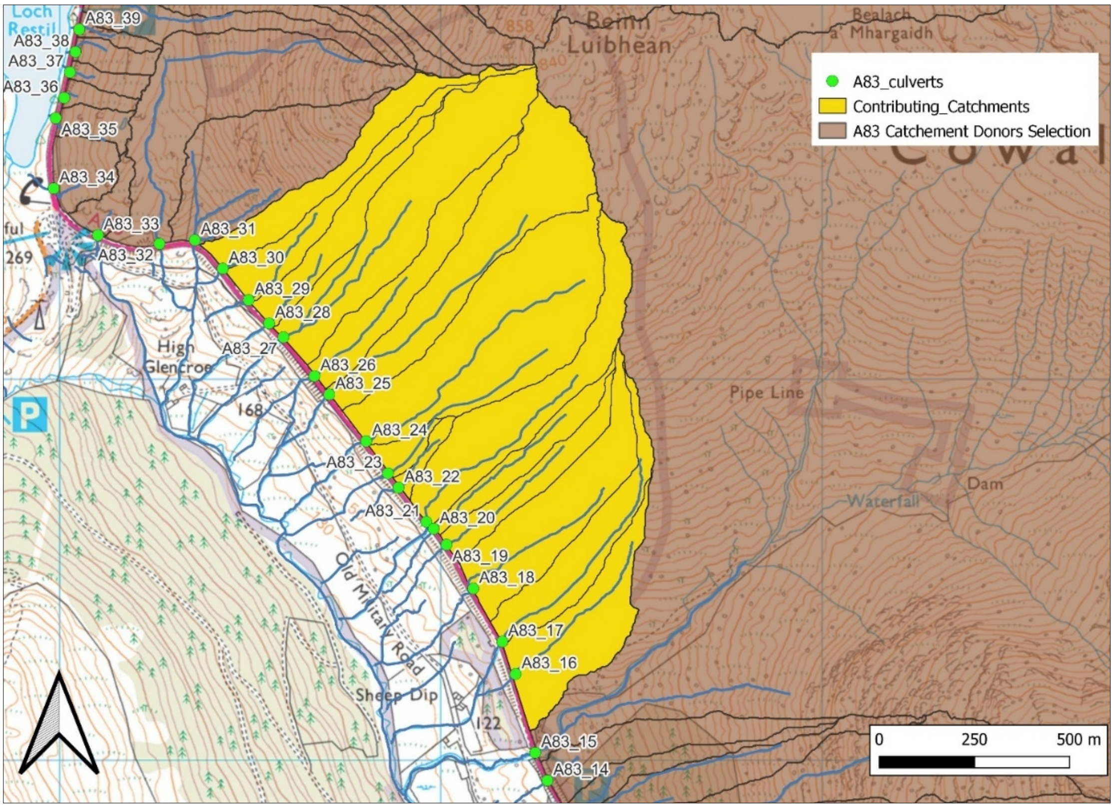
- potential impact on small watercourse flow
- potential impact in small watercourse velocity
- potential impact on attenuation and

- realisation of the potential impact of the scheme (through sensitivity testing).

Potential impact on small watercourse flow

A19-1.6.2. When considering flood risk to an area it is important to understand the impact of the proposed scheme on the baseline flood risk. In the Proposed Scheme there will be no alterations to the areas of contributing catchments, see Plate 19.4, on the eastern side of Glen Croe, upslope of the DFS and DFW. All works will take place in very close proximity to the A83 or downslope in the valley. This means that none of the catchments that contribute to the flow in the baseline scenario that interact with the Debris Flow Shelter + Debris Flow Wall (DFS) + (DFW) will be altered due to engineering works. The result of this is that there will be no net change in flow contributing to the Croe Water catchment as part of the Proposed Scheme.

Plate 19. 4 – Contributing area.



A19-1.6.3. Furthermore, the contributing hydrological catchment that will interact with the DFS and DFW on the eastern side of Glen Croe only accounts for approximately 9% of overall flow within the total of Glen Croe at the downstream extent of the hydraulic model.

A19-1.6.4. The Proposed Scheme would actually likely have a net reduction in flows to Glen Croe due to the improved drainage solutions. In the baseline scenario, there is no formal road drainage which results in all flows that fall within the catchment, and on the A83, contributing to the runoff in Glen Croe. In the Proposed Scheme there are hardstanding's that will be drained and discharged to a SuDS pond which will be located in Glen Croe just downstream of the OMR. Its location is outside the 0.5% AEP+CC floodplain, on the left bank of the Croe Water in the bend as it comes off the Beinn Luibhean slope.

A19-1.6.5. These hardstanding's that will drain to the SuDS ponds include but are not limited to, the slip road to the southern end of the site, a portion of the road under the DFS and the section of road to the north at the DFW. The SuDS pond will be designed to store flows from these areas for the 0.5%AEP +CC event. The total area that will be drained to the SuDS pond is 1.51ha. The catchment area on the eastern slope of the valley that would be impacted by the Proposed Scheme is 153ha (1.53km^2), so there will be an overall reduction in runoff of around 1% for the 0.5%AEP +CC event.

Potential impact on small watercourse velocities

A19-1.6.6. 1D modelling was undertaken of a number of the small watercourses on the eastern slope of Glen Croe that interact with the DFS and DFW. This was required to understand the potential change to velocity when compared to the baseline, due to new design of the Proposed Scheme culverts. Further details of the baseline and proposed model set up along with culvert schematics can be found in the accompanying Small Watercourses report (Annex C).

A19-1.6.7. Tables 19.5 and 19.6 below outline the percentage differences in velocities and depths between the baseline and those with the Proposed Scheme implemented. The 1D models allowed for review of the Proposed Scheme's influence on peaks flows, depths and velocities

A19-1.6.8. The 1D modelling suggests the Proposed Scheme does not influence peak flows, depths or velocities except in a short reach downstream of the A83. The results show that in each model, the variation when comparing the baseline and proposed velocity, returns to zero at point "9" in Plate 19.5 below. The distance between point 7 (the end of the open channel section after the culvert outlet) and 9 varies between each model but is approximately 20m in length. This shows that although the velocity and timing of the peak will vary through the structure, the impact on depth and velocity is relatively localised (approx. 20m).

Plate 19. 5 – Long section of the proposed model schematic

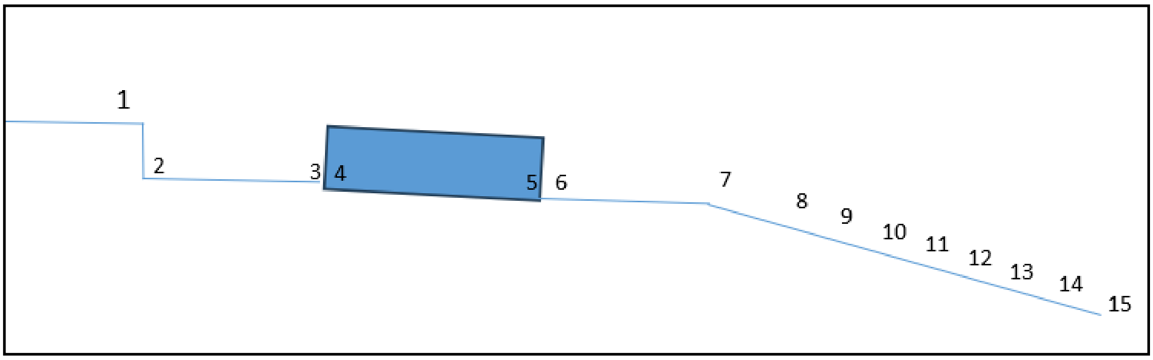


Table 19.5 – Percentage change in velocities from Baseline vs The Proposed Scheme culverts

Note – Table shows the percentage difference in velocity between base and proposed culverts (%)

* denotes locations that are not comparable with the baseline model cross sections

Scheme Ref Node	Location	A83_23	A83_24	A83_25	A83_26	A83_27	A83_28	A83_29	A83_30
1	Cascade	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
2*	Cascade	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
3*	Culvert inlet	1395	742	1765	833	346	1002	425	560
4	Culvert inlet	18	-40	-30	593	20	-14	737	-33
5	Culvert outlet	-95	-26	-64	99	-87	-83	190	-93
6	Culvert outlet	-55	-42	-46	-57	-29	-37	-65	-5
7	Open Channel	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

Scheme Ref Node	Location	A83_23	A83_24	A83_25	A83_26	A83_27	A83_28	A83_29	A83_30
8	Existing Channel	Not applicable	-20	Not applicable	0	0	0	0	0
9	Existing Channel	0	0	0	0	0	0	0	0
10	Existing Channel	0	0	0	0	0	0	0	0
11	Existing Channel	0	0	0	0	0	0	0	0
12	Existing Channel	0	0	0	0	0	0	0	Shorter reaches
13	Existing Channel	0	0	0	0	0	0	0	Shorter reaches
14	Existing Channel	0	0	0	0	0	0	0	Shorter reaches
15	Existing Channel	0	0	0	0	0	0	Shorter reaches	Shorter reaches

Table 19.6 – Percentage change in depth from Baseline vs The Proposed Scheme

Note – Table shows the Percentage difference in depth between base and proposed culverts (%)

Scheme Ref Node	Location	A83_23	A83_24	A83_25	A83_26	A83_27	A83_28	A83_29	A83_30
1	Cascade	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
2	Cascade	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
3	Culvert inlet	-1	-1	-1	-1	-1	-1	-1	-1
4	Culvert inlet	-1	0	0	-1	-1	-1	-1	-1
5	Culvert outlet	1	2	2	-2	-1	1	-1	3
6	Culvert outlet	1	2	3	-1	-1	1	-1	3
7	Open Channel	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
8	Existing Channel	Not applicable	Not applicable	Not applicable	0	0	0	0	0

Scheme Ref Node	Location	A83_23	A83_24	A83_25	A83_26	A83_27	A83_28	A83_29	A83_30
9	Existing Channel	0	0	0	0	0	0	0	0
10	Existing Channel	0	0	0	0	0	0	0	0
11	Existing Channel	0	0	0	0	0	0	0	0
12	Existing Channel	0	0	0	0	0	0	0	-
13	Existing Channel	0	0	0	0	0	0	0	-
14	Existing Channel	0	0	0	0	0	0	0	-
15	Existing Channel	0	0	0	0	0	0	Shorter reaches	Shorter reaches

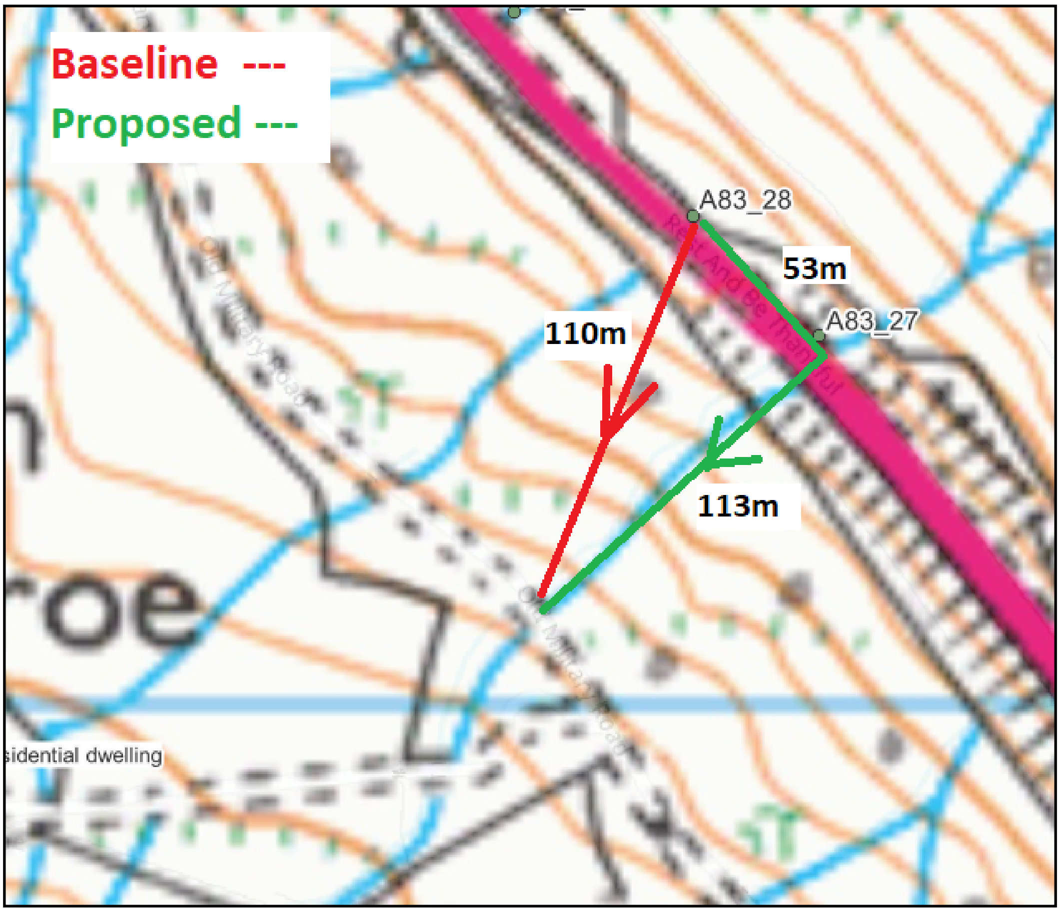
Potential impact on attenuation

A19-1.6.9. The Proposed Scheme will change existing flow paths in a number of locations. The most notable will overland flows in the baseline scenario, that are not contained to a watercourse and spill over the A83 discharging to the hillside downslope. From this location flows will make their way overland towards the OMR either crossing under, via a culvert or spilling over the OMR.

A19-1.6.10. In the Proposed Scheme, all flows that originate on the hillside above the A83, will spill into the catchpit that is located upslope of the DFS + DFW and be directed towards a culvert entrance. Once the flows enter the culvert, they will be directed under the A83 and exit towards a newly designed channel via energy dissipation measures. This newly designed channel will accommodate the 0.5% AEP +CC 46% flow down to the OMR.

A19-1.6.11. To understand what impact the proposed flow path may have on the travel time of the existing flow route, hydraulic modelling and calculations were carried out. The longest potential drainage path for flow spilling over the A83 in the baseline scenario would be from a location just south (downslope) of an existing culvert and travelling across the hillside downslope of the A83 to the OMR If flows at a baseline culvert were to back up and spill over the A83 at this location, they would have to travel the longest distance across the existing slope towards the OMR crossing (assuming the next southern watercourse crossing on the OMR). In the Proposed Scheme all flow that originates upstream of the A83, will spill into the catchpit and discharged to a channel as described above. This can be seen in Plate 19.6 below that shows the baseline and proposed drainage paths for flows spilling just south of structure A83_28.

Plate 19.6 - Baseline and The Proposed Scheme flow path lengths for A83_27 (flows spilling just south of A83_28)



A19-1.6.12. Baseline – Time of travel calculation. To calculate the estimated travel time in the baseline scenario the 110m distance was divided by a range of velocities. Photographs of the existing hillslope were reviewed, and conversations with the hydrology team led to the suggestion of a range of velocities beginning at 0.5m/s. It is believed that for a 0.5% AEP +CC 46% event 0.5m/s is a conservative value for the slowest potential velocity. It is likely flows would not be lower than this due to the steepness of the slopes, the vegetation is sparce, grass is short, the ground is rocky, and the ground is likely to be saturated at the peak of the event. A selection of site visit pictures showing these features can be seen in Plate 19.7. Time for overland flow to travel this distance was estimated using velocities from 0.5m/s to 2.5m/s, these velocities can be seen in the table 19.7 below

Table 19.7- Potential velocities and the time taken to travel 110m (Baseline Scenario)

Baseline Velocity (m/s)	Distance (m)	Time to travel (min)
0.5	110	3.7
1.0	110	1.8
1.5	110	1.2
2.0	110	0.9
2.5	110	0.7

Plate 19. 7 - Selection of photos showing the slope downstream of the A83 which informed the baseline velocity selection for the assessment.

A19-1.6.13. The Proposed scheme – Time of travel calculation. Analysis was carried out to understand what impact the new proposed flow route would have on timing of flow reaching the Croe valley. Two locations were selected, the shortest path along the catch pit (A83_28 – A83_27), 53m, and the longest (A83_23 – A83_22), 163m.

A19-1.6.14. A hydraulic model of the catchpit was constructed assuming a 5% longitudinal slope along the length road, and a 5% transverse slope towards the culvert inlet, as per the proposed design, and flows for each of the 2 contributing catchments were used as inflows. A range of manning's values were used ranging from 0.015 to 0.03 to represent smooth concrete and also superficial deposits that are likely to seen in the catchpit during the operation for the structure (even with regular clearing /maintenance).

A19-1.6.15. Velocities were extracted from the catchpit model and were used to calculate the time of travel along the catchpit. These can be seen in the Table 6.8 below.

Table 19.8- Potential velocities and the time taken from A83_28 to A83_27

Mannings n	Catchpit velocity (m/s)	Distance travelled (m)	Time to travel (min)
0.015	3.16	53	0.3
0.02	2.579	53	0.3
0.025	2.178	53	0.4
0.03	1.885	53	0.5

A19-1.6.16. The table highlights that regardless of the manning's values used, the total travel times remain at under a minute.

A19-1.6.17. The time flow would take to travel down the new proposed watercourse was then calculated. 1D models had previously been built to understand the velocities in the proposed channels to inform scour design calculations. Proposed velocities were extracted in the reaches downstream of the A83 culvert exit, and the average velocity used to calculate the predicted travel time. The Small Watercourses modelling report (Annex C) provides model results for each proposed crossing. The average velocity in the downstream section was calculated to be 5 m/s. this resulted in flow travelling down the watercourse in 0.4 min.

A19-1.6.18. Results – a comparison was made between the baseline and the Proposed Schemes route time of travel. To understand the potential range of variation between travel times, the slowest and fastest potential travel times were compared for both the baseline and proposed routes. The slowest times for flow to travel from the A83 and down the hillside were seen when then the lowest velocity (0.5m/s) was used in the baseline calculation, alongside a high manning's in the catchpit (0.03). The fastest times were when the highest velocity (2.5m/s) was used in the baseline, and the lowest manning's value (0.015) was used in the catchpit for the proposed calculation. The results of these 2 comparisons can be seen in Table 19.9 below.

Table 19.9 - Slowest and fastest travel times Baseline vs The Proposed Scheme A83_28 to A83_27

Scenario ref	Scenario Description	Time
Slowest travel times (A83_28 – A83_27)	Baseline Scenario	3.7 min
	The Proposed Scheme	0.8 min
Fastest travel times (A83_28 – A83_27)	Baseline Scenario	0.7 min
	The Proposed Scheme	0.7 min

A19-1.6.19. As can be seen in table 19.9, there is very little difference between the baseline and the Proposed Scheme scenarios. The fastest likely travel times are the same (0.7 min) and the slowest likely times showing a very slight reduction in travel time (2.9 min) when compared to the baseline scenario due to the short distances and velocities involved.

A19-1.6.20. Above was looking at the smallest distance between the proposed culverts, to understand the potential variation in travel times along the largest distance between proposed culverts (A83_23 – A83_21) which is 163m, the same process was followed. The result of this can be found in the technical note in annex C – Crow Water and a summary of the results can be seen in Table 19.10.

Table 19.10 -Slowest and fastest travel times Baseline vs The Proposed Scheme A83_23 to A83_21

Scenario ref	Scenario Description	Time
Slowest travel times-11 - Test (A83_23 – A83_21)	Baseline Scenario	8.8 min
Slowest travel times-12 - Test (A83_23 – A83_21)	The Proposed Scheme	1.7 min
Fastest travel times (A83_23 – A83_21)	Baseline Scenario	8.1 min
Fastest travel times (A83_23 – A83_21)	The Proposed Scheme	1.4 min

A19-1.6.21. As can be seen above, the max likely variation in travel times is very small approximately seven minutes. When this is compared to the critical storm duration that was used for the model (3.5 hours) it can be assumed that the overall variation in travel time between all of the watercourses on the hillside will be negligible.

A19-1.6.22. Potential Attenuation – DFS roof design. The scheme is likely to impact attenuation in the catchment is due to the drainage of the DFS roof drainage. The entire roof will be formed of a granular material that will be designed to be accessed by plant when the catch pit requires to have material removed from behind the DFS. This roof will treat and discharge runoff intermittently along the length of the DFS back to the catchpit. It is currently unknown how much the flows from the roof will be attenuated by, however the area covered by the roof is approximately 2ha, which is approximately 1.3% of contributing catchment that will be attenuated by the roof during the design event.

A19-1.6.23. Potential Attenuation –Habitat modification. Areas of the Croe valley have been outlined to make improvements to natural habitats. These areas included the removal of invasive species of trees and shrubs replacing then with native ones. There is also work being carried out to introduce additional areas of riparian habitats. This may include the introduction of new grasslands or shrubs where there is currently short pasture. Discussions were held with both aquatic and terrestrial ecologists who have explained that overall, the land use type will remain the same, however there will be small scale improvements to biodiversity in the valley, further information on this can be found in Volume 4, Appendix 4.1: Biodiversity Net Gain/ Natural Capital Assessment. In terms of flood risk this will potentially slow down existing flows in the valley and reduce peak flows. The proposed locations for these are currently under review but it is understood that the key locations that are being looked into in the Croe valley are partially covered by the 0.5% AEP +CC 46% flood extent. Modelling of these locations has not been carried out as the locations are still being finalised, but the inclusion of these locations may provide a small benefit with regards to flood risk.

Potential Realisation of The Proposed Scheme (through sensitivity testing)

A19-1.6.24. As the potential impact of the Proposed Scheme on flood risk cannot be defined with accuracy based on the challenging baseline condition and available methods, sensitivity testing has been used to represent potential realisations of the scheme. The following section outlines the approach that was taken to carry out this sensitivity.

A19-1.6.25. As covered in the above sections it is believed that the Proposed Scheme will likely have no change / negligible impact of flood risk in the valley. This is because there will be an overall reduction in flow in the valley for the design event as approximately 1% of the flow for the 0.5%AEP event +CC will be diverted to a SuDS pond. The above sections have also discussed the potential impact to flow path timings on flows from the eastern side of the valley behind the DFS +DFW.

A19-1.6.26. In the baseline model there is no discrete representation of the A83 trunk road or any of the hydraulic structures on the hillside. Any flows that originate from this hillside are applied directly to 1D cross sections in the Croe water via a lateral inflow called RES01 see Plate19.8. This inflow covers a portion of both the eastern and western slopes in the Croe valley.

A19-1.6.27. The With Scheme model required RES01 to be split into RES01-W and RES01-E (West and East) so the hydrological inflows that will interact with the DFS and DFW (RES01-E) can be edited. This can be seen in Plate 19.9.

A19-1.6.28. As previously mentioned, the associated drainage features of the Proposed Scheme design will remove approximately 1% of the flows from RES01-E and divert them to a SuDS pond for the 0.5%AEP +CC event. Although it is believed that the Proposed Scheme will have a net reduction in flows. A number of sensitivity tests have been set up to understand what impact flow variation would have to flood risk in the valley

A19-1.6.29. The with scheme model, like the baseline, does not have a representation of The Proposed Scheme. Therefore, sensitivity tests were used to understand the potential range of flood risk impacts that could be realised. The sensitivity tests required the altering of inflows that originate on the eastern slope of the Croe valley, which will be potentially impacted by The Proposed Scheme. To do this the original hydrological catchment RES01 was split into RES01-W and RES01-E. RES01-W accounted for 41% and RES01-E accounted for 59% of the original area RES01. Any variation to flows to test the potential impact of The Proposed Scheme on the flood risk in the valley have been applied to RES01-E. A visual representation of the baseline and proposed mode, with the split eastern and western catchments can be seen in Plate 19.9.

Plate 19.8 – Visualisation of all of the Croe Baseline model set up showing 1D and 2D boundaries and the Hydrological inflow locations

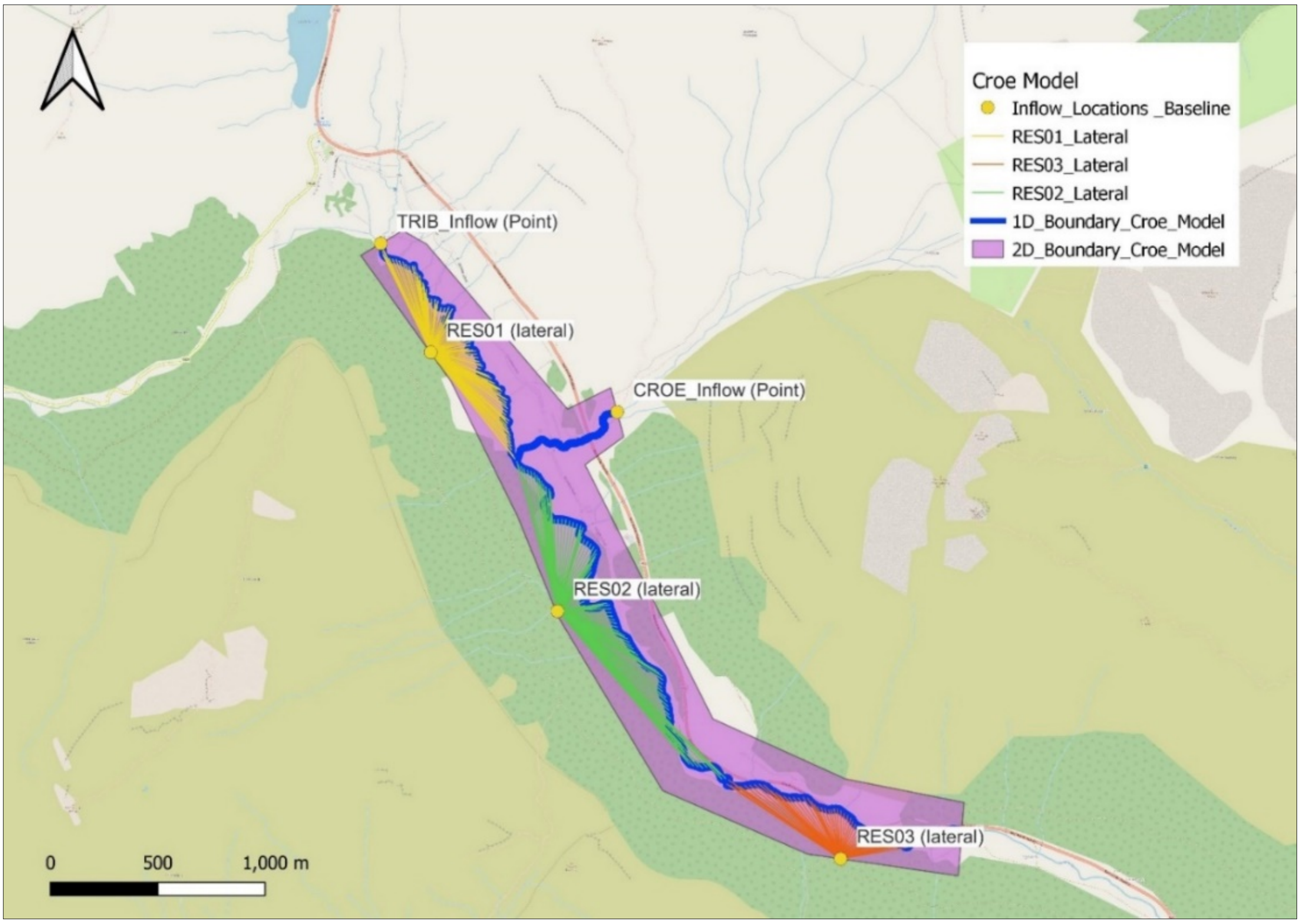
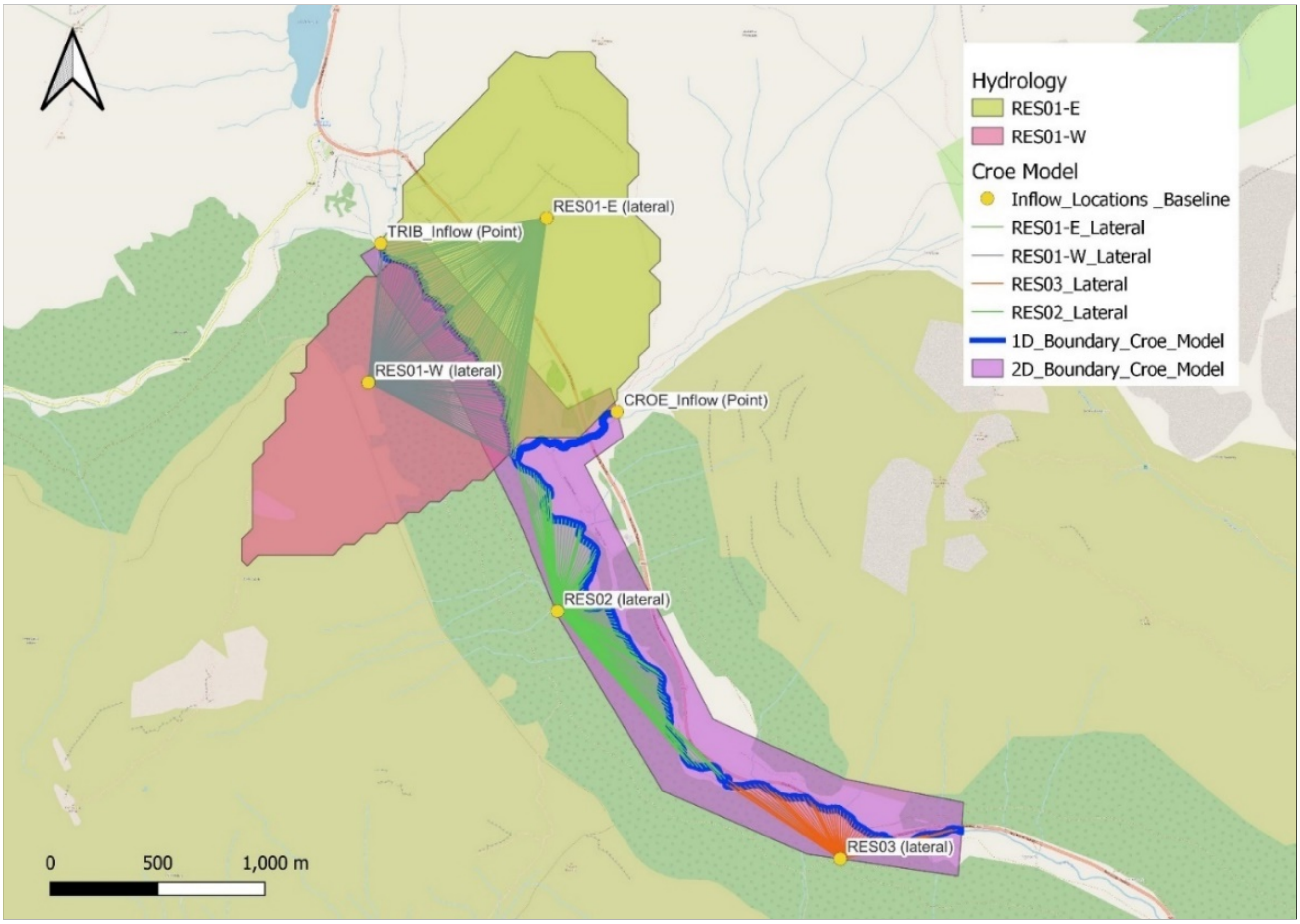


Plate 19. 9 – Visualisation of the With Scheme model setup, showing the 2 new inflows RES01-E and RES01-W and their hydrological catchments



A19-1.6.30. As there will potentially be unquantifiable changes to existing flow paths and flow routing timings in the valley, sensitivity analysis was used to understand the potential net result in time to peak of the hydrograph RES01-E.

A19-1.6.31. The results of the timing of the overland flow analysis has shown that the inclusion of the Proposed Scheme will likely have a small impact on overland flow. The estimated max variation in time taken for overland flow to travel from upstream of the DFS+DFW to the OMR is approximately 7 minutes. This is based on the longest potential drainage path. It does not consider the cumulative impact of multiple flow paths being altered at once during a storm event.

A19-1.6.32. This approach enables us to get an understanding to the potential variation in timing of the hillside runoff that we may see due to the inclusion of the scheme. It makes assumptions relating to flow path direction, surface topography and gradient and so there is potential for this value to vary.

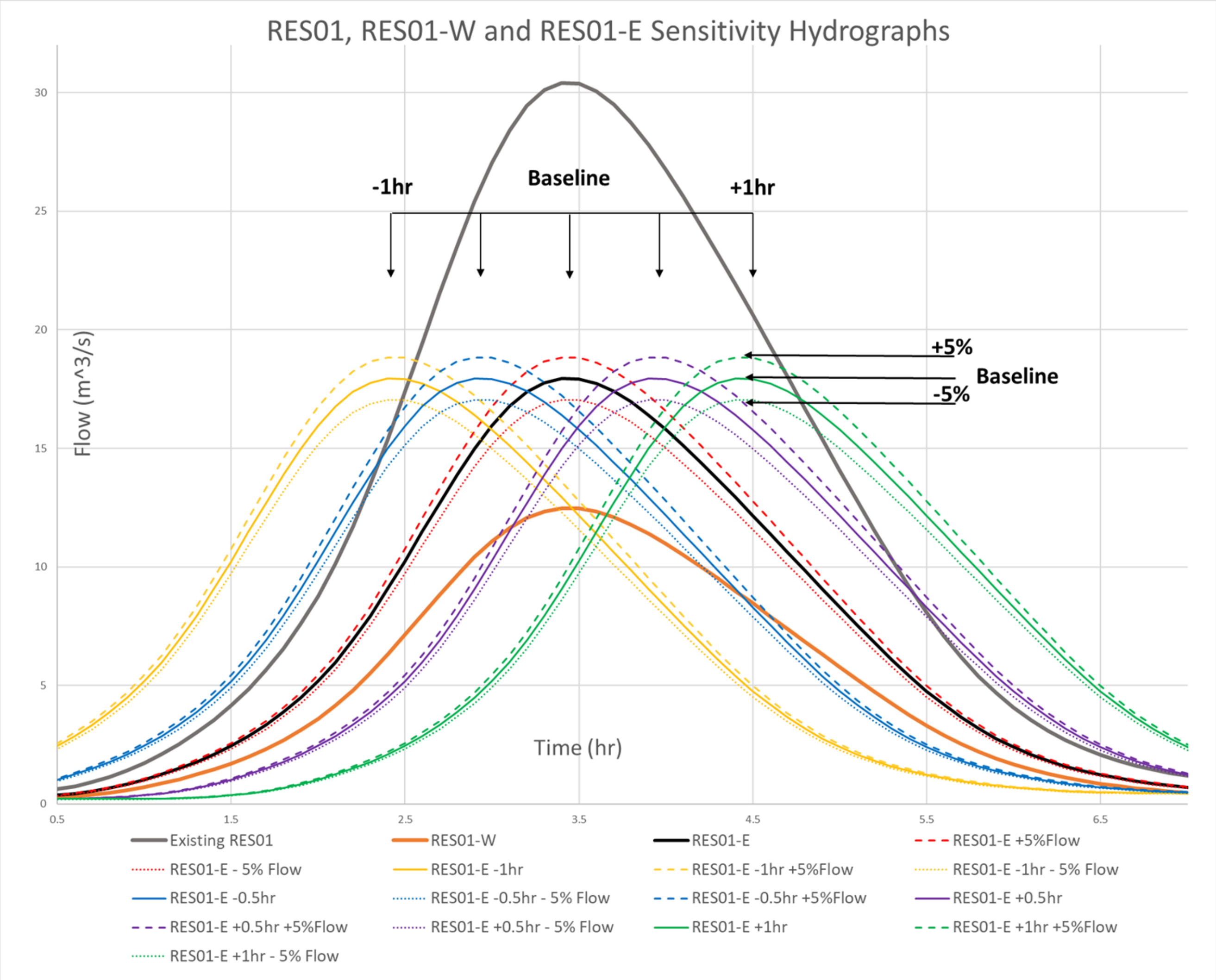
A19-1.6.33. There are also uncertainties and limitations that are included in the hydraulic modelling and limitations to the hydrology software and the resolution of its outputs. For this reason, it was decided to take a conservative approach when carrying out sensitivity tests on the lateral inflow RES01-E and use variations of +/-0.5hr and +/- 1hr, which were applied to the peaks of the inflow hydrographs.

A19-1.6.34. We are aware that any de-synchronisation from the existing inflow will have a beneficial benefit to flood risk in the valley, as it will alter the timing of the peak of one of the six inflows, reducing flow during the peak of the event in the Croe water. These variations to the timing of the inflow hydrograph peak, alongside baseline scenarios (where we have modelled no attenuation), enable us to understand the impact to flows and receptors in the Croe valley for a wider range of temporal variation and give us a better picture onto the bounds of the potential impact in the valley.

A19-1.6.35. A range of sensitivity tests set up and ran through the model. These included increasing the flows in the model by +/-5%, +/-10% and +/-20%. These variations in inflow were also combined with a de-synchronisation of the time to peak when compared to the 5 other model inflows. The critical storm duration for the model was 3.5 hours, and the Hydrographs for RES01-E were edited by -1hr. -0.5hr, +0.5hr and +1hr. These sensitivity tests were carried out, not to check the model's performance, but rather to test the assumption that were made around the modelling.

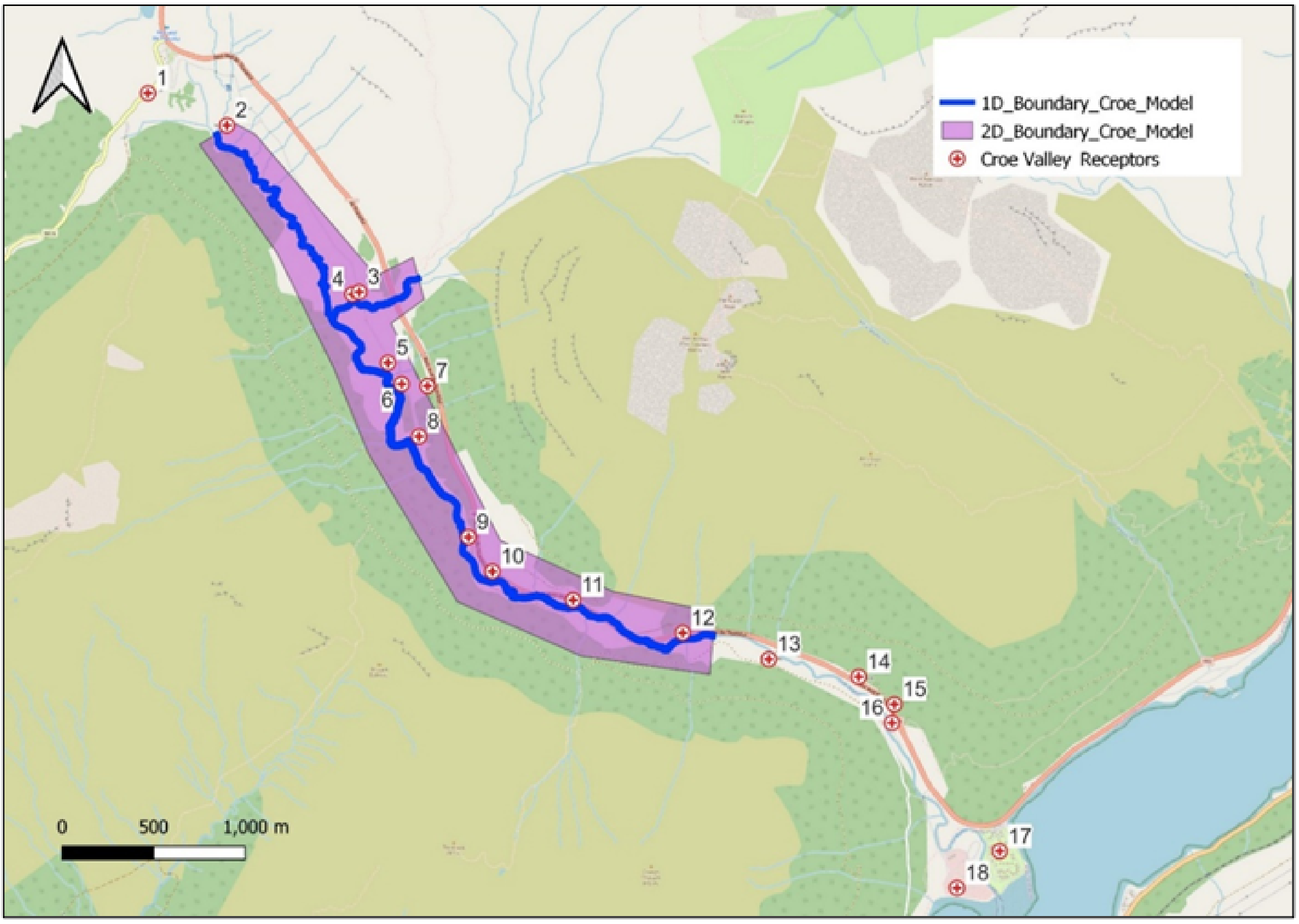
A19-1.6.36. A full set of results for all of these simulations can be found in the accompanying Croe Water Hydraulic Modelling Technical Note. From this point on this report will focus on the results of the baseline and +/- 5% flow only. It is believed that this value is the Higher / Lower Credible limit of flow variation for the Proposed Scheme. Multidisciplinary calls between hydrologists, drainage engineers and the flood risk team were held regularly to discuss the potential impact of the Proposed Scheme with regards to flood risk in the Croe valley. Using all the evidence that has been presented above, as well as the current Proposed Scheme design and using professional judgement the project team are confident that +5% flow is much more than any variation we expect to see in the valley after the construction of the Proposed Scheme. It is actually expected that there will be less flow in the valley as explained in previous sections. A visualisation of the inflows for RES01-E that have been used in the sensitivity tests can be seen below in Plate 19.10.

Plate 19.10 - A visual of the inflow hydrographs used at RES01-E. Above shows the original RES01, the E+W split, RES01-E and RES01-W and the sensitivity variations carried out on RES01-E



A19-1.6.37. To assess the impact of the Proposed Scheme to flood risk in the valley, the flood depths across the scheme have been extracted for each of the modelled scenarios at sensitive receptors throughout the valley. Flows have also been extracted at the downstream end of the model to understand what impact the potential variations in flow may have on other receptors in the valley that are outside the model extents. A map of the locations of these sensitive receptors can be seen below in Plate 19.11.

Plate 19.11 - Receptors in Glen Croe and the Croe Water hydraulic model extent



Croe Water sensitivity Testing - Results

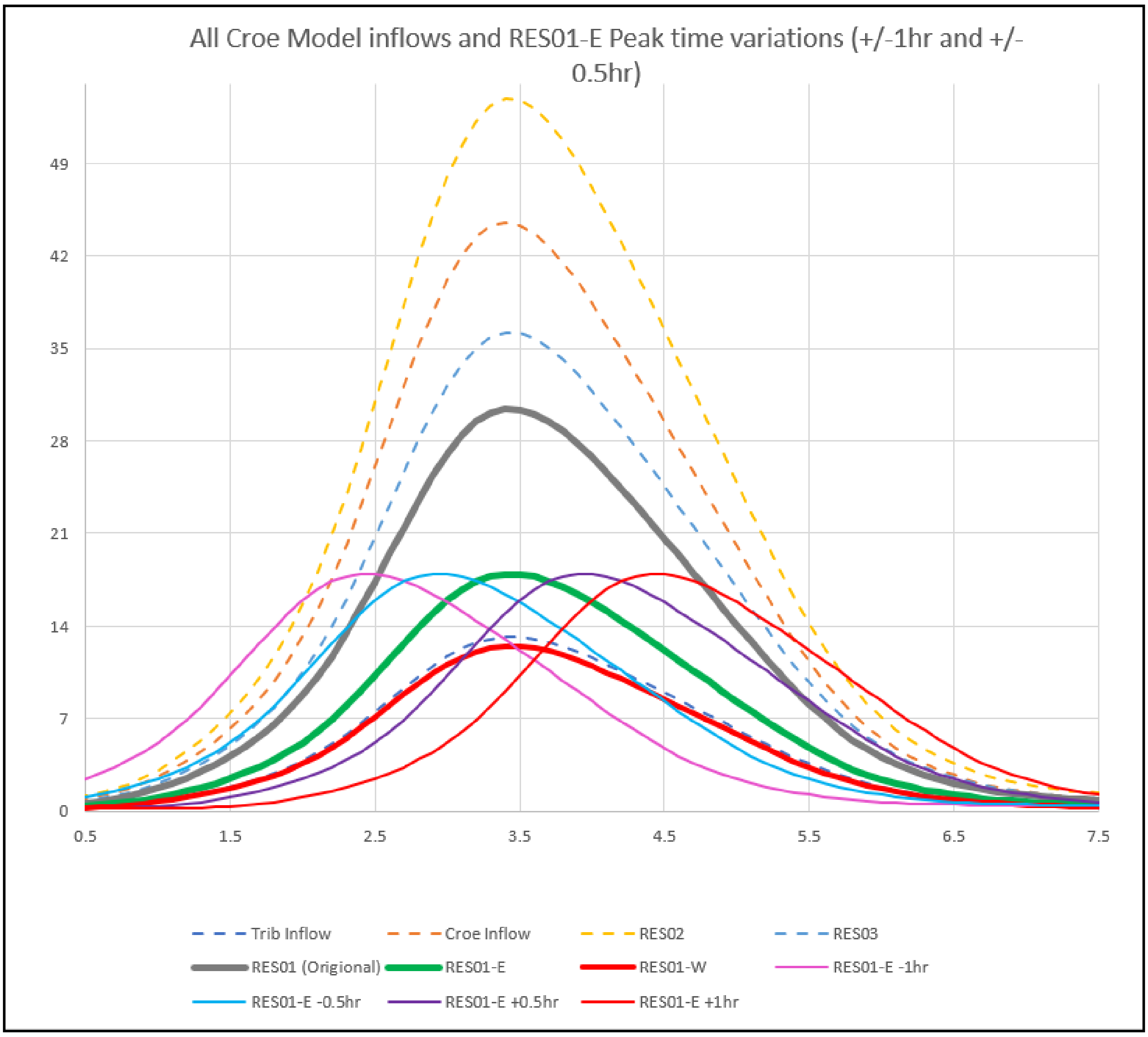
A19-1.6.38. A total of 14 sensitivity scenarios were run through the model of the Croe valley. These included variations to the time of the peak of the lateral inflow RES01-E and on each of these variations a +/-5% flow variation was also carried out. Results for each of these scenarios have been compared against the baseline scenario with results extracted at the sensitivity locations mentioned above.

A19-1.6.39. The results show that when RES01-E has the timing of its peak altered, it reduces the flood risk in the valley. In the initial 4 scenarios where the inflow peak was only varied (-1hr, -0.5hr, +0.5hr and +1hr) there was a reduction in flood depths at all of the previously flooded sensitive receptors in the baseline scenario. The smallest reduction was seen for the -/+ 0.5hr scenarios (min -0.01m, max -0.04m respectively) and the larger reduction seen when the hydrograph peak was altered by -/+ 1hr (min -0.04, max -0.09m respectively). This implies that the more attenuation applied to the lateral that covers the

Proposed Scheme RES01-E the more beneficial it is for flood risk in the Croe valley. This reduction across all of these scenarios is because the peak of the inflow RES01-E is now desynchronised from the peaks of the 5 other inflow hydrographs which are set to the critical storm duration of 3.5 hours, this has the impact of lowering the peak flow in the critical storm event which is why we see a reduction in flood depths.

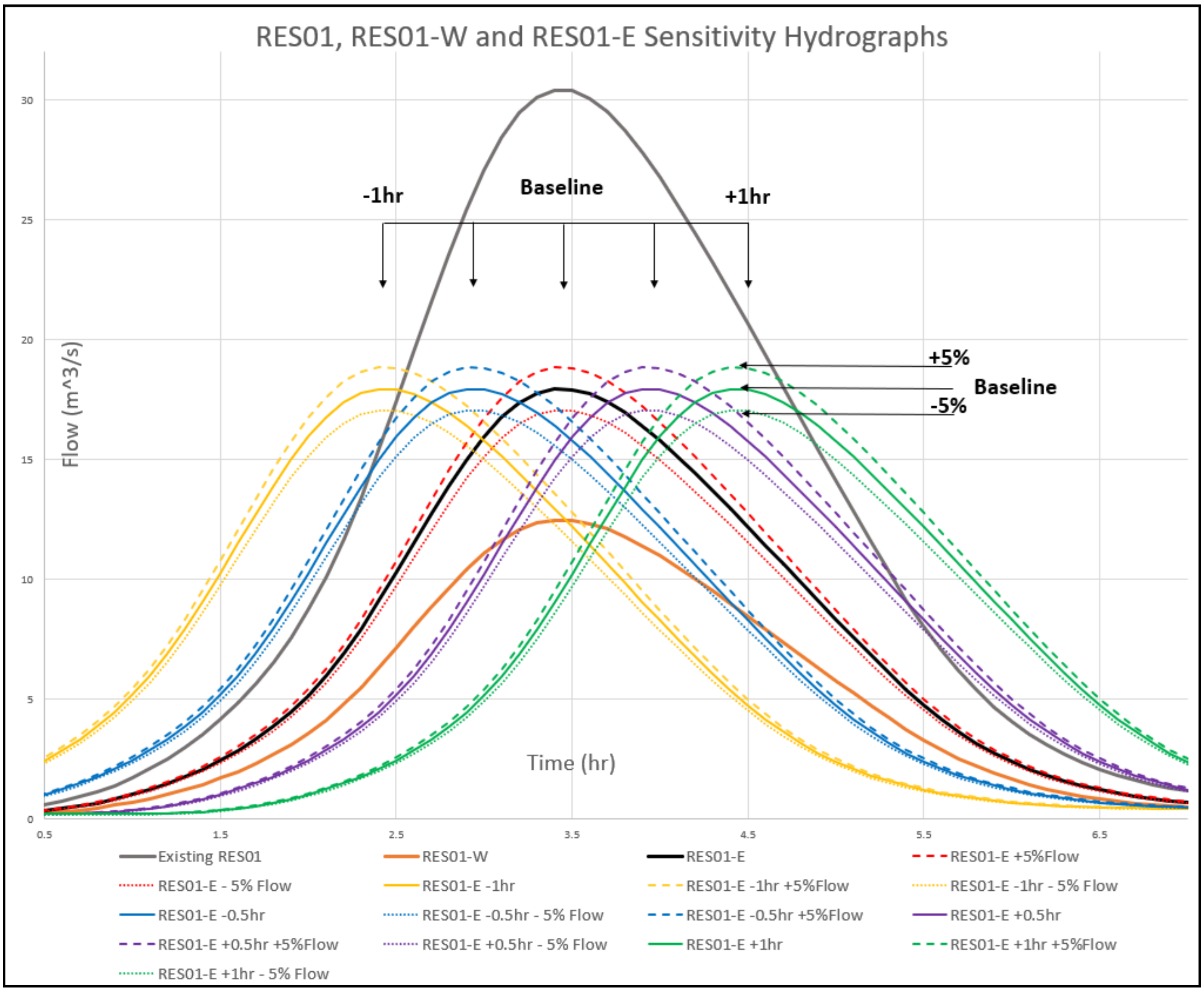
A19-1.6.40. Plate 19.12 shows all of the Croe valley hydraulic model inflow hydrographs and the sensitivity tests that were carried out by varying the timing of the peak of RES01-E.

Plate 19.12 – Visualisation of all of the Croe Model inflows, and the variations applied to the timing of the peak of RES01-E



A19-1.6.41. The second part of the sensitivity test was to look at the flow volume being applied to the Croe model and understand if the upper credible limit of +/-5% flow would have an impact of the sensitive receptors in the valley. To do this +/-5% was added to the existing time to peak variations mentioned above. A visual representation of these inflow hydrographs can be seen below in 19.13

Plate 19.13 – Visualisation of the +/- 5% peak inflow sensitivity test including variation applied to the hydrographs that have had the timing of their peaks altered by -1hr - +1hr.



A19-1.6.42. The results of these sensitivity tests showed that the only scenario where there was an increase to flood depths at the sensitive receptors was where there was no variation in the time to peak and the flow was increased by 5%. For this scenario there were increases of +0.01m and all of them were located on the A83 and OMR at locations that already experienced flooding in the baseline scenario. For all the other scenarios where the Timing of the peak or RES01-E was altered and the flow was increased by 5% there was either no change, or a net reduction in flood depths. A full table of results can be seen below in Table 19.13. This can be read in conjunction with Plate 19.11 which shows the location of the sensitive receptors in the Croe valley.

Table 19.13 - Receptor water level impact sensitivity results baseline vs scenarios

Table note – it should be noted that the following sensitive receptors were not in the model domain and are therefore not included in the table below – Receptor 1 (B828), Receptor 13, 14 and 15 (Residential Dwellings), Receptor 16 (Cabin / Visitor Centre), Receptor 17 (Caravan Holiday Park) and Receptor 18 (Ardgartan Hotel).

Type or Receptor / Location	Sensitive Receptor Number	Baseline	-1hr	-0.5hr	+0.5hr	+1hr	-1hr +5%	-0.5hr +5%	+5pc	+0.5hr +5%	+1hr +5%	-1hr -5%	-0.5hr -5%	-5pc	+0.5hr -5%	+1hr -5%
Residential dwelling	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	3	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	4	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential Dwelling	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	8	0.23	-0.04	-0.01	-0.03	-0.09	-0.04	0.00	0.01	-0.02	-0.08	-0.05	-0.02	-0.01	-0.04	-0.10
OMR	9	0.74	-0.03	-0.01	-0.03	-0.07	-0.03	0.00	0.01	-0.02	-0.07	-0.04	-0.01	-0.01	-0.03	-0.08

A83	10	0.38	-0.01	0.00	-0.01	-0.02	-0.01	0.00	0.00	-0.01	-0.02	-0.01	0.00	0.00	-0.01	-0.03
A83	11	0.53	-0.04	-0.01	-0.04	-0.11	-0.03	0.00	0.01	-0.03	-0.10	-0.05	-0.02	-0.01	-0.05	-0.11
A83	12	0.91	-0.02	0.00	-0.02	-0.05	-0.01	0.00	0.01	-0.01	-0.04	-0.02	0.00	0.00	-0.02	-0.05

A19-1.6.43. As can be seen in the table 6.12, the only scenario where results show an increase in max flood depths (+0.01m) when compared to the baseline is when an additional 5% flow is applied to the lateral inflow RES01-E. As explained above, using all available information, modelling results, and professional judgement it is believed that the Proposed Scheme will result in an overall net reduction in inflows. It is also understood that the Proposed Scheme will result in a degree of attenuation which would act to de-synchronise the inflow peaks however the exact scale of this is not certain.

A19-1.6.44. The Higher / Lower Credible limit of (+/-5% Flow) has been run through the model and the results show that the sensitive receptors in the valley are only very slightly impacted with max variation of +0.01m depth for the +5% sensitivity test, and -0.01m for the -5% scenario. Both of these scenarios assume no attenuation has taken place.

A19-1.6.45. As can be seen in Plate 19.11 above, there are some receptors that are not included in the model domain. Number 1 is the B828 which runs west from the rest and be thankful carpark. This receptor sits in the Croe valley however, it is not at risk of flooding due to any impact from the Proposed Scheme.

A19-1.6.46. Five receptors 13-18 inclusive sit outside of the model domain and are located towards the downstream end of the project extent. To understand the potential flood risk impact to these receptors, peak flows were extracted at the downstream end of the model and compared to the baseline scenario.

A19-1.6.47. 14 scenarios were compared. These included variations of +/- 5% flow and attenuation from -1hr to +1hr. Results for these sensitivity tests can be seen in below in Table 19.13.

Table 19.14 – Downstream end of model Sensitivity Results

Variables	Baseline RES-E +W	-1hr	- 0.5hr	+ 0.5hr	+ 1hr	- 1hr -5%	- 0.5hr -5%	-5%	+ 0.5hr -5%	+1hr -5%	- 1hr +5%	- 0.5hr +5%	+5%	+ 0.5hr +5%	+1hr +5%
Peak Flow at DS Section (m^3/s)	154.64	151.31	154.41	151.46	145.65	150.65	153.49	153.97	150.70	145.16	152.02	154.98	155.77	152.21	146.12
Variation from Baseline (m^3/s)	Not applicable	-3.33	-0.23	-3.18	-8.99	-4.0	-1.1	-0.7	-3.9	-9.5	-2.6	0.3	1.1	-2.4	-8.5
Variation from Baseline (%)	Not applicable	-2.2	-0.1	-2.1	-5.8	-2.6	-0.7	-0.4	-2.5	-6.1	-1.7	0.2	0.7	-1.6	-5.5

A19-1.6.48. As can be seen above in Table 19.13 the sensitivity tests show that for the majority of scenarios there is a reduction in flow at the downstream end of the model. When there is no variation to the model inflows and the sensitivity is only carried out on the timing of the peak, there is a reduction in flow for all scenarios, ranging from -0.1% to -5.8% (-0.2m3/s to -9.0m3/s) of the total baseline inflow.

A19-1.6.49. When the flow is reduced by 5%, as expected the flow seen at the downstream and of the model also reduces. For this scenario, the removal of 5% of flow from RES_01-E inflow results in a reduction in total flow of -0.4% (-0.7m3/s). When the reduction in inflow is combined with the variation of the timing of the peak, flow variations are all reduced and range from -0.7% to -6.1% (-1.1m3/s to -9.5 m3/s) of the total baseline model inflows with the largest variation (-6.1%) for the "+1hr -5% flow" scenario.

A19-1.6.50. When the flow is increased by 5%, as expected the flow seen at the DS end of the model also increases. For this scenario, the addition of 5% of flow from RES_01-E inflow results in an increase in total flow of +0.7% (+1.1m3/s). When the 5% increase in flow is combined with the variation in the timing of the peak, peak flow increases for the "-0.5hr +5%" scenario only, resulting in an increase of +0.2% (+0.3m3/s). For all other time to peak variations for the +5%flow scenario there is an overall flow reduction at the downstream end of the model. The maximum reduction is for the "+1hr +5% flow" sees a reduction of -5.5% (-8.5 m3/s).

A19-1.6.51. Out of the 14 scenarios ran only 2 scenarios result in an increase in flow at the downstream end of the model and the increase is +0.7% of total model inflows, (+1.1m^3/s). The other 12 scenarios show an overall reduction in downstream model inflows when compared to the baseline. The reduction ranges from -0.1% to -6.1% (-0.23m^3/s to -9.5m^3/s).

Table 19.15 – Summary of Flood Risk Impact Analysis

Description	Magnitude of Impact	Reasoning
Change in small watercourse flow	No change. No additional flow due to The Proposed Scheme and those influenced are only a small proportion.	The Proposed Scheme will not generate additional flow in the small watercourses. The small watercourses that interact with the Proposed Scheme only account for a small proportion of flow within valley.
Change in small watercourse velocities	No change. No velocity changes from Scheme	The flow velocity will only be impacted in close proximity to the scheme and will remain unchanged by the time it meets the Croe water. This is because the downstream slope is the controlling factor on velocity (and this will not be altered as part of the scheme).
Change in attenuation	Beneficial / slight change to attenuation	The Proposed Scheme will alter existing flow paths and influence attenuation on the eastern slope of the Croe valley that hosts the DFS and DFW. Although the degree of attenuation is believed to be small, it is currently unknown. Sensitivity testing found that any variation to the hydrograph inflows has a beneficial impact on flood risk in the valley due to the desynchronising of peak flow hydrographs.

Description	Magnitude of Impact	Reasoning
Impacts from realisation of the scheme	Beneficial / slight Overall reduction in flow in the Croe Valley	The small watercourses on the eastern side of the Croe Valley that interact with the DFS and DFW only account for 9% of the over contributing catchments to the Croe Water. The Proposed Scheme will introduce additional drainage features such as a SuDS pond which is designed to remove approximately 1% of this contributing flow for the 0.5%AEP +CC event
Impacts from realisation of the scheme	No change / slight +/- 5% sensitivity testing	Whilst uncertainty has been accounted for within the hydrology derivation with a conservative approach adopted. Additional sensitivity testing of the inflow representing the small watercourse to the Croe have been undertaken understand flow variation (amount and type to peak) and minimal / no impacts were noted at receptors. Sensitivity testing of the time to peak shows this is the worst-case scenario with all peaks of hydrographs synchronised.

A19-1.7. Flood Risk Impact Assessment to Receptors from the Proposed Scheme

A19-1.7.1. Based on the rationale and reasoning outlined above an assessment of the flood risk impact has been made below. Alongside the sensitivity classification are the factors/ rationale associated with each of the receptor's classification determination.

Small Watercourses

A19-1.7.2. The only receptor the small watercourse will impact would be the OMR. Several locations along the OMR were selected for the flood risk impact assessment.

Table 19.16 – Impact from Small watercourse on receptors

Receptor*	Description	Importance (DMRB / SEPA)	Magnitude	Sensitivity	Rationale
OMR	Road	High / Highly Vulnerable Uses (given its diversion status)	Negligible	Slight Adverse	The small watercourse modelling showed no changed in depths or velocities with the introduction of The Proposed Scheme.

Croe Water

A19-1.7.3. As outlined in previous section receptors importance were classified using SEPA guidance and the assessment of magnitude has been undertaken using professional judgment based on the analysis outlined in Proposed Impact section. With the importance and magnitude classification made the sensitivity of impact can then be determined, the resultant sensitivity classification is provided in the table below along with the rationale for each classification.

Table 19.17 – Impact from Croe Water on receptors

Receptor ID	Grid Ref	Receptor Description	Importance (DMRB / SEPA)	Magnitude	Sensitivity	Rationale
1	NN 22947 07210	B828 Road	Medium / Least Vulnerable Use	No change	Neutral	Receptor not impacted by the Proposed Scheme as upstream.
2	NN 23328 06978	Residential dwelling	High/ Highly Vulnerable Uses	No change	Neutral	Receptor not impacted by the Proposed Scheme as upstream.
3	NN 24056 06056	OMR Location 1	High / Highly Vulnerable Uses (given its diversion status)	Negligible	Slight Adverse	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. Sensitivity testing illustrated with plus 5% flow increase of 0.01m and with minus 5% decrease of -0.01m. Refer to Table 19.13 above.
4	NN 24013 06056	Structure used for agricultural purposes	Medium / Least Vulnerable Use	No change	Neutral	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. With 5% increase in flow no change in flood depth at receptor. Refer to Table 19.13 above.
5	NN 24207 05681	Structure used for agricultural purposes	Medium / Least Vulnerable Use	No change	Neutral	Receptor lies outside of 0.5% AEP +CC 46% event flood extent. With + 5% flow increase receptor is still out with the flood extent.
6	NN 24282 05565	Structure used for agricultural purposes	Medium / Least Vulnerable Use	No change	Neutral	Receptor lies outside of 0.5% AEP +CC 46% event flood extent. With + 5% flow increase receptor is still out with the flood extent.
7	NN 24423 05554P01	Residential dwelling	High / Highly Vulnerable Uses	No change	Neutral	Receptor lies outside of 0.5% AEP +CC 46% event flood extent. With + 5% flow increase receptor is still out with the flood extent.
8	NN 24380 05282	OMR Location 2	High / Highly Vulnerable Uses (given its diversion status)	Negligible	Slight Adverse	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. Sensitivity testing illustrated with plus 5% flow increase of 0.01m and with minus 5% decrease of -0.01m. Refer to Table 19.13 above.
9	NN 24645 04731	OMR Location 3	High / Highly Vulnerable Uses (given its diversion status)	Negligible	Slight Adverse	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. Sensitivity testing illustrated with plus 5% flow increase of 0.01m and with minus 5% decrease of -0.01m. Refer to Table 19.13 above.

Receptor ID	Grid Ref	Receptor Description	Importance (DMRB / SEPA)	Magnitude	Sensitivity	Rationale
10	NN 24776 04540	A83 Location 1	High / Highly Vulnerable Uses	Negligible	Neutral	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. Sensitivity testing illustrated with plus 5% flow increase of 0.01m and with minus 5% decrease of -0.01m. Refer to Table 19.13 above.
11	NN 25218 04386	A83 Location 2	High / Highly Vulnerable Uses	Negligible	Neutral	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. Sensitivity testing illustrated with plus 5% flow increase of 0.01m and with minus 5% decrease of -0.01m. Refer to Table 19.13 above.
12	NN 25817 04200	A83 Location 3	High / Highly Vulnerable Uses	Negligible	Neutral	Receptor currently lies within 0.5% AEP +CC 46% event flood extent. Sensitivity testing illustrated with plus 5% flow increase of 0.01m and with minus 5% decrease of -0.01m. Refer to Table 19.13 above.
13	NN 26286 04062	Residential dwelling	High / Highly Vulnerable Uses	Negligible	Slight Adverse	Downstream of model boundary As anticipated with increase/ decrease in flow sensitivity analysis flow at downstream end of model varied according. With a +5% increase to the flow there was an increase by 0.7%. With a -5% decrease to the flow there was a -0.4% flow. The +/- variations in time only had the effect of reducing the flow up to – 2% (as a result of desynchronising the peaks). For more detail refer to section sensitivity testing.
14	NN 26777 03966	Residential dwelling	Medium/ Least Vulnerable Uses (appears to be uninhabited from DTS)	Negligible	Slight Adverse / Neutral	Downstream of model boundary As anticipated with increase/ decrease in flow sensitivity analysis flow at downstream end of model varied according. With a +5% increase to the flow there was an increase by 0.7%. With a -5% decrease to the flow there was a -0.4% flow. The +/- variations in time only had the effect of reducing the flow up to -2% (as a result of desynchronising the peaks). For more detail refer to section sensitivity testing.
15	NN 26972 03816	Residential dwelling	High / Highly Vulnerable Uses	Negligible	Slight Adverse	Downstream of model boundary As anticipated with increase/ decrease in flow sensitivity analysis flow at downstream end of model varied according. With a +5% increase to the flow there was an increase by 0.7%. With a -5% decrease to the flow there was a -0.4% flow. The +/- variations in time only had the effect of reducing the flow up to - 2% (as a result of desynchronising the peaks). For more detail see section sensitivity testing.

Receptor ID	Grid Ref	Receptor Description	Importance (DMRB / SEPA)	Magnitude	Sensitivity	Rationale
16	NN 26959 03714	Dwelling (cabin/visitor centre)	High / Highly Vulnerable Uses	Negligible	Slight Adverse	Downstream of model boundary As anticipated with increase/ decrease in flow sensitivity analysis flow at downstream end of model varied according. With a +5% increase to the flow there was an increase by 0.7%. With a -5% decrease to the flow there was a -0.4% flow. The +/- variations in time only had the effect of reducing the flow up to - 2% (as a result of desynchronising the peaks). For more detail refer to section sensitivity testing.
17	NN 27547 03013	Caravan Holiday Park – Forest Holidays Ardgartan	Very High / Most Vulnerable Uses	Negligible	Slight Adverse	Downstream of model boundary As anticipated with increase/ decrease in flow sensitivity analysis flow at downstream end of model varied according. With a +5% increase to the flow there was an increase by 0.7%. With a -5% decrease to the flow there was a -0.4% flow. The +/- variations in time only had the effect of reducing the flow up to -2% (as a result of desynchronising the peaks). For more detail refer to section sensitivity testing.
18	NN 27314 02812	Ardgartan Hotel	High / Highly Vulnerable Uses	Negligible	Slight Adverse	Downstream of model boundary As anticipated with increase/ decrease in flow sensitivity analysis flow at downstream end of model varied according. With a +5% increase to the flow there was an increase by 0.7%. With a -5% decrease to the flow there was a -0.4% flow. The +/- variations in time only had the effect of reducing the flow up to – 2% (as a result of desynchronising the peaks). For more detail refer to section sensitivity testing.
19	BT Underground Lines	Underground Lines following OMR & A83(T)	Very High / Essential Infrastructure	Negligible	Slight Adverse/ Neutral	Receptor currently lies within 0.5% AEP plus climate extent. Given nature of underground assets not affected by flood risk.

A19-1.8. Mitigation

A19-1.8.1. The Proposed Scheme is being designed to deal with debris flow / surface water flood risk with embedded mitigation therefore will be of flood risk benefit to the existing road by managing flows, so they do not pass over the road during extreme events. This specific flood risk embedded mitigation takes the form of:

- Catchpit – The catchpit will be designed to capture all hillside runoff that originates upslope of the DFS + DFW and direct it to a culvert that will pass under the A83 mainline. Prior to the catchpit, flows could spill onto the road during a storm event. The introduction of a catchpit will remove this risk.
- Culvert Upsizing – All culverts along the Proposed Scheme will be upsized to the 0.5%AEP+CC event in line with DMRB. Currently a number of culverts along the route of the Proposed Scheme are undersized and flow is able to back up and spill onto / over the A83.
- Improvements / upsizing of roadside drainage – All existing roadside drainage will be upsized to the 1%+CC event. This will improve surface water runoff and help direct over land flow towards the culverts rather than spilling onto the A83.
- SuDS basin – There will be a new SuDS basin introduced to the Croe valley that will look to collect, treat and attenuate flows from hard standings associated with the Proposed Scheme. This will reduce the volume and improve the quality of the existing runoff.

A19-1.8.2. With regards to any mitigation required to alleviate impacts of the Proposed Scheme, the significance of the effect of the Proposed Scheme on flood risk is considered to be slight/ neutral. Therefore, mitigation is not considered to be required.

A19-1.9. Residual Risk

A19-1.9.1. Given the slight/ neutral flood risk impact sensitivity to receptors this FRA has presented no proposed mitigation (other than the embedded mitigation). Therefore, the residual risk is considered to be the same as the existing baseline flood risk.

A19-1.10. Construction

A19-1.10.1. Volume 2, Chapter 21: Schedule of Environmental Commitments will be incorporated into the works construction documents and the Appointed Contractor will be obliged to adhere to these requirements through the contract period. The construction commitments will be addressed through the

Construction Environmental Management Plan (CEMP). The section below highlights those pertaining to flood risk.

A19-1.10.2. Standard is for the Appointed Contractor to prepare a CEMP to set out how they intend to operate the construction site, including construction-related mitigation measures. The relevant section(s) of the CEMP will be in place prior to the start of construction work.

A19-1.10.3. The CEMP will include a Flood Response Plan and reference should be made to SEPA's Floodline service. Although The Proposed Scheme is not within a specific SEPA Flood Warning area, the alignment does fall within the general Argyll and Bute Flood Alert area. Flood alerts indicate that flooding is possible to a wider geographical area and gives an early indication of potential flooding.

A19-1.10.4. The Flood Response Plan will be prepared and submitted to Transport Scotland for approval before construction work commences and will include the following:

- how information gathered from SEPA's Flood Alert should be provided and disseminated
- what will be done to protect the critical infrastructure of the development and how easily damaged items will be relocated
- the availability of staff and time taken to respond to a flood alert
- the use of high-level refuges for staff within the plant
- the time needed to evacuate the site
- provision of safe access to and from the development
- the ability to maintain key operations during a flood event and
- expected time taken to re-establish normal operation following a flood event.

A19-1.10.5. The Appointed Contractor will implement during construction in relation to flood risk. These measures include:

- the Flood Response Plan (as part of the CEMP) will set out the following mitigation measures to be implemented when working within the functional floodplain (defined here as the 0.5% AEP plus climate change flood extent):
    - o routinely check the MET office Weather Warnings and the SEPA Floodline alert service for potential storm events (or snow melt), flood alerts relevant to the area of the construction works
    - o during periods of heavy rainfall or extended periods of wet weather (in the immediate locality or wider river catchment) river levels will be

monitored using, for example, SEPA Water Level Data when available or visual inspection of water features. The Appointed Contractor will assess any change from base flow condition and be familiar with the normal dry weather flow conditions for the water feature, and be familiar with the likely hydrological response of the water feature to heavy rainfall (in terms of time to peak, likely flood extents) and windows of opportunity to respond should river levels rise;

- should flooding be predicted, works close or within the water features should be immediately withdrawn (if practicable) from high-risk areas (defined as: within the channel or within the bankfull channel zone – usually the 50% AEP flood extent. Works should retreat to above the 10% AEP flood extent with monitoring and alerts for further mobilisation outside the functional floodplain should river levels continue to rise
- plant and materials will be stored in areas outside the functional floodplain where practicable, with the aim for temporary construction works to be resistant or resilient to flooding impacts, to minimise/prevent movement or damage during potential flooding events. Where this is not possible, agreement will be required with the EnvCoW
- temporary drainage systems will be implemented to alleviate localised surface water flood risk and prevent obstruction of existing surface runoff pathways
- where practicable, haul routes will be located out of the functional floodplain. When in the floodplain stockpiling of material must be carefully controlled with limits to the extent of stockpiling within an area to prevent compartmentalisation of the floodplain and stockpiles should be away from water feature banks (not within 10m of the water feature banks). This is in order to limit floodplain encroachment, associated increased flood risk and sediment entering the water feature.

A19-1.11. Conclusion

A19-1.11.1. The focus of this FRA has been the potential impact to and from the Proposed Scheme at the A83 Rest and Be Thankful.

A19-1.11.2. The Proposed Scheme will be of flood risk benefit given the current road is liable to flooding from culvert blockage and undersized culverts. The Proposed Scheme would reduce this risk by managing flows, so they do not pass over the road during extreme events.

A19-1.11.3. Under NPF4 the land use classification for the Proposed Scheme is classified as Essential infrastructure.

A19-1.11.4. Surface Water flood risk was shown to be the major potential risk to the Scheme. Whilst no risk was shown on SEPA flood maps, historic records have highlighted the risk to The Proposed Scheme and is in fact part of the reason for the Proposed Scheme. Therefore, under NPF4 the Proposed Scheme would fall within the “essential infrastructure where the location is required for operational reasons”. All other sources of flood risk were considered low/ none.

A19-1.11.5. This FRA has demonstrated quantified as far as reasonable possible all risks of flooding are understood and through appropriate design the Proposed Scheme will remain safe and operational during flooding and future ready adaptations have been already made to accommodate the effects of climate change (new culverts as part of Proposed Scheme designed to 0.5% AEP plus climate change levels).

A19-1.11.6. To understand the potential increase in flood risk to others because of construction of the Proposed Scheme several different analyses were undertaken to reach an informed decision about the potential of effect. The analysis steered in the direction of there being negligible impact as a result of the Proposed Scheme. Principally, no new additional flow would be generated with the Proposed Scheme and with the terrain being the controlling factor flows would not be increased in velocity. If anything, analysis show any small amount of attenuation would be beneficial by offsetting peak flows from the watercourses and the new SuDS pond/ road drainage would remove the road contributing flows. However, taking a precautionary approach taking into account uncertainty it was decided a negligible impact was the conclusion.

A19-1.11.7. A review of the flood risk receptors from the scheme shows slight adverse/ neutral impact on the downstream flood risk receptors due to the negligible impact created. The slight adverse sensitivity classification was largely driven by the importance classification of most / highly vulnerable users with a negligible impact gives a slight adverse significance within the DMRB matrix.

A19-1.11.8. Overall, given the acceptance of the location of the Proposed Scheme with its benefits for flood risk to the road and the negligible impacts for others it is therefore considered the Proposed Scheme is compliant with NPF4, Argyll and Bute and SEPA policy and guidance.

Annex A - SEPA meeting notes

Date: Wednesday 26 June 2024

Time: 2pm-5pm

Location: Microsoft Teams

Attendees:

Alistair Cargil	AC	SEPA
Jess Taylor	JT	SEPA
Stuart Bone	SB	Atkins-WSP Joint Venture
Tim Jolley	TJ	Atkins-WSP Joint Venture
Mike Arnott	MA	Atkins-WSP Joint Venture
Alex Atkinson	AA	Atkins-WSP Joint Venture

Agenda:

Ref	Agenda Item	Lead
1	Introduction and Meeting Purpose	AA
2	Scheme overview	AA
3	Policy / standards / guidance	AA
4	Site Setting	MA
5	Receptors	MA
6	Approach • Hydrology • Small watercourses • River Croe • Flood Risk Assessment	TJ / MA
7	Feedback	ALL

Item	Description and Action	Action
1	Welcome and meeting purpose AA welcomed attendees to the meeting and introductions were made. AA briefly ran through the purpose of the meeting – to provide an update to SEPA on the flood risk assessments general approach (inc. hydrology and modelling).	Not applicable
2	Scheme Overview AA provided overview of the preferred option for the long-term solution (LTS) which comprises of the debris flow shelter.	Not applicable
3	Policy / Standards / Guidance AA presented the various policy and guidance applicable to the scheme. Noting NPF4 as the main overriding document however DMRB in addition to various SEPA guidance also applicable. AA queried if there were going to be any updates to the SEPA guidance – in particular “Technical Flood Risk Guidance for Stakeholders” which currently has a caveat of an imminent update in line with NPF4. AC replied noting that this is coming soon however fundamentally no major changes that would affect the approach to the scheme will be in it.	Not applicable
4	Site Setting MA ran through the catchment characteristics highlighting the steep hillside topography with no attenuation and the watercourse having very localised catchments. Also presented the drone survey to show the area in 3D which further emphasised the steep terrain of the valley / watercourses.	Not applicable
5	Receptors MA provided a map of the proposed receptors to be assessed as part of the FRA – these were identified at stage 2 (have not changed).	Not applicable
6	Approach	Not applicable

Item	Description and Action	Action
	TJ outlined the general approach noting the use of 1D models for the hillside watercourses and 1D/ 2D models for the Croe water and Loch Restil. 6.1 Hydrology TJ ran through the hydrology approach with the key points being: • All sub-catchments were delineated from the UAV survey data (January 2024) • All sub-catchments (apart from the Croe Water) are less than 5km2 • Design flows for the numerous hillside watercourses are based on a donor approach whereby design flows are estimated for a nearby donor catchment (where FEH catchment descriptor data is available) and the calculated specific discharge $m^3/s/km^2$ is calculated. • FEH statistical method (using WINFAP software) and the FEH rainfall-runoff method (using ReFH2 software) applied. • Statistical method has been deemed suitable for the majority of the A83 culvert catchments using scaled results from Donor 5. • For the Croe Water, the ReFH2 method was applied, using (very slightly) scaled results from Donor 3. Overall, a conservative approach has been taken using statical method and also a conservative donor catchment used. 6.2 Small Watercourses MA talked through the approach to the modelling of the hillside watercourses highlighting some of the limitations (steep terrain, cross sections extracted from LiDAR). He also presented some preliminary results from the modelling of the baseline vs the proposed scheme highlighting: • Comparison of baseline and proposed models show that variation in velocity is negligible by location 9 (approx. 30m downstream of the A83)	

Item	Description and Action	Action
	• 1D modelling suggests the proposed scheme does not influence peak flows, depths or velocities except in a short reach downstream of the A83. • No impact is seen at the confluence with the Croe water. 6.3 Croe Water MA presented information on the 1D/2D model Croe model. The emphasis was showing the inflow representing the scheme area only accounts 15% of the total flow to the model. 6.4 Flood Risk Assessment TJ provided an explanation of the approach being taken forward to understand the flood risk impacts in the FRA. A precautionary approach (given uncertainty in hydrology and hydraulic) is being undertaken through the use of sensitivity analysis to demonstrate that receptors are not put at risk from the proposed scheme. This will be done initial with a 20% flow increase of the lateral inflow. Additional to this to account for uncertainty in the baseline model +/- 20% will be added to the baseline in addition to the plus 20% to the lateral.	
7	Feedback and End of meeting AA started discussion on any feedback SEPA could provide based on the presentation given in particular around the approach to hydrology, the modelling approach, the use of the Q200 plus Climate change (0.5% AEP +CC 46%) as the baseline flood risk event and the proposed use of sensitivity to understand flood risk impact to receptors. Hydrology AC accepted the precautionary approach taken towards hydrology. AC suggested potential use/ comparison of FEH13 to instead on FEH22 could be another avenue to explore. Modelling Approach No comments/ concerns raised.	WSP/ Atkins JV to consider if use of

Item	Description and Action	Action
	AC agreed use of 200year plus CC (0.5% AEP +CC 46%) was appropriate to use for assessment of flood risk, in accordance with NPF4. Proposed use of sensitivity for Flood risk impact No major concerns raised using this approach. Additional comments • AC enquired about consideration for scenarios such as a back-to-back storm with culverts being blocked. MA explained scenario has been considered and along the upstream side of scheme there is a connecting channel so if water cannot flow via one culvert, will pass along to next culvert in the system. • AC asked about water quality and treatment. SB highlighted treatment of highway water had been considered and is in separate system which will head toward SuDS detention basin for Network 1, discharging via filter drains for Networks 2 and 3. Generally, no concerns raised by SEPA in the meeting and appear to be happy with the approach proposed for understanding flood risk. AC enquired when formal chapter may be available for review. SB suggested currently this is anticipated around Autumn.	FEH13 data in hydrology

Annex B - A83 Baseline Hydrology

Overview

A19-1.11.9. Atkins and WSP Joint Venture (AWJV) has been commissioned to provide hydrological inflows for four areas within the wider A83 scheme, as follows:

- A83 Culverts – inflows used to size culverts beneath the A83, taking flows from the uphill (north-eastern) side of the road to the downhill (south-western) side;
- B828 Cycleway Culverts – inflows used to size culverts beneath the B828 cycleway, taking flows from the uphill (north-western) side of the route to the downhill (south-eastern) side;
- Loch Restil / Easan Dubh catchment – inflows for the hydraulic model of this catchment, used to model flood extents;
- Croe Water catchment – inflows for the hydraulic model of this catchment, used to model flood extents.

A19-1.11.10. The methodology and results for each are provided below, in order. (Note, the hydrological inflows for the B828 Cycleway Culverts and Loch Restil / Easan Dubh hydraulic model use the same methodology as the A83 culverts).

A83 Culverts Hydrology

Introduction

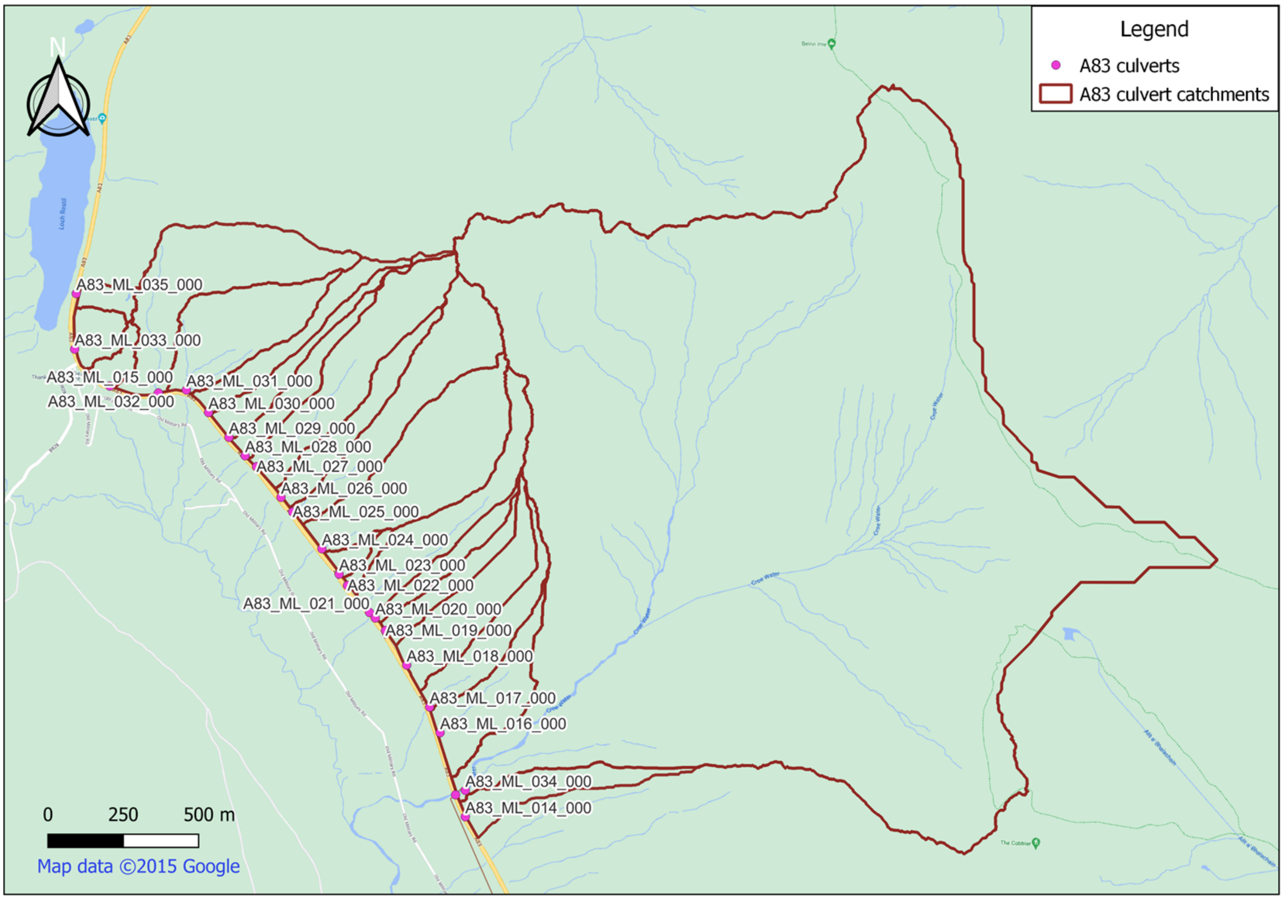
A19-1.11.11. The purpose of the A83 culverts hydrology is to provide inflows to recommend options for flood risk management at the proposed debris shelter. This assessment has been completed to derive the peak flow at all the culvert crossings on the section of the A83 affected by the proposed 'brown alignment' route. Based on the 'Baseline Flood Study Report' published by Jacobs/AECOM in April 2022, 60 watercourse crossings of the A83 were identified. 22 of these are relevant to the current study, being within the area potentially affected by the proposed new alignment. As per this report, 18 of the 60 culverts have been confirmed by a topographic survey. Of the 18 confirmed crossings, 13 of these are pipe culverts with diameters ranging between 375mm to 900mm and five are box culverts. The remaining 42 crossings of the A83 have been identified through interrogation of Ordnance Survey (OS) mapping, satellite imagery, and Google Street View. A fresh review will be undertaken by AWJV to confirm these culverts.

A19-1.11.12. As a part of the A83 LTS (Long Term Study), AWJV has revised the baseline hydrology to derive flows to these culverts. The catchments contributing flows to the culverts were delineated again and they have been found similar to the catchment delineations carried out by Jacobs/AECOM in their Hydrological Assessment Report published in February 2022. Hence the catchments from the Jacobs/AECOM 2022 study are used here as well. The catchments (and associated catchment descriptors) contributing to the A83 culverts are generally not defined on the FEH Digital Terrain Model (DTM) on the FEH web (https://fehweb.ceh.ac.uk) because they are less than 0.5km^2 in area. The exception to this is the Croe Water catchment. Hence, the proposed approach for deriving design flows for the numerous hillside watercourses is based on a donor approach whereby design flows are estimated for a nearby donor catchment where FEH catchment descriptor data is available and the calculated specific discharge m^3/s/km^2 is calculated. This is then multiplied by the catchment area of the respective catchment where FEH catchment descriptor data is unobtainable. These catchments where the catchment descriptors are available will be hereby referred to as Donor catchments.

A19-1.11.13. The hydrological assessment has been undertaken using both the FEH statistical method (using WINFAP software) and the FEH rainfall-runoff method (using ReFH2 software).

A19-1.11.14. As shown in Plate 19.1B, the study has been carried out for culverts annotated A83_ML_014_000 to A83_ML_035_000 as this stretch will be the location for the construction of the debris shelter and associated tie-ins. There is also a new proposed structure upstream of A83_ML_015_000 named A83_ML_015_A01 which is a total of 23 culverts for which the flows will be calculated.

Plate 19.1B - A83 culverts and their associated catchments

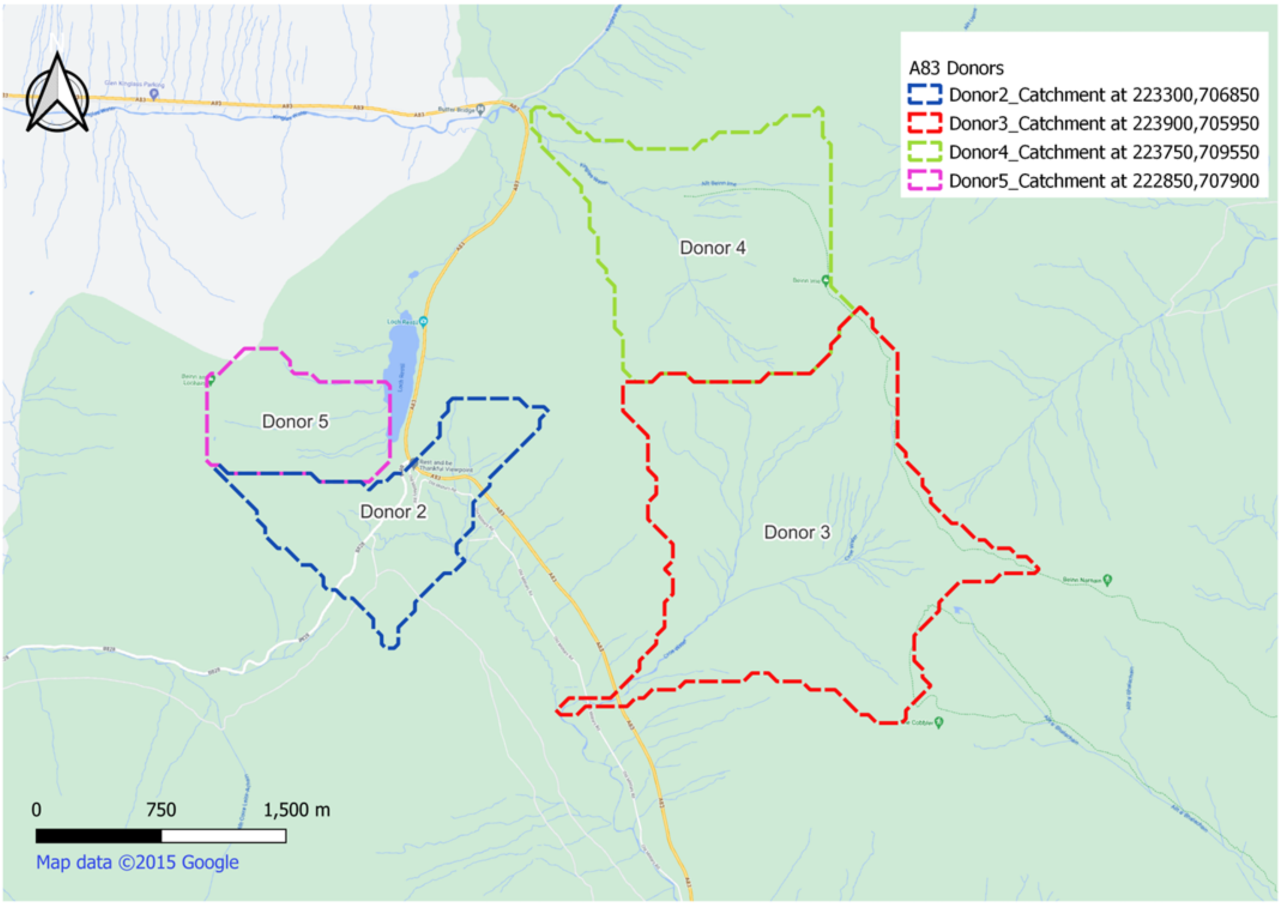


Study Catchments

A19-1.11.15. The watercourses that will potentially be intercepted by the proposed scheme drain steeply sloping hillsides. Some watercourses may be ephemeral in nature, with the rivers flowing during wetter periods while others have permanent flows. The south end of the catchment is majorly drained by River Croe and its tributaries. For the hydrological assessment, four donors have been selected to assess the flows to the A83 culverts. A review of the previous Hydrological Assessment Report published by Jacobs/AECOM was undertaken to select the donors for this study. The donors for the previous Jacobs study were annotated as 'Donor 2', 'Donor 3', and 'Donor 4' (An additional 'Donor 1' was only relevant to culverts outside of the current study area). After careful evaluation of these donor sites, AWJV concluded that, in addition to these donors, an additional new 'Donor 5' was added to the list of Donors as it was considered to better represent the steep, narrow A83 culvert catchments. The geographical locations of the 4 donors are shown in Plate 19.2B.

A19-1.11.16. As per the British Geological Survey (https://www.bgs.ac.uk/), the underlying bedrock geology is mostly composed of low permeability Psammite and Pelite (metamorphosed sedimentary bedrock) of the Upper Dalradian, Southern Highland Group which extends throughout the study area. An unnamed igneous intrusion of Late Silurian to Early Devonian Mafic Igneous-Rock partially underlies the catchment of the Croe Water and partially extends into catchments to the Old Military Road. A review of this location as per Scotland's soil is carried out has been populated in Addendum 2.

Plate 19.2B - Geographical location of the Donor sites of the A83 culvert catchments



A19-1.11.17. The study catchments are located within a rural area. The catchments are small and have no urban area. A brief review of OS mapping, satellite imagery and soil/geology mapping has not identified any other unusual features. OS mapping shows no ponds/lakes located on/near the watercourses of interest and hence no significant attenuation effects. The areas of the donor catchments were not delineated/checked as they will be used as donor catchments not as actual areas of runoff. The donor catchments are summarised in the Table 19.1B below.

Table 19.1B- Donor catchment feature descriptions

Table Note – the AREA source for each entry in the table below has been extracted from the FEH Web data.

Site Code	Watercourse	Site name (description)	Easting, Northing	AREA source	AREA (km^2)	Peak Flow, hydrograph or both needed?
Donor 2	Confluence of Car Pk, Memi Stone and High Glen Croe	Donor 2	223300, 706850	The area has been extracted from the FEH Web data.	1.13	Both peak and hydrograph needed
Donor 3	Croe Water and its tributaries	Donor 3	223900, 705950	The area has been extracted from the FEH Web data.	3.38	Both peak and hydrograph needed
Donor 4	Kinglas Waster and Allt Beinn Ime tributary	Donor 4	223750, 709550	The area has been extracted from the FEH Web data.	2.105	Both peak and hydrograph needed
Donor 5	Streams draining to Loch Restil	Donor 5	222850, 707900	The area has been extracted from the FEH Web data.	0.6975	Both peak and hydrograph needed

Derivation of FEH catchment descriptors

A19-1.11.18. Catchment descriptors were obtained from the FEH web service for the catchment for the different donor watercourses. The catchment descriptors were not changed prior to application as a donor.

Table 19.2B – FEH Catchment descriptors of the donor sites

Site Code	Original / Final	AREA (km^2)	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	FARL	FPEXT	PROPWET	SAAR	URBEXT2000
Donor 2	Original	1.128	0.265	0.82	365.8	1	0.0022	0.74	3091	0
Donor 3	Original	3.38	0.25	2.3	350.7	1	0.0096	0.74	3569	0
Donor 4	Original	2.105	0.254	1.7	458.1	1	0.0083	0.74	3534	0
Donor 5	Original	0.698	0.251	0.78	573.2	1	0	0.74	3310	0

A19-1.11.19. From the above table it can be concluded that:

- There is little difference in soil type between donors, with BFIHOST ranging from 0.25 to 0.265.
- The donors lie in fully rural areas, and this is reflected in the URBEXT values as they are all 0.
- Donors 3 and 4 have the highest SAAR. Donor 3 represents the Croe Water catchment and will be used for inflows in this area, which captures rainfall on the top of the mountain rather than just the side.
- There are no unusual catchment features such as permeable catchments (BFIHOST<0.65), highly urbanised areas, reservoir influence (FARL < 1), extensive floodplain storage etc.
- Since the catchment is rural, URBEXT2000 was not updated.
- Slopes (as shown by DPSBAR) are steep, Donor 5 has the steepest slope most representative of the catchments (the topography shows gradients of up to 600m/km). Hence, this donor will be used as the donor for most of the catchments so that they better represent the flows in the A83 culvert catchments.

ReFH2 application

A19-1.11.20. The ReFH2 version 4. was used for Revitalised Flood Hydrograph modelling. The default FEH catchment descriptors from the web are directly used. The area of study was selected as Scotland. The Tp and BL parameters were defined in accordance with ReFH2 application guidance. Flows have been derived for a single design storm, the recommended storm for the whole study catchment. Climate Change allowances were applied in line with current SEPA guidance document "Climate change allowances for flood risk assessment in land use planning," SEPA, April 2023. For the Argyll river catchment, a change in peak rainfall intensity of +46% to the year 2080 is applicable (for catchments less than 30 km^2). For the ReFH2 method, this has been added to the rainfall depth and run through the model to provide results.

Table 19.3B shows the adopted storm parameters (the default values were used in all cases). The growth curves that are used for the different return periods are listed in Table 19.4B.

Table 19.3B– Design Inputs

Site Code	Seasonality	Storm Duration (hours)	Tp	SCF (Seasonal correction factor)	ARF (Areal reduction factor)
Donor 2	Winter	4:06	1	0.95	0.98
Donor 3	Winter	4:30	1	0.97	0.97
Donor 4	Winter	4:30	1	0.97	0.97
Donor 5	Winter	4:18	1	0.98	0.96

Table 19.4B - ReFH method Growth Curve for different donors

Return period	ReFH method Growth Curves Donor 2	ReFH method Growth Curves Donor 3	ReFH method Growth Curves Donor 4	ReFH method Growth Curves Donor 5
50% AEP	1.00	1.00	1.00	1.00
20% AEP	1.35	1.34	1.34	1.34
10% AEP	1.59	1.57	1.57	1.58
5% AEP	1.84	1.81	1.81	1.82
4% AEP	1.92	1.89	1.88	1.90
3.33 %AEP	1.98	1.95	1.95	1.96
2% AEP	2.17	2.14	2.13	2.15
1.33 %AEP	2.33	2.29	2.29	2.30

Return period	ReFH method Growth Curves Donor 2	ReFH method Growth Curves Donor 3	ReFH method Growth Curves Donor 4	ReFH method Growth Curves Donor 5
1% AEP	2.45	2.40	2.40	2.42
0.5% AEP	2.74	2.68	2.68	2.71
0.5% AEP +CC 46%	4.28	4.10	4.12	4.15
0.1% AEP	3.52	3.41	3.43	3.45
0.1% AEP +CC 46%	2.00	5.13	5.18	5.22

A19-1.11.21. The final flood estimates from ReFH2 method are as shown in Table 19.5B. The specific discharge (i.e.) the flow per square kilometre (cumec/km^2) is calculated which when multiplied by the area of the A83 culvert catchments produces flows (in cumecs) that can be input as flows to the A83 culverts. These values are tabulated in Table 19.6B.

Table 19.5B - Final Flood estimates from ReFH2 (m^3/s)

Site Code	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5%AEP +CC 46%	0.1%AEP	0.1%AEP +CC 46%
Donor 2	3.07	4.13	4.89	5.64	5.89	6.10	6.68	7.16	7.52	8.42	13.15	10.82	16.78
Donor 3	11.27	15.06	17.70	20.38	21.26	21.99	24.08	25.81	27.07	30.25	46.17	38.45	57.88
Donor 4	6.89	9.21	10.82	12.45	12.98	13.42	14.70	15.76	16.53	18.48	28.39	23.59	35.69
Donor 5	2.16	2.89	3.41	3.93	4.10	4.24	4.64	4.97	5.22	5.84	8.97	7.45	11.28

Table 19.6B - Specific discharge ($m^3/s/km2$) for the donors derived from ReFH – for stated return periods

Site Code	Area (km^2)	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5%AEP+CC 46%	0.1%AEP	0.1%AEP+CC 46%
Donor 2	1.13	2.73	3.67	4.33	5.00	5.22	5.41	5.92	6.35	6.67	7.46	11.66	9.60	14.88
Donor 3	3.38	3.34	4.45	5.24	6.03	6.29	6.51	7.12	7.63	8.01	8.95	13.66	11.37	17.12
Donor 4	2.11	3.27	4.37	5.14	5.91	6.17	6.37	6.98	7.48	7.85	8.78	13.49	11.20	16.95
Donor 5	0.70	3.10	4.15	4.89	5.63	5.88	6.08	6.66	7.13	7.48	8.38	12.85	10.69	16.17

Statistical method

A19-1.11.22. The version of WINFAP used was v5 and NRFA database used was version 11-1. The FEH equation was used to estimate QMED from catchment descriptors. Since the catchment was less than <25km^2, the QMED defaulted to one donor. However, the closest pooling sites for QMED do not accurately represent any of the donor sites. Thereby the QMED estimation is done using the QMED equation. The initial QMED for the various donor sites is listed in Appendix A3.

Table 19.6B - QMED at ungauged subject site

Site Code	Initial QMED (rural) from CDs (m^3/s)
Donor 2	4.04
Donor 3	11.43
Donor 4	7.55
Donor 5	2.86

A19-1.11.23. Pooling has been used for the estimation of growth curves of the ungauged donor sites for the various return periods. The pooling group and the reason for the rejection of donors from the individual donor sites have been listed in Hydrology Addendum. The growth curves for the various return periods are shown in table 19.7B.

A19-1.11.24. The flood peaks for the different donors for the various return periods are computed and tabulated in table 19.8B shows the specific discharge of different donors derived from the statistical method is tabulated in table 19.9B.

A19-1.11.25. For the statistical method, the climate change allowance has been added to the peak flows calculated. The climate change multiplication factor is obtained by dividing the peak flow of the climate change event and the peak flow for that return period in ReFH method.

Table 19.7B - Growth factors for the donors for calculated return periods - Statistical Method

Return period / AEP	Growth Factors - Statistical Method Donor 2	Growth Factors - Statistical Method Donor 3	Growth Factors - Statistical Method Donor 4	Growth Factors - Statistical Method Donor 5
50% AEP	1.00	1.00	1.00	1.00
20% AEP	1.29	1.27	1.28	1.30
10% AEP	1.50	1.46	1.48	1.51
5% AEP	1.73	1.66	1.70	1.75
4% AEP	1.81	1.73	1.77	1.83
3.33 %AEP	1.88	1.79	1.84	1.90
2% AEP	2.08	1.96	2.02	2.11
1.33 %AEP	2.26	2.11	2.18	2.29
1% AEP	2.39	2.22	2.31	2.42
0.5% AEP	2.75	2.50	2.63	2.78
0.1%AEP	3.82	3.32	3.57	3.85

Table 19.8B - Final flood peak (m^3/s) from Statistical method for calculated return periods

Site Code	Urban/ rural?	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1%AEP	0.1% AEP +CC 46%
Donor 2	Rural	4.04	5.21	6.07	7.00	7.33	7.60	8.42	9.14	9.68	11.13	17.38	15.43	23.91
Donor 3	Rural	11.43	14.51	16.70	19.01	19.79	20.46	22.41	24.08	25.34	28.62	43.68	37.96	57.14
Donor 4	Rural	7.55	9.66	11.18	12.82	13.38	13.86	15.27	16.49	17.41	19.85	30.49	26.94	40.76
Donor 5	Rural	2.86	3.71	4.33	5.00	5.24	5.44	6.03	6.54	6.93	7.96	12.22	11.01	16.67

Table 19.9B - Specific discharge ($m^3/s/km^2$) for the donors derived from Statistical Method for calculated return periods

Site Code	Area (km2)	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
Donor 2	1.128	3.58	4.62	5.38	6.21	6.50	6.74	7.47	8.10	8.59	9.87	15.42	13.68	21.21
Donor 3	3.38	3.38	4.29	4.94	5.62	5.85	6.05	6.63	7.12	7.50	8.47	12.92	11.23	16.91
Donor 4	2.105	3.59	4.59	5.31	6.09	6.36	6.58	7.26	7.83	8.27	9.43	14.48	12.80	19.36
Donor 5	0.698	4.10	5.31	6.21	7.17	7.51	7.79	8.64	9.37	9.93	11.41	17.51	15.79	23.89

A19-1.11.26. The final pooling group is provided in Appendix A1.

Computation of flows for A83 culverts

A19-1.11.27. Once the specific discharge is calculated, the flows to each of the A83 culverts can be computed for the different return periods. They are obtained by multiplying the area of each of the A83 culvert catchment areas by the specific discharge of the selected donor catchments. The donor catchments for each of the A83 culvert catchments are selected based on hydrological similarities between the donor catchment and the A83 culvert catchment. Listed below in Table 19.10B are the donors that are selected for the different A83 culvert catchments.

A19-1.11.28. The A83 culverts A83_ML_015_A01 and A83_ML_015_000 are on the Croe Water. This catchment is best hydrologically represented by Donor 3 which is the FEH catchment for this watercourse to its confluence with the upstream tributary to the north-west. (The actual area of the catchment to the A83 culvert has been measured as being 0.387km2 to crossing A83_ML_015_000 and this area is also applied to A83_ML_015_A01 for a conservative and consistent flow estimate, in comparison to the FEH DTM area of 3.87km2. Hence some very minor scaling is applied to Donor 3 to produce the required flows). The ReFH2 flows were chosen as a conservative estimate as they are higher than the statistical flows for this catchment.

A19-1.11.29. The specific discharge calculated for Donor 5 using the statistical method was used to represent the rest of the small catchments on the eastern side of the A83, draining both to the Croe Water and upper Loch Restil catchments. This was selected using the precautionary approach, as the highest specific discharge was calculated for this donor using the FEH statistical method. It is also considered to be the most geographically similar to the small catchments, which have a similar steep slope. In comparison, the western part of Donor 2 is much flatter, as are the upper parts of the Donor 4 and Donor 3 catchments which drain the top of the hill. The exception to the use of this donor is for the crossings on the Croe Water, for which the specific discharge for Donor 3 (the Croe Water itself) was used, using the ReFH2 method (which gave higher results than the statistical method) as a worst case.

Table 19.10B - Adopted donor catchments

Watercourse ID	AWJV adopted donor
A83_ML_014_000	Donor 5 - stats
A83_ML_015_A01	Donor 3 - ReFH2
A83_ML_015_000	Donor 3 - ReFH2
A83_ML_016_000	Donor 5 - stats

Watercourse ID	AWJV adopted donor
A83_ML_017_000	Donor 5 - stats
A83_ML_018_000	Donor 5 - stats
A83_ML_019_000	Donor 5 - stats
A83_ML_020_000	Donor 5 - stats
A83_ML_021_000	Donor 5 - stats
A83_ML_022_000	Donor 5 - stats
A83_ML_023_000	Donor 5 - stats
A83_ML_024_000	Donor 5 - stats
A83_ML_025_000	Donor 5 - stats
A83_ML_026_000	Donor 5 - stats
A83_ML_027_000	Donor 5 - stats
A83_ML_028_000	Donor 5 - stats
A83_ML_029_000	Donor 5 - stats
A83_ML_030_000	Donor 5 - stats
A83_ML_031_000	Donor 5 - stats
A83_ML_032_000	Donor 5 - stats
A83_ML_033_000	Donor 5 - stats
A83_ML_034_000	Donor 5 - stats
A83_ML_035_000	Donor 5 - stats

A19-1.11.30. The peak flows and the hydrographs for each of the A83 culvert catchments have been determined and the peak flows for the different return periods have been tabulated in Appendix A3.

A19-1.11.31. The hydrographs for each return period have been calculated by scaling the relevant ReFH2 generated hydrograph (for Donor 3 or Donor 5 as appropriate) for the relevant return period, and then scaling this to the required peak discharge.

Summary of results

A19-1.11.32. Statistical method has been deemed suitable for the majority of the A83 culvert catchments using scaled results from Donor 5.

A19-1.11.33. For the Croe Water, the ReFH2 method was applied, using (very slightly) scaled results from Donor 3.

A19-1.11.34. The peak flows and the hydrographs for each of the A83 culvert catchments have been determined and the peak flows for the different return periods have been tabulated in Appendix A3.

Limitations

A19-1.11.35. There are no catchment descriptors for the actual culvert catchments for A83. Hence, the flow to each culvert is calculated using donor catchments that have similar hydrologic characteristics as that of the donor catchments.

A19-1.11.36. The QMED is calculated based on the catchment descriptors and not through the pooling of donors as none of catchments are representative of the donor sites.

B828 Cycleway Culverts Hydrology

A19-1.11.37. The hydrological inflows for the B828 cycle culverts were calculated in a similar manner to the A83 culvert inflows, using specific discharge for an appropriate donor, and applying it to the relevant catchment area.

A19-1.11.38. The donor (proxy) catchment selected was Donor 5, FEH web catchment at NGR 222850, 707900 (small, unnamed tributary entering Loch Restil). This was considered more representative of the flows for these culverts than available FEH donors within the Croe Water catchment which were larger and less steep overall. The FEH statistical method flows were used.

A19-1.11.39. Three catchments were identified to the proposed uphill culvert entry points and numbered from north-east to south-west as US_Cycle_01, US_Cycle_02 and US_Cycle_03.

A19-1.11.40. The catchment areas of each were then delineated in GIS as 0.019, 0.072 and 0.064 km2 respectively, and these areas then multiplied by the relevant specific discharge obtained from Donor 5 for the required return period events. Peak discharges for the required return periods are provided below in Table 19.11B.

Table 19.11B – Cycleway Culverts Peak Flows (m^3/s) for calculated return periods

Watercourse ID	Area (km^2)	WSP Adopted Donor	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
US_Cycle_01	0.019	Donor 5 - stats	0.078	0.101	0.118	0.136	0.143	0.148	0.164	0.178	0.189	0.217	0.333	0.300	0.454
US_Cycle_02	0.072	Donor 5 - stats	0.295	0.383	0.447	0.517	0.541	0.561	0.622	0.675	0.715	0.822	1.261	1.137	1.720
US_Cycle_03	0.064	Donor 5 - stats	0.262	0.340	0.397	0.459	0.481	0.499	0.553	0.600	0.635	0.730	1.121	1.010	1.529

Loch Restil Model Hydrology

A19-1.11.41. The hydrological inflows for the Loch Restil / Easan Dubh catchment were calculated in a similar manner to the A83 culvert inflows, using specific discharge for an appropriate donor, and applying it to the relevant catchment area.

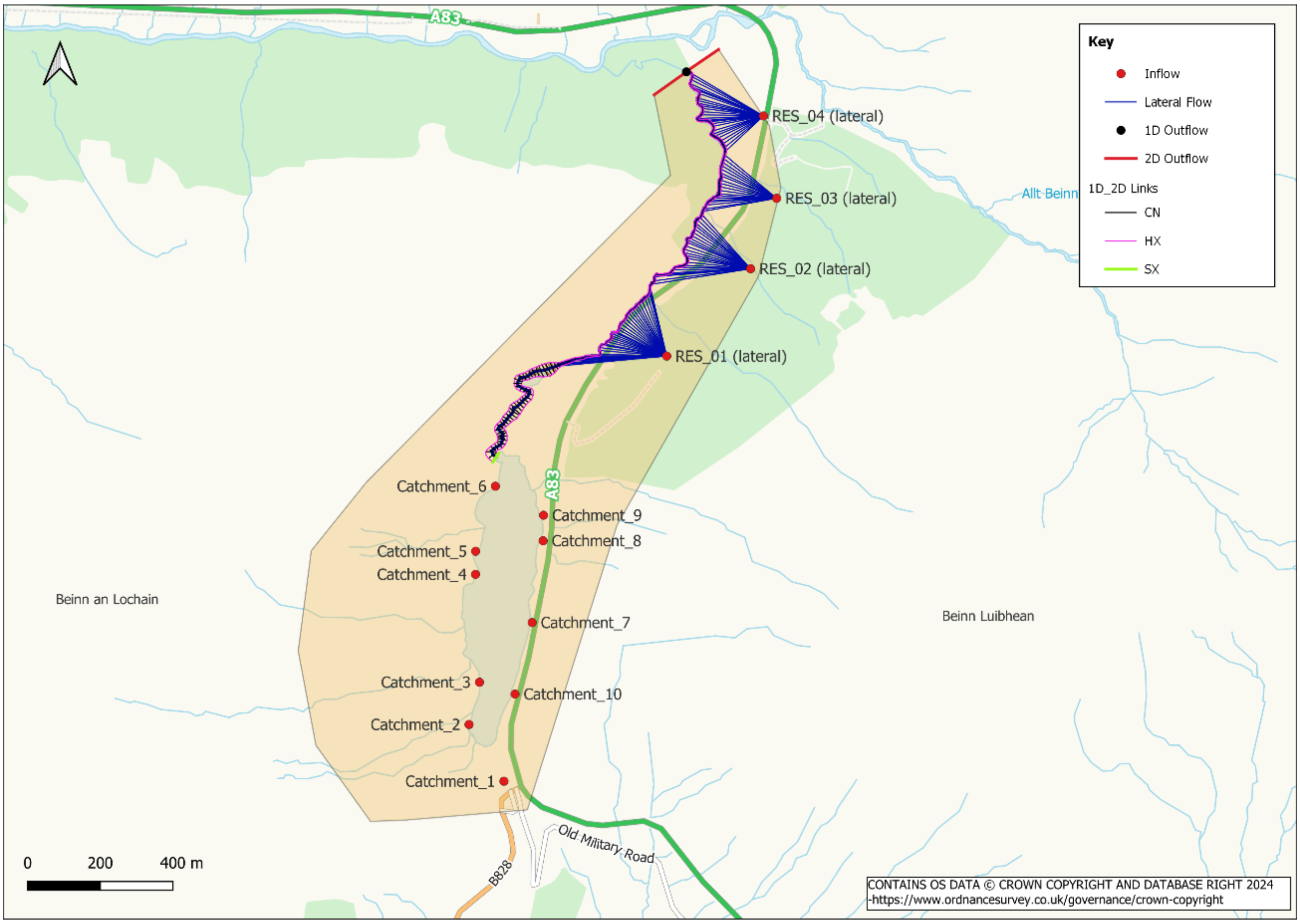
A19-1.11.42. The catchment being modelled was for the Easan Dubh to a point just upstream of its confluence with the Kinglass. The relevant FEH web catchment is to NGR 223250, 709400 and has an area of 3.26 km2. The FEH catchment to the downstream end of Loch Restil is at NGR 222950, 708350 and has an area of 1.58 km2.

A19-1.11.43. The donor (proxy) catchments selected were Donor 4, FEH catchment at NGR 223750 709550 (Alt Beinn Ime/ Upper Kinglas Water) and Donor 5, FEH web catchment at NGR 222850, 707900 (small, unnamed tributary entering Loch Restil). Donor 4 was used for inflows downstream of Loch Restil and Donor 5 for inflows upstream.

A19-1.11.44. The Easan Dubh catchment was sub-divided into 15 sub-catchments: 10 flowing into Loch Restil (including direct inflows to / on the loch), numbered Catchment 1 to Catchment 10 and modelled as direct inflows, and 5 downstream. The furthest downstream sub-catchment (area 0.021 km2) was not included. The other four were applied as lateral inflows and numbered RES_01 to RES_04.

A19-1.11.45. The schematic below shows how these were applied in the model (beige area is 2D model extent):

Plate 19.3B Loch Restil Model inflow locations



A19-1.11.46. Hydrological inflows were provided for the default storm duration of 4.5 hours, and also longer durations for the purposes of sensitivity testing (6.5 hours and 8.5 hours) for the Loch Restil inflows.

A19-1.11.47. The peak flows are provided in the Table 19.12B below.

Table 19.12B – Loch Restil Hydrological Peak Flows (m^3/s)

Inflow ID	Area (km2)	WSP Adopted Donor	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
RES_00*	0.021	Donor 4 - stats	0.076	0.098	0.113	0.130	0.135	0.140	0.154	0.167	0.176	0.201	0.308	0.272	0.412
RES_01	0.504	Donor 4 - stats	1.809	2.314	2.679	3.071	3.206	3.320	3.659	3.951	4.172	4.756	7.305	6.455	9.767
RES_02	0.401	Donor 4 - stats	1.437	1.838	2.128	2.439	2.547	2.637	2.906	3.138	3.313	3.777	5.802	5.126	7.757
RES_03	0.251	Donor 4 - stats	0.901	1.153	1.335	1.530	1.597	1.654	1.823	1.968	2.078	2.369	3.640	3.216	4.866
RES_04	0.403	Donor 4 - stats	1.444	1.847	2.138	2.451	2.559	2.650	2.920	3.153	3.329	3.795	5.830	5.151	7.794
Catchment 1	0.099	Donor 5 - stats	0.407	0.527	0.616	0.712	0.745	0.773	0.857	0.930	0.985	1.132	1.737	1.566	2.369
Catchment 2	0.221	Donor 5 - stats	0.908	1.177	1.374	1.588	1.663	1.725	1.913	2.075	2.198	2.526	3.878	3.496	5.289
Catchment 3	0.308	Donor 5 - stats	1.263	1.637	1.913	2.210	2.314	2.401	2.662	2.887	3.059	3.516	5.396	4.864	7.360

Inflow ID	Area (km2)	WSP Adopted Donor	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
Catchment 4	0.257	Donor 5 - stats	1.054	1.366	1.596	1.844	1.930	2.003	2.221	2.409	2.552	2.933	4.501	4.058	6.140
Catchment 5	0.230	Donor 5 - stats	0.944	1.224	1.430	1.653	1.730	1.795	1.990	2.159	2.287	2.628	4.034	3.637	5.503
Catchment 6	0.151	Donor 5 - stats	0.618	0.801	0.936	1.081	1.132	1.175	1.302	1.413	1.497	1.720	2.640	2.380	3.601
Catchment 7	0.058	Donor 5 - stats	0.238	0.309	0.361	0.417	0.436	0.453	0.502	0.545	0.577	0.663	1.018	0.917	1.388
Catchment 8	0.122	Donor 5 - stats	0.501	0.649	0.758	0.876	0.917	0.952	1.055	1.145	1.213	1.394	2.139	1.928	2.918
Catchment 9	0.148	Donor 5 - stats	0.607	0.788	0.920	1.063	1.113	1.155	1.280	1.389	1.471	1.691	2.595	2.340	3.540
Catchment 10	0.085	Donor 5 - stats	0.348	0.451	0.526	0.608	0.637	0.661	0.733	0.795	0.842	0.967	1.485	1.339	2.025

*Table Note - * RES_00 is not applied in the model.*

Croe Water Model Hydrology

Introduction

A19-1.11.48. Hydrological inflows were required for the Croe Water hydraulic model to be used to assess options for flood risk management in the catchment related to the proposed debris shelter and associated works. The report provides an updated record of the baseline hydrological understanding within the study area, which represents the Croe Water. The report provides details of the hydrological assessment undertaken, deriving fluvial design flows for the Croe Water; the calculations, assumptions and decisions made during the course of the assessment; and the final results. This assessment is an update to the 'Baseline Flood Study Report' published by Jacobs/AECOM in April 2022 (Jacobs AECOM (April 2022). Access to Argyll and Bute (A83). Baseline Flood Study Report. Appendix B: Baseline Hydrological Assessment (Pre-DMRB Stage 2)), using the most up to date available data (FEH22 rainfall and NRFA dataset 12.1, October 2023. The methodology adopted by Jacobs/AECOM has been reviewed and found to be appropriate, therefore, this study is primarily a data update, with the same method applied.

A19-1.11.49. It has been advised that the relevant design standard is up to the 0.5% AEP +CC 46%, although the 0.1% AEP +CC 46% may also be checked. Additionally, in line with the Jacobs/AECOM report, estimates of peak flood flows for the full range of return period are provided. Reference is made to SEPA climate change allowance for Flood Risk Assessment (FRA) in Land Use Planning (Version 4) for climate change allowances which states that for catchments smaller than 30km^2, the peak rainfall intensity allowances should be used. The study is within the Argyll River Basin Region, therefore 46% uplift for total predicted change by 2080 is applied.

A19-1.11.50. FEH Stats and ReFH2 (catchment scale) methodologies have been used for assessment as they are deemed appropriate for the nature of the catchment, and it is a suitable method as defined in the Technical Flood Risk Guidance for Stakeholders. For small catchments, such as the catchments assessed for this study, there is no clear preference for either method. However, due to the purpose of the study, both methods have been applied and the ReFH2 flows taken forward as they provided the more conservative results. This is the same approach undertaken by Jacobs/AECOM in their report for the Croe Water hydraulic model.

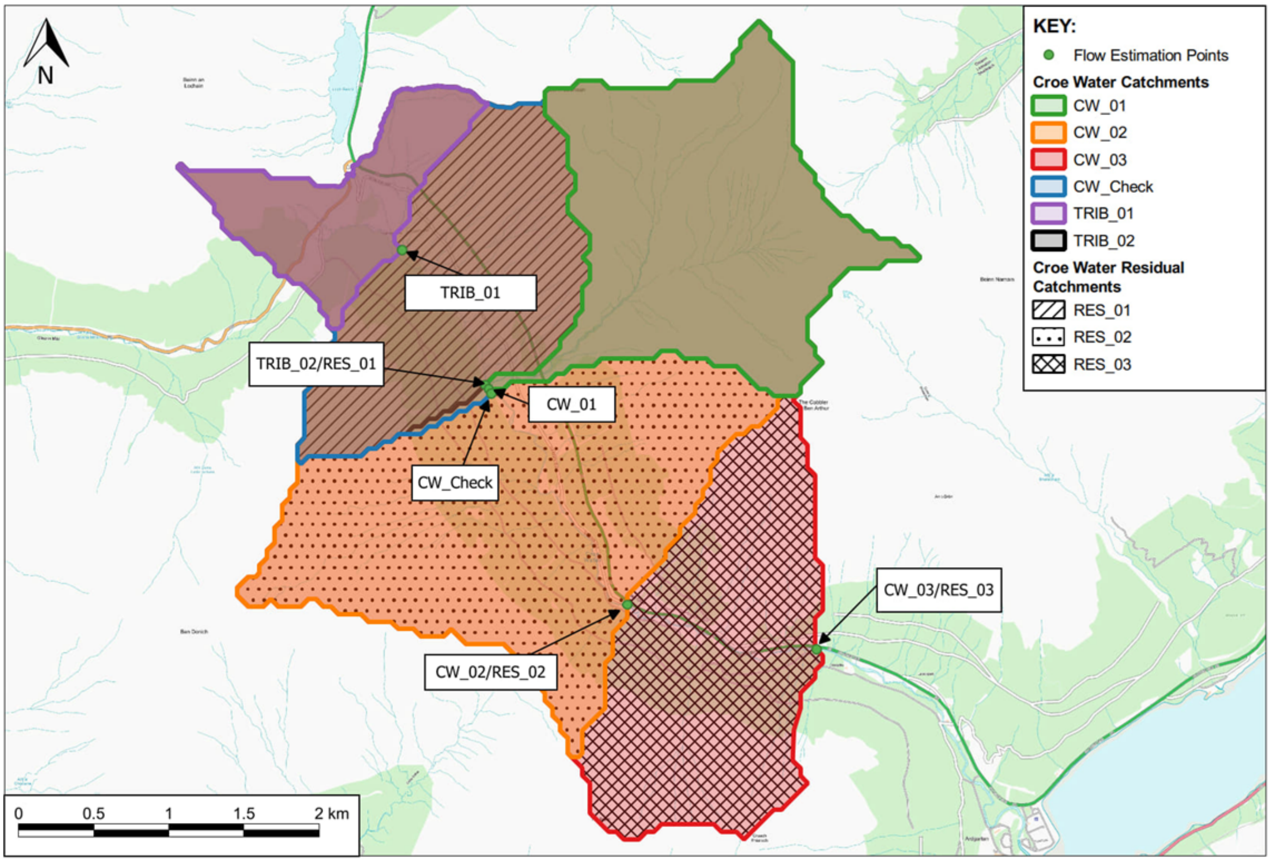
Study Catchments

A19-1.11.51. The study catchment is located along the A83, covering the catchment of the Croe Water and several unnamed tributaries of Croe Water. The downstream point of the catchment is located close to Creagdhu (xy: 226082, 704192) and extends up the A83/B828 junction at the upstream extent. This is the same hydrological extent of the study area for Croe Water.

A19-1.11.52. The same Croe Water hydraulic model catchment flow estimation points from the previous Jacobs/AECOM report were used and the catchments used to derive the fluvial inflows to the hydraulic model. See Plate 19.4B for the catchments used to derive the fluvial inflows to the hydraulic model for Croe Water. Appendix A shows z at a greater extent. Note, the areas pre-fixed with ‘CW’ and ‘TRIB’ represent the complete upstream catchment to each named point on the watercourse. The ‘RES’ areas represent the ‘residual’ catchment, i.e. the intervening catchment area between points (for which lateral model inflows will be required). ‘CW_Check’ is the point downstream of the confluence of CW_01 and TRIB_02.

A19-1.11.53. Since the previous Jacobs/AECOM report, high resolution 25cm LiDAR terrain data from January 2024 was obtained for the purpose of this study. This only partially covered the hydrological extent of the study area for Croe Water, but, in combination with OS mapping, was used to make updates to the FEH catchments where appropriate. For the areas of the catchments not covered with the 25cm LiDAR terrain data, 30m EU-DEM dataset, which in turn is based on SRTM and ASTER GDEM data, was used. The FEH catchment and the areas covered by the 30m EU-DEM data showed that the catchment boundaries were very similar, for areas of the boundary where this is the case, the FEH catchment boundary was retained. Only minor changes were made with the catchment area with a change in area of <10% compared to the FEH boundary.

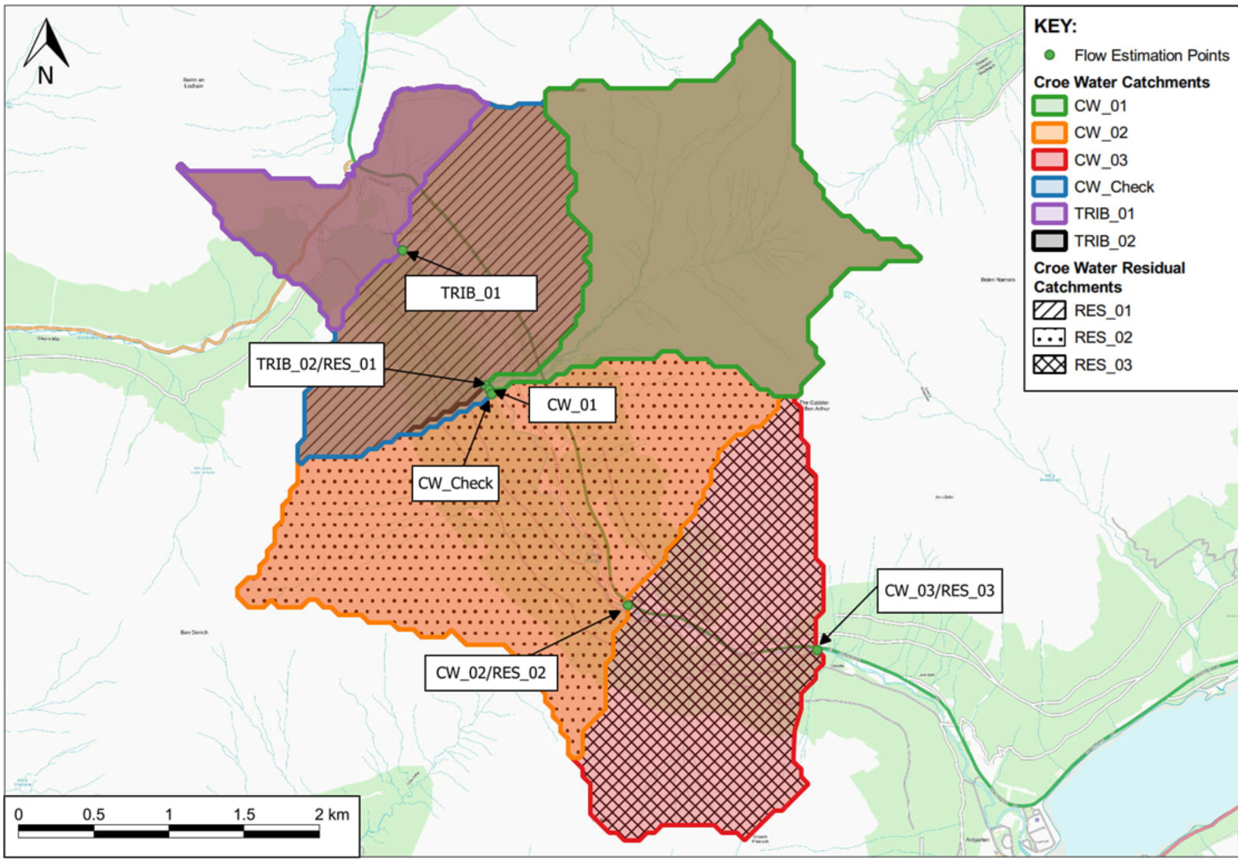
Plate 19.4B - Croe Water catchment including the residual catchments



A19-1.11.54. A review of the National Soil Map for Scotland and the World Reference Base Soil Map, showed that the underlying bedrock geology is mostly composed of low permeability Psammite and Pelite (metamorphosed sedimentary bedrock) of the Upper Dalradian, Southern Highland Group which extends throughout the study area. An unnamed igneous intrusion of Late Silurian to Early Devonian Mafic igneous rock partially underlies the catchments of Croe Water. Jacobs / AECOM noted that the soils are poorly drained peat and gleys and that the BFIHOST19 values seem appropriate. This conclusion seems reasonable and the BFIHOST19 values have been retained for the current study.

A19-1.11.55. As the FEH catchment area has changed by less than 10%, characteristics such as catchment slope (DPSBAR) and drainage path length (DPLBAR) have not been updated. FARL has been retained at its default value of 1 after evaluating the OS mapping which showed there is no sign of any reservoir/lake influence across the Croe Water catchments. URBEXT2000 has a value of 0 for all Croe Water catchments, and after evaluating the OS mapping there was no indication of urbanised development, therefore, the URBEXT2000 value was retained.

A19-1.11.56. For the purpose of the study, model inflows are required for the two upstream sub-catchments (‘TRIB_01’ and ‘CW_01’) as well as for three lateral inflow catchments (referred to as residual catchments). Additionally, flows at the downstream model boundary (‘CW_03’) are useful for model calibration and required for the statistical method which will use scaling. As shown in Plate 19.4B



, the first residual catchment area (known as ‘RES_01’), is the area of ‘TRIB_02’, subtracted by the area of ‘TRIB_01’. The second residual catchment area (‘RES_02’), is the area of ‘CW_02’, subtracted by the area of ‘CW_Check’. The third residual catchment area (‘RES_03’), is the area of ‘CW_03’, subtracted by the area of ‘CW_02’. The catchment descriptors for these residual catchments are calculated using the area-weighting method outlined in the Flood Estimation Handbook Volume 5 (Chapter 7).

A19-1.11.57. The catchments obtained from the FEH-web used as a basis for the analysis, and the residual catchments calculated from them for purposes of model inflow calculation, are shown below in Table 19.13B.

Table 19.13B - FEH-web catchments and required model inflows and locations.

Site Code	Watercourse	Location	Easting	Northing	Model Inflow
TRIB_01	Unnamed Tributary of Croe Water	Upstream model extent	223300	706850	Point inflow
TRIB_02	Unnamed Tributary of Croe Water	Immediately upstream of confluence with Croe Water	223850	705950	Not applicable
CW_Check	Croe Water	Immediately downstream of confluence with unnamed tributary	223900	705900	Not applicable
CW_01	Croe Water	Immediately upstream of confluence with unnamed tributary	223900	705950	Point inflow
CW_02	Croe Water	A83 / Old Military Road junction	224800	704450	Not applicable
CW_03	Croe Water	Downstream model extent	226100	704150	Downstream check
RES_01	Unnamed Tributary of Croe Water	Between TRIB_01 and TRIB_02	Same as TRIB_02	Same as TRIB_02	Lateral inflow
RES_02	Croe Water	Between CW_01 and CW_02	Same as CW_02	Same as CW_02	Lateral inflow
RES_03	Croe Water	Between CW_02 and CW_03	Same as CW_03	Same as CW_03	Lateral inflow

A19-1.11.58. Table 19.14B shows the catchment descriptors used in the assessment. This includes the catchment descriptors obtained directly from the FEH-web data and the residual catchments which were calculated based on the area-weighting method.

Table 19.14B - FEH catchment descriptors. Red bold text indicates a change from the original, this does not apply for the residual catchments which have been calculated.

Site Code	AREA (km^2)	FEH Area (km^2)	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
TRIB_01	1.17	1.13	0.344	0.82	365.80	3091	0	0.002
TRIB_02	3.76	3.72	0.266	1.48	412.70	3003	0	0.060
CW_Check	7.17	7.13	0.259	1.93	383.00	3271	0	0.036
CW_01	3.38	3.38	0.205	2.30	350.70	3569	0	0.010
CW_02	11.71	11.67	0.260	3.16	383.20	3219	0	0.034
CW_03	14.78	14.75	0.261	3.99	403.50	3235	0	0.034
RES_01	2.59	-	0.266	1.68	433.90	2963	0	0.086
RES_02	4.54	-	0.262	2.29	383.52	3137	0	0.030
RES_03	3.07	-	0.265	1.85	480.93	3296	0	0.030

Both the FEH Statistical method using WINFAP and FEH Rainfall-runoff method using ReFH2 have been applied.

FEH Statistical Method Application (WINFAP)

A19-1.11.59. The FEH Statistical method was carried out using WINFAP 5.1 and based on the latest version of the NRFA peak flow dataset (v12.1, released in November 2023).

QMED

A19-1.11.60. QMED was initially assessed through WINFAP for the most downstream catchment (CW_03) which encompasses all of the other assessed catchments.

A19-1.11.61. The conclusions of Jacobs / AECOM were agreed with, i.e. that although donor gauges were investigated for data transfer at CW_03 and other sites, these "were found to be poor candidates for data transfer due to significant differences in catchment hydrological characteristics such as the drainage area, the amount of rainfall across the catchments, the location of the catchment and the slope steepness of the catchment. The small upland catchments under consideration are atypical of many of the catchments within the NRFA Peak Flows dataset". Therefore, the catchment descriptors method has been used to determine the QMED for CW_03. as undertaken by Jacobs/AECOM in the previous report.

A19-1.11.62. As the site is ungauged, the FEH equation was used to estimate QMED from catchment descriptors for all of those for which flows are required by using the equation below, established for 'Essentially Rural' catchments.

$$QMED = 8.3062 \times AREA^{0.8510} \times 0.1536^{\frac{1000}{SAAR}} \times FARL^{3.4451} \times 0.0460^{(BFIHOST19)^2}$$

A19-1.11.63. To calculate the QMED equation, knowledge of the AREA, SAAR, FARL and the BFIHOST19 is required. FARL can be assumed as 1 as a review of the satellite mapping indicates that there is no lake influence across the delineated catchments.

Table 19.15B - QMED flows calculated from catchment descriptors

Site Code	Rural/Urban QMED (m^3/s)
TRIB_01	4.17
CW_01	11.43
CW_03	37.33
RES_01	7.98
RES_02	13.41
RES_03	9.85

The total of all of the Qmed sub-catchment inflows is 46.84 m^3/s, which is higher than for CW_03. This is discussed further below.

Pooling Group

A19-1.11.64. The pooling group for the assessed catchment (CW_03) only considered donor stations that were considered suitable, with the default URBEXT2000 threshold applied (< 0.03) and the small catchment pooling procedure also applied. The final pooling group in WINFAP, including all the assumptions is included in Appendix B. Changes made to the original pooling group are outlined below:

- Removed '76001 (Haweswater Beck @ Burnbanks)' from the original pooling group. The FARL value was very low at 0.645 and the discordancy was high at > 3. The donor station had a much lower growth curve than the rest of the pooling group when the logistic reduced variable was < 0 and was much greater than the rest of the pooling group when the logistic reduced variable was > 0. It was therefore much steeper than the rest of the pooling group. Due to a combination of these factors, the station was rejected.

- Removed '71003 (Croasdale @ Croasdale Flume)' from the original pooling group. The donor station has a much steeper growth curve than the majority of the other donor stations within the pooling group. After further investigation, there was no anomalous catchment descriptors, but there are significant periods of missing data (hydrological years 1974-75; 1977-82; 1989-03; 2014-present day), with only 11 years of recorded data in the last 34 years and 18 years of recorded data within the last 47 years.
- Removed '106002 (Laxdale @ Laxdale)' from the original pooling group. The donor station has a much flatter growth curve than the majority of the other donor stations within the pooling group. After further investigation, the station had a relatively low FARL value of 0.888 (< 0.9), which would likely contribute to the flatter growth curve. As a result of these factors the station was removed.
- Removed '73002 (Crake @ Low Nibtwaite)' from the original pooling group. The station has a low FARL value of 0.73 (< 0.9), so it has therefore been further assessed. The growth curve of the station is a little steeper than the assessed catchment (CW_03) but fits in well with the rest of the pooling group. However, the FARL value was considered low enough for the data to be considered unrepresentative.

A19-1.11.65. Due to the above stations being rejected from the original pooling group, other stations were needed to be brought in to reach the recommended 500-year threshold for the pooling group. Two stations were decided to not be brought in to reach the 500-year threshold:

- '206006 (Annalong @ Recorder)' was rejected because the station was decommissioned in 1943 when a tunnel upstream to the Silent Valley Reservoir was opened, rendering the records no longer natural. As there have been no records for 80 years, the station was not brought into the pooling group.
- '93001 (Carron @ New Kelso)' was rejected as it had a low FARL value of 0.858 (< 0.9).

A19-1.11.66. Three stations were accepted to reach the recommended 500-year threshold for the pooling group; '96004 (Strathmore @ Allnabad)', 58006 (Mellte @ Pontneddfechan)' and '21017 (Ettrick Waters @ Brockhoperig)'. All these donor stations were reviewed and deemed appropriate.

FEH Statistical Growth Curve

A19-1.11.67. A growth curve was obtained for the above pooling group representing the downstream end of CW_03 at the bottom of the catchment. The Generalised Logistic (GL) distribution gave the best fit, with a z value of 0.31. Other distribution parameters were as follows: Location: 1.0; Scale: 0.159; Shape: -0.175; Bound: 0.093.

A19-1.11.68. The growth curve parameters are as follows:

Table 19.16B - Statistical Growth Curve for the downstream catchment point (CW_03)

Return Period / AEP	QMED	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5 % AEP	0.1 % AEP
CW_03	1.00	1.25	1.43	1.61	1.68	1.73	1.89	2.03	2.12	2.39	3.14

FEH Statistical Peak Flows

A19-1.11.69. Table 17 provides a summary of the peak flows generated from the using the FEH equation QMED from catchment descriptors4 for each of the assessed catchments. The peak flows for the higher return periods are then based on the growth factors from the pooling group for the most downstream catchment point (CW_03), estimated using General Logistic (GL) applied to each catchment's respective QMED value.

A19-1.11.70. Flows have been produced for the inflow catchments (TRIB_02, CW_01), the residual catchments (RES_01, RES_02 and RES_03) and the downstream check catchment (CW_03). The climate change flows have been calculated by adding 46% to the 0.5% AEP event and 0.1% AEP event peak flows respectively.

Table 19.17B - FEH Statistical method flood frequency estimates based on Growth Curve for CW_03.

Site Code	QMED	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
TRIB_01	4.17	5.21	5.95	6.73	7.00	7.22	7.88	8.44	8.86	9.96	14.54	13.09	19.11
CW_01	11.43	14.28	16.30	18.43	19.17	19.77	21.58	23.11	24.26	27.29	39.84	35.86	52.36
RES_01	7.98	9.97	11.38	12.87	13.38	13.80	15.06	16.13	16.94	19.05	27.82	25.04	36.55
RES_02	13.41	16.76	19.12	21.63	22.49	23.20	25.32	27.11	28.47	32.02	46.75	42.08	61.43
RES_03	9.85	12.31	14.04	15.88	16.51	17.03	18.59	19.91	20.90	23.51	34.32	30.89	45.10
TOTAL	46.84	58.53	66.79	75.54	78.55	81.02	88.43	94.7	99.43	111.83	163.27	146.96	214.55
CW_03	37.33	46.65	53.25	60.22	62.59	64.59	70.48	75.50	79.27	89.14	130.16	117.16	171.03

A19-1.11.71. On comparing the flows, it can be seen that the total of the inflows is higher than the independently calculated catchment total flow at the downstream end (CW_03). This therefore adds further weight to the method being conservative. Although Jacobs / AECOM did not explicitly calculate their totals, a check of their results shows both individual catchment peak flows and summed flows to be similar to this study, i.e. the statistical method as applied by Jacobs / AECOM also had a discrepancy between the summed inflows and predicted flow at CW_03 using the statistical method. This may be due to the oddly shaped and sloped downstream part of the catchment not well reflected by the catchment descriptors which perhaps underestimates Qmed at CW_03.

FEH Rainfall-Runoff Method Application (Refh2)

A19-1.11.72. For the ReFH2 analysis, catchment scale equations have been used to derive model parameters.

A19-1.11.73. The default recommended storm duration for the most downstream catchment (CW_03) of 4 hours and 18 minutes has been applied for all catchments. Additionally, sensitivity tests of the storm duration were also undertaken, one for a shorter duration (3 hours 6 minutes) and another for a longer duration (6 hours 6 minutes). The catchment has no urban influence and is therefore considered ‘Essentially Rural’ (URBEXT < 0.03). Therefore, the default winter seasonality has been adopted together with the rural loss model.

A19-1.11.74. The time to peak (Tp), the areal reduction factor (ARF) and the seasonal correction factor (SCF) have been set to the recommended default values for the downstream catchment (CW_03) for all catchments, for each respective storm duration, to enable accurate representation in the model of a storm across the area. This storm duration as defined for the whole catchment is suitable for defining flows at the outlet and for mapping. For other points of interest, the critical duration at the sub-catchment scale would be required.

A19-1.11.75. The default storm duration for the downstream end of the catchment was found to be 4 hours, 18 minutes. Hydrographs for two additional storm durations (3 hours, 6 minutes and 6 hours, 6 minutes) have also been calculated so that the hydraulic model can be tested for sensitivity to storm duration.

A19-1.11.76. Table 19.18B shows the adopted storm parameters for the study catchment for each storm duration.

Table 19.18B - ReFH2 adopted storm parameters for all catchments

Rainfall Model	Urban / Rural	Season of Design Event	Storm Duration	Tp	ARF	SCF
FEH22	Rural	Winter	3 hours 6 mins	1	0.934	0.949
FEH22	Rural	Winter	4 hours 18 mins	1	0.942	0.961
FEH22	Rural	Winter	6 hours 6 mins	1	0.949	0.974

A19-1.11.77. The additional model parameters used for each sub-catchment are provided in Table 19.19B below.

Table 19.19B- ReFH2 model parameters by sub-catchment

Site Code	Cini (mm)	Cmax (mm)	PRimp	BL (hrs)	BR 2-year
TRIB_01	172.221	260.85	70%	13.608	0.381
CW_01	177.942	252.695	70%	17.783	0.285
RES_01	171.846	261.403	70%	16.36	0.382
RES_02	171.350	259.198	70%	17.727	0.359
RES_03	171.221	260.850	70%	16.773	0.376
TOTAL	173.728	258.650	70%	20.450	0.354
CW_03	172.221	260.850	70%	13.608	0.381

ReFH2 Peak Flows

A19-1.11.78. Table 19,20B provides a summary of the peak flow estimates generated from the ReFH2 methodology and with a 46% climate change uplift applied for the 0.5% AEP and the 0.1% AEP events. The climate change allowances have been applied to the rainfall within the ReFH software. The rural model has been used as the catchments are all deemed ‘Essentially Rural’ (URBEXT < 0.03), see the rural/urban peak flows in Table 19.20B below for the default recommended storm duration (4 hours 18 mins).

A19-1.11.79. Flows have been produced for the inflow catchments (TRIB_02, CW_01), the residual catchments (RES_01, RES_02 and RES_03) and check catchment (CW_03). The totals of the inflows have also been calculated to compare with the downstream end of the catchment at CW_03 as a comparison check.

Table 19.20B - ReFH method flood frequency flows (m³/s) for all catchments for the 4 hr 18 min storm duration.

Site Code	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
TRIB_01	3.11	4.17	4.92	5.67	5.91	6.12	6.70	7.18	7.54	8.42	13.16	10.83	16.81
CW_01	10.80	14.44	16.99	19.57	20.42	21.13	23.13	24.79	26.01	29.07	44.51	37.02	55.89
RES_01	7.14	9.59	11.31	13.05	13.62	14.09	15.44	16.54	17.35	19.43	30.40	25.02	38.82
RES_02	12.72	17.06	20.12	23.20	24.21	25.05	27.44	29.40	30.84	34.53	53.86	44.44	68.56
RES_03	8.53	11.44	13.49	15.55	16.23	16.78	18.39	19.70	20.67	23.13	36.17	29.79	46.15
TOTAL	42.3	56.7	66.83	77.04	80.39	83.17	91.1	97.61	102.41	114.58	178.1	147.1	226.23
CW_03	41.53	55.71	65.69	75.74	79.04	81.77	89.58	95.99	100.69	112.72	175.74	145.08	223.51

A19-1.11.80. It can be seen that the total of the ReFH2 inflows for the sub-catchments is very similar to the predicted downstream flows for the whole catchment (CW_03), with the summed flows being typically 1 – 2 m3/s greater.

A19-1.11.81. The calculated growth curve for the ReFH2 method is also provided below.

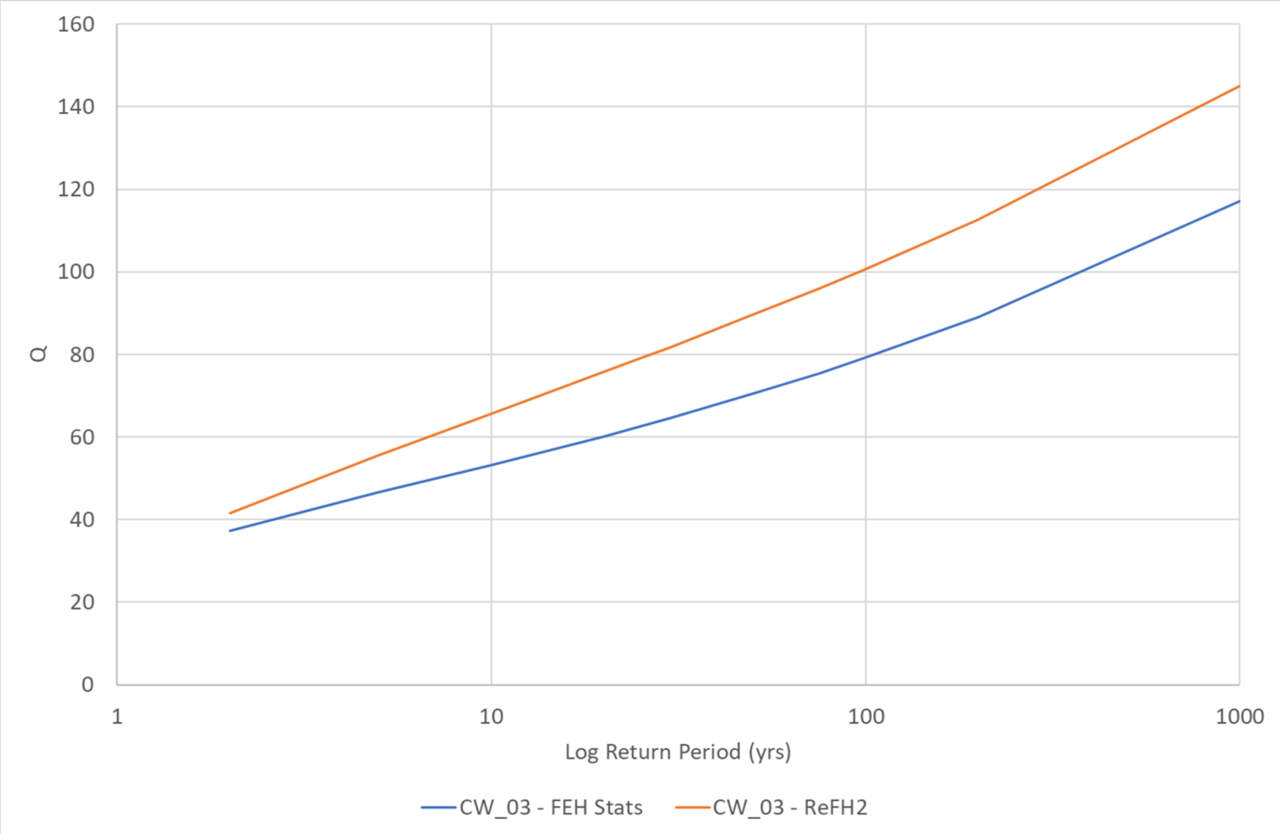
Table 19.21B – ReFH2 Growth Curve for the downstream catchment point (CW_03)

Return Period / AEP	QMED	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.1% AEP
CW_03	1.00	1.34	1.58	1.82	1.90	1.97	2.16	2.31	2.42	2.71	3.49

Comparison of Methods

A19-1.11.82. Plate 19.5B displays the derived flood frequency curves for ‘CW_03’, the most downstream catchment point assessed, for the FEH Statistical method and the ReFH2 method. The predicted flows are shown to be greater for the ReFH2 flows for the range of return periods, including the 0.5% AEP +CC 46% event. At the downstream study extent (‘CW_03’), the flows from the ReFH2 methodology are ~23% greater than the FEH Stats methodology for the 0.5% AEP event.

Plate 19.5B - Comparison of flood frequency curves for CW_03 by method.



A19-1.11.83. When comparing the total of the summed sub-catchment inflows for the two methods, the results are very similar, but with ReFH2 showing flows of approximately 1-3 m3/s greater than the statistical method, apart from for Qmed which is slightly lower. (In other words, the discrepancy is less).

A19-1.11.84. A comparison with the Jacobs / Aecom study undertaken in 2022 was also undertaken and the key results are presented below for comparison with the current study, for both the 'whole catchment' results at CW_03 and the total of summed inflows. It can be seen that the results for both studies were similar, with general agreement between flows, apart from the FEH statistical method for CW_03 which has lower results for both studies.

A19-1.11.85. It is recommended from this assessment that the ReFH2 distributed method is taken forward as it has the most conservative peak flows for all return periods, apart from Qmed, including the 0.5% AEP event

Table 19.22B - Comparison of peak flows (m^3/s) at the downstream end of the catchment

Site	Method	Year	Qmed	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.1% AEP
Total	Stats	2024	46.8	58.5	66.8	75.5	78.6	81.0	88.4	94.7	99.4	111.8	147.0
CW_03	Stats	2024	37.3	46.7	53.2	60.2	62.6	64.6	70.5	75.8	79.3	89.2	117.2
Total	ReFH2	2024	42.3	56.7	66.8	77.0	80.4	83.2	91.1	97.6	102.4	114.6	147.1
CW_03	ReFH2	2024	41.5	55.7	65.7	75.7	79.0	81.8	89.6	96.0	100.7	112.7	145.1
Total	Stats	2022	38.7	50.2	58.6	67.6	70.8	73.5	81.4	88.3	93.5	107.3	148.2
CW_03	Stats	2022	30.9	40.0	46.7	54.0	56.5	58.6	64.9	70.4	74.6	85.6	118.0
Total	ReFH2	2022	40.3	54.5	64.5	74.7	78.0	80.8	88.6	95.6	100.5	113.5	152.5
CW_03	ReFH2	2022	40.0	54.1	64.0	74.1	77.4	80.2	88.1	94.8	99.8	113.0	152.0

Summary of Results

A19-1.11.86. For all return periods apart from Qmed, including the 0.5% AEP event , the ReFH2 peak flows are greater than the FEH Stats peak flows when comparing both the methods applied to the whole catchment at the downstream end (CW_03) and the summed sub-catchment inflows. Therefore, ReFH2 peak flows have been taken forward as they are more conservative and provide more consistent results across the catchments.

A19-1.11.87. It is difficult to quantify the uncertainty in design flows estimated for the ReFH2 rainfall-runoff model. Therefore, an assessment of the confidence limits has not been undertaken for these catchments.

A19-1.11.88. It is recommended that the distributed method is used, applying inflows to the five sub-catchments in the model, and those at CW_03 used as a sense check at the downstream end (while accepting that hydraulic models may introduce some attenuation). Hydrographs for the 50% AEP, 10% AEP, 3.33% AEP, 1% AEP, 0.5% AEP, 0.5% AEP +CC 46%, 0.1% AEP and the 0.1% AEP +CC 46%, flood events have been derived from the ReFH2 design parameters based on a distributed approach: TRIB_02, CW_01, RES_01, RES_02 and RES_03. Appendix C shows hydrographs for the 0.5% AEP +CC 46% event for the recommended storm duration (4.3 hours) for the whole catchment at its downstream end at CW_03, as well as two additional storm durations provided for sensitivity analysis of 3.1 hours and 6.1 hours respectively.

Assumptions and Limitations

A19-1.11.89. Flow estimates for small catchments and with catchment characteristics such as these are inherently uncertain due to the lack of suitable data in the derivation of flow estimation methods and lack of local data to calibrate or verify the estimates obtained. Hence the importance of considering the range of estimates where it is important to the design.

A19-1.11.90. For the residual catchments, the catchment characteristics had to be estimated with the majority of them area-weighted; only the area (subtracted from two different areas) and DPLBAR (equation using a factor) were calculated differently. This was in line with guidance from the Flood Estimation Handbook Chapter 5 (Volume 7).

A19-1.11.91. A significant limitation of this study, and a recommendation for any future study, is that a temporary flow monitor should be implemented to provide an estimate of QMED that is more reliable than the current methodology.

Hydrology Addendum A1 – Donor Pooling Groups

Table 19.1A1 - Pooling Group Donor 2

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
91802 (Allt Leachdach @ Intake)	1.494	34	6.350	0.153	0.153	0.257	0.257	0.962
54022 (Severn @ Plynlimon flume)	1.739	38	14.988	0.156	0.156	0.171	0.171	0.896
57017 (Rhondda Fawr @ Tynewydd)	2.229	20	24.320	0.145	0.146	0.051	0.049	0.825
71003 (Croasdale Beck @ Croasdale Flume)	2.279	37	10.900	0.212	0.212	0.323	0.323	0.520
25003 (Trout Beck @ Moor House)	2.296	48	15.142	0.167	0.167	0.291	0.291	0.567
46005 (East Dart @ Bellever)	2.610	57	40.116	0.153	0.153	0.047	0.047	1.075
206006 (Annalong @ Recorder)	2.642	48	15.330	0.189	0.189	0.052	0.052	2.126
28033 (Dove @ Hollinsclough)	2.838	46	4.138	0.223	0.223	0.379	0.379	1.455

25011 (Langdon Beck @ Langdon)	2.878	35	15.647	0.226	0.226	0.324	0.324	1.555
49003 (De Lank @ De Lank)	2.972	55	13.671	0.213	0.213	0.165	0.165	1.296
73009 (Sprint @ Sprint Mill)	2.976	52	43.655	0.177	0.177	0.185	0.185	0.074
76011 (Coal Burn @ Coalburn)	2.985	44	1.840	0.168	0.168	0.302	0.302	0.649

Table 19.2A1 – Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
106002 (Laxdale @ Laxdale)	2.176	14	17.199	0.097	0.097	0.160	0.160
76001 (Haweswater Beck @ Burnbanks)	2.741	42	16.670	0.418	0.418	0.125	0.125

A19-1.11.92. The reason for the rejection of the above-mentioned sites at Donor 2 is elaborated below:

- 106002 (Laxdale @ Laxdale) has been rejected as this station has only 14 years of record. Also, this station has a FARL of 0.888 which will not be hydrologically representative of the donor site, as the donor site has a FARL of 1.
- 76001 (Haweswater Beck @ Burnbanks) lies in the wrong seasonality as compared to the rest of the pooling group. The rest of the stations in the pooling groups lie in the autumn season quadrant and 76001 Haweswater lies in the winter quadrant of the season. Hence this data is very discordant compared to the rest of the pooling group.

Goodness of Fit

A19-1.11.93. The goodness of fit (Z) for the various distributions for Donor 2 are as listed below:

GL-0.7841 *

GEV-2.3698

P3-3.6659

GP-6.0447

KAP3-1.3464 *

A19-1.11.94. Since the absolute value of Z is the least for GL distribution, this will be adopted for growth curves at this donor.

Pooling Group Donor 3

Table 19.3A1 - Pooling Group Donor 3

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
91802 (Allt Leachdach @ Intake)	1.092	34	6.350	0.153	0.153	0.257	0.257	0.762
54022 (Severn @ Plynlimon flume)	1.285	38	14.988	0.156	0.156	0.171	0.171	1.240
57017 (Rhondda Fawr @ Tynewydd)	1.653	20	24.320	0.145	0.146	0.051	0.049	0.564
25003 (Trout Beck @ Moor House)	2.040	48	15.142	0.167	0.167	0.291	0.291	0.796
71003 (Croasdale Beck @ Croasdale Flume)	2.048	37	10.900	0.212	0.212	0.323	0.323	1.175

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
46005 (East Dart @ Bellever)	2.134	57	40.116	0.153	0.153	0.047	0.047	0.932
206006 (Annalong @ Recorder)	2.410	48	15.330	0.189	0.189	0.052	0.052	2.161
90003 (Nevis @ Claggan)	2.459	39	121.753	0.114	0.114	0.101	0.101	1.418
73009 (Sprint @ Sprint Mill)	2.467	52	43.655	0.177	0.177	0.185	0.185	0.012
46007 (West Dart @ Dunnabridge)	2.681	40	71.101	0.171	0.171	0.152	0.152	0.089
49003 (De Lank @ De Lank)	2.686	55	13.671	0.213	0.213	0.165	0.165	1.271
25011 (Langdon Beck @ Langdon)	2.764	35	15.647	0.226	0.226	0.324	0.324	1.580

Table 19.4A1 – Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
106002 (Laxdale @ Laxdale)	1.900	14	17.199	0.097	0.097	0.160	0.160
76001 (Haweswater Beck @ Burnbanks)	2.094	42	16.670	0.418	0.418	0.125	0.125

A19-1.11.95. The reason for the rejection of the above-mentioned sites at Donor 3 is as elaborated below:

- 106002 (Laxdale @ Laxdale) has been rejected as this station has only 14 years of record. Also, this station has a FARL of 0.888 which will not be hydrologically representative of the donor site, as the donor site has a FARL of 1.
- 76001 (Haweswater Beck @ Burnbanks) lies in the wrong seasonality as compared to the rest of the pooling group. The rest of the stations in the pooling groups lie in the autumn season quadrant and 76001 Haweswater lies in the winter quadrant of the season. Hence this data is very discordant compared to the rest of the pooling group.

Goodness of Fit

A19-1.11.96. The goodness of fit (Z) for the various distributions for Donor 3 are as listed below:

GL-0.3648 *

GEV-1.5700 *

P3-2.4922

GP-5.8208

KAP3-0.3486 *

A19-1.11.97. The absolute value of Z is the least for KAP3 distribution. Since this is only marginally lower than GL distribution, the GL distribution will be adopted for growth curves at this donor.

Pooling Group Donor 4

Table 19.5A1 - Pooling Group Donor 4

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
91802 (Allt Leachdach @ Intake)	1.292	34	6.350	0.153	0.153	0.257	0.257	0.754
54022 (Severn @ Plynlimon flume)	1.516	38	14.988	0.156	0.156	0.171	0.171	0.980
57017 (Rhondda	1.938	20	24.320	0.145	0.146	0.051	0.049	0.560

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
Fawr @ Tynewydd)								
71003 (Croasdale Beck @ Croasdale Flume)	2.217	37	10.900	0.212	0.212	0.323	0.323	0.546
25003 (Trout Beck @ Moor House)	2.218	48	15.142	0.167	0.167	0.291	0.291	0.612
46005 (East Dart @ Bellever)	2.393	57	40.116	0.153	0.153	0.047	0.047	0.815
206006 (Annalong @ Recorder)	2.586	48	15.330	0.189	0.189	0.052	0.052	2.065
73009 (Sprint @ Sprint Mill)	2.741	52	43.655	0.177	0.177	0.185	0.185	0.032
90003 (Nevis @ Claggan)	2.818	39	121.753	0.114	0.114	0.101	0.101	1.322
49003 (De Lank @ De Lank)	2.886	55	13.671	0.213	0.213	0.165	0.165	1.350
25011 (Langdon Beck @ Langdon)	2.902	35	15.647	0.226	0.226	0.324	0.324	1.536
28033 (Dove @ Hollinsclough)	2.958	46	4.138	0.223	0.223	0.379	0.379	1.428

Table 19.6A1 – Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
106002 (Laxdale @ Laxdale)	2.083	14	17.199	0.097	0.097	0.160	0.160
76001 (Haweswater Beck @ Burnbanks)	2.409	42	16.670	0.418	0.418	0.125	0.125

A19-1.11.98. The reason for the rejection of the above-mentioned sites at Donor 4 is as elaborated below:

- 106002 (Laxdale @ Laxdale) has been rejected as this station has only 14 years of record. Also, this station has a FARL of 0.888 which will not be hydrologically representative of the donor site, as the donor site has a FARL of 1.
- 76001 (Haweswater Beck @ Burnbanks) lies in the wrong seasonality as compared to the rest of the pooling group. The rest of the stations in the pooling groups lie in the autumn season quadrant and 76001 Haweswater lies in the winter quadrant of the season. Hence this data is very discordant compared to the rest of the pooling group.

Goodness of Fit

A19-1.11.99. The goodness of fit (Z) for the various distributions for Donor 4 are as listed below:

GL-0.1506 *

GEV-1.9721

P3-3.1639

GP-6.0916

KAP3-0.8084 *

A19-1.11.100. Since the absolute value of Z is the least for GL distribution, this will be adopted for growth curves at this donor.

Pooling Group Donor 5

Table 19.7A1 - Pooling Group Donor 5

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
91802 (Allt Leachdach @ Intake)	1.920	34	6.350	0.153	0.153	0.257	0.257	0.989
54022 (Severn @ Plynlimon flume)	2.165	38	14.988	0.156	0.156	0.171	0.171	0.796
57017 (Rhondda Fawr @ Tynewydd)	2.650	20	24.320	0.145	0.146	0.051	0.049	0.921
71003 (Croasdale Beck @ Croasdale Flume)	2.699	37	10.900	0.212	0.212	0.323	0.323	0.557
25003 (Trout Beck @ Moor House)	2.718	48	15.142	0.167	0.167	0.291	0.291	0.563
46005 (East Dart @ Bellever)	3.037	57	40.116	0.153	0.153	0.047	0.047	1.092
206006 (Annalong @ Recorder)	3.060	48	15.330	0.189	0.189	0.052	0.052	2.232
28033 (Dove @ Hollinsclough)	3.216	46	4.138	0.223	0.223	0.379	0.379	1.602

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
76011 (Coal Burn @ Coalburn)	3.237	44	1.840	0.168	0.168	0.302	0.302	0.557
25011 (Langdon Beck @ Langdon)	3.282	35	15.647	0.226	0.226	0.324	0.324	1.064
49003 (De Lank @ De Lank)	3.393	55	13.671	0.213	0.213	0.165	0.165	0.516
47022 (Tory Brook @ Newnham Park)	3.395	26	6.649	0.250	0.252	0.149	0.146	2.043
73009 (Sprint @ Sprint Mill)	3.404	52	43.655	0.177	0.177	0.185	0.185	0.068

Table 19.8A1 – Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
106002 (Laxdale @ Laxdale)	2.600	14	17.199	0.097	0.097	0.160	0.160
76001 (Haweswater Beck @ Burnbanks)	3.159	42	16.670	0.418	0.418	0.125	0.125
45816 (Haddeo @ Upton)	3.400	28	3.352	0.293	0.294	0.424	0.423

A19-1.11.101. The reason for the rejection of the above-mentioned sites at Donor 5 is as elaborated below:

- 106002 (Laxdale @ Laxdale) has been rejected as this station has only 14 years of record. Also, this station has a FARL of 0.888 which will not be hydrologically representative of the donor site, as the donor site has a FARL of 1.

- 76001 (Haweswater Beck @ Burnbanks) lies in the wrong seasonality as compared to the rest of the pooling group. The rest of the stations in the pooling groups lie in the autumn season quadrant and 76001 Haweswater lies in the winter quadrant of the season. Hence this data is very discordant compared to the rest of the pooling group.
- 45816 (Haddeo @ Upton) has been rejected as it has a very high BFIHOST19 as compared to the donor 5.

Goodness of Fit

A19-1.11.102. The goodness of fit (Z) for the various distributions for Donor 5 are as listed below:

GL-0.1458 *

GEV-1.8422

P3-3.1758

GP-5.7557

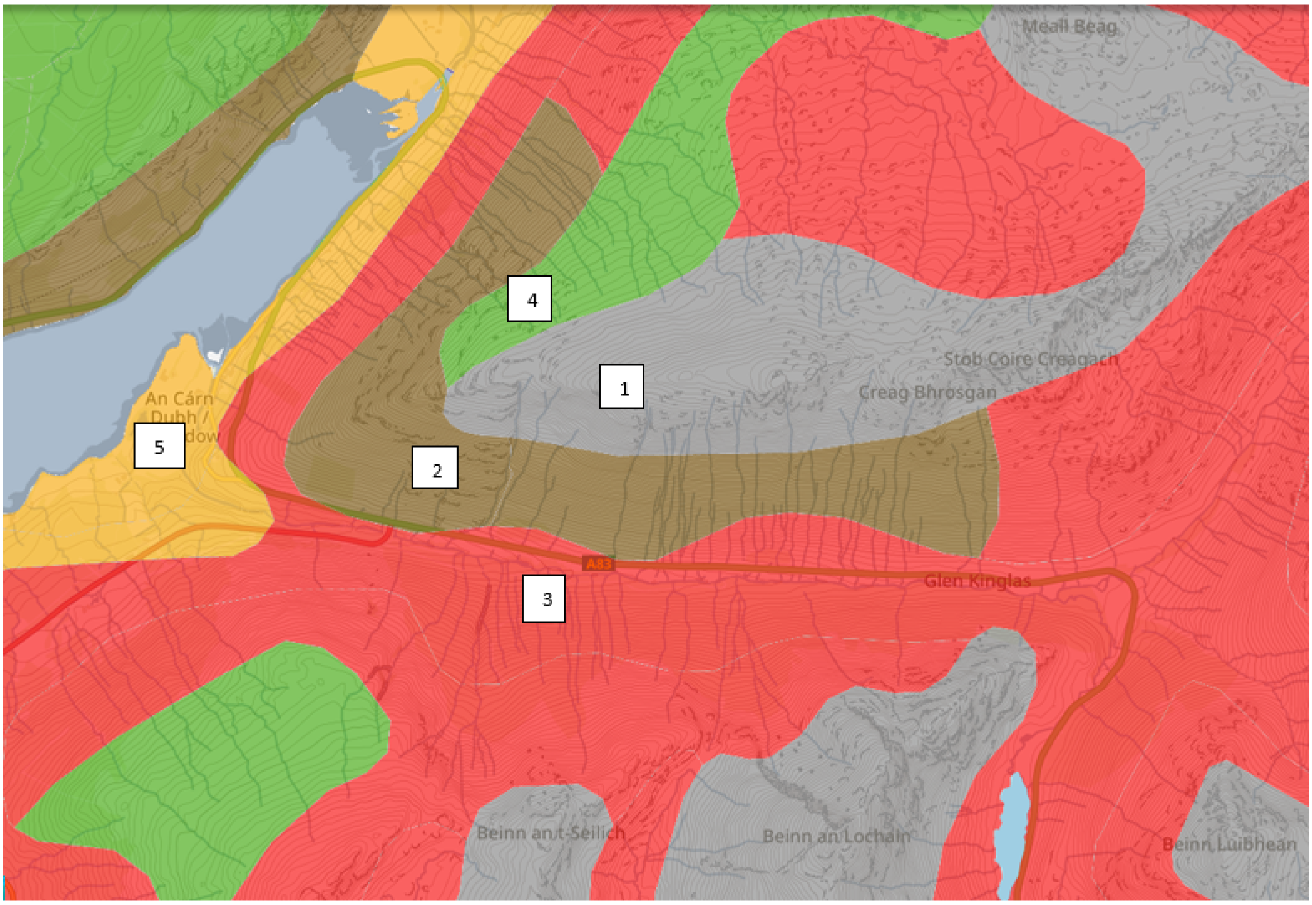
KAP3-0.7494 *

A19-1.11.103. Since the absolute value of Z is the least for GL distribution, this will be adopted for growth curves at this donor.

Hydrology Addendum A2 – Soil Information

Soil Map at Argyll

Plate A2 - A representation of the soil map at Argyll



A19-1.11.104. The details of the soil map of Argyll have been obtained from The soil map at Argyll is shown above, and is numbered based on the different types of soil. The different types of soil are marked as shown in the map. The details of each kind of soil are tabulated below.

Table A2 - Soil Types of Argyll

Soil Identifier	Soil Association	Component Soils	Major Soil Group	Major Soil Subgroup	Parent Material	Landform	Generalized Soil Type
1	Strichen	Dystrophic blanket peat with subalpine podzols	Blanket peats	Dystrophic blanket peat	Drifts derived from arenaceous schists and strongly metamorphosed argillaceous schists of the Dalradian Series	Mountains with gentle and strong slopes: non- to moderately rocky	Montane soils
2	Tarves	Brown earths	Brown soils	Brown earths	Drifts derived from intermediate rocks or mixed acid and basic rocks, both metamorphic and igneous	Hill and valley sides with steep slopes: slightly to moderately rocky	Brown soils
3	Strichen	Peaty gleyed podzols with peaty gleys with dystrophic semi-confined peat	Podzols	Peaty gleyed podzols	Drifts derived from arenaceous schists and strongly metamorphosed argillaceous schists of the Dalradian Series	Hummocky valley and slope moraines	Peaty podzols
4	Strichen	Peaty gleys with dystrophic semi-confined peat	Gleys	Peaty gleys	Drifts derived from arenaceous schists and strongly metamorphosed argillaceous schists of the Dalradian Series	Hill sides with gentle and strong slopes: moderately rocky	Peaty gleys

Soil Identifier	Soil Association	Component Soils	Major Soil Group	Major Soil Subgroup	Parent Material	Landform	Generalized Soil Type
5	Corby	Humus-iron podzols	Podzols	Humus-iron podzols	Fluvioglacial and raised beach sands and gravels derived from acid rock	Valley floors and lowland with gentle slopes	Mineral podzols

Addendum A3 – A83 Culverts Peak Flows (m^3/s)

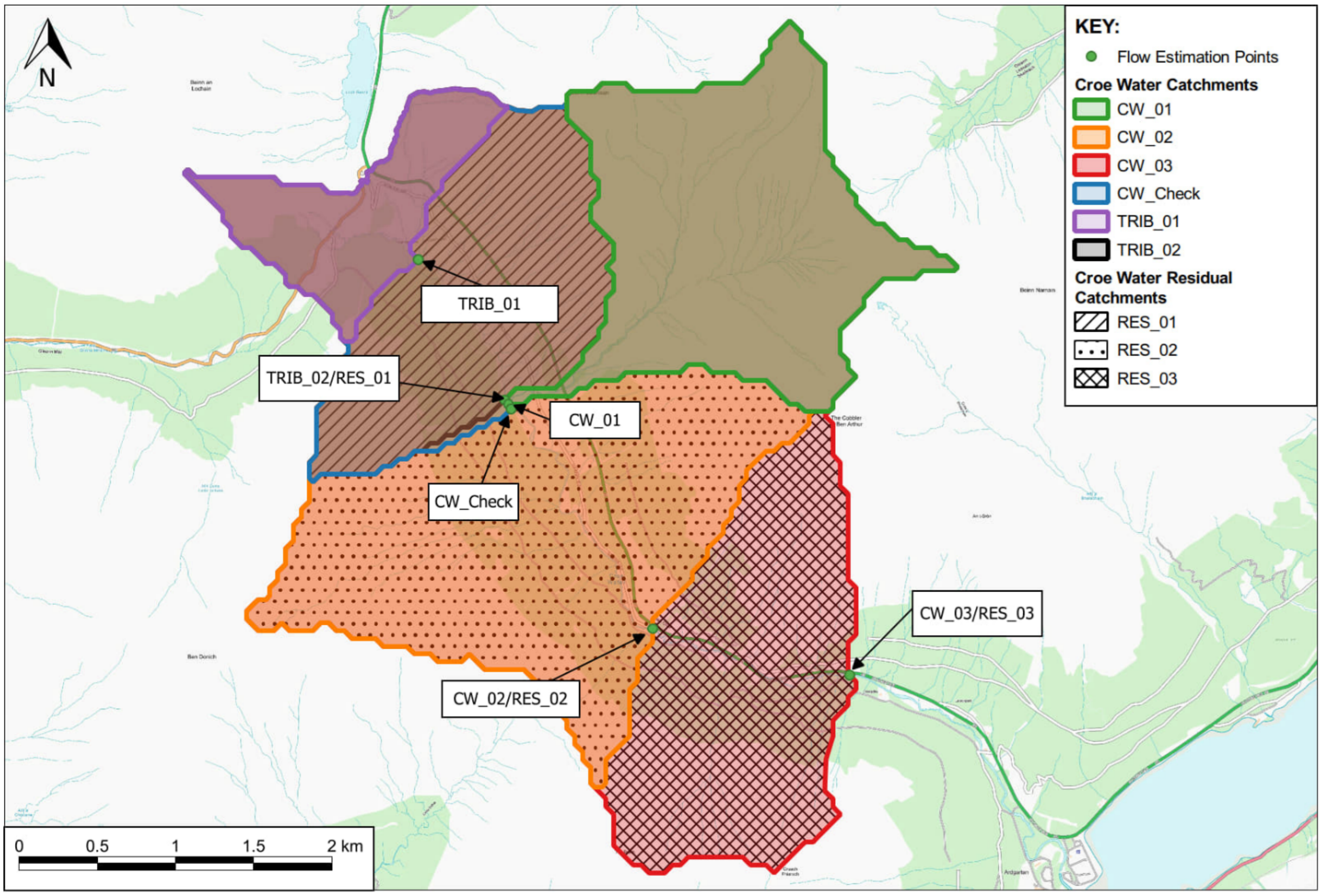
New Watercourse ID	Area (km2)	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
A83_ML_014_000	0.023	0.093	0.121	0.141	0.163	0.171	0.177	0.197	0.213	0.226	0.260	0.398	0.359	0.543
A83_ML_015_A01	3.387	11.296	15.087	17.736	20.418	21.303	22.034	24.125	25.859	27.130	30.311	46.262	38.525	57.999
A83_ML_015_000	3.387	11.296	15.087	17.736	20.418	21.303	22.034	24.125	25.859	27.130	30.311	46.262	38.525	57.999
A83_ML_016_000	0.065	0.265	0.344	0.401	0.464	0.485	0.504	0.558	0.606	0.642	0.738	1.132	1.021	1.544
A83_ML_017_000	0.094	0.384	0.497	0.581	0.671	0.703	0.729	0.808	0.877	0.929	1.068	1.639	1.477	2.235
A83_ML_018_000	0.073	0.299	0.388	0.453	0.524	0.549	0.569	0.631	0.685	0.725	0.833	1.279	1.153	1.745
A83_ML_019_000	0.039	0.159	0.206	0.240	0.278	0.291	0.301	0.334	0.363	0.384	0.441	0.678	0.611	0.924
A83_ML_020_000	0.033	0.136	0.177	0.207	0.239	0.250	0.259	0.288	0.312	0.330	0.380	0.583	0.525	0.795

New Watercourse ID	Area (km2)	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
A83_ML_021_000	0.096	0.392	0.508	0.593	0.685	0.717	0.744	0.825	0.895	0.948	1.090	1.673	1.508	2.282
A83_ML_022_000	0.005	0.020	0.027	0.031	0.036	0.037	0.039	0.043	0.047	0.050	0.057	0.087	0.079	0.119
A83_ML_023_000	0.014	0.057	0.074	0.086	0.100	0.105	0.108	0.120	0.130	0.138	0.159	0.244	0.220	0.333
A83_ML_024_000	0.207	0.847	1.099	1.283	1.483	1.553	1.611	1.786	1.938	2.053	2.359	3.621	3.264	4.939
A83_ML_025_000	0.122	0.499	0.647	0.756	0.874	0.915	0.949	1.052	1.142	1.209	1.390	2.133	1.923	2.910
A83_ML_026_000	0.058	0.239	0.310	0.362	0.418	0.437	0.454	0.503	0.546	0.578	0.665	1.020	0.919	1.391
A83_ML_027_000	0.129	0.528	0.685	0.800	0.924	0.968	1.004	1.113	1.208	1.279	1.470	2.257	2.034	3.078
A83_ML_028_000	0.056	0.231	0.299	0.349	0.404	0.423	0.439	0.486	0.527	0.559	0.642	0.986	0.889	1.344

New Watercourse ID	Area (km2)	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
A83_ML_029_000	0.041	0.169	0.219	0.255	0.295	0.309	0.320	0.355	0.385	0.408	0.469	0.720	0.649	0.983
A83_ML_030_000	0.050	0.205	0.266	0.310	0.358	0.375	0.389	0.432	0.468	0.496	0.570	0.875	0.789	1.194
A83_ML_031_000	0.129	0.530	0.688	0.803	0.928	0.971	1.008	1.118	1.212	1.284	1.476	2.265	2.042	3.090
A83_ML_032_000	0.162	0.663	0.860	1.004	1.160	1.215	1.260	1.397	1.516	1.606	1.846	2.833	2.554	3.864
A83_ML_033_000	0.020	0.083	0.108	0.126	0.146	0.153	0.158	0.176	0.191	0.202	0.232	0.356	0.321	0.486
A83_ML_034_000	0.028	0.116	0.151	0.176	0.204	0.213	0.221	0.245	0.266	0.282	0.324	0.497	0.448	0.678
A83_ML_035_000	0.017	0.071	0.092	0.108	0.124	0.130	0.135	0.150	0.162	0.172	0.198	0.303	0.273	0.414

Addendum B1 – Croe Water Catchments

Plate B1 – Croe Water Catchments



Hydrology Addendum B2 – Croe Water Pooling Group

Pooling Group – CW_03

Station	Distance	Years of data	QMED AM	L-CV Observed	L-SKEW Observed	AREA	SAAR	FARL	URBEXT2000	BFIHOST19	SPRHOST	IN PG0?
57017 (Rhondda Fawr @ Tynewydd)	0.793	21	24.30	0.141	0.143	16.64	2458	0.999	0.016	0.27	52.88	Yes
54022 (Severn @ Plynlimon flume)	0.866	38	14.99	0.156	0.156	8.75	2481	1	0	0.266	52.68	Yes
91802 (Allt Leachdach @ Intake)	0.936	34	6.35	0.153	0.153	6.52	2555	0.992	0	0.277	53.32	Yes
90003 (Nevis @ Claggan)	1.258	40	121.64	0.117	0.117	69.21	2913	0.998	0.001	0.337	47.03	Yes
46005 (East Dart @ Bellever)	1.287	58	37.61	0.164	0.164	22.27	2095	1	0	0.325	47.42	Yes
73009 (Sprint @ Sprint Mill)	1.518	53	43.46	0.175	0.175	34.70	2013	0.997	0	0.391	44.14	Yes

Station	Distance	Years of data	QMED AM	L-CV Observed	L-SKEW Observed	AREA	SAAR	FARL	URBEXT2000	BFIHOST19	SPRHOST	IN PG0?
25003 (Trout Beck @ Moor House)	1.531	49	15.12	0.165	0.165	11.40	1905	1	0	0.255	59.86	Yes
46007 (West Dart @ Dunnabridge)	1.674	41	71.56	0.169	0.17	47.50	1987	1	0.003	0.309	47.75	Yes
74001 (Duddon @ Duddon Hall)	1.721	55	122.25	0.155	0.155	85.26	2267	0.985	0	0.303	53.69	Yes
96004 (Strathmore @ Allnabad)	1.744	19	198.528	0.183	0.183	105.36	2455	0.938	0	0.277	55.28	No
58006 (Mellte @ Pontneddfechan)	1.832	51	89.15	0.175	0.175	65.32	1981	0.975	0	0.298	51.30	No
21017 (Ettrick Waters @ Brockhoperig)	1.932	57	60.36	0.173	0.173	38.59	1740	1	0	0.331	43.70	No

Rejected Stations from Pooling Group – CW_03

Station	Distance	Years of data	QMED AM	L-CV Observed	L-SKEW Observed	AREA	SAAR	FARL	URBEXT2000	BFIHOST19	SPRHOST	IN PG0?
76001 (Haweswater Beck @ Burnbanks)	1.02	43	16.25	0.419	0.134	32.34	2438	0.645	0	0.439	54.31	Yes
71003 (Croasdale Beck @ Croasdale Flume)	1.573	37	10.9	0.212	0.323	10.71	1882	1	0	0.283	54.51	Yes
106002 (Laxdale @ Laxdale)	1.412	15	17.224	0.093	0.131	10.64	1993	0.888	0	0.299	53.36	Yes
73002 (Crake @ Low Nibthwaite)	1.716	51	21.058	0.175	0.205	72.34	2152	0.73	0.001	0.412	50.41	Yes
206006 (Annalong @ Recorder)	3.119	48	15.33	0.189	0.052	14.44	1704	0.981	0	0.267	51.27	No
93001 (Carron @ New Kelso)	1.876	27	181.095	0.182	0.172	139.21	2616	0.858	0	0.329	49.12	No

Goodness of Fit

A19-1.11.105. The goodness of fit (Z) for the various distributions for the CW_03 pooling group. * indicates an absolute goodness of fit (z) of < 1.645, which is considered an acceptable fit:

GL– 0.3091 *

GEV- -1.6538

P3- -2.6357

KAP3- -0.4127 *

Hydrology Addendum B3 – Croe Water Fluvial Inflow Hydrographs

Plate B3a – ReFH2 Flow 4-hour hydrograph

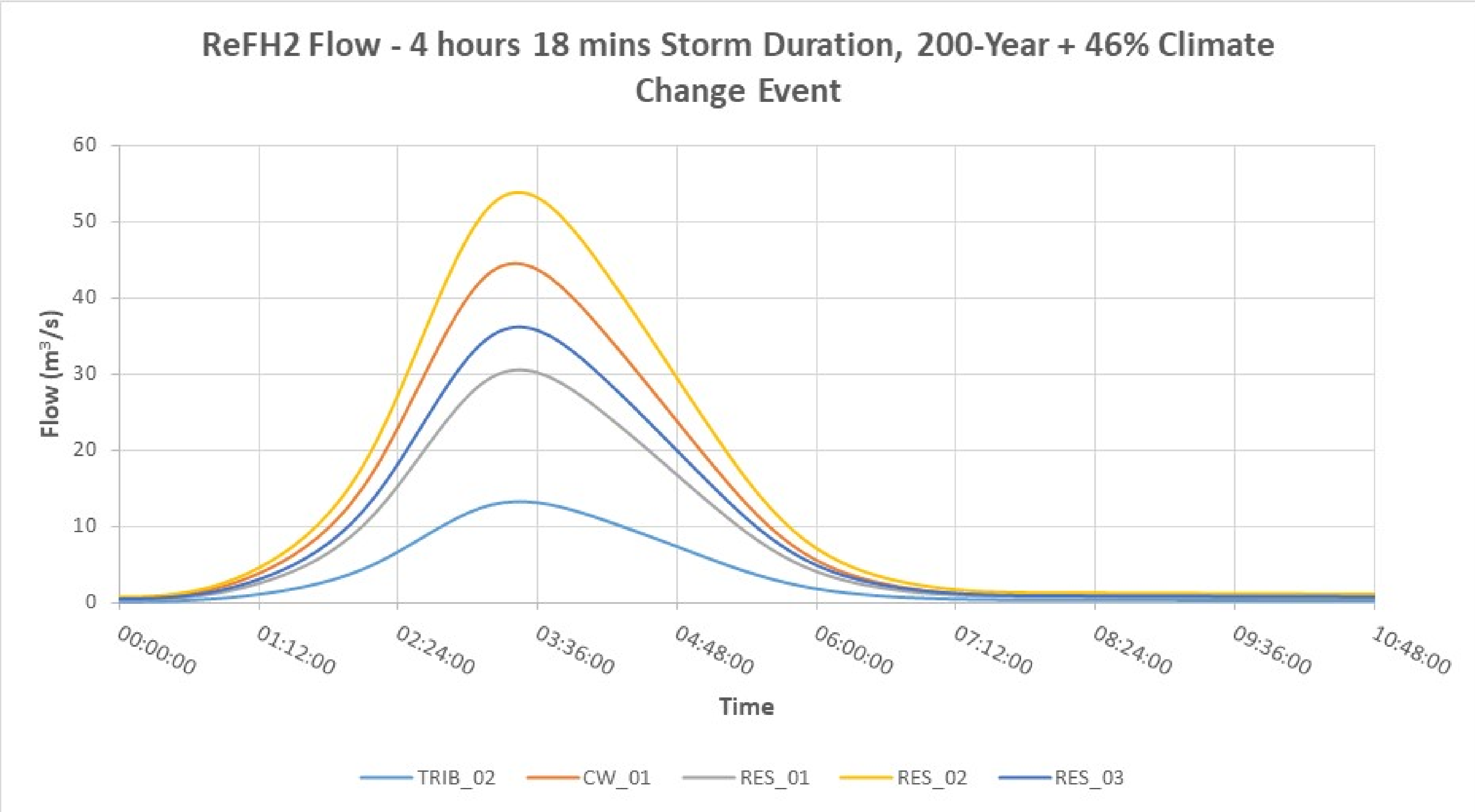


Plate B3b – ReFH2 Flow 3-hour hydrograph

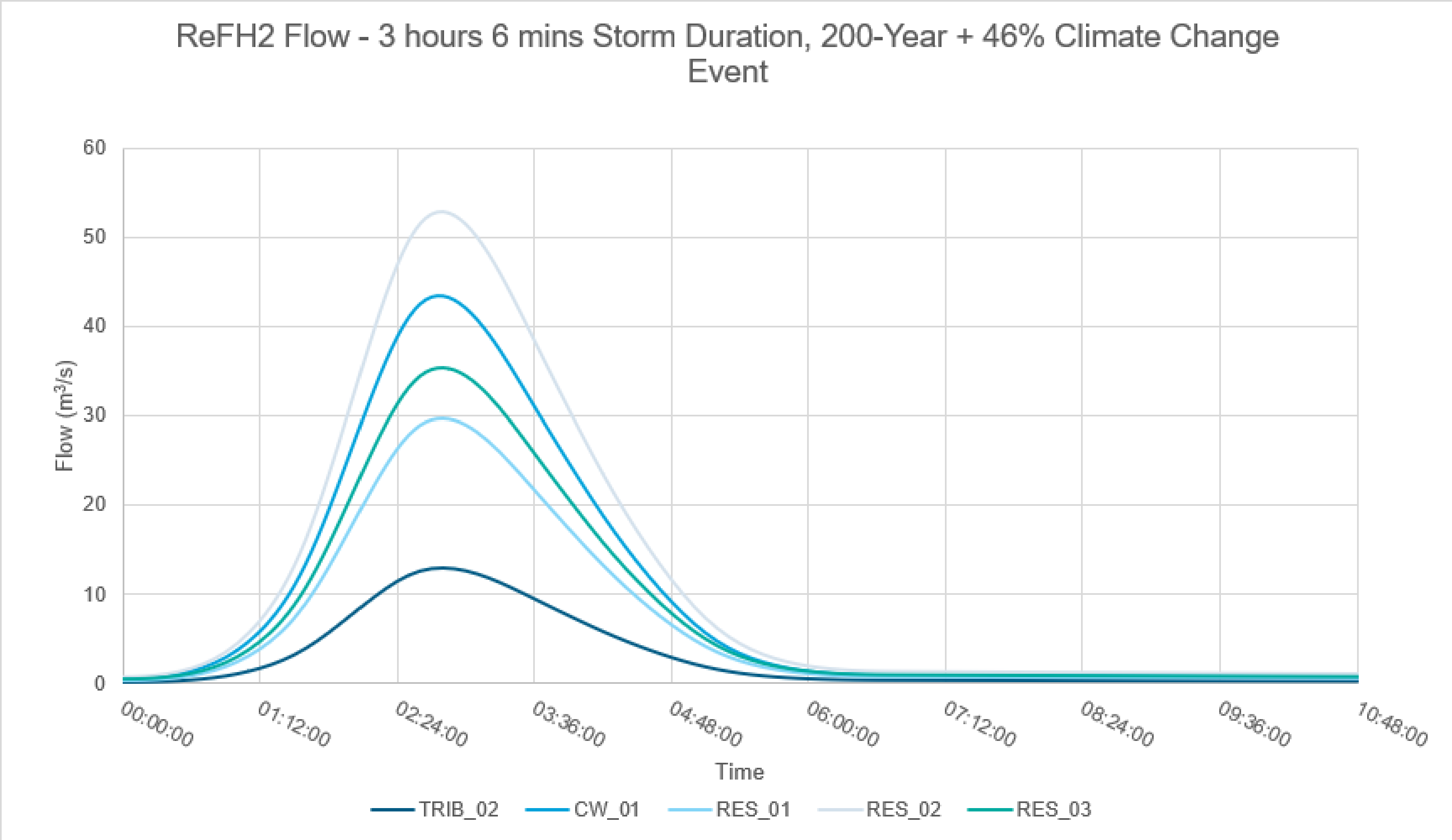
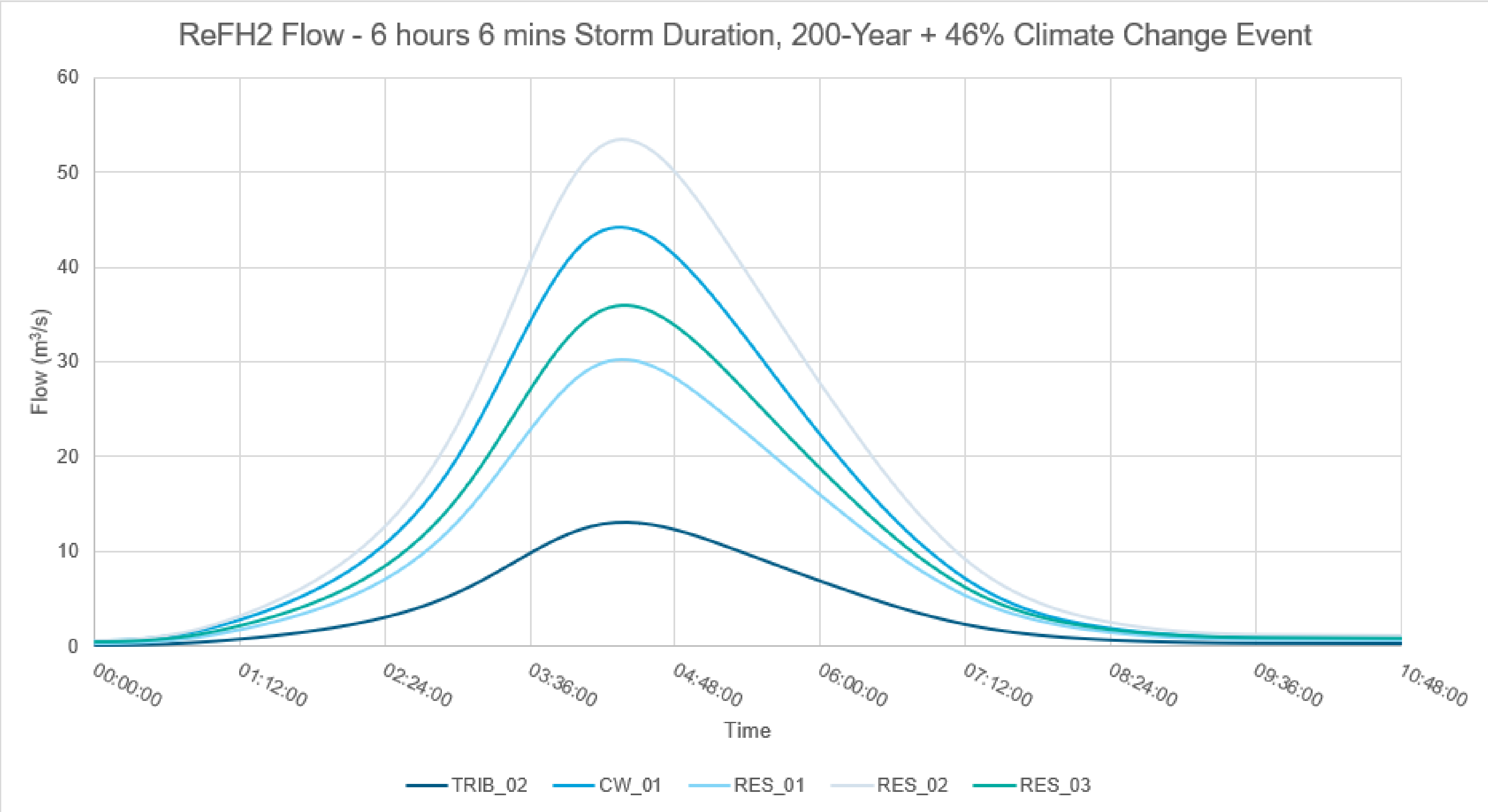


Plate B3c – ReFH2 Flow 6-hour hydrograph



Annex C - Small Watercourses

Introduction

A19-1.11.106. This report explains the modelling approach for The Proposed Scheme of A83 road. The Proposed Scheme consists of a debris flow shelter (DFS) that covers approximately 1.4km of the A83, as well as a standalone retaining wall that spans approximately 160m that sits to the northern end of the scheme. The entire length of the Proposed Scheme, including road upgrades along the A83 route is approximately 2.4km. Along this 2.4km reach there are 21 watercourses that cross the existing road, and culverts will require upgrade.

A19-1.11.107. The Proposed Scheme consists of a large catchpit that sits on the upstream (US) side of the DFS. This catchpit will be excavated out of the existing hillside and will provide storage for any unconsolidated material in the event of a landslip event. The design of this catchpit intercepts 15 existing small watercourses requiring alterations to their exiting flow paths. The design of the catchpit allows flows from existing watercourses US of the structure to pass over the back wall, into the catchpit, and then proceed through a grated drop structure, ultimately passing under the road via a culvert.

A19-1.11.108. This design results in a split in the natural watercourse. An assessment was required to determine the optimum location for the watercourses to intersect with the structure and understand if any horizontal or vertical adjustments are required. Using a combination of OS mapping, arial imagery, Google Streetview, project flown LiDAR and site pictures, each of the known A83 watercourse crossings had their US and downstream (DS) inlet/outlet locations mapped. This allowed the current route and crossing locations of the existing watercourses to be confirmed and mapped.

A19-1.11.109. Discussions were held with the geomorphology team who carried out an assessment into the condition of the state of the watercourses and adjacent land downstream of the existing A83. They concluded that the watercourses were showing clear signs of erosion due to the sizing of the existing culvert dimensions which, due to them being undersized, were resulting in large velocities which “Jetted” out on to the DS slopes. They also noted that the material DS of the A83 was unconsolidated and could be easily eroded if new flow paths were to be introduced DS of the A83. To reduce the likelihood of future erosion it was decided it would be important to maintain the existing DS culvert tie-in locations to the watercourses.

A19-1.11.110. Identifying the culvert inlet / outlet locations coupled with an understanding of the condition of the hillside DS of the existing A83 guided the structures team in determining the optimal initial placement of the proposed culverts. The culverts were included in the design so that they would pass under the A83 perpendicular to the road with the DS end tying in with the DS watercourses.

The perpendicular alignment was necessary to allow culverts to fit between the DFS piles.

A19-1.11.111. Of the 21 existing watercourses, 15 intercept the DFS and section of retaining wall (structure A83_29 is located under the standalone retaining wall) which are structure A83_16 to A83_30 and 5 pass under sections of the A83 not protected by the DFS or retaining wall which are structure A83_31 to A83_35. A separate model has been developed for structure A83_15 (Croe Water), therefore not covered in this report.

A19-1.11.112. Location of culverts are shown in Plate 19.1C.

Input Data

A19-1.11.113. The data used to construct the hydraulic models are summarised in Table 19.1C.

Table 19.1C - Data used to build the hydraulic model

Data	Description	Source
Topographic data	0.25m Digital Surface Model (DSM) provided by Jacobs/AECOM and was checked with recently available AWJV data	Fugro
OS Maps	Mastermap data	Transport Scotland

Hydrology

A19-1.11.114. This assessment has been completed to derive the peak flow at all the culvert crossings on the section of the A83 affected by the proposed route. Based on the 'Baseline Flood Study Report' published by Jacobs/AECOM in April 2022, 60 watercourse crossings of the A83 were identified. 21 of these are relevant to the current study, being within the area potentially affected by the proposed new alignment.

A19-1.11.115. As a part of the Proposed Scheme, AWJV has revised the baseline hydrology to derive flows to the culverts. The catchments contributing flows to the culverts were delineated again and they have been found similar to the catchment delineations carried out by Jacobs/AECOM in their Appendix A Hydrological Assessment Report published in February 2022. Hence the catchments from the Jacobs/AECOM 2022 study are used here as well. The catchments (and associated catchment descriptors) contributing to the culverts are generally not defined in the Flood Estimation Handbook (FEH) Digital Terrain Model (DTM) (https://fehweb.ceh.ac.uk) because they are less than 0.5km2 in area. Hence, design flows for the numerous hillside watercourses are based on a donor approach whereby flows are calculated using a specific discharge (m3/s/km) estimated at a nearby donor catchment (where FEH catchment descriptors are available).

A19-1.11.116. The culverts and associated catchments are shown in Plate 19.1C.

A19-1.11.117. The hydrological assessment has been undertaken using both the FEH statistical method (using WINFAP software) and the FEH rainfall-runoff method (using ReFH2 software).

A19-1.11.118. A review of the previous Hydrological Assessment Report published by Jacobs/AECOM was undertaken to select the donors for this study. The donors for the previous Jacobs study were annotated as ‘Donor 2’, ‘Donor 3’, and ‘Donor 4’ (An additional ‘Donor 1’ was only relevant to culverts outside of the current study area). After careful evaluation of these donor sites, AWJV concluded that, in addition to these donors, an additional new ‘Donor 5’ was added to the list of Donors as it was considered to better represent the steep, narrow A83 culvert catchments. The geographical locations of the 4 donors are shown in Plate 19.2C.

Plate 19.1C - A83 culverts and their associated catchments

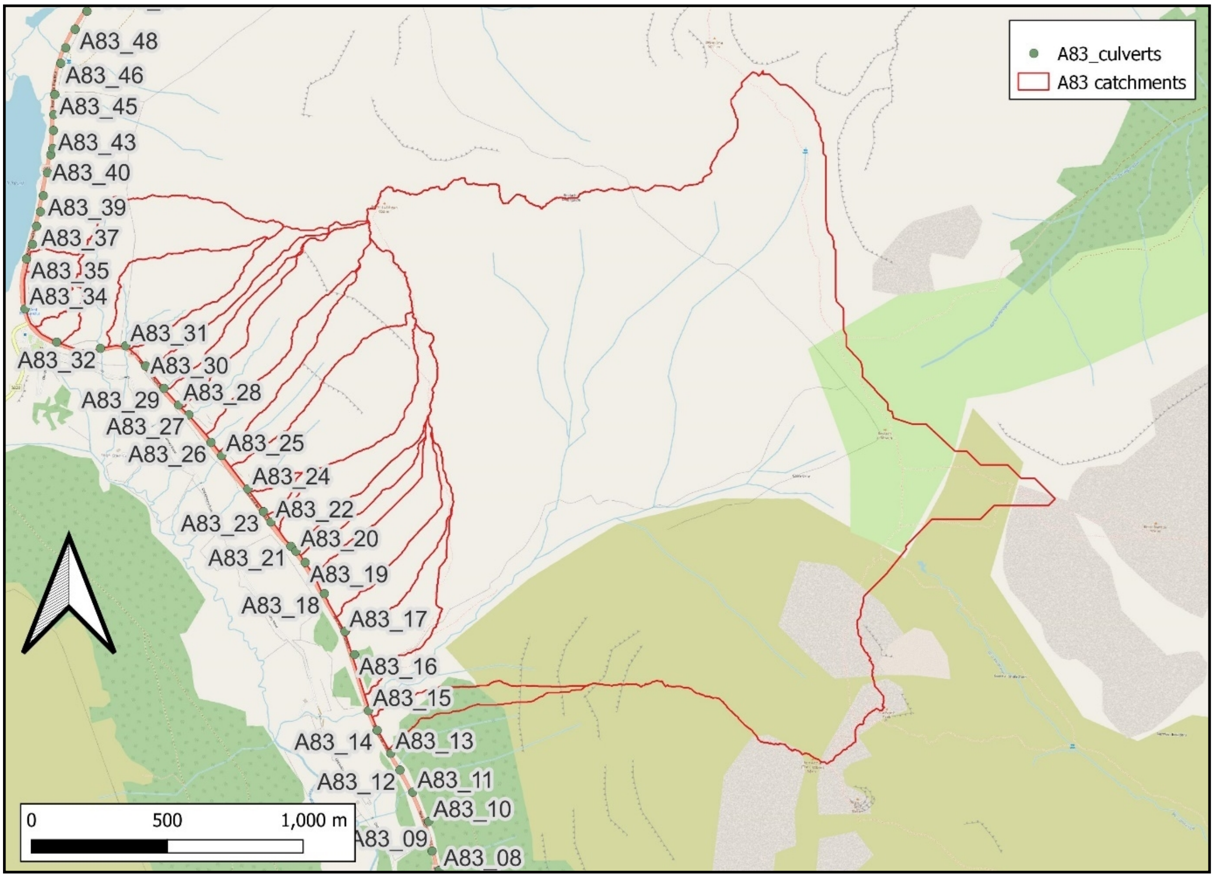
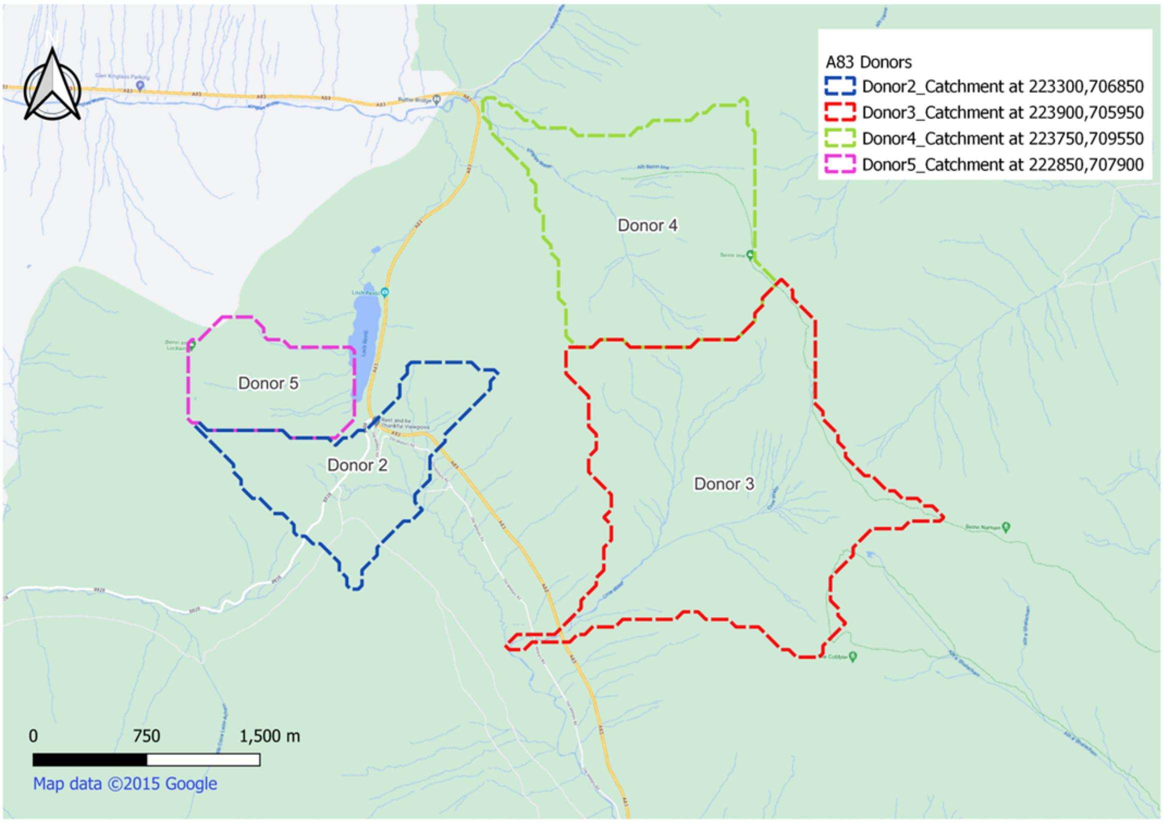


Plate 19.2C Geographical locations of the donor catchments



A19-1.11.119. The final flood estimates from Statistical and ReFH2 method are as shown in Table 19.2C. The specific discharge (i.e.) the flow per square kilometre (cumec/km^2) is calculated which when multiplied by the area of the A83 culvert catchments produces flows (in cumecs). These values are tabulated in table 19.3C. For the statistical method, 46% climate change allowance has been added to the peak flows calculated. The climate change multiplication factor is obtained by dividing the peak flow of the climate change event and the peak flow for that return period in ReFH2 method.

Table 19.2C - Final Flood estimates from Donor 5 (m^3/s)

Site Code	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
Statistical	2.86	3.71	4.33	5.00	5.24	5.44	6.03	6.54	6.93	7.96	12.22	11.01	16.67
ReFH2	2.16	2.89	3.41	3.93	4.10	4.24	4.64	4.97	5.22	5.84	8.97	7.45	11.28

Table 19.3C - Specific discharge for the donors derived from Donor 5

Site Code	50% AEP	20% AEP	10% AEP	5% AEP	4% AEP	3.33 %AEP	2% AEP	1.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%	0.1% AEP	0.1% AEP +CC 46%
Statistical	4.10	5.31	6.21	7.17	7.51	7.79	8.64	9.37	9.93	11.41	17.51	15.79	23.89
ReFH2	3.10	4.15	4.89	5.63	5.88	6.08	6.66	7.13	7.48	8.38	12.85	10.69	16.17

A19-1.11.120. Once the specific discharge is calculated, the flows to each of the A83 culverts can be computed for the different return periods. They are obtained by multiplying the area of each of the A83 culvert catchment by the specific discharge of the selected donor catchments. The donor catchments for each of the A83 culvert catchments are selected based on hydrological similarities between the donor catchment and the A83 culvert catchment. Donar 5 catchment looks more hydrologically similar with all A83 culvert catchments.

A19-1.11.121. The specific discharge calculated for Donor 5 using the statistical method was used to represent the A83 culvert catchments. This was selected using the precautionary approach, as the highest specific discharge was calculated for this donor using the FEH statistical method.

A19-1.11.122. The peak flows and the hydrographs for each of the A83 culvert catchments have been determined and the peak flows for the 0.5% AEP +CC 46% return periods have been provided in Table 19.4C.

A19-1.11.123. The hydrographs for each return period have been calculated by scaling the relevant ReFH2 generated hydrograph for the relevant return period, and then scaling this to the required peak discharge.

Table 19.4C - Hydrological peak inflow estimates within the model for 0.5% AEP +CC 46% event

No	New Watercourse ID	Area (km^2)	Flows (m^3/s)
1	A83_016	0.065	1.132
2	A83_017	0.094	1.639
3	A83_018	0.073	1.279
4	A83_019	0.039	0.678
5	A83_020	0.033	0.583
6	A83_021	0.096	1.673
7	A83_022	0.005	0.087
8	A83_023	0.014	0.244
9	A83_024	0.207	3.621
10	A83_025	0.122	2.133
11	A83_026	0.058	1.020
12	A83_027	0.129	2.257
13	A83_028	0.056	0.986

No	New Watercourse ID	Area (km^2)	Flows (m^3/s)
14	A83_029	0.041	0.720
15	A83_030	0.050	0.875
16	A83_031	0.129	2.265
17	A83_032	0.162	2.833
18	A83_033	0.020	0.356
19	A83_034	0.028	0.497
20	A83_035	0.017	0.303

Modelling Approach

A19-1.11.124. This section provides the detailed information on hydraulic model developed for modelling of A83 culverts. Of the 21 existing watercourses, 15 intercept the DFS and section of retaining wall (structure A83_29 is located under the standalone retaining wall) which are structure A83_16 to A83_30 and 5 pass under sections of the A83 not protected by the DFS or retaining wall which are structure A83_31 to A83_35. Baseline model exists only for the culverts A83_23 to A83_35.

A19-1.11.125. A one dimensional (1D) hydraulic model has been used to simulate the hydraulics (flow depth and velocity) for each culvert. The objectives of the modelling are:

- to confirm that all culverts can pass the 0.5% AEP +CC 46% flow
- to estimate flow depths and velocity in the watercourses and culvert and
- to provide an objective approach for informing reference design based on accepted engineering principles and industry guidance.

A19-1.11.126. Th approach was to use a constant peak flow of 0.5% AEP +CC 46% for the baseline and proposed model.

Model parameters

A19-1.11.127. Hydraulic roughness (Manning's 'n' coefficient) values were determined via a desktop study of the area using aerial imagery. The roughness values adopted were taken from standard guidance (Chow 1959).

A19-1.11.128. The in-channel manning value is 0.035 and for floodplain is 0.04 has been used for baseline and proposed scenario.

A19-1.11.129. The culverts are old so some deposition/blockage might be in place, hence the roughness value for the culvert invert is 0.035 and for the wall and soffit is 0.02 has been used.

A19-1.11.130. For all Proposed scenarios, 0.02 roughness value has been used for all culvert invert, walls and soffits as well as cascades upstream of the culverts.

Boundary Condition

A19-1.11.131. A Flow-Time boundary unit has been used as an inflow boundary and normal depth boundary unit has been used at downstream end for all A83 culvert models.

A19-1.11.132. As described in hydrology section an inflow derived from statistical method has been selected as a most conservative approach. A constant peak flow of 0.5% AEP +CC 46% has been used for baseline and proposed model.

Baseline modelling

A19-1.11.133. This section describes the model development for baseline scenario with existing culvert dimensions without including Debris Flow Shelter.

A19-1.11.134. A 1D Flood Modeller model has been developed for A83_23 to A83_35 to estimate flow depths and velocity in the watercourses and culvert. Cross-sections for each model have been extracted from DTM. The topographic survey of watercourses was not available due to health and safety reasons, The cross-sections generated from the DTM were sufficiently defined to use for modelling. The cross-section location selected at inlet and outlet of the culvert and 10m interval up to 50m and then 20m interval up to 100m upstream and downstream of the culvert. Road levels and dimensions of the culvert (Size, US and DS invert level) has been taken from Appendix E of Jacobs Baseline Flood study report[1].

A19-1.11.135. The schematic of A83 culvert model extent and cross-section locations has been provided in the Addendum at the end of this section.

Proposed modelling

A19-1.11.136. This section describes the proposed approach of model development by including DFS or updating culvert dimensions.

A19-1.11.137. Of the 20 existing watercourses covered in this report, 15 intercept the DFS and section of retaining wall (structure A83_29 is located under the standalone retaining wall) which are structure A83_16 to A83_30 and 5 pass under sections of the A83 not protected by the DFS or retaining wall which are structure A83_31 to A83_35. A separate model has been developed for Structure A83_15 (Croe Water), therefore not covered in this report.

[1] Access to Argyll and Bute (A83), Baseline Flood Study Report, A83AAB-JAC-EWE-XX_XX-RP-LE-0001, Appendix E.

Culvert within DFS

A19-1.11.138. Each of these 15 structures consists of a grated entrance (Approx 6m x 4m) that is situated level with the catchpit bed, sitting over the US end of the proposed A83 culverts. Flow from the upstream watercourses will spill into the catchpit and be directed towards the grated entrance by means of a 5% longitudinal and horizontal gradient. The plan is for the watercourse to make its way into the grated opening whilst also transporting sediment and small rocks / pebbles up to 100mm, which is the dimension of the opening of the grate.

A19-1.11.139. Once the flow passes through the grate it enters a drop structure which consist of angled sides and an angled step to dissipate energy and direct flow and sediment into the culvert. Each of the proposed culverts that pass under the A83 are currently 1.9m x 1.9m box culverts. These structures have been oversized for the flows that are expected and have been sized principally to satisfy CDM and safe maintenance. To ensure flow does not spread across the base of the culvert, a “V” notch channel is proposed along the bed, this will ensure the flow is focused in one part of the culvert and help to ensure sediment is able to be carried through the structure.

A19-1.11.140. The proposed design includes a section of open channel after the flow exits the culvert. This open channel includes engineering measures designed to reduce the exit velocity of the flow from the culvert. The open channel section also be wider than the base diameter of the culvert in an effort to further dissipate the energy from the culverted flow.

A19-1.11.141. A key design consideration involves the use of piles to support the proposed DFS structure. The design calls for a large number of piles at regular spacing in both the northbound and southbound directions. The quantity and spacing of the piles have influenced the proposed angle of the culverts, which limits the deviation from perpendicular alignment with the road. For this reason, the culverts have all initially been placed perpendicular to the road with the DS end of the culvert aligned with the existing watercourse. There are a couple of locations on the Existing Scheme that had culverts that crossed the A83 at a considerable angle. When replacing these culverts an US realignment, likely along the base of the proposed catchpit, will be required to ensure the continuation of flow.

A19-1.11.142. The water flow path between the existing watercourses upslope of the DFS and where the watercourses will return to their existing alignment downslope of the DFS has been conceptualised as comprising in Table 19.5C.

Table 19.5C - Section of flow path

Section	Description	Assumptions
1	Existing watercourse upslope of the DFS	Cross sections can be taken from the DSM for baseline model.
2	The upslope face of the DFS	Flows will be allowed to freefall into the DFS where the DFS intersects the existing channel.
3	Water in the DFS will flow to the next culvert inlet downslope.	The bed of the DFS has a gradient of 5% and culvert inlets are maintained unblocked.
4	Flow passes through a 100mm grill, over a cascade and enters a closed channel upstream of the culvert inlet.	The grill remains unblocked.
5	The culverted section	The bed gradient is 5%; the inlet type is assumed to be a square edge Type A – concrete with square edge headwall.
6	An open channel section to act as a transition between the culvert and the existing channel.	The bed slope of the channel is 2.5%
7	The existing channel	Cross sections can be taken from the DSM, which represents the cross-sections reasonably well

A19-1.11.143. Plate 19.3C is the proposed model schematic which shows the sections flow path from the location where the flow enters the proposed cascade via 100mm grill to the existing channel. A simplified long profile of the proposed features (sections 2 to 7) is shown in Plate 19.4C

Plate 19.3C - Proposed Model Schematic

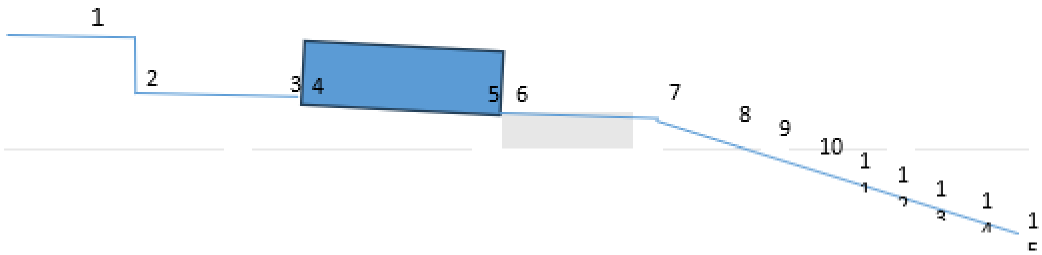
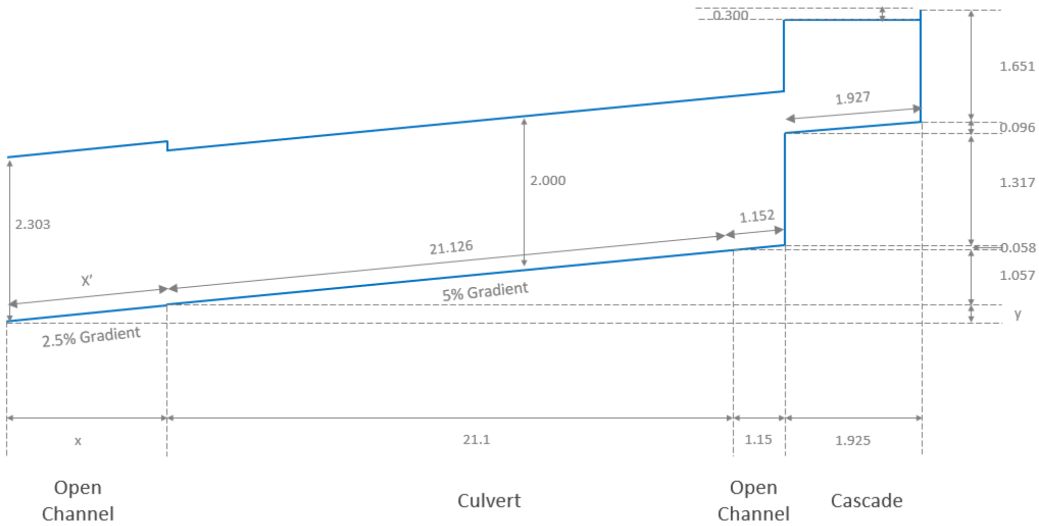


Plate 19.4C - Simplified long section of proposed features



A19-1.11.144. The proposed culvert model starts from the cascade step below debris flow shelter toe. The length of the cascade step, length of the open channel between cascade and the culvert and length of the culvert remains same in each of the culvert model. Length of the proposed open channel downstream of the culvert outlet was adjusted based on the tying/intersection point with the existing watercourse.

Culvert outside DFS

A19-1.11.145. Along the proposed route there are 5 other crossings which are A83_31 to A83_35. These crossings sit outside the approximately 1.6km of road that is having a retaining feature installed. These culverts have been sized to accommodate the 0.5% AEP +CC 46% flow with minimum freeboard allowance of 600mm.

Modelled Events

A19-1.11.146. Model runs have been carried out using Flood Modeller version 5.0. All baseline and proposed models have been run in steady state for 0.5% AEP +CC 46% event.

A19-1.11.147. In order to test the model sensitivity to Manning's 'n' roughness coefficient, a simulation was undertaken for proposed model. Table 19.6C shows the events and model scenarios that were simulated with the hydraulic model.

Table 19.6C - Model scenarios

Scenario	RP / AEP event
Baseline	0.5% AEP +CC 46%
Proposed	0.5% AEP +CC 46%
Sensitivity (Roughness)	0.5% AEP +CC 46%

Modelling Results

A19-1.11.148. This chapter provides an overview of the baseline, proposed and sensitivity model results.

Baseline versus Proposed

A19-1.11.149. Table 19.7C and Table 19.8C show the comparison of velocity and water levels for baseline and proposed scenarios respectively.

A19-1.11.150. The objective of this assessment was to assess the impact of the scheme at the downstream existing channel. The results show that both the velocity and the water levels at the existing channel downstream of culverts remain unaltered (point 8 to point 15). Like to like comparison of the results is not possible at the points 3 to 6 due to difference in location, size, inverts and length of the culvert in the baseline and proposed scenarios. It has also to be noted that the cascade (point 1 & 2) and the open channel downstream of the proposed culvert (point 7) outlet do not exist in the baseline scenario.

Table 19.7C - Comparison of velocity for baseline and proposed model

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_23	1	cascade	Not applicable	0.48	Not applicable
A83_23	2	cascade	Not applicable	0.51	Not applicable

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_23	3	Culvert inlet	0.03	0.41	1395.24
A83_23	4	Culvert inlet	1.54	1.82	18.36
A83_23	5	Culvert outlet	10.47	0.50	-95.23
A83_23	6	Culvert outlet	4.28	1.94	-54.71
A83_23	7	Open channel	Not applicable	9.04	Not applicable
A83_23	8	Existing channel	Not applicable	Not applicable	Not applicable
A83_23	9	Existing channel	4.02	4.02	0.00
A83_23	10	Existing channel	2.85	2.85	0.00
A83_23	11	Existing channel	3.60	3.60	0.00
A83_23	12	Existing channel	2.63	2.63	0.00
A83_23	13	Existing channel	1.78	1.78	0.00
A83_23	14	Existing channel	3.14	3.14	0.00
A83_23	15	Existing channel	2.79	2.79	0.00
A83_24	1	cascade	Not applicable	1.19	Not applicable
A83_24	2	cascade	Not applicable	1.50	Not applicable
A83_24	3	Culvert inlet	0.17	1.43	741.86
A83_24	4	Culvert inlet	5.70	3.39	-40.47

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_24	5	Culvert outlet	1.49	1.11	-25.93
A83_24	6	Culvert outlet	8.92	5.16	-42.12
A83_24	7	Open channel	Not applicable	9.85	Not applicable
A83_24	8	Existing channel	Not applicable	7.15	Not applicable
A83_24	9	Existing channel	7.09	7.09	0.00
A83_24	10	Existing channel	6.64	6.64	0.00
A83_24	11	Existing channel	5.63	5.63	0.00
A83_24	12	Existing channel	5.66	5.66	0.00
A83_24	13	Existing channel	6.03	6.03	0.00
A83_24	14	Existing channel	5.42	5.42	0.00
A83_24	15	Existing channel	5.34	5.34	0.00
A83_25	1	cascade	Not applicable	0.99	Not applicable
A83_25	2	cascade	Not applicable	0.79	Not applicable
A83_25	3	Culvert inlet	0.04	0.76	1764.75
A83_25	4	Culvert inlet	5.75	4.00	-30.46
A83_25	5	Culvert outlet	3.06	1.09	-64.25
A83_25	6	Culvert outlet	7.03	3.78	-46.27

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_25	7	Open channel	Not applicable	9.58	Not applicable
A83_25	8	Existing channel	Not applicable	5.72	Not applicable
A83_25	9	Existing channel	7.32	7.32	0.00
A83_25	10	Existing channel	6.99	6.99	0.00
A83_25	11	Existing channel	5.91	5.91	0.00
A83_25	12	Existing channel	6.31	6.31	0.00
A83_25	13	Existing channel	5.43	5.43	0.00
A83_25	14	Existing channel	5.44	5.44	0.00
A83_25	15	Existing channel	5.22	5.22	0.00
A83_26	1	cascade	Not applicable	0.78	Not applicable
A83_26	2	cascade	Not applicable	0.65	Not applicable
A83_26	3	Culvert inlet	0.07	0.61	833.14
A83_26	4	Culvert inlet	0.45	3.09	592.83
A83_26	5	Culvert outlet	0.45	0.89	98.94
A83_26	6	Culvert outlet	6.67	2.86	-57.10
A83_26	7	Open channel	Not applicable	7.17	Not applicable

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_26	8	Existing channel	3.43	3.43	0.00
A83_26	9	Existing channel	5.13	5.13	0.00
A83_26	10	Existing channel	4.61	4.61	0.00
A83_26	11	Existing channel	4.54	4.54	0.00
A83_26	12	Existing channel	5.32	5.32	0.00
A83_26	13	Existing channel	5.15	5.15	0.00
A83_26	14	Existing channel	4.08	4.08	0.00
A83_26	15	Existing channel	4.30	4.30	0.00
A83_27	1	cascade	Not applicable	1.01	Not applicable
A83_27	2	cascade	Not applicable	0.82	Not applicable
A83_27	3	Culvert inlet	0.18	0.79	345.77
A83_27	4	Culvert inlet	3.36	4.04	20.41
A83_27	5	Culvert outlet	8.17	1.07	-86.94
A83_27	6	Culvert outlet	5.65	4.00	-29.16
A83_27	7	Open channel	Not applicable	7.80	Not applicable
A83_27	8	Existing channel	6.89	6.89	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_27	9	Existing channel	5.80	5.80	0.00
A83_27	10	Existing channel	7.34	7.34	0.00
A83_27	11	Existing channel	6.67	6.67	0.00
A83_27	12	Existing channel	6.73	6.73	0.00
A83_27	13	Existing channel	6.64	6.64	0.00
A83_27	14	Existing channel	4.60	4.60	0.00
A83_27	15	Existing channel	4.67	4.67	0.00
A83_28	1	cascade	Not applicable	0.77	Not applicable
A83_28	2	cascade	Not applicable	0.64	Not applicable
A83_28	3	Culvert inlet	0.05	0.60	1002.48
A83_28	4	Culvert inlet	3.58	3.07	-14.12
A83_28	5	Culvert outlet	5.31	0.88	-83.39
A83_28	6	Culvert outlet	4.44	2.82	-36.57
A83_28	7	Open channel	Not applicable	8.08	Not applicable
A83_28	8	Existing channel	5.10	5.10	0.00
A83_28	9	Existing channel	5.74	5.74	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_28	10	Existing channel	5.31	5.31	0.00
A83_28	11	Existing channel	4.79	4.79	0.00
A83_28	12	Existing channel	4.05	4.05	0.00
A83_28	13	Existing channel	4.46	4.46	0.00
A83_28	14	Existing channel	3.96	3.96	0.00
A83_28	15	Existing channel	4.06	4.06	0.00
A83_29	1	cascade	Not applicable	0.69	Not applicable
A83_29	2	cascade	Not applicable	0.60	Not applicable
A83_29	3	Culvert inlet	0.10	0.55	425.46
A83_29	4	Culvert inlet	0.33	2.74	737.22
A83_29	5	Culvert outlet	0.33	0.95	190.20
A83_29	6	Culvert outlet	5.92	2.05	-65.34
A83_29	7	Open channel	NA	0.71	NA
A83_29	8	Existing channel	5.21	5.21	0.00
A83_29	9	Existing channel	4.63	4.63	0.00
A83_29	10	Existing channel	3.18	3.18	0.00
A83_29	11	Existing channel	3.79	3.79	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_29	12	Existing channel	4.44	4.44	0.00
A83_29	13	Existing channel	4.14	4.14	0.00
A83_29	14	Existing channel	4.07	4.07	0.00
A83_29	15	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	1	cascade	Not applicable	0.74	Not applicable
A83_30	2	cascade	Not applicable	0.62	Not applicable
A83_30	3	Culvert inlet	0.09	0.58	560.33
A83_30	4	Culvert inlet	4.38	2.94	-32.86
A83_30	5	Culvert outlet	12.09	0.85	-92.96
A83_30	6	Culvert outlet	2.83	2.70	-4.56
A83_30	7	Open channel	Not applicable	5.30	Not applicable
A83_30	8	Existing channel	5.60	5.60	0.00
A83_30	9	Existing channel	6.14	6.14	0.00
A83_30	10	Existing channel	3.54	3.54	0.00
A83_30	11	Existing channel	3.73	3.73	0.00
A83_30	12	Existing channel	Not applicable	Not applicable	Not applicable

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in Velocity (%)
A83_30	13	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	14	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	15	Existing channel	Not applicable	Not applicable	Not applicable

Table 19.8C - Comparison of water level for baseline and proposed model

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_23	1	cascade	Not applicable	204.34	Not applicable
A83_23	2	cascade	Not applicable	203.19	Not applicable
A83_23	3	Culvert inlet	205.34	203.20	-2.14
A83_23	4	Culvert inlet	205.16	202.95	-2.20
A83_23	5	Culvert outlet	199.55	202.08	2.53
A83_23	6	Culvert outlet	199.55	201.89	2.34
A83_23	7	Open channel	Not applicable	201.75	Not applicable
A83_23	8	Existing channel	Not applicable	Not applicable	Not applicable
A83_23	9	Existing channel	195.33	195.33	0.00
A83_23	10	Existing channel	189.28	189.28	0.00
A83_23	11	Existing channel	185.54	185.54	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_23	12	Existing channel	181.41	181.41	0.00
A83_23	13	Existing channel	173.00	173.00	0.00
A83_23	14	Existing channel	165.98	165.98	0.00
A83_23	15	Existing channel	158.06	158.06	0.00
A83_24	1	cascade	Not applicable	210.34	Not applicable
A83_24	2	cascade	Not applicable	209.78	Not applicable
A83_24	3	Culvert inlet	211.31	209.79	-1.52
A83_24	4	Culvert inlet	208.83	209.02	0.19
A83_24	5	Culvert outlet	204.94	209.13	4.19
A83_24	6	Culvert outlet	203.01	207.77	4.76
A83_24	7	Open channel	Not applicable	207.42	Not applicable
A83_24	8	Existing channel	Not applicable	199.63	Not applicable
A83_24	9	Existing channel	194.88	194.88	0.00
A83_24	10	Existing channel	190.33	190.33	0.00
A83_24	11	Existing channel	187.10	187.10	0.00
A83_24	12	Existing channel	183.58	183.58	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_24	13	Existing channel	176.78	176.78	0.00
A83_24	14	Existing channel	170.26	170.26	0.00
A83_24	15	Existing channel	163.98	163.98	0.00
A83_25	1	cascade	Not applicable	217.11	Not applicable
A83_25	2	cascade	Not applicable	216.85	Not applicable
A83_25	3	Culvert inlet	219.01	216.86	-2.16
A83_25	4	Culvert inlet	216.48	215.66	-0.82
A83_25	5	Culvert outlet	211.07	215.35	4.28
A83_25	6	Culvert outlet	208.97	214.62	5.66
A83_25	7	Open channel	Not applicable	214.28	Not applicable
A83_25	8	Existing channel	Not applicable	210.91	Not applicable
A83_25	9	Existing channel	203.82	203.82	0.00
A83_25	10	Existing channel	197.39	197.39	0.00
A83_25	11	Existing channel	192.09	192.09	0.00
A83_25	12	Existing channel	187.67	187.67	0.00
A83_25	13	Existing channel	178.89	178.89	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_25	14	Existing channel	171.11	171.11	0.00
A83_25	15	Existing channel	164.25	164.25	0.00
A83_26	1	cascade	Not applicable	220.55	Not applicable
A83_26	2	cascade	Not applicable	219.84	Not applicable
A83_26	3	Culvert inlet	222.00	219.84	-2.15
A83_26	4	Culvert inlet	221.98	219.13	-2.85
A83_26	5	Culvert outlet	221.98	218.51	-3.47
A83_26	6	Culvert outlet	220.08	218.09	-1.99
A83_26	7	Open channel	Not applicable	217.80	Not applicable
A83_26	8	Existing channel	209.03	209.03	0.00
A83_26	9	Existing channel	202.03	202.03	0.00
A83_26	10	Existing channel	196.52	196.52	0.00
A83_26	11	Existing channel	191.96	191.96	0.00
A83_26	12	Existing channel	187.79	187.79	0.00
A83_26	13	Existing channel	179.27	179.27	0.00
A83_26	14	Existing channel	171.97	171.97	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_26	15	Existing channel	165.64	165.64	0.00
A83_27	1	cascade	Not applicable	227.63	Not applicable
A83_27	2	cascade	Not applicable	227.39	Not applicable
A83_27	3	Culvert inlet	229.13	227.39	-1.74
A83_27	4	Culvert inlet	228.22	226.17	-2.04
A83_27	5	Culvert outlet	227.10	225.94	-1.16
A83_27	6	Culvert outlet	227.10	225.12	-1.98
A83_27	7	Open channel	Not applicable	224.79	Not applicable
A83_27	8	Existing channel	224.47	224.47	0.00
A83_27	9	Existing channel	219.34	219.34	0.00
A83_27	10	Existing channel	213.98	213.98	0.00
A83_27	11	Existing channel	207.89	207.89	0.00
A83_27	12	Existing channel	202.59	202.59	0.00
A83_27	13	Existing channel	192.07	192.07	0.00
A83_27	14	Existing channel	183.28	183.28	0.00
A83_27	15	Existing channel	179.36	179.36	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_28	1	cascade	Not applicable	229.97	Not applicable
A83_28	2	cascade	Not applicable	229.25	Not applicable
A83_28	3	Culvert inlet	231.38	229.25	-2.12
A83_28	4	Culvert inlet	230.40	228.55	-1.85
A83_28	5	Culvert outlet	225.61	227.91	2.30
A83_28	6	Culvert outlet	225.61	227.51	1.90
A83_28	7	Open channel	Not applicable	227.22	Not applicable
A83_28	8	Existing channel	220.78	220.78	0.00
A83_28	9	Existing channel	215.26	215.26	0.00
A83_28	10	Existing channel	210.49	210.49	0.00
A83_28	11	Existing channel	205.04	205.04	0.00
A83_28	12	Existing channel	201.20	201.20	0.00
A83_28	13	Existing channel	192.81	192.81	0.00
A83_28	14	Existing channel	186.82	186.82	0.00
A83_28	15	Existing channel	181.43	181.43	0.00
A83_29	1	cascade	Not applicable	233.93	Not applicable

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_29	2	cascade	Not applicable	233.08	Not applicable
A83_29	3	Culvert inlet	234.83	233.08	-1.75
A83_29	4	Culvert inlet	234.82	232.52	-2.31
A83_29	5	Culvert outlet	234.82	231.72	-3.10
A83_29	6	Culvert outlet	233.04	231.51	-1.53
A83_29	7	Open channel	Not applicable	231.54	Not applicable
A83_29	8	Existing channel	231.26	231.26	0.00
A83_29	9	Existing channel	225.66	225.66	0.00
A83_29	10	Existing channel	222.05	222.05	0.00
A83_29	11	Existing channel	218.74	218.74	0.00
A83_29	12	Existing channel	209.64	209.64	0.00
A83_29	13	Existing channel	201.47	201.47	0.00
A83_29	14	Existing channel	193.99	193.99	0.00
A83_29	15	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	1	cascade	Not applicable	238.93	Not applicable
A83_30	2	cascade	Not applicable	238.16	Not applicable
A83_30	3	Culvert inlet	240.73	238.16	-2.57

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_30	4	Culvert inlet	239.26	237.52	-1.74
A83_30	5	Culvert outlet	229.69	236.84	7.15
A83_30	6	Culvert outlet	229.69	236.47	6.78
A83_30	7	Open channel	Not applicable	236.21	Not applicable
A83_30	8	Existing channel	227.93	227.93	0.00
A83_30	9	Existing channel	221.90	221.91	0.00
A83_30	10	Existing channel	215.33	215.33	0.00
A83_30	11	Existing channel	211.37	211.37	0.00
A83_30	12	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	13	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	14	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	15	Existing channel	Not applicable	Not applicable	Not applicable

Sensitivity Analysis (Manning's roughness)

A19-1.11.151. To assess the impact of inclusion of baffle blocks in the geometry of the proposed culvert and open channel downstream, roughness value has been increased by 20%.

A19-1.11.152. Table 19.9C shows the impact of increasing the roughness by 20% in the proposed culvert and the open channel downstream of the culvert. The result shows that increase in roughness by 20% decreases the velocity at the proposed open channel section including the location where the intersects with the existing channel (location 7). There is no impact further downstream in the existing channel.

Table 19.9C - Impact of sensitivity analysis over proposed model in terms of velocity

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_16	1	cascade	0.80	0.80	0.00
A83_16	2	cascade	0.66	1.14	71.77
A83_16	3	Culvert inlet	0.62	1.01	61.42
A83_16	4	Culvert inlet	3.22	2.22	-31.11
A83_16	5	Culvert outlet	1.01	1.19	17.84
A83_16	6	Culvert outlet	2.69	1.98	-26.39
A83_16	7	Open channel	6.72	4.54	-32.53
A83_16	8	Existing channel	5.50	5.50	0.00
A83_16	9	Existing channel	3.83	3.83	0.00
A83_16	10	Existing channel	4.44	4.44	0.00
A83_16	11	Existing channel	Not applicable	Not applicable	Not applicable
A83_16	12	Existing channel	3.23	3.23	0.00
A83_16	13	Existing channel	5.58	5.58	0.00
A83_16	14	Existing channel	5.52	5.52	0.00
A83_16	15	Existing channel	Not applicable	Not applicable	Not applicable
A83_17	1	cascade	0.91	0.91	0.00
A83_17	2	cascade	0.73	1.23	67.89
A83_17	3	Culvert inlet	0.70	1.12	60.66
A83_17	4	Culvert inlet	3.67	2.55	-30.50

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_17	5	Culvert outlet	1.05	1.30	23.95
A83_17	6	Culvert outlet	3.32	2.48	-25.25
A83_17	7	Open channel	2.05	1.97	-3.47
A83_17	8	Existing channel	4.99	4.99	0.00
A83_17	9	Existing channel	6.63	6.63	0.00
A83_17	10	Existing channel	5.03	5.03	0.00
A83_17	11	Existing channel	Not applicable	Not applicable	Not applicable
A83_17	12	Existing channel	4.40	4.40	0.00
A83_17	13	Existing channel	4.39	4.39	0.00
A83_17	14	Existing channel	4.13	4.13	0.00
A83_17	15	Existing channel	3.72	3.72	0.00
A83_18	1	cascade	0.67	0.67	0.00
A83_18	2	cascade	0.21	0.33	57.43
A83_18	3	Culvert inlet	0.20	0.31	52.50
A83_18	4	Culvert inlet	3.36	2.32	-30.98
A83_18	5	Culvert outlet	1.04	1.23	18.29
A83_18	6	Culvert outlet	2.82	2.08	-26.15
A83_18	7	Open channel	7.31	4.98	-31.82
A83_18	8	Existing channel	3.73	3.73	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_18	9	Existing channel	3.71	3.71	0.00
A83_18	10	Existing channel	2.51	2.51	0.00
A83_18	11	Existing channel	3.57	3.57	0.00
A83_18	12	Existing channel	2.78	2.78	0.00
A83_18	13	Existing channel	4.34	4.34	0.00
A83_18	14	Existing channel	4.05	4.05	0.00
A83_18	15	Existing channel	3.91	3.91	0.00
A83_19&20	1	cascade	0.83	0.83	0.00
A83_19&20	2	cascade	0.68	1.16	70.58
A83_19&20	3	Culvert inlet	0.64	1.04	61.26
A83_19&20	4	Culvert inlet	3.34	2.31	-30.95
A83_19&20	5	Culvert outlet	0.91	1.18	29.33
A83_19&20	6	Culvert outlet	3.20	2.34	-26.82
A83_19&20	7	Open channel	9.93	5.16	-47.99
A83_19&20	8	Existing channel	5.61	5.61	0.00
A83_19&20	9	Existing channel	3.73	3.73	0.00
A83_19&20	10	Existing channel	Not applicable	Not applicable	Not applicable

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_19&20	11	Existing channel	5.06	5.06	0.00
A83_19&20	12	Existing channel	2.98	2.98	0.00
A83_19&20	13	Existing channel	4.05	4.05	0.00
A83_19&20	14	Existing channel	2.92	2.92	0.00
A83_19&20	15	Existing channel	3.16	3.16	0.00
A83_21&22	1	cascade	0.93	0.93	0.00
A83_21&22	2	cascade	0.75	1.25	67.01
A83_21&22	3	Culvert inlet	0.71	1.14	60.24
A83_21&22	4	Culvert inlet	3.76	2.62	-30.31
A83_21&22	5	Culvert outlet	1.01	1.31	28.77
A83_21&22	6	Culvert outlet	3.58	2.65	-25.99
A83_21&22	7	Open channel	7.27	4.51	-37.97
A83_21&22	8	Existing channel	5.77	5.77	0.00
A83_21&22	9	Existing channel	6.02	6.02	0.00
A83_21&22	10	Existing channel	5.57	5.57	0.00
A83_21&22	11	Existing channel	4.83	4.83	0.00
A83_21&22	12	Existing channel	3.79	3.79	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_21&22	13	Existing channel	3.45	3.45	0.00
A83_21&22	14	Existing channel	4.44	4.44	0.00
A83_21&22	15	Existing channel	3.00	3.00	0.00
A83_23	1	cascade	0.48	0.48	0.00
A83_23	2	cascade	0.51	1.12	121.76
A83_23	3	Culvert inlet	0.41	0.65	59.54
A83_23	4	Culvert inlet	1.82	1.22	-32.86
A83_23	5	Culvert outlet	0.50	0.72	43.31
A83_23	6	Culvert outlet	1.94	1.15	-40.74
A83_23	7	Open channel	9.04	3.56	-60.59
A83_23	8	Existing channel	Not applicable	Not applicable	Not applicable
A83_23	9	Existing channel	4.02	4.02	0.00
A83_23	10	Existing channel	2.85	2.85	0.00
A83_23	11	Existing channel	3.60	3.60	0.00
A83_23	12	Existing channel	2.63	2.63	0.00
A83_23	13	Existing channel	1.78	1.78	0.00
A83_23	14	Existing channel	3.14	3.14	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_23	15	Existing channel	2.79	2.79	0.00
A83_24	1	cascade	1.19	1.19	0.00
A83_24	2	cascade	1.50	1.53	1.59
A83_24	3	Culvert inlet	1.43	1.45	1.47
A83_24	4	Culvert inlet	3.39	3.35	-1.38
A83_24	5	Culvert outlet	1.11	1.49	34.63
A83_24	6	Culvert outlet	5.16	3.96	-23.25
A83_24	7	Open channel	9.85	7.92	-19.61
A83_24	8	Existing channel	7.15	7.15	0.00
A83_24	9	Existing channel	7.09	7.09	0.00
A83_24	10	Existing channel	6.64	6.64	0.00
A83_24	11	Existing channel	5.63	5.63	0.00
A83_24	12	Existing channel	5.66	5.66	0.00
A83_24	13	Existing channel	6.03	6.03	0.00
A83_24	14	Existing channel	5.42	5.42	0.00
A83_24	15	Existing channel	5.34	5.34	0.00
A83_25	1	cascade	0.99	0.99	0.00
A83_25	2	cascade	0.79	1.30	64.37
A83_25	3	Culvert inlet	0.76	1.21	58.76

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_25	4	Culvert inlet	4.00	2.81	-29.73
A83_25	5	Culvert outlet	1.09	1.39	27.00
A83_25	6	Culvert outlet	3.78	2.84	-24.89
A83_25	7	Open channel	9.58	5.85	-38.96
A83_25	8	Existing channel	5.72	5.72	0.00
A83_25	9	Existing channel	7.32	7.32	0.00
A83_25	10	Existing channel	6.99	6.99	0.00
A83_25	11	Existing channel	5.91	5.91	0.00
A83_25	12	Existing channel	6.31	6.31	0.00
A83_25	13	Existing channel	5.43	5.43	0.00
A83_25	14	Existing channel	5.44	5.44	0.00
A83_25	15	Existing channel	5.22	5.22	0.00
A83_26	1	cascade	0.78	0.78	0.00
A83_26	2	cascade	0.65	1.12	71.98
A83_26	3	Culvert inlet	0.61	0.98	60.68
A83_26	4	Culvert inlet	3.09	2.13	-31.02
A83_26	5	Culvert outlet	0.89	1.13	26.73
A83_26	6	Culvert outlet	2.86	2.06	-28.20
A83_26	7	Open channel	7.17	3.74	-47.85

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_26	8	Existing channel	3.43	3.43	0.00
A83_26	9	Existing channel	5.13	5.13	0.00
A83_26	10	Existing channel	4.61	4.61	0.00
A83_26	11	Existing channel	4.54	4.54	0.00
A83_26	12	Existing channel	5.32	5.32	0.00
A83_26	13	Existing channel	5.15	5.15	0.00
A83_26	14	Existing channel	4.08	4.08	0.00
A83_26	15	Existing channel	4.30	4.30	0.00
A83_27	1	cascade	1.01	1.01	-0.01
A83_27	2	cascade	0.82	1.32	61.72
A83_27	3	Culvert inlet	0.79	1.23	56.54
A83_27	4	Culvert inlet	4.04	2.87	-29.04
A83_27	5	Culvert outlet	1.07	1.39	29.95
A83_27	6	Culvert outlet	4.00	3.00	-24.93
A83_27	7	Open channel	7.80	5.30	-32.09
A83_27	8	Existing channel	6.89	6.89	0.00
A83_27	9	Existing channel	5.80	5.80	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_27	10	Existing channel	7.34	7.34	0.00
A83_27	11	Existing channel	6.67	6.67	0.00
A83_27	12	Existing channel	6.73	6.73	0.00
A83_27	13	Existing channel	6.64	6.64	0.00
A83_27	14	Existing channel	4.60	4.60	0.00
A83_27	15	Existing channel	4.67	4.67	0.00
A83_28	1	cascade	0.77	0.77	0.00
A83_28	2	cascade	0.64	1.11	73.09
A83_28	3	Culvert inlet	0.60	0.96	61.40
A83_28	4	Culvert inlet	3.07	2.11	-31.18
A83_28	5	Culvert outlet	0.88	1.12	26.41
A83_28	6	Culvert outlet	2.82	2.02	-28.32
A83_28	7	Open channel	8.08	4.21	-47.86
A83_28	8	Existing channel	5.10	5.10	0.00
A83_28	9	Existing channel	5.74	5.74	0.00
A83_28	10	Existing channel	5.31	5.31	0.00
A83_28	11	Existing channel	4.79	4.79	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_28	12	Existing channel	4.05	4.05	0.00
A83_28	13	Existing channel	4.46	4.46	0.00
A83_28	14	Existing channel	3.96	3.96	0.00
A83_28	15	Existing channel	4.06	4.06	0.00
A83_29	1	cascade	0.69	0.69	0.00
A83_29	2	cascade	0.60	1.07	78.69
A83_29	3	Culvert inlet	0.55	0.88	62.06
A83_29	4	Culvert inlet	2.74	1.87	-31.86
A83_29	5	Culvert outlet	0.95	1.03	8.34
A83_29	6	Culvert outlet	2.05	1.63	-20.66
A83_29	7	Open channel	0.71	0.63	-10.82
A83_29	8	Existing channel	5.21	5.21	0.00
A83_29	9	Existing channel	4.63	4.63	0.00
A83_29	10	Existing channel	3.18	3.18	0.00
A83_29	11	Existing channel	3.79	3.79	0.00
A83_29	12	Existing channel	4.44	4.44	0.00
A83_29	13	Existing channel	4.14	4.14	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (m)	Sensitivity Scenario S6 (m)	Difference in velocity (%)
A83_29	14	Existing channel	4.07	4.07	0.00
A83_29	15	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	1	cascade	0.74	0.74	0.00
A83_30	2	cascade	0.62	1.10	75.50
A83_30	3	Culvert inlet	0.58	0.94	62.06
A83_30	4	Culvert inlet	2.94	2.01	-31.60
A83_30	5	Culvert outlet	0.85	1.08	26.46
A83_30	6	Culvert outlet	2.70	1.92	-28.98
A83_30	7	Open channel	5.30	3.71	-29.91
A83_30	8	Existing channel	5.60	5.60	0.00
A83_30	9	Existing channel	6.14	6.14	0.00
A83_30	10	Existing channel	3.54	3.54	0.00
A83_30	11	Existing channel	3.73	3.73	0.00
A83_30	12	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	13	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	14	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	15	Existing channel	Not applicable	Not applicable	Not applicable

Table 19.10C - Impact of sensitivity analysis over proposed model in terms of water level

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_16	1	cascade	173.53	173.53	0.00
A83_16	2	cascade	172.88	172.50	-0.37
A83_16	3	Culvert inlet	172.88	172.51	-0.36
A83_16	4	Culvert inlet	172.11	172.19	0.08
A83_16	5	Culvert outlet	171.46	171.37	-0.09
A83_16	6	Culvert outlet	171.09	171.17	0.08
A83_16	7	Open channel	170.82	170.86	0.04
A83_16	8	Existing channel	167.71	167.71	0.00
A83_16	9	Existing channel	162.71	162.71	0.00
A83_16	10	Existing channel	159.79	159.79	0.00
A83_16	11	Existing channel	Not applicable	Not applicable	Not applicable
A83_16	12	Existing channel	153.43	153.43	0.00
A83_16	13	Existing channel	149.73	149.73	0.00
A83_16	14	Existing channel	140.54	140.54	0.00
A83_16	15	Existing channel	Not applicable	Not applicable	Not applicable
A83_17	1	cascade	177.88	177.88	0.00
A83_17	2	cascade	177.44	176.96	-0.48

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_17	3	Culvert inlet	177.45	176.98	-0.47
A83_17	4	Culvert inlet	176.44	176.54	0.10
A83_17	5	Culvert outlet	175.97	175.81	-0.16
A83_17	6	Culvert outlet	175.41	175.50	0.09
A83_17	7	Open channel	175.25	175.26	0.01
A83_17	8	Existing channel	175.23	175.23	0.00
A83_17	9	Existing channel	171.84	171.84	0.00
A83_17	10	Existing channel	167.51	167.51	0.00
A83_17	11	Existing channel	Not applicable	Not applicable	Not applicable
A83_17	12	Existing channel	161.11	161.11	0.00
A83_17	13	Existing channel	156.64	156.64	0.00
A83_17	14	Existing channel	152.77	152.77	0.00
A83_17	15	Existing channel	147.74	147.74	0.00
A83_18	1	cascade	185.57	185.57	0.00
A83_18	2	cascade	184.94	184.58	-0.37
A83_18	3	Culvert inlet	184.94	184.58	-0.37
A83_18	4	Culvert inlet	184.08	184.17	0.09
A83_18	5	Culvert outlet	183.47	183.37	-0.10
A83_18	6	Culvert outlet	183.06	183.15	0.08

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_18	7	Open channel	182.78	182.83	0.04
A83_18	8	Existing channel	177.29	177.29	0.00
A83_18	9	Existing channel	175.24	175.24	0.00
A83_18	10	Existing channel	172.74	172.74	0.00
A83_18	11	Existing channel	170.46	170.46	0.00
A83_18	12	Existing channel	168.33	168.33	0.00
A83_18	13	Existing channel	164.08	164.08	0.00
A83_18	14	Existing channel	158.37	158.37	0.00
A83_18	15	Existing channel	152.35	152.35	0.00
A83_19&20	1	cascade	192.83	192.83	0.00
A83_19&20	2	cascade	192.23	191.83	-0.40
A83_19&20	3	Culvert inlet	192.23	191.84	-0.39
A83_19&20	4	Culvert inlet	191.40	191.49	0.09
A83_19&20	5	Culvert outlet	190.87	190.71	-0.17
A83_19&20	6	Culvert outlet	190.35	190.43	0.08
A83_19&20	7	Open channel	190.07	190.11	0.04
A83_19&20	8	Existing channel	186.93	186.93	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_19&20	9	Existing channel	183.74	183.74	0.00
A83_19&20	10	Existing channel	Not applicable	Not applicable	Not applicable
A83_19&20	11	Existing channel	177.28	177.28	0.00
A83_19&20	12	Existing channel	174.13	174.13	0.00
A83_19&20	13	Existing channel	165.25	165.25	0.00
A83_19&20	14	Existing channel	160.19	160.19	0.00
A83_19&20	15	Existing channel	156.31	156.31	0.00
A83_21&22	1	cascade	195.89	195.89	0.00
A83_21&22	2	cascade	195.50	195.00	-0.50
A83_21&22	3	Culvert inlet	195.50	195.01	-0.49
A83_21&22	4	Culvert inlet	194.44	194.55	0.11
A83_21&22	5	Culvert outlet	194.05	193.85	-0.20
A83_21&22	6	Culvert outlet	193.40	193.49	0.09
A83_21&22	7	Open channel	193.08	193.13	0.05
A83_21&22	8	Existing channel	179.50	179.50	0.00
A83_21&22	9	Existing channel	176.06	176.06	0.00
A83_21&22	10	Existing channel	172.47	172.47	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_21&22	11	Existing channel	168.87	168.87	0.00
A83_21&22	12	Existing channel	164.64	164.64	0.00
A83_21&22	13	Existing channel	159.61	159.61	0.00
A83_21&22	14	Existing channel	154.99	154.99	0.00
A83_21&22	15	Existing channel	151.56	151.56	0.00
A83_23	1	cascade	204.34	204.34	0.00
A83_23	2	cascade	203.19	203.07	-0.12
A83_23	3	Culvert inlet	203.20	203.08	-0.11
A83_23	4	Culvert inlet	202.95	202.99	0.03
A83_23	5	Culvert outlet	202.08	201.93	-0.15
A83_23	6	Culvert outlet	201.89	201.93	0.04
A83_23	7	Open channel	201.75	201.76	0.01
A83_23	8	Existing channel	Not applicable	Not applicable	Not applicable
A83_23	9	Existing channel	195.33	195.30	-0.03
A83_23	10	Existing channel	189.28	189.26	-0.02
A83_23	11	Existing channel	185.54	185.50	-0.03
A83_23	12	Existing channel	181.41	181.57	0.17

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_23	13	Existing channel	173.00	172.93	-0.07
A83_23	14	Existing channel	165.98	166.06	0.08
A83_23	15	Existing channel	158.06	158.05	-0.01
A83_24	1	cascade	210.34	210.34	0.00
A83_24	2	cascade	209.78	209.76	-0.02
A83_24	3	Culvert inlet	209.79	209.77	-0.02
A83_24	4	Culvert inlet	209.02	209.02	0.01
A83_24	5	Culvert outlet	209.13	208.68	-0.44
A83_24	6	Culvert outlet	207.77	207.88	0.11
A83_24	7	Open channel	207.42	207.45	0.03
A83_24	8	Existing channel	199.63	199.63	0.00
A83_24	9	Existing channel	194.88	194.88	0.00
A83_24	10	Existing channel	190.33	190.33	0.00
A83_24	11	Existing channel	187.10	187.10	0.00
A83_24	12	Existing channel	183.58	183.58	0.00
A83_24	13	Existing channel	176.78	176.78	0.00
A83_24	14	Existing channel	170.26	170.26	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_24	15	Existing channel	163.98	163.98	0.00
A83_25	1	cascade	217.11	217.11	0.00
A83_25	2	cascade	216.85	216.85	0.00
A83_25	3	Culvert inlet	216.86	216.86	0.00
A83_25	4	Culvert inlet	215.66	215.66	0.00
A83_25	5	Culvert outlet	215.35	215.35	0.00
A83_25	6	Culvert outlet	214.62	214.62	0.00
A83_25	7	Open channel	214.28	214.28	0.00
A83_25	8	Existing channel	210.91	210.91	0.00
A83_25	9	Existing channel	203.82	203.82	0.00
A83_25	10	Existing channel	197.39	197.39	0.00
A83_25	11	Existing channel	192.09	192.09	0.00
A83_25	12	Existing channel	187.67	187.67	0.00
A83_25	13	Existing channel	178.89	178.89	0.00
A83_25	14	Existing channel	171.11	171.11	0.00
A83_25	15	Existing channel	164.25	164.25	0.00
A83_26	1	cascade	220.55	220.55	0.00
A83_26	2	cascade	219.84	219.49	-0.35

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_26	3	Culvert inlet	219.84	219.51	-0.33
A83_26	4	Culvert inlet	219.13	219.21	0.08
A83_26	5	Culvert outlet	218.51	218.38	-0.13
A83_26	6	Culvert outlet	218.09	218.16	0.07
A83_26	7	Open channel	217.80	217.84	0.04
A83_26	8	Existing channel	209.03	209.03	0.00
A83_26	9	Existing channel	202.03	202.03	0.00
A83_26	10	Existing channel	196.52	196.52	0.00
A83_26	11	Existing channel	191.96	191.96	0.00
A83_26	12	Existing channel	187.79	187.79	0.00
A83_26	13	Existing channel	179.27	179.27	0.00
A83_26	14	Existing channel	171.97	171.97	0.00
A83_26	15	Existing channel	165.64	165.64	0.00
A83_27	1	cascade	227.63	227.63	0.00
A83_27	2	cascade	227.39	226.84	-0.55
A83_27	3	Culvert inlet	227.39	226.85	-0.55
A83_27	4	Culvert inlet	226.17	226.29	0.12
A83_27	5	Culvert outlet	225.94	225.68	-0.26
A83_27	6	Culvert outlet	225.12	225.22	0.10

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_27	7	Open channel	224.79	224.83	0.05
A83_27	8	Existing channel	224.47	224.47	0.00
A83_27	9	Existing channel	219.34	219.34	0.00
A83_27	10	Existing channel	213.98	213.98	0.00
A83_27	11	Existing channel	207.89	207.89	0.00
A83_27	12	Existing channel	202.59	202.59	0.00
A83_27	13	Existing channel	192.07	192.07	0.00
A83_27	14	Existing channel	183.28	183.28	0.00
A83_27	15	Existing channel	179.36	179.36	0.00
A83_28	1	cascade	229.97	229.97	0.00
A83_28	2	cascade	229.25	228.91	-0.34
A83_28	3	Culvert inlet	229.25	228.92	-0.33
A83_28	4	Culvert inlet	228.55	228.63	0.08
A83_28	5	Culvert outlet	227.91	227.79	-0.12
A83_28	6	Culvert outlet	227.51	227.58	0.07
A83_28	7	Open channel	227.22	227.25	0.04
A83_28	8	Existing channel	220.78	220.78	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_28	9	Existing channel	215.26	215.26	0.00
A83_28	10	Existing channel	210.49	210.49	0.00
A83_28	11	Existing channel	205.04	205.04	0.00
A83_28	12	Existing channel	201.20	201.20	0.00
A83_28	13	Existing channel	192.81	192.81	0.00
A83_28	14	Existing channel	186.82	186.82	0.00
A83_28	15	Existing channel	181.43	181.43	0.00
A83_29	1	cascade	233.93	233.93	0.00
A83_29	2	cascade	233.08	232.80	-0.28
A83_29	3	Culvert inlet	233.08	232.81	-0.27
A83_29	4	Culvert inlet	232.52	232.58	0.06
A83_29	5	Culvert outlet	231.72	231.69	-0.03
A83_29	6	Culvert outlet	231.51	231.56	0.05
A83_29	7	Open channel	231.54	231.58	0.04
A83_29	8	Existing channel	231.26	231.26	0.00
A83_29	9	Existing channel	225.66	225.66	0.00
A83_29	10	Existing channel	222.05	222.05	0.00

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_29	11	Existing channel	218.74	218.74	0.00
A83_29	12	Existing channel	209.64	209.64	0.00
A83_29	13	Existing channel	201.47	201.47	0.00
A83_29	14	Existing channel	193.99	193.99	0.00
A83_29	15	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	1	cascade	238.93	238.93	0.00
A83_30	2	cascade	238.16	237.84	-0.32
A83_30	3	Culvert inlet	238.16	237.85	-0.31
A83_30	4	Culvert inlet	237.52	237.59	0.07
A83_30	5	Culvert outlet	236.84	236.73	-0.11
A83_30	6	Culvert outlet	236.47	236.54	0.07
A83_30	7	Open channel	236.21	236.23	0.02
A83_30	8	Existing channel	227.93	227.93	0.00
A83_30	9	Existing channel	221.91	221.91	0.00
A83_30	10	Existing channel	215.33	215.33	0.00
A83_30	11	Existing channel	211.37	211.37	0.00
A83_30	12	Existing channel	Not applicable	Not applicable	Not applicable

Culvert Name	Schematic reference Node	Location	Proposed Model (mAOD)	Sensitivity Scenario S6 (mAOD)	Difference in water level (m)
A83_30	13	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	14	Existing channel	Not applicable	Not applicable	Not applicable
A83_30	15	Existing channel	Not applicable	Not applicable	Not applicable

Proposed culverts outside DFS

A19-1.11.153. There are 5 culverts outside the DFS which are A83_31 to A83_35. Assessment has been carried out to investigate the size of these culverts to accommodate the 0.5% AEP +CC 46% flow with minimum freeboard allowance of 600mm. Table 19.11C shows existing and proposed size of these culverts.

Table 19.11C - Proposed capacity of the culverts outside DFS

Culvert Name	Length (m)	Existing size of culvert (m)	Proposed size of culvert (m)	Minimum Available Freeboard (m)	Available Cover (m)
A83_31	28.5	1.2W x 1.5H (Box culvert)	2.7W x 2.4H (Box culvert)	0.61	1.48
A83_32	12.1	0.9 Dia (Circular culvert)	2.7W x 2.7H (Box culvert)	0.70	1.30
A83_33	41.0	0.4 Dia (Circular culvert)	1.2W x 1.2H (Box culvert)	0.75	1.30
A83_34	16.3	0.6 Dia (Circular culvert)	1.2W x 1.2H (Box culvert)	0.61	0.90
A83_35	11.7	0.45 Dia (Circular culvert)	1.2W x 1.2H (Box culvert)	0.76	0.86

A19-1.11.154. Table 19.12 and Table 19.13D shows the comparison of velocity and water level between baseline and proposed model. Plates showing locations where the results are compared is presented in Addendum A.

Table 19.12C - Comparison of velocity for baseline and proposed model of culverts outside DFS

Culvert Name	Schematic reference Node	Location	Baseline Model (m/s)	Proposed Model (m/s)	Difference in velocity (%)
A83_31	1	US1	5.42	5.42	0.00
A83_31	2	US2	6.40	6.40	0.00
A83_31	3	US3	6.31	6.31	0.00
A83_31	4	US4	6.19	6.19	0.00
A83_31	5	US5	4.30	4.30	0.00
A83_31	6	US6	5.40	5.40	0.01
A83_31	7	US7	7.67	7.86	2.46
A83_31	8	US8	0.35	0.44	28.03
A83_31	9	CUL1	6.04	4.61	-23.75
A83_31	10	CUL2	1.26	0.88	-29.83
A83_31	11	DS_XS_01	6.31	3.74	-40.78
A83_31	12	DS_XS_02	6.06	6.06	-0.01
A83_31	13	DS_XS_03	5.41	5.41	0.01
A83_31	14	DS_XS_04	5.73	5.74	0.00
A83_31	15	DS_XS_05	4.44	4.44	0.00
A83_31	16	DS_XS_06	5.56	5.56	0.00
A83_31	17	DS_XS_07	5.42	5.42	0.01
A83_31	18	DS_XS_08	4.36	4.36	0.00
A83_32	1	US1	4.16	4.16	0.00
A83_32	2	US2	5.59	5.59	0.00
A83_32	3	US3	5.28	5.28	0.00
A83_32	4	US4	7.71	7.71	0.00
A83_32	5	US5	4.93	4.93	0.00
A83_32	6	US6	4.32	4.32	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (m/s)	Proposed Model (m/s)	Difference in velocity (%)
A83_32	7	US7	5.38	6.07	12.84
A83_32	8	US8	0.42	1.12	170.84
A83_32	9	CAS1	0.82	1.22	47.63
A83_32	10	CUL1	4.60	1.46	-68.20
A83_32	11	CUL2	11.62	0.53	-95.47
A83_32	12	OUTLET	1.19	1.19	0.00
A83_32	13	DS_XS_01	7.47	5.93	-20.56
A83_32	14	DS_XS_02	6.31	6.31	0.00
A83_32	15	DS_XS_03	6.47	6.47	0.00
A83_32	16	DS_XS_04	4.87	4.87	0.00
A83_32	17	DS_XS_05	4.83	4.83	0.00
A83_32	18	DS_XS_06	8.41	8.41	0.00
A83_32	19	DS_XS_07	7.62	7.62	0.00
A83_33	1	US1	2.87	2.87	0.00
A83_33	2	US2	2.93	2.93	0.00
A83_33	3	US3	2.91	2.91	0.00
A83_33	4	US4	3.12	3.12	0.00
A83_33	5	US5	2.94	2.94	0.00
A83_33	6	US6	1.93	1.93	0.31
A83_33	7	US7	0.05	0.61	1110.00
A83_33	8	INLET	0.00	0.00	0.00
A83_33	9	CUL1	4.77	3.56	-25.50
A83_33	10	CUL2	2.85	0.68	-76.31
A83_33	11	OUTLET	3.93	3.93	0.00
A83_33	12	DS_XS_01	3.11	1.01	-67.35

Culvert Name	Schematic reference Node	Location	Baseline Model (m/s)	Proposed Model (m/s)	Difference in velocity (%)
A83_33	13	DS_XS_02	3.17	1.02	-67.89
A83_34	1	US1	1.28	1.28	-0.00
A83_34	2	US2	2.82	2.82	0.00
A83_34	3	US3	2.49	2.49	-0.00
A83_34	4	US4	2.56	2.56	0.00
A83_34	5	US5	2.70	2.70	0.01
A83_34	6	US6	2.01	2.01	-0.02
A83_34	7	US7	2.27	2.27	0.01
A83_34	8	US8	1.74	1.74	0.02
A83_34	9	US9	1.61	1.84	14.47
A83_34	10	US10	0.30	0.69	127.25
A83_34	11	CUL1	2.94	2.42	-17.67
A83_34	12	CUL2	4.42	2.39	-45.95
A83_34	13	DS_XS_01	2.32	2.32	0.00
A83_34	14	DS_XS_02	1.40	1.40	0.00
A83_34	15	DS_XS_03	1.36	1.36	0.00
A83_35	1	US_xs_18	2.09	2.09	0.00
A83_35	2	US_xs_17	2.20	2.20	0.00
A83_35	3	US_xs_16	1.68	1.68	0.00
A83_35	4	US_xs_15	2.06	2.06	0.00
A83_35	5	US_xs_14	3.22	3.22	0.00
A83_35	6	US_xs_13	2.38	2.38	0.00
A83_35	7	US_xs_12	1.99	1.99	0.00
A83_35	8	US_xs_11	1.73	1.73	0.00
A83_35	9	US_xs_10	1.32	1.32	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (m/s)	Proposed Model (m/s)	Difference in velocity (%)
A83_35	10	US_xs_1s	0.29	0.29	0.00
A83_35	11	US_xs_9	2.08	2.08	0.00
A83_35	12	US_xs_8	1.66	1.66	0.00
A83_35	13	US_xs_7	1.75	1.75	0.00
A83_35	14	US_xs_6	2.16	2.16	0.00
A83_35	15	US_xs_5	2.15	2.15	0.00
A83_35	16	US_xs_4	2.03	2.03	0.00
A83_35	17	US_xs_3	1.81	1.81	0.00
A83_35	18	US_xs_2	0.88	0.88	0.00
A83_35	19	US_xs_1n	0.14	0.14	0.00
A83_35	20	US_xs_1	0.43	0.43	0.00
A83_35	21	US_xs_1e	0.45	0.45	0.00
A83_35	22	box_ds	0.38	0.70	86.74
A83_35	23	US_xs_1c	0.30	0.49	62.25
A83_35	24	Cul_in	0.01	0.01	0.00
A83_35	25	Cul_1	2.55	2.08	-18.22
A83_35	26	Cul_2	7.01	3.70	-47.22
A83_35	27	Cul_out	4.76	4.76	0.00
A83_35	28	DS_xs_1	3.84	3.35	-12.72
A83_35	29	DS_xs_2	3.36	3.18	-5.45

Table 19.13C - Comparison of water level (mAOD) for baseline and proposed model of culverts outside DFS

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_31	1	US1	291.69	291.69	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_31	2	US2	278.46	278.46	0.00
A83_31	3	US3	267.30	267.30	0.00
A83_31	4	US4	262.16	262.16	0.00
A83_31	5	US5	256.58	256.58	0.00
A83_31	6	US6	254.08	254.08	0.00
A83_31	7	US7	249.48	249.48	0.00
A83_31	8	US8	244.82	243.52	-1.30
A83_31	9	CUL1	242.03	241.90	-0.13
A83_31	10	CUL2	237.20	235.01	-2.19
A83_31	11	DS_XS_01	235.17	234.30	-0.87
A83_31	12	DS_XS_02	232.90	232.90	0.00
A83_31	13	DS_XS_03	228.67	228.67	0.00
A83_31	14	DS_XS_04	225.76	225.76	0.00
A83_31	15	DS_XS_05	221.92	221.93	0.00
A83_31	16	DS_XS_06	218.07	218.07	0.00
A83_31	17	DS_XS_07	212.51	212.51	0.00
A83_31	18	DS_XS_08	206.66	206.66	0.00
A83_32	1	US1	270.96	270.96	0.00
A83_32	2	US2	269.62	269.62	0.00
A83_32	3	US3	267.82	267.82	0.00
A83_32	4	US4	263.79	263.79	0.00
A83_32	5	US5	258.47	258.47	0.00
A83_32	6	US6	255.80	255.80	0.00
A83_32	7	US7	252.77	252.75	-0.02
A83_32	8	US8	250.54	249.49	-1.06

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_32	9	CAS1	250.54	247.10	-3.44
A83_32	10	CUL1	248.93	247.01	-1.92
A83_32	11	CUL2	247.40	247.09	-0.30
A83_32	12	OUTLET	247.40	245.30	-2.10
A83_32	13	DS_XS_01	247.40	245.30	-2.10
A83_32	14	DS_XS_02	241.16	241.16	0.00
A83_32	15	DS_XS_03	237.36	237.36	0.00
A83_32	16	DS_XS_04	234.11	234.11	0.00
A83_32	17	DS_XS_05	231.49	231.49	0.00
A83_32	18	DS_XS_06	228.25	228.25	0.00
A83_32	19	DS_XS_07	221.53	221.53	0.00
A83_33	1	US1	283.07	283.07	0.00
A83_33	2	US2	279.94	279.94	0.00
A83_33	3	US3	275.49	275.49	0.00
A83_33	4	US4	270.45	270.45	0.00
A83_33	5	US5	266.04	266.04	0.00
A83_33	6	US6	261.66	261.66	0.00
A83_33	7	US7	259.74	258.88	-0.85
A83_33	8	INLET	259.74	258.88	-0.85
A83_33	9	CUL1	258.73	258.58	-0.15
A83_33	10	CUL2	240.81	240.44	-0.36
A83_33	11	OUTLET	240.32	240.39	0.07
A83_33	12	DS_XS_01	240.32	240.39	0.07
A83_33	13	DS_XS_02	240.13	240.38	0.25
A83_34	1	US1	281.53	281.53	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_34	2	US2	274.43	274.43	0.00
A83_34	3	US3	269.03	269.03	0.00
A83_34	4	US4	266.73	266.73	0.00
A83_34	5	US5	264.58	264.58	0.00
A83_34	6	US6	259.52	259.52	0.00
A83_34	7	US7	258.99	258.99	0.00
A83_34	8	US8	258.39	258.39	0.00
A83_34	9	US9	257.70	257.67	-0.03
A83_34	10	US10	257.70	257.44	-0.26
A83_34	11	CUL1	257.05	255.67	-1.38
A83_34	12	CUL2	254.27	254.27	0.00
A83_34	13	DS_XS_01	254.27	254.27	0.00
A83_34	14	DS_XS_02	251.65	251.65	0.00
A83_34	15	DS_XS_03	250.26	250.26	0.00
A83_35	1	US_xs_18	290.66	290.66	0.00
A83_35	2	US_xs_17	277.80	277.80	0.00
A83_35	3	US_xs_16	273.44	273.44	0.00
A83_35	4	US_xs_15	270.75	270.75	0.00
A83_35	5	US_xs_14	267.28	267.28	0.00
A83_35	6	US_xs_13	262.77	262.77	0.00
A83_35	7	US_xs_12	258.67	258.67	0.00
A83_35	8	US_xs_11	256.17	256.17	0.00
A83_35	9	US_xs_10	253.51	253.51	0.00
A83_35	10	US_xs_1s	253.40	253.40	0.00
A83_35	11	US_xs_9	275.78	275.78	0.00

Culvert Name	Schematic reference Node	Location	Baseline Model (mAOD)	Proposed Model (mAOD)	Difference in water level (m)
A83_35	12	US_xs_8	272.37	272.37	0.00
A83_35	13	US_xs_7	269.08	269.08	0.00
A83_35	14	US_xs_6	265.34	265.34	0.00
A83_35	15	US_xs_5	261.87	261.87	0.00
A83_35	16	US_xs_4	258.11	258.11	0.00
A83_35	17	US_xs_3	257.03	257.03	0.00
A83_35	18	US_xs_2	254.15	254.15	0.00
A83_35	19	US_xs_1n	253.40	253.40	0.00
A83_35	20	US_xs_1	253.40	253.40	0.00
A83_35	21	US_xs_1e	253.40	253.40	0.00
A83_35	22	box_ds	252.72	251.75	-0.97
A83_35	23	US_xs_1c	252.72	251.76	-0.97
A83_35	24	Cul_in	252.72	251.76	-0.97
A83_35	25	Cul_1	252.23	251.44	-0.79
A83_35	26	Cul_2	250.93	250.25	-0.67
A83_35	27	Cul_out	250.93	250.25	-0.67
A83_35	28	DS_xs_1	250.93	250.25	-0.67
A83_35	29	DS_xs_2	246.51	246.51	0.00

Modelling Assumptions and Limitations

A19-1.11.155. The key modelling assumptions introduced as part of this study and of key relevance are outlined below:

- The cross-sections have been generated based on DSM data. The existing culvert size, inverts and length have been taken from Jacob’s report (Baseline Flood Study Report Appendix E: Baseline Culvert Hydraulic Assessment, Jacobs/AECOM), 2022.
- Modelling has been carried out based on the information given on the typical culvert plan and cross-sections: (A83AAB-AWJ-SBR-SCW_C01_M01-SK-CB-000001) and proposed cross-section profile (A83AAB-AWJ-HML-

LTS_POC_M01-M2-CH-000003) of the catchpit/roads downloaded in October 2023, which presents proposed cross-sections of catchpit in every 10m intervals. The model inverts are based on the proposed elevation of the catchpit nearest to the culvert (at nearest 10m chainage). The current updated cross-section profile (May 2024) shows slight changes in the elevation compared to October 2023 profile. The changes ranges from 0.05 to 0.12m depending upon locations of the culverts. We have not updated the model elevations based on the May 2024 updated cross-section profiles yet. It is assumed that the changes will not differ the overall conclusion in terms of velocity in the existing downstream channels.

- The reach between the end of the proposed open channel (d/s of the proposed culvert) and start of the existing watercourse has been assumed as an open channel. However, shape and size of this channel has not been defined in the model.
- Where the location of existing channel matches with the end of the proposed open channel and if the bed elevation of the existing channel is higher than the invert of the proposed open channel. Then, that cross-section has been excluded from the model.

B828 Culverts

A19-1.11.156. In addition to the A83 and RaBT car park upgrades, there is a plan to construct approximately 550m of active travel corridor to the southern edge of the B828 travelling southwest from the car park. Along this route there are 3 culverts located in Plate 19.4C. These culverts are all to be extended as part of the upgrade.

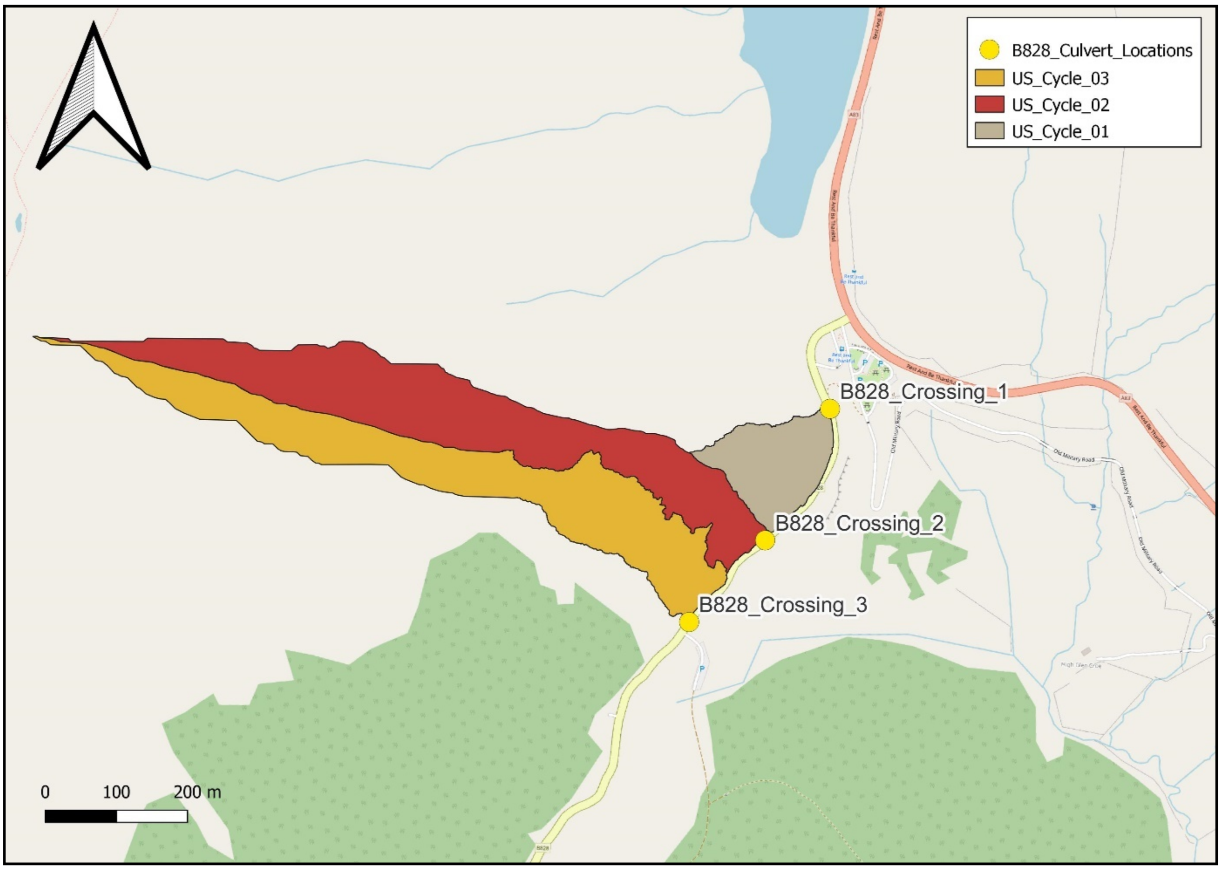


Plate 19.4C B828 culverts and hydrological catchments

A19-1.11.157. These 3 culverts were not picked up as part of a culvert specific survey but were partially captured in a survey of the road. As such, not all the culvert parameters were recorded and detailed cross sections upstream and downstream of the structures were not available. Details of the survey can be seen in Table 19.13D.

Table 19.13D – B828 culvert survey

ID	Diameter (m)	Invert Level (mAOD)
Upstream Culvert 01	0.5	271.617
Downstream Culvert 01	Not Surveyed	Not Surveyed
Upstream Culvert 02	0.3	288.037
Downstream Culvert 02	0.3	287.428
Upstream Culvert 03	0.65	282.768

Downstream Culvert 03	0.65	282.358

A19-1.11.158. 1D steady state model were built in Flood Modeller Pro, and cross sections were extracted from the project 0.25m LiDAR dataset for culverts 1 and 2 however culvert 3 was not covered so cross sections were assumed.

A19-1.11.159. An initial capacity check was carried out on these three culverts which suggested that culverts 1 and 3 had capacity of more than the 0.5%AEP event but culvert 2 has a capacity of less than the 50%AEP event. Results of this capacity check can be seen below in table 19.13E.

Table 19.13E – Results of the 1D culvert capacity check for B828 culverts 1,2 and 3.

ID	Dia (m)	0.5%AEP+CC flow (Cumecs)	Culvert capacity (Cumecs)	Max capacity event (AEP)
Culvert 1	0.5	0.33	0.29	>0.5%
Culvert 2	0.3	1.26	0.17	<50%
Culvert 3	0.65	1.12	0.82	>0.5%

A19-1.11.160. During a site visit in May 2024, a fourth culvert was identified that sits between culverts 2 and 3 however no information is currently available for this structure. It is believed that this structure may assist in draining the catchment that is associated with culvert 2, and this may be why the modelling results show culvert 2 has such a small capacity.

A19-1.11.161. Due to the lack of confidence in the current data, culvert sizing has not been carried out for these culverts. It is suggested that further investigations and additional topographical survey is carried out on these culverts, and the sizing of these culverts is picked up during detailed design.

Small Watercourses Addendum

The schematic of A83 culvert model extent and cross-section locations

Plate SMA1 - A83 culvert model extent and cross-section location 1

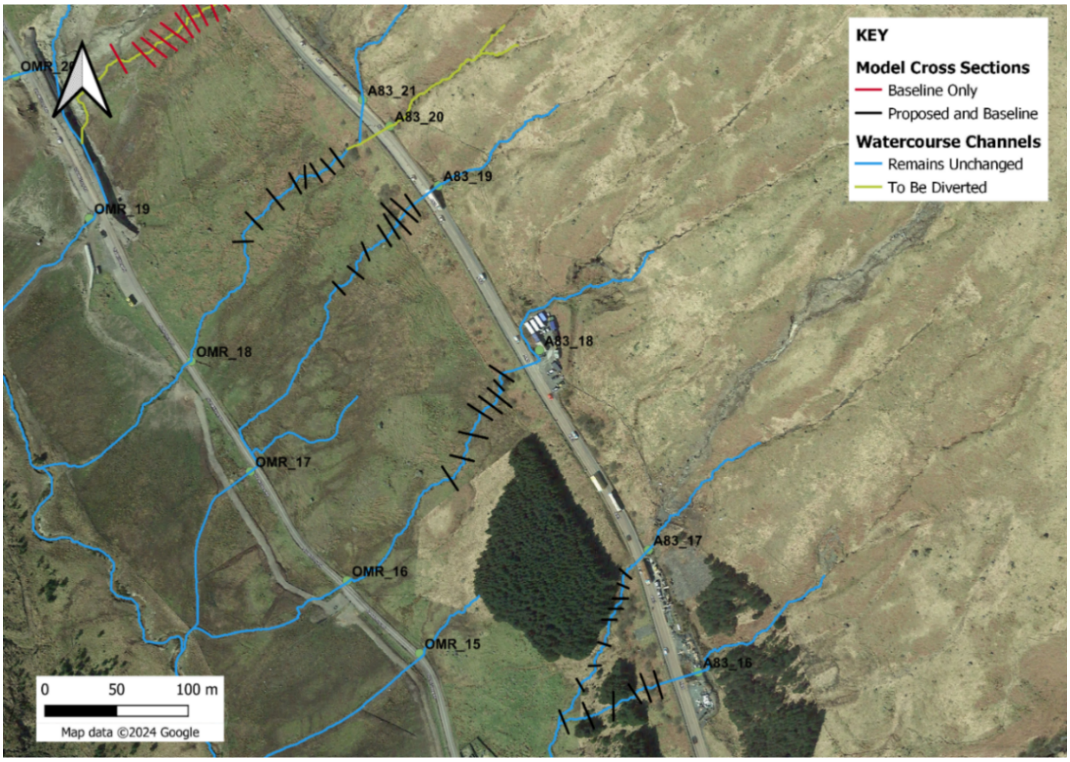


Plate SMA2 - A83 culvert model extent and cross-section location 2

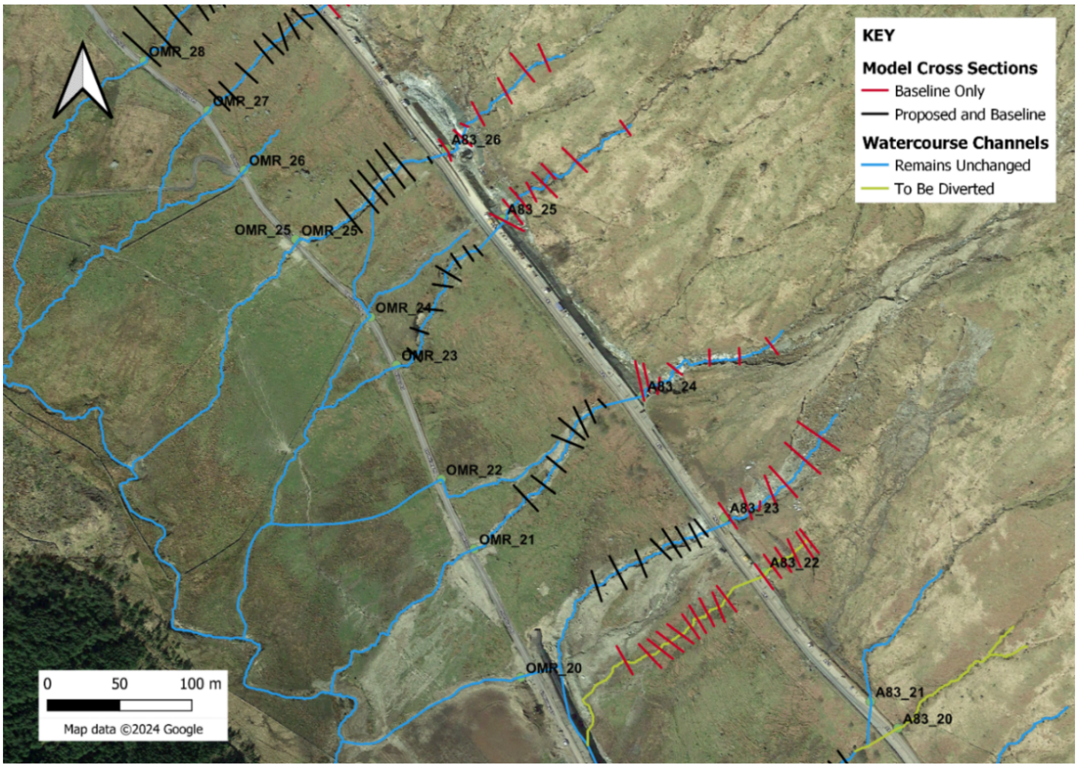


Plate SMA3 - A83 culvert model extent and cross-section location 3

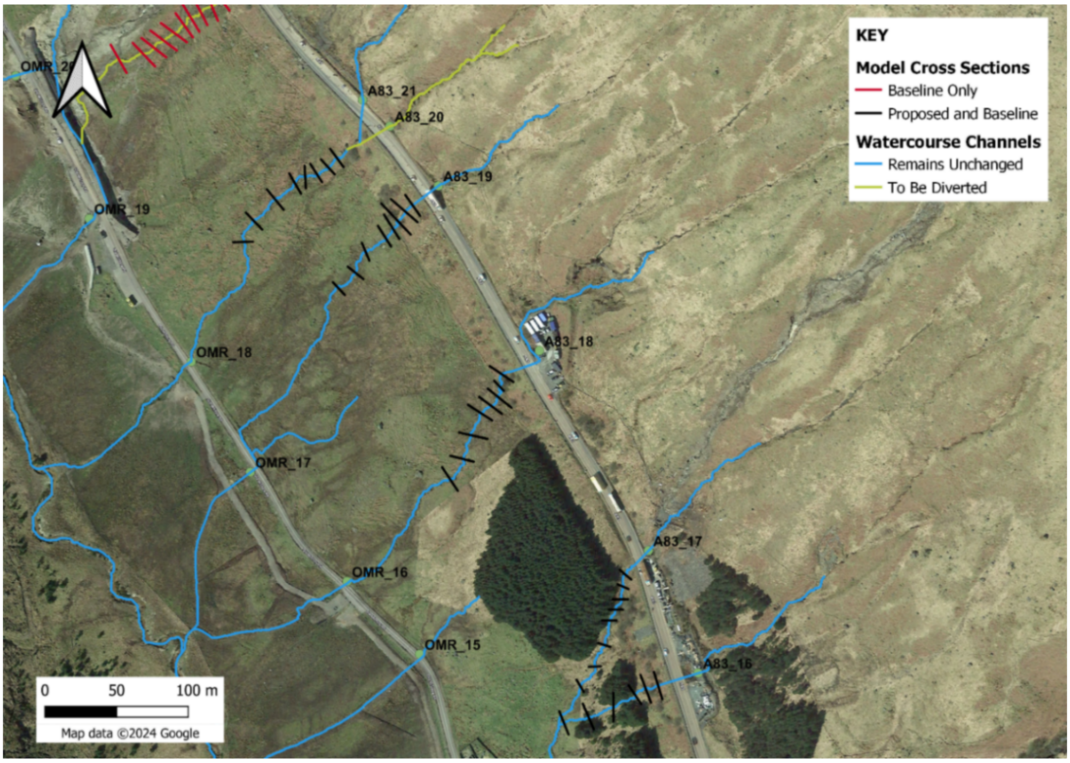


Plate SMA4 - A83 culvert model extent and cross-section location 4

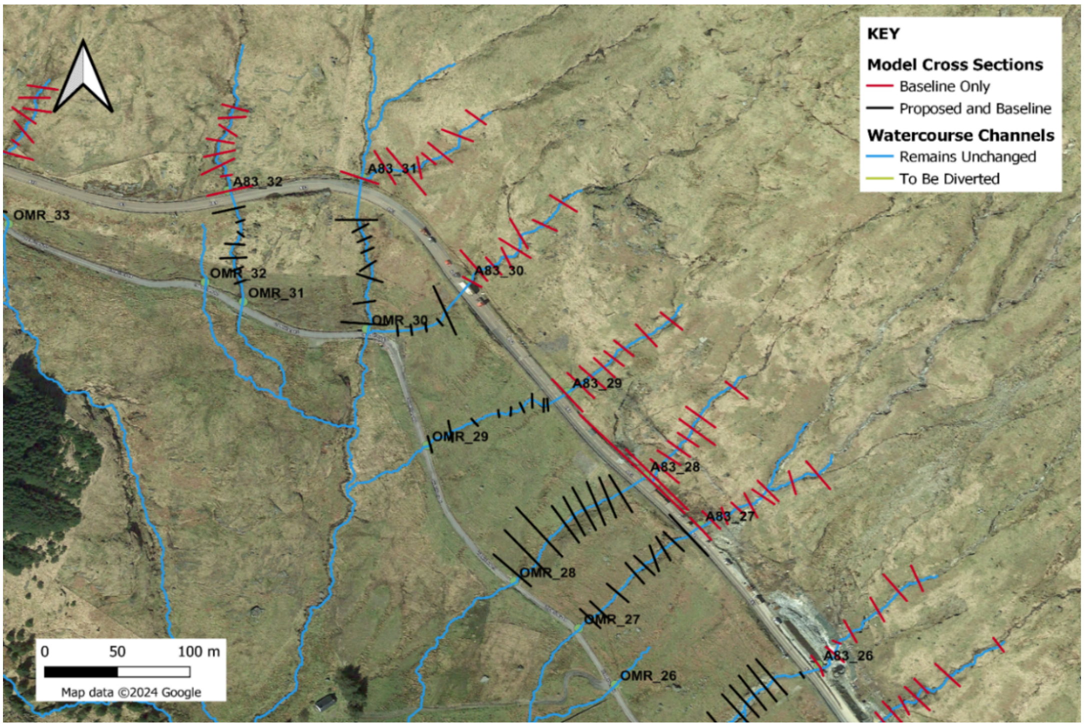
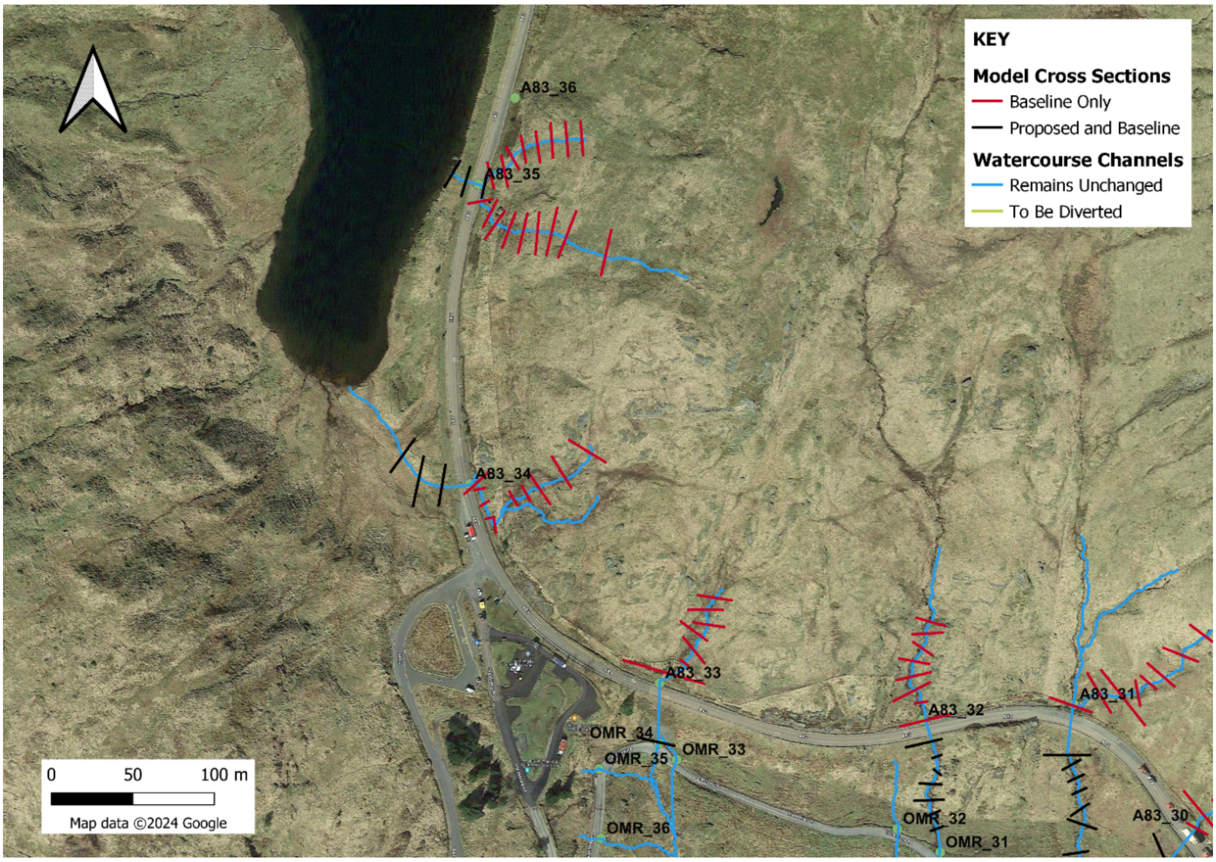


Plate SMA5 - A83 culvert model extent and cross-section location 5



Annex D - Croe Water

Introduction

A19-1.11.162. The Atkins WSP Joint Venture (AWJV) was appointed by Transport Scotland to undertake a DMRB Stage 3 Assessment for the upgrade of the A83 Trunk Road between Ardgartan and the Rest and Be Thankful car park. This included a preliminary Flood Risk Assessment (FRA) of the Proposed Scheme Options for the upgrade of the A83. The preliminary assessment included a review of all available data, identified potential sources of flooding and Croe valley receptors, and presented an assessment of the flood risk associated with the route alignment options considered at DMRB Stage 2. The preliminary assessment identified the primary source of flooding to the Proposed Scheme as being fluvial.

A19-1.11.163. The study area for the FRA presents challenging conditions to quantify baseline and proposed flood risk. Therefore, a pragmatic approach has been taken to understand the various mechanisms of flood risk and thus potential impact of the Proposed Scheme.

A19-1.11.164. This technical note focuses on the fluvial flood risk from the Glen Croe Valley and the potential impacts from the Proposed Scheme. It should detail the modelling approach, the key assumptions, with the main objective this study was to understand the existing flood risk within the Croe valley and assess the potential impact of the Proposed Scheme on the baseline flood risk.

A19-1.11.165. This document provides the detailed modelling and assessment of fluvial flooding within Glen Croe valley to inform the detailed alignment design and flood mitigation measures referred to in the DMRB Stage 3 Environmental Statement.

A19-1.11.166. This appendix supports the LTS EIAR VOLUME 4, APPENDIX 19.6 - FLOOD RISK ASSESSMENT.

Study Area

A19-1.11.167. The study area extents from North of the Croe Water at Cobbler Bridge to the junction of B828 Glen Mhor at Loch Restil with 19 sensitive receptors being identified within the Croe Valley. These are shown in Plate below and described in Table 19.1D.

Plate 19.1D – Glen Croe Valley Sensitive Receptors

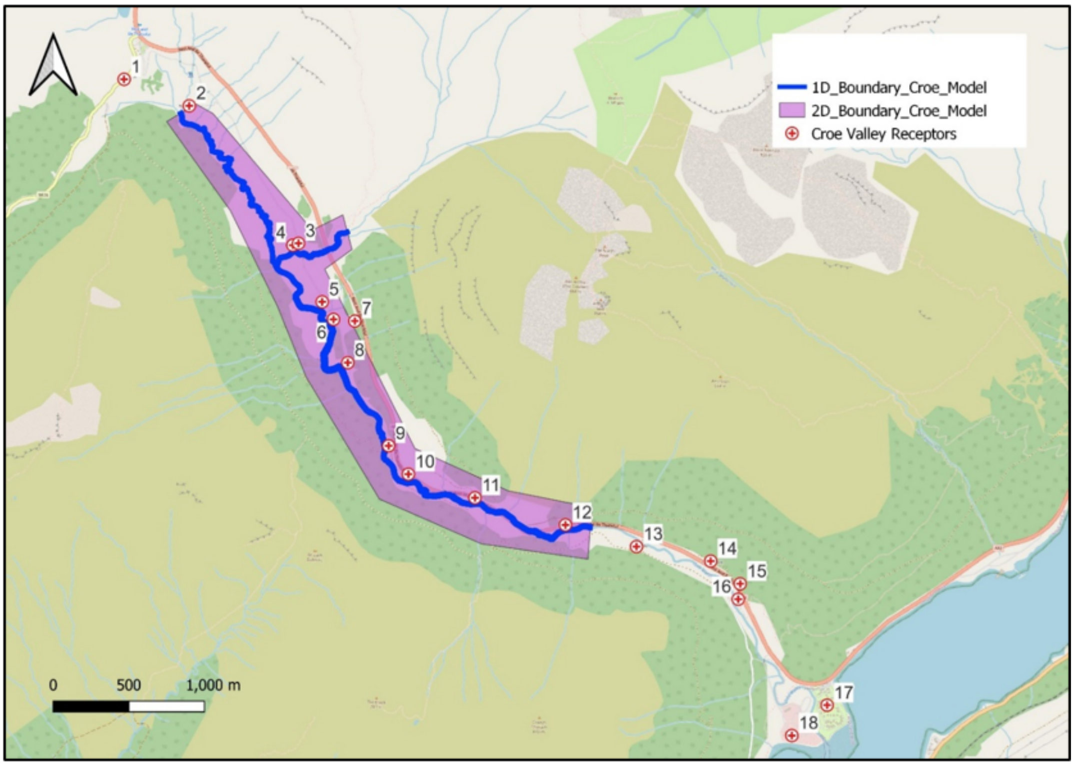


Table 19.1D- Glen Croe Valley Sensitive Receptors Description

Receptor ID	Grid Reference	Receptor Descriptor	Importance (DMRB/SEPA)
1	NN 22947 07210	B828 Road	Medium / Least Vulnerable Use
2	NN 23328 06978	Residential dwelling	High/ Highly Vulnerable Uses
3	NN 24056 06056	OMR Location 1	High / Highly Vulnerable Uses (given its diversion status)
4	NN 24013 06056	Structure used for agricultural purposes	Medium / Least Vulnerable Use
5	NN 24207 05681	Structure used for agricultural purposes	Medium / Least Vulnerable Use
6	NN 24282 05565	Structure used for agricultural purposes	Medium / Least Vulnerable Use

Receptor ID	Grid Reference	Receptor Descriptor	Importance (DMRB/SEPA)
7	NN 24423 05554	Residential dwelling	High / Highly Vulnerable Uses
8	NN 24380 05282	OMR Location 2	High / Highly Vulnerable Uses (given its diversion status)
9	NN 24645 04731	OMR Location 3	High / Highly Vulnerable Uses (given its diversion status)
10	NN 24776 04540	A83 Location 1	High / Highly Vulnerable Uses
11	NN 25218 04386	A83 Location 2	High / Highly Vulnerable Uses
12	NN 25817 04200	A83 Location 3	High / Highly Vulnerable Uses
13	NN 26286 04062	Residential dwelling	High / Highly Vulnerable Uses
14	NN 26777 03966	Residential dwelling	Medium/ Least Vulnerable Uses (appears to be uninhabited from DTS)
15	NN 26972 03816	Residential dwelling	High / Highly Vulnerable Uses
16	NN 26959 03714	Dwelling (cabin/visitor centre)	High / Highly Vulnerable Uses
17	NN 27547 03013	Caravan Holiday Park – Forest Holidays Ardgartan	Very High / Most Vulnerable Uses
18	NN 27314 02812	Ardgartan Hotel	High / Highly Vulnerable Uses
19	BT Underground Lines	Underground Lines following OMR & A83(T)	Very High / Essential Infrastructure

Proposed Scheme – Summary

A19-1.11.168. 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 the Croe Valley; consisting of works to approximately 2.4km of the A83. It would also include upgrading works to existing infrastructure, including the RaBT car park, B828 junction, watercourse crossings and drainage infrastructure.

A19-1.11.169. A more detailed description of the Proposed Scheme design and construction methodology can be found in Volume 2, Chapter 4: The Proposed Scheme of the Environmental Impact Assessment (EIA).

Data Available

A19-1.11.170. As part of this study the following data was made available:

- Jacobs Stage 2 DMRB Baseline Flood Study Report Appendix C: Glen Croe Hydraulic Modelling Report:
- Jacobs Stage 2 DMRB Baseline 1D/2D Hydraulic Model for the Croe Valley
- Furgro, 2021, LiDAR Data – 0.2m LiDAR
- Jacobs Sitey Survey, 2021, Channel Survey Croe Water Upstream
- Jacobs Site Survey 2019, Channel Survey Croe Water Downstream

A19-1.11.171. This information has been reviewed and utilised to undertake the baseline assessment for the study area.

Hydrology

A19-1.11.172. The AMJV undertook a review of the hydrology, undertaken in 2022 and detailed in the Jacobs Appendix C: Glen Croe Hydraulic modelling report. The report details that both peak flows and inflow hydrographs were calculated for 4 locations using the Revitalised Flood Hydrograph rainfall-runoff method version 2 (ReFH2.3). The AMJV undertook minor adjustments to the catchment delineation to reflect the change in study area. Hydrographs have been calculated by the AMJV for the 50% AEP (2-year), 3.33% AEP (30-year), 1% AEP (100-year), 0.5% AEP (200-year) and 0.5% AEP +CC 46% (200-year) plus climate change (CC) events, using the Revitalised Flood Hydrograph rainfall-runoff method version 2 (ReFH2.33). Annex B provides further detail of the hydrology.

A19-1.11.173. The Proposed Scheme is located on the eastern side of the Croe valley and will impact flows from the catchment RES01. For the assessment of The Proposed Scheme hydrological catchment RES01 was split into RES01-W and RES01-E. RES01-W accounted for 41% and RES01-E accounted for 59% of the original area RES01. Any variation to flows to test the potential impact of the Proposed Scheme on the flood risk in the valley have been applied to RES01-E only.

A19-1.11.174. The peak flows for the modelled catchment are shown in Table 19.2D.

Table 18.2D – Hydrological event peak inflow estimates (m^3/s) and names of inflow locations within the Model.

Inflow location	Catchment area (km2)	50% AEP	3.33 %AEP	1% AEP	0.5% AEP	0.5% AEP +CC 46%
CROE_Inflow	3.38	10.8	21.13	26.01	29.07	44.51
TRIB_inflow	1.17	3.11	6.12	7.54	8.42	13.16
RES_01 (E+W)	2.59	7.14	14.09	17.35	19.43	30.4
RES_01E	1.53	4.21	8.31	10.24	11.47	17.94
RES_01W	1.06	2.93	5.77	7.11	7.96	12.46
RES_02	4.54	12.72	25.05	30.84	34.53	53.86
RES_03	3.07	8.53	16.78	20.67	23.13	36.17

Modelling Approach

A19-1.11.175. Jacobs developed a linked One-Dimensional/Two-Dimensional (1D/2D) model for the Croe Water. Within this model the river channel is represented as a 1D component using Flood Modeller Pro (FM) version 5.1 software and the floodplain is represented using TUFLOW 2020 software version AB.

A19-1.11.176. The linked 1D/2D modelling approach means that the model dynamically transfers water between the watercourses and the floodplain. The flow exchange at the link in this approach is controlled by the bank crest levels, which were informed by topographical survey and a Digital Terrain Model (DTM).

A19-1.11.177. The model covers a 4.2km long reach of the Croe Water as well as a 1.7km long reach of a tributary called High Glen Croe. The upstream extent of the Croe Water is approximately 219m upstream of the A83 Trunk Road crossing (NN 24374 06143), whilst the upstream extent of High Glen Croe tributary is 1.7km upstream of its confluence with the Croe Water (NN 23271 06930). The downstream extent of the model is approximately 415m downstream from the second A83 Trunk Road crossing of the Croe Water (A83 Bridge 40 (Little rest)), near Creagdhu (NN 25981, 04191).

A19-1.11.178. The model consists of 69 cross section and 5 hydraulic structures, which are detailed in Table 19.3D. The model extents are shown in Plate 19.7 and Plate

19.8. Table 19.4D details the channel roughness values applied to the river cross sections and 19.4D details the floodplain roughness which are defined using Manning's 'n' coefficient in the model. These are unchanged from those applied in the original model.

Table 19.3D –In-channel hydraulic structures (represented in Flood Modeller)

S. No.	Watercourse	Structure	Flood Modeller Node	Specification	Specification
1	Croe Water	Footbridge	CROE_3639b	Type	Arch bridge
1	Croe Water	Footbridge	CROE_3639b	Bed Level	165.28 mAOD
1	Croe Water	Footbridge	CROE_3639b	Width	7.45 m
1	Croe Water	Footbridge	CROE_3639b	Springing level	168.28 mAOD
1	Croe Water	Footbridge	CROE_3639b	Crown level	168.28 mAOD
2	Croe Water	Old Military Road crossing	CROE_3374b	Type	Rectangular Orifice
2	Croe Water	Old Military Road crossing	CROE_3374b	Invert level	125.05 mAOD
2	Croe Water	Old Military Road crossing	CROE_3374b	Throat soffit level	126.55 mAOD
3	Croe Water	Bridge crossing for Glen Croe Lower Forestry Track	CROE_1301b	Type	Arch bridge
3	Croe Water	Bridge crossing for Glen Croe Lower Forestry Track	CROE_1301b	Bed Level	89.49 mAOD

S. No.	Watercourse	Structure	Flood Modeller Node	Specification	Specification
3	Croe Water	Bridge crossing for Glen Croe Lower Forestry Track	CROE_1301b	Width	7.77 m
3	Croe Water	Bridge crossing for Glen Croe Lower Forestry Track	CROE_1301b	Springing level	91.39 mAOD
3	Croe Water	Bridge crossing for Glen Croe Lower Forestry Track	CROE_1301b	Crown level	91.39 mAOD
4	Croe Water	A83 Bridge 50	CROE_0335b	Type	Arch bridge
4	Croe Water	A83 Bridge 50	CROE_0335b	Bed Level	80.34 mAOD
4	Croe Water	A83 Bridge 50	CROE_0335b	Width arch 1	6.30 m
4	Croe Water	A83 Bridge 50	CROE_0335b	Springing level arch 1	83.17 mAOD
4	Croe Water	A83 Bridge 50	CROE_0335b	Crown level arch 1	83.31 mAOD
4	Croe Water	A83 Bridge 50	CROE_0335b	Width arch 2	5.96 m
4	Croe Water	A83 Bridge 50	CROE_0335b	Springing level arch 2	83.13 mAOD
4	Croe Water	A83 Bridge 50	CROE_0335b	Crown level arch 2	83.26 mAOD
5	Croe Water	A83 Bridge 40 (Little Rest)	CROE_0034b	Type	Arch bridge
5	Croe Water	A83 Bridge 40 (Little Rest)	CROE_0034b	Bed Level	59.47 mAOD

S. No.	Watercourse	Structure	Flood Modeller Node	Specification	Specification
5	Croe Water	A83 Bridge 40 (Little Rest)	CROE_0034b	Width	13.16 m
5	Croe Water	A83 Bridge 40 (Little Rest)	CROE_0034b	Springing level	66.18 mAOD
5	Croe Water	A83 Bridge 40 (Little Rest)	CROE_0034b	Crown level	66.37 mAOD

Table 19.4D - In-channel Manning's 'n' Roughness Values

Watercourse	Bed Manning's 'n'	Bed Material	Bank Manning's 'n'	Bank Material
High Glen Croe	0.045	Clean, winding, with some weeds and stones	0.050	Same as bed with more stones
Croe Water	0.035-0.06	Clean, straight, full stage, weedy and more stone	0.05-0.08	Same as bed with more stones

Table 19.5D – 2D Floodplain Manning's 'n' Roughness Values

Land Cover	Manning's 'n' roughness
General Surface	0.055
Inland Water	0.02
Landform	0.05
Thick Vegetation/Trees	0.1
Road or Track	0.025
Roadside	0.025

A19-1.11.179. The AMJV reviewed the Jacobs model for Glen Croe and determined that no changes were required to the model hydraulics or extents. The only adjustments made to the model were to inflow hydrographs at RES01 to reflect the contributions of flow from the east and west.

A19-1.11.180. Full details of the baseline modelling of the Glen Croe can be found in Jacobs Stage 2 DMRB Baseline Flood Study Report Appendix C: Glen Croe Hydraulic Modelling Report.

Plate 19.7D - Model Extent and Survey Cross Sections.

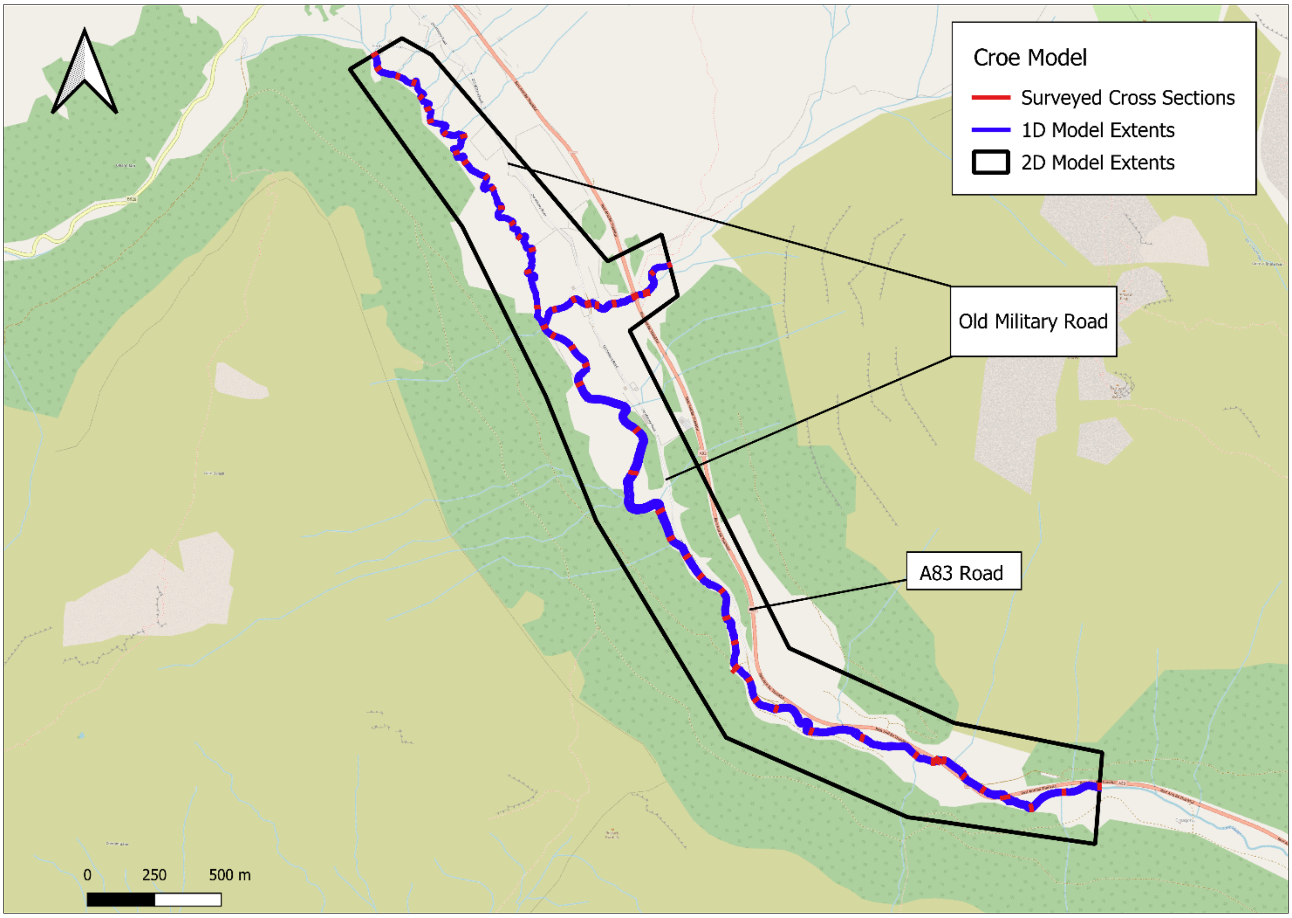
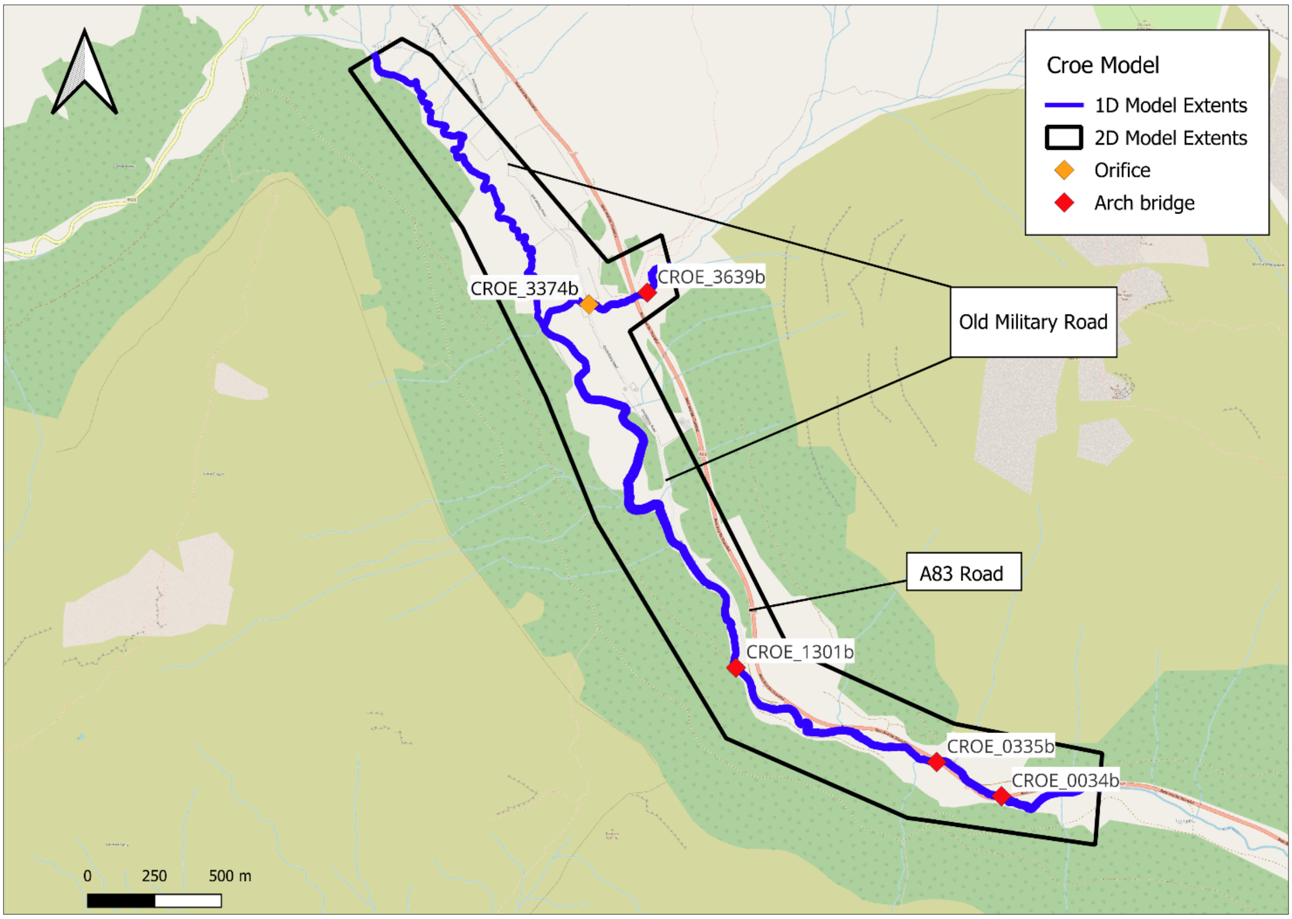


Plate 19.8D - Model Extents and 1- D structure locations



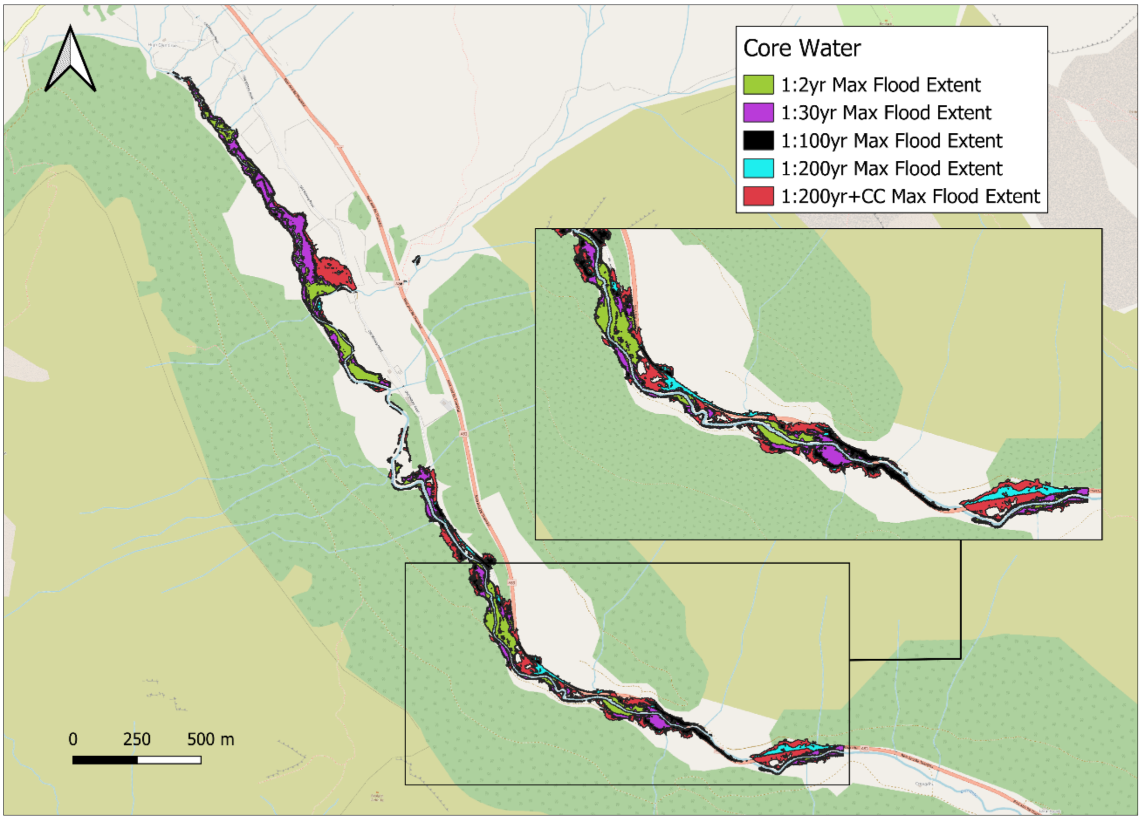
Baseline Model Results

A19-1.11.181. To assess the fluvial flood risk in the Glen Croe area, a set of simulations were conducted with the following return periods: 50% AEP,3.33% AEP, 1% AEP,0.5% AEP and 0.5% AEP plus climate change (CC) events

A19-1.11.182. Maximum flood extents for all the abovementioned events are presented in Plate 19.9D. Flood extents along the majority of the upper half of the Croe Water and its tributary (High Glen Croe) are confined close to the banks. There is one exception to this close to the confluence of the tributary where a large area of floodplain is evident for the 0.5%AEP+CC event, This occurs as the Old Military Road (OMR) Bridge that crosses the Croe Water becomes surcharged and spills onto the floodplain upstream of the structure via the right bank, flowing north before entering the High Glen Croe Tributary.

A19-1.11.183. In the lower third of the model the floodplain intersects with the OMR and A83 at multiple locations, with the A83 experiencing flooding for the 1% AEP event and above whereas OMR floods in event 50% AEP and above.

Plate 19.9D Flood Extents for All the Baseline Simulated Flood Events



A19-1.11.184. The flood extents for the 3.33%AEP event are shown in 19.10D have greater depths in the lower half of the model due to the lower gradient and velocities, enabling the flow to pond, the watercourse is also more channelised in the lower portion of the model.

A19-1.11.185. The water depths for the 0.5%AEP + CC event, shown in Plate 19.1D. are larger than the 3.33%AEP event, however the maximum extents are relatively similar.

Plate 19.10D Maximum Water Depth for the 3.33AEP event (Baseline)

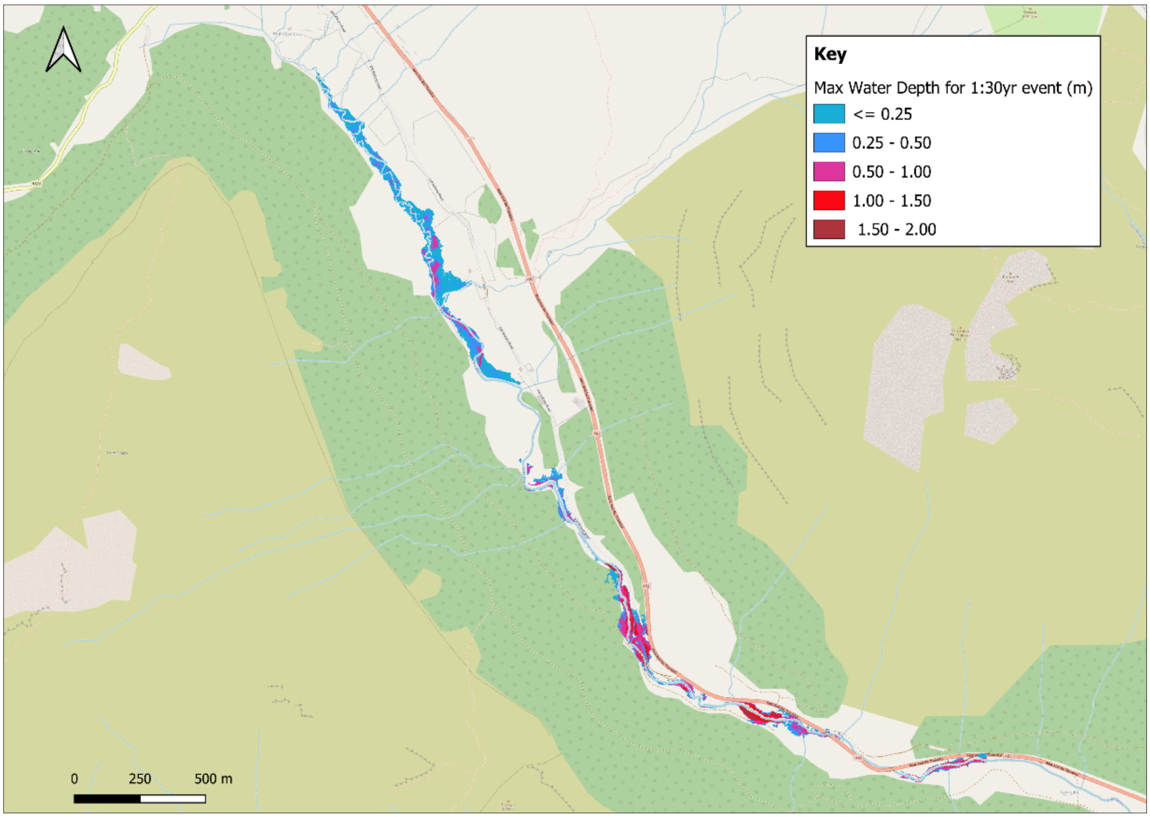
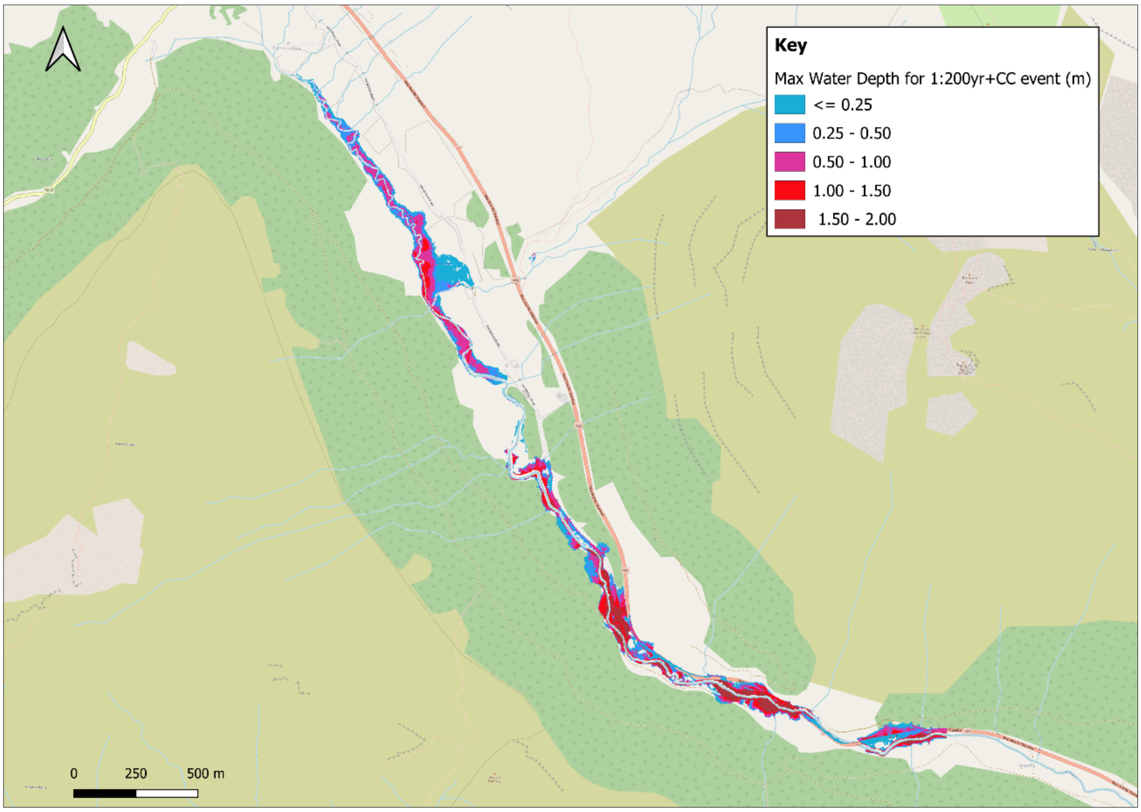


Plate 19.11D Maximum Water Depth for the 0.5% AEP +CC event (Baseline)



The Proposed Scheme – Model Representation

A19-1.11.186. The Proposed Scheme contains approximately 1.4km of Debris Flow Shelter (DFS) and Debris Flow Wall (DFW). These 2 components will have an impact on the existing flow paths on the eastern side of the Croe valley.

A19-1.11.187. In the baseline scenario flows make their way down the hillside in a manner of ways. They can flow freely down watercourses upstream of the A83, through the culvert and then down the watercourse downslope of the A83. They can back up behind undercapacity culverts and spill over the road close to the culvert and continue down the hillside, and during large events, overland flow can spill over the road along the majority of its length and then continue down the hillside.

A19-1.11.188. In the Proposed Scheme, 16 watercourses and any overland flow that is upstream of the 1.4km proposed scheme will spill into the proposed catchpit (designed to “catch” unconsolidated material in the event of a landslide event) and make its way towards a culvert that passes under the A83. All of these flows will be directed into a watercourse downstream of the A83 which leads to the Croe Water after crossing the OMR.

A19-1.11.189. The associated drainage features of the proposed design will remove approximately 1% of the flow, when compared to the baseline scenario, from

RES01-E via the creation of a SUDS pond that will store and attenuate flows for the 0.5%AEP event plus an allowance for climate change.

A19-1.11.190. In the baseline model there is no discrete representation of the A83 trunk road or any of the hydraulic structures on the hillside. Any flows that originate from this hillside are applied directly to 1D cross sections in the Croe Water via a lateral inflow called RES01. This inflow covers a portion of both the eastern and western slopes in the Croe valley.

A19-1.11.191. The proposed model does not have a representation of the A83 or the DFS, DFW or drainage features. To understand the potential impact that the DFS, DFW and drainage features will have on the flood risk in the valley, the following sensitivity analysis was undertaken:

- adjustment to lateral inflow RES01, to allow the assessment of flow on the eastern side of the Croe Valley
- adjustment to lateral inflow RES01E Time to Peak (Tp) and
- adjustment to lateral inflow RES01E peak flow

A19-1.11.192. A total of 14 sensitivity tests have been undertaken to understand what impact flow variations would have to flood risk in the valley.

Inflow Boundary Adjustment

A19-1.11.193. The Proposed Scheme will alter the flow regime into the Glen Croe from lateral inflow RES01. The inflow hydrograph for RES01 accounts for both the eastern and western side of the Croe Valley, as detailed in Annex B. Hydrological catchment RES01 was split into RES01-W and RES01-E (West and East). RES01-W accounted for 41% and RES01-E accounted for 59% of the original area RES01. A visual representation of set up of the baseline and with scheme model, with the split eastern and western catchments, can be seen in 19.12D and 19.13D below.

Plate 19.12D - Baseline model set up showing 1D and 2D boundaries and the Hydrological inflow locations

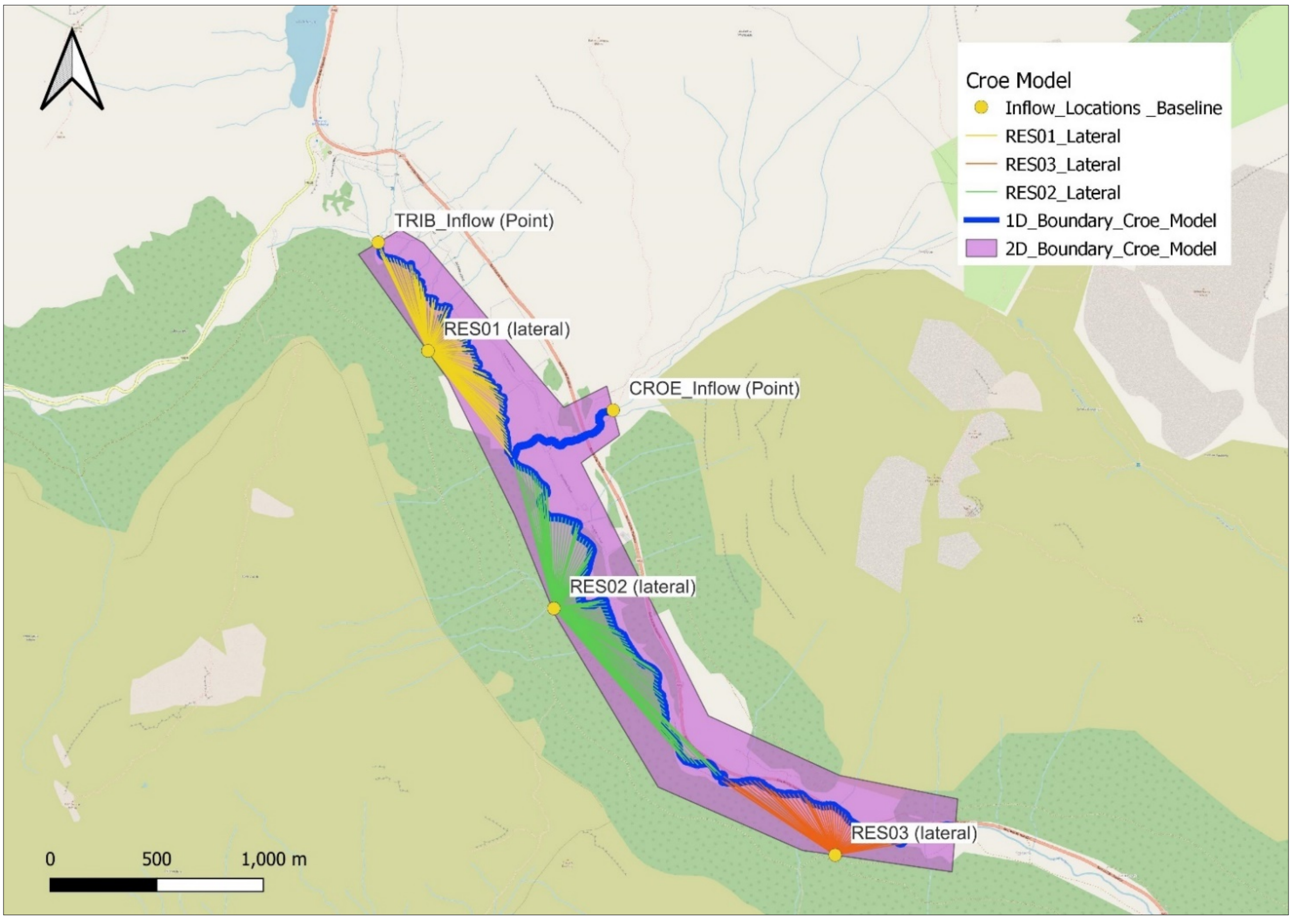
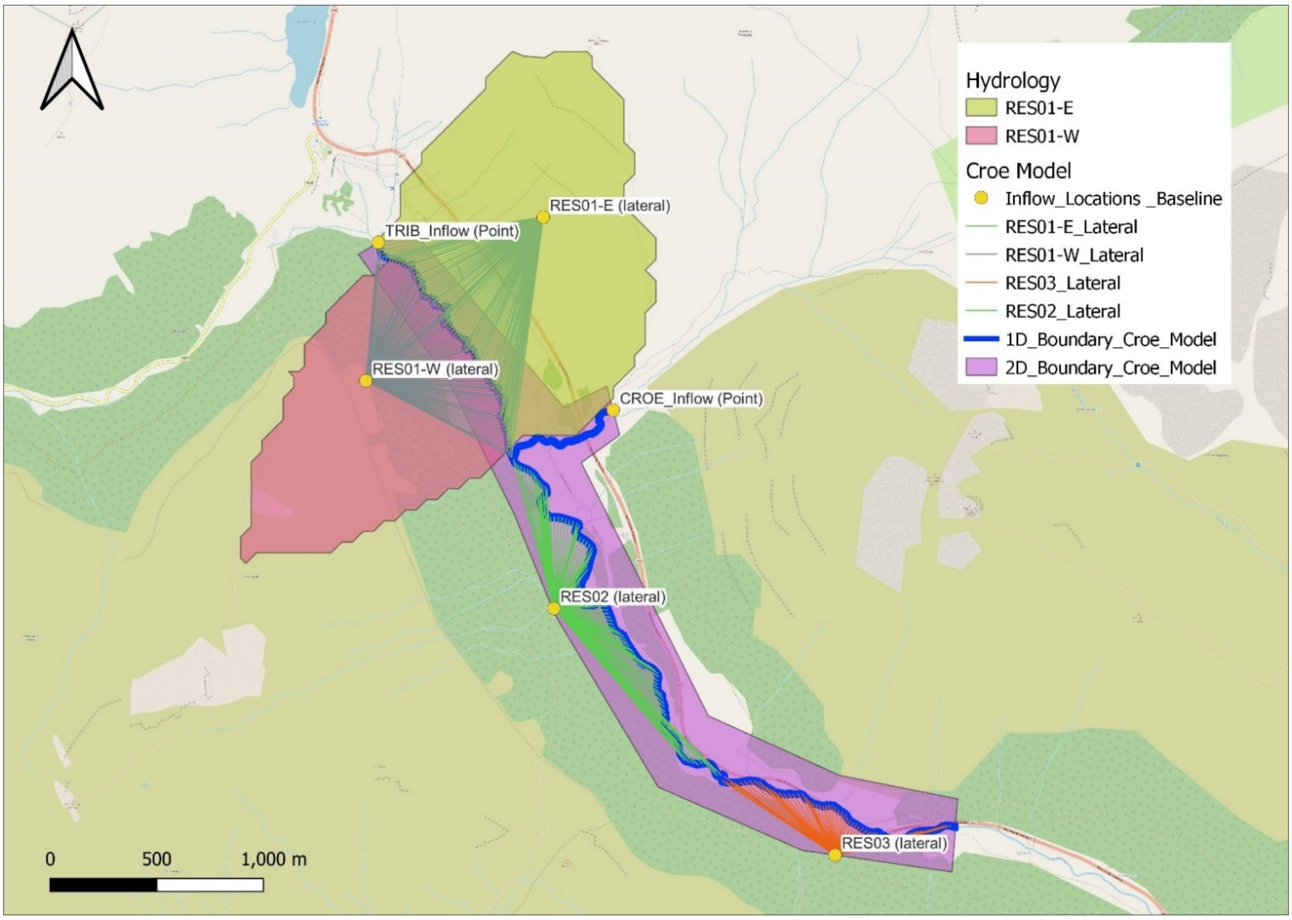


Plate 19.13D - With Scheme model setup, showing the 2 new inflows RES01-E and RES01-W and their hydrological catchments.



Adjustment to lateral inflow RES01E Time to Peak (Tp);

A19-1.11.194. As there will be a multitude of changes to the existing flow paths and flow route timings in the valley, it is difficult to understand what the overall variation in time to peak will be. To test the impact, sensitivity tests were carried out where the timing of the peak of the inflow of RES01-E was edited to be de-synchronised from the other model inflows. The critical storm duration for RES01-E is 3.5hours, and the hydrographs were edited by -1hr. -0.5hr, +0.5hr and +1hr.

Adjustment to lateral inflow RES01E peak flow

A19-1.11.195. There were a range of sensitivity tests set up and ran through the model. These included increasing the flows in the model by +/-5%, +/-10% and +/-20%. These variations in inflow were also combined with a de-synchronisation of the time to peak of RES01-E when compared to the other model inflows.

A19-1.11.196. In the FRA an Upper Credible Range of inflow variation was discussed. After numerous multidisciplinary calls between hydrologists, drainage engineers and the flood risk team to name a few we are confident that +/-5% flow is much more variation than we expect to see in the valley after the construction of the Proposed Scheme with the Proposed Scenario expected to have a reduction in flows due to the attenuation of the drainage features.

A19-1.11.197. A visual representation of the sensitivity tests that have been carried out by varying RES01-E, can be seen below, with the +/-5% sensitivity variation (which the FRA is based upon) shown in Plate 19.14D, and the +/- 5%,10% and 20% variation can be seen in Plate 19.15D.

Plate 19.14D - A visual of the inflow hydrographs used at RES01-E. Above details the original inflow for the 0.5% AEP +CC 46% event for RES01, the E+W split, RES01-E and RES01-W and the sensitivity variations carried out for +/-5% on RES01-E.

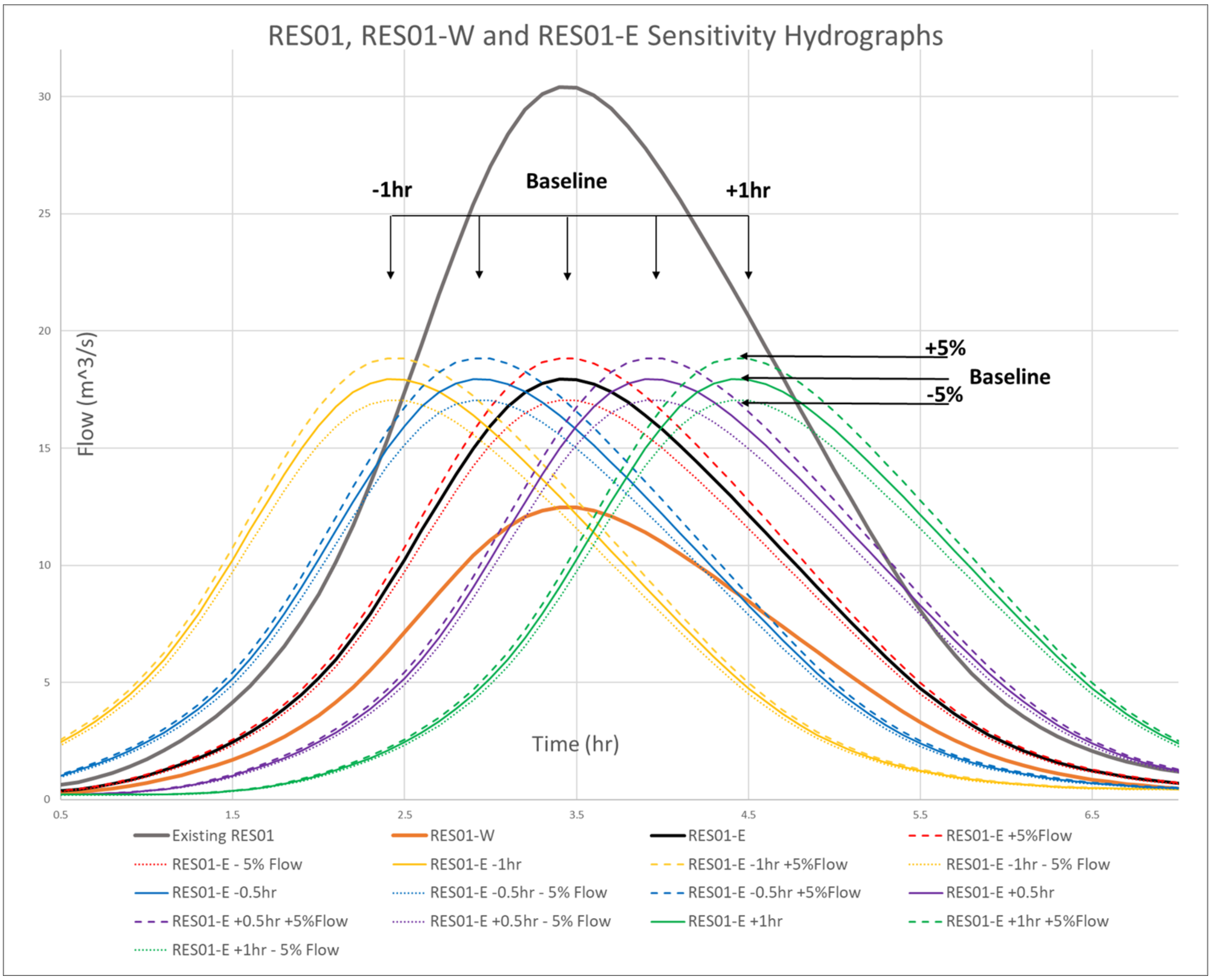
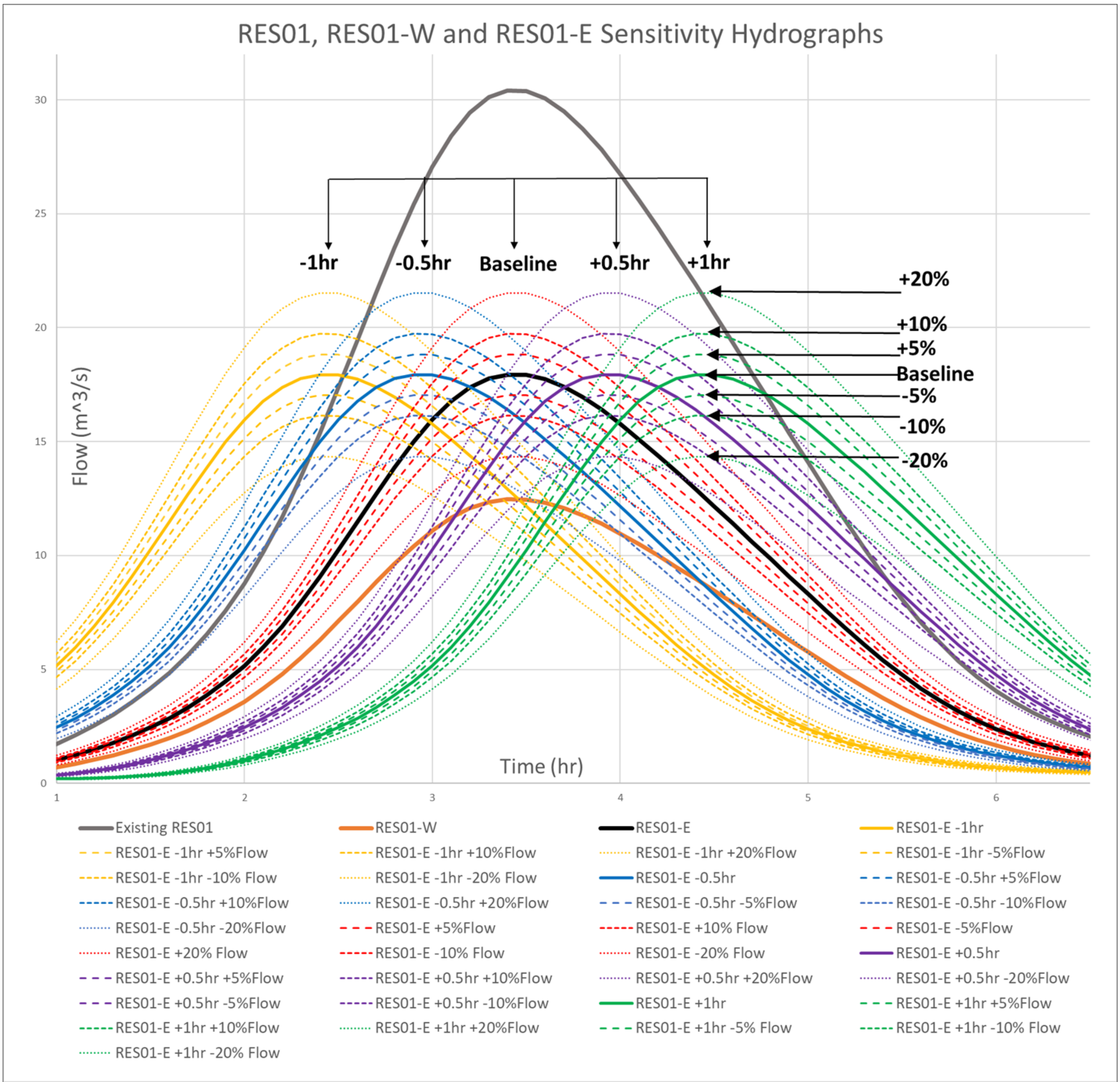


Plate 19.15D - A visual of the sensitivity inflow hydrographs for the 0.5% AEP +CC 46% event RES01-E. Below details the original RES01, the E+W split, RES01-E and RES01-W and the sensitivity variations carried out for +/-5%, 10% and 20% on RES01-E



Scheme Model Results

A19-1.11.198. To assess the potential impact of the proposed scheme to flood risk in the valley, the flood depths across the scheme have been extracted for each of the modelled scenarios at key receptors (as detailed in Section A19-6.7). Flows have also been extracted at the downstream end of the model to understand what impact the potential variations to flow may have on other receptors in the valley that are outside the model extents.

A19-1.11.199. The results of these sensitivity tests showed that the only scenario where there was an increase to flood depths at the Croe valley receptors was where there was no variation in the time to peak and the flow was increased by 5%. For this scenario the max increases there were only +0.01m and all of them were located on the A83 and OMR at locations that already experienced flooding in the baseline scenario. For all the other scenarios where the Timing of the peak or RES01-E was altered and the flow was increased by 5% there was either no change, or a net reduction in flood depths.

+/-5% flow and attenuation from -1hr to +1hr

A19-1.11.200. The sensitivity results for the +/-5% flow and attenuation from -1hr to +1hr can be seen in below in Table 19.6D.

Table 19.6D – Flood depth at the Croe valley receptors for various scenarios (+/-5% flow and attenuation from -1hr to +1hr) 0.5% AEP +CC 46% event

Type or Receptor / Location	Croe valley Receptor Number	Baseline	-1hr	-0.5hr	+0.5hr	+1hr	-1hr +5%	-0.5hr +5%	+5pc	+0.5hr +5%	+1hr+5%	-1hr -5%	-0.5hr -5%	-5pc	+0.5hr - 5%	+1hr-5%
B828	1	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	3	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	4	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential Dwelling`	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	8	0.23	-0.04	-0.01	-0.03	-0.09	-0.04	0.00	0.01	-0.02	-0.08	-0.05	-0.02	-0.01	-0.04	-0.10
OMR	9	0.74	-0.03	-0.01	-0.03	-0.07	-0.03	0.00	0.01	-0.02	-0.07	-0.04	-0.01	-0.01	-0.03	-0.08
A83	10	0.38	-0.01	0.00	-0.01	-0.02	-0.01	0.00	0.00	-0.01	-0.02	-0.01	0.00	0.00	-0.01	-0.03
A83	11	0.53	-0.04	-0.01	-0.04	-0.11	-0.03	0.00	0.01	-0.03	-0.10	-0.05	-0.02	-0.01	-0.05	-0.11
A83	12	0.91	-0.02	0.00	-0.02	-0.05	-0.01	0.00	0.01	-0.01	-0.04	-0.02	0.00	0.00	-0.02	-0.05
Residential dwelling	13	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	14	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	15	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Dwelling (cabin/visitor centre)	16	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Caravan Holiday Park – Forest Holidays Ardgartan	17	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Ardgartan Hotel	18	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain

A19-1.11.201. As can be seen in Table 19.6D, the only scenario where results show a slight increase in max flood depths (+0.01m) when compared to the baseline is when an additional 5% flow is applied to the lateral inflow RES01-E.

A19-1.11.202. The Higher / Lower Credible limit of (+/-5% Flow) has been run through the model and the results show that the receptors in the valley are only very slightly impacted, with max variation recorded as a +0.01m increase in depth for the +5% simulation, and -0.01m for the -5% simulation. Both of these scenarios assume no attenuation has taken place. The table above shows that for all other scenarios where attenuation of the peak is applied, there is a reduction in max depths when compared to these 2 scenarios.

A19-1.11.203. As can be seen in Table 19.6D above, there are some Croe valley receptors that are not included in the model domain. Number 1 is the B828 which runs west from the rest and be thankful carpark. This receptor sits in the Croe valley however, due to its location and elevated position, it is not at risk of flooding from the Proposed Scheme.

A19-1.11.204. Five receptors 13-18 inclusive sit outside of the model domain and are located towards the downstream end of the project extent. To understand the potential flood risk impact to these receptors, peak flows were extracted at the downstream end of the model for 14 scenarios (using +/-5% flow and attenuation from -1hr to +1hr) and compared to the baseline scenario.

Table 19.7D –Flow variation for each scenario compared against baseline 0.5% AEP +CC 46% event, flow extracted at downstream PO line.

	Baseline RES01-E	-1hr	-0.5hr	+0.5hr	+1hr	-1hr - 5%	-0.5hr - 5%	-5pc	+0.5hr -5%	+1hr-5%	-1hr +5%	-0.5hr +5%	+5pc	+0.5hr +5%	+1hr+5%
Peak Flow at DS Section (m^3/s)	154.64	151.31	154.41	151.46	145.65	150.65	153.49	153.97	150.70	145.16	152.02	154.98	155.77	152.21	146.12
Variation from Baseline (m^3/s)	Not applicable	-3.33	-0.23	-3.18	-8.99	-4.0	-1.1	-0.7	-3.9	-9.5	-2.6	0.3	1.1	-2.4	-8.5
Variation from Baseline (%)	Not applicable	-2.2	-0.1	-2.1	-5.8	-2.6	-0.7	-0.4	-2.5	-6.1	-1.7	0.2	0.7	-1.6	-5.5

A19-1.11.205. As can be seen above in 19.7D the sensitivity tests show that for the majority of scenarios there is a reduction in flow at the downstream end of the model. When there is no variation to the model inflow, and the sensitivity is only carried out on the timing of the peak, there is a reduction in flow for all scenarios, ranging from -0.1% to -5.8% (-0.2 m3/s to -9.0 m3/s) of the total baseline inflow.

A19-1.11.206. When the flow is reduced by 5%, as expected the flow seen at the downstream (DS) end of the model also reduces. For this scenario, the removal of 5% of flow from RES_01-E inflow results in a reduction in total flow of -0.4% (-0.7 m3/s). When the reduction in inflow is combined with the variation of the timing of the peak, flow variations are all reduced and range from -0.7% to -6.1% (-1.1 m3/s to -9.5 m3/s) of the total baseline model inflows with the largest variation (-6.1%) for the "+1hr -5%flow" scenario.

A19-1.11.207. When the flow is increased by 5%, as expected the flow seen at the DS end of the model also increases. For this scenario, the addition of 5% of flow from RES_01-E inflow results in an increase in total flow of +0.7% (+1.1 m3/s). When the 5% increase in flow is combined with the variation in the timing of the peak, peak flow increases for the "-0.5hr +5%" scenario only, resulting in an increase of +0.2% (+0.3 m3/s). For all other time to peak variations for the +5% flow scenario there is an overall flow reduction at the downstream end of the model. The maximum reduction is for the "+1hr +5% flow" sees a reduction of -5.5% (-8.5 m3/s).

A19-1.11.208. Out of the 14 scenarios run only 2 scenarios result in an increase in flow at the downstream end of the model. Both of these are when an additional 5% flow has been added to RES01-E and one when the timing of the peak has been reduced by 30 mins. The resultant increase at the downstream end of the mode is +0.7% and +0.2% of total model inflows, (+0.3 m^3/s and +1.1 m^3/s respectively). The other 12 scenarios show an overall reduction in downstream model inflows when compared to the baseline. The reduction ranges from -0.1% to -6.1% (-0.23 m^3/s to -9.5 m^3/s).

+/-10% flow and attenuation from -1hr to +1hr

A19-1.11.209. The sensitivity results for the +/-10% flow and attenuation from -1hr to +1hr can be seen in below in 19.8D.

Table 19.8D – Flood depth at the Croe valley receptors for various scenarios (+/-10% flow and attenuation from -1hr to +1hr) 0.5% AEP +CC 46% event

Type or Receptor / Location	Croe valley Receptor Number	Baseline	-1hr	-0.5hr	+0.5hr	+1hr	-1hr +10%	-0.5hr +10%	+10pc	+0.5hr +10%	+1hr+10%	-1hr -10%	-0.5hr - 10%	-10pc	+0.5hr - 10%	+1hr-10%
B828	1	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	3	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	4	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential Dwelling	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	8	0.23	-0.04	-0.01	-0.03	-0.09	-0.03	0.01	0.02	-0.01	-0.08	-0.06	-0.03	-0.02	-0.04	-0.10
OMR	9	0.74	-0.03	-0.01	-0.03	-0.07	-0.02	0.01	0.01	-0.01	-0.06	-0.04	-0.02	-0.02	-0.04	-0.08
A83	10	0.38	-0.01	0.00	-0.01	-0.02	-0.01	0.00	0.00	0.00	-0.02	-0.01	-0.01	0.00	-0.01	-0.03
A83	11	0.53	-0.04	-0.01	-0.04	-0.11	-0.03	0.02	0.02	-0.02	-0.10	-0.06	-0.03	-0.02	-0.06	-0.12
A83	12	0.91	-0.02	0.00	-0.02	-0.05	-0.01	0.01	0.01	-0.01	-0.04	-0.02	-0.01	-0.01	-0.02	-0.05
Residential dwelling	13	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	14	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	15	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Dwelling (cabin/visitor centre)	16	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Caravan Holiday Park – Forest Holidays Ardgartan	17	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Ardgartan Hotel	18	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain

A19-1.11.210. A variation of +/-10% inflow to RES01-E results in a slight increase in max flood depths (+0.02m) when compared to the baseline.

A19-1.11.211. An increase from the Higher / Lower Credible limit of (+/-5 % Flow) to (+/-10% Flow) has been run through the model to understand the impact of a larger variation. The results show that the receptors in the valley are only very slightly impacted with max variation of +0.02m depth for the +10% sensitivity test, and -0.02m for the -10% scenario. Both of these scenarios assume no attenuation has taken place. The table above shows that for all other scenarios where attenuation of the peak is applied, there is a reduction in max depths when compared to these 2 scenarios.

Table 19.9D – Flow variation for each scenario compared against baseline 0.5% AEP +CC 46% event, flow extracted at downstream PO line.

	Baseline RES01-E	-1hr	-0.5hr	+0.5hr	+1hr	-1hr -10%	-0.5hr -10%	-10pc	+0.5hr -10%	+1hr-10%	-1hr +10%	-0.5hr +10%	+10pc	+0.5hr +10%	+1hr+10%
Peak Flow at DS Section (m^3/s)	154.64	151.31	154.41	151.46	145.65	149.76	152.61	153.22	149.95	144.67	152.72	155.95	156.72	152.96	146.74
Variation from Baseline (m^3/s)	Not applicable	-3.33	-0.23	-3.18	-8.99	-4.88	-2.03	-1.4	-4.69	-9.97	-1.92	1.31	2.1	-1.67	-7.90
Variation from Baseline (%)	Not applicable	-2.2	-0.1	-2.1	-5.8	-3.16	-1.31	-0.9	-3.03	-6.44	-1.24	0.85	1.3	-1.08	-5.11

A19-1.11.212. As can be seen above in Table 19.9D. the sensitivity tests show that for the majority of scenarios there is a reduction in flow at the downstream end of the model. When there is no variation to the model inflows and the sensitivity is only carried out on the timing of the peak, there is a reduction in flow for all scenarios, ranging from -0.1% to -5.8% (-0.2 m3/s to -9.0 m3/s) of the total baseline inflow.

A19-1.11.213. When the flow is reduced by 10%, as expected the flow seen at the DS end of the model also reduces. For this scenario, the removal of 10% of flow from RES_01-E inflow results in a reduction in total flow of -0.9% (-1.4 m3/s). When the reduction in inflow is combined with the variation of the timing of the peak, flow variations are all reduced and range from -1.31% to -6.44% (-2.03 m3/s to -9.9 m3/s) of the total baseline model inflows with the largest variation (-6.44%) for the “+1hr -10%flow” scenario.

A19-1.11.214. When the flow is increased by 10%, as expected the flow seen at the DS end of the model also increases. For this scenario, the addition of 10% of flow from RES_01-E inflow results in an increase in total flow of +1.3% (+2.1 m3/s). When the 10% increase in flow is combined with the variation in the timing of the peak, peak flow increases for the “-0.5hr +10%” scenario only, resulting in an increase of +0.85% (+1.3 m3/s). For all other time to peak variations for the +10% flow scenario there is an overall flow reduction at the downstream end of the model. The maximum reduction is for the “+1hr +10% flow” sees a reduction of -5.1% (-7.9 m3/s).

A19-1.11.215. Out of the 14 scenarios run only 2 scenarios result in an increase in flow at the downstream end of the model and the increase is +1.3% of total model inflows, (+2.1 m3/s). The other 12 scenarios show an overall reduction in downstream model inflows when compared to the baseline. The reduction ranges from -0.1% to -6.4% (-0.23 m^3/s to -9.97 m^3/s).

+/-20% flow and attenuation from -1hr to +1hr

A19-1.11.216. The sensitivity results for the +/-20% flow and attenuation from -1hr to +1hr can be seen in below in Table 19.10D.

Table 19.10D – Flood depth at the Croe valley receptors for various scenarios (+/-20% flow and attenuation from -1hr to +1hr) 0.5% AEP +CC 46% event

Type or Receptor / Location	Croe valley Receptor Number	Baseline	-1hr	-0.5hr	+0.5hr	+1hr	-1hr +20%	-0.5hr +20%	+20pc	+0.5hr +20%	+1hr+20 %	-1hr - 20%	-0.5hr -20%	-20pc	+0.5hr - 20%	+1hr-20%
B828	1	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	3	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	4	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture Structure	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential Dwelling	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OMR	8	0.23	-0.04	-0.01	-0.03	-0.09	-0.02	0.03	0.04	0.00	-0.06	-0.07	-0.04	-0.04	-0.06	-0.12
OMR	9	0.74	-0.03	-0.01	-0.03	-0.07	-0.01	0.02	0.03	0.00	-0.06	-0.06	-0.03	-0.03	-0.05	-0.09
A83	10	0.38	-0.01	0.00	-0.01	-0.02	0.00	0.01	0.01	0.00	-0.02	-0.02	-0.01	-0.01	-0.02	-0.03
A83	11	0.53	-0.04	-0.01	-0.04	-0.11	-0.01	0.03	0.04	-0.01	-0.09	-0.08	-0.05	-0.04	-0.08	-0.13
A83	12	0.91	-0.02	0.00	-0.02	-0.05	0.00	0.02	0.02	0.00	-0.04	-0.03	-0.02	-0.02	-0.03	-0.05
Residential dwelling	13	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	14	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Residential dwelling	15	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Dwelling (cabin/visitor centre)	16	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Caravan Holiday Park – Forest Holidays Ardgartan	17	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain
Ardgartan Hotel	18	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain	Not In Model Domain

A19-1.11.217. As can be seen in the above table, the results show a slight increase in max flood depths (+0.04m) when compared to the baseline is when an additional 20% flow is applied to the lateral inflow RES01-E.

A19-1.11.218. An increase from the Higher / Lower Credible limit of (+/-5 % Flow) to (+/-20% Flow) has been run through the model to understand the impact of a larger flow variation. The results show that the receptors in the valley are again only slightly impacted with max variation of +0.04m depth for the +20% sensitivity test, and -0.04m for the -20% scenario. Both of these scenarios assume no attenuation has taken place. The table above shows that for all other scenarios where attenuation of the peak is applied, there is a reduction in max depths when compared to these 2 scenarios.

Table 19.11D – Flow variation at downstream PO line in compare with the Baseline 0.5% AEP +CC 46% event (+/-20% flow and attenuation from -1hr to +1hr)

	Baseline RES01-E	-1hr	-0.5hr	+0.5hr	+1hr	-1hr -20%	-0.5hr -20%	-20pc	+0.5 hr -20%	+1hr-20%	-1hr +20%	-0.5hr +20%	+20pc	+0.5 hr +20%	+1hr+20%
Peak Flow at DS Section (m^3/s)	154.64	151.31	154.41	151.46	145.65	148.46	150.89	151.36	148.20	143.78	154.11	157.71	158.30	154.44	147.55
Variation from Baseline (m^3/s)	N/A	-3.33	-0.23	-3.18	-8.99	-6.18	-3.75	-3.3	-6.44	-10.86	-0.52	3.07	3.7	-0.20	-7.09
Variation from Baseline (%)	N/A	-2.2	-0.1	-2.1	-5.8	-4.00	-2.42	-2.1	-4.16	-7.02	-0.34	1.98	2.4	-0.13	-4.59

A19-1.11.219. As can be seen above in Table 19.11D the sensitivity tests show that for the majority of scenarios there is a reduction in flow at the downstream end of the model. When there is no variation to the model inflows and the sensitivity is only carried out on the timing of the peak, there is a reduction in flow for all scenarios, ranging from -0.1% to -7.02% (-0.2 m3/s to -10.86 m3/s) of the total baseline inflow.

A19-1.11.220. When the flow is reduced by 20%, as expected the flow seen at the DS end of the model also reduces. For this scenario, the removal of 20% of flow from RES_01-E inflow results in a reduction in total flow of -2.1% (-3.3 m3/s). When the reduction in inflow is combined with the variation of the timing of the peak, flow variations are all reduced and range from -2.42% to -7.02% (-3.75 m3/s to -10.86 m3/s) of the total baseline model inflows with the largest variation (-7.02%) for the “+1hr -20%flow” scenario.

A19-1.11.221. When the flow is increased by 20%, as expected the flow seen at the DS end of the model also increases. For this scenario, the addition of 20% of flow from RES_01-E inflow results in an increase in total flow of +2.4% (+3.7 m3/s). When the 20% increase in flow is combined with the variation in the timing of the peak, peak flow increases for the “-0.5hr +20%” scenario only, resulting in an increase of +1.98% (+3.07 m3/s). For all other time to peak variations for the +20% flow scenario there is an overall flow reduction at the downstream end of the model. The maximum reduction is for the “+1hr +20% flow” sees a reduction of -4.59% (-7.09 m3/s).

A19-1.11.222. Out of the 14 scenarios run only 2 scenarios result in an increase in flow at the downstream end of the model and the increase is +2.4% of total model inflows, (+3.7 m3/s). The other 12 scenarios show an overall reduction in downstream model inflows when compared to the baseline. The reduction ranges from -0.1% to -7.02% (-0.23 m^3/s to -10.86 m^3/s).

Conclusion

A19-1.11.223. Jacobs developed a linked 1D/2D hydraulic model using FMP/TUFLOW to assess the risk of fluvial flooding in the Glen Croe valley. The AMJV reviewed this model and deemed it acceptable to be used to assess the Proposed Scheme. No changes were made to the hydraulic model.

A19-1.11.224. Due to the complexity of overland flow pathways and steep slopes within the catchment, there is no discrete representation of the A83 trunk road or any of the hydraulic structures on the hillside.

A19-1.11.225. The Proposed Scheme is anticipated to provide additional attenuation within the Croe Valley up to the 0.5% AEP +CC 46%, with flow pathways being directed to a culvert under the A83 and OMR before discharging to the Croe Water.

A19-1.11.226. It is believed that the Proposed Scheme will have a net reduction in flow to the Croe valley.

A19-1.11.227. The Proposed Scheme solely impacts lateral inflow RES01, on the eastern side of the Croe Valley. RES01 has been adjusted to allow for the assessment of impact to the eastern flows. Revised inflow boundaries were created for the western valley (RES01-W) of the Croe Water and the eastern valley RES01-E.

A19-1.11.228. To assess the impact of the Proposed Scheme the hydrological inflow RES01-E was adjusted to reflect potential changes to time to peak, and increases and decreases in flow.

A19-1.11.229. The RES01-E hydrograph timing of peak was adjusted by +/ - 0.5hours and +/- 1hours. Peak flows were adjusted by +/- 5, 10 and 20%. The AMJV believe the credible change in flow variation from the Proposed Scheme is no more than 5%.

A19-1.11.230. The results show that when the flow is increased by 5%, as expected the flow seen at the DS end of the model also increases. For this scenario, the addition of 5% of flow from RES_01-E inflow results in an increase in total flow of +0.7% (+1.1 m3/s). When the 5% increase in flow is combined with the variation in the timing of the peak, peak flow increases for the “-0.5hr +5%” scenario only, resulting in an increase of +0.2% (+0.3 m3/s). For all other time to peak variations for the +5%flow scenario there is an overall flow reduction at the downstream end of the model. The maximum reduction is for the “+1hr +5% flow” sees a reduction of -5.5% (-8.5 m3/s).

A19-1.11.231. This has an increase in water depth of 0.01m at receptors 8, 9, 10, 11 and 12. This change in flood depth does not change flood extent or flood frequency.

A19-1.11.232. The results from the -0.5hr +5%” scenario have been applied in the overall FRA.

Annex E - Loch Restil Modelling Note

Introduction

A19-1.11.233. The Atkins WSP Joint Venture (AWJV) was appointed by Transport Scotland to undertake a DMRB Stage 2 Assessment for the upgrade of the A83 Trunk Road between Ardgartan and the Rest and Be Thankful car park. This included a preliminary Flood Risk Assessment (FRA) of the Proposed Scheme Options for the upgrade of the A83. The preliminary assessment included a review of all available data, identified potential sources of flooding and sensitive receptors, and presented an assessment of the flood risk associated with the route alignment options considered at DMRB Stage 2. The preliminary assessment identified the primary source of flooding to The Proposed Scheme as being fluvial.

A19-1.11.234. This document provides the detailed modelling and assessment of fluvial flooding from Loch Restil to inform the detailed alignment design and flood mitigation measures referred to in the DMRB Stage 3 Environmental Statement.

A19-1.11.235. This appendix supports the Access to Argyll and Bute (A83) FRA.

Hydrology

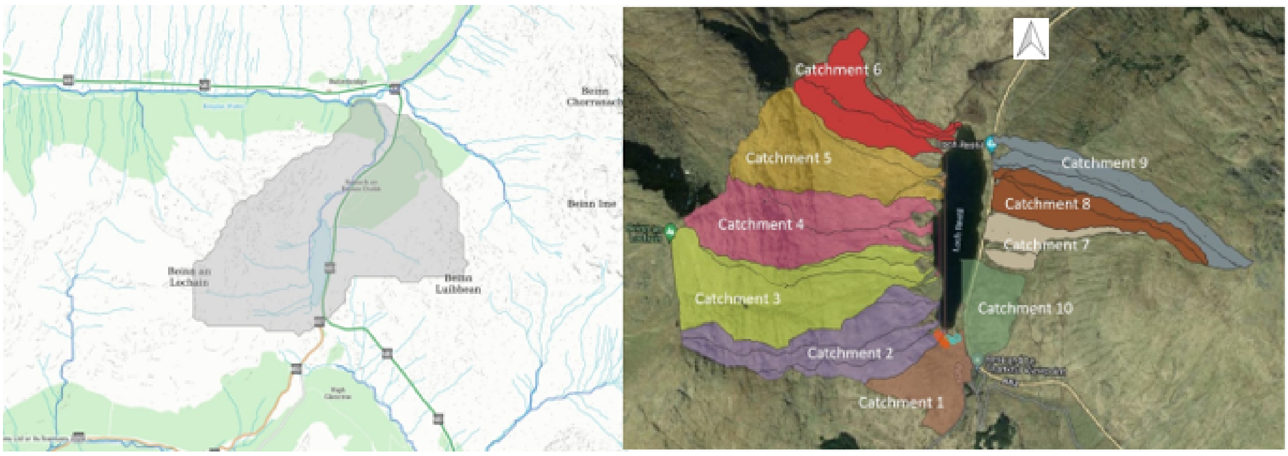
A19-1.11.236. The details of the hydrology analysis to calculate design inflows for the hydraulic model are provided in this section. Hydrographs have been provided for the 50% AEP (2-year), 3.33% AEP (30-year), 1% AEP (100-year), 0.5% AEP (200-year) and 0.5% AEP (200-year) plus climate change (CC) events.

A19-1.11.237. The inflows for the Easan Dubh catchment are derived by using a hybrid Flood Estimation Handbook (FEH approach using the Revitalised Flood Hydrograph rainfall-runoff method version 2 (ReFH2.3) and the Statistical method (WINFAP version 5). Two proxy donors were identified, one for the upper catchment and one for the lower catchment. The statistical method was used to calculate the specific discharge for each, and hydrograph shape was obtained using the rainfall-runoff method. The specific discharge was then multiplied by the sub-catchment area of 14 identified sub-catchments to provide distributed inflows. In the hydraulic model, ten (10) point inflows and four (4) lateral inflows were then applied, as shown in Plate 19.1E. Runoff from the areas in-between the catchments have also been included in the calculations. A climate change allowance of 46% has been applied to the peak rainfall and routed through ReFH2 for the 0.5% AEP, in line with SEPA guidance for small catchments. For full details, see the A83 Hydrology report (Annex B). The peak flows for the modelled catchment are shown in Table 19.1E for all the return periods.

Table 19.1E – Hydrological Peak Inflow Estimates and Locations within the Model

Inflow location	Catchment area (km^2)	Peak Flow 0.5% AEP +CC 46% event)
Catchment 1	0.099	1.737
Catchment 2	0.221	3.878
Catchment 3	0.308	5.396
Catchment 4	0.257	4.501
Catchment 5	0.230	4.034
Catchment 6	0.151	2.640
Catchment 7	0.058	1.018
Catchment 8	0.122	2.139
Catchment 9	0.148	2.595
Catchment 10	0.085	1.485
Residual 1	0.021	7.305
Residual 2	0.504	5.802
Residual 3	0.401	3.640
Residual 4	0.251	5.830

Plate 19.1E – Loch Restil Catchment (left) at the Downstream Boundary of the Model and Sub-Catchment Distribution (right) within the Loch

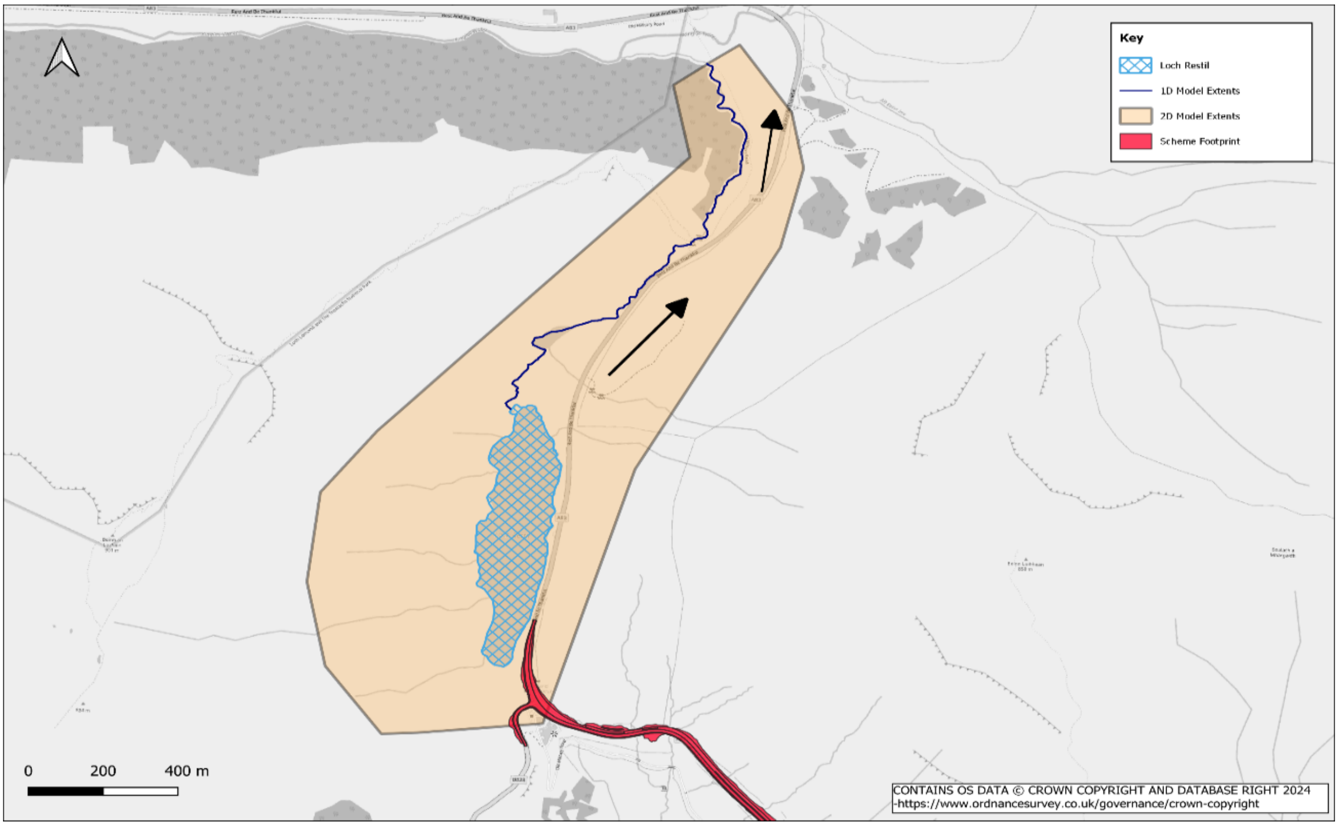


Modelling Approach

A19-1.11.238. The hydraulic model was built using a linked One-Dimensional/Two-Dimensional (1D/2D) method, where the river channel is represented with a 1D model using Flood Modeller Pro (FMP) software version 5.1 and the lake (Loch Restil) and the active floodplain are represented using TUFLOW software version 2020-10. The model dynamically transfers the water between the linked 1D/2D boundaries of the river and the lake. Plate 19.2E illustrates the extent of the modelling work undertaken for the area of study.

A19-1.11.239. The 1D model covers a 1,618m long reach of the Easan Dubh and the 2D model, covers the entire Loch Restil with a surface area of 110,923m2 (see Plate 19.2E). The model's upstream extent is located at the north of Rest and Be Thankful viewpoint (NN 22893 07552) and its downstream extent is upstream of Easan Dubh's confluence with the Kinglas Water watercourse (NN 23453 09417). The total watercourse reach modelled is approximately 2,400m long. The lake has a maximum depth of more than 6m (according to LiDAR).

Plate 19.2E – 1D and 2D Model Extents



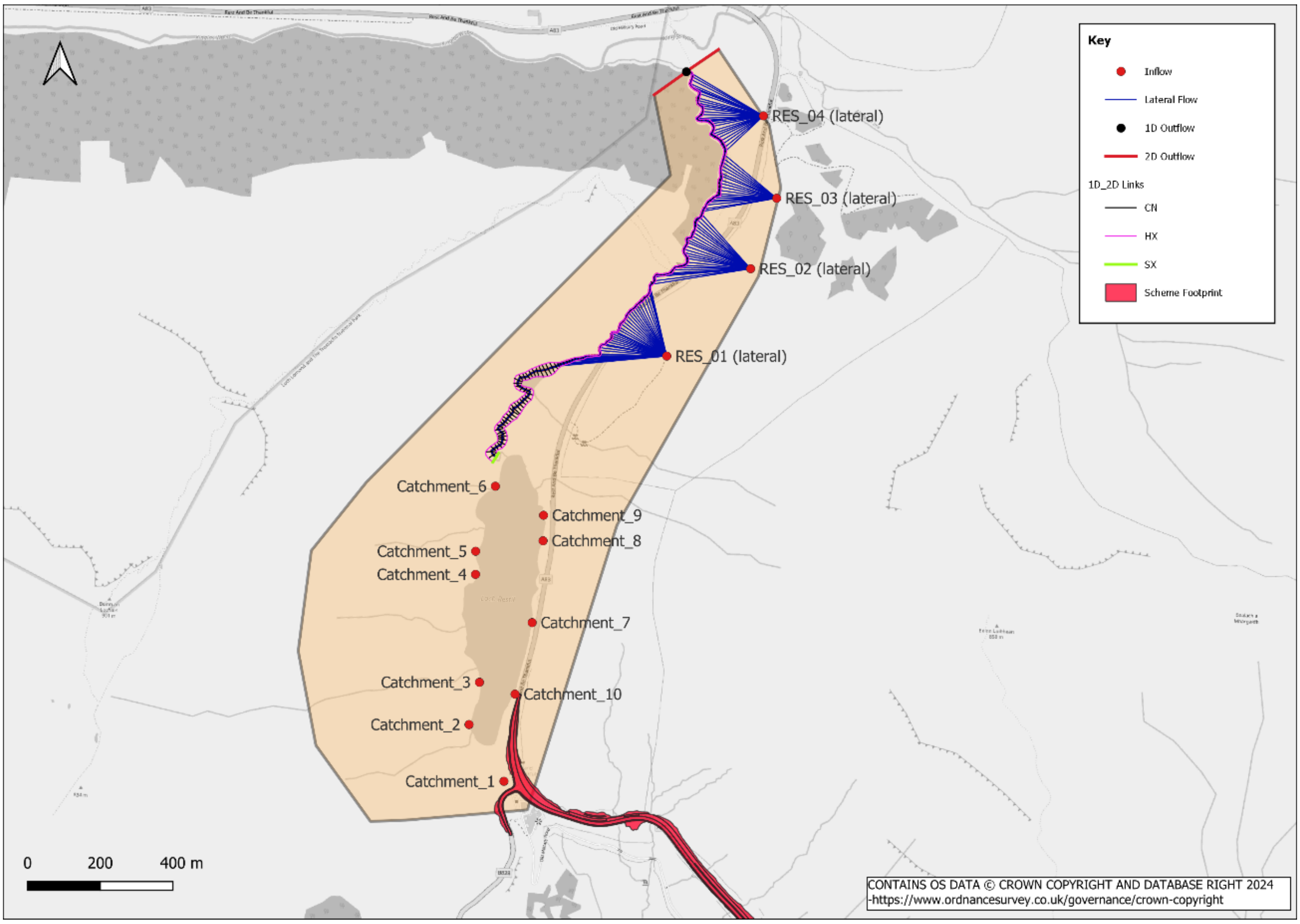
Data Availability

A19-1.11.240. The LiDAR Digital Terrain Model (DTM) was sourced from the Scottish Remote Sensing Portal. The LiDAR has a resolution of 0.2m which is considered sufficient for representing the floodplain topology, cross section geometries as well as 1D /2D model linking.

Cross Section Geometry

A19-1.11.241. The LiDAR data has been used to generate the channel geometry of the watercourse since surveyed data was not available in this location. The LiDAR resolution and accuracy was deemed suitable for hydraulic assessment in this area. The locations of the modelled cross sections are shown in Plate 19.3E. Interpolated cross sections were added between the extrapolated cross sections to improve model performance and stability.

Plate 19.3E – 1D and 2D Model Boundaries and Lateral Flow Application



In-channel Roughness

A19-1.11.242. Hydraulic roughness values are defined using Manning's 'n' coefficient in the model. The roughness values are determined from aerial imagery of the floodplain and the channel and using Chow 1959 Manning roughness values as shown in Table 19.2E.

Table 19.2E – In-channel Manning's 'n' Roughness Values

Watercourse	Bed Manning's 'n'	Bed Material	Bank Manning's 'n'	Bank Material
Easan Dubh	0.045	Clean, winding, with some weeds and stones	0.050	Same as bed with more stones

1D and 2D Boundary Conditions

A19-1.11.243. Point inflows are applied using flow-time (QT) boundary points for each sub-catchment draining to Loch Restil (points labelled Catchment 1 to Catchment_10 in Plate 19.3E). Downstream water levels are defined using a HQ outflow boundary, which assigns a water level to the grid cells based on the stage-discharge curve.

A19-1.11.244. Flow-Time hydrographs were applied along the 1D channel to distribute the flow laterally along the watercourse, as shown in Plate 19.3E (RES_01, RES_02, RES_03 and RES_04). A normal depth boundary condition is applied to the downstream end of the 1D watercourse. The 1D to 2D connection at the intersection of the reservoir and the watercourse is defined using an External Source (SX) flow boundary in TUFLOW connected to a 1D node in FMP, so the 1D water level is linked to the average water level along the 2D SX cells. Along the river, a set of HX/CN lines have been used at the downstream boundary of each domain to ensure smooth transition of flows from 2D to 1D model. 1D water level lines (WLL) are used to represent the 1D results in combination with the 2D results.

2D Floodplain

A19-1.11.245. The ground levels are based on the 0.2m resolution DTM data mentioned in the "Data Availability" section. The 2D domain, shown in 19.3E has a grid cell size of 2m to accurately represent the floodplain. The LiDAR data informs the bank top levels which govern the 1D to 2D spill mechanism.

2D Floodplain Roughness

A19-1.11.246. Different land use types within the floodplain in the 2D domain have been defined using OS MasterMap and represented in the combined model with varying roughness values.

A19-1.11.247. Table 19.3E shows the roughness values used across the floodplain to represent different land uses. No buildings or houses are located within the domain, therefore high roughness values are not necessary.

Table 19.3E – 2D Manning's 'n' Roughness Values

Land Cover	Manning's 'n' roughness
General Surface	0.055
Inland Water	0.02
Landform	0.05
Thick Vegetation/Trees	0.1
Road or Track	0.025
Roadside	0.025

Hydraulic Structures

A19-1.11.248. There are no hydraulic structures within the modelled 1D and 2D domain.

Sensitivity Testing and Calibration

A19-1.11.249. Model calibration was not possible due to lack of hydrometric data and gauging stations on the watercourse.

A19-1.11.250. Model sensitivity testing has been carried out to assess the effect of key parameters in the model such as the manning's roughness values, downstream boundary levels and the storm duration.

Baseline Model Results

A19-1.11.251. To assess the existing fluvial flood risk in the Loch Restil area, a set of simulations were conducted with the following return periods: 50% AEP, 3.33% AEP, 1% AEP, 0.5% AEP, and 0.5% AEP +CC 46% event.

A19-1.11.252. Maximum flood extents for all the abovementioned events are presented in Plate 19.4E. It is evident that in the vicinity of Lock Restil, flooding remains within the lake area. The main region which shows flooding outside the watercourse is in the vicinity of the pond downstream of the lake, where the watercourse takes a sharp turn. However, it must be noted that for all the simulated events, the A83 Trunk Road remain clear of flooding.

A19-1.11.253. The flood extent and water depths are largest in the 0.5% AEP +CC 46% event compared to other simulated events. Plate 19.4E shows the flood extent of 0.5% AEP +CC 46% event. The flood extents for the rest of the simulated events are presented in the addendum plates LRA1 to LRA4. Plate 19.5E shows that the flood depths above 1m are mainly limited to the lake and pond area, and in the rest of the simulated domain, the water depths remain below 1m.

A19-1.11.254. Findings from this study indicate that the area upstream the Rest and Be Thankful viewpoint is not at risk of fluvial flooding and flood waters are not expected to reach any roads and assets in this region.

Plate 19.4E – Maximum Flood Extents for All the Simulated Flood Events

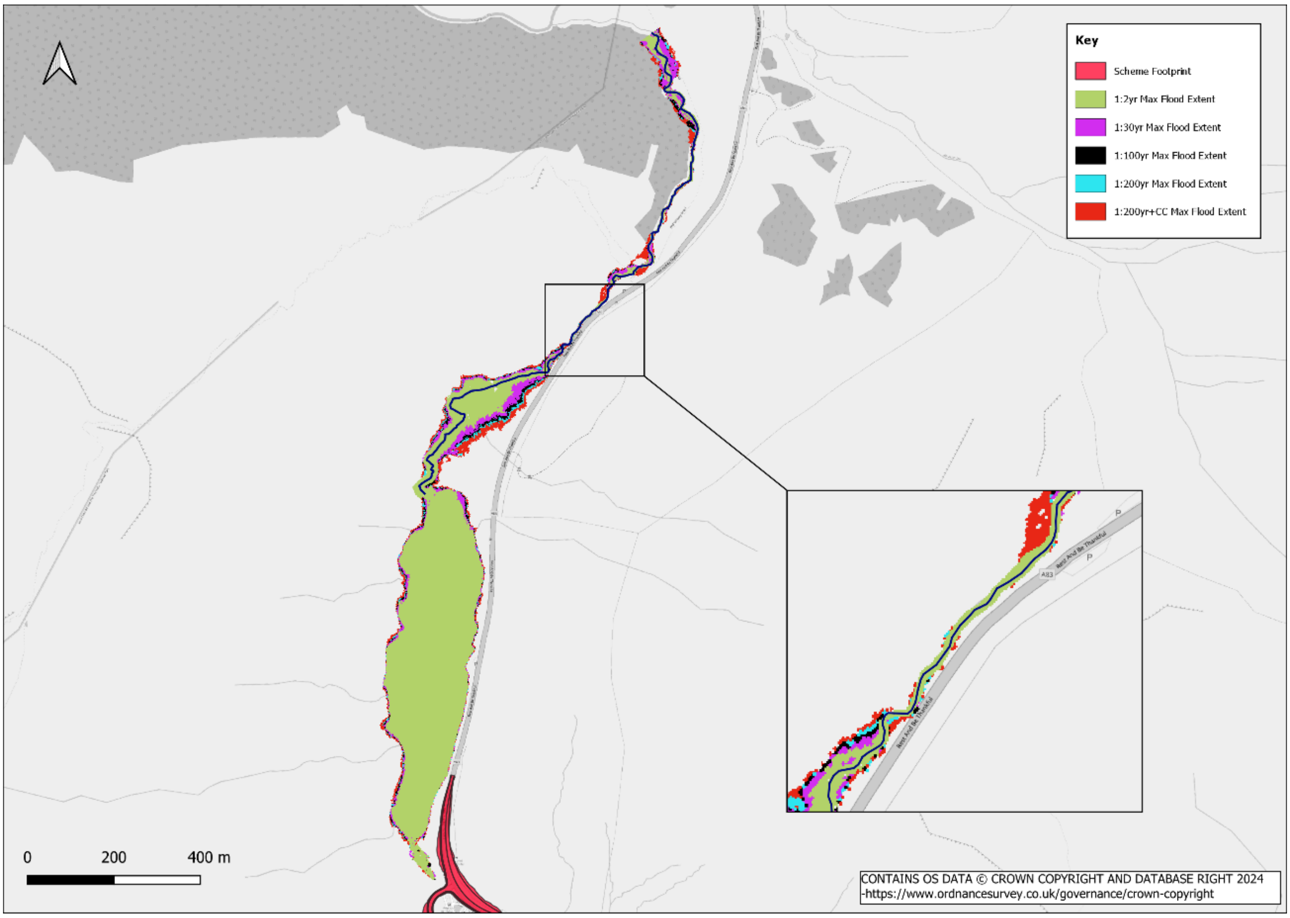
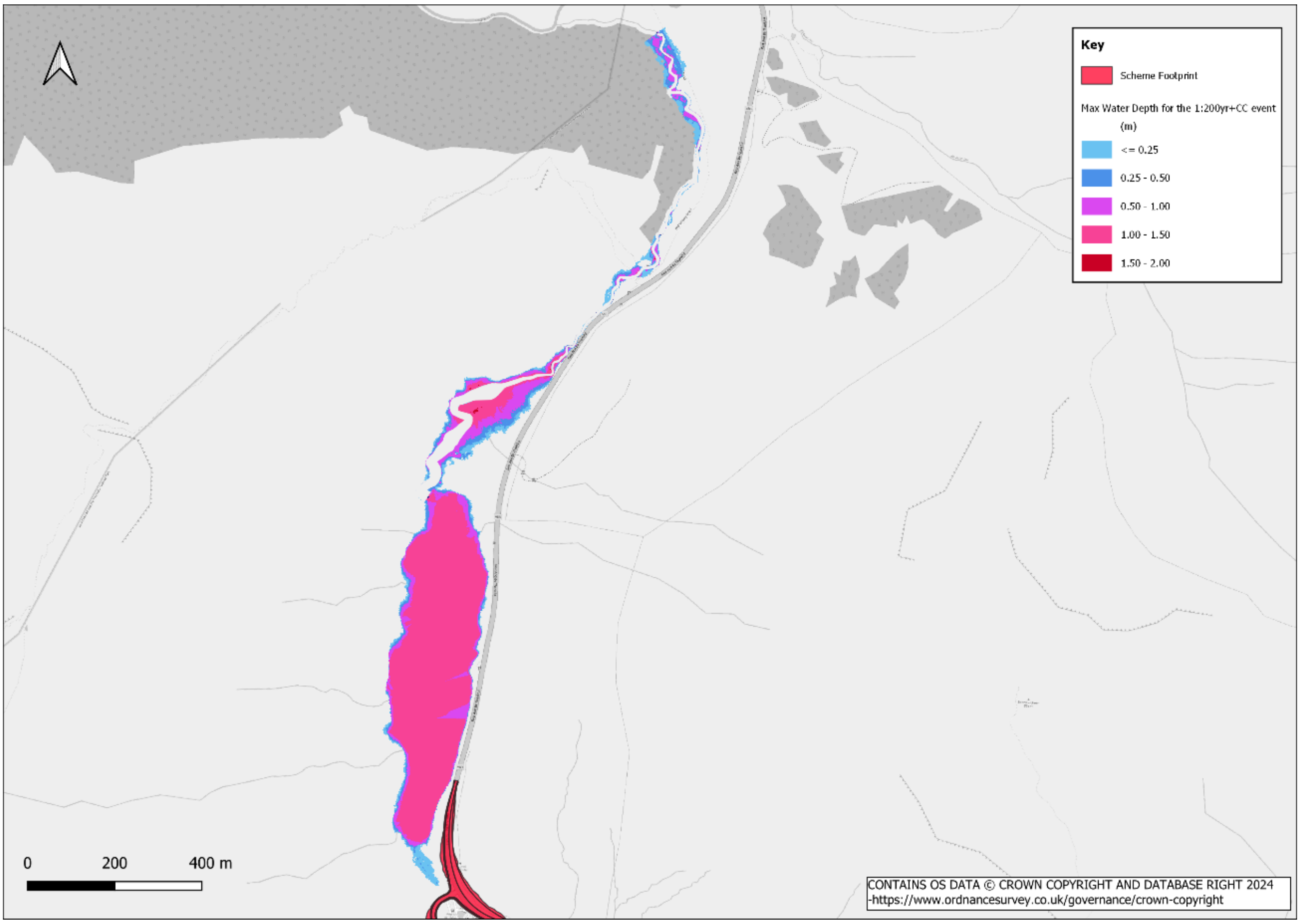


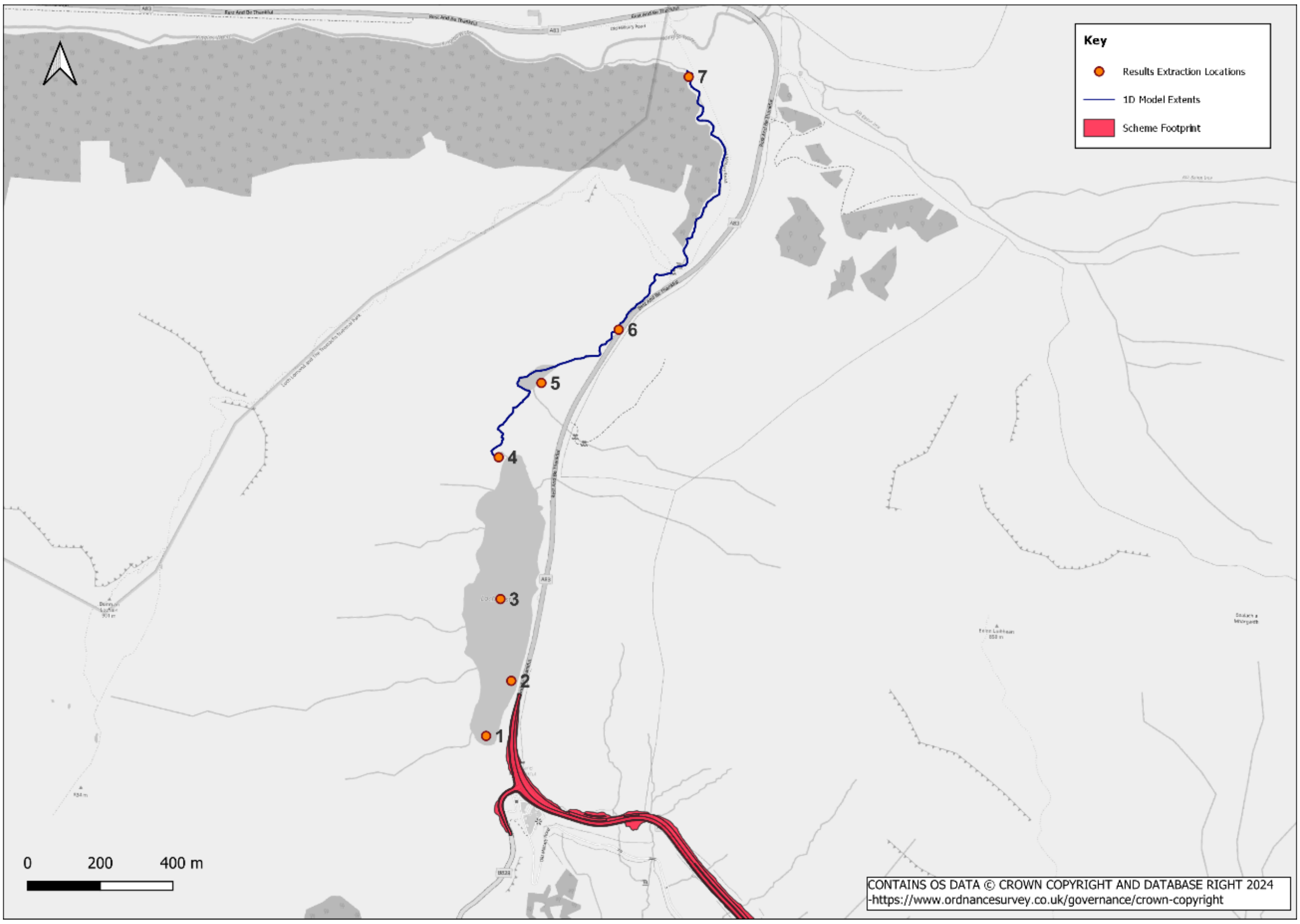
Plate 19.5E – Maximum Water Depth for the 0.5% AEP +CC 46%event



Sensitivity Model Results

A19-1.11.255. A sensitivity analysis has been undertaken using the combined 1D/2D model to assess the potential changes in model results, due to changing the model parameters. SEPA's "Flood Modelling Guidance for Responsible Authorities" advises to undertake sensitivity studies to demonstrate confidence in the model outputs and it suggests a range of parameters to be considered for testing such as design flow, surface roughness, boundary conditions and hydrology inputs. The model parameters altered for the sensitivity tests are those which are considered to be most influential on water levels in this model, which is surface roughness, storm durations and downstream boundary of the model. The sensitivity runs have been undertaken for the design flood event 0.5% AEP +CC 46% and the water levels have been compared and reported in the following sub-sections. Plate 19.6E shows the locations selected for the result comparison. These locations were selected to cover the entire model reach and critical locations. Flood extents where not significantly altered in the sensitivity runs, therefore only the water level results are presented in this section.

Plate 19.6E – Locations for Results Comparison



Roughness Sensitivity

A19-1.11.256. A 20% increase and decrease in the roughness values (Manning's 'n') was applied to the model in both the channel and the floodplain. The changes in peak water levels compared to the baseline scenario for 0.5% AEP +CC 46% event at the selected locations is presented in Table 19.4E.

A19-1.11.257. The results show that reducing the roughness values can reduce the water levels by up to 79mm and increasing the roughness can increase the water levels by up to 102mm, indicating that the water levels are not significantly sensitive to this parameter within the tested range.

Table 19.4E – Manning's Roughness 'n' Sensitivity Results

Location	Baseline 0.5% AEP +CC 46% event - Water depth (m)	Water depth Difference for the +20% Increased Roughness Case (m)	Water depth Difference for the -20% Decreased Roughness Case (m)
1	1.137	0.047	-0.051
2	1.120	0.048	-0.053

Location	Baseline 0.5% AEP +CC 46% event - Water depth (m)	Water depth Difference for the +20% Increased Roughness Case (m)	Water depth Difference for the -20% Decreased Roughness Case (m)
3	1.069	0.048	-0.052
4	0.980	0.050	-0.055
5	1.416	0.044	-0.041
6	2.375	0.102	-0.079
7	0.519	0.051	-0.069

Sensitivity with Storm Duration

A19-1.11.258. The model sensitivity to storm duration was evaluated by simulating the model for storm durations of 6.5 hr and 8.5 hr compared to the original 4.5 hr storm duration. Longer storm durations result in larger rainfall volumes being discharged into the catchment, which can potentially increase the water levels and flood extents. Table 19.5E shows the impact of changing the model inflows on the water levels at the selected locations for the 0.5% AEP +CC 46% design flow

A19-1.11.259. The results indicate that for the storm duration of 6. 5hr and 8.5hr, the water levels increase on an average by approximately 60mm, 120mm respectively compared to the 4.5 hr storm duration. This indicates that the model is moderately sensitive to the hydrological flow conditions. It is worth mentioning that the flood extents are not sensitive to the tested storm durations and the road remains clear of flooding in these events.

Table 19.5E – Storm Duration Sensitivity Results

Location	Baseline 0.5% AEP +CC 46% Water Depth (4.5 hours Storm duration) (m)	Water Depth Difference for the 6.5 hr Storm Duration Case (m)	Water Depth Difference for the 8.5 hr Storm Duration Case (m)
1	1.137	0.063	0.121
2	1.120	0.061	0.118
3	1.069	0.063	0.117
4	0.980	0.062	0.116
5	1.416	0.071	0.134
6	2.375	0.099	0.172
7	0.519	0.023	0.045

Downstream Boundary

A19-1.11.260. The downstream boundary conditions of a model can have an impact on upstream modelled water levels in the vicinity of the boundary, therefore sensitivity runs have been carried out to assess the potential effects of changes in the boundary on the model results. The downstream boundary slope was changed by +20% and -20% at the normal depth boundary unit for the purpose of this sensitivity study. The changes in peak water levels compared to the baseline scenario for the 0.5% AEP +CC 46% event is presented in Table 19.6E.

A19-1.11.261. The results indicate that the model is relatively unaffected by the downstream boundary within the tested range, with only limited changes directly upstream of the downstream boundary. No changes in the flood extents are observed in the downstream boundary sensitivity tests and the scheme area remains clear of flooding in all the simulations.

Table 19.6E – Downstream Boundary Sensitivity Results

Location	Baseline 0.5% AEP +CC 46% Water Depth (m)	Water depth Difference for the +20% Increased DS Boundary Case (m)	Water Depth Difference for the -20% Decreased DS Boundary Case (m)
1	1.137	0	0
2	1.120	0	0
3	1.069	0	0
4	0.980	0	0
5	1.416	0	0
6	2.375	0	0
7	0.519	0.02	0

Modelling Assumptions and Limitations

A19-1.11.262. It is necessary to make some assumptions when performing a hydraulic modelling study which results in some degree of uncertainty and limitations. The accuracy of the modelling results depends mainly on the accuracy of the hydrological and topological data and efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process. The assumptions made are considered to be generally conservative for modelled water levels along the affected reach and are therefore appropriate for the flood risk assessment.

Channel and Floodplain Roughness

A19-1.11.263. Channel roughness has been assigned using the best available information (aerial photographs). The roughness values are based on standard industry guidance (Chow 1959). The channel roughness values may vary over the year and the sensitivity tests have been carried out to quantify the impact, which ranges from -79mm to 102mm changes in water depths.

Channel Cross Sections and Floodplain Topography

A19-1.11.264. No survey data was available for the cross sections and the ground topography in this model and so the best available LiDAR data have been used to extract this data. The LiDAR has a resolution of 0.2m which is deemed sufficient for this purpose.

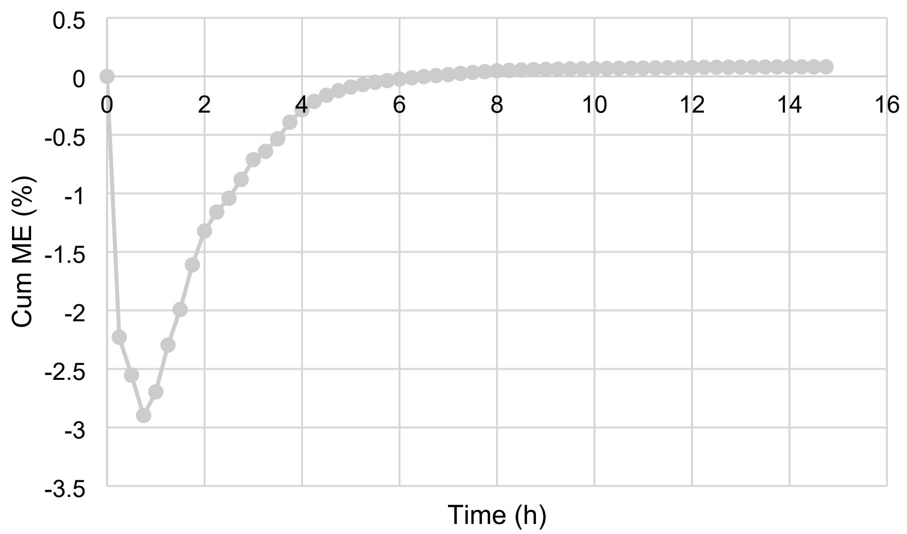
Cell Size

A19-1.11.265. TUFLOW utilises a fix sized square mesh to represent the ground profile. A fix size of 2m has been used and is deemed appropriate to represent key elements in the floodplain correctly.

Model Stability

A19-1.11.266. SEPA's "Flood Modelling Guidance for Responsible Authorities" requires the mass balance error (MBE) to be reported in the modelling report. The acceptable limits for MBE are withing ±1% according to the guidance. In all the simulated scenarios, the MBE remains within the tolerance limit of ±1% for most of the simulation time. Plate19.2E shows the 2D cumulative mass error (Cum ME) for the 0.5% AEP +CC 46% event. For a short span of initial time (~2 hours) the Cum ME is higher than ±1%, until a stable solution is reached and then it remains below the ±1% limit for the rest of the simulation time, including at the time of peak.

Plate 19.2E – Cumulative Mass Error for the 0.5% AEP +CC 46% event



Conclusion

A19-1.11.267. A linked 1D/2D hydraulic model was built using FMP/TUFLOW to assess the fluvial flood risk in the Loch Restil region. The model covers approximately a 2,400m reach of the watercourse starting at the north of the Rest and Be Thankful viewpoint and terminating at its confluence with Kinglas Water. The main objective of this study was to determine whether the A83 Trunk Road or any other critical areas in this region may be at risk of flooding from Loch Restil and the watercourse downstream of this lake. For this purpose, a set of simulations has been carried out for various return periods for 50%AEP, 3.33% AEP, 1% AEP, 0.5% AEP and 0.5% AEP +CC 46% flood events.

A19-1.11.268. The model performance and behaviour were examined by running sensitivity tests for the roughness values, the storm duration and the downstream boundary levels. It was shown that the model is moderately sensitive to roughness values and storm duration and relatively insensitive to the downstream boundary. Notably, in all the sensitivity test the flood extents were not changed, meaning that these factors do not impact the outcomes of this study. Model assumptions and limitations as well as model stability and errors were also reported.

A19-1.11.269. The hydraulic modelling assessment of Loch Restil shows that the A83 Trunk Road is not at the risk of flooding from the watercourse in any of the simulated events. As shown in the report plates, Loch Restil is located outside of the scheme and the footprint of the proposed scheme does not impact the flooding conditions in the modelled area. These results are used to inform the Access to Argyll and Bute (A83) FRA.

Loch Restil Addendum

Plate LRA1 - A1 – Maximum Water Depth for the 50% AEP event

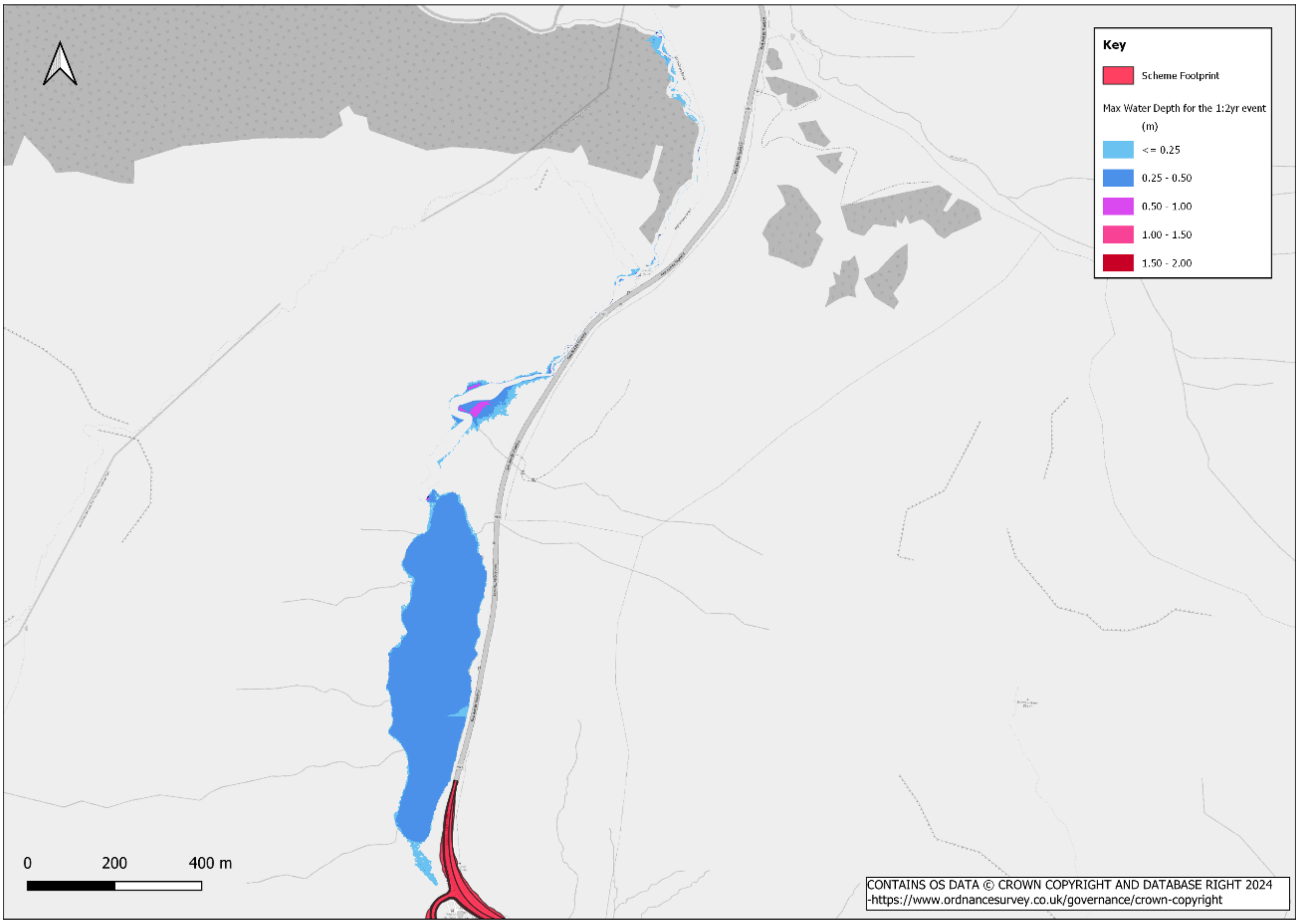


Plate LRA2 - Maximum Water Depth for the 3.33 %AEP event

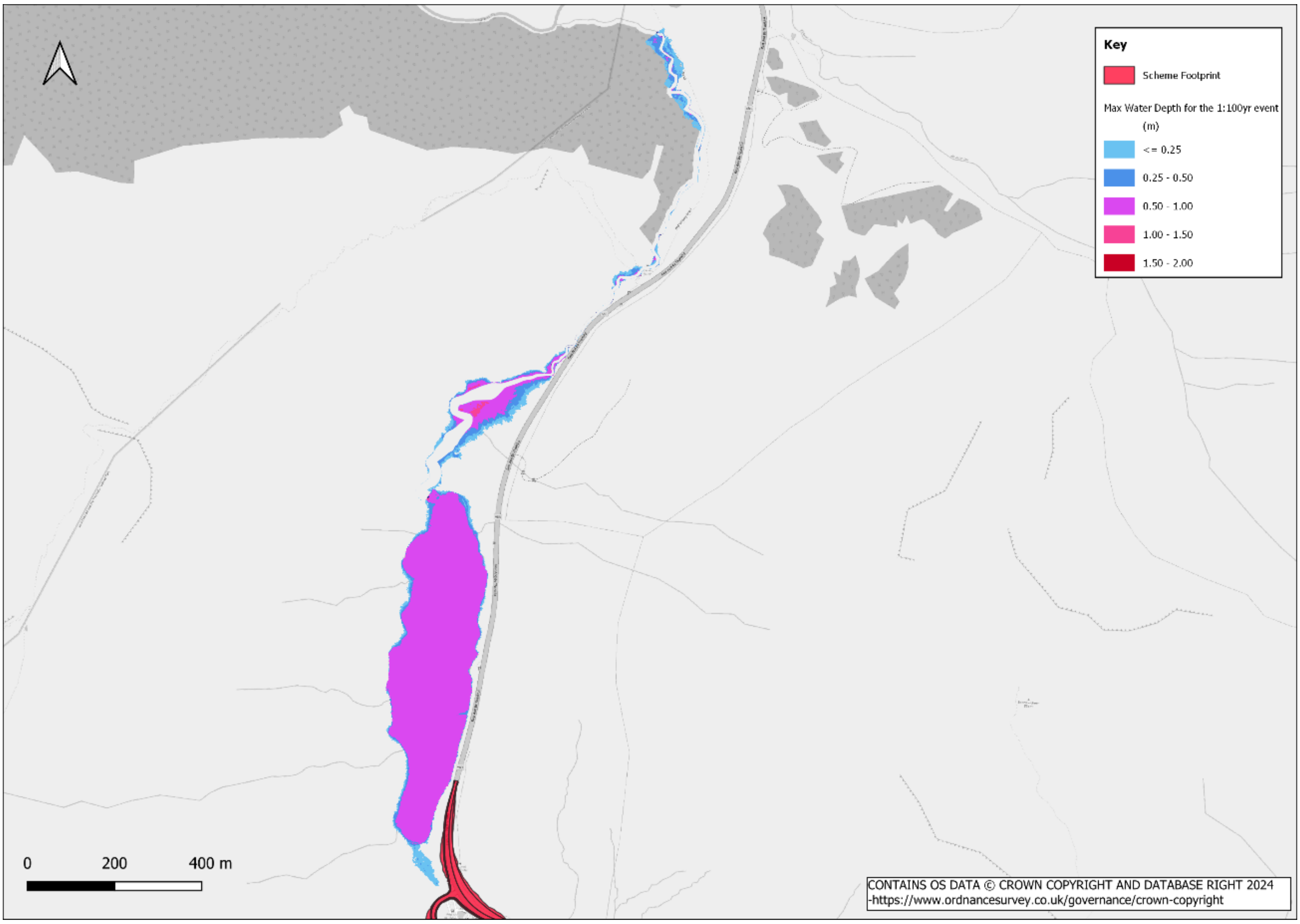


Plate LRA3 – Maximum Water Depth for the 1% AEP event

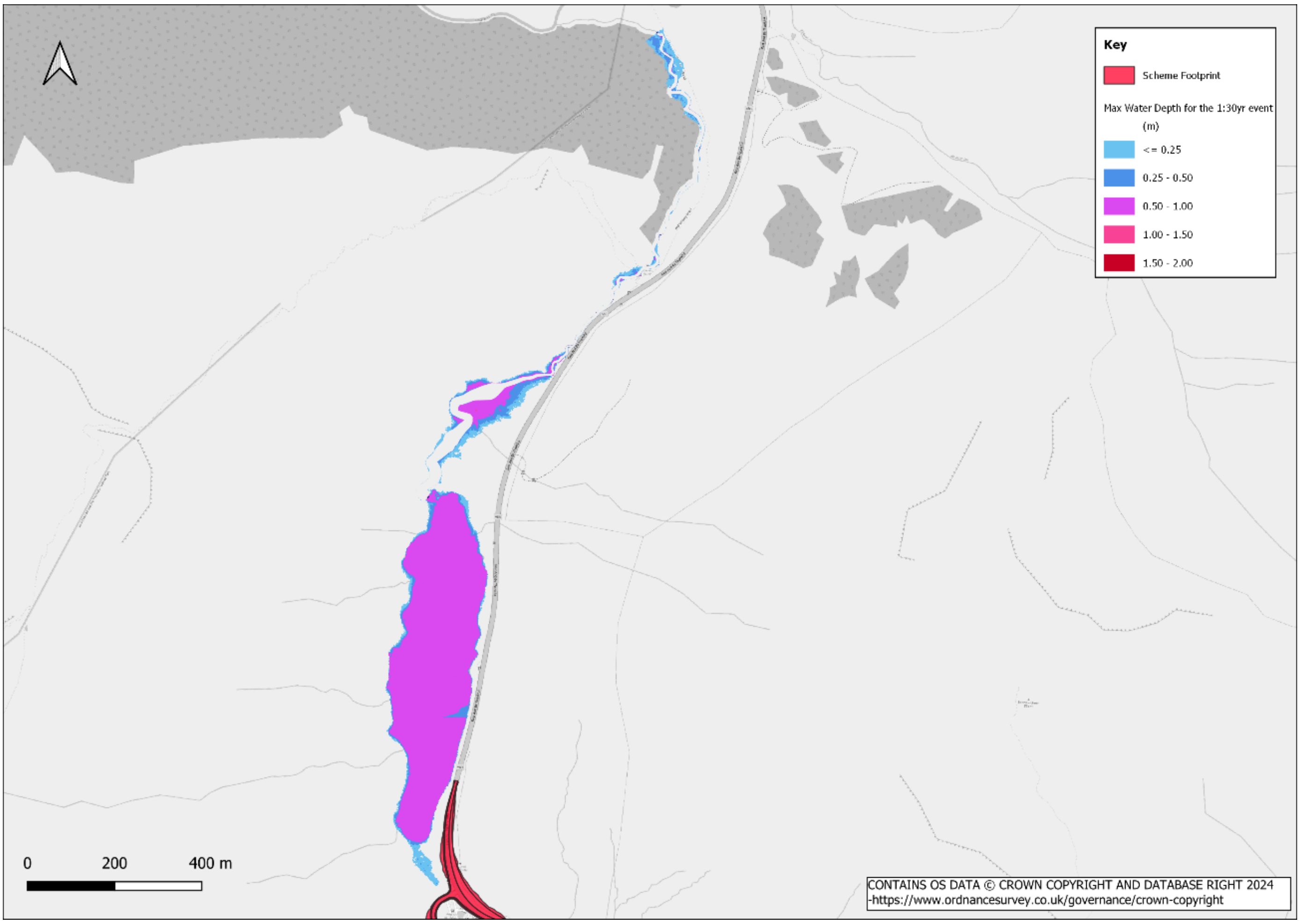
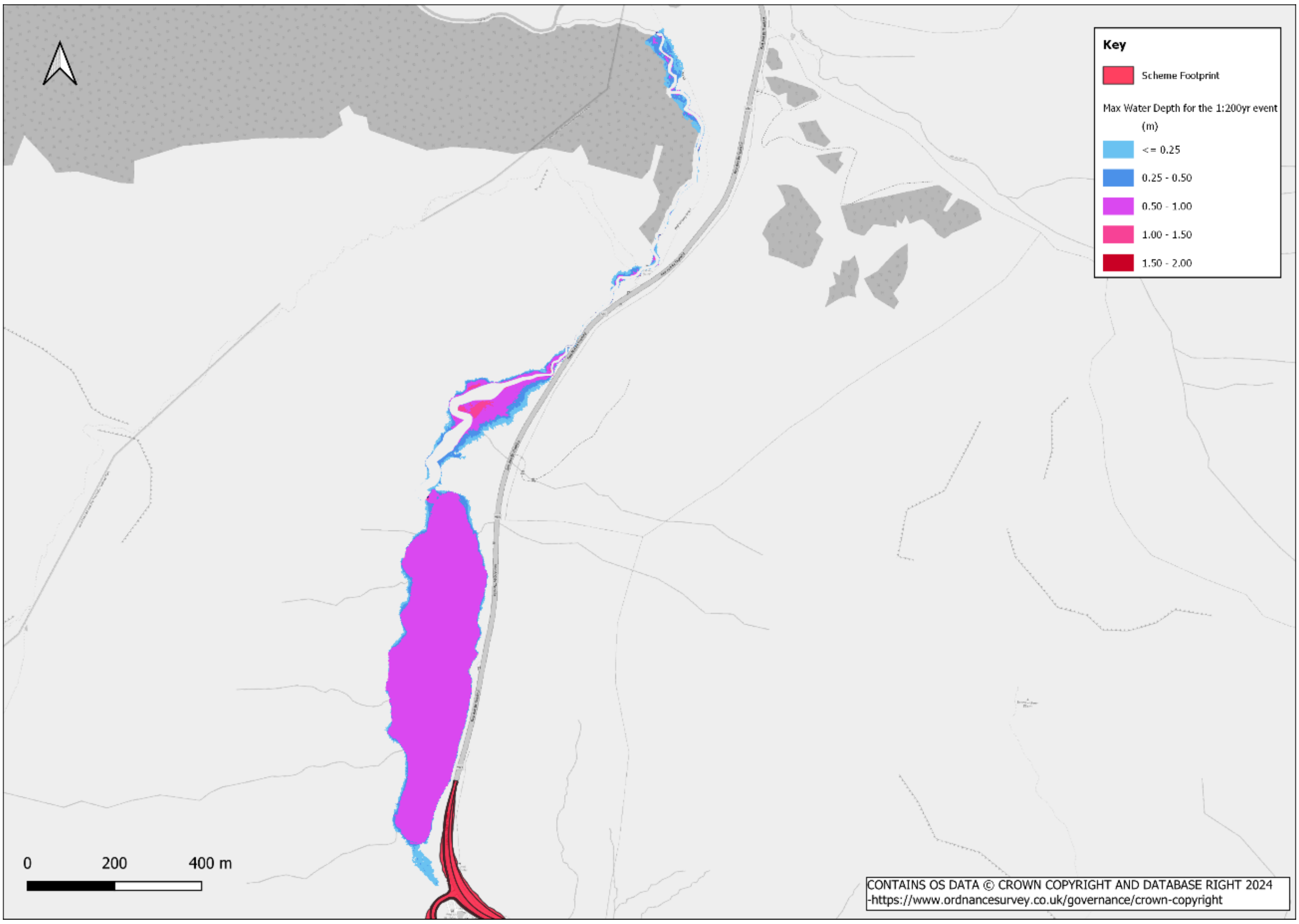


Plate LRA4 – Maximum Water Depth for the 0.5% AEP event



Annex F - SEPA Flood Risk Assessment Checklist

SEPA

Flood Risk Assessment (FRA) Checklist

Scotland's 4th National Planning Framework has recently been published. This document is therefore being reviewed and updated to reflect the new policies. You can still find useful and relevant information here but be aware that some parts may be out of date and our responses to planning applications may not match the information set out here.

(SS-NFR-F-001 - Version 16 - Last updated 27/08/2019

This document must be attached within the front cover of any Flood Risk Assessments issued to Local Planning Authorities (LPA) in support of a development proposal which may be at risk of flooding. The document will take only a few minutes to complete and will assist SEPA in reviewing FRAs, when consulted by LPAs. This document should not be a substitute for a FRA.

Development Proposal Summary					
Site Name:		A83 Rest and Be Thankful			
Grid Reference:	Easting:	223714	Northing:	706929	
Local Authority:		Argyll and Bute Council			
Planning Reference number (if known):		N/A			
Nature of the development:		Infrastructure	If residential, state type:	N/A	
Size of the development site:			Ha		
Identified Flood Risk:	Source:	Fluvial	Source name:	Hillside unnamed watercourses and Croe Water	
Land Use Planning					
Is any of the site within the functional floodplain? (refer to SPP para 255)		No	If yes, what is the net loss of storage?	N/A	m^3
Is the site identified within the local development plan?		No	Local Development Plan Name: / Allocation Number / Reference:		Year of Publication:
If yes, what is the proposed use for the site as identified in the local plan?		Infrastructure	If Other please specify:		
Does the local development plan and/or any pre-application advice, identify any flood risk issues with or requirements for the site.		No	If so, please specify:		
What is the proposed land use vulnerability?		Essential Infrastructure	Do the proposals represent an increase in land use vulnerability?	Select from List	
Supporting Information					
Have clear maps / plans been provided within the FRA (including topographic and flood inundation plans)?		Yes			
Has sufficient supporting information, in line with our Technical Guidance, been provided? For example: site plans, photos, topographic information, structure information and other site specific information.		Yes			
Has a historic flood search been undertaken?		Yes	If flood records in vicinity of the site please provide details:	Multiple occasions of landslips and flooding along the A83, hence the reason for the project.	
Is a formal flood prevention scheme present?		No	If known, state the standard of protection offered:	N/A	
Current / historical site use:		Transport infrastructure			
Is the site considered vacant or derelict?		No			
Development Requirements					
Freeboard on design water level:		N/A	m		
Is safe / dry access and egress available?		Vehicular and Pedestrian	Min access/egress level:	N/A	m AOD
Design levels:	Ground level:	N/A	m AOD / Min FFL:	N/A	mAOD
Mitigation					
Can development be designed to avoid all areas at risk of flooding?		No			
Is mitigation proposed?		Yes	*Embedded mititagtion as part of Propsoed Scheme - SEE FRA*		
If yes, is compensatory storage necessary?		No			
Demonstration of compensatory storage on a "like for like" basis?		Select from List	*N/A*		
Should water resistant materials and forms of construction be used?		Select from List	*N/A*		

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SEPA

Flood Risk Assessment (FRA) Checklist

(SS-NFR-F-001 - Version 16 - Last updated 27/08/2019)

Hydrology

Is there a requirement to consider fluvial flooding?	Yes			
Area of catchment:		km²	Is a map of catchment area included in FRA?	Yes
Estimation method(s) used (please select all that apply):	Pooled Analysis ☐ Single Site Analysis ☐ Enhanced Single Site ☐ ReFH2 ☑ FEH RRM ☐ Other ☐		If Pooled analysis have group details been included?	Yes
			If other (please specify methodology used):	
Estimate of 200 year design flood flow:		m³/s		
Qmed estimate:		m³/s	Method:	Catchment Descriptors
Statistical Distribution Selected:	Select from List		Reasons for selection:	

Multiple parts to hydrology derivation see Annex B for hydrology technical note.

Hydraulics

Hydraulic modelling method:	Linked 1D 2D		Software used:	TuFlow
			If other please specify:	
Number of cross sections:				
Source of data (i.e. topographic survey, LiDAR etc):	LiDAR		Date obtained / surveyed:	
Modelled reach length:		m		
Any changes to default simulation parameters?			If yes please provide details:	
Model timestep:				
Model grid size:	1m			
Any structures within the modelled length?	Bridges		Specify, if combination:	
Maximum observed velocity:		m/s		
Brief summary of sensitivity tests, and range:				
variation on flow (%)		%	o considered:	
variation on channel roughness (%)		%		
blockage of structure (range of % blocked)		%		
boundary conditions:	Upstream		am	
(1) type	Flow			List
Specify if other:			Specify if other:	
(2) does it influence water levels at the site?	Select from List			Select from List
Has model been calibrated (gauge data / flood records)?	Select from List			
Is the hydraulic model available to SEPA?	Select from List			
Design flood levels: 200 year		m AOD	200 year plus climate change	m AOD
Cross section results provided?	Select from List			
Long section results provided?	Select from List			
Cross section ratings provided?	Select from List			
Tabular output provided (i.e. levels, velocities)?				
Mass balance error:		%		

Multiple models used to inform FRA as part of Proposed Scheme. See -
Annex C - Small watercourses modelling
Annex D - Croe Water modelling
Annex E - Loch Restil Modelling

Coastal

Is there a requirement to consider coastal / tidal flooding?	Select from List			
Estimate of 200 year design flood level:		m AOD		
Estimation method(s) used:	Select from List		If other please specify methodology used:	
Allowance for climate change (m):		m		
Allowance for wave action etc (m):		m		
Overall design flood level:		m AOD		

Comments

Any additional comments:

Approved by: T.Jolley
Organisation: WSP
Date: 27/09/2024