Annex 11.3a

Hydrological & Hydraulic Modelling Technical Note

Transport Scotland

August 2018

Contains *sensitive* information

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Abbreviations & Glossary

Terminology	Abbreviation	Description
Annual Exceedance Probability	AEP	The probability of a natural hazard occurring annually, usually expressed as a percentage
Annual Maximum Flood	AMAX	The maximum recorded flow
Atkins-Mouchel Joint Venture	AMJV	The collaboration of Atkins Limited and Mouchel.
Baseline		The existing conditions which form the basis or start point of the environmental assessment.
Centre for Ecology and Hydrology	CEH	The Centre for Ecology & Hydrology is the United Kingdom's Centre of Excellence for integrated research in hydrology, terrestrial and freshwater ecosystems and their interaction with the atmosphere
Catchment		The area contributing flow to a point on a drainage system.
Catchment Wetness Index	CWI	The antecedent conditions within the catchment prior to an event.
Design Manual for Roads & Bridges.	DMRB	A series of 15 volumes that provide standards, advice notes and other documents relating to the design, assessment and operation of trunk roads, including motorways in the United Kingdom.
Dualling		The widening of an existing road in order to provide two carriageways in both directions.
Digital Terrain Model	DTM	A topographical model of the bare earth- terrain relief that can be manipulated by computer programmes.
Environment Agency	EA	Regulating body responsible for the welfare of the water environment and enforcing the WFD within England and Wales.
Environmental Impact Assessment	EIA	The process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse.
Flood Estimation Handbook	FEH	The guidance document for practitioners concerned with rainfall and flood frequency estimation.
Flood Risk Assessment	FRA	A flood risk assessment is an assessment of the risk of flooding from all flooding mechanisms, and the identification of flood mitigation measures.
Geographical Information System	GIS	A geographic information system is a computer system for capturing, storing, checking and displaying data related to positions on Earth’s surface.
Joint Venture	JV	The collaboration of two or more companies.
Minor watercourse		Not shown on 1:50k OS maps.
Metres above Ordnance Datum	m AOD	The height above the vertical datum used by an ordnance survey for deriving altitudes on maps.
National Grid Reference	NGR	The National Grid is the map reference system used on all Ordnance Survey maps to identify the position of any feature

Terminology	Abbreviation	Description
Ordnance Survey	OS	Mapping provider.
Potentially Vulnerable Areas	PVA	Areas identified as being at the greatest risk to the impact of flooding.
Flow	Q	
Median Annual Maximum Flood (m3/s)	QMED	The middle ranking value in a sample of ranked maximum flows.
Revitalised Flood Hydrograph	ReFH	A method for estimating peak flows.
Rainfall Runoff	RR	A method for estimating peak flows.
Root mean square error	RMSE	Standard error measurement technique
Standard Average Rainfall	SAAR	The 1961-1990 standard period average rainfall.
Scottish Environment Protection Agency	SEPA	Regulating body responsible for the welfare of the water environment and enforcing the WFD within Scotland
Time to Peak	T(p)	The unit hydrograph time to peak, expressed in hours.
Transport Scotland	TS	Transport Scotland is the national transport agency of Scotland

Event Severity

- The severity of the events discussed in this document are defined 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.

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
3.3%	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 climate change	1 in 200 years with climate change

1. Introduction

1.1.1 Following the completion of the Preliminary Engineering Support Services Report and Strategic Environmental Assessment, the Atkins-Mouchel Joint Venture (AMJV) was appointed by Transport Scotland to undertake a DMRB Stage 2 Assessment for the upgrade to dual carriageway of the stretch of the northern section of the A9 Trunk road between Dalraddy and Inverness. The Proposed Scheme referred to in this report is the upgrade of the A9 Dalraddy – Slochd which includes approximately 25km of new road and new watercourse crossings.

1.1.2 The DMRB Stage 3 Assessment includes a Flood Risk Assessment (FRA) (Appendix 11.3) which focuses on confirming the existing flood risk to the A9 and the surrounding area and assess the potential impacts of the Proposed Scheme Options.

1.1.3 The assessment study area is based on the catchment of the River Spey. This is to allow for the assessment of the impacts on downstream sensitive receptors as well as in the immediate vicinity of The Proposed Scheme. The immediate vicinity is considered to be 5km surrounding The Proposed Scheme, beginning south of Dalraddy at 285100 188000 and extending to north of Slochd Summit at 283450 825660.

1.1.4 The Proposed Scheme lies between approximately 33km and 55km southeast of Inverness, skirting the southern extent of the Monadliath Mountains and northern extent of the Cairngorms Mountains and National Park. The Proposed Scheme is located in the glacial valley of the River Spey.

1.1.5 The southern extent of the study area at Dalraddy lies at approximately 220 AOD (above Ordnance Datum), where the Allt an Fhearna crosses the existing A9. Continuing north the elevation of The Proposed Scheme rises to 280 AOD at Carrbridge and 405 AOD at Slochd Summit.

1.1.6 There are two parts to the assessment of fluvial flood risk:

- Assessment of the flow capacity of all existing watercourse crossings using 1D hydraulic models.
- Assessment of existing floodplains using 1D/2D linked models

1.1.7 The purpose of this Annex is to provide details of the hydrological and hydraulic modelling methodologies, key assumptions and the results which informed the Stage 3 DMRB Flood Risk Assessment:

  - Section 2 details the available data and comments on its suitability
  - Section 3 describes the method used to assess the capacity of water crossings including the alternative hydrological methods used to estimate flow and the 1D modelling. The results are given for each water crossing
  - Section 4 explains the method used to establish the existing floodplains using flood estimation techniques and linked 1D/2D models.
  - Sections 5 to 15 give the results for each of the 1D/2D models.

2. Data Review

2.1 Topographical Survey

2.1.1 Transport Scotland appointed Blom AEROFILMS, to undertake topographical survey works to provide information to facilitate outline and detailed design work for the A9

Dualling Programme. Transport Scotland provided the following key information as part of the contract with the AMJV:

- 1:2500 ortho-photo and grid DTM;
- Topographical survey at 1:500 Scale; (Captured to an accuracy of +/- 0.13m rmse in plan and +/- 0.020m rmse in height on hard surfaces and +/- 0.300m rmse in plan and +/- 0.100m rmse in height for other surfaces).
- High precision 1:500 survey of the carriageway envelopes; (Captured to an accuracy of +/- 0.06m rmse in plan and +/- 0.005m rmse in height on hard surfaces and +/- 0.15m rmse in plan and +/- 0.030m rmse in height for other surfaces). and,
- 3D models, including elevations and information of spans, headroom and clearance for each watercourse crossing and road structure.

2.1.2 In addition to the above information, Transport Scotland provided the NextMAP DTM ground model for a 10km wide strip surrounding the A9. NextMAP DTM data provides elevations at 5m x 5m grid postings and is quoted to have a vertical accuracy of +/- 700mm.

2.1.3 AMJV undertook additional topographical survey of watercourses and their floodplains in December 2015, April 2016 and October 2017. This included:

- Allt an Fhearna
- Allt Chriochaidh
- Loch Alvie
- Allt na Criche (Lynwilg)
- Aviemore Burn
- The Shieling / Easter Aviemore Burn
- Allt na Criche (Granish)
- Avielochan
- Allt Cnapach
- Fèith Mhòr
- River Dulnain
- Allt nan Ceatharnach
- Bogbain Burn
- Allt Slochd Mhuic

2.2 Hydrometric Data

2.2.1 The National River Flow Archivei provides hydrometric data for the gauging station networks across the UK.

2.2.2 The archive shows that there are number of gauging stations in the River Spey catchment, which are operated by SEPA. All the gauging stations are quality checked and are suitable for peak flow estimations.

2.2.3 Table 2-1 details the gauges identified within the study area of The Proposed Scheme.

Table 2-1: Gauging Stations within the River Spey Catchment

Gauging Station Number	Name	Watercourse	NGR	Catchment Area (km^2)	Record Length (years)
7008	Balnafoich	River Nairn	NH 685351	128	1993-Present
8002	Kinrara	River Spey	NH 880082	1012	1951-Present
8005	Boat of Garten	River Spey	NH 946192	1268	1951-Present
8007	Invertruim	River Spey	NN 687964	400	1952-Present
8009	Balnaan Bridge	River Dulnain	NH 977247	272	1952-Present
8010	Grantown	River Spey	NJ 032267	1749	1951-Present

2.2.4 In addition to the gauges identified in Table 2-1, a level only gauge was identified at Sluggan on the River Dulnain upstream of The Proposed Scheme. This gauge is operated and maintained by SEPA as part of the flood warning system.

2.2.5 Annual maxima (AMAX) flow series were received from SEPA for Boat of Garten, Balnaan Bridge and Grantown. Based on the available information eight high flow events were identified for potential use in model calibration or verification:

- 18/12/1966
- 05/02/1990
- 03/01/1992
- 17/01/1993
- 02/03/1997
- 11/01/2005
- 05/12/2014
- 30/12/2014

2.2.6 SEPA provided 15 minute rainfall data for 3 gauges located within the River Spey catchment and a further 2 gauges within the River Findhorn Catchment. Gauges' summary and their location in relation to the study area (Table 2-2). Figure A11.3.1 within Appendix A11.3: Flood Risk Assessment shows the location of the hydrometric gauging stations.

2.2.7 In addition to the eight identified high flow events outlined above, SEPA identified an event in August 2014 which resulted in flooding at Carrbridge. SEPA have provided level information for the flood wrack marks for this event.

Table 2-2: Rain Gauges relevant to the modelled reach

Rain Gauge	NGR	Catchment Location	Record Type	Records Available 1966	Records Available 1990	Record Available 1992	Record Available 1993	Record Available 1997	Record Available 2005	Record Available 2014
Coignafearn	270963 817820	River Findhorn	15 minute		Yes	Yes	Yes	Yes		
Freeburn	279547 830023	River Findhorn	15 minute					Yes	Yes	Yes
Sluggan	286980 821930	River Dulnain	15 minute					Yes		Yes
Auchdergannach	300345 815642	River Spey	15 minute							Yes
Glenmore Lodge No2	298640 809400	River Spey	15 minute						Yes	Yes

3. 1D Hydraulic Modelling

3.1 Existing Watercourse Crossings

3.1.1 All watercourses and crossings along The Proposed Scheme have been identified from the OS Mastermap, information provided by Transport Scotland relating to structures, and confirmed from site visits undertaken on the 22nd and 23rd March 2016.

3.1.2 There are 44 existing watercourse crossings under the A9 carriageway within The Proposed Scheme which all discharge into River Spey catchment. There are 18 that are identified on the digital river network and a total of 34 shown on the 1:10,000 OS Map. An additional 10 crossings were identified from the topographical survey and site visit information, with a total of 44 being considered. Figures A11.1.2a – A11.1.2i, within Appendix A11.2: Hydromorphology Assessment shows the watercourse crossing locations.

3.2 Hydrology

3.2.1 The FEH CD-ROM was applied to extract catchment descriptors for all of the delineated catchments. Donor catchments have been applied at specific locations where there is no FEH catchment. The choice of a 'donor' catchment was based on a location near the site, and comparison of the catchment steepness (DPSBAR), extent of urbanisation (URBEXT), standard percentage runoff (SPR) and catchment shape. The 'donor' catchments were scaled to the delineated inflow catchments.

3.2.2 Donor catchments have been used where:

- The subject catchment area <0.5km^2
- If the subject catchment is a small area within a very large FEH catchment a smaller section of the larger FEH catchment area has been identified with similar characteristics to the subject site and the descriptors scaled as appropriate.

3.2.3 The FEH scaled method has been used where an inflow location is close to but not co-located to the FEH catchment outflow point (e.g. where the inflow to a culvert crossing is required and the FEH catchments is cut by the road alignment). Small modifications have then been made to the descriptors.

3.2.4 The choice of donors and the scaling of FEH catchments involves professional judgment. For example, donor catchments can be a few kilometres from the inflow catchment where the inflow catchment is a small fraction of the FEH catchment.

3.2.5 Comparison of the delineated and FEH CD-ROM catchment areas are shown in Table 3.1.

3.2.6 The delineated catchment areas are considered more accurate than the catchment areas extracted from the FEH CD-ROM. For the existing crossings the inflow point is the entrance to the structure.

3.2.7 Table 3.2 shows the important catchment descriptors at each site, incorporating any changes that were made.

3.2.8 The URBEXT$_{1990}$ has been updated using the Council for the Protection of Rural England (CPRE) formula detailed in FEH Volume 5.

$$UEF = 0.8165 + 0.2254 \tan -1\{(\frac{year - 1967.5}{21.25})\}$$

3.2.9 The catchment descriptors were checked against the solid and superficial geological map, the land classification for agricultural map, Base Flow Index Scotland Map. There were no adjustments made to the catchment descriptors.

3.2.10 Table 3.1 details all waterbodies along The Proposed Scheme. Only 44 of these have been assessed at the Stage 3 FRA, as these are considered to be watercourse catchments, the table includes standing water and ponds.

Table 3-1: Waterbody Information and Flow Estimation Methodology

Watercourse Crossing ID	Waterbody	Watercourse	Easting	Northing	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	Easting	Northing	FEH Area (km^2)	Revised Catchment Area (km^2)
DS-WC-001	Watercourse	Allt an Fhearna	285411	809201	DS-WS-038	FEH	285350	809150	20.06	20.21
DS-WC-002	Watercourse	Allt Chriochaidh	285673	809525	DS-WS-037	FEH	285700	809500	2.56	2.58
DS-WC-003**	Watercourse	Allt Chriochaidh	285841	809604						
DS-WC-004	Watercourse	Caochan Ruadh	286649	810090	DS-WS-036	FEH	286650	810050	1.83	1.94
DS-WC-005	Watercourse	Ballinluig Burn	286864	810179	DS-WS-035	FEH	286900	810150	0.94	0.99
DS-WC-005A	Watercourse	Unnamed drain	287783	810491	DS-WS-034B	Donor	286950	810750	0.63	0.21
DS-WC-006	Watercourse	Unnamed drain	287870	810350	DS-WS-034A	Donor	286950	810750	0.63	0.008
DS-WC-007	Watercourse	Allt-na-Criche (Lynwilg)	288373	810606	DS-WS-034	FEH	288400	810600	6.17	6.47
DS-WC-008**	Watercourse	Unnamed drain	289085	811256						
DS-WC-009	Standing water body	Unnamed pond	289125	811969	DS-WS-033	FEH	289100	812100	0.78	1.18
DS-WC-010	Standing water body	Loch Puladdern	289103	812137	DS-WS-033	FEH	289100	812100	0.78	1.18
DS-WC-011	Standing water body	Loch Puladdern	289103	812137	DS-WS-033	FEH	289100	812100	0.78	1.18
DS-WC-012**	Watercourse	Unnamed drain	289088	812806						
DS-WC-013	Watercourse	Unnamed drain	289091	812951	DS-WS-032	Donor	288350	814100	0.9	0.44
DS-WC-013A	Watercourse	Unnamed drain	289308	813780	DS-WS-031	Donor	287850	813150	1.18	0.23
DS-WC-014	Watercourse	Aviemore Burn	289328	813857	DS-WS-030	FEH	289350	813000	6.95	6.29
DS-WC-015**	Watercourse	Unnamed drain	289412	814016						

Watercourse Crossing ID	Waterbody	Watercourse	Easting	Northing	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	Easting	Northing	FEH Area (km^2)	Revised Catchment Area (km^2)
DS-WC-016	Watercourse	The Shieling / Easter Aviemore Burn	289439	814153	DS-WS-029	FEH	289450	814150	0.52	0.6
DS-WC-017	Watercourse	Unnamed drain	289678	814722	DS-WS-028B	FEH	289650	815100	1.8	1.71
DS-WC-018**	Standing water body	Unnamed pond	289786	814868						
DS-WC-019	Watercourse	Bifurcated channel of Allt na Criche (Granish)	289818	815020	DS-WS-028A	FEH	289650	815100	1.8	0.22
DS-WC-020**	Standing water body	Unnamed pond	289949	815325						
DS-WC-021**	Watercourse	Allt na Criche (Granish)	289837	815399						
DS-WC-022	Watercourse	Allt na Criche (Granish)	290082	815665	DS-WS-028	FEH	290050	815650	2.73	2.71
DS-WC-023	Watercourse	Unnamed drain	290205	816295	DS-WS-027	Donor	288650	815650	0.61	0.12
DS-WC-024	Watercourse	Southern Avie Lochan Burn	290231	816404	DS-WS-026	FEH	290300	815650	2.78	1.15
DS-WC-025	Watercourse	Unnamed drain	290242	816463	DS-WS-025	Donor	290750	816800	0.63	0.16
DS-WC-026	Watercourse	Northern Avie Lochan Burn	290355	816744	DS-WS-024	Donor	290750	816800	0.63	0.51
DS-WC-027	Watercourse	Unnamed drain	290455	816905	DS-WS-023	Donor	290750	816800	0.63	0.31
DS-WC-028**	Standing water body	Unnamed pond	290646	817098						
DS-WC-029	Watercourse	Unnamed drain	290874	817531	DS-WS-022	Donor	290750	816800	0.63	0.16
DS-WC-030**	Standing water body	Unnamed pond	290921	817509						

Watercourse Crossing ID	Waterbody	Watercourse	Easting	Northing	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	Easting	Northing	FEH Area (km^2)	Revised Catchment Area (km^2)
DS-WC-031**	Watercourse	Unnamed drain	290931	817718						
DS-WC-032	Watercourse	Allt Cnapach	291044	818519	DS-WS-020	FEH	291050	818550	1.1	2.08
DS-WC-032A	Watercourse	Unnamed drain	291074	818984	DS-WS-019	Donor	291050	818550	1.1	0.11
DS-WC-033**	Watercourse	Unnamed drain	291075	818935						
DS-WC-034**	Watercourse	Unnamed drain	291095	819032						
DS-WC-035	Watercourse	Unnamed drain	290929	820175	DS-WS-018	Donor	291050	818550	1.1	0.27
DS-WC-035A	Watercourse	Unnamed drain	290920	820173	DS-WS-017	Donor	290400	819800	0.5	0.08
DS-WC-036	Watercourse	Feith Mhor	290762	820742	DS-WS-016	FEH	290700	820750	2.47	2.37
DS-WC-037**	Watercourse	Unnamed drain	290762	820798						
DS-WC-038**	Watercourse	Unnamed drain	290704	820831						
DS-WC-039	Watercourse	Unnamed drain	290708	820878	DS-WS-015	Donor	290850	820800	0.64	0.6
DS-WC-040**	Watercourse	Unnamed drain	290677	820904						
DS-WC-041	Watercourse	Unnamed drain	290637	821030	DS-WS-014	Donor	290400	819800	0.5	0.004
DS-WC-042	Watercourse	Unnamed drain	290598	821123	DS-WS-013	Donor	290400	819800	0.5	0.02
DS-WC-043	Watercourse	Unnamed drain	290561	821235	DS-WS-012	Donor	290300	820000	0.9	0.87
DS-WC-044**	Watercourse	Unnamed drain	289891	822342						
DS-WC-045	Watercourse	Unnamed drain	289761	822453	DS-WS-011	Donor	287600	820250	0.52	0.18
DS-WC-046	Watercourse	River Dulnain	289668	822548	DS-WS-010*	FEH	289650	822550	190.4	188.1
DS-WC-047**	Watercourse	Unnamed tributary of Allt nan Ceatharnach	289194	823003						
DS-WC-048	Watercourse	Allt nan Ceatharnach	289116	823155	DS-WS-009*	FEH	289300	822450	16.95	16.02
DS-WC-049	Watercourse	Unnamed drain	288509	823837	DS-WS-008	Donor	285950	821400	0.5	0.1

Watercourse Crossing ID	Waterbody	Watercourse	Easting	Northing	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	Easting	Northing	FEH Area (km^2)	Revised Catchment Area (km^2)
DS-WC-050	Watercourse	Unnamed drain	286840	823959	DS-WS-007	Donor	285950	821400	0.5	0.17
DS-WC-051	Watercourse	Unnamed drain	286246	823877	DS-WS-006	Donor	282800	822950	0.53	0.01
DS-WC-052	Watercourse	Unnamed drain	284620	824154	DS-WS-005	Donor	282800	822950	0.53	0.24
DS-WC-053	Watercourse	Unnamed drain	284382	824424	DS-WS-004	Donor	282800	822950	0.53	0.27
DS-WC-054**	Watercourse	Unnamed drain	284278	824565						
DS-WC-055	Watercourse	Unnamed drain	284276	824646	DS-WS-004A	Donor	282800	822950	0.53	0.27
DS-WC-056	Watercourse	Slochd Mhuic	284057	824933						
DS-WC-057	Watercourse	Slochd Mhuic	284085	824987	DS-WS-003	Donor	282800	822950	0.53	0.27
DS-WC-058**	Watercourse	Slochd Mhuic	284017	825180						
DS-WC-059**	Watercourse	Slochd Mhuic	283766	825398						
DS-WC-060	Watercourse	Unnamed tributary of Slochd Mhuic	283712	825451	DS-WS-002	FEH	283400	825650	1.23	1.4
DS-WC-061	Watercourse	Slochd Mhuic	283540	825610	DS-WS-002	FEH	283400	825650	1.23	1.4
DS-WC-062	Watercourse	Slochd Mhuic	283479	825672	DS-WS-002	FEH	283400	825650	1.23	1.4

*ID is for calculation purposes only ** Not been assessed.

Table 3-2: Key Catchment Descriptors

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST (%)	URBEXT	FPEXT
DS-WC-001	Watercourse	Allt an Fhearna	DS-WS-038	FEH	1	0.68	0.435	5.28	182.7	1075	47.07	0	0.0163
DS-WC-002	Watercourse	Allt Chriochaidh	DS-WS-037	FEH	1	0.68	0.45	2.46	212.4	1129	42.41	0	0.0066

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST (%)	URBEXT	FPEXT
DS-WC-004	Watercourse	Caochan Ruadh	DS-WS-036	FEH	1	0.68	0.505	1.58	195.7	982	39.48	0	0.0301
DS-WC-005	Watercourse	Ballinluig Burn	DS-WS-035	FEH	1	0.68	0.617	1.23	205.4	937	32.17	0	0.02
DS-WC-005A	Watercourse	Unnamed drain	DS-WS-034B	Donor Scaled	1	0.68	0.516	0.75	264	959	38.52	0	0.0237
DS-WC-006	Watercourse	Unnamed drain	DS-WS-034A	Donor Scaled	1	0.68	0.516	0.75	264	959	38.52	0	0.0237
DS-WC-007	Watercourse	Allt-na-Criche (Lynwilg)	DS-WS-034	FEH	0.982	0.68	0.44	2.78	203.5	1053	43.85	0	0.0089
DS-WC-009	Standing water body	Unnamed Pond	DS-WS-033	FEH	0.892	0.68	0.376	1.09	331.9	918	51.26	0	0.0032
DS-WC-010 DS-WC-011	Standing water body	Loch Puladdern	DS-WS-033	FEH	0.892	0.68	0.376	1.09	331.9	918	51.26	0	0.0032
DS-WC-013	Watercourse	Unnamed drain	DS-WS-032	Donor Scaled	1	0.68	0.334	1.27	116.2	1015	50.64	0	0.0306
DS-WC-013A	Watercourse	Unnamed drain	DS-WS-031	Donor Scaled	1	0.68	0.463	0.86	205.1	1028	41.47	0	0.0043
DS-WC-014	Watercourse	Aviemore Burn	DS-WS-030	FEH	0.988	0.68	0.421	2.74	158.8	999	44.9	0.0002	0.0243
DS-WC-016	Watercourse	The Shieling / Easter Aviemore Burn	DS-WS-029	FEH	1	0.68	0.428	1.03	137.8	922	44.73	0	0.0097
DS-WC-017	Watercourse	Unnamed drain	DS-WS-028B	FEH	1	0.68	0.402	1.34	149.9	945	47.01	0	0.0208
DS-WC-019	Watercourse	Bifurcated channel of Allt na Criche (Granish)	DS-WS-028A	FEH Scaled	1	0.68	0.402	1.85	149.9	945	47.01	0	0.0208
DS-WC-022	Watercourse	Allt na Criche (Granish)	DS-WS-028	FEH	1	0.68	0.416	1.73	163.6	928	46.64	0	0.0183
DS-WC-023	Watercourse	Unnamed drain	DS-WS-027	Donor Scaled	1	0.68	0.349	0.64	155.1	972	50.8	0	0

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST (%)	URBEXT	FPEXT
DS-WC-024	Watercourse	Southern Avie Lochan Burn	DS-WS-026	FEH	1	0.68	0.425	1.08	161.9	927	46.07	0	0.0225
DS-WC-025	Watercourse	Unnamed drain	DS-WS-025	Donor Scaled	1	0.68	0.584	0.63	173.9	854	36.66	0	0.1071
DS-WC-026	Watercourse	Northern Avie Lochan Burn	DS-WS-024	Donor Scaled	1	0.68	0.584	0.63	173.9	854	36.66	0	0.1071
DS-WC-027	Watercourse	Unnamed drain	DS-WS-023	Donor Scaled	1	0.68	0.584	0.63	173.9	854	36.66	0	0.1071
DS-WC-029	Watercourse	Unnamed drain	DS-WS-022	Donor	1	0.68	0.584	0.63	173.9	854	36.66	0	0.1071
DS-WC-031	Watercourse	Unnamed drain	DS-WS-021	Donor Scaled	1	0.68	0.346	0.55	196.1	871	52.88	0	0
DS-WC-032	Watercourse	Allt Cnapach	DS-WS-020	FEH Scaled	1	0.68	0.426	1.32	195.9	858	47.46	0	0.0038
DS-WC-032A	Watercourse	Unnamed drain	DS-WS-019	Donor Scaled	1	0.68	0.426	1.32	195.9	858	47.46	0	0.0038
DS-WC-035	Watercourse	Unnamed drain	DS-WS-018	Donor Scaled	1	0.68	0.426	1.32	195.9	858	47.46	0	0.0038
DS-WC-035A	Watercourse	Unnamed drain	DS-WS-017	Donor	1	0.68	0.473	0.62	169.7	828	44.48	0	0.0100
DS-WC-036	Watercourse	Feith Mhor	DS-WS-016	FEH	1	0.68	0.519	1.44	128.7	820	40.97	0	0.0171
DS-WC-039	Watercourse	Unnamed drain	DS-WS-015	Donor	1	0.68	0.661	0.86	70.7	787	35.51	0	0.0394
DS-WC-041	Watercourse	Unnamed drain	DS-WS-014	Donor	1	0.68	0.473	0.62	169.7	828	44.48	0	0.0100
DS-WC-042	Watercourse	Unnamed drain	DS-WS-013	Donor	1	0.68	0.473	0.62	169.7	828	44.48	0	0.0100
DS-WC-043	Watercourse	Unnamed drain	DS-WS-012	Donor	1	0.68	0.456	0.94	137.3	831	43.59	0	0.0139
DS-WC-045	Watercourse	Unnamed drain	DS-WS-011	Donor	1	0.68	0.664	0.82	74	865	33.6	0	0.0483
DS-WC-046	Watercourse	River Dulnain	DS-WS-010*	FEH	0.997	0.68	0.486	15.11	129.5	1086	49.6	0	0.0367

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Flow Estimation FEH/ FEH Scaled/Donor	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST (%)	URBEXT	FPEXT
DS-WC-048	Watercourse	Allt nan Ceatharnach	DS-WS-009*	FEH	0.993	0.68	0.338	5.47	114.4	979	51.49	0	0.0407
DS-WC-049	Watercourse	Unnamed drain	DS-WS-008	Donor	1	0.68	0.432	0.79	136.5	898	44.04	0	0.0100
DS-WC-050	Watercourse	Unnamed drain	DS-WS-007	Donor	1	0.68	0.432	0.79	136.5	898	44.04	0	0.0100
DS-WC-051	Watercourse	Unnamed drain	DS-WS-006	Donor	1	0.68	0.38	0.59	173.5	1037	55.06	0	0.0048
DS-WC-052	Watercourse	Unnamed drain	DS-WS-005	Donor	1	0.68	0.38	0.59	173.5	1037	55.06	0	0.0048
DS-WC-053	Watercourse	Unnamed drain	DS-WS-004	Donor	1	0.68	0.38	0.59	173.5	1037	55.06	0	0.0048
DS-WC-055	Watercourse	Unnamed drain	DS-WS-004A	Donor	1	0.68	0.38	0.59	173.5	1037	55.06	0	0.0048
DS-WC-057	Watercourse	Slochd Mhuic	DS-WS-003	Donor	1	0.68	0.38	0.59	173.5	1037	55.06	0	0.0048
DS-WC-060	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	FEH	1	0.68	0.277	0.81	215.8	1001	55.95	0	0.0224
DS-WC-061	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	FEH	1	0.68	0.277	0.81	215.8	1001	55.95	0	0.0224
DS-WC-062	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	FEH	1	0.68	0.277	0.81	215.8	1001	55.95	0	0.0224

Peak flow Estimation

3.2.11 Peak flow estimations were derived for each catchment using the FEH standard methodologies:

- FEH Rainfall Runoff Method
- FEH Statistical Approach (where catchment > 5km^2)

3.2.12 Table 3-3 details the methodology limitations and guidance on appropriate methodologies.

Table 3-3: FEH Methodologies and Limits of application

	Return Period Limits	Catchment Area Limits	Urbanisation Limits	Other limits
FEH Statistical Method	50- 0.5% (has been applied up to 0.1%)	Over 0.5km^2 but can be applied to smaller areas	$URBEXT_{1990}$ up to 0.5	Suitable for Permeable catchments
Rainfall Runoff Method	50%-0.5%	0.5 to 1000km^2 but can be applied to smaller areas	$URBEXT_{1990}$ up to 0.5	

Table Source: EA, 2015

3.2.13 Design peak flows were derived for the following return periods; 50%, 20%, 10%, 4%, 3.3%, 2%, 1%, 0.5%, 0.5% including a 20% allowance for climate change and 0.1% Annual Exceedance Probability event.

3.2.14 For all catchments the Rainfall Runoff method was undertaken. The Statistical Method was applied for all catchments with an area greater than 5km^2, this includes:

- DS-WC-001
- DS-WC-007
- DS-WC-014
- DS-WC-046
- DS-WC-048

Rainfall Runoff

3.2.15 The rainfall runoff method uses the FEH DDF (depth duration frequency) model to estimate rainfall totals, these are then distributed according to either a 75% winter or 50% summer profile. They take account of the Catchment Wetness Index (CWI) which is estimated for SAAR (Standard Average Annual Rainfall) and base flow which is calculated using equation 2.19 in the FEH volume 4. Flows are estimated using the unit hydrograph and losses model. For the design events, the rainfall totals, rainfall profiles, CWI, base flow and unit hydrograph and losses model for each sub-catchment were estimated using FEH boundaries in ISIS 3.7.

3.2.16 Table 3-4 details the parameters for the FEH rainfall Runoff models and Table 3-5 details peak flow outputs from the FEH rainfall Runoff model.

3.2.17 For each of the subject sites the storm duration has been optimised to generate the highest peak flow.

Table 3-4: Rainfall Runoff Method Input Parameters

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Rural (R) Urban (U)	Tp (0): Method	Tp Value (hours)	SPR Method	SPR Value (%)	Baseflow Method	Baseflow Value (m3/s)
DS-WC-001	Watercourse	Allt an Fhearna	DS-WS-038	R	CD	2.357	CD	44.33	CD	0.014
DS-WC-002	Watercourse	Allt Chriochaidh	DS-WS-037	R	CD	1.50	CD	42.41	CD	0.086
DS-WC-004	Watercourse	Caochan Ruadh	DS-WS-036	R	CD	1.22	CD	39.48	CD	0.053
DS-WC-005	Watercourse	Ballinluig Burn	DS-WS-035	R	CD	1.058	CD	32.17	CD	0.026
DS-WC-005A	Watercourse	Unnamed drain	DS-WS-034B	R	CD	0.248	CD	38.52	CD	0.018
DS-WC-006	Watercourse	Unnamed drain	DS-WS-034A	R	CD	0.248	CD	38.52	CD	0.018
DS-WC-007	Watercourse	Allt-na-Criche (Lynwilg)	DS-WS-034	R	CD	1.621	CD	51.75	CD	0.203
DS-WC-010	Standing water body	Loch Puladdern	DS-WS-033	R	CD	0.849	CD	51.26	CD	0.032
DS-WC-013	Watercourse	Unnamed drain	DS-WS-032	R	CD	1.30	CD	50.64	CD	0.027
DS-WC-013A	Watercourse	Unnamed drain	DS-WS-031	R	CD	0.881	CD	41.47	CD	0.036
DS-WC-014	Watercourse	Aviemore Burn	DS-WS-030	R	CD	1.748	CD	44.9	CD	0.187
DS-WC-016	Watercourse	The Shieling / Easter Aviemore Burn	DS-WS-029	R	CD	1.103	CD	44.73	CD	0.014
DS-WC-017	Watercourse	Unnamed drain	DS-WS-028B	R	CD	1.229	CD	47.01	CD	0.048

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Rural (R) Urban (U)	Tp (0): Method	Tp Value (hours)	SPR Method	SPR Value (%)	Baseflow Method	Baseflow Value (m3/s)
DS-WC-019	Watercourse	Bifurcated channel of Allt na Criche (Granish)	DS-WS-028A	R	CD	1.453	CD	47.01	CD	0.05
DS-WC-022	Watercourse	Allt na Criche (Granish)	DS-WS-028	R	CD	1.363	CD	46.64	CD	0.074
DS-WC-023	Watercourse	Unnamed drain	DS-WS-027	R	CD	0.83	CD	50.8	CD	0.018
DS-WC-024	Watercourse	Southern Avie Lochan Burn	DS-WS-026	R	CD	1.071	CD	46.07	CD	0.187
DS-WC-025	Watercourse	Unnamed drain	DS-WS-025	R	CD	0.795	CD	36.66	CD	0.015
DS-WC-026	Watercourse	Northern Avie Lochan Burn	DS-WS-024	R	CD	0.795	CD	36.66	CD	0.015
DS-WC-027	Watercourse	Unnamed drain	DS-WS-023	R	CD	0.795	CD	36.66	CD	0.015
DS-WC-029	Watercourse	Unnamed drain	DS-WS-022	R	CD	0.795	CD	36.66	CD	0.015
DS-WC-031	Watercourse	Unnamed drain	DS-WS-021	R	CD	0.714	CD	52.88	CD	0.013
DS-WC-032	Watercourse	Allt Cnapach	DS-WS-020	R	CD	1.115	CD	47.46	CD	0.027
DS-WC-032A	Watercourse	Unnamed drain	DS-WS-019	R	CD	1.115	CD	47.46	CD	0.027
DS-WC-035	Watercourse	Unnamed drain	DS-WS-018	R	CD	1.115	CD	47.46	CD	0.027
DS-WC-035A	Watercourse	Unnamed drain	DS-WS-017	R	CD	1.7	CD	44.48	CD	0.002

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Rural (R) Urban (U)	Tp (0): Method	Tp Value (hours)	SPR Method	SPR Value (%)	Baseflow Method	Baseflow Value (m3/s)
DS-WC-036	Watercourse	Feith Mhor	DS-WS-016	R	CD	2.9	CD	40.97	CD	0.053
DS-WC-039	Watercourse	Unnamed drain	DS-WS-015	R	CD	2.7	CD	35.51	CD	0.012
DS-WC-041	Watercourse	Unnamed drain	DS-WS-014	R	CD	1.1	CD	44.48	CD	0.011
DS-WC-042	Watercourse	Unnamed drain	DS-WS-013	R	CD	1.5	CD	44.48	CD	0.011
DS-WC-043	Watercourse	Unnamed drain	DS-WS-012	R	CD	2.3	CD	43.59	CD	0.020
DS-WC-045	Watercourse	Unnamed drain	DS-WS-011	R	CD	2.5	CD	33.6	CD	0.005
DS-WC-046	Watercourse	River Dulnain	DS-WS-010*	R	CD	10.3	CD	49.6	CD	6.008
DS-WC-048	Watercourse	Allt nan Ceatharnach	DS-WS-009*	R	CD	6.3	CD	51.49	CD	0.465
DS-WC-049	Watercourse	Unnamed drain	DS-WS-008	R	CD	2.0	CD	44.04	CD	0.003
DS-WC-050	Watercourse	Unnamed drain	DS-WS-007	R	CD	2.0	CD	44.04	CD	0.005
DS-WC-051	Watercourse	Unnamed drain	DS-WS-006	R	CD	1.5	CD	55.06	CD	0.016
DS-WC-052	Watercourse	Unnamed drain	DS-WS-005	R	CD	1.5	CD	55.06	CD	0.007
DS-WC-053	Watercourse	Unnamed drain	DS-WS-004	R	CD	1.5	CD	55.06	CD	0.008

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Rural (R) Urban (U)	Tp (0): Method	Tp Value (hours)	SPR Method	SPR Value (%)	Baseflow Method	Baseflow Value (m3/s)
DS-WC-055	Watercourse	Unnamed drain	DS-WS-004A	R	CD	1.5	CD	55.06	CD	0.008
DS-WC-057	Watercourse	Slochd Mhuic	DS-WS-003	R	CD	1.5	CD	55.06	CD	0.008
DS-WC-060	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	R	CD	1.8	CD	55.95	CD	0.042
DS-WC-061	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	R	CD	1.8	CD	55.95	CD	0.042
DS-WC-062	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	R	CD	1.8	CD	55.95	CD	0.042

Table 3-5: Rainfall Runoff Peak Flows

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Storm Duration (hours)	50%	20%	10%	4%	3.3%	2%	1%	0.5%	0.5% including CC	0.1%
DS-WC-001	Watercourse	Allt an Fhearna	DS-WS-038	5.1	13.38	18.28	21.75	26.74	28.07	31.96	36.86	42.69	51.23	61.39
DS-WC-002	Watercourse	Allt Chriochaidh	DS-WS-037	3.3	2.11	2.88	3.43	4.21	4.36	4.89	5.69	6.60	7.92	9.51
DS-WC-004	Watercourse	Caochan Ruadh	DS-WS-036	3.1	1.59	2.18	2.60	3.20	3.32	3.71	4.31	5.02	6.03	7.30
DS-WC-005	Watercourse	Ballinluig Burn	DS-WS-035	2.9	0.65	0.90	1.07	1.32	1.37	1.52	1.77	2.08	2.50	3.07
DS-WC-005A	Watercourse	Unnamed drain	DS-WS-034B	1.1	0.41	0.59	0.72	0.91	0.95	1.04	1.23	1.42	1.71	2.11
DS-WC-006	Watercourse	Unnamed drain	DS-WS-034A	1.1	0.16	0.22	0.27	0.35	0.36	0.40	0.47	0.54	0.65	0.80

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Storm Duration (hours)	50%	20%	10%	4%	3.3%	2%	1%	0.5%	0.5% including CC	0.1%
DS-WC-007	Watercourse	Allt-na-Criche (Lynwilg)	DS-WS-034	3.5	4.78	6.53	7.77	9.55	9.90	11.07	12.88	14.95	17.94	21.52
DS-WC-010 DS-WC-011	Standing water body	Loch Puladdern	DS-WS-033	1.7	1.53	2.14	2.58	3.23	3.36	3.77	4.29	4.97	5.97	7.33
DS-WC-013	Watercourse	Unnamed drain	DS-WS-032	2.9	0.47	0.65	0.78	0.97	1.00	1.13	1.31	1.53	1.84	2.22
DS-WC-013A	Watercourse	Unnamed drain	DS-WS-031	1.7	0.25	0.35	0.42	0.52	0.54	0.61	0.70	0.82	0.98	1.22
DS-WC-014	Watercourse	Aviemore Burn	DS-WS-030	3.9	4.83	6.61	7.87	9.69	10.05	11.41	13.21	15.32	18.39	22.08
DS-WC-016	Watercourse	The Shieling / Easter Aviemore Burn	DS-WS-029	2.7	0.53	0.74	0.89	1.10	1.15	1.29	1.50	1.76	2.11	2.59
DS-WC-017	Watercourse	Unnamed drain	DS-WS-028B	2.7	1.72	2.39	2.88	3.59	3.73	4.19	4.91	5.75	6.90	8.44
DS-WC-019	Watercourse	Bifurcated channel of Allt na Criche (Granish)	DS-WS-028A	3.1	0.20	0.28	0.33	0.41	0.43	0.49	0.57	0.66	0.79	0.97
DS-WC-022	Watercourse	Allt na Criche (Granish)	DS-WS-028	3.3	2.52	3.50	4.20	5.21	5.42	6.15	7.16	8.35	10.02	12.18
DS-WC-023	Watercourse	Unnamed drain	DS-WS-027	1.7	0.17	0.24	0.29	0.37	0.38	0.43	0.50	0.59	0.71	0.88
DS-WC-024	Watercourse	Southern Avie Lochan Burn	DS-WS-026	2.5	1.23	1.72	2.07	2.59	2.69	3.02	3.53	4.14	4.97	6.11

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Storm Duration (hours)	50%	20%	10%	4%	3.3%	2%	1%	0.5%	0.5% including CC	0.1%
DS-WC-025	Watercourse	Unnamed drain	DS-WS-025	1.7	0.16	0.22	0.27	0.34	0.36	0.40	0.46	0.55	0.66	0.83
DS-WC-026	Watercourse	Northern Avie Lochan Burn	DS-WS-024	1.7	0.50	0.71	0.86	1.09	1.13	1.28	1.46	1.75	2.10	2.66
DS-WC-027	Watercourse	Unnamed drain	DS-WS-023	1.7	0.31	0.43	0.53	0.66	0.69	0.78	0.89	1.06	1.27	1.61
DS-WC-029	Watercourse	Unnamed drain	DS-WS-022	1.7	0.16	0.22	0.27	0.34	0.36	0.40	0.46	0.55	0.66	0.83
DS-WC-031	Watercourse	Unnamed drain	DS-WS-021	1.5	0.80	1.17	1.40	1.75	1.82	2.04	2.35	2.76	3.31	3.71
DS-WC-032	Watercourse	Allt Cnapach	DS-WS-020	2.7	1.15	1.68	2.03	2.52	2.62	2.93	3.39	3.98	4.78	5.70
DS-WC-032A	Watercourse	Unnamed drain	DS-WS-019	2.7	0.12	0.16	0.20	0.24	0.25	0.28	0.33	0.38	0.46	0.56
DS-WC-035	Watercourse	Unnamed drain	DS-WS-018	2.7	0.28	0.40	0.47	0.59	0.61	0.68	0.80	0.93	1.12	1.35
DS-WC-035A	Watercourse	Unnamed drain	DS-WS-017	1.7	0.10	0.14	0.17	0.22	0.23	0.25	0.29	0.35	0.41	0.52
DS-WC-036	Watercourse	Feith Mhor	DS-WS-016	2.9	1.81	2.58	3.10	3.85	4.00	4.49	5.28	6.19	7.43	9.14
DS-WC-039	Watercourse	Unnamed drain	DS-WS-015	2.7	0.40	0.58	0.70	0.87	0.90	1.01	1.20	1.42	1.70	2.13
DS-WC-041	Watercourse	Unnamed drain	DS-WS-014	1.3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
DS-WC-042	Watercourse	Unnamed drain	DS-WS-013	1.7	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.08	0.10
DS-WC-043	Watercourse	Unnamed drain	DS-WS-012	2.3	0.84	1.20	1.45	1.81	1.89	2.12	2.46	2.90	3.48	4.29

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Storm Duration (hours)	50%	20%	10%	4%	3.3%	2%	1%	0.5%	0.5% including CC	0.1%
DS-WC-045	Watercourse	Unnamed drain	DS-WS-011	2.5	0.13	0.19	0.23	0.28	0.30	0.33	0.39	0.47	0.56	0.70
DS-WC-046*	Watercourse	River Dulnain	DS-WS-010*	10.5	90.08	122.45	146.25	182.54	189.72	212.71	242.17	277.08	332.49	387.78
DS-WC-048	Watercourse	Allt nan Ceatharnach	DS-WS-009*	6.5	11.12	15.37	18.17	22.91	23.86	26.88	30.75	35.34	42.41	49.96
DS-WC-049	Watercourse	Unnamed drain	DS-WS-008	2.1	0.11	0.16	0.19	0.23	0.24	0.27	0.32	0.38	0.45	0.56
DS-WC-050	Watercourse	Unnamed drain	DS-WS-007	2.1	0.19	0.27	0.33	0.41	0.43	0.48	0.56	0.66	0.79	0.97
DS-WC-051	Watercourse	Unnamed drain	DS-WS-006	1.3	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.09	0.11
DS-WC-052	Watercourse	Unnamed drain	DS-WS-005	1.5	0.39	0.58	0.70	0.88	0.92	1.03	1.20	1.41	1.69	2.09
DS-WC-055	Watercourse	Unnamed drain	DS-WS-004A	1.5	0.45	0.66	0.80	1.00	1.05	1.18	1.36	1.61	1.93	2.39
DS-WC-053	Watercourse	Unnamed drain	DS-WS-004	1.5	0.44	0.64	0.78	0.98	1.02	1.15	1.33	1.56	1.88	2.32
DS-WC-057	Watercourse	Slochd Mhuic	DS-WS-003	1.5	0.45	0.65	0.79	1.00	1.04	1.17	1.36	1.60	1.92	2.38
DS-WC-060	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	1.9	2.21	3.18	3.83	4.78	4.97	5.58	6.47	7.56	9.07	11.04
DS-WC-061	Watercourse	Unnamed tributary of Slochd Mhuic	DS-WS-002	1.9	2.21	3.18	3.83	4.78	4.97	5.58	6.47	7.56	9.07	11.04
DS-WC-062	Watercourse	Unnamed tributary of	DS-WS-002	1.9	2.21	3.18	3.83	4.78	4.97	5.58	6.47	7.56	9.07	11.04

Watercourse Crossing ID	Waterbody	Watercourse	Catchment ID*	Storm Duration (hours)	50%	20%	10%	4%	3.3%	2%	1%	0.5%	0.5% including CC	0.1%
		Slochd Mhuic												

*See section on River Dulnain Verification

Statistical Method

3.2.18 The Statistical Method uses an index flood, the median annual flood (QMED). This is multiplied by a growth curve factor to obtain a flood frequency curve. The flood frequency curve is based on a sample of at least 500 years of data from catchments identified as being similar to the subject site. All calculations were undertaken using WINFAP FEH 4 software and are recorded in a FEH Calculation Record.

3.2.19 The statistical method has been completed for the following watercourse crossings, as these have catchment areas greater than $5km^2$ and the methodology is considered appropriate.

- DS-WC-001
- DS-WC-007
- DS-WC-014
- DS-WC-046
- DS-WC-048

3.2.20 DS-WC-001 was previously assessed as part of the A9 Kincraig –Dalraddy Flood Risk Assessment. The peak flow estimates were reviewed as part of this study.

3.2.21 Donor catchments were sought to improve the QMED estimates. Table 3.6 details the donor catchments which were considered.

3.2.22 SEPA provided updated gauge information for 8009 including the Annual Maximum. The QMED estimate for 8009 is based on this revised data, all other estimates are based on the Annual Maximum (AM) series available on the National River Flow Archive (NRFA).

Table 3-6: Potential Donor Sites

NRFA Number	Name	Reason for Choosing or Rejecting	Method for Estimating QMED	QMED from Flow (A)	QMED from Catchment Descriptors (B)	Adjustment Ratio
8009	Dulnain @ Balnaan Bridge	Accepted as a donor for DS-WC-046, and DS-WC-48. Gauge is located downstream of the subject site. For all other sites the catchment area is significantly larger.	AM	98.72	70.29	1.40
8001	Spey @ Aberlour	Rejected: The catchment areas are significantly larger than the subject site.	AM	415.62	541.11	0.77
8006	Spey @ Boat o Brig	Rejected: The catchment areas are significantly larger than the subject site.	AM	478.53	569.52	0.84
8010	Spey @ Grantown	Rejected: The catchment areas are significantly larger than the subject site.	AM	227.23	387.19	0.59

NRFA Number	Name	Reason for Choosing or Rejecting	Method for Estimating QMED	QMED from Flow (A)	QMED from Catchment Descriptors (B)	Adjustment Ratio
7001	Findhorn @ Shenachie	Rejected: The catchment areas are significantly larger than the subject site.	AM	248.08	151.42	1.64

3.2.23 The initial QMED has been estimated from catchment descriptors using the equation below, as recommended in EA Science Report: SC50050 Improving the FEH statistical procedures for flood estimation.

3.2.24 $QMED = 8.3062\ xAREA^{0.8510}\ x0.1536^{\frac{1000}{SAAR}}\ x\ FARL^{3.4451} x\ 0.0460^{BFIHOST}$

3.2.25 Table 3-7 details the initial QMED estimate including any adjustments to determine the Final QMED. The URBEXT2000 has been updated based on equation below.

$$UEF = 0.7851 + 0.2124\ tan -1\{\frac{year - 1967.5}{20.32})\}$$

Table 3-7: QMED Estimates

Watercourse Crossing ID	Watercourse	Catchment ID	Initial QMED Estimate	Donor Site	Moderate Adjustment	Final Estimate of QMED (m3/s)
DS-WC-001	Allt an Fhearna	DS-WS-038	10.42	N/A		10.42
DS-WC-007	Allt-na-Criche (Lynwilg)	DS-WS-034	3.41	N/A		3.41
DS-WC-014	Aviemore Burn	DS-WS-030	3.71	N/A		3.71
DS-WC-046	River Dulnain	DS-WS-010	61.01	8009	1.15	70.32
DS-WC-048	Allt nan Ceatharnach	DS-WS-009	8.92	8009	1.13	10.10

3.2.26 For each subject site pooling groups were derived using the WINFAP-FEH 4 software, with version 4 and 5 WINFAP files. A target of 500 years was used for each pooling group. Each default pooling group was reviewed and Table 3.8 details the changes that were made.

3.2.27 All the sites are essentially rural and no urban adjustments were made Table 3.9 shows the distribution applied to generate the growth curve and the parameters. Table 3.10 shows the peak flow estimated.

Table 3-8: Pooling Group Composition

Watercourse Crossing ID	Watercourse	Catchment ID	Changes made to the default pooling group	Weighted average L-CV & L-SKEW
DS-WC-001	Allt an Fhearna	DS-WS-038	44008 - Station removed: chalk catchment, SPRHOST=19.55 22003 – Station removed: Uncertainty about the highest flows 50009 – Station removed: bypassing occurs 448009 – Station removed: Chalk Catchment 26802 - Station removed: hydrological response predominantly dominated by groundwater, SPRHOST = 5.67, record length 13 years which is a little short 44006 – Station removed: Chalk catchment 73015 – Station removed: Flat growth curve Other sites removed to bring length of record to 500 years	L-CV - 0.214 L- Skew – 0.216
DS-WC-007	Allt-na-Criche (Lynwilg)	DS-WS-034	45816 – Station removed: 49006 – Station removed: Short record length 44008- Station removed: Chalk catchment. 26802 – Station removed: Chalk catchment. 47022 – Station removed: Catchment is affected by china clay workings 48004 – Station removed: Use with caution. It can be retained but has been removed to reduce the record length 48009 – Station removed: Use with caution and discordant.	L-CV -0.237 L- Skew – 0.270
DS-WC-014	Aviemore Burn	DS-WS-030	49006 – Station removed: Short record length 44008 – Station removed: Chalk catchment. 47022 – Station removed: Catchment is affected by china clay workings. 48004 – Station removed: Use with caution, it can be retained but has been removed to reduce the record length. 48009 – Station removed: Discordant and only used for pooling with caution. 26802 – Station removed: Chalk catchment.	L-CV – 0.236 L-Skew – 0.269
DS-WC-046	River Dulnain (at A9 Crossing)	DS-WS-010	47006 – Station removed: Reservoir operation affects flows. FARL value in FEH catchment descriptors is pre-reservoir FARL is now 0.95. 28023 – Station removed: Permeable chalk catchment, SPR low at 14.32.	L-CV – 0.212 L-SKEW – 0.185

Watercourse Crossing ID	Watercourse	Catchment ID	Changes made to the default pooling group	Weighted average L-CV & L-SKEW
DS-WC-048	Allt nan Ceatharnach	DS-WS-009	44008 – Station removed: Chalk catchment. 26802 – Station removed: Chalk catchment. 47022 – Station removed: High Urbext and low FARL. 49006 – Station removed: Short record length 6 years. 51002 – Station removed: Growth curve fitting. 44013 – Station removed: Chalk catchment. 48009 - Station removed: Negative SKEW 73015 – Station removed: Flat growth curve and 0 L-skew value 26803 – Station removed: Chalk catchment.	L-CV 0.229 L-Skew- 0.233

Table 3-9: Derivation of Flood Growth Curves

Watercourse Crossing ID	Watercourse	Catchment ID	Distribution used and reason for choice	Note Permeable or Urban adjustment	Parameters	Growth factor for 100 year return period
DS-WC-001	Allt an Fhearna	DS-WS-038	GL – Provides the best fit and is recommended for UK catchments. GEV also provides an acceptable fit but not used	N/A	Location: 1.00 Scale:0.214 Shape: -0.217	2.684
DS-WC-007	Allt-na-Criche (Lynwilg)	DS-WS-034	GL – Provides the best fit and is recommended for UK catchments.	N/A	Location: 1.00 Scale: 0.233 Shape: -0.270	3.122
DS-WC-014	Aviemore Burn	DS-WS-030	GL – Provides the best fit and is recommended for UK catchments.	N/A	Location: 1.00 Scale: 0.233 Shape: =-0.269	3.114

Watercourse Crossing ID	Watercourse	Catchment ID	Distribution used and reason for choice	Note Permeable or Urban adjustment	Parameters	Growth factor for 100 year return period
DS-WC-046	River Dulnain	DS-WS-010	GL – Provides the best fit and is recommended for UK catchments.	N/A	Location: 1.00 Scale: 0.199 Shape: -0.199	2.556
DS-WC-048	Allt nan Ceatharnach	DS-WS-009	GL – Provides the best fit and is recommended for UK catchments.	N/A	Location: 1.00 Scale: 0.229 Shape: -0.233	2.880

Table 3-10: Statistical Peak Flow Estimates (m^3/s)

Watercourse Crossing ID	Watercourse	Catchment ID*	50%	20%	10%	4%	3.3%	2%	1%	0.5%	0.5% including CC
DS-WC-001	Allt an Fhearna	DS-WS-038	10.4	14.0	16.7	20.6	21.5	24.0	28.0	32.5	39.0
DS-WC-007	Allt-na-Criche (Lynwilg)	DS-WS-034	3.4	4.8	5.8	7.4	7.8	8.9	10.7	12.8	15.3
DS-WC-014	Aviemore Burn	DS-WS-030	3.4	4.7	5.8	7.3	7.7	8.8	10.5	12.6	15.2
DS-WC-046*	River Dulnain (using distance weighted adjustment)	DS-WS-010	70.6	94.4	111.5	135.8	141.0	156.5	179.8	206.1	247.3
DS-WC-046*	River Dulnain (using direct adjustment)	DS-WS-010	83.8	112.1	132.4	161.3	167.5	185.9	213.5	244.7	293.7
DS-WC-048	Allt nan Ceatharnach	DS-WS-009	10.1	13.9	16.7	21.0	21.9	24.7	29.1	34.2	41.0

*See section on River Dulnain Verification

Revitalised Flood Hydrograph Version 2.2

3.2.28 The revitalised flood hydrograph 2 (ReFH2) is an update on the ReFH method published in 2005. Until recently ReFH had not been verified by SEPA as an accepted methodology in Scotland.

3.2.29 The ReFH model has three components; a loss model, a routing model and a baseflow model. The loss model uses a soil moisture accounting approach to define the rainfall which is converted to direct runoff. The model allows for the use of FEH13 Depth Duration and Frequency rainfall models. The depth for a given duration and frequency is assigned a seasonal storm profile and area correction factor.

3.2.30 A sensitivity analysis was undertaken for a sample of catchments across the study area for comparison purposes only to check for anomalies in the hydrological outputs. Table 3.12 details peak flow outputs from the REFH2 model for the sample catchments.

River Dulnain Validation

3.2.31 Available rainfall data from the gauge at Sluggan in the catchment, and flow data recorded at Balnaan gauging station were analysed. The information was used to calibrate a FEH rainfall-runoff model at the site.

3.2.32 Rainfall data from 01/11/93 to 07/07/16 and flow data for events in Jan/Feb 1990, Dec 1991/Jan 1992, Jan 1993, Feb/Mar 1997, Jan 2005, Aug 2014 and Nov/Dec 2014 were available.

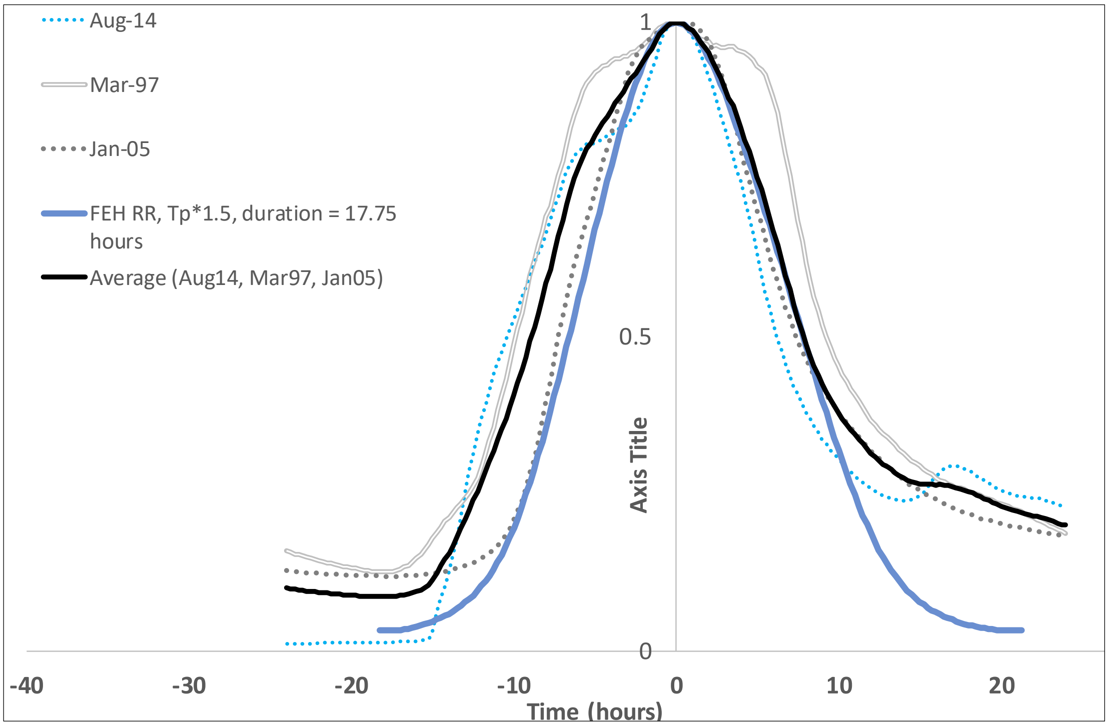
3.2.33 The Balnaan gauging station is located downstream of the hydraulic model reach. The catchment area at this location is 272 km^2, whereas the catchment boundary at the A9 crossing is 189 km^2.

Standardised Hydrograph

3.2.34 So that a recorded flood hydrograph could be compared with the FEH rainfall-runoff hydrograph, a standardised hydrograph analysis was carried out. Time series data for 6 flood events was available; however, 3 of these were discarded because they have more than 1 peak, or a long-duration peak.

3.2.35 A FEH rainfall-runoff model at the gauge was also created, using the recommended critical duration of 17.75 hours. Using Tp*1.5 in the FEH rainfall-runoff model produced a design hydrograph which compares well with the standardised hydrographs. This is shown in Figure 3.1.

Figure 3-1 Standardised Hydrographs at Balnaan gauge

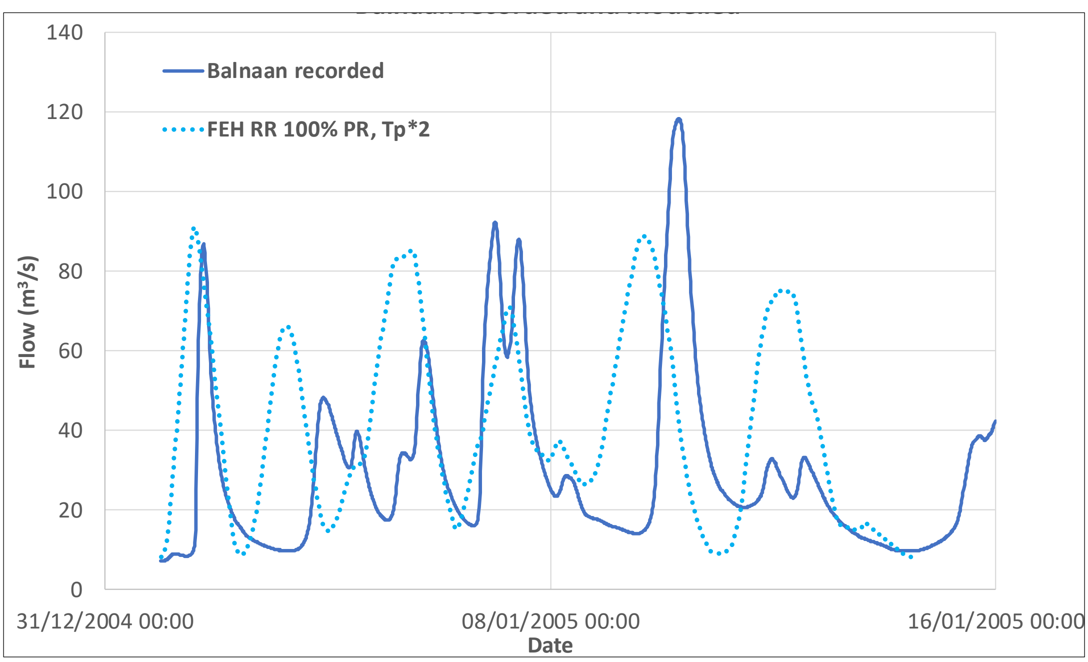


FEH Rainfall Runoff Calibration

3.2.36 A calibration of the FEH rainfall-runoff hydrograph at Balnaan was also undertaken, using rainfall data recorded at the Sluggan gauge in the catchment and flow data recorded at Balnaan. The results are summarised below:

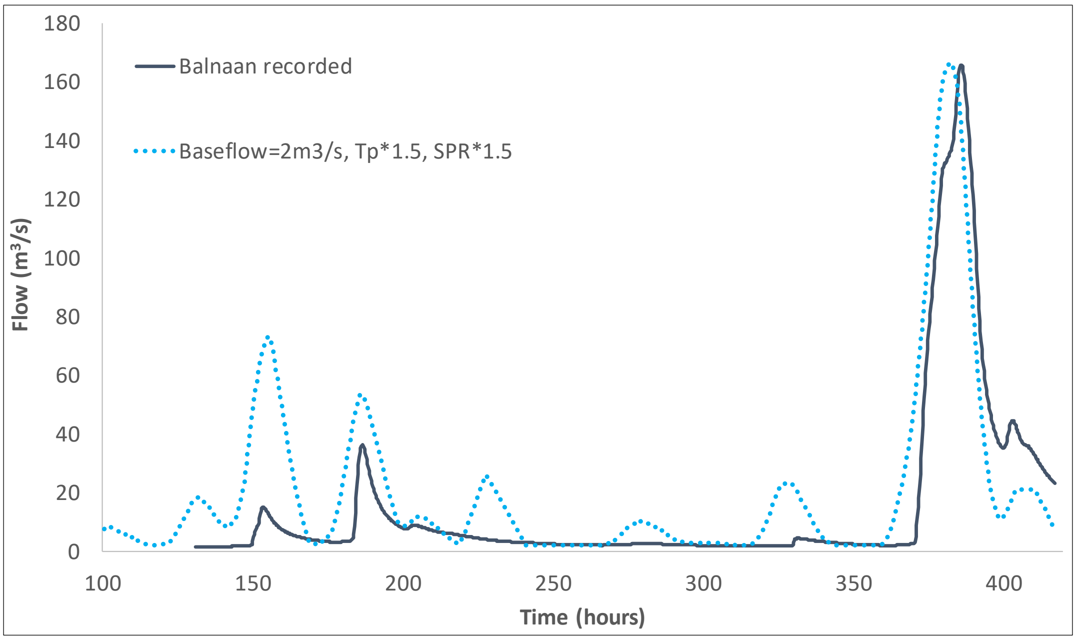
1. December 2014- no time series data was available for Balnaan, but using the Tp*1.5 the modelled peak is close to the recorded AMAX (modelled = 113 cumecs, recorded = 116 cumecs).
2. January 2005 - calibration not possible, even with 100% runoff.

Figure 3-2 January 2005 Calibration



3. August 2014 - reasonable calibration with Tp*1.5 and SPR 70% (SPR*1.5). API5 estimated and used to calculate CWI, but no SMD data available (so assumed to be 0).

Figure 3-3 August 2014 Calibration



3.2.37 The return period of the August 2014 event at Balnaan was estimated using the available AMAX data. The peak flow of the event provided in the SEPA time series data is 165.807 m^3/s on the 11/08/2014. The WINFAP data only goes up to 2005. There are 63 years of SEPA AMAX data, and using a single site analysis a peak flow of 165.807 m^3/s has a return period of 32 years.

Statistical Flow Estimation

3.2.38 Flows have been estimated using a pooling group analysis, with Balnaan used as a donor gauge with adjustment ratio modified according to the distance between the catchment centroids (1.15) for the A9 crossing and the gauge and also with QMED adjustment (1.37) applied directly.

FEH Rainfall Runoff Estimation

3.2.39 The FEH rainfall-runoff method was used to calculate flow hydrographs for the model inflows. The results of the standardised hydrograph analysis and the rainfall-runoff calibration indicate that it would be appropriate to adjust the Tp parameter, and therefore Tp*1.5 was used. A storm duration of 10.3 hours, which is the critical duration at the A9 crossing, was used.

Flow Comparison

3.2.40 A comparison of the peak flows calculated for the 200-year event is provided in Table 3.11. The FEH statistical method peak flows are used, with the QMED adjustment ratio applied directly. The FEH statistical method is based on recorded data, and the catchment is gauged at Balnaan, so QMED has been based on the AMAX data recorded at this gauge. The FEH rainfall-runoff method is used to estimate the model inflows, with Tp*1.5. Since the most important location in the hydraulic model is the A9 crossing, the model inflows have been scaled to match the peak flow at the A9 for the different return periods.

Table 3-11: Dulnain Peak Flow Estimates (m^3/s)

Location	FEH Stat, QMED direct adjust	Peak flow m^3/s for the 200-year return period			
		FEH Stat, QMED modified adjust	FEH RR default parameters	FEH RR Tp*1.5	FEH RR, Tp*1.5, SPR*1.5
A9 crossing	245	206	275	206	297

Comparison of Methodologies

3.2.41 Table 3-12 shows the peak flow ratios for the 50% AEP event and 0.5% AEP events. It can be seen that the FEH Rainfall Runoff method provides the highest peak flow estimates. The table shows that there are a number of catchments where the statistical method gives higher flows compared to ReFH2 but for these catchments the preferred method is to use Statistical.

3.2.42 With the exception of DS-WC-001, DS-WC-002, DS-WC-014, DS-WC-046 and DS-WC-048 the FEH Rainfall Runoff peak flow estimates have been applied to the 1D hydraulic models. DS-WC-001 and DS-WC-046 have used the statistical method results. DS-WC-001 was previously assessed under the A9 Kincraig Dalraddy scheme and for consistency the statistical estimates from this study have been applied. DS-WC-046 is the gauge downstream of the proposed crossing and a review of the gauge record indicates that the statistical estimates are in line with the gauge record. The outcome of the comparison showed that the FEH rainfall runoff and FEH Statistical approaches were appropriate.

Table 3-12: Comparison of Peak flow estimates

Watercourse Crossing ID	Catchment ID	Watercourse	Rainfall Runoff		Statistical		ReFH2 using FEH13		Rainfall Runoff Ratio 50% AEP		Rainfall Runoff Ratio 0.5% AEP		Preferred Results
			0.5%	50%	0.5%	50%	0.5%	50%	Statistical	REFH	Statistical	REFH	
DS-WC-0001	DS-WS-038	Allt an Fhearna	13.38	42.69	10.42	35.17	11.71	36.96	1.28	1.14	1.21	1.16	Statistical
DS-WC-0002	DS-WS-037	Allt Chriochaidh	2.11	6.6			1.7	5.78		1.24		1.14	Statistical
DS-WC-0007	DS-WS-034	Allt-na-Criche (Lynwilg)	4.78	14.95	3.41	12.78	3.94	13.19	1.40	1.21	1.17	1.13	Rainfall Runoff
DS-WC-0014	DS-WS-030	Aviemore Burn	15.32	4.83	12.62	3.39			1.21		1.42		Statistical
DS-WC-0024	DS-WS-026	Southern Avielocham Burn	1.23	4.14			0.81	2.69		1.52		1.54	Rainfall Runoff
DS-WC-0032	DS-WS-020	Allt Cnapach	2.12	6.91			1.39	5.1		1.53		1.35	Rainfall Runoff
DS-WC-0036	DS-WS-016	Feith Mor	1.81	6.19			1.04	3.87		1.74		1.60	Rainfall Runoff
DS-WC-0043	DS-WS-012	Unnamed Drain	0.84	2.9			0.52	1.92		1.62		1.51	Rainfall Runoff
DS-WC-0046	DS-WS-010	River Dulnain	275	87	245	84			1.12		1.04		Statistical
DS-WC-0048	DS-WS-009	Allt nan Ceatharnach	11.12	35.34	10.1	34.2	13.31	42.62	1.10	0.84	1.03	0.83	Statistical
DS-WC-0057	DS-WS-003	Slochd Mhuic	0.45	1.6			0.23	0.93		1.96		1.72	Rainfall Runoff
DS-WC-0060	DS-WS-002	Unnamed tributary of Slochd Mhuic	2.21	7.56			1.95	6.56		1.13		1.15	Rainfall Runoff

3.3 1D Hydraulic Modelling

3.3.1 Unsteady one-dimensional (1D) hydraulic models were built for each proposed watercourse crossing using either ISIS 3.7 or Flood modeller software. The purpose of the models was to ensure each of the proposed culverts had a 1 in 200 year flow capacity plus a suitable allowance for climate change and freeboard to assess the resultant magnitude of impacts downstream

Modelling Approach

3.3.2 Representative channel cross sections were extracted from existing topographic data (BLOM Ortho Topo). The topographic data included details of the relevant hydraulic structures.

3.3.3 The models typically extend 5 cross sections upstream of the A9 crossings, with a spacing of approximately 15m between each section. Sufficient cross sections were added to the downstream end of the models to minimise the potential for downstream boundary impact on the culverts.

3.3.4 Table 3-13 details the D-S watercourse crossing structures and their representation within the 1D hydraulic models.

Table 3-13: Details of the A9 D-S Watercourse Crossings

Water crossing ID	TS Structure ID	Structure Size	ISIS unit used to represent structure	SIS Inlet Control Type
DS-WC-001	A9 1090	4.38m x 7.3	USPBR 1978 Bridge Unit	N.A.
DS-WC-002	A91100	1.5 x 4m	Rectangular Conduit	N.A.
DS-WC-004	A9 1100 C70	2.0m Ø	Circular Conduit	Corrugated, Circular Culvert with Concrete headwall and wing walls.
DS-WC-005	A9 1110 C10	2.4m Ø	Circular Conduit	Corrugated, Circular Culvert with Concrete headwall and wing walls
DS-WC-05A	A9 1120	0.85m	Circular Conduit	Concrete, Circular Culvert with Concrete headwall and wing walls
DS-WC-006	A9 1120 C19	0.9 m Ø	Circular Conduit	Concrete, Circular Culvert with Concrete headwall and wing walls
DS-WC-007	A9 1130	4mx6m	USPBR 1978 Bridge Unit	N.A.
DS-WC-010 DS-WC-011	Unrecorded	0.9m Ø 0.5m Ø	Circular Conduit	Corrugated Metal-Headwall with wing walls
DS-WC-014	A9 1150 C95	2.4m Ø	Circular Conduit	Full Arched Mitred to Slope - Corrugated Culvert.
DS-WC-016	A9 1150 C11	0.9m Ø	Circular Conduit	Corrugated Circular Culvert with Concrete wing walls.

Water crossing ID	TS Structure ID	Structure Size	ISIS unit used to represent structure	SIS Inlet Control Type
DS-WC-017	3534	1.2m Ø	Circular Conduit	Corrugated Circular Culvert with Concrete head wall.
DS-WC-019	Unrecorded	0.4m Ø	Circular Conduit	Concrete, Circular
DS-WC-022	A9 1170 C12	1.1m Ø	Circular Conduit	Corrugated Circular Culvert with Concrete wing walls.
DS-WC-023	A9-1170 C18	0.9m Ø	Circular Conduit	Corrugated Circular Culvert with Concrete head wall
DS-WC-024	3690 or A9 1170 C22	1.45m Ø	Circular Conduit	Corrugated Metal-Headwall with wing walls
DS-WC-025	3689 or A9 1170 C20	0.9 m Ø	Circular Conduit	Corrugated Metal-Headwall with wing walls-Circular Conduit
DS-WC-026	3688	0.9 m Ø	Circular Conduit	Corrugated Metal-Headwall with wing walls
DS-WC-027	A9 1170 C26	0.4m Ø	Circular Conduit	Concrete, Circular Culvert with Concrete headwall and wingwalls.
DS-WC-029	A9 1170 C32	0.6m Ø	Circular Conduit	Circular Corrugated Culvert, Concrete headwall mitred to slope.
DS-WC-032	-	1.5m Ø	Circular Conduit	Corrugated Circular Culvert with Concrete head wall
DS-WC-032A	A9 1170 C53	0.8m Ø	Circular Conduit	Circular Corrugated Culvert, Concrete headwall mitred to slope
DS-WC-035	-	0.3 m Ø	Circular Conduit	No photos available for U/S and D/S locations. Typical culvert parameters assumed.
DS-WC-035A	-	0.3 m Ø	Circular Conduit	Circular Corrugated Culvert, Concrete headwall mitred to slope
DS-WC-036	A9 1170 C75	2m Ø	Circular culvert	Corrugated headwall
DS-WC-039	A9 1170 C77	1.58m Ø	Circular culvert	Corrugated headwall
DS-WC-041	A9 1170 C81	0.5m Ø	Circular culvert	Circular Corrugated
DS-WC-042	n/a	0.5m Ø	Circular culvert	Corrugated mitred
DS-WC-043	4160	1.1m Ø	Circular culvert	Corrugated Square headwall
DS-WC-045	n/a	0.45m Ø	Circular culvert	Corrugated headwall
DS-WC-046	A9 1190	14m x 34m	USBPR1978 Bridge Unit	N.A.

Water crossing ID	TS Structure ID	Structure Size	ISIS unit used to represent structure	SIS Inlet Control Type
DS-WC-048	A9 1200	10m x 13m	USBPR1978 Bridge Unit	N.A.
DS-WC-049	4159	0.45m Ø	Circular culvert	Corrugated mitred
DS-WC-050	3421	0.6m Ø	Circular culvert	Corrugated mitred
DS-WC-051	n/a	0.45m Ø	Circular culvert	Corrugated mitred
DS-WC-052	n/a	0.5m Ø	Circular culvert	Corrugated mitred
DS-WC-053	3422	1.0m Ø	Circular culvert	Corrugated headwall
DS-WC-055	n/a	0.7m Ø	Circular culvert	Corrugated mitred
DS-WC-057	A9 1210 C31	2.7m x 1.6 m	Rectangular culvert	Corrugated headwall
DS-WC-060	3649	2.7m x 1.6m	Rectangular culvert	Concrete headwall 45° bevels
DS-WC-061	A9 1210 C45	1.6m Ø	Circular culvert	Concrete headwall 45° bevels
DS-WC-062	3648 or A9 1210 C46	1.6m Ø	Circular culvert	Corrugated headwall

3.3.5 The surface roughness of bank and bed materials have been represented in the hydraulic model using Manning's 'n' parameter. The values of 'n' have been applied based on the site visit undertaken on the 21st to 23rd of March 2016 with reference to "Open Channel Hydraulic, V T Chow, 1959. McGraw-Hill".

3.3.6 The bed of the modelled watercourses is typically characterised by a stony substrate with some instream vegetation. Therefore, a Manning's roughness value of 0.045 has been used for this sub-reach of the model.

3.3.7 The floodplains and top of bank areas associated with the watercourses are typically characterised by long grass / heather, therefore the same Manning's 'n' value of 0.045 has been assigned to them.

3.3.8 For the concrete culverts passing under the A9, a Manning's 'n' roughness value of 0.035 and 0.020 has been used to represent the invert and the soffit respectively.

3.3.9 For the corrugated culverts, a Manning's roughness value of 0.035 and 0.025 has been used to represent the invert and soffit of the culvert respectively.

Boundary Conditions

3.3.10 A steady state flow-time (QT) boundary was used as the upstream boundary. Inflows were iterated in order to achieve an inlet water level at the soffit and the headwater levels for each culvert.

3.3.11 A normal depth boundary was used at the downstream extent of the model reach. This is based on the flow-stage rating relationship generated by the ISIS river sections for the furthest downstream section.

Sensitivity Analysis

3.3.12 In the absence of hydrometric data sensitivity analysis was carried out to assess the possible impact of variation in critical design parameters on the modelled peak flood levels. This is a standard validation exercise in hydraulic modelling as it quantifies the degree to which assumed values can impact on model results. The variables selected for sensitivity testing were downstream boundary condition sensitivity and roughness sensitivity

3.3.13 The downstream boundary was tested by using the following approach.

- Examine the downstream results for each culvert model and determine the stage for the full-to-soffit run.
- Calculate the depth of water this equates to (stage – bed level)
- Then apply a fixed level downstream boundary with Stage equivalent to a 10% increase in depth

Two different roughness sensitivity tests were run for each model. Manning's roughness sensitivity was tested by:

- +20% variation on the internal culvert roughness values: and
- +25% uplift globally to all of the cross sections and culverts.

3.3.14 Table 3-14 details the baseline and variation in result for each of the sensitivity tests for the modelled 1D culverts (Soffit surcharge values only).

3.3.15 Of the 36 culverts modelled, 33 of the models showed a low to moderate sensitivity to the tested parameters.

3.3.16 The downstream boundary sensitivity test showed little to no variation from the baseline model results. This was expected due to the relatively steep catchment topography. The exception to this are the following crossings which show moderate sensitivity:

- DS-WC-010
- DS-WC-024
- DS-WC-027
- DS-WC-035
- DS-WC-036
- DS-WC-060
- DS-WC-061

3.3.17 The two other sensitivity tests involved, i) Varying the Manning's 'n' value of the modelled cross sections by 20%, and ,ii) Varying the Manning's 'n' value globally over all modelled structures and cross sections. This was carried out to understand the influence of roughness on the results.

3.3.18 Increasing the total culvert roughness by 20%, resulted in a larger increase in stage than when the culvert was subjected to the maximum headwater level flow.

3.3.19 Increasing the roughness globally by 25% had a larger impact on the increase in stage compared to just adjusting the culvert roughness. This was notable at the following watercourse crossings:

- DS-WC-004
- DS-WS-006
- DS-WC-016

- DS-WC-022
- DS-WC-024
- DS-WC-029
- DS-WC-32A
- DS-WC-035
- DS-WC-035A

Table 3-14: 1D Model Sensitivity Results

Crossing	Inflow (m^3/s)	Baseline Stage (m A.O.D.)	Sensitivity Test. Variation from baseline. (m A.O.D.)		
			Culvert roughness increased by 20%	Global roughness increased by 25%	Downstream boundary changed sensitivity
DS-WC-002	20.92	225.289	0	0.04	0
DS-WC-004	5.42	217.12	0	0	0
DS-WC-005	9.1	223.38	0	0	0
DS-WC-005A	0.33	218.59	0.207	0.271	0
DS-WC-006	0.98	222.13	0	0.06	-0.1
DS-WC-010	0.3	218.43	0.38	0.02	-0.22
DS-WC-013A	0.42	233.76	0	0	0
DS-WC-014	8.05	233.76	0	0	0
DS-WC-016	0.89	231	0	0	0.02
DS-WC-017	1.78	235.83	0	0	0
DS-WC-019	0.39	240.193	0.9	1.161	-0.004
DS-WC-022	1.44	241.1	-0.03	0.03	0
DS-WC-023	0.25	252.26	0	0	0
DS-WC-024	1.43	254.79	0.59	0.04	-0.62
DS-WC-025	1	255.93	0	0	0
DS-WC-026	0.9	256.34	0	0	
DS-WC-027	0.42	255.177	0.083	0.165	0.047
DS-WC-029	0.38	242.69	0	0	
DS-WC-032	3.17	254.83	0	0	
DS-WC-032A	0.65	271.02	0	0.22	
DS-WC-035	0.11	275.48	0	0.48	0.72
DS-WC-035A	0.04	277.28	0	0.11	0
DS-WC-036	4.74	259.84	0.08	0.33	-0.63
DS-WC-039	2.69	258.74	-0.23	-0.21	
DS-WC-041	0.007	267.73	1.15	0.203	0.001
DS-WC-042	0.16	267.76	0.08	0.11	-0.01
DS-WC-043	1.35	269.03	0	0.01	-0.02

Crossing	Inflow (m^3/s)	Baseline Stage (m A.O.D.)	Sensitivity Test. Variation from baseline. (m A.O.D.)		
			Culvert roughness increased by 20%	Global roughness increased by 25%	Downstream boundary changed sensitivity
DS-WC-045	0.15	274.55	0.13	0.25	-0.01
DS-WC-046	208.66 (0.5%AEP)	266.44	See further details below		
DS-WC-048	31.49 (0.5%AEP)	282.89	See further details below		
DS-WC-049	0.15	313.48	0	0.03	0
DS-WC-050	0.24	348.26	0.07	0.16	-0.02
DS-WC-051	0.15	359.9	-0.01	-0.01	0
DS-WC-052	0.20	381.16	-0.01	-0.01	0
DS-WC-053	0.65	376.95	0.064	0.088	0
DS-WC-055	0.47	375.18	0.01	0.01	0.01
DS-WC-057	10.35	360.69	-0.01	-0.01	-0.01
DS-WC-060	7.6	393.633	-0.64	-0.63	-0.62
DS-WC-061	2.7	396.7	5.48	4.46	4.24
DS-WC-062	3.53	397.7	0.25	0.3	0.15

3.3.20 The dimensions of structures DS-WC-046 and DS-WC-048 are considerably larger than the others modelled along the Dalraddy – Slochd route. DS-WC-046 and DS-WC-048 were modelled in 1D and the results show that for the 0.5% AEP event the maximum stage was 12.3m and 9.1m below the structures surveyed soffit levels respectively. To reach the soffit levels of DS-WC-046 and DS-WC-048, flows of 5550m^3/s and 3765m^3/s would be needed respectively. Due to the clear over-capacity of these structures, these models have not been further tested for sensitivity at this full capacity flow.

3.3.21 These models have been used to estimate the capacity of the existing culverts and provide a good basis upon which to identify the potential impact of the Proposed Scheme. The modelling has been refined as part of the Stage 3 Assessment of the Preferred Route Option for a number of locations, described further in the following sections.

4. 1D-2D Hydrodynamic Models

4.1.1 The SEPA flood maps provide a strategic national overview of areas estimated to be at risk of flooding from river and/or sea, showing the indicative flood extents from fluvial and coastal flooding. It is acknowledged that the maps have limitations, as these are based on broad scale hydrological and hydraulic modelling techniques along with a coarse digital terrain model. They also do not take account of hydraulic structures or flood prevention schemes. The maps provide only a broad indication of flood risk at the community scale as they do not map catchments with areas less than 3km^2. However, the flood maps are a valuable tool when screening and identifying flood sources and potential flood extents.

4.1.2 It is considered that these maps were suitable to use as part of the screening exercise for establishing the general location of the floodplains in relation to the existing A9 and The Proposed Scheme Options to allow for the specification of additional topographical survey information and improve the confidence in the floodplain extents.

4.1.3 The additional topographical survey was undertaken in April 2016 and October 2017, and included open channel river sections, hydraulic structures, embankments and spot levels at numerous locations.

4.1.4 To improve the floodplain definition hydrological and 1D/2D linked hydraulic models were required for the following watercourses:

- Allt an Fhearna
- Loch Alvie
- Allt na Criche (Lynwilg)
- Aviemore Burn
- The Shieling / Easter Aviemore Burn
- Allt na Criche (Granish),
- Avielochan
- Allt Cnapach
- Fèith Mhòr
- River Dulnain
- Allt nan Ceatharnach
- Bogbain Burn
- Allt Slochd Mhuic

4.1.5 With the exception of the Allt an Fhearna and Loch Alvie all the 1D/2D linked hydraulic models were constructed in ISIS 3.7 or Flood Modeller and run using TuFlow link. The Allt an Fhearna and Loch Alvie had been previously modelled using InfoWorks RS, as part of the Kincraig to Dalraddy scheme. This model was reviewed and updated to incorporate additional survey and requirements for the Dalraddy to Slochd scheme. It should be noted that the 2D domains for the Loch Alvie and Allt an Fhearna models are different. Loch Alvie has been included within the Allt an Fhearna model to ensure a suitable downstream boundary and therefore, the flood extents for Loch Alvie are not fully represented within this model. Please refer to Sections 5 of this report for more information.

4.1.6 For each of the identified areas a baseline model was produced using topographical survey data and NextMAP DTM. Where the baseline showed there would be a potential impact from The Proposed Scheme options, the 1D/2D linked models were revised to simulate the worst case scenario of the Proposed Scheme options. This was done through the alteration of the 2D domains with the scheme embankments represented as a glass wall. This gives a conservative estimate of the impacts associated with The Proposed Scheme.

4.1.7 Table 4-1 details the status of each hydraulic model, and the work undertaken as part of the Stage 3 Assessment. For all the models the approach is detailed in Section 4.2.

4.1.8 For specific details regarding each of the model reaches including results and sensitivity testing please refer to the relevant sections as detailed in Table 4-1.

Table 4-1: 1D/2D Linked Hydraulic Model Status

River Name	Modelling Software	Report Section	Purpose of Modelling
Allt an Fhearna and Loch Alvie	Infoworks RS	Section 5	Baseline model, Proposed Scheme and Mitigation Options
Allt na Criche (Lynwilg)	ISIS TuFlow	Section 6	Baseline model, Proposed Scheme – no mitigation required
Aviemore Burn	ISIS TuFlow	Section 7	Baseline model, Proposed Scheme and Mitigation Options
The Shieling/Easter Aviemore Burn	ISIS TuFlow	Section 8	Baseline model, Proposed Scheme – no mitigation required
Allt na Criche (Granish)	ISIS TuFlow	Section 9	Baseline model, Proposed Scheme and Mitigation Options
Avielochan	ISIS TuFlow	Section 10	Baseline model, Proposed Scheme and Mitigation Options
Allt Cnapach	ISIS TuFlow	Section 11	Baseline model, Proposed Scheme and Mitigation Options
Feith Mhor	ISIS TuFlow	Section 12	Baseline model, Proposed Scheme and Mitigation Options
River Dulnain	ISIS TuFlow	Section 13	Baseline model, Proposed Scheme and Mitigation Options
Bogbain Burn	ISIS TuFlow	Section 14	Baseline model, Proposed Scheme and Mitigation Options
All Slochd Mhuic	Flood Modeller v 4.3	Section 15	Baseline model, , Proposed Scheme – no mitigation required

4.2 Standard Modelling Approach

4.2.1 For each of the model reaches identified a similar modelling approach has been adopted. This section will set out the common approaches which have been adopted for each of the hydraulic models.

Open Channel

4.2.2 The open channel river sections were defined from the AMJV topographical survey, which was completed in December 2015, April 2016 and October 2017.

4.2.3 The Manning's 'n' roughness coefficient values were based on a visual inspection during site visits and defined in accordance with values depicted in 'Open Channel Hydraulics' (Chow, 1959). Table 4-2 details the Manning's range applied, for further details please refer to the relevant model section.

Table 4-2: Manning's values assigned to channel section within the D-S models

River Reach	River Channel Manning's 'n' values
Allt an Fhearna	0.030
Loch Alvie	0.030
Allt Na Criche (Lynwilg)	0.015-0.040
Aviemore Burn	0.015-0.035
The Shieling/ Easter Aviemore Burn	0.015-0.035

River Reach	River Channel Manning's 'n' values
Allt Na Criche (Granish)*	0.025 – 0.040
Avielochan	0.035
Allt Cnapach	0.040
Feith Mhor	0.040
River Dulnain	0.030-0.060
Bogbain Burn	0.035
All Slochd Mhuic	0.020-0.020

Floodplains

4.2.4 The floodplains have been defined using the NextMAP DTM, which was supplied as part of the project. Where additional topographical data has been available this ground model has been updated to improve the resolution. A representative 2D domain was generated to represent the floodplains.

4.2.5 The Manning's 'n' roughness coefficient values were based on a visual inspection during site visits and defined in accordance with values depicted in 'Open Channel Hydraulics' (Chow, 1959). Table 4-3 details the Manning's range applied, for further details please refer to the relevant model section.

Table 4-3: Manning's values assigned within floodplain areas of the D-S models

River Reach	Bank / Floodplain Manning's 'n' values
Allt an Fhearna	0.050
Loch Alvie	0.030 – 0.050
Allt Na Criche (Lynwilg)	0.015- 0.045
Aviemore Burn	0.060
The Shieling/ Easter Aviemore Burn	0.060
Avielochan	0.045 – 0.060
Allt Cnapach	0.045 – 0.060
Allt Na Criche (Granish)*	0.045 – 0.060
Feith Mhor	0.045-0.060
River Dulnain	0.030-0.060
Bogbain Burn	0.040
All Slochd Mhuic	0.020 - 0030

Structures

4.2.6 The culverts were represented using standard conduit units and upstream/ downstream culvert Inlet/ Outlet units. Values of Manning's for the culverts were split into "upper half" and a "lower half".

4.2.7 The "upper" and "lower" values of the concrete culverts were set to 0.035 and 0.020 respectively and corrugated culverts were set to 0.025 and 0.035 respectively. Higher values were used on the on the lower half of the culverts to represent bed material and any organic growth commonly found within hydraulic structures.

4.2.8 Bridges were represented using either USBPR1978, arch bridge units or culvert units, depending on the geometry and dimension of the structures. All bridges, regardless of their representation in the model have inline spill units attached to represent overtopping.

4.2.9 The exceptions to this is where a structure is of such a large dimension that the calculated flows, for the 0.1% event, result in the stage at the structure registering well below the soffit.

Sensitivity Analysis

4.2.10 A sensitivity analysis was carried out to assess the possible impact of variation in critical design parameters on the modelled peak flood levels. This is a standard validation exercise in hydraulic modelling as it quantifies the degree to which assumed values can impact on model results.

4.2.11 The 1D/2D hydraulic models have been checked in terms of parameter sensitivity to determine the response / stability of the model for changes in roughness and downstream boundary conditions. The variables selected for sensitivity testing were:

- Channel and floodplain roughness coefficients (adjusted - 20%)
- Channel and floodplain roughness coefficients (adjusted + 20%)
- Downstream Boundary stage increased by 20% relative to the depth

4.2.12 The sensitivity testing was undertaken using the 0.5%AEP event.

5. Allt an Fhearna and Loch Alvie

5.1.1 Loch Alvie has a catchment area of approximately 32km^2, with its headwaters rising on the steep mountainous slopes between An Suidhe, Carn Coire Dhugain and Garbh-mheall which rise to an altitude of 590m AOD. Loch Alvie outflows to the east via the Allt Dibheach, which then discharges into the River Spey at NGR 2884 8100.

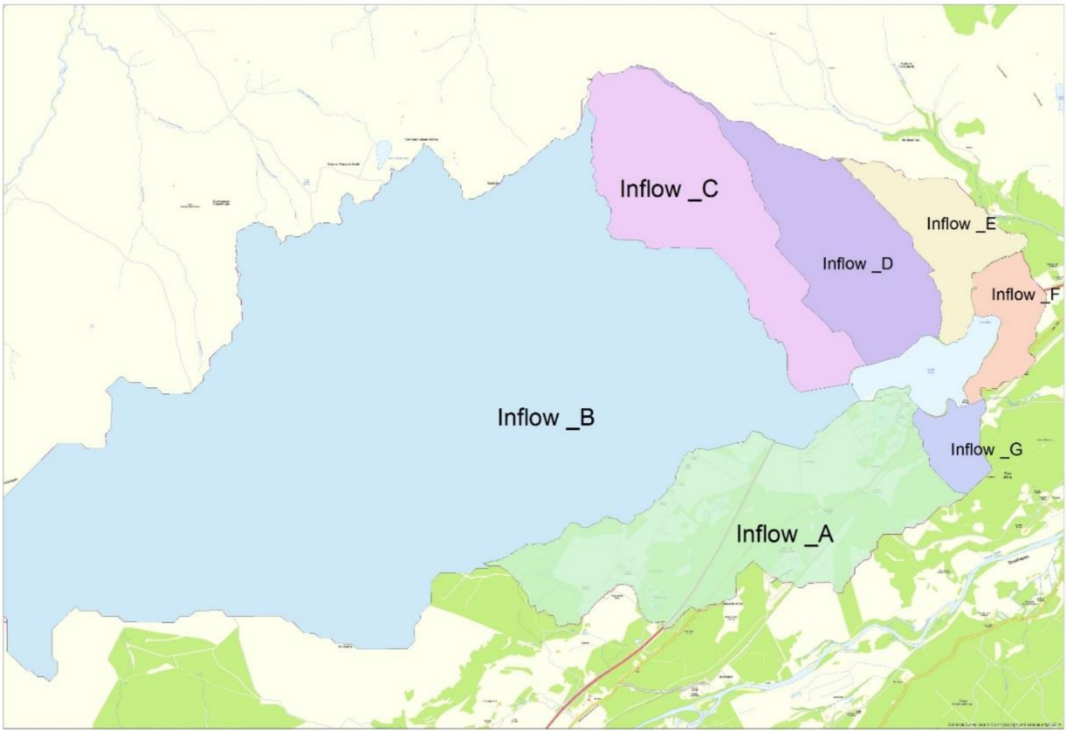
5.1.2 There are a number of sub-catchments that drain into Loch Alvie with the largest being the Allt an Fhearna which has a catchment area of 22.4km^2. The Allt an Fhearna watercourse crosses underneath the A9 at the northern end of the Kincraig to Dalraddy section and this crossing is not proposed to be further upgraded as part of the Dalraddy to Slochd project. However, the Dalraddy to Slochd road alignment, side roads and associated earthworks are located in the vicinity of the Allt an Fhearna and its floodplain. The A9 Dalraddy to Slochd section is located approximately 100m from the north-western shore of Loch Alvie.

Table 5-1: Loch Alvie Hydrological Estimation Points

Water-course	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Loch Beag	Inflow A	Loch Alvie Tributary, applied directly to 2D model	Direct	FEH RR	286160	809350	4.4
Allt an Fhearna	Inflow B	Loch Alvie Tributary, applied to upstream extent of 1D model	Direct	FEH RR scaled to Statistical Peak	285700	809350	20.4

Water-course	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Allt Chriochaidh	Inflow C	Loch Alvie Tributary, applied directly to 2D model	Direct	FEH RR	259500	809600	2.8
Caochan Ruadh	Inflow D	Loch Alvie Tributary, applied directly to 2D model	Direct	FEH RR	286700	809900	1.90
Unnamed Drained	Inflow E	Loch Alvie Tributary, applied directly to 2D model	Direct	FEH RR	287050	809500	1.01
N/A	Inflow F	Loch Alvie Tributary, applied directly to 2D model	Direct	FEH RR	287050	809500	0.58
N/A	Inflow G	Loch Alvie Tributary, applied directly to 2D model	Direct	FEH RR	287150	809300	0.71
River Spey	Downstream Boundary	Point of interest, applied to separate 2D routing model for downstream boundary	Direct	FEH Statistical Peak	288432	810062	

Figure 5-1 Loch Alvie subcatchment delineation



5.1.3 Peak flows were calculated for each inflow using the FEH Rainfall Runoff methods. The FEH statistical estimate from the 2013 study was considered suitable for use at the Allt an Fhearna inflow. No other Statistical estimates were undertaken, due to the catchment sizes. Considering the lake attenuation factor from Loch Alvie, a statistical estimate downstream of Loch Alvie was deemed unsuitable and was therefore not undertaken. Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events. The model storm duration was optimised to 40 hours to maximise the water levels within the loch. A different critical duration was used to optimise the model at the Allt an Fhearna and for this a 5 hour storm was used. Table 5.2 shows the peak flow estimates.

5.1.4 Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

Table 5-2: Allt an Fhearna and Loch Alvie peak flow estimates

Watercourse	Inflow ID	0.5%+CC (40 hr)	0.5%+CC (5 hr)	0.5% (40 hr)	0.5% (5 hr)	3.33% (40 hr)	3.33% (5 hr)
Loch Beag	Inflow A	3.25	4.43	2.71	3.69	1.87	2.34
Allt an Fhearna	Inflow B	21.97	38.96	18.31	32.43	13.31	21.50
Allt Chriochaidh	Inflow C	3.64	8.25	3.04	6.87	2.18	5.08
Caochan Ruadh	Inflow D	2.76	6.30	2.30	5.25	1.64	3.89

Watercourse	Inflow ID	0.5%+CC (40 hr)	0.5%+CC (5 hr)	0.5% (40 hr)	0.5% (5 hr)	3.33% (40 hr)	3.33% (5 hr)
Unnamed Drained	Inflow E	1.13	2.55	0.94	2.12	0.67	1.58
N/A	Inflow F	0.43	0.77	0.36	0.64	0.24	0.47
N/A	Inflow G	0.24	0.39	0.20	0.32	0.14	0.23

5.2 Baseline Hydraulic Model

5.2.1 The modelling for Allt an Fhearna was based upon an existing InfoWorks RS model that was developed for the A9 Kincraig-Dalraddy scheme. This model was originally developed to assess impacts of changes to the Allt an Fhearna crossing structure and floodplain volume loss for this previous dualling project. This model formed the basis of the hydraulic modelling for Allt an Fhearna and Loch Alvie for Dalraddy to Slochd. Updated ground model data was used to update the surface elevations in the 2D model.

5.2.2 The Allt an Fhearna model reach has an upstream extent at NGR 284770 809020 775m upstream of the A9 crossing and a downstream extent located at the inflow point to Loch Alvie at NGR 289595 809430.

5.2.3 The Loch Alvie element of the model consists of a 2D domain extending South and East from the A9 alignment as far as Dalraddy to the South and a farm access track to the north-west of Loch Alvie. The real bathymetry of the Loch is not modelled and instead the dry-weather water surface of the loch is used as a boundary condition. This boundary level was set at 209.40mAOD. This water surface level was derived directly from the ground model and verified as being representative by comparing with surveyed cross-sections at the Allt an Fhearna inlet and Allt Dibheach outlet to the loch. The 2D domain representing the loch is connected to a 1D reach of the Allt Dibheach outlet channel which was defined by topographical survey cross-sections. This has a downstream extent at NGR 287225 809310.

5.2.4 Table 5.3 below details the model extents and key features.

Table 5-3: Loch Alvie Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of Surveyed Cross Sections	Number of A9 Crossings	Total number of modelled structures
Allt an Fhearna	1430	284794, 809020	285955 809430	19	2	1
Loch Alvie	2D Domain only	285690, 809075	287045, 809285	0	0	0
Allt Dibheach	300	287045, 809285	287210, 809330	4	0	0

5.2.5 The 2D domain covers an area of 2.15 million m^2. InfoWorks RS defines 2D domains using a triangular mesh with flexible mesh element size. The Loch Alvie model used a maximum element size of 5,000m^2 and a minimum of 25m^2. This large element size was appropriate as the variation in elevation across the ground-model, in particular across the loch, is very low. A Manning's 'n' value of 0.030 was used for the 2D domain. This was considered to be a conservative (high) value for a deep, slow flowing water body.

5.2.6 The model was run using a fixed 1 second time steps. For the Loch Alvie critical storm duration (40 hour storm) a stage-time boundary was applied to the downstream model extent on the Allt Dibheach. As the downstream extent of the model is located close to the River Spey functional floodplain an indicative stage hydrograph for the Spey was applied at the boundary. The indicative stage hydrograph for the Spey was generated using a separate coarse 2D mesh covering the Spey floodplain 2km upstream and downstream of the Loch Alvie model boundary. The hydrograph for the Spey catchment was routed through the Spey floodplain model to generate a stage hydrograph at the downstream extent of the Allt Dibheach. This was then combined with the stage-time hydrograph produced running the model with a normal depth boundary to produce a hybrid stage-time curve that initiated a backwater effect from the Spey from the point in time that the outflow from Loch Alvie begins to rise.

5.2.7 Figure 5.2, Figure 5.3 and Figure 5.4 show the hydraulic model schematic.

5.2.8 The open channel river sections were defined from the topography survey, with the 1D Manning's 'n' values defined from the site visits, which were undertaken in March 2016. 2D floodplain Manning's 'n' values were defined using aerial photographs of the site. Table 5.4 provides the Manning's 'n' value range and justification of the value.

Table 5-4: Allt an Fheana and Loch Alvie Manning's 'n' Values

Section Type	Minimum	Maximum	Commentary
1D			
River Channel	0.030	0.030	Straight channel, no major meandering. Gravel substrate
Structures	0.030	0.030	Natural river gravels on invert
Floodplain	0.050	0.050	Scattered brush, heavy weeds
2D			
Floodplain	0.03	0.03	Default, Loch Alvie
Floodplain	0.050	0.050	Rough grassland, scrub
Floodplain	0.070	0.070	Trees

5.2.9 Table 5.5 provides the details of how the structures are represented within the model and Figure 5.2 – 5.4 show the location of these modelled structures.

5.2.10 An ARCH BRIDGE unit has been used to represent the existing A9 crossing of the Allt an Fhearna. This is appropriate as this unit allows the complicated cross-sectional geometry of the combined underpass and watercourse to be represented. This structure does not experience any surcharged flow at any modelled return periods. A second structure, on the Allt Dibheach channel downstream of the outlet of Loch Alvie was not included in the model. This structure resulted in severe model instability when the Spey stage-time downstream boundary was applied. It was judged that the application of the Spey boundary and the resulting backwater effect overrides any local hydraulic effect due to this structure.

Table 5-5: Allt an Fhearna and Loch Alvie Modelled Structures

Water Crossing ID	Structure	Model ID	Watercourse	Dimensions (m)	Representation in the model	Photograph
DS-WC-001	A9 1090 Bridge passing under A9	Allt_0542	Allt an Fhearna	4.38m x7.3m	ARCH BRIDGE	

Figure 5-2 Model Schematic. Cross sections Allt_0000 to Allt_1306

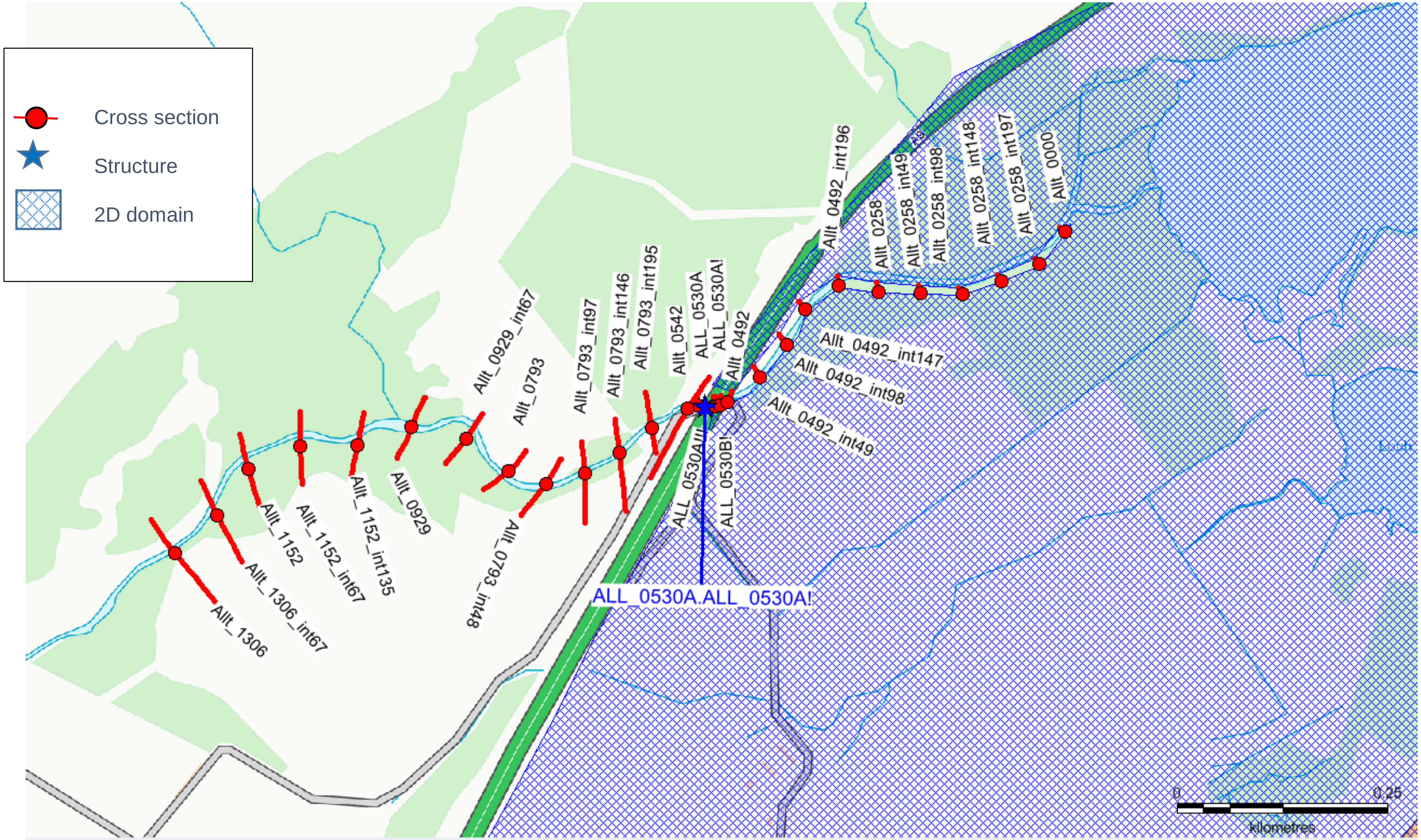


Figure 5-3 - 1D Model Schematic. Cross sections DALXS16-DALXS14

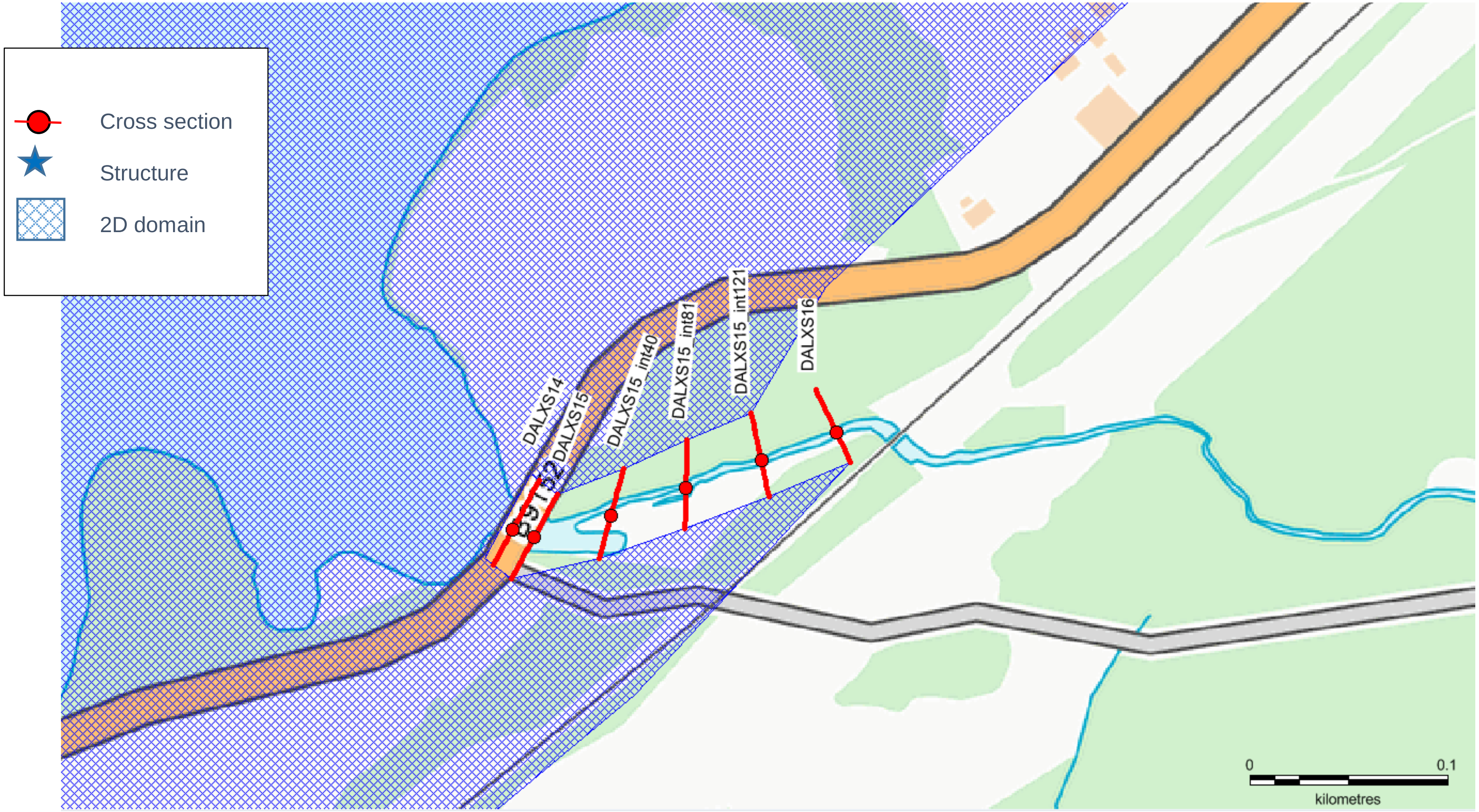
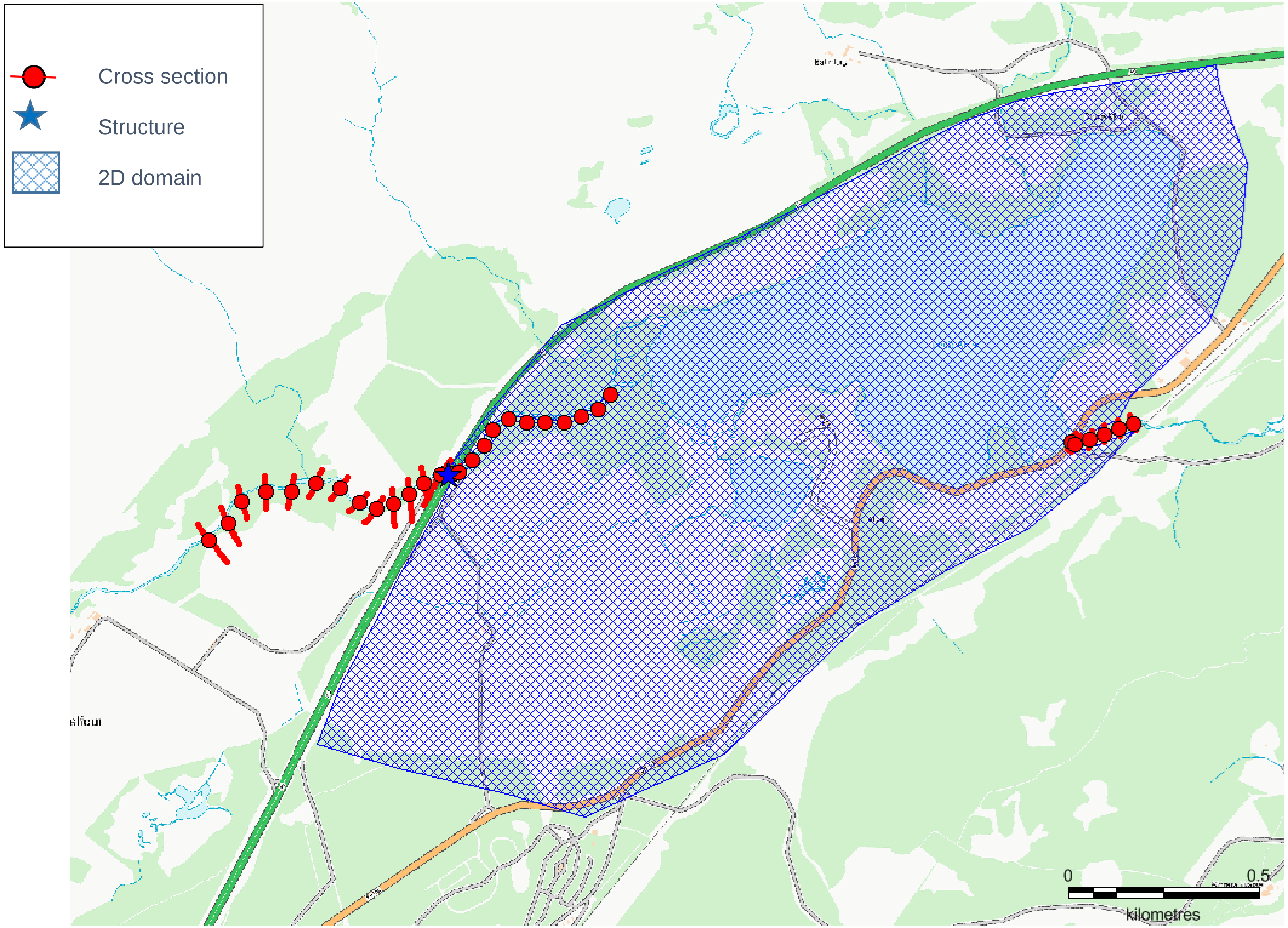


Figure 5-4 ID Model Schematic. Whole Model Overview



Baseline Model Performance

1D model performance

5.2.11 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. Over the duration of the flood event, model stability is generally good although it is noted that there are localised instabilities in the Loch Alvie outlet channel when the Spey stage-time downstream boundary is applied which results in backflow into the loch. Modelled loch levels are stable however.

2D model performance

5.2.12 The cumulative mass error output reports from the 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The mass balance of the model is 0% for all of the modelled flood events.

Sensitivity Analysis

5.2.13 In order to analyse the sensitivity of the hydraulic models, the models have been updated to represent a change in parameters. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- 50% blockage scenario
- Downstream Boundary +/ - 20%

5.2.14 The sensitivity of the 1D is tested using comparison of results at each of the model cross sections. To test the sensitivity within the 2D domain, 5 locations have been selected in the 2D floodplain based on their proximity to sensitive receptors and the A9. Figure 5.5 shows the locations, and Table 5.6 below provides the Grid Reference.

Table 5-6: Allt an Fhearna and Loch Alvie 2D Results Location

Reference Id	Location of receptor	Easting	Northing
A	Right bank of Allt an Fhearna, upstream of proposed side road and crossing	285590	809300
B	Left bank of Allt an Fhearna, upstream of proposed side road and crossing	285620	809360
C	Right bank of Allt an Fhearna, downstream of proposed side road and crossing	285740	809300
D	Left bank of Allt an Fhearna, downstream of proposed side road and crossing	285735	809380
E	Loch Alvie	286360	809600

5.2.15 Table 5.7 shows the variation in sensitivity of the baseline model for each of the modelled survey cross sections. Figure 5.6 – 5.8 shows variation within the modelled long section.

5.2.16 Overall, the results from the 1D or ‘in channel’ sections show a relatively low sensitivity to the +/-20% variation in Manning’s. At most 1D cross-sections the model shows variation of less than -/+0.10 m for both the +20% and -20% Manning’s tests respectively. There are exceptions to this at cross-sections ALL_0492, ALL_0530B!

which are located downstream of the existing A9 Allt an Fhearna crossing and ALL_0542 and Allt_0793_int195 which are upstream of the same structure. With a maximum variation of 0.286m for increasing Manning's 'n' by 20% and 0.279 for decreasing Manning's 'n' by 20%. This localised sensitivity relates to a structure that is to be left unchanged by the Dalraddy to Slochd scheme and is therefore not considered to be of significance for the assessment of impacts arising due to the scheme.

5.2.17 Overall, the majority of the model shows little sensitivity to +/-20% variation in downstream boundary water level. However, the downstream reach of the 1D model (Loch Alvie outlet channel/Allt Dibheach) and the modelled 2D area of Loch Alvie do demonstrate a noticeable sensitivity to variation in the downstream boundary condition. This is not surprising as the model is run with the downstream stage controlled by elevated water levels in the Spey which results in a strong backwater effect on the loch. Water levels in the model downstream of the Allt an Fhearna discharge into Loch Alvie are sensitive to the downstream boundary condition which supports the justification for using a conservative approach to modelling this boundary condition using a representation of Spey flood levels.

5.2.18 The +/-20% variation in flow results for the 1D or 'in channel' sections show a variation in water levels of between 0.069 m and 0.283 m for +20% and 0m and -0.311m for -20%. The largest variations for this test are at the cross-sections in the location of the existing Allt an Fhearna A9 crossing. This location is more susceptible to changes in modelled stage with a change in flow as the floodplain is constrained at this point in the model and the structure acts as a "pinch point" in the out-of-bank flow being conveyed.

5.2.19 A 50% blockage at the Allt an Fhearna culvert has no discernible effect on model results. This structure has a large span and capacity well in excess of the peak design flows meaning that blockage risks are low.

5.2.20 Table 5.8 provides the summary of the 2D results at the 5 sensitivity test locations.

5.2.21 The +/- 20% Manning's sensitivity tests show that the hydraulic model 2D domain has a low sensitivity to the tested parameters with changes less than +/- 0.042 m at all locations.

5.2.22 Location E is the only location to show a change in water levels with +/- 20% change in downstream boundary water levels, with + 0.558 m and -0.124 m for +20% and -20% change respectively. This reflects the proximity of the Loch Alvie (within which Location E is situated) to the downstream boundary.

5.2.23 A +/- 20% change in flow has a small impact at all locations, but more so at Location E, Loch Alvie, where a 0.128 m increase in water level results from a +20% increase in flow. A -20% reduction in flow results in no change in water level at Location E. This reflects the interaction of inflows to the loch and the downstream boundary condition; when lowering the flows by 20% the maximum loch level is controlled by the downstream boundary, when increasing the flows by 20% this appears to raise the loch levels above the level set by the downstream control.

5.2.24 The 50% blockage scenario shows the model is not sensitive to this test.

Figure 5-5 2D Sensitivity Test Locations

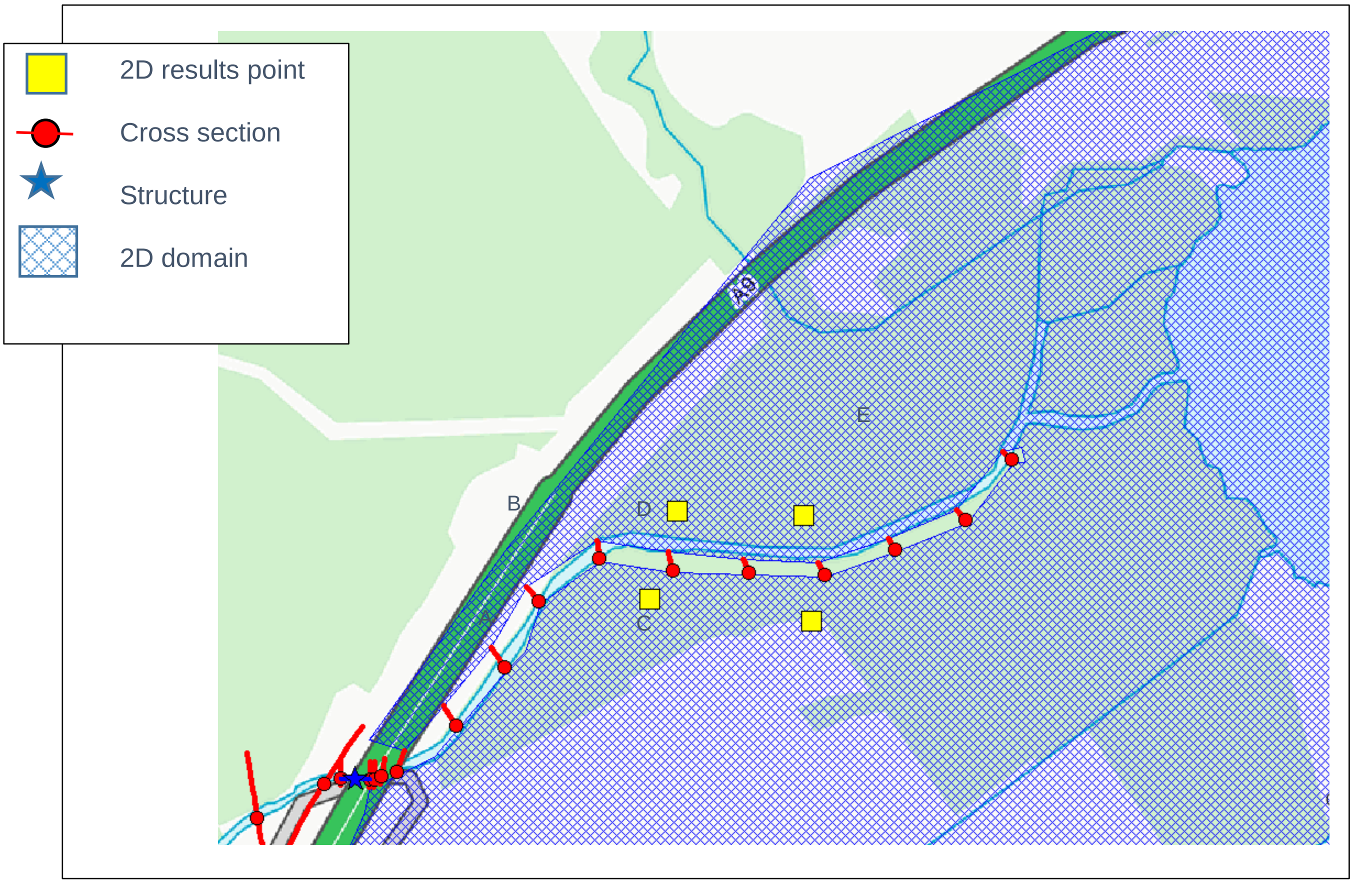


Table 5-7: Allt an Fhearna and Loch Alvie 1D Sensitivity Results for 0.5% AEP Event Baseline

Cross-section	Baseline Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
DALXS16	212.009	0	0	0.534	-0.534	0.123	0	0
DALXS15	212.018	0.004	0.011	0.508	-0.357	0.125	0.008	0.017
DALXS15_int81	212.028	-0.002	-0.001	0.536	-0.47	0.122	-0.004	-0.005
DALXS15_int121	212.031	-0.001	-0.005	0.553	-0.314	0.13	-0.003	-0.005
DALXS15_int40	212.032	0.002	-0.001	0.493	-0.283	0.11	-0.005	0.002
DALXS14	212.039	-0.001	-0.001	0.609	-0.288	0.125	0.001	-0.009
Allt_0000	212.703	0.095	-0.083	-0.001	0.002	0.021	-0.026	0
Allt_0258_int197	212.948	-0.038	0.018	0	0.002	0.013	-0.011	0
Allt_0258_int148	213.869	0.028	-0.012	-0.001	0.001	0.019	-0.027	0
Allt_0258_int98	214.453	-0.037	0.029	-0.002	0	0.028	-0.034	0
Allt_0258_int49	215.214	-0.004	0.005	-0.005	-0.002	0.027	-0.042	0
Allt_0258	215.814	-0.032	0.033	-0.005	-0.003	0.041	-0.055	0
Allt_0492_int196	216.383	-0.037	0.024	-0.008	-0.003	0.035	-0.052	0
Allt_0492_int147	216.845	-0.056	0.043	-0.009	-0.002	0.034	-0.045	0
Allt_0492_int98	217.465	-0.114	0.084	-0.003	0.002	0.117	-0.140	0
Allt_0492_int49	217.769	-0.088	0.087	0.004	0.004	0.056	-0.080	0
Allt_0492	218.358	-0.183	0.144	0.001	-0.001	0.152	-0.178	0
ALL_0530B!	218.495	-0.172	0.286	0.012	0.005	0.165	-0.175	0
ALL_0530A!!!	219.412	-0.007	0.015	-0.017	0.008	0.26	-0.311	0
ALL_0530A	219.486	-0.01	-0.017	-0.007	0.001	0.252	-0.264	0
ALL_0530A!	219.486	-0.01	-0.017	-0.007	0.001	0.252	-0.264	0

Cross-section	Baseline Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Allt_0793_int195	219.791	0.261	0.007	0.004	-0.006	0.283	-0.297	0
Allt_0542	219.8	0.279	0.012	-0.002	-0.006	0.279	-0.308	0
Allt_0793_int146	219.888	0.194	0.032	0.003	-0.007	0.218	-0.177	0
Allt_0793_int97	220.26	0.021	0.063	0.004	-0.006	0.112	-0.093	0
Allt_0793_int48	220.786	-0.059	0.08	0.006	-0.003	0.069	-0.096	0
Allt_0793	221.314	-0.081	0.081	0.006	-0.002	0.089	-0.092	0
Allt_0929_int67	222.255	-0.044	0.082	0.008	0	0.077	-0.081	0
Allt_0929	223.25	-0.042	0.071	0.008	0.001	0.078	-0.066	0
Allt_1152_int135	224.373	-0.038	0.076	0.008	0.001	0.073	-0.076	0
Allt_1152_int67	225.601	-0.068	0.07	0.01	0.003	0.076	-0.071	0
Allt_1152	226.755	-0.017	0.071	0.009	0.001	0.068	-0.076	0
Allt_1306_int67	227.878	-0.046	0.076	0.011	0.004	0.081	-0.074	0
Allt_1306	228.944	-0.05	0.089	0.008	0.001	0.087	-0.088	0

Table 5-8: Allt an Fhearna and Loch Alvie 2D Sensitivity Results for 0.5% AEP Event Baseline

Sensitivity Test	Baseline Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Location A	215.017	-0.02	0.024	0	0	0.024	-0.02	0
Location B	215.663	-0.042	0.032	0	0	0.032	-0.042	0
Location C	212.684	-0.037	0.027	0	0	-0.036	0.027	0
Location D	213.993	0.002	0.006	0.001	0	0.034	-0.041	0
Location E	212.033	-0.001	0	0.558	-0.124	0.128	0	0.001

Figure 5-6 Loch Alvie Outlet Channel Modelled Long Section Scheme Sensitivity Results for 0.5% AEP event

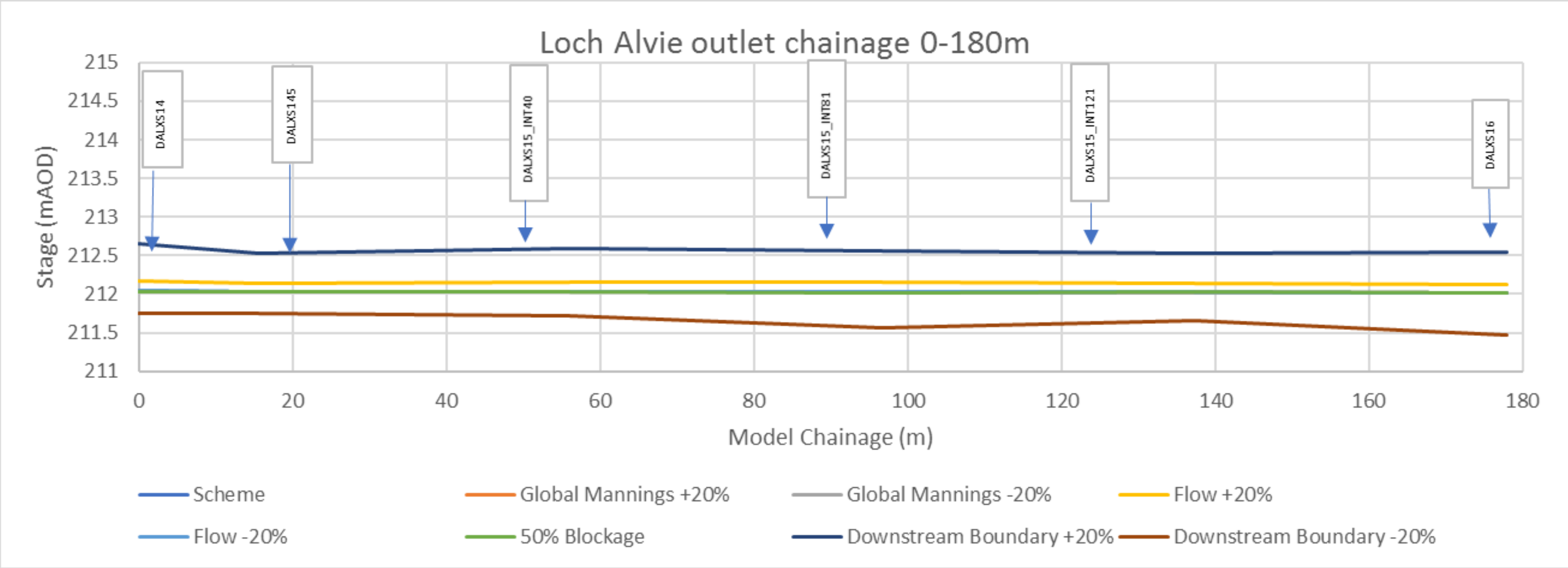


Figure 5-7 Allt an Fhearna (0m-780m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP event

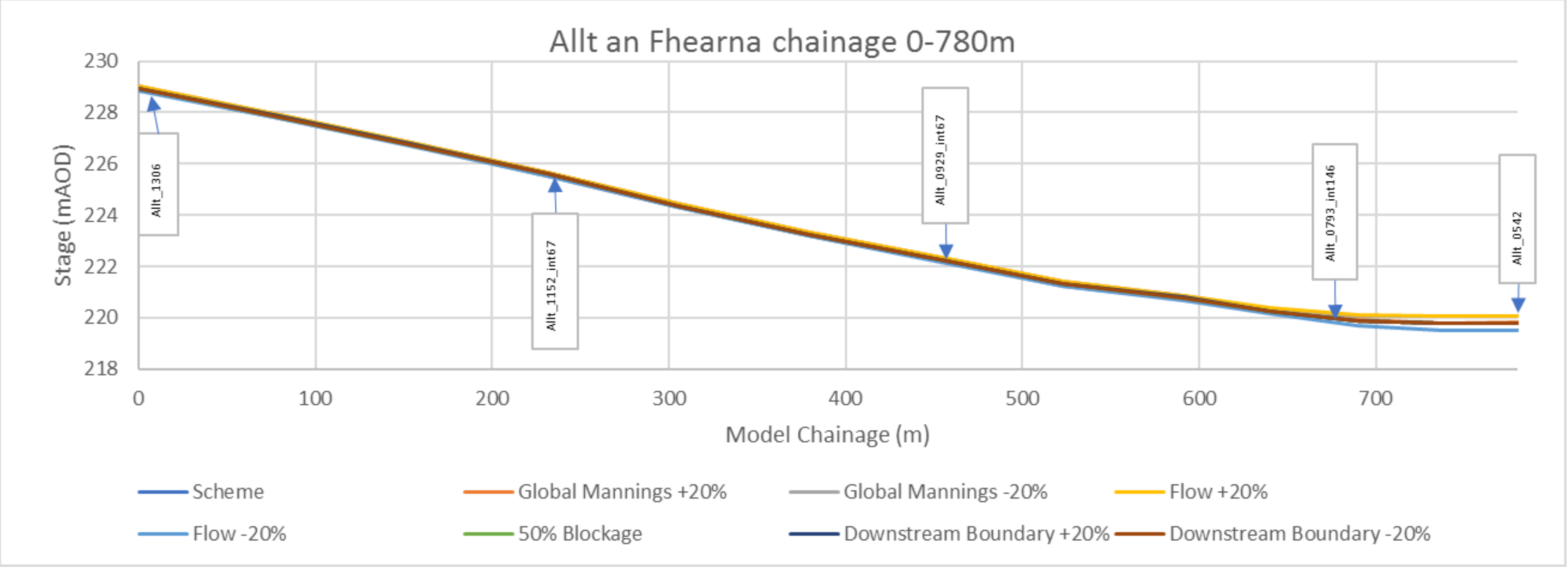
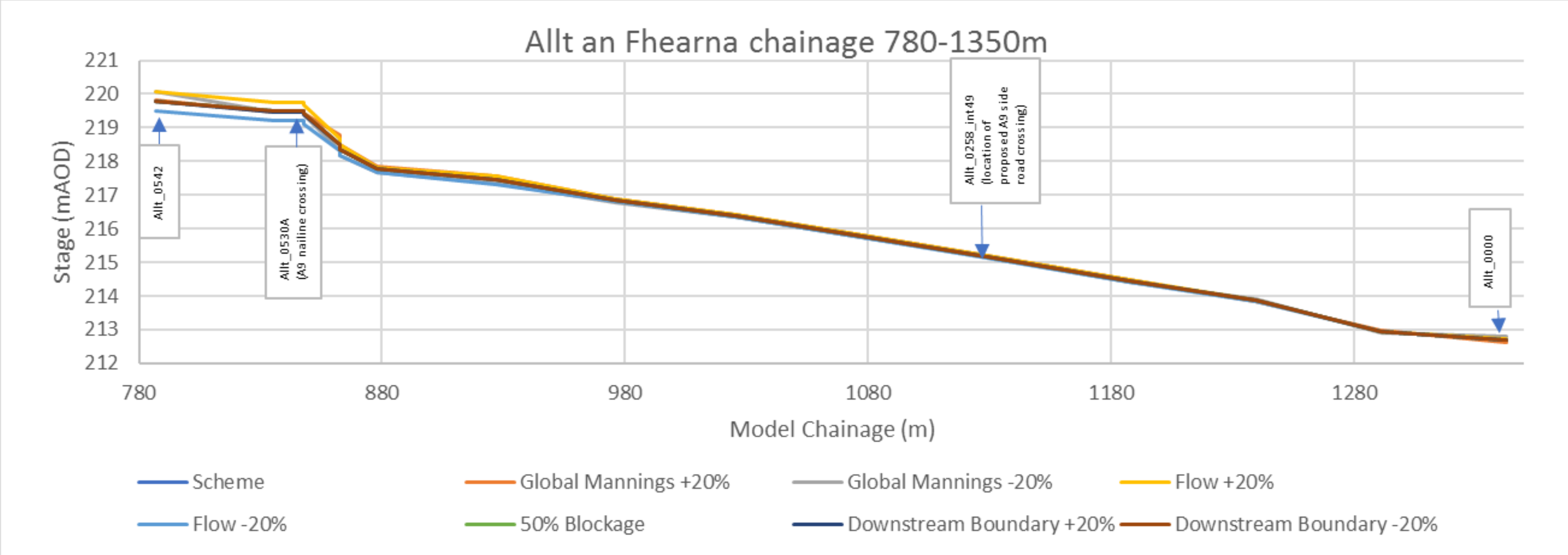


Figure 5-8 Allt an Fhearna (780m-1350m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP event



5.3 Proposed Model ('with-scheme' modelling)

Proposed Scheme Changes

5.3.1 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with the A9 mainline. Proposed works to the A9 in the vicinity of Allt an Fhearna and Loch Alvie include widening of the mainline carriageway to dual-lanes.

5.3.2 Figure 5.9 shows the extent of the proposed scheme in the area of Allt an Fhearna/Loch Alvie.

5.3.3 Earthworks associated with the dualling of the A9 mainline have been represented by importing Design Refresh 7a levels into the ground model that informs the InfoWorks model. There are no locations where changes in the mainline earthworks ground levels impinge on the Allt an Fhearna and Loch Alvie modelled flood extents.

5.3.4 There are a number of locations where side roads are proposed and these do interact with the modelled flood extents:

- SUDS pond access road which crosses Allt an Fhearna floodplain. This road is required to cross the floodplain to enable it to tie-in to the nominated access point from the existing track. The elevation of the road surface has been kept to a minimum and for the majority of the tracks length is lower than the culvert soffit level. Earthworks associated with this track are incorporated into the 2D model for the Proposed scenario. The flood storage volume losses associated with this have been reduced as part of a realignment of the access track in Design Refresh 7a.
- SUDS pond access (using an existing minor road/track) on the north shore of Loch Alvie. This is proposed to use the existing road elevation so there is no change to the model relating to this.
- Side road on eastern shore of Loch Alvie. Again, this is proposed to be built at existing grade so no associated change to the model.

5.3.5 The mainline alignment cycle track encroaches onto the floodplain; however the cycle track is at or very close to existing ground level and so floodplain losses are negligible.

5.3.6 There is a single new structure proposed within the Allt an Fhearna/Loch Alvie model. This is a new culvert which allows the SUDS pond access road to cross the Allt an Fhearna. Following iterations of model runs this structure has been sized as a 6.5m wide x 2.5m high portal frame structure. The 6.5m span has been set to maximise conveyance capacity and retain riparian connectivity through the structure. The road surface over this structure has been set based on a deck thickness of 330mm and this is represented in the model by an inline spill, allowing flow to overtop this structure.

5.3.7 Table 5.9 shows proposed updates that have been made to existing structures as a results of scheme amendments.

5.3.8 In addition, three of the tributaries of Loch Alvie (Allt Chriochaidh, Caochan Rudh and Ballinluig Burn) have proposed replacement A9 mainline structures. These structures are not included in the Loch Alvie model but have been assessed separately using standalone 1D models. To allow for remaining uncertainty in potential upsizing of these structures an additional sensitivity test has been run on the proposed model using a nominal 20% increase in flows in these tributaries.

Proposed Mitigation Measures

5.3.9 Floodplain losses have been minimised through ensuring access tracks are only raised where required, e.g. to allow structure crossings

5.3.10 The encroachment of the scheme is calculated to have a moderate impact on available floodplain storage at the site in terms of potential displaced volumes. In total there is approximately 336m^3 of floodplain loss due to the SUDS pond access road crossing of the Allt an Fhearna and its floodplain.

5.3.11 However, due to the absence of sensitive flood receptors in the vicinity of this crossing location there is a very low potential for increased flood risk and hazard. In addition, the model of the Proposed Scheme shows that the effect of the side road earthworks are in fact to lower the peak water levels in both the 1D channel model and the 2D floodplain model downstream of the proposed crossing (cross section Allt_0258_int49). This is due to impounding of floodplain flow on the upstream of the side road which results in defacto online flood storage.

5.3.12 The increased flood depth associated with the SuDS access track is to the woodland area which is comprised of ancient woodland and SSSI designation. The only technical viable solution to reduce flood depths is to provide compensatory storage which would result in a loss of woodland and SSSI encroachment. The defacto online storage for the proposed scheme is considered to have the least potential detrimental impact on the environment. Therefore, additional flood risk mitigation is not proposed at this location.

Figure 5-9 - Proposed Scheme

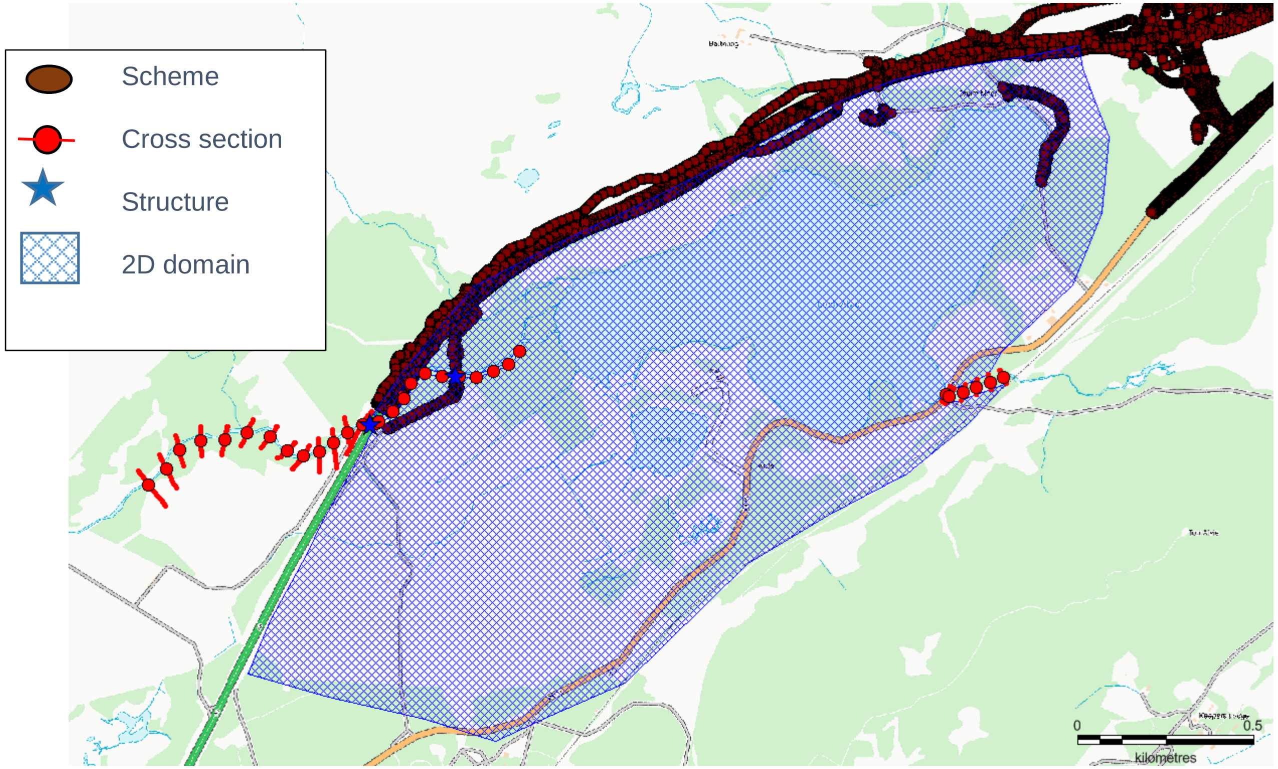


Table 5-9: Allt an Fhearna and Loch Alvie Proposed Scheme Modelled Structures

Water Crossing ID	Structure ID	Model ID	Watercourse	Dimensions (m)	Representation in the model
N/A	A9 1090 S SUDS Pond Access	AVI_XS15Aa	Allt an Fhearna	6.5 x 2.5 m portal	Represented in a 1D model by an ORIFICE unit.

Scheme Model Performance

1D model performance

5.3.13 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. During model simulations InfoWorks indicates that all convergence criteria have been met. Over the duration of the flood event, model stability is generally good although it is noted that there are localised instabilities in the Loch Alvie outlet channel when the Spey stage-time downstream boundary is applied which results in backflow into the loch. Modelled loch levels are stable however.

2D model performance

5.3.14 The cumulative mass error output reports from the 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The mass balance of the model is comfortably is 0% for all of the modelled flood events.

Model Results Analysis

5.3.15 The following sections provides a comparison of 1D and 2D modelling results.

5.3.16 The following results tables provide comparisons between baseline and scheme 1D and 2D results.

5.3.17 Table 5.10 provides 1D max stage results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. Max water levels downstream of the A9 side road Allt an Fhearna crossing are within 70mm of baseline conditions for all events. Upstream of this crossing (Allt_0258_int49) there is an increase in water level by up to 0.515m for the 0.5%AEP + climate change event as water is held back by the new structure and earthworks. This upstream effect extends only as far as Allt_0492_int196 and does not impact on the upstream existing A9 crossing.

5.3.18 The small increases in peak water level downstream should be considered in the context of the larger decrease in water level in the 2D domain shown in Table 5.11. This shows that the proposed model reduces water levels on the floodplain immediately downstream of the side road crossing by up to 0.685m (Location D, 0.5%AEP + climate change).

5.3.19 The increase in water level shown at Locations A and B upstream of the side road crossing are significant in magnitude (up to 0.251m at Location B, 0.5%AEP + climate change). However, the impact at this location is minor with no sensitive flood receptors. The increase in flood water level is experienced in an area of riparian woodland and no ecological or landscape concern has been identified by the relevant environmental specialists. No impact is observed in the model on Loch Alvie water levels at Location E.

5.3.20 Table 5.12 provides peak flow results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. Peak flow is reduced at section Allt_0258_int98 (downstream of the A9 side road crossing) by 0.687m^3/s and 0.033m^3/s compared to the baseline for 0.5%AEP and 0.5%+climate change respectively but increases at the 1%, 1.33% and 50% AEP events. These model results are due to the complex interaction of 1D channel and 2D floodplain flow; in the baseline model flow is unimpeded as it is conveyed across the floodplain south of the Allt an Fhearna with a contribution to in-channel flows from returning floodplain flow at the less frequent events. This effect is curtailed in the proposed model with overland flow still occurring but only once the side road has been overtopped. At the lower return periods less flow overtops the side road and is stored by the earthworks before being preferentially conveyed onwards in the river channel. This results in the increase in-channel flow for more frequent events at the same time as a reduced water level and extents on the floodplain.

Table 5-10: Allt an Fhearna and Loch Alvie Baseline and Scheme 1D Stage Results Comparison

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
DALXS16	212.132	212.132	0	212.009	212.009	0	211.926	211.926	0	211.795	211.795	0	211.512	211.512	0
DALXS15_int81	212.143	212.161	0.011	212.018	212.058	0.030	211.947	211.941	0	211.811	211.817	0.004	211.529	211.535	0.012
DALXS15_int121	212.15	212.16	0.017	212.028	212.038	0.020	211.941	211.94	-0.007	211.813	211.811	0	211.523	211.523	-0.006
DALXS15_int40	212.161	212.145	-0.016	212.031	212.071	0.040	211.943	211.944	0.001	211.815	211.817	0.002	211.525	211.535	0.010
DALXS15	212.142	212.151	0.009	212.032	212.08	0.048	211.945	211.941	-0.004	211.816	211.816	0	211.527	211.528	0.001
DALXS14	212.164	212.179	0.015	212.039	212.081	0.042	211.95	211.952	0.002	211.817	211.817	0	211.527	211.536	0.009
Allt_0000	212.724	212.775	0.051	212.703	212.763	0.060	212.696	212.760	0.064	212.664	212.731	0.067	212.564	212.632	0.068
Allt_0258_int197	212.961	212.98	0.019	212.948	212.973	0.025	212.946	212.973	0.027	212.924	212.955	0.031	212.85	212.884	0.034
Allt_0258_int148	213.888	213.853	-0.035	213.869	213.84	-0.029	213.861	213.835	-0.026	213.823	213.799	-0.024	213.645	213.615	-0.030
Allt_0258_int98	214.481	214.45	-0.031	214.453	214.438	-0.015	214.441	214.434	-0.007	214.389	214.396	0.007	214.214	214.219	0.005
Allt_0258_int49	215.241	215.756	0.515	215.214	215.691	0.477	215.198	215.666	0.468	215.127	215.53	0.403	214.876	215.111	0.235
Allt_0258	215.855	215.961	0.106	215.814	215.914	0.100	215.791	215.893	0.102	215.709	215.793	0.084	215.517	215.516	-0.001
Allt_0492_int196	216.418	216.378	-0.040	216.383	216.347	-0.036	216.363	216.331	-0.032	216.286	216.257	-0.029	216.046	216.042	-0.004
Allt_0492_int147	216.879	216.888	0.009	216.845	216.852	0.007	216.828	216.837	0.009	216.762	216.769	0.007	216.452	216.452	0
Allt_0492_int98	217.582	217.562	-0.02	217.465	217.453	-0.012	217.416	217.409	-0.007	217.229	217.229	0	216.821	216.821	0
Allt_0492_int49	217.825	217.827	0.002	217.769	217.772	0.003	217.747	217.743	-0.004	217.609	217.611	0.002	217.191	217.191	0

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Allt_0492	218.510	218.519	0.009	218.358	218.366	0.008	218.29	218.296	0.006	218.041	218.045	0.004	217.559	217.559	0
ALL_0530B!	218.660	218.659	-0.001	218.495	218.498	0.003	218.435	218.431	-0.004	218.201	218.198	-0.003	217.666	217.666	0
ALL_0530A!!!	219.672	219.659	-0.013	219.412	219.385	-0.027	219.314	219.323	0.009	218.938	218.92	-0.018	218.338	218.339	0.001
ALL_0530A	219.738	219.731	-0.007	219.486	219.484	-0.002	219.387	219.389	0.002	219.024	219.024	0	218.443	218.443	0
ALL_0530A!	219.738	219.731	-0.007	219.486	219.484	-0.002	219.387	219.389	0.002	219.024	219.024	0	218.443	218.443	0
Allt_0793_int195	220.074	220.088	0.014	219.791	219.802	0.011	219.678	219.684	0.006	219.263	219.275	0.012	218.769	218.543	-0.226
Allt_0542	220.079	220.08	0.001	219.800	219.797	-0.003	219.683	219.680	-0.003	219.268	219.271	0.003	218.543	218.769	0.226
Allt_0793_int146	220.106	220.118	0.012	219.888	219.894	0.006	219.832	219.831	-0.001	219.573	219.579	0.006	219.271	219.271	0
Allt_0793_int97	220.372	220.38	0.008	220.260	220.266	0.006	220.226	220.228	0.002	220.079	220.086	0.007	219.818	219.818	0
Allt_0793_int48	220.855	220.865	0.010	220.786	220.793	0.007	220.759	220.758	-0.001	220.608	220.612	0.004	220.347	220.346	-0.001
Allt_0793	221.403	221.405	0.002	221.314	221.321	0.007	221.283	221.285	0.002	221.135	221.14	0.005	220.870	220.87	0
Allt_0929_int67	222.332	222.34	0.008	222.255	222.263	0.008	222.232	222.232	0	222.101	222.103	0.002	221.863	221.863	0
Allt_0929	223.328	223.329	0.001	223.25	223.258	0.008	223.23	223.231	0.001	223.113	223.118	0.005	222.885	222.886	0.001
Allt_1152_int135	224.446	224.451	0.005	224.373	224.38	0.007	224.352	224.352	0	224.232	224.234	0.002	223.979	223.979	0
Allt_1152_int67	225.677	225.677	0	225.601	225.61	0.009	225.581	225.583	0.002	225.459	225.463	0.004	225.192	225.192	0
Allt_1152	226.823	226.827	0.004	226.755	226.762	0.007	226.735	226.734	-0.001	226.612	226.613	0.001	226.375	226.375	0
Allt_1306_int67	227.959	227.958	-0.001	227.878	227.888	0.010	227.861	227.862	0.001	227.729	227.732	0.003	227.460	227.46	0

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Allt_1306	229.031	229.035	0.004	228.944	228.951	0.007	228.917	228.917	0	228.787	228.787	0	228.473	228.473	0

Table 5-11: Allt an Fhearna and Loch Alvie Baseline and Scheme 2D Stage Results Comparison

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Location A	215.041	215.095	0.054	215.017	215.049	0.032	215.010	215.028	0.018	214.979	214.953	-0.026	214.941	214.582	-0.359
Location B	215.663	215.939	0.276	215.663	215.886	0.223	215.648	215.863	0.215	215.584	215.758	0.174	215.362	215.393	0.031
Location C	212.711	dry	-	212.684	dry	-	212.672	dry	-	212.617	dry	-	212.487	dry	-
Location D	214.027	213.924	-0.103	213.993	213.918	-0.075	213.979	213.915	-0.064	213.917	213.902	-0.015	213.679	dry	-
Location E	212.161	212.161	0	212.033	212.033	0	211.945	211.943	-0.002	211.812	211.810	-0.002	211.533	211.532	-0.001

Table 5-12: Allt an Fhearna and Loch Alvie Baseline and Scheme 1D Flow Results Comparison

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Allt_0258_int98	25.989	25.299	-0.690	23.964	23.805	-0.159	23.078	23.182	0.104	19.272	19.645	0.373	10.358	10.363	0.005

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
DALXS14	28.917	27.839	-1.078	24.182	22.819	-1.363	19.454	18.895	-0.559	15.803	15.424	-0.379	6.671	6.497	-0.174

Sensitivity Analysis

5.3.21 Sensitivity analysis was undertaken for proposed scheme modelling using the same test scenarios as baseline modelling. The results from both the 1D and 2D domains have been compared against the scheme results, these are shown in Table 5.13 and Table 5.14. Figures 5.10 – 5.12 show variation within the modelled long section.

5.3.22 Due to the minor impact of the proposed scheme on baseline conditions, the results for sensitivity testing show trends consistent with the outputs from baseline simulations.

Table 5-13: Allt an Fhearna and Loch Alvie Scheme 1D Sensitivity Results for 0.5% AEP Event Proposed Scheme

Cross-section	Proposed Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
DALXS16	212.009	0	0	0.534	-0.534	0.123	0	0
DALXS15_int81	212.058	-0.016	0	0.474	-0.403	0.086	-0.028	-0.009
DALXS15_int121	212.038	-0.01	0	0.439	-0.486	0.104	-0.011	-0.006
DALXS15_int40	212.071	-0.019	0	0.493	-0.361	0.083	-0.046	-0.010
DALXS15	212.08	-0.021	0	0.431	-0.338	0.080	-0.047	-0.011
DALXS14	212.081	-0.022	0	0.506	-0.337	0.048	-0.047	-0.012
Allt_0000	212.763	0.057	-0.065	-0.001	-0.002	0.012	-0.014	0.003
Allt_0258_int197	212.973	-0.045	0.027	0.001	0.001	0.007	-0.008	0.001
Allt_0258_int148	213.840	0.020	-0.011	0	0.008	0.013	-0.019	0
Allt_0258_int98	214.438	-0.045	0.035	0	0	0.012	-0.018	0.001
Allt_0258_int49	215.691	0.081	-0.051	0.001	0	0.065	-0.08	0
Allt_0258	215.914	0.033	-0.012	0	0	0.047	-0.059	-0.002
Allt_0492_int196	216.347	-0.048	0.039	0	0	0.031	-0.045	-0.001
Allt_0492_int147	216.852	-0.045	0.035	0	0	0.036	-0.043	0.002
Allt_0492_int98	217.453	-0.122	0.083	-0.001	0	0.109	-0.123	0
Allt_0492_int49	217.772	-0.081	0.074	0	0	0.055	-0.081	-0.005
Allt_0492	218.366	-0.174	0.139	-0.001	0	0.153	-0.181	-0.002
ALL_0530B!	218.498	-0.202	0.282	-0.001	0	0.161	-0.175	-0.002
ALL_0530A!!!	219.385	-0.009	0.031	0	-0.001	0.274	-0.236	0.027
ALL_0530A	219.484	-0.045	-0.008	-0.002	-0.001	0.247	-0.265	0.004
ALL_0530A!	219.484	-0.045	-0.008	-0.002	-0.001	0.247	-0.265	0.004

Cross-section	Proposed Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Allt_0542	219.802	-0.040	0.012	0.002	0	0.286	-0.301	-0.004
Allt_0793_int195	219.797	-0.048	-0.003	-0.001	0	0.283	-0.303	-0.004
Allt_0793_int146	219.894	-0.039	0.031	0	0	0.224	-0.176	-0.006
Allt_0793_int97	220.266	-0.077	0.057	0	0	0.114	-0.100	-0.006
Allt_0793_int48	220.793	-0.090	0.078	0	0	0.072	-0.096	-0.006
Allt_0793	221.321	-0.097	0.075	0	0	0.084	-0.100	-0.007
Allt_0929_int67	222.263	-0.074	0.079	0	0	0.077	-0.082	-0.008
Allt_0929	223.258	-0.073	0.065	-0.001	0	0.071	-0.074	-0.004
Allt_1152_int135	224.380	-0.068	0.075	0.001	0	0.071	-0.077	-0.008
Allt_1152_int67	225.61	-0.081	0.063	-0.001	0	0.067	-0.078	-0.003
Allt_1152	226.762	-0.067	0.069	0.001	0	0.065	-0.076	-0.008
Allt_1306_int67	227.888	-0.086	0.068	-0.001	0	0.07	-0.082	-0.003
Allt_1306	228.951	-0.078	0.088	0.001	0	0.084	-0.087	-0.009

Table 5-14: Allt an Fhearna and Loch Alvie Scheme 2D Sensitivity Results for 0.5% AEP Event Proposed Scheme

Sensitivity Test	Proposed Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Location A	215.051	-0.033	0.035	0.002	0.002	0.89	-0.055	0
Location B	215.862	0.044	-0.017	0	0	0.053	-0.069	0
Location C	212.405	0	0	0	0	0	0	0
Location D	213.33	0.001	0.001	0	0	0.109	-0.010	0

Sensitivity Test	Proposed Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Location E	212.11	0.068	0.088	0.556	-0.540	0.128	-0.001	0

Figure 5-10 - Loch Alvie Outlet Channel (Allt Dibheach) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP event

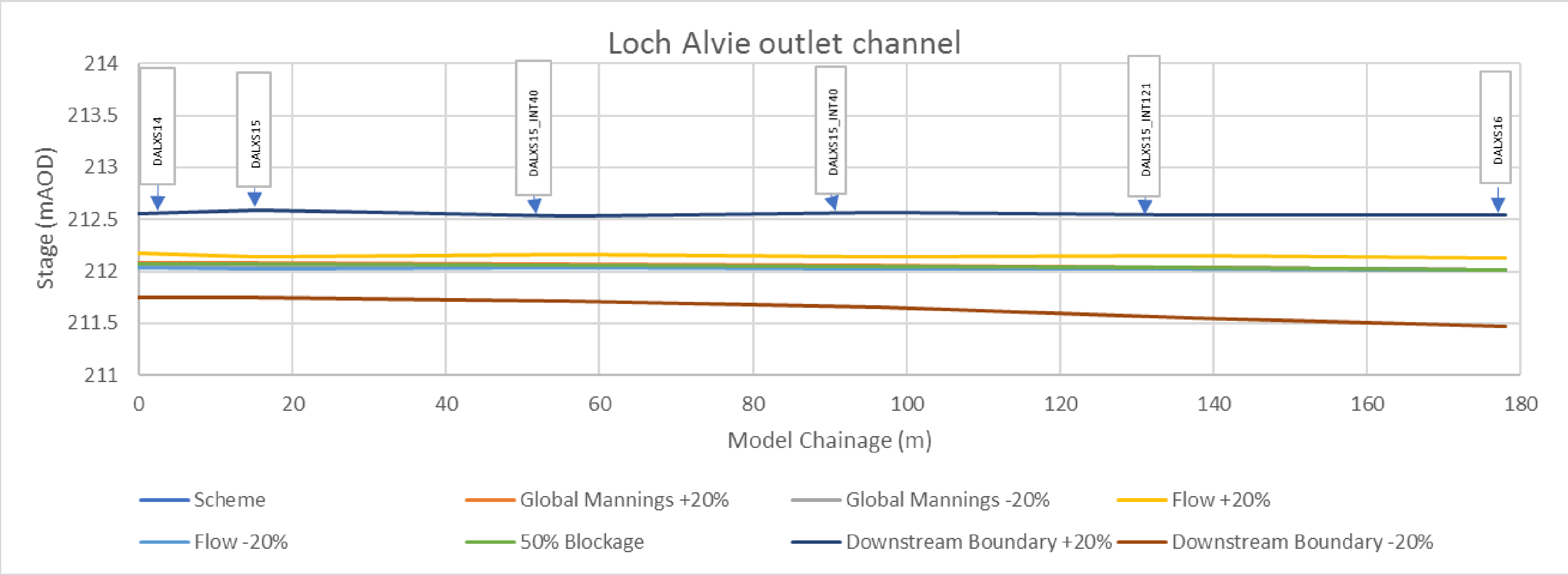


Figure 5-11 - Allt an Fhearna (0m-780m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP event

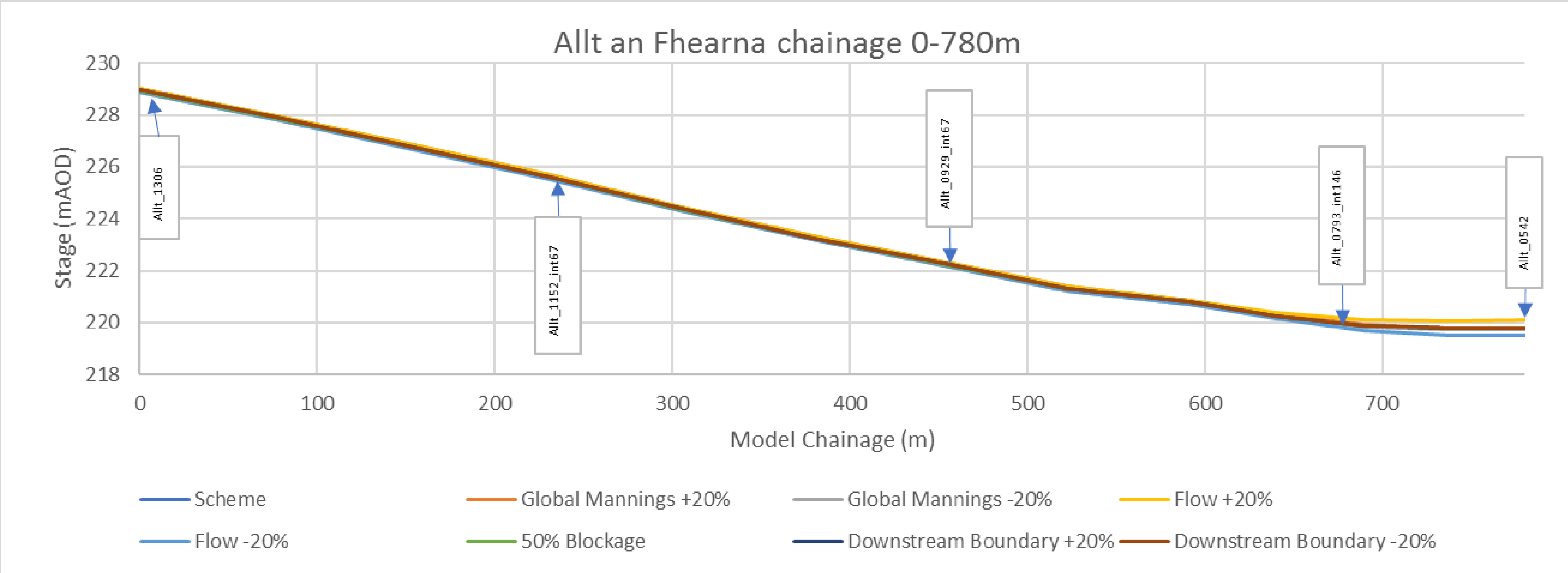
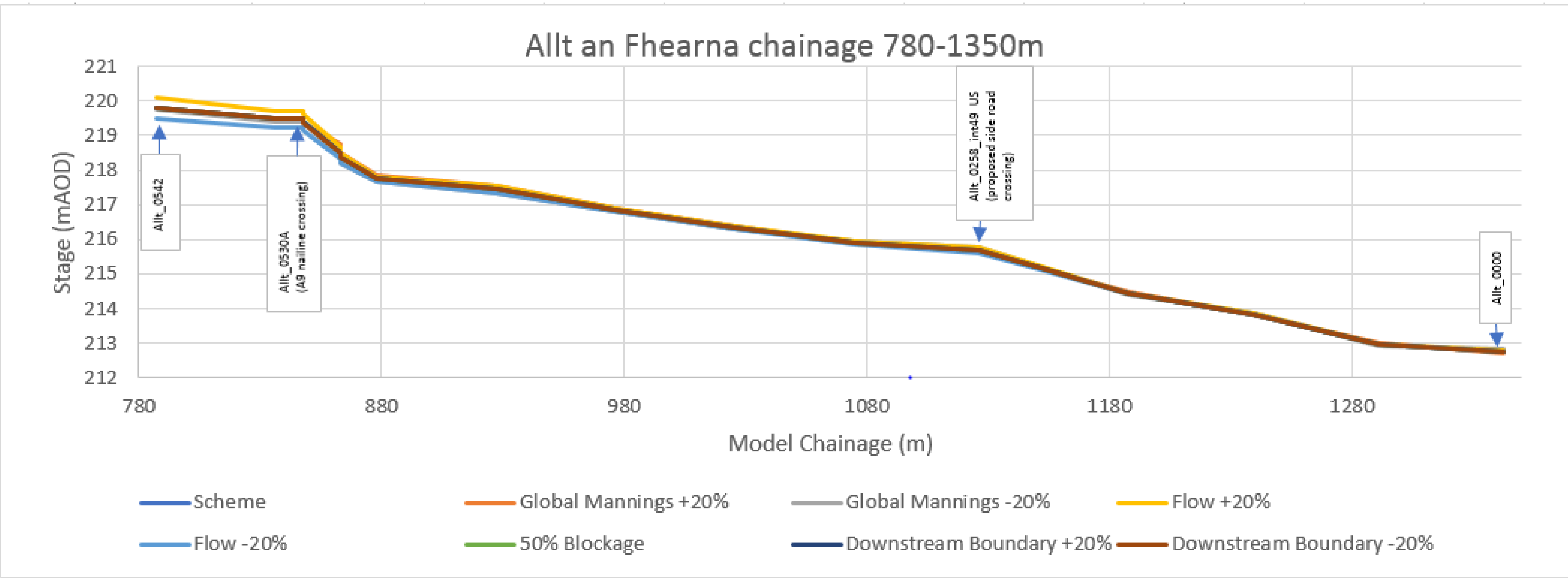


Figure 5-12 - Allt an Fhearna (780m-1350m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP event



5.4 Summary

5.4.1 The Allt an Fhearna and Loch Alvie hydraulic model has been developed using a 1d/2d InfoWorks RS model, and includes the reach of the Allt an Fhearna from upstream of the A9 to the Allt Dibeach channel at the outlet of Loch Alvie.

5.4.2 The baseline model includes a single existing A9 crossing (Allt an Fhearna).

5.4.3 The proposed scheme modelling has been undertaking using data contained within Design Refresh 7a, including earthworks associated with widening of the A9 mainline to accommodate a dual carriageway. Updates to the baseline model for the proposed scheme included the provision of SUDS pond access roads and a new culvert structure to carry a side road across the Allt an Fhearna.

5.4.4 The encroachment of the scheme has an impact on available floodplain storage at the site. In total there is approximately 336m^3 of floodplain loss when comparing the baseline flood levels to the proposed side road earthworks.

5.4.5 Results show that downstream water levels are reduced on the floodplain downstream of the scheme. Modelled water levels in Loch Alvie are unchanged by the proposed scenario. 1D water levels do increase downstream of the A9 side road crossing for some AEP events, however, this increase does not propagate into the 2D domain and is not considered to be within proximity of any sensitive receptors. Modelled water levels upstream of the side road crossing and downstream of the A9 mainline are increased due to the earthworks effectively forming defacto online flood storage. This localised increase in water level does not impact any sensitive receptors and has the consequence of reducing water levels in the downstream floodplain.

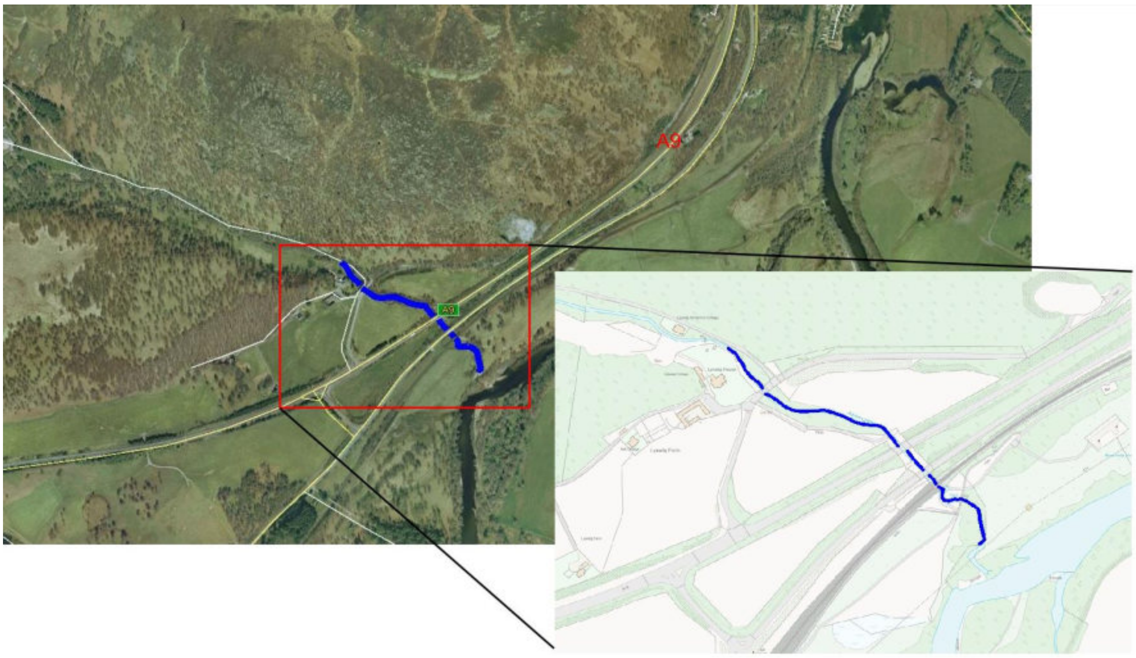
5.4.6 The impact of the scheme at Allt an Fhearna and Loch Alvie is considered to be minor, and as such, compensatory floodplain storage or scheme mitigation measures are not considered necessary at this site.

6. Allt na Criche (Lynwilg)

6.1.1 Allt na Criche at Lynwilg is a relatively small watercourse with a catchment area of around 6.1 km^2 upstream of the A9. The watercourse captures runoff from the eastern slope of the Monadhliath Mountains between Alvie and Aviemore. The watercourse is relatively steep and flows southeast, joining the River Spey located at around 260 m downstream of the A9 (see Figure 6.1).

6.1.2 The hydraulic model was built using a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller Pro (version 4.2.6050), and the 2D component was constructed using TUFLOW (version 2016.03).

Figure 6-1 - Lynwilg Study Area



6.1.3 The data used to construct the baseline hydraulic model for the Allt na Criche at Lynwilg model is summarised in Table 6.1.

Table 6-1 - Data used to build the baseline hydraulic model

Data	Description	Source
Topographical Survey	The 1d model cross-sections are based on survey data carried out in 2016.	Topographical survey data 2016 carried out by Blom AEROFILMS appointed by Transport Scotland
LiDAR	The floodplain ground model has been generated based on LiDAR data	Provided by Transport Scotland.
FEH Catchment descriptors	Model inflow has been generated based on the catchment descriptors	FEH web service

6.1.4 The Allt na Criche at Lynwilg catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. One inflow catchment was identified for the Allt na Criche at Lynwilg. Two surface water catchments were identified to the west and east of the A9 crossing[1]. However, these surface water inflows were not included into the final fluvial model.

6.1.5 Figure 6.2 shows the Catchment area of the Allt Na Criche at Lynwilg. The catchment area was altered to reflect the surrounding topography. Details can be found in Table 6.2.

[1] Likely flow path of these two surface water catchments were assessed by including point flows directly into the 2D model. It was noted that the flow from these surface water drains towards the A9 road and the flow builds up north of the A9 road.

Figure 6-2 - Allt na Criche at Lynwilg catchment

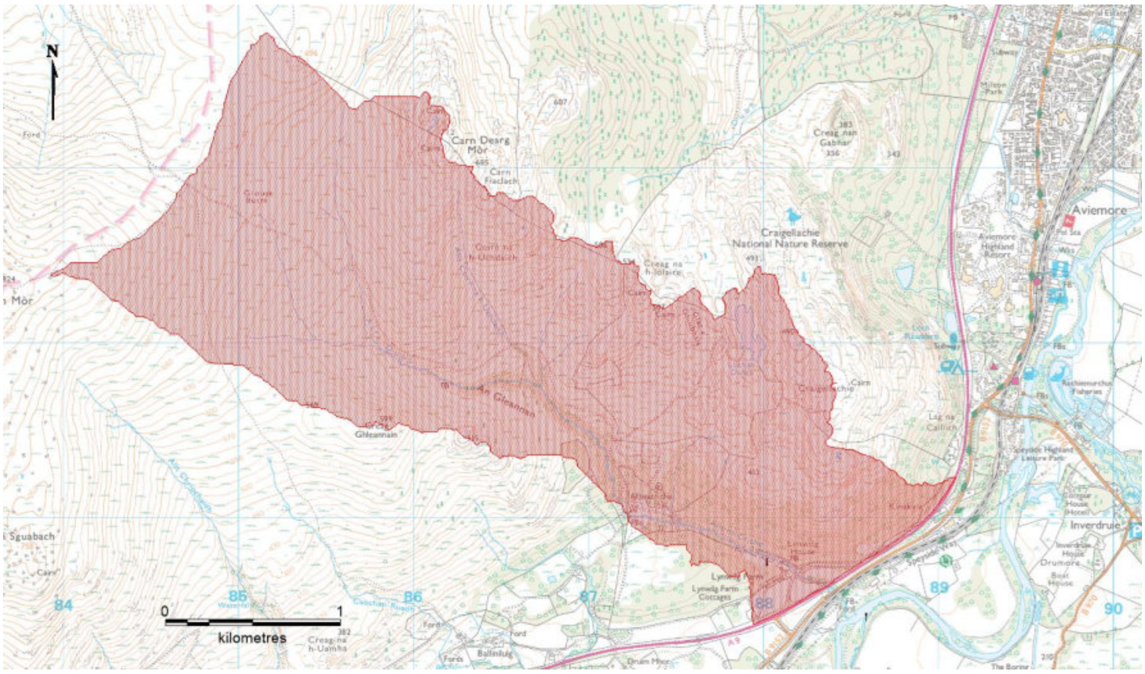


Table 6-2 Allt na Criche at Lynwilg Hydrological Parameters

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Allt na Criche	DS-WC-007	Allt na Criche Upstream	Direct	Rainfall-Runoff	288144	810749	6.52

6.1.6 Peak flows were calculated for the inflow point using the FEH Rainfall Runoff methods, an FEH statistical estimate was undertaken at the A9 crossing for comparison purpose.

6.1.7 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events. The critical storm duration for the Allt na Criche at Lynwilg was set as 3.7 hours. Table 6.3 shows the peak flow estimates.

Table 6-3 - Allt na Criche at Lynwilg Peak Flow Estimates

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
Allt na Criche	DS-WC-007	Allt na Criche Upstream	14.0	16.8

6.1.8 Applying the precautionary approach, the FEH Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

6.1.9 Hydrographs were generated using FEH Rainfall-Runoff methods.

6.1.10 Modelled events are indicated in Table 6.4.

Table 6-4 - Modelled Events

Scenario	AEP					
	50%	4%	3.33%	0.5%	0.5%+CC	0.1%
Baseline	Modelled	Modelled	Modelled	Modelled	Modelled	Modelled

Scenario	AEP					
	50%	4%	3.33%	0.5%	0.5%+CC	0.1%
Roughness sensitivity	Not Modelled	Not Modelled	Not Modelled	Modelled	Not Modelled	Not Modelled
Hydrological inflow sensitivity	Not Modelled	Not Modelled	Not Modelled	Modelled	Not Modelled	Not Modelled
Downstream boundary sensitivity	Not Modelled	Not Modelled	Not Modelled	Modelled	Not Modelled	Not Modelled
Model 'with – scheme'	Modelled	Modelled	Modelled	Modelled	Modelled	Modelled
With-scheme and mitigation	Modelled	Modelled	Modelled	Modelled	Modelled	Not Modelled

6.2 Baseline Hydraulic Model

Model assumptions and limitations

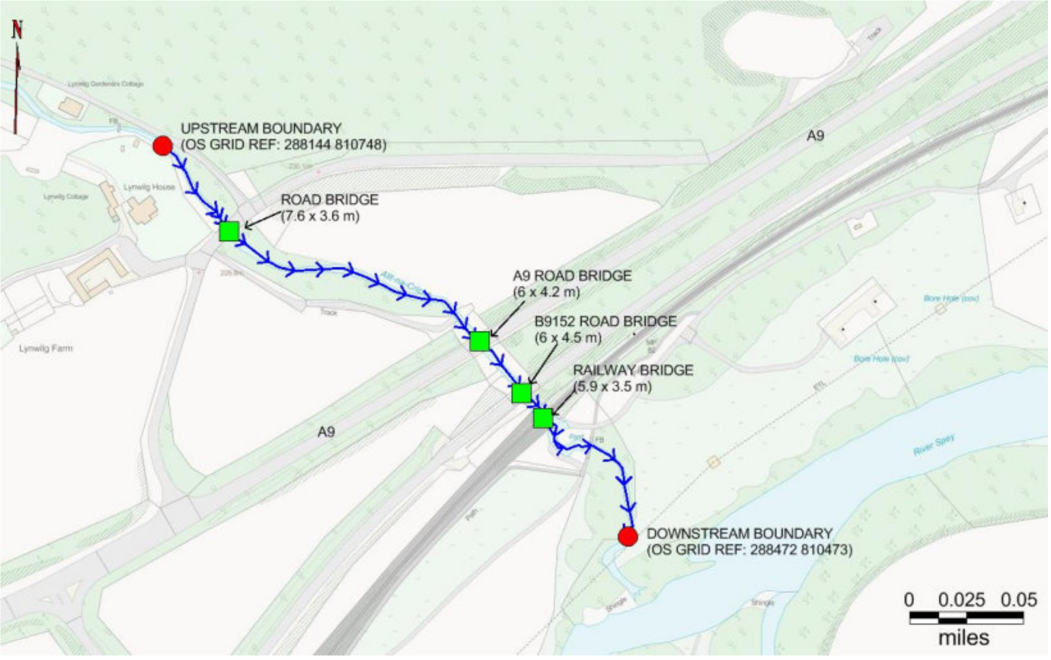
6.2.1 A detailed 1D/2D model of a section of Allt na Criche at Lynwilg was built using Flood Modeller (1D) and Tuflow (2D) softwares. The 1D model extends from around 75 m upstream of a road bridge crossing adjacent to Lynwilg House to around 120 m downstream of a railway crossing, ensuring that the boundaries do not influence model results.

6.2.2 The upstream and downstream boundary of the model is located at NGR 288144 810748 and 288472 810473 respectively. The 1D model reach is around 470 m in length and has 19 cross-sections. Details of four bridge crossings and a weir structure were surveyed and included in the model. The bridge crossings were modelled without a spill unit as the structures were estimated to have a capacity in excess of 1000 year design flow.

6.2.3 The 1D channels dynamically connect to the floodplains modelled in 2D. The 2D domain had an area of 354,400m^2 and is represented using the 5m grid.

6.2.4 Elevated river banks along agricultural areas are extensive in some locations. Bank top levels are of key hydraulic significance as they define the spill threshold between the main channel and floodplains. For model accuracy, existing surveyed bank top levels were included within the 2D domain. Figure 6.3 shows model domain extent including location and size of the structures.

Figure 6-3 - Model Domain Extent



6.2.5 Table 6.5 below details the model extents and key features.

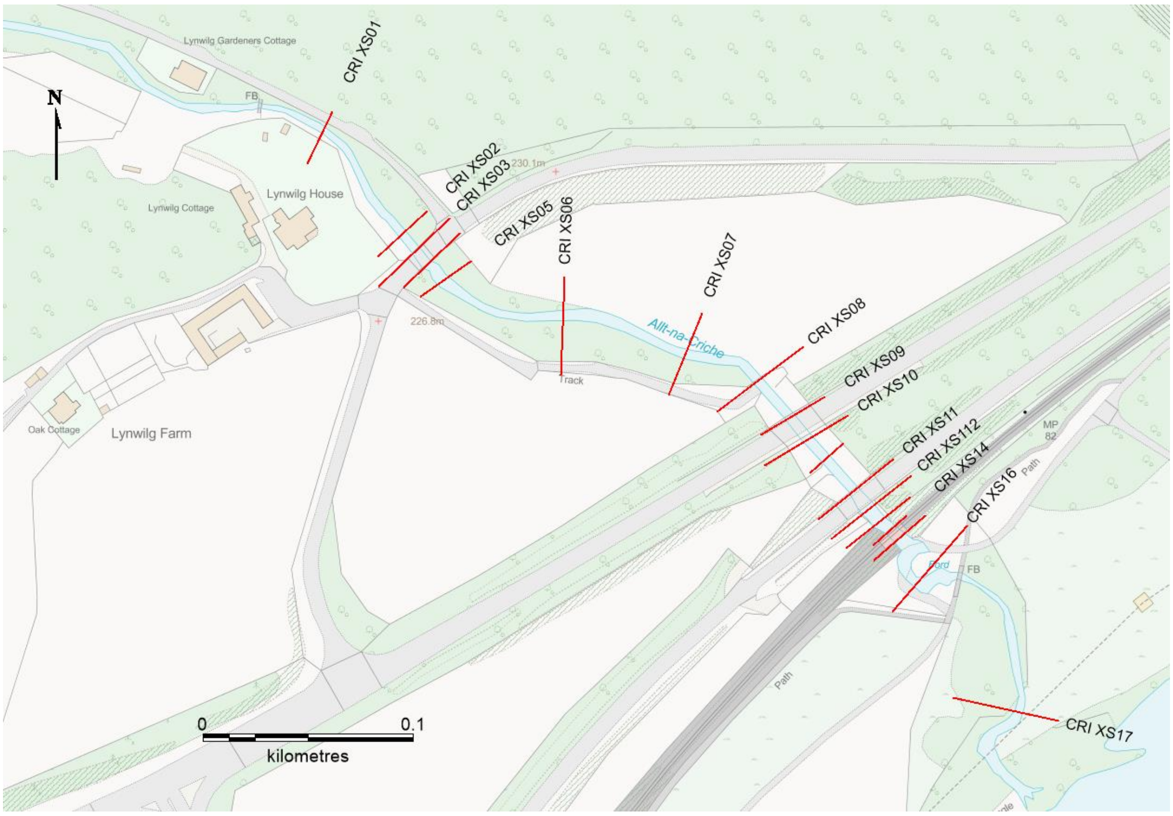
Table 6-5 Allt na Criche at Lynwilg, Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of A9 Crossings	Total number of modelled structures
Allt na Criche (Lynwilg)	470	288144 810748	288472 810473	1	5

6.2.6 A direct inflow hydrograph is applied to the hydraulic model at the upstream extent of the model. A Normal Depth boundary was used at the downstream extent of all the models.

6.2.7 Location of the model cross-sections are presented in Figure 6.4.

Figure 6-4 - Allt na Criche at Lynwilg schematic detailing cross section locations



In- channel geometry (1D)

6.2.8 The open channel river sections were defined from the topographical survey, with the Manning's 'n' values defined from the site visits, which were undertaken in March 2016. Table 6.6 provides the Manning's value range and justification of the value.

Table 6-6 - Allt na Criche at Lynwilg, roughness values

Section Type	Minimum	Maximum	Commentary
River Channel (Manning's)	0.040	0.040	Straight channel, no major meandering. Gravel substrate
Structures (Colebrook white)	0.030	0.030	Natural river gravels on invert
Floodplain (Manning's)	0.015	0.050	Ranging from Scattered brush, heavy weeds

In channel's hydraulic structures

6.2.9 Table 6.7 provides the details of how the structures are represented within the model. Figure 6.3 shows the location of these modelled structures.

Table 6-7 - Allt na Criche at Lynwilg Modelled Structure Details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Re presentation in the model	Photograph
N/A	Road Bridge	Allt na Criche (Lynwilg)	7.6 x 3.6	Arch Bridge	
A9 1130	A9 Road Bridge	Allt na Criche (Lynwilg)	6.0 x 4.2	USBPR1978 Bridge	
N/A	B9152 Road Bridge	Allt na Criche (Lynwilg)	6.0 x 4.5	USBPR1978 Bridge	
N/A	Railway Bridge	Allt na Criche (Lynwilg)	5.9 x 3.5	Arch Bridge	

Flood plain schematisation – 2D domain

6.2.10 The 2D domain had an area of 354,400m^2 and is represented using the 5m grid. No hydraulic structures are present in the model 2D domain.

6.2.11 The flood plain roughness values considered are shown in:

- General land cover – 0.05
- Roads – 0.02
- Building - 2

6.2.12 The 1D flood modeller model was dynamically linked with 2D TUFLOW model with the help of HX boundary. The model could not be verified/calibrated due to the absence of any gauge data or historical anecdotal records.

Model Sensitivity, baseline

6.2.13 The sensitivity of the baseline hydraulic model to the key parameter values used was tested as detailed below:

- Global roughness + / - 20%
- Flow + 20%
- 50% blockage scenario (N/A for this model)
- Downstream Boundary + 20%

6.2.14 The model results have been compared against the baseline results, these are shown in Table 6.8 and Table 6.9. The sensitivity results were considered on all of the modelled cross-sections.

Table 6-8 - Comparison of Baseline and Proposed Flows (m^3/s) for comparative model cross sections

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
Cross section	Q200+CC	Q200+CC	Q200	Q200	Q25	Q25	Q30	Q30	Q2	Q2
CRIXS01	16.837	16.837	14.026	14.026	8.954	8.954	9.284	9.284	4.298	4.298
CRIXS02	16.965	16.96	14.086	14.087	8.954	8.954	9.289	9.284	4.298	4.298
CRIXS03	16.969	16.962	14.087	14.084	8.954	8.954	9.289	9.284	4.298	4.298
CRIXS03b	16.969	16.962	14.087	14.084	8.954	8.954	9.289	9.284	4.298	4.298
CRIXS04	16.968	16.965	14.087	14.086	8.954	8.954	9.288	9.284	4.298	4.298
CRIXS04_low	16.968	16.965	14.087	14.087	8.954	8.954	9.288	9.284	4.298	4.298
CRIXS05	16.965	16.964	14.087	14.087	8.954	8.954	9.292	9.284	4.298	4.298
CRIXS06	16.977	16.964	14.089	14.095	8.954	8.954	9.298	9.284	4.298	4.298
CRIXS07	16.971	16.963	14.097	14.094	8.954	8.954	9.294	9.283	4.297	4.297
CRIXS08	16.893	16.962	14.096	14.096	8.954	8.954	9.297	9.283	4.297	4.297
CRIXS09	17.001	16.962	14.100	14.098	8.953	8.953	9.295	9.283	4.297	4.297
CRIXS09b	17.001	16.962	14.100	14.095	8.953	8.953	9.295	9.283	4.297	4.297
CRIXS10	17.001	16.962	14.098	14.093	8.953	8.953	9.297	9.283	4.297	4.297
CRIXS10A	17.002	16.962	14.099	14.095	8.953	8.953	9.296	9.283	4.297	4.297
CRIXS11	17.005	16.962	14.097	14.098	8.953	8.953	9.298	9.283	4.297	4.297
CRIXS11_b	17.005	16.962	14.097	14.098	8.953	8.953	9.298	9.283	4.297	4.297
CRIXS12	17.006	16.962	14.098	14.098	8.953	8.953	9.297	9.283	4.297	4.297
CRIXS13	17.008	16.962	14.096	14.099	8.953	8.953	9.297	9.283	4.297	4.297
CRIXS14	17.008	16.962	14.097	14.099	8.953	8.953	9.298	9.283	4.297	4.297
CRIXS14_b	17.008	16.962	14.097	14.099	8.953	8.953	9.298	9.283	4.297	4.297
CRIXS15	17.008	16.961	14.096	14.100	8.953	8.953	9.298	9.283	4.297	4.297
CRIXS16	17.013	16.961	14.095	14.100	8.953	8.953	9.301	9.283	4.297	4.297

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
Cross section	Q200+CC	Q200+CC	Q200	Q200	Q25	Q25	Q30	Q30	Q2	Q2
CRIXS17	16.86	16.81	14.074	14.073	8.952	8.952	9.311	9.282	4.297	4.298

Table 6-9 - Comparison of Baseline and Proposed Stage (mAOD)

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
Cross section	Q200+CC	Q200+CC	Q200	Q200	Q25	Q25	Q30	Q30	Q2	Q2
CRIXS01	227.285	227.285	227.17	227.17	226.93	226.93	226.948	226.947	226.616	226.616
CRIXS02	225.438	225.438	225.229	225.229	225.051	225.051	225.075	225.074	224.779	224.779
CRIXS03	225.350	225.350	225.175	225.175	224.861	224.861	224.881	224.881	224.572	224.572
CRIXS03b	225.173	225.173	225.059	225.059	224.835	224.835	224.851	224.851	224.572	224.572
CRIXS04	225.192	225.192	225.068	225.068	224.817	224.817	224.835	224.834	224.531	224.531
CRIXS04_low	224.039	224.039	223.966	223.966	223.819	223.819	223.830	223.829	223.649	223.649
CRIXS05	223.572	223.571	223.498	223.498	223.350	223.350	223.361	223.361	223.165	223.165
CRIXS06	221.145	221.144	221.096	221.096	221.002	221.002	221.008	221.008	220.848	220.848
CRIXS07	218.807	218.841	218.759	218.761	218.574	218.575	218.589	218.589	218.335	218.337
CRIXS08	217.558	217.759	217.488	217.611	217.363	217.385	217.373	217.339	217.212	217.203
CRIXS09	216.751	217.700	216.626	217.504	216.42	217.076	216.434	217.107	216.250	216.601
CRIXS09b	216.689	216.913	216.610	216.826	216.458	216.610	216.470	216.624	216.285	216.375
CRIXS10	216.438	216.436	216.360	216.360	216.212	216.212	216.222	216.222	216.039	216.039
CRIXS10A	216.123	216.121	216.023	216.023	215.857	215.857	215.869	215.868	215.672	215.672
CRIXS11	215.835	215.832	215.661	215.661	215.353	215.353	215.376	215.375	215.081	215.081
CRIXS11_b	215.615	215.614	215.538	215.538	215.369	215.369	215.382	215.382	215.172	215.172
CRIXS12	215.336	215.334	215.254	215.254	215.084	215.084	215.097	215.096	214.870	214.870
CRIXS13	215.159	215.158	215.065	215.065	214.890	214.890	214.904	214.903	214.697	214.697

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
Cross section	Q200+CC	Q200+CC	Q200	Q200	Q25	Q25	Q30	Q30	Q2	Q2
CRIXS14	215.035	215.033	214.928	214.928	214.727	214.727	214.741	214.74	214.512	214.512
CRIXS14_b	214.906	214.904	214.829	214.829	214.679	214.679	214.690	214.689	214.501	214.501
CRIXS15	214.767	214.765	214.689	214.689	214.532	214.532	214.543	214.543	214.340	214.340
CRIXS16	214.164	214.162	214.103	214.104	213.943	213.943	213.957	213.956	213.749	213.749
CRIXS17	211.338	211.337	211.294	211.294	211.185	211.185	211.193	211.192	210.986	210.987

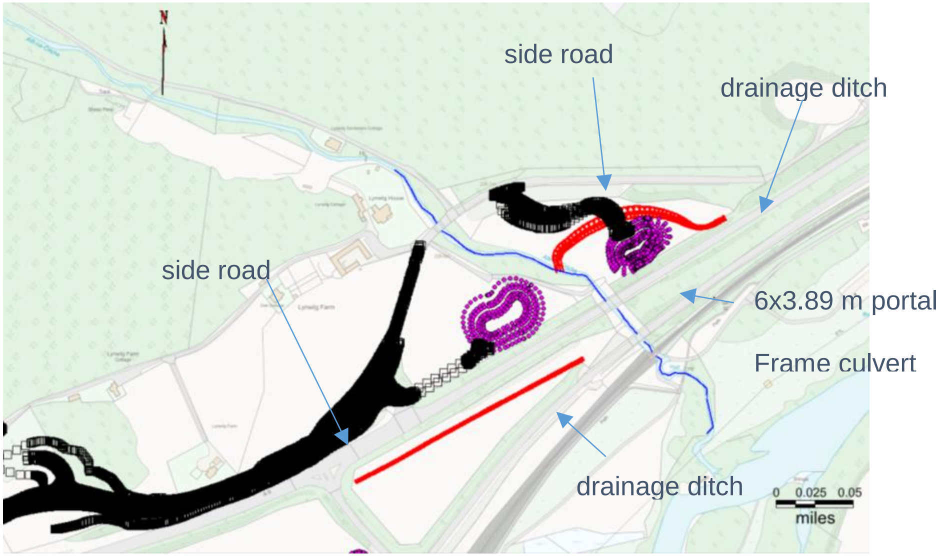
6.3 Proposed Model ('with-scheme' modelling)

6.3.1 The proposed scheme within the model area of the Allt Na Criche at Lynwilg includes:

- Proposed geometry and elevation of A9 road
- Proposed geometry and elevations of the culvert crossing at A9 road;
- Side roads to provide access to the Sustainable Urban Drainage (SuDS) pond;
- 2 number of Sustainable Urban Drainage (SuDS) ponds; and
- Drainage ditches.

6.3.2 Figure 6.5 shows location of the proposed SuDS ponds, drainage channel and side roads. The geometry of the proposed A9 road has not been shown for clarity.

Figure 6-5 - Lynwilg Proposed Scheme



6.3.3 As a part proposed model, the following updates have been made to the baseline model:

- Ground model has been updated to take account of the proposed elevations and alignment of the A9 road. It was not deemed necessary to include the side road in the model as the model results for 200+CC showed that the flow is contained within the river channel and there is no out of bank spill. Therefore, presence of the side road will not have any impact;
- The A9 bridge crossing has been replaced by 6 x 3.89m portal frame culvert (based on drawing: A9P11-AMJ-SBR-H_MLCRI_ST-DR-ST-0001.pdf). A mammal shelf has been included 150mm above 1 in 25 years water level. A sensitivity has also been carried out with the culvert size of 6 x 3.4 m.
- The bed of the cross-sections upstream and downstream of the proposed 1D culverts have been smoothened to tie with the size of the culvert.

6.4 Proposed Model + mitigation measures ('with-scheme + mitigation measure' modelling)

6.4.1 The hydraulic model results have shown that water levels increase immediately upstream of the culvert when the preferred option is in place. However, this increment is local. There is no out of bank flow throughout the whole model reach in both baseline and proposed scheme scenario. Therefore, both baseline and proposed scenario do not pose flood risks to any receptors. Hence, mitigation measures were not deemed necessary.

Modelling Results Analysis

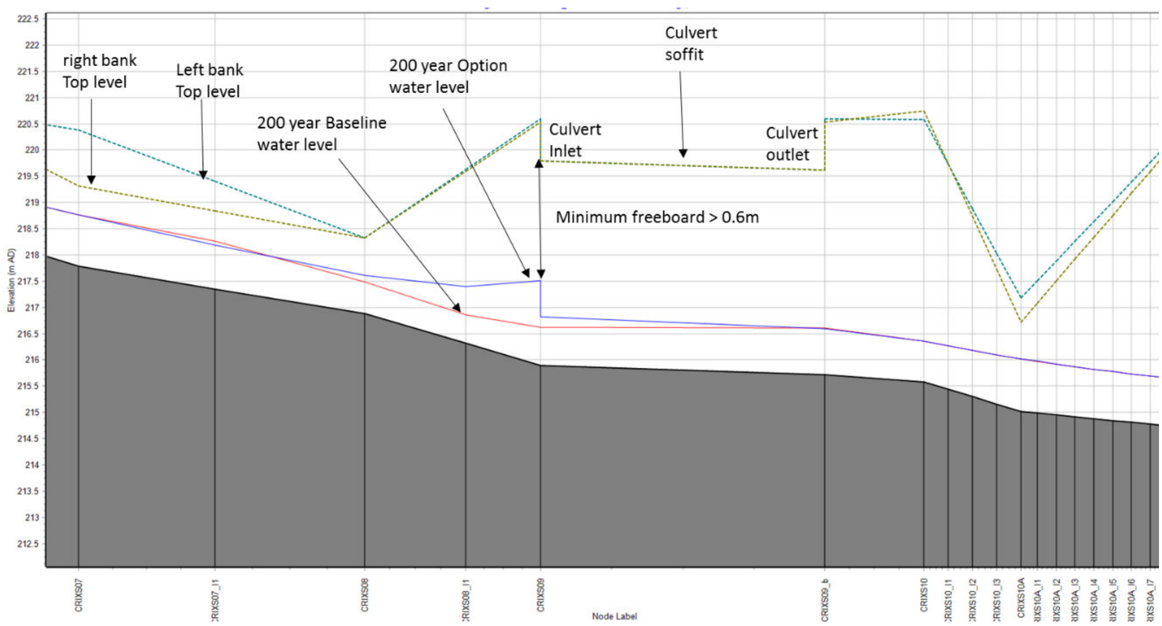
6.4.2 Table 6.8 and Table 6.9 give results of the maximum flow and water level respectively, of the baseline model for the 50%, 3.33%, 0.5% and 0.5%+CC AEP.

6.4.3 Table 6.8 and Table 6.9 give results of the maximum flow and water level respectively, of proposed scheme model for the 50%, 4%, 3.33%, 0.5% and 0.5%+CC AEP.

Comparison of Baseline and Proposed results.

6.4.4 Table 6.8 and Table 6.9 compare the maximum flow and the water levels respectively in all the model cross sections. Table 6.9 compares the preferred option water levels with the baseline in few cross-sections upstream and downstream of the A9 culvert crossing, where the water levels change locally. The culverts will have more than 600mm freeboard throughout its length.

Figure 6-6 - Preferred option v Baseline 200 years maximum stage comparison



6.4.5 As shown in Figure 6.6 and Table 6.9, with the preferred option water levels increase locally by up to 0.87 m immediately upstream of the A9 road bridge for the 200 year return period. However, this increased water levels is contained well within the channel and doesn't pose flood risk to any receptor.

Sensitivity Analysis, proposed scheme

6.4.6 To analyse the sensitivity of the proposed hydraulic model, 3 sensitivity tests have been run to test how sensitive the models are to variable parameters and scenarios.

6.4.7 Table 6.10 shows the variation in flow between the Proposed model and each of the sensitivity results for the Q200 event, whereas Table 6.11 does this for maximum water level.

6.4.8 The increase in water level upstream of the bridge is due to the change in type of the structure from a 6 x 2.4 m rectangular bridge (in baseline) to a 6 x 3.4m portal frame culvert with mammal ledges (in the scheme model). The existing bridge causes head-loss of only 3 cm whereas the proposed culvert has the head-loss of approx. 70 cm at the inlet. The impact is local and propagates only approximately 35m upstream of the bridge contained within channel.

Table 6-10 - Variation in flow for sensitivity tests

	Sensitivity tests Q200 Variation in Flow (m3/s)				
	Baseline	Man +20% Global	Man -20% Global	Q +20%	DSB + 20% XSO2
	Q200	Q200	Q200	Q200	Q200
CRIXS01	14.026	0.000	0.000	+2.811	0.000
CRIXS02	14.086	+0.075	-0.05	+2.879	0.000
CRIXS03	14.087	+0.072	-0.053	+2.882	-0.001
CRIXS03b	14.087	+0.072	-0.053	+2.882	-0.001
CRIXS04	14.087	+0.074	-0.051	+2.881	-0.001
CRIXS04_low	14.087	+0.074	-0.051	+2.881	-0.001
CRIXS05	14.087	+0.071	-0.053	+2.878	-0.002
CRIXS06	14.089	+0.070	-0.054	+2.888	0.006
CRIXS07	14.097	+0.069	-0.050	+2.874	-0.002
CRIXS08	14.096	+0.035	-0.048	+2.797	-0.003
CRIXS09	14.100	+0.104	-0.053	+2.901	-0.001
CRIXS09b	14.100	+0.104	-0.053	+2.901	-0.001
CRIXS10	14.098	+0.106	-0.049	+2.903	-0.001
CRIXS10A	14.099	+0.106	-0.050	+2.903	-0.004
CRIXS11	14.097	+0.108	-0.050	+2.908	-0.002
CRIXS11_b	14.097	+0.108	-0.050	+2.908	-0.002
CRIXS12	14.098	+0.106	-0.052	+2.908	-0.004
CRIXS13	14.096	+0.110	-0.050	+2.912	-0.001
CRIXS14	14.097	+0.108	-0.051	+2.911	0.000
CRIXS14_b	14.097	+0.108	-0.051	+2.911	0.000
CRIXS15	14.096	+0.108	-0.050	+2.912	+0.002
CRIXS16	14.095	+0.108	-0.050	+2.918	0.000
CRIXS17	14.074	+0.008	-0.031	+2.786	-0.557

Table 6-11 - Variation in stage for sensitivity tests

	Sensitivity tests Q200 Variation in stage (m)				
	Baseline	Man +20% Global	Man -20% Global	Q +20%	DSB + 20% XSO2
Cross section	Q200	Q200	Q200	Q200	Q200
CRIXS01	227.17	+0.116	-0.148	+0.115	0.000
CRIXS02	225.229	+0.039	-0.051	+0.139	0.000
CRIXS03	225.175	+0.014	-0.017	+0.175	0.000
CRIXS03b	225.059	+0.009	-0.012	+0.114	0.000
CRIXS04	225.068	+0.004	-0.002	+0.124	0.000

	Sensitivity tests Q200 Variation in stage (m)				
	Baseline	Man +20% Global	Man -20% Global	Q +20%	DSB + 20% XSO2
Cross section	Q200	Q200	Q200	Q200	Q200
CRIXS04_low	223.966	+0.074	-0.098	+0.073	0.000
CRIXS05	223.498	+0.074	-0.082	+0.074	0.000
CRIXS06	221.096	+0.049	-0.060	+0.049	0.000
CRIXS07	218.759	+0.059	-0.114	+0.048	0.000
CRIXS08	217.488	+0.069	-0.086	+0.070	0.000
CRIXS09	216.626	+0.089	-0.126	+0.125	0.000
CRIXS09b	216.61	+0.079	-0.102	+0.079	0.000
CRIXS10	216.36	+0.074	-0.095	+0.078	0.000
CRIXS10A	216.023	+0.076	-0.094	+0.100	0.000
CRIXS11	215.661	+0.073	-0.083	+0.174	0.000
CRIXS11_b	215.538	+0.078	-0.095	+0.077	0.000
CRIXS12	215.254	+0.083	-0.095	+0.082	0.000
CRIXS13	215.065	+0.096	-0.100	+0.094	0.000
CRIXS14	214.928	+0.108	-0.114	+0.107	0.000
CRIXS14_b	214.829	+0.078	-0.083	+0.077	0.000
CRIXS15	214.689	+0.078	-0.096	+0.078	0.000
CRIXS16	214.104	+0.06	-0.083	+0.06	-0.001
CRIXS17	211.294	+0.045	-0.078	+0.044	+0.213

6.4.9 As the results show, change of Manning's roughness by +/- 20% resulted in changes to water levels ranging from around -0.148 m to +0.116 m compared to baseline, as shown in Figure 6.7 and Table 6.11. The most notable changes in water level are at the upstream model reach (CRIXS01) and downstream the Railway Bridge (CRIXS14).

6.4.10 Increase in flow by 20% also produces an increase in water level throughout the modelled watercourse, as shown in Figure 6.8 and Table 6.11. The highest increase in water level is about 0.17 m and take place at the inlet of the B9152 road bridge.

6.4.11 The model is relatively insensitive to changes in the downstream boundary slope with negligible changes in water level at the downstream boundary, with the only exception of the last cross section (detail shown in Figure 6.9.

6.4.12 A sensitivity analysis has also been carried out with the proposed culvert size. Proposed model run has been carried out with the change in the proposed culvert size from 6 x 3.89 m to 6 x 3.4 m. The results show that there is no change in water levels with this change in the culvert size. With the 6 x 3.4 culvert, the freeboard still remains more than 600 mm throughout the entire length of the culvert and also at the inlet and outlet from the outside.

Floodplain Sensitivity Results

6.4.13 The results show that there is no floodplain flow. Therefore, sensitivity results are not presented for the floodplain.

Figure 6-7 - Modelled Long Section Sensitivity Results (Global Roughness)

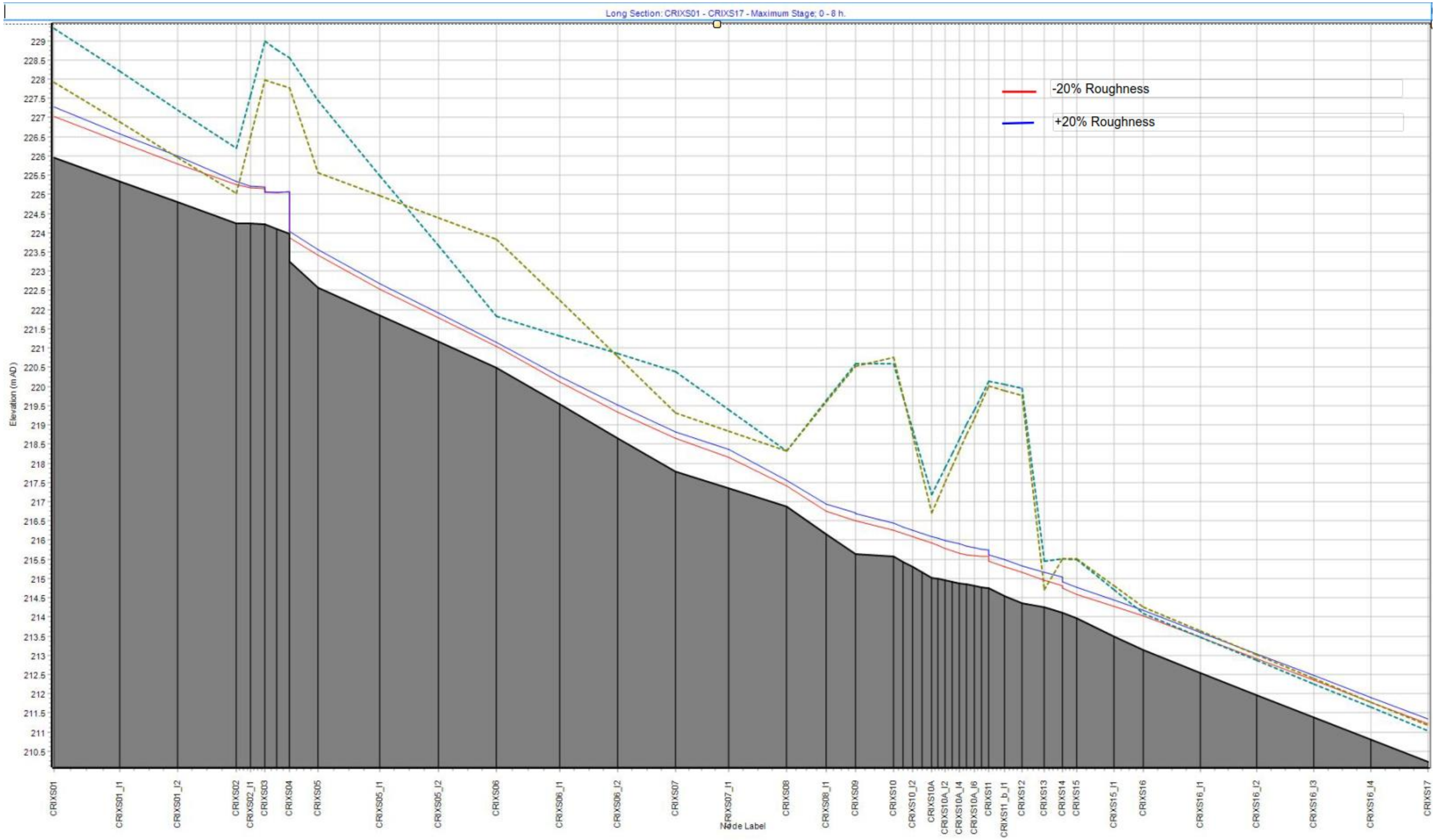


Figure 6-8 - Modelled Long Section Sensitivity Results (Flow Variation)

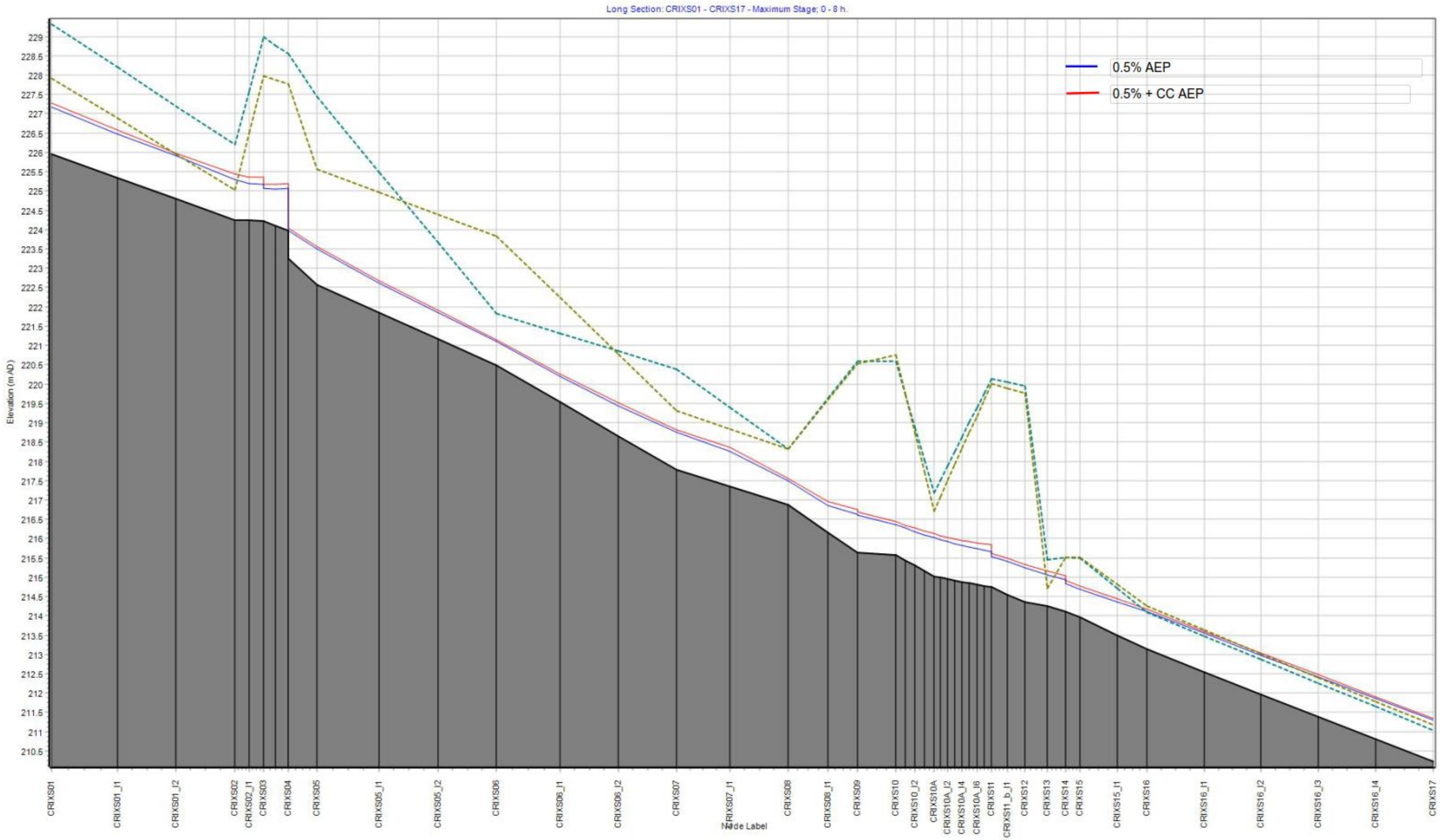
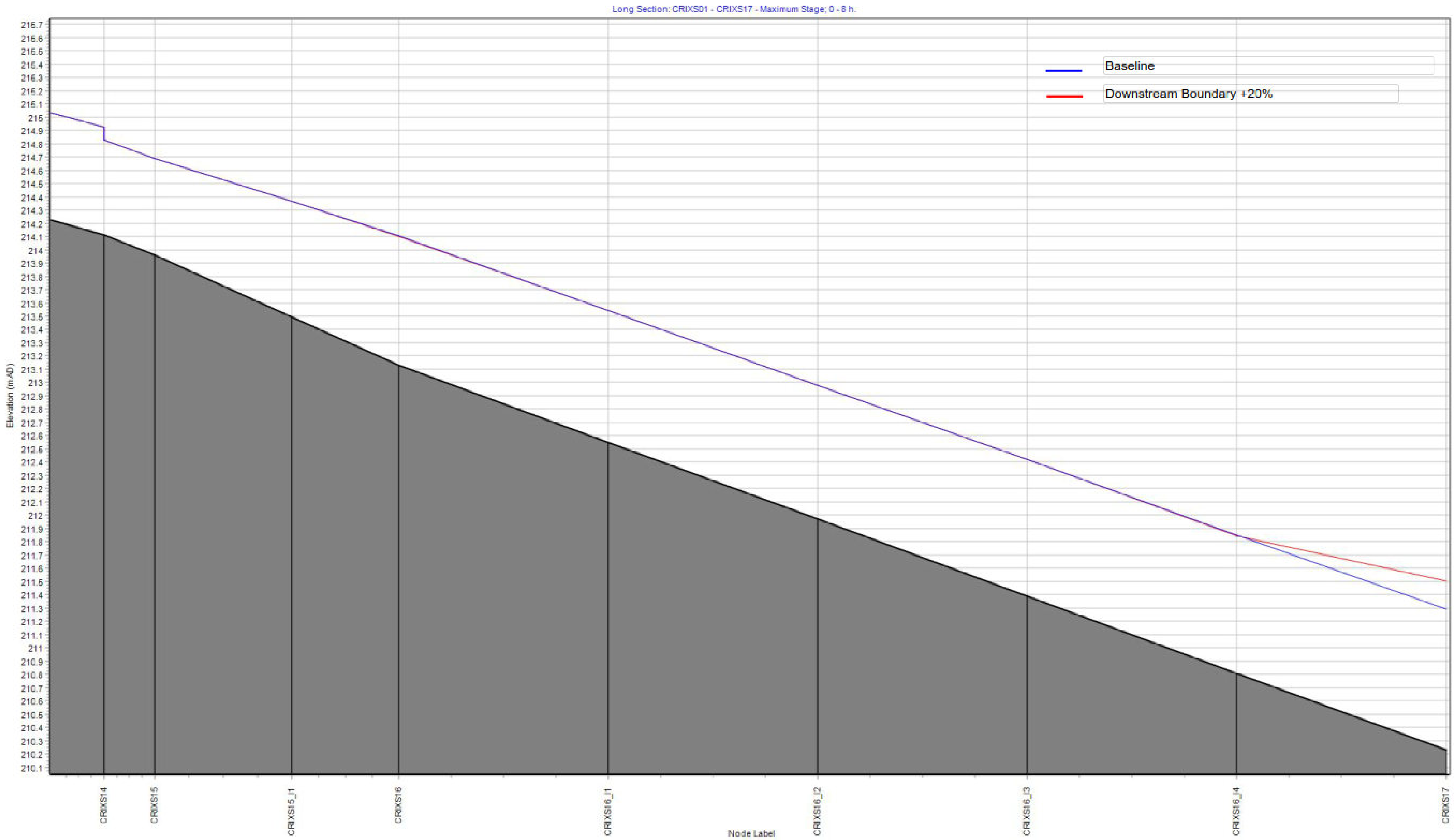


Figure 6-9 - Modelled Long Section Detail Sensitivity Results (Downstream Boundary Variation)



6.5 Summary

6.5.1 The proposed scheme has local impacts which will be contained within the channel geometry. No receptors are at risk of flooding due to the inclusion of the proposed scheme. Therefore, mitigation measures are not required.

6.5.2 The model reach at the upstream end and the reach downstream of the railway bridge are comparatively sensitive to the changes in Manning roughness value.

6.5.3 The highest increase in water level due to the increase in 20% flow occurs at the inlet of the B9152 road bridge.

6.5.4 The model is relatively insensitive to changes in the downstream boundary.

7. Aviemore Burn

7.1.1 The Aviemore Burn has a catchment area of 7.45 km^2 and predominantly drains forestry via several smaller tributaries, including the Milton Burn, on the northbound side of the existing A9 carriageway. These tributaries converge upstream of the A9 before flowing east to the existing A9 crossing located at 289332 813856. The watercourse then flows south via a straightened and realigned channel that has been diverted to accommodate properties on the western fringe of Aviemore, before flowing southeast through the town to discharge to the River Spey at 289802 812503.

7.1.2 The Aviemore Burn catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment area was altered to reflect the surrounding topography.

7.1.3 Applying a distributed model, the catchment was subdivided into four catchments to take account of the Milton Burn and any lateral inflows to the Aviemore Burn. Figure 7.1 and Figure 7.2 show the hydrological model schematic, with Table 7.1 detailing the delineated catchment areas.

7.1.4 A direct inflow hydrograph is applied to the hydraulic model at the upstream extent of the model and again immediately upstream of the A9. Downstream of the existing A9, two lateral inflows are distributed evenly along the two halves of the channel.

7.1.5 It should be noted that there is a fifth catchment potentially contributing to the model at 289091 812948, however, due to a lack of outlet information pertaining to the structure it drains to, it has not been included in this version of modelling. Should further information reveal its contribution to the Aviemore Burn, it will be included as necessary. Sensitivity testing on flow has been undertaken to determine any potential variance in flood levels.

Table 7-1 - Aviemore Burn Hydrological Estimation Points

Water course	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Aviemore Burn	Aviso_UPSI	Upstream of the A9 Crossing DS-WC-000	Direct	FEH Direct	289200	813850	6.12
Milton Burn	Aviso_UPSCUL	Downstream of Cairn Elrig View	Direct	Donor Scale	289277	813900	0.26
Aviemore Burn	Aviso_DS_LAT	Downstream of Crossing to Morlich Pl	Lateral	Donor Scale	289348	813857	0.13

Water course	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Aviemore Burn	Aviso_DS_2	Downstream of Morlich Pl to Bynack More Bridge	Lateral	Donor Scale	289393	813417	0.21

7.1.6 Peak flows were calculated for each inflow using the FEH Rainfall Runoff methods, an FEH statistical estimate was undertaken at the A9 crossing for comparison.

7.1.7 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events, and as a result the Aviemore Burn storm duration was also applied for all inflows. The critical storm duration was set as 3.5 hours. Table 7.2 shows the peak flow estimates.

Table 7-2: Aviemore Burn Peak Flow Estimates

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
Aviemore Burn	Aviso_UPSI	Upstream of the A9 Crossing DS-WC-000	15.55	18.66
Milton Burn	Aviso_UPSCUL	Downstream of Cairn Elrig View	1.14	1.37
Aviemore Burn	Aviso_DS_LAT	Downstream of Crossing to Morlich Pl	0.59	0.70
Aviemore Burn	Aviso_DS_2	Downstream of Morlich Pl to Bynack More Bridge	1.06	1.28
Aviemore Burn*	DS-WC-14	DS-WC-14	12.62	15.15

*denotes the FEH Statistical estimates.

7.1.8 Applying the precautionary approach and considering the size of the catchment the FEH Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

7.1.9 Hydrographs were generated from the FEH Rainfall Runoff method.

7.2 Baseline Hydraulic Model

7.2.1 The upstream extent of the Aviemore Burn model is located within a housing estate West of the A9 at 289189 813889. The burn flows downstream in an easterly direction before crossing the A9 at 289320 813850. The downstream extent of the model is located 1.53 km downstream, at the Bynack More Bridge, at 289402 813627.

7.2.2 Table 7.3 below details the model extents and key features.

Table 7-3: Aviemore Burn Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of Surveyed Cross Sections	Number of A9 Crossings	Total number of modelled structures
Aviemore Burn	1530	289189 813889	289402 813627	40	4	9

7.2.3 The 2D domain has a dimension of 1400m x 1600m and uses a 5m grid. The models were run using time steps of 1 second in the 1D model and 2 seconds in the 2D domain.

A Normal Depth boundary was used at the downstream extent of all the models. Figure 7.1 and Figure 7.2 show the hydraulic model schematic.

7.2.4 A 2m ground model was used to represent the 2D domain. Ground model adjustments were made based on spot survey data captured in areas upstream and downstream of the Aviemore Burn A9 crossing. Survey was undertaken to capture recent development in these areas which may impact floodplain extent.

7.2.5 The open channel river sections were defined from the topography survey, with the 1D Manning's 'n' values defined from the site visits, which were undertaken in March 2016. 2D floodplain Manning's 'n' values were defined using aerial photographs of the site. Table 7.4 provides the Manning's value range and justification of the value.

Table 7-4: Aviemore Burn Mannings 'n' Values

Section Type	Minimum	Maximum	Commentary
1D			
River Channel	0.015	0.035	Ranging from finished concrete culvert entrances to Clean winding channels with pools and shoals.
Structures	0.025	0.045	Ranging from smooth concrete, top half of culvert to Gravel bottom with dry rubble sides.
2D			
Floodplain	0.06	0.06	Default
Floodplain	0.03	0.03	Roads, Concrete, Manmade surfaces
Floodplain	0.360	0.360	Buildings
Floodplain	0.072	0.072	Marshland
Floodplain	0.072	0.072	Rough grassland, scrub
Floodplain	0.096	0.096	Trees (scattered)

7.2.6 Table 7.5 provides the details of how the structures are represented within the model and Figure 7.1 and Figure 7.2 show the location of these modelled structures.

7.2.7 Orifice units have been used to represent A'Anside Bridge, Black Grouse Bridge, and Grampian View Bridge due to their small size and tendency to surcharge under high flows, causing unstable flow through the structure. It is considered standard practice to model surcharge flow as orifice flow, and in this instance, modelling as an orifice unit provides more stable, representative results under different flow conditions than a bridge unit.

7.2.8 The 2D representation of the Aviemore Burn model also contains three orifice units within the 2D floodplain. These were included to represent a culvert, a cattle creep and an underpass that influence the 2D floodplain flow paths, connecting three areas within the 2D domain that are otherwise disconnected by the existing A9 alignment, but which are not categorised as watercourses under normal conditions, and hence are not included within the 1D hydraulic model.

Table 7-5: Aviemore Burn Modelled Structures

Water Crossing ID	Structure	Model ID	Watercourse	Dimensions (m)	Representation in the model	Photograph
DS-WC-014	A9 1150 C95 Culvert passing under A9	AVI_XS15Aa	Aviemore Burn	2.4m Ø	Represented in a 1D 2D ISIS-Tuflow model - Circular Conduit	
Carn Elrig View Bridge	Road Bridge	AVI_XS11Aa	Aviemore Burn (289217,813858)	3.4 x 1.2	USBPR1978 Bridge Unit	
A'Anside Bridge	Small Bridge	AVI_XS17Aa	Aviemore Burn (289377,813853)	3.0 x 0.9	Orifice Unit	
Black Grouse Bridge	Small Bridge	AVI_XS20Aa	Aviemore Burn (289421, 813892)	2.3 x 1.1	Orifice Unit	
Grampian View Bridge	Road Bridge	AVI_XS25a	Aviemore Burn (289494, 813729)	3.19 x 1	Orifice Unit	

Water Crossing ID	Structure	Model ID	Watercourse	Dimensions (m)	Representation in the model	Photograph
Grampian View Footbridge	Foot Bridge	AVI_XS28a	Aviemore Burn (289484, 813706)	9.5 x 1.1	Arch Bridge Unit	
DS-WC-013A Milton Culvert	A9 1150 C92 Flood Relief Culvert	CREEP_US	Aviemore Burn (DRY) (289307, 813778)	0.8 m Ø	Orifice unit in 2D domain	
The Steading Underpass	A9 1160 Underpass	UNDERPASS_US	Aviemore Burn (Dry) (289355, 813950)	4.0 m Ø	Orifice unit in 2D domain	
Milton Sheep Creep	A9 1150 C87 Sheep Creep	ROAD_US	Aviemore Burn (DRY) (289270, 813700)	1.9 m Ø	Orifice unit in 2D domain	

Figure 7-1. 1D Model Schematic. Cross sections AVI_XS10 - AVI_XS34

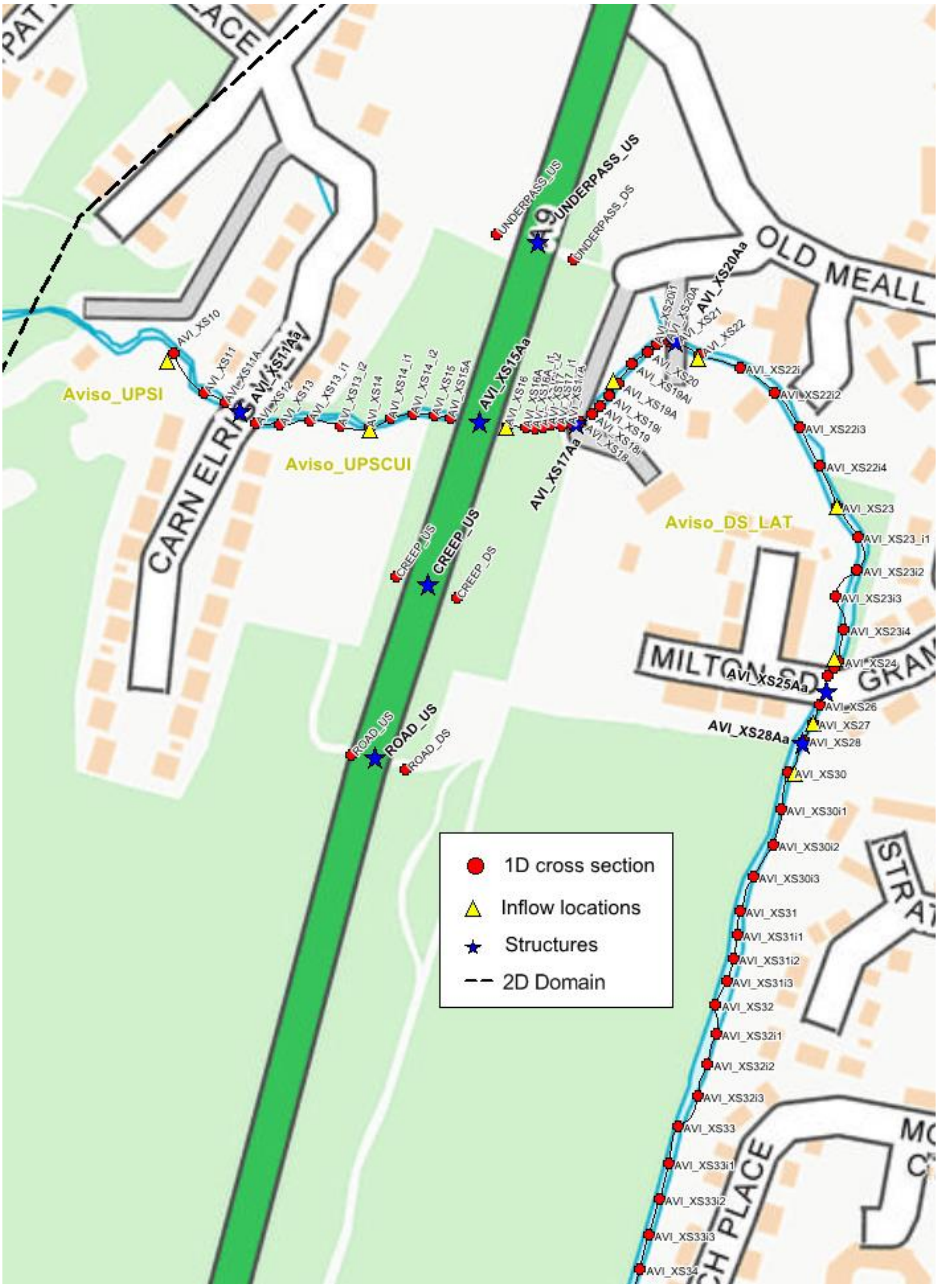
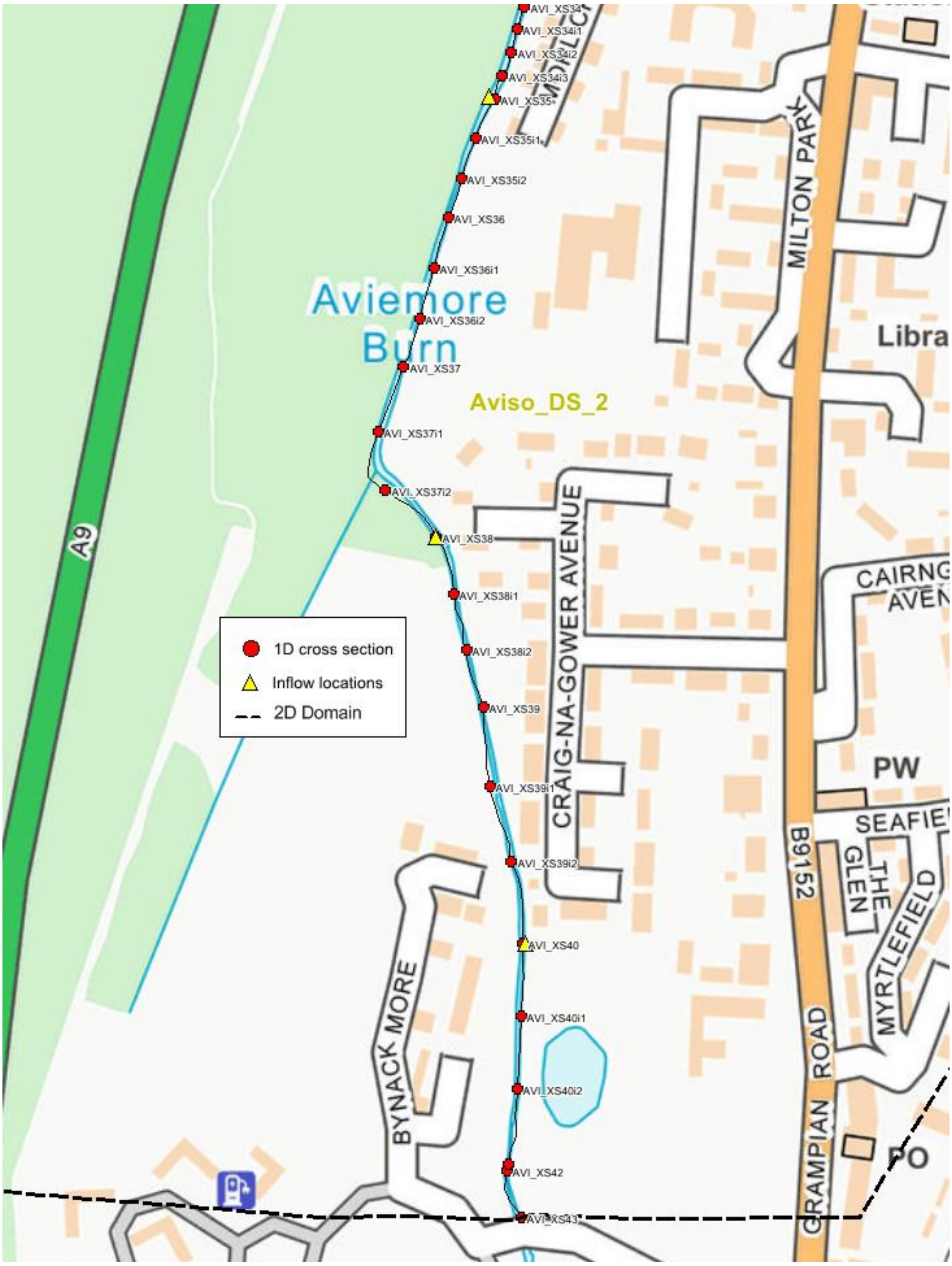


Figure 7-2. 1D Model Schematic. Cross sections AVI_XS34 - AVI_XS43

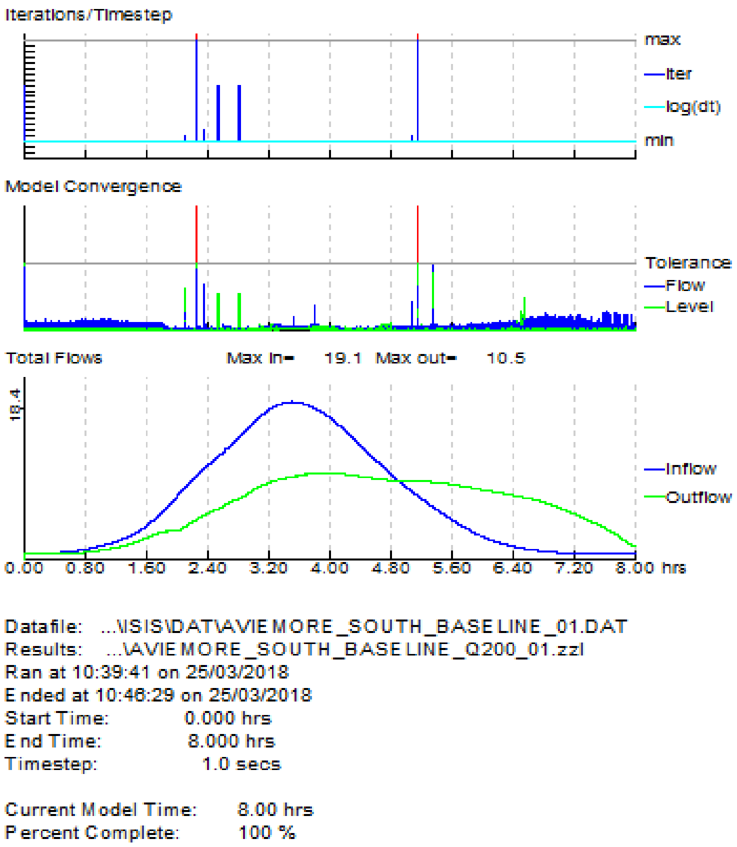


Baseline Model Performance

1D model performance

7.2.9 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Figure 7.3 shows model convergence for the 1% AEP event.

Figure 7-3. 1D Model Convergence for the 0.5% AEP Event

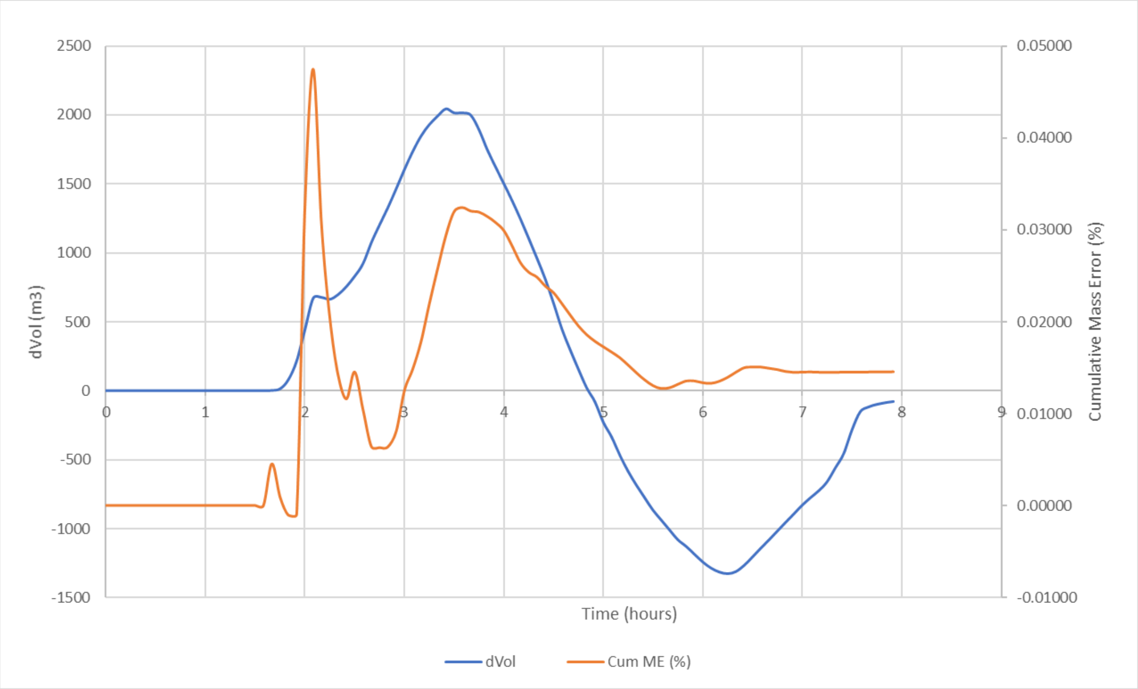


2D model performance

7.2.10 The cumulative mass error output reports from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The latest TUFLOW guidance does state that this can raise to 3% with anything above the higher value indicating an underlying issue with the model. The mass balance of the model is comfortably within the 1% range for the duration of the flood event. Figure 7.4 shows that the cumulative mass error is within the tolerance ranges.

7.2.11 The change in volume curve shows a broadly smooth variation which is another indicator of stable computation within the 2D domain during the simulation process.

Figure 7-4. Baseline 0.5% AEP Event Tuflow 2D Cumulative Mass Error (%) and Change in Volume (dVol)



Sensitivity Analysis

7.2.12 In order to analyse the sensitivity of the hydraulic models, the models have been updated to represent a change in parameters. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- 50% blockage scenario
- Downstream Boundary +/ - 20%

7.2.13 The sensitivity of the 1D is tested using the surveyed cross sections. To test the sensitivity within the 2D domain, 11 locations have been selected in the 2D floodplain based on their proximity to sensitive receptors and the A9. Figure 7.5 shows the locations, and Table 7.6 below provides the Grid Reference.

Table 7-6: Aviemore Burn 2D Results Location

Reference Id	Location of receptor	Easting	Northing
1	Behind A9 north of Aviemore Burn	289329	813906
2	Behind A9 south of Aviemore Burn	289291	813804
3	Old Meall downstream of underpass	289406	813926
4	Old Meall Rd	289436	813859
5	Grampian View	289536	813744
6	Milton Street	289407	813743
7	Strathspey Ave	289583	813613
8	Burnside Road	289799	813548
9	Old High School grounds	289433	813243

Reference Id	Location of receptor	Easting	Northing
10	Bynack More North	289365	813035
11	Grampian Pond	289434	812815

7.2.14 Table 7.7 shows the variation in sensitivity of the baseline model for each of the modelled survey cross sections. Figures 7.6 to 7.8 show variation within the modelled long section.

7.2.15 Overall, the results from the 1D or 'in channel' sections show a relatively low sensitivity to the +/-20% variation in Manning's. The model shows variation of less than -0.11 m and 0.11 m for +20% and -20% Manning's respectively.

7.2.16 The +/-20% variation in downstream boundary water level results for the 1D or 'in channel' sections show no change between section AVI_XS10 and AVI_XS36. Downstream of AVI_XS36 change in water levels varies between 0.08 m and 0.17 m, +20%, and between -0.21 and -0.33 for -20%. These results suggest that the model is more sensitive to a reduction in downstream water levels. AVI_XS36 is approximately 620 m upstream of the downstream boundary.

7.2.17 The +/-20% variation in flow results for the 1D or 'in channel' sections show a variation in water levels of between 0 m and 0.28 m for +20% and -0.01m and -0.28m for -20%.

7.2.18 A large 1.26 m and -0.63 m change in water level occurs upstream of the CREEP culvert as a result of a +20% and -20% change in flow respectively, compared with a 0.14 m and -0.18 m changes upstream of the UNDERPASS respectively. These results suggest that the CREEP culvert is more sensitive to flow variation in the Aviemore Burn.

7.2.19 A 50% blockage at the Aviemore Burn culvert caused increase water levels upstream of the A9 between AVI_XS15A and AVI_XS12, located 95 m upstream. Increase in levels range from 0.02m and 0.30m. Conversely, cross sections downstream of the A9 decrease in water levels between 0.27m and 0.02m from AVI_XS16 to AVI_XS32, which is approximately 470 m. Cross sections downstream of AVI_XS32 experience less than 0.09 m in change. Similarly described above for flow, a large increase in water levels of 1.61 m also occur upstream of CREEP culvert during blockage conditions, again suggesting CREEP culvert is most sensitive to change in water levels upstream of the A9.

7.2.20 Table 7.8 provides the summary of the 2D results at the 11 sensitivity test locations.

7.2.21 The +/- 20% Manning's sensitivity tests show that the hydraulic model 2D domain has a low sensitivity to the tested parameters with changes less than +/- 0.03 m at locations 1-8. Locations 9, 10 and 11 recorded decreases in water levels of 0.17 m for -20% and from 0.11-0.12 m increase in water levels for +20%. These locations are situated at the lower end of the model within 525 m of the downstream boundary.

7.2.22 Locations 9-11 experienced the only change in water levels with +/- 20% change in downstream boundary water levels, with between 0.14 m and 0.15 m, and -0.22 and -0.27 m, for +20% and -20% change respectively.

7.2.23 A +/- 20% change in flow has an impact at all locations, but most prominently at Location 2, behind the A9 in close proximity to the CREEP culvert, where a 0.47 m increase in water level results from a +20% increase in flow. A -20% reduction in flow causes largest decreases in water levels of between -0.20 m and -0.21 m at Locations 9-11, situated at the downstream portion of the model. Location 1, located behind the A9 also has a -0.19m decrease in levels.

7.2.24 Similarly, during the 50% blockage scenario, Location 1 and 2, located upstream of the A9 experience the greatest increases in water level of 0.26 m and 0.84 m respectively, whilst water levels at other locations change by less than +/- 0.07m.

Figure 7-5. 2D Sensitivity Test Locations

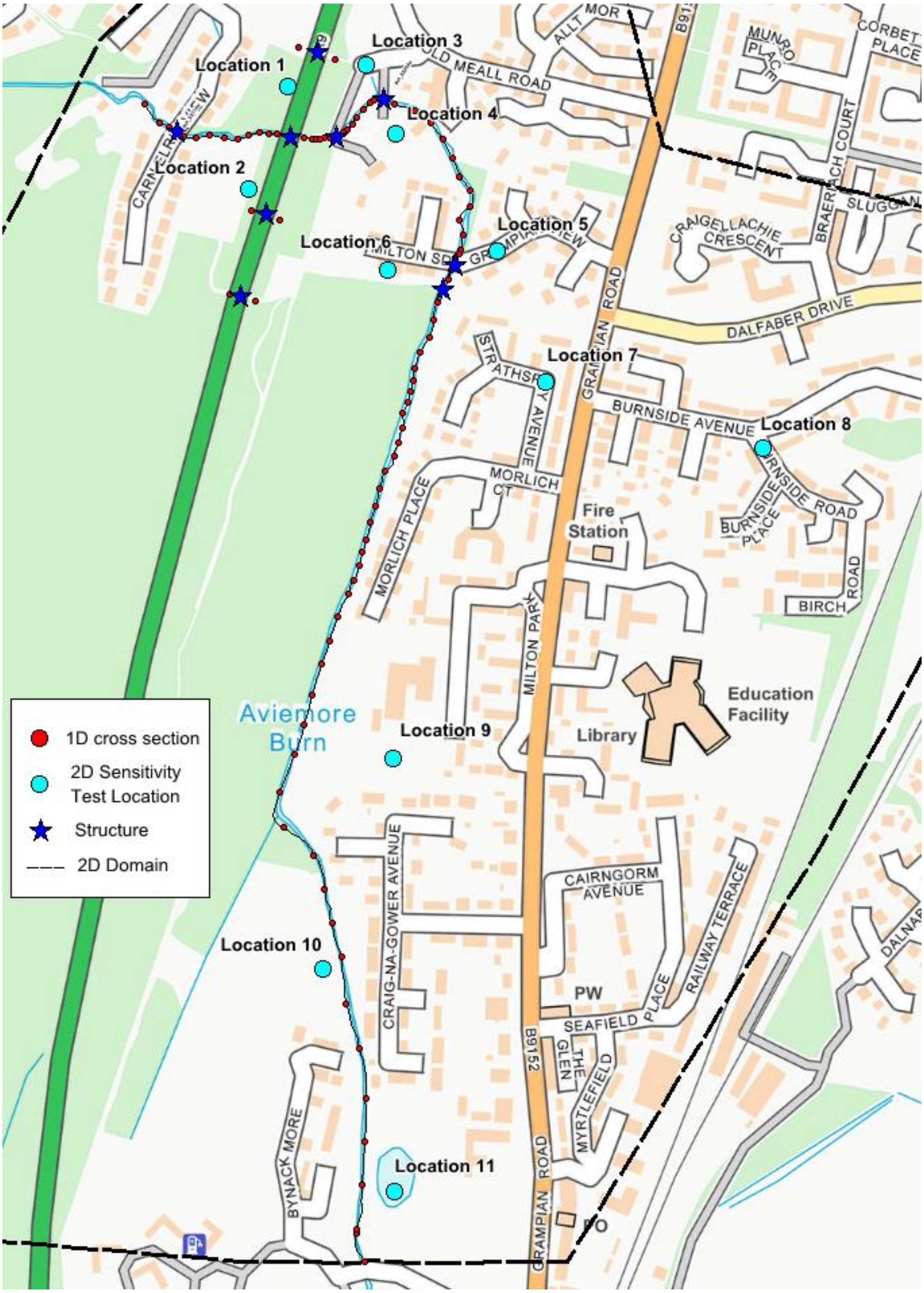


Table 7-7: Aviemore Burn 1D Sensitivity Results for 0.5% AEP Event Baseline

Cross-section	Baseline Stage (m AOD)	Variation in stage for -20% Manning’s (m)	Variation in stage for +20% Manning’s (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
AVI_XS10	237.82	-0.11	0.09	0.00	0.00	0.09	-0.10	0.00
AVI_XS11	236.69	-0.05	0.07	0.00	0.00	0.25	-0.23	0.00
AVI_XS11A	236.59	-0.02	0.05	0.00	0.00	0.28	-0.28	0.00
AVI_XS12	235.76	-0.12	0.11	0.00	0.00	0.10	-0.12	0.02
AVI_XS13	235.40	-0.11	0.09	0.00	0.00	0.09	-0.10	0.01
AVI_XS14	234.19	-0.04	0.05	0.00	0.00	0.10	-0.11	0.17
AVI_XS15	234.15	-0.02	0.02	0.00	0.00	0.12	-0.17	0.30
AVI_XS15A	234.17	-0.02	0.02	0.00	0.00	0.14	-0.18	0.29
AVI_XS16	230.85	-0.05	0.06	0.00	0.00	0.04	-0.04	-0.11
AVI_XS16A	229.72	-0.09	0.08	0.00	0.00	0.02	-0.05	-0.23
AVI_XS17	229.35	-0.04	0.03	0.00	0.00	0.00	-0.03	-0.13
AVI_XS17A	229.46	-0.02	0.02	0.00	0.00	0.02	-0.04	-0.27
AVI_XS18	228.67	-0.07	0.06	0.00	0.00	0.03	-0.04	-0.26
AVI_XS19	228.13	-0.03	0.02	0.00	0.00	0.04	-0.06	-0.27
AVI_XS19A	227.60	-0.08	0.06	0.00	0.00	0.03	-0.05	-0.21
AVI_XS20	227.02	-0.08	0.07	0.00	0.00	0.04	-0.05	-0.07
AVI_XS20A	227.11	-0.03	0.02	0.00	0.00	0.04	-0.05	-0.11
AVI_XS21	226.76	-0.04	0.06	0.00	0.00	0.07	-0.06	-0.12
AVI_XS22	225.98	-0.07	0.05	0.00	0.00	0.01	-0.10	-0.15
AVI_XS23	222.30	-0.08	0.07	0.00	0.00	0.05	-0.06	-0.10
AVI_XS24	221.02	-0.01	0.01	0.00	0.00	0.03	-0.06	-0.10

Cross-section	Baseline Stage (m AOD)	Variation in stage for -20% Manning’s (m)	Variation in stage for +20% Manning’s (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
AVI_XS25	221.01	-0.01	0.01	0.00	0.00	0.08	-0.12	-0.20
AVI_XS26	219.88	-0.09	0.07	0.00	0.00	0.05	-0.05	-0.07
AVI_XS27	219.46	-0.07	0.06	0.00	0.00	0.01	-0.02	-0.03
AVI_XS28	219.29	-0.07	0.06	0.00	0.00	0.01	-0.02	-0.03
AVI_XS29	219.26	-0.07	0.05	0.00	0.00	0.01	-0.02	-0.03
AVI_XS30	218.95	-0.07	0.06	0.00	0.00	0.01	-0.02	-0.03
AVI_XS31	217.58	-0.06	0.04	0.00	0.00	0.01	-0.01	-0.02
AVI_XS32	216.71	-0.07	0.05	0.00	0.00	0.02	-0.02	-0.02
AVI_XS33	216.00	-0.07	0.05	0.00	0.00	0.05	-0.05	0.08
AVI_XS34	215.31	-0.08	0.04	0.00	0.00	0.05	-0.05	0.09
AVI_XS35	214.80	-0.09	0.06	0.00	0.00	0.06	-0.05	0.09
AVI_XS36	214.26	-0.07	0.10	0.08	0.00	0.11	-0.06	0.09
AVI_XS37	214.15	-0.16	0.12	0.14	-0.21	0.15	-0.20	0.03
AVI_XS38	214.14	-0.16	0.11	0.14	-0.24	0.15	-0.20	0.03
AVI_XS39	214.13	-0.17	0.12	0.15	-0.27	0.15	-0.21	0.03
AVI_XS40	214.11	-0.17	0.12	0.15	-0.29	0.15	-0.21	0.03
AVI_XS41	214.10	-0.17	0.12	0.16	-0.33	0.15	-0.21	0.03
AVI_XS42	214.10	-0.18	0.12	0.16	-0.33	0.15	-0.22	0.03
AVI_XS43	214.07	-0.18	0.12	0.17	-0.35	0.15	-0.21	0.03
CREEP_US	232.38	-0.05	0.04	0.00	0.00	1.26	-0.63	1.61
CREEP_DS	230.13	0.00	0.00	0.00	0.00	0.08	-0.09	0.09
ROAD_US	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Cross-section	Baseline Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
ROAD_DS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNDERPASS_DS	230.14	0.00	0.00	0.00	0.00	0.10	-0.16	0.20
UNDERPASS_US	230.69	0.00	0.00	0.00	0.00	0.14	-0.18	0.29

Table 7-8: Aviemore Burn 2D Sensitivity Results for 0.5% AEP Event Baseline

Sensitivity Test	Baseline Stage (m AOD)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Location 1	233.88	-0.03	0.02	0.00	0.00	0.14	-0.19	0.26
Location 2	233.16	-0.01	0.01	0.00	0.00	0.47	-0.07	0.84
Location 3	229.25	0.00	0.01	0.00	0.00	0.04	-0.05	0.07
Location 4	226.32	-0.01	0.02	0.00	0.00	0.03	-0.04	-0.05
Location 5	219.54	0.00	0.01	0.00	0.00	0.01	-0.01	-0.02
Location 6	219.66	-0.02	0.01	0.00	0.00	0.01	-0.06	0.04
Location 7	216.19	-0.01	0.02	0.00	0.00	0.02	-0.04	-0.06
Location 8	213.95	-0.01	0.02	0.00	0.00	0.02	-0.03	-0.05
Location 9	214.15	-0.17	0.11	0.14	-0.22	0.15	-0.20	0.03
Location 10	214.13	-0.17	0.11	0.16	-0.27	0.15	-0.21	0.03
Location 11	214.11	-0.17	0.12	0.15	-0.30	0.15	-0.21	0.03

Figure 7-6: Aviemore Burn (0m-300m) Modelled Long Section Baseline Sensitivity Results for 0.5% AEP Event

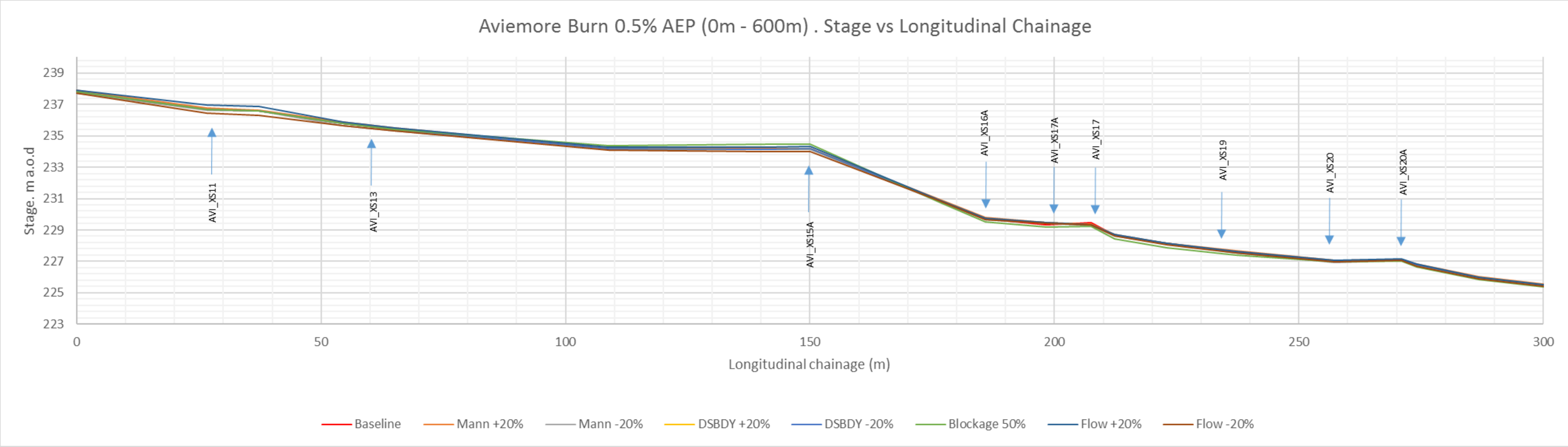


Figure 7-7: Aviemore Burn (300m-600m) Modelled Long Section Baseline Sensitivity Results for 0.5% AEP Event

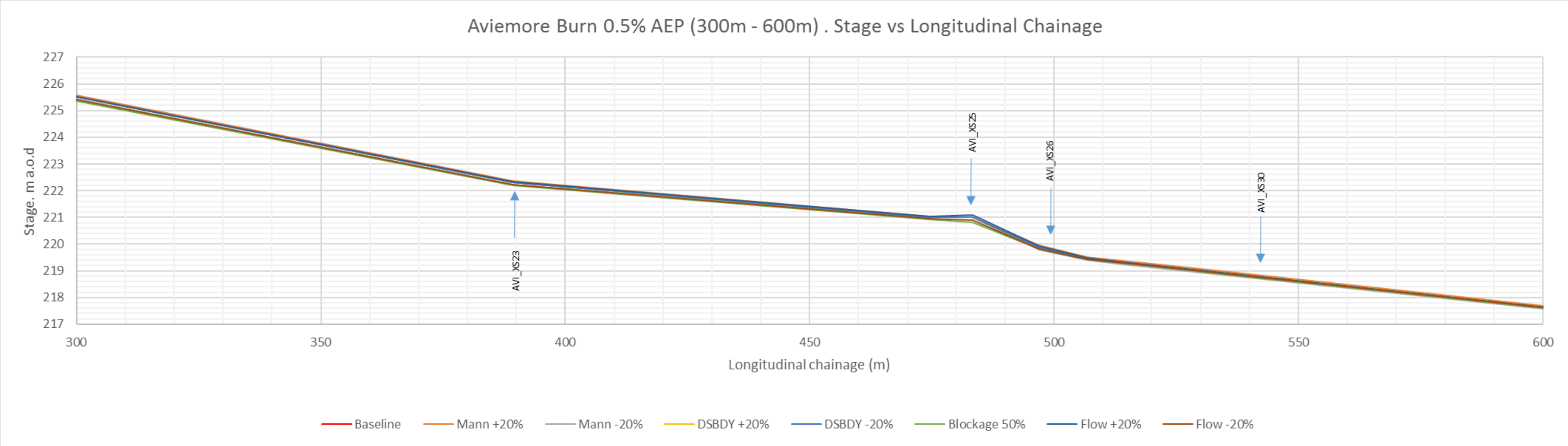
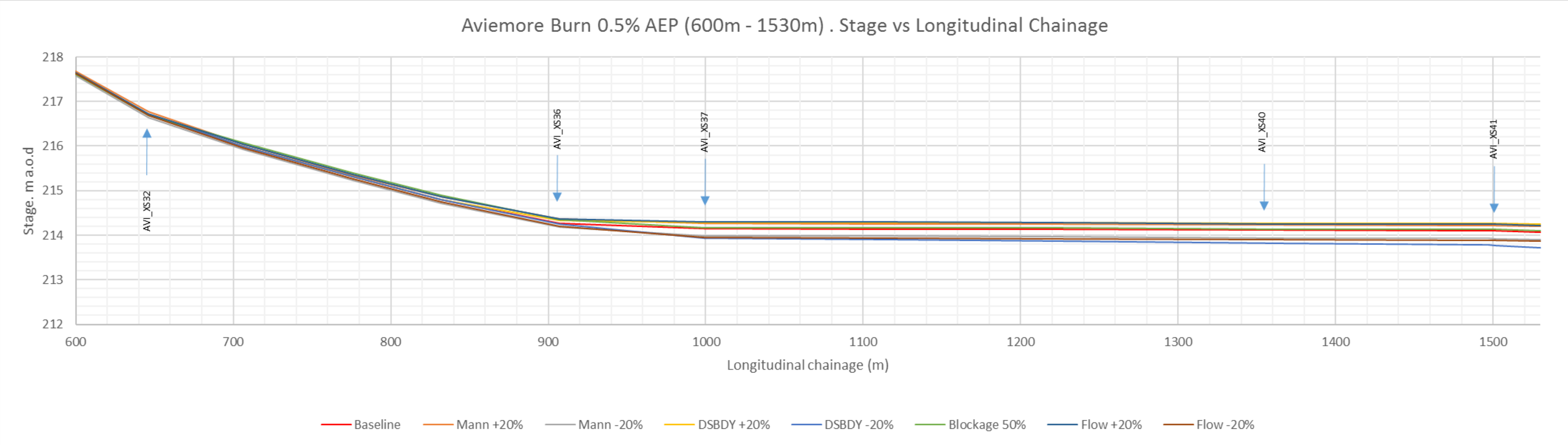


Figure 7-8: Aviemore Burn (600m-1530m) Modelled Long Section Baseline Sensitivity Results for 0.5% AEP Event



7.3 Proposed Model ('with-scheme' modelling)

Proposed Scheme Changes

7.3.1 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with the A9 mainline. Proposed works to the A9 in the vicinity of Aviemore Burn include widening of the mainline carriageway to dual-lanes in a downstream east direction.

7.3.2 Figure 7.9 shows the extent of the proposed scheme at Aviemore Burn and the small portions of the 0.5% AEP floodplain that are impacted.

7.3.3 Scheme updates include upgrading of structures. Culvert AVI_XS15Aa has been set to a 2.5x2.5m portal culvert with two 500mm mammal ledges and culvert CREEP_US has been set to a 1.2x1.2m box, whilst lengths of either culvert have increased to 32m and 43m respectively. UNDERPASS_US structure has been set to a size of 4.9x5.8m with a length of 27m, and ROAD_US structure set to a 2x2m box culvert, with a length of 34m.

7.3.4 Table 7.9 shows proposed updates that have been made to existing structures as a result of scheme amendments.

7.3.5 Additional updates to the 1D model include the removal of cross sections downstream of the A9 to cater for the increase in width of the carriageway. All culverts passing beneath the A9 have therefore been increased in length to accommodate the widening. As such, structure invert levels have been adjusted accordingly.

7.3.6 Proposed structure inlets/outlets have been offset from existing locations for constructability reasons. By building the culverts offline, it will allow construction to take place without contaminating the watercourse. After this, the existing watercourse will be diverted through the new culvert, and allow demolition of the existing culvert to take place, again with reduced risk of contamination of the watercourse. Constructing the culverts offline has the added benefit of realigning the watercourses to their historical alignments. These watercourses were diverted when the A9 was first constructed, and we have taken care to match them to their historical alignment wherever possible.

7.3.7 Therefore, watercourse cross section upstream and downstream of all structures have been replaced with a standardised earthworks design that ties in with the existing channel.

7.3.8 Updates to the 2D domain ground model were undertaken using proposed scheme earthworks drawings issued as Design Refresh 7a.

Proposed Mitigation Measures

7.3.9 There are several sensitive receptors located downstream of the A9 and therefore the scheme should not exacerbate flooding of these receptors compared to baseline conditions.

7.3.10 The encroachment of the scheme has very little impact on available floodplain storage at the site. In total there is approximately 68m^3 of floodplain loss, much of which comes from isolated pockets at locations upstream of the A9 where battering of the A9 has been increased compared with existing conditions. The reduction of floodplain upstream and downstream of AVI_XS15Aa and UNDERPASS_US is replaced by increasing proposed culvert lengths, which match or exceed the existing floodplain capacity lost. Furthermore, plunge pools have been factored into watercourse alignments downstream of crossings AVI_XS15Aa and CREEP_US which increases the capacity of the existing channel.

7.3.11 Due to the small volume of floodplain lost, compensatory floodplain storage is not considered necessary at this site

7.3.12 Furthermore, model results described in sections below show that water levels are within 10 mm of baseline conditions downstream of the A9 for all AEP events. 1D and 2D water levels do increase upstream of the A9 for some AEP events, however, this occurs mostly in-channel and within existing parkland and is not within proximity of any sensitive receptors.

7.3.13 Figure 7.10 is a depth difference map and shows where there are increases and decreases in max flood depth at the site for the 0.5% AEP event. The majority of the floodplain impacts are changes of less than +/- 5mm whilst in close proximity to Milton Side, flood levels decrease and are less extensive compared to baseline. There are a few very small areas upstream of the A9 where flood levels have increased but these are isolated and in areas with no sensitive receptors.

7.3.14 As total floodplain loss is only minor, and the impact of the proposed scheme is only minor, mitigation measures are not considered necessary at the site

7.3.15 Due to the known flood risk downstream of the A9 at Aviemore, the sizing of culverts AVI_XS15Aa and CREEP_US has not taken into consideration design criteria such as freeboard and ecological criteria associated with mammal ledge passage. Instead, implementation of the scheme has ensured that flood risk is not exacerbated. It should be noted however that mammal ledges have been included at AVI_XS15Aa as a means of restricting peak flows to match baseline conditions as well as providing benefits to mammal passage during low flows.

7.3.16 It should be noted that culvert ROAD_US is not wetted in events up to including the 0.5% AEP +CC however has been included for flood relief, should blockage of culvert CREEP_US or AVI_XS15Aa occur, and passage of livestock.

Figure 7-9. Proposed scheme

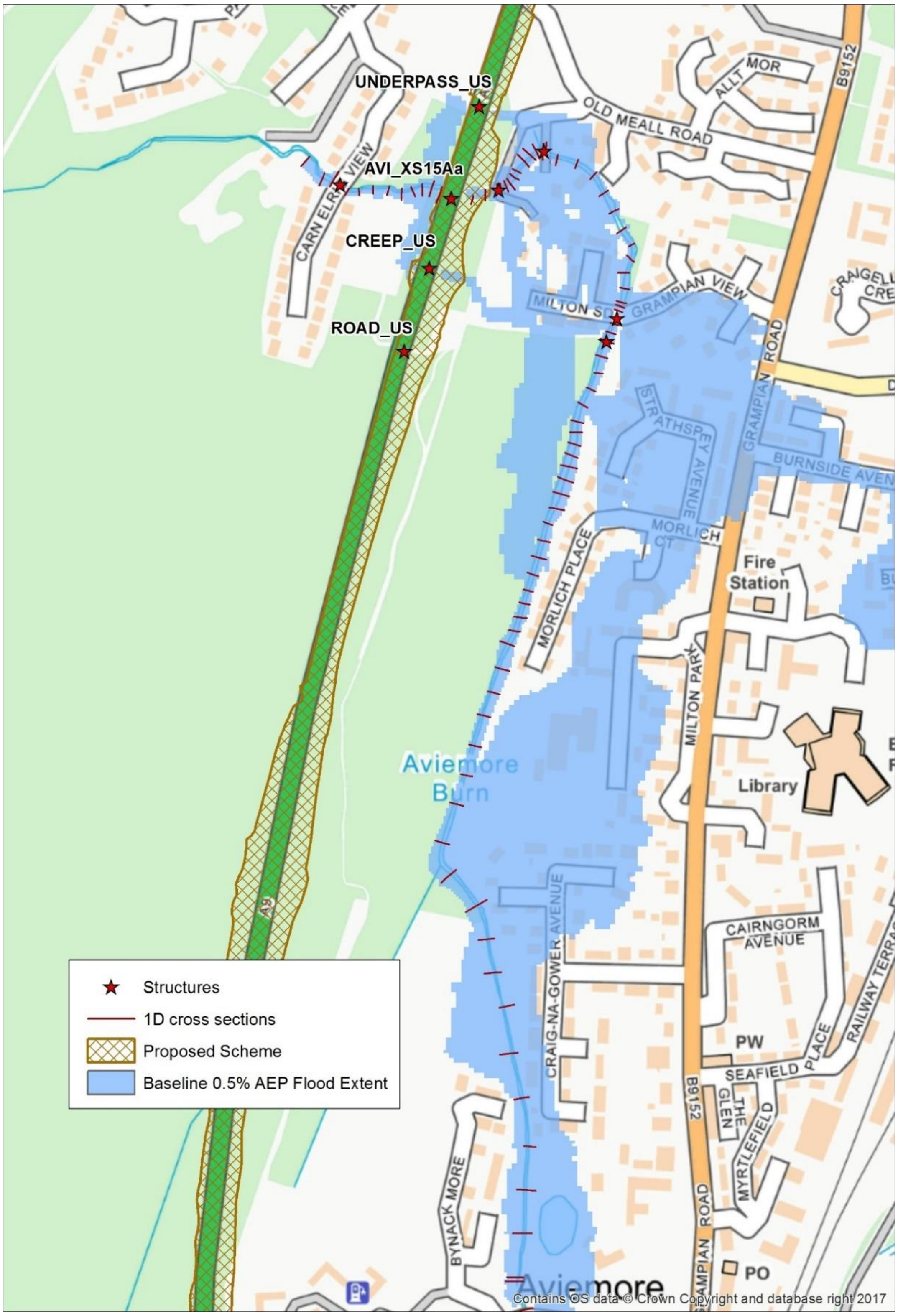


Figure 7-10: Maximum flood depth difference between baseline and scheme

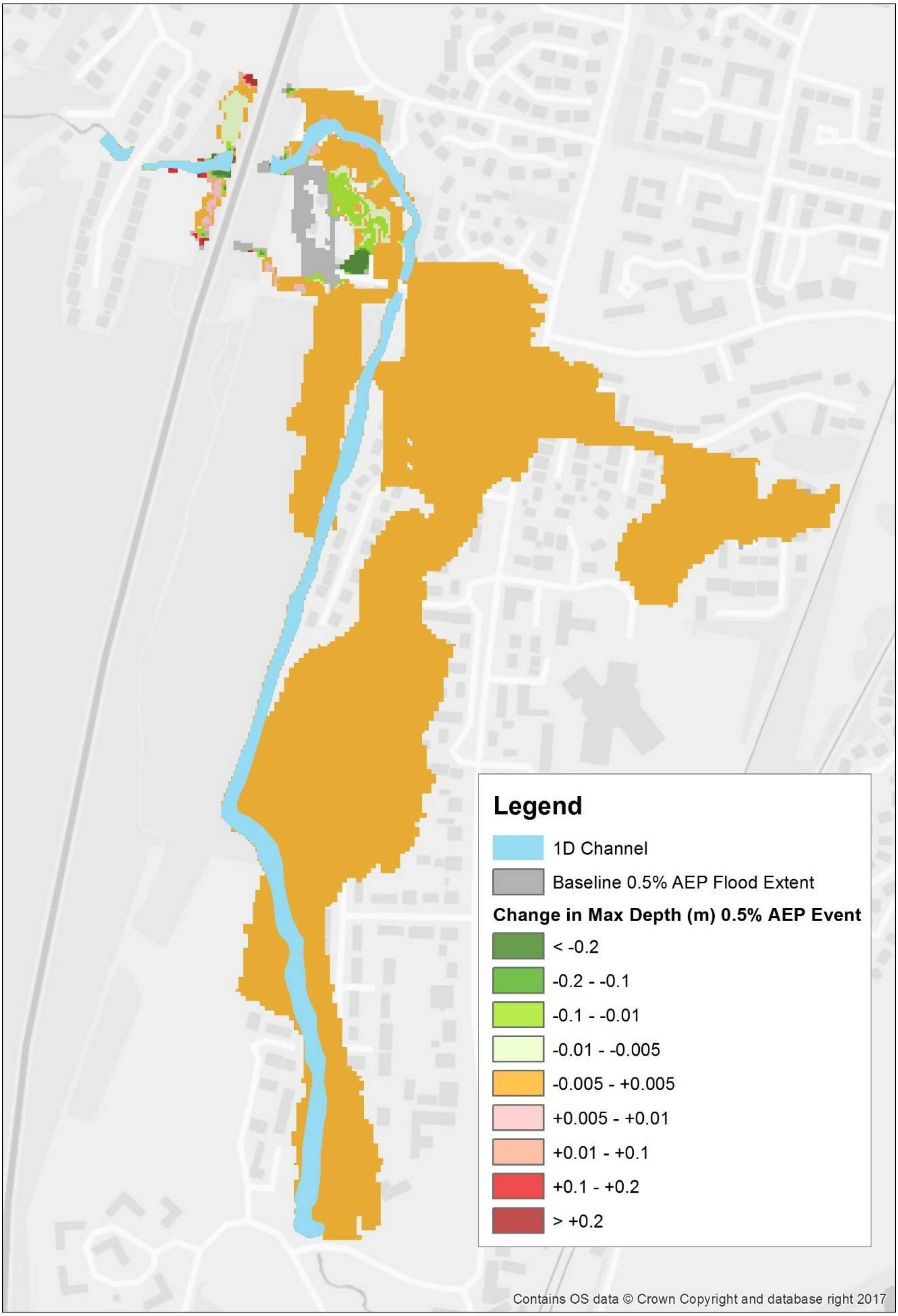


Table 7-9: Aviemore Burn Proposed Scheme Modelled Structures

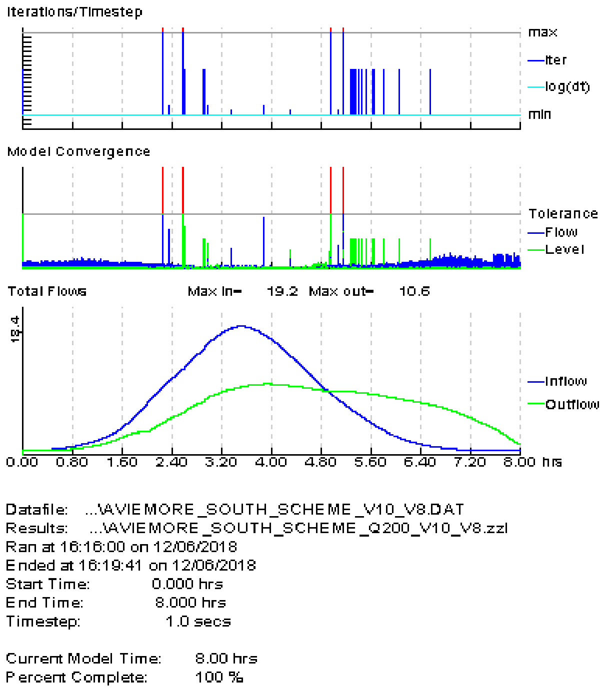
Water Crossing ID	Structure ID	Model ID	Watercourse	Dimensions (m)	Representation in the model
DS-WC-014	A9 1150 C95 Culvert passing under A9	AVI_XS15Aa	Aviemore Burn	2.5 x 2.5 m portal with 1x 500mm mammal ledges	Represented in a 1D 2D ISIS-Tuflow model - Symmetrical Conduit
DS-WC-013A Milton Culvert	A9 1150 C92 Flood Relief Culvert	CREEP_US	Aviemore Burn (Dry) (289307, 813778)	1.2 x 1.2 m box culvert	Orifice unit in 2D domain
The Steading Underpass	A9 1160 Underpass	UNDERPASS_US	Aviemore Burn (Dry) (289355, 813950)	4.9 x 5.8 m underpass	Orifice unit in 2D domain
Milton Sheep Creep	A9 1150 C87 Sheep Creep	ROAD_US	Aviemore Burn (Dry) (289270, 813700)	2 x 2 m box culvert	Orifice unit in 2D domain

Scheme Model Performance

1D model performance

7.3.17 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Figure 7.11 shows model convergence for the 1% AEP event.

Figure 7-11. 1D Model Convergence for the 0.5% AEP Event

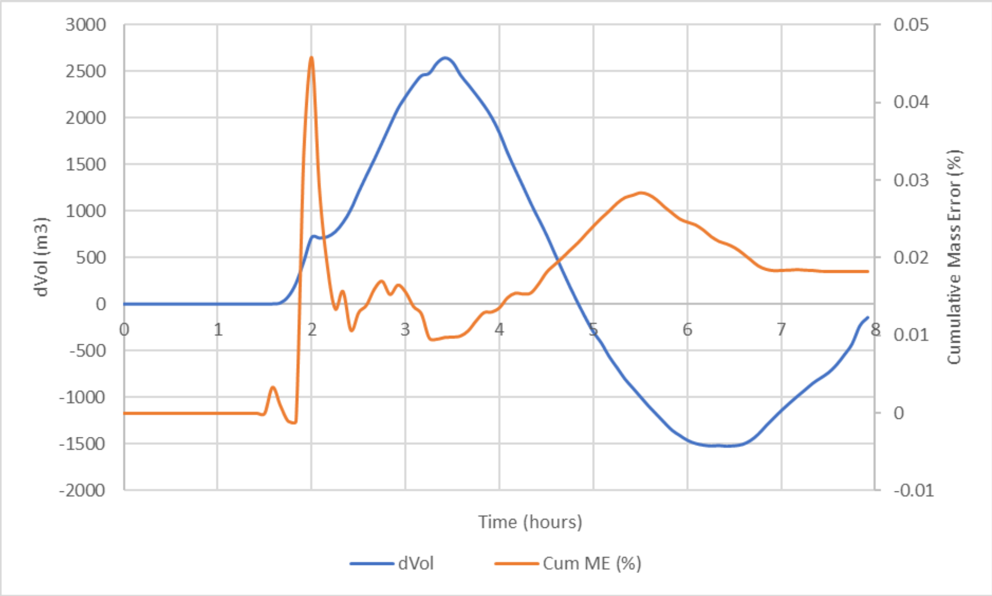


2D model performance

7.3.18 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The latest TUFLOW guidance does state that this can raise to 3% with anything above the higher value indicating an underlying issue with the model. The mass balance of the model is comfortably within the 1% range for the duration of the flood event. Figure 7.12 shows that the cumulative mass error is within the tolerance ranges.

7.3.19 The change in volume curve shows a broadly smooth variation which is another indicator of stable computation within the 2D domain during the simulation process.

Figure 7-12. Scheme 0.5% AEP Event Tuflow 2D Cumulative Mass Error (%) and Change in Volume (dVol)



Model Results Analysis

7.3.20 The following sections provides a comparison of 1D and 2D modelling results. Because Aviemore is considered an especially sensitive area to flooding and flood risk, the proposed scheme aims to ensure flood levels are within 10mm of baseline conditions and neutral or better for highly sensitive receptors.

7.3.21 Table 7.10 provides comparisons between baseline and scheme 1D and 2D results. It should be noted that some cross sections cannot be compared immediately upstream and downstream of the culvert crossing due to changes that have occurred to cross sections geometry and invert levels, to accommodate upgrades to culvert dimensions and changes made to channel alignments.

7.3.22 Table 7.10 provides 1D max stage results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. Max water levels downstream of the A9 crossing are within 10mm of baseline conditions for all events. This trend is the same upstream of the A9, however max water levels at AVI_XS14 and AVI_XS15 are slightly higher, between 0.011m and 0.014m, for 0.5%+CC and 0.5% AEP events.

7.3.23 Table 7.11 provides 2D max stage results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. Max water levels across all locations are within 10mm of baseline conditions.

7.3.24 Table 7.12 provides peak flow results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. Peak flow is within 0.09m^3/s of the baseline for all AEP events at all culverts, except the 0.5%+CC event where flow through the CREEP_US culvert is 0.377m^3/s higher than baseline conditions. This variation is still only a very small percentage of the total flow volume in the Aviemore Burn and does not adversely impact water levels downstream.

7.3.25 Figures 7.13 – 7.15 provide comparisons of baseline and scheme flood extents for 0.5%+CC, 0.5% and 3.33% AEP events.

Table 7-10: Aviemore Burn Baseline and Scheme 1D Stage Results Comparison

Cross-section	0.5 AEP + CC			0.5% AEP			1% AEP			1.33% AEP			50% AEP		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
AVI_XS10	237.912	237.912	0.000	237.821	237.821	0.000	237.755	237.755	0.000	237.649	237.649	0.000	237.405	237.405	0.000
AVI_XS11	236.941	236.940	-0.001	236.689	236.689	0.000	236.523	236.523	0.000	236.297	236.297	0.000	235.951	235.951	0.000
AVI_XS11A	236.87	236.869	-0.001	236.591	236.591	0.000	236.399	236.400	0.001	236.122	236.122	0.000	235.689	235.692	0.003
AVI_XS12	235.862	235.878	0.016	235.76	235.772	0.012	235.68	235.691	0.011	235.551	235.555	0.004	235.257	235.244	-0.013
AVI_XS13	235.489	235.562	0.606	235.398	235.471	0.600	235.327	235.402	0.596	235.209	235.284	0.589	234.934	234.996	0.552
A9 Crossing															
AVI_XS18	228.700	228.678	-0.022	228.674	228.655	-0.019	228.645	228.625	-0.020	228.576	228.569	-0.007	228.274	228.274	0.000
AVI_XS19	228.170	228.178	0.008	228.131	228.141	0.010	228.093	228.090	-0.003	228.001	227.998	-0.003	227.744	227.744	0.000
AVI_XS19A	227.636	227.638	0.002	227.603	227.610	0.007	227.570	227.565	-0.005	227.499	227.488	-0.011	227.286	227.286	0.000
AVI_XS20	227.063	227.069	0.006	227.022	227.022	0.000	226.991	226.992	0.001	226.936	226.936	0.000	226.641	226.641	0.000
AVI_XS20A	227.149	227.153	0.004	227.111	227.115	0.004	227.082	227.079	-0.003	227.004	227.003	-0.001	226.569	226.569	0.000
AVI_XS21	226.840	226.847	0.007	226.767	226.772	0.005	226.742	226.738	-0.004	226.591	226.590	-0.001	225.982	225.982	0.000
AVI_XS22	225.994	225.994	0.000	225.979	225.981	0.002	225.932	225.926	-0.006	225.798	225.797	-0.001	225.403	225.403	0.000
AVI_XS23	222.349	222.352	0.003	222.300	222.303	0.003	222.261	222.258	-0.003	222.184	222.183	-0.001	221.978	221.978	0.000
AVI_XS24	221.048	221.048	0.000	221.015	221.015	0.000	220.980	220.980	0.000	220.900	220.901	0.001	220.158	220.158	0.000

Cross-section	0.5 AEP + CC			0.5% AEP			1% AEP			1.33% AEP			50% AEP		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
AVI_XS25	221.088	221.089	0.001	221.009	221.012	0.003	220.936	220.939	0.003	220.779	220.781	0.002	220.053	220.053	0.000
AVI_XS26	221.048	221.048	0.000	221.015	221.015	0.000	220.980	220.975	-0.005	220.900	220.899	-0.001	220.158	220.158	0.000
AVI_XS27	221.088	221.090	0.002	221.009	221.013	0.004	220.936	220.928	-0.008	220.779	220.778	-0.001	220.053	220.053	0.000
AVI_XS28	219.925	219.924	-0.001	219.876	219.877	0.001	219.841	219.837	-0.004	219.800	219.800	0.000	219.530	219.530	0.000
AVI_XS29	219.475	219.475	0.000	219.463	219.463	0.000	219.452	219.450	-0.002	219.423	219.423	0.000	219.235	219.235	0.000
AVI_XS30	219.302	219.302	0.000	219.290	219.290	0.000	219.279	219.278	-0.001	219.252	219.252	0.000	219.072	219.072	0.000
AVI_XS31	219.271	219.271	0.000	219.258	219.259	0.001	219.249	219.247	-0.002	219.220	219.220	0.000	219.036	219.036	0.000
AVI_XS32	218.959	218.960	0.001	218.946	218.947	0.001	218.936	218.934	-0.002	218.908	218.908	0.000	218.715	218.715	0.000
AVI_XS33	217.591	217.591	0.000	217.581	217.581	0.000	217.574	217.573	-0.001	217.552	217.552	0.000	217.393	217.393	0.000
AVI_XS34	216.728	216.727	-0.001	216.712	216.713	0.001	216.703	216.701	-0.002	216.672	216.672	0.000	216.471	216.471	0.000
AVI_XS35	216.049	216.046	-0.003	215.997	216.001	0.004	215.971	215.972	0.001	215.920	215.919	-0.001	215.688	215.688	0.000
AVI_XS36	215.358	215.354	-0.004	215.306	215.310	0.004	215.271	215.279	0.008	215.220	215.220	0.000	215.011	215.011	0.000
AVI_XS37	214.861	214.857	-0.004	214.804	214.808	0.004	214.768	214.777	0.010	214.716	214.715	-0.001	214.496	214.496	0.000
AVI_XS38	214.367	214.366	-0.001	214.259	214.259	0.000	214.218	214.227	0.009	214.165	214.165	0.000	213.939	213.939	0.000

Cross-section	0.5 AEP + CC			0.5% AEP			1% AEP			1.33% AEP			50% AEP		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
AVI_XS39	214.296	214.294	-0.002	214.147	214.148	0.001	214.012	214.017	0.005	213.792	213.792	0.000	213.428	213.428	0.000
AVI_XS40	214.292	214.290	-0.002	214.143	214.144	0.001	214.003	214.009	0.006	213.737	213.737	0.000	213.190	213.190	0.000
AVI_XS41	214.280	214.278	-0.002	214.130	214.132	0.002	213.988	213.994	0.006	213.716	213.716	0.000	213.110	213.110	0.000
AVI_XS42	214.257	214.255	-0.002	214.110	214.112	0.002	213.968	213.974	0.006	213.691	213.691	0.000	213.039	213.039	0.000
AVI_XS43	214.252	214.250	-0.002	214.104	214.105	0.001	213.958	213.964	0.006	213.670	213.670	0.000	213.002	213.002	0.000

Table 7-11: Aviemore Burn Baseline and Scheme 2D Stage Results Comparison

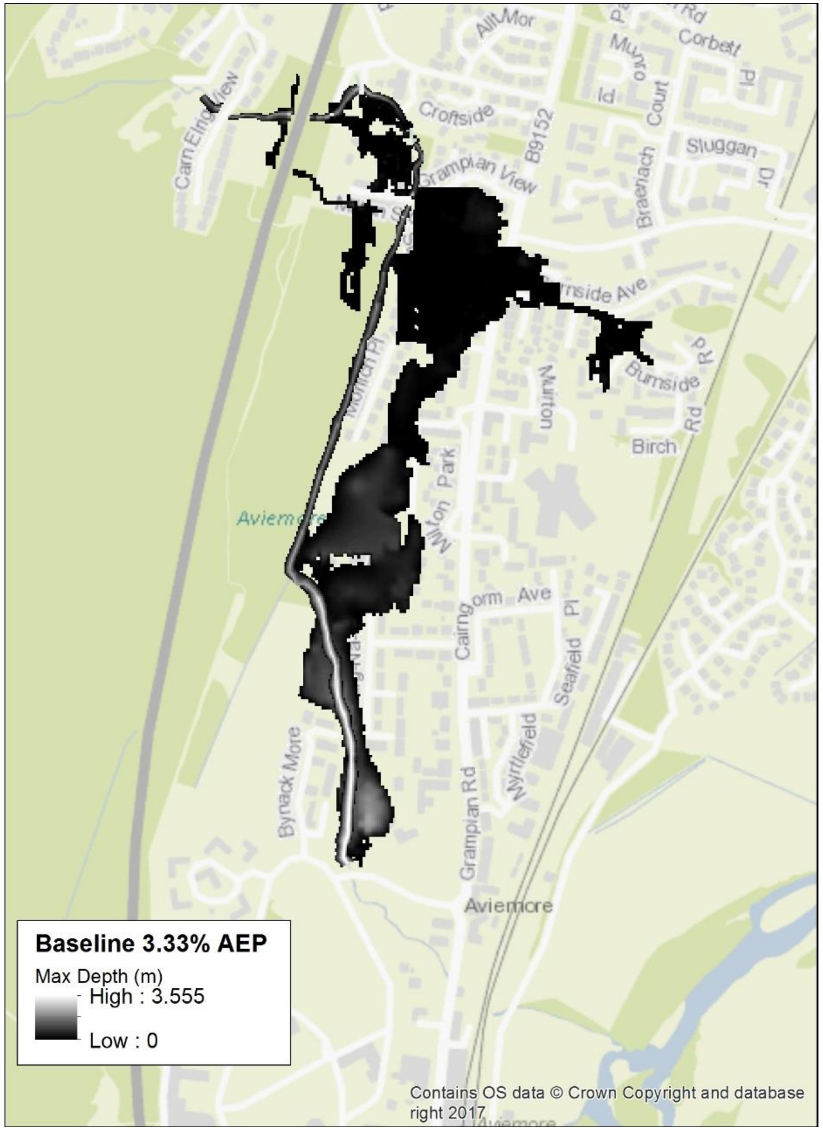
Cross-section	0.5 AEP + CC			0.5% AEP			1% AEP			1.33% AEP			50% AEP		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Location 1	234.014	234.030	0.016	233.879	233.873	-0.006	233.758	233.768	0.010	232.973	-	0.000	-	-	-
Location 2	233.639	233.610	-0.029	233.164	233.169	0.005	233.116	233.136	0.020	233.031	233.045	0.014	-	-	-
Location 3	229.291	229.295	0.004	229.254	229.253	-0.001	229.223	229.226	0.003	-	-	-	-	-	-
Location 4	226.340	226.335	-0.004	226.315	226.313	-0.002	226.285	226.282	-0.003	226.268	226.267	-0.001	-	-	-
Location 5	219.551	219.551	0.000	219.542	219.542	0.000	219.535	219.534	-0.001	219.523	219.523	0.000	-	-	-
Location 6	219.276	219.275	-0.001	219.263	219.263	0.000	219.253	219.256	0.003	219.239	219.242	0.003	-	-	-

Cross-section	0.5 AEP + CC			0.5% AEP			1% AEP			1.33% AEP			50% AEP		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Location 7	216.212	216.212	0.000	216.193	216.193	0.000	216.172	216.169	-0.003	216.128	216.128	0.000	-	-	-
Location 8	213.969	213.969	0.000	213.950	213.951	0.000	213.930	213.927	-0.003	213.891	213.891	0.000	-	-	-
Location 9	214.296	214.294	-0.002	214.147	214.148	0.002	214.010	214.016	0.005	213.756	213.756	0.000	-	-	-
Location 10	214.279	214.278	-0.002	214.130	214.132	0.002	213.988	213.994	0.006	213.715	213.715	0.000	213.106	213.106	0.000
Location 11	214.255	214.253	-0.002	214.109	214.111	0.002	213.967	213.973	0.006	213.689	213.689	0.000	213.035	213.035	0.000

Table 7-12: Aviemore Burn Baseline and Scheme Flow Results Comparison

Cross-section	0.5 AEP + CC			0.5% AEP			1% AEP			1.33% AEP			50% AEP		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
AVI_XS15AaUS	14.28	13.99	-0.29	13.38	13.32	-0.06	12.50	12.19	-0.31	10.55	10.49	-0.06	5.05	5.05	0.00
CREEP_US	2.41	2.55	+0.14	1.39	1.50	+0.11	0.72	0.98	+0.26	0.07	0.129	+0.06	-	-	-
UNDERPASS_US	2.32	2.47	+0.15	1.29	1.25	-0.04	0.63	0.68	+0.05	-	-	-	-	-	-

Figure 7-13. Baseline and Scheme Flood Extents 3.33% AEP Event



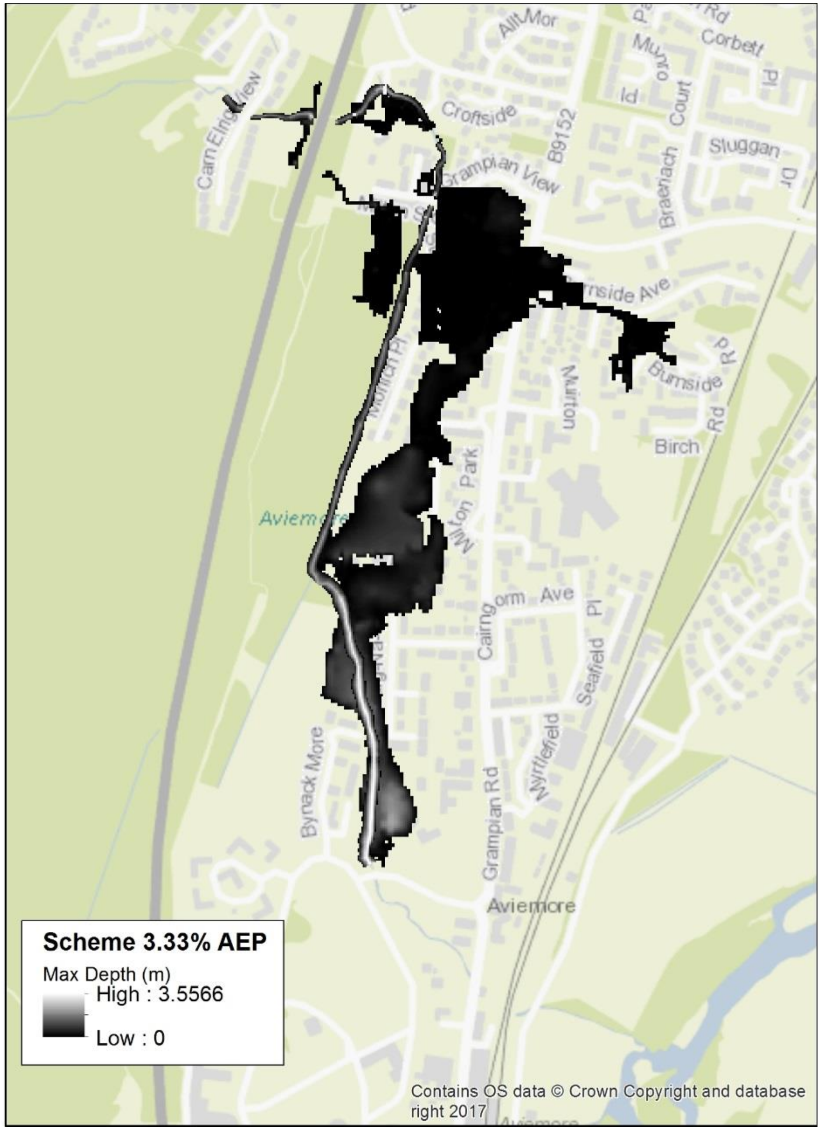
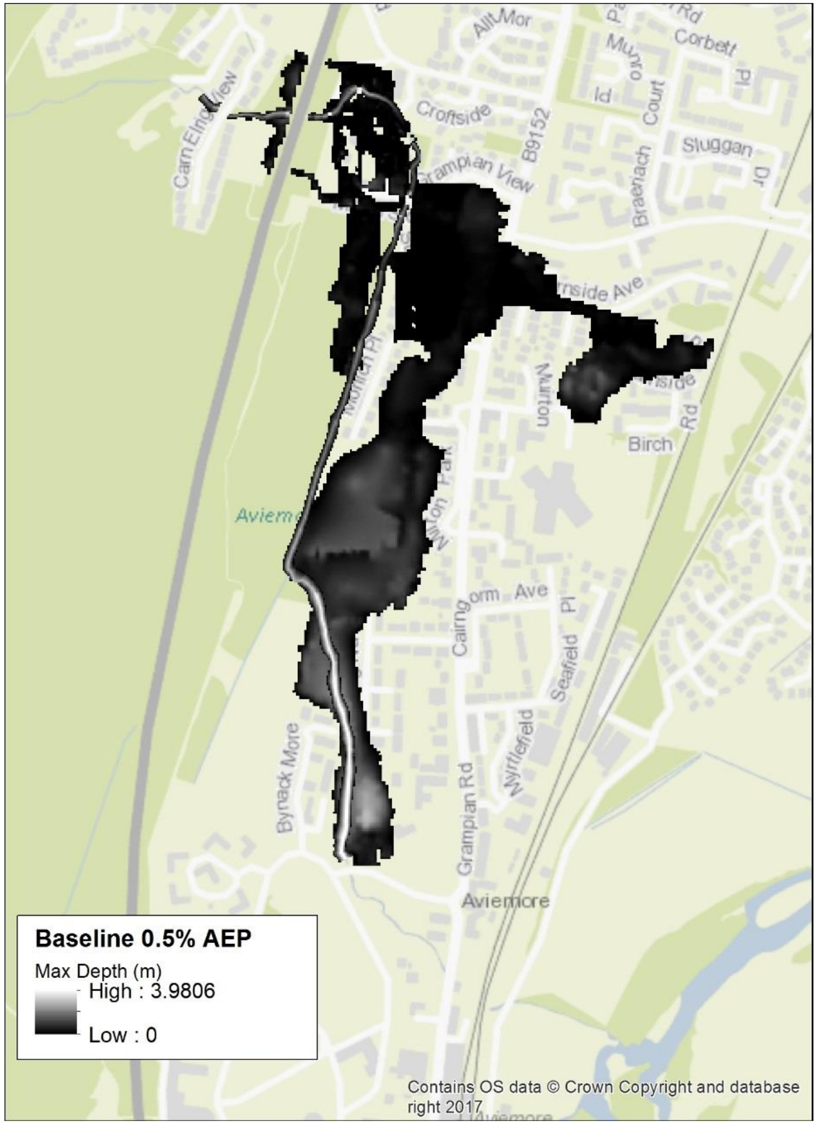


Figure 7-14. Baseline and Scheme Flood Extents 0.5% AEP Event



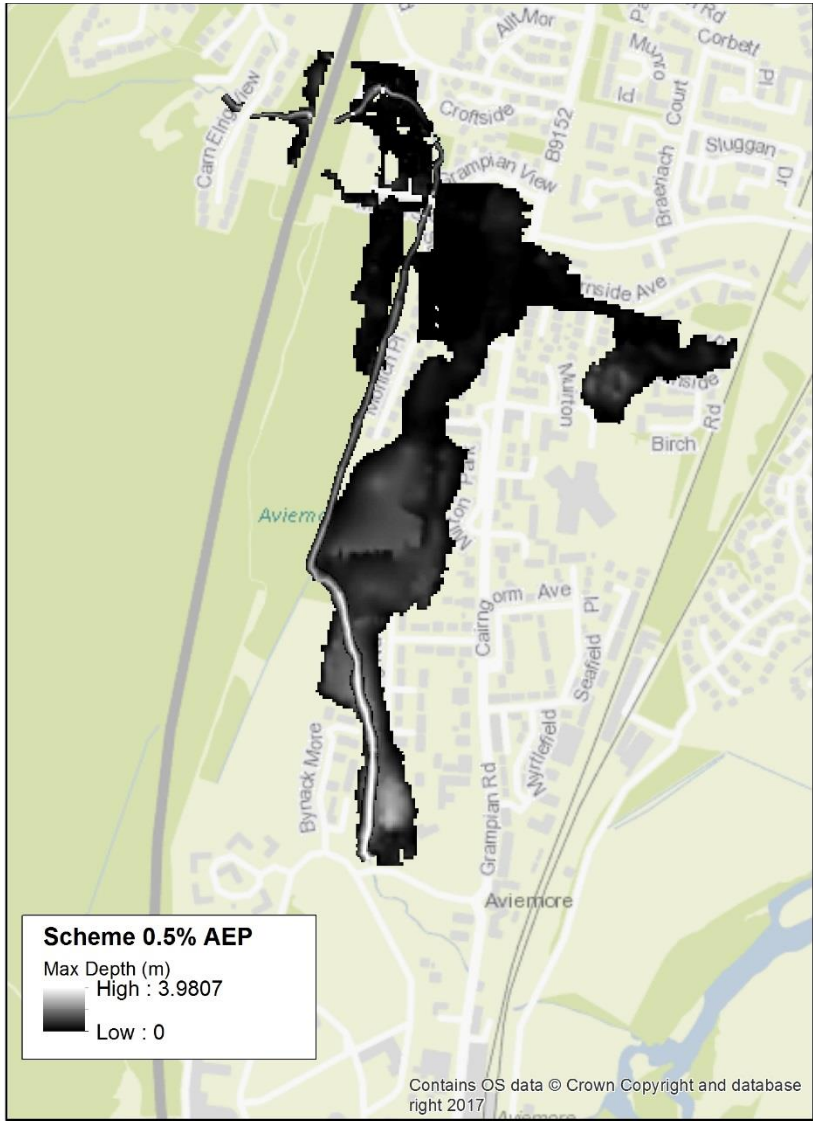
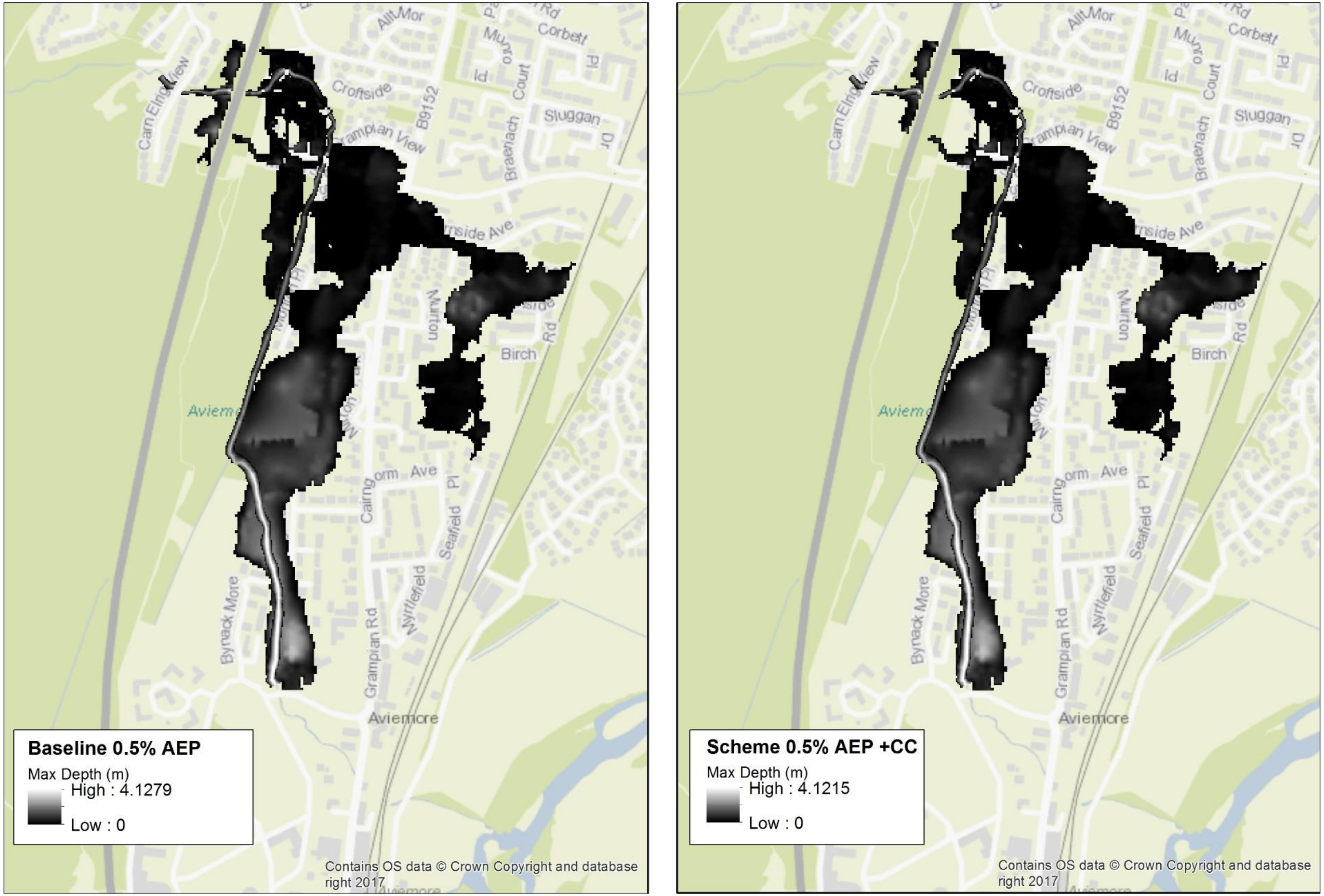


Figure 7-15. Baseline and Scheme Flood Extents 0.5% AEP +CC Event



Sensitivity Analysis

7.3.26 Sensitivity analysis was undertaken for proposed scheme modelling using the same test scenarios as baseline modelling. The results from both the 1D and 2D domains have been compared against the scheme results, these are shown in Table 7.13 and Table 7.14. Figures 7.16 – 7.18 shows variation within the modelled long section.

7.3.27 Due to the minor impact of the proposed scheme on baseline conditions, the results for sensitivity testing show trends consistent with the outputs from baseline simulations.

Table 7-13: Aviemore Burn Scheme 1D Sensitivity Results for 0.5% AEP Event

Cross-section	Scheme Stage (m AOD)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
AVI_XS10	237.82	0.09	-0.11	0.00	0.00	0.09	-0.10	0.00
AVI_XS11	236.69	0.07	-0.05	0.00	0.00	0.25	-0.24	0.00
AVI_XS11A	236.59	0.05	-0.02	0.00	0.00	0.28	-0.28	0.00
AVI_XS12	235.77	0.11	-0.13	0.00	0.00	0.11	-0.12	0.00
AVI_XS13	235.47	0.09	-0.11	0.00	0.00	0.09	-0.10	0.00
AVI_XS14	234.33	0.05	-0.05	0.00	0.00	0.07	-0.08	0.11
AVI_XS14_i1	234.15	0.03	-0.03	0.00	0.00	0.11	-0.12	0.24
AVI_XS14_i2	234.14	0.04	-0.04	0.00	0.00	0.10	-0.13	0.24
AVI_XS15	234.15	0.03	-0.03	0.00	0.00	0.10	-0.13	0.24
AVI_XS15_i01	234.21	0.01	-0.02	0.00	0.00	0.13	-0.16	0.24
AVI_XS15_i02	234.21	0.01	-0.01	0.00	0.00	0.13	-0.16	0.24
AVI_XS15A	234.22	0.01	-0.02	0.00	0.00	0.13	-0.16	0.23
AVI_XS17	229.71	0.07	-0.08	0.00	0.00	0.02	-0.03	-0.21
AVI_XS17_i1	229.41	0.04	-0.03	0.00	0.00	0.00	-0.01	-0.16
AVI_XS17A	229.47	0.02	-0.03	0.00	0.00	0.02	-0.05	-0.28
AVI_XS18	228.66	0.06	-0.07	0.00	0.00	0.02	-0.04	-0.24
AVI_XS19	228.14	0.02	-0.03	0.00	0.00	0.04	-0.07	-0.28
AVI_XS19A	227.61	0.06	-0.08	0.00	0.00	0.03	-0.06	-0.22
AVI_XS20	227.02	0.07	-0.08	0.00	0.00	0.05	-0.05	-0.06
AVI_XS20A	227.12	0.02	-0.03	0.00	0.00	0.04	-0.06	-0.11
AVI_XS21	226.77	0.06	-0.03	0.00	0.00	0.08	-0.07	-0.11

Cross-section	Scheme Stage (m AOD)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow - 20% (m)	Variation in stage 50% blockage (m)
AVI_XS22	225.98	0.05	-0.06	0.00	0.00	0.01	-0.10	-0.14
AVI_XS23	222.30	0.07	-0.08	0.00	0.00	0.05	-0.07	-0.10
AVI_XS24	221.02	0.01	-0.01	0.00	0.00	0.03	-0.06	-0.09
AVI_XS25	221.01	0.01	-0.01	0.00	0.00	0.08	-0.13	-0.19
AVI_XS26	219.88	0.07	-0.09	0.00	0.00	0.05	-0.05	-0.07
AVI_XS27	219.46	0.05	-0.07	0.00	0.00	0.01	-0.02	-0.03
AVI_XS28	219.29	0.05	-0.07	0.00	0.00	0.01	-0.02	-0.03
AVI_XS29	219.26	0.05	-0.07	0.00	0.00	0.01	-0.02	-0.03
AVI_XS30	218.95	0.06	-0.07	0.00	0.00	0.01	-0.02	-0.03
AVI_XS31	217.58	0.04	-0.05	0.00	0.00	0.01	-0.01	-0.02
AVI_XS32	216.71	0.05	-0.07	0.00	0.00	0.01	-0.02	-0.02
AVI_XS33	216.00	0.05	-0.06	0.00	0.00	0.04	-0.04	0.08
AVI_XS34	215.31	0.04	-0.08	0.00	0.00	0.04	-0.05	0.08
AVI_XS35	214.81	0.06	-0.09	0.00	0.00	0.05	-0.05	0.09
AVI_XS36	214.26	0.11	-0.07	0.08	0.00	0.11	-0.05	0.09
AVI_XS37	214.15	0.12	-0.16	0.14	-0.21	0.15	-0.19	0.03
AVI_XS38	214.14	0.11	-0.16	0.14	-0.24	0.15	-0.20	0.03
AVI_XS39	214.13	0.12	-0.16	0.14	-0.27	0.15	-0.21	0.03
AVI_XS40	214.11	0.12	-0.17	0.15	-0.29	0.14	-0.21	0.03
AVI_XS41	214.11	0.12	-0.17	0.16	-0.32	0.15	-0.21	0.03
AVI_XS42	214.10	0.12	-0.17	0.16	-0.34	0.15	-0.21	0.03
AVI_XS43	214.08	0.13	-0.18	0.17	-0.35	0.15	-0.21	0.03

Cross-section	Scheme Stage (m AOD)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow - 20% (m)	Variation in stage 50% blockage (m)
CREEP_US	232.25	0.11	-0.04	0.00	0.00	1.35	-0.59	1.73
CREEP_DS	227.92	0.08	-0.06	0.00	0.00	0.19	-0.16	0.22
ROAD_US	-9999.99	0.00	0.00	0.00	0.00	0.00	0.00	0.75
ROAD_DS	-9999.99	0.00	0.00	0.00	0.00	0.00	0.00	0.31
UNDERPASS_US	230.332	-0.021	0.02	0.00	0.00	0.144	-0.145	0.27
UNDERPASS_DS	230.24	-0.01	0.00	0.00	0.00	0.10	-0.10	0.18

Table 7-14: Aviemore Burn Scheme 2D Sensitivity Results for 0.5% AEP Event

Sensitivity Test	Scheme Stage (m AOD)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage (m)
Location 1	233.879	0.00	-0.02	-0.01	-0.01	0.15	-0.18	0.27
Location 2	233.164	0.02	-0.01	0.00	0.00	0.45	-0.05	0.82
Location 3	229.254	0.00	0.00	0.00	0.00	0.04	-0.05	0.08
Location 4	226.315	0.01	-0.01	0.00	0.00	0.02	-0.04	-0.05
Location 5	219.542	0.01	-0.01	0.00	0.00	0.01	-0.01	-0.02
Location 6	219.263	0.00	0.00	0.00	0.00	0.01	-0.01	0.02
Location 7	216.193	0.01	-0.02	0.00	0.00	0.02	-0.04	-0.05
Location 8	213.95	0.01	-0.01	0.00	0.00	0.02	-0.04	-0.04
Location 9	214.147	0.12	-0.16	0.14	-0.22	0.15	-0.20	0.03
Location 10	214.13	0.12	-0.16	0.15	-0.27	0.15	-0.21	0.03
Location 11	214.109	0.12	-0.16	0.15	-0.29	0.14	-0.20	0.03

Figure 7-16: Aviemore Burn (0m-300m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP Event

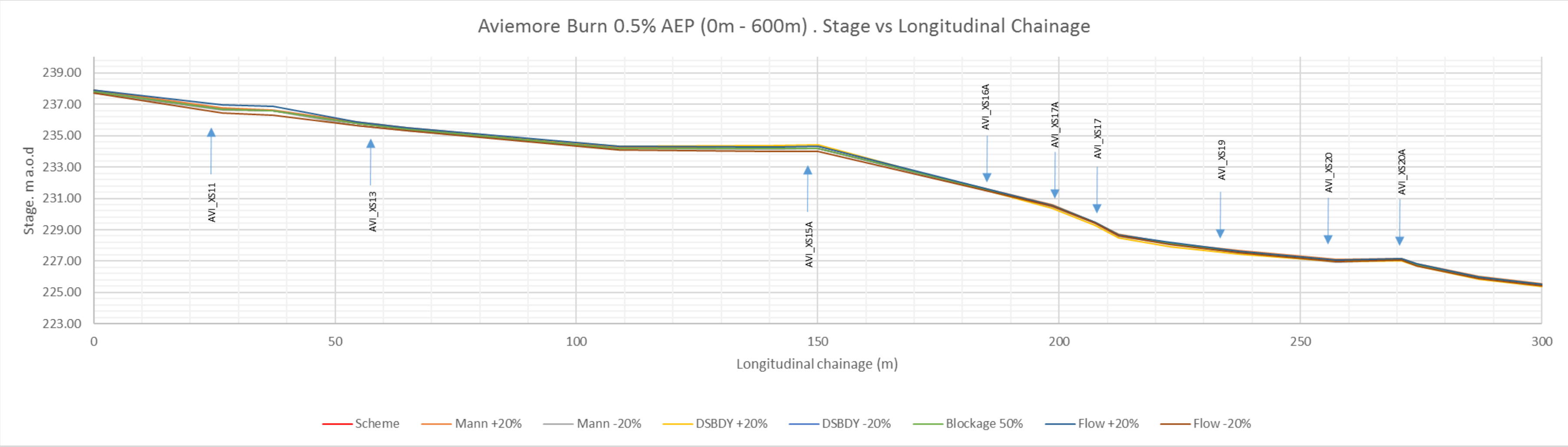


Figure 7-17: Aviemore Burn (300m-600m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP Event

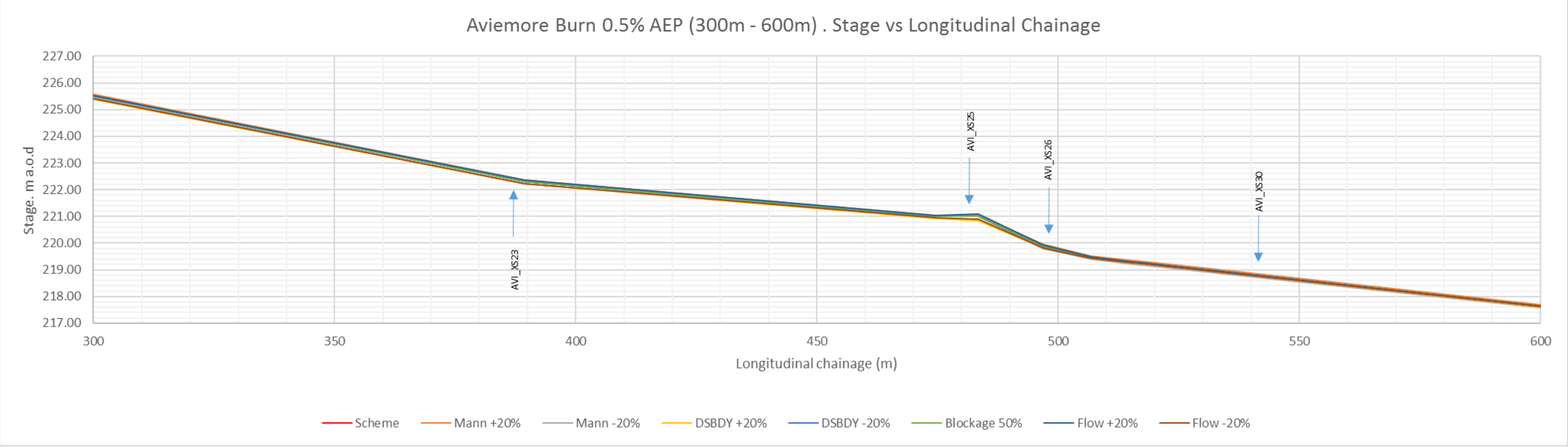
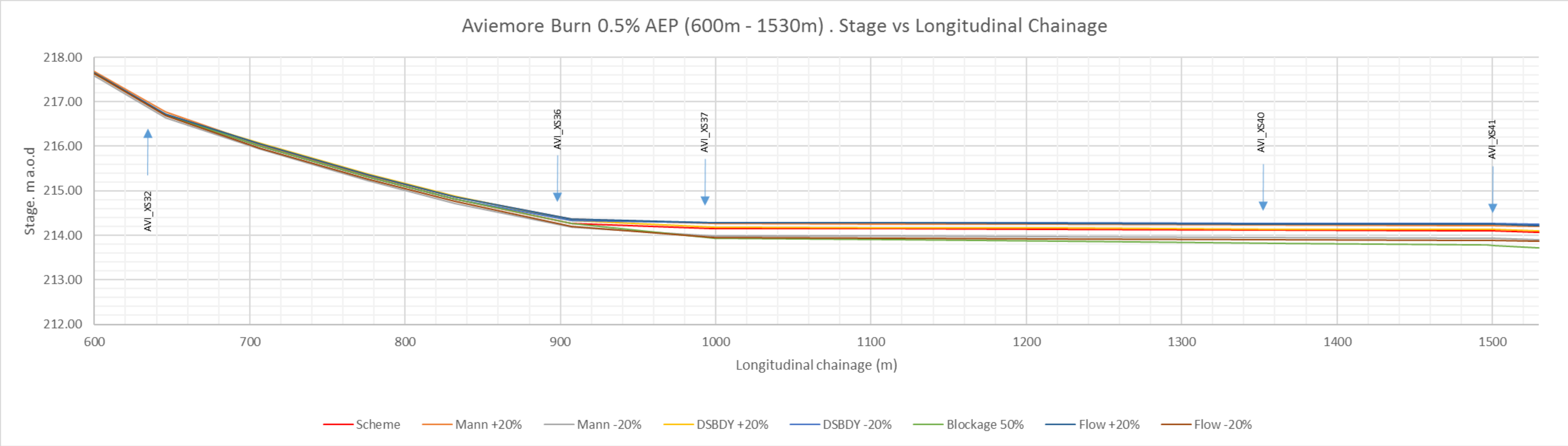


Figure 7-18: Aviemore Burn (600m-1500m) Modelled Long Section Scheme Sensitivity Results for 0.5% AEP Event



7.4 Summary

7.4.1 The Aviemore South hydraulic model has been created using a 1d/2d linked ISIS-TUFLOW model, and includes the portion of Aviemore Burn ranging from upstream of the A9 to the Bynack More Bridge at the downstream extent, covering a total distance of approximately 1.5km.

7.4.2 The baseline model includes four A9 crossings; one of which consider the main Aviemore Burn watercourse, and three others located in the floodplain north and south of the Burn. There are several other, mostly footbridge structures crossing the Burn at various points along its length.

7.4.3 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with widening of the A9 mainline in an easterly downstream direction to accommodate a dual carriageway. Updates to the baseline model for the proposed scheme included upgrading of four culvert structures beneath the A9.

7.4.4 The encroachment of the scheme has very little impact on available floodplain storage at the site. In total there is approximately 68m^3 of floodplain loss, much of which comes from isolated pockets at locations upstream of the A9 where battering has been increased compared with existing conditions. Due to the small volume of floodplain lost, compensatory floodplain storage is not considered necessary at this site.

7.4.5 Any shortening of watercourse channels immediately downstream of the A9 is replaced by increasing proposed culvert lengths, all of which have capacity matching or exceeding the existing channel capacity lost. The A9 crossing structure has been optimised to manage flows downstream whilst ensuring any increased water levels are contained within the channel upstream so as not to increase flood risk to upstream properties. The result is that there are some beneficial impacts of a reduction in 1-2mm on flood risk areas for the 0.5% AEP event within the residential area with only a minimal 2mm increase further downstream. Results show that water levels are within 10 mm of baseline conditions downstream of the A9 for all AEP events.

7.4.6 The embedded mitigation included as part of the scheme design at Aviemore South results in a negligible impact, and as such, compensatory floodplain storage or further scheme mitigation measures are not considered necessary at this site.

8. The Shieling / Easter Aviemore Burn

8.1.1 The Shieling/Easter Aviemore Burn has a catchment area of 0.57km^2 at the A9 crossing. It predominantly drains forestry on the northbound side of the existing A9 carriageway. The watercourse then flows north east around the northern fringe of Aviemore, before discharging into the River Spey at 290600 814000.

8.1.2 The Shieling/Easter Aviemore Burn catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment area was altered to reflect the surrounding topography.

8.1.3 The catchment was subdivided into 2 catchments to take account of the Shieling/Easter Aviemore Burn and any lateral inflows east of the A9. Table 8.1 details the delineated catchment areas.

Table 8-1: The Shieling/ Easter Aviemore Burn Hydrological Parameters

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Shieling/ Easter Aviemore Burn	US_XS_MA_01	Upstream of the A9 Crossing DS-WC-016	Direct	FEH Direct	289450	814150	0.57
Shieling/ Easter Aviemore Burn	AVINO__DSC	Downstream of Extent from Crossing,	Lateral	Donor Scale	289450	814150	0.057

8.1.4 Peak flows were calculated for each inflow using the FEH Rainfall Runoff methods, an FEH statistical estimate was undertaken at the downstream boundary for comparison.

8.1.5 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events, and as a result the Shieling/Easter Aviemore Burn storm duration was also applied for all inflows. The critical storm duration was set as 2.5 hours. Table 8.2 shows the peak flows.

Table 8-2: The Shieling/ Easter Aviemore Burn Peak Flow Estimates

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
Shieling/Easter Aviemore Burn	US_XS_MA_01	Upstream of the A9 Crossing DS-WC-016	1.93	2.36
Shieling/Easter Aviemore Burn	AVINO__DSC	Downstream of Extent from Crossing,	0.26	0.31

8.1.6 Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the FEH Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

8.2 Baseline Hydraulic Model

8.2.1 The upstream extent of the Shieling/Easter Aviemore Burn model is located within woodland to the north of a residential housing estate, it flows downstream in an easterly direction before crossing the A9 at 289400 814100 and entering fields upstream of Grampian Road. The downstream extent of the model is located upstream of Grampian Road at 289612 814177.

8.2.2 Table 8.3 below details the model extents and key features and Figure 8.1 shows the baseline model schematic.

Table 8-3: The Shieling/Easter Aviemore Burn Key Model Features

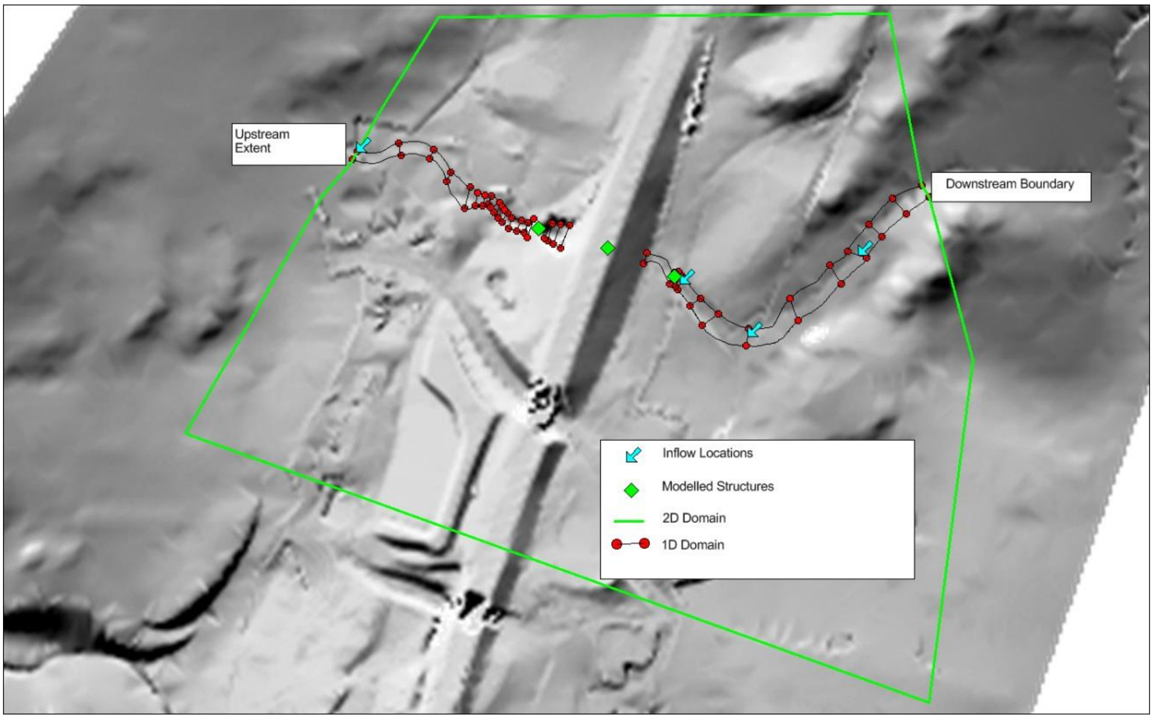
Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of A9 Crossings	Total number of modelled structures
The Shieling / Easter Aviemore Burn	400	289291 814199	289612 814177	1	3

8.2.3 The 2D domain has dimensions of 600m x700m and uses a 5m grid. The models were run using time steps of 0.5 seconds in the 1D model and 1 second in the 2D domain. A Normal Depth boundary was used at the downstream extent of both the models.

8.2.4 A 2m ground model was used to represent the 2D domain. Ground model adjustments were made based on spot survey data captured in areas upstream and downstream of the Aviemore Burn A9 crossing. Survey was undertaken to capture recent development in these areas which may impact floodplain extent.

8.2.5 A direct inflow hydrograph is applied at the upstream extent of the hydraulic model. Downstream of the existing A9, a lateral inflow is distributed evenly along the model reach.

Figure 8-1: Baseline Model Schematic



8.2.6 The open channel river sections were defined from the topography survey, with the 1D Manning's 'n' values defined from the site visits, which were undertaken in March 2016. Table 8.4 provides the Manning's value range and justification of the value.

Table 8-4: The Shieling/Easter Aviemore Burn. Manning's 'n' Values

Section Type	Minimum	Maximum	Commentary
1D			
River Channel	0.015	0.035	Ranging from finished concrete culvert entrances to Clean winding channels with pools and shoals.
Structures	0.025	0.045	Ranging from smooth concrete, top half of culvert to Gravel bottom with dry rubble sides.
2D			
Floodplain	0.03	0.36	Ranging from roads to Buildings. Default Manning's value is set to 0.04
Floodplain	0.06	0.06	Default
Floodplain	0.03	0.03	Roads, Concrete, Manmade surfaces

Floodplain	0.360	0.360	Buildings
Floodplain	0.072	0.072	Marshland
Floodplain	0.072	0.072	Rough grassland, scrub
Floodplain	0.096	0.096	Trees (scattered)

8.2.7 Table 8.5 provides the details of how the structures are represented within the model. Figure 8.1 shows the location of these modelled structures.

Table 8-5: The Shieling/Easter Aviemore Burn Modelled Structures Details

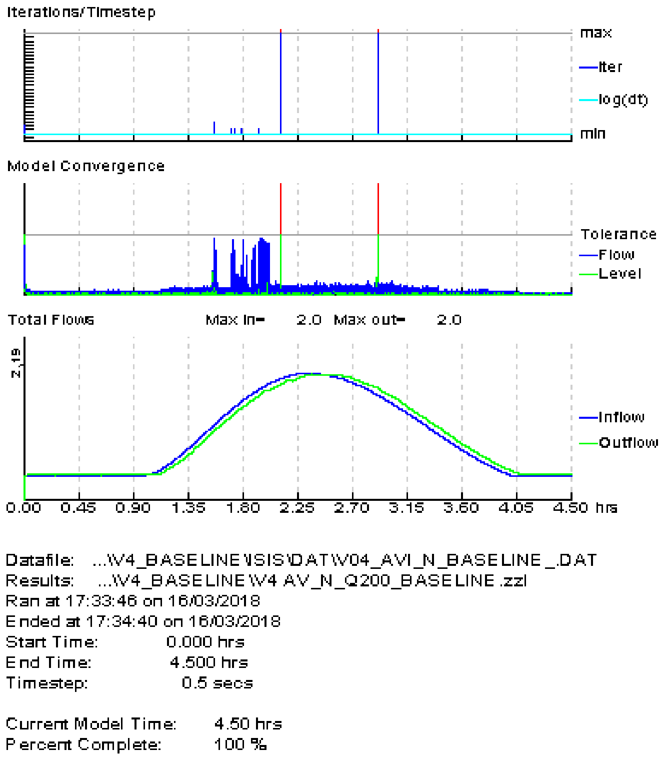
Water Crossing ID	Structure	Watercourse	Dimensions (m)	Re presentation in the model	Photograph
DS-WC-016	A9 1150 C11 Culvert passing under A9	The Shieling /Easter Aviemore Burn	0.9m Ø	Represented in a 1D Isis Model and a 2D ISIS-Tuflow model Circular Conduit	
The Shieling Culvert	Culvert	The Shieling /Easter Aviemore Burn (289390,814156)	0.9 Ø	Circular Conduit	
The Shieling Foot Bridge	Foot Bridge	The Shieling /Easter Aviemore Burn (289471,8141270)	2.8 x 0.6	USBPR1978 Bridge Unit	

Baseline Model Performance

1D model performance

8.2.8 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with only 2 small periods of poor model convergence. Figure 8.2 shows model convergence for the 0.5% AEP / Q200 event.

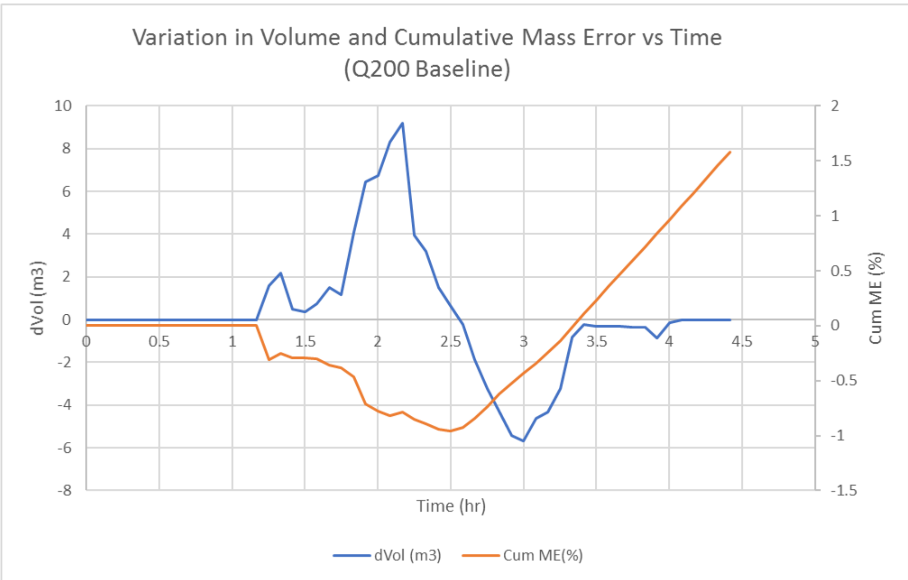
Figure 8-2. Model Convergence for the Q200 event



2D model performance

8.2.9 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The latest TUFLOW guidance does state that this can raise to 3% with anything above the higher value indicating an underlying issue with the model. The mass balance of the model is comfortably within the 1% range for the duration of the flood event. Figure 8.3 shows that the cumulative mass error is within the tolerance ranges.

Figure 8-3. Flow variance and Cumulative Mass Error vs Time (Q200 - Baseline)



Model Results Analysis

8.2.10 Baseline Flow and Stage results, extracted from the modelled 1D cross sections, are shown below in Table 8.6 and Table 8.7.

Table 8-6. Baseline stage for modelled return periods.

	Stage (mAOD)								
Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
US_XS_MA_01	243.57	243.54	243.48	243.43	243.41	243.40	243.36	243.33	243.28
US_XS_MA_02	240.14	240.13	240.11	240.09	240.08	240.08	240.05	240.03	239.99
US_XS_MA_03	238.95	238.94	238.94	238.94	238.94	238.94	238.93	238.92	238.91
US_XS_MA_04	237.41	237.40	237.39	237.37	237.36	237.36	237.34	237.33	237.31
US_XS_MA_05	235.96	235.90	235.89	235.88	235.87	235.86	235.84	235.83	235.81
XS02_US_Cpy	233.99	233.38	233.09	232.88	232.80	232.77	232.66	232.62	232.56
AVI_XS02	234.00	233.42	233.14	232.94	232.81	232.77	232.61	232.50	232.35
XS02A_US_Cpy	232.98	231.55	231.44	231.39	231.36	231.34	231.29	231.27	231.21
AVI_XS02A	232.98	231.54	231.38	231.31	231.25	231.22	231.11	231.06	231.00
AVI_XS03	232.98	231.52	231.33	231.20	231.11	231.07	230.92	230.84	230.71
AVI_XS04	227.80	227.75	227.71	227.69	227.67	227.66	227.63	227.61	227.56
AVI_XS05	227.05	227.02	226.99	226.96	226.94	226.93	226.89	226.86	226.81
AVI_XS05_i1	227.04	227.01	226.98	226.95	226.92	226.92	226.87	226.84	226.79
AVI_XS05A	226.89	226.85	226.83	226.80	226.78	226.78	226.74	226.71	226.67
AVI_XS06	224.28	224.26	224.24	224.23	224.22	224.22	224.21	224.20	224.19
AVI_XS07	222.25	222.23	222.22	222.21	222.21	222.20	222.19	222.18	222.16
AVI_XS08	220.08	220.04	220.00	219.97	219.95	219.94	219.90	219.86	219.81

Table 8-7 Baseline Flow for modelled return periods.

Flow (m3/s)									
Cross-section	**Q200+CC**	**Q200**	**Q100**	**Q50**	**Q30**	**Q25**	**Q10**	**Q5**	**Q2**
US_XS_MA_01	2.36	1.93	1.64	1.41	1.26	1.21	0.97	0.81	0.58
US_XS_MA_02	1.94	1.66	1.51	1.37	1.25	1.21	0.97	0.81	0.58
US_XS_MA_03	1.90	1.62	1.47	1.31	1.18	1.14	0.92	0.76	0.56
US_XS_MA_04	2.13	1.80	1.60	1.40	1.25	1.21	0.97	0.81	0.58
US_XS_MA_05	2.22	1.85	1.62	1.40	1.26	1.21	0.97	0.81	0.58
XS02_US_Cpy	2.21	1.85	1.62	1.40	1.26	1.21	0.97	0.81	0.58
AVI_XS02	2.11	1.88	1.62	1.41	1.26	1.21	0.97	0.81	0.58
XS02A_US_Cpy	2.11	1.88	1.62	1.41	1.26	1.21	0.97	0.81	0.58
AVI_XS02A	2.12	1.88	1.62	1.41	1.26	1.21	0.97	0.81	0.58
AVI_XS03	2.27	1.90	1.62	1.40	1.26	1.21	0.97	0.81	0.58
AVI_XS04	2.27	1.90	1.62	1.40	1.26	1.21	0.97	0.81	0.58
AVI_XS05	2.27	1.90	1.62	1.40	1.26	1.21	0.97	0.81	0.58
AVI_XS05_i1	2.27	1.90	1.62	1.40	1.26	1.21	0.97	0.81	0.58
AVI_XS05A	2.27	1.90	1.62	1.40	1.26	1.21	0.97	0.81	0.58
AVI_XS06	2.31	1.94	1.66	1.44	1.29	1.24	1.00	0.84	0.62
AVI_XS07	2.33	1.99	1.69	1.48	1.33	1.28	1.04	0.88	0.65
AVI_XS08	2.36	2.03	1.72	1.51	1.36	1.31	1.07	0.91	0.68

Sensitivity Analysis

8.2.11 To analyse the sensitivity of the hydraulic models, the models have been updated to represent a change in parameters. The results from both the 1D and 2D domains have been compared against the baseline results. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- 50% blockage scenario
- Downstream Boundary +/ - 20%

8.2.12 The sensitivity of the 1D is analysed by extracting the flow and stage from the surveyed cross sections within the model. To test the sensitivity within the 2D domain 5 locations have been selected in the 2D floodplain based on their proximity to sensitive receptors and the A9.

1D sensitivity. Baseline

8.2.13 Figure 8.4 shows the locations of the modelled cross sections where flow and stage data was compared. Table 8.9 shows the value of stage for each of the sensitivity tests compared with the Q200 baseline levels measured in m AOD. Table 8.10 shows the variance in stage from the baseline levels, measured in m. Table 8.8 shows the resulting flow due to the sensitivity tests. Figure 8.5 shows the variation within the modelled long section.

8.2.14 As can be seen from the data, the baseline A9 crossing is sensitive to a variety of the sensitivity tests. Results show that cross sections immediately upstream of the A9 (Cross sections XS02_US_Cpy" to "AVI_XS03 have large variances in stage when the flow is increased (maximum variation of 1.45m occurring at AVI_XS03), or the roughness values are increased, (maximum variation of 0.88m occurring at AVI_XS03). The largest variation in stage is associated with the 50% blockage scenario. This increases the depth in stage by 2.68 m when compared with the Q200 levels. These large variances are due to the A9 culvert becoming submerged.

Figure 8-4. Location of 1D modelled cross sections. Baseline model

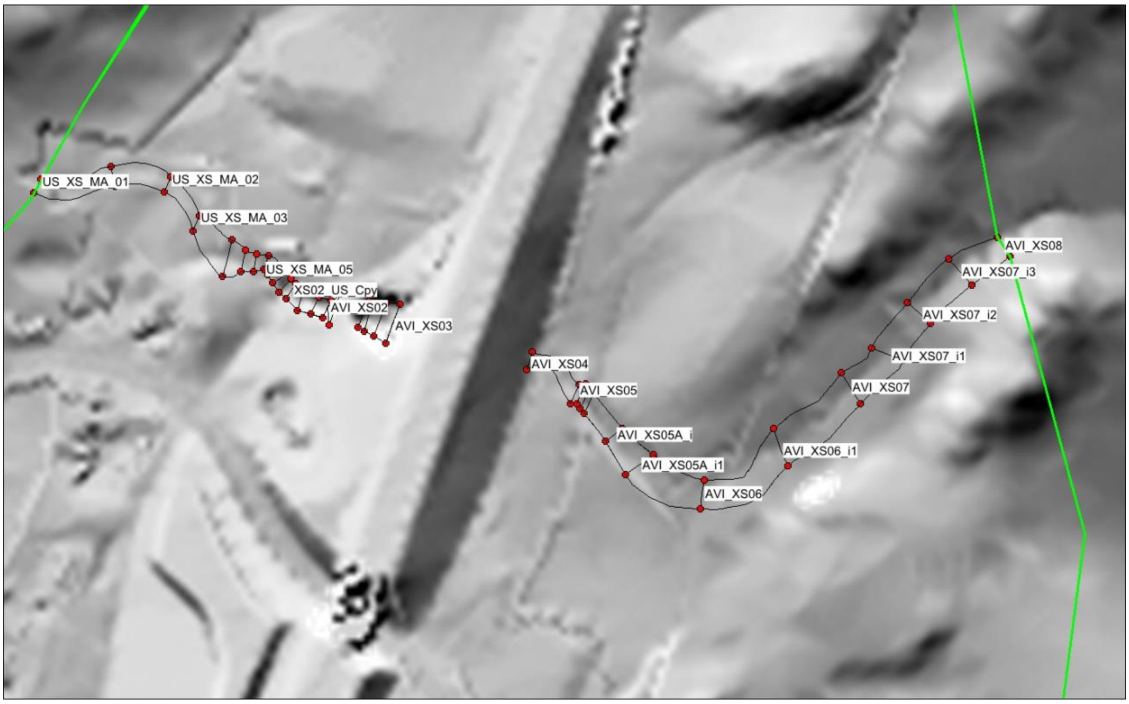


Table 8-8 The Shieling /Aviemore Burn 1D sensitivity results (Flow. m^3/s). Baseline model

Cross-section	Baseline Model Flow Q200 (m^3/s)	Flow. Flow +20% (m^3/s)	Flow. Flow -20% (m^3/s)	Flow. Manning's. +20% (m^3/s)	Flow. Manning's -20% ((m^3/s)	Flow. D/S Boundary +20% (m^3/s)	Flow. D/S Boundary +20% (m^3/s)	Flow 50% blockage (m^3/s)
US_XS_MA_01	1.93	2.36	1.54	1.93	1.93	1.93	1.93	1.93
US_XS_MA_02	1.66	1.94	1.45	1.57	1.80	1.66	1.66	1.70
US_XS_MA_03	1.62	1.90	1.40	1.54	1.74	1.62	1.62	1.66
US_XS_MA_04	1.80	2.13	1.52	1.72	1.88	1.79	1.79	1.83
US_XS_MA_05	1.85	2.22	1.53	1.80	1.90	1.84	1.84	1.87
XS02_US_Cpy	1.85	2.21	1.53	1.79	1.90	1.84	1.84	1.87
AVI_XS02	1.88	2.11	1.53	1.81	1.90	1.88	1.88	1.59
XS02A_US_Cpy	1.88	2.11	1.53	1.81	1.90	1.88	1.88	1.59
AVI_XS02A	1.88	2.12	1.53	1.83	1.90	1.88	1.88	1.79
AVI_XS03	1.90	2.27	1.53	1.85	1.90	1.90	1.90	1.77
AVI_XS04	1.90	2.27	1.53	1.85	1.90	1.90	1.90	1.77
AVI_XS05	1.90	2.27	1.53	1.85	1.90	1.90	1.90	1.77
AVI_XS05A	1.90	2.27	1.53	1.85	1.90	1.90	1.90	1.77
AVI_XS06	1.94	2.30	1.57	1.89	1.95	1.94	1.94	1.80
AVI_XS07	1.99	2.33	1.62	1.93	2.00	1.99	1.99	1.84
AVI_XS08	2.03	2.36	1.65	1.96	2.04	2.02	2.03	1.87

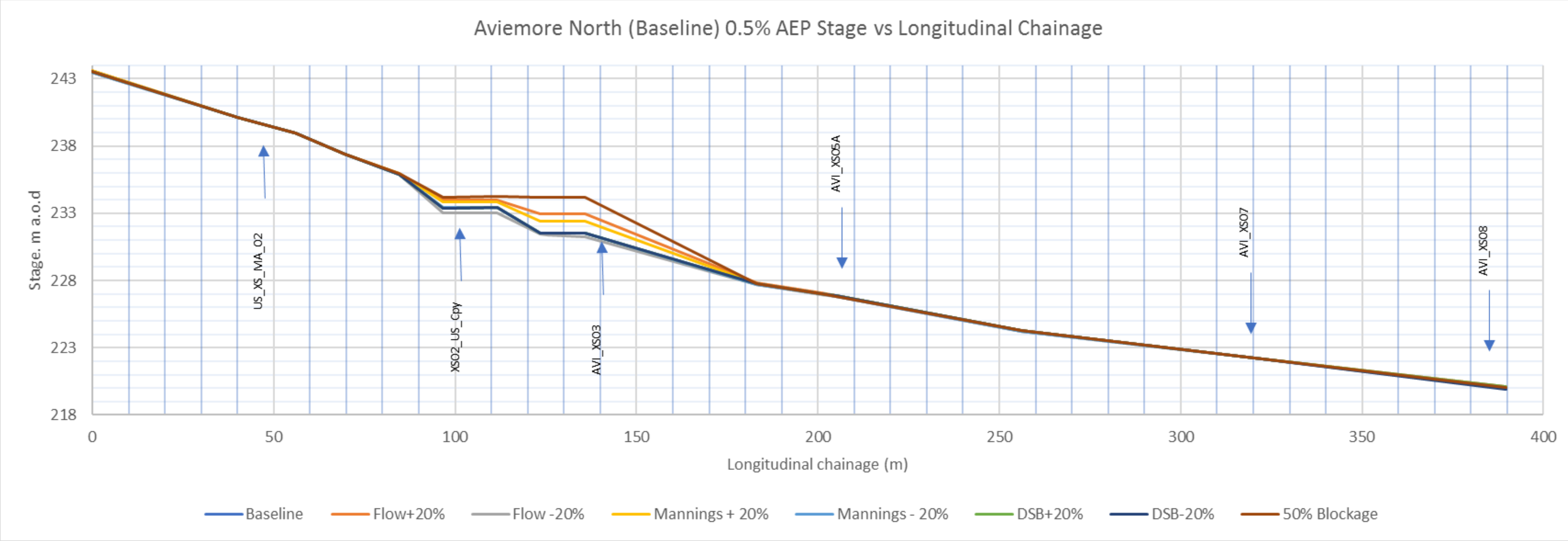
Table 8-9: The Shieling/Easter Aviemore Burn 1D Sensitivity Results Baseline Model (Stage- m AOD)

Cross-section	Baseline Stage (m AOD)	Flow +20% Stage (m A.O.D.)	Flow - 20% Stage (m A.O.D.))	Manning's + 20% Stage (m A.O.D.))	Manning's - 20% Stage (m A.O.D.))	D/S Boundary +20% Stage (m A.O.D.))	D/S Boundary - 20% Stage (m A.O.D.))	50% blockage Stage (m A.O.D.))
US_XS_MA_01	243.54	243.57	243.46	243.57	243.47	243.54	243.54	243.52
US_XS_MA_02	240.13	240.14	240.10	240.14	240.11	240.13	240.13	240.12
US_XS_MA_03	238.94	238.95	238.94	238.95	238.94	238.94	238.94	238.95
US_XS_MA_04	237.40	237.41	237.38	237.41	237.38	237.40	237.40	237.39
US_XS_MA_05	235.90	235.96	235.88	235.94	235.87	235.90	235.90	235.94
XS02_US_Cpy	233.38	233.99	232.99	233.84	233.41	233.38	233.38	234.22
AVI_XS02	233.42	234.00	233.05	233.85	233.45	233.42	233.42	234.22
XS02A_US_Cpy	231.55	232.98	231.43	232.40	231.54	231.55	231.55	234.22
AVI_XS02A	231.54	232.98	231.37	232.40	231.52	231.54	231.54	234.22
AVI_XS03	231.52	232.98	231.27	232.40	231.52	231.52	231.52	234.22
AVI_XS04	227.75	227.80	227.70	227.79	227.70	227.75	227.75	227.73
AVI_XS05	227.02	227.05	226.98	227.04	226.98	227.02	227.02	227.00
AVI_XS05A	226.85	226.89	226.82	226.88	226.82	226.85	226.85	226.84
AVI_XS06	224.26	224.28	224.24	224.28	224.24	224.26	224.27	224.25
AVI_XS07	222.23	222.25	222.22	222.24	222.22	222.23	222.24	222.23
AVI_XS08	220.04	220.08	219.99	220.08	219.99	220.14	219.92	220.02

Table 8-10. The Shieling/Easter Aviemore Burn 1D Sensitivity Results (Variance in Stage- m AOD

Cross-section	Baseline Stage Q200 (m AOD)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage 50% blockage (m)
US_XS_MA_01	243.54	0.03	-0.08	0.03	-0.07	0	0	-0.02
US_XS_MA_02	240.13	0.01	-0.03	0.02	-0.02	0	0	-0.01
US_XS_MA_03	238.94	0.01	0	0	0	0	0	0
US_XS_MA_04	237.40	0.01	-0.02	0.01	-0.01	0	0	0
US_XS_MA_05	235.90	0.06	-0.02	0.04	-0.03	0	0	0.04
XS02_US_Cpy	233.38	0.61	-0.39	0.46	0.03	0	0	0.84
AVI_XS02	233.42	0.59	-0.36	0.43	0.03	0	0	0.81
XS02A_US_Cpy	231.55	1.43	-0.12	0.85	-0.01	0	0	2.67
AVI_XS02A	231.54	1.44	-0.17	0.86	-0.01	0	0	2.68
AVI_XS03	231.52	1.45	-0.25	0.88	0	0	0	2.69
AVI_XS04	227.75	0.05	-0.05	0.04	-0.05	0	0	-0.02
AVI_XS05	227.02	0.04	-0.04	0.03	-0.03	0	0	-0.01
AVI_XS05A	226.85	0.03	-0.03	0.03	-0.03	0	0	-0.01
AVI_XS06	224.26	0.02	-0.02	0.02	-0.02	0	0.01	-0.01
AVI_XS07	222.23	0.01	-0.01	0.01	-0.02	0	0.01	-0.01
AVI_XS08	220.04	0.04	-0.05	0.04	-0.05	0.10	-0.12	-0.02

Figure 8-5: The Shieling / Easter Aviemore Burn Modelled Long Section Sensitivity Results



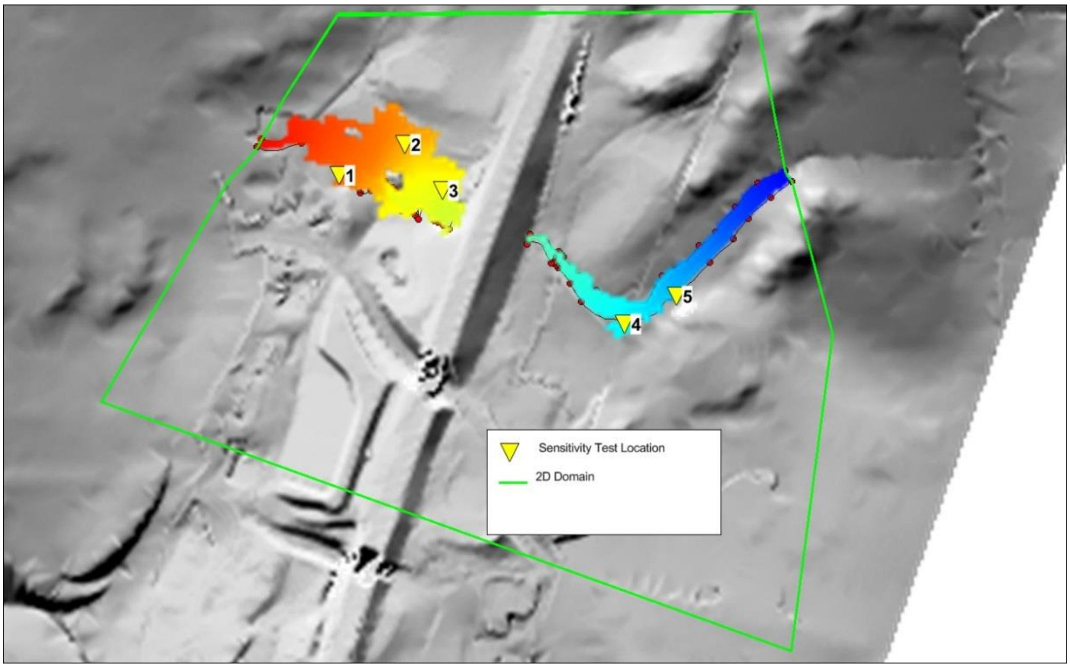
2D Sensitivity, Baseline

8.2.15 In order to assess the 2D sensitivity of the Baseline model, a set of 7 tests were carried out and results analysed at 5 locations throughout the 2D domain. These tests are designed to better understand how specific parameters, that are used in the calculations carried out by the model software, impact the output results, and get a better understanding into the robustness of the hydraulic model. Table 8.11 details these sensitivity test locations, and Figure 8.6 shows the location of the sensitivity test locations relative to the modelled reach and the baseline Q200+CC results.

Table 8-11: The Shieling/ Easter Aviemore Burn 2D Model sensitivity test Locations

Location of sensitivity test	Description of location	Easting	Northing
1	Approximately 70m Upstream of the A9.	289339	814177
2	25m north of the Left bank. Approximately 40m upstream of A9	289379	814196
3	5m Upstream of A9 Crossing, Left bank.	289402	814168
4	75m Downstream of the A9 crossing. Right Bank	289509	814088
5	110m downstream of A9 crossing. Right bank	289544	814104

Figure 8-6. Location of 2D sensitivity test locations and the baseline Q200+CC flood outline



8.2.16 7 sensitivity tests based on the Q200 event were modelled. Table 8.12 provides the summary of the 2D results at the 5 sensitivity test locations along with the Average and Maximum variations.

Table 8-12: The Shieling /Easter Aviemore Burn 2D Sensitivity Results Baseline model

Sensitivity Test	Baseline	+20% Flow	-20% Flow	+20% Mann	-20% Mann	+20% DSB	-20% DSB	+ 50% Blockage
Location 1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Location 2	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.01
Location 3	0.01	0.14	0.08	0.13	0.11	0.01	0.01	0.36
Location 4	0.10	0.12	0.08	0.11	0.08	0.10	0.10	0.09
Location 5	0.05	0.06	0.04	0.06	0.04	0.05	0.05	0.05
Average	0.05	0.08	0.05	0.08	0.06	0.05	0.05	0.11
Max	0.10	0.14	0.08	0.13	0.11	0.10	0.10	0.36

8.2.17 The Baseline model does not show much variation to the sensitivity tests. The maximum variation is located at sensitivity test location 3 which is upstream of the A9 crossing. The maximum variation from the baseline is 0.36m which is attributed to the 50% blockage scenario just upstream of the A9.

8.3 Proposed Model (‘with-scheme’ modelling)

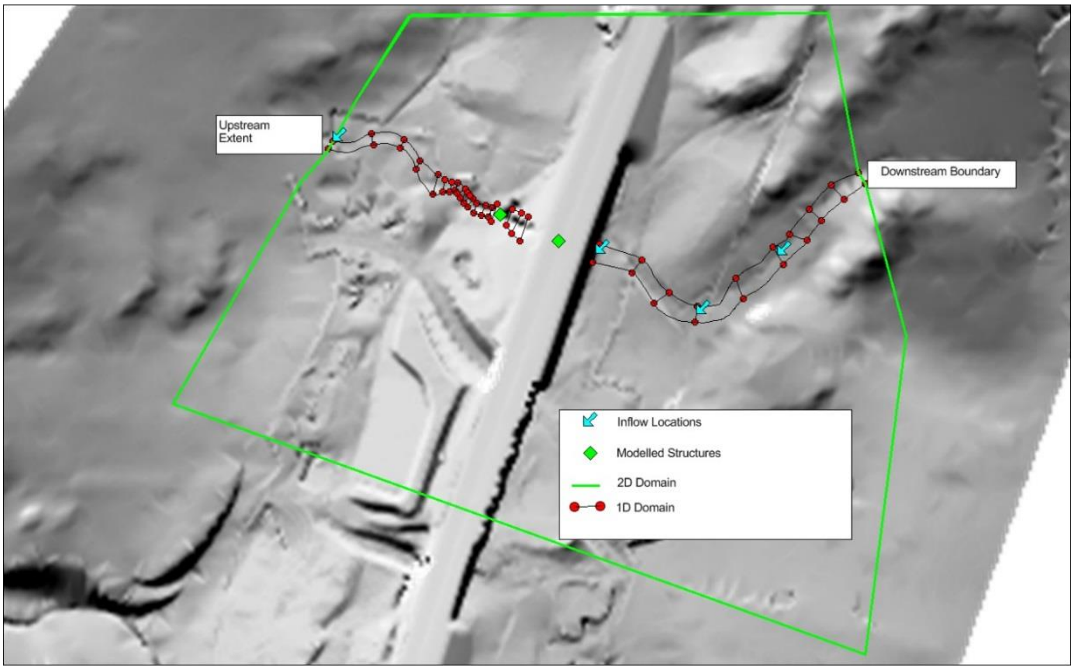
8.3.1 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with mainline and access track roadways. Proposed works to the A9 in the vicinity of Easter Aviemore Burn include widening earthworks to the East and extending the mainline carriageway to accommodate dual-lanes in a Northerly direction.

Table 8-13 Aviemore Burn Baseline and Proposed Scheme A9 Structure details

	Structure Type	Inlet level (m a.o.d.)	Outlet Level (m a.o.d.)	Modelled Length (m)
Baseline	0.9m diameter corrugated culvert	230.09	227.29	47.25
Proposed Scheme	2.5m x 2.5m portal Frame with 2x mammal ledges	230.90	227.6	46.0

8.3.2 Additional updates to the model include the removal of modelled cross section XS02A_US_Cpy, upstream of the A9 Crossing, and Cross sections AVI_XS04 to AVI_XS05A including the small footbridge D/S of the existing crossing AVI_XS05a. The culvert passing beneath the A9 has therefore been increased in length to accommodate the widening. As such, invert levels have been adjusted accordingly. Updates to the 2D domain ground model were undertaken using proposed scheme earthworks drawings from Design Refresh 7a. Figure 8.7 details the model schematisation for the preferred option.

Figure 8-7 Proposed Model Schematic



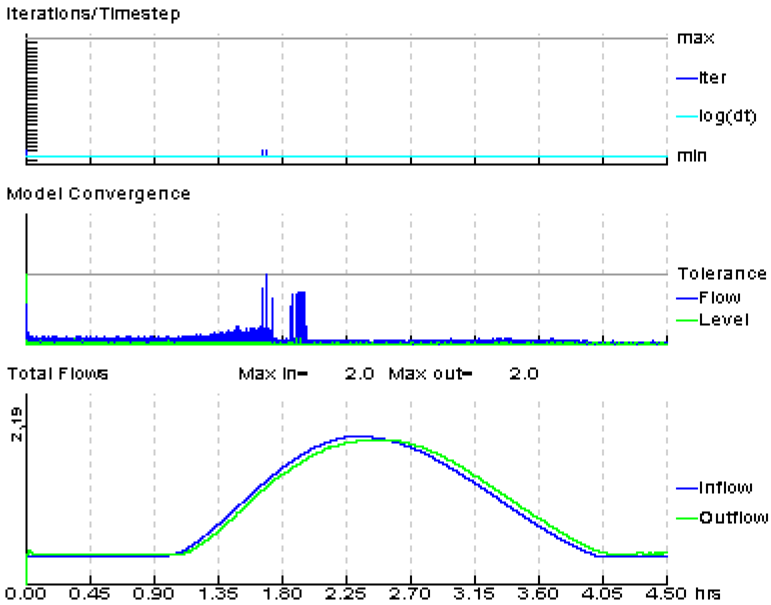
8.3.3 The Proposed Scheme model includes a new crossing under the A9, details of this structure can be found in Table 8.13. The Roughness values for this structure were imputed using Colebrook White. Values used were 0.15m for the bed of the culvert and 0.0015m for the top and sides. The other structure upstream of the A9 was unchanged as it is not part of the A9 infrastructure.

Proposed Scheme Model Performance

1D model performance

8.3.4 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Figure 8.8 shows model convergence for the 0.5% AEP / Q200 event.

Figure 8-8 Model Convergence for the Proposed Scheme model Q200 event



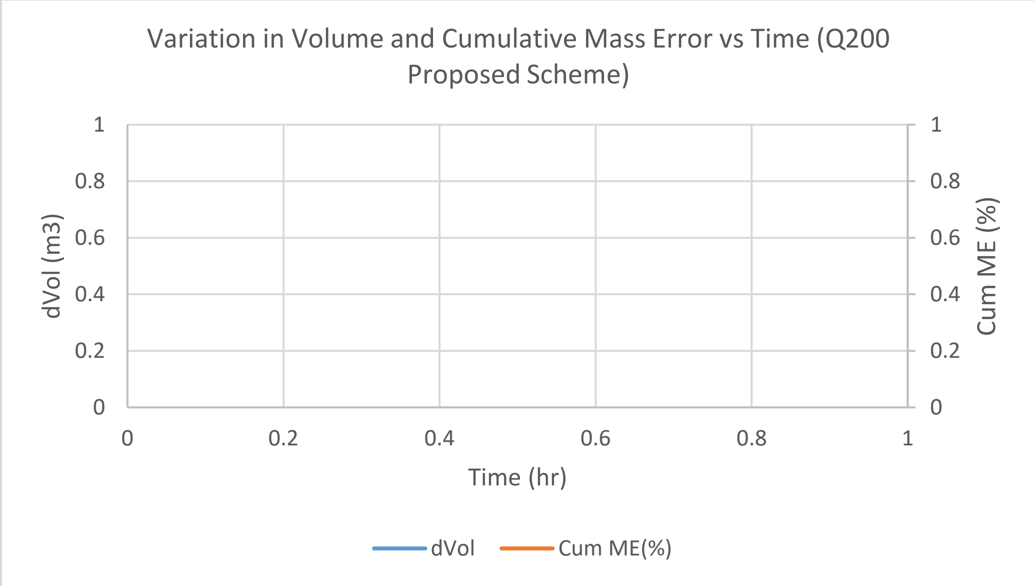
Results: ...\V4_RE-ALLIGNED_2.5M_AV_N_PROP_Q200.zzl
Ran at 11:24:58 on 17/05/2018
Ended at 11:26:10 on 17/05/2018
Start Time: 0.000 hrs
End Time: 4.500 hrs
Timestep: 0.5 secs

Current Model Time: 4.50 hrs
Percent Complete: 100 %

2D model performance

8.3.5 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The latest TUFLOW guidance does state that this can raise to 3% with anything above the higher value indicating an underlying issue with the model. The mass balance of the model is comfortably within the 1% range for the duration of the flood event. Figure 8.9 shows that the cumulative mass error is within the tolerance ranges, with the upper value of error registering at 1.6 % at the tail end of the event.

Figure 8-9 Flow Variance and Cumulative Mass Error v Time (Q200 Proposed Scheme)



Model Results Analysis

8.3.6 Flow and stage results have been extracted from the modelled sections for a range of return periods. The results of this are shown below in Table 8.14 and Table 8.15.

Table 8-14 Proposed model. Stage (mAOD) for modelled return periods

Stage (mAOD)									
Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
US_XS_MA_01	243.58	243.54	243.48	243.43	243.41	243.40	243.36	243.32	243.28
US_XS_MA_02	240.14	240.13	240.11	240.09	240.08	240.08	240.05	240.03	239.99
US_XS_MA_03	238.95	238.94	238.94	238.94	238.94	238.94	238.93	238.92	238.91
US_XS_MA_04	237.41	237.40	237.38	237.37	237.36	237.36	237.34	237.33	237.31
US_XS_MA_05	235.94	235.90	235.88	235.87	235.86	235.86	235.84	235.83	235.81
XS02_US_Cpy	233.84	233.39	233.10	232.89	232.81	232.79	232.68	232.64	232.57
AVI_XS02	233.85	233.41	233.13	232.94	232.80	232.77	232.61	232.50	232.35
AVI_XS02A	231.44	231.37	231.34	231.32	231.31	231.30	231.26	231.23	231.17
AVI_XS03	231.10	230.97	230.88	230.81	230.76	230.74	230.66	230.59	230.50
A9_DS_Cpy1	227.34	227.31	227.29	227.26	227.24	227.23	227.20	227.17	227.13
AVI_XS06	224.29	224.27	224.26	224.24	224.24	224.23	224.22	224.21	224.20
AVI_XS07	222.25	222.23	222.22	222.21	222.21	222.20	222.19	222.18	222.16

Stage (mAOD)									
Cross-section	**Q200+CC**	**Q200**	**Q100**	**Q50**	**Q30**	**Q25**	**Q10**	**Q5**	**Q2**
AVI_XS08	220.10	220.03	220.00	219.97	219.95	219.94	219.90	219.86	219.82

Table 8-15 - Proposed model. Flow (m^3/s) for modelled return periods

Flow (m^3/s)									
Cross-section	**Q200 +CC**	**Q200**	**Q100**	**Q50**	**Q30**	**Q25**	**Q10**	**Q5**	**Q2**
US_XS_MA_01	2.36	1.92	1.64	1.41	1.26	1.21	0.97	0.81	0.58
US_XS_MA_02	1.94	1.66	1.51	1.37	1.25	1.21	0.97	0.81	0.58
US_XS_MA_03	1.89	1.63	1.46	1.30	1.18	1.14	0.92	0.76	0.56
US_XS_MA_04	2.12	1.79	1.58	1.40	1.25	1.20	0.97	0.81	0.58
US_XS_MA_05	2.21	1.85	1.60	1.40	1.25	1.21	0.97	0.81	0.58
XS02_US_Cpy	2.20	1.84	1.60	1.40	1.25	1.20	0.97	0.81	0.58
AVI_XS02	2.22	1.87	1.61	1.40	1.25	1.21	0.97	0.81	0.58
AVI_XS02A	2.23	1.87	1.61	1.40	1.25	1.21	0.97	0.81	0.58
AVI_XS03	2.35	1.90	1.61	1.40	1.25	1.21	0.97	0.81	0.58
A9_DS_Cpy1	2.34	1.90	1.61	1.40	1.25	1.21	0.97	0.81	0.58
AVI_XS06	2.37	1.93	1.64	1.43	1.29	1.24	1.01	0.84	0.61
AVI_XS07	2.43	1.96	1.68	1.47	1.32	1.28	1.04	0.88	0.65
AVI_XS08	2.47	1.99	1.72	1.50	1.36	1.31	1.08	0.91	0.68

8.3.7 To compare the impact of the proposed scheme on the baseline modelling results, depths have been extracted at the sensitivity test locations for a range of return periods in both the baseline and proposed scheme models. Table 8.16 details these results.

Table 8-16 - The Shieling / Easter Aviemore Burn Baseline and Proposed Scheme 2D Results for Q200+CC, Q200, Q100 and Q30

Location	**Q200+CC**			**Q200**			**Q100**			**Q30**		
	Baseline	**Proposed**	**Difference**	**Baseline**	**Proposed**	**Difference**	**Baseline**	**Proposed**	**Difference**	**Baseline**	**Proposed**	**Difference**
Location 1	0.08	0.08	0	0.06	0.03	-0.03	0.06	0.03	-0.03	0.06	0.03	-0.03

Location	Q200+CC			Q200			Q100			Q30		
	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference
Location 2	0.02	0.01	-0.01	0.02	0.01	-0.01	0.01	0.01	0	0.01	0.01	0
Location 3	0.14	0.08	-0.04	0.12	0.07	-0.05	0.11	0.07	-0.04	0.11	0.06	-0.05
Location 4	0.12	0.1	-0.02	0.1	0.08	-0.02	0.08	0.07	-0.01	0.07	0.05	-0.02
Location 5	0.06	0.1	0.04	0.05	0.08	0.03	0.04	0.07	0.03	0	0	0

8.3.8 As can be seen in Table 8.16, the results from the depths extracted from the baseline and proposed scheme at 4 of the sensitivity test locations show that the proposed scheme alignment has a positive impact on local water levels for each of the modelled return periods. At Location 5 there is a small increase in water levels of 0.04 m but the flood extents are largely contained in this area which is low sensitivity receptor.

8.3.9 Optimisation of the scheme to manage flood risk impacts through structure sizing has been considered and the proposed scheme has minimised the potential impacts on the sensitive receptor of the new housing and park upstream but this has resulted in a minor increase in water levels within a contained floodplain area downstream. The impact is considered to have a neutral impact as it is a minor significant impact in low sensitivity receptor.

Sensitivity Analysis

8.3.10 To analyse the sensitivity of the proposed scheme hydraulic model, it was updated to represent the same change in parameters as was carried out in the baseline model, to do this the following sensitivity tests were set up and run again;

- Global roughness including structures + / - 20%
- Flow + / - 20%
- 50% blockage scenario
- Downstream Boundary +/ - 20%

8.3.11 Similar to the baseline scenario, to test the sensitivity of the 2d domain, the same 5 sensitivity test locations have used as in Table 8.11.

1D Sensitivity. Proposed Scheme

8.3.12 The results from both the 1D and 2D domains have been compared against the baseline results. The cross sections where results have been extracted can be seen below in Figure 8.10. The extracted results of stage, measured in metres (AOD) can be seen in Table 8.18 and the variance from the baseline results measured in metres can be seen in Table 8.19, and the extracted flow as a result of the sensitivity tests can be seen in Table 8.17. Figure 8.10 shows the variation within the modelled long section.

Figure 8-10 - Modelled 1D cross section locations. Proposed Scheme

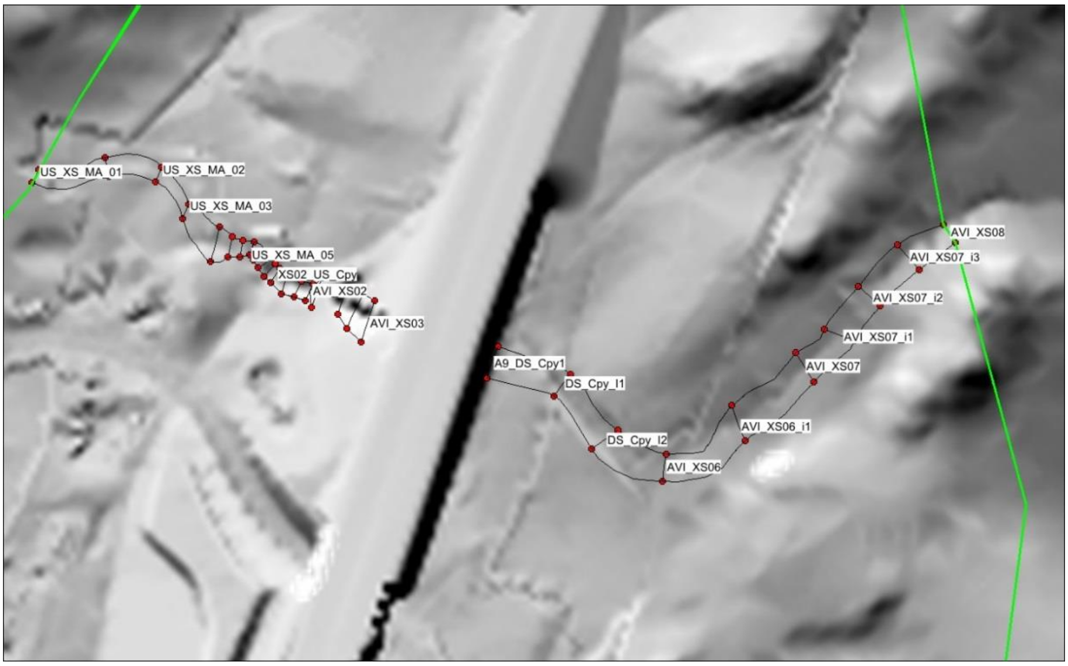


Table 8-17 The Shieling / Aviemore Burn 1D Sensitivity results (Flow m³/s) Proposed model

1D Sensitivity Test	Baseline Model Flow Q200 (m3/s)	Flow +20% (m3/s)	Flow - 20% (m3/s)	Manning's. +20% (m3/s)	Manning's - 20% ((m3/s)	D/S Boundary +20% (m3/s)	D/S Boundary +20% (m3/s)	50% blockage (m3/s)
US_XS_MA_01	1.92	2.31	1.54	1.92	1.92	1.92	1.92	1.92
US_XS_MA_02	1.66	1.90	1.45	1.57	1.81	1.66	1.66	1.66
US_XS_MA_03	1.63	1.86	1.40	1.55	1.75	1.63	1.63	1.62
US_XS_MA_04	1.79	2.08	1.51	1.72	1.89	1.79	1.79	1.79
US_XS_MA_05	1.85	2.17	1.52	1.80	1.90	1.85	1.84	1.84
XS02_US_Cpy	1.85	2.16	1.52	1.79	1.90	1.85	1.84	1.84
AVI_XS02	1.87	2.21	1.52	1.85	1.91	1.87	1.87	1.87
AVI_XS02A	1.87	2.21	1.52	1.85	1.91	1.87	1.87	1.87
AVI_XS03	1.90	2.27	1.52	1.89	1.91	1.90	1.90	1.90
A9_DS_Cpy1	1.90	2.27	1.52	1.89	1.91	1.90	1.90	1.90
AVI_XS06	1.94	2.32	1.56	1.93	1.95	1.94	1.94	1.93
AVI_XS07	1.98	2.36	1.58	1.98	1.98	1.97	1.97	1.97
AVI_XS08	2.02	2.41	1.62	2.02	2.02	2.01	2.01	2.01

Table 8-18 - The Shieling / Aviemore Burn 1D sensitivity results (Stage mAOD) Proposed model

1D Sensitivity Test	Proposed Scheme Flow Q200 (m3/s)	Flow +20% (m3/s)	Flow - 20% (m3/s)	Manning's .+20% (m3/s)	Manning's .- 20% ((m3/s)	D/S Boundary +20% (m3/s)	D/S Boundary +20% (m3/s)	50% blockage (m3/s)
US_XS_MA_01	243.54	243.57	243.46	243.57	243.47	243.54	243.54	243.54
US_XS_MA_02	240.13	240.14	240.10	240.14	240.10	240.13	240.13	240.13
US_XS_MA_03	238.94	238.95	238.94	238.95	238.94	238.94	238.94	238.94
US_XS_MA_04	237.40	237.41	237.38	237.41	237.38	237.40	237.40	237.40
US_XS_MA_05	235.90	235.94	235.88	235.93	235.87	235.90	235.90	235.90

1D Sensitivity Test	Proposed Scheme Flow Q200 (m3/s)	Flow +20% (m3/s)	Flow - 20% (m3/s)	Manning's .+20% (m3/s)	Manning's .-20% ((m3/s)	D/S Boundary +20% (m3/s)	D/S Boundary +20% (m3/s)	50% blockage (m3/s)
XS02_US_Cpy	233.39	233.83	233.01	233.37	233.42	233.39	233.39	233.45
AVI_XS02	233.41	233.84	233.05	233.38	233.45	233.41	233.41	233.47
AVI_XS02A	231.67	231.75	231.59	231.68	231.67	231.67	231.67	232.15
AVI_XS03	231.67	231.78	231.55	231.66	231.67	231.67	231.67	232.16
A9_DS_Cpy1	227.91	227.93	227.88	227.93	227.88	227.91	227.91	227.91
AVI_XS06	224.26	224.28	224.24	224.28	224.24	224.26	224.27	224.26
AVI_XS07	222.23	222.25	222.22	222.25	222.22	222.23	222.24	222.23
AVI_XS08	220.04	220.09	219.98	220.09	219.98	220.14	219.92	220.04

Table 8-19 - The Shieling / Aviemore Burn 1D sensitivity results. Variation in Stage (m) Proposed model

1D Sensitivity Test	Proposed Stage Q200 (m AOD)	Variation in stage for Flow +20% (m)	Variation in stage for Flow - 20% (m)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage 50% blockage (m)
US_XS_MA_01	243.54	0.03	-0.08	0.03	-0.07	0	0	0
US_XS_MA_02	240.13	0.02	-0.03	0.02	-0.02	0	0	0
US_XS_MA_03	238.94	0	0	0	0	0	0	0
US_XS_MA_04	237.40	0.01	-0.02	0.01	-0.01	0	0	0
US_XS_MA_05	235.90	0.04	-0.02	0.03	-0.03	0	0	0
XS02_US_Cpy	233.40	0.43	-0.39	-0.04	0.02	0	0	0
AVI_XS02	233.42	0.41	-0.37	-0.05	0.03	0	0	0
AVI_XS02A	231.56	0.14	-0.12	0.02	-0.01	0	0	0.49
AVI_XS03	231.54	0.15	-0.15	0	0.01	0	0	0.52
A9_DS_Cpy1	226.23	0.03	-0.02	0.03	-0.02	0	0	0

1D Sensitivity Test	Proposed Stage Q200 (m AOD)	Variation in stage for Flow +20% (m)	Variation in stage for Flow - 20% (m)	Variation in stage for +20% Manning's (m)	Variation in stage for -20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage 50% blockage (m)
AVI_XS06	224.26	0.02	-0.02	0.02	-0.02	0	0.01	0
AVI_XS07	222.23	0.02	-0.01	0.02	-0.01	0	0.01	0
AVI_XS08	220.04	0.06	-0.05	0.05	-0.05	0.10	-0.12	0

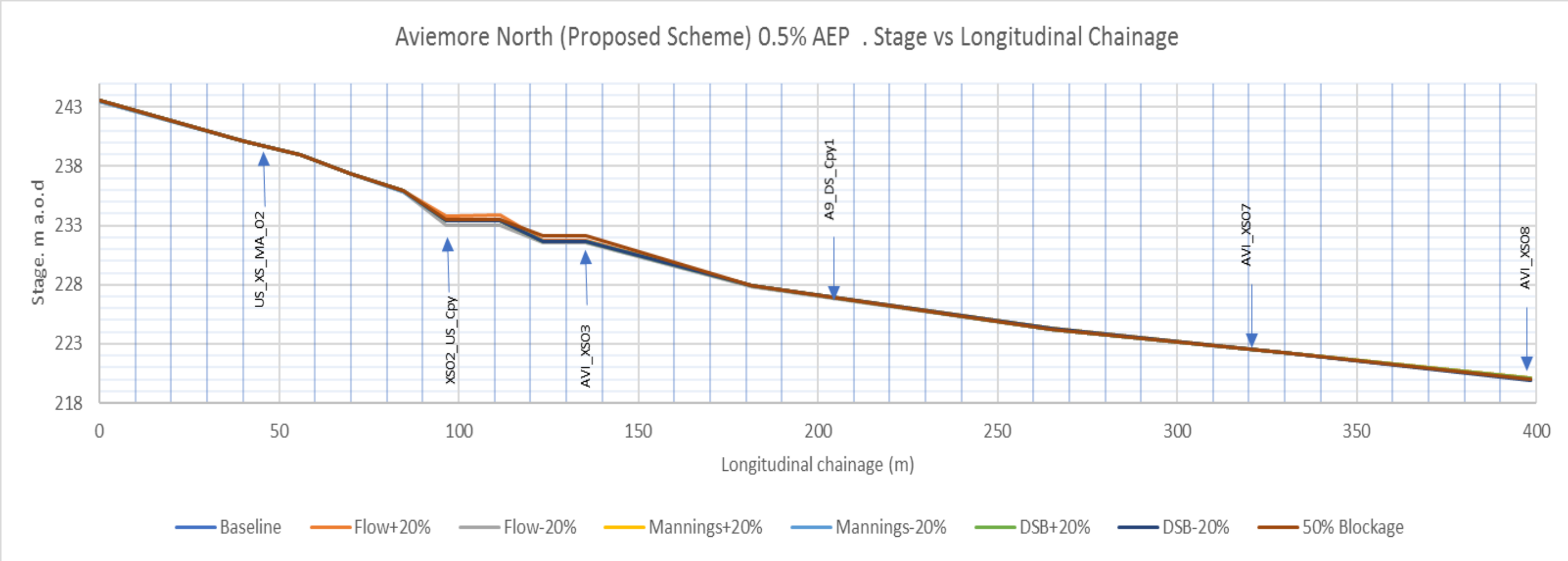
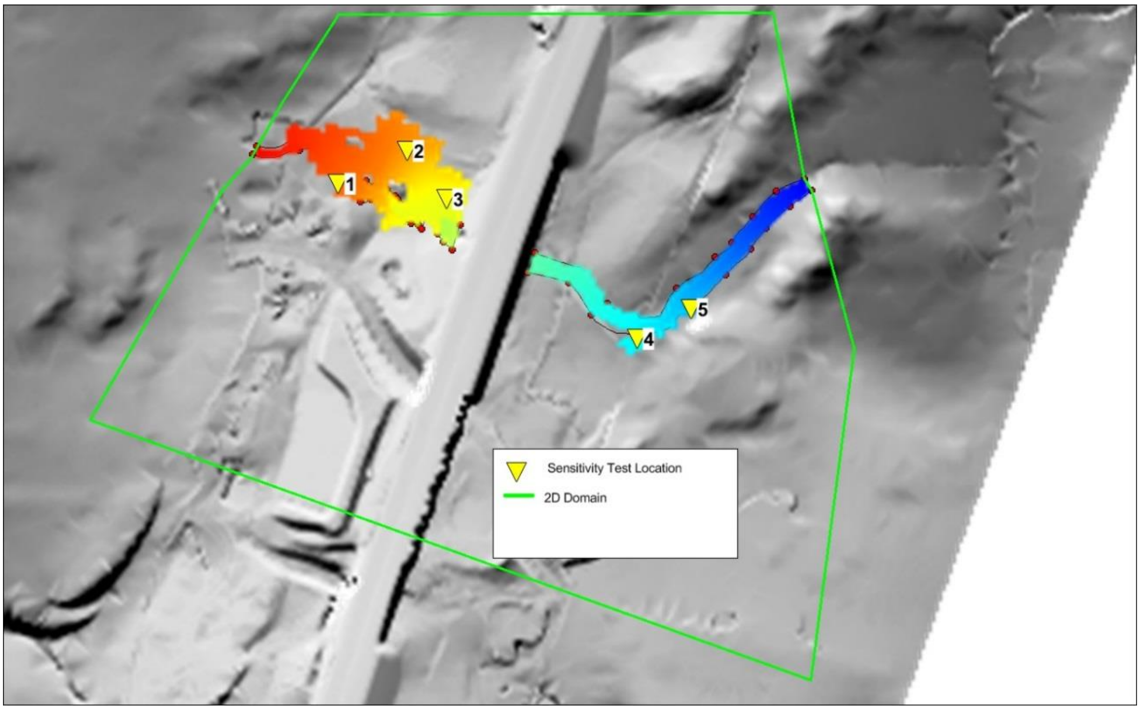


Figure 8-11 - The Shieling / Easter Aviemore Burn Modelled Long Section sensitivity results (Proposed Scheme)

2D Sensitivity, Proposed Scheme

8.3.13 Similarly, to the baseline model, to assess the sensitivity of the proposed scheme model a set of 7 sensitivity tests were carried out in 5 locations throughout the 2d domain. Details of these 5 locations are in Table 8.11 and shown in Figure 8.12.

Figure 8-12 - Location of 2D sensitivity test locations and the Proposed scheme Q200+CC outline



8.3.14 Results of the 7 sensitivity tests for the 5 locations can be found in Table 8.20. These results show the depth on the 2D floodplain for the Q200 event and the variance for the sensitivity tests, measured in metres. The proposed scheme, generally has a low sensitivity to the tested parameters with the values of the sensitivity tests showing a low variation in comparison to the baseline values.

Table 8-20 - The Shieling / Easter Aviemore Burn 2D Sensitivity Results. Variation from Q200 depth (m)

Sensitivity Test	Baseline depth (m)	+20% Flow (m)	-20% Flow (m)	+20% Mann (m)	-20% Mann (m)	+20% DSB (m)	-20% DSB (m)	+ 50% Blockage (m)
Location 1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Location 2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Location 3	0.07	0.08	0.04	0.08	0.07	0.07	0.07	0.07
Location 4	0.08	0.10	0.06	0.10	0.06	0.08	0.07	0.08
Location 5	0.08	0.10	0.06	0.10	0.06	0.08	0.08	0.08
Average	0.05	0.06	0.04	0.06	0.05	0.05	0.05	0.05
Max	0.08	0.10	0.06	0.10	0.07	0.08	0.08	0.08

8.4 Summary

8.4.1 The Easter Shieling / Aviemore North hydraulic model has been created using a 1d/2d linked ISIS-TUFLOW model, and includes 400m of watercourse extending from the woodland to the north of a residential housing estate to Grampian Road downstream of the A9 crossing

8.4.2 The baseline model includes one A9 crossings one of which consider the main Aviemore Burn watercourse, and two others, Shieling Culvert and footbridge.

8.4.3 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with mainline and access track roadways. Proposed works to the A9 in the vicinity of Easter Aviemore Burn include widening earthworks to the East and extending the mainline carriageway to accommodate dual-lanes in a Northerly direction.

8.4.4 Optimisation of the scheme to manage flood risk impacts through structure sizing has been considered and the proposed scheme has minimised the potential impacts on the sensitive receptor of the new housing and park upstream but this has resulted in a minor increase in water levels within a contained floodplain area downstream.

8.4.5 The encroachment of the scheme has no impact on available floodplain storage at the site. Results show that water levels remain the same or depths are reduced in highly sensitive receptor locations as a result of the scheme compared to baseline for all AEP events.

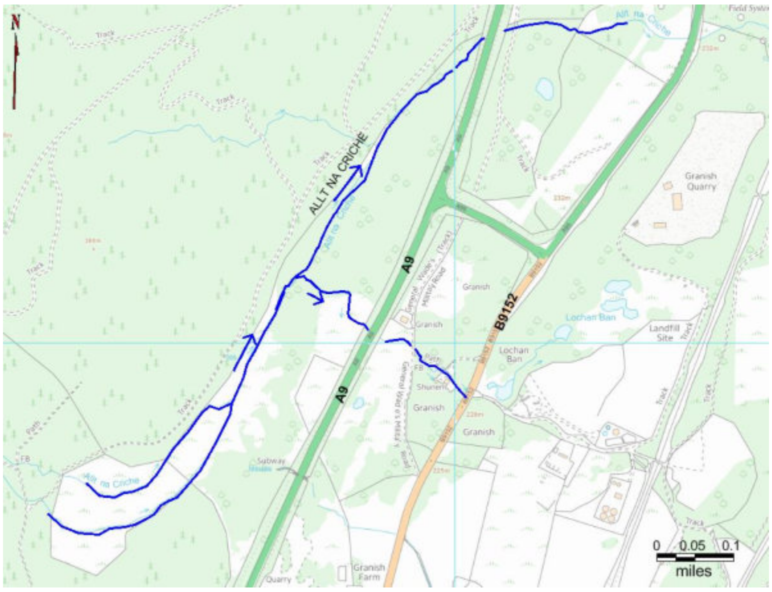
8.4.6 The impact of the scheme at The Shieling / Aviemore North is considered to be negligible, and as such, compensatory floodplain storage or scheme mitigation measures are not considered necessary at this site.

9. Allt na Criche (Granish)

9.1.1 The Allt na Criche at Granish is a relatively small watercourse with a catchment area of around 2.82 km^2 upstream of the A9 road. The watercourse captures runoff from the northern slope of the Carn Mor. The channel splits north of Granish with part of the channel flowing east (hereinafter referred to as the ‘bifurcation channel’), passing under the A9 and the other branch of the channel flowing north (hereinafter referred to as the ‘main channel’). Approximately 300m north of the channel split, an unnamed tributary flows into the main channel prior to flowing north where it passes under the A9. The watercourse is relatively steep and flows northeast, discharging to the Loch Nan Carraigean located at around 500 m downstream of the A9 crossing. Figure 9.1 shows the study area.

9.1.2 The hydraulic model was built using a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller Pro (version 4.2.6050), and the 2D component was constructed using TUFLOW (version 2016.03).

Figure 9-1: Study Area



9.1.3 The data used to construct the baseline hydraulic model for the Allt Na Criche is summarised in Table 9.1.

Table 9-1: Data used to build the baseline hydraulic model

Data	Description	Source
Topographical survey data	The 1d model cross-sections are based survey data carried out in October 2016. The model was extended later based on October 2017 survey data	Topographical survey data October 2016; October 2017
LiDAR	The floodplain ground model has been generated based on LiDAR data	Provided by Transport Scotland.
FEH Catchment descriptors	Model inflow has been generated based on the catchment descriptors	FEH CD-ROM (version 3)

9.1.4 The Allt na Criche (Granish) catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment area was altered to reflect the surrounding topography.

9.1.5 Applying a distributed model the catchment was subdivided into 6 sub-catchments, to take account of the small channels, any lateral inflows and culverts in the floodplain. It should be noted that the catchment areas of sub-catchment 3 slightly differs in the baseline and proposed scenario due to the planned demolition of structure A9 1170 C18 to the north and routing of its catchment (DS-WC-024) to the Allt na Criche culvert. Figure 9.2 and Figure 9.3 show the hydrological model schematic for the baseline and proposed scenario, with Table 9.2 detailing the delineated catchment areas.

Figure 9-2: Allt Na Criche at Granish Catchment Area (Baseline Scenario)

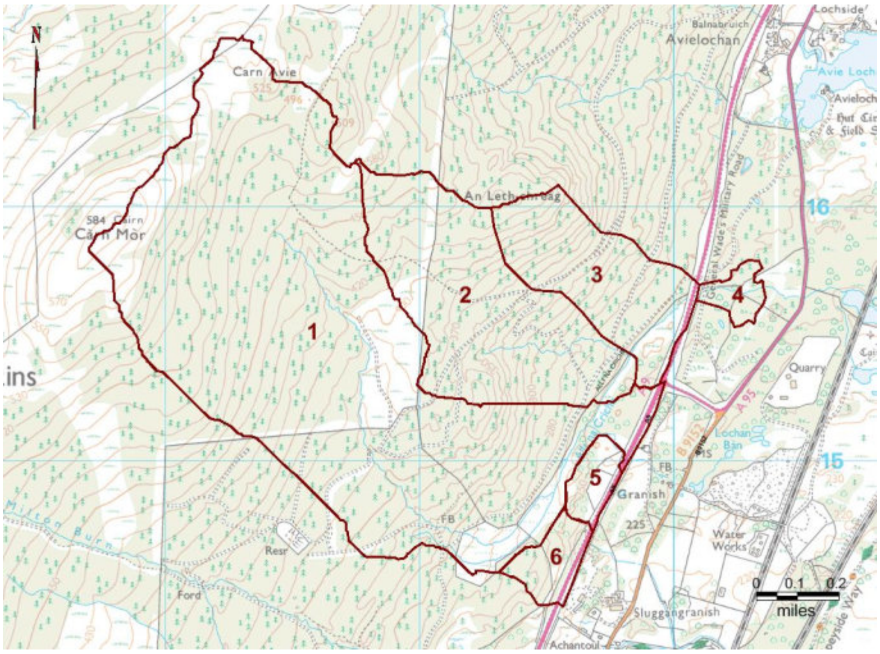


Figure 9-3: Allt Na Criche at Granish Catchment Area (Proposed Scenario)

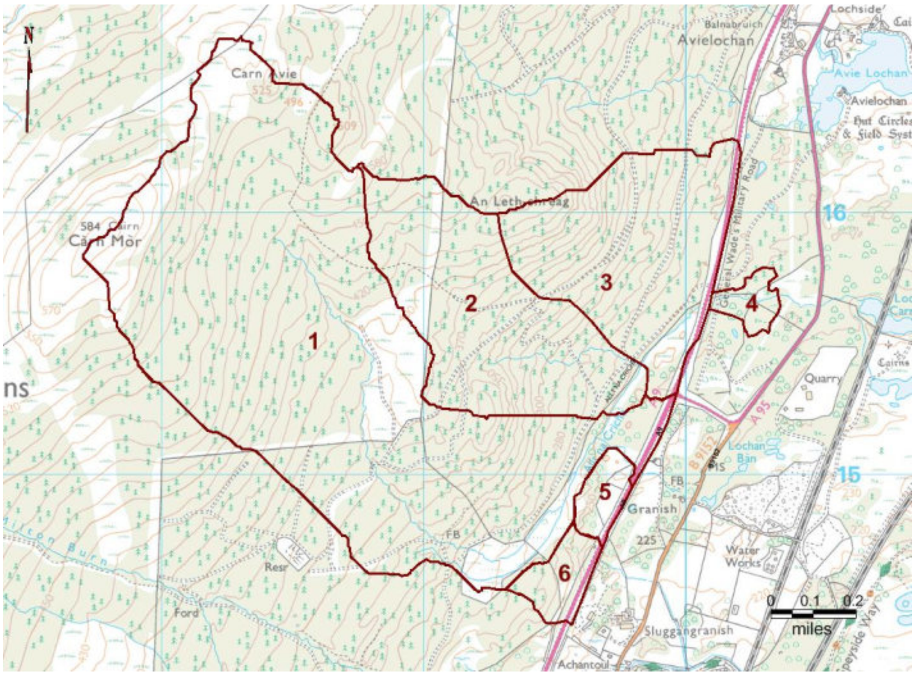


Table 9-2: Allt na Criche (Granish) Hydrological Estimation Points

Watercourse	Catchment Number	Inflow Location	Inflow Type	Easting	Northing	Area (km²)
Allt na Criche	1	Downstream of overflow channel	Direct	290781	820832	1.88
Allt na Criche	2	Downstream of tributary	Lateral	290691	820872	0.55
Allt na Criche	3	Upstream of A9	Lateral	290742	820727	0.31 (this area is 0.51

Watercourse	Catchment Number	Inflow Location	Inflow Type	Easting	Northing	Area (km^2)
						km2 under design scenario)
Allt na Criche	4	Downstream of A9	Lateral	290768	820886	0.04
Allt na Criche	5	Pond feed culvert	Direct	289717	814841	0.05
Allt na Criche	6	Granish Underpass culvert	Direct	289659	814728	0.07

9.1.6 Peak flows were calculated for each inflow point using the FEH Rainfall Runoff method.

9.1.7 The critical storm duration varies for each subcatchment. However, a catchment wide storm duration provides a more realistic representation of actual rainfall events and gives maximum flow downstream of the A9. The critical storm duration for the Allt Na Criche was set as 3.1 hours. Table 9.3 shows the peak flows.

Table 9-3: Allt na Criche (Granish) Peak Flows

Watercourse	Inflow Location	0.5%	0.5% +CC
Allt na Criche	Downstream of overflow channel	5.49	6.59
Allt na Criche	Downstream of tributary	1.6	1.92
Allt na Criche	Upstream of A9	0.9 (This flow is 1.50 m3/s under design scenario)	1.08 (This flow is 1.8 m3/s under design scenario)
Allt na Criche	Model downstream boundary	0.12	0.14
Allt na Criche	Pond feed culvert	0.15	0.18
Allt na Criche	Granish Underpass culvert	0.21	0.25

9.1.8 Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the FEH Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model. Hydrographs were generated from the FEH Rainfall Runoff method.

9.1.9 Modelled events are indicated in Table 9.4.

Table 9-4: Modelled Events

Scenario	AEP					
	50%	4%	3.33%	0.5%	0.5%+CC	0.1%
Baseline	x	x	x	x	x	
Roughness sensitivity				x		
Hydrological inflow sensitivity				x		
Downstream boundary sensitivity				x		
Model ‘with – scheme’	x	x	x	x	x	

With-scheme and mitigation	x	x	x	x	x	

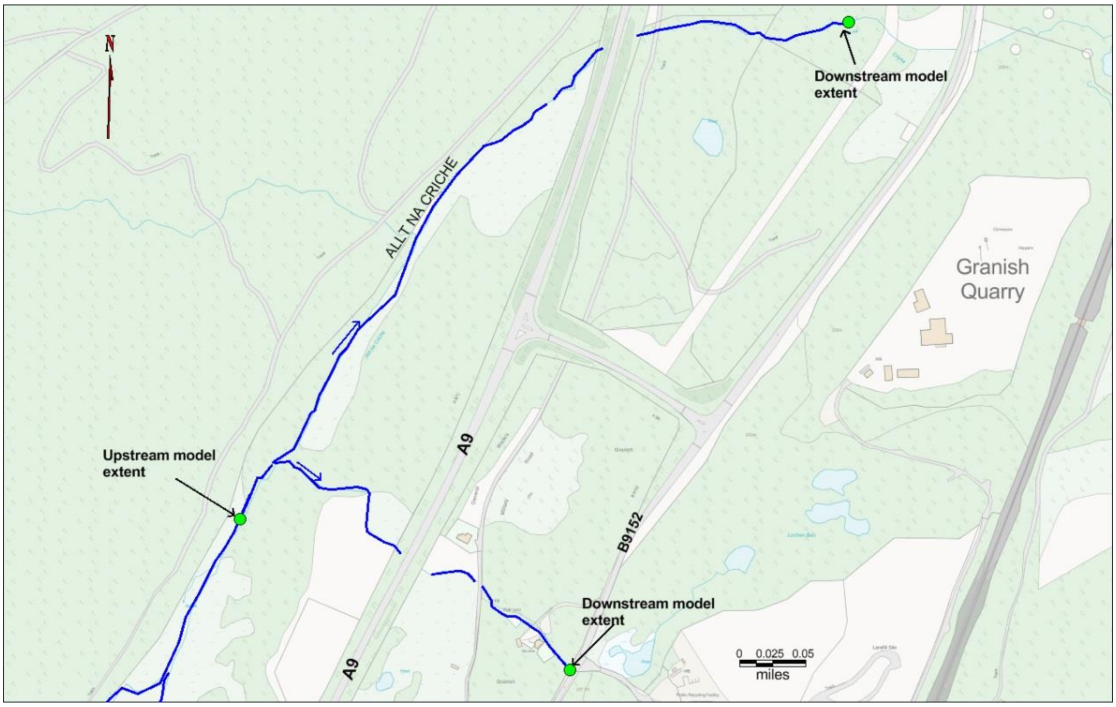
9.2 Baseline Hydraulic Model

Model assumptions and limitations

9.2.1 A detailed 1D/2D model of Allt na Criche at Granish was built using Flood Modeller (1D) and Tuflow (2D). The 1D model is composed of two legs: main channel and bifurcation. The main channel and the bifurcation extends from around 750 m and 224m upstream of the A9 crossing respectively. The reaches extend 270 m and 170 m downstream of the A9 crossing. This ensures that the boundaries do not influence model results.

9.2.2 The upstream boundary of the model is located at 289619, 815072. There are two downstream boundaries associated with the model. These are located at 290360, 815677 and 290021, 814888. The total 1D model reach is approximately 1.4km in length and has 40 surveyed cross-sections. Details of two A9 culverts crossings were surveyed and included within the model. Two small culverts that allow the bifurcation and main channels to pass under an existing farm access track are represented using a Bernoulli loss module in the baseline model. Figure 9.4 shows model domain extent.

Figure 9-4: Model Domain Extent



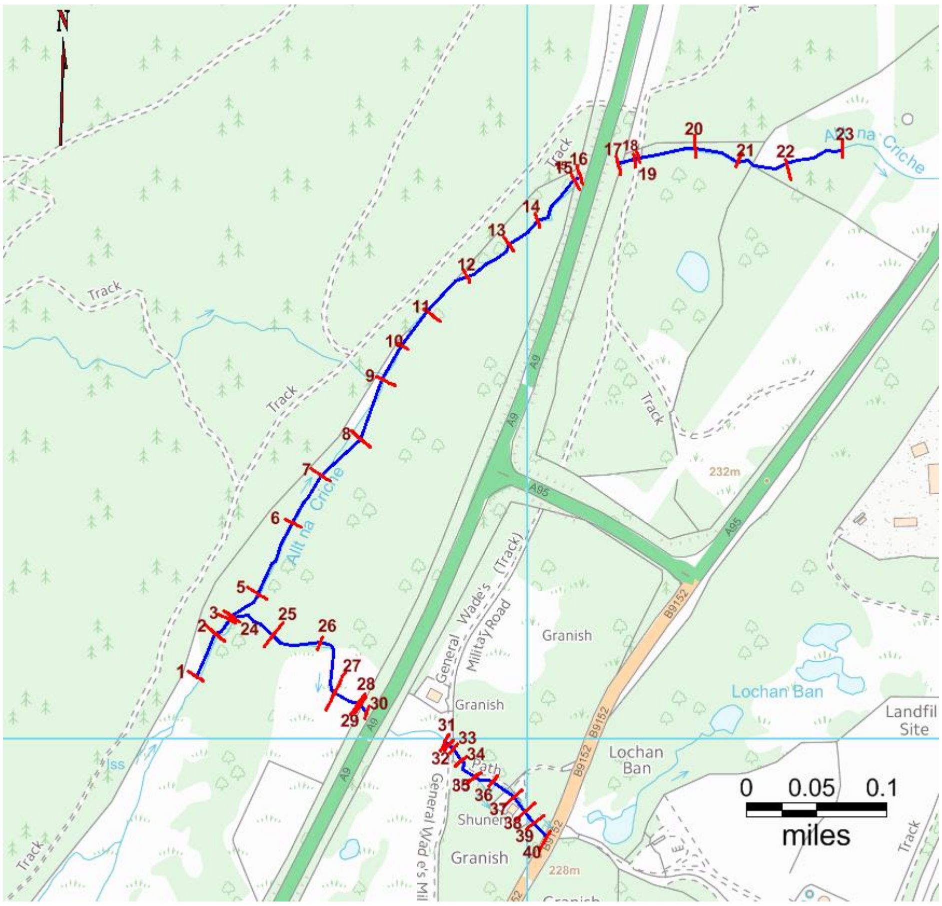
9.2.3 Table 9.5 below details the model extents and key features.

Table .9-5: Allt na Criche (Granish) Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of Cross Sections	Number of A9 Crossings	Total number of modelled structures
Allt na Criche (Granish)	1410	289619, 815072	290360, 815677 290021, 814888	40	4	6

9.2.4 The 1D channels dynamically connect to the floodplains modelled in 2D. Location of the model cross-sections are presented in Figure 9.5.

Figure 9-5: Allt na Criche at Granish schematic detailing cross section locations.



In- channel geometry (1D)

9.2.5 The open channel river sections were defined from the topography survey, with the Manning's 'n' values defined from site visits. Table 9.6 provides the Manning's value range and justification of the value.

Table 9-6: Allt na Criche (Granish) Manning 'n' Values

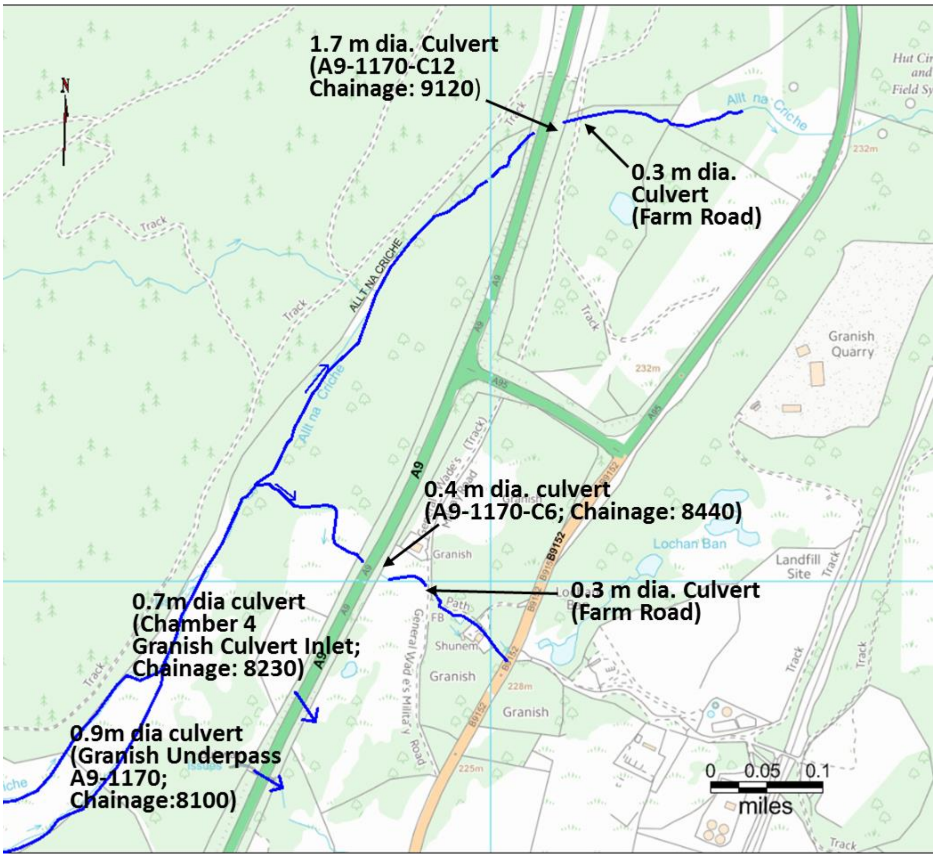
Section Type	Minimum	Maximum	Commentary
River Channel	0.025	0.040	Straight channel, no major meandering. Gravel substrate
Structures	0.020	0.025	Natural river gravels on invert and brickwork walls
Floodplain	0.045	0.060	Ranging from Scattered brush, heavy weeds

9.2.6 Table 9.7 provides the details of how the structures are represented within the model. Figure 9.6 shows the location of these modelled structures.

Table 9-7: Allt na Criche (Granish) Modelled Structure Details

Water Crossing ID	Structure	Water course	Dimensions (m)	Representation in the model	Photograph
DS-WC-019	A9 1170 C6 A9 crossing (bifurcation)	Allt na Criche – Granish (Bifurcation channe)	0.4 Ø	Included in the model with open channel sump followed by circular culvert	
DS-WC-022	A9 1170 C12 A9 crossing (main channel)	Allt na Criche – Granish (Main channel)	1.7 Ø	Represented in a 1D ISIS model. Circular Conduit	
NA	Farm access track crossing d/s of A9 crossing in bifurcation	Allt na Criche – Granish (Bifurcation channel)	0.3 Ø	Represented in a 1D ISIS model as a Bernoulli loss.	
NA	Farm access track crossing d/s of A9 crossing in main channel)	Allt na Criche – Granish (Main channel)	0.3 Ø	Represented in a 1D ISIS model as a Bernoulli loss.	
NA	A9 crossing (Chamber 4)	Unknown	0.7 Ø	Represented as an Estry culvert (circular) in TUFLOW.	NA
Granish Underpass	A9 1170 Granish Underpass	Unknown	0.9 Ø	Represented as an Estry culvert (circular) in TUFLOW.	NA

Figure 9-6: Allt na Criche at Granish schematic detailing structures



9.2.7 A direct inflow hydrograph is applied to the hydraulic model at the upstream extent of the model. Normal Depth boundaries were used at the two downstream extents of the model.

Flood plain schematisation – 2D domain

9.2.8 The 2D domain had an area of 1,088,000m^2 is represented using the 2m grid. LiDAR data has been used to replicate floodplain topography. 2 structures (DS_WC_018 and DS_WC_019), as shown in Figure 9.6 and Table 9.7 have been modelled as Estry[2] culverts. Following Manning's roughness value have been used in the 2D domain.

- buildings – 1
- long grass/bushes and general land – 0.04
- road – 0.02
- smooth surface/short grass – 0.03
- trees – 0.07

9.2.9 A small patch of high roughness (0.1) has also been applied for model stability. The 1D flood modeller model was dynamically linked with 2D TUFLOW model using HX boundary.

9.2.10 The model could not be verified/calibrated due to the absence of any gauge data or historical anecdotal records.

[2] 1d element in 2D domain

Model Sensitivity, baseline

9.2.11 The sensitivity of the baseline hydraulic model to the key parameter values used was tested as detailed below:

- Global roughness + / - 20%
- Flow + 20%
- 50% blockage scenario at the two A9 crossings
- Downstream Boundary + 20%

9.2.12 The model results have been compared against the baseline results, these are shown in Table 9.13 and Table 9.14. The sensitivity results were considered on all of the modelled cross-sections.

9.3 Proposed Model (‘with-scheme’ modelling)

9.3.1 The proposed scheme within the model area of the Allt Na Criche at Granish includes:

- Proposed geometry and elevation of A9 road;
- Proposed geometry and elevations of the culvert crossings at A9 and side roads;
- Side roads to provide access to the Sustainable Urban Drainage (SuDS) pond;
- 4 number of Sustainable Urban Drainage (SuDS) ponds; and
- Drainage ditches.

9.3.2 Figure 9.7 shows the location and proposed geometry of the structures. Figure 9.8 shows location of the proposed SuDS ponds, drainage channel and side roads. The geometry of the proposed A9 road has not been shown in either of figures for clarity.

Figure 9-7: Proposed structures

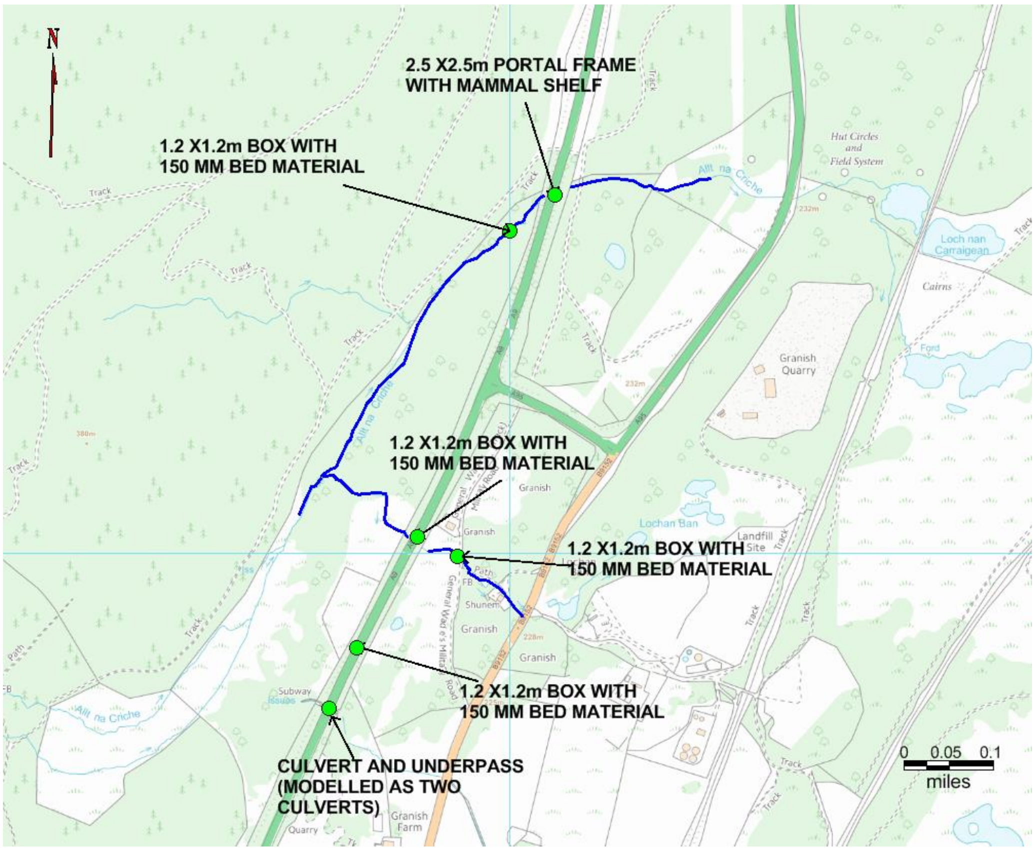
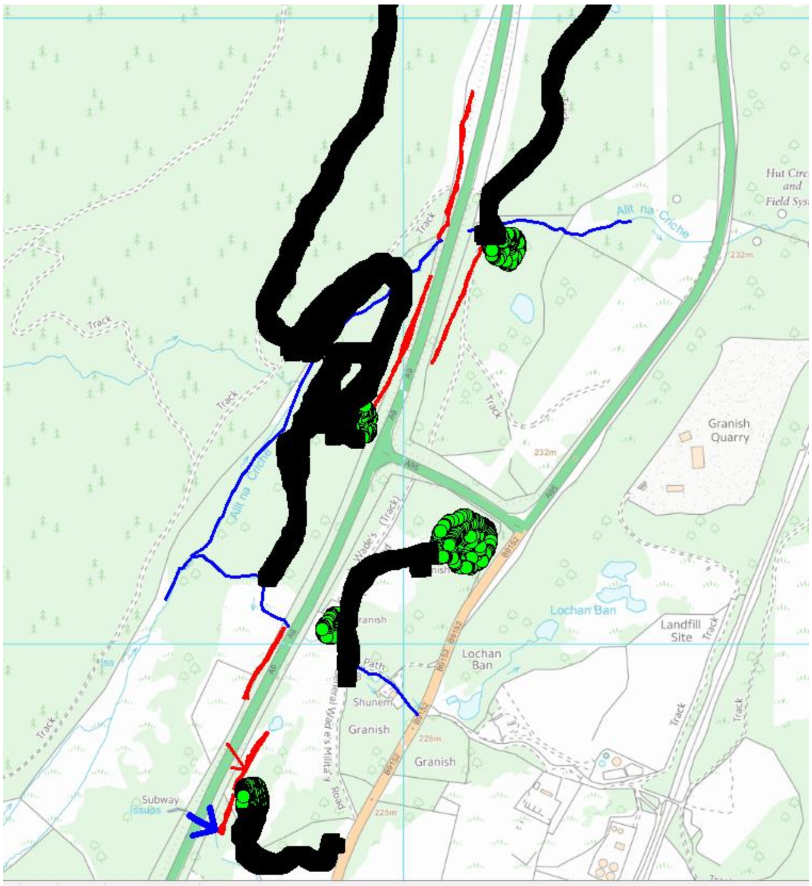


Figure 9-8: Proposed features



9.3.3 As part of the proposed model, the following updates have been made to the baseline model:

- Ground model has been updated to take account of the proposed elevations and alignment of the A9 and the side roads as per the latest design (Design refresh 7a);
- The geometry and elevation of the culverts, both in 1D and 2D domain, updated as presented in Figure 9.7. Mammal shelves have been included in the proposed portal frame culvert (A9 1170 C12). The top of the mammal shelves are kept 150mm above the 1 in 25 year water level from the proposed model results.
- The cross-sections upstream and downstream of the proposed 1D culverts have been smoothened to tie with the size of the culvert and road levels.
- Model inflow has been updated for sub-catchment 3 to take account of the diversion of catchment DS-WC-024 following the demolition of structure A9 1170 C18 as described in section 3.

9.4 Proposed Model + mitigation measures (‘with-scheme + mitigation measure’ modelling)

9.4.1 Mitigation measures are required in the Allt Na Criche Granish scheme for the following reasons:

- To ensure that the A9 is not flooded during the 0.5% AEP plus climate change event with appropriate freeboard allowance; and
- To reduce the water levels in a number of locations in floodplain such that they are comparable to baseline water levels.

9.4.2 As part of the mitigation measures three options were tested:

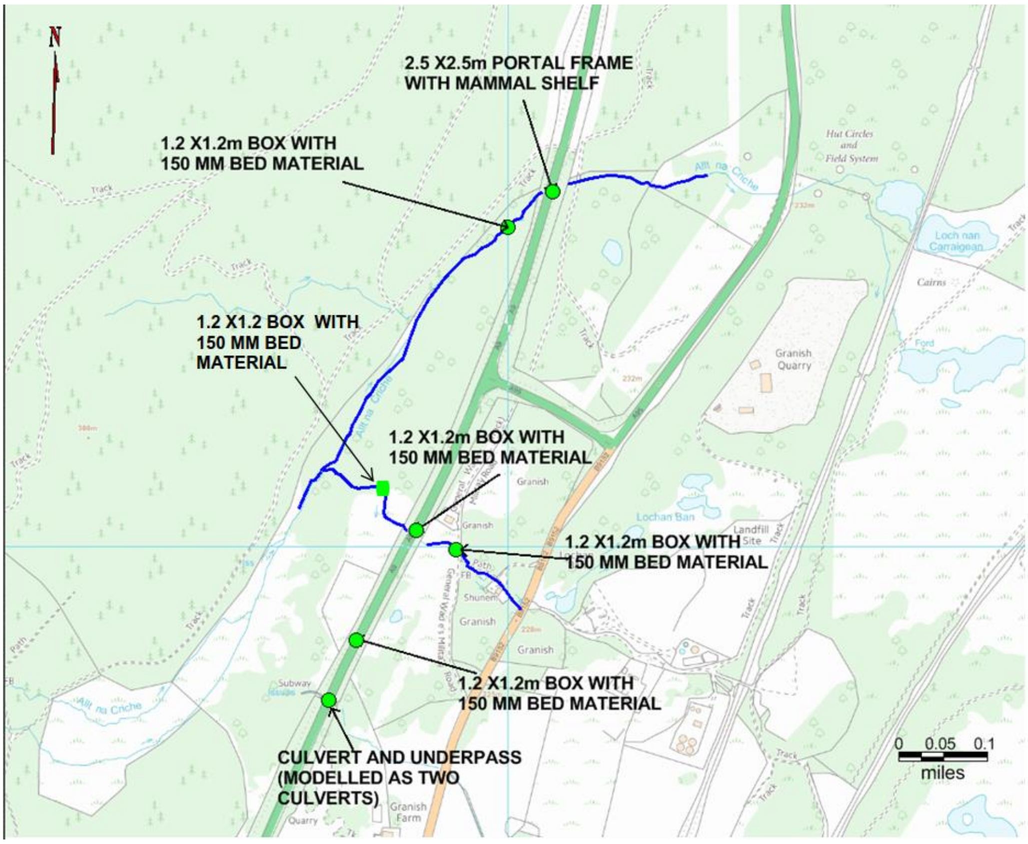
- Option 1 - Upstream storage. This option was to assess the potential for natural flood management options to attenuate flood runoff and flow.
- Option 2 - A flood retention basin to provide compensation flood storage as shown in Figure 9.9.
- Option 3 - Approximately 115m long bund along the right bank of the bifurcation channel as shown in Figure 9.10.

Figure 9-9: Mitigation option 2

Figure 9-10: Mitigation option 3

9.4.3 Option 3 has been taken forward for further investigation. Detailed results are provided in section 7 of this report. Compared to the 'with scheme model', the model with scheme and mitigation includes one additional culvert (1.2 x 1.2 m with 150 mm bed material) in the bifurcation channel upstream of the A9 crossing. This culvert has been included for an access to the proposed bund. Figure 9.11 shows location and proposed geometry of the structures.

Figure 9-11 Proposed structures (Option + Mitigation)



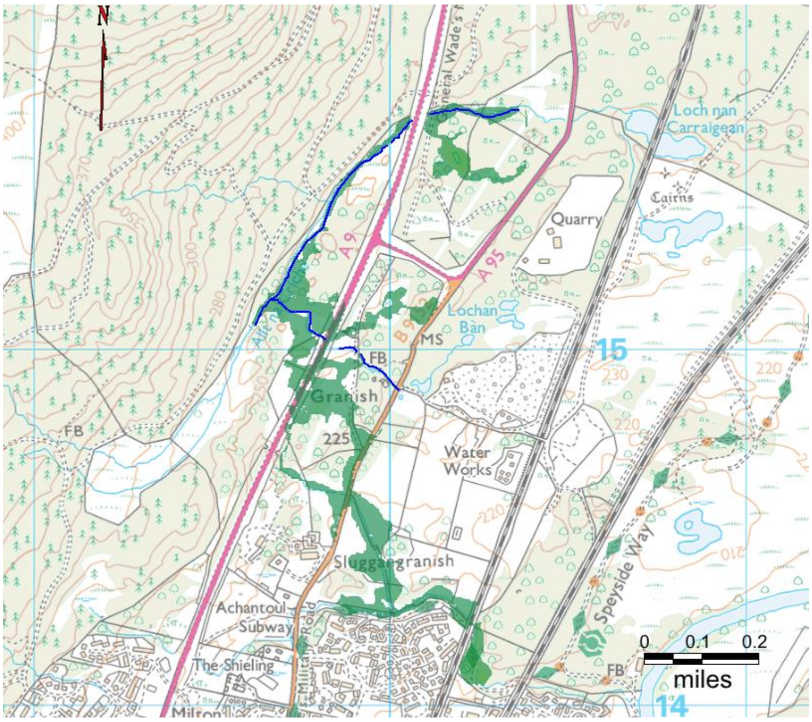
9.5 Modelling Results Analysis

Baseline scenario

9.5.1 Table 9.8 -Table.9.12 give results of the maximum flow and water level respectively, of the baseline model for the 50%, 4%, 3.33%, 0.5% and 0.5%+CC AEP in 13 selected model cross-sections.

9.5.2 The 0.5% AEP baseline model results show that the existing A9, B1952, farm access tracks and agricultural lands are at risk of flooding as shown in Figure 9.12. The model results also show that the flows are very low for the downstream reach of the bifurcation channel (section 37, 38 and 40) for all return periods as shown in Table 9.8 and 9.9.

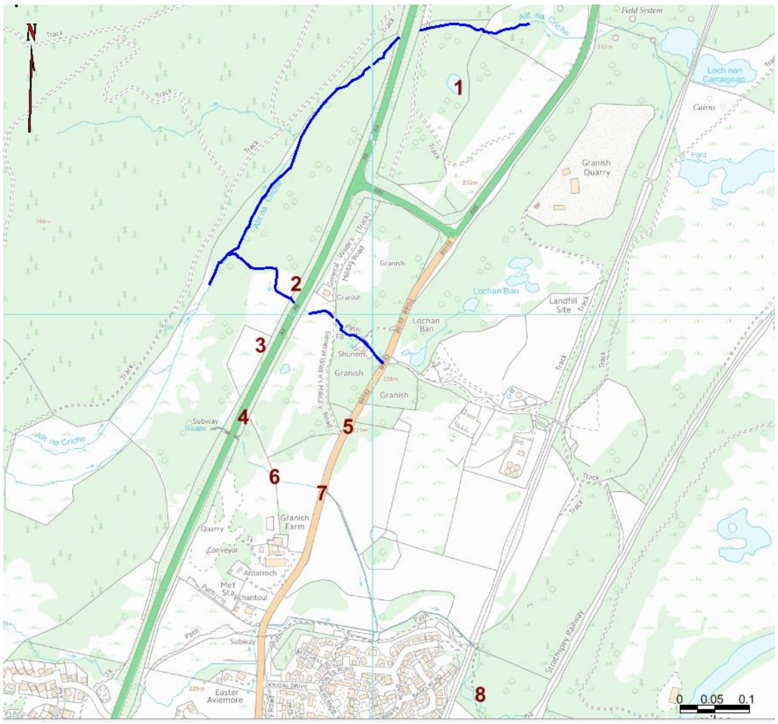
Figure 9-12: Baseline Floodplain



Proposed Model 'with – scheme'

9.5.3 Tables 9.9 - 9.11 compare maximum flow and water level respectively of the of the proposed model with the baseline model for the 50%, 4%, 3.33%, 0.5% and 0.5%+CC AEP in 13 selected model cross-sections. See Figure 9.5 for the cross-section locations. The proposed model results have also been compared at 8 locations in the flood-plain. Figure 9.13 shows the locations where the water levels have been compared and Table 9.12 presents water levels results at these 8 locations.

Figure 9-13: Floodplain locations selected for results comparison

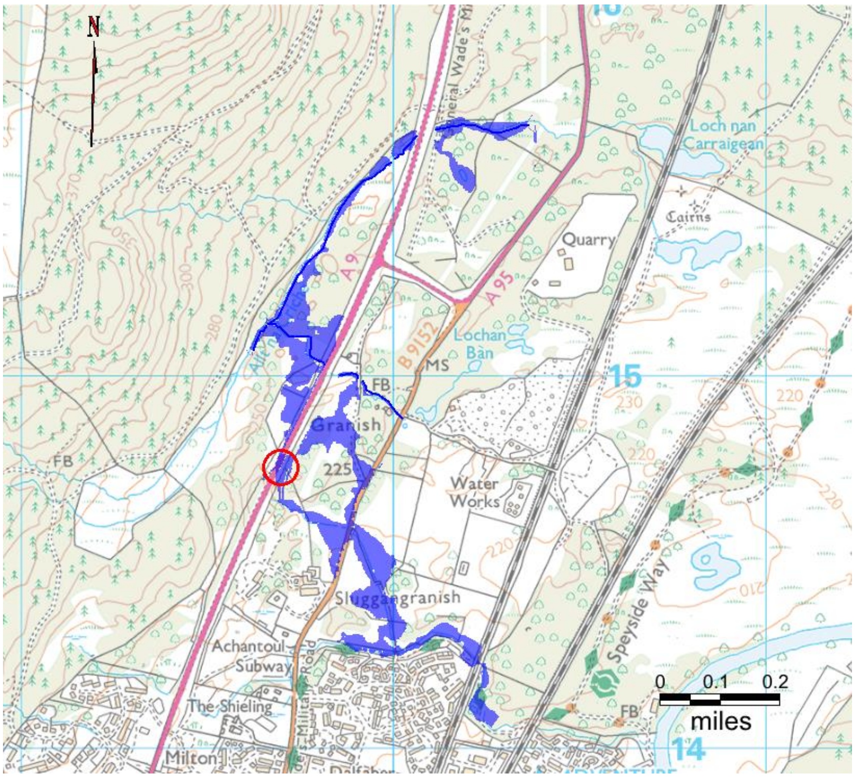


9.5.4 The model results show that when the proposed scheme is in place, flows in the bifurcation channel (cross-section 26 to 40) increase compared to baseline scenario for each of the return periods as shown in Table 9.8 and 9.9. Flows also increase in the main channel downstream of the A9 crossing (section 22 and 23). Upstream of A9 crossing, the flows in the channel are more comparable with baseline except for section 11.

9.5.5 With the scheme, the water levels in the channel generally increase in all locations. Noticeable increase in water levels occur in the downstream reach of the bifurcation channel (section 37, 38 and 40), where the increase ranges from 19 to 48 cm for 0.5% AEP. The increase in water levels in the main channel ranges from 0 to 19 cm depending upon locations.

9.5.6 The 0.5% AEP proposed model results in the floodplain show that the proposed A9 road is at potential risks of flooding as shown in Figure 9.14. The depth of the flooding ranges from 2 to 15 cm. The results also show that the water levels in the floodplain increase at three locations (2, 3 and 6 in Figure 9.13) under the 'proposed scenario' compared to the baseline.

Figure 9-14: "With-Scheme" Floodplain



Proposed model +mitigation measure ('with-scheme +mitigation measure') results

9.5.7 Tables 9.8- 9.9 compare maximum flow and water level respectively of the proposed model with scheme and mitigation measures (Option 3) with the baseline model for the 50%, 4%, 3.33%, 0.5% and 0.5% AEP plus climate change in 13 selected model cross-sections. See Figure 9.5 for the cross-section locations. The results from the proposed model with scheme have also been compared in 8 locations in the flood-plain. Figure 9.13 shows the locations where the water levels have been compared and Table 9.10 presents water levels results at these 8 locations.

9.5.8 Option 1 mitigation measure (upstream storage) model results show that even a 30% reduction in the flow at the upstream boundary cannot eliminate the flooding of the A9. The catchment is small and with no opportunity for upstream storage. Furthermore, upstream storage would require access to additional land. There is with limited opportunity for upstream attenuation within the catchment and therefore this option was not progressed.

9.5.9 Option 2 mitigation measure (compensatory floodplain storage – Figure 9.9) eliminates the flooding of A9 and also negate the impacts of the proposed scheme in terms of increase in water levels at some locations. However, the storage volume required is very large (approx.15000 to 20000m^3) and the ground slopes steeply in this area slope from west to east leading to a high quantity of earthworks and a high cost option. Therefore, this option has also been disregarded.

9.5.10 Option 3 mitigation measure (A shallow bund over the length of approximately 115m – Figure 9.10) eliminates the flooding of A9 and also negate the impacts of the proposed scheme in terms of increase in water levels at some locations by increasing the extent of floodplain west of the A9. This option is simple and cost effective compared to option 2. Therefore, this option has been taken forward for further assessment. The results in the succeeding tables are presented only for this mitigation option.

9.5.11 The model results show that the flows increase in the bifurcation channel in section 37 to 40 compared to both baseline and the proposed scenario. In the remaining sections the flows are similar compared to the 'proposed scenario'. Increase in the water levels in the bifurcation channel ranges from 0 to 54 cm for 0.5% AEP.

9.5.12 The results in the floodplain show that when the mitigation measure is included in the scheme, the proposed A9 road is not flooded and the water levels in the floodplains are either lower than or equal to the baseline water levels in all locations except for the location 2 as shown in Figure 9.13. The increase in flood levels at location 2 confirms that this location west of the A9 compensates for the displacement of floodplain due to the scheme and ensures neutral impact at the downstream receptors.

Table 9-8: Comparison of Baseline and Proposed Flows (m^3/s) for comparative 1d model cross sections.

	Baseline	Proposed	Proposed + mitigation	Baseline	Proposed	Proposed + mitigation	Baseline	Proposed	Proposed + mitigation	Baseline	Proposed	Proposed + mitigation
Cross section	**Q200+CC**	**Q200+CC**	**Q200+CC**	**Q200**	**Q200**	**Q200**	**Q30**	**Q30**	**Q30**	**Q2**	**Q2**	**Q2**
1	6.6	6.6	6.6	5.5	5.5	5.5	3.6	3.6	3.6	1.6	1.6	1.6
2	5.8	5.8	5.8	5.1	5.1	5.1	3.6	3.6	3.6	1.6	1.6	1.6
6	1.0	1.1	1.1	1.0	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
7	1.1	1.2	1.2	1.1	1.2	1.2	1.0	1.1	1.1	1.0	1.0	1.0
11	0.5	2.3	2.3	0.5	2.0	2.0	0.5	0.8	0.8	0.5	0.8	0.8
12	3.6	3.6	3.6	3.2	3.4	3.4	2.4	2.5	2.5	1.4	1.6	1.6
22	1.0	1.7	1.7	1.0	1.4	1.4	0.9	1.3	1.3	0.7	1.0	1.0
23	1.5	4.6	4.6	1.3	3.8	3.8	1.1	2.9	2.9	0.6	1.7	1.7
26	2.9	3.0	3.0	2.5	2.5	2.5	1.6	1.6	1.6	0.4	0.4	0.4
27	0.6	0.7	0.7	0.5	0.7	0.6	0.5	0.6	0.4	0.2	0.3	0.3
37	0.1	0.7	0.9	0.1	0.7	0.8	0.1	0.5	0.6	0.04	0.1	0.4
38	0.1	0.7	0.9	0.1	0.7	0.9	0.1	0.5	0.6	0.04	0.1	0.4
40	0.1	0.7	0.9	0.1	0.7	0.9	0.1	0.5	0.6	0.04	0.1	0.4

Table 9-9: Comparison of Baseline and Proposed Stage (mAOD) for comparative 1d model cross sections.

	Baseline	Proposed	Proposed + mitigation	Baseline	Proposed	Proposed + mitigation	Baseline	Proposed	Proposed + mitigation	Baseline	Proposed	Proposed + mitigation
Cross section	Q200+CC	Q200+CC	Q200+CC	Q200	Q200	Q200	Q30	Q30	Q30	Q2	Q2	Q2
1	256.51	256.51	256.51	256.47	256.47	256.47	256.38	256.38	256.38	256.17	256.17	256.17
2	253.73	253.72	253.72	253.69	253.68	253.68	253.57	253.57	253.57	253.35	253.35	253.35
6	248.18	248.20	248.20	248.18	248.19	248.19	248.18	248.19	248.19	248.16	248.16	248.16
7	247.12	247.14	247.14	247.09	247.11	247.11	247.03	247.01	247.01	247.01	247.01	247.01
11	244.28	244.23	244.23	244.24	244.22	244.22	244.11	244.18	244.18	243.97	244.04	244.04
12	242.87	243.07	243.07	242.83	242.99	242.99	242.78	242.77	242.77	242.67	242.66	242.66
22	235.88	235.95	235.95	235.87	235.93	235.93	235.86	235.91	235.91	235.81	235.88	235.88
23	234.91	235.04	235.04	234.90	235.01	235.01	234.89	234.98	234.98	234.86	234.92	234.92
26	244.86	244.87	244.89	244.84	244.84	244.84	244.74	244.75	244.67	244.33	244.34	244.29
27	242.78	242.79	243.17	242.78	242.78	242.97	242.77	242.77	242.93	242.71	242.70	242.71
37	232.53	233.02	233.07	232.53	233.00	233.05	232.52	232.90	232.98	232.48	232.57	232.83
38	231.66	231.86	231.89	231.66	231.85	231.88	231.65	231.80	231.84	231.62	231.67	231.77
40	228.00	228.23	228.27	228.00	228.21	228.25	227.99	228.16	228.20	227.96	228.01	228.14

Table 9-10: Comparison of baseline and proposed stage (mAOD) in the floodplain for 1 in 200 year return period

Location (See Figure 9-13)	Location description	Baseline Water Levels	Proposed Scenario		Proposed Scenario with Scheme	
			Water Level, mAOD	Difference with Baseline, m	Proposed +Scheme Water Level	Difference with Baseline
1	Right floodplain d/s of A9 crossing	236.8	236.4	-0.4	236.4	-0.4

Location (See Figure 9-13)	Location description	Baseline Water Levels	Proposed Scenario		Proposed Scenario with Scheme	
			Water Level, mAOD	Difference with Baseline, m	Proposed +Scheme Water Level	Difference with Baseline
2	Upstream floodplain	242.22	242.84	0.62	242.95	0.73
3	Upstream floodplain	241.54	242.42	0.88	241.37	-0.17
4	A9 Road	NA	241.98	NA	NA	NA
5	Road - B9152	224.55	224.54	-0.01	224.54	-0.01
6	Floodplain d/s of Granish Underpass	224.91	225	0.09	224.91	0
7	Road - B9152	221.16	221.15	-0.01	221.14	-0.02
8	D/S railway embankment	215.88	215.17	-0.71	215.39	-0.49

Sensitivity Analysis, proposed

9.5.13 To analyse the sensitivity of the proposed hydraulic model, 9 sensitivity tests have been run on the Proposed (Baseline) model. These aim to test how sensitive the models are to variable parameters and scenarios. The following tests were run on the Proposed (Baseline) model.

- Global roughness + / - 20%
- Flow + 20%
- 50% blockage scenario in the 2 structures under A9
- Downstream Boundary + 20%

9.5.14 Table 9.11 shows the variation in flow between the Proposed (baseline) model and each of the sensitivity results for the Q200 event. Variation is given in m^3/s. Whereas Table 9.12 gives the variation in maximum stage (m).

Table 9-11: Variation in flow for sensitivity tests.

	Sensitivity tests Q200 Variation in Flow (m3/s)									
	Baseline	Man +20% Global	Man -20% Global	Man +20% Culvert	Man -20% Culvert	Q +20%	Q -20%	50% Blockage	DSB + 20% XSO2	DSB - 20% XSO2
Cross Section	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200
1	5.485	0	0	NA	NA	+1.097	NA	0	0	NA
2	5.065	-0.272	+0.26	NA	NA	+0.747	NA	-0.035	0	NA
6	1.016	-0.238	+0.25	NA	NA	-0.007	NA	-0.015	-0.02	NA
7	1.062	-0.158	+0.28	NA	NA	+0.007	NA	-0.004	+0.003	NA
11	0.531	-0.067	+0.21	NA	NA	+0.002	NA	0	+0.008	NA
12	3.174	-0.256	+0.15	NA	NA	+0.439	NA	-0.037	-0.008	NA
22	0.986	-0.164	+0.26	NA	NA	+0.022	NA	-0.004	-0.005	NA
23	1.341	-0.031	+0.13	NA	NA	+0.179	NA	-0.008	-0.264	NA
26	2.506	-0.183	+0.31	NA	NA	+0.4	NA	+0.001	0.001	NA
27	0.547	-0.067	+0.08	NA	NA	+0.012	NA	0	-0.001	NA
37	0.077	-0.021	+0.073	NA	NA	+0.001	NA	0	0	NA
38	0.077	-0.021	+0.073	NA	NA	+0.001	NA	0	+0.034	NA
40	0.077	-0.021	+0.073	NA	NA	+0.001	NA	0	+0.048	NA

Table 9-12: Variation in Stage for sensitivity tests

	Sensitivity tests Q200 Variation in stage (m)									
	"Baseline"	Man +20% Global	Man - 20% Global	Man +20% Culvert	Man - 20% Culvert	Q +20%	Q - 20%	50% Blockage	DSB + 20% XSO2	DSB - 20% XSO2
Cross section	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200
1	256.471	+0.04	-0.05	NA	NA	+0.04	NA	+0.001	-0.001	NA

	Sensitivity tests Q200 Variation in stage (m)									
	"Baseline"	Man +20% Global	Man - 20% Global	Man +20% Culvert	Man - 20% Culvert	Q +20%	Q - 20%	50% Blockage	DSB + 20% XSO2	DSB - 20% XSO2
Cross section	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200	Q200
2	253.686	+0.03	-0.06	NA	NA	+0.04	NA	0	-0.002	NA
6	248.183	-0.01	0.01	NA	NA	+0.00	NA	0	0	NA
7	247.087	+0.00	-0.05	NA	NA	+0.03	NA	-0.003	0	NA
11	244.236	-0.02	-0.02	NA	NA	+0.04	NA	-0.01	0	NA
12	242.834	+0.03	-0.04	NA	NA	+0.03	NA	+0.001	-0.001	NA
22	235.872	-0.01	0.00	NA	NA	+0.01	NA	0	+0.001	NA
23	234.902	-0.00	0.01	NA	NA	+0.01	NA	0	+0.119	NA
26	244.835	+0.05	-0.05	NA	NA	+0.03	NA	0	0	NA
27	242.779	-0.01	-0.01	NA	NA	+0.00	NA	0	0	NA
37	232.528	-0.02	0.04	NA	NA	+0.00	NA	0	+0.046	NA
38	231.655	-0.01	0.03	NA	NA	+0.00	NA	0	+0.015	NA
40	227.995	-0.02	0.02	NA	NA	+0.00	NA	0	+0.053	NA

9.5.15 As the results show, change of Manning's roughness by +/- 20% resulted in changes to water levels ranging from around -0.06 m to +0.05 m compared to baseline, as shown in Table 9.12, Figure 9.15 and Figure 9.16. The most notable changes in water level are at the upstream model reach (section 1 and 2) and section 26.

9.5.16 Increase in flow by 20% also produces an increase in water level throughout the modelled watercourse, as shown in Figure 9.17 and Table 9.12. The highest increase in water level is about 0.04m and take place at the sections 1, 2 and 11.

9.5.17 The model is relatively insensitive to changes in the downstream boundary slope with negligible changes in water level at the downstream boundary, with the only exception of some cross sections immediately upstream of the boundary (section 23, 37, 38 and 40) as shown in Figure 9.18.

9.5.18 When 50% blockage is applied at the two A9 culverts, the water levels change locally upstream of the bridge as shown in Figure 9.19.

Figure 9-15: Modelled Long Section Sensitivity Results (Global Roughness +20%)

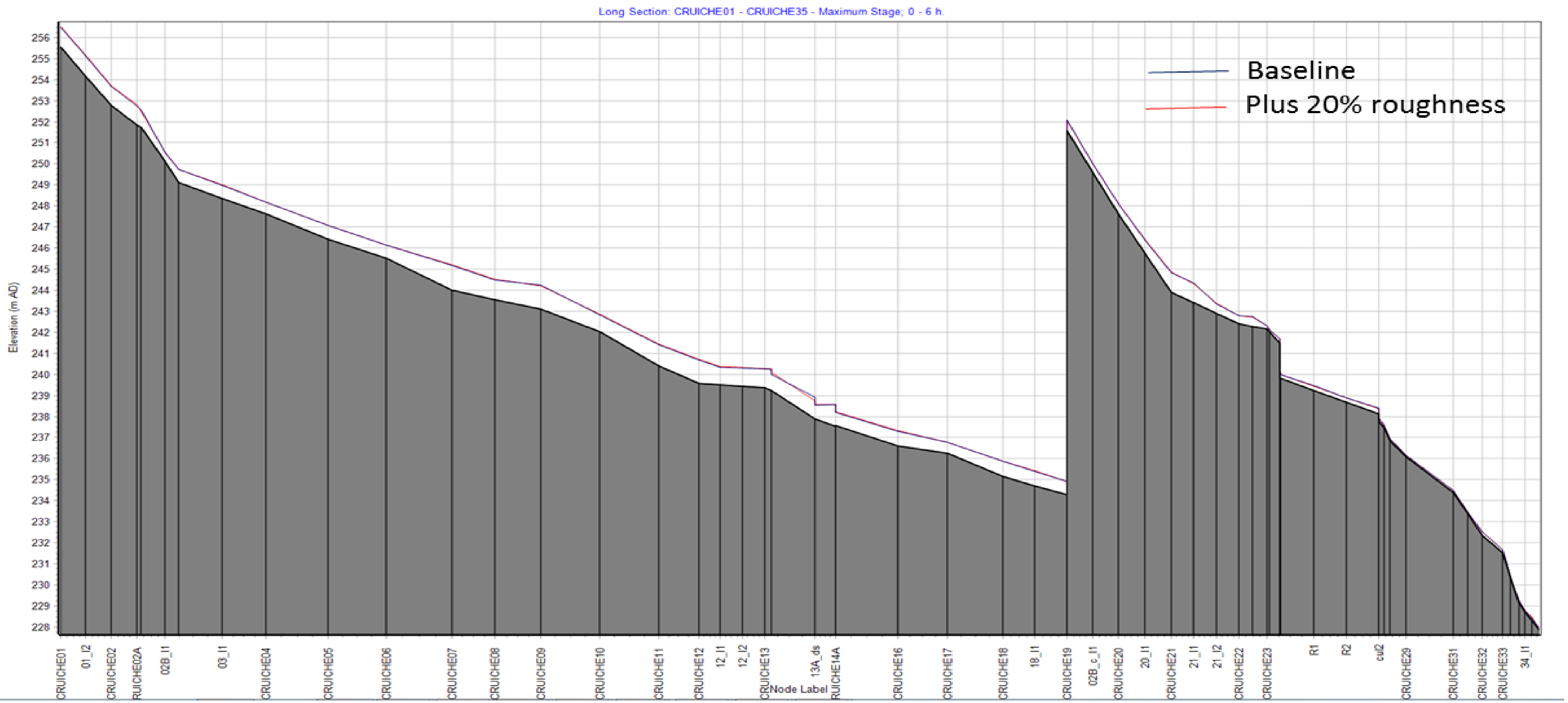


Figure 9-16: Modelled Long Section Sensitivity Results (Global Roughness -20%)

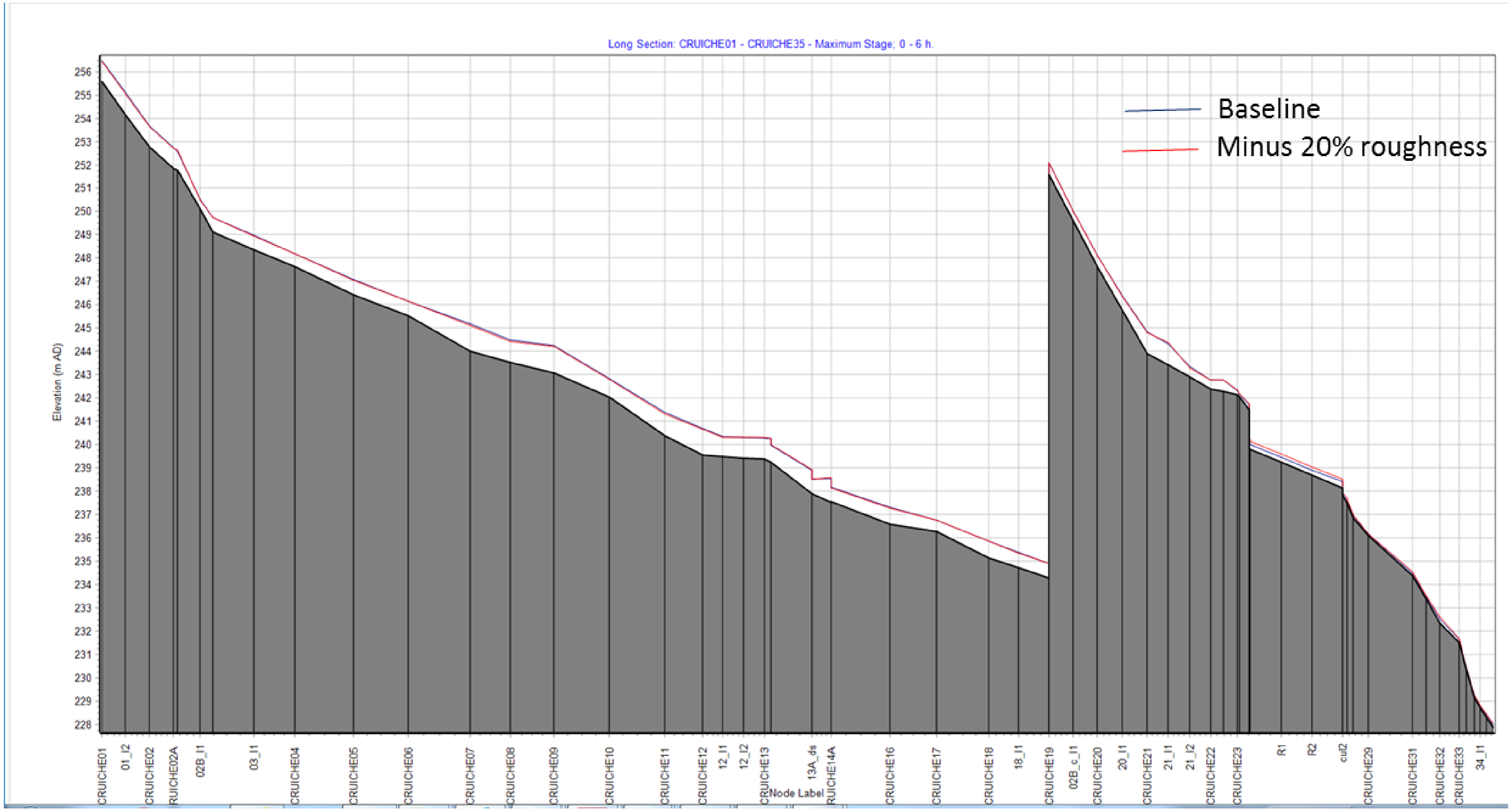


Figure 9-17: Modelled Long Section Sensitivity Results (Flow Variation)

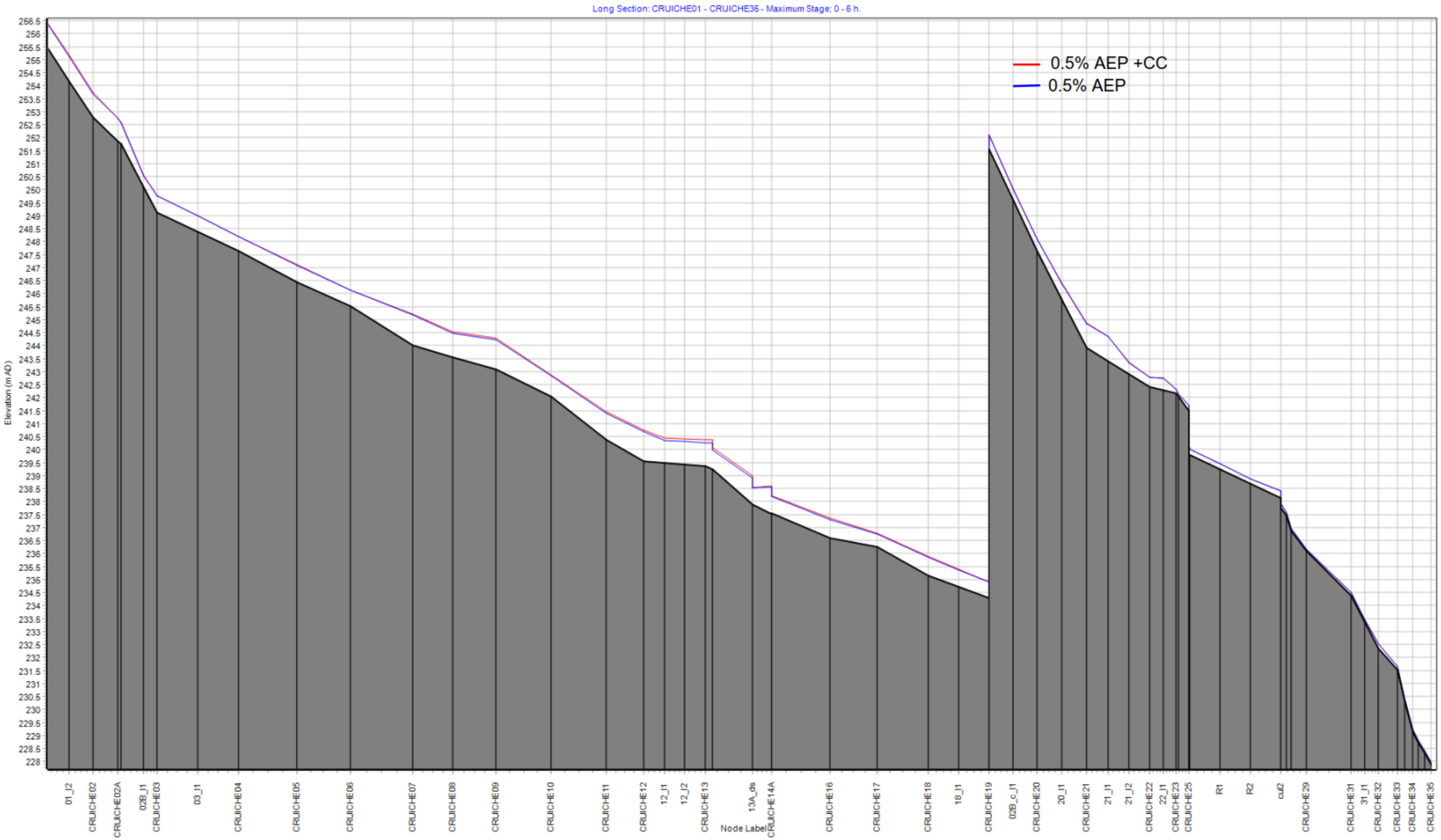


Figure 9-18: Modelled Long Section Sensitivity Results (DSB variation)

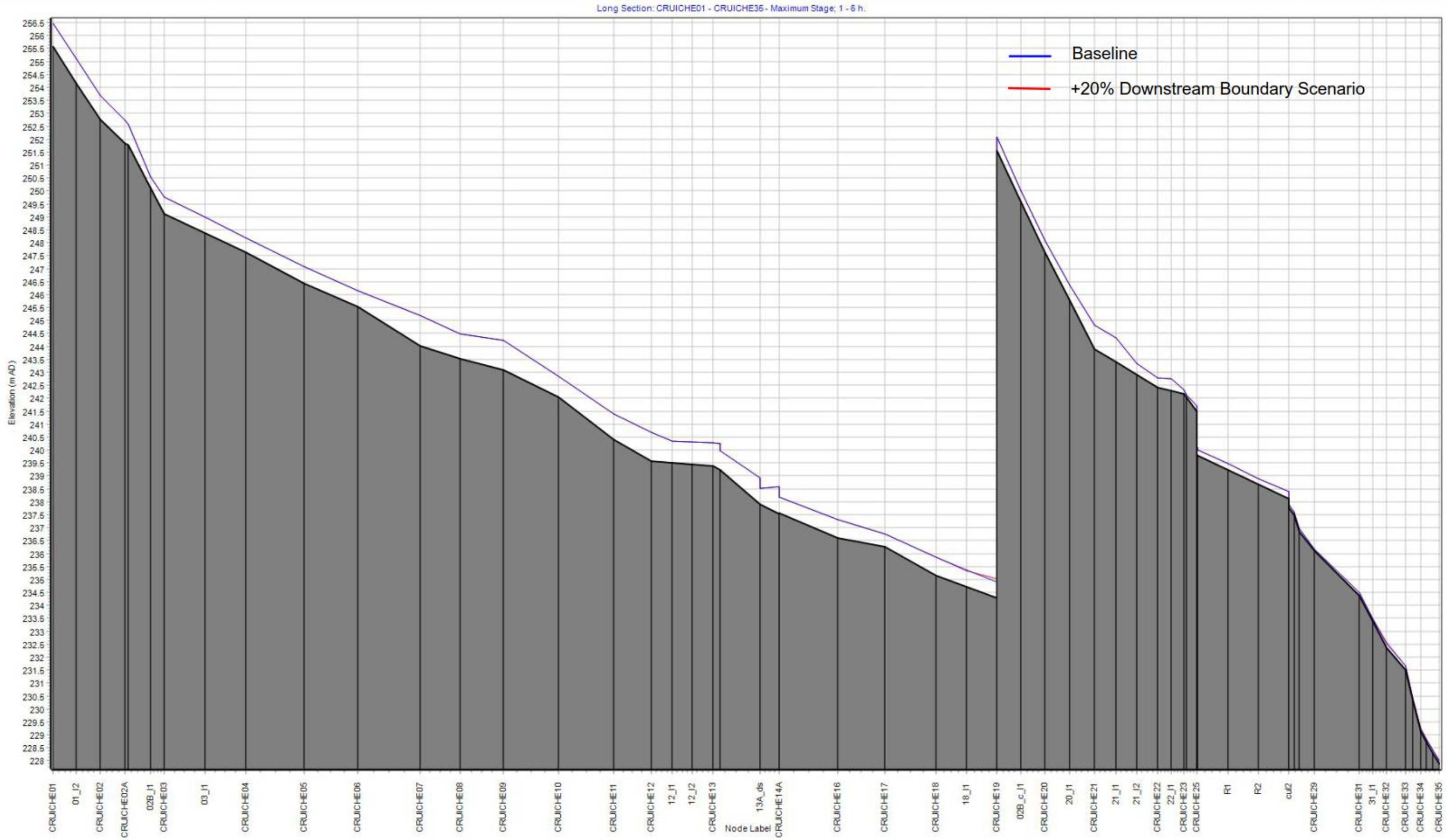
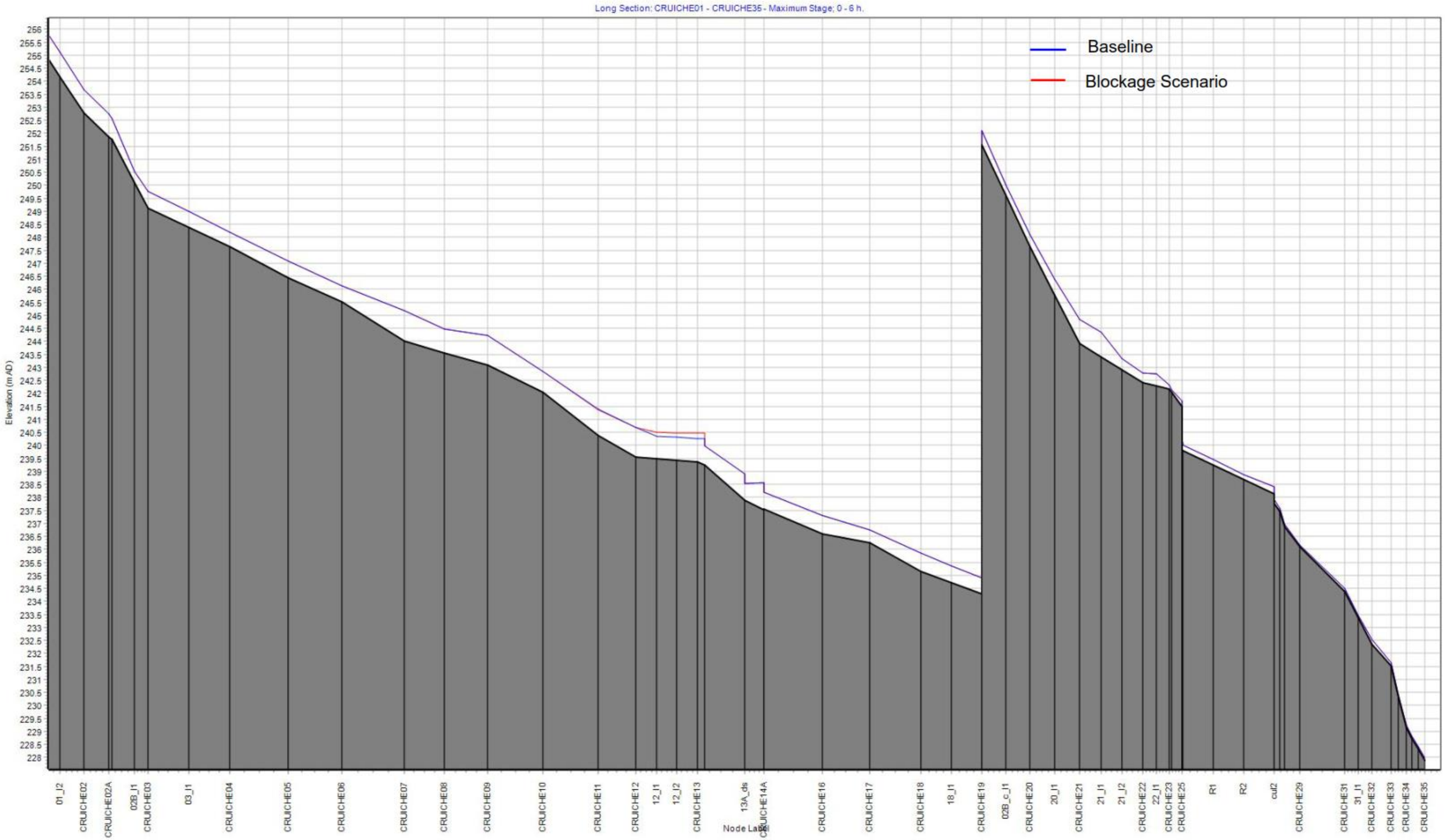


Figure 9-19: Modelled Long Section Sensitivity Results (Blockage Scenario)



9.6 Summary

9.6.1 Existing A9, B1952, farm access tracks and agricultural lands lie within the 0.5% AEP baseline floodplain. The bifurcation channel has negligible flow at its downstream reach for each of the return periods under baseline scenario.

9.6.2 The proposed A9 road lies within the 0.5% AEP plus climate change floodplain with no mitigation. Also, water levels in the floodplain increase in three locations with the scheme compared to the baseline.

9.6.3 Providing direct compensation storage would require a volume of up to 20,000 m^3 to be excavated and was therefore rejected given the indirect impacts and the lack of high sensitive receptors in this area. Indirect impacts include the removal of ancient woodland and associated landscape; the need to dispose of the excavated material either as fill or waste; and the impacts on the current land use (and access) are significant given the limited space for storage between the Allt na Criche and Bifurcation channel.

9.6.4 Mitigation option 3 (the inclusion of a shallow bund along the right bank of the bifurcation channel over the length of approximately 115m) eliminates the flooding of A9 and also negates the impacts of the proposed scheme in terms of increase in water levels at some locations.

9.6.5 The embankment eliminates the flooding of the A9 when the bifurcation channel overtops. It leads to a greater proportion of the 0.5% AEP flow being held in the bifurcation channel and spilling onto the left floodplain of the bifurcation channel.

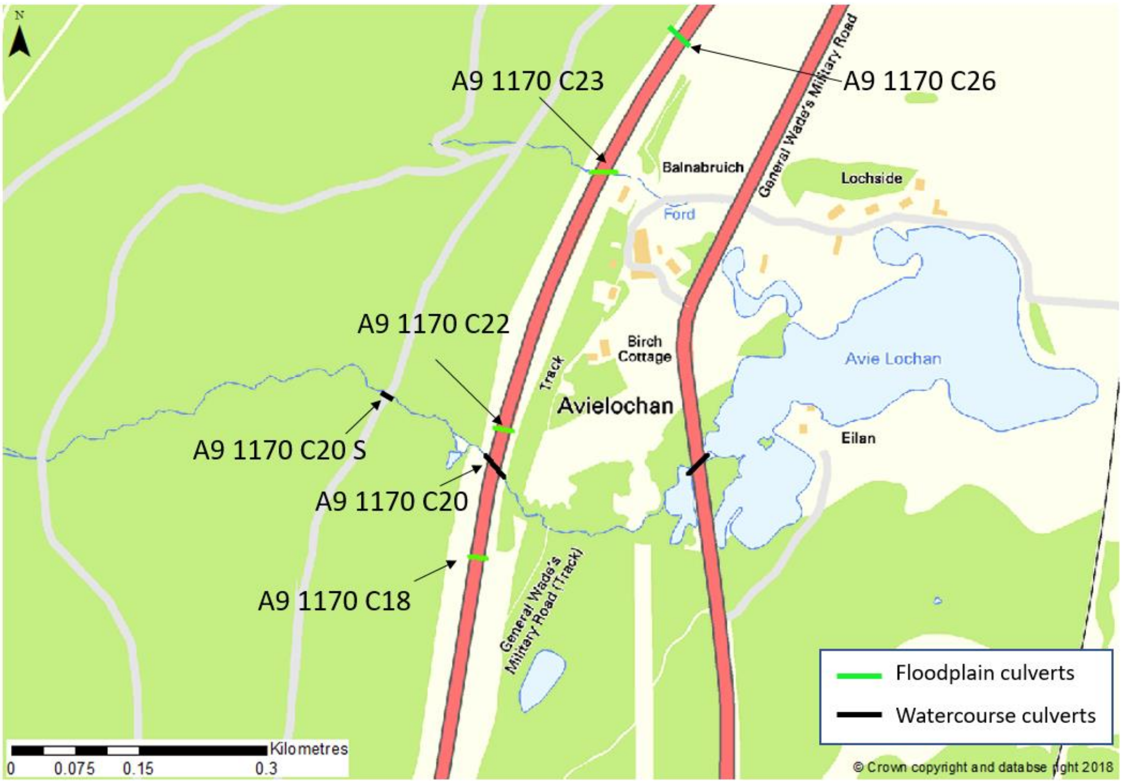
9.6.6 Water levels range from -0.06 to +0.05 with the change in Manning's roughness of +/-20%. The highest increase in water level is about 0.04m with the 20% additional flow. The model is relatively insensitive to the change in downstream boundary due to its steep slope. The 50% blockage in the A9 crossing raises the water levels locally in few cross-sections immediately upstream of the culvert.

10. Avielochan

10.1.1 Avielochan is located in Strathspey in central, northern Scotland within the Cairngorms National Park. The village is located south of Kinveachy and north of Granish. The settlement takes its name from the body of water Avie Lochan. It is located north of Aviemore, on the A9 road. The river reach modelled is approximately 1.7km long and flows in an easterly direction, discharging into Avie Lochan. The river crosses the A9 and the A95. The study area is provided in Figure 10.1 with structures that will be affected by the A9 scheme labelled. The culvert under the A9 on the Avielochan river is A9 1170 C20, there are a number of floodplain culverts to the north and south of this structure underneath the A9.

10.1.2 The hydraulic model was built using a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller (version 4.3), and the 2D component was constructed using TUFLOW (version 2016-03-AE).

Figure 10-1 Study Area



10.1.3 The data used to construct the baseline hydraulic model for the Avielochan river is summarised in Table 10.1

Table 10-1 Data used to build the baseline hydraulic model

Data	Description	Source
Topographic Survey November 2015	River cross-section data collected as part of A9 project	WSP (formerly Mouchel)
5m NEXTMAP	DTM covering entire study area	Transport Scotland
10m BLOM LiDAR	DTM covering part of study area only	Transport Scotland
BLOM topo	Surveyed contours and points covering part of the study area only	Transport Scotland

10.1.4 Hydrological analysis has been undertaken to derive design flow estimates as input to the hydraulic model developed for assessment. The Avielochan catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. Figure 10.2 shows the delineated catchment area for the Avielochan river, DS_WS_026.

10.1.5 The catchment areas extracted from the FEH CD-ROM were altered to reflect the surrounding topography. Details can be found in Table 10.2. Catchment descriptors were extracted from the FEH CD-ROM for delineating the catchment. An appropriate method for estimating peak flows for the catchment was chosen as shown in Table 10.2. The main inflow to the model for the DS_WS_026 catchment represents the main watercourse inflows (upstream boundaries) to the hydraulic model. In addition to this main inflow, one lateral inflow has been produced which has been applied to the model to represent additional flows generated over the catchment areas downstream of the main inflow location. The lateral inflow has been distributed along the Avielochan river reach.

Figure 10-2 Catchment area

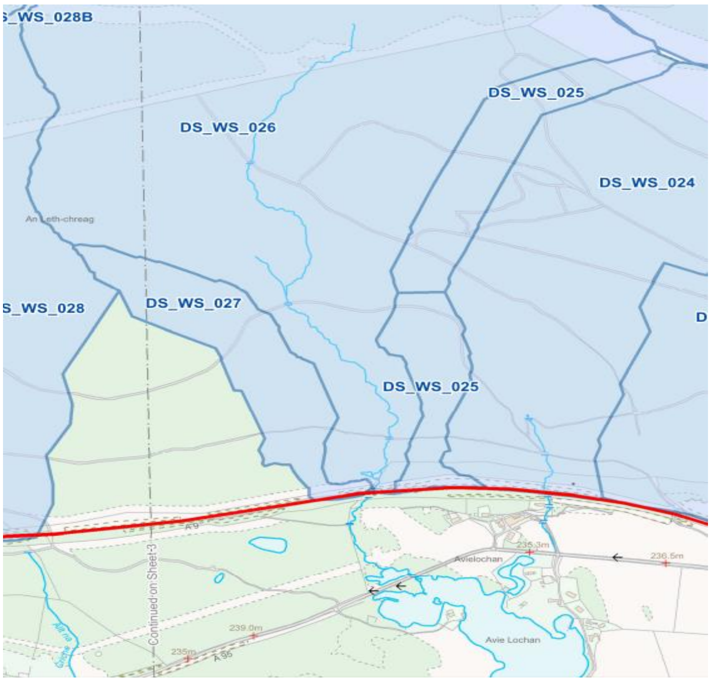


Table 10-2 Avielochan Hydrological Parameters

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Avielochan	DS026Areaadj	Upstream modelled extent of Avielochan	FEH Boundary	Rainfall Runoff	290300	815650	1.15
Lateral Flow	Lateral	Distributed along the river reach	FEH Boundary	Rainfall Runoff			1.63

10.1.6 Peak flows were calculated for each inflow using the FEH rainfall runoff method.

10.1.7 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events. The critical storm duration for the Avielochan model was set to 2.5 hours. Table 10.3 shows the peak flows. Hydrographs were generated using the FEH rainfall runoff method.

Table 10-3 Avielochan Peak Flow Estimates

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
Avielochan	DS026Areaadj		3.19 m^3/s	3.83 m^3/s
Lateral	Lateral		5.50 m^3/s	6.60 m^3/s

10.1.8 Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

10.1.9 Modelled events are summarised in Table 10.4.

Table 10-4 Modelled Events

Scenario	AEP					
	50%	20%	3.33%	0.5%	0.5%+CC	0.1%
Baseline	x	x	x	x	x	x
Roughness sensitivity				x		
Hydrological inflow sensitivity				x		
Downstream boundary sensitivity				x		
Model ‘with – scheme’	x	x	x	x	x	x
With-scheme and mitigation				x	x	

10.2 Baseline Hydraulic Model

Model assumptions and limitations

10.2.1 The downstream boundary of the hydraulic model is Avie Lochan and it has been assumed that the water level recorded on the day of the survey is a typical water level in the loch, this level has been applied at the downstream boundary of the 1D model and across the area of Avie Lochan in 2D. The sensitivity of the model results to the downstream boundary level has been tested.

10.2.2 Lateral inflows along the Avie Lochan modelled reach have been applied based on the increase in catchment area to each lateral inflow location.

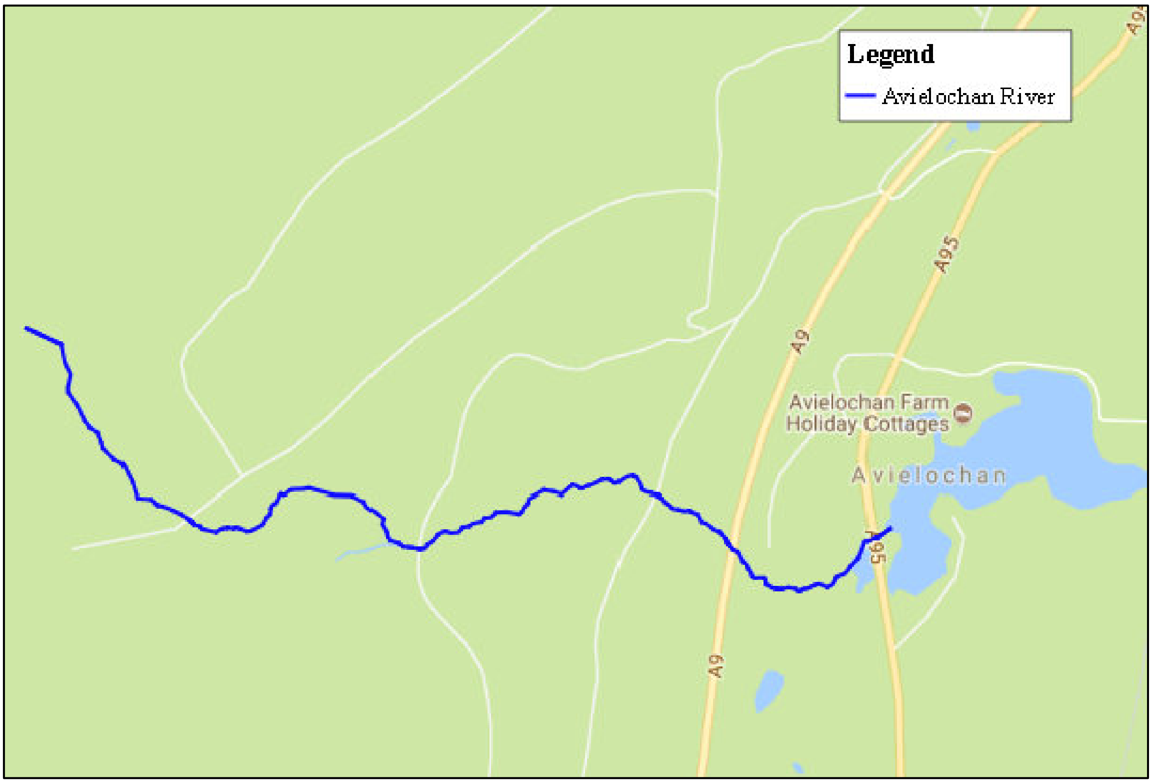
10.2.3 It has been assumed that the existing structures within the baseline model are free-flowing and no blockages have been included in the model.

10.2.4 It is assumed that the topographic survey used to define the river channels within the model accurately represents the geometry of the watercourses and that the interpolation between river cross-sections within the 1D model is acceptable.

In- channel geometry (1D)

10.2.5 The 1D model is based on topographic survey of river cross-sections collected on the Avielochan river. The extent of the watercourse represented in the 1D model is shown in Figure 10.3. This watercourse has not previously been modelled, therefore there is no SEPA flood map in the area.

Figure 10-3 Model Domain Extent



10.2.6 Table 10.5 below details the model extents and key features.

Table 10-5 Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of A9 Crossings	Total number of modelled structures
Avielochan	1698	289127.06, 816674.77	290478.69, 816406.85	1	6

10.2.7 A direct inflow hydrograph is applied at the upstream extent of the watercourse in the model. A lateral inflow is used in the river reach to distribute water along the watercourse. The downstream boundary of the model is a Head-Time (HT) boundary representing levels within Avie Lochan.

10.2.8 A model schematic showing the location of 1D cross-sections within the model can be found in Figure 10.4.

Figure 10-4 Schematic detailing cross section locations

10.2.9 The open channel river sections were defined from the topographic survey, with the Manning's 'n' values defined from the site visits, which were undertaken in July 2015. Table 10.6 provides the Manning's 'n' value ranges within the 1D model and justification of the values used.

Table 10-6 Manning's n roughness values in 1D model

Section Type	Minimum	Maximum	Commentary
River Channel	0.035	0.035	Representing fairly rough bed material. A consistent value has been used throughout the model to aid stability.
Structures	0.015	0.024	Ranging from smooth concrete to rougher concrete/stone materials.
Floodplain	0.045	0.05	(Chow, 1959).3.C.2 / 3 = "Light brush and trees in Summer / Winter"

In channel's hydraulic structures

10.2.10 All the structures and cross-sections were taken from the survey data. Table 10.7 provides the details of how the structures are represented within the model. Figure 10.5 shows the locations of these modelled structures. In total, there are 7 structures modelled in the 1D model and 2 structures modelled as floodplain culverts going underneath the A9 road.

Table 10-7 Modelled Structure Details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
AvLo_XS_003A AvLo_XS_004A	Culvert	Avielochan	Dia 0.5m Len 6.32m	Culvert, Conduit	
AvLo_XS_007A AvLo_XS_007A	Culvert	Avielochan	Dia 0.45m Len 6.16m	Culvert, Conduit	
AvLo_XS_0013A AvLo_XS_0013A	Culvert	Avielochan	Dia 1.5m Len 5.84m	Culvert, Conduit	
AvLo_XS_017 AvLo_XS_017A	Weir	Avielochan	Level 257.23m	Weir, spill unit	
AvLo_XS_017B AvLo_XS_018A	Culvert	Avielochan	Dia 1.5m Len 20.26m	Arch Bridge	
AvLo_XS_022A AvLo_XS_022B	Footbridge	Avielochan	Len 1.53m	Arch Bridge	

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
AvLo_XS_033A AvLo_XS_033B	Rectangular Culvert	Avielochan	Width 0.84m H 1m, L 15.37m	Culvert, Conduit	

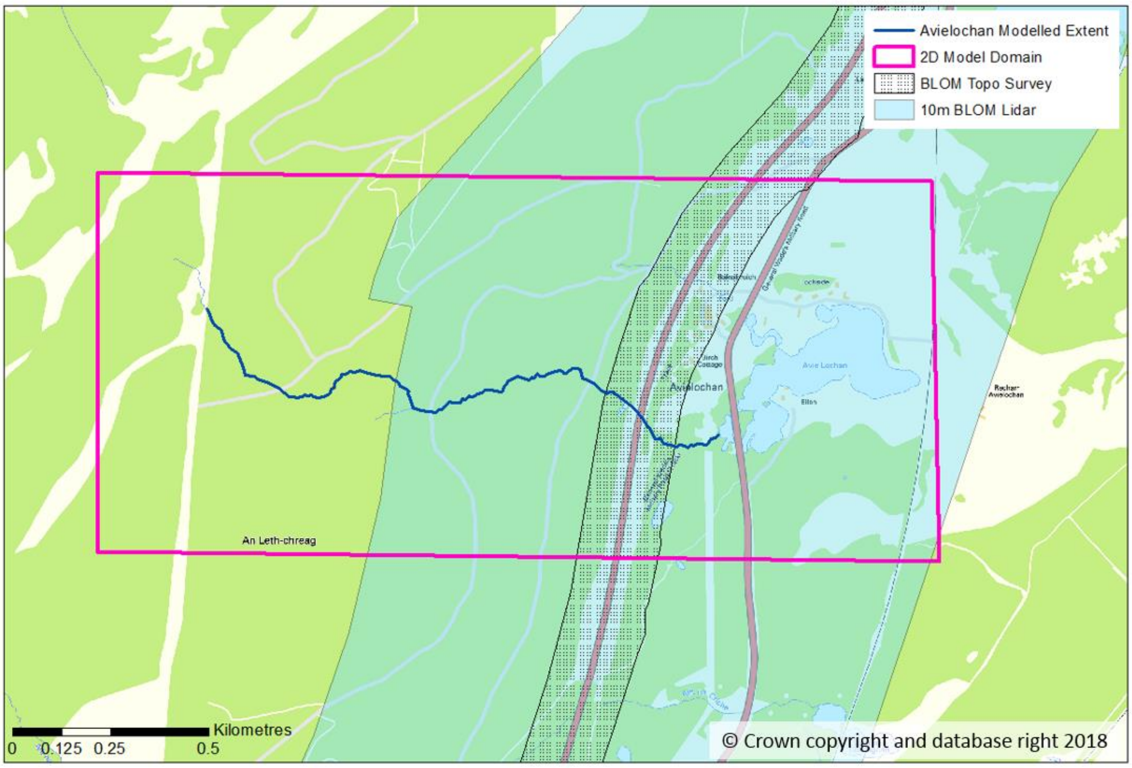
Figure 10-5 Location of the structures in Avielochan Model

Flood plain schematisation – 2D domain

Floodplain topography

10.2.11 A key component of any 2D model is the detailed ground model. The data used for the model were the Nextmap 5m DTM, 10m BLOM Lidar and the BLOM Topo Survey data for the A9 Dualling Corridor. The 2D component of the TUFLOW model was constructed mainly using a mosaic of these three terrains. The 5m DTM is extended enough to cover the whole area of interest, but the accuracy doesn't cover small watercourses and drains. The two sets of BLOM data include more detail but they don't cover all the area of interest. Figure 10.6 shows the extents of each dataset section as well as the 2D domain extent within the model.

Figure 10-6 Terrain Data Coverage



Floodplains' hydraulic structures

10.2.12 The 2D model has two hydraulic structures, which are culverts underneath the A9 on the floodplain. The culverts are located to the north and south of the Avielochan river. These floodplain structures are represented in ESTRY, the 1D component of TUFLOW as they represent the flow of water underneath a structure in the floodplain.

Floodplain hydraulic friction

10.2.13 Floodplain hydraulic friction varies according the land use types across the study area and this has been represented in the model by varying Manning's 'n' roughness values across the 2D domain depending on the features represented. The majority of the floodplain represented in the model covered with dense forest. Table 10.8 shows the Manning's 'n' roughness values that have been applied within the 2D domain to represent different land use types on the floodplain.

Table 10-8 Floodplain Manning's 'n' roughness values

Land Use	Manning's 'n' value	Commentary
Green grass	0.045	Used to represent land area covered with grasses
Dense trees	0.06	Used to represent forested areas
Water	0.035	Used to represent the water body areas, i.e., ponds, lakes etc.
Roads	0.02	Used to represent smoothness of tarmac

Boundary conditions

10.2.14 The 2D model domain has been sized to be large enough to contain the largest flood extent modelled (0.1%), therefore 2D boundaries are not required within the model. Although the downstream extent of the 1D model is where the Avielochan river flows into Avie Lochan, the 2D model extends east beyond this and includes the loch and its predicted flood extent completely meaning a downstream boundary is not required in 2D.

1d/2d Linking

10.2.15 The 1D and 2D components of the model have been linked using the HX approach where the water levels in the 1D model are applied along the banks of the channel represented in 1D. When water levels are high enough to overtop the bank top level in 1D, water is transferred to the 2D domain. The HX boundaries are two-way meaning that water from the 2D floodplain model can flow into the 1D channel model as well. The whole extent of 1D watercourses represented in the model is linked to the 2D domain using this method.

10.2.16 An SX line is also used in the model to transfer water from the downstream extent of the 1D model into the 2D domain at Avie Lochan to represent water discharging from the watercourse into the loch.

Model Proving

10.2.17 There are no gauges within the modelled extent, therefore it has not been possible to calibrate the model developed for this area. In order to determine how robust the model is and to understand the uncertainty in the model results, a suite of sensitivity tests have been undertaken on the baseline model.

Model performance

10.2.18 The model is stable in both 1D and 2D. Figure 10.7 shows the runtime output from Flood Modeller for the 0.5% AEP baseline model and shows the model convergence graph, there are small instances of poor convergence but review of the 1D model showed that this does not have an impact on the results. Figure 10.8 shows the cumulative mass balance error in the 2D domain throughout the 0.5% AEP baseline model run. Over the entire model simulation, the mass balance error is within the acceptable range (+/- 1%).

Figure 10-7 Flood Modeller routine information - 0.5% AEP baseline model

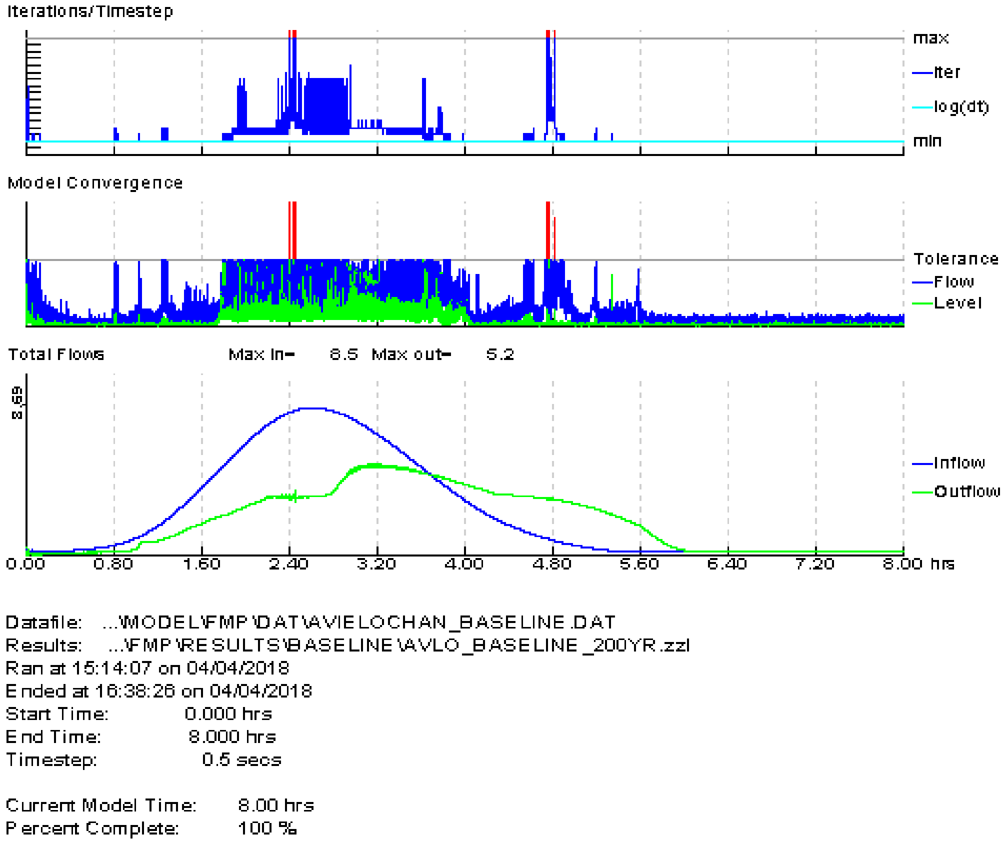
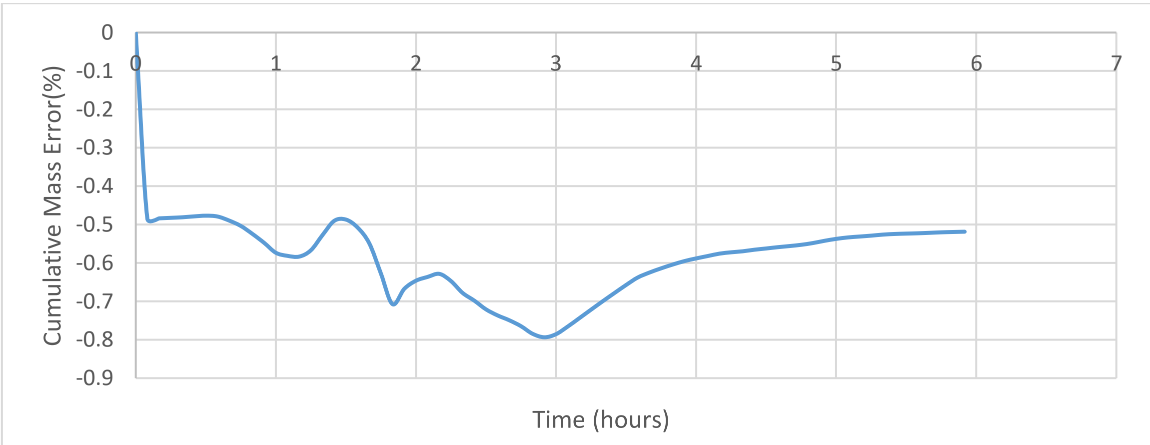


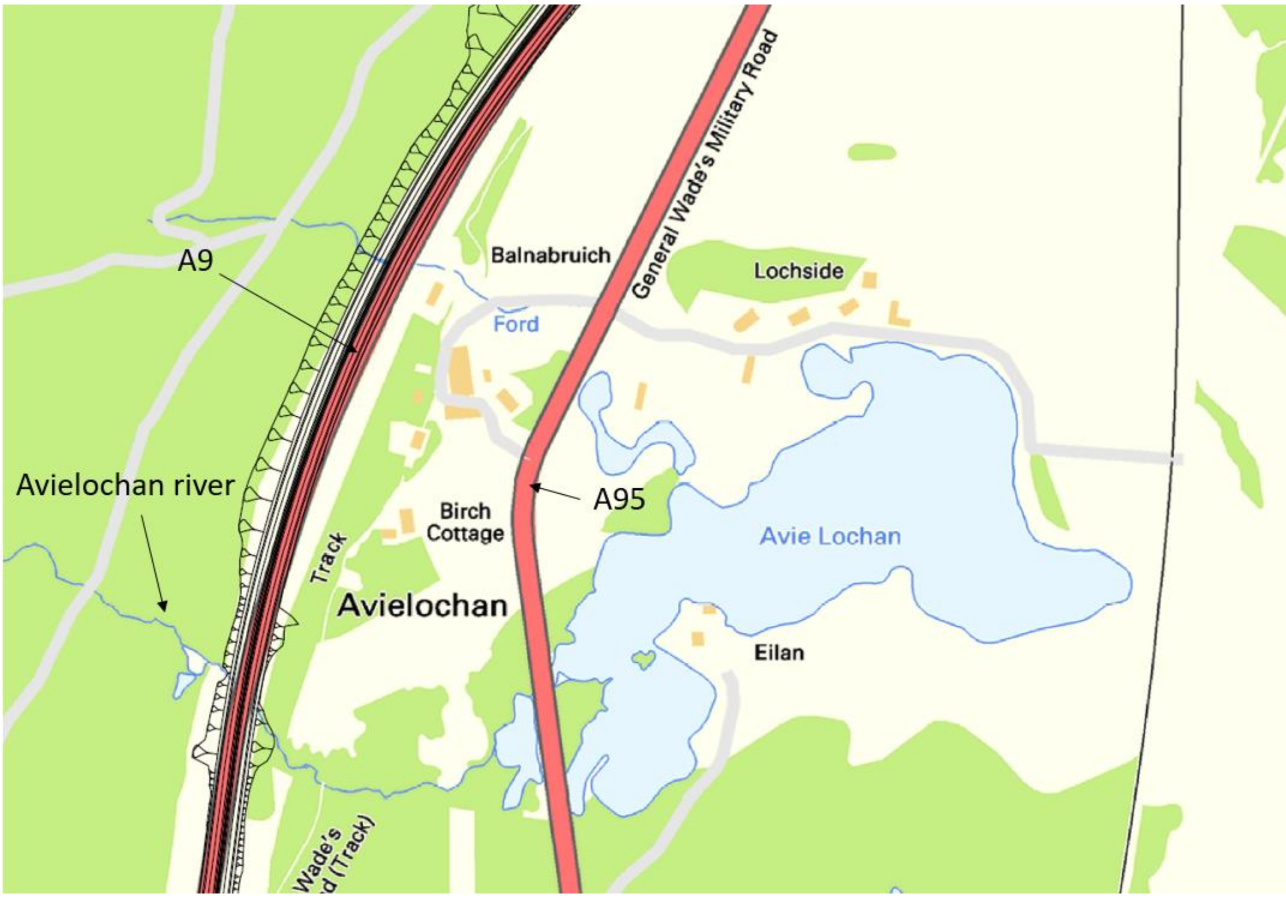
Figure 10-8 TUFLOW cumulative mass balance error – 0.5% AEP baseline model



10.3 Proposed Model ('with-scheme' modelling)

10.3.1 The proposed A9 alignment in the vicinity of Avielochan consists of a wider highway. Figure 10-9 shows the proposed alignment. The scheme also involves changes to the culverts under the A9, this is discussed below.

Figure 10-9 Proposed Alignment Plan



Modelling approach

1D model updates

10.3.2 To create the proposed (with-scheme) version of the 1D model, the existing culvert on the Avielochan river underneath the A9 (A9 1170 C20) was changed to represent the proposed culvert. The existing culvert is a 1.5m diameter circular culvert, this is being replaced by a 1.8m x 1.2m rectangular culvert to meet design standards and fit within the constraints of the proposed alignment and levels. This size ensures that sufficient freeboard is maintained and the A9 remains operable during the 0.5%AEP plus CC event.

10.3.3 The culvert upstream of the A9 on the Avielochan river underneath a side road (A9 1170 C20 S) will also be replaced as part of the scheme. The existing side road culvert is a 1.5m diameter circular culvert and this will be replaced with a standard 1.2m x 1.2m box culvert. The culvert under the A95 will not be changed as part of the scheme. Channel works are also proposed upstream and downstream of both new culverts on the watercourse, these have been represented in the proposed (with-scheme) model. The channel works involve re-grading the channel and a small diversion upstream of the A9 to accommodate the wider road and new culvert.

2D model updates

10.3.4 In the 2D model, representation of the proposed A9 scheme has been included in the 2D domain by raising the elevation of the road and widening it. Furthermore, the 2D roughness values applied along the A9 corridor have been updated to represent the widening of the road. The road levels and embankment data are represented as an ASCII file for the exact representation of the data, which is read in after the base DTM.

The two floodplain culverts that were included in the baseline model have been removed from the proposed (with-scheme) model as it is proposed that they will be demolished as part of the scheme.

Model performance

10.3.5 The model is stable in both 1D and 2D. Figure 10-10 shows the runtime output from Flood Modeller for 0.5% AEP proposed model, there is only one spike of poor convergence. Figure 10-11 shows the cumulative mass balance error in the 2D domain throughout the 0.5% AEP proposed model run. There is a spike in the cumulative mass error around 1.8 hours where the mass error is outside of the acceptable +/-1% range but the peak is 1.01% and is not sustained. The mass error is within the acceptable range throughout the rest of the model run.

Figure 10-10 Flood Modeller runtime information – proposed (with scheme)

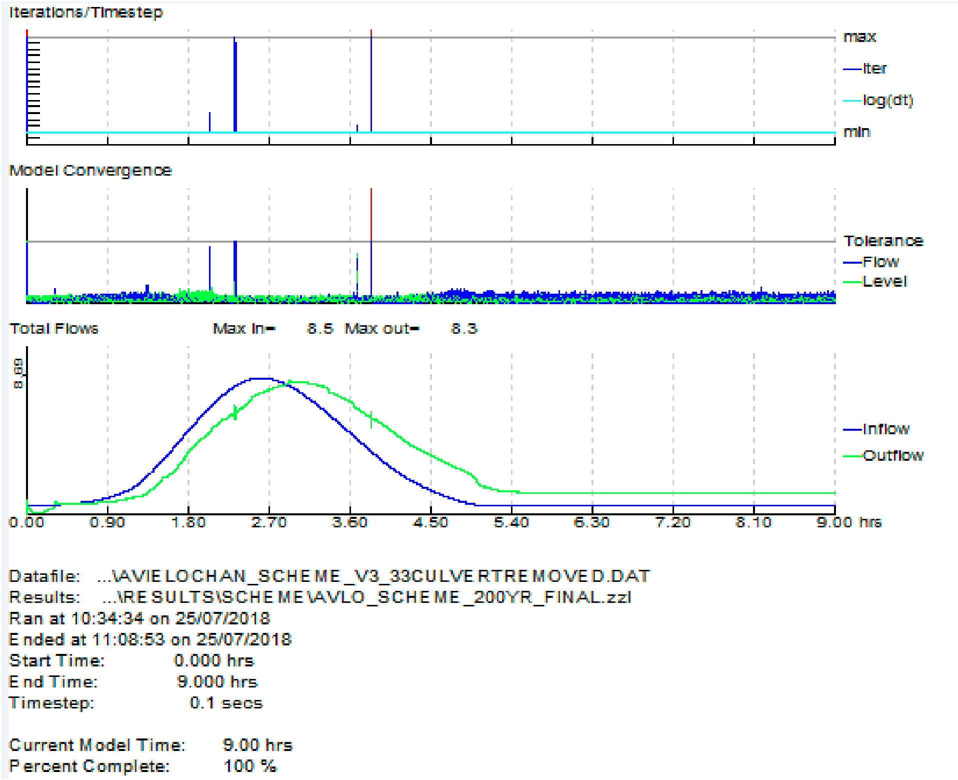
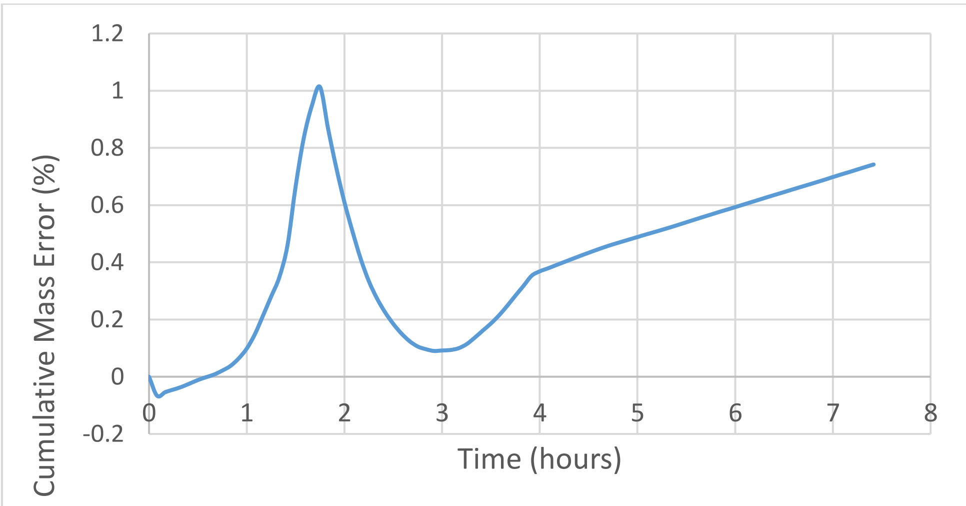


Figure 10-11 TUFLOW cumulative mass balance error – proposed (with scheme)



10.4 Proposed Model + mitigation measures ('with-scheme + mitigation measure' modelling)

10.4.1 The proposed (with-scheme) model does not predict flooding to the A9 during the 0.5% AEP event, therefore it has not been necessary to include mitigation for flooding at Avielochan as part of the A9 scheme.

Modelling Results Analysis

Baseline scenario

10.4.2 The baseline flood extent shows that currently during a 0.5% AEP event, the A9 is predicted to flood where the Avielochan river crosses the road. The topography is very steep in the area and water flows over the floodplain from upstream, across the road and towards Avie Lochan. There is no flow through the floodplain culverts in the model as the predicted flood extent does not extend to these locations during the 0.5% AEP event.

Comparison of Baseline and Proposed model ('with-scheme') results

10.4.3 The results of the 0.5% AEP proposed (with-scheme) model have been compared to the baseline model to determine the impact of the scheme on flood risk within the catchment and ascertain the need for mitigation. Figure 10-12 shows a comparison of the baseline and proposed (with-scheme) predicted flood extents for the 0.5% AEP event. Figure 10-12 shows that the flood extent is reduced overall for the proposed (with-scheme) model compared to the baseline as the proposed A9 acts as a barrier to flooding and conveyance has been improved in the channel through channel works and improved culverts. Immediately upstream of the A9, water levels on the floodplain to the north and south of the watercourse are increased by up to 30mm. However, in the area of flooding immediately west of the A95, water levels are reduced by up to 1m in the proposed (with-scheme) scenario compared to the baseline scenario.

10.4.4 Table 10-9 shows the impacts of the proposed (with-scheme) scenario at key receptors within the catchment compared to the baseline scenario. Both the A9 and the A95 are predicted to flood in the baseline scenario and are not predicted to flood in the proposed (with-scheme) scenario for the 0.5% AEP event, therefore the impact on these receptors is major beneficial. Neither road is predicted to flood in the 0.5% plus climate change event either. As the extent of flooding on the Forestry Commissions' land upstream of the A9 is reduced, there is a beneficial impact here too. The grassland between the A95 and A9 also sees a reduction in flooding with the scheme in place.

10.4.5 Tables 10-10 and 10-11 show the changes in flow and stage respectively between the baseline and proposed (with-scheme) models. Flows are increased in the Avielochan channel with the scheme in place due to improvements to the channel, which allow more water to be contained in the channel (leading to the reduction in flooding seen). The capcity of the culvert underneath the A9 has also been increased allowing more water to stay in channel. There is some increase in water levels within the channel but it is not as pronouced as the increase in flows as the channel is steep and therefore velocities remain high.

10.4.6 Replacing the existing culverts A9 1170 C20 and A9 1170 C20S increases the peak flows in the AvieLochan river. However, there is no increase in the downstream floodplain (Figure 10-12).

Figure 10-12 Comparison of baseline and proposed (with-scheme) modelled flood extents

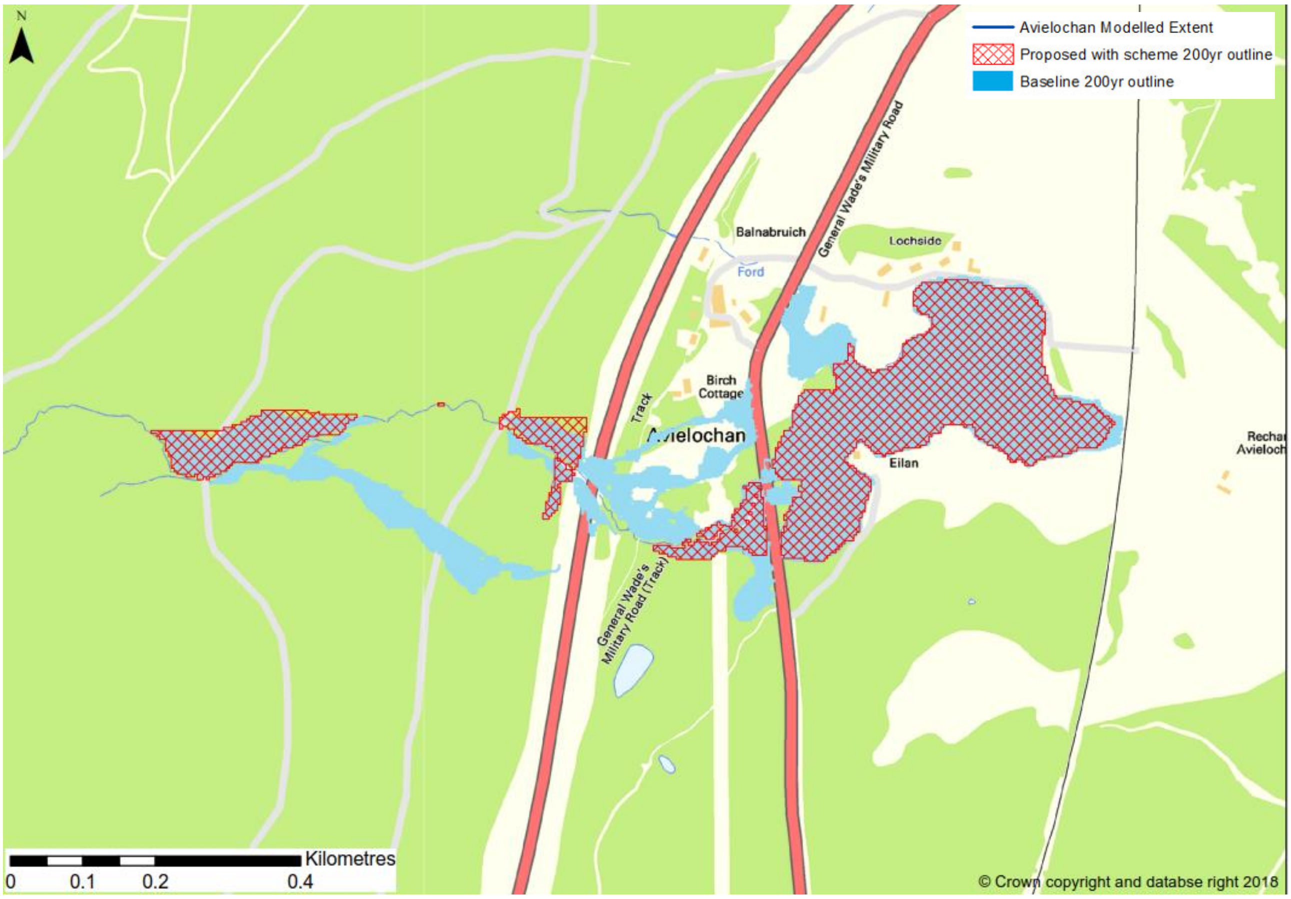


Table 10-9 Magnitude of impact on water levels between baseline and proposed (with-scheme) scenarios

Floodplain	Receptor	Location (NGR)	Sensitivity	Magnitude	Impact
Avielochan	A9	290227 816405	Very High	Major Beneficial	Very Large Benefit
	A95	290470 816403	Very High	Major Beneficial	Very Large Benefit
	Forestry Commission Land	289926 816387	Medium	Minor Benefit	Slight Beneficial
	Grassland and scrub	290269 816371	Low	Minor Benefit	Neutral

Table 10-10 Comparison of Baseline and Proposed Flows (m3/s) for comparative model cross sections

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
Cross section	Q1000	Q1000	Q200+CC	Q200+CC	Q200	Q200	Q30	Q30	Q5	Q5	Q2	Q2
AvLo_XS_001	4.70	4.70	3.83	3.83	3.19	3.19	2.070	2.070	1.33	1.33	0.93	0.93
AvLo_XS_009	4.28	6.54	4.17	6.13	4.07	5.35	3.33	3.84	2.48	2.79	1.85	2.06
AvLo_XS_011	10.19	11.13	7.84	8.61	7.05	7.27	4.63	4.67	2.97	3.17	2.07	2.14
AvLo_XS_022	11.74	12.32	8.64	9.56	8.34	8.97	5.52	5.21	3.31	3.54	2.32	2.43
AvLo_XS_033	6.03	12.53	5.88	9.61	5.16	9.02	3.30	5.67	2.83	4.05	2.07	2.60

Table 10-11 Comparison of Baseline and Proposed Stage (m) for comparative model cross sections

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
Cross section	Q1000	Q1000	Q200+CC	Q200+CC	Q200	Q200	Q30	Q30	Q5	Q5	Q2	Q2
AvLo_XS_001	435.52	435.62	435.42	435.48	435.42	435.43	435.35	435.33	435.25	435.23	435.19	435.17
AvLo_XS_009	322.48	322.56	322.42	322.47	322.39	322.44	322.32	322.36	322.27	322.27	322.20	322.20
AvLo_XS_011	283.85	283.94	283.78	283.93	283.76	283.86	283.61	283.63	283.47	283.48	283.37	283.38
AvLo_XS_022	245.57	245.95	245.41	245.89	245.22	245.73	244.97	244.94	244.78	244.80	244.71	244.71
AvLo_XS_033	234.13	234.47	234.07	234.42	234.01	234.28	233.77	234.06	233.70	233.87	233.58	233.67

Sensitivity Analysis

10.4.7 To analyse the sensitivity of the proposed hydraulic model, 5 sensitivity tests have been run on the baseline model. These aim to test how sensitive the models are to variable parameters and scenarios. The following tests were run on the baseline model.

- Global roughness + / - 20%
- Flow + 20%
- Downstream Boundary +/ - 20%

10.4.8 Table 10.12 below shows the variation in flow between the baseline model and each of the sensitivity results for the 0.5% AEP event. Variation is given in m^3/s. Table 10.13 shows the variation in stage between the baseline model and each sensitivity test. Figures 10.13-10.15 show long-sections of water level in the model comparing the baseline and sensitivity test results, these figures show that none of the sensitivity tests have a significant impact on water levels in the Avielochan channel.

Table 10-12 Variation in flow for sensitivity tests

	Sensitivity tests Q200 Variation in Flow (m3/s)					
	Baseline	Man +20% Global	Man - 20% Global	Q +20%	DSB + 20%	DSB - 20%
Cross Section	Q200	Q200	Q200	Q200	Q200	Q200
AvLo_XS_001	3.188	3.188	3.188	3.831	3.188	3.188
AvLo_XS_009	4.073	3.623	4.868	4.165	4.071	3.956
AvLo_XS_011	7.052	7.015	7.116	7.842	7.068	7.046
AvLo_XS_022	8.342	7.746	8.133	8.635	8.133	8.870
AvLo_XS_033	5.159	5.036	4.541	5.877	4.274	4.851

Table 10-13 Variation in stage for sensitivity tests

	Sensitivity tests Q200 Variation in stage (m)					
	Baseline	Man +20% Global	Man - 20% Global	Q +20%	DSB + 20%	DSB - 20%
Cross section	Q200	Q200	Q200	Q200	Q200	Q200
AvLo_XS_001	435.423	435.462	435.385	435.423	435.423	435.423
AvLo_XS_009	322.392	322.395	322.378	322.416	322.393	322.391
AvLo_XS_011	283.757	283.807	283.695	283.784	283.757	283.756
AvLo_XS_022	245.216	245.322	245.325	245.412	245.268	245.223
AvLo_XS_033	234.009	233.990	234.072	234.067	234.429	233.972

Figure 10-13 Modelled Long Section Sensitivity Results (Global Roughness)

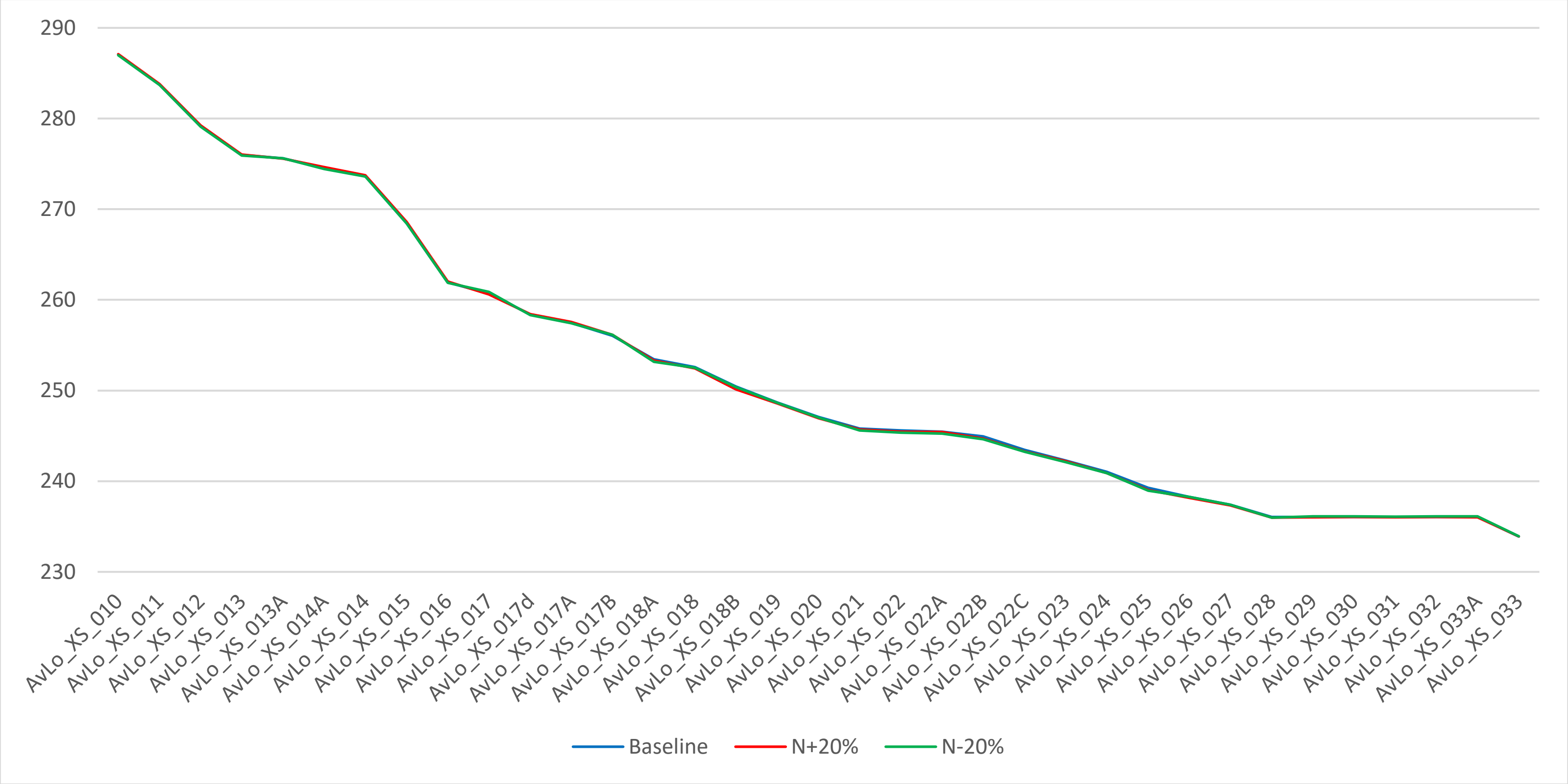


Figure 10-14 Modelled Long Section Sensitivity Results (Flow Variation)

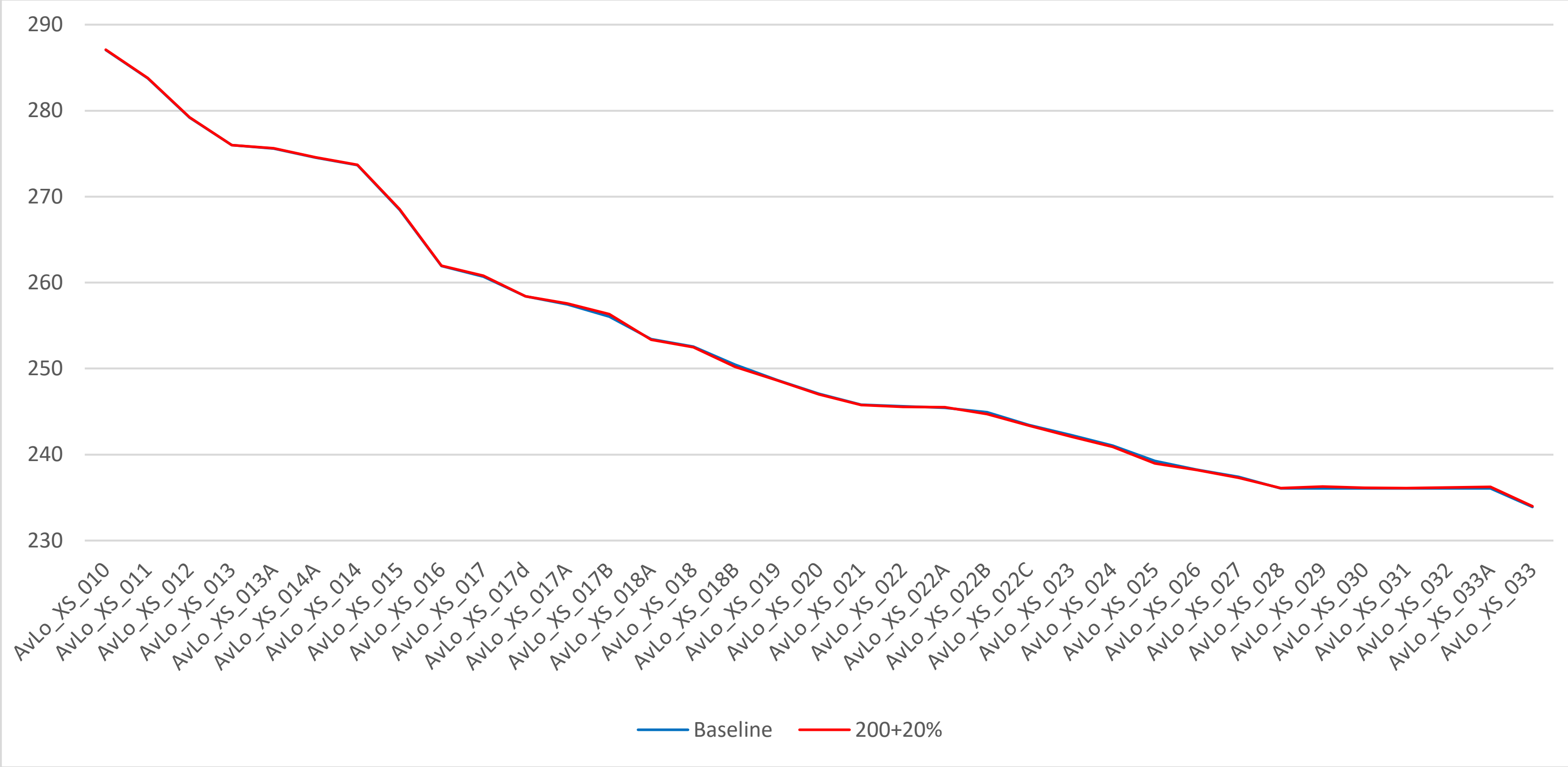
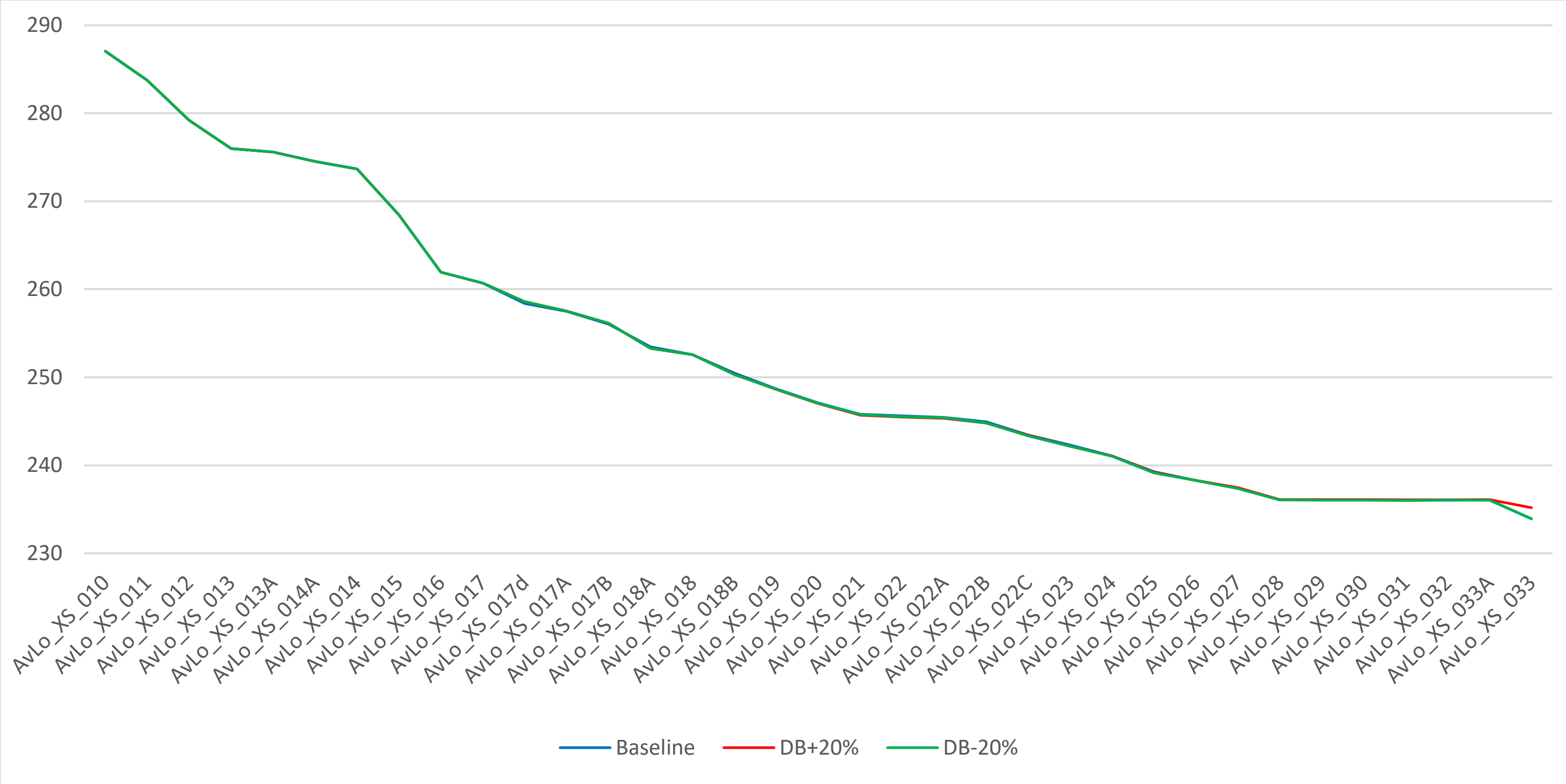


Figure 10-15 Modelled Long Section Sensitivity Results (DSB variation)



10.5 Summary

10.5.1 A model has been developed to determine the current level of flood risk upstream of Avie Lochan from the Avielochan river. The model has been used to test the impact of the proposed A9 dualling scheme on flood risk in the area. The model complies with SEPA's currently modelling standards (v1.1, 2015) and is stable. Sensitivity testing has been undertaken to understand the impact of a number of parameters on the model results.

10.5.2 The testing undertaken has shown that the model is suitable for use in this assessment and has therefore been used to determine that mitigation is not required at this location as part of the A9 dualling scheme.

10.5.3 The A95 road is downstream of the A9 1170 C20 S and C23 and has a sensitivity of Very High. Vegetation is mixed woodland and there are no flood risk receptors between the A9 and the A95. There are a number of holiday cottages and caravans situated around the loch downstream of the A95. The proposed main alignment culvert A9 1170 C23 has been sized to ensure that flood risks to this Very High sensitive receptor does not increase. The culverts were included include in the floodplain assessment for this area to assess the impact of loss of floodplain storage and to ensure that the risk to all receptors remains unchanged.

10.5.4 Modelling has shown that the A9 and A95 receptors are within the 0.5% AEP baseline floodplain but not the with-scheme floodplain. Mitigation is not therefore required.

11. Allt Cnapach

11.1.1 The Allt Cnapach is a small stream having its source from the north face of Beinn Ghuilb, its course to Kinveachy where it spreads is easterly. A stream running through the woodland. The gradient upper course is steep and the river channel is narrow.

11.1.2 The River Allt Cnapach primarily flows as an open channel through a study area with bridges and culverts beneath a number of roads in the area as shown in Figure 11.1.

11.1.3 Model extents were carefully selected to ensure that the model boundaries did not have any impact on the flood extent in the area of interest.

11.1.4 The hydraulic model was built using a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller (version 4.3), and the 2D component was constructed using TUFLOW (version 2016).

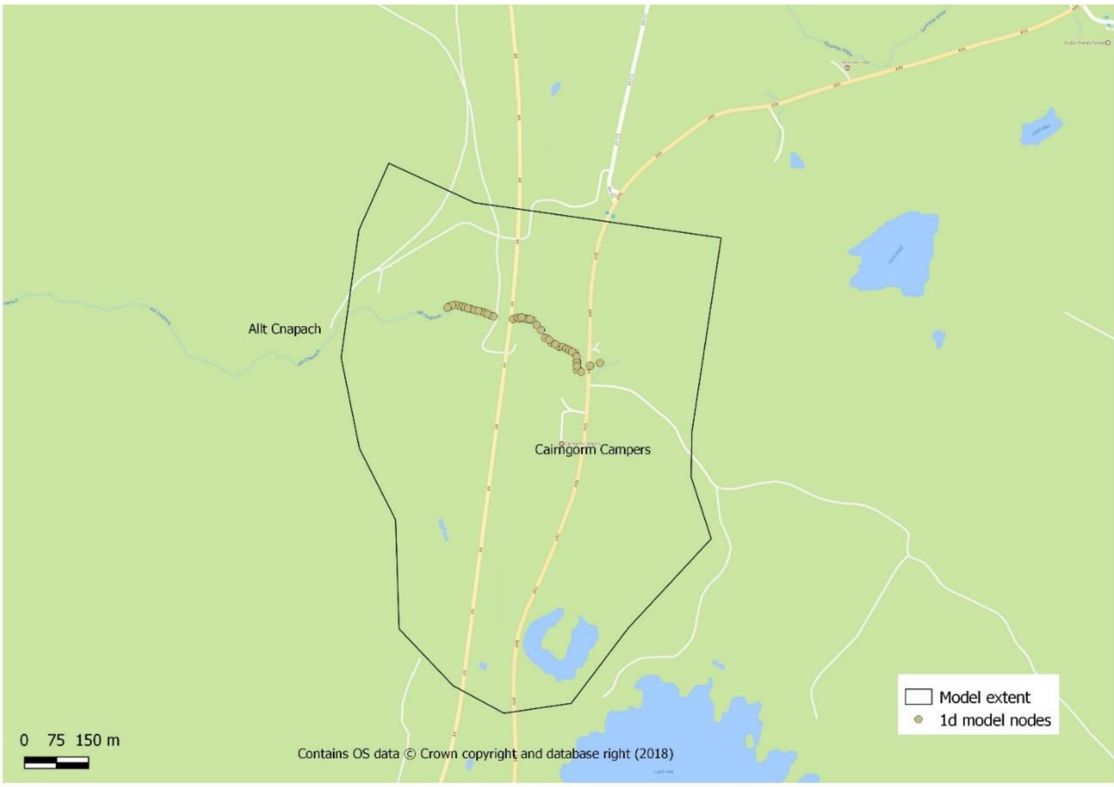
11.1.5 River channels for watercourses are defined using surveyed watercourse cross sections undertaken in 2017 for the 1D element as illustrated by Figure 11.1. River's banks are defined as lateral spills using either survey or LiDAR data. The spills define the linkage from the open channel 1D domain to the 2D domain.

11.1.6 The addition of panel markers was used to ensure that the conveyance increases monotonically with increasing water level

11.1.7 The model was run under a baseline scenario (existing situation) to simulate fluvial flooding associated with series of storm events with the following Annual Exceedance Probabilities (AEP): 50%, 20%, 10%, 4%, 3.3%, 2%, 1.33%, 1%, 0.5%, 0.5% +CC and 0.2%.

11.1.8 The hydraulic model has been constructed to provide an awareness of existing flood risk to inform the Proposed Scheme design. The detail included identifies potential impacts of the Proposed Scheme on surrounding land, and to ensure that design criteria are met.

Figure 11-1 River Allt Cnapach study area



11.1.9 The data used to construct the baseline hydraulic model for the River Allt Cnapach is summarised in Table 11.1.

Table 11-1. Data used to build the baseline hydraulic model

Data	Description	Source
Cross section surveyed data	2017	WSP
Lidar Digital terrain model (DTM) 2m resolution	2016	Transport Scotland
Ordnance Survey maps	Background maps and Master Maps data	Ordnance Survey
Watercourses photographs	From survey 2017	WSP
Hydrological analysis	2017	WSP/ATKINS
Site visit notes and photos for drain 8 inspections	2017 and 2018	WSP

11.1.10 The River Allt Cnapach catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment areas were altered to reflect the surrounding topography and are shown in Figure 11.2.

11.1.11 Applying a distributed model, the catchment was subdivided into 6 catchments to take account of the small channels and any lateral inflows. Figured 11.2 shows the hydrological model schematic, with Table 11.2 detailing the delineated catchment areas.

Figure 11-2. Catchment area

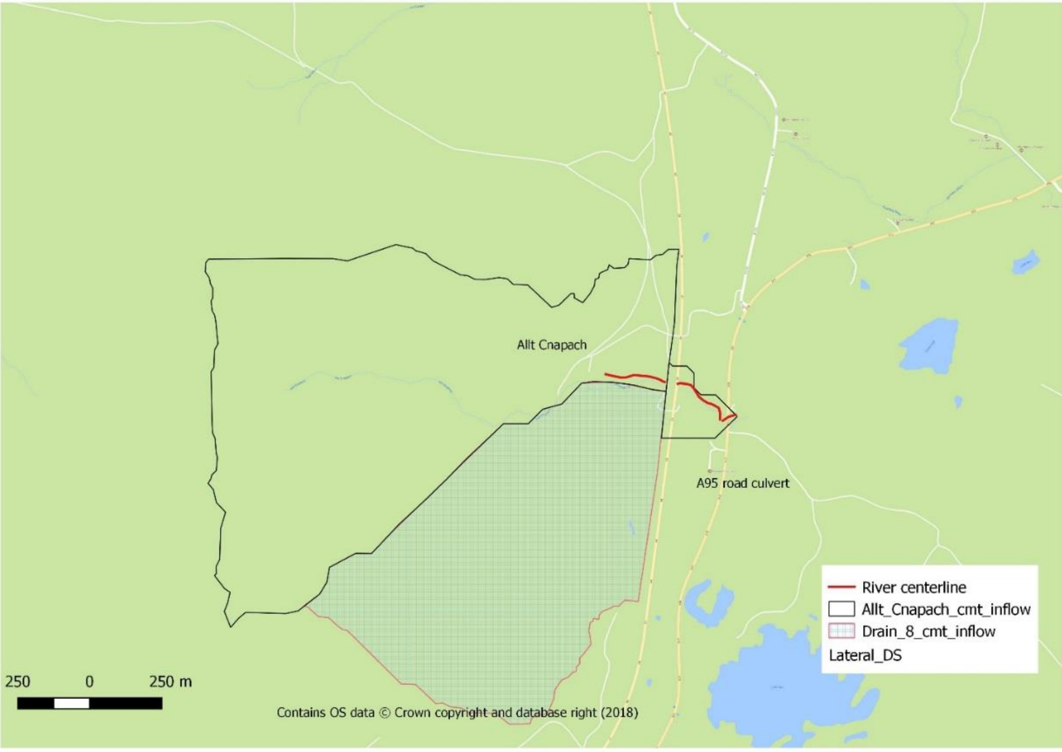


Table 11-2. River Allt Cnapach Hydrological Estimation points

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
River Allt Cnapach	DS-WC-032	291036 818515	Direct	FEH	289300	822400	151.29
Drain 8		291036 818515	Lateral	FEH	289350	822450	16.96

11.1.12 Flows have been estimated for the FEH catchment. The boundary has been checked against OS maps, but not amended to tie in with the Stage 2 catchments.

11.1.13 There are likely to be some changes to the drainage design in this area.

11.1.14 The flows have been estimated for the FEH catchment, and can be updated if additional areas of the catchment are to be drained under the A9 at the location of the Allt Cnapach watercourse.

11.1.15 FEH rainfall-runoff is recommended (this is the same approach as for most of the study catchments). The flows are highest and therefore most conservative.

11.1.16 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events. The critical storm duration was set as 2.3 hours. Table 11.3 shows the peak flows.

Table 11-3. Peak Flow Estimates (m^3/s)

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
River Allt Cnapach	DS-WC-032^	291036,818515	3.976	4.771
Drain 8		291036,818515	2.76	3.312
Lateral_DS		291113,818509	0.143	0.172

11.1.17 The River Allt Cnapach assessment point in Table 11.3 differs to the assessment point for the 1D crossing at DS-WC-032. The inflow location is US of the crossing location and therefore, the flow is lower than that estimated within the 1D hydrological analysis.

11.1.18 Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

11.1.19 Hydrographs were generated from the Rainfall Runoff method, with the storm duration optimised within the hydraulic model.

11.1.20 Modelled events are provided in Table 11.4.

Table 11-4. Modelled Events

Scenario	AEP										
	50%	20%	10%	4%	3.3%	2%	1.33%	1%	0.5%	0.5%+CC	0.2%
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Roughness sensitivity									✓		
Hydrological inflow sensitivity									✓		
Downstream boundary sensitivity									✓		
Model 'with – scheme'					✓				✓		

11.2 Baseline Hydraulic Model

11.2.1 The baseline hydraulic model was built using the November 2017 survey data. The details for the structures and other topography details were also provided in the survey.

Model assumptions and limitations

11.2.2 The accuracy and reliability of the model results is heavily dependent on the accuracy of the hydrological and topographical data utilised in the model. While the most appropriate up to date information has been used to build the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

11.2.3 The key sources of uncertainty in the model in addition to the limitations associated with the model are:

- The LiDAR data horizontal resolution used at 2m. As a result, small features such as small drains, kerbs heights might not be represented accurately within the model.
- There are uncertainties in how accurately LiDAR reflects the topography of the area. It has been assumed that existing LiDAR o be correct as no other information is available.
- The accuracy of the hydrological data utilised in the model
- The lack of survey for small water features such as drains
- Channel roughness has been assigned using the best available information such as site visit photos, survey data and aerial photographs
- Calibration has not been able to be carried out due to a lack of available data

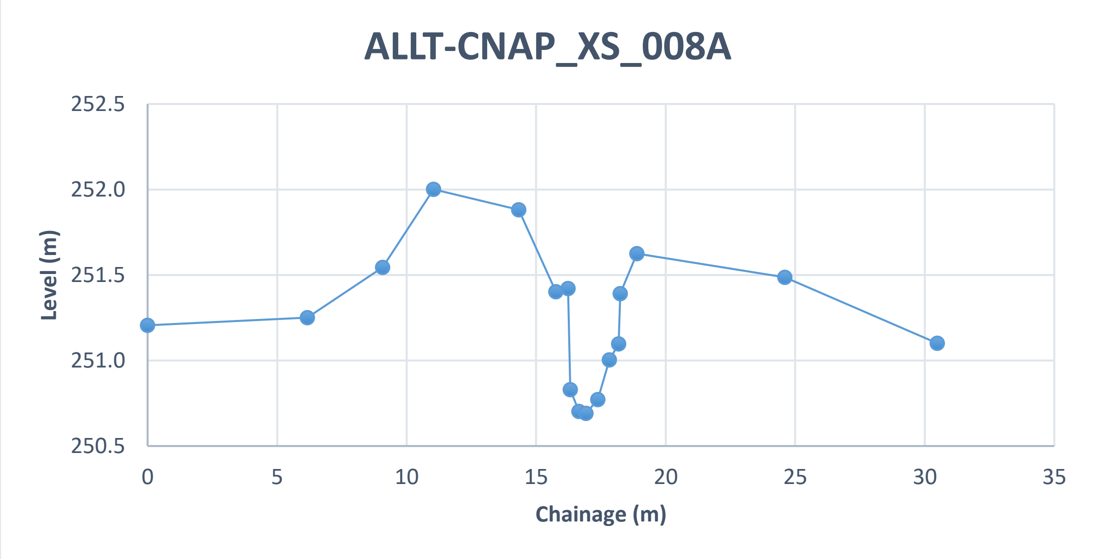
11.2.4 Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process.

In- channel geometry (1D)

11.2.5 Surveyed river cross-section data has been used to inform the in-channel geometry of the modelled watercourses. The locations of the 2017 surveyed river sections are shown in Figure 11.3 and Figure 11.4 represents a typical surveyed cross-section. Both the right and left banks go steep into the floodplains

Figure 11-3. Survey location

Figure 11-4. Typical surveyed cross-section



Model Extent

11.2.6 The model extends 200m upstream of A9 highway at OSNGR (291023.65 818519.83) and 300m downstream of A9 highway at OSNGR (291269.32 818404.84). The river crosses A9 side road culvert at OSNGR (291009.13 818526.21) and A95 highway at OSNGR (291215.16 818389.65). Drain 8 meets the main channel at OSNGR (291068.41 818513.02) via circular culvert of dimension 0.5m passing beneath A9 mainline.

11.2.7 Table 11.5. below details the model extents and key features.

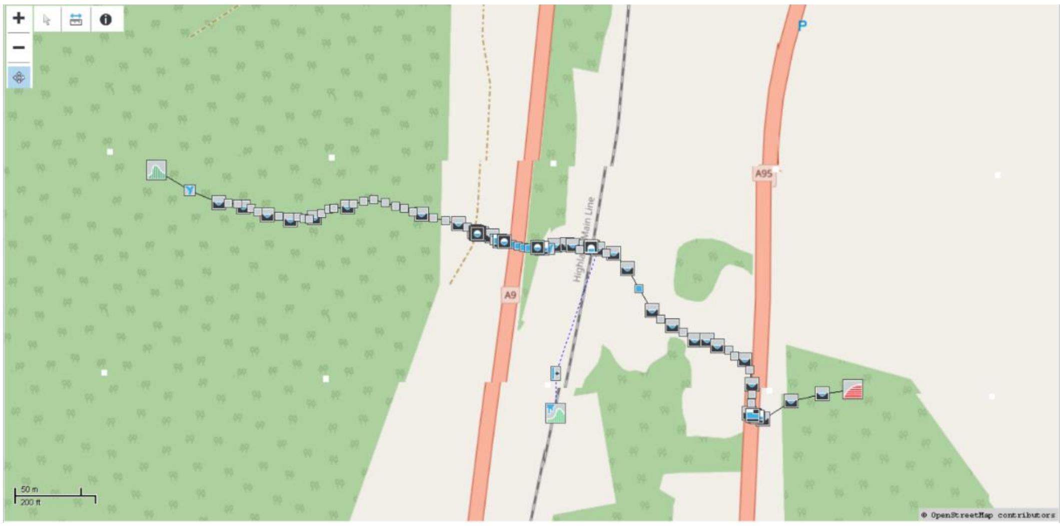
Table 11-5. Key Model Features.

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of Cross Sections	Number of A9 Crossings	Total number of modelled structures
River Allt Cnapach (Main Channel)	570	290818, 818547	291269, 818404	22	1	4

11.2.8 A direct inflow hydrograph is applied to the hydraulic model at the upstream extent of the model. A Normal Depth boundary was used at the downstream extent of all the models.

11.2.9 A model schematic is provided in Figure 11.5.

Figure 11-5 . Model Schematic for 1D element of model



Roughness

11.2.10 Roughness coefficient for cross sections and 1D structures within 1D river models are taken from "Open Channel Hydraulics' (Chow, 1959). Through site visit, photographs included within the topographical survey information, an appropriate Manning's value have been selected for each cross section and structure by the modeller. Table 11.6 details the Manning's 'n' values applied to the 1D channel sections and floodplains.

Table 11-6. Roughness values

Section Type	Minimum	Maximum	Commentary
River Channel	0.04	0.05	Varying from "Clean, straight, full stage, no rifts or deep pools" to "Clean winding, some pools and shoals, with weeds and large amounts of stones"
Floodplain	0.045	0.05	"Light brush and trees in Summer / Winter"
Structures	0.013	0.045	Ranging from smooth concrete, top half of culvert to Gravel bottom with dry rubble sides.

In channel's hydraulic structures

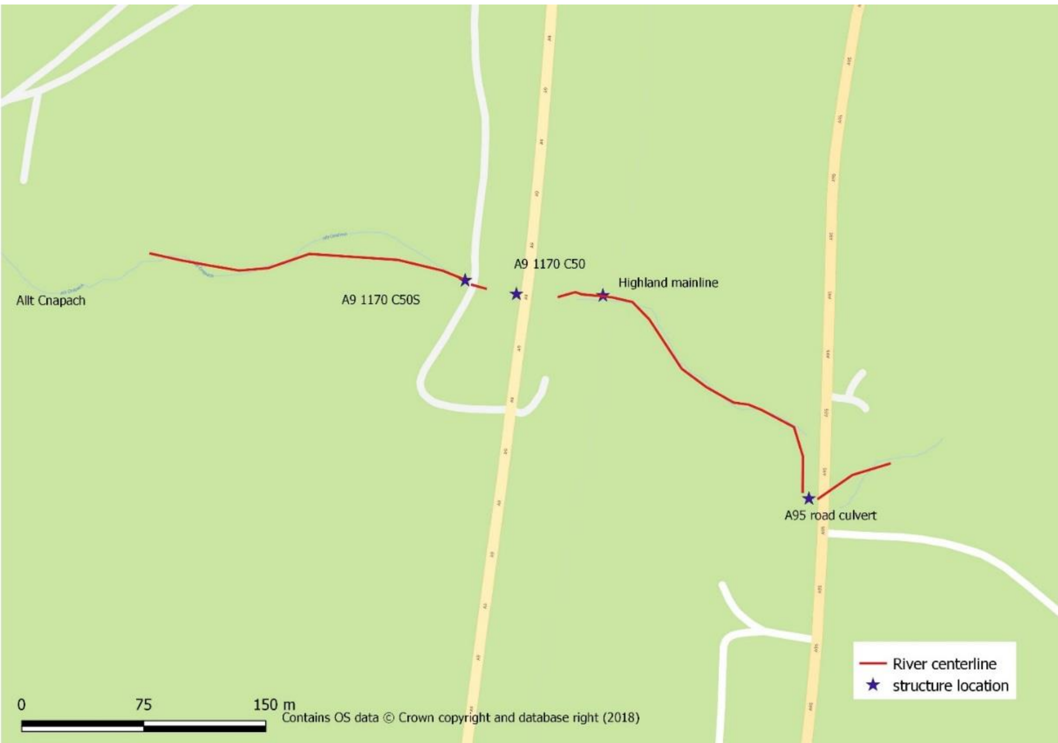
11.2.11 Table 11.7 provides the details of how the structures are represented within the model. Figure 11.6 shows the location of these modelled structures.

Table 11-7. Modelled Structures Details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
DS-WC-032	A9 1170 C50S	Allt Cnapach (291009, 818526)	0.5	Two pipe circular conduit	
DS-WC-032	A9 1170 C50	Allt Cnapach (291023, 818519)	1.5	Circular conduit	

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
Highland Main line	Road Bridge	Allt Cnapach (291097, 818512)	4.2m X 5.5m	USBPR Bridge unit	
A95	Road culvert	Allt Cnapach (291215, 818389)	0.34m X 0.7m	Box culvert	

Figure 11-6. Location of the structures



Flood plain schematisation – 2D domain

Floodplain topography

11.2.12 The catchment topography for the 2D element has been represented by available LiDAR data provided for this study. The filtered LiDAR (i.e. with buildings and vegetation removed) was used for the modelling.

11.2.13 A mesh has been generated based on LiDAR data. The typical mesh size used is from 4m X 4m.

11.2.14 Appropriate use has been made of 2D break lines (z – lines) and elevation polygons (z-shapes) to accurately represent roads, drains and ridges where they have an impact on flow across the floodplain. Elevations for these topographic features were informed by the DTM data.

Floodplains' hydraulic structures

11.2.15 Hydraulic structures in the floodplain (2D) were included using invert levels from the DTM, where they were considered important for flow connectivity and flood risk.

11.2.16 One culvert connecting Drain 8 to the main channel was included in study area, under A9 mainline. The details of the culvert provided in the Table 11.8.

Table 11-8 . Culvert details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model
Drain 8	Single pipe culvert	Drain 8	0.5m	ESTRY Box culvert U/S invert level: 251.545 mAOD D/S invert level: 250.975 mAOD

Floodplain hydraulic friction

11.2.17 The selection of roughness values used for the 2D domains has been based on the OS Master map land use datasets.

11.2.18 A high Manning's n value for a building has been used to represent the presence of buildings. The use of a high Manning's n value for a building makes it very difficult for water to enter/ flow through a building.

Table 11-9. 2D Roughness

Landuse Type	Roughness Value
Building (10021)	0.3
General surface – multi surface (10053)	0.05
General surface (10056)	0.06
Inland water (10089)	0.045
Landform – slope (10096)	0.06
Coniferous trees (10111)	0.12
Marsh Reeds or Saltmarsh (10111)	0.06
Non-coniferous trees (10111)	0.09
Rough grassland (10111)	0.06
Scrub (10111)	0.07
Rail (10167)	0.04
Road (10172)	0.025
Roadside (10183)	0.05
Structure (10185)	0.3
Heath (10111)	0.09
Stability (N/A)	0.3

Boundary conditions

11.2.19 Drain 8 inflows are applied directly to the 2D domain.

11.2.20 Stage-Discharge (HQ) boundaries have been applied at the downstream end of both models at the edge of 2D domain. This controls the rate at which floodplain flows leave the model according to the local topography.

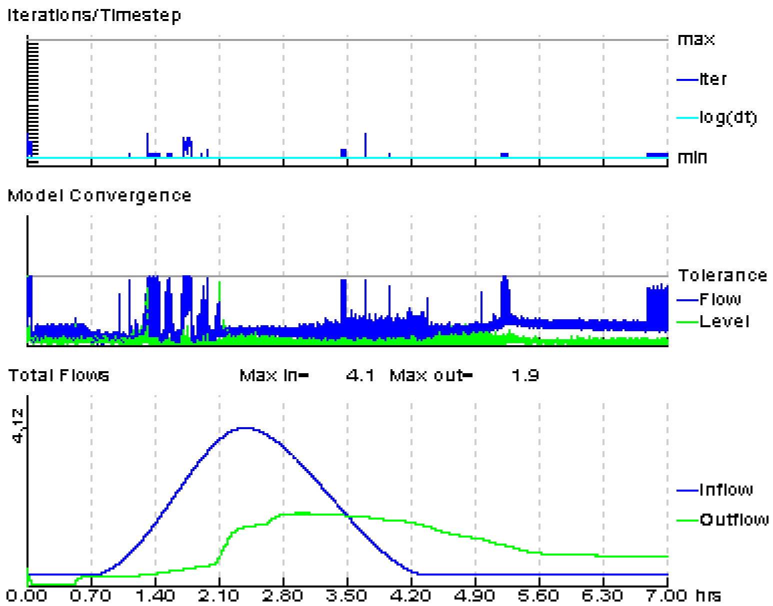
1d/2d Linking

11.2.21 The link between the 1D and the 2D domain was defined along the banks of the River Allt Cnapach and its tributaries using bank crest levels informed by the DTM data. In places where the DTM data did not capture the channel shape, the channel alignment and bank levels were informed by the surveyed cross sections.

Model performance

11.2.22 Run performance has been monitored throughout the model built process and then during each simulation carried out to ensure a suitable model convergence was achieved.

Figure 11-7 1D model convergence plot-Q200

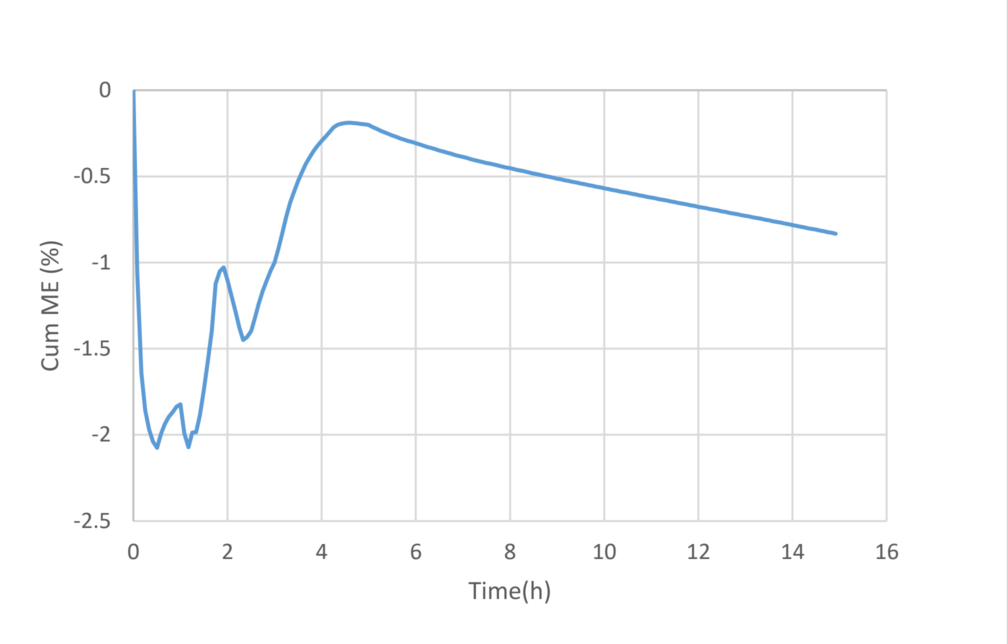


11.2.23 Convergence is calculated for each modelled time step and Figure 11.7 shows the consistency of the modelled water level and flow within the iterations that are computed for each model time step.

11.2.24 The cumulative mass error output from the 2D model is within the acceptable tolerance range recommended by the software manuals of +/- 1% mass balance error.

11.2.25 Figure 11.8 shows that for the 0.5% AEP (1in 200yr) flood event the cumulative mass error tolerance initially goes up to an average of -2% for the initial few hours but later at the peak, the mass error values fall well within the permissible limits of +/-1 %. This mass error check is typical for all events simulated.

Figure 11-8. Mass Balance plot for Q200



Model Results Analysis

11.2.26 Baseline Flow and Stage results, extracted from the modelled 1D cross sections, are shown below in Table 11-10 and Table 11-11.

Table 11-10 Baseline stage (mAOD) for modelled return periods

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
ALLT_CNAP_Q	277.857	277.829	277.800	277.778	277.762	277.758	277.734	277.711	277.671
CNAP_001	277.857	277.829	277.800	277.778	277.762	277.758	277.734	277.711	277.671
CNAP_001In1	277.857	277.829	277.800	277.778	277.762	277.758	277.734	277.711	277.671
CNAP_001In2	276.175	276.143	276.120	276.101	276.089	276.085	276.054	276.032	275.999
CNAP_001In3	275.361	275.330	275.306	275.288	275.276	275.272	275.242	275.219	275.183
CNAP_001In4	274.569	274.530	274.502	274.480	274.465	274.460	274.431	274.405	274.367
CNAP_001In5	273.885	273.837	273.801	273.775	273.757	273.749	273.703	273.672	273.624
CNAP_001In6	273.088	273.046	273.016	272.991	272.971	272.962	272.916	272.884	272.834
CNAP_001In7	272.048	272.019	271.996	271.970	271.949	271.942	271.909	271.885	271.849
CNAP_001In8	271.157	271.133	271.115	271.090	271.072	271.067	271.039	271.020	270.990
CNAP_001In9	270.346	270.320	270.301	270.280	270.260	270.254	270.223	270.202	270.170
CNAP_001In10	269.538	269.511	269.491	269.476	269.461	269.455	269.418	269.393	269.356
CNAP_001In11	269.538	269.511	269.491	269.476	269.461	269.455	269.418	269.393	269.356
CNAP_001In12	267.943	267.908	267.883	267.864	267.851	267.847	267.821	267.794	267.754
CNAP_001In13	267.127	267.092	267.064	267.043	267.028	267.024	266.995	266.969	266.928
CNAP_001In14	266.344	266.312	266.280	266.257	266.241	266.236	266.210	266.191	266.139
CNAP_001In15	265.513	265.478	265.448	265.424	265.407	265.402	265.375	265.355	265.306
CNAP_002	264.813	264.770	264.737	264.701	264.675	264.667	264.626	264.598	264.556
CNAP_002In1	264.085	264.044	264.016	263.983	263.958	263.950	263.912	263.885	263.841
CNAP_002In2	263.433	263.367	263.320	263.281	263.251	263.242	263.196	263.166	263.120
CNAP_002In3	262.624	262.599	262.574	262.545	262.524	262.517	262.482	262.455	262.405
CNAP_002In4	262.129	262.065	261.974	261.890	261.841	261.826	261.764	261.732	261.678

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_002In5	262.129	262.065	261.974	261.890	261.841	261.826	261.764	261.732	261.678
CNAP_002In6	260.458	260.437	260.413	260.385	260.366	260.359	260.324	260.294	260.234
CNAP_002In7	259.718	259.709	259.700	259.687	259.672	259.667	259.638	259.605	259.545
CNAP_003	259.126	259.050	258.993	258.949	258.928	258.921	258.881	258.847	258.787
CNAP_003In1	258.253	258.242	258.233	258.235	258.230	258.226	258.213	258.173	258.066
CNAP_003In2	257.303	257.278	257.254	257.228	257.215	257.211	257.186	257.179	257.161
CNAP_004	256.720	256.673	256.634	256.594	256.579	256.577	256.544	256.500	256.437
CNAP_004In1	256.718	256.672	256.634	256.599	256.567	256.558	256.505	256.453	256.349
CNAP_005US	256.719	256.672	256.634	256.599	256.566	256.558	256.506	256.454	256.348
CNAP_005_C1i	256.719	256.672	256.634	256.599	256.566	256.558	256.506	256.454	256.348
CNAP_005_C1u	256.719	256.672	256.634	256.599	256.566	256.558	256.506	256.454	256.348
005_C1_In	256.715	256.668	256.630	256.593	256.559	256.551	256.498	256.443	256.249
CNAP_005_C1d	256.713	256.666	256.628	256.591	256.557	256.549	256.495	256.439	256.218
CNAP_005_C1o	256.713	256.666	256.628	256.591	256.557	256.549	256.495	256.439	256.218
CNAP_005_C2i	256.719	256.672	256.634	256.599	256.566	256.558	256.506	256.454	256.348
CNAP_005_C2u	256.716	256.669	256.631	256.595	256.561	256.553	256.500	256.446	256.281
005_C2_In	256.715	256.668	256.630	256.593	256.559	256.551	256.498	256.443	256.249
CNAP_005_C2d	256.713	256.666	256.628	256.591	256.557	256.549	256.495	256.439	256.218
CNAP_005_C2o	256.713	256.666	256.628	256.591	256.557	256.549	256.495	256.439	256.218
CNAP_005DS	256.713	256.666	256.628	256.591	256.557	256.549	256.495	256.439	256.218
CNAP_006	256.713	256.666	256.628	256.591	256.557	256.549	256.495	256.439	256.218
CNAP_006_Ci	256.713	256.666	256.627	256.591	256.557	256.548	256.495	256.438	256.218
CNAP_006_Cu	254.038	254.033	254.030	254.027	254.024	254.023	254.019	254.014	253.975
CNAP_006CIn1	253.462	253.458	253.455	253.452	253.449	253.448	253.444	253.440	253.400
CNAP_006CIn2	252.913	252.908	252.905	252.901	252.898	252.898	252.893	252.888	252.848
CNAP_006CIn3	252.321	252.317	252.315	252.312	252.309	252.309	252.305	252.300	252.262
CNAP_006CIn4	251.816	251.809	251.803	251.798	251.793	251.792	251.784	251.778	251.732
CNAP_006_Cd	251.658	251.644	251.633	251.624	251.618	251.615	251.602	251.591	251.539
CNAP_006_Co	251.658	251.644	251.633	251.624	251.617	251.615	251.602	251.591	251.539
CNAP_007	251.658	251.644	251.633	251.624	251.617	251.615	251.602	251.591	251.539
CNAP_008A	251.658	251.644	251.633	251.624	251.617	251.615	251.602	251.591	251.539
CNAP_009	251.102	251.088	251.078	251.068	251.058	251.055	251.037	251.021	250.922
CNAP_009In1	250.949	250.934	250.923	250.914	250.906	250.903	250.889	250.878	250.811
CNAP_010	250.557	250.538	250.523	250.511	250.499	250.496	250.477	250.462	250.371
CNAP_010d	250.514	250.497	250.485	250.474	250.464	250.461	250.445	250.431	250.351
CNAP_010B	250.557	250.538	250.523	250.511	250.499	250.496	250.477	250.462	250.371
CNAP_010Bd	250.514	250.497	250.485	250.474	250.464	250.461	250.445	250.431	250.351
CNAP_011	250.077	250.052	250.033	250.013	249.999	249.994	249.970	249.951	249.853
CNAP_011In1	249.548	249.530	249.515	249.505	249.496	249.493	249.479	249.467	249.442
CNAP_012	249.025	249.009	249.006	248.997	248.990	248.987	248.975	248.965	248.879
CNAP_012A	249.025	249.009	249.006	248.997	248.990	248.987	248.975	248.965	248.879
CNAP_012A_R	246.825	246.818	246.813	246.811	246.808	246.808	246.804	246.801	246.774
CNAP_013	245.940	245.932	245.917	245.914	245.910	245.910	245.904	245.900	245.880
CNAP_013In1	250.557	250.538	250.523	250.511	250.499	250.496	250.477	250.462	250.371
CNAP_014	250.514	250.497	250.485	250.474	250.464	250.461	250.445	250.431	250.351

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_014In1	250.557	250.538	250.523	250.511	250.499	250.496	250.477	250.462	250.371
CNAP_015	250.514	250.497	250.485	250.474	250.464	250.461	250.445	250.431	250.351
CNAP_015A	250.077	250.052	250.033	250.013	249.999	249.994	249.970	249.951	249.853
CNAP_016	249.548	249.530	249.515	249.505	249.496	249.493	249.479	249.467	249.442
CNAP_016In1	249.025	249.009	249.006	248.997	248.990	248.987	248.975	248.965	248.879
CNAP_016In2	249.025	249.009	249.006	248.997	248.990	248.987	248.975	248.965	248.879
CNAP_017	246.825	246.818	246.813	246.811	246.808	246.808	246.804	246.801	246.774
CNAP_017In1	245.940	245.932	245.917	245.914	245.910	245.910	245.904	245.900	245.880
CNAP_018	244.252	244.247	244.237	244.232	244.229	244.228	244.222	244.217	244.183
CNAP_018In1	244.252	244.247	244.237	244.232	244.229	244.228	244.222	244.217	244.183
CNAP_018In2	244.251	244.247	244.237	244.232	244.228	244.228	244.222	244.217	244.183
CNAP_019	244.250	244.246	244.236	244.231	244.227	244.226	244.221	244.216	244.182
CNAP_019_Ci	244.250	244.246	244.236	244.231	244.227	244.226	244.221	244.216	244.182
CNAP_019_Cu	243.927	243.920	243.907	243.901	243.897	243.895	243.888	243.882	243.879
CNAP_019I	243.696	243.688	243.672	243.665	243.661	243.659	243.650	243.643	243.584
CNAP_019_Cd	243.696	243.688	243.672	243.665	243.661	243.659	243.650	243.643	243.584
CNAP_019_Co	243.157	243.145	243.123	243.115	243.109	243.107	243.096	243.086	243.079
CNAP_020	243.157	243.145	243.123	243.115	243.109	243.107	243.096	243.086	243.079
CNAP_021	242.684	242.679	242.669	242.664	242.660	242.658	242.651	242.643	242.568
CNAP_022	242.315	242.310	242.302	242.297	242.293	242.292	242.285	242.278	242.214
CNAP_011_L1	250.077	250.052	250.033	250.013	249.999	249.994	249.970	249.951	249.853

Table 11-11 Baseline Flow (m^3/s) for modelled return periods

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
ALLT_CNAP_Q	4.761	3.968	3.384	2.928	2.612	2.514	2.021	1.681	1.152
CNAP_001	4.761	3.968	3.384	2.928	2.612	2.514	2.021	1.681	1.152
CNAP_001In1	4.761	3.968	3.384	2.928	2.612	2.514	2.021	1.681	1.152
CNAP_001In2	4.762	3.968	3.384	2.928	2.613	2.514	2.021	1.682	1.152
CNAP_001In3	4.763	3.969	3.384	2.928	2.613	2.515	2.021	1.682	1.152
CNAP_001In4	4.763	3.969	3.385	2.928	2.613	2.515	2.021	1.681	1.152
CNAP_001In5	4.764	3.969	3.385	2.928	2.613	2.514	2.021	1.681	1.152
CNAP_001In6	4.764	3.970	3.385	2.928	2.613	2.514	2.022	1.682	1.152
CNAP_001In7	4.763	3.970	3.385	2.929	2.613	2.515	2.022	1.682	1.152
CNAP_001In8	4.764	3.970	3.386	2.929	2.614	2.515	2.023	1.682	1.153
CNAP_001In9	4.764	3.970	3.385	2.929	2.614	2.515	2.023	1.682	1.153
CNAP_001In10	4.764	3.970	3.386	2.930	2.614	2.515	2.023	1.682	1.153
CNAP_001In11	4.764	3.970	3.386	2.930	2.614	2.515	2.023	1.682	1.153
CNAP_001In12	4.764	3.971	3.386	2.930	2.614	2.516	2.023	1.682	1.153
CNAP_001In13	4.765	3.971	3.386	2.931	2.614	2.517	2.024	1.682	1.154
CNAP_001In14	4.765	3.971	3.386	2.931	2.615	2.518	2.024	1.683	1.154
CNAP_001In15	4.764	3.971	3.385	2.931	2.614	2.518	2.023	1.683	1.154
CNAP_002	4.765	3.972	3.386	2.931	2.615	2.518	2.024	1.684	1.154
CNAP_002In1	4.765	3.972	3.387	2.931	2.615	2.517	2.024	1.683	1.154

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_002In2	4.766	3.973	3.388	2.932	2.616	2.518	2.024	1.685	1.155
CNAP_002In3	4.767	3.973	3.388	2.932	2.616	2.517	2.024	1.685	1.154
CNAP_002In4	4.311	3.787	3.389	2.933	2.616	2.518	2.024	1.685	1.154
CNAP_002In5	4.311	3.787	3.389	2.933	2.616	2.518	2.024	1.685	1.154
CNAP_002In6	3.251	3.061	2.859	2.616	2.424	2.361	2.007	1.684	1.154
CNAP_002In7	3.250	3.060	2.859	2.615	2.423	2.361	2.007	1.683	1.153
CNAP_003	3.251	3.062	2.860	2.615	2.424	2.362	2.008	1.683	1.153
CNAP_003In1	3.249	3.061	2.859	2.616	2.424	2.361	2.007	1.682	1.153
CNAP_003In2	2.593	2.474	2.319	2.106	1.971	1.926	1.652	1.494	1.137
CNAP_004	1.256	1.244	1.227	1.207	1.191	1.182	1.135	1.078	0.917
CNAP_004In1	0.612	0.537	0.588	0.528	0.506	0.542	0.505	0.432	0.378
CNAP_005US	0.875	0.864	0.864	0.863	0.864	0.861	0.854	0.853	0.834
CNAP_005_C1i	0.439	0.434	0.434	0.434	0.434	0.433	0.429	0.429	0.421
CNAP_005_C1u	0.439	0.434	0.434	0.434	0.434	0.433	0.429	0.429	0.421
005_C1_In	0.439	0.434	0.434	0.433	0.434	0.432	0.428	0.429	0.421
CNAP_005_C1d	0.439	0.434	0.434	0.433	0.434	0.432	0.428	0.429	0.421
CNAP_005_C1o	0.439	0.434	0.434	0.433	0.434	0.432	0.428	0.429	0.421
CNAP_005_C2i	0.436	0.430	0.430	0.430	0.430	0.429	0.425	0.425	0.415
CNAP_005_C2u	0.436	0.430	0.430	0.430	0.430	0.429	0.425	0.425	0.415
005_C2_In	0.436	0.430	0.430	0.429	0.430	0.428	0.425	0.425	0.414
CNAP_005_C2d	0.436	0.430	0.430	0.429	0.430	0.428	0.425	0.425	0.414
CNAP_005_C2o	0.436	0.430	0.430	0.429	0.430	0.428	0.425	0.425	0.414
CNAP_005DS	0.875	0.864	0.863	0.863	0.864	0.861	0.853	0.853	0.832
CNAP_006	0.875	0.864	0.863	0.863	0.864	0.861	0.853	0.853	0.832
CNAP_006_Ci	1.471	1.427	1.395	1.365	1.336	1.330	1.288	1.243	0.959
CNAP_006_Cu	1.471	1.427	1.395	1.365	1.336	1.330	1.288	1.243	0.959
CNAP_006CIn1	1.469	1.427	1.394	1.365	1.336	1.330	1.288	1.243	0.959
CNAP_006CIn2	1.466	1.427	1.394	1.365	1.336	1.330	1.288	1.244	0.959
CNAP_006CIn3	1.466	1.427	1.394	1.365	1.336	1.331	1.287	1.244	0.959
CNAP_006CIn4	1.466	1.427	1.394	1.365	1.336	1.330	1.287	1.244	0.959
CNAP_006_Cd	1.468	1.427	1.395	1.364	1.335	1.330	1.287	1.244	0.959
CNAP_006_Co	1.468	1.427	1.395	1.364	1.335	1.330	1.287	1.244	0.959
CNAP_007	1.468	1.427	1.395	1.364	1.335	1.330	1.287	1.244	0.959
CNAP_008A	1.468	1.427	1.395	1.364	1.335	1.330	1.287	1.244	0.959
CNAP_009	2.113	2.040	1.981	1.928	1.885	1.870	1.793	1.727	1.343
CNAP_009In1	2.111	2.040	1.980	1.929	1.885	1.870	1.793	1.727	1.343
CNAP_010	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_010d	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_010B	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_010Bd	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_011	2.113	2.039	1.981	1.929	1.885	1.870	1.793	1.727	1.343
CNAP_011In1	2.258	2.162	2.086	2.019	1.963	1.946	1.852	1.776	1.374
CNAP_012	2.258	2.161	2.085	2.019	1.962	1.945	1.851	1.776	1.375
CNAP_012A	2.258	2.161	2.085	2.019	1.962	1.945	1.851	1.776	1.375
CNAP_012A_R	1.385	1.325	1.279	1.248	1.219	1.211	1.164	1.132	0.974

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_013	0.441	0.418	0.390	0.385	0.378	0.376	0.366	0.366	0.385
CNAP_013In1	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_014	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_014In1	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_015	2.111	2.040	1.981	1.929	1.885	1.870	1.793	1.728	1.343
CNAP_015A	2.113	2.039	1.981	1.929	1.885	1.870	1.793	1.727	1.343
CNAP_016	2.258	2.162	2.086	2.019	1.963	1.946	1.852	1.776	1.374
CNAP_016In1	2.258	2.161	2.085	2.019	1.962	1.945	1.851	1.776	1.375
CNAP_016In2	2.258	2.161	2.085	2.019	1.962	1.945	1.851	1.776	1.375
CNAP_017	1.385	1.325	1.279	1.248	1.219	1.211	1.164	1.132	0.974
CNAP_017In1	0.441	0.418	0.390	0.385	0.378	0.376	0.366	0.366	0.385
CNAP_018	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.302
CNAP_018In1	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301
CNAP_018In2	0.302	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301
CNAP_019	0.613	0.613	0.613	0.613	0.612	0.611	0.612	0.612	0.577
CNAP_019_Ci	0.613	0.613	0.613	0.613	0.612	0.611	0.612	0.612	0.577
CNAP_019_Cu	0.613	0.613	0.613	0.613	0.612	0.611	0.612	0.612	0.577
CNAP_019I	0.613	0.613	0.613	0.613	0.612	0.611	0.612	0.612	0.577
CNAP_019_Cd	0.613	0.613	0.613	0.613	0.612	0.611	0.612	0.612	0.577
CNAP_019_Co	0.613	0.613	0.613	0.613	0.612	0.613	0.612	0.612	0.577
CNAP_020	0.613	0.613	0.613	0.613	0.612	0.613	0.612	0.612	0.577
CNAP_021	2.328	2.226	2.039	1.970	1.911	1.894	1.798	1.703	1.147
CNAP_022	2.329	2.227	2.040	1.969	1.912	1.896	1.801	1.708	1.149
CNAP_011_L1	0.171	0.142	0.121	0.105	0.093	0.090	0.072	0.060	0.041

Sensitivity Analysis

1D Sensitivity. Baseline

11.2.27 In order to analyse the sensitivity of the hydraulic model, the models have been updated to represent a change in parameters. The results from the 1D have been compared against the baseline results for the 0.5% AEP event, these are shown in Table 11-12 and Table 11-13. Variation in flow is given in m^3/s and variation in stage is given in metres. Variations in stage for the long section are provided in Figure 11-9. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- Downstream Boundary +/ - 20%

11.2.28 As can be seen from the data, the baseline A9 crossing is sensitive to changes in flow and roughness for some sections. The maximum increase associated with a 20% increase in flow is 76mm and for increase in Manning's roughness is 90mm. The model is not very sensitive to changes to the downstream boundary or the 50% blockage scenario.

Table 11-12 Allt Cnapach 1D Sensitivity Results for 0.5% AEP Event (Variation in Baseline Stage)

Cross Section	Baseline Stage (m AOD)	Variation in stage for Flow -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage Mannings -20% (m)	Variation in stage for Mannings +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage 50% blockage (m)
ALLT_CNAP_Q	277.829	-0.070	0.028	-0.039	0.028	0.000	0.000	0.000
CNAP_001	277.829	-0.070	0.028	-0.039	0.028	0.000	0.000	0.000
CNAP_001In1	276.997	-0.065	0.031	-0.036	0.031	0.000	0.000	0.000
CNAP_001In2	276.143	-0.057	0.032	-0.032	0.032	0.000	0.000	0.000
CNAP_001In3	275.330	-0.057	0.031	-0.032	0.032	0.000	0.000	0.000
CNAP_001In4	274.530	-0.068	0.039	-0.038	0.039	0.000	0.000	0.000
CNAP_001In5	273.837	-0.086	0.047	-0.049	0.048	0.000	0.000	0.000
CNAP_001In6	273.046	-0.081	0.042	-0.041	0.042	0.000	0.000	0.000
CNAP_001In7	272.019	-0.075	0.029	-0.033	0.029	0.000	0.000	-0.001
CNAP_001In8	271.133	-0.064	0.024	-0.029	0.024	0.000	0.000	0.000
CNAP_001In9	270.320	-0.065	0.026	-0.026	0.026	0.000	0.000	0.000
CNAP_001In10	269.511	-0.054	0.027	-0.027	0.027	0.000	0.000	0.000
CNAP_001In11	268.701	-0.057	0.030	-0.031	0.031	0.000	0.000	0.000
CNAP_001In12	267.908	-0.060	0.035	-0.034	0.035	0.000	0.000	0.000
CNAP_001In13	267.092	-0.067	0.035	-0.037	0.035	0.000	0.000	0.000
CNAP_001In14	266.312	-0.075	0.032	-0.043	0.032	0.000	0.000	0.000
CNAP_001In15	265.478	-0.075	0.035	-0.041	0.036	0.000	0.000	0.000
CNAP_002	264.770	-0.100	0.043	-0.048	0.041	0.000	0.000	0.000
CNAP_002In1	264.044	-0.093	0.041	-0.044	0.044	0.000	0.000	0.000
CNAP_002In2	263.367	-0.120	0.066	-0.058	0.049	0.000	0.000	0.001
CNAP_002In3	262.599	-0.084	0.025	-0.045	0.039	0.000	0.000	0.000
CNAP_002In4	262.065	-0.223	0.064	-0.049	0.030	0.000	0.000	0.001
CNAP_002In5	261.089	-0.027	0.004	-0.029	0.036	0.000	0.000	-0.001
CNAP_002In6	260.437	-0.070	0.021	-0.030	0.024	0.000	0.000	0.000
CNAP_002In7	259.709	-0.050	0.009	-0.038	0.025	0.000	0.000	-0.006
CNAP_003	259.050	-0.109	0.076	-0.020	0.022	0.000	0.000	0.021
CNAP_003In1	258.242	-0.022	0.011	-0.010	0.004	0.000	0.000	-0.012
CNAP_003In2	257.278	-0.043	0.025	-0.017	0.020	0.000	0.000	0.007
CNAP_004	256.673	-0.028	0.046	0.017	0.010	0.000	0.000	0.022
CNAP_004In1	256.672	-0.018	0.045	0.014	0.010	0.000	0.000	0.021
CNAP_005US	256.672	-0.018	0.046	0.016	0.011	0.000	0.000	0.021
CNAP_005_C1i	256.672	-0.018	0.046	0.016	0.011	0.000	0.000	0.021
CNAP_005_C1u	256.669	-0.018	0.046	0.017	0.010	0.000	0.000	0.022
005_C1_In	256.668	-0.018	0.046	0.017	0.009	0.000	0.000	0.022
CNAP_005_C1d	256.666	-0.018	0.047	0.019	0.009	0.000	0.000	0.023
CNAP_005_C1o	256.666	-0.018	0.047	0.019	0.009	0.000	0.000	0.023

Cross Section	Baseline Stage (m AOD)	Variation in stage for Flow -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage Mannings -20% (m)	Variation in stage for Mannings +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage 50% blockage (m)
CNAP_005_C2i	256.672	-0.018	0.046	0.016	0.011	0.000	0.000	0.021
CNAP_005_C2u	256.669	-0.018	0.046	0.017	0.010	0.000	0.000	0.022
005_C2_In	256.668	-0.018	0.046	0.017	0.009	0.000	0.000	0.022
CNAP_005_C2d	256.666	-0.018	0.047	0.019	0.009	0.000	0.000	0.023
CNAP_005_C2o	256.666	-0.018	0.047	0.019	0.009	0.000	0.000	0.023
CNAP_005DS	256.666	-0.018	0.047	0.019	0.009	0.000	0.000	0.023
CNAP_006	256.666	-0.018	0.046	0.019	0.009	0.000	0.000	0.023
CNAP_006_Ci	256.666	-0.018	0.046	0.019	0.009	0.000	0.000	0.023
CNAP_006_Cu	254.033	-0.076	0.004	-0.074	0.002	0.000	0.000	0.035
CNAP_006CIn1	253.458	-0.080	0.004	-0.078	0.001	0.000	0.000	0.041
CNAP_006CIn2	252.908	-0.076	0.004	-0.073	0.003	0.000	0.000	0.029
CNAP_006CIn3	252.317	-0.074	0.004	-0.070	0.001	0.000	0.000	0.047
CNAP_006CIn4	251.809	-0.086	0.007	-0.079	0.010	-0.001	0.000	0.004
CNAP_006_Cd	251.644	-0.067	0.013	-0.050	0.027	0.000	0.000	-0.125
CNAP_006_Co	251.644	-0.067	0.013	-0.050	0.027	0.000	0.000	-0.125
CNAP_007	251.644	-0.067	0.013	-0.050	0.027	0.000	0.000	-0.125
CNAP_008A	251.246	-0.152	0.012	-0.139	0.074	-0.001	0.000	-0.133
CNAP_009	251.088	-0.193	0.014	-0.179	0.086	0.000	0.000	-0.172
CNAP_009In1	250.934	-0.151	0.015	-0.138	0.076	0.000	0.000	-0.131
CNAP_010	250.538	-0.196	0.020	-0.179	0.090	0.000	0.000	-0.168
CNAP_010d	250.497	-0.173	0.018	-0.157	0.078	0.000	0.000	-0.147
CNAP_010B	250.538	-0.196	0.020	-0.179	0.090	0.000	0.000	-0.168
CNAP_010Bd	250.497	-0.173	0.018	-0.157	0.078	0.000	0.000	-0.147
CNAP_011	250.052	-0.190	0.027	-0.161	0.070	0.000	0.000	-0.153
CNAP_011In1	249.530	-0.145	0.016	-0.131	0.067	0.000	0.000	-0.109
CNAP_012	249.009	-0.111	0.016	-0.093	0.045	0.000	0.000	-0.092
CNAP_012A	248.156	-0.128	-0.002	-0.060	-0.057	-0.001	-0.001	-0.164
CNAP_012A_R	246.818	-0.039	0.008	-0.036	0.031	0.000	0.000	-0.030
CNAP_013	245.932	-0.034	0.006	-0.042	0.006	-0.001	-0.001	-0.053
CNAP_013In1	245.546	-0.034	0.003	-0.039	0.014	-0.003	-0.003	-0.038
CNAP_014	245.205	-0.028	-0.002	-0.042	0.002	-0.005	-0.005	-0.040
CNAP_014In1	244.963	-0.007	0.007	-0.017	0.005	0.001	0.001	-0.028
CNAP_015	244.679	-0.006	-0.002	-0.015	0.003	-0.003	-0.002	-0.015
CNAP_015A	244.344	-0.002	0.005	-0.002	0.014	-0.002	-0.002	-0.002
CNAP_016	244.241	-0.041	0.007	-0.041	0.008	-0.001	0.000	-0.054
CNAP_016In1	244.247	-0.047	0.006	-0.048	0.012	-0.001	0.000	-0.059
CNAP_016In2	244.247	-0.047	0.005	-0.050	0.012	-0.001	0.000	-0.059
CNAP_017	244.247	-0.047	0.005	-0.050	0.012	-0.001	0.000	-0.059
CNAP_017In1	244.247	-0.047	0.005	-0.049	0.012	-0.001	0.000	-0.059
CNAP_018	244.247	-0.047	0.005	-0.050	0.012	-0.001	0.000	-0.059
CNAP_018In1	244.247	-0.047	0.005	-0.049	0.011	-0.001	0.000	-0.059

Cross Section	Baseline Stage (m AOD)	Variation in stage for Flow -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage Mannings -20% (m)	Variation in stage for Mannings +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage 50% blockage (m)
CNAP_018In2	244.247	-0.047	0.005	-0.049	0.011	-0.001	0.000	-0.059
CNAP_019	244.246	-0.047	0.005	-0.049	0.012	-0.001	0.000	-0.059
CNAP_019_Ci	244.246	-0.047	0.005	-0.049	0.012	-0.001	0.000	-0.059
CNAP_019_Cu	243.920	-0.131	0.007	-0.127	0.075	0.004	-0.005	-0.129
CNAP_019I	243.688	-0.086	0.009	-0.080	0.037	0.007	-0.009	-0.180
CNAP_019_Cd	243.145	-0.056	0.012	-0.043	0.009	0.024	-0.018	-0.097
CNAP_019_Co	243.145	-0.056	0.012	-0.043	0.009	0.024	-0.018	-0.097
CNAP_020	243.145	-0.056	0.012	-0.043	0.009	0.024	-0.018	-0.097
CNAP_021	242.679	-0.075	0.005	-0.067	0.025	-0.005	0.008	-0.069
CNAP_022	242.310	-0.068	0.005	-0.061	0.020	0.013	-0.008	-0.060
CNAP_011_L1	250.052	-0.190	0.027	-0.161	0.070	0.000	0.000	-0.153

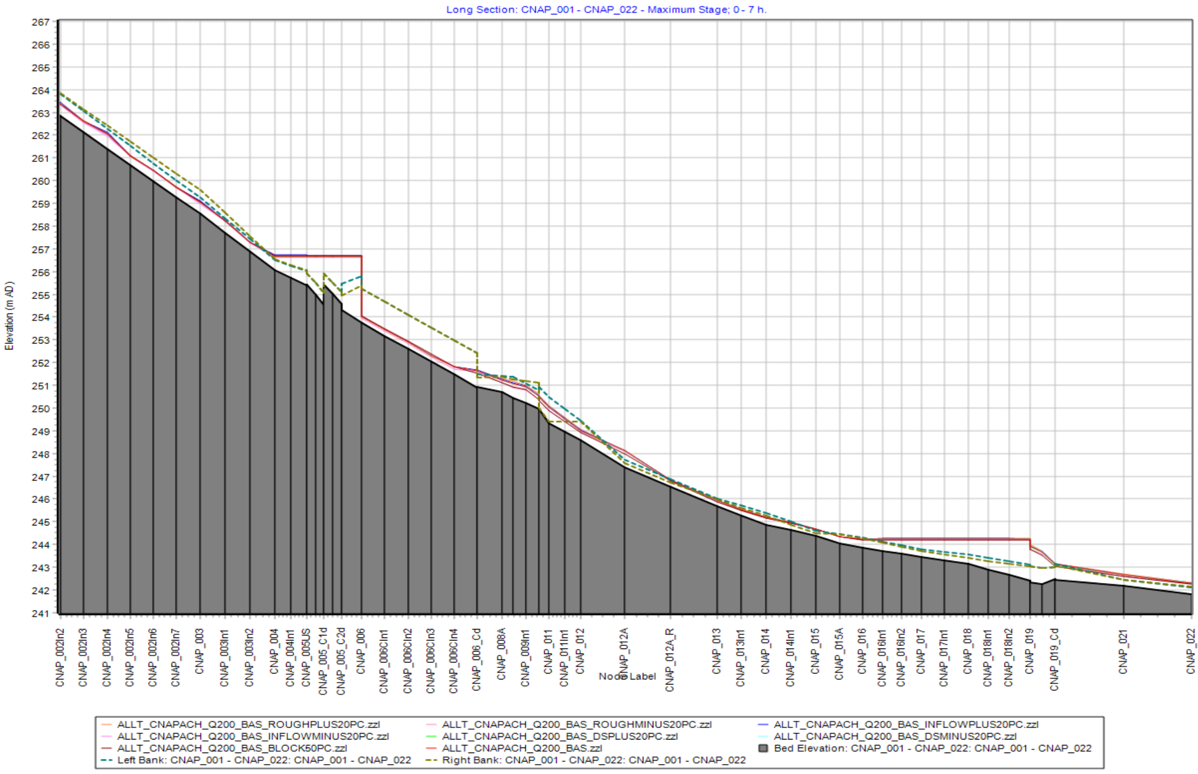
Table 11-13 Allt Cnapach 1D Sensitivity Results for 0.5% AEP Event (Variation in Baseline Flow)

Cross Section	Baseline Flow (m^3/s)	Variation in flow for Flow -20% (m^3/s)	Variation in flow for Flow +20% (m^3/s)	Variation in flow Mannings -20% (m^3/s)	Variation in flow for Mannings +20% (m^3/s)	Variation in flow for D/S Boundary +20% (m^3/s)	Variation in flow for D/S Boundary -20% (m^3/s)	Variation in flow 50% blockage (m^3/s)
ALLT_CNAP_Q	3.968	-0.794	0.793	0.000	0.000	0.000	0.000	0.000
CNAP_001	3.968	-0.794	0.793	0.000	0.000	0.000	0.000	0.000
CNAP_001In1	3.968	-0.793	0.794	0.000	0.000	0.000	0.000	0.000
CNAP_001In2	3.968	-0.793	0.794	0.001	0.001	0.001	0.001	0.001
CNAP_001In3	3.969	-0.794	0.793	0.000	0.000	0.000	0.000	0.000
CNAP_001In4	3.969	-0.794	0.793	0.000	0.001	0.000	0.001	-0.001
CNAP_001In5	3.969	-0.793	0.794	0.000	0.000	0.000	0.001	-0.001
CNAP_001In6	3.970	-0.795	0.793	0.000	0.000	-0.001	0.000	-0.002
CNAP_001In7	3.970	-0.795	0.793	-0.001	0.001	-0.001	0.000	-0.001
CNAP_001In8	3.970	-0.794	0.794	-0.001	0.001	0.000	0.001	-0.001
CNAP_001In9	3.970	-0.794	0.795	-0.001	0.001	-0.001	0.001	0.000
CNAP_001In10	3.970	-0.794	0.795	0.000	0.002	0.001	0.001	-0.001
CNAP_001In11	3.971	-0.795	0.794	-0.001	0.001	0.000	0.000	-0.002
CNAP_001In12	3.971	-0.795	0.794	-0.001	0.001	0.000	0.001	-0.002
CNAP_001In13	3.971	-0.795	0.794	-0.001	0.001	0.000	0.001	-0.001
CNAP_001In14	3.971	-0.794	0.794	-0.001	0.001	0.000	0.001	-0.001
CNAP_001In15	3.971	-0.794	0.795	-0.001	0.001	0.000	0.001	0.000
CNAP_002	3.972	-0.794	0.793	-0.002	0.000	0.000	0.000	-0.001
CNAP_002In1	3.972	-0.794	0.794	0.000	0.001	0.000	0.000	0.000
CNAP_002In2	3.973	-0.795	0.794	-0.001	0.000	0.000	-0.001	-0.001
CNAP_002In3	3.973	-0.795	0.794	-0.001	0.000	0.000	-0.001	-0.001

Cross Section	Baseline Flow (m^3/s)	Variation in flow for Flow -20% (m^3/s)	Variation in flow for Flow +20% (m^3/s)	Variation in flow Mannings -20% (m^3/s)	Variation in flow for Mannings +20% (m^3/s)	Variation in flow for D/S Boundary +20% (m^3/s)	Variation in flow for D/S Boundary -20% (m^3/s)	Variation in flow 50% blockage (m^3/s)
CNAP_002In4	3.787	-0.609	0.524	0.148	-0.082	0.000	-0.001	-0.004
CNAP_002In5	3.780	-0.602	0.377	0.155	-0.127	0.001	0.001	-0.005
CNAP_002In6	3.061	-0.071	0.192	0.335	-0.283	0.001	0.001	-0.010
CNAP_002In7	3.060	-0.070	0.192	0.335	-0.282	0.001	0.001	-0.012
CNAP_003	3.062	-0.072	0.189	0.332	-0.284	0.000	0.000	-0.010
CNAP_003In1	3.061	-0.071	0.187	0.332	-0.284	0.000	0.000	-0.010
CNAP_003In2	2.474	0.141	0.118	0.424	-0.339	-0.001	-0.001	-0.012
CNAP_004	1.244	0.178	0.014	0.193	-0.223	-0.001	0.000	-0.033
CNAP_004In1	0.537	0.408	0.071	0.444	0.062	-0.001	-0.001	0.400
CNAP_005US	0.864	-0.001	0.012	-0.006	-0.006	0.000	0.000	-0.001
CNAP_005_C1i	0.434	-0.002	0.006	0.000	-0.003	0.000	0.000	-0.001
CNAP_005_C1u	0.434	-0.002	0.006	0.000	-0.003	0.000	0.000	-0.001
005_C1_In	0.434	-0.002	0.006	0.026	-0.003	0.000	0.000	-0.001
CNAP_005_C1d	0.434	-0.002	0.006	0.026	-0.003	0.000	0.000	-0.001
CNAP_005_C1o	0.434	-0.002	0.006	0.026	-0.003	0.000	0.000	-0.001
CNAP_005_C2i	0.430	0.000	0.006	-0.001	-0.003	0.000	0.000	-0.001
CNAP_005_C2u	0.430	0.000	0.006	-0.001	-0.003	0.000	0.000	-0.001
005_C2_In	0.430	0.041	0.006	-0.001	-0.003	0.000	0.000	-0.001
CNAP_005_C2d	0.430	0.040	0.006	-0.001	-0.003	0.000	0.000	-0.001
CNAP_005_C2o	0.430	0.040	0.006	-0.001	-0.003	0.000	0.000	-0.001
CNAP_005DS	0.864	-0.001	0.012	-0.006	-0.006	0.000	0.000	-0.001
CNAP_006	1.427	-0.496	0.039	-0.472	0.014	0.000	0.000	-0.341
CNAP_006_Ci	1.427	-0.496	0.039	-0.472	0.014	0.000	0.000	-0.341
CNAP_006_Cu	1.427	-0.496	0.039	-0.472	0.014	0.000	0.000	-0.341
CNAP_006CIn1	1.427	-0.496	0.038	-0.473	0.014	0.000	0.000	-0.341
CNAP_006CIn2	1.427	-0.496	0.038	-0.473	0.015	0.000	0.000	-0.342
CNAP_006CIn3	1.427	-0.496	0.039	-0.473	0.015	0.000	0.000	-0.343
CNAP_006CIn4	1.427	-0.496	0.039	-0.474	0.015	0.000	0.000	-0.343
CNAP_006_Cd	1.427	-0.497	0.038	-0.473	0.016	0.000	0.000	-0.343
CNAP_006_Co	1.427	-0.497	0.038	-0.473	0.016	0.000	0.000	-0.343
CNAP_007	1.427	-0.497	0.038	-0.473	0.016	0.000	0.000	-0.343
CNAP_008A	2.040	-0.516	0.071	-0.433	0.002	-0.002	-0.001	-0.713
CNAP_009	2.040	-0.516	0.071	-0.434	0.001	-0.002	-0.001	-0.713
CNAP_009In1	2.040	-0.516	0.073	-0.436	0.000	-0.002	-0.001	-0.714
CNAP_010	2.040	-0.517	0.070	-0.435	0.000	-0.001	-0.001	-0.714
CNAP_010d	2.040	-0.517	0.070	-0.435	0.000	-0.001	-0.001	-0.714
CNAP_010B	2.040	-0.517	0.070	-0.435	0.000	-0.001	-0.001	-0.714
CNAP_010Bd	2.040	-0.517	0.070	-0.435	0.000	-0.001	-0.001	-0.714
CNAP_011	2.039	-0.515	0.073	-0.433	0.001	0.000	0.000	-0.713
CNAP_011In1	2.162	-0.550	0.095	-0.451	0.000	-0.001	0.000	-0.703
CNAP_012	2.161	-0.548	0.097	-0.450	0.001	0.000	0.001	-0.701

Cross Section	Baseline Flow (m^3/s)	Variation in flow for Flow -20% (m^3/s)	Variation in flow for Flow +20% (m^3/s)	Variation in flow Mannings -20% (m^3/s)	Variation in flow for Mannings +20% (m^3/s)	Variation in flow for D/S Boundary +20% (m^3/s)	Variation in flow for D/S Boundary -20% (m^3/s)	Variation in flow 50% blockage (m^3/s)
CNAP_012A	2.162	-0.549	0.138	-0.453	-0.001	0.000	0.000	-0.703
CNAP_012A_R	1.325	-0.177	0.077	-0.220	0.033	-0.001	-0.001	-0.329
CNAP_013	0.418	0.093	0.026	0.056	0.001	0.005	0.004	-0.057
CNAP_013In1	0.752	-0.068	0.020	-0.115	-0.042	-0.009	-0.009	-0.234
CNAP_014	0.714	-0.030	0.009	-0.076	-0.079	-0.017	-0.018	-0.192
CNAP_014In1	0.743	-0.058	0.006	-0.102	-0.074	-0.025	-0.023	-0.220
CNAP_015	0.739	-0.053	0.018	-0.084	-0.066	-0.028	-0.027	-0.206
CNAP_015A	0.470	0.039	-0.001	0.000	-0.067	-0.013	-0.013	-0.101
CNAP_016	0.302	0.020	0.000	0.000	0.000	0.000	0.000	0.000
CNAP_016In1	0.302	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CNAP_016In2	0.302	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CNAP_017	0.302	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CNAP_017In1	0.302	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CNAP_018	0.301	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CNAP_018In1	0.301	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CNAP_018In2	0.301	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CNAP_019	0.613	0.081	-0.007	0.078	-0.083	-0.018	0.004	-0.001
CNAP_019_Ci	0.613	0.081	-0.007	0.078	-0.083	-0.018	0.004	-0.001
CNAP_019_Cu	0.613	0.081	-0.007	0.078	-0.083	-0.018	0.004	-0.001
CNAP_019I	0.613	0.081	-0.007	0.078	-0.083	-0.018	0.004	-0.001
CNAP_019_Cd	0.613	0.081	-0.006	0.078	-0.083	-0.018	0.004	0.000
CNAP_019_Co	0.613	0.081	-0.006	0.078	-0.083	-0.018	0.004	0.000
CNAP_020	0.613	0.081	-0.006	0.078	-0.083	-0.018	0.004	0.000
CNAP_021	2.226	-0.718	0.108	-0.610	-0.003	0.026	0.004	-0.918
CNAP_022	2.227	-0.721	0.111	-0.607	-0.001	0.024	0.007	-0.918
CNAP_011_L1	0.142	-0.028	0.029	0.000	0.000	0.000	0.000	0.000

Figure 11-9 Modelled Long Section Sensitivity Results - Baseline



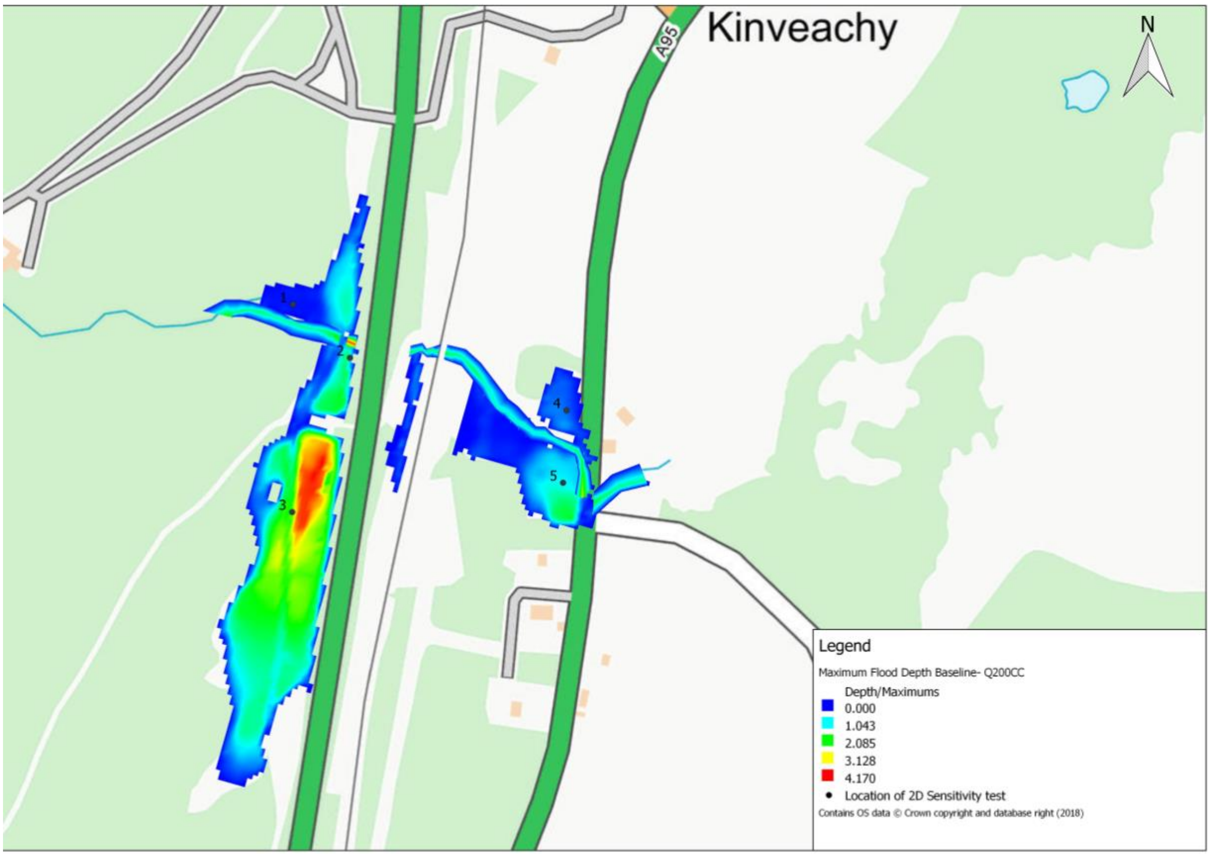
2D Sensitivity, Baseline

11.2.29 In order to assess the 2D sensitivity of the Baseline model, a set of 7 tests were carried out and results analysed at 5 locations throughout the 2D domain. These tests are designed to better understand how specific parameters, that are used in the calculations carried out by the model software, impact the output results, and get a better understanding into the robustness of the hydraulic model. Table 11-14 details these sensitivity test locations, and Figure 11.10 shows the location of the sensitivity test locations relative to the modelled reach and the baseline Q200+CC results.

Table 11-14 2D Model sensitivity test locations – baseline

Location of sensitivity test.	Description of location	Easting	Northing
1	Upstream Left floodplain	290969	818554
2	A9 crossing	291018	818509
3	Upstream of Drain 8 within existing low spot	290969	818378
4	Left floodplain at A95 crossing at proposed access track	291202	818464
5	Right floodplain at A95 crossing	291199	818403

Figure 11-10 Location of 2D Sensitivity test locations and the baseline Q200+CC flood outline



11.2.30 Table 11-15 summarises the variation in depth in metres from the Q200 baseline depth.

Table 11-15 2D Sensitivity Results Baseline model. Variation in depth from Q200 (m)

Sensitivity Test	Baseline	+20% Flow	-20% Flow	+20% Mann	-20% Mann	+20% DSB	-20% DSB	+ 50% Blockage
Location 1	0.055	0.020	-0.019	0.018	-0.018	0.000	0.000	0.000
Location 2	0.782	0.047	-0.054	0.009	0.018	0.000	0.000	0.022
Location 3	1.945	0.464	-0.499	-0.009	0.223	0.000	0.000	0.366
Location 4	0.382	0.005	-0.013	0.012	-0.049	0.000	0.000	-0.058
Location 5	1.055	0.005	-0.013	0.012	-0.048	0.000	0.000	-0.058

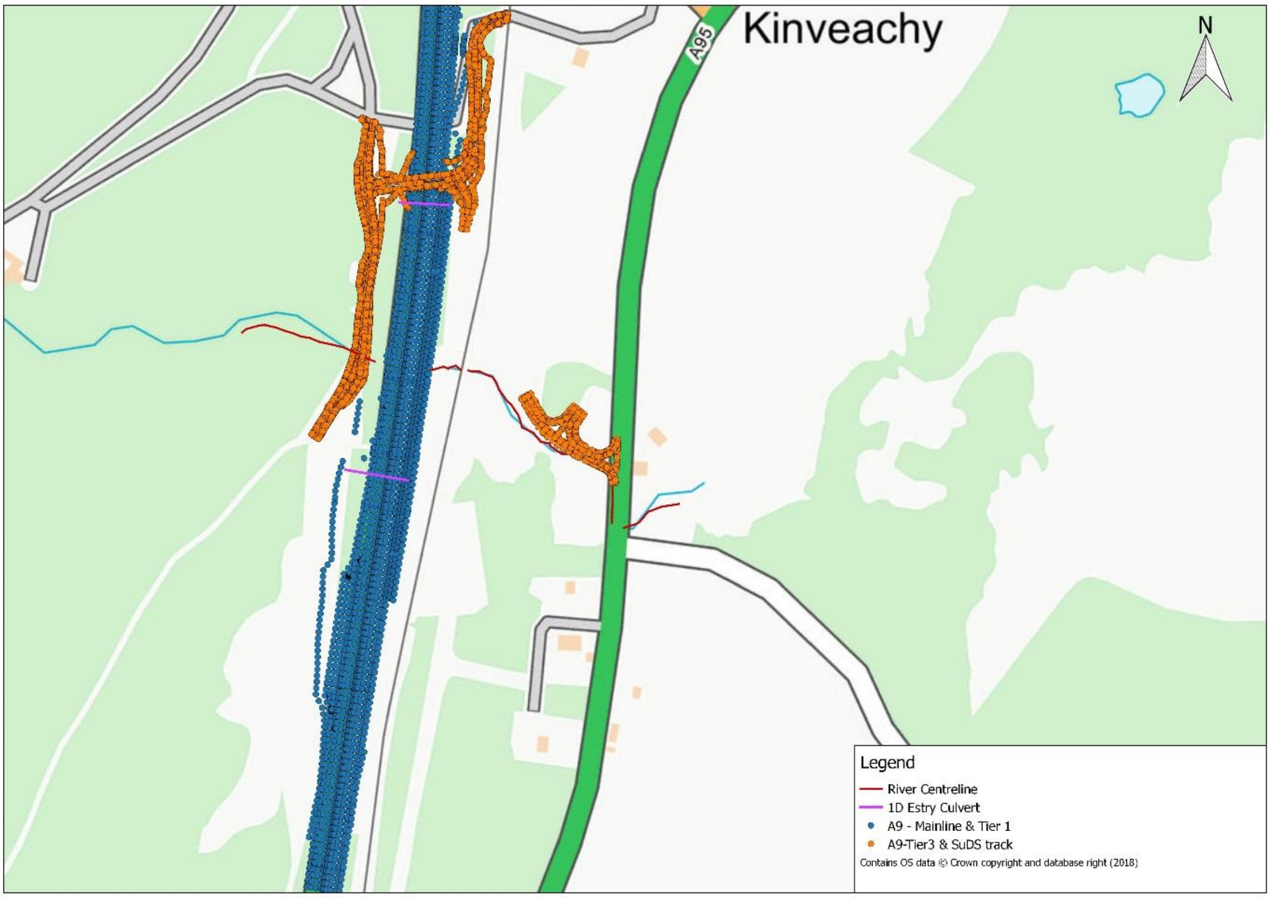
11.2.31 The Baseline model does not show much variation to the sensitivity tests at Location 1, 4 and 5. The maximum variations are located at sensitivity test location 2 which is upstream of the A9 crossing and location 3 which is the hollow between the A9 crossing of Allt Cnapach and Drain 8.

11.3 Proposed Model ('with-scheme' modelling)

11.3.1 Design refresh 7a (DR7a) provides the final proposed levels for A9 mainline, new access roads and the Sustainable urban drainage system (SuDS) tracks.

11.3.2 Figure 11.11 shows the layout of the proposed scheme in the vicinity of the model.

Figure 11-11. Proposed Scheme Arrangement



11.3.3 The proposed scheme includes an update to the model for:

- A9 mainline (widening)
- A9 mainline structure
- Access road tracks and new design access road structure
- SuDS Pond

1D model updates

11.3.4 The A9 structure is a 1.2m wide x 2.5m high portal including single mammal ledge and bed material. Due to the impact on the downstream A95 receptor, the culvert opening has been optimised to ensure there is no increased flood risk downstream. Due to the length of culvert being greater than 40m, sufficient headroom for maintenance has been required from a health and safety perspective for maintenance.

11.3.5 The A9 side road culvert dimensions have been increased from 0.5m to 0.75m.

11.3.6 An access track has been added to the model as shown in Figure 11.11.

2D model updates

11.3.7 The proposed scheme elevations (tracks) were added to the hydraulic model. Within the footprint of the proposed scheme these raster grids replaced the existing ground elevations for the road embankments.

11.3.8 New access road culvert has been modelled as 1D ESTRY culvert unit.

11.3.9 Where it has been required, the modifications of the floodplain structures for the drains and other structure under the A9 have been added to the model. The Table 11.16 summarises all these changes.

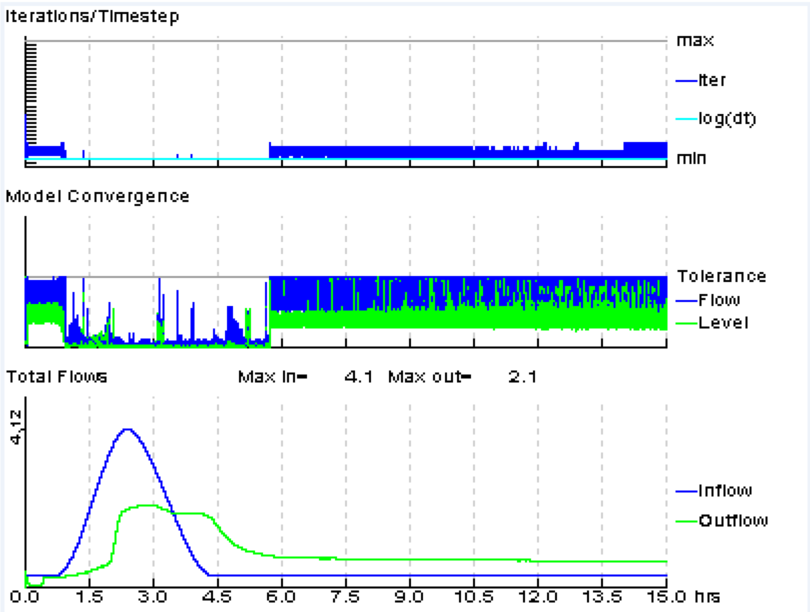
Table 11-16. 2D model updates

S.No	2D model changes	Source of data	Structure details
1.	The proposed levels for the mainline, Access road, access tracks are stamped on the base Lidar	Design Refresh 7a - Mainline & Tier 1 XYZ NG.xls	Based on DR7a
3.	New access road bridge near River Allt Cnapach is modelled as 1D ESTRY culvert unit	Design Refresh 7a - Tier 3 & Suds tracks XYZ NG.txt	Based on DR7a

Model performance

11.3.10 Run performance has been monitored throughout the model build process and then during each simulation carried out to ensure a suitable model convergence was achieved, Figure 11.12.

Figure 11-12.Model convergence plot for 1in 200yr flood event - "model with scheme"



11.3.11 Convergence is calculated for each modelled time step and shows the consistency of the modelled water level and flow within the iterations that are computed for each model time step.

11.3.12 The cumulative mass error output from the 2D model is within the acceptable tolerance range recommended by the software manuals of +/- 1% mass balance error.

11.3.13 Figure 11.13 shows that for the 0.5% AEP (1in 200yr) flood event the cumulative mass error tolerance is well within the permissible limits of +/-1 %. This mass error check is typical for all events simulated.

Figure 11-13 - Mass Balance plot

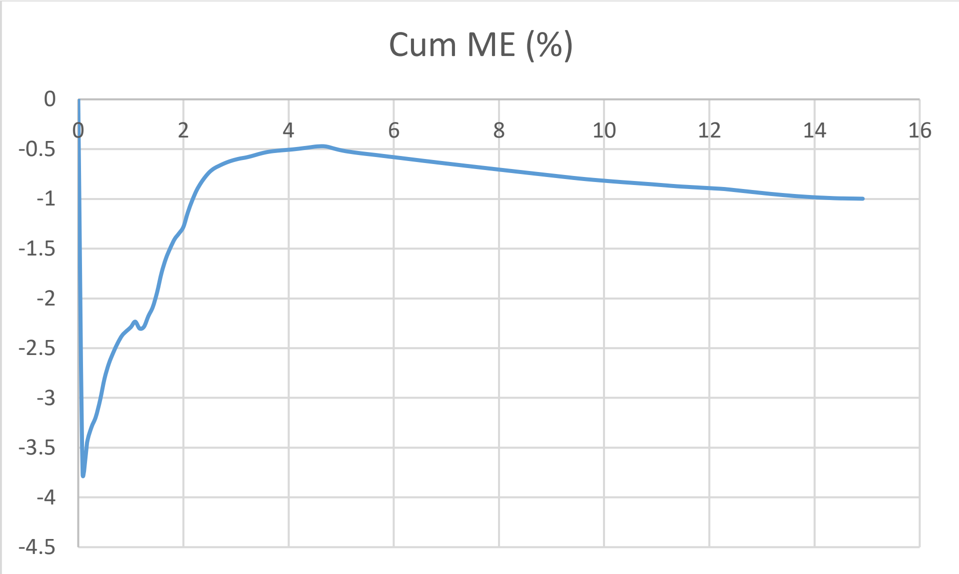


Table 11-17 Proposed stage (mAOD) for modelled return periods

Cross Section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
ALLT_CNAP_Q	277.842	277.811	277.778	277.769	277.756	277.752	277.734	277.711	277.672
CNAP_001	277.842	277.811	277.778	277.769	277.756	277.752	277.734	277.711	277.672
CNAP_001In1	277.013	276.983	276.951	276.943	276.931	276.927	276.906	276.880	276.839
CNAP_001In2	276.162	276.135	276.106	276.098	276.087	276.084	276.049	276.026	275.983
CNAP_001In3	275.353	275.324	275.294	275.286	275.275	275.271	275.232	275.204	275.163
CNAP_001In4	274.554	274.520	274.485	274.475	274.461	274.457	274.426	274.394	274.344
CNAP_001In5	273.879	273.844	273.786	273.764	273.733	273.723	273.680	273.656	273.618
CNAP_001In6	273.076	273.044	272.995	272.978	272.952	272.944	272.900	272.863	272.807
CNAP_001In7	272.034	272.005	271.974	271.966	271.954	271.949	271.924	271.883	271.817
CNAP_001In8	271.156	271.133	271.102	271.089	271.072	271.066	271.038	271.019	270.990
CNAP_001In9	270.344	270.318	270.290	270.277	270.257	270.251	270.221	270.201	270.168
CNAP_001In10	269.532	269.504	269.477	269.470	269.450	269.443	269.410	269.387	269.352
CNAP_001In11	268.724	268.694	268.662	268.653	268.636	268.629	268.594	268.569	268.531
CNAP_001In12	267.937	267.912	267.872	267.857	267.836	267.831	267.800	267.778	267.745
CNAP_001In13	267.119	267.091	267.052	267.038	267.018	267.011	266.978	266.955	266.920
CNAP_001In14	266.333	266.301	266.269	266.260	266.240	266.232	266.192	266.164	266.121
CNAP_001In15	265.503	265.470	265.437	265.427	265.402	265.395	265.357	265.331	265.291
CNAP_002	264.808	264.768	264.719	264.701	264.675	264.667	264.626	264.598	264.556
CNAP_002In1	264.078	264.041	264.000	263.983	263.958	263.950	263.912	263.885	263.841
CNAP_002In2	263.423	263.362	263.302	263.280	263.250	263.241	263.195	263.165	263.119
CNAP_002In3	262.622	262.599	262.558	262.545	262.524	262.517	262.482	262.454	262.403
CNAP_002In4	262.126	262.052	261.916	261.885	261.837	261.823	261.762	261.730	261.675

Cross Section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_002In5	261.094	261.093	261.085	261.081	261.075	261.072	261.053	261.025	260.967
CNAP_002In6	260.456	260.434	260.395	260.383	260.363	260.357	260.322	260.291	260.227
CNAP_002In7	259.733	259.729	259.705	259.692	259.676	259.670	259.636	259.605	259.543
CNAP_003	259.078	259.003	258.954	258.939	258.917	258.910	258.874	258.843	258.776
CNAP_003In1	258.240	258.237	258.236	258.235	258.232	258.232	258.212	258.179	258.082
CNAP_003In2	257.288	257.252	257.224	257.215	257.207	257.204	257.198	257.193	257.176
CNAP_004	256.676	256.611	256.582	256.571	256.556	256.550	256.519	256.503	256.463
CNAP_004In1	256.660	256.591	256.498	256.471	256.428	256.413	256.327	256.296	256.297
CNAP_005US	256.649	256.581	256.482	256.453	256.410	256.395	256.312	256.289	256.293
CNAP_005_C1i	256.649	256.581	256.482	256.453	256.410	256.395	256.312	256.289	256.293
CNAP_005_C1u	256.303	256.249	256.142	256.107	256.052	256.037	255.961	255.904	255.795
005_C1_In	256.162	256.113	256.026	256.002	255.953	255.935	255.848	255.784	255.626
CNAP_005_C1d	256.028	255.977	255.897	255.872	255.836	255.823	255.761	255.711	255.594
CNAP_005_C1o	256.028	255.977	255.897	255.872	255.836	255.823	255.761	255.711	255.594
CNAP_005_C2i	256.649	256.581	256.482	256.453	256.410	256.395	256.312	256.289	256.293
CNAP_005_C2u	256.303	256.250	256.143	256.107	256.052	256.038	255.960	255.905	255.794
005_C2_In	256.162	256.113	256.026	256.002	255.953	255.935	255.847	255.783	255.623
CNAP_005_C2d	256.028	255.977	255.897	255.872	255.836	255.823	255.761	255.711	255.594
CNAP_005_C2o	256.028	255.977	255.897	255.872	255.836	255.823	255.761	255.711	255.594
CNAP_005spl	256.028	255.977	255.897	255.872	255.836	255.823	255.761	255.711	255.594
CNAP_005DS	256.026	255.971	255.890	255.865	255.828	255.815	255.754	255.703	255.585
CNAP_006	256.027	255.975	255.894	255.869	255.832	255.819	255.757	255.706	255.588
CNAP_006_Ci	256.027	255.975	255.894	255.869	255.832	255.819	255.757	255.706	255.588
CNAP_006_Cu	254.873	254.873	254.873	254.873	254.873	254.873	254.873	254.873	254.873
CNAP_006CIn1	253.983	253.971	253.951	253.945	253.937	253.934	253.920	253.908	253.881
CNAP_006CIn2	253.472	253.472	253.472	253.472	253.472	253.472	253.472	253.472	253.472
CNAP_006CIn3	252.877	252.867	252.849	252.843	252.835	252.832	252.819	252.807	252.796
CNAP_006CIn4	252.236	252.236	252.236	252.236	252.236	252.236	252.236	252.236	252.236
CNAP_006_Cd	251.681	251.650	251.633	251.627	251.620	251.620	251.607	251.600	251.580
CNAP_006_Co	251.681	251.650	251.633	251.627	251.620	251.620	251.607	251.600	251.580
CNAP_007	251.681	251.650	251.633	251.627	251.620	251.620	251.607	251.600	251.580
CNAP_008A	251.272	251.242	251.221	251.214	251.205	251.201	251.187	251.174	251.144
CNAP_009	251.115	251.081	251.058	251.049	251.039	251.035	251.017	251.001	250.960
CNAP_009In1	250.966	250.934	250.913	250.905	250.895	250.892	250.876	250.864	250.835
CNAP_010	250.571	250.534	250.505	250.496	250.484	250.480	250.460	250.444	250.406
CNAP_010B	250.571	250.534	250.505	250.496	250.484	250.480	250.460	250.444	250.406
CNAP_010Bd	250.526	250.494	250.469	250.461	250.450	250.447	250.430	250.416	250.382
CNAP_010d	250.526	250.494	250.469	250.461	250.450	250.447	250.430	250.416	250.382
CNAP_011	250.076	250.048	250.012	250.001	249.986	249.981	249.956	249.936	249.891
CNAP_011In1	249.545	249.525	249.501	249.495	249.485	249.482	249.466	249.455	249.428
CNAP_012	249.025	249.012	248.992	248.987	248.978	248.975	248.962	248.949	248.923
CNAP_012A	248.155	248.141	248.120	248.113	248.104	248.100	248.084	248.046	247.987

Cross Section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_012A_R	246.816	246.809	246.803	246.802	246.799	246.798	246.795	246.791	246.786
CNAP_013	245.940	245.923	245.915	245.912	245.908	245.907	245.901	245.896	245.880
CNAP_013In1	245.549	245.542	245.537	245.536	245.534	245.533	245.530	245.527	245.519
CNAP_014	245.214	245.210	245.212	245.212	245.211	245.212	245.211	245.208	245.198
CNAP_014In1	244.957	244.957	244.955	244.959	244.956	244.957	244.955	244.959	244.961
CNAP_015	244.676	244.674	244.676	244.678	244.676	244.677	244.677	244.676	244.671
CNAP_015A	244.330	244.324	244.320	244.320	244.320	244.320	244.320	244.320	244.320
CNAP_016	244.250	244.241	244.232	244.230	244.227	244.225	244.220	244.216	244.192
CNAP_016In1	244.250	244.241	244.232	244.230	244.226	244.226	244.220	244.216	244.192
CNAP_016In2	244.250	244.242	244.232	244.230	244.227	244.225	244.220	244.216	244.192
CNAP_017	244.250	244.242	244.232	244.230	244.227	244.225	244.220	244.216	244.192
CNAP_017In1	244.250	244.241	244.232	244.230	244.227	244.226	244.220	244.216	244.192
CNAP_018	244.250	244.242	244.232	244.230	244.227	244.226	244.220	244.216	244.192
CNAP_018In1	244.250	244.242	244.232	244.230	244.227	244.226	244.220	244.216	244.192
CNAP_018In2	244.250	244.241	244.232	244.230	244.227	244.226	244.220	244.216	244.192
CNAP_019	244.249	244.240	244.231	244.229	244.226	244.224	244.219	244.215	244.191
CNAP_019_Ci	244.249	244.240	244.231	244.229	244.226	244.224	244.219	244.215	244.191
CNAP_019_Cu	243.926	243.921	243.910	243.906	243.902	243.900	243.893	243.888	243.815
CNAP_019I	243.695	243.689	243.676	243.672	243.667	243.665	243.656	243.650	243.542
CNAP_019_Cd	243.181	243.155	243.139	243.133	243.125	243.123	243.111	243.101	243.062
CNAP_019_Co	243.181	243.155	243.139	243.133	243.125	243.123	243.111	243.101	243.062
CNAP_020	243.181	243.155	243.139	243.133	243.125	243.123	243.111	243.101	243.062
CNAP_021	242.670	242.656	242.647	242.644	242.640	242.639	242.633	242.627	242.604
CNAP_022	242.291	242.279	242.272	242.269	242.267	242.265	242.260	242.256	242.238
CNAP_011_L1	250.076	250.048	250.012	250.001	249.986	249.981	249.956	249.936	249.891

Table 11-18 Proposed Flow (m^3/s) for modelled return periods

Cross Section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
ALLT_CNAP_Q	4.761	3.968	3.150	2.928	2.612	2.514	2.021	1.681	1.152
CNAP_001	4.761	3.968	3.150	2.928	2.612	2.514	2.021	1.681	1.152
CNAP_001In1	4.761	3.968	3.150	2.928	2.612	2.513	2.020	1.682	1.153
CNAP_001In2	4.762	3.969	3.151	2.928	2.612	2.514	2.021	1.682	1.153
CNAP_001In3	4.761	3.968	3.151	2.930	2.613	2.514	2.022	1.681	1.153
CNAP_001In4	4.762	3.968	3.152	2.929	2.613	2.514	2.022	1.681	1.152
CNAP_001In5	4.762	3.968	3.152	2.929	2.612	2.515	2.022	1.681	1.153
CNAP_001In6	4.763	3.967	3.152	2.929	2.613	2.514	2.022	1.681	1.152
CNAP_001In7	4.763	3.967	3.152	2.929	2.614	2.514	2.022	1.681	1.152
CNAP_001In8	4.763	3.969	3.152	2.930	2.615	2.514	2.021	1.681	1.152
CNAP_001In9	4.763	3.969	3.152	2.930	2.614	2.515	2.021	1.682	1.152
CNAP_001In10	4.764	3.970	3.153	2.931	2.614	2.515	2.022	1.682	1.151
CNAP_001In11	4.764	3.970	3.153	2.931	2.614	2.515	2.022	1.682	1.152
CNAP_001In12	4.765	3.970	3.154	2.931	2.614	2.515	2.023	1.683	1.152
CNAP_001In13	4.764	3.970	3.154	2.930	2.614	2.516	2.023	1.682	1.153
CNAP_001In14	4.764	3.970	3.154	2.931	2.614	2.517	2.023	1.683	1.153

Cross Section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_001In15	4.765	3.969	3.154	2.931	2.615	2.517	2.023	1.683	1.153
CNAP_002	4.764	3.970	3.154	2.931	2.615	2.517	2.024	1.683	1.152
CNAP_002In1	4.766	3.970	3.153	2.932	2.616	2.517	2.023	1.683	1.153
CNAP_002In2	4.766	3.971	3.154	2.932	2.617	2.517	2.024	1.684	1.153
CNAP_002In3	4.767	3.971	3.153	2.932	2.617	2.518	2.024	1.684	1.153
CNAP_002In4	4.325	3.827	3.154	2.932	2.617	2.518	2.024	1.685	1.154
CNAP_002In5	4.176	3.826	3.154	2.932	2.617	2.518	2.024	1.684	1.154
CNAP_002In6	3.284	3.128	2.763	2.632	2.438	2.373	2.011	1.685	1.153
CNAP_002In7	3.285	3.128	2.763	2.632	2.437	2.373	2.011	1.685	1.154
CNAP_003	3.285	3.129	2.764	2.632	2.437	2.373	2.011	1.685	1.154
CNAP_003In1	3.284	3.128	2.765	2.632	2.438	2.373	2.011	1.684	1.154
CNAP_003In2	2.641	2.498	2.208	2.111	1.955	1.902	1.669	1.482	1.134
CNAP_004	1.188	1.190	1.169	1.160	1.128	1.117	1.071	0.990	0.894
CNAP_004In1	1.772	1.769	1.769	1.668	1.598	1.570	1.418	1.334	1.113
CNAP_005US	1.958	1.921	1.911	1.872	1.782	1.743	1.518	1.399	1.147
CNAP_005_C1i	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.699	0.574
CNAP_005_C1u	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.699	0.574
005_C1_In	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.700	0.574
CNAP_005_C1d	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.700	0.574
CNAP_005_C1o	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.700	0.574
CNAP_005_C2i	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.700	0.573
CNAP_005_C2u	0.979	0.961	0.956	0.936	0.891	0.872	0.759	0.700	0.573
005_C2_In	0.979	0.961	0.955	0.936	0.891	0.872	0.759	0.700	0.573
CNAP_005_C2d	0.979	0.961	0.955	0.936	0.891	0.872	0.759	0.700	0.573
CNAP_005_C2o	0.979	0.961	0.955	0.936	0.891	0.872	0.759	0.700	0.573
CNAP_005spl	1.958	1.922	1.911	1.872	1.782	1.744	1.518	1.399	1.147
CNAP_005DS	1.958	1.922	1.911	1.872	1.782	1.744	1.518	1.399	1.147
CNAP_006	1.637	1.573	1.476	1.446	1.402	1.388	1.318	1.264	1.264
CNAP_006_Ci	1.637	1.573	1.476	1.446	1.402	1.388	1.318	1.264	1.264
CNAP_006_Cu	1.637	1.573	1.476	1.446	1.402	1.388	1.318	1.264	1.264
CNAP_006CIn1	1.637	1.573	1.476	1.446	1.403	1.388	1.317	1.261	1.132
CNAP_006CIn2	1.637	1.573	1.476	1.446	1.403	1.388	1.318	1.261	1.131
CNAP_006CIn3	1.637	1.573	1.476	1.446	1.403	1.388	1.318	1.260	1.130
CNAP_006CIn4	1.637	1.571	1.476	1.446	1.402	1.388	1.318	1.260	1.129
CNAP_006_Cd	1.637	1.570	1.476	1.447	1.402	1.388	1.318	1.260	1.128
CNAP_006_Co	1.637	1.570	1.476	1.447	1.402	1.388	1.318	1.260	1.128
CNAP_007	1.637	1.570	1.476	1.447	1.402	1.388	1.318	1.260	1.128
CNAP_008A	2.208	2.028	1.911	1.872	1.824	1.807	1.728	1.665	1.510
CNAP_009	2.208	2.028	1.912	1.873	1.824	1.807	1.728	1.665	1.510
CNAP_009In1	2.208	2.028	1.912	1.872	1.824	1.807	1.728	1.665	1.510
CNAP_010	2.208	2.027	1.912	1.873	1.825	1.807	1.728	1.665	1.510
CNAP_010B	2.208	2.027	1.912	1.873	1.825	1.807	1.728	1.665	1.510

Cross Section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CNAP_010Bd	2.208	2.027	1.912	1.873	1.825	1.807	1.728	1.665	1.510
CNAP_010d	2.208	2.027	1.912	1.873	1.825	1.807	1.728	1.665	1.510
CNAP_011	2.208	2.027	1.912	1.873	1.824	1.807	1.728	1.665	1.510
CNAP_011In1	2.254	2.154	2.009	1.970	1.910	1.890	1.794	1.721	1.549
CNAP_012	2.255	2.153	2.008	1.969	1.909	1.889	1.793	1.721	1.550
CNAP_012A	2.256	2.153	2.007	1.968	1.908	1.888	1.795	1.724	1.551
CNAP_012A_R	1.437	1.384	1.317	1.298	1.269	1.262	1.217	1.172	1.101
CNAP_013	0.479	0.461	0.455	0.463	0.458	0.456	0.471	0.460	0.460
CNAP_013In1	0.818	0.767	0.738	0.730	0.717	0.713	0.692	0.675	0.617
CNAP_014	0.761	0.726	0.705	0.699	0.690	0.688	0.675	0.664	0.622
CNAP_014In1	0.797	0.753	0.730	0.722	0.713	0.707	0.698	0.685	0.633
CNAP_015	0.807	0.752	0.725	0.720	0.710	0.704	0.699	0.684	0.631
CNAP_015A	0.555	0.522	0.507	0.504	0.498	0.495	0.493	0.485	0.454
CNAP_016	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
CNAP_016In1	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305
CNAP_016In2	0.299	0.299	0.299	0.299	0.299	0.299	0.299	0.299	0.299
CNAP_017	0.299	0.299	0.299	0.299	0.299	0.299	0.299	0.299	0.299
CNAP_017In1	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305
CNAP_018	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
CNAP_018In1	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308
CNAP_018In2	0.291	0.291	0.291	0.291	0.291	0.291	0.291	0.291	0.291
CNAP_019	0.618	0.619	0.618	0.617	0.617	0.616	0.618	0.617	0.618
CNAP_019_Ci	0.618	0.619	0.618	0.617	0.617	0.616	0.618	0.617	0.618
CNAP_019_Cu	0.618	0.619	0.618	0.617	0.617	0.616	0.618	0.617	0.618
CNAP_019I	0.618	0.619	0.618	0.617	0.617	0.616	0.618	0.617	0.618
CNAP_019_Cd	0.618	0.619	0.618	0.618	0.617	0.617	0.618	0.617	0.618
CNAP_019_Co	0.618	0.619	0.618	0.618	0.617	0.617	0.618	0.617	0.618
CNAP_020	0.618	0.619	0.618	0.618	0.617	0.617	0.618	0.617	0.618
CNAP_021	2.337	2.125	1.977	1.930	1.882	1.860	1.768	1.686	1.357
CNAP_022	2.335	2.121	1.978	1.930	1.885	1.861	1.767	1.689	1.360
CNAP_011_L1	0.171	0.142	0.113	0.105	0.093	0.090	0.072	0.060	0.041

11.3.14 To compare the impact of the proposed scheme on the baseline modelling results, depths have been extracted at the sensitivity test locations for a range of return periods in both the baseline and proposed scheme models. Figure 11-14, Figure 11-15 and Table 11-19 detail these results.

11.3.15 Water depths within the floodplain near to A95 are very sensitive to changes in the proposed A9 structure. The opening size has been optimised to provide mammal passage and for health and safety for maintenance as well as flood risk. The proposed structure constricts flow downstream ensuring there is no increased flow to receptors and holds more water within the hollow between the A9 and Drain 8 crossing. Whilst the depths increase there is no increased flood outline to this low sensitivity receptor.

Figure 11-14 Maximum flood depth grid (m) Q200- Depth Difference (Proposed-Baseline)

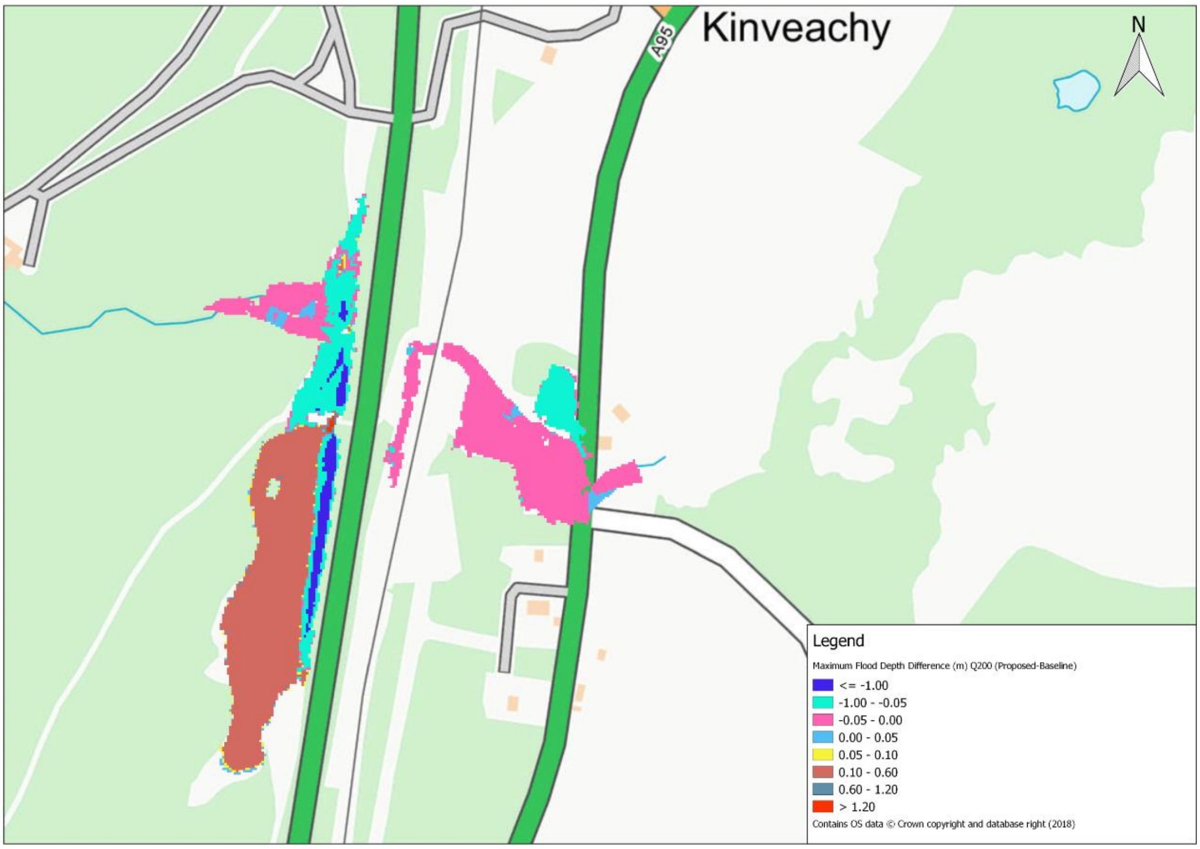


Figure 11-15 Maximum stage comparison for Q200, Baseline Vs With Scheme

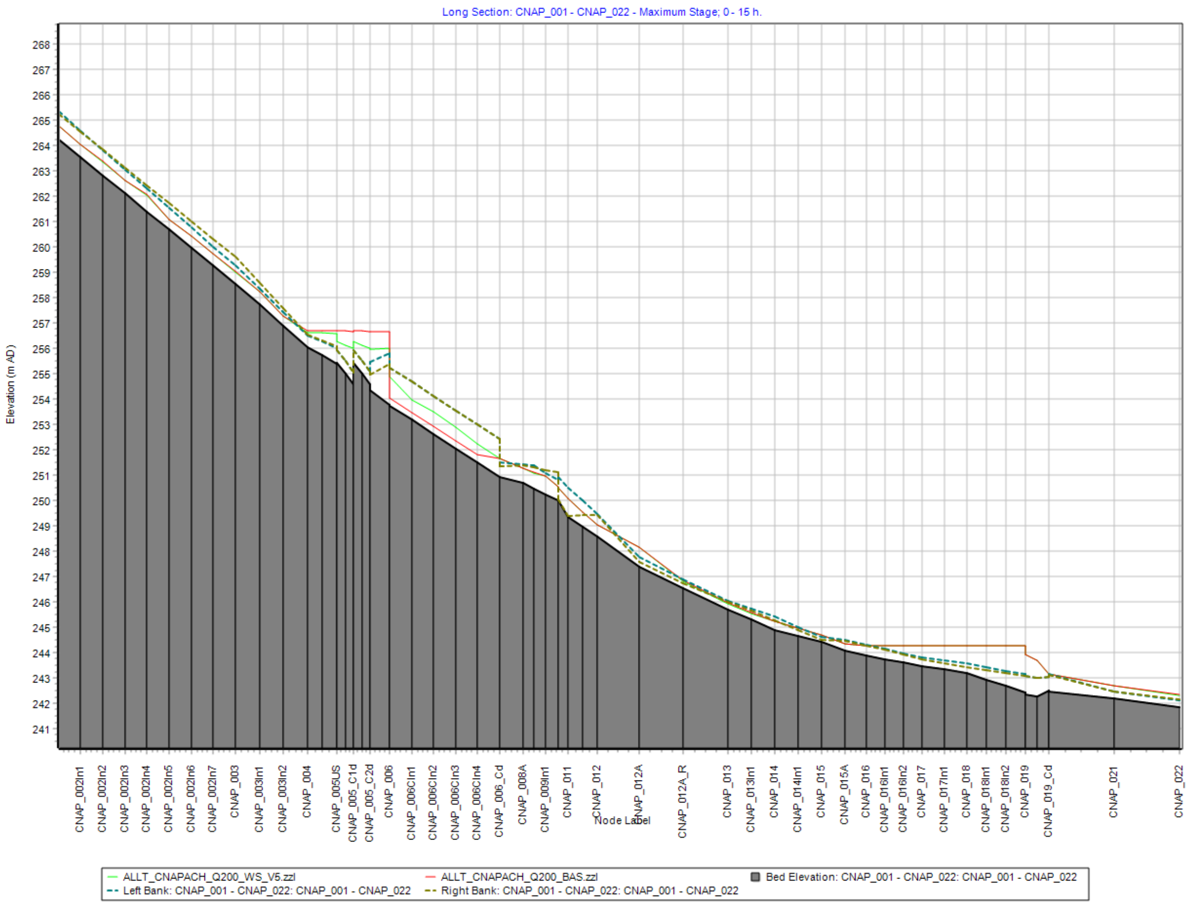


Table 11-19 Baseline and Proposed Scheme 2D Results for Q200+CC, Q200, and Q30 (depths in m)

Location	Q200+CC			Q200			Q30		
	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference
Location 1	0.075	0.074	-0.001	0.055	0.053	-0.002	0.020	0.019	-0.001
Location 2	0.830	0.179	-0.650	0.782	0.143	-0.639	0.675	0.117	-0.558
Location 3	2.410	2.484	0.074	1.945	2.272	0.327	1.072	1.894	0.822
Location 4	0.386	0.000	-0.386	0.382	0.000	-0.382	0.364	0.000	-0.364
Location 5	1.059	1.058	-0.002	1.055	1.049	-0.005	1.037	1.035	-0.002

Sensitivity Analysis

1D sensitivity. Proposed

11.3.16 In order to analyse the sensitivity of the hydraulic model, the models have been updated to represent a change in parameters. The results from the 1D have been compared against the baseline results for the 0.5% AEP event, these are shown in Table 11-20 and Table 11-21. Variation in flow is given in m^3/s and variation in stage is given in metres. Variations in stage for the long section are provided in Figure 11-16.

11.3.17 Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- Downstream Boundary +/ - 20%

11.3.18 As can be seen from the data, the proposed scheme model is sensitive to changes in flow and roughness for some sections. The maximum increase associated with a 20% increase in flow is 212mm and for increase in Manning’s roughness is 89mm. The model is not very sensitive to changes to the 50% blockage scenario but the lower reaches of the model are sensitive to changes in the downstream boundary.

Table 11-20 Allt Cnapach 1D Sensitivity Results for 0.5% AEP Event (Variation in Proposed Stage)

Cross Section	Proposed Stage (m AOD)	Variation in stage for Flow -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage Mannings -20% (m)	Variation in stage for Mannings +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage 50% blockage (m)
ALLT_CNAP_Q	277.811	-0.032	0.031	-0.032	0.031	0.000	-0.001	0.000
CNAP_001	277.811	-0.032	0.031	-0.032	0.031	0.000	-0.001	0.000
CNAP_001In1	276.983	-0.031	0.030	-0.031	0.030	0.000	0.000	0.000
CNAP_001In2	276.135	-0.028	0.027	-0.028	0.027	0.000	-0.001	0.000
CNAP_001In3	275.324	-0.029	0.029	-0.029	0.029	0.000	0.000	0.000
CNAP_001In4	274.520	-0.034	0.035	-0.034	0.035	0.000	0.000	0.000
CNAP_001In5	273.844	-0.055	0.035	-0.055	0.035	0.000	0.000	0.000
CNAP_001In6	273.044	-0.047	0.032	-0.047	0.032	0.000	0.000	0.000
CNAP_001In7	272.005	-0.030	0.029	-0.030	0.029	0.000	0.000	0.000
CNAP_001In8	271.133	-0.030	0.023	-0.030	0.023	0.000	-0.001	0.000
CNAP_001In9	270.318	-0.027	0.026	-0.027	0.026	0.000	0.000	0.000
CNAP_001In10	269.504	-0.026	0.028	-0.026	0.028	0.001	0.000	0.001
CNAP_001In11	268.694	-0.031	0.030	-0.031	0.030	0.000	0.000	0.000
CNAP_001In12	267.912	-0.039	0.025	-0.039	0.026	0.000	0.000	0.000
CNAP_001In13	267.091	-0.037	0.028	-0.037	0.028	0.000	0.000	0.000
CNAP_001In14	266.301	-0.032	0.032	-0.032	0.032	0.000	0.000	0.000
CNAP_001In15	265.470	-0.032	0.033	-0.032	0.033	0.000	0.000	0.000
CNAP_002	264.768	-0.047	0.040	-0.046	0.038	0.000	0.000	0.000
CNAP_002In1	264.041	-0.039	0.037	-0.041	0.041	0.000	0.000	0.001
CNAP_002In2	263.362	-0.057	0.061	-0.055	0.044	0.000	0.000	0.000
CNAP_002In3	262.599	-0.040	0.023	-0.045	0.036	0.000	0.000	0.000
CNAP_002In4	262.052	-0.132	0.074	-0.071	0.033	0.000	0.000	0.000
CNAP_002In5	261.093	-0.008	0.001	-0.030	0.038	0.000	0.000	0.000
CNAP_002In6	260.434	-0.037	0.022	-0.034	0.022	0.000	0.000	-0.001
CNAP_002In7	259.729	-0.023	0.004	-0.030	0.018	0.000	0.000	0.001
CNAP_003	259.003	-0.047	0.075	-0.037	0.030	-0.001	0.001	-0.001
CNAP_003In1	258.237	-0.001	0.003	0.031	0.003	0.000	0.000	-0.001
CNAP_003In2	257.252	-0.027	0.036	-0.027	0.028	-0.001	0.001	-0.001
CNAP_004	256.611	-0.028	0.065	-0.002	0.019	-0.001	0.000	-0.003
CNAP_004In1	256.591	-0.091	0.069	-0.021	0.010	0.000	0.000	-0.003
CNAP_005US	256.581	-0.097	0.068	-0.021	0.007	-0.001	0.000	-0.003
CNAP_005_C1i	256.581	-0.097	0.068	-0.021	0.007	-0.001	0.000	-0.003
CNAP_005_C1u	256.249	-0.101	0.054	-0.016	0.008	-0.001	0.001	-0.011
005_C1_In	256.113	-0.084	0.121	-0.014	0.009	-0.003	0.000	-0.015
CNAP_005_C1d	255.977	-0.077	0.207	-0.012	0.009	-0.004	0.000	-0.018
CNAP_005_C1o	255.977	-0.077	0.207	-0.012	0.009	-0.004	0.000	-0.018
CNAP_005_C2i	256.581	-0.097	0.068	-0.021	0.007	-0.001	0.000	-0.003
CNAP_005_C2u	256.250	-0.102	0.053	-0.017	0.007	-0.002	0.000	-0.012
005_C2_In	256.113	-0.084	0.121	-0.014	0.009	-0.002	0.000	-0.014

Cross Section	Proposed Stage (m AOD)	Variation in stage for Flow -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage Mannings -20% (m)	Variation in stage for Mannings +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage 50% blockage (m)
CNAP_005_C2d	255.977	-0.077	0.207	-0.012	0.009	-0.004	0.000	-0.018
CNAP_005_C2o	255.977	-0.077	0.207	-0.012	0.009	-0.004	0.000	-0.018
CNAP_005DS	255.971	-0.078	0.212	-0.012	0.010	-0.003	0.000	-0.018
CNAP_006	255.975	-0.077	0.207	-0.012	0.008	-0.004	0.000	-0.019
CNAP_006_Ci	255.975	-0.077	0.207	-0.012	0.008	-0.004	0.000	-0.019
CNAP_006_Cu	254.873	0.000	0.000	0.002	-0.002	0.000	0.000	-0.120
CNAP_006CIn1	253.971	-0.019	0.051	-0.003	0.001	-0.001	0.000	0.047
CNAP_006CIn2	253.472	0.000	0.000	0.002	-0.002	0.000	0.000	-0.023
CNAP_006CIn3	252.867	-0.017	0.047	-0.002	0.000	-0.001	0.000	0.045
CNAP_006CIn4	252.236	0.000	0.029	0.003	-0.004	0.000	0.000	0.023
CNAP_006_Cd	251.650	-0.024	0.056	-0.011	0.026	0.000	0.000	0.025
CNAP_006_Co	251.650	-0.024	0.056	-0.011	0.026	0.000	0.000	0.025
CNAP_007	251.650	-0.024	0.056	-0.011	0.026	0.000	0.000	0.025
CNAP_008A	251.242	-0.025	0.064	-0.079	0.072	0.000	0.000	0.035
CNAP_009	251.081	-0.027	0.072	-0.103	0.087	0.000	0.000	0.039
CNAP_009In1	250.934	-0.025	0.070	-0.082	0.070	0.000	-0.001	0.036
CNAP_010	250.534	-0.034	0.080	-0.092	0.089	0.001	0.000	0.052
CNAP_010d	250.494	-0.029	0.069	-0.081	0.076	0.001	0.000	0.045
CNAP_010B	250.534	-0.034	0.080	-0.092	0.089	0.001	0.000	0.052
CNAP_010Bd	250.494	-0.029	0.069	-0.081	0.076	0.001	0.000	0.045
CNAP_011	250.048	-0.040	0.042	-0.070	0.072	0.000	0.000	0.046
CNAP_011In1	249.525	-0.027	0.052	-0.075	0.071	0.000	-0.001	0.040
CNAP_012	249.012	-0.023	0.032	-0.050	0.040	0.000	0.000	0.022
CNAP_012A	248.141	-0.025	0.013	0.011	-0.040	0.000	0.000	0.010
CNAP_012A_R	246.809	-0.007	0.016	-0.032	0.037	0.000	0.000	0.012
CNAP_013	245.923	-0.010	0.030	-0.006	0.015	0.000	0.000	0.025
CNAP_013In1	245.542	-0.006	0.013	-0.020	0.022	0.001	0.000	0.011
CNAP_014	245.210	-0.004	0.009	-0.005	0.002	-0.004	0.000	0.007
CNAP_014In1	244.957	-0.001	0.005	0.006	0.009	0.005	0.000	0.008
CNAP_015	244.674	0.000	0.002	0.000	0.000	-0.002	0.001	0.003
CNAP_015A	244.324	-0.004	0.011	-0.004	0.022	0.005	0.000	0.010
CNAP_016	244.241	-0.010	0.018	-0.017	0.009	0.012	0.000	0.015
CNAP_016In1	244.241	-0.010	0.018	-0.017	0.013	0.013	0.000	0.014
CNAP_016In2	244.242	-0.011	0.018	-0.018	0.011	0.012	-0.001	0.014
CNAP_017	244.242	-0.011	0.018	-0.018	0.011	0.012	-0.001	0.014
CNAP_017In1	244.241	-0.010	0.019	-0.017	0.012	0.013	0.000	0.015
CNAP_018	244.242	-0.011	0.018	-0.018	0.011	0.012	-0.001	0.014
CNAP_018In1	244.242	-0.011	0.018	-0.017	0.011	0.012	-0.001	0.014
CNAP_018In2	244.241	-0.010	0.019	-0.016	0.012	0.013	0.000	0.015
CNAP_019	244.240	-0.010	0.018	-0.017	0.012	0.014	0.000	0.014
CNAP_019_Ci	244.240	-0.010	0.018	-0.017	0.012	0.014	0.000	0.014
CNAP_019_Cu	243.921	-0.013	0.005	-0.011	0.010	0.303	-0.005	0.005

Cross Section	Proposed Stage (m AOD)	Variation in stage for Flow - 20% (m)	Variation in stage for Flow +20% (m)	Variation in stage Mannings -20% (m)	Variation in stage for Mannings +20% (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage 50% blockage (m)
CNAP_019_Cd	243.155	-0.019	0.051	0.017	0.015	0.995	-0.004	0.040
CNAP_019_Co	243.155	-0.019	0.051	0.017	0.015	0.995	-0.004	0.040
CNAP_020	243.155	-0.019	0.051	0.017	0.015	0.995	-0.004	0.040
CNAP_021	242.656	-0.011	0.028	-0.031	0.034	1.494	0.005	0.022
CNAP_022	242.279	-0.009	0.024	-0.025	0.029	-0.153	-0.005	0.019
CNAP_011_L1	250.048	-0.040	0.042	-0.070	0.072	0.000	0.000	0.046
CNAP_019I	243.689	-0.015	0.006	-0.006	0.009	0.512	-0.006	0.006

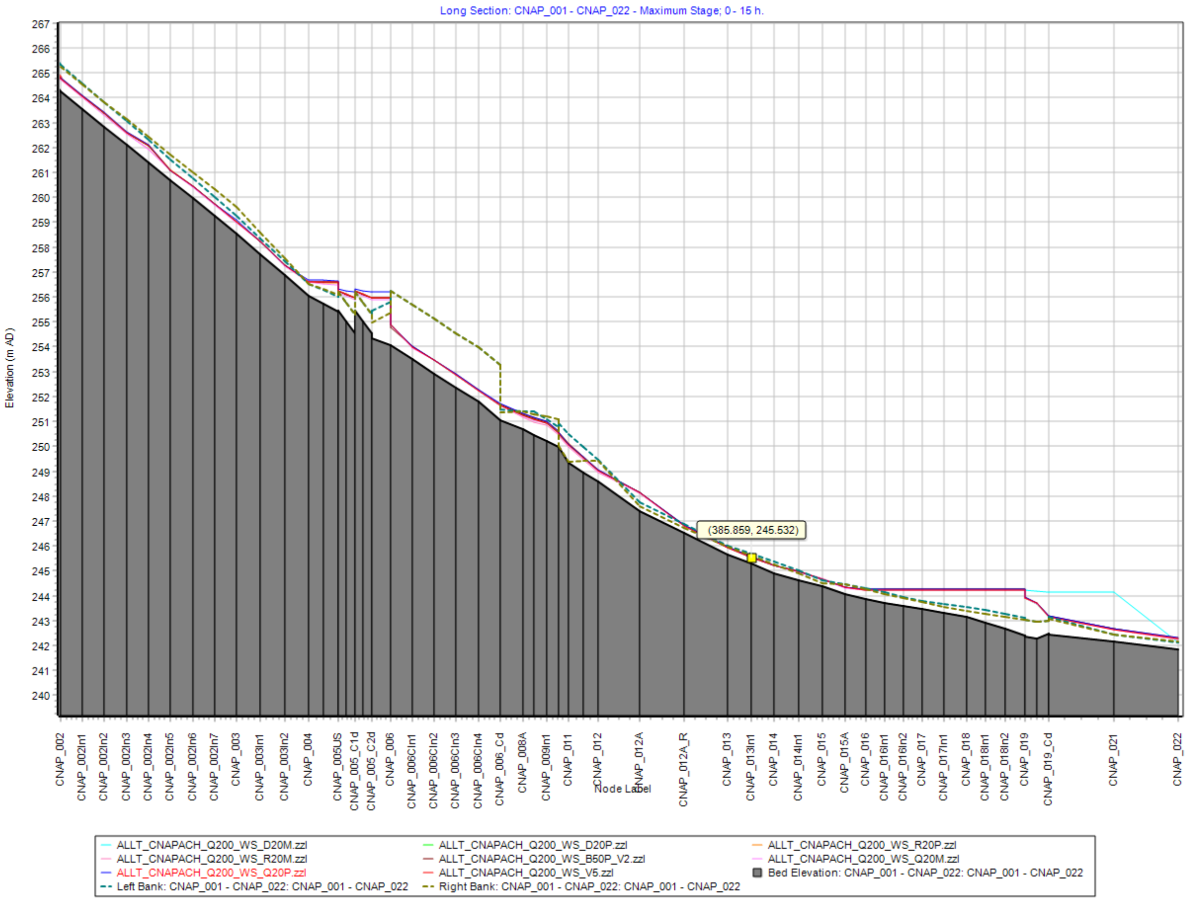
Table 11-21 Allt Cnapach 1D Sensitivity Results for 0.5% AEP Event (Variation in Proposed Flow)

Cross Section	Baseline Flow (m^3/s)	Variation in flow for Flow - 20% (m^3/s)	Variation in flow for Flow +20% (m^3/s)	Variation in flow Mannings -20% (m^3/s)	Variation in flow for Mannings +20% (m^3/s)	Variation in flow for D/S Boundary +20% (m^3/s)	Variation in flow for D/S Boundary -20% (m^3/s)	Variation in flow 50% blockage (m^3/s)
ALLT_CNAP_Q	3.968	-0.794	0.793	0.000	0.000	0.000	0.000	0.000
CNAP_001	3.968	-0.794	0.793	0.000	0.000	0.000	0.000	0.000
CNAP_001In1	3.968	-0.793	0.793	0.000	0.000	0.000	0.000	0.000
CNAP_001In2	3.969	-0.796	0.793	0.000	-0.001	0.000	0.000	-0.001
CNAP_001In3	3.968	-0.794	0.794	0.001	0.000	0.000	0.000	-0.001
CNAP_001In4	3.968	-0.794	0.795	0.002	0.000	0.001	0.002	-0.001
CNAP_001In5	3.968	-0.794	0.795	0.001	0.001	0.001	0.001	0.000
CNAP_001In6	3.967	-0.793	0.796	0.002	0.002	0.002	0.003	0.001
CNAP_001In7	3.967	-0.792	0.797	0.003	0.003	0.003	0.002	0.001
CNAP_001In8	3.969	-0.794	0.795	0.002	0.001	0.001	0.001	0.000
CNAP_001In9	3.969	-0.793	0.796	0.001	0.001	0.002	0.000	0.000
CNAP_001In10	3.970	-0.793	0.795	0.000	0.001	0.001	-0.001	-0.001
CNAP_001In11	3.970	-0.794	0.795	-0.001	0.001	0.000	-0.001	0.000
CNAP_001In12	3.970	-0.793	0.796	-0.001	0.002	0.000	0.000	0.000
CNAP_001In13	3.970	-0.793	0.795	-0.001	0.002	0.000	-0.001	0.000
CNAP_001In14	3.970	-0.792	0.795	-0.001	0.002	0.000	0.000	0.001
CNAP_001In15	3.969	-0.792	0.797	0.000	0.004	0.000	0.000	0.002
CNAP_002	3.970	-0.793	0.796	-0.001	0.003	0.000	0.000	0.001
CNAP_002In1	3.970	-0.793	0.797	0.000	0.004	0.001	0.000	0.001
CNAP_002In2	3.971	-0.793	0.795	0.000	0.002	0.001	-0.001	0.001
CNAP_002In3	3.971	-0.792	0.795	0.000	0.003	0.001	-0.001	0.000
CNAP_002In4	3.827	-0.648	0.497	0.145	-0.087	0.001	-0.004	0.001
CNAP_002In5	3.826	-0.648	0.349	0.146	-0.128	0.000	-0.005	0.000
CNAP_002In6	3.128	-0.352	0.156	0.355	-0.283	0.000	-0.003	0.000
CNAP_002In7	3.128	-0.351	0.157	0.356	-0.316	0.000	0.003	0.001
CNAP_003	3.129	-0.351	0.156	0.355	-0.314	0.000	0.001	0.001
CNAP_003In1	3.128	-0.349	0.157	0.356	-0.315	0.001	0.004	0.002

Cross Section	Baseline Flow (m^3/s)	Variation in flow for Flow -20% (m^3/s)	Variation in flow for Flow +20% (m^3/s)	Variation in flow Mannings -20% (m^3/s)	Variation in flow for Mannings +20% (m^3/s)	Variation in flow for D/S Boundary +20% (m^3/s)	Variation in flow for D/S Boundary -20% (m^3/s)	Variation in flow 50% blockage (m^3/s)
CNAP_003In2	2.498	-0.281	0.144	0.422	-0.332	0.000	0.005	-0.002
CNAP_004	1.190	-0.020	-0.002	0.293	-0.208	-0.002	0.001	-0.002
CNAP_004In1	1.769	-0.051	0.005	-0.017	-0.039	0.000	0.001	0.019
CNAP_005US	1.921	-0.011	0.041	0.022	0.001	0.001	0.003	0.019
CNAP_005_C1i	0.961	-0.006	0.020	0.011	0.000	0.000	0.001	0.009
CNAP_005_C1u	0.961	-0.006	0.020	0.011	0.000	0.000	0.001	0.009
005_C1_In	0.961	-0.006	0.020	0.011	0.000	0.000	0.001	0.009
CNAP_005_C1d	0.961	-0.006	0.020	0.011	0.000	0.000	0.001	0.009
CNAP_005_C1o	0.961	-0.006	0.020	0.011	0.000	0.000	0.001	0.009
CNAP_005_C2i	0.961	-0.006	0.020	0.010	0.000	0.000	0.001	0.009
CNAP_005_C2u	0.961	-0.006	0.020	0.010	0.000	0.000	0.001	0.009
005_C2_In	0.961	-0.006	0.020	0.010	0.000	0.000	0.001	0.009
CNAP_005_C2d	0.961	-0.006	0.020	0.010	0.000	0.000	0.001	0.009
CNAP_005_C2o	0.961	-0.006	0.020	0.010	0.000	0.000	0.001	0.009
CNAP_005DS	1.922	-0.012	0.040	0.021	-0.001	0.000	0.002	0.018
CNAP_006	1.573	-0.093	0.263	-0.014	0.010	-0.003	0.000	0.245
CNAP_006_Ci	1.573	-0.093	0.263	-0.014	0.010	-0.003	0.000	0.245
CNAP_006_Cu	1.573	-0.093	0.263	-0.014	0.010	-0.003	0.000	0.245
CNAP_006CIn1	1.573	-0.093	0.263	-0.014	0.009	-0.003	0.000	0.245
CNAP_006CIn2	1.573	-0.093	0.263	-0.014	0.009	-0.002	0.000	0.245
CNAP_006CIn3	1.573	-0.093	0.263	-0.014	0.009	-0.003	-0.001	0.244
CNAP_006CIn4	1.571	-0.091	0.265	-0.012	0.011	-0.001	0.000	0.246
CNAP_006_Cd	1.570	-0.090	0.267	-0.011	0.012	0.001	0.000	0.245
CNAP_006_Co	1.570	-0.090	0.267	-0.011	0.012	0.001	0.000	0.245
CNAP_007	1.570	-0.090	0.267	-0.011	0.012	0.001	0.000	0.245
CNAP_008A	2.028	-0.137	0.393	0.007	-0.001	-0.001	-0.001	0.220
CNAP_009	2.028	-0.137	0.392	0.008	-0.001	0.000	-0.001	0.221
CNAP_009In1	2.028	-0.137	0.392	0.007	-0.001	-0.001	-0.001	0.221
CNAP_010	2.027	-0.136	0.393	0.009	0.000	0.001	0.000	0.222
CNAP_010d	2.027	-0.136	0.393	0.009	0.000	0.001	0.000	0.222
CNAP_010B	2.027	-0.136	0.393	0.009	0.000	0.001	0.000	0.222
CNAP_010Bd	2.027	-0.136	0.393	0.009	0.000	0.001	0.000	0.222
CNAP_011	2.027	-0.136	0.393	0.009	0.000	0.001	0.000	0.222
CNAP_011In1	2.154	-0.167	0.313	0.009	0.000	-0.001	0.000	0.226
CNAP_012	2.153	-0.166	0.314	0.010	0.001	0.000	0.001	0.227
CNAP_012A	2.153	-0.166	0.315	0.014	0.002	0.001	0.000	0.225
CNAP_012A_R	1.384	-0.076	0.153	-0.013	0.000	0.002	0.001	0.110
CNAP_013	0.461	-0.006	0.030	0.117	-0.017	0.002	0.000	0.025
CNAP_013In1	0.767	-0.034	0.092	0.063	-0.027	0.001	0.000	0.076
CNAP_014	0.726	-0.025	0.062	0.096	-0.065	0.000	0.000	0.051
CNAP_014In1	0.753	-0.027	0.075	0.092	-0.057	-0.002	0.001	0.063

Cross Section	Baseline Flow (m^3/s)	Variation in flow for Flow -20% (m^3/s)	Variation in flow for Flow +20% (m^3/s)	Variation in flow Mannings -20% (m^3/s)	Variation in flow for Mannings +20% (m^3/s)	Variation in flow for D/S Boundary +20% (m^3/s)	Variation in flow for D/S Boundary -20% (m^3/s)	Variation in flow 50% blockage (m^3/s)
CNAP_015	0.752	-0.029	0.090	0.088	-0.041	-0.006	0.001	0.079
CNAP_015A	0.522	-0.016	0.054	0.096	-0.061	-0.011	0.000	0.048
CNAP_016	0.294	0.000	0.000	0.030	-0.011	-0.001	0.000	0.000
CNAP_016In1	0.305	0.000	0.000	0.010	-0.011	0.000	0.000	0.000
CNAP_016In2	0.299	0.000	0.000	0.009	-0.011	0.000	0.000	0.000
CNAP_017	0.299	0.000	0.000	0.010	-0.012	0.000	0.000	0.000
CNAP_017In1	0.305	0.001	0.000	0.007	-0.007	0.000	0.001	0.000
CNAP_018	0.294	-0.001	0.000	-0.001	-0.001	0.001	-0.001	0.000
CNAP_018In1	0.308	0.001	0.000	0.002	-0.001	-0.002	0.003	0.000
CNAP_018In2	0.291	0.000	0.000	0.001	-0.001	0.006	-0.005	0.000
CNAP_019	0.619	-0.003	-0.002	-0.004	-0.024	-0.102	-0.030	-0.001
CNAP_019_Ci	0.619	-0.003	-0.002	-0.004	-0.024	-0.102	-0.030	-0.001
CNAP_019_Cu	0.619	-0.003	-0.002	-0.004	-0.024	-0.102	-0.030	-0.001
CNAP_019_Cd	0.619	-0.002	-0.001	-0.004	-0.024	-0.102	-0.030	-0.001
CNAP_019_Co	0.619	-0.002	-0.001	-0.004	-0.024	-0.102	-0.030	-0.001
CNAP_020	0.619	-0.002	-0.001	-0.004	-0.024	-0.102	-0.030	-0.001
CNAP_021	2.125	-0.172	0.437	-0.066	0.086	-1.419	0.001	0.344
CNAP_022	2.121	-0.173	0.440	-0.062	0.089	-1.543	0.002	0.347
Lateral_DS	0.142	-0.028	0.029	0.000	0.000	0.000	0.000	0.000
CNAP_011_L1	0.142	-0.028	0.029	0.000	0.000	0.000	0.000	0.000
CNAP_019I	0.619	-0.003	-0.002	-0.004	-0.024	-0.102	-0.030	-0.001

Figure 11-16 Modelled Long Section Sensitivity Results – Proposed



2D Sensitivity, Proposed

11.3.19 In order to assess the 2D sensitivity of the Proposed model, a set of 7 tests were carried out and results analysed at 5 locations throughout the 2D domain. These tests are designed to better understand how specific parameters, that are used in the calculations carried out by the model software, impact the output results, and get a better understanding into the robustness of the hydraulic model. Table 11-14 details these sensitivity test locations, and Figure 11-10 shows the location of the sensitivity test locations relative to the modelled reach and the baseline Q200+CC results.

11.3.20 Table 11-22 summarises the variation in depth in metres from the Q200 proposed depth.

Table 11-22 2D Sensitivity Results Proposed model, Variation from Q200 depth (m)

Sensitivity Test	Proposed	+20% Flow	-20% Flow	+20% Mann	-20% Mann	+20% DSB	-20% DSB	+ 50% Blockage
Location 1	0.053	0.021	-0.019	0.018	-0.019	0.000	0.000	0.000
Location 2	0.143	0.196	-0.017	0.001	-0.001	0.000	0.000	-0.003
Location 3	2.272	0.369	-0.439	-0.004	0.005	-0.001	-0.001	-0.089
Location 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Location 5	1.049	0.019	-0.010	0.012	-0.016	0.000	0.013	0.015

11.3.21 The Proposed Scheme model does not show much variation to the sensitivity tests at Location 1, 2, 4 and 5. The maximum variations are located at sensitivity test location 2 location 3 which is the hollow between the A9 crossing of Allt Cnapach and Drain 8.

11.4 Summary

11.4.1 The baseline model was updated post DMRB FRA stage 2 modelling, with new survey data obtained from November 2017, updated hydrology, missing structures in stage 2, improved roughness and other 2D layer modifications.

11.4.2 Hydraulic models of the existing conditions and with the Proposed Scheme included have been evaluated to assess the impact of the Proposed Scheme on risk and to derive peak flood water levels relative to the proposed structures.

11.4.3 Water depths within the floodplain near to A95 are very sensitive to changes in the proposed A9 structure. The opening size has been optimised to provide mammal passage and for health and safety for maintenance as well as flood risk. The proposed structure constricts flow downstream ensuring there is no increased flood risk to sensitive receptors of the A95 and properties. The proposed A9 structure holds more water upstream of the A9 within the hollow between the A9 and Drain 8 crossing. Whilst the depths increase there is no increased flood outline to this low sensitivity receptor.

11.4.4 Flood risk impacts have been mitigated through optimising the structure opening size and no further mitigation measures are required.

12. Feith Mhor

12.1.1 The Feith Mhor Burn has a catchment area of around 3 km^2 upstream of the A9 road. The watercourse consists of two main channels, north and south, that capture runoff from the northern slope of the Carn na h-Eilde and eastern slope of Carn Lethendry respectively. Downstream of the A9, both channels converge into one upstream of the railway crossing. A third channel, middle stream, begins downstream of the A9 and converges upstream of the railway crossing. The Feith Mhor watercourse is relatively steep and flows northeast, joining the River Dulnain located at around 5 km downstream of the A9 crossing.

12.1.2 In addition to the Feith Mhor Burn are two small watercourses crossing the A9 with unknown names located approximately 300 m northwards of the Burn. Initially it was thought that these would eventually drain beneath the railway at a location north of the Feith Mhor Burn, and thus be considered separately to the Feith Mhor Burn. However, a recent Network Rail survey report of one known railway culvert at this location described it as being severely blocked.

12.1.3 Conversations with survey contractors confirmed that there did not appear to be railway crossings and that water was observed to be ponding where the channels ended. Therefore, based on the above information, it is assumed that runoff generated by these watercourses eventually drain into the northern stream of the Feith Mhor Burn, and have been routed through the same railway culvert.

12.1.4 The Feith Mhor catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment area was altered to reflect the surrounding topography.

12.1.5 Applying a distributed model, the catchment was subdivided into eight sub-catchments to take account of the small channels and any lateral inflows. Figure 12.1 shows inflow locations in the model, with Table 12.1 detailing the delineated sub-catchment areas.

Table 12-1: Feith Mhor Hydrological Estimation Points

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
Feith Mhor	Southern stream	DS-WC-36	Direct	FEH	290742	820727	2.4
Feith Mhor	Northern stream	DS-WC-39	Direct	FEH	290691	820872	0.60
Feith Mhor	Middle stream	Middle stream located between the A9 and Highland Mainline Railway.	Direct	Donor	290781	820832	0.009
Name unknown	Lateral Northern Stream 1	DS-WC-41	2D Direct inflow	Donor	290568	821241	0.87
Name unknown	Lateral Northern Stream 2-3	Inflow associated with ‘Drain 14’ north of northern stream A9 crossing.	2D Direct inflow	Donor	290604	821146	0.02
Feith Mhor	Lateral Northern Stream 4	Lateral inflow north of the northern stream between A9 and the Highland Mainline Railway	Lateral	Donor	290775	820908	0.14
Feith Mhor	Lateral Southern Stream	Lateral inflow between the Southern Stream and	Lateral	Donor	290796	820766	0.19

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
		the Highland Mainline Railway					
Feith Mhor	Lateral downstream of confluence	Lateral inflow downstream of the Highland Mainline Railway	Lateral	Donor	290884	820928	0.52

12.1.6 Peak flows were calculated for each inflow using the FEH Rainfall Runoff methods. Given the size of the catchment, a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the FEH Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model. Table 12.2 shows the calculated peak flows.

Table 12-2: Feith Mhor Peak Flows

Watercourse	Inflow ID	Inflow Location	0.5%	0.5% +CC
Feith Mhor	Southern stream	DS-WC-36	6.19	7.43
Feith Mhor	Northern stream	DS-WC-39	1.42	1.70
Feith Mhor	Middle stream	Middle stream located between the A9 and Highland Mainline Railway.	0.035	0.042
Name unknown	Lateral Northern Stream 1	DS-WC-41	2.86	3.43
Name unknown	Lateral Northern Stream 2-3	Inflow associated with 'Drain 14' north of northern stream A9 crossing.	0.07	0.08
Feith Mhor	Lateral Northern Stream 4	Lateral inflow north of the northern stream between A9 and the Highland Mainline Railway	0.47	0.56
Feith Mhor	Lateral Southern Stream	Lateral inflow between the Southern Stream and the Highland Mainline Railway.	0.74	0.88
Feith Mhor	Lateral downstream of confluence	Lateral inflow downstream of the Highland Mainline Railway	2.0	2.4

12.1.7 Hydrographs were generated from the FEH Rainfall Runoff method.

12.2 Baseline Hydraulic Model

12.2.1 The baseline model can be split into two areas; north and south. The northern portion of the model, along with one drain situated between northern and southern Feith Mhor Burn watercourses, has been simulated in 1D ESTRY due the limited availability of detailed information and the small size of the contributing drains/watercourses, while the southern portion of the model, incorporating the main tributaries of the Feith Mhor Burn, has been simulated in 1d/2d ISIS-TUFLOW.

12.2.2 The 1D ISIS model extends from around 170 m upstream of the A9 crossing to around 80 m downstream of the railway crossing. The upstream boundaries of the model are located at 290650 820627, 290615 820845 and 290780 820832; one for each of the main channels. NGR co-ordinates for the downstream boundary are 290890 820955.

12.2.3 Table 12.3 details the model extents and key features represented in the 1D ISIS element of the model. Figure 12.1 shows the hydraulic model schematic.

Table 12-3: Feith Mhor Key 1D Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of Cross Sections	Number of A9 Crossings	Total number of modelled structures
Feith Mhor	780	290650, 820627	290889, 820955	35	2	3

12.2.4 The 1D ESTRY portion of the model includes three watercourse crossing located at 290552 821233, 290596 821123 and 290702 820838.

12.2.5 The 2D domain has a dimension of 625m x 820m and uses a 5m grid. The models were run using time steps of 0.5 second in the 1D model and 1 second in the 2D domain. A Normal Depth boundary was used at the downstream extent of all the models. Figure 12.1 shows the hydraulic model schematic.

12.2.6 The open channel river sections were defined from the topography survey, with the Manning's 'n' values defined from the site visits, which were undertaken in March 2016. Table 12.4 provides the manning value range for 1D and 2D portions of the model and justification of the value.

Table 12-4: Feith Mhor Manning 'n' Values

Section Type	Minimum	Maximum	Commentary
1D			
River Channel	0.040	0.055	Straight channel, no major meandering. Gravel substrate with some weeds and stones
Structures	0.020	0.040	Natural river gravels on invert and brickwork walls
Access track	0.080	0.120	Non-sealed earth, low lying access track obstacle
2D			
Floodplain	0.045	0.060	Ranging from Scattered brush, heavy weeds

12.2.7 Table 12.5 provides the details of how all structures are represented within the model and Figure 12.1 shows the location of all modelled structures.

12.2.8 Circular and vertical ellipse conduits have been used to represent the north and south Feith Mhor watercourse and the railway bridge in 1D ISIS.

12.2.9 Three additional A9 crossings have been represented as 1D conduits in ESTRY-TUFLOW. Drain 12 is located between the northern and southern streams, with no known watercourse, whilst Drain 14 and A9 1170 C81 relate to small watercourse crossings north of the Feith Mhor Burn. A 2d gully line has been used to represent the small ditch surveyed downstream of A9 1170 C81, while no define watercourse was identified at Drain 14.

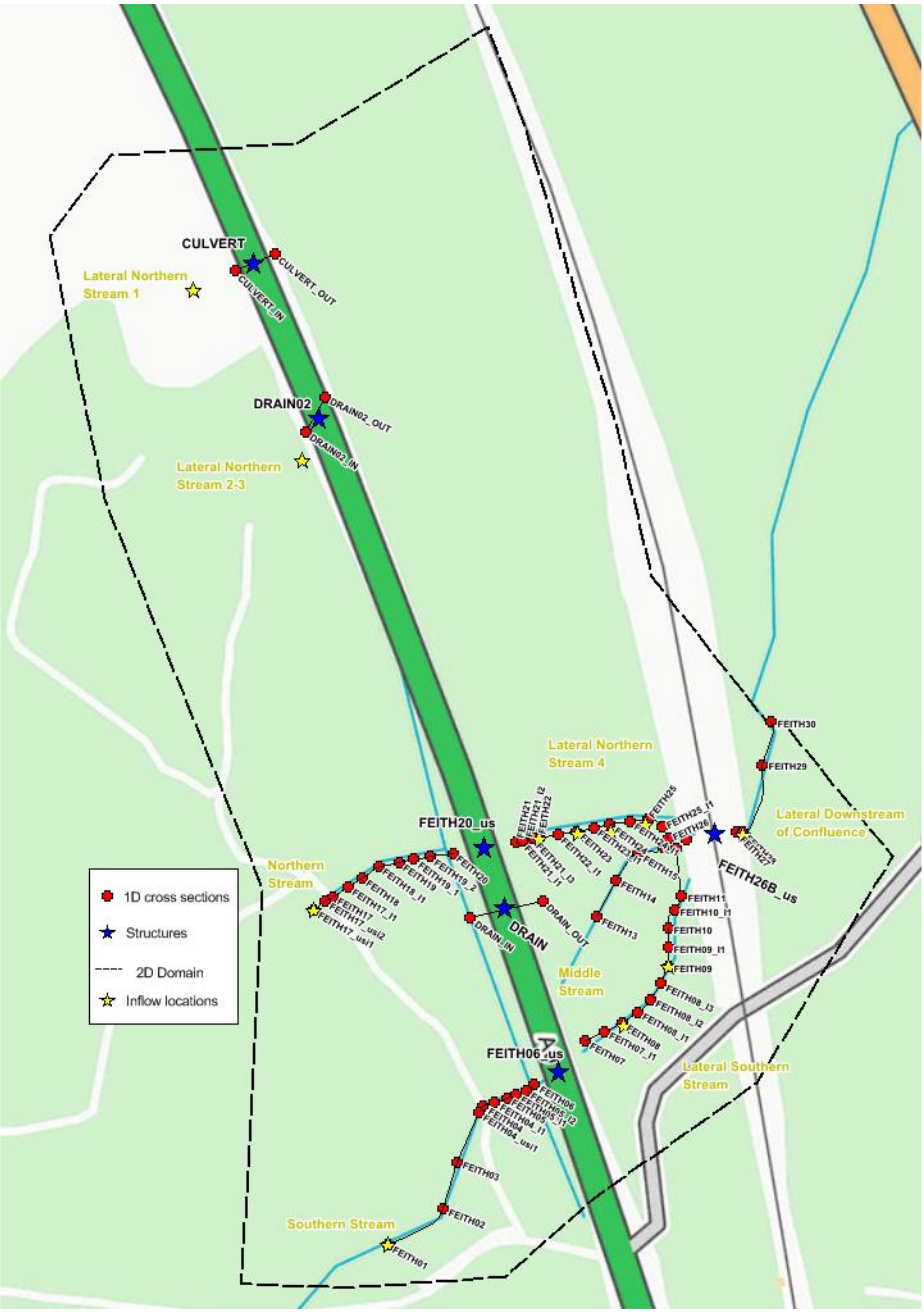
12.2.10 It should be noted that an access track travels from north-south upstream of the A9 and intersects the northern and southern channel between ISIS cross sections FEITH03-FEITH04, of the southern channel, and upstream of cross section FEITH17, of the northern channel. It is unknown whether culvert structures pass beneath the access track, however, survey teams did not locate structures at these locations and analysis of the ground model suggests that the track is not elevated above surrounding topography. Due to the absence of detailed information at these two locations, interpolate cross sections have been added upstream and downstream of the access track (FEITH04_usi1, and FEITH17_usi2), and in-channel Manning's 'n' values increased from between 0.08-1.12 to represent a non-sealed exposed earth, low lying access track obstacle.

Table 12-5: Feith Mhor All Modelled Structure Details

Water Crossing ID	Structure	Model ID	Water course	Dimensions (m)	Representation in the model	Photograph
DS-WC-051	A9 crossing (Northern Stream) A9 1170 C77	FEITH20_us	Feith Mhor	2.0 Ø	Represented in 1D ISIS model. Circular Conduit	
DS-WC-055	A9 crossing (Southern Stream) A9 1170 C75	FEITH06_us	Feith Mhor	1.58 Ø	Represented in 1D ISIS model. Circular Conduit	
Feith Mhor Railway Bridge	Railway culvert	FEITH26B_us	Feith Mhor	Height: 2.17* Width:1.26*	Represented in 1D ISIS. Vertical ellipse conduit	
DS-WC-041	A9 1170 C81 (Lateral Northern Stream 1)	CULVERT	Name unknown	Height: 1.65 Width: 1.66	Represented as 1D conduit in ESTRY-TUFLOW.	
Lateral Northern Stream 2-3	'Drain 14' (Lateral Northern Stream 2-3)	DRAIN_02	Name unknown	0.5 Ø	Represented as 1D conduit in ESTRY-TUFLOW.	No image available
A9 drainage crossing	'Drain 12'	DRAIN	No watercourse	0.5 Ø	Represented as 1D conduit in ESTRY-TUFLOW.	No image available

12.2.11 *Note that surveyed bridge openings upstream and downstream of the railway vary in dimension. As a conservative approach, the smaller opening has been used for modelling purposes.

Figure 12-1. 1D Model Schematic

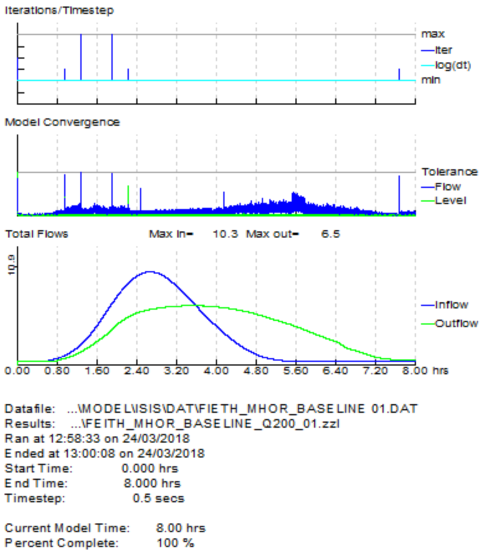


Baseline Model Performance

1D model performance

12.2.12 Run performance has been monitored throughout the model build process and then during each simulation carried out to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Figure 12.2 shows model convergence for the 0.5% AEP event.

Figure 12-2. 1D Model Convergence for the 0.5% AEP Event

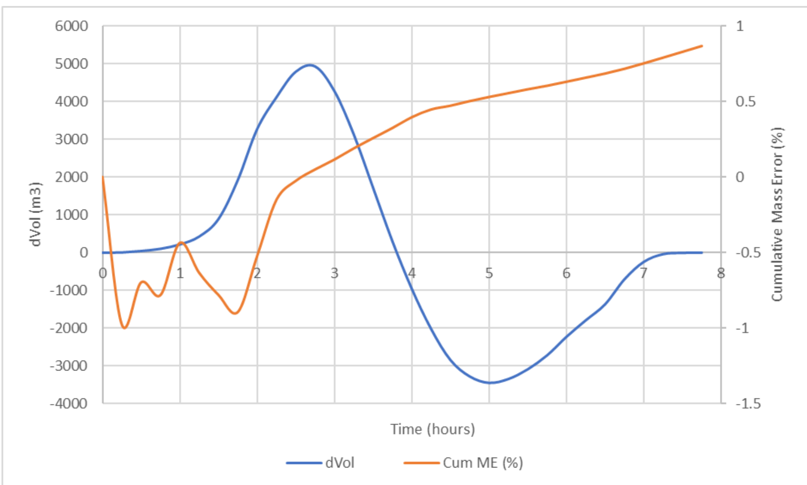


2D model performance

12.2.13 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The latest TUFLOW guidance does state that this can raise to 3% with anything above the higher value indicating an underlying issue with the model. The mass balance of the model is within the 1% range for the duration of the flood event (Figure 12.3).

12.2.14 The change in volume curve shows a broadly smooth variation which is another indicator of stable computation within the 2D domain during the simulation process.

Figure 12-3. Baseline 0.5% AEP Event Tuflow 2D Cumulative Mass Error (%) and Change in Volume (dVol)



Sensitivity Analysis

12.2.15 To analyse the sensitivity of the hydraulic models, the models have been updated to represent a change in parameters. The results from both the 1D and 2D domains have been compared against the baseline results. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- 50% blockage scenario
- Downstream Boundary +/ - 20%

12.2.16 The sensitivity of the 1D is tested using the surveyed cross sections. To test the sensitivity within the 2D domain seven locations have been selected in the 2D floodplain based on their proximity to sensitive receptors and the A9. Figure 12.4 shows the locations of the sensitivity tests, and Table 12.6 below provides the Grid Reference.

Table 12-6: Feith Mhor 2D Results Location

	Location of sensitivity test.	Sensitive Receptor	Easting	Northing
NGR of Sensitivity test locations at Feith Mhor south	1	Upstream of A9, on Right hand side of the Northern reach.	290685	820839
	2	Upstream of A9, on RHS of the Southern reach.	290729	820690
	3	Downstream of the A9 on the RHS of the floodplain, upstream of the railway.	290842	820816
	4	Downstream of the A9 on the LHS of the floodplain upstream of the Railway	290800	821011
NGR of Sensitivity test locations at Feith Mhor north	5	Upstream of A9, on Right hand side of the Northern reach.	290563	821197
	6	Downstream of the A9 on the RHS of the floodplain, upstream of the railway.	290765	821159
	7	Downstream of the A9 on the LHS of the floodplain upstream of the Railway	290730	821293

12.2.17 Table 12.7 shows the variation in baseline for each of the modelled survey cross sections. Figures 12.5-12.8 shows variation within the modelled long section for each of the modelled watercourse.

12.2.18 Change of Manning’s roughness by +/- 20% results in sensible and uniform changes. The change in water levels is around 0.01 and 0.41 m. The most notable changes in water level are immediately upstream of the culvert crossings, particularly the railway culvert where highest variances occur.

12.2.19 Increase and decrease of the downstream boundary rating curve by 20% results in a change in water level of between 0.01 and 0.21m in 1D channel areas immediately upstream and downstream of the railway bridge. These results suggest that the model is not particularly sensitive to a reduction in downstream water levels. There are no impacts on 2D sensitivity locations as a results of downstream boundary testing.

12.2.20 Increase and decrease of flow by 20% results in a change in water level of between +/-0.01 and 0.42m. As expected, changes in water level occur immediately upstream of culvert crossings and at cross sections located between the A9 and railway. Relatively small changes occur downstream of the railway and at the upstream end of the northern and southern reaches.

12.2.21 Blockage of the railway culvert has the most impact across watercourse cross sections with a consistent increase in water levels between the railway and A9 of 0.58m. Increase in levels propagates upstream of the A9 as far as cross section FEITH19 of the northern stream.

12.2.22 Blockage of FEITH20_us has minimum impact on water levels with increases from 0.02-0.33m limited to immediately upstream of the culvert.

12.2.23 Blockage of FEITH06_us causes upstream water levels to increase by 0.01-0.25m. This increase in water causes additional flow northwards, parallel to the A9 and eventual discharge into the northern stream. As such water levels upstream of FEITH20_us increase by 0.01-0.59m. Water levels downstream of the A9 stay mostly the same with a slight decrease in levels of 0.01m.

12.2.24 Blockage of CULVERT has a minimal impact on 1D water levels in the Feith Mhor Burn with a decrease of 0.01-0.03m.

12.2.25 Table 12.8 provides the summary of the 2D results at the 7 sensitivity test locations. These results follow a similar pattern to 1D variations.

Figure 12-4. 2D Sensitivity Test Locations

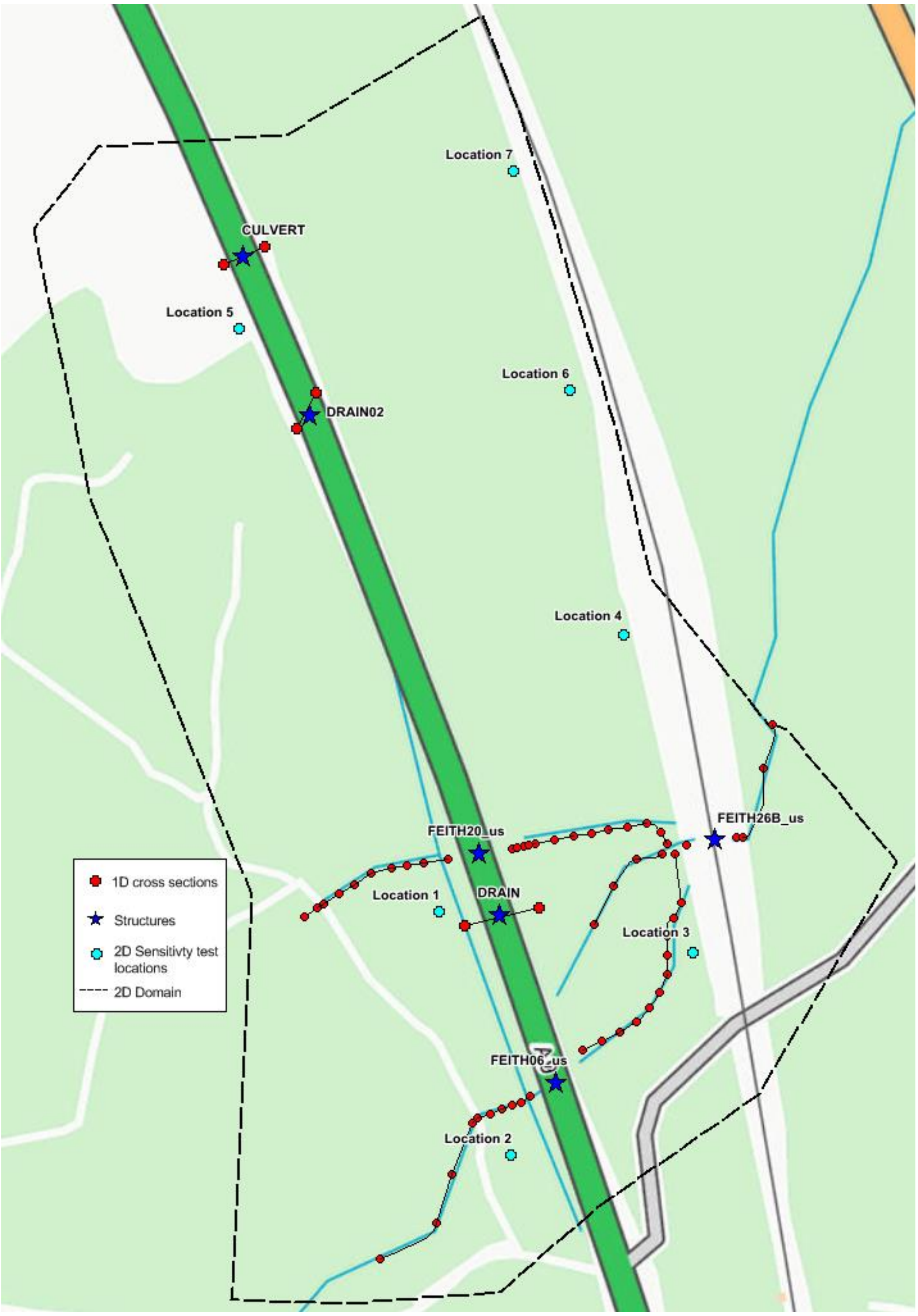


Table 12-7: Feith Mhor Burn 1D Model Sensitivity Results for 0.5% AEP Event

Cross Section	Watercourse ID	Baseline Stage (m)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
FEITH01	Southern Stream	262.042	-0.05	0.04	0.00	0.00	0.02	-0.04	0.00	0.01	0.00	0.00
FEITH02		261.099	-0.08	0.06	0.00	0.00	0.09	-0.09	0.00	-0.02	0.00	0.00
FEITH03		260.145	-0.06	0.05	0.00	0.00	0.05	-0.05	0.00	0.02	0.00	0.00
FEITH04		259.564	-0.03	0.04	0.00	0.00	0.07	-0.09	0.00	0.16	0.00	0.00
FEITH05		259.451	-0.02	0.06	0.00	0.00	0.09	-0.12	0.00	0.25	0.00	0.00
FEITH06		259.457	-0.01	0.05	0.00	0.00	0.08	-0.12	0.00	0.25	0.00	0.00
FEITH06_us		259.322	-0.17	0.09	0.00	0.00	0.07	-0.09	0.00	-0.46	0.00	0.00
FEITH06_ds		258.589	-0.07	0.04	0.00	0.00	0.19	-0.07	0.00	-0.20	0.38	0.00
FEITH07		258.396	-0.04	0.10	0.00	0.00	0.23	-0.06	0.00	-0.09	0.51	-0.01
FEITH08		258.326	-0.01	0.16	0.00	0.00	0.31	-0.28	0.00	-0.01	0.58	-0.02
FEITH09		258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH10		258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH11		258.325	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH12		258.324	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH17	Northern Stream	261.642	-0.03	0.00	0.00	0.00	0.03	-0.03	0.00	0.01	0.00	0.00
FEITH18		259.876	-0.05	0.05	0.00	0.00	0.05	-0.05	0.00	0.01	0.00	0.00
FEITH19		258.826	-0.04	0.03	0.00	0.00	0.06	-0.04	0.02	0.20	0.10	0.00
FEITH20		258.375	-0.03	0.19	0.00	0.00	0.42	-0.30	0.33	0.59	0.54	-0.03
FEITH20_us		258.365	-0.03	0.19	0.00	0.00	0.42	-0.31	0.00	0.58	0.55	-0.02
FEITH20_ds		258.333	-0.01	0.16	0.00	0.00	0.33	-0.32	0.00	0.08	0.58	-0.03
FEITH21		258.325	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.02	0.58	-0.02
FEITH22		258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.02	0.58	-0.02
FEITH23		258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH24		258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH25		258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH26		258.324	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH13	Middle Stream	258.326	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH14		258.325	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH15		258.325	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH16		258.325	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH26B	Confluence upstream of railway	258.322	-0.01	0.16	0.00	0.00	0.31	-0.31	0.00	-0.01	0.58	-0.02
FEITH26B_us		258.239	-0.41	0.24	-0.01	0.03	0.30	-0.31	0.00	-0.01	-0.68	-0.02
FEITH26B_ds		256.950	-0.07	-0.02	0.01	-0.02	0.05	-0.06	0.00	0.00	-0.16	0.00

Cross Section	Watercourse ID	Baseline Stage (m)	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
FEITH27	Downstream of railway	256.950	-0.07	-0.02	0.01	-0.02	0.05	-0.06	0.00	0.00	-0.16	0.00
FEITH28		256.913	-0.06	0.02	0.03	-0.02	0.05	-0.06	0.00	0.00	-0.14	0.00
FEITH29		256.842	-0.04	0.00	0.04	-0.03	0.06	-0.06	0.00	0.00	-0.14	-0.01
FEITH30		256.538	0.00	-0.03	0.20	-0.22	0.03	-0.04	0.00	0.00	-0.08	0.00

Table 12-8: Feith Mhor Baseline 2D Sensitivity Results for 0.5% AEP Event

Sensitivity Test	Baseline	Variation in stage for -20% Manning's (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
Feith Mhor South											
Location 1	258.94	-0.01	0.03	0.00	0.00	0.06	-0.44	0.00	0.15	0.00	0.00
Location 2	259.57	-0.03	0.04	0.00	0.00	0.07	-	0.00	0.17	0.00	0.00
A9 Crossing											
Location 3	258.33	-0.01	0.15	0.00	0.00	0.31	-0.32	0.00	-0.02	0.58	-0.02
Location 4	258.33	-0.01	0.15	0.00	0.00	0.31	-0.32	0.00	-0.02	0.58	-0.02
Feith Mhor North											
Location 5	269.15	0.00	0.01	0.00	0.00	0.11	-0.10	0.00	0.00	0.00	0.19
A9 Crossing											
Location 6	262.70	-0.02	0.01	0.00	0.00	0.01	-0.02	0.00	0.00	0.00	-0.01
Location 7	265.41	-0.02	0.01	0.00	0.00	0.02	-0.03	0.00	0.00	0.00	-0.01

Figure 12-5. Feith Mhor Southern Stream Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event

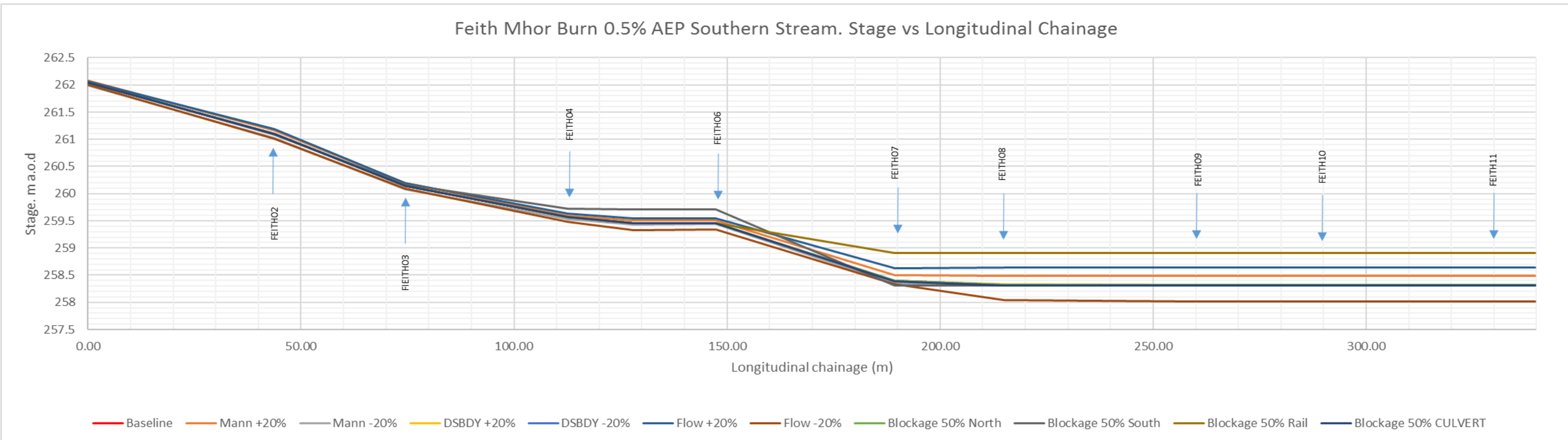


Figure 12-6. Feith Mhor Middle Stream Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event

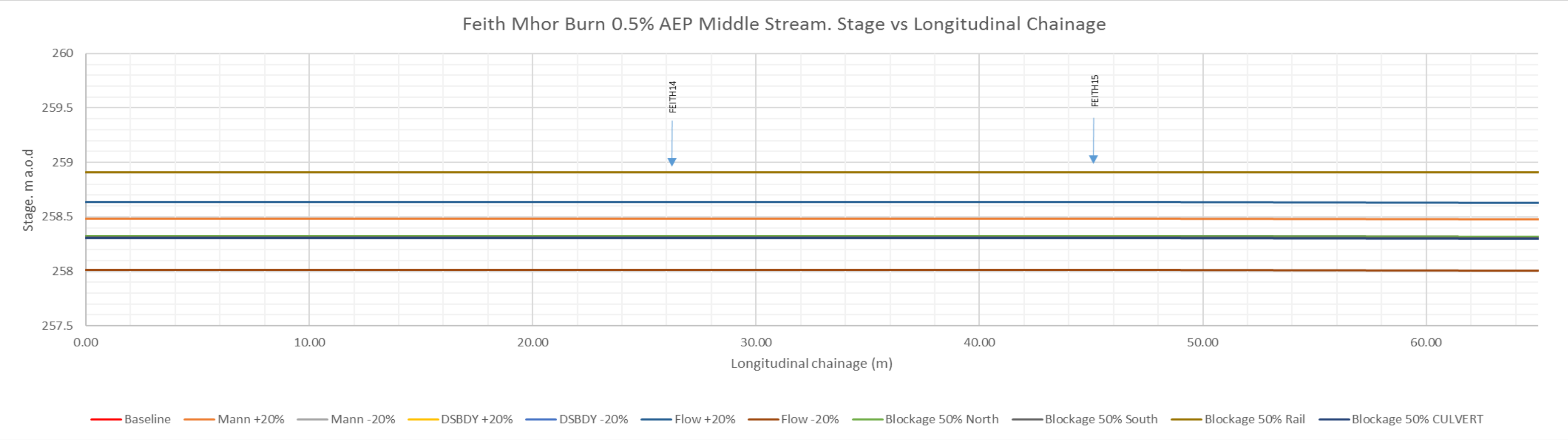


Figure 12-7. Feith Mhor Middle Stream Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event

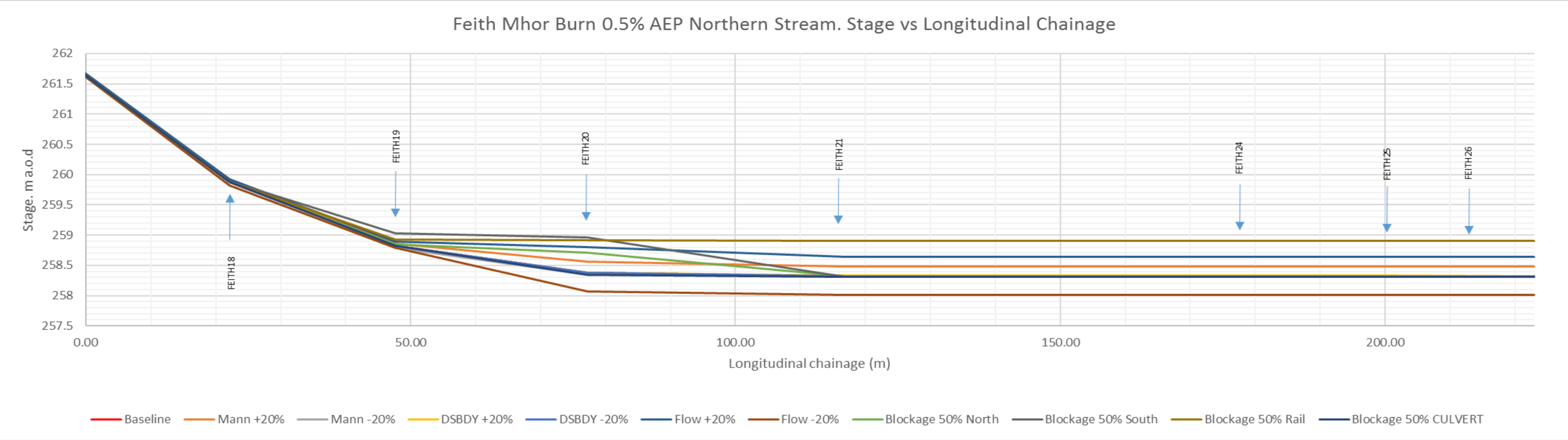
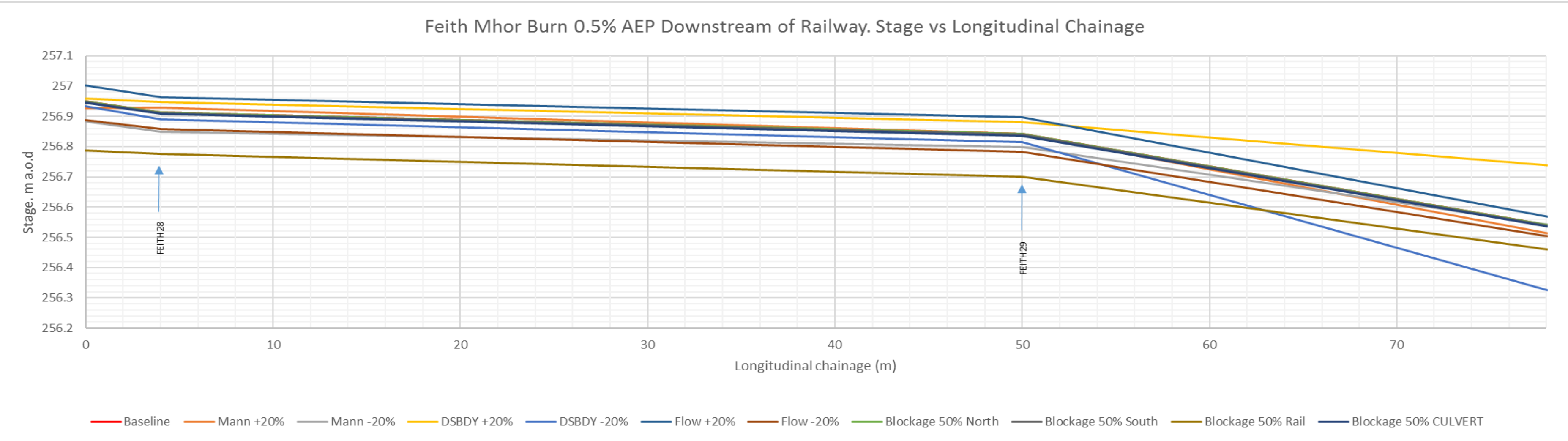


Figure 12-8. Feith Mhor Downstream of Railway Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event



12.3 Proposed Model ('with-scheme' modelling)

Proposed Scheme Changes

12.3.1 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with mainline and access track roadways. Proposed works to southern portion of the model, in the vicinity of the Feith Mhor Burn, include widening of the A9 mainline carriageway to dual-lanes in an east direction and the addition of an elevated SUDS (C14) access track running north-south parallel to the A9.

12.3.2 Culverts FEITH20_us and FEITH06_us passing beneath the A9 have each been set to a size of 1.8mx1.8m with two 500mm mammal ledges, while lengths have increase to 73m and 64m respectively, and inlet/outlet positions have been offset slightly compared to baseline.

12.3.3 An existing access track located upstream of the A9, crossing both northern and southern channels of the Feith Mhor Burn, is also proposed to be upgraded and, where previously sat roughly at the elevation of surrounding topography, will now be elevated to incorporate culverts beneath. Under baseline conditions, there does not appear to be any form of flow structure at these locations, thus to ensure ease of access and longevity of the access track, and so the access track remains passable in at least a 1.33% AEP event, culverts are required to control the watercourse and elevation of the access track (as it crosses the watercourse) is necessary. The proposed culverts have been set to the size of 1.2x1.2m and 1.8x1.8m box culverts for northern and southern channels respectively.

12.3.4 The northern portion of the Feith Mhor model also has proposed A9 widening in a downstream (easterly) directlion. CULVERT and DRAIN02 have been set to proposed sizes of a 1.8x1.8m box culvert and 0.5 m diameter circular culvert respectively. Lengths have increased to 38m for CULVERT and 75m for DRAIN02.

12.3.5 As described above, the C14 access track extends northwards, at which point it cuts across the floodplain to service the C14 SUDS pond. The access track is elevated above the ground to accommodate the inclusion of a 1.2x1.2m box culvert and DRAIN02, which again, is necessary to ensure longevity of the access track and so the access track remains passable in at least a 1.33% AEP event.

12.3.6 Table 12.9 shows proposed updates that have been made to existing structures as a result of scheme amendments and new structures included within the model.

12.3.7 Additional updates to the 1D model include the removal of cross sections downstream of the A9 to cater for the increase in width of the carriageway. All culverts passing beneath the A9 have therefore been increased in length to accommodate the widening. As such, structure invert levels have been adjusted accordingly.

12.3.8 Proposed structure inlets/outlets have all been offset from existing locations for constructability reasons. By building the culverts offline, it will allow construction to take place without contaminating the watercourse. After this, the existing watercourse will be diverted through the new culvert, and allow demolition of the existing culvert to take place, again with reduced risk of contamination of the watercourse. Constructing the culverts offline has the added benefit of realigning the watercourses to their historical alignments. These watercourses were diverted when the A9 was first constructed, and we have taken care to match them to their historical alignment wherever possible.

12.3.9 Therefore, watercourse cross sections upstream and downstream of all structures have been replaced with a standardised earthworks design that ties in with the existing channel.

12.3.10 Updates to the 2D domain ground model were undertaken using proposed scheme earthworks drawings issued as Design Refresh 7a.

12.3.11 Figure 12.9 shows proposed scheme changes including mainline widening, access tracks and SuDS ponds.

Figure 12-9. Proposed scheme schematic including mainline and access tracks

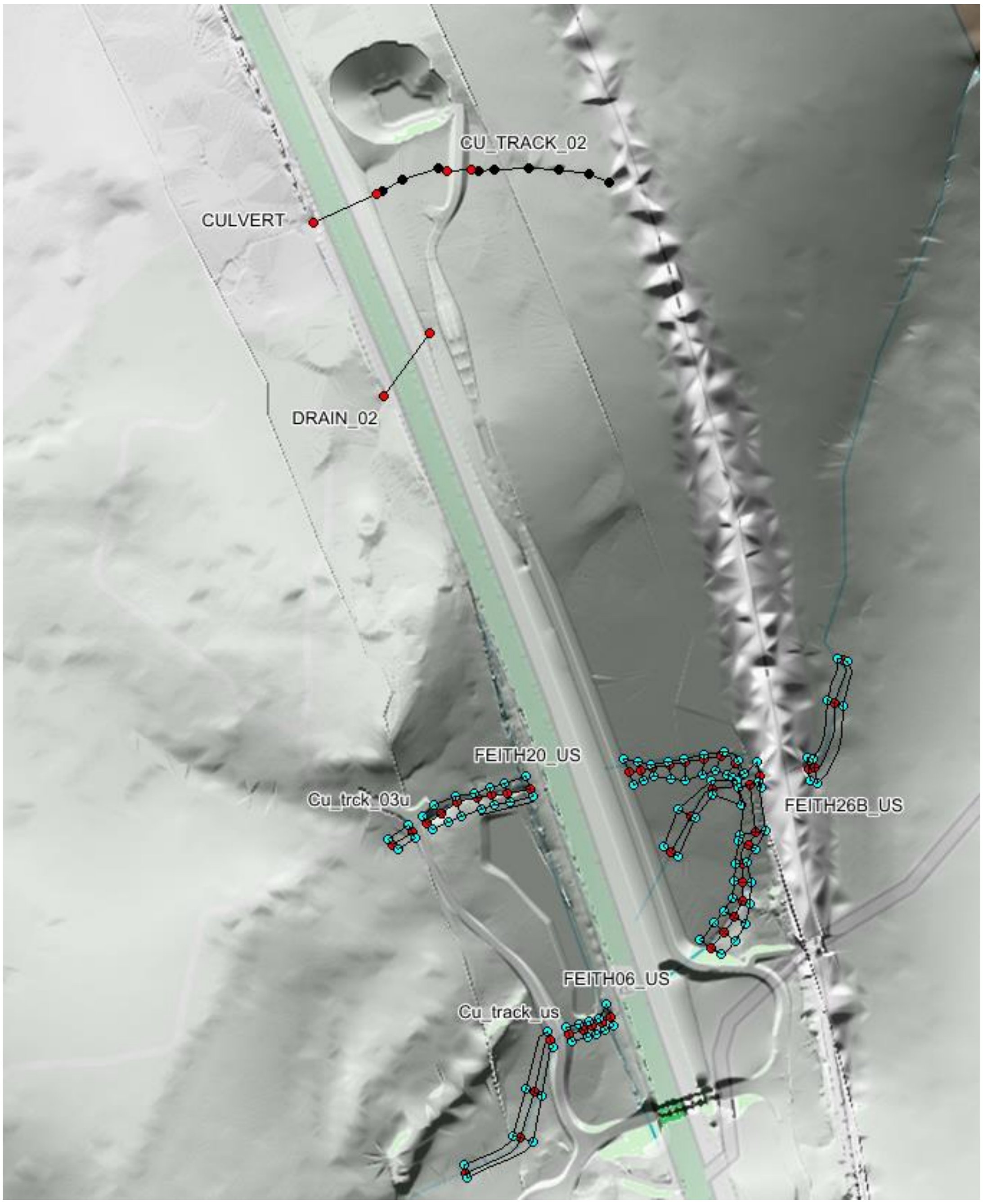


Table 12-9: Feith Mhor Proposed Scheme Modelled Structures

Water Crossing ID	Structure ID	Model ID	Water course	Dimensions (m)	Representation in the model
DS-WC-051	A9 crossing (Northern Stream) A9 1170 C77	FEITH20_us	Feith Mhor	Height: 1.8* Width: 1.8 2x500mm ML with 600mm headroom	Represented in 1D ISIS model. Symmetrical Conduit
DS-WC-055	A9 crossing (Southern Stream) A9 1170 C75	FEITH06_us	Feith Mhor	Height: 1.8* Width: 1.8 2x500mm ML with 600mm headroom	Represented in 1D ISIS model. Symmetrical Conduit
Feith Mhor Railway Bridge	Railway culvert	FEITH26B_us	Feith Mhor	Height: 2.17 Width:1.26	Represented in 1D ISIS. Vertical ellipse conduit
DS-WC-041	A9 crossing (Lateral Northern Stream 1) A9 1170 C81	CULVERT	Name unknown	Height: 1.8* Width: 1.8	Represented as 1D conduit in ESTRY-TUFLOW.
Lateral Northern Stream 2-3	'Drain 14'	DRAIN_02	Name unknown	0.5 Ø	Represented as 1D conduit in ESTRY-TUFLOW.
A9 drainage crossing	'Drain 12'	DRAIN	No watercourse	Demolished	
Access track crossing	N/A	Cu_track_us	Feith Mhor	Height: 1.8* Width: 1.8	Represented in 1D ISIS model. Rectangular conduit
Access track crossing	N/A	Cu_trck_03u	Feith Mhor	Height: 1.2* Width: 1.2	Represented in 1D ISIS model. Rectangular conduit
Access track crossing	N/A	CU_TRACK_02	Name unknown	Height: 1.2* Width: 1.2	Represented as 1D conduit in ESTRY-TUFLOW.

* Note that culvert heights have been modelled taking into consideration 300mm of bed material.

Proposed Mitigation Measures

12.3.12 The following section has been split into north and south portions of the model as although these ultimately work as one, their interaction with the A9 and changes implemented as part of the proposed scheme are different.

South

12.3.13 The encroachment of the scheme on the existing floodplain causes a loss of floodplain storage of approximately 5150m^3 for the 0.5% AEP event, between the A9 and the railway, and an increase in flood levels greater than the appropriate threshold of 10mm for all AEP events simulated. The railway is considered a very high sensitivity asset, and in order to mitigate against the increased flood levels mitigation measures were deemed necessary.

12.3.14 Two mitigation measures were considered at the site, the first involved providing like-for-like floodplain compensation between the railway and the A9. This would involve excavating into the side of existing sloping topography and would be highly constrained between the A9 and the railway. Due to the sensitivities involved with large amounts of excavation in such close proximity to the railway, this option was not progressed any further.

12.3.15 The second, preferred option, would involve the attenuation and storage of flood water upstream of the A9. The benefit of storing water upstream of the A9 is that it works with the existing processes of the watercourse and the natural topography of the area without having to undertake large amounts of excavation.

12.3.16 The southern channel of the Feith Mhor Burn provides approximately four times more flow than the northern channel, and when water backs up and spills out of bank behind culvert FEITH06_us it is naturally directed northwards towards the northern channel and culvert FEITH20_us. Retaining water upstream of the A9 requires blocking off the flow path between the southern and northern channel. By blocking this flow route, water accumulates in a natural low point located between the two culvert crossings, thus reducing the amount of flow passing beneath the A9 and reducing flood levels between the A9 and the railway.

12.3.17 To simulate this in the modelling, a bund has been set to a level of 260.3 m AOD parallel to the right bank of the northern channel, which prevents water from overflowing into the northern channel in events up to and including the 0.5% AEP. Additionally, a storage area has been defined within the natural low point in topography, with ground levels at the base of the proposed storage area set to 258.5 m AOD (the lowest point of existing topography). This provides up to 1.8m of storage depth before water overtops the bund. The total available storage behind the A9, up to the 260.3 m AOD contour, is approximately 7400 m^3, which is significantly more than the floodplain volume lost by the scheme. Note that in the baseline 0.5% AEP event, the maximum volume of water stored at this location is approximately 1000 m^3, making the net difference approximately 6400 m^3 of additional storage.

12.3.18 In more frequently occurring flood events modelled (50% AEP – 10% AEP), there is no culvert head loss associated with culvert FEITH06_us, and as such water is not directed out of bank to the proposed storage area. This means water levels between the A9 and railway are still elevated above baseline conditions. To utilise the storage area and lower water levels between the A9 and the railway under frequent flood events, the left bank of cross section FEITH05 was lowered to 258.6 m AOD, allowing water to spill into the available storage area and reducing peak flow through culvert FEITH06_us.

12.3.19 Figure 12.10 shows an overview of mitigation measures for the southern portion of Feith Mhor.

12.3.20 It should be noted that culvert FEITH06_us has been sized at 1.8mx1.8m, which is smaller than required to adequately pass the 0.5% AEP +20% CC event and does not meet ecological criteria for mammal ledges. Mammal ledges have however still been included within the culvert as further means of restricting peak flows as well as providing benefits to mammal passage during low flows. The deliberate under sizing of this culvert is proposed in order to provide sufficient attenuation of flow and storage of water behind the A9. Peak water levels are at least 600mm from the road surface.

12.3.21 FEITH20_us adequately passes the 0.5% AEP +20%CC event and has at least 600mm of freeboard between peak water levels and the road surface, but does not meet ecological criteria for mammal ledges due to outlet maximum water levels being greater than mammal ledge height in a 4% AEP event. Mammal ledges have however still been included within the culvert as they will provide benefits to mammal passage during low flows.).

12.3.22 Mitigation measures at the site have been designed to ensure that water levels are within 10 mm of baseline conditions between the A9 and the railway for all AEP events. Water levels do increase upstream of the A9, however, there are no sensitive receptors in this area and these increases are considered to be offset by the benefits of ensuring there is a neutral impact to the railway asset.

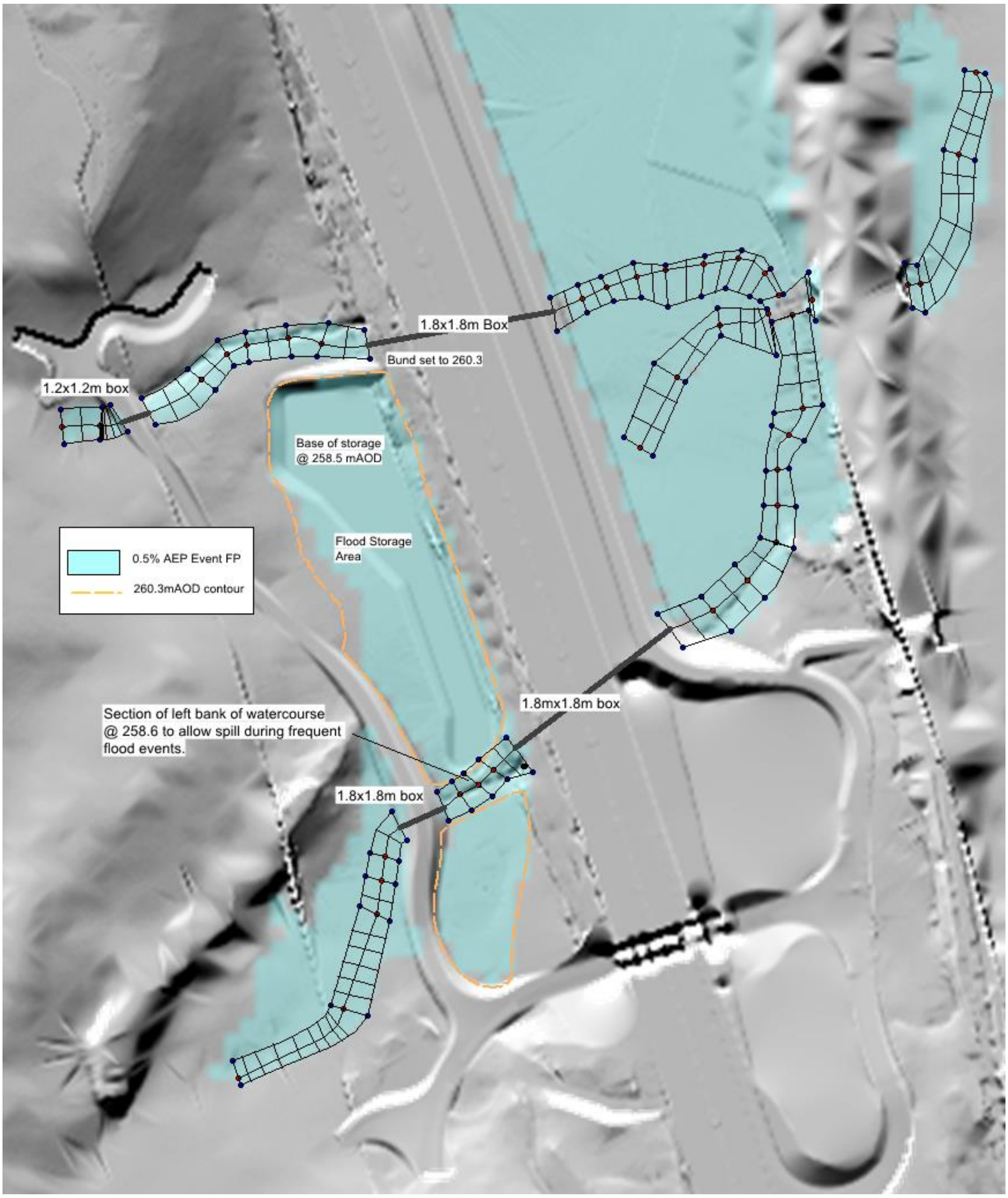
North

12.3.23 The encroachment of the scheme and access track C14 on the existing floodplain causes a loss of floodplain storage of approximately 230m^3 for the 0.5% AEP event. The majority of this loss is associated with the elevated C14 access track. Despite this loss, flood levels in close proximity to the railway have decreased in all AEP events, which is caused by water becoming impounded behind the C14 access track and the incorporated culvert controlling the flow of water that is directed towards the railway.

12.3.24 As a result, flow volume has been redistributed across the floodplain with isolated areas of increase/decrease in levels. Due to the improvement (decrease) in levels in close proximity to the railway, and the increase in levels located away from any sensitive receptors, compensatory floodplain storage is not considered necessary at this northern portion of the Feith Mhor site.

12.3.25 CULVERT and DRAIN02 both adequately pass the 0.5% AEP +20%CC event and have at least 600mm of freeboard between peak water levels and the road surface.

Figure 12-10. Mitigation measures proposed at the southern portion of Feith Mhor

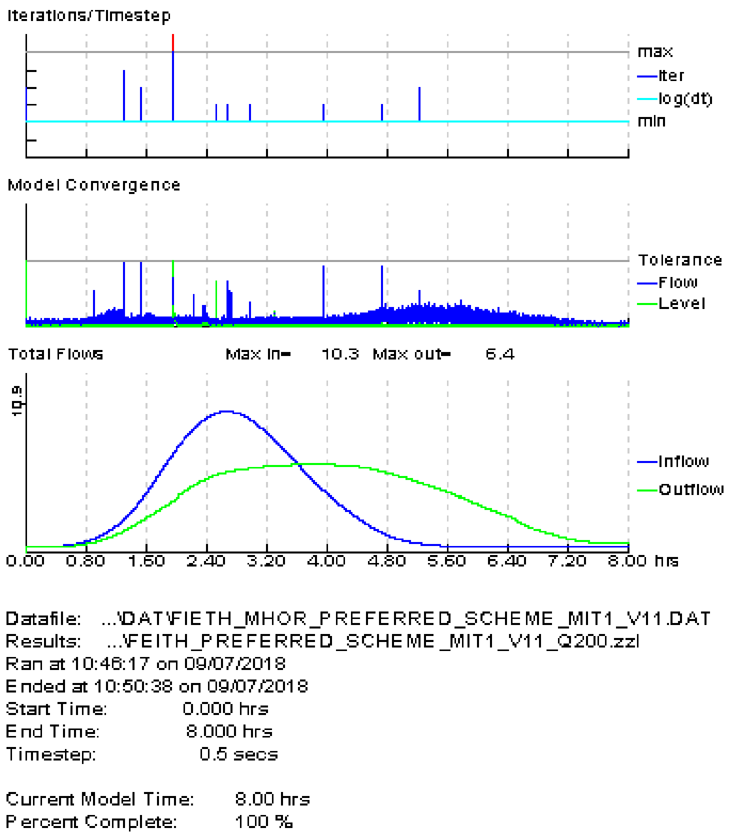


Model Performance

1D model performance

12.3.26 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Figure 12.11 shows model convergence for the 0.5% AEP event.

Figure 12-11. Scheme 1D Model Convergence for the 0.5% AEP Event

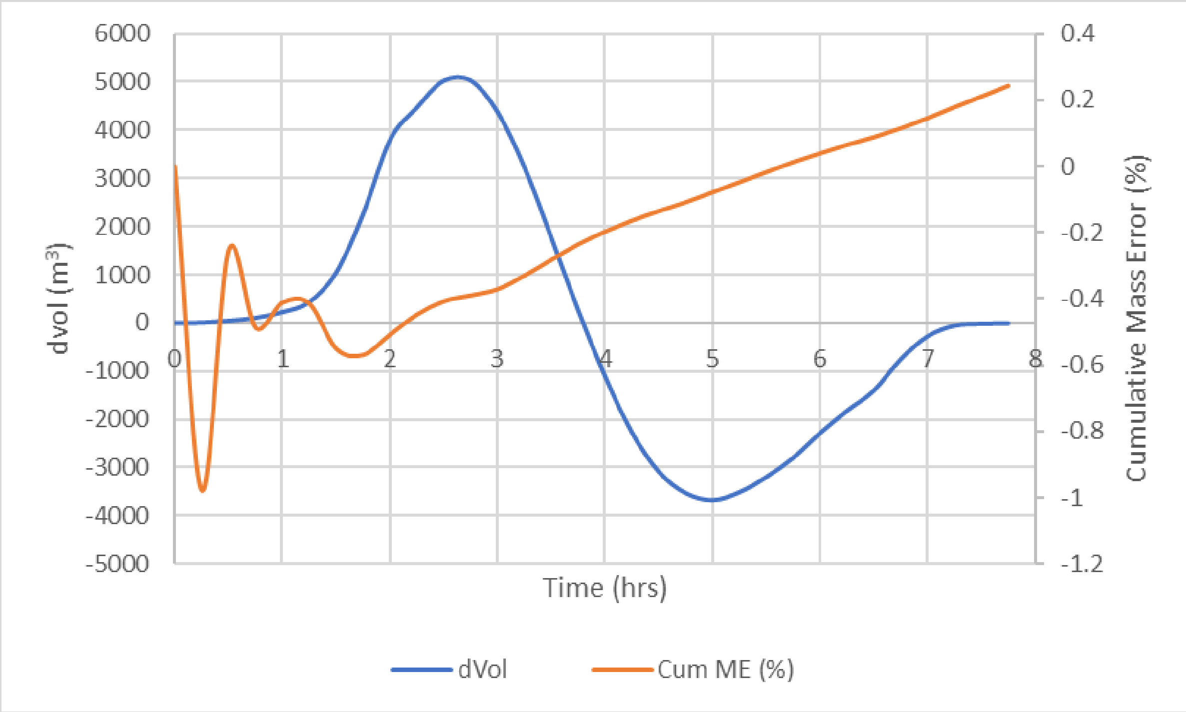


2D model performance

12.3.27 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% mass balance error. The latest TUFLOW guidance does state that this can raise to 3% with anything above the higher value indicating an underlying issue with the model. The mass balance of the 0.5% AEP event reaches -2% within the first hour of the simulation but is then comfortably within the 1% range for the remaining duration of the flood event (see Figure 12.12).

12.3.28 The change in volume curve shows a broadly smooth variation which is another indicator of stable computation within the 2D domain during the simulation process

Figure 12-12. Scheme 0.5% AEP Event Tuflow 2D Cumulative Mass Error (%) and Change in Volume (dV)



Model Results Analysis

12.3.29 The following sections provide a comparison of 1D and 2D modelling results for baseline modelling and scheme modelling with mitigation measures. As mentioned previously, the aim of the scheme model with mitigation measures was to ensure that water levels were within 10mm of baseline conditions at locations considered to be sensitive receptors, in particular, the railway.

12.3.30 It should be noted that some cross sections cannot be compared immediately upstream and downstream of the culvert crossing due to changes that have occurred to cross section geometry and invert levels, to accommodate changes made to culvert dimensions and changes made to channel alignments. Cross sections in close proximity to the railway have not changed and are considered the most important for comparison.

12.3.31 Table 12.10 provides 1D max stage results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change.

12.3.32 At the southern channel, max water levels upstream of the A9 increase at cross section FEITH01 by +0.048m to +0.092m across all AEP events, but decrease at FEITH02 by 0.027m to 0.098m. In general flooding upstream of the A9 is slightly worse due to the attenuation of flow to prevent increases in water levels at the railway.

12.3.33 At all cross sections downstream of the A9, max water levels are less than or equal to baseline conditions for all AEP events.

12.3.34 Table 12.11 provides 2D max stage results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change.

12.3.35 There is a similar trend to 2D results as for 1D. At Locations 1, now residing in the proposed storage area upstream of the A9, max water levels increase by +1.328m for the 0.5% +CC AEP event, and where previously not wetted in the baseline, increases to a depth of 0.979m in the 3.33% AEP event and 0.36m in the 50% AEP event. Similarly, at Location 2, water levels increase by +0.682m for the 0.5% +CC AEP event.

12.3.36 At Locations 3 and 4 between the A9 and the railway max water levels are less than or equal to baseline conditions for all AEP events

12.3.37 At Location 5 upstream of the A9 in the northern portion of the model, max water levels in general decrease compared to baseline conditions by approximately 0.17-0.3m for 0.5%+CC, 0.5%, 1% and 3.33% AEP events, due to the implementation of a slightly larger standardised culvert size at 1.8mx1.8m as appose to the existing 1.65mx1.65m culvert in the baseline model.

12.3.38 At Locations 6 and 7, downstream of the A9 in the northern portion of the model, max water levels are less than baseline conditions for all AEP events which is due to the impoundment and redirection of flow caused by the elevated access track.

12.3.39 Table 12.12 provides comparisons of peak flow results for all culverts crossing the A9. Peak flows across all culverts is generally consistent with the baseline for FEITH06_us, FEITH26B_us, CULVERT and DRAIN_02. Flow through culvert FEITH20_us is considerably less than baseline conditions due to the embankment associated with proposed storage prevent the transfer of water from FEITH06_us.

12.3.40 Figure 12.13 – Figure 12.15 provide comparisons of baseline and scheme flood extents for 0.5%+CC, 0.5% and 3.33% AEP events.

Table 12-10: Feith Mhor Burn Baseline and Scheme 1D Stage Results Comparison

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Southern Channel															
FEITH01	262.062	262.154	0.092	262.042	262.121	0.079	262.017	262.078	0.061	261.939	262.002	0.063	261.708	261.756	0.048
FEITH02	261.186	261.159	-0.027	261.099	261.001	-0.098	261.031	260.974	-0.057	260.919	260.879	-0.040	260.65	260.620	-0.030
FEITH10	258.637	258.641	0.004	258.326	258.317	-0.009	258.087	258.089	0.002	257.749	257.740	-0.009	257.136	257.117	-0.019
FEITH11	258.637	258.640	0.003	258.325	258.317	-0.008	258.087	258.089	0.002	257.749	257.740	-0.009	257.125	257.104	-0.021
FEITH12	258.636	258.639	0.003	258.324	258.317	-0.007	258.086	258.088	0.002	257.748	257.739	-0.009	257.122	257.101	-0.021
Northern Channel															
FEITH24	258.637	258.640	0.003	258.326	258.317	-0.009	258.087	258.089	0.002	257.749	257.740	-0.009	257.123	257.102	-0.021
FEITH25	258.637	258.640	0.003	258.326	258.317	-0.009	258.087	258.088	0.001	257.749	257.740	-0.009	257.123	257.101	-0.022
FEITH26	258.636	258.639	0.003	258.324	258.316	-0.008	258.085	258.087	0.002	257.747	257.738	-0.009	257.121	257.099	-0.022
Middle Channel															
FEITH13	258.636	258.639	0.003	258.324	258.315	-0.009	258.085	258.087	0.002	257.746	257.737	-0.009	257.118	257.097	-0.021
FEITH14	257.003	256.996	-0.007	256.95	256.945	-0.005	256.902	256.901	-0.001	256.828	256.824	-0.004	256.635	256.624	-0.011
FEITH15	256.963	256.953	-0.010	256.913	256.903	-0.010	256.872	256.864	-0.008	256.807	256.797	-0.010	256.62	256.604	-0.016

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
FEITH16	256.897	256.893	-0.004	256.842	256.837	-0.005	256.798	256.796	-0.002	256.722	256.719	-0.003	256.499	256.485	-0.014
FEITH26B	258.635	258.638	0.003	258.322	258.314	-0.008	258.083	258.084	0.001	257.742	257.732	-0.010	257.106	257.084	-0.022
Downstream of Railway															
FEITH27	257.003	256.996	-0.007	256.95	256.945	-0.005	256.902	256.901	-0.001	256.828	256.824	-0.004	256.635	256.624	-0.011
FEITH28	256.963	256.953	-0.010	256.913	256.903	-0.010	256.872	256.864	-0.008	256.807	256.797	-0.010	256.62	256.604	-0.016
FEITH29	256.897	256.893	-0.004	256.842	256.837	-0.005	256.798	256.796	-0.002	256.722	256.719	-0.003	256.499	256.485	-0.014
FEITH30	256.565	256.560	-0.005	256.538	256.527	-0.011	256.511	256.503	-0.008	256.469	256.463	-0.006	256.337	256.326	-0.011

Table 12-11: Feith Mhor Baseline 2D Sensitivity Results

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Feith Mhor South															
Location 1	258.997	260.325	1.328	258.940	260.135	1.195	258.796	259.888	1.092	-	259.579	0.979	-	258.960	0.360
Location 2	259.641	260.323	0.682	259.572	260.136	0.564	259.504	259.889	0.385	-	259.579	0.079	-	-	-
A9 Crossing															

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
Location 3	258.637	258.637	0.000	258.326	258.315	-0.011	258.087	258.089	0.002	257.750	257.744	-0.006	-	-	-
Location 4	258.637	258.637	0.000	258.326	258.315	-0.011	258.087	258.088	0.001	257.749	257.743	-0.006	257.132	257.120	-0.012
Feith Mhor North															
Location 5	269.256	268.956	-0.300	269.152	268.898	-0.254	269.075	268.864	-0.211	268.969	268.797	-0.172	268.837	-	-
A9 Crossing															
Location 6	262.713	262.708	-0.005	262.695	262.695	0.000	262.682	262.683	0.001	262.663	262.663	0.000	262.611	262.610	-0.001
Location 7	265.426	265.390	-0.036	265.406	265.393	-0.013	265.390	265.379	-0.011	265.364	265.353	-0.011	265.286	265.277	-0.009

Table 12-12: Feith Mhor Burn Baseline and Scheme Flow Results Comparison

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
FEITH06_us	5.72	5.81	+0.09	5.28	5.35	+0.07	4.87	4.77	-0.10	4.07	3.81	-0.27	1.75	1.59	-0.16
FEITH20_us	3.08	2.65	-0.43	2.04	1.43	-0.61	1.21	1.21	0.00	0.91	0.91	0.00	0.40	0.39	-0.01
FEITH26B_us	8.22	8.23	+0.01	7.14	7.11	-0.03	6.28	6.29	+0.01	5.07	5.04	-0.03	2.62	2.53	-0.09
CULVERT	3.13	3.28	+0.13	2.65	2.74	+0.09	2.29	2.34	+0.05	1.78	1.78	0.00	0.79	0.78	-0.01
DRAIN01	0.08	0.11	+0.03	0.07	0.07	0.00	0.06	0.06	0.00	0.04	0.04	0.00	0.02	0.02	0.00

Figure 12-13. Baseline and Scheme Flood Extents 3.33% AEP Event

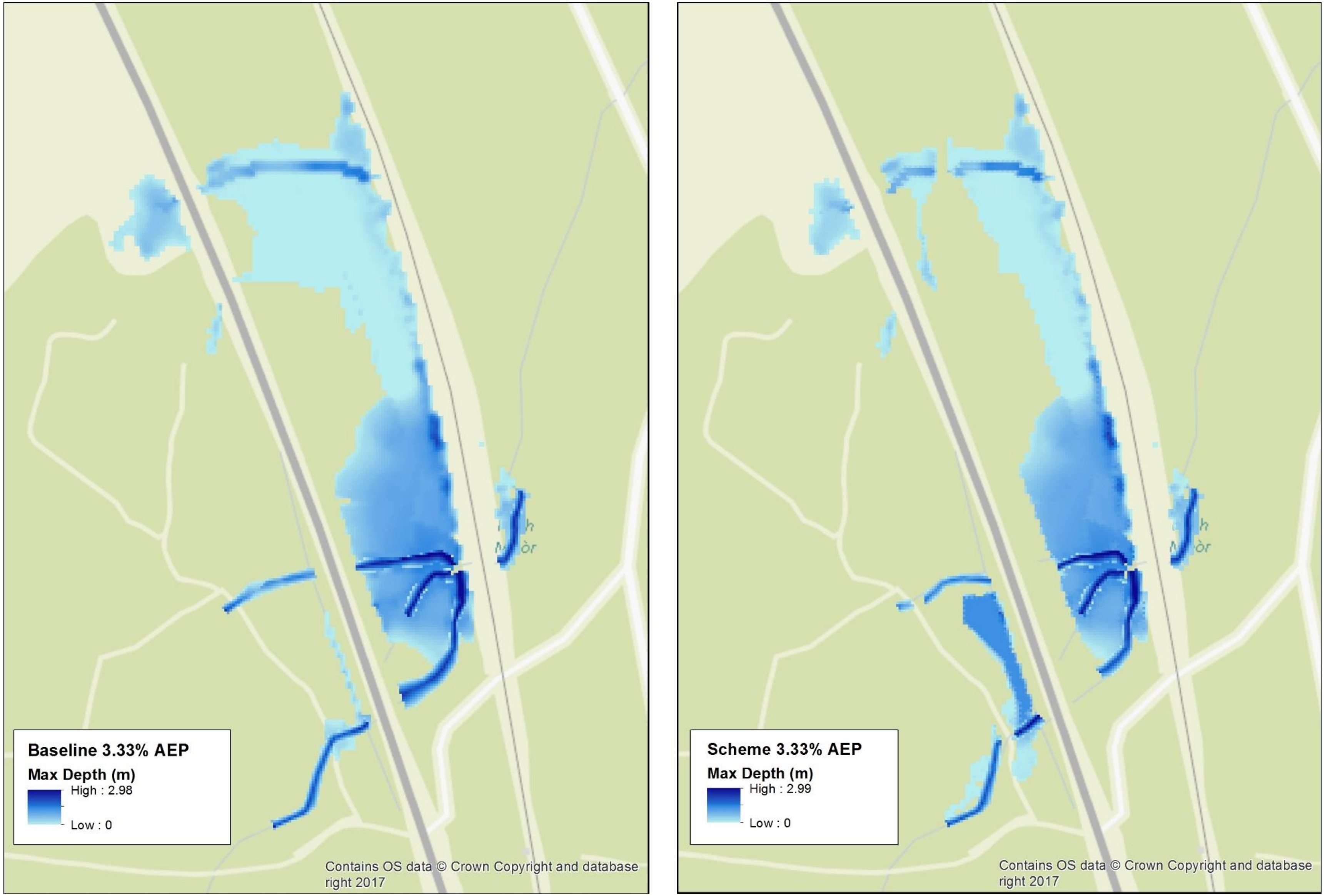


Figure 12-14. Baseline and Scheme Flood Extents 0.5% AEP Event

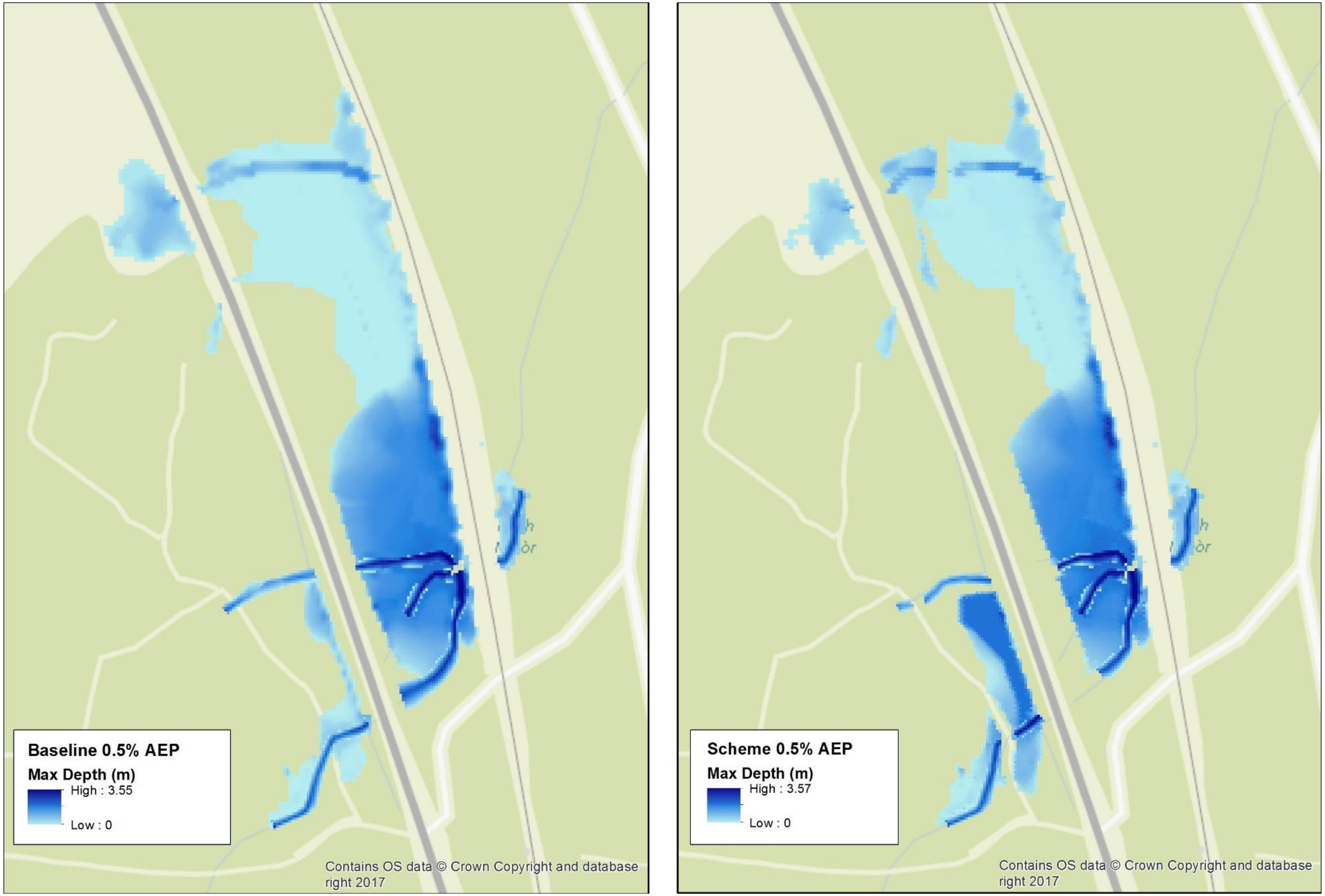
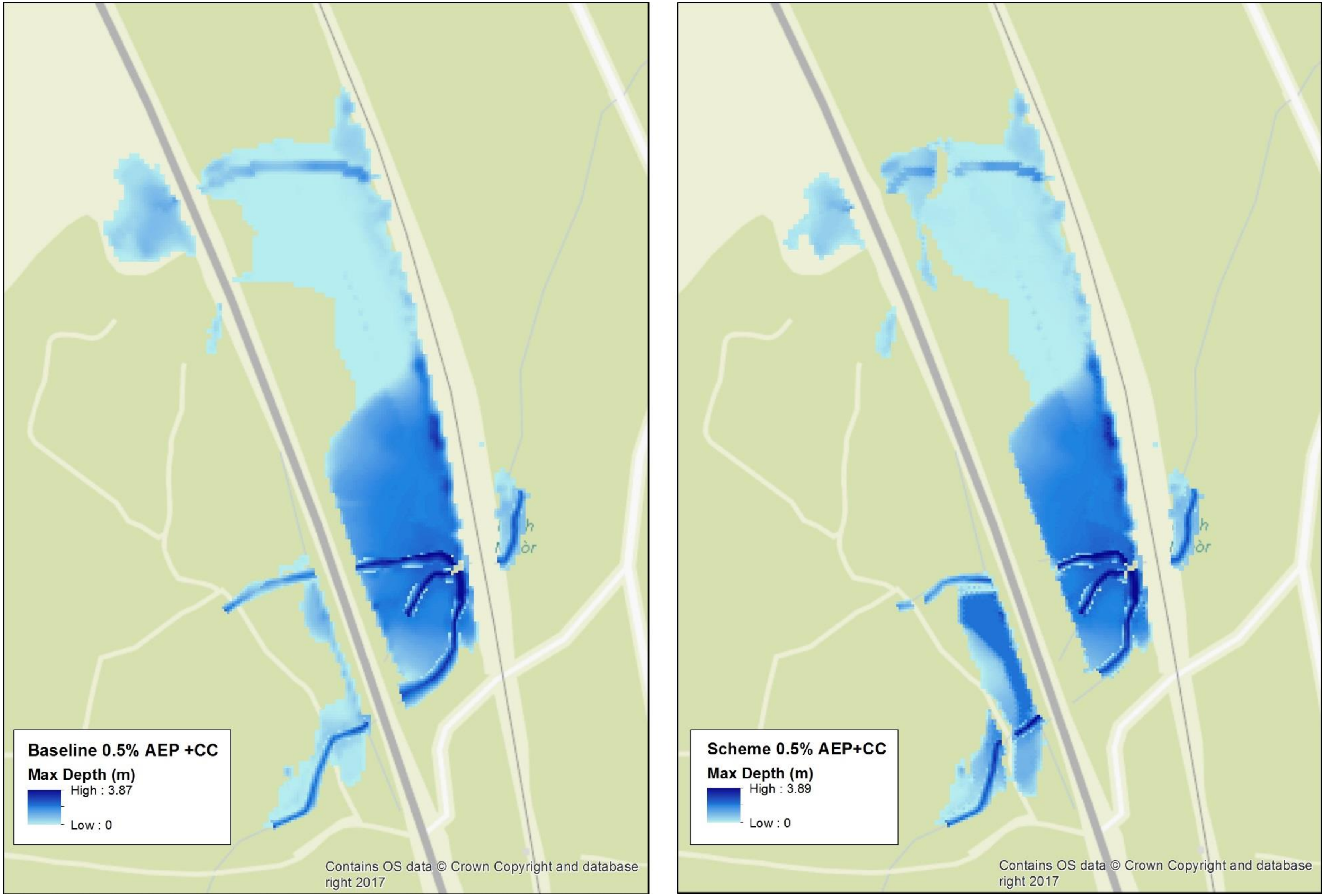


Figure 12-15. Baseline and Scheme Flood Extents 0.5% AEP +CC Event



Sensitivity Analysis

12.3.41 Sensitivity analysis was undertaken for proposed scheme modelling using the same test scenarios as baseline modelling.

12.3.42 Table 12.13 shows the variation in baseline from each of the modelled survey cross sections and Figure 12.16 – Figure 12.19 show variation within the modelled long section for each of the modelled watercourse.

12.3.43 Change of Manning's roughness by +20% results in sensible and uniform changes. The change in water levels is small around 0.01 - 0.28 m. The most notable changes in water level are immediately upstream of the culvert crossings, particularly the railway culvert where highest variances occur. There were issues with stability when running the -20% Manning's test and as such they have not been included in this part of the reporting. Based on simulations for baseline, sensitivity is likely to be minor.

12.3.44 Increase and decrease of the downstream boundary rating curve by 20% results in a minor change in water level of between +/- 0.01 - 0.21m in 1D channel areas immediately upstream and downstream of the railway bridge. There are no impacts on 2D sensitivity locations as a results of downstream boundary testing.

12.3.45 Increase and decrease of flow by 20% results in a change in water level from +/- 0.01 – 0.49m. As expected most notable changes in water level occur immediately upstream of culvert crossings and at cross sections located between the A9 and railway. Relatively small changes occur downstream of the railway.

12.3.46 Blockage of the rail culvert has the most impact at watercourse cross sections with a consistent increase in water levels between the railway and A9 of up to 1.06m. Increase in levels propagates upstream of the A9 as far as cross section FEITH19 of the northern stream but does not impact water levels upstream of the A9 for the southern stream.

12.3.47 Blockage of FEITH20_us has minimum impact on water levels with increases from 0.13-0.24m limited to immediately upstream of the culvert.

12.3.48 Blockage of FEITH06_us causes upstream water levels to increase by up to 0.34m. This increase in water causes additional flow northwards, parallel to the A9 and overtopping of the storage bund and into the northern channel. As such water levels upstream of FEITH20_us increase by up to 0.88m. Water levels downstream of the A9 stay mostly the same with a slight decrease in levels.

12.3.49 Blockage of CULVERT has a very minimal impact on water levels.

12.3.50 Table 12.14 provides the summary of the 2D results at the 7 sensitivity test locations. These results follow a similar pattern to 1D variations described above.

Table 12-13: Feith Mhor Burn 1D Model Scheme Sensitivity Results for 0.5% AEP Event

Cross Section	Watercourse ID	Scheme Stage (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow - 20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
FEITH01	Southern Stream	262.121	0.05	0.00	0.00	0.03	-0.06	0.00	-0.02	0.00	0.00
FEITH02		261.001	0.05	0.00	0.00	0.16	-0.05	0.00	0.09	0.00	0.00
FEITH03		260.583	0.06	0.00	0.00	0.44	-0.37	0.00	0.33	0.00	0.00
FEITH04		260.546	0.05	0.00	0.00	0.44	-0.49	0.00	0.34	0.00	0.00
FEITH05		260.13	-0.01	0.00	0.00	0.20	-0.34	0.00	0.26	0.00	0.00
FEITH06		260.132	-0.01	0.00	0.00	0.19	-0.34	0.00	0.25	0.00	0.00
FEITH06_us		260.138	-0.01	0.00	0.00	0.18	-0.34	0.00	0.22	0.00	0.00
FEITH06_ds		260.13	-0.01	0.00	0.00	0.20	-0.34	0.00	0.26	0.00	0.00
FEITH08		258.317	0.20	0.00	0.00	0.34	-0.23	0.00	-0.04	0.91	0.00
FEITH09		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.89	0.00
FEITH10		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.81	0.00
FEITH11		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.78	0.00
FEITH12		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.78	0.00
FEITH18_usi1	Northern Stream	263.151	0.04	0.00	0.00	0.01	-0.02	0.00	0.00	0.00	0.00
FEITH18_usi2		262.594	0.04	0.00	0.00	0.07	-0.06	0.00	0.00	0.00	0.00
FEITH18_usi3		262.503	0.00	0.00	0.00	0.11	-0.12	0.00	0.00	0.00	0.00
FEITH18_usi4		261.757	0.03	0.00	0.00	0.06	-0.04	0.00	0.00	0.00	0.00
FEITH18		260.022	0.03	0.00	0.00	0.06	-0.04	0.00	0.00	0.00	0.00
FEITH18_I1		259.257	0.04	0.00	0.00	0.06	-0.05	0.00	0.08	0.00	0.00

Cross Section	Watercourse ID	Scheme Stage (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow - 20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
FEITH19		258.885	0.04	0.00	0.00	0.12	-0.04	0.00	0.37	0.14	0.00
FEITH19_1		258.448	0.09	0.00	0.00	0.28	-0.07	0.13	0.77	0.58	0.00
FEITH19_2		258.332	0.20	0.00	0.00	0.39	-0.19	0.24	0.88	0.69	0.00
FEITH20		258.33	0.20	0.00	0.00	0.41	-0.22	0.24	0.87	0.69	0.00
FEITH20_us		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.00
FEITH20_ds		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.00
FEITH22		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.00
FEITH23		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.00
FEITH24		258.316	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	1.03	0.00
FEITH25		262.503	0.00	0.00	0.00	0.11	-0.12	0.00	0.00	0.00	0.00
FEITH26		261.757	0.03	0.00	0.00	0.06	-0.04	0.00	0.00	0.00	0.00
FEITH13	Middle Stream	258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.82	0.00
FEITH14		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.00
FEITH15		258.317	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.00
FEITH16		258.316	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.86	0.00
FEITH26B	Confluence upstream of railway	257.314	0.00	0.00	0.00	0.32	-0.31	0.00	-0.04	0.79	0.00
FEITH27	Downstream of railway	256.945	-0.01	0.01	-0.02	0.05	-0.06	0.00	0.00	-0.15	0.00
FEITH28		256.903	0.02	0.03	-0.02	0.05	-0.06	0.00	0.00	-0.14	0.00
FEITH29		256.837	0.00	0.04	-0.03	0.06	-0.06	0.00	0.00	-0.13	0.00

Cross Section	Watercourse ID	Scheme Stage (m)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
FEITH30		256.527	-0.02	0.20	-0.21	0.03	-0.03	0.00	0.00	-0.08	0.00

Table 12-14: Feith Mhor Baseline 2D Scheme Sensitivity Results

Sensitivity Test	Scheme Stage (mAOD)	Variation in stage for +20% Manning's (m)	Variation in stage for D/S Boundary +20% (m)	Variation in stage for D/S Boundary -20% (m)	Variation in stage for Flow +20% (m)	Variation in stage for Flow -20% (m)	Variation in stage 50% blockage north (m)	Variation in stage 50% blockage south (m)	Variation in stage 50% blockage rail (m)	Variation in stage 50% blockage CULVERT (m)
Feith Mhor South										
Location 1	260.14	-0.01	0.00	0.00	0.19	-0.34	0.00	0.25	0.00	0.000
Location 2	260.14	-0.01	0.00	0.00	0.19	-0.34	0.00	0.24	0.00	0.000
A9 Crossing										
Location 3	258.32	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.88	0.001
Location 4	258.32	0.20	0.00	0.00	0.32	-0.31	0.00	-0.04	0.70	0.000
Feith Mhor North										
Location 5	269.23	0.03	0.00	0.00	0.06	-0.06	0.00	0.00	0.00	0.002
A9 Crossing										
Location 6	262.67	0.01	0.00	0.00	0.01	-0.01	0.00	0.00	0.00	0.000
Location 7	265.39	0.01	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.000

Figure 12-16. Feith Mhor Southern Stream Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event

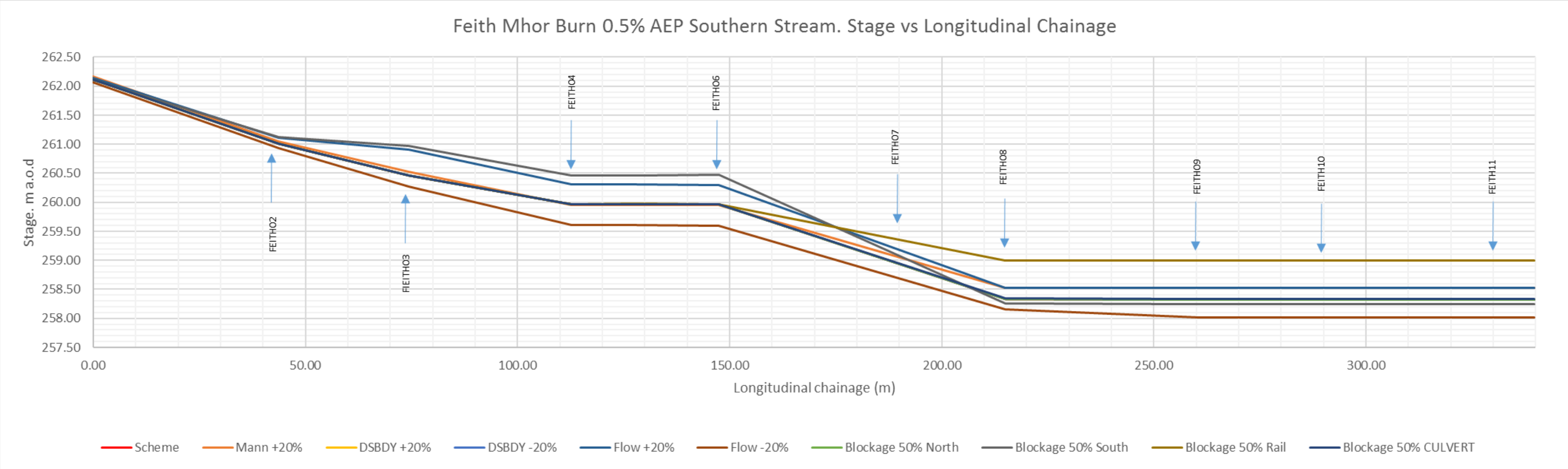


Figure 12-17. Feith Mhor Middle Stream Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event

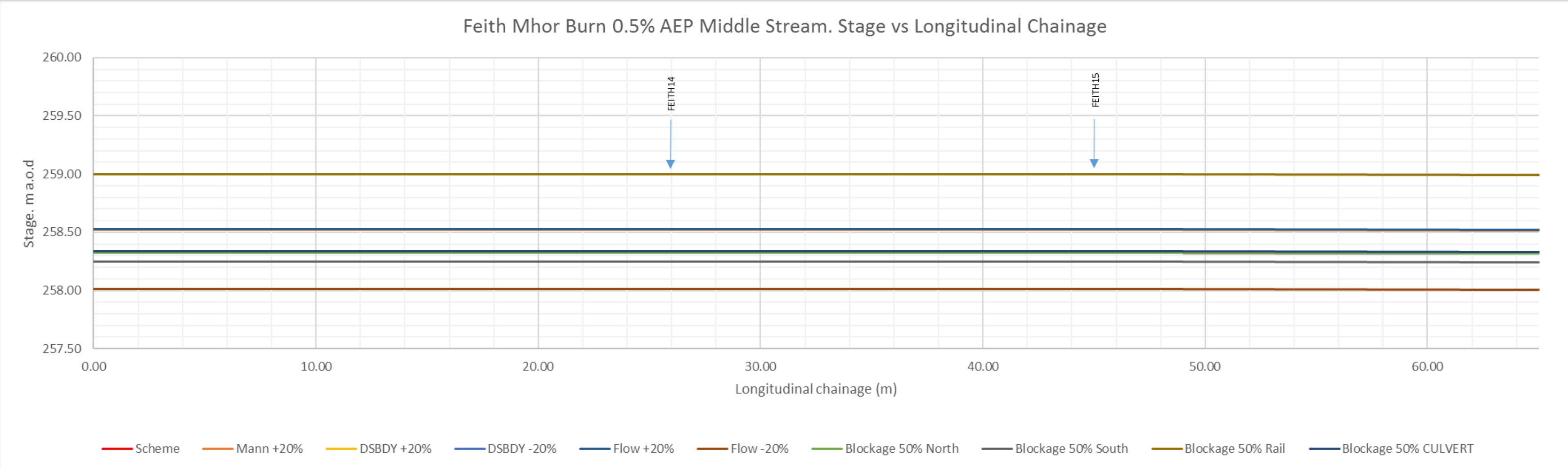


Figure 12-18. Feith Mhor Northern Stream Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event

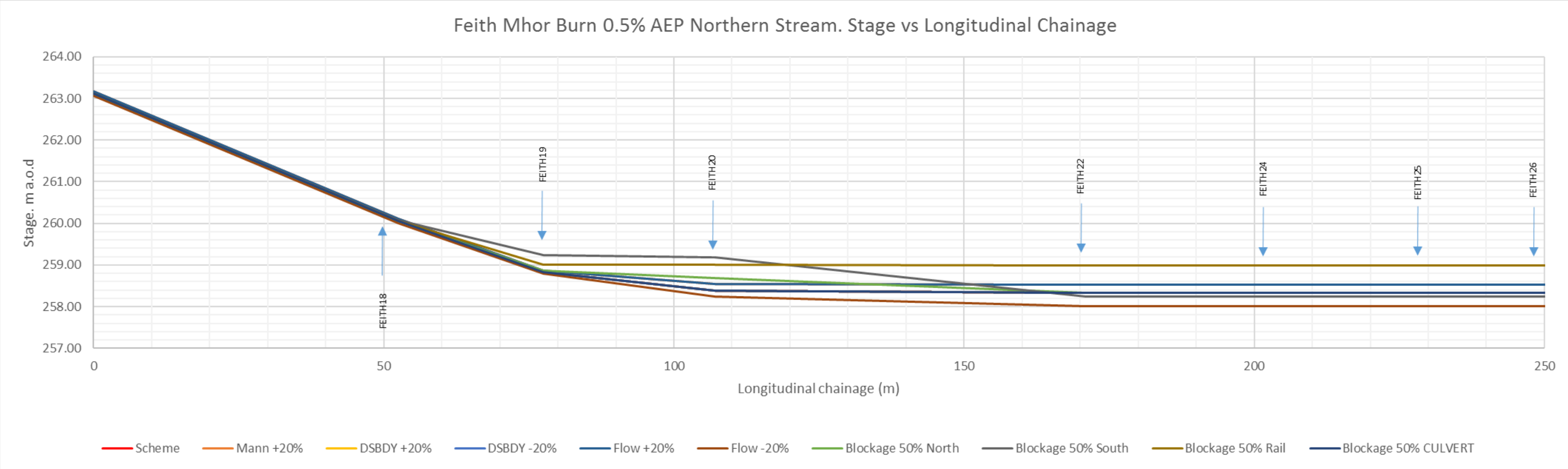
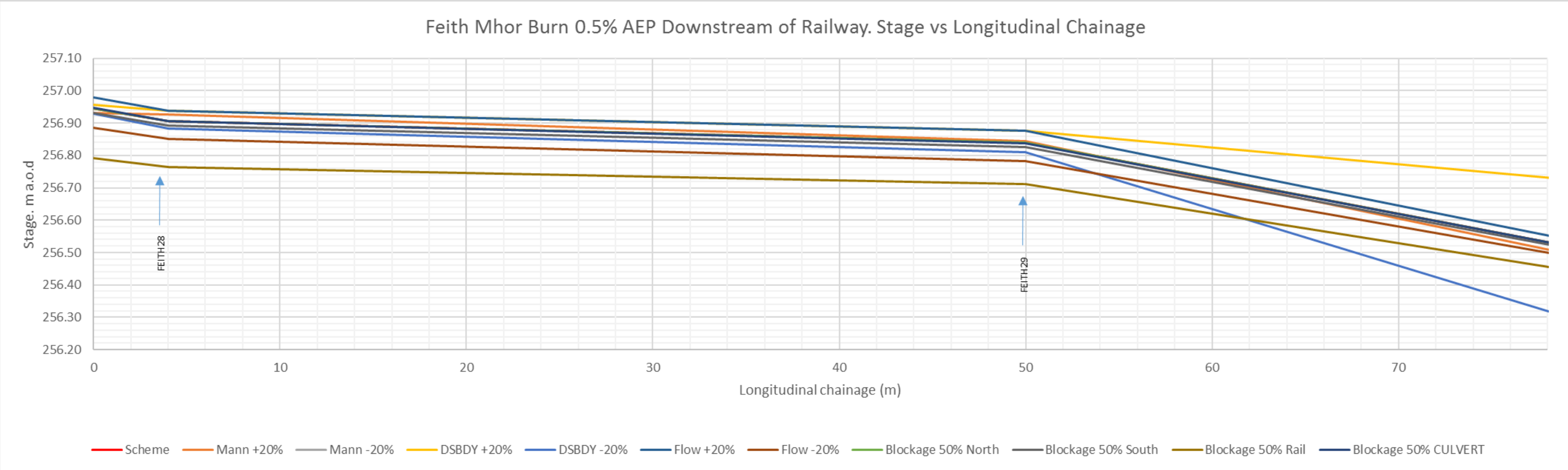


Figure 12-19. Feith Mhor Downstream Railway Modelled 1D Long Section Sensitivity Results for 0.5% AEP Event



12.4 Summary

12.4.1 The Feith Mhor hydraulic model has been created using a combination of 1d/2d linked ISIS-TUFLOW model and ESTRY-TUFLOW components, and includes both the main Feith Mhor Burn, comprised of three watercourse channels, and two smaller additional watercourses with unknown names located to the north.

12.4.2 The baseline model includes five A9 crossing; two of which consider northern and southern channels of the Feith Mhor Burn, along with a drainage culvert, at the southern portion of the model, and two of which consider small watercourse crossing located at the northern portion of the model. Flow from all culvert crossings is the routed through one culvert structure located beneath the railway, downstream of the A9.

12.4.3 The proposed scheme modelling has been undertaken using data contained within Design Refresh 7a, including earthworks associated with widening of the A9 mainline in an easterly downstream direction to accommodate a dual carriageway and the inclusion of elevated access tracks, upstream of the A9 in the southern portion of the model, and downstream of the A9 in the northern portion of the model. Watercourse diversion cross sections have also been applied to the model to accommodate the offset of culvert inlets/outlets.

12.4.4 Updates to the baseline model for the proposed scheme included upgrading of culvert structures beneath the A9, the addition of culvert structures beneath access tracks, and the implementation of mitigation measures to ensure a neutral impact to flood risk from the proposed scheme.

12.4.5 Implementation of the proposed scheme results in floodplain loss at both northern and southern portions of the model. At the southern portion of the model losses are approximately 5150m^3 for the 0.5% AEP event, and as such, water levels become elevated between the A9 and the railway. The railway is considered a sensitive asset. Mitigation measures at the southern portion of the model included storage of water behind the A9 which in turn reduces water levels between the A9 and the railway.

12.4.6 Mitigation measures for the southern portion of the model include the implementation of a flood storage area. This area provides approximately 6400 m^3 of floodplain storage. Results show that scheme water levels are within 10 mm of baseline conditions between the A9 and the railway for all AEP events when mitigation measures are applied. Water levels do increase upstream of the A9, however, there are no sensitive receptors in this area and these increases are considered to be offset by the benefits of ensuring there are not impacts to the railway asset.

12.4.7 At the northern portion of the model, the proposed scheme causes a loss of floodplain storage of approximately 230m^3 for the 0.5% AEP event. Results show that despite this loss, flood levels in close proximity to the railway have decreased in all AEP events, which is caused by water becoming impounded behind the proposed access track and the incorporated culvert controlling the flow of water that is directed towards the railway. Due to an improvement in water levels, compensatory floodplain storage is not considered necessary at this northern portion of the Feith Mhor site.

13. River Dulnain

13.1.1 The River Dulnain is a major tributary of the River Spey with an upstream catchment area of 272.2km^2 from the NRFA gauging station 8009 (NGR 2977 8247). Its headwaters rise in the Monadhliath Mountains between the hills of Carn an Fhreiceadain, Carn Sgulain and Carn Icean Duibhe, at an altitude of approximately 800mAOD, flowing northeast towards its confluence with the River Spey at NGR 3004 8238. The River Dulnain is crossed by the existing A9 carriageway at NGR 2897, 8226 and then the Highland Mainline railway, approximately 90m downstream.

13.1.2 Alt nan Ceatharnach is a tributary joining River Dulnain on the left bank with an upstream catchment area of 16.96 km^2. The A9 carriageway crosses the tributary at OSNGR (289121.98 ,823161.54).

13.1.3 Allt Lorgy is a tributary joining River Dulnain on the right bank with an upstream catchment area of 18.66 km^2

13.1.4 The River Dulnain primarily flows as an open channel through a study area with bridges and culverts beneath a number of roads in the area as shown in Figure 13.1.

13.1.5 Model extents were carefully selected to ensure that the model boundaries did not have any impact on the flood extent in the area of interest.

13.1.6 The hydraulic model was built using a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller (version 4.3), and the 2D component was constructed using TUFLOW (version 2016).

13.1.7 River channels for watercourses are defined using surveyed watercourse cross sections undertaken in 2016 and 2017 for the 1D element as illustrated by Figure 13.1. River banks are defined as lateral spills using either survey or LiDAR data. The spills define the linkage from the open channel 1D domain to the 2D domain.

13.1.8 The addition of panel markers was used to ensure that the conveyance increases monotonically with increasing water level.

13.1.9 The model was run under a baseline scenario (existing situation) to simulate fluvial flooding associated with series of storm events with the following Annual Exceedance Probabilities (AEP): 50%, 20%, 10%, 4%, 3.3%, 2%, 1.33%, 1%, 0.5%, 0.5% +CC and 0.2%.

13.1.10 Model extents were carefully selected to ensure that the model boundaries did not have any impact on the flood extent in the area of interest.

Figure 13-1 River Dulnain study area

13.1.11 The data used to construct the baseline hydraulic model for the River Dulnain is summarised in Table 13.1

Table 13-1. Data used to build the baseline hydraulic model

Data	Description	Source
Cross section surveyed data	2016	WSP
Cross section surveyed data	2017	WSP
Lidar Digital terrain model (DTM) 2m resolution	2016	SEPA
Watercourses photographs	From survey 2016 and 2017	WSP
Hydrological analysis	2016 and updated 2017 and approved by SEPA	WSP/ATKINS
Scottish Environment Protection Agency (SEPA) Flood Maps	Flood maps showing the fluvial flood extent for different likelihood of flooding (high, medium, and low)	SEPA
Scottish Environment Protection Agency (SEPA) - observed flood event levels	Screenshot of the flood levels SEPA surveyed following the August 2014 flooding on the River Dulnain and some attached photos from the vicinity	SEPA

13.1.12 The River Dulnain catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment area was altered to reflect the surrounding topography.

13.1.13 Applying a distributed model, the catchment was subdivided into 6 catchments to take account of the small channels and any lateral inflows. shows the hydrological model schematic, with Table 13.2 detailing the delineated catchment areas.

Table 13-2. River Dulnain Hydrological Estimation points

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km^2)
River Dulnain	C-UPSC	River Dulnain upstream of DS-WC-046	Direct	FEH	289300	822400	151.29
Allt nan Ceatharnach	LB-USC	Allt nan Ceatharnach left bank tributary	Direct	FEH	289350	822450	16.96
Allt Lorgy	RB-USC	Allt Lorgy right bank tributary	Direct	FEH	289300	822350	18.66
River Dulnain	DS-Lat	Lateral area between A9 Crossing and downstream extent.	Lateral	FEH Scaled	292050	823100	7.4
River Dulnain	DSC	Downstream Model extent		FEH Scaling Point	292050	823100	194.31

13.1.14 Peak flows were calculated for each inflow using the FEH Statistical methods, with QMED adjusted based on the gauge record located downstream. The FEH rainfall runoff estimate was undertaken at the A9 crossing for comparison. Flows at the gauge downstream of the model reach at Balnaan have also been analysed.

13.1.15 All 4 inflows to the hydraulic were FEH Rainfall Runoff boundaries, which were scale proportionally to the FEH statistical estimate at the downstream extent to the model

13.1.16 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events. The critical storm duration was set as 10 hours. Table 13.3 shows the peak flows.

Table 13-3. Peak Flow Estimates (cumecs)

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
River Dulnain	C-UPSC	River Dulnain upstream of DS-WC-046*	201.12	241.34
Allt nan Ceatharnach	LB-USC	Allt nan Ceatharnach left bank tributary	34.55	41.44
Allt Lorgy	RB-USC	Allt Lorgy right bank tributary	30.23	36.28
River Dulnain	DS-Lat	Lateral area between A9 Crossing and downstream extent.	15.73	18.88
River Dulnain	DSC	Downstream Model extent	214.38	252.71

13.1.17 The C-UPSC Inflow assessment point differs to the assessment point for the 1D crossing at DS-WC-046. The inflow location is US of the crossing location and therefore, the flow is lower than that estimated within the 1D hydrological analysis.

13.1.18 Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model.

13.1.19 Hydrographs were generated from the Rainfall Runoff method, with the storm duration optimised within the hydraulic model.

13.1.20 Table 13.4 summarises the modelled events.

Table 13-4. Modelled Events

Scenario	AEP										
	50%	20%	10%	4%	3.3%	2%	1.33%	1%	0.5%	0.5%+CC	0.2%
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Roughness sensitivity									✓		
Hydrological inflow sensitivity									✓		

Scenario	AEP										
	50%	20%	10%	4%	3.3%	2%	1.33%	1%	0.5%	0.5%+CC	0.2%
Downstream boundary sensitivity									✓		
Model 'with – scheme'					✓				✓		
With-scheme and mitigation					✓				✓		

13.2 Baseline Hydraulic Model

13.2.1 Updates to the DMRB FRA Stage 2 baseline model.

13.2.2 The baseline model was updated with the following changes since DMRB FRA Stage 2:

- Cross-sections from 2017 survey were added in the model for Allt Nan Ceathernach tributary.
- Three-piped culvert of 1.23m diameter on Allt Lorgy tributary was included in the model.
- The 2D HX-CN boundary at the tributary junctions was modified to appropriately represent the joining of tributaries to River Dulnain.
- Roughness values was increased for the complete model pertaining to the topography captured in the survey photographs.
- More interpolates were added to represent the natural meandering of the river.
- The structure beneath Carrbridge railway track was modelled as 1D ESTRY culvert unit.
- The hydrology is updated post discussion with SEPA on confirming the updated inflows.

Model assumptions and limitations

13.2.3 The accuracy and reliability of the model results is heavily dependent on the accuracy of the hydrological and topographical data utilised in the model. While the most appropriate up to date information has been used to build the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

13.2.4 The key sources of uncertainty in the model in addition to the limitations associated with the model are:

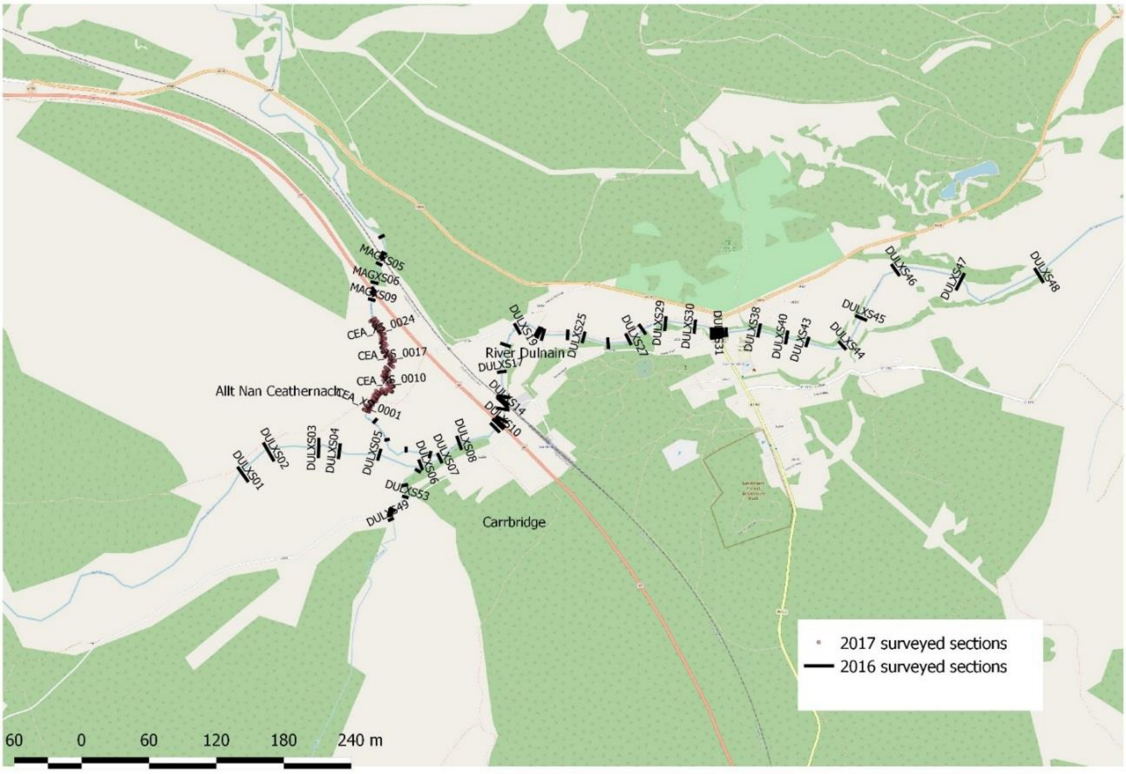
- The LiDAR data horizontal resolution used at 2m. As a result, small features such as small drains, kerbs heights might not be represented accurately within the model.
- There are uncertainties in how accurately LiDAR reflects the topography of the area. It has been assumed that existing LiDAR is correct as no other information is available.
- The observed stage data provided at the old packhorse bridge is ambiguous. Further clarity on calibration required.
- Channel roughness has been assigned using the best available information such as site visit photos, survey data and aerial photographs

13.2.5 Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process.

In- channel geometry (1D)

13.2.6 Surveyed river cross-section data has been used to inform the in-channel geometry of the modelled watercourses. The locations of the 2016 and 2017 surveyed river sections are shown in Figure 13.2

Figure 13-2. Survey location



Model Extent

13.2.7 The upstream extent of the River Dulnain model is located approximately 2.3 km west of Carrbridge at 288506 822374. The modelled reach of the River Dulnain flows west to east for approximately 4.4km crossing the A9 at 289664 822541. The model includes Ellan Bridge and Carrbridge. The downstream extent is located at 292077 823156.

13.2.8 There are two tributaries included in the model reach, the Allt nan Ceatharnach enters from the left bank at 289378 822425 and the Allt Lorgy enters at the right bank at 289340 822370. The Allt nan Ceatharnach has a modelled reach of approximately 1.3 km and crosses the A9 once at 289122 823162. The Allt Lorgy has a modelled reach of approximately 0.3km. The upstream model extent of the Allt Lorgy is located at 289178 822141.

13.2.9 Table 13.5 details the model extents and key features.

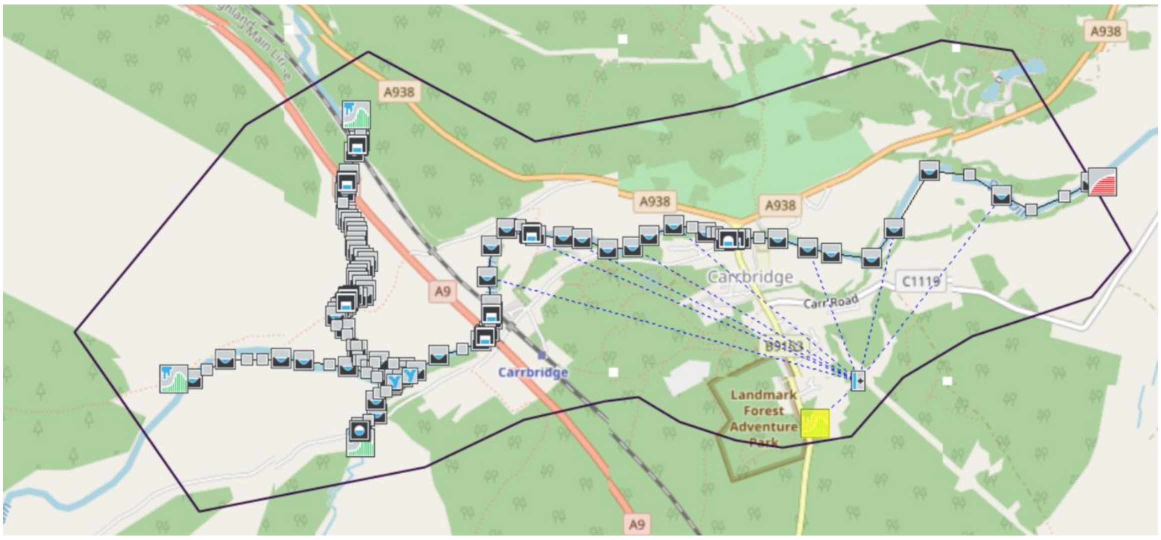
Table 13-5. Key Model Features.

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of Cross Sections	Number of A9 Crossings	Total number of modelled structures
River Dulnain (Main Channel)	4400	288506, 822374	292077, 823156	49	1	5
Allt nan Ceatharnach	1300	289166, 823397	289378, 822425	46	1	4
Allt Lorgy	300	289178, 822141	289340, 822370	8	0	1

13.2.10 A direct inflow hydrograph is applied to the hydraulic model at the upstream extent of the model. A Normal Depth boundary was used at the downstream extent of all the models.

13.2.11 A model schematic can be found in Figure 13.3

Figure 13-3 . Model Schematic



Roughness

13.2.12 Roughness coefficient for cross sections and 1d structures within 1D river models are taken from “Open Channel Hydraulics’ (Chow, 1959). Through site visit, photographs included within the topographical survey information, an appropriate Manning’s value has been selected for each cross section and structure by the modeller. These initial Manning’s n values have been amended within acceptable ranges to facilitate achieving model calibration. Table 13.6 details the Manning’s ‘n’ values applied to the 1D channel sections and floodplains.

Table 13-6. Roughness values.

Section Type	Minimum	Maximum	Commentary
River Channel	0.04	0.05	Varying from "Clean, straight, full stage, no rifts or deep pools" to "Clean winding, some pools and shoals, with weeds and large amounts of stones"
Floodplain	0.045	0.06	Light brush and trees in Summer / Winter
Structures	0.025	0.045	Ranging from smooth concrete, top half of culvert to Gravel bottom with dry rubble sides.

In channel's hydraulic structures

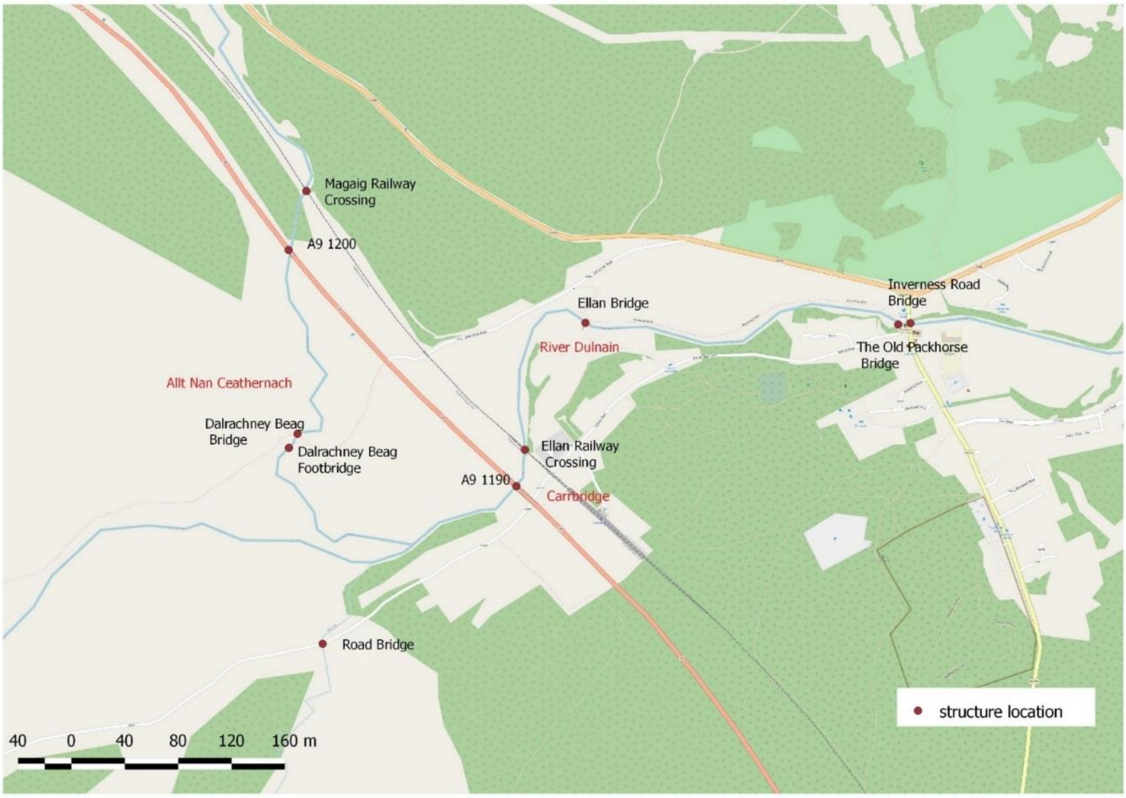
13.2.13 Table 13.7 provides the details of how the structures are represented within the model. Figure 13.4 shows the location of these modelled structures.

Table 13-7. Modelled Structures Details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
Magaig Railway Crossing	Railway crossing	Allt nan Ceatharnach (289167,8232 970)	9.5 x 7.4	USBPR1978 Bridge Unit	
DS-WC-048	A9 1200	Allt nan Ceatharnach	10m x 13m	Represented as a USBPR1978 bridge Unit.	
Dalrachney Beag Bridge	Small Bridge	Allt nan Ceatharnach (289207, 822692)	4.8 x 1.7	USBPR1978 Bridge Unit	
Dalrachney Beag Footbridge	Footbridge	Allt nan Ceatharnach (289121,8226 82)	8.5 x 1.3	USBPR1978 Bridge Unit	
U2239	Road crossing	Allt Lorgy	1.23m	Circular Conduit culvert unit	
DS-WC-046	A9 1190	River Dulnain	Main Span 14m x 34m	USBPR1978 bridge Unit.	
Ellan Railway Crossing	Railway crossing	River Dulnain (289690,8226 44)	28 x 14	USBPR1978 Bridge Unit	

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
Ellan Bridge	Footbridge	River Dulnain (289851,822951)	37 x 4.4	USBPR1978 Bridge Unit	
The Old Packhorse Bridge	Old Footbridge	River Dulnain (290636,822927)	8.9 x 10.7	Arch Bridge Unit	
Inverness Road Bridge	Road Bridge	River Dulnain (290655,822912)	25.8 x 5.9	USBPR1978 Bridge Unit	

Figure 13-4. Location of the structures



Flood plain schematisation – 2D domain

Floodplain topography

13.2.14 The catchment topography for the 2D element has been represented by available LiDAR data provided for this study. The filtered LiDAR (i.e. with buildings and vegetation removed) was used for the modelling.

13.2.15 A mesh has been generated based on LiDAR data. The typical mesh size used is from 5m X 5m

13.2.16 Appropriate use has been made of 2D break lines (z – lines) and elevation polygons (z-shapes) to accurately represent roads, drains and ridges where they have an impact on flow across the floodplain. Elevations for these topographic features were informed by the DTM data.

Floodplains' hydraulic structures

13.2.17 Hydraulic structures in the floodplain (2D) were included using invert levels from the DTM, where they were considered important for flow connectivity and flood risk.

13.2.18 One culvert at Carrbridge was included in the study area, under the A9 mainline. The details of the culvert are provided in Table 13.8.

Table 13-8 . Culvert details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model
Carrbridge Underpass	Railway crossing	Adjacent to River Dulnain 289708 , 822507	8.2 X 4.4	ESTRY Box culvert U/S invert level : 274.945 mAOD D/S invert level : 274.852 mAOD

Floodplain hydraulic friction

13.2.19 The selection of roughness values used for the 2D domains has been based on the OS Master map land use datasets (See Table 13.9).

13.2.20 A high Manning's n value for a building has been used to represent the presence of buildings. The use of a high Manning's n value for a building makes it very difficult for water to enter/ flow through a building.

Table 13-9. 2D Roughness

Landuse Type	Roughness Value
Roads, Concrete, Manmade surfaces	0.03
Short grass	0.035
Trees	0.12
Buildings	0.36
Default	0.048

Boundary conditions

13.2.21 No inflow has been applied directly to the 2D domain. Any flows across the 2D domain is a result of the 1D channel being overtopped.

13.2.22 Stage-Discharge (HQ) boundaries have been applied at the downstream end of both models at the edge of 2D domain. This controls the rate at which floodplain flows leave the model according to the local topography.

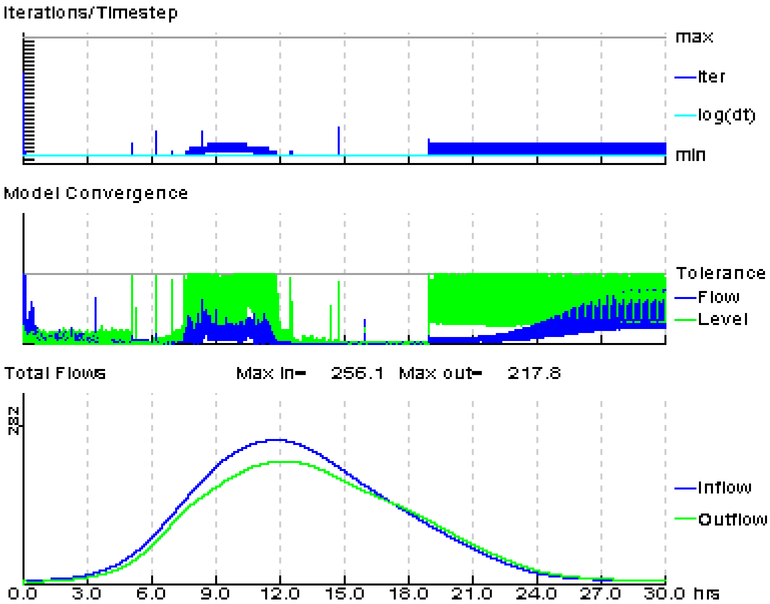
1d/2d Linking

13.2.23 The link between the 1D and the 2D domain was defined along the banks of the River Dulnain and its tributaries using bank crest levels informed by the DTM data. In places where the DTM data did not capture the channel shape, the channel alignment and bank levels were informed by the surveyed cross sections.

Model performance

13.2.24 Run performance has been monitored throughout the model built process and then during each simulation carried out to ensure a suitable model convergence was achieved.

Figure 13-5 . Model convergence plot for 1in 200yr flood event - "Baseline"

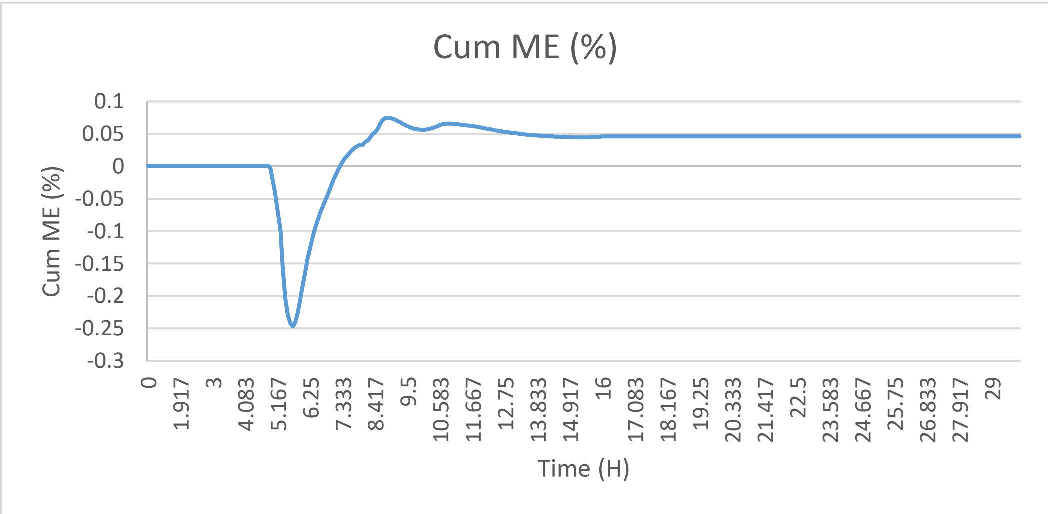


13.2.25 Convergence is calculated for each modelled time step and shows the consistency of the modelled water level and flow within the iterations that are computed for each model time step.

13.2.26 The cumulative mass error output from the 2D model is within the acceptable tolerance range recommended by the software manuals of +/- 1% mass balance error.

13.2.27 Figure 13.6 shows that for the 0.5% AEP (1in 200yr) flood event the cumulative mass error tolerance is well within the permissible limits of +/-1 %. This mass error check is typical for all events simulated.

Figure 13-6. Mass Balance plot



Model Results Analysis

13.2.28 Baseline Flow and Stage results, extracted from the modelled 1D cross sections, are shown below in Table 13-10 and Table 13-11.

Table 13-10 Baseline stage (mAOD) for modelled return periods

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS01	287.501	287.362	287.262	287.171	287.105	287.082	286.964	286.863	286.711
MAGXS1i	286.701	286.560	286.460	286.373	286.308	286.285	286.177	286.085	285.947
MAGXS02	286.004	285.861	285.762	285.676	285.614	285.592	285.490	285.408	285.282
MAGXS02i	285.810	285.666	285.567	285.481	285.420	285.399	285.295	285.218	285.094
MAGXS03	285.632	285.487	285.388	285.301	285.240	285.220	285.113	285.041	284.912
MAGXS03_Sp	285.632	285.487	285.388	285.301	285.240	285.220	285.113	285.041	284.912
MAGXS03_SpDS	285.627	285.483	285.382	285.296	285.234	285.212	285.110	285.029	284.906
MAGXS03a	285.632	285.487	285.388	285.301	285.240	285.220	285.113	285.041	284.912
MAGXS04b	285.627	285.483	285.382	285.296	285.234	285.212	285.110	285.029	284.906
MAGXS04	285.627	285.483	285.382	285.296	285.234	285.212	285.110	285.029	284.906
MAGXS05	285.067	284.907	284.799	284.705	284.640	284.617	284.511	284.426	284.300
MAGXS06	284.372	284.147	283.993	283.860	283.769	283.737	283.593	283.481	283.333
MAGXS07	284.296	284.078	283.927	283.794	283.700	283.668	283.515	283.390	283.213
MAGXS07_Sp	284.296	284.078	283.927	283.794	283.700	283.668	283.515	283.390	283.213
MAGXS07_SpDS	283.151	283.026	282.944	282.871	282.819	282.802	282.723	282.661	282.566
MAGXS07a	284.296	284.078	283.927	283.794	283.700	283.668	283.515	283.390	283.213
MAGXS08b	284.335	284.116	283.964	283.830	283.736	283.702	283.548	283.422	283.243
MAGXS08_spd	283.151	283.026	282.944	282.871	282.819	282.802	282.723	282.661	282.566
MAGXS08	283.151	283.026	282.944	282.871	282.819	282.802	282.723	282.661	282.566
MAGXS09	282.806	282.647	282.541	282.447	282.388	282.368	282.278	282.204	282.103
MAGXS09i1	281.562	281.513	281.479	281.446	281.415	281.404	281.346	281.283	281.180
CEA_XS_0028	280.962	280.846	280.762	280.683	280.629	280.611	280.524	280.439	280.314
CEA_XS_0027	280.562	280.478	280.423	280.372	280.329	280.315	280.244	280.175	280.067
CEA_XS_0026	280.241	280.160	280.111	280.064	280.028	280.015	279.955	279.894	279.795
CEA_XS_0025	279.812	279.767	279.743	279.716	279.697	279.691	279.652	279.616	279.589
CEA_XS_0024	279.833	279.793	279.761	279.721	279.684	279.673	279.622	279.567	279.495
CEA_XS_0023	279.521	279.469	279.439	279.412	279.411	279.406	279.344	279.283	279.190
CEA_XS_0022	279.362	279.311	279.281	279.252	279.243	279.239	279.176	279.112	279.017
CEA_XS_0021	279.255	279.184	279.131	279.082	279.041	279.030	278.953	278.886	278.791
CEA_XS_0020	278.934	278.865	278.803	278.749	278.710	278.696	278.627	278.576	278.482
CEA_XS_0019	278.606	278.535	278.484	278.442	278.409	278.395	278.388	278.364	278.250
CEA_XS_0018	278.515	278.429	278.370	278.317	278.280	278.265	278.202	278.154	278.056
CEA_XS_0017	278.455	278.362	278.290	278.216	278.160	278.138	278.031	277.930	277.772
CEA_XS_0016	277.869	277.787	277.733	277.682	277.644	277.631	277.562	277.502	277.390
CEA_XS_0015	277.432	277.375	277.334	277.295	277.265	277.254	277.202	277.164	277.091
CEA_XS_0014	277.269	277.218	277.182	277.150	277.124	277.114	277.063	277.012	276.907
CEA_XS_0013	277.073	277.018	276.969	276.906	276.863	276.848	276.778	276.719	276.612
CEA_XS_0012	277.004	276.928	276.858	276.763	276.701	276.678	276.585	276.515	276.394
CEA_XS_0011	276.472	276.435	276.408	276.397	276.369	276.355	276.304	276.247	276.124
CEA_XS_0010	276.253	276.196	276.156	276.117	276.093	276.084	276.038	275.988	275.883
CEA_XS_0009	276.180	276.114	276.055	275.999	275.972	275.965	275.881	275.786	275.641
CEA_XS_0008	276.013	275.864	275.781	275.677	275.590	275.556	275.391	275.283	275.137

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CEA_XS_0007	275.642	275.453	275.299	275.195	275.126	275.105	274.999	274.910	274.756
CEA_XS_0006	275.034	274.953	274.904	274.887	274.842	274.824	274.730	274.649	274.454
MAGXS15	274.807	274.760	274.759	274.760	274.726	274.710	274.627	274.554	274.333
MAGXS15_Sp	274.807	274.760	274.759	274.760	274.726	274.710	274.627	274.554	274.333
MAGXS15_SpDS	275.035	274.969	274.915	274.902	274.853	274.832	274.728	274.639	274.414
MAGXS15a	274.807	274.760	274.759	274.760	274.726	274.710	274.627	274.554	274.333
MAGXS16b	275.035	274.969	274.915	274.902	274.853	274.832	274.728	274.639	274.414
MAGXS16	275.035	274.969	274.915	274.902	274.853	274.832	274.728	274.639	274.414
MAGXS16In1	274.971	274.906	274.860	274.860	274.857	274.854	274.818	274.771	274.477
CEA_XS_0005	275.111	275.052	275.011	274.975	274.953	274.943	274.887	274.824	274.489
CEA_XS_005I1	274.982	274.942	274.921	274.911	274.903	274.898	274.856	274.802	274.456
MAGXS17	275.294	275.206	275.133	275.047	274.989	274.968	274.863	274.764	274.332
MAGXS17_Sp	275.294	275.206	275.133	275.047	274.989	274.968	274.863	274.764	274.332
MAGXS17_SpDS	274.700	274.658	274.626	274.592	274.559	274.548	274.486	274.419	274.310
MAGXS17a	275.294	275.206	275.133	275.047	274.989	274.968	274.863	274.764	274.332
MAGXS17Ab	274.700	274.658	274.626	274.592	274.559	274.548	274.486	274.419	274.310
MAGXS17cpds	274.700	274.658	274.626	274.592	274.559	274.548	274.486	274.419	274.310
CEA_XS_0004	274.526	274.484	274.451	274.417	274.394	274.384	274.326	274.263	274.153
MAGXS18	274.439	274.382	274.340	274.306	274.286	274.277	274.213	274.153	274.049
CEA_XS_0003	274.265	274.231	274.199	274.167	274.143	274.133	274.075	273.994	273.850
CEA_XS_0002	274.092	274.041	274.002	273.962	273.934	273.926	273.874	273.817	273.726
CEA_XS_0001	273.812	273.768	273.741	273.715	273.695	273.688	273.645	273.591	273.503
MAGXS19i1	273.158	273.094	273.046	273.009	272.987	272.978	272.940	272.904	272.845
MAGXS19	273.161	273.031	272.913	272.807	272.743	272.716	272.583	272.466	272.316
MAGXS19i2	272.376	272.321	272.297	272.284	272.258	272.239	272.140	272.050	271.926
MAGXS19i3	271.991	271.944	271.858	271.749	271.674	271.655	271.562	271.484	271.342
MAGXS19i4	271.536	271.413	271.342	271.303	271.285	271.282	271.260	271.241	271.165
MAGXS20	271.358	271.325	271.295	271.275	271.270	271.271	271.252	271.227	271.137
MAGXS20i1	271.381	271.275	271.227	271.168	271.125	271.107	271.038	270.978	270.859
MAGXS20i2	271.191	271.020	270.891	270.789	270.713	270.703	270.654	270.539	270.393
MAGXS20i3	271.228	271.040	270.889	270.744	270.685	270.663	270.546	270.433	270.269
MAGXS20i4	271.032	270.818	270.653	270.503	270.390	270.370	270.310	270.209	270.037
MAGXS20i5	270.530	270.383	270.300	270.228	270.188	270.172	270.078	269.977	269.791
MAGXS20i6	270.406	270.252	270.140	270.039	269.991	269.973	269.901	269.809	269.630
MAGXS21	270.310	270.215	270.101	269.997	269.957	269.941	269.855	269.761	269.593
MAGXS21i1	270.033	269.720	269.575	269.456	269.402	269.385	269.293	269.203	269.031
MAGXS22	269.469	269.257	269.064	268.945	268.856	268.834	268.669	268.548	268.362
MAGXS22cpds	269.433	269.226	269.038	268.868	268.756	268.716	268.528	268.382	268.136
DULXS49	274.851	274.893	274.815	274.653	274.599	274.583	274.418	274.279	274.023
DULXS50	274.806	274.756	274.716	274.645	274.594	274.576	274.405	274.265	273.999
DULXS50A	274.954	274.862	274.761	274.663	274.595	274.571	274.391	274.239	273.962
Spill_50A_us	274.954	274.862	274.761	274.663	274.595	274.571	274.391	274.239	273.962
Spill_50A_ds	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.083	272.938
DULXS50_In1	274.954	274.862	274.761	274.663	274.595	274.571	274.391	274.239	273.962
DULXS50_a1	273.963	273.882	273.825	273.731	273.637	273.605	273.455	273.289	273.267

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS50_b1	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.156	273.153
DUMMY1	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.083	272.938
DULXS50_I2	274.954	274.862	274.761	274.663	274.595	274.571	274.391	274.239	273.962
DULXS50_a2	273.962	273.882	273.825	273.731	273.637	273.605	273.455	273.289	273.267
DULXS50_b2	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.156	273.153
DUMMY2	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.083	272.938
DULXS50_I3	274.954	274.862	274.761	274.663	274.595	274.571	274.391	274.239	273.962
DULXS50_a3	273.963	273.882	273.825	273.731	273.637	273.605	273.455	273.289	273.266
DULXS50_b3	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.156	273.153
DUMMY3	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.083	272.938
DULXS51A	273.653	273.562	273.514	273.422	273.332	273.305	273.187	273.083	272.938
DULXS52	273.523	273.372	273.259	273.155	273.100	273.074	272.967	272.883	272.716
DULXS52i	272.593	272.540	272.498	272.450	272.405	272.387	272.308	272.231	272.076
DULXS53	272.145	272.021	271.927	271.849	271.791	271.768	271.675	271.597	271.441
DULXS54	271.129	271.064	271.008	270.944	270.897	270.879	270.784	270.703	270.552
DULXS54i1	270.576	270.473	270.388	270.313	270.260	270.240	270.136	270.051	269.906
DULXS54i2	270.148	270.018	269.891	269.768	269.692	269.667	269.542	269.444	269.292
DULXS55	269.989	269.834	269.729	269.588	269.486	269.447	269.263	269.116	268.901
DULXS55cpds	269.980	269.833	269.733	269.600	269.505	269.468	269.283	269.135	268.909
DULXS01	275.924	275.783	275.685	275.595	275.531	275.510	275.404	275.318	275.179
DULXS01i	275.497	275.367	275.278	275.197	275.138	275.117	274.964	274.874	274.715
DULXS02	274.844	274.710	274.612	274.529	274.469	274.449	274.282	274.157	273.982
DULXS02i1	274.232	274.079	273.971	273.872	273.803	273.779	273.660	273.532	273.334
DULXS02i2	273.696	273.551	273.453	273.359	273.294	273.292	273.292	273.292	273.292
DULXS03	273.376	273.268	273.194	273.123	273.073	273.055	272.942	272.862	272.728
DULXS04	272.709	272.586	272.501	272.427	272.378	272.361	272.286	272.204	272.068
DULXS04i	272.202	271.996	271.845	271.703	271.599	271.560	271.383	271.254	271.063
DULXS05	271.448	271.263	271.138	271.019	270.932	270.901	270.728	270.583	270.357
DULXS05i1	270.954	270.783	270.633	270.497	270.404	270.372	270.201	270.048	269.809
DULXS05i2	270.494	270.363	270.254	270.144	270.069	270.042	269.879	269.724	269.478
DULXS06cpus	269.980	269.833	269.733	269.600	269.505	269.468	269.283	269.135	268.909
DULXS06	269.980	269.833	269.733	269.600	269.505	269.468	269.283	269.135	268.909
DULXS07cpus	269.433	269.226	269.038	268.868	268.756	268.716	268.528	268.382	268.136
DULXS07	269.433	269.226	269.038	268.868	268.756	268.716	268.528	268.382	268.136
DULXS08	268.679	268.411	268.210	268.019	267.881	267.830	267.584	267.383	267.087
DULXS08i	268.141	267.855	267.653	267.471	267.319	267.267	267.007	266.802	266.487
DULXS09	267.618	267.363	267.174	267.009	266.778	266.731	266.561	266.401	266.134
DULXS10	267.518	267.261	267.061	266.893	266.773	266.722	266.481	266.292	266.007
DULXS10_Sp	267.518	267.261	267.061	266.893	266.773	266.722	266.481	266.292	266.007
DULXS10_SpDS	267.119	266.880	266.708	266.552	266.439	266.398	266.203	266.052	265.830
DULXS10_a	267.518	267.261	267.061	266.893	266.773	266.722	266.481	266.292	266.007
DULXS10_b	267.119	266.880	266.708	266.552	266.439	266.398	266.203	266.052	265.830
DULXS11	267.119	266.880	266.708	266.552	266.439	266.398	266.203	266.052	265.830
DULXS12	266.962	266.722	266.547	266.388	266.272	266.230	266.033	265.877	265.642
DULXS12In1	266.733	266.493	266.317	266.155	266.037	265.993	265.792	265.637	265.399

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS13	266.529	266.291	266.112	265.947	265.824	265.774	265.557	265.397	265.154
DULXS14	266.548	266.336	266.143	265.956	265.822	265.772	265.580	265.409	265.159
DULXS14_Sp	266.548	266.336	266.143	265.956	265.822	265.772	265.580	265.409	265.159
DULXS14_SpDS	266.478	266.275	266.086	265.901	265.769	265.720	265.534	265.367	265.120
DULXS14_a	266.548	266.336	266.143	265.956	265.822	265.772	265.580	265.409	265.159
DULXS14_b	266.478	266.275	266.086	265.901	265.769	265.720	265.534	265.367	265.120
DULXS15	266.478	266.275	266.086	265.901	265.769	265.720	265.534	265.367	265.120
DULXS16	266.148	265.927	265.747	265.578	265.456	265.411	265.196	265.025	264.784
DULXS17	265.276	265.034	264.847	264.674	264.550	264.504	264.285	264.105	263.828
DULXS18	264.428	264.178	263.975	263.795	263.670	263.629	263.441	263.294	263.072
DULXS19	263.614	263.335	263.138	262.955	262.832	262.791	262.596	262.449	262.232
DULXS19i1	263.026	262.743	262.543	262.334	262.201	262.155	261.932	261.768	261.524
DULXS20	262.683	262.422	262.224	261.967	261.816	261.763	261.499	261.310	261.019
DULXS21	262.627	262.368	262.171	261.907	261.753	261.700	261.427	261.234	260.932
DULXS21_Sp	262.627	262.368	262.171	261.907	261.753	261.700	261.427	261.234	260.932
DULXS21_SpDS	262.627	262.368	262.170	261.907	261.753	261.700	261.426	261.233	260.932
DULXS21_a	262.627	262.368	262.171	261.907	261.753	261.700	261.427	261.234	260.932
DULXS21_b	262.627	262.368	262.170	261.907	261.753	261.700	261.426	261.233	260.932
DULXS21i	262.627	262.368	262.170	261.907	261.753	261.700	261.426	261.233	260.932
DULXS22	262.588	262.330	262.133	261.866	261.711	261.657	261.380	261.186	260.880
DULXS23	262.460	262.209	262.015	261.832	261.689	261.637	261.427	261.227	260.890
DULXS24	261.667	261.422	261.233	261.060	260.935	260.890	260.644	260.499	260.274
DULXS25	261.278	261.097	260.912	260.736	260.611	260.565	260.297	260.077	259.781
DULXS26	260.472	260.190	260.018	259.860	259.748	259.705	259.501	259.340	259.097
DULXS27	259.880	259.625	259.440	259.279	259.166	259.124	258.942	258.795	258.577
DULXS28	259.378	259.093	258.901	258.741	258.612	258.567	258.339	258.163	257.909
DULXS29	258.446	258.177	257.983	257.791	257.661	257.613	257.387	257.210	256.938
DULXS29i1	257.806	257.545	257.382	257.244	257.148	257.119	256.936	256.792	256.567
DULXS30	257.028	256.610	256.313	256.100	255.961	255.909	255.697	255.534	255.305
DULXS30i1	256.776	256.282	255.890	255.611	255.427	255.352	255.082	254.883	254.611
DULXS30i2	256.818	256.147	255.612	255.276	255.047	254.946	254.604	254.351	254.002
DULXS30i3	256.793	256.126	255.611	255.152	254.813	254.693	254.282	253.982	253.565
DULXS31	256.740	256.073	255.543	255.075	254.742	254.626	254.215	253.891	253.431
DULXS32	256.281	255.605	255.117	254.686	254.367	254.256	253.919	253.644	253.257
DULXS32_Sp	256.281	255.605	255.117	254.686	254.367	254.256	253.919	253.644	253.257
DULXS32_SpDS	254.993	254.570	254.284	254.023	253.819	253.750	253.611	253.449	253.177
DULXS32_a	256.281	255.605	255.117	254.686	254.367	254.256	253.919	253.644	253.257
DULXS32_b	254.993	254.570	254.284	254.023	253.819	253.750	253.611	253.449	253.177
DULXS33	254.993	254.570	254.284	254.023	253.819	253.750	253.611	253.449	253.177
DULXS34	254.857	254.520	254.285	254.074	253.917	253.869	253.650	253.440	253.118
DULXS35	254.773	254.410	254.160	253.937	253.775	253.720	253.474	253.287	252.990
DULXS35_Sp	254.773	254.410	254.160	253.937	253.775	253.720	253.474	253.287	252.990
DULXS35_SpDS	254.666	254.337	254.112	253.911	253.764	253.712	253.473	253.290	252.997
DULXS35_a	254.773	254.410	254.160	253.937	253.775	253.720	253.474	253.287	252.990
DULXS35_b	254.666	254.337	254.112	253.911	253.764	253.712	253.473	253.290	252.997

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS36	254.666	254.337	254.112	253.911	253.764	253.712	253.473	253.290	252.997
DULXS37	254.552	254.242	254.037	253.860	253.728	253.681	253.449	253.257	252.947
DULXS37i1	254.197	253.922	253.717	253.532	253.398	253.352	253.114	252.920	252.619
DULXS38	253.663	253.409	253.207	253.025	252.894	252.847	252.582	252.364	252.039
DULXS40	252.895	252.773	252.579	252.380	252.236	252.184	251.917	251.724	251.407
DULXS43	252.178	252.081	251.986	251.859	251.739	251.694	251.481	251.381	251.126
DULXS44	251.180	251.014	250.885	250.750	250.639	250.597	250.397	250.202	249.952
DULXS45	249.889	249.784	249.664	249.536	249.434	249.395	249.213	249.064	248.831
DULXS46	248.361	248.147	247.979	247.840	247.738	247.700	247.524	247.389	247.188
DULXS46i1	247.059	246.956	246.858	246.763	246.698	246.676	246.567	246.465	246.288
DULXS47	246.120	245.957	245.845	245.746	245.678	245.655	245.556	245.463	245.279
DULXS47i1	245.368	245.203	245.083	244.976	244.902	244.877	244.773	244.673	244.472
DULXS47i2	244.520	244.340	244.207	244.097	244.023	243.995	243.873	243.755	243.526
DULXS48	243.423	243.243	243.109	242.992	242.910	242.882	242.759	242.642	242.415
DS_Lat_01	265.276	265.034	264.847	264.674	264.550	264.504	264.285	264.105	263.828
DS_Lat_02	263.614	263.335	263.138	262.955	262.832	262.791	262.596	262.449	262.232
DS_Lat_03	261.667	261.422	261.233	261.060	260.935	260.890	260.644	260.499	260.274
DS_Lat_04	259.880	259.625	259.440	259.279	259.166	259.124	258.942	258.795	258.577
DS_Lat_05	258.446	258.177	257.983	257.791	257.661	257.613	257.387	257.210	256.938
DS_Lat_06	252.895	252.773	252.579	252.380	252.236	252.184	251.917	251.724	251.407
DS_Lat_07	249.889	249.784	249.664	249.536	249.434	249.395	249.213	249.064	248.831
DS_Lat_08	246.120	245.957	245.845	245.746	245.678	245.655	245.556	245.463	245.279

Table 13-11 Baseline Flow (m^3/s) for modelled return periods

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS01	41.441	34.534	29.993	26.174	23.588	22.709	18.749	15.688	11.687
MAGXS1i	41.445	34.537	29.992	26.177	23.592	22.711	18.748	15.690	11.690
MAGXS02	41.438	34.538	29.990	26.179	23.586	22.714	18.744	15.689	11.691
MAGXS02i	41.439	34.537	29.990	26.180	23.588	22.714	18.744	15.690	11.692
MAGXS03	41.440	34.537	29.989	26.181	23.587	22.714	18.745	15.689	11.692
MAGXS03_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS03_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS03a	41.440	34.537	29.989	26.181	23.588	22.714	18.745	15.689	11.692
MAGXS04b	41.440	34.537	29.989	26.181	23.588	22.714	18.745	15.689	11.692
MAGXS04	41.440	34.537	29.989	26.181	23.587	22.714	18.745	15.689	11.692
MAGXS05	41.445	34.541	29.987	26.177	23.587	22.715	18.746	15.689	11.690
MAGXS06	41.438	34.532	29.989	26.168	23.590	22.704	18.740	15.688	11.690
MAGXS07	41.439	34.531	29.990	26.174	23.584	22.702	18.736	15.689	11.687
MAGXS07_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS07_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS07a	41.439	34.531	29.990	26.174	23.584	22.702	18.736	15.689	11.687
MAGXS08b	41.439	34.531	29.990	26.174	23.584	22.702	18.736	15.689	11.687
MAGXS08_spd	41.439	34.531	29.990	26.174	23.584	22.702	18.736	15.689	11.687
MAGXS08	41.439	34.531	29.990	26.174	23.584	22.702	18.736	15.689	11.687
MAGXS09	41.441	34.530	30.002	26.186	23.588	22.703	18.745	15.691	11.684

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS09i1	41.438	34.526	29.981	26.153	23.579	22.698	18.751	15.689	11.688
CEA_XS_0028	29.942	26.852	24.712	22.830	21.265	20.696	17.873	15.347	11.686
CEA_XS_0027	34.512	30.103	27.123	24.493	22.571	21.875	18.576	15.659	11.685
CEA_XS_0026	34.722	30.151	27.162	24.567	22.576	21.881	18.551	15.662	11.688
CEA_XS_0025	32.983	28.419	25.588	23.142	21.276	20.615	17.575	14.890	11.114
CEA_XS_0024	25.922	21.888	19.661	17.819	16.618	16.166	13.851	11.993	9.178
CEA_XS_0023	26.123	22.982	21.102	19.340	18.058	17.612	15.584	13.738	11.238
CEA_XS_0022	24.405	21.578	20.037	18.703	18.184	18.000	15.938	14.059	11.346
CEA_XS_0021	23.405	20.905	19.606	18.400	18.054	17.888	15.949	14.052	11.341
CEA_XS_0020	26.484	23.565	21.736	20.098	19.037	18.818	16.374	14.206	11.351
CEA_XS_0019	28.146	25.210	23.010	21.034	19.661	19.290	16.357	14.008	11.389
CEA_XS_0018	25.185	22.557	20.605	18.938	17.751	17.367	15.564	14.102	11.241
CEA_XS_0017	22.378	19.942	18.330	17.032	16.155	15.855	14.453	13.325	11.106
CEA_XS_0016	32.431	28.766	26.124	23.677	21.894	21.233	18.167	15.473	11.625
CEA_XS_0015	33.261	29.111	26.312	23.784	21.952	21.310	18.229	15.620	11.645
CEA_XS_0014	30.088	26.380	23.851	21.519	19.870	19.292	16.614	14.448	11.298
CEA_XS_0013	28.260	25.015	22.897	21.084	19.698	19.210	16.838	14.773	11.483
CEA_XS_0012	26.455	23.772	22.019	20.537	19.329	18.897	16.714	14.740	11.493
CEA_XS_0011	31.459	28.195	25.669	22.944	21.204	20.524	17.582	15.207	11.647
CEA_XS_0010	28.617	26.077	24.120	22.440	20.920	20.240	17.691	15.365	11.650
CEA_XS_0009	24.581	22.388	20.991	19.727	18.512	17.940	16.310	14.850	11.643
CEA_XS_0008	26.137	24.985	23.372	21.827	20.704	20.264	18.069	15.504	11.645
CEA_XS_0007	30.799	30.525	28.525	25.673	23.431	22.573	18.666	15.648	11.643
CEA_XS_0006	36.579	33.775	29.890	26.152	23.595	22.722	18.724	15.663	11.646
MAGXS15	36.871	33.783	29.891	26.157	23.594	22.723	18.725	15.661	11.645
MAGXS15_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS15_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS15a	36.871	33.783	29.890	26.157	23.594	22.723	18.725	15.661	11.645
MAGXS16b	36.871	33.783	29.890	26.157	23.594	22.723	18.725	15.661	11.645
MAGXS16	36.871	33.783	29.891	26.157	23.594	22.723	18.725	15.661	11.645
MAGXS16In1	36.863	33.778	29.887	26.149	23.593	22.721	18.725	15.674	11.644
CEA_XS_0005	35.162	31.805	28.780	24.844	22.197	21.303	17.154	14.196	11.641
CEA_XS_005I1	35.126	31.777	28.760	24.832	22.187	21.294	17.146	14.173	11.641
MAGXS17	22.462	20.636	19.112	17.337	16.334	15.983	14.348	13.192	11.643
MAGXS17_Sp	5.542	4.383	3.486	2.532	1.947	1.754	0.885	0.307	0.000
MAGXS17_SpDS	5.542	4.383	3.486	2.532	1.947	1.754	0.885	0.307	0.000
MAGXS17a	16.920	16.253	15.626	14.806	14.388	14.229	13.463	12.887	11.643
MAGXS17Ab	16.920	16.253	15.626	14.806	14.388	14.229	13.463	12.887	11.643
MAGXS17cpds	22.462	20.636	19.112	17.337	16.334	15.983	14.348	13.192	11.643
CEA_XS_0004	22.814	21.064	19.660	18.058	16.985	16.630	14.957	13.551	11.641
MAGXS18	22.356	20.952	19.848	18.573	17.647	17.342	15.861	14.234	11.650
CEA_XS_0003	24.009	22.120	20.796	19.454	18.507	18.178	16.450	14.587	11.650
CEA_XS_0002	23.181	21.714	20.542	19.423	18.611	18.311	16.558	14.622	11.650
CEA_XS_0001	24.744	22.801	21.300	19.880	18.876	18.533	16.635	14.644	11.647
MAGXS19i1	25.405	22.991	21.347	19.900	18.875	18.529	16.637	14.644	11.643

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS19	14.148	14.140	14.142	14.117	14.122	14.116	13.956	13.222	11.399
MAGXS19i2	30.026	26.538	23.870	21.565	20.018	19.503	16.953	14.717	11.643
MAGXS19i3	26.339	23.500	22.616	22.078	21.083	20.476	17.442	14.908	11.643
MAGXS19i4	30.937	28.484	26.390	24.269	22.476	21.793	18.368	15.530	11.644
MAGXS20	32.027	28.534	26.042	23.793	21.969	21.239	17.877	15.199	11.605
MAGXS20i1	24.158	21.948	20.145	18.961	18.069	17.870	16.042	14.442	11.595
MAGXS20i2	24.934	22.685	21.040	19.519	18.466	18.048	16.076	14.501	11.596
MAGXS20i3	21.943	20.375	19.108	18.418	18.006	17.807	16.435	14.532	11.597
MAGXS20i4	27.684	24.964	22.802	21.235	20.010	19.551	17.192	14.874	11.596
MAGXS20i5	34.718	29.191	25.015	21.221	19.915	19.574	17.562	15.128	11.596
MAGXS20i6	34.235	28.832	25.024	21.809	20.659	20.323	17.945	15.381	11.600
MAGXS21	35.462	28.927	25.091	21.883	20.700	20.329	18.135	15.600	11.645
MAGXS21i1	34.199	31.122	26.665	22.645	21.201	20.730	18.204	15.597	11.648
MAGXS22	48.035	37.135	29.418	23.953	21.914	21.347	18.422	15.666	11.646
MAGXS22cpds	53.605	40.187	29.196	24.292	21.890	21.319	18.401	15.652	11.639
DULXS49	36.280	30.233	26.147	22.723	20.398	19.610	16.013	13.555	10.088
DULXS50	30.068	26.426	24.540	20.638	18.464	17.751	15.052	12.817	10.053
DULXS50A	19.177	18.148	17.049	16.375	15.765	15.499	13.586	12.124	10.031
Spill_50A_us	5.968	5.009	4.285	3.549	3.025	2.852	1.653	0.827	0.000
Spill_50A_ds	5.968	5.009	4.285	3.549	3.025	2.852	1.653	0.827	0.000
DULXS50_In1	4.403	4.379	4.301	4.289	4.247	4.216	3.978	3.766	3.344
DULXS50_a1	4.403	4.379	4.301	4.289	4.247	4.216	3.978	3.766	3.344
DULXS50_b1	4.407	4.384	4.302	4.291	4.247	4.216	3.978	3.766	3.344
DUMMY1	4.407	4.384	4.302	4.291	4.247	4.216	3.978	3.766	3.344
DULXS50_I2	4.405	4.381	4.301	4.289	4.247	4.216	3.978	3.766	3.344
DULXS50_a2	4.405	4.381	4.301	4.289	4.247	4.216	3.978	3.766	3.344
DULXS50_b2	4.406	4.383	4.302	4.291	4.247	4.216	3.978	3.766	3.343
DUMMY2	4.406	4.383	4.302	4.291	4.247	4.216	3.978	3.766	3.343
DULXS50_I3	4.403	4.379	4.301	4.289	4.247	4.216	3.978	3.766	3.344
DULXS50_a3	4.403	4.379	4.301	4.289	4.247	4.216	3.978	3.766	3.344
DULXS50_b3	4.407	4.384	4.302	4.291	4.247	4.216	3.978	3.766	3.344
DUMMY3	4.407	4.384	4.302	4.291	4.247	4.216	3.978	3.766	3.344
DULXS51A	19.181	18.160	17.053	16.375	15.765	15.499	13.586	12.124	10.031
DULXS52	23.868	22.724	21.838	20.341	17.955	17.325	14.489	12.400	10.033
DULXS52i	33.916	29.331	26.061	22.740	20.396	19.519	16.008	13.557	10.085
DULXS53	29.694	26.946	24.393	21.764	19.840	19.077	15.956	13.557	10.088
DULXS54	34.613	29.630	26.109	22.731	20.404	19.520	16.010	13.559	10.086
DULXS54i1	33.939	29.620	26.163	22.721	20.406	19.521	16.008	13.560	10.087
DULXS54i2	34.440	29.761	26.107	22.725	20.400	19.519	16.009	13.561	10.087
DULXS55	35.834	30.361	26.152	22.715	20.396	19.512	16.007	13.558	10.087
DULXS55cpds	39.122	32.323	26.820	22.703	20.382	19.507	15.994	13.542	10.076
DULXS01	241.341	201.118	174.433	152.055	136.915	131.776	108.574	91.780	68.670
DULXS01i	241.357	201.126	174.430	152.015	136.863	131.809	108.612	91.805	68.632
DULXS02	241.375	201.141	174.430	151.994	136.910	131.805	108.632	91.799	68.613
DULXS02i1	241.336	201.082	174.437	151.984	136.879	131.815	108.616	91.778	68.610

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS02i2	241.369	201.095	174.458	151.994	136.864	131.800	108.632	91.787	68.623
DULXS03	238.546	199.978	174.175	151.991	136.874	131.789	108.575	91.807	68.649
DULXS04	208.417	176.880	156.681	138.575	126.641	122.582	103.937	90.239	68.625
DULXS04i	191.872	168.074	151.613	137.030	126.993	123.423	106.660	91.758	68.637
DULXS05	219.840	190.060	168.653	149.391	135.693	130.860	108.564	91.892	68.620
DULXS05i1	217.663	187.297	166.876	148.436	135.469	130.949	108.684	91.888	68.620
DULXS05i2	224.861	191.593	168.361	148.413	135.125	130.588	108.701	91.886	68.620
DULXS06cpus	216.386	186.869	165.511	147.350	134.959	130.628	108.710	91.903	68.631
DULXS06	248.796	211.889	185.579	163.000	147.649	142.633	118.257	99.896	74.698
DULXS07cpus	230.322	201.047	182.757	161.720	147.637	142.622	118.243	99.894	74.699
DULXS07	283.913	241.072	211.818	185.547	167.290	160.913	132.490	111.831	83.663
DULXS08	293.511	245.708	213.206	185.718	167.299	160.956	132.495	111.802	83.685
DULXS08i	293.534	245.846	213.198	185.716	167.279	160.944	132.487	111.818	83.659
DULXS09	295.027	245.820	213.203	185.726	167.252	160.941	132.489	111.814	83.667
DULXS10	295.062	245.821	213.207	185.727	167.252	160.937	132.491	111.805	83.668
DULXS10_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS10_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS10_a	295.062	245.821	213.207	185.727	167.252	160.937	132.491	111.805	83.668
DULXS10_b	295.062	245.821	213.207	185.727	167.252	160.937	132.491	111.805	83.668
DULXS11	295.062	245.821	213.207	185.727	167.252	160.937	132.491	111.805	83.668
DULXS12	295.033	245.802	213.203	185.730	167.256	160.933	132.484	111.803	83.669
DULXS12In1	295.051	245.817	213.209	185.722	167.261	160.931	132.485	111.809	83.670
DULXS13	295.041	245.814	213.214	185.742	167.260	160.955	132.495	111.797	83.670
DULXS14	295.058	245.816	213.272	185.721	167.259	160.958	132.491	111.810	83.666
DULXS14_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS14_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS14_a	295.058	245.816	213.272	185.721	167.259	160.958	132.491	111.810	83.666
DULXS14_b	295.058	245.816	213.272	185.721	167.259	160.958	132.491	111.810	83.666
DULXS15	295.058	245.816	213.272	185.721	167.259	160.958	132.491	111.810	83.666
DULXS16	295.034	245.802	213.323	185.709	167.266	160.984	132.518	111.833	83.664
DULXS17	283.805	240.763	211.092	185.031	167.097	160.843	132.494	111.804	83.675
DULXS18	284.824	242.321	212.146	185.851	167.763	161.536	133.228	112.403	84.084
DULXS19	289.798	246.433	214.313	186.783	168.168	161.777	133.214	112.394	84.076
DULXS19i1	294.809	247.797	214.866	187.267	168.619	162.221	133.579	112.669	84.276
DULXS20	296.789	247.802	214.878	187.258	168.608	162.226	133.566	112.659	84.269
DULXS21	296.886	247.797	214.876	187.256	168.616	162.231	133.573	112.662	84.272
DULXS21_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS21_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS21_a	296.886	247.797	214.876	187.256	168.616	162.231	133.573	112.662	84.272
DULXS21_b	296.886	247.797	214.876	187.256	168.616	162.231	133.573	112.662	84.272
DULXS21i	296.886	247.797	214.876	187.256	168.616	162.231	133.573	112.662	84.272
DULXS22	296.888	247.800	214.873	187.259	168.614	162.233	133.572	112.664	84.274
DULXS23	296.886	247.811	214.885	187.254	168.616	162.233	133.574	112.661	84.279
DULXS24	293.877	246.203	214.220	187.021	168.541	162.243	133.543	112.651	84.285
DULXS25	291.340	243.566	212.250	185.732	167.699	161.451	133.708	113.007	84.549

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS26	292.682	247.850	215.400	187.867	169.126	162.676	133.992	113.000	84.550
DULXS27	286.789	244.263	214.006	187.480	169.124	162.680	133.974	113.002	84.523
DULXS28	292.449	247.323	215.379	188.250	169.751	163.207	134.414	113.397	84.840
DULXS29	299.570	249.467	216.306	188.433	169.721	163.203	134.402	113.395	84.836
DULXS29i1	300.484	250.216	216.944	188.983	170.249	163.674	134.793	113.738	85.061
DULXS30	299.776	250.222	216.938	188.986	170.244	163.673	134.770	113.718	85.060
DULXS30i1	300.496	250.226	216.935	188.986	170.241	163.669	134.774	113.722	85.068
DULXS30i2	300.486	250.216	216.933	188.988	170.241	163.671	134.775	113.722	85.063
DULXS30i3	300.465	250.211	216.934	188.988	170.242	163.676	134.775	113.722	85.060
DULXS31	300.456	250.219	216.940	188.991	170.239	163.673	134.776	113.713	85.070
DULXS32	300.449	250.214	216.942	188.989	170.235	163.673	134.775	113.718	85.063
DULXS32_Sp	3.485	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS32_SpDS	3.485	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS32_a	296.964	250.214	216.942	188.989	170.235	163.673	134.775	113.718	85.063
DULXS32_b	296.964	250.214	216.942	188.989	170.235	163.673	134.775	113.718	85.063
DULXS33	300.449	250.214	216.942	188.989	170.235	163.673	134.775	113.718	85.063
DULXS34	300.454	250.215	216.938	188.991	170.231	163.678	134.774	113.720	85.064
DULXS35	300.445	250.212	216.943	188.995	170.238	163.681	134.776	113.716	85.066
DULXS35_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS35_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS35_a	300.445	250.212	216.943	188.995	170.238	163.681	134.776	113.716	85.066
DULXS35_b	300.445	250.212	216.943	188.995	170.238	163.681	134.776	113.716	85.066
DULXS36	300.445	250.212	216.943	188.995	170.238	163.681	134.776	113.716	85.066
DULXS37	300.455	250.212	216.939	188.997	170.231	163.679	134.776	113.719	85.071
DULXS37i1	300.445	250.215	216.954	189.001	170.230	163.676	134.774	113.724	85.064
DULXS38	300.455	250.224	216.930	188.998	170.214	163.698	134.772	113.709	85.073
DULXS40	300.491	250.232	216.965	189.014	170.220	163.669	134.796	113.736	85.094
DULXS43	301.289	251.307	217.877	189.774	170.967	164.357	135.312	114.181	85.416
DULXS44	269.460	236.868	213.051	189.311	170.928	164.361	135.332	114.191	85.424
DULXS45	269.804	236.896	213.020	189.299	170.949	164.354	135.330	114.275	85.458
DULXS46	265.948	242.400	216.152	191.217	173.092	166.283	136.850	115.647	86.566
DULXS46i1	290.291	250.641	218.591	191.490	173.002	166.295	136.884	115.721	86.586
DULXS47	244.092	215.743	191.347	169.846	156.169	151.727	131.551	114.444	86.608
DULXS47i1	248.340	212.538	187.750	166.933	153.518	149.052	130.741	114.721	87.093
DULXS47i2	250.591	213.449	188.114	167.126	153.528	149.076	130.768	114.714	87.076
DULXS48	252.707	214.380	188.392	167.180	153.582	149.096	130.779	114.695	87.111
DS_Lat_01	2.600	2.167	1.876	1.632	1.467	1.411	1.159	0.967	0.717
DS_Lat_02	1.229	1.024	0.887	0.772	0.693	0.667	0.548	0.457	0.339
DS_Lat_03	1.549	1.291	1.118	0.973	0.874	0.841	0.691	0.576	0.427
DS_Lat_04	1.669	1.390	1.204	1.047	0.941	0.906	0.744	0.621	0.460
DS_Lat_05	1.430	1.192	1.032	0.898	0.807	0.776	0.638	0.532	0.394
DS_Lat_06	2.037	1.697	1.470	1.279	1.149	1.105	0.908	0.758	0.561
DS_Lat_07	5.851	4.876	4.221	3.673	3.301	3.175	2.608	2.176	1.613
DS_Lat_08	2.512	2.093	1.812	1.577	1.417	1.363	1.120	0.934	0.692

Sensitivity Analysis

1D sensitivity. Baseline

13.2.29 In order to analyse the sensitivity of the hydraulic model, the models have been updated to represent a change in parameters. The variation in stage (m) results from the 1D have been compared against the baseline results for the 0.5% AEP event, these are shown in Figures 13-7 to 13-9. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- Downstream Boundary +/ - 20%

13.2.30 As can be seen from the data, the baseline model is sensitive to changes in flow and roughness for some sections, especially upstream of structures or changes in channel gradient. The model is not very sensitive to changes to the downstream boundary or the 50% blockage

Figure 13-7 Modelled Long Section Baseline Sensitivity Results - Allt Nan Ceatharnach

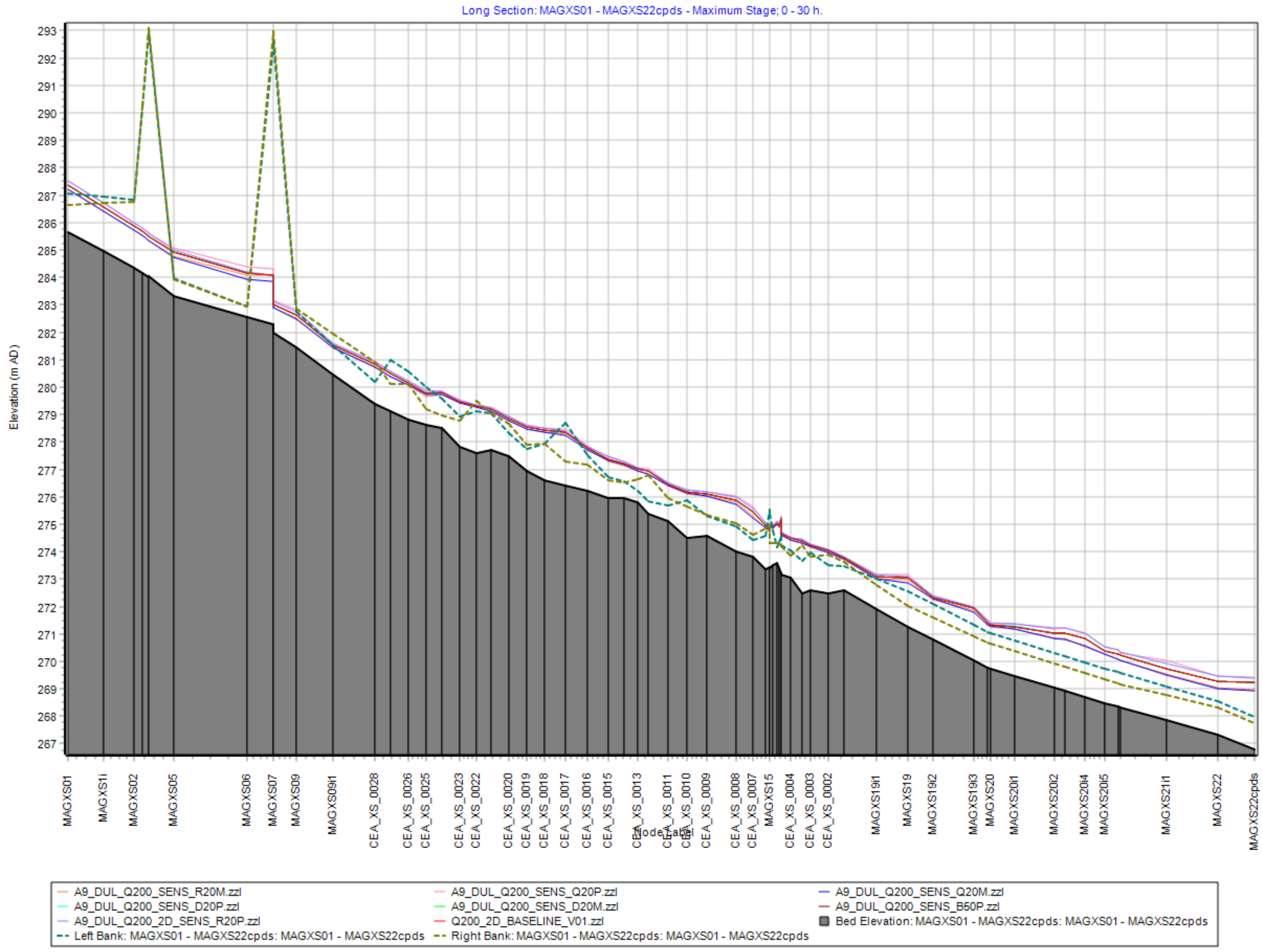


Figure 13-8 Modelled Long Section Baseline Sensitivity Results - Allt Lorgy

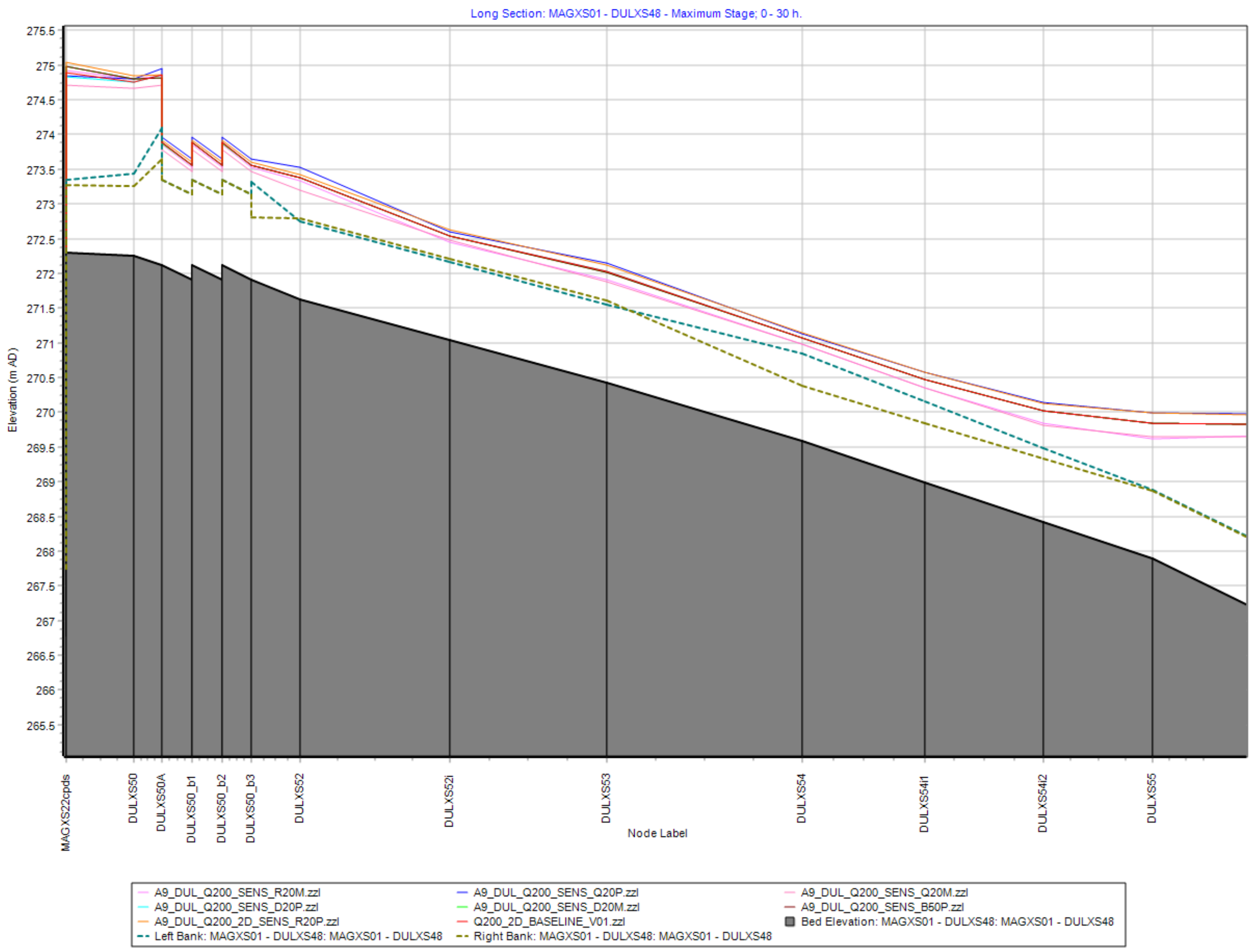
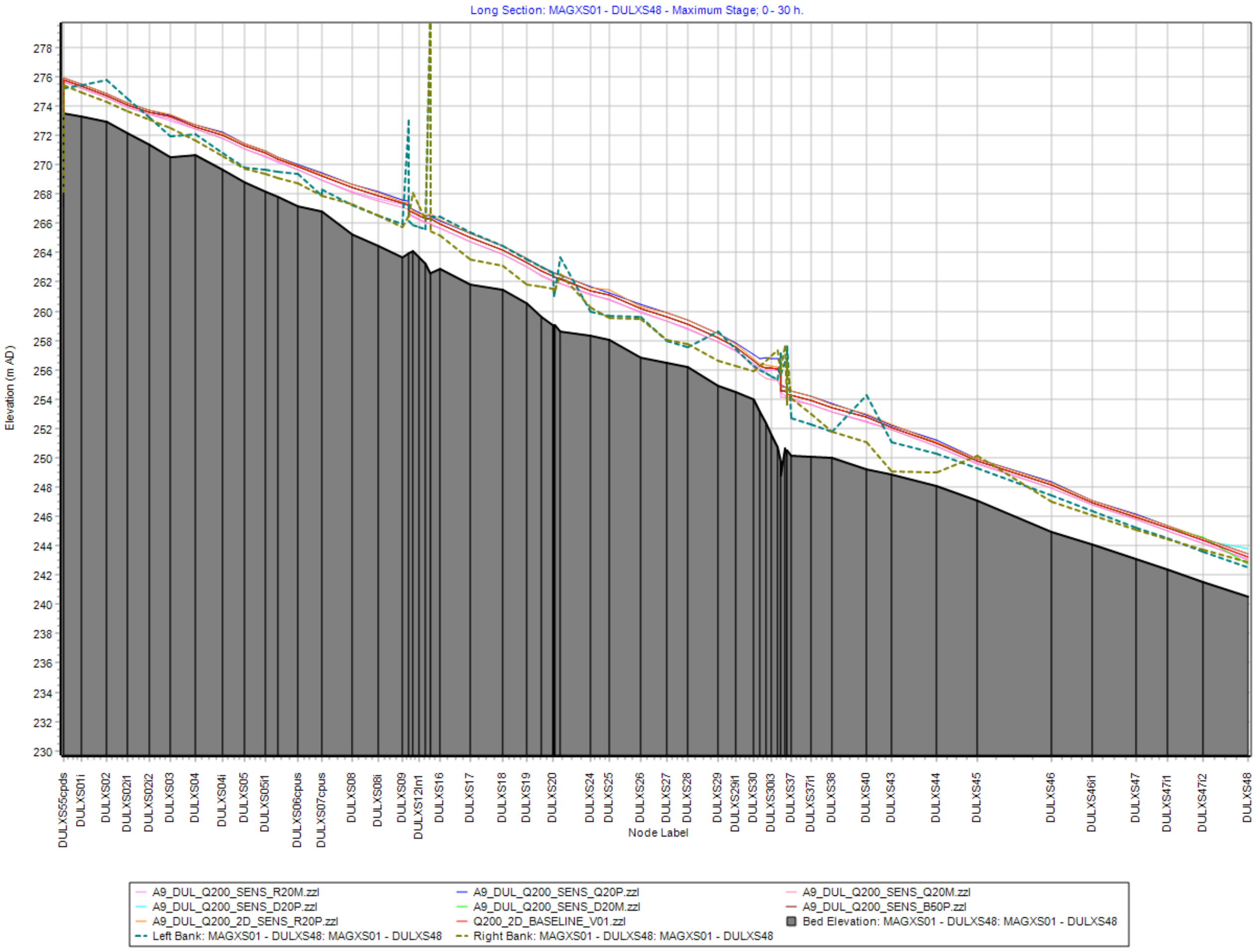


Figure 13-9 Modelled Long Section Baseline Sensitivity Results- River Dulnain



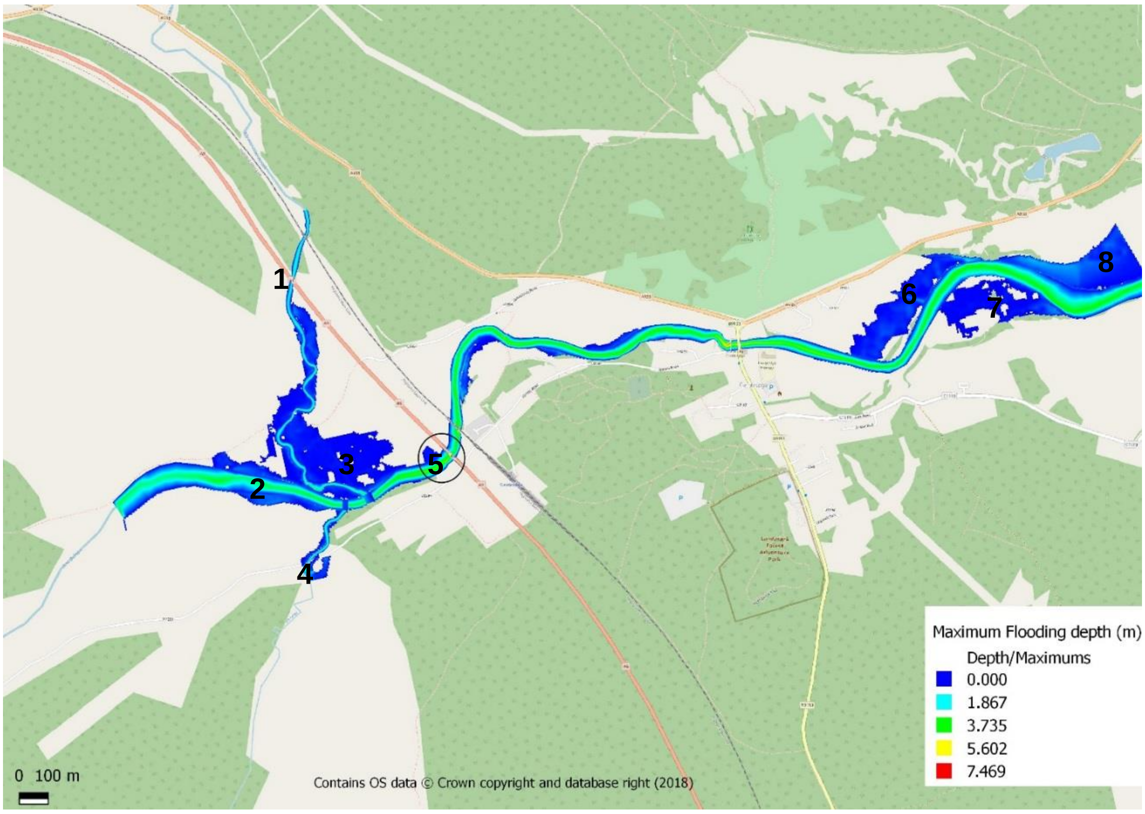
2D Sensitivity, Baseline

13.2.31 In order to assess the 2D sensitivity of the Baseline model, a set of 7 tests were carried out and results analysed at 5 locations throughout the 2D domain. These tests are designed to better understand how specific parameters, that are used in the calculations carried out by the model software, impact the output results, and get a better understanding into the robustness of the hydraulic model. Table 13-12 details these sensitivity test locations, and Figure 13-10 shows the location of the sensitivity test locations relative to the modelled reach and the baseline Q200+CC results.

Table 13-12 2D Model sensitivity test Locations – Baseline

Location of sensitivity test	Description of location	Easting	Northing
1	Allt nan Ceatharnach A9 crossing	289129	823046
2	River Dulnain upstream floodplain area	289050	822399
3	Allt nan Ceatharnach floodplain at Dulnain confluence	289252	822534
4	Allt Lorgy	289207	822128
5	River Dulnain at A9 crossing	289622	822506
6	Left bank floodplain at Carrbridge on the River Dulnain	291171	822982
7	Right bank floodplain at Carrbridge on the River Dulnain	291506	823083
8	Floodplain downstream of Carrbridge on the River Dulnain	291880	823151

Figure 13-10 Location of 2D sensitivity test locations and the baseline Q200+CC flood outline



13.2.32 Table 13-13 provides the variation in depth in metres from the baseline at each of the locations for the sensitivity tests undertaken.

Table 13-13 Sensitivity Results Baseline model. Variation in depth from Q200 (m)

Sensitivity Test	Baseline	+20% Flow	-20% Flow	+20% Mann	-20% Mann	+20% DSB	-20% DSB	+ 50% Blockage
Location 1	0.969	0.109	-0.147	0.083	-0.118	0	0	0
Location 2	0.756	0.2	-0.226	0.139	-0.21	0	0	0
Location 3	0.045	0.021	-0.022	0.014	-0.013	0	0	0
Location 4	0.307	0.044	-0.105	0.027	-0.019	0	0	0
Location 5	4.550	0.267	-0.299	0.183	-0.1	0	0	0
Location 6	0.473	0.161	-0.285	0.203	-0.289	0	0	0
Location 7	0.031	0.199	-0.031	0.175	-0.031	-0.001	-0.001	-0.001
Location 8	0.289	0.083	-0.097	0.078	-0.104	-0.001	0	0

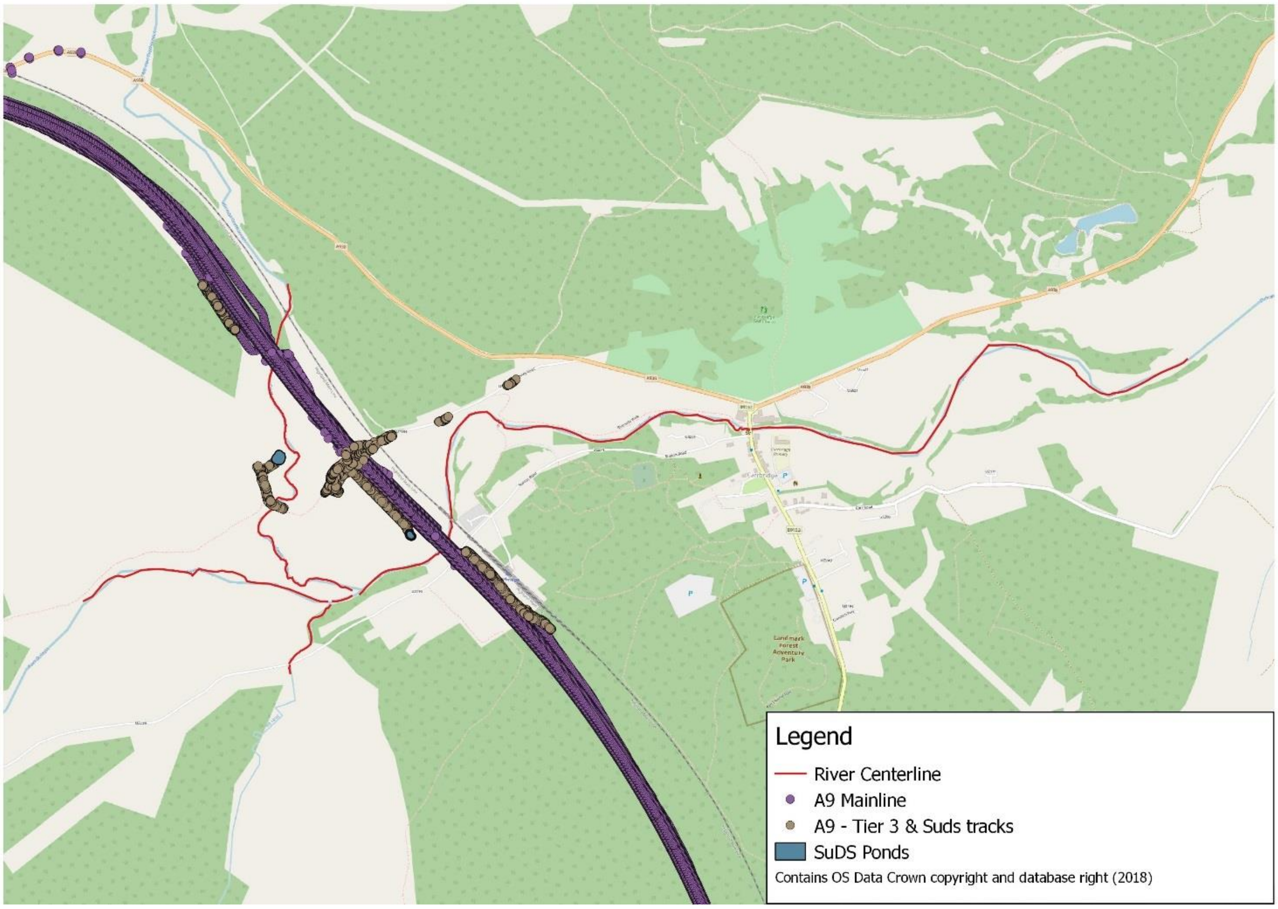
13.2.33 The Baseline model does not show much variation to the sensitivity tests at Location 3 and 4. The maximum variations are located at sensitivity test location 5 which is upstream of the A9 crossing and downstream within the extensive floodplain at Carrbridge. The model is not sensitive to downstream boundary changes or 50% blockage scenario

13.3 Proposed Model (‘with-scheme’ modelling)

13.3.1 Design refresh 7a (DR7a) provided with the final proposed levels for A9 mainline, new access roads and for the Sustainable urban drainage system (SuDS) tracks.

13.3.2 Figure 13.11 shows the layout of the proposed scheme in the vicinity of the model.

Figure 13-11. Proposed Scheme Arrangement



13.3.3 The proposed scheme in model includes an update to:

- A9 mainline (widening)
- A9 mainline new bridges at River Dulnain and River Allt nan Ceatharnach
- Access road tracks and new design access bridge structure
- SuDS Ponds

1D model updates

13.3.4 The proposed scheme retains the A9 existing bridge structures and includes an additional single span bridge on the downstream side. The existing bridge structures within the model have not been modelled as a dual bridge but have been modelled in explicit manner as a separate structure alongside the existing bridge.

13.3.5 A new A9 bridge, Baddengorm Bridge, Allt nan Ceatharnach has been added to the model 4.93m upstream of the existing bridge

13.3.6 A new A9 bridge across the River Dulnain has been added to the model 4m downstream of the existing bridge.

13.3.7 Figure 13-12 and Figure 13-13 show the modelled sections representing the new A9 bridges. The new bridges are freespan structures which do not encroach on the existing channels which contain the 0.5% AEP flow.

Figure 13-12 - New Baddengorm Bridge on Allt nan Ceatharnach

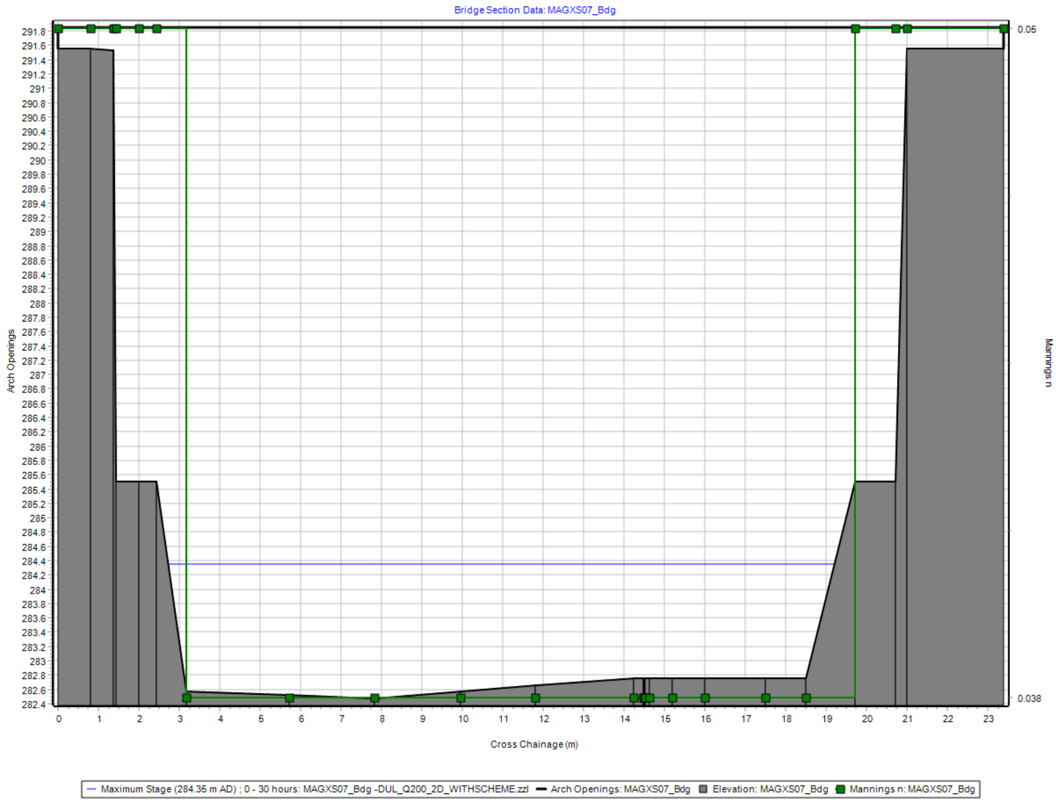
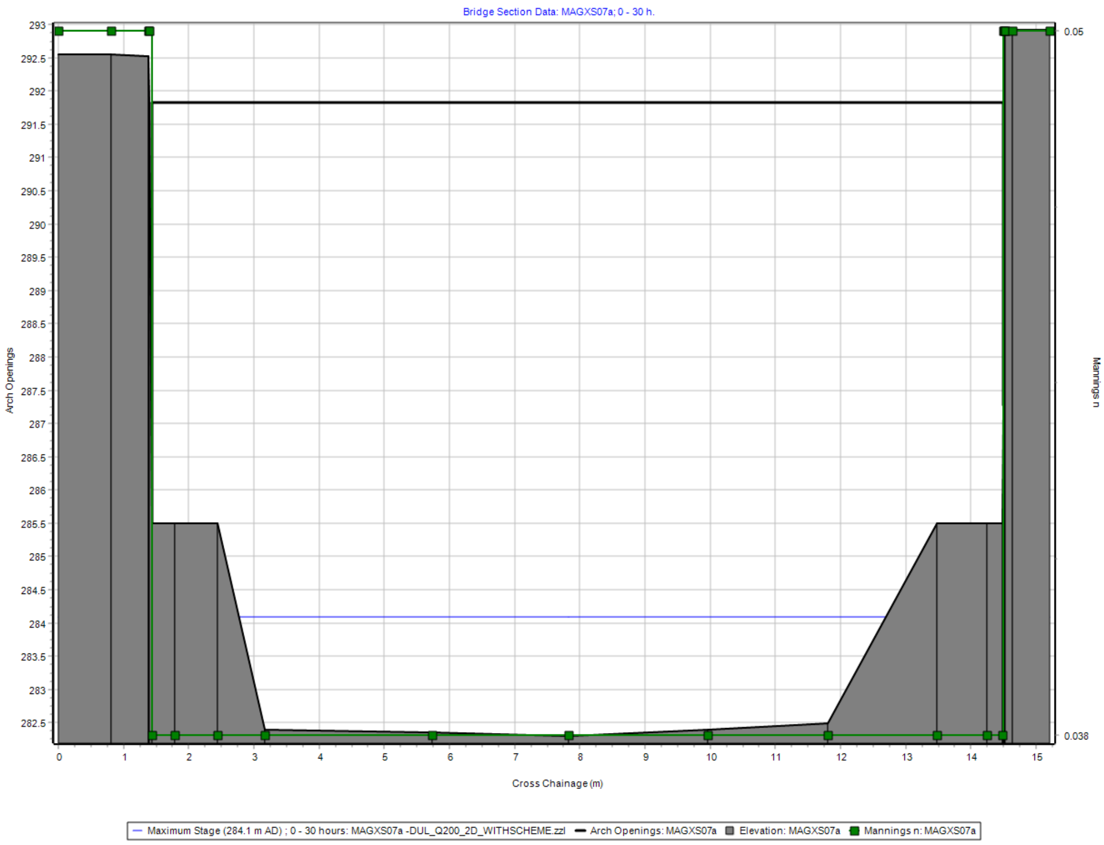


Figure 13-13 A91200 Bridge on River Dulnain



13.3.8 Access tracks and SuDS locations have been added to the model as shown in Figure 13.11.

13.3.9 A new access road bridge has been added to the model at 289162,822885 on the Allt nan Ceatharnach.

13.3.10 The preliminary bridge design had a soffit level at 274.825mAOD, and with this design arrangement, the bridge is predicted to be flooding for 0.5 % AEP (Annual exceedance probability) and the flooding level predicted is 275.3mAOD. A number of iterations of soffit level and increased span of the structure were modelled to assess the impact on water levels in the floodplain for a 0.5% AEP. Raising soffit levels above existing bank levels would require the access road to be on an embankment resulting in increased water levels upstream due to restricted conveyance within the floodplain. As the purpose of the access track is for maintenance of the SuDS pond, the requirement for 600mm freeboard for a 0.5% AEP event was deemed unnecessary. The final design of the bridge is, therefore a 15m span with soffit level set at 275.30 mAOD and three floodplain culverts of 5m width x 1 m height within the left floodplain. This structure passes the 0.5% AEP flow with no freeboard allowance.

2D model updates

13.3.11 The proposed scheme elevations (tracks) were added to the hydraulic model. Within the footprint of the proposed scheme these raster grids replaced the existing ground elevations for the road embankments. Few of the proposed new access road levels at Allt nan Ceatharnach are lower than the LiDAR DTM, hence only the levels which are higher than the DTM are used in the with-scheme model.

13.3.12 SuDS features have been included in the model with an initial water level set such that the retention ponds and detention basins are already full of water at the start of the simulation. Access tracks and SuDS locations have been added to the model as shown in Figure 13.11.

13.3.13 Where it has been required, the modifications of the floodplain structures for the drains and other structure under the A9 have been added to the model. Table 13.14 summarises all these changes.

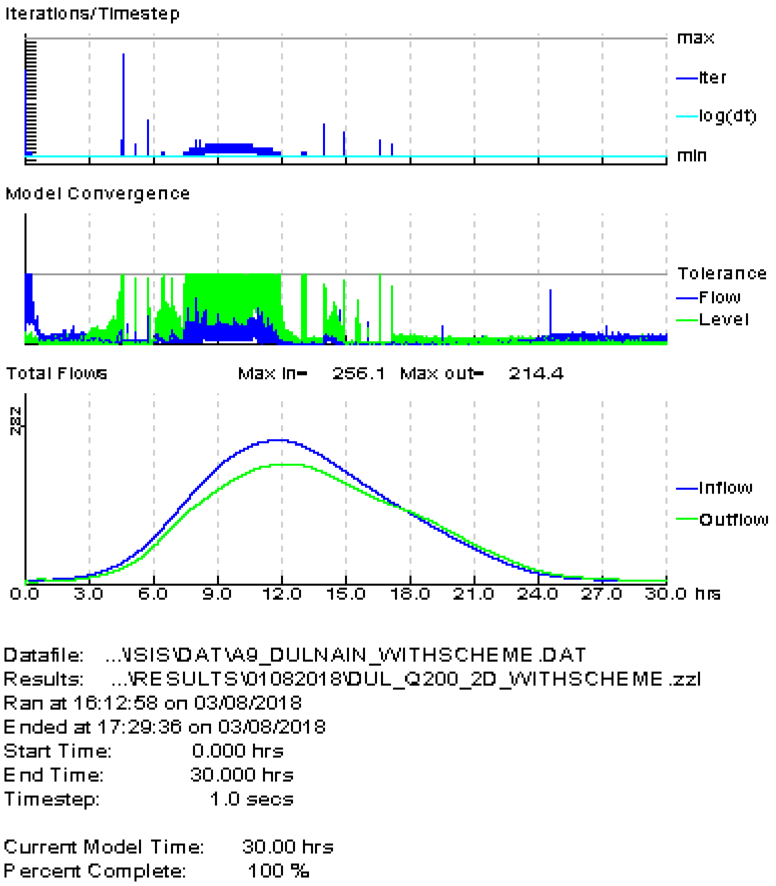
Table 13-14. 2D model updates

S.No	2D model changes	Source of data	Structure details
1.	The proposed levels for the mainline, Access road, SuDS tracks are stamped on the base Lidar	Design Refresh 7a - Mainline & Tier 1 XYZ NG.xlsx A9 D-S Pond Track N2 XYZ file NG.xlsx	Based on DR7a
2.	SuDS pond N1 and N2 are included in the 2D domain	Design Refresh 7 - Tier 3 & Suds tracks XYZ NG.txt	Based on DR7a
3.	New access road bridge near River Dulnain is modelled as 1D ESTRY culvert unit	A9P11-AMJ-SGN-Z_ZZZZZ_ZZ-DO-ST-0001.xls	5.3m X 5.5m X 38m
4.	Carrbridge underpass bridge dimensions	A9P11-AMJ-SBR-H_MLCAR_ST-M2-ST-0002.dwg	13m X 5.5m X 7.5m

Model performance

13.3.14 Run performance has been monitored throughout the model build process and then during each simulation carried out to ensure a suitable model convergence was achieved, Figure 13.12.

Figure 13-14 Model convergence plot for 1in 200yr flood event - “model with scheme”

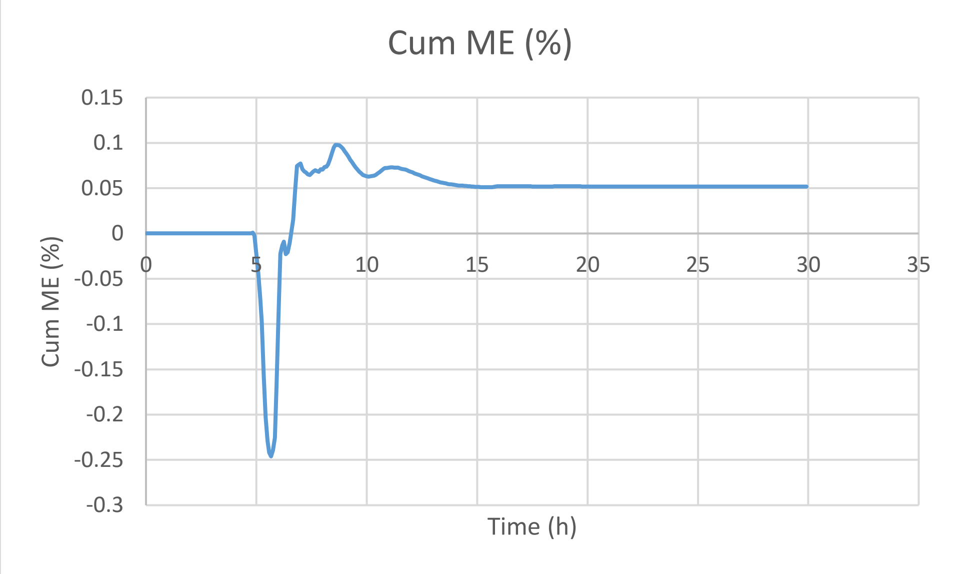


13.3.15 Convergence is calculated for each modelled time step and shows the consistency of the modelled water level and flow within the iterations that are computed for each model time step.

13.3.16 The cumulative mass error output from the 2D model is within the acceptable tolerance range recommended by the software manuals of +/- 1% mass balance error.

13.3.17 Figure 13.13 shows that for the 0.5% AEP (1in 200yr) flood event the cumulative mass error tolerance is well within the permissible limits of +/-1 %. This mass error check is typical for all events simulated.

Figure 13-15 Mass Balance Plot



13.4 Mitigation measures

13.4.1 There is no impact of floodplain encroachments of A9 mainline so potential compensation is not considered.

13.4.2 The proposed scheme resulted in an increase in flood extent at the new access road on Allt nan Ceathernach so to mitigate that, the new access road was raised by 0.5m and 3 flood relief culverts of 5m width and 1m height have been added to provide conveyance of flow downstream to match the baseline.

13.4.3 A proposed pond at (OSNGR 289140,822860) is located outside of 0.5% AEP floodplain so compensation (replacement) flood storage is not considered.

13.4.4 A proposed pond at (OSNGR 289642,822540) is located outside of 0.5% AEP floodplain so compensation (replacement) flood storage is not considered.

13.5 Modelling Results Analysis

Proposed model (‘with-scheme’) results

13.5.1 Table 13-15 and Table 13-16 summarise the stage and flow for the proposed scheme with embedded mitigation measures.

Table 13-15 Proposed stage (mAOD) for modelled return periods

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS01	287.501	287.362	287.262	287.171	287.105	287.082	286.964	286.863	286.711
MAGXS1i	286.702	286.560	286.460	286.373	286.308	286.285	286.178	286.085	285.947
MAGXS02	286.008	285.864	285.763	285.677	285.614	285.592	285.490	285.407	285.281
MAGXS02i	285.817	285.673	285.571	285.483	285.421	285.399	285.295	285.218	285.094
MAGXS03	285.643	285.498	285.394	285.304	285.241	285.220	285.113	285.041	284.912
MAGXS03_Sp	285.643	285.498	285.394	285.304	285.241	285.220	285.113	285.041	284.912
MAGXS03_SpDS	285.639	285.493	285.388	285.299	285.235	285.212	285.109	285.029	284.906
MAGXS03a	285.643	285.498	285.394	285.304	285.241	285.220	285.113	285.041	284.912
MAGXS04b	285.639	285.493	285.388	285.299	285.235	285.212	285.109	285.029	284.906

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS04	285.639	285.493	285.388	285.299	285.235	285.212	285.109	285.029	284.906
MAGXS05	285.108	284.949	284.826	284.721	284.648	284.623	284.509	284.420	284.300
MAGXS06	284.572	284.320	284.143	283.986	283.877	283.838	283.660	283.518	283.332
MAGXS07u	284.591	284.346	284.173	284.020	283.914	283.876	283.700	283.558	283.356
MAGXS07_Bdg	284.591	284.346	284.173	284.020	283.914	283.876	283.700	283.558	283.356
MAGXS07sp	284.603	284.358	284.186	284.034	283.927	283.890	283.715	283.573	283.373
MAGXS07spd	284.515	284.277	284.110	283.962	283.858	283.821	283.651	283.512	283.313
MAGXS07_spu	284.591	284.346	284.173	284.020	283.914	283.876	283.700	283.558	283.356
MAGXS07_spd	284.515	284.277	284.110	283.962	283.858	283.821	283.651	283.512	283.313
MAGXS07d	284.515	284.277	284.110	283.962	283.858	283.821	283.651	283.512	283.313
MAGXS07	284.317	284.097	283.943	283.806	283.710	283.676	283.521	283.392	283.212
MAGXS07a	284.317	284.097	283.943	283.806	283.710	283.676	283.521	283.392	283.212
MAGXS08b	284.333	284.116	283.964	283.830	283.736	283.703	283.549	283.422	283.243
MAGXS08_spd	283.313	283.179	283.087	283.009	282.954	282.932	282.839	282.767	282.654
MAGXS07_Sp	284.317	284.097	283.943	283.806	283.710	283.676	283.521	283.392	283.212
MAGXS07_SpDS	283.313	283.179	283.087	283.009	282.954	282.932	282.839	282.767	282.654
MAGXS08	283.313	283.179	283.087	283.009	282.954	282.932	282.839	282.767	282.654
MAGXS09	282.805	282.647	282.542	282.450	282.391	282.369	282.278	282.204	282.103
MAGXS09i1	281.561	281.513	281.477	281.445	281.417	281.404	281.344	281.283	281.180
CEA_XS_0028	280.961	280.845	280.763	280.687	280.632	280.612	280.524	280.439	280.314
CEA_XS_0027	280.561	280.479	280.421	280.371	280.332	280.315	280.243	280.176	280.067
CEA_XS_0026	280.241	280.159	280.112	280.068	280.031	280.016	279.954	279.894	279.795
CEA_XS_0025	279.812	279.768	279.741	279.716	279.700	279.692	279.652	279.619	279.589
CEA_XS_0024	279.833	279.793	279.764	279.726	279.689	279.675	279.620	279.568	279.495
CEA_XS_0023	279.520	279.469	279.440	279.413	279.409	279.407	279.343	279.286	279.190
CEA_XS_0022	279.361	279.311	279.281	279.255	279.246	279.240	279.176	279.114	279.017
CEA_XS_0021	279.255	279.185	279.131	279.086	279.043	279.032	278.954	278.889	278.791
CEA_XS_0020	278.934	278.865	278.803	278.753	278.715	278.697	278.626	278.579	278.482
CEA_XS_0019	278.605	278.535	278.484	278.447	278.414	278.397	278.386	278.368	278.250
CEA_XS_0018	278.514	278.430	278.370	278.320	278.285	278.267	278.200	278.157	278.056
CEA_XS_0017	278.454	278.362	278.291	278.223	278.168	278.139	278.034	277.932	277.772
CEA_XS_0016	277.868	277.787	277.732	277.684	277.651	277.633	277.560	277.504	277.390
CEA_XS_0015	277.431	277.375	277.335	277.302	277.277	277.256	277.205	277.165	277.091
CEA_XS_0014	277.268	277.219	277.181	277.156	277.133	277.116	277.060	277.011	276.907
CEA_XS_0013	277.073	277.017	276.969	276.914	276.877	276.852	276.781	276.720	276.611
CEA_XS_0012	277.002	276.929	276.858	276.772	276.712	276.679	276.582	276.519	276.394
CEA_XS_0011	276.472	276.434	276.410	276.406	276.381	276.360	276.308	276.250	276.123
CEA_XS_0010	276.250	276.198	276.157	276.131	276.103	276.088	276.035	275.994	275.883
CEA_XS_0009	276.180	276.113	276.055	276.007	275.974	275.977	275.884	275.792	275.640
CEA_XS_0008	276.001	275.877	275.794	275.702	275.609	275.556	275.391	275.297	275.138
CEA_XS_0007	275.587	275.487	275.424	275.308	275.244	275.106	275.032	274.958	274.786
CEA_XS_0006	275.620	275.603	275.571	275.021	275.003	274.995	274.983	274.878	274.554
MAGXS15	275.828	275.689	275.602	274.937	274.859	274.804	274.785	274.722	274.482
MAGXS15_Sp	275.828	275.689	275.602	274.937	274.859	274.804	274.785	274.722	274.482
MAGXS15_SpDS	275.402	275.293	275.234	275.055	274.973	274.903	274.847	274.775	274.540

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS15a	275.828	275.689	275.602	274.937	274.859	274.804	274.785	274.722	274.482
MAGXS16b	275.402	275.293	275.234	275.055	274.973	274.903	274.847	274.775	274.540
MAGXS16	275.402	275.293	275.234	275.055	274.973	274.903	274.847	274.775	274.540
MAGXS16In1	275.367	275.254	275.202	275.162	275.137	275.088	274.954	274.864	274.620
CEA_XS_0005	275.356	275.274	275.273	275.228	275.195	275.135	274.985	274.892	274.651
MAGXS17	275.314	275.231	275.231	275.175	275.125	275.053	274.883	274.774	274.333
MAGXS17_Sp	275.314	275.231	275.231	275.175	275.125	275.053	274.883	274.774	274.333
MAGXS17_SpDS	274.686	274.653	274.642	274.626	274.603	274.578	274.489	274.414	274.310
MAGXS17a	275.314	275.231	275.231	275.175	275.125	275.053	274.883	274.774	274.333
MAGXS17Ab	274.686	274.653	274.642	274.626	274.603	274.578	274.489	274.414	274.310
MAGXS17cpds	274.686	274.653	274.642	274.626	274.603	274.578	274.489	274.414	274.310
CEA_XS_0004	274.525	274.478	274.441	274.423	274.397	274.384	274.316	274.249	274.153
MAGXS18	274.398	274.339	274.309	274.285	274.258	274.240	274.173	274.124	274.048
CEA_XS_0003	274.253	274.217	274.198	274.178	274.157	274.139	274.060	273.971	273.850
CEA_XS_0002	274.090	274.038	274.000	273.976	273.948	273.930	273.865	273.803	273.726
CEA_XS_0001	273.805	273.762	273.752	273.734	273.712	273.694	273.635	273.576	273.503
MAGXS19i1	273.158	273.093	273.043	273.018	272.996	272.982	272.933	272.895	272.845
MAGXS19	273.160	273.030	272.908	272.825	272.760	272.722	272.581	272.445	272.316
MAGXS19i2	272.380	272.322	272.296	272.290	272.268	272.243	272.139	272.036	271.926
MAGXS19i3	271.990	271.945	271.858	271.755	271.676	271.656	271.572	271.487	271.342
MAGXS19i4	271.546	271.417	271.344	271.301	271.284	271.281	271.263	271.242	271.165
MAGXS20	271.359	271.325	271.296	271.276	271.270	271.270	271.252	271.225	271.137
MAGXS20i1	271.381	271.276	271.227	271.172	271.131	271.112	271.041	270.974	270.859
MAGXS20i2	271.191	271.020	270.890	270.790	270.716	270.703	270.658	270.534	270.393
MAGXS20i3	271.228	271.040	270.888	270.751	270.693	270.666	270.552	270.427	270.269
MAGXS20i4	271.033	270.818	270.653	270.505	270.391	270.371	270.314	270.204	270.037
MAGXS20i5	270.531	270.383	270.299	270.233	270.192	270.174	270.084	269.972	269.791
MAGXS20i6	270.407	270.252	270.139	270.046	269.999	269.975	269.905	269.804	269.629
MAGXS21	270.310	270.214	270.100	270.004	269.962	269.944	269.860	269.756	269.593
MAGXS21i1	270.035	269.721	269.576	269.456	269.401	269.385	269.304	269.203	269.031
MAGXS22	269.470	269.258	269.064	268.944	268.854	268.834	268.678	268.546	268.361
MAGXS22cpds	269.434	269.227	269.038	268.868	268.756	268.717	268.529	268.382	268.135
DULXS49	275.078	274.967	274.820	274.675	274.608	274.590	274.418	274.279	274.023
DULXS50	274.894	274.820	274.731	274.656	274.603	274.585	274.405	274.265	273.999
DULXS50A	274.985	274.852	274.772	274.684	274.607	274.583	274.390	274.239	273.962
Spill_50A_us	274.985	274.852	274.772	274.684	274.607	274.583	274.390	274.239	273.962
Spill_50A_ds	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.083	272.938
DULXS50_In1	274.985	274.852	274.772	274.684	274.607	274.583	274.390	274.239	273.962
DULXS50_a1	274.099	273.982	273.924	273.835	273.747	273.723	273.581	273.431	273.380
DULXS50_b1	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.173	273.172
DUMMY1	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.083	272.938
DULXS50_I2	274.985	274.852	274.772	274.684	274.607	274.583	274.390	274.239	273.962
DULXS50_a2	274.099	273.983	273.924	273.835	273.747	273.723	273.581	273.431	273.380
DULXS50_b2	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.173	273.172
DUMMY2	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.083	272.938

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS50_I3	274.985	274.852	274.772	274.684	274.607	274.583	274.390	274.239	273.962
DULXS50_a3	274.112	273.995	273.936	273.847	273.759	273.735	273.582	273.439	273.358
DULXS50_b3	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.155	273.151
DUMMY3	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.083	272.938
DULXS51A	273.650	273.562	273.519	273.426	273.335	273.310	273.187	273.083	272.938
DULXS52	273.517	273.366	273.262	273.159	273.104	273.077	272.967	272.883	272.716
DULXS52i	272.593	272.539	272.498	272.449	272.405	272.388	272.308	272.232	272.076
DULXS53	272.138	272.013	271.928	271.849	271.791	271.770	271.675	271.597	271.441
DULXS54	271.129	271.063	271.010	270.943	270.897	270.880	270.785	270.703	270.552
DULXS54i1	270.571	270.466	270.389	270.313	270.260	270.242	270.136	270.050	269.906
DULXS54i2	270.148	270.016	269.890	269.769	269.691	269.667	269.542	269.445	269.292
DULXS55	269.989	269.835	269.729	269.588	269.484	269.447	269.263	269.116	268.900
DULXS55cpds	269.980	269.833	269.733	269.601	269.504	269.468	269.283	269.135	268.910
DULXS01	275.924	275.783	275.685	275.595	275.531	275.510	275.404	275.318	275.179
DULXS01i	275.497	275.367	275.278	275.197	275.138	275.117	274.964	274.874	274.715
DULXS02	274.844	274.711	274.612	274.529	274.469	274.449	274.282	274.157	273.982
DULXS02i1	274.232	274.079	273.970	273.872	273.803	273.779	273.659	273.532	273.334
DULXS02i2	273.696	273.551	273.453	273.360	273.294	273.292	273.292	273.292	273.292
DULXS03	273.376	273.268	273.194	273.123	273.073	273.055	272.942	272.862	272.728
DULXS04	272.709	272.586	272.501	272.427	272.378	272.361	272.286	272.204	272.068
DULXS04i	272.202	271.996	271.845	271.703	271.597	271.560	271.383	271.253	271.063
DULXS05	271.448	271.263	271.137	271.020	270.931	270.900	270.728	270.583	270.357
DULXS05i1	270.954	270.783	270.632	270.498	270.402	270.372	270.201	270.048	269.809
DULXS05i2	270.494	270.363	270.254	270.144	270.068	270.042	269.879	269.724	269.478
DULXS06cpus	269.980	269.833	269.733	269.601	269.504	269.468	269.283	269.135	268.910
DULXS06	269.980	269.833	269.733	269.601	269.504	269.468	269.283	269.135	268.910
DULXS07cpus	269.434	269.227	269.038	268.868	268.756	268.717	268.529	268.382	268.135
DULXS07	269.434	269.227	269.038	268.868	268.756	268.717	268.529	268.382	268.135
DULXS08	268.680	268.408	268.211	268.020	267.880	267.831	267.583	267.383	267.087
DULXS08i	268.139	267.849	267.655	267.473	267.317	267.266	267.001	266.790	266.467
DULXS09	267.614	267.351	267.178	267.012	266.769	266.723	266.536	266.363	266.081
DULXS10	267.512	267.239	267.068	266.897	266.752	266.699	266.435	266.225	265.917
DULXS10_Sp	267.512	267.239	267.068	266.897	266.752	266.699	266.435	266.225	265.917
DULXS10_SpDS	267.009	266.739	266.544	266.365	266.234	266.189	265.981	265.837	265.615
DULXS10_a	267.512	267.239	267.068	266.897	266.752	266.699	266.435	266.225	265.917
DULXS10_b	267.009	266.739	266.544	266.365	266.234	266.189	265.981	265.837	265.615
DULXS11	267.009	266.739	266.544	266.365	266.234	266.189	265.981	265.837	265.615
DULXS11a	266.988	266.717	266.519	266.338	266.206	266.161	265.953	265.809	265.587
DULXS11_Sp	266.988	266.717	266.519	266.338	266.206	266.161	265.953	265.809	265.587
DULXS11_Spd	266.963	266.722	266.548	266.388	266.272	266.231	266.033	265.877	265.642
DULXS11a_Bdg	266.988	266.717	266.519	266.338	266.206	266.161	265.953	265.809	265.587
DULXS12a	266.963	266.722	266.548	266.388	266.272	266.231	266.033	265.877	265.642
DULXS12	266.963	266.722	266.548	266.388	266.272	266.231	266.033	265.877	265.642
DULXS12In1	266.734	266.493	266.318	266.156	266.036	265.994	265.793	265.637	265.399
DULXS13	266.530	266.292	266.112	265.948	265.823	265.775	265.557	265.397	265.154

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS14	266.549	266.337	266.145	265.957	265.819	265.773	265.580	265.410	265.159
DULXS14_Sp	266.549	266.337	266.145	265.957	265.819	265.773	265.580	265.410	265.159
DULXS14_SpDS	266.479	266.276	266.088	265.902	265.766	265.721	265.534	265.367	265.120
DULXS14_a	266.549	266.337	266.145	265.957	265.819	265.773	265.580	265.410	265.159
DULXS14_b	266.479	266.276	266.088	265.902	265.766	265.721	265.534	265.367	265.120
DULXS15	266.479	266.276	266.088	265.902	265.766	265.721	265.534	265.367	265.120
DULXS16	266.149	265.927	265.748	265.579	265.455	265.412	265.196	265.025	264.784
DULXS17	265.277	265.035	264.848	264.675	264.548	264.505	264.286	264.106	263.828
DULXS18	264.429	264.178	263.975	263.796	263.669	263.630	263.441	263.294	263.073
DULXS19	263.615	263.336	263.138	262.956	262.831	262.792	262.596	262.450	262.232
DULXS19i1	263.027	262.743	262.543	262.334	262.199	262.156	261.933	261.768	261.525
DULXS20	262.684	262.423	262.224	261.968	261.815	261.764	261.499	261.310	261.020
DULXS21	262.628	262.369	262.171	261.908	261.752	261.701	261.427	261.234	260.933
DULXS21_Sp	262.628	262.369	262.171	261.908	261.752	261.701	261.427	261.234	260.933
DULXS21_SpDS	262.628	262.369	262.171	261.908	261.752	261.701	261.427	261.234	260.932
DULXS21_a	262.628	262.369	262.171	261.908	261.752	261.701	261.427	261.234	260.933
DULXS21_b	262.628	262.369	262.171	261.908	261.752	261.701	261.427	261.234	260.932
DULXS21i	262.628	262.369	262.171	261.908	261.752	261.701	261.427	261.234	260.932
DULXS22	262.589	262.331	262.134	261.867	261.710	261.658	261.380	261.186	260.880
DULXS23	262.461	262.210	262.016	261.833	261.689	261.638	261.427	261.228	260.891
DULXS24	261.668	261.422	261.233	261.060	260.934	260.891	260.645	260.499	260.274
DULXS25	261.279	261.098	260.912	260.736	260.609	260.566	260.298	260.078	259.781
DULXS26	260.473	260.191	260.018	259.860	259.747	259.707	259.502	259.340	259.097
DULXS27	259.880	259.626	259.440	259.280	259.165	259.125	258.942	258.796	258.578
DULXS28	259.379	259.094	258.901	258.741	258.611	258.568	258.340	258.164	257.910
DULXS29	258.447	258.178	257.983	257.791	257.660	257.614	257.387	257.211	256.938
DULXS29i1	257.807	257.546	257.383	257.245	257.147	257.119	256.937	256.793	256.567
DULXS30	257.030	256.611	256.313	256.101	255.961	255.910	255.697	255.535	255.305
DULXS30i1	256.778	256.284	255.890	255.611	255.426	255.353	255.083	254.883	254.611
DULXS30i2	256.820	256.149	255.612	255.277	255.046	254.948	254.604	254.352	254.003
DULXS30i3	256.794	256.129	255.611	255.153	254.812	254.695	254.283	253.983	253.565
DULXS31	256.742	256.075	255.543	255.076	254.740	254.628	254.216	253.892	253.431
DULXS32	256.283	255.608	255.117	254.687	254.365	254.258	253.920	253.645	253.258
DULXS32_Sp	256.283	255.608	255.117	254.687	254.365	254.258	253.920	253.645	253.258
DULXS32_SpDS	254.995	254.571	254.284	254.024	253.819	253.751	253.611	253.449	253.177
DULXS32_a	256.283	255.608	255.117	254.687	254.365	254.258	253.920	253.645	253.258
DULXS32_b	254.995	254.571	254.284	254.024	253.819	253.751	253.611	253.449	253.177
DULXS33	254.995	254.571	254.284	254.024	253.819	253.751	253.611	253.449	253.177
DULXS34	254.858	254.521	254.285	254.074	253.916	253.870	253.651	253.441	253.119
DULXS35	254.775	254.411	254.160	253.937	253.774	253.721	253.474	253.287	252.990
DULXS35_Sp	254.775	254.411	254.160	253.937	253.774	253.721	253.474	253.287	252.990
DULXS35_SpDS	254.667	254.338	254.112	253.911	253.764	253.713	253.474	253.291	252.998
DULXS35_a	254.775	254.411	254.160	253.937	253.774	253.721	253.474	253.287	252.990
DULXS35_b	254.667	254.338	254.112	253.911	253.764	253.713	253.474	253.291	252.998
DULXS36	254.667	254.338	254.112	253.911	253.764	253.713	253.474	253.291	252.998

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS37	254.553	254.243	254.037	253.860	253.728	253.682	253.450	253.258	252.947
DULXS37i1	254.198	253.923	253.717	253.533	253.398	253.352	253.115	252.921	252.619
DULXS38	253.664	253.410	253.207	253.025	252.893	252.848	252.583	252.365	252.039
DULXS40	252.896	252.773	252.579	252.381	252.236	252.185	251.917	251.725	251.407
DULXS43	252.178	252.081	251.986	251.859	251.739	251.694	251.481	251.381	251.126
DULXS44	251.180	251.015	250.886	250.750	250.638	250.598	250.398	250.202	249.953
DULXS45	249.889	249.785	249.665	249.537	249.435	249.396	249.213	249.064	248.831
DULXS46	248.362	248.147	247.979	247.840	247.739	247.700	247.525	247.390	247.188
DULXS46i1	247.059	246.956	246.858	246.764	246.698	246.676	246.567	246.465	246.288
DULXS47	246.121	245.958	245.845	245.746	245.679	245.655	245.556	245.464	245.279
DULXS47i1	245.368	245.204	245.083	244.976	244.903	244.877	244.774	244.674	244.472
DULXS47i2	244.520	244.340	244.207	244.097	244.024	243.995	243.873	243.756	243.526
DULXS48	243.423	243.244	243.110	242.991	242.910	242.882	242.759	242.643	242.414
DS_Lat_01	265.277	265.035	264.848	264.675	264.548	264.505	264.286	264.106	263.828
DS_Lat_02	263.615	263.336	263.138	262.956	262.831	262.792	262.596	262.450	262.232
DS_Lat_03	261.668	261.422	261.233	261.060	260.934	260.891	260.645	260.499	260.274
DS_Lat_04	259.880	259.626	259.440	259.280	259.165	259.125	258.942	258.796	258.578
DS_Lat_05	258.447	258.178	257.983	257.791	257.660	257.614	257.387	257.211	256.938
DS_Lat_06	252.896	252.773	252.579	252.381	252.236	252.185	251.917	251.725	251.407
DS_Lat_07	249.889	249.785	249.665	249.537	249.435	249.396	249.213	249.064	248.831
DS_Lat_08	246.121	245.958	245.845	245.746	245.679	245.655	245.556	245.464	245.279
CEA_05_Sp	275.356	275.274	275.273	275.228	275.195	275.135	274.985	274.892	274.651
CEA_05_Bdg	275.356	275.274	275.273	275.228	275.195	275.135	274.985	274.892	274.651
CEA_05_S	275.188	275.109	275.107	275.069	275.043	275.010	274.900	274.820	274.578
MAGXS17u	274.993	274.955	274.945	274.940	274.934	274.917	274.833	274.759	274.382
CEA_05_Sd	274.993	274.955	274.945	274.940	274.934	274.917	274.833	274.759	274.382
CEA_05_spd	274.993	274.955	274.945	274.940	274.934	274.917	274.833	274.759	274.382

Table 13-16 Proposed Flow (m^3/s) for modelled return periods

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS01	41.441	34.534	29.993	26.174	23.588	22.709	18.749	15.688	11.687
MAGXS1i	41.442	34.535	29.992	26.181	23.591	22.711	18.747	15.688	11.690
MAGXS02	41.445	34.533	29.990	26.177	23.598	22.715	18.752	15.688	11.689
MAGXS02i	41.446	34.535	29.989	26.177	23.600	22.714	18.751	15.689	11.688
MAGXS03	41.447	34.535	29.991	26.177	23.600	22.713	18.751	15.689	11.689
MAGXS03_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS03_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS03a	41.447	34.535	29.991	26.178	23.600	22.714	18.751	15.689	11.689
MAGXS04b	41.447	34.535	29.991	26.178	23.600	22.714	18.751	15.689	11.689
MAGXS04	41.447	34.535	29.991	26.177	23.600	22.714	18.751	15.689	11.689
MAGXS05	41.441	34.534	29.990	26.181	23.603	22.711	18.750	15.688	11.694
MAGXS06	41.377	34.534	29.990	26.168	23.597	22.709	18.750	15.690	11.689
MAGXS07u	41.361	34.530	29.991	26.165	23.597	22.707	18.750	15.687	11.690

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
MAGXS07_Bdg	41.361	34.530	29.991	26.165	23.597	22.707	18.750	15.687	11.690
MAGXS07sp	41.361	34.530	29.991	26.165	23.597	22.707	18.750	15.687	11.690
MAGXS07spd	41.361	34.530	29.991	26.165	23.597	22.707	18.750	15.687	11.690
MAGXS07_spu	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492
MAGXS07_spd	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492
MAGXS07d	41.361	34.530	29.991	26.165	23.597	22.707	18.750	15.687	11.690
MAGXS07	41.361	34.532	29.990	26.165	23.597	22.706	18.749	15.688	11.691
MAGXS07a	41.361	34.532	29.990	26.165	23.597	22.706	18.749	15.688	11.691
MAGXS08b	41.361	34.532	29.990	26.165	23.597	22.706	18.749	15.688	11.691
MAGXS08_spd	41.361	34.532	29.990	26.165	23.597	22.706	18.749	15.688	11.691
MAGXS07_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS07_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS08	41.361	34.532	29.990	26.165	23.597	22.706	18.749	15.688	11.691
MAGXS09	41.354	34.541	29.986	26.178	23.598	22.707	18.748	15.693	11.689
MAGXS09i1	41.366	34.526	30.004	26.193	23.628	22.719	18.755	15.693	11.689
CEA_XS_0028	29.902	26.860	24.693	22.823	21.311	20.693	17.876	15.350	11.687
CEA_XS_0027	34.475	30.097	27.152	24.561	22.653	21.906	18.552	15.654	11.684
CEA_XS_0026	34.671	30.170	27.125	24.521	22.642	21.883	18.550	15.668	11.689
CEA_XS_0025	32.951	28.418	25.631	23.206	21.292	20.642	17.551	14.886	11.109
CEA_XS_0024	25.884	21.897	19.644	17.837	16.623	16.167	13.859	12.021	9.174
CEA_XS_0023	26.102	22.982	21.128	19.415	18.138	17.644	15.550	13.747	11.233
CEA_XS_0022	24.371	21.582	20.017	18.738	18.124	18.015	15.946	14.108	11.345
CEA_XS_0021	23.386	20.900	19.614	18.509	18.085	17.926	15.945	14.096	11.345
CEA_XS_0020	26.449	23.573	21.734	20.133	19.055	18.822	16.377	14.259	11.351
CEA_XS_0019	28.120	25.211	23.000	21.064	19.712	19.296	16.357	14.037	11.395
CEA_XS_0018	25.169	22.556	20.617	19.036	17.838	17.379	15.565	14.157	11.240
CEA_XS_0017	22.353	19.947	18.309	17.049	16.264	15.871	14.450	13.365	11.108
CEA_XS_0016	32.395	28.769	26.149	23.809	21.998	21.247	18.182	15.519	11.623
CEA_XS_0015	33.216	29.111	26.298	23.790	22.053	21.325	18.204	15.619	11.645
CEA_XS_0014	30.053	26.372	23.866	21.604	20.059	19.345	16.657	14.476	11.296
CEA_XS_0013	28.216	25.028	22.884	21.124	19.841	19.227	16.794	14.790	11.485
CEA_XS_0012	26.449	23.761	22.021	20.599	19.415	18.955	16.747	14.783	11.496
CEA_XS_0011	31.403	28.223	25.658	23.004	21.345	20.536	17.540	15.347	11.649
CEA_XS_0010	28.604	26.055	24.123	22.500	20.966	20.280	17.755	15.489	11.647
CEA_XS_0009	24.515	22.419	20.999	20.107	18.814	18.026	16.261	14.980	11.649
CEA_XS_0008	26.308	24.846	23.264	21.906	20.765	20.559	18.131	15.568	11.647
CEA_XS_0007	31.454	29.923	27.431	25.665	23.372	22.600	18.615	15.702	11.647
CEA_XS_0006	31.194	28.830	28.856	26.810	24.546	21.870	16.302	14.221	11.648
MAGXS15	29.201	29.039	29.077	26.838	24.619	21.859	16.279	14.165	11.648
MAGXS15_Sp	2.648	1.223	0.593	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS15_SpDS	2.648	1.223	0.593	0.000	0.000	0.000	0.000	0.000	0.000
MAGXS15a	29.201	29.039	29.077	26.838	24.619	21.859	16.279	14.165	11.649
MAGXS16b	29.201	29.039	29.077	26.838	24.619	21.859	16.279	14.165	11.649
MAGXS16	29.201	29.039	29.077	26.838	24.619	21.859	16.279	14.165	11.649
MAGXS16In1	28.981	28.824	28.902	26.479	24.409	21.735	16.350	14.231	11.648

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
CEA_XS_0005	31.247	28.152	28.144	25.960	24.100	21.580	16.383	14.215	11.648
MAGXS17	23.197	21.523	21.531	20.309	19.241	17.790	14.806	13.526	11.648
MAGXS17_Sp	5.803	4.682	4.691	3.987	3.383	2.600	1.028	0.350	0.000
MAGXS17_SpDS	5.803	4.682	4.691	3.987	3.383	2.600	1.028	0.350	0.000
MAGXS17a	17.399	16.842	16.840	16.326	15.858	15.190	13.778	13.176	11.648
MAGXS17Ab	17.399	16.842	16.840	16.326	15.858	15.190	13.778	13.176	11.648
MAGXS17cpds	23.197	21.523	21.531	20.309	19.241	17.790	14.806	13.526	11.648
CEA_XS_0004	23.123	21.892	21.897	20.798	19.871	18.438	15.344	13.771	11.647
MAGXS18	23.159	21.740	21.677	20.788	19.777	18.711	16.064	14.118	11.645
CEA_XS_0003	23.919	21.992	21.628	20.718	19.670	18.708	16.129	14.122	11.643
CEA_XS_0002	22.900	21.375	21.103	20.330	19.456	18.626	16.136	14.125	11.648
CEA_XS_0001	24.585	22.535	21.608	20.650	19.594	18.796	16.236	14.142	11.646
MAGXS19i1	25.110	22.707	21.676	20.702	19.587	18.798	16.259	14.145	11.646
MAGXS19	14.481	14.462	14.389	14.419	14.413	14.245	13.570	12.976	11.399
MAGXS19i2	30.034	26.466	23.723	22.102	20.542	19.699	16.754	14.279	11.645
MAGXS19i3	26.488	23.474	22.704	22.387	21.466	20.631	17.398	14.567	11.646
MAGXS19i4	30.955	28.494	26.339	24.563	22.768	21.922	18.486	15.350	11.646
MAGXS20	32.151	28.576	26.007	24.041	22.221	21.389	18.026	15.067	11.606
MAGXS20i1	24.223	21.964	20.131	19.094	18.181	17.880	16.119	14.363	11.597
MAGXS20i2	25.010	22.722	21.029	19.649	18.611	18.128	16.164	14.407	11.598
MAGXS20i3	21.991	20.388	19.082	18.477	18.076	17.855	16.527	14.434	11.599
MAGXS20i4	27.773	24.976	22.791	21.385	20.170	19.628	17.313	14.758	11.598
MAGXS20i5	34.714	29.179	24.986	21.304	20.031	19.639	17.676	15.000	11.598
MAGXS20i6	34.241	28.821	24.995	21.869	20.732	20.375	18.091	15.245	11.602
MAGXS21	35.474	28.918	25.062	21.953	20.804	20.386	18.259	15.461	11.649
MAGXS21i1	34.126	31.104	26.626	22.759	21.353	20.813	18.341	15.464	11.645
MAGXS22	48.109	37.222	29.463	23.955	21.932	21.373	18.721	15.616	11.645
MAGXS22cpds	53.680	40.276	29.274	24.266	21.883	21.359	18.703	15.607	11.637
DULXS49	36.280	30.233	26.147	22.723	20.398	19.610	16.013	13.555	10.088
DULXS50	33.837	28.976	24.930	20.655	18.464	17.742	15.051	12.817	10.054
DULXS50A	18.721	17.704	16.595	15.913	15.457	15.280	13.608	12.124	10.032
Spill_50A_us	6.221	5.309	4.416	3.664	3.116	2.937	1.646	0.827	0.000
Spill_50A_ds	6.221	5.309	4.416	3.664	3.116	2.937	1.646	0.827	0.000
DULXS50_In1	4.165	4.128	4.119	4.114	4.119	4.114	3.993	3.766	3.344
DULXS50_a1	4.165	4.128	4.119	4.114	4.119	4.114	3.993	3.766	3.344
DULXS50_b1	4.163	4.125	4.119	4.114	4.119	4.115	3.994	3.766	3.344
DUMMY1	4.163	4.125	4.119	4.114	4.119	4.115	3.994	3.766	3.344
DULXS50_I2	4.164	4.127	4.119	4.114	4.119	4.114	3.993	3.766	3.344
DULXS50_a2	4.164	4.127	4.119	4.114	4.119	4.114	3.993	3.766	3.344
DULXS50_b2	4.164	4.126	4.119	4.114	4.119	4.115	3.994	3.766	3.344
DUMMY2	4.164	4.126	4.119	4.114	4.119	4.115	3.994	3.766	3.344
DULXS50_I3	4.177	4.140	4.130	4.126	4.130	4.126	3.976	3.766	3.344
DULXS50_a3	4.177	4.140	4.130	4.126	4.130	4.126	3.976	3.766	3.344
DULXS50_b3	4.175	4.137	4.130	4.126	4.130	4.126	3.976	3.766	3.344
DUMMY3	4.175	4.137	4.130	4.126	4.130	4.126	3.976	3.766	3.344

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS51A	18.717	17.697	16.589	15.914	15.457	15.280	13.610	12.124	10.032
DULXS52	23.113	22.267	21.614	20.138	17.791	17.297	14.480	12.403	10.030
DULXS52i	33.933	29.240	26.090	22.698	20.422	19.575	16.013	13.557	10.087
DULXS53	29.333	26.551	24.415	21.781	19.840	19.128	15.961	13.558	10.085
DULXS54	34.652	29.675	26.203	22.699	20.403	19.576	16.012	13.555	10.088
DULXS54i1	33.585	29.144	26.204	22.713	20.392	19.572	16.019	13.557	10.085
DULXS54i2	34.416	29.650	26.161	22.695	20.401	19.573	16.004	13.555	10.085
DULXS55	35.602	30.073	26.141	22.689	20.385	19.566	16.016	13.553	10.083
DULXS55cpds	39.107	32.126	26.816	22.674	20.372	19.563	15.984	13.546	10.074
DULXS01	241.341	201.118	174.433	152.055	136.915	131.776	108.574	91.780	68.670
DULXS01i	241.393	201.171	174.432	152.017	136.894	131.826	108.628	91.794	68.640
DULXS02	241.368	201.169	174.421	151.991	136.874	131.817	108.620	91.804	68.608
DULXS02i1	241.358	201.153	174.415	151.981	136.888	131.807	108.648	91.809	68.621
DULXS02i2	241.344	201.147	174.408	151.990	136.896	131.825	108.617	91.799	68.610
DULXS03	238.513	200.091	174.121	152.030	136.888	131.801	108.661	91.792	68.658
DULXS04	208.423	176.900	156.666	138.530	126.547	122.606	103.947	90.216	68.632
DULXS04i	191.835	168.078	151.601	137.017	126.908	123.400	106.680	91.742	68.637
DULXS05	219.827	190.060	168.608	149.360	135.503	130.856	108.569	91.888	68.622
DULXS05i1	217.630	187.329	166.865	148.450	135.266	130.925	108.695	91.880	68.627
DULXS05i2	224.842	191.627	168.335	148.429	134.859	130.579	108.687	91.877	68.618
DULXS06cpus	216.349	186.890	165.488	147.358	134.693	130.624	108.724	91.909	68.634
DULXS06	248.885	211.864	185.604	163.066	147.563	142.618	118.227	99.888	74.689
DULXS07cpus	230.306	200.984	182.829	161.847	147.549	142.606	118.250	99.914	74.701
DULXS07	283.957	241.078	211.859	185.613	167.283	161.065	132.498	111.821	83.677
DULXS08	293.689	245.800	213.254	185.799	167.280	161.086	132.506	111.841	83.674
DULXS08i	293.814	245.936	213.263	185.806	167.173	161.042	132.503	111.817	83.662
DULXS09	295.348	245.894	213.283	185.809	167.270	161.068	132.502	111.815	83.661
DULXS10	295.342	245.895	213.277	185.803	167.244	161.074	132.501	111.812	83.659
DULXS10_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS10_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS10_a	295.342	245.895	213.277	185.803	167.244	161.074	132.501	111.812	83.659
DULXS10_b	295.342	245.895	213.277	185.803	167.244	161.074	132.501	111.812	83.659
DULXS11	295.342	245.895	213.277	185.803	167.244	161.074	132.501	111.812	83.659
DULXS11a	295.338	245.898	213.279	185.803	167.246	161.074	132.501	111.810	83.659
DULXS11_Sp	6.063	6.063	6.063	6.063	6.063	6.063	6.063	6.063	6.063
DULXS11_Spd	6.063	6.063	6.063	6.063	6.063	6.063	6.063	6.063	6.063
DULXS11a_Bdg	295.338	245.898	213.279	185.803	167.246	161.074	132.501	111.810	83.659
DULXS12a	295.338	245.898	213.279	185.803	167.246	161.074	132.501	111.810	83.659
DULXS12	295.338	245.898	213.279	185.803	167.246	161.074	132.501	111.810	83.659
DULXS12In1	295.350	245.902	213.270	185.794	167.220	161.068	132.493	111.807	83.661
DULXS13	295.334	245.897	213.263	185.793	167.179	161.075	132.507	111.807	83.652
DULXS14	295.333	245.931	213.259	185.787	167.180	161.064	132.519	111.809	83.642
DULXS14_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS14_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS14_a	295.333	245.931	213.259	185.787	167.180	161.064	132.519	111.809	83.642

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS14_b	295.333	245.931	213.259	185.787	167.180	161.064	132.519	111.809	83.642
DULXS15	295.333	245.931	213.259	185.787	167.180	161.064	132.519	111.809	83.642
DULXS16	295.342	245.962	213.271	185.809	167.192	161.050	132.530	111.826	83.668
DULXS17	284.013	240.820	211.040	185.083	166.914	160.984	132.511	111.809	83.655
DULXS18	285.026	242.405	212.146	185.914	167.627	161.660	133.242	112.407	84.088
DULXS19	289.994	246.539	214.344	186.869	168.011	161.924	133.243	112.408	84.112
DULXS19i1	295.070	247.925	214.885	187.339	168.409	162.388	133.635	112.704	84.332
DULXS20	297.010	247.901	214.879	187.326	168.390	162.400	133.623	112.702	84.334
DULXS21	297.105	247.894	214.877	187.324	168.403	162.403	133.623	112.701	84.331
DULXS21_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS21_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS21_a	297.105	247.894	214.877	187.324	168.403	162.403	133.623	112.701	84.331
DULXS21_b	297.105	247.894	214.877	187.324	168.403	162.403	133.623	112.701	84.331
DULXS21i	297.105	247.894	214.877	187.324	168.403	162.403	133.623	112.701	84.331
DULXS22	297.113	247.899	214.877	187.322	168.401	162.399	133.623	112.702	84.336
DULXS23	297.125	247.890	214.883	187.322	168.414	162.389	133.630	112.708	84.322
DULXS24	294.084	246.302	214.197	187.085	168.407	162.323	133.570	112.692	84.312
DULXS25	291.537	243.675	212.235	185.788	167.599	161.570	133.759	113.065	84.568
DULXS26	292.855	247.973	215.395	187.942	168.963	162.810	134.034	113.054	84.550
DULXS27	286.964	244.351	213.998	187.548	168.959	162.805	134.029	113.049	84.556
DULXS28	292.630	247.458	215.395	188.300	169.630	163.337	134.447	113.475	84.869
DULXS29	299.758	249.580	216.319	188.504	169.586	163.323	134.444	113.466	84.869
DULXS29i1	300.676	250.377	216.961	189.031	170.155	163.777	134.833	113.794	85.086
DULXS30	299.931	250.356	216.965	189.051	170.124	163.786	134.837	113.793	85.092
DULXS30i1	300.657	250.367	216.956	189.048	170.129	163.791	134.838	113.797	85.092
DULXS30i2	300.657	250.357	216.956	189.045	170.125	163.786	134.838	113.789	85.096
DULXS30i3	300.657	250.361	216.948	189.041	170.118	163.795	134.838	113.793	85.098
DULXS31	300.629	250.361	216.947	189.039	170.129	163.797	134.836	113.788	85.096
DULXS32	300.631	250.361	216.951	189.040	170.136	163.795	134.837	113.791	85.095
DULXS32_Sp	3.512	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS32_SpDS	3.512	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS32_a	297.119	250.361	216.951	189.040	170.136	163.795	134.837	113.791	85.095
DULXS32_b	297.119	250.361	216.951	189.040	170.136	163.795	134.837	113.791	85.095
DULXS33	300.631	250.361	216.951	189.040	170.136	163.795	134.837	113.791	85.095
DULXS34	300.632	250.363	216.956	189.037	170.144	163.802	134.836	113.792	85.095
DULXS35	300.621	250.363	216.961	189.041	170.147	163.802	134.840	113.789	85.099
DULXS35_Sp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS35_SpDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DULXS35_a	300.621	250.363	216.961	189.041	170.147	163.802	134.840	113.789	85.099
DULXS35_b	300.621	250.363	216.961	189.041	170.147	163.802	134.840	113.789	85.099
DULXS36	300.621	250.363	216.961	189.041	170.147	163.802	134.840	113.789	85.099
DULXS37	300.631	250.363	216.959	189.040	170.145	163.803	134.836	113.797	85.094
DULXS37i1	300.633	250.363	216.953	189.048	170.154	163.802	134.836	113.800	85.099
DULXS38	300.646	250.385	216.960	189.025	170.153	163.799	134.835	113.801	85.097
DULXS40	300.665	250.395	216.983	189.058	170.164	163.805	134.853	113.802	85.110

Cross-section	Q200+CC	Q200	Q100	Q50	Q30	Q25	Q10	Q5	Q2
DULXS43	301.452	251.443	217.905	189.805	170.960	164.458	135.380	114.262	85.438
DULXS44	269.565	236.946	213.077	189.346	170.957	164.454	135.398	114.263	85.445
DULXS45	269.846	236.950	213.071	189.335	170.951	164.472	135.410	114.365	85.478
DULXS46	265.985	242.483	216.157	191.253	173.221	166.365	136.918	115.733	86.555
DULXS46i1	290.407	250.703	218.656	191.556	173.217	166.358	136.947	115.784	86.575
DULXS47	244.098	215.793	191.421	169.912	156.281	151.736	131.577	114.513	86.629
DULXS47i1	248.480	212.560	187.755	167.011	153.634	149.063	130.747	114.795	87.062
DULXS47i2	250.743	213.486	188.148	167.189	153.646	149.065	130.772	114.798	87.068
DULXS48	252.815	214.400	188.418	167.163	153.627	149.096	130.785	114.769	87.068
DS_Lat_01	2.600	2.167	1.876	1.632	1.467	1.411	1.159	0.967	0.717
DS_Lat_02	1.229	1.024	0.887	0.772	0.693	0.667	0.548	0.457	0.339
DS_Lat_03	1.549	1.291	1.118	0.973	0.874	0.841	0.691	0.576	0.427
DS_Lat_04	1.669	1.390	1.204	1.047	0.941	0.906	0.744	0.621	0.460
DS_Lat_05	1.430	1.192	1.032	0.898	0.807	0.776	0.638	0.532	0.394
DS_Lat_06	2.037	1.697	1.470	1.279	1.149	1.105	0.908	0.758	0.561
DS_Lat_07	5.851	4.876	4.221	3.673	3.301	3.175	2.608	2.176	1.613
DS_Lat_08	2.512	2.093	1.812	1.577	1.417	1.363	1.120	0.934	0.692
CEA_05_Sp	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492
CEA_05_Bdg	31.247	28.152	28.144	25.960	24.100	21.580	16.383	14.215	11.648
CEA_05_S	31.247	28.152	28.144	25.960	24.100	21.580	16.383	14.215	11.648
MAGXS17u	31.247	28.152	28.144	25.960	24.100	21.580	16.383	14.215	11.648
CEA_05_Sd	31.247	28.152	28.144	25.960	24.100	21.580	16.383	14.215	11.648
CEA_05_spd	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492

Comparison of Baseline and Proposed model ('with-scheme and mitigation') results

13.5.2 Table 13.17 shows the maximum stage compared at significant locations in the study area to understand the impact of the scheme on the model. The impact of the scheme is mainly neutral. There is a 3mm increase in maximum stage at Allt Lorgy (location 4) for a 0.5% AEP but water levels remain within the defined channel. A comparison of baseline and scheme flood depths in the floodplain are shown in Figure 13.14. Comparison stage on long sections for Allt nan Ceathernach, Allt Lorgy and River Dulnain are in Figures 13.15, 13.16 and 13.17 respectively.

Table 13-17 Comparison of Baseline and Proposed Maximum Stage (mAOD)

Location	Q200+CC			Q200			Q30		
	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference
Location 1	1.078	1.077	-0.001	0.969	0.969	0.000	0.732	0.732	0.001
Location 2	0.956	0.956	0.000	0.756	0.756	0.000	0.374	0.372	-0.002

Location	Q200+CC			Q200			Q30		
	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference
Location 3	0.066	0.067	0.001	0.045	0.047	0.002	0.014	0.013	-0.002
Location 4	0.351	0.357	0.006	0.307	0.309	0.003	0.126	0.133	0.007
Location 5	4.817	4.815	-0.003	4.550	4.540	-0.009	3.991	3.985	-0.006
Location 6	0.634	0.634	0.000	0.473	0.474	0.001	0.000	0.000	0.000
Location 7	0.230	0.230	0.001	0.031	0.031	0.000	0.000	0.000	0.000
Location 8	0.372	0.372	0.000	0.289	0.289	0.000	0.107	0.108	0.001

Figure 13-16 Maximum flood depth grid (m) Q200- Depth Difference (Proposed Scheme – Baseline)

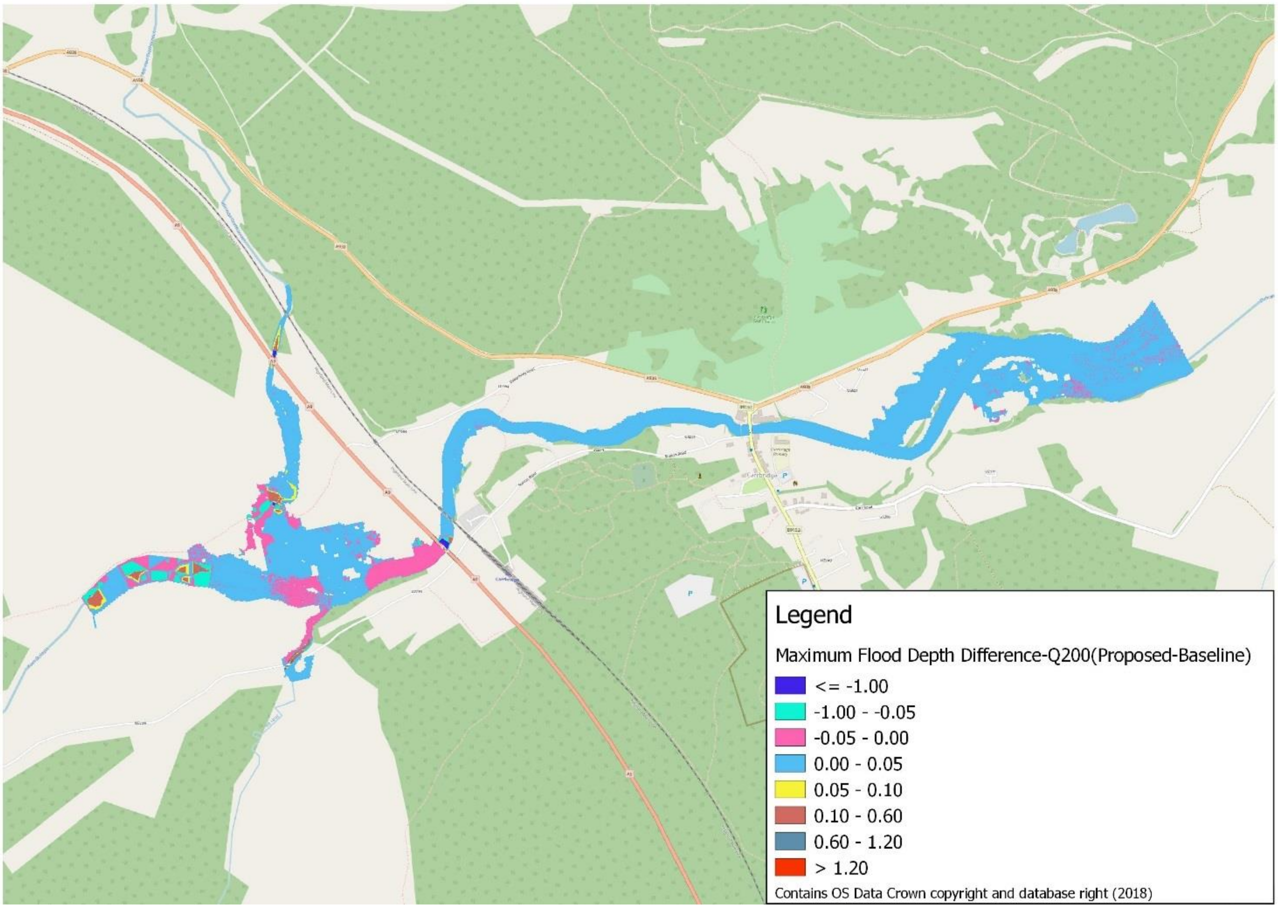


Figure 13-17. Maximum stage comparison for Q200, Baseline Vs With Scheme - Allt nan Ceatharnach

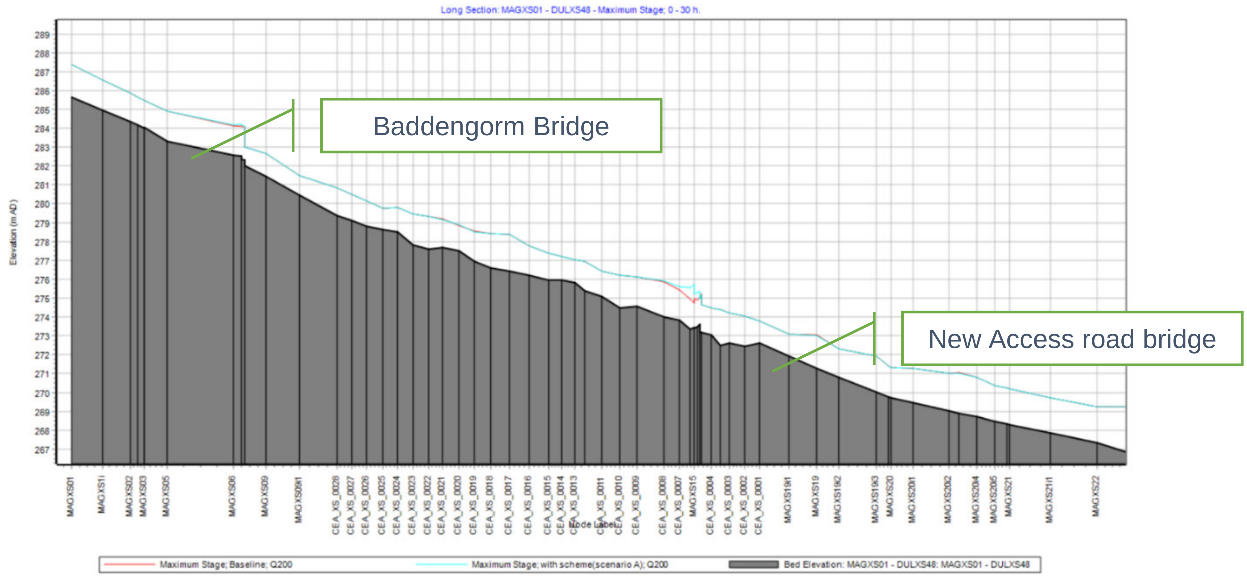


Figure 13-18 Maximum stage comparison for Q200, Baseline Vs With Scheme- Allt Lorgy

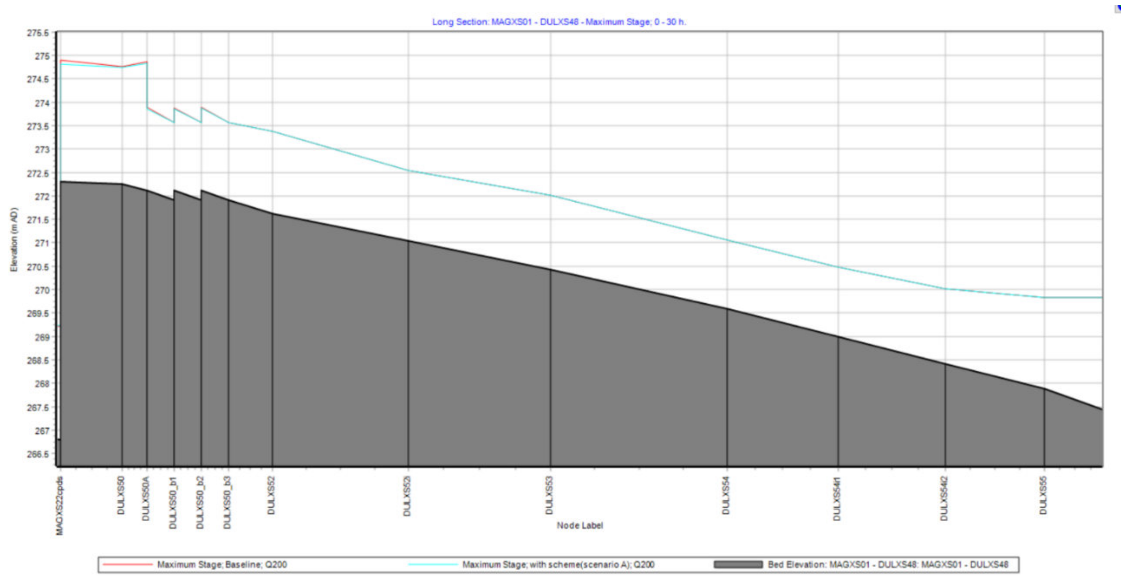
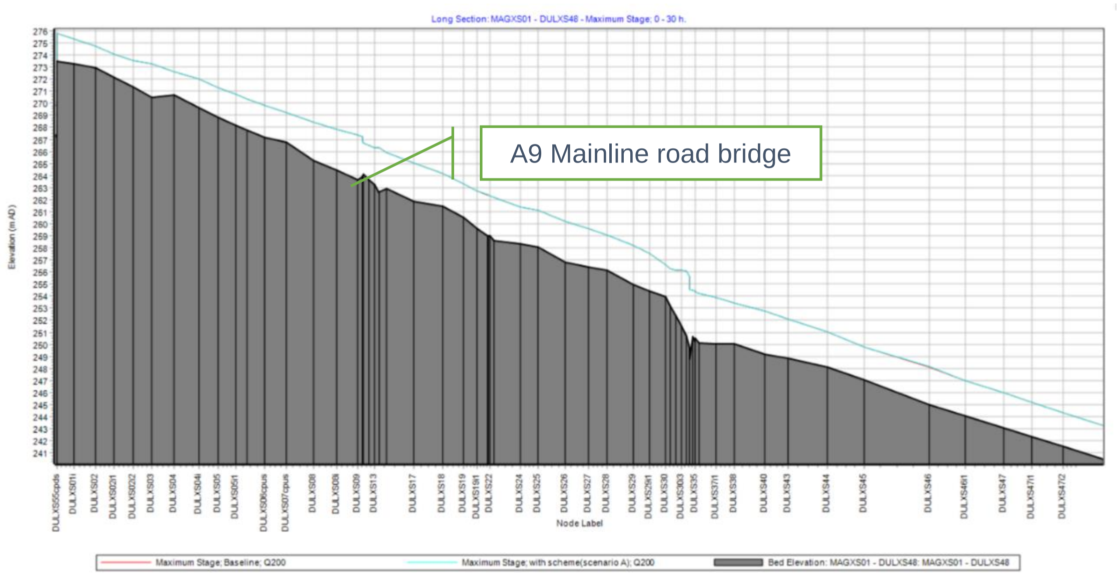


Figure 13-19. Maximum stage comparison for Q200, Baseline Vs With Scheme - Dulnain



Sensitivity Analysis

13.5.3 To analyse the sensitivity of the proposed hydraulic model, 7 sensitivity tests have been run on the Proposed model. These aim to test how sensitive the models are to variable parameters and scenarios. The following tests were run on the Proposed (Baseline) model.

- Global roughness + / - 20%
- Flow + / - 20%
- 50% blockage scenario
- Downstream Boundary +/ - 20%

13.5.4 Table 13.18 below shows the variation in stage between the Proposed Scheme model and each of the sensitivity results for the Q200 event.

Table 13-18. Sensitivity Results Proposed Model, Variation in stage (mAOD)

Sensitivity Test	Proposed	+20% Flow	-20% Flow	+20% Mann	-20% Mann	+20% DSB	-20% DSB	+ 50% Blockage
Location 1	0.969	0.108	-0.147	0.083	-0.118	0	0	0
Location 2	0.756	0.2	-0.224	0.139	-0.21	0	0	0
Location 3	0.047	0.02	-0.028	0.013	-0.013	0.001	0.001	0.001
Location 4	0.309	0.048	-0.1	0.03	-0.019	0	0	0
Location 5	4.540	0.275	-0.281	0.146	0.002	0	0	0
Location 6	0.474	0.16	-0.289	0.202	-0.29	-0.001	-0.001	-0.001
Location 7	0.031	0.199	-0.031	0.176	-0.031	0	0	0

Sensitivity Test	Proposed	+20% Flow	-20% Flow	+20% Mann	-20% Mann	+20% DSB	-20% DSB	+ 50% Blockage
Location 8	0.289	0.083	-0.098	0.078	-0.104	0	0	0

13.5.5 From Table 13.18 it can be observed that the model is sensitive to roughness and change in inflows. Increase in roughness by 20 % causes the maximum stage to be increased up to a maximum of 20cm and decrease in roughness by 20 % causes the maximum stage to be decreased up to maximum of 29cm. Increase in inflows by 20 % causes the maximum stage to increase up to maximum of 28cm, and decrease in inflows by 20% causes the maximum stage to decrease up to maximum of 29cm.

13.5.6 The model is not sensitive to blockage or change in downstream boundary.

13.5.7 Figures 13.18-13.20 show the sensitivity results for the modelled long sections.

Figure 13-20. Modelled Long Section Sensitivity Results -Allt Nan Ceatharnach

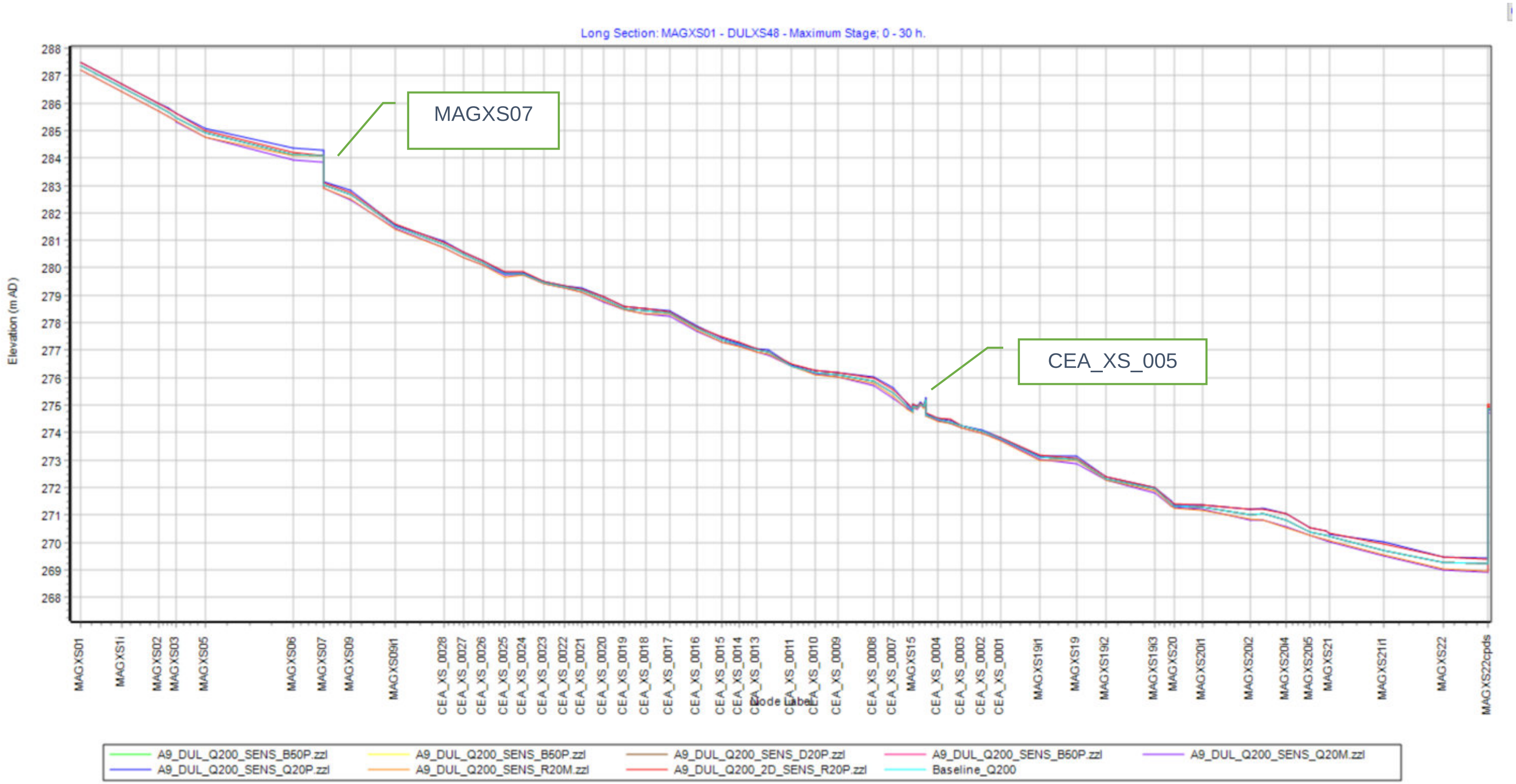
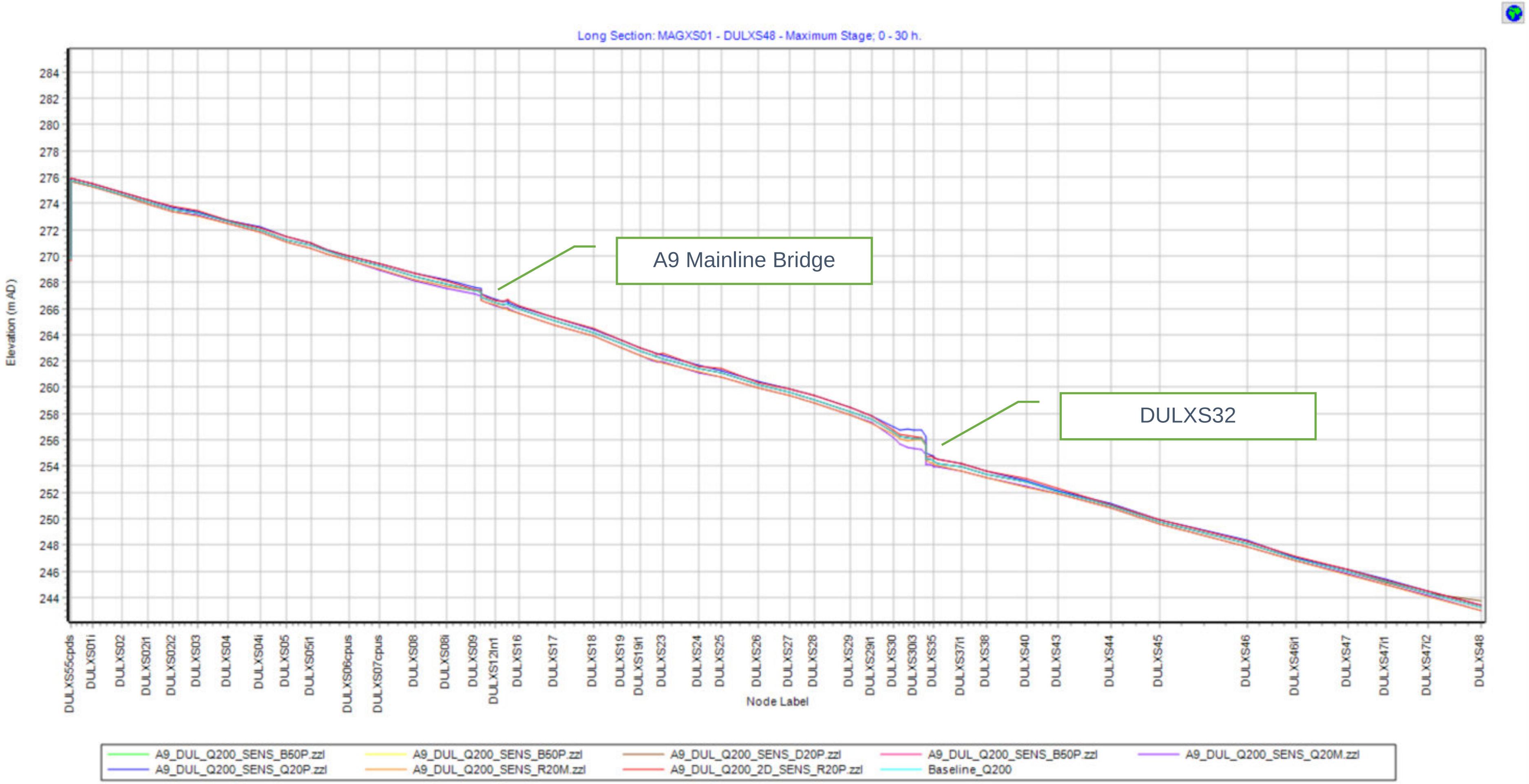


Figure 13-21 Modelled Long Section Sensitivity Results – Allt Lorgy

Figure 13-22 Modelled Long Section Sensitivity Results- River Dulnain



13.6 Summary

13.6.1 The baseline model was updated post DMRB FRA stage 2 modelling, with new survey data obtained from November 2017 for Allt Nan Ceatharnach tributary, updated hydrology, missing structures in stage 2, improved roughness and other 2d layer modifications.

13.6.2 Hydraulic models of the existing conditions and with the Proposed Scheme included have been evaluated to assess the impact of the Proposed Scheme on risk and to derive peak flood water levels relative to the proposed structures.

13.6.3 The Lidar used in the model is spliced using three different sources of data, which affected the quality the DTM, because the DTM was coarser in the upstream extent of the model up to the tributary junctions and was of finer resolution in the remaining extent of the model.

13.6.4 The proposed scheme was incorporated into the model for the design scenarios in order to assess its impact on the baseline flood risk and to ensure SuDS ponds were located outside of the floodplain.

13.6.5 The with scheme shows that the SuDS ponds are located outside of the floodplain and the new bridges at Carrbridge and Baddengorm Bridge have no impact on flood risk levels and the free span structures do not encroach on the existing river channels.

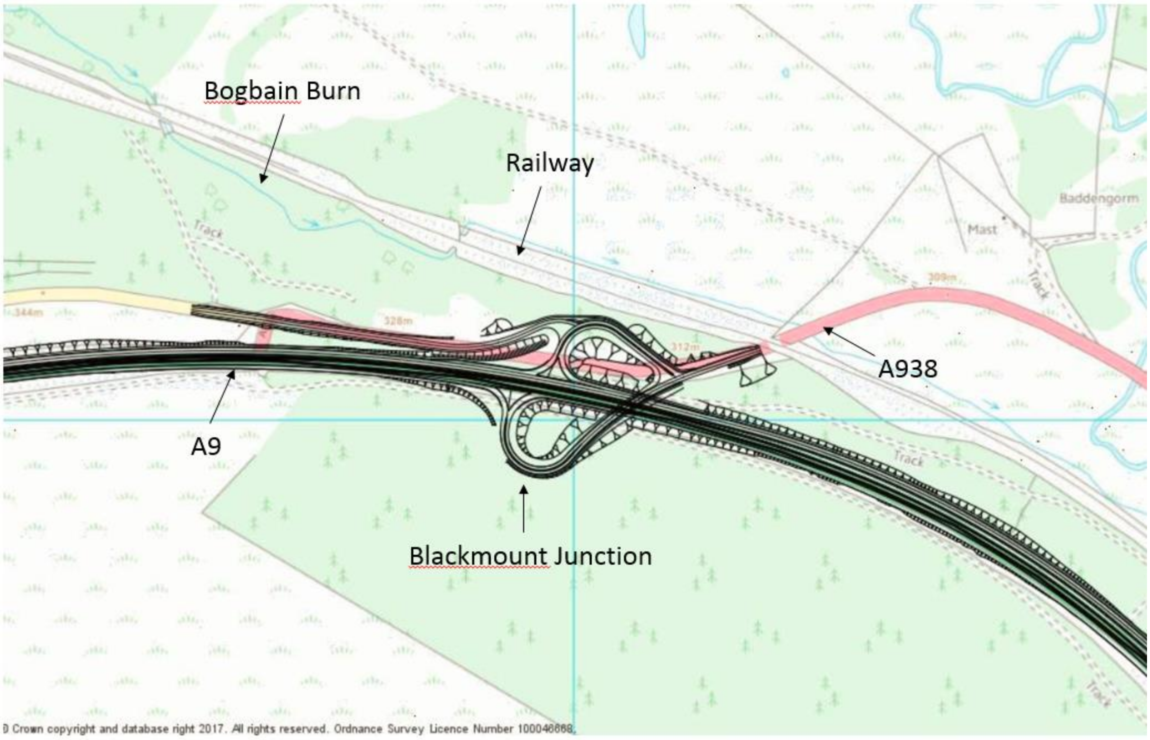
13.6.6 The new access road for the SuDS pond on Allt Nan Ceathernach does not meet the 600mm freeboard criteria but passes the 0.5% AEP flow and does not impact on existing water levels within the floodplain. To mitigate any increase in flood risk within the extensive floodplain from the new access road, 3 flood relief culverts of 5m width and 1m height are added to provide conveyance through the floodplain and ensuring water levels within the floodplain are maintained as per the baseline.

14. Bogbain Burn

14.1.1 The modelled watercourse is an unnamed stream which flows downwards from the Bogbain Farms and the Slochd Summit into a tributary of the River Dulhain. The stream is referenced as Bogbain Burn throughout this report. The watercourse is located adjacent to the A9 highway and crosses A938 highway. The watercourse does not cross the A9, therefore there are no A9 crossings at this location but flood modelling has been undertaken for the watercourse given its proximity to the A9. Bogbain Burn and its tributary have not been modelled before and there are no existing SEPA flood maps for the watercourses. Figure 14.1 shows the study area.

14.1.2 The hydraulic model was built using a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller (version 4.3), and the 2D component was constructed using TUFLOW (version 2016-03-AE).

Figure 14-1 Bogbain Study area



14.1.3 The data used to construct the baseline hydraulic model for the Bogbain Burn is summarised in Table 14.1.

Table 14-1 Data used to build the baseline hydraulic model

Data	Description	Source
Topographic Survey October 2017	River cross-section data collected as part of the A9 project	WSP (formerly Mouchel)
5m NEXTMAP	DTM covering entire study area	Transport Scotland
10m BLOM LiDAR	DTM covering most of the study area	Transport Scotland
BLOM topo	Surveyed contours and points covering part of study area only	Transport Scotland

14.1.4 Hydrological analysis has been undertaken to derive design flow estimates as inputs to the hydraulic model developed for assessment. Three catchments were derived within the Bogbain study area; at the upstream modelled extent of the watercourse, at the downstream modelled extent of the watercourse and a tributary catchment. The Bogbain Burn catchments were delineated from the FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. A catchment for the tributary was not available on the FEH CD-ROM, therefore this catchment was derived using topographic survey data and the 5m NextMAP DTM data only. Figure 14.2 shows the delineated catchment areas.

14.1.5 The Bogbain Burn catchment areas extracted from the FEH CD-ROM were altered to reflect the surrounding topography. For the tributary catchment, the FEH catchment descriptors for the downstream Bogbain Burn catchment were adjusted to represent the small tributary catchment. An appropriate method for estimating peak flows for each catchment was chosen as shown in Table 14.2. There are two main inflows to the model, at the upstream extent of Bogbain Burn and at the upstream extent of the tributary. As the length of Bogbain Burn modelled was relatively small and there is not a large increase in catchment size along the modelled reach, it was not deemed necessary to add a lateral inflow to represent additional catchment flows. Flows at the downstream extent of the tributary catchment were calculated and entered at the inflow at the upstream modelled extent of the tributary due to its small size.

Figure 14-2 Catchment areas

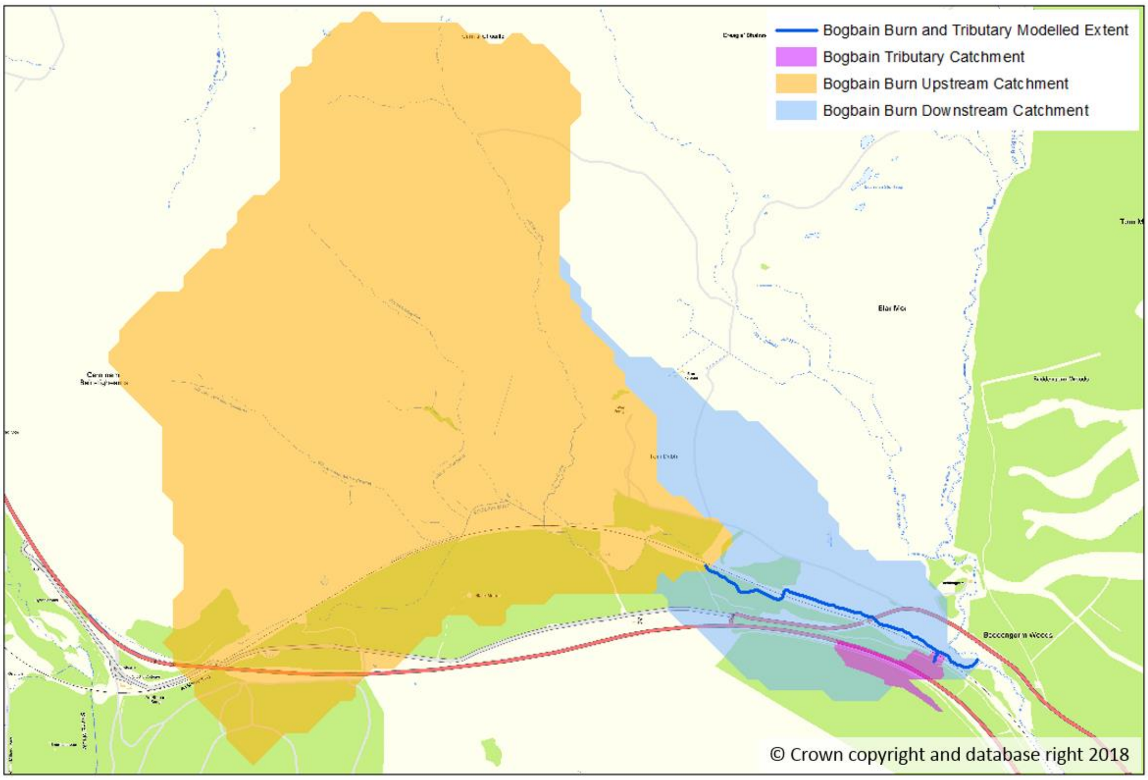


Table 14-2 Bogbain Hydrological Parameters

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting	Northing	Area (km²)
Bogbain Burn	BOG_XS_049	Upstream modelled extent of Bogbain Burn	FEH Boundary	Rainfall Runoff	288583	823953	5.67
Bogbain Tributary	Tributary	Upstream modelled extent of tributary	Boundary Condition Database (ESTRY)	Rainfall Runoff	288562	823910	0.03

14.1.6 Peak flows were calculated for each inflow using the FEH rainfall runoff method, an FEH statistical estimate was undertaken at the downstream boundary for comparison.

14.1.7 The critical storm duration for Bogbain Burn as calculated using the FEH rainfall runoff method is 3.90 hours, this has been set as the critical storm duration for both inflows to the model. Table 14.3 shows the peak flows at the upstream modelled extent of Bogbain Burn as this is the main inflow to the model with the tributary catchment flows being very small.

Table 14-3 Bogbain Peak Flow Estimates

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
Bogbain Burn	BOG_XS_049	Upstream modelled extent of Bogbain Burn	17.21	20.65

14.1.8 Given the rural nature of the Bogbain Burn catchment and the small size of the tributary catchment, statistical flows estimates would not be appropriate for either catchment. Applying the precautionary approach and considering the size of the catchment the Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model. Hydrographs were also generated using the Rainfall Runoff method.

14.1.9 Modelled events are summarised in Table 14.4.

Table 14-4 Modelled Events

Scenario	AEP					
	50%	20%	3.33%	0.5%	0.5%+CC	0.1%
Baseline	x	x	x	x	x	x
Roughness sensitivity				x		
Hydrological inflow sensitivity				x		
Downstream boundary sensitivity				x		
Model 'with – scheme'	x	x	x	x	x	x
With-scheme and mitigation				x	x	

14.2 Baseline Hydraulic Model

Model assumptions and limitations

14.2.1 The downstream boundary of the model is at the confluence of Bogbain Burn with a tributary of the River Dulnain. No information was available regarding the water levels within the watercourse that Bogbain Burn flows into, therefore a normal depth boundary has been used to represent the downstream condition on Bogbain Burn. Sensitivity testing has been undertaken to determine the impact of the downstream boundary on modelled results at the area of interest, which is approximately 550m upstream of the downstream extent of the model.

14.2.2 It has been assumed that it is appropriate not to include lateral inflows on either Bogbain Burn or the tributary watercourse. This is deemed appropriate as the FEH Rainfall Runoff method provides a conservative estimate of flows on Bogbain Burn compared to the statistical method. The increase in catchment area from upstream to downstream on the modelled reach of Bogbain burn is relatively small (1.13km^2) with the majority of flows generated in the upper catchment upstream of the modelled extent. A lateral inflow on the tributary catchment was not deemed necessary given the small length of this watercourse represented in the model.

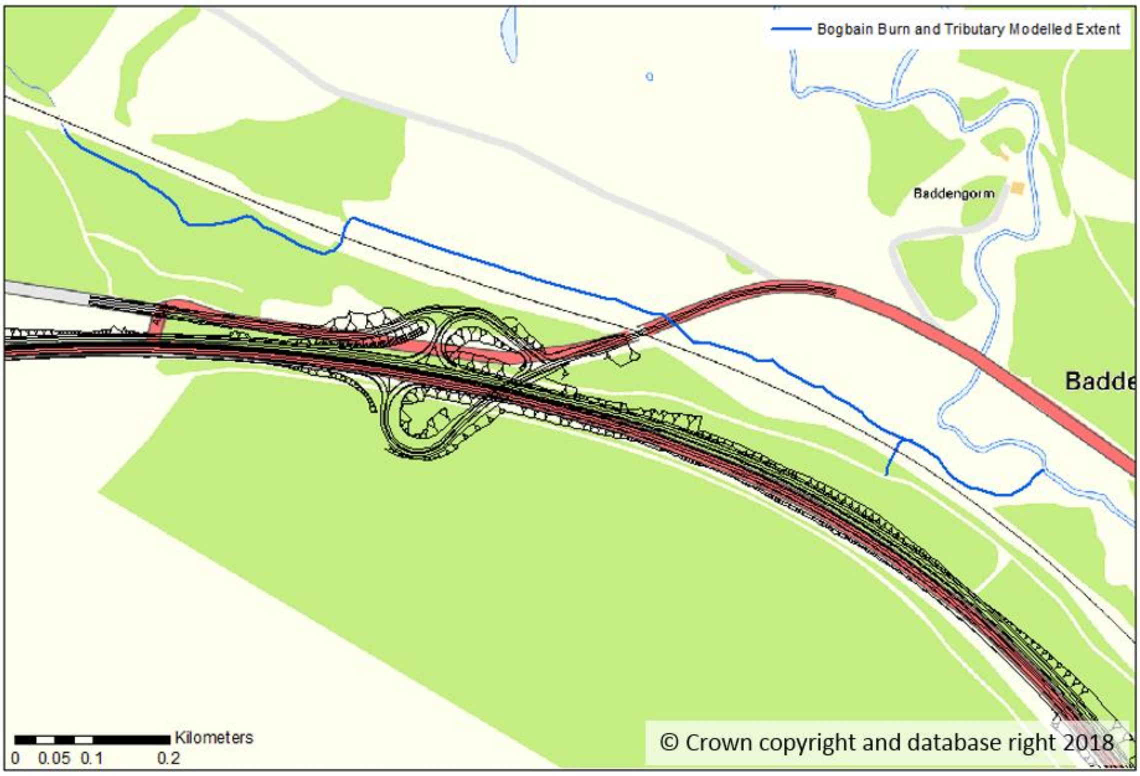
14.2.3 It has been assumed that the existing structures within the baseline model are free-flowing and no blockages have been included in the model.

14.2.4 It is assumed that the topographic survey used to define the river channels within the model accurately represents the geometry of the watercourses and that the interpolation between river cross-sections within the 1D model is acceptable.

In- channel geometry (1D)

14.2.5 The 1D model is based on topographic survey of river cross-sections collected on Bogbain Burn and its tributary. The extent of each watercourse represented in the 1D model is shown in Figure 14.3, Bogbain Burn has been represented in Flood Modeller and the tributary has been represented in ESTRY (the 1D component of TUFLOW), due to the variation in size between the two watercourses this approach was considered most stable.

Figure 14-3 1D Model domain extent



14.2.6 Table 14.5 details the model extents and key features.

Table 14-5 Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of A9 Crossings	Total number of modelled structures
Bogbain Burn	1437	287497, 824353	288761, 823918	0	2
Tributary	63	288562, 823910	288594, 823953	0	1

14.2.7 Direct inflow hydrographs are applied at the upstream extents of each watercourse in the model. A normal depth boundary has been used at the downstream extent of the model as the no information was available about the levels in the watercourse that Bogbain Burn discharges into. The downstream boundary is approximately 550m downstream of the area of interest and has been subject to sensitivity testing as part of this assessment.

14.2.8 The open channel river sections were defined from the topographic survey, with the Manning's 'n' values defined from the site visits, which were undertaken in July 2015. Table 14.6 provides the Manning's 'n' value ranges within the 1D model and justification of the values used.

Table 14-6 Manning's n roughness values in 1D model

Section Type	Minimum	Maximum	Commentary
River Channel	0.035	0.035	Representing a fairly rough bed material. A consistent value has been used throughout the model to aid stability.

Section Type	Minimum	Maximum	Commentary
(Manning's)			
Structures	0.015	0.035	Both structures on Bogbain Burn are effectively bridges, therefore the same roughness as the river bed has been applied through these. The culvert on the tributary catchment has been set to 0.015 roughness to represent a smooth pipe.
Floodplain (Manning's)	0.04	0.04	Manning's n for the floodplain is considered to be 0.040 throughout the 1D model.

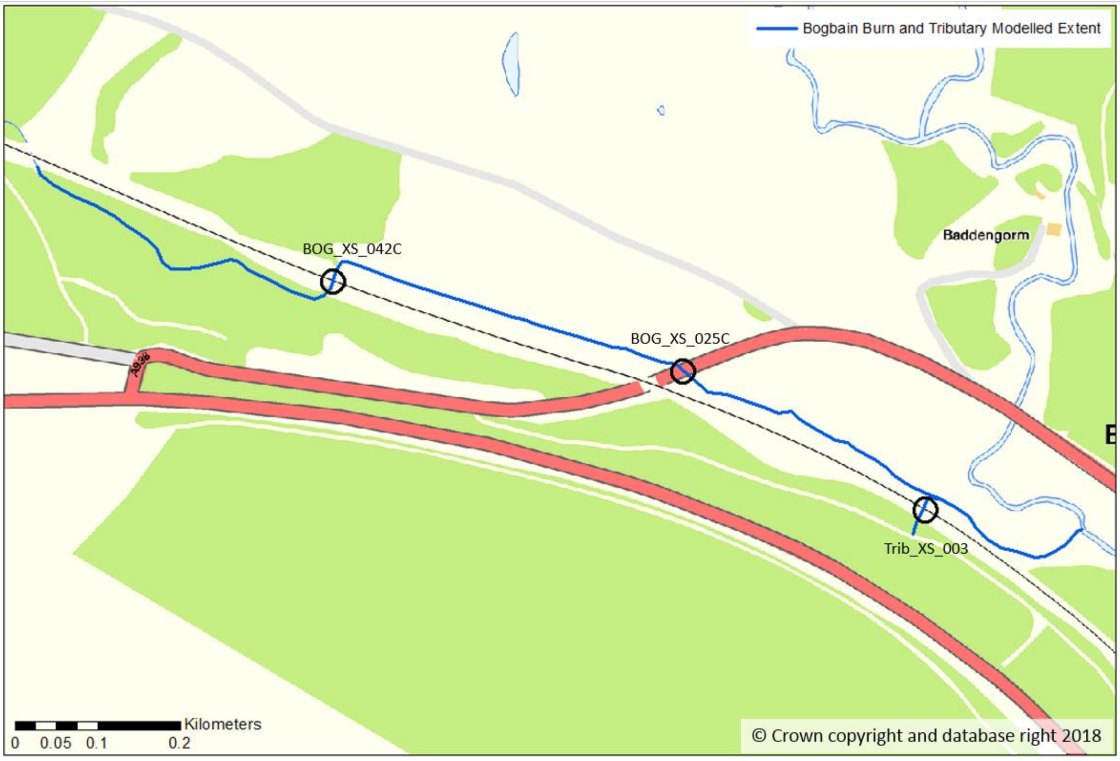
In channel's hydraulic structures

14.2.9 All the structures and cross sections were taken from survey data. Table 14.7 provides the details of how the structures are represented within the model. Figure 14.4 shows the location of these modelled structures. In total there are 2 structures modelled in the 1D Flood Modeller component and 1 structure modelled in the 1D ESTRY component.

Table 14-7 Modelled Structures Details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Representation in the model	Photograph
BOG_XS_042C	Bridge	Bogbain Burn	Max width = 3.12m Max height = 3.56m	Arch Bridge	
BOG_XS_025C	Bridge	Bogbain Burn	Width = 7.66m Max height = 1.57	Flat soffit bridge (arch bridge unit with flat soffit used)	
Trib_XS_003	Culvert	Tributary	1.20m Ø	ESTRY Culvert	

Figure 14-4 Location of the Structures in the Model

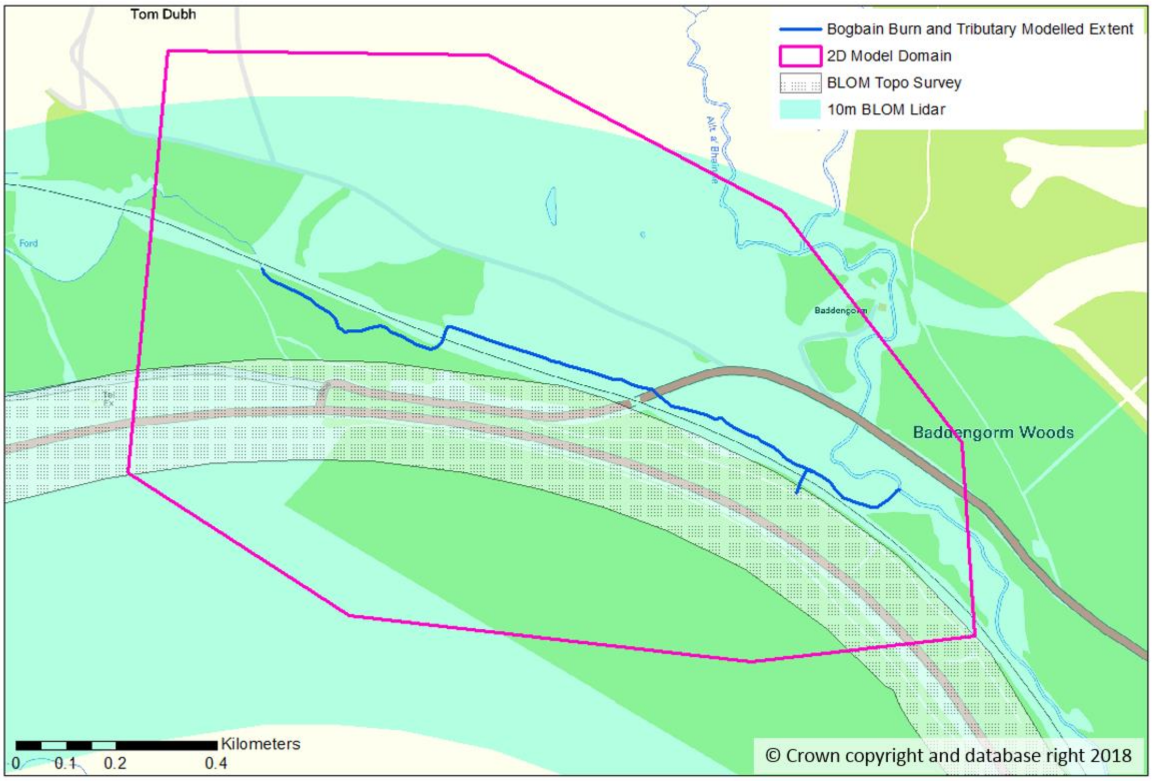


Flood plain schematisation – 2D domain

Floodplain topography

14.2.10 A key component of any 2D model is the detailed ground model. The data used for the model were the 5m NEXTMAP, 10m BLOM Lidar and the BLOM Topo Survey data for the A9 Dualling Corridor. The 2D component of the TUFLOW model was constructed using a mosaic of these three datasets. The 5m DTM is extended enough to cover the whole area of interest, but the accuracy doesn't cover small watercourses and drains. The two sets of BLOM data include more detail but they don't cover all the area of interest. The 10m BLOM Lidar is extended enough to cover most of the area of interest but the BLOM Topo provides greater detail along the A9 corridor. Figure 14.5 shows the extents of each dataset in the vicinity of Blackmount Junction as well as the 2D domain extent within the model.

Figure 14-5 Terrain Data Coverage



Floodplains' hydraulic structures

14.2.11 There are no relevant hydraulic structures in the floodplain that need to be modelled.

Floodplain hydraulic friction

14.2.12 The catchment is rural and mainly consists of grassland as seen from maps and Google Earth images, therefore Manning's n for the floodplain has been set to 0.045.

Boundary conditions

14.2.13 The 2D model domain has been sized to be large enough to contain the largest flood extent modelled (0.5% plus climate change), therefore across the majority of the model domain 2D boundaries are not required.

1d/2d Linking

14.2.14 The 1D and 2D components of the model have been linked using the HX approach where the water levels in the 1D model are applied along the banks of the channel represented in 1D. When water levels are high enough to overtop the bank top level in 1D, water is transferred to the 2D domain. The HX boundaries are two-way meaning that water from the 2D floodplain model can flow into the 1D channel model as well. The whole extent of 1D watercourses represented in the model is linked to the 2D domain using this method.

Model Proving

14.2.15 There are no gauges within the modelled extent, therefore it has not been possible to calibrate the model developed for this area. In order to determine how robust the model is and to understand the uncertainty in the model results, a suite of sensitivity tests have been undertaken on the baseline model.

Model performance

14.2.16 The model is stable in both 1D and 2D. Figure 14.6 is the runtime output from Flood Modeller for the 0.5% AEP baseline model and shows that there is no poor convergence during the run. Figure 14.7 shows the cumulative mass balance error in the 2D domain throughout the 0.5% AEP baseline model run, for the initial 2 hours and 27 mins at the beginning of the model run the mass balance error is outside of the acceptable range (+/- 1%) but this can be attributed to the large volume of water entering the 2D domain from the 1D channels. The cumulative mass balance error is within the acceptable range from 2 hour 27 minutes into the model run until the end of the run meaning that the peak of the event is not affected by high mass balance error, therefore the maximum flood extent and depth results are not affected by model stability.

Figure 14-6 Flood Modeller runtime information – baseline model

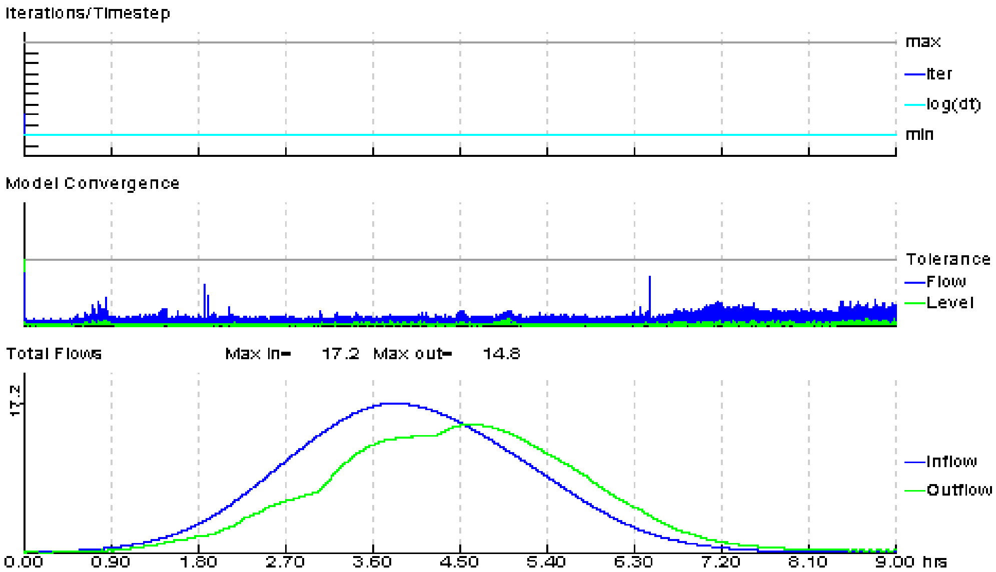
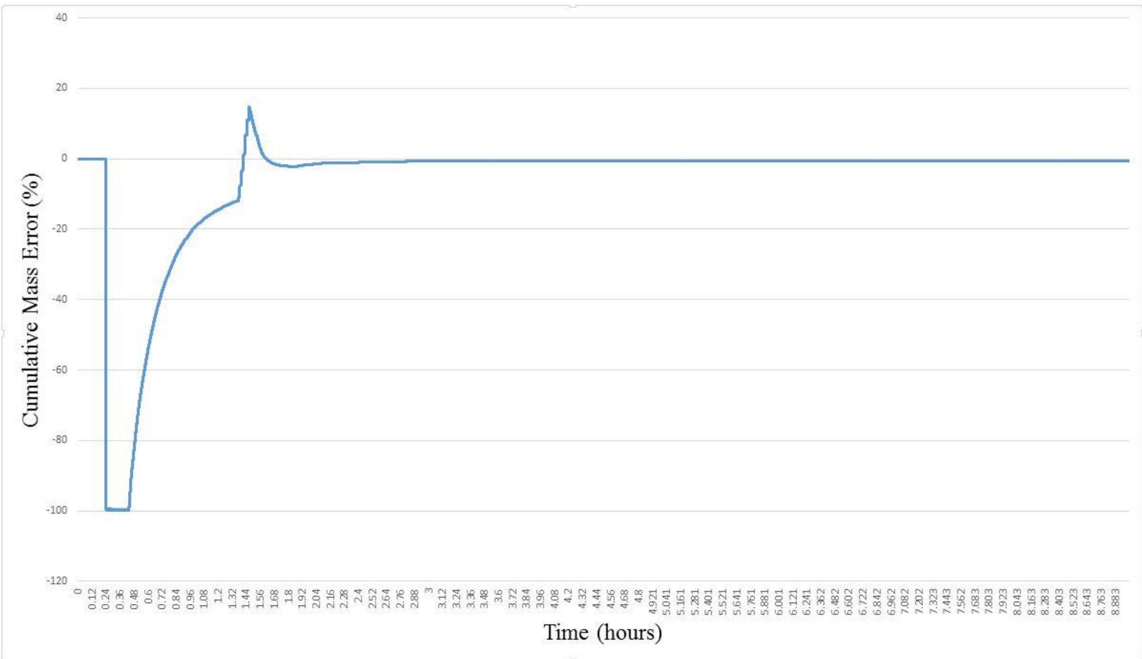


Figure 14-7 TUFLOW cumulative mass balance error – baseline model

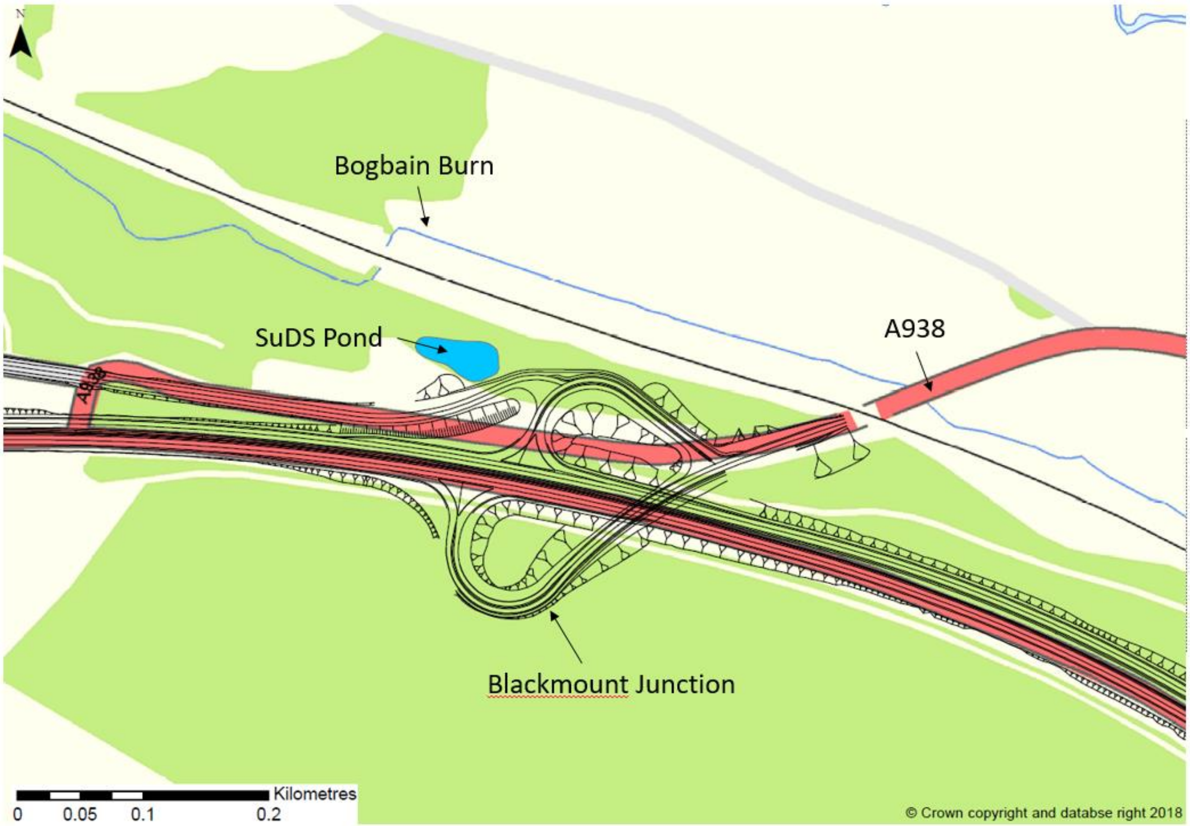


14.3 Proposed Model ('with-scheme' modelling)

Scheme arrangements

14.3.1 The proposed A9 alignment in the vicinity of the Bogbain Burn model includes a wider highway and a new junction with the A938 known as Blackmount Junction. The A9 does not cross Bogbain Burn but the watercourse has been modelled given its proximity to the road and to understand the floodplain in the area as Bogbain Burn has not been modelled previously. The A938 does cross Bogbain Burn. Figure 14.8 shows the proposed alignment.

Figure 14-8 Proposed Alignment Plan



Modelling approach

1D model updates

14.3.2 There were no changes made to the baseline 1D model for the proposed (with scheme) model as no changes were required in the 1D baseline model.

2D model updates

14.3.3 The A9 alignment and A938 road have been represented in the 2D domain of the proposed (with-scheme) model by adjusting the levels of the base grid using an ASCII file which represents the levels of these roads in the scheme. The levels of the SuDS pond proposed adjacent to the junction have also been represented in the model. The SuDS pond has a bund around it to prevent it becoming inundated during river flooding events.

Model performance

14.3.4 The model is stable in both 1D and 2D. Figure 14.9 is the runtime output from Flood Modeller for the 0.5% AEP proposed (with-scheme) model and shows that there is no poor convergence during the run. Figure 14.10 shows the cumulative mass balance error in the 2D domain throughout the 0.5% AEP proposed (with scheme) model run, for the initial 1.5 hours at the beginning of the model run the mass balance error is outside of the acceptable range (+/- 1%) but this can be attributed to the large volume of water entering the 2D domain from the 1D channels. The cumulative mass balance error is within the acceptable range from 1.5 hours into the model run until the end of the run meaning that the peak of the event is not affected by high mass balance error.

Figure 14-9 Flood Modeller runtime information – proposed (with-scheme)

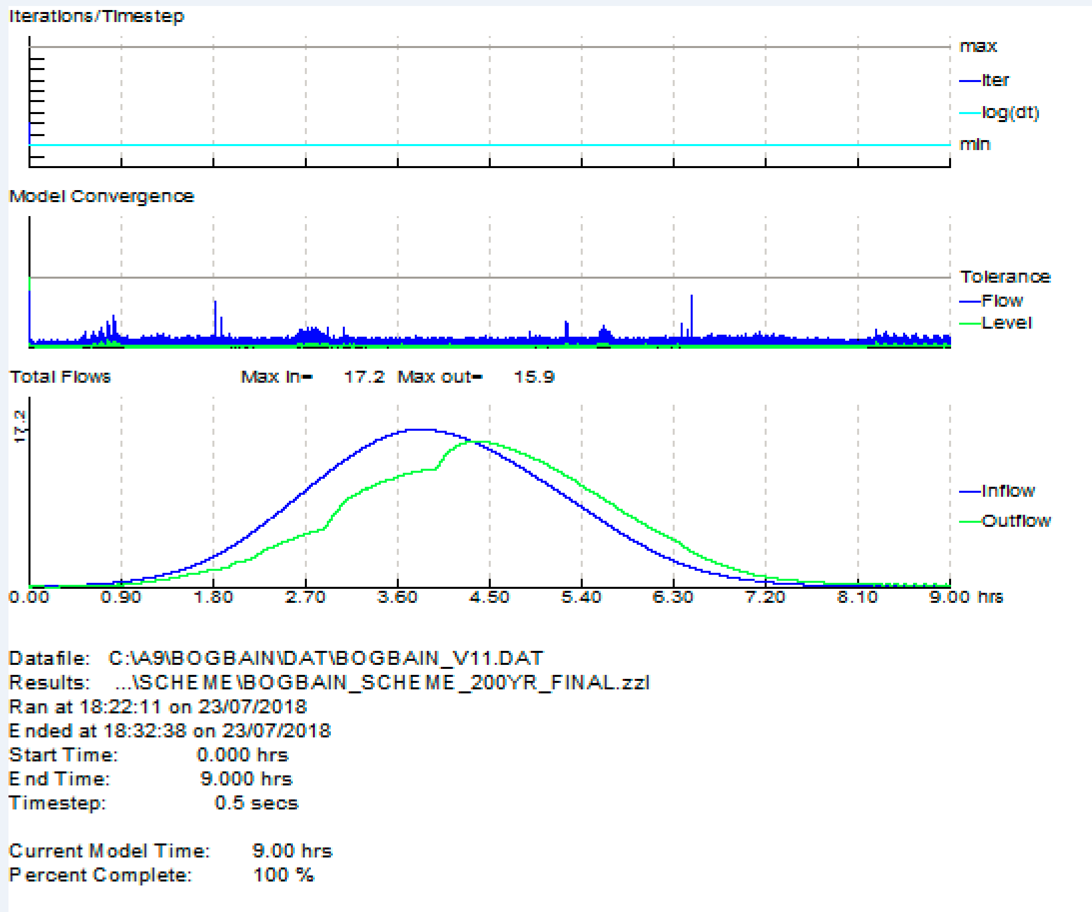
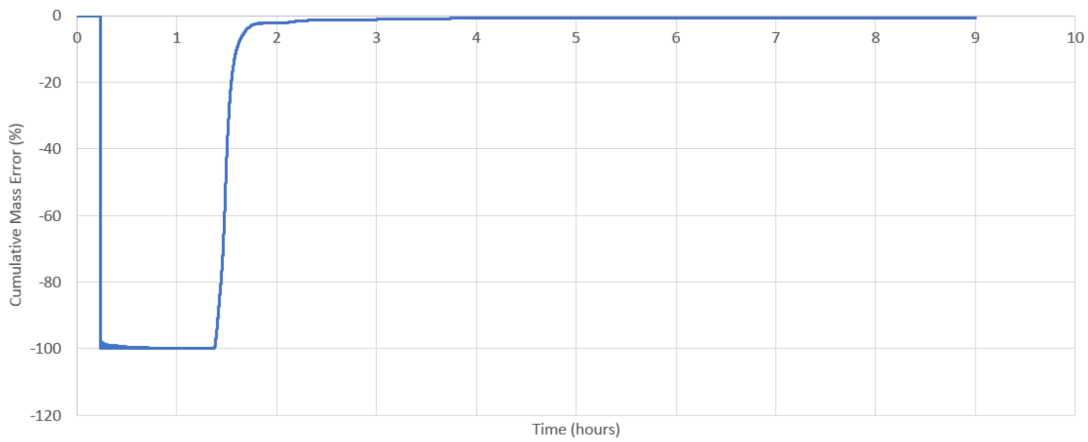


Figure 14-10 TUFLOW cumulative mass balance error – proposed (with-scheme)



14.4 Proposed Model + mitigation measures ('with-scheme + mitigation measure' modelling)

Scheme arrangements

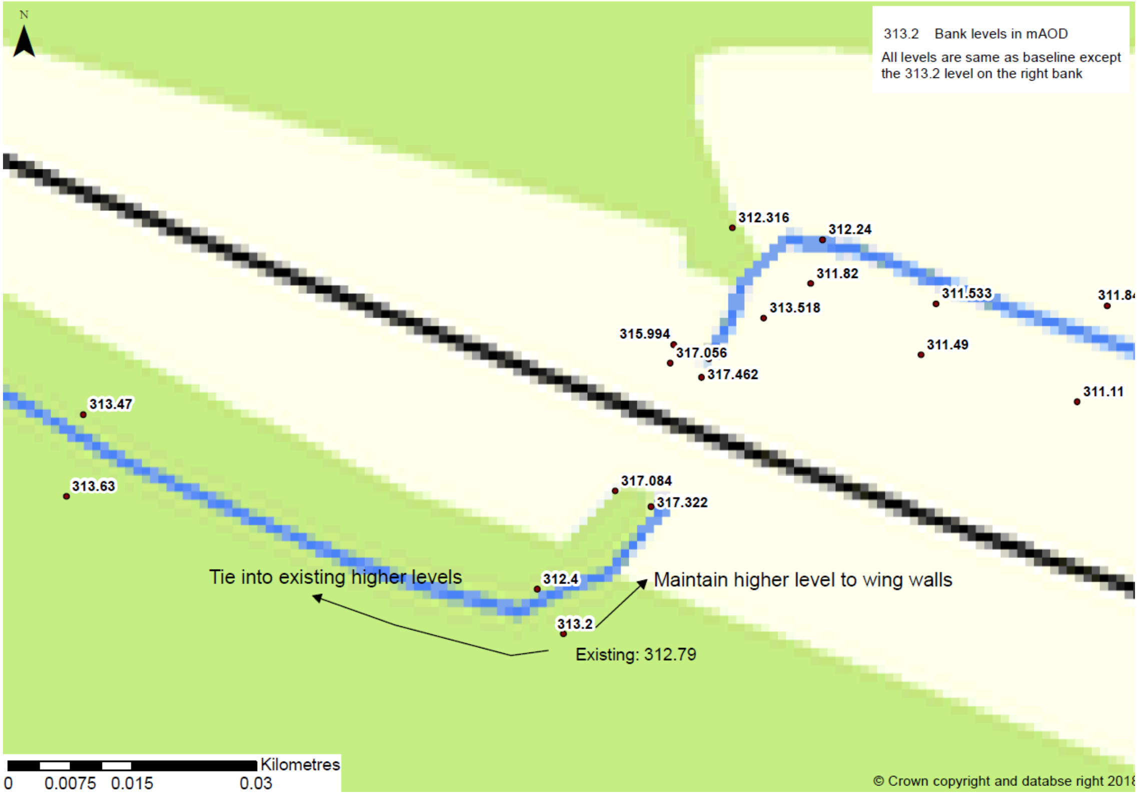
14.4.1 The proposed alignment encroaches onto the floodplain of Bogbain Burn and as a result there is an increase in flood levels on the A938 (a sensitive receptor) with the scheme in place compared to the baseline scenario, therefore mitigation is required to ensure the scheme does not increase flood risk to the A938.

14.4.2 Initially, mitigation in the form of storage on the floodplain was investigated using the hydraulic model. Approximately 2500m^3 of storage was included on the existing floodplain near to the A938, this acted to reduce flood levels on the A938 compared to the baseline scenario along most of the length of road affected by flooding but there was still an increase in flood levels at the lowest part of the road underneath the railway bridge. Storage further upstream adjacent to Bogbain Burn to the west of Blackmount junction was also investigated but an increase in flood levels on the A938 compared to the baseline scenario still occurred.

14.4.3 Bogbain Burn has been diverted from its natural course and to the west of the proposed Blackmount junction, there is a right-angled bend on the watercourse where it has been diverted underneath the railway line. Historic mapping shows that the original course of Bogbain Burn was to the south of the railway line near the proposed Blackmount junction. Flooding occurs in the vicinity of the proposed junction as the right bank of the watercourse on the right-angled bend is low compared to the bank upstream and downstream and water flows over the bank onto the floodplain. The floodplain slopes towards the A938 on the south side of the railway embankment and once water reaches the A938 it flows underneath the railway line on the road and back into Bogbain Burn to the north of the railway. The proposed mitigation measure is to raise the level of the right bank around the right-angled bend to reduce the amount of water overtopping in this location and therefore reduce flooding to the A938 with the scheme in place.

14.4.4 The existing bank level on the right bank of the right-angled bend is 312.79mAOD, in the scheme + mitigation scenario, the bank level has been raised to 313.20mAOD as shown on Figure 14-11. Upstream of the 313.2 mAOD point shown on Figure 14-11, the right bank would be raised to tie in with the existing higher bank upstream and downstream the bank would have to be raised to where it abuts the wingwall of the railway bridge.

Figure 14-11 Proposed Mitigation



Modelling approach

14.4.5 In order to represent the raised bank in the model, the bank level on the right bank of the right-angled bend was increase within the 2D TUFLOW model. The bank height in 2D overwrites the bank height in the 1D model. Increasing the bank height allows a larger volume of water to remain within the channel and reduces the amount of water spilling onto the floodplain.

Model performance

14.4.6 The model is stable in both 1D and 2D and exhibits the same patterns as the with scheme model. Figure 14.12 is the runtime output from Flood Modeller for the 0.5% AEP proposed (with-scheme + mitigation) model and shows that there is no poor convergence during the run. Figure 14.13 shows the cumulative mass balance error in the 2D domain throughout the 0.5% AEP proposed (with scheme + mitigation) model run, with the initial spike in mass balance error outside of the acceptable range (+/- 1%) but this can be attributed to the large volume of water entering the 2D domain from the 1D channels. The cumulative mass balance error is within the acceptable range for the majority of the model run meaning that the peak of the event is not affected by high mass balance error.

Figure 14-12 Flood Modeller runtime information – proposed (with-scheme + mitigation)

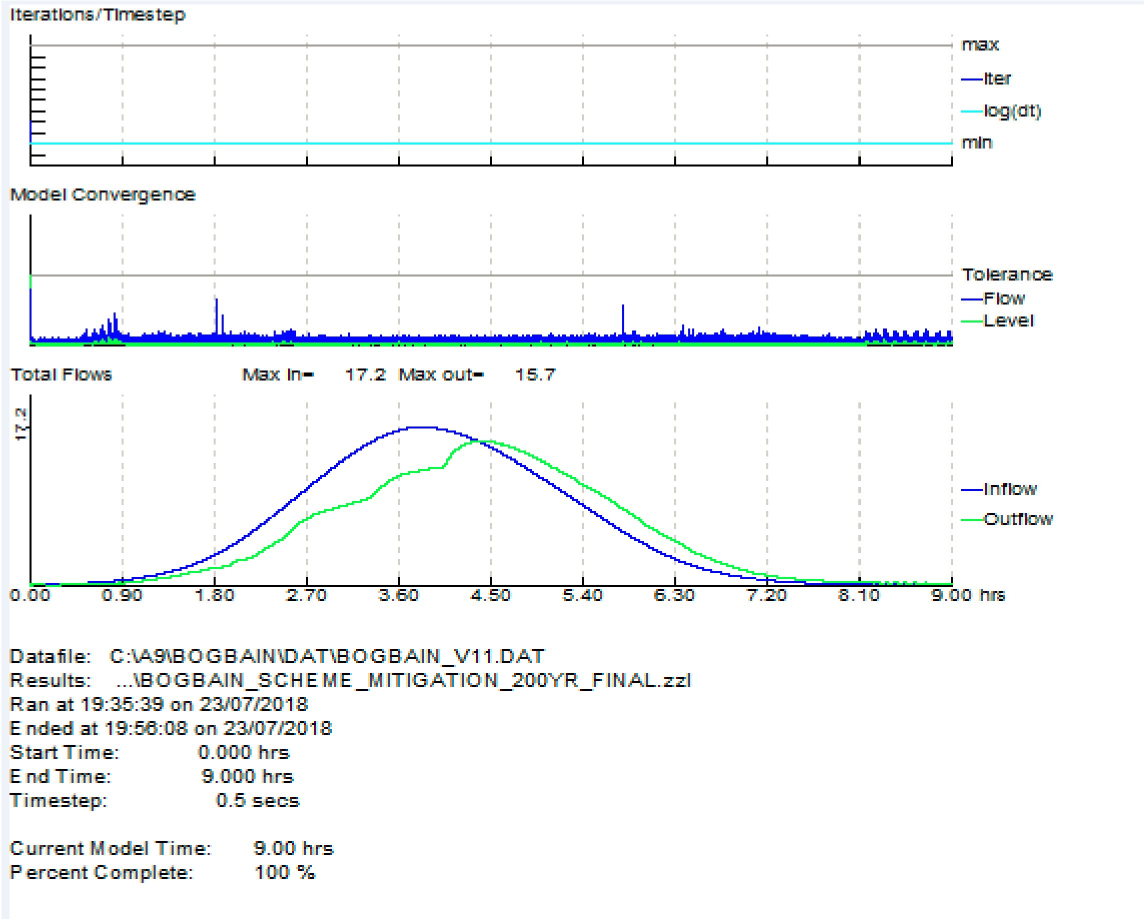
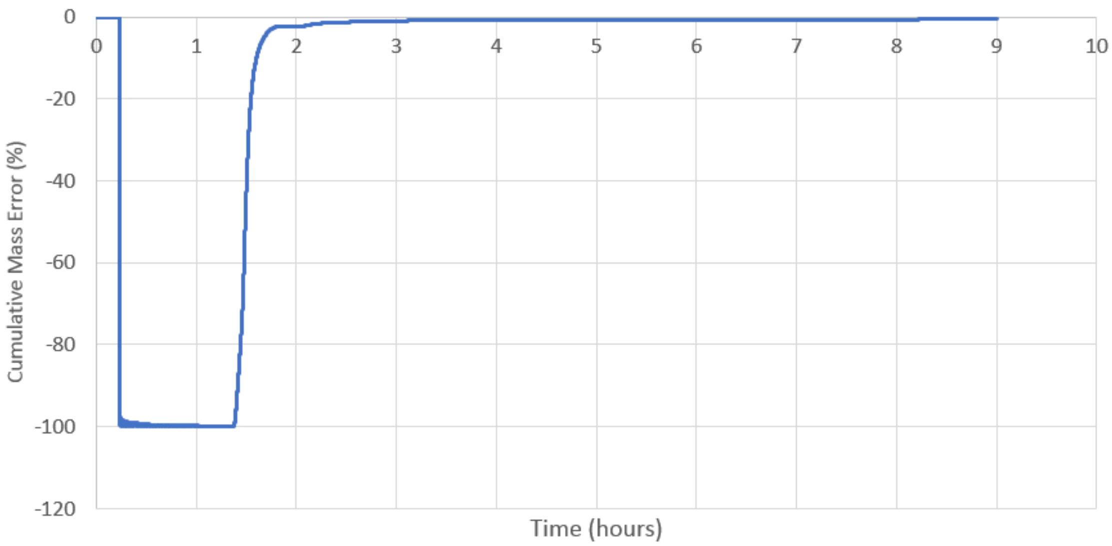


Figure 14-13 TUFLOW cumulative mass balance error – proposed (with-scheme)



14.5 Modelling Results Analysis

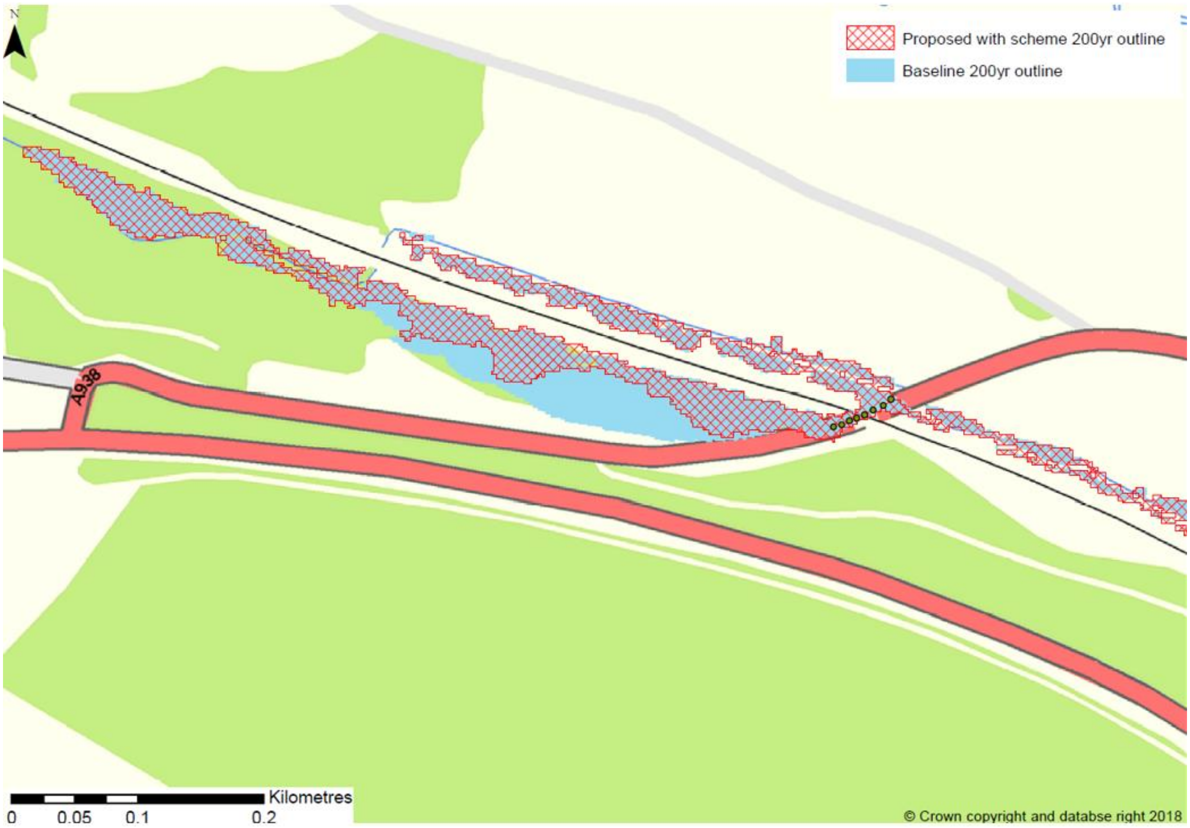
Baseline scenario

14.5.1 The baseline flood extent from Bogbain Burn does not flood onto the A9 but flooding is shown to the A938 for all events from the 20% AEP event upwards. The 0.5% AEP event baseline flood extent is shown in Figure 14.14 below. The flooding mechanism that leads to flooding of the A938 is that water flows out of the Bogbain Burn channel where there is a right angle in the watercourse immediately upstream of the railway culvert at NGR 289860, 824220 (labelled on Figure 14.14) and flows across the floodplain alongside the railway to the A938. Water flows along the A938 in a north easterly direction underneath the railway bridge over the road and back into the Bogbain Burn channel.

Comparison of Baseline and Proposed model ('with-scheme') results

14.5.2 The results of the 0.5% AEP proposed (with-scheme) model have been compared to the baseline model to determine the impact of the scheme on flood risk within the catchment and ascertain the need for mitigation. Figure 14.14 shows a comparison of the baseline and proposed (with-scheme) predicted flood extents for the 0.5% AEP event.

Figure 14-14 Comparison of baseline and proposed (with-scheme) modelled flood extents



14.5.3 Figure 14.13 shows that the proposed Blackmount Junction that is included in the 'with-scheme' model displaces water on the floodplain between the A938 and the railway. Other than that, the flood extents in the baseline and with scheme scenarios are the same both upstream and downstream of the proposed Blackmount junction. The depth of flooding predicted by the model for each scenario does vary due to the displacement of water. As the A938 is the only receptor affected by flooding in the area and is a low sensitivity receptor, a comparison was undertaken between the water levels predicted for the baseline and with scheme scenarios on the A938 at the points shown on Figure 14-15. The points were queried for the 3.33% and 0.5% AEP event and the water levels in the baseline and with scheme scenarios for each of these events are shown in Table 14-8.

Figure 14-15 Points on A938 where water levels are reported in Table 14-8

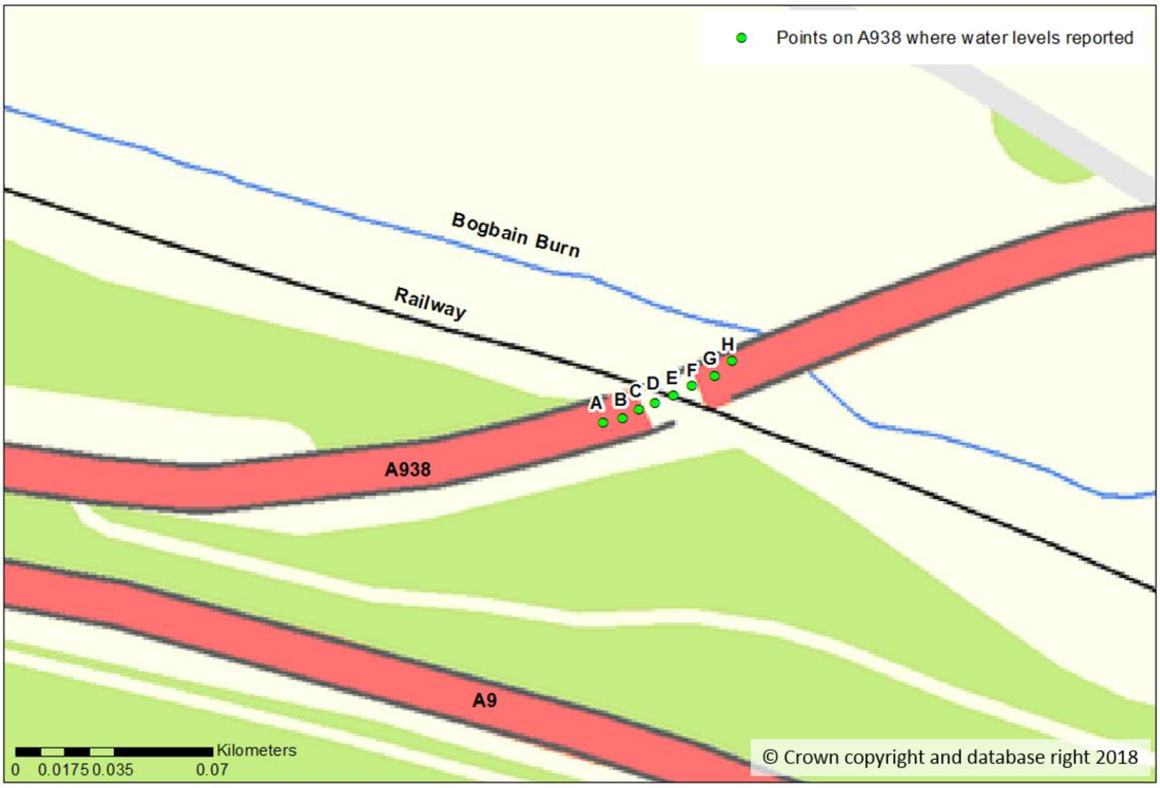


Table 14-8 Water level at points on A938

Points on A938 (Figure 15)	30yr Return Period			200yr Return Period		
	Baseline Water Level (mAOD)	Scheme Water Level (mAOD)	Difference (m)	Baseline	Scheme	Difference (m)
A	310.05	309.45	-0.60	310.29	309.95	-0.34
B	309.87	309.54	-0.33	310.08	309.99	-0.09
C	309.63	309.49	-0.14	309.83	309.93	0.10
D	309.44	309.37	-0.07	309.59	309.67	0.08
E	309.20	309.02	-0.18	309.39	309.30	-0.09
F	308.88	308.75	-0.13	309.03	309.00	-0.03
G	308.80	308.57	-0.23	308.91	308.77	-0.14
H	308.80	308.67	-0.13	308.90	308.82	-0.08

14.5.4 Table 14-8 shows that for the 30 year return period, the water level on the A938 is reduced for each point queried (A-H) in the with scheme scenario compared to the baseline. In the 200 year return period, a reduction in water level compared to the baseline scenario is seen at all of the points queried except C and D. As the A938 is a sensitive receptor, mitigation is required as part of the scheme to ensure there is no increase in flooding to the road with the scheme in place.

14.5.5 Checks were subsequently carried out to assess for impacts on flows in the Bogbain Burn. Tables 14-9 and 14-10 give a comparison of the flows and stage respectively in the Bogbain Burn channel. Generally, there is an increase in flow and stage with the scheme in place

Table 14-9 Comparison of Baseline and Proposed Flows (m3/s) for comparative model cross sections

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
	Q1000		Q200+CC		Q200		Q30		Q5		Q2	
BOG_XS_049	24.64	24.64	20.64	20.64	17.2	17.2	11.35	11.35	7.39	7.39	5.41	5.41
BOG_XS_035	4.52	5.97	4.31	5.64	4.00	4.45	3.28	3.67	2.67	3.09	2.59	2.95
BOG_XS_023	31.86	24.08	18.81	20.32	15.77	15.76	10.67	10.51	5.84	6.67	4.77	4.83
BOG_XS_012	20.311	21.05	17.93	19.82	15.65	15.99	10.64	10.43	5.85	6.67	4.76	4.83
BOG_XS_005	16.26	16.51	14.21	15.02	11.42	11.95	8.49	8.72	5.63	6.42	4.73	4.85

Table 14-10 Comparison of Baseline and Proposed Stage (m) for comparative model cross sections

	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
	Q1000		Q200+CC		Q200		Q30		Q5		Q2	
BOG_XS_049	320.86	320.86	320.79	320.79	320.72	320.72	320.59	320.59	320.47	320.47	320.40	320.40
BOG_XS_035	310.93	310.85	310.90	310.83	310.81	310.78	311.63	310.72	311.56	310.67	311.50	310.62
BOG_XS_023	307.31	307.40	307.24	307.27	307.18	307.18	306.99	306.98	306.77	306.8	306.67	306.68
BOG_XS_012	304.22	304.29	304.15	304.19	304.05	304.04	303.85	303.83	303.59	303.64	303.51	303.52
BOG_XS_005	302.38	302.45	302.35	302.42	302.33	302.35	302.21	302.21	301.97	302.03	301.89	301.90

Sensitivity Analysis

14.5.6 There are no gauges within the modelled extent, therefore it has not been possible to calibrate the model developed for this area. In order to determine how robust the model is and to understand the uncertainty in the model results, a suite of sensitivity tests have been undertaken. The sensitivity tests undertaken are as follows:

- Global roughness +/-20%
- Downstream boundary +/- 20%
- Flows +20%

14.5.7 The sensitivity tests have been carried out using the baseline model as the model is uncalibrated. Table 14-11 shows the variation in flow between the baseline model and each of the sensitivity tests for the 0.5% AEP event and Table 14-12 shows the variation in stage. There is up to a 100mm increase in water levels for the roughness+20% sensitivity test compared to the baseline and up to 110mm decrease in water levels for the roughness-20% sensitivity test. Increasing flows by 20% has the biggest maximum increase in water levels of 135mm but this increase does not occur uniformly throughout the model as shown in Figure 14-16.

14.5.8 Changes to the downstream boundary had the least impact on the model as the impact of the change is only seen for 38m upstream of the downstream boundary and water levels are the same as for the baseline throughout the rest of the model. The maximum change is at the downstream boundary itself, there is a 54mm increase in water level with the slope of the downstream boundary reduced by 20% and a 31mm reduction in water level at the downstream boundary with the gradient of the downstream boundary increased by 20%.

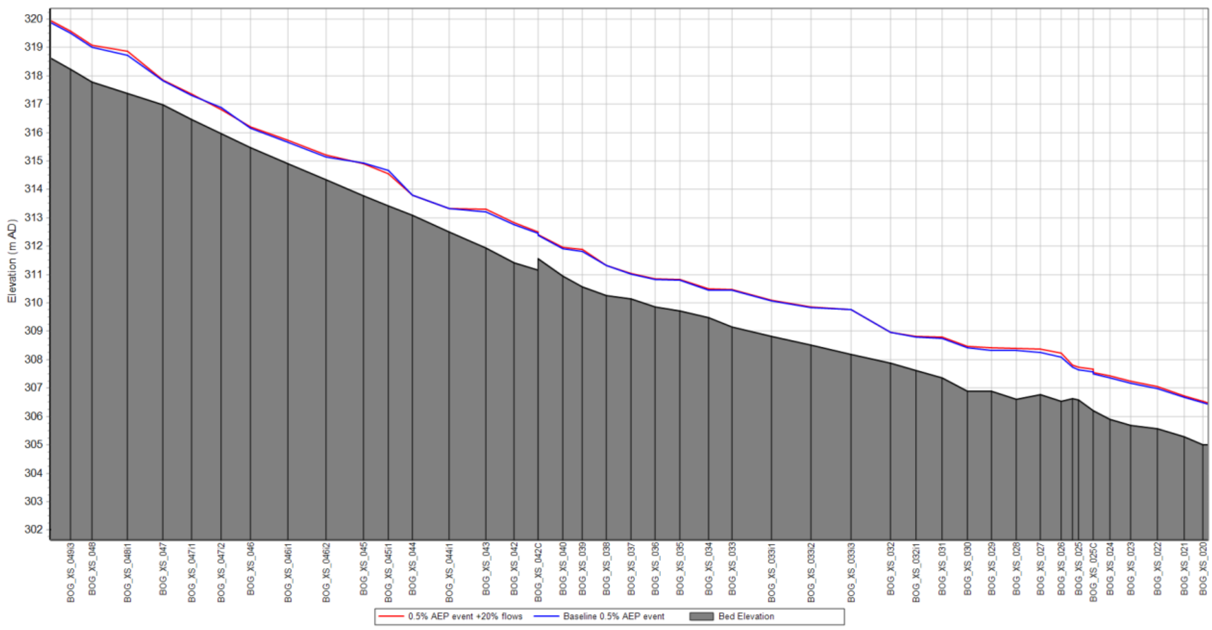
Table 14-11 Variation in flow for sensitivity tests

	Sensitivity tests Q200 Variation in flow (m³/s)				
	Baseline 0.5% AEP flow (m³/s)	Man +20% Global	Man -20% Global	DSB + 20% XSO2	DSB - 20% XSO2
Cross section	Q200	Q200	Q200	Q200	Q200
BOG_XS_049	17.21	17.21	17.21	17.21	17.21
BOG_XS_035	4.01	3.31	7.22	4.01	4.01
BOG_XS_023	15.81	15.38	16.39	15.81	15.81
BOG_XS_012	15.67	14.89	16.10	15.66	15.66
BOG_XS_005	11.44	10.77	12.46	11.43	11.43

Table 14-12 Variation in stage for sensitivity tests

	Sensitivity tests Q200 Variation in stage (mAOD)				
	Baseline 0.5% AEP flow (mAOD)	Man +20% Global	Man -20% Global	DSB + 20% XSO2	DSB - 20% XSO2
Cross section	Q200	Q200	Q200	Q200	Q200
BOG_XS_049	320.72	320.79	320.69	320.72	320.72
BOG_XS_035	310.81	310.83	310.75	310.81	310.81
BOG_XS_023	307.18	307.28	307.11	307.18	307.18
BOG_XS_012	304.05	304.14	303.94	304.05	304.05
BOG_XS_005	302.33	302.39	302.30	302.33	302.33

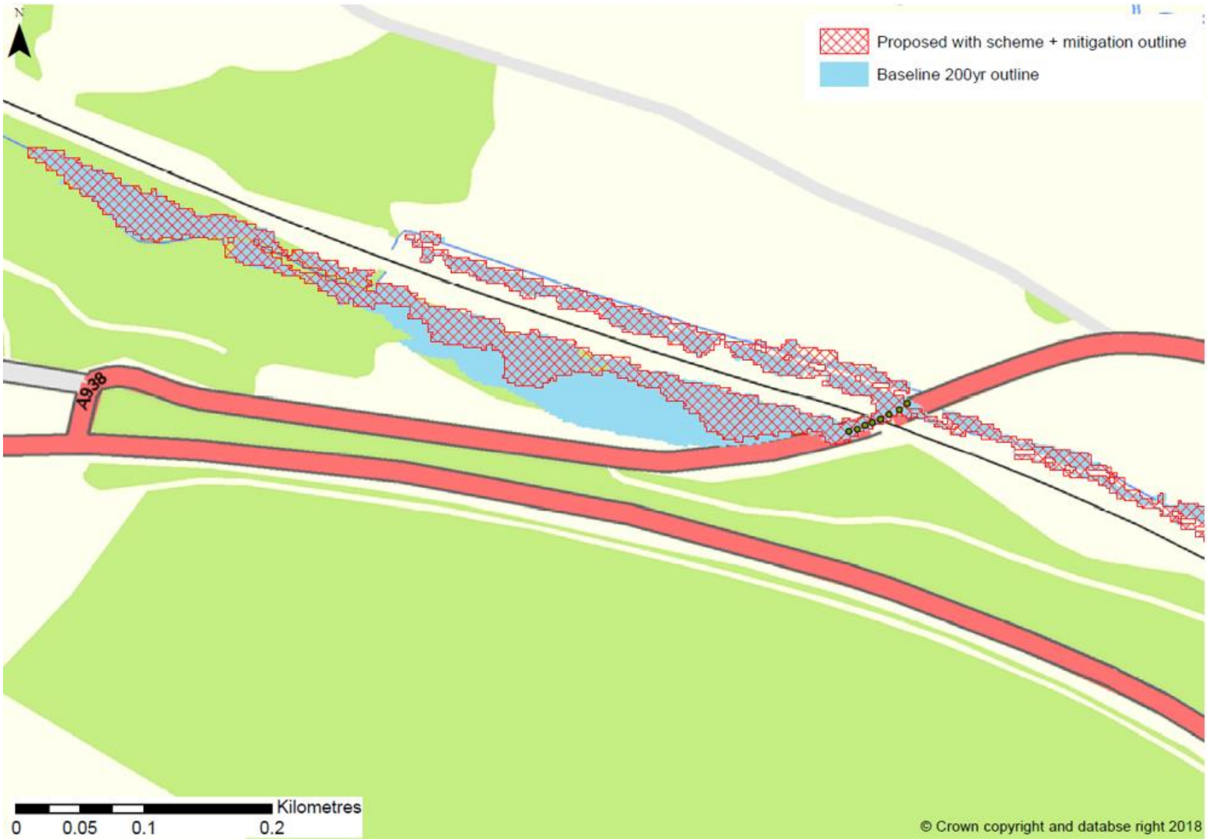
Figure 14-16 Flow sensitivity test water levels compared to baseline



Comparison of Baseline and Proposed ('with-scheme + mitigation measure') results

14.5.9 With the mitigation measures in place, the flood extent predicted by the model is similar to the proposed (with scheme) modelled flood extent, there is slightly less water on the floodplain to the south of the railway and slightly more on the floodplain to the north of the railway. A comparison of the proposed with scheme plus mitigation and baseline flood extents is shown in Figure 14-17.

Figure 14-17 Comparison of baseline and proposed (with-scheme) modelled flood extents



14.5.10 Raising the level of the bank on the right-angled bend upstream of the railway bridge does mean that water levels on the A938 are not increased compared to the baseline scenario. A comparison between water levels on the A938 at the points shown on Figure 14-15 between the baseline and proposed (with scheme plus mitigation) scenarios for the 0.5% AEP event is shown in Table 14-13. For each point (A-H), there is a reduction in water level during the 0.5% AEP event with the scheme + mitigation in place compared to the baseline scenario.

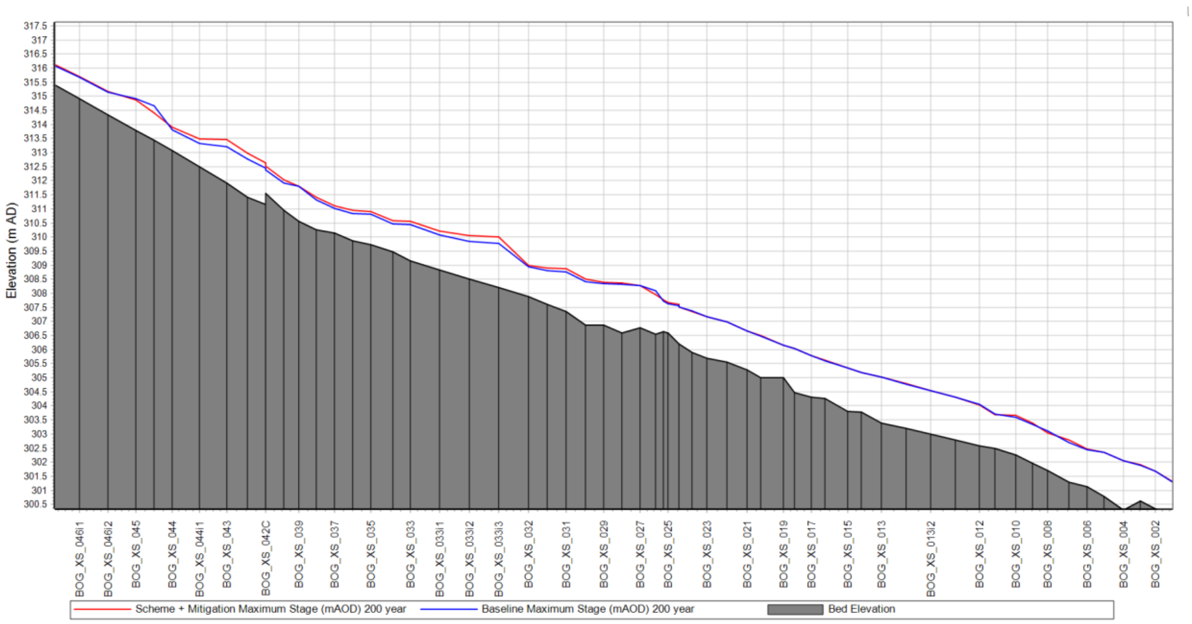
14.5.11 There are increases in water level within the Bogbain channel and on the floodplain to the north of the railway as more water is kept within the channel and passes under the railway bridge with the mitigation in place. Figure 14-18 shows the difference in water levels for the 0.5% AEP event between the baseline scenario and the proposed (scheme + mitigation) scenario. The biggest increases in water level within the Bogbain channel are near to where the bank has been raised. At the cross-section where the bank has been raised (BOG_XS_043), there is an increase in water level compared to the baseline scenario of 240mm during the 0.5% AEP event with the scheme and mitigation in place. For the same event, there is an increase of 170mm through the railway bridge with the scheme and mitigation in place compared to the baseline scenario. The increase in water levels decreases further downstream on Bogbain Burn, at the confluence with Allt nan Ceatharnach there is a 30mm increase in water levels compared to the baseline scenario due to the increase in flows being conveyed along the channel with the bank raised at BOG_XS_043.

14.5.12 There are no immediate flood risk receptors at risk downstream of the confluence with Allt nan Ceatharnach. The Carrbridge Potentially Vulnerable Area (PVA) is approximately 2.3km downstream of the confluence.

Table 14-13 Water level at points on A938

	200yr Return Period		
Points on A938 (Figure 14-15)	**Baseline Water Level (mAOD)**	**Scheme + Mitigation Water Level (mAOD)**	**Difference (m)**
A	310.29	309.76	-0.53
B	310.08	309.81	-0.27
C	309.83	309.73	-0.10
D	309.59	309.54	-0.05
E	309.39	309.23	-0.16
F	309.03	308.90	-0.13
G	308.91	308.70	-0.21
H	308.90	308.77	-0.13

Figure 14-18 Comparison of water levels along Bogbain Burn for the 0.5% AEP event baseline and proposed (scheme+mitigation) scenarios



14.6 Geomorphological Impacts of Proposed (Scheme + Mitigation) Scenario

14.6.1 As the mitigation measures involve increases in flows and water level within Bogbain Burn, a high level geomorphological assessment has been undertaken to determine the impact of the mitigation measures on the channel and the railway bridge downstream of the bank raising.

Baseline

14.6.2 The channel is a tributary to Allt nan Ceatharnach, but is not itself directly affected by the existing A9. It has been, however, substantially affected by the railway and other roads, having been crossed a dozen times over a 2km distance. The planform has clearly been realigned and straightened, but appears to possess some diverse and dynamic morphological features. The channel bed comprises sand, gravel and cobbles at the railway crossing which is a stone bridge structure with wingwalls. The banks beyond the wingwalls are bimodal consisting of cobbles/gravels and finer material. There is no evidence of scour at the structure but there was some bank erosion observed downstream of the crossing on the left bank at the apex of the tight bend as shown on Figure 14-19 (2017 network rail assessment).

Figure 14-19 Erosion on bend downstream of railway bridge

Proposed mitigation and impact

14.6.3 The mitigation involves a slight increase (410mm) to the right bank height upstream of the railway crossing (313.2mAOD compared to 312.79mAOD). The existing channel cross section dimensions remain unchanged downstream. This leads to increased flow through the railway bridge and downstream. There is an increase in velocity both upstream and downstream of the railway bridge. There is no increase in velocities at BOG_XS_040 just downstream of bend where erosion has been observed however there is a slight increase in stage (113mm) and flow. Table 14-14 provides velocity change and Stage difference.

Table 14-14 Comparison of Baseline and Proposed (scheme + mitigation) Velocity and Stage

Cross Section	Comparison of Baseline and Proposed (Scheme + Mitigation)	
	Velocity Change (%)	Stage Difference (m)
BOG_XS_040	99.38%	0.113
BOG_XS_041	116.15%	0.144
BOG_XS_042	114.00%	0.218
BOG_XS_043	99.93%	0.243
BOG_XS_044	74.71%	0.09
BOG_XS_045	90.11%	-0.048

Stream Powers and Recommendations

14.6.4 At BOG_XS_041 where the velocity change is highest, the stream power increases from 222 to 306 Wm-2. At BOG_XS_040, stream powers increase from 213 to 295 Wm-2. These are approximately a 38% increase in stream powers downstream of the railway crossing. This may exacerbate the erosion risk on the left bank therefore monitoring would be advised. No assets are at risk from this potential bank erosion. Some bed movement may also occur, but this is likely to be within the norm of natural adjustment at higher flows, but monitoring is advised. To alleviate the pressure on the bend (and bed), the right bank could be pulled back (reprofiled) to take the pressure off the left bank which has been historically realigned at nearly a 90 degree bend, although at BOG_XS_040 the right hand bank is lower compared to the left hand bank. Upstream (BOG_XS_041) towards the crossing outlet the banks are significantly higher (over 4m deep) due to the presence of wingwalls. A site visit would be required to identify the most appropriate mitigation for potential scour in this area.

14.7 Summary

14.7.1 A model has been developed to determine the current level of flood risk from Bogbain Burn, there was not previously a model of this watercourse. The model has been used to test the impact of the proposed A9 dualling scheme on flood risk in the area. The model complies with SEPA's currently modelling standards (v1.1, 2015) and is stable. Sensitivity testing has been undertaken to understand the impact of a number of parameters on the model results.

14.7.2 The testing undertaken has shown that the model is suitable for use in this assessment. A version of the model representing the proposed (with scheme) scenario and the results showed that the scheme displaces water on the floodplain and leads to an increase in water levels on the A938 during the 0.5% AEP event. Therefore, mitigation is required as part of the scheme as the A938 is a sensitive receptor.

14.7.3 Mitigation has been provided in the model by increasing the level of the right hand bank on the right-angled bend upstream of the railway bridge where water overtops Bogbain Burn and subsequently flows across the floodplain south of the railway towards the A938. The raising of the bank level reduces the amount of water flowing onto the floodplain and therefore reduces the water levels predicted on the A938 compared to the baseline scenario. However, raising the bank does keep more water in the channel and increases water levels, flows and velocities in Bogbain Burn. The impact of the bank raising reduces towards the downstream extent of Bogbain Burn but there is still an increase in water level of 30mm at the confluence with Allt nan Ceatharnach for the proposed (scheme + mitigation) model compared to the baseline scenario. There are no sensitive receptors at the confluence. The Carrbridge PVA is approximately 2.3km downstream of the confluence but given the slight increase in water level, it is unlikely that the introduction of the proposed mitigation measures will impact on the PVA.

14.7.4 The impact of increasing flows, water levels and velocities in the vicinity of the railway bridge has been assessed in terms of geomorphological impact. There is some scour evident on the left bank downstream of the railway bridge on a bend, which may be slightly exacerbated if more water is kept in the channel through the mitigation measures put in place. It is recommended that a site visit is undertaken to identify the most appropriate mitigation for potential scour in this area.

15. Allt Slochd Mhor

15.1.1 The Schlod Mhor hydraulic model was developed to support the design of river realignments and cascade through this section of the A9 dualling.

15.1.2 Slochd Mhor is a relatively small watercourse with a catchment area of around 4 km^2 in the vicinity of the A9 road. The watercourse consists of one main channel that captures runoff from the western slopes of Carn nam bain-tighearnalde and eastern slope of Torr Mor. This channel intercepts the A9 alignment at four crossings, before the fourth and final crossing Slochd Mhor is joined by the lateral inflows from Sputan Dubha. Downstream of the A9 crossings there is a confluence with Allt Ruighe an t-sabnail. The watercourse is relatively steep, with a cascade occurring upstream of the Sputan Dubha confluence. The watercourse flows south towards its confluence with the River Dulnain.

15.1.3 The Slochd Mhor catchment was delineated from FEH CD-ROM (version 3), topographic survey data, Ordnance Survey mapping and 5m NextMAP DTM data of the area. The catchment area was altered to reflect the surrounding topography.

15.1.4 Applying a distributed model, the catchment was subdivided into 6 catchments to take account of the small channels and any lateral inflows. Figure 15.1 shows the hydrological model schematic, with Table 15.1 detailing the delineated catchment areas.

Table 15-1 Slochd Mhor Hydrological Estimation Points

Watercourse	Inflow ID	Inflow Location	Inflow Type	Method	Easting Approx.	Northing Approx.	Area (km^2)
Slochd Mhor	Inflow A	Upstream of the A9 Crossing SLO_XS_062	Direct	Donor scale	283538	825638	0.84
Slochd Mhor	Inflow B	Downstream of second A9 crossing SLO_XS_054U	Direct	Donor scale	283753	825393	0.57
Sputan Dubha	Inflow C	Upstream of fourth A9 crossing SLO_XS_048U	Direct	Donor scale	284048	825051	0.28
Slochd Mhor	Inflow D	Upstream of confluence with Allt Ruighe an t-sabnail SLO_XS_024	Lateral	Donor scale	284299	824282	0.93
Allt Ruighe an t-sabnail	Inflow E	Tributary of Allt Ruighe an t-sabnail SLO_XS012U	Direct	FEH scale	284154	824271	1.29
Slochd Mhor	Inflow F	Lateral inflow to Slochd Mhor SLO_XS_009	Lateral	Donor scale	284501	823974	0.36

15.1.5 Peak flows were calculated for each inflow using the FEH Rainfall Runoff methods. Given the size of the catchment a statistical estimate would not be appropriate. Applying the precautionary approach and considering the size of the catchment the Rainfall Runoff peak flow estimates have been applied, and optimised within the hydraulic model. Table 15.2 shows the calculated peak flows.

15.1.6 Critical storm durations vary across the catchment. A catchment wide storm duration provides a more realistic representation of actual rainfall events. The critical storm duration for the Slochd Mhor was set as 1.3 hours.

Table 15-2 Slochd Mhor Peak Flow Estimates

Watercourse	Inflow ID	Inflow Location	0.5%	0.5+CC
Slochd Mhor	Inflow A	Upstream of the A9 Crossing SLO_XS_062	5.3	6.4
Slochd Mhor	Inflow B	Downstream of second A9 crossing SLO_XS_054U	3.6	4.3
Sputan Dubha	Inflow C	Upstream of fourth A9 crossing SLO_XS_048U	1.8	2.1
Slochd Mhor	Inflow D	Upstream of confluence with Allt Ruighe an t-sabnail SLO_XS_024	5.9	7.1
Allt Ruighe an t-sabnail	Inflow E	Tributary of Allt Ruighe an t-sabnail SLO_XS012U	5.3	5.8
Slochd Mhor	Inflow F	Lateral inflow to Slochd Mhor SLO_XS_009	1.7	2.7

15.2 Baseline Hydraulic Model

15.2.1 The hydraulic model was built using a one-dimensional schematisation, where the river channel and floodplain is represented as a 1D component. The model was constructed using the river modelling package Flood Modeller (version 4.3).

15.2.2 The 1D model extends from around 250 m upstream of the A9 alignment. The upstream boundary of the model is located at 283360 825600. NGR co-ordinates for the downstream boundary are 284504 823975.

15.2.3 Table 15.3 below details the model extents and key features. Figure 15.1 shows the hydraulic model schematic.

Table 15-3 Key Model Features

Model Reach	Modelled Reach (m)	Upstream model extent (grid ref)	Downstream model extent (grid ref)	Number of A9 Crossings	Total number of modelled structures
Slochd Mhor	2448	283360 825600	284504 823975	4	9

15.2.4 The open channel river sections were defined from the topography survey, with the Manning's 'n' values defined from the site visits, which were undertaken in March 2016. Table 15.4 provides the manning value range and justification of the value.

Table 15-4 Slochd Mhor, roughness values

Section Type	Minimum	Maximum	Commentary
River Channel (Mannings)	0.024	0.036	Ranging from finished concrete culvert entrances to Clean winding channels with pools and shoals.
Structures (Mannings)	0.016	0.03	Ranging from concrete, to rough bed material.

Section Type	Minimum	Maximum	Commentary
Floodplain (Mannings)	0.024	0.036	(Chow, 1959) D. C.2 / 3 = “High Grass” and “Light brush and trees in Summer / Winter”

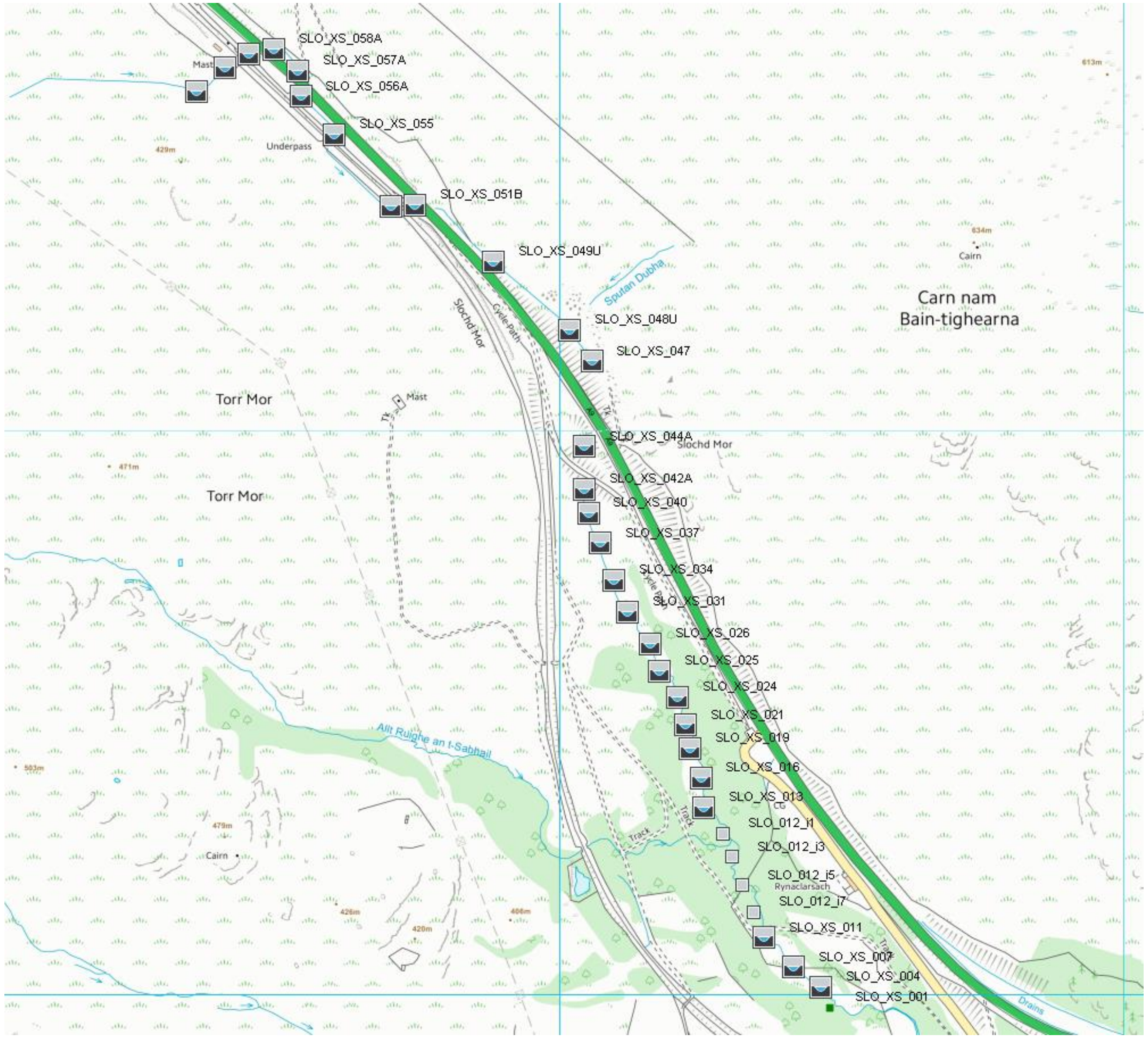
15.2.5 Table 15.5 provides the details of how the structures are represented within the model.

Table 15-5 The Slochd Mhor Modelled Structures Details

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Re presentation in the model	Photograph
SLO_XS_061A	Access road upper catchment culvert	Slochd Mhor	1.54 (w) x 0.82 (S) x 0.59 (c)	Conduit sprung	
SLO_XS_059A	A9 crossing upper catchment culvert	Slochd Mhor	1.2 Ø	Circular conduit	
SLO_XS_057A	A9 crossing Upper catchment Culvert	Slochd Mhor	2.61 (w) x 1.12 (h)	Conduit Full arch	
SLO_XS_055A	Access road upper catchment Small bridge	Slochd Mhor	1.76 (w) x 0.12 (s) x 0.78 (c)	Bridge Arch	

Water Crossing ID	Structure	Watercourse	Dimensions (m)	Re presentation in the model	Photograph
SLO_XS_055A	Access road upper catchment Bridge	Slochd Mhor	2.78 (w) x 2.07 (s) x 0.39 (c)	Bridge Arch	
SLO_XS_052A	Access road Upper catchment Bridge/culvert	Slochd Mhor	2.66 (w) x 0.37 (S) x 0.45 (c)	Conduit sprung	
SLO_XS_052A	A9 crossing Upper catchment	Slochd Mhor	1.53 (w) x 2.2 (h)	Conduit Rectangular	
SLO_XS_046A	A9 Crossing downstream of Sputan Dubha	Slochd Mhor	1.6 (w) x 2.18 (h)	Conduit Rectangular	
SLO_XS_043A	Access road Upper catchment	Slochd Mhor	1.77 (w) x 1.05 (S) x 0.71 (c)	Conduit sprung	

Figure 15-1 1D Model Schematic. All Cross sections SLO_XS_062 – SLO_XS_001

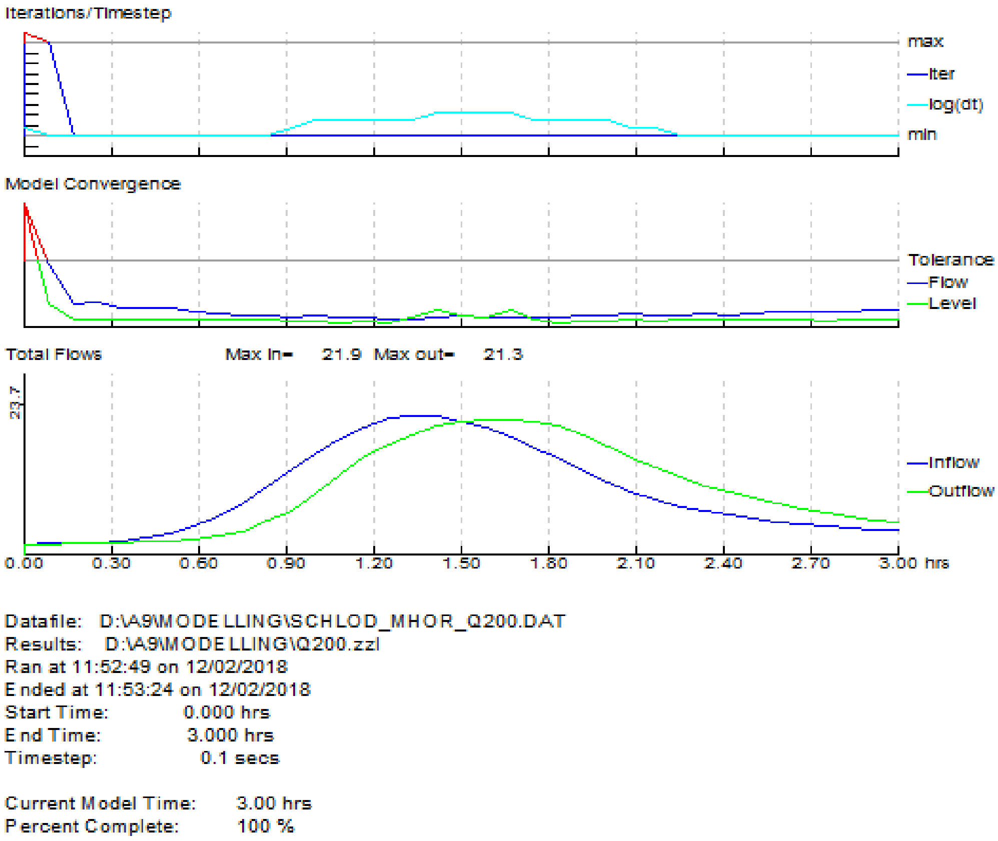


15.3 Baseline Model Performance

1D model performance

15.3.1 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Poor model convergence is observed at low flows due to the cascade that is included within the model extent. Figure 15.2 shows model convergence for the 0.5% AEP event.

Figure 15-2 1D Model Convergence for the 0.5% AEP Event



15.4 Sensitivity Analysis

15.4.1 In order to analyse the sensitivity of the hydraulic model, the models have been updated to represent a change in parameters. The results from the 1D have been compared against the baseline results for the 0.5% AEP event, these are shown in Table 15.6 and Table 15.7. Variation in flow is given in m^3/s and variation in stage is given in metres. Sensitivity analysis has been undertaken for the following scenarios:

- Global roughness including structures + / - 20%
- Flow + / - 20%
- Downstream Boundary +/ - 20%

Table 15-6 Variation in flow for sensitivity tests (m3/s) - Baseline.

Cross Section	Baseline	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_062	5.265	0.00	0.00	+1.05	-1.05	0.00	0.00
SLO_XS_061	5.272	+0.01	+0.00	+1.05	-1.05	0.00	0.00
SLO_XS_061A	5.272	+0.01	+0.00	+1.03	-1.04	0.00	0.00
SLO_XS_060A	5.271	+0.00	0.00	+1.03	-1.04	0.00	0.00
SLO_XS_060	5.269	-0.00	+0.00	+1.03	-1.04	0.00	0.00
SLO_XS_059A	5.263	-0.03	+0.00	+1.01	-1.04	0.00	0.00
SLO_XS_058A	5.26	-0.02	+0.00	+1.02	-1.04	0.00	0.00
SLO_XS_058	5.257	-0.03	+0.00	+1.01	-1.03	0.00	-0.01
SLO_XS_057	5.219	-0.04	+0.02	+1.00	-1.02	0.00	+0.01
SLO_XS_057A	5.136	-0.16	+0.02	+0.71	-0.97	0.00	0.00
SLO_XS_056A	5.134	-0.16	+0.02	+0.71	-0.97	0.00	0.00
SLO_XS_056	5.113	-0.15	+0.02	+0.69	-0.97	0.00	0.00
XS_056DUMMY	5.121	-0.15	+0.01	+0.65	-0.98	0.00	0.00
SLO_XS_055	5.12	-0.13	+0.01	+0.71	-0.99	0.00	0.00
SLO_XS_055A	5.121	-0.13	+0.01	+0.71	-0.98	0.00	0.00
SLO_XS_055B	5.121	-0.13	+0.01	+0.71	-0.98	0.00	0.00
SLO_XS_054A	5.127	-0.12	+0.01	+0.72	-0.98	0.00	0.00
054copy	5.127	-0.12	+0.01	+0.72	-0.98	0.00	0.00
SLO_XS_054U	5.132	-0.11	+0.01	+0.73	-0.98	0.00	0.00
SLO_XS_054D	8.525	-0.25	+0.04	+1.16	-1.64	+0.01	0.00
XS_054Dummy	8.509	-0.26	+0.02	+1.05	-1.62	0.00	0.00
SLO_XS_053	8.432	-0.23	+0.04	+0.96	-1.55	0.00	0.00
SLO_XS_053A	8.427	-0.23	+0.03	+0.97	-1.55	0.00	0.00
SLO_XS_052C	8.427	-0.23	+0.03	+0.97	-1.55	0.00	0.00
SLO_XS_052B	8.427	-0.24	+0.02	+0.97	-1.56	0.00	0.00
052copy	8.427	-0.24	+0.02	+0.97	-1.56	0.00	0.00
SLO_XS_052A	8.426	-0.24	+0.02	+0.90	-1.56	0.00	0.00
SLO_XS_051B	8.426	-0.24	+0.02	+0.90	-1.56	0.00	0.00
SLO_XS_051A	8.426	-0.25	+0.02	+0.90	-1.56	0.00	0.00
SLO_XS_050A	8.429	-0.25	+0.02	+0.90	-1.56	0.00	0.00
SLO_XS_050	8.429	-0.25	+0.02	+0.90	-1.56	0.00	0.00
SLO_XS_049U	8.425	-0.24	+0.02	+0.91	-1.55	0.00	0.00
SLO_XS_049D	8.425	-0.24	+0.02	+0.91	-1.55	0.00	0.00
SLO_XS_048U	8.42	-0.23	+0.03	+0.91	-1.54	0.00	0.00
SLO_XS_048D	10.023	-0.26	+0.05	+1.21	-1.82	0.00	0.00
SLO_XS_047	10.025	-0.26	+0.06	+1.24	-1.84	0.00	0.00

Cross Section	Baseline	Man +20% Global	Man -20% Global	Q +20%	Q -20%	DSB +20% XSO2	DSB -20% XSO2
SLO_XS_046A	10.029	-0.27	+0.05	+1.22	-1.85	0.00	0.00
SLO_XS_044A	10.031	+0.41	+0.04	+1.17	-1.85	0.00	0.00
SLO_XS_044	10.03	+0.21	+0.04	+1.18	-1.85	0.00	0.00
SLO_XS_043	10.023	-0.10	+0.05	+1.18	-1.85	0.00	0.00
SLO_XS_43A	10.019	-0.25	+0.05	+1.19	-1.84	0.00	0.00
SLO_XS_042A	10.019	-0.25	+0.05	+1.19	-1.84	0.00	0.00
SLO_XS_042	10.019	-0.25	+0.05	+1.19	-1.84	0.00	0.00
SLO_XS_041	10.02	-0.26	+0.05	+1.20	-1.84	0.00	0.00
SLO_XS_040	10.015	-0.27	+0.05	+1.21	-1.84	0.00	0.00
SLO_XS_039	10.014	-0.28	+0.06	+1.21	-1.84	0.00	0.00
SLO_XS_038	10.014	-0.26	+0.05	+1.22	-1.84	0.00	0.00
SLO_XS_037	10.013	-0.24	+0.05	+1.23	-1.83	0.00	0.00
SLO_XS_036	10.014	-0.25	+0.05	+1.23	-1.84	0.00	0.00
SLO_XS_035	10.012	-0.25	+0.06	+1.24	-1.83	0.00	0.00
SLO_XS_034	10.013	-0.25	+0.05	+1.25	-1.83	0.00	0.00
SLO_XS_033	10.015	-0.26	+0.05	+1.23	-1.84	0.00	0.00
SLO_XS_032	10.016	-0.26	+0.05	+1.24	-1.84	0.00	0.00
SLO_XS_031	10.025	-0.27	+0.04	+1.24	-1.84	0.00	0.00
SLO_XS_030	10.023	-0.25	+0.04	+1.26	-1.84	0.00	0.00
SLO_XS_029	10.026	-0.28	+0.04	+1.25	-1.85	0.00	0.00
SLO_XS_028	10.034	-0.27	+0.04	+1.26	-1.80	+0.01	0.00
SLO_XS_027	10.028	-0.25	+0.09	+1.24	-1.84	+0.03	+0.02
SLO_XS_026	10.033	-0.26	+0.08	+1.32	-1.81	+0.03	+0.01
SLO_XS_025	13.332	-0.25	+0.10	+1.99	-2.46	0.00	+0.01
SLO_XS_024	14.305	-0.27	+0.11	+2.18	-2.66	-0.01	-0.01
SLO_XS_023	15.412	-0.29	+0.11	+2.37	-2.90	-0.01	0.00
SLO_XS_022	15.393	-0.27	+0.13	+2.39	-2.88	0.00	0.00
SLO_XS_021	15.401	-0.29	+0.14	+2.45	-2.88	0.00	-0.01
SLO_XS_020	15.426	-0.32	+0.10	+2.38	-2.90	-0.02	-0.01
SLO_XS_019	15.42	-0.31	+0.12	+2.39	-2.89	0.00	-0.01
SLO_XS_018	15.422	-0.31	+0.11	+2.43	-2.89	-0.01	0.00
SLO_XS_017	15.424	-0.31	+0.11	+2.43	-2.88	0.00	0.00
SLO_XS_016	15.434	-0.32	+0.11	+2.43	-2.87	0.00	-0.01
SLO_XS_015	15.435	-0.32	+0.12	+2.45	-2.87	0.00	0.00
SLO_XS_014	15.434	-0.32	+0.14	+2.47	-2.86	0.00	0.00
SLO_XS_013	15.435	-0.34	+0.14	+2.47	-2.86	0.00	0.00
SLO_XS012U	15.435	-0.34	+0.16	+2.54	-2.86	0.00	0.00

Cross Section	Baseline	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS012D	19.478	-0.18	+0.11	+3.58	-3.63	0.00	0.00
SLO_XS_011	19.49	-0.21	+0.14	+3.48	-3.61	0.00	+0.02
SLO_XS_010	19.497	-0.21	+0.14	+3.50	-3.62	-0.01	+0.01
SLO_XS_009	19.498	-0.20	+0.14	+3.51	-3.61	-0.02	-0.01
SLO_XSD008	20.077	-0.20	+0.18	+3.73	-3.78	0.00	+0.02
SLO_XS_007	20.768	-0.20	+0.20	+4.07	-3.93	-0.03	-0.01
SLO_XS_006	21.386	-0.16	+0.23	+4.32	-4.07	-0.03	-0.01
SLO_XS_005	21.378	-0.23	+0.25	+4.40	-4.06	-0.03	0.00
SLO_XS_004	21.386	-0.24	+0.25	+4.35	-4.03	-0.04	-0.03
SLO_XS_003	21.394	-0.27	+0.20	+4.45	-4.02	-0.06	-0.03
SLO_XS_002	21.346	-0.23	+0.25	+4.37	-3.98	-0.04	+0.03
SLO_XS_001	21.336	-0.24	+0.27	+4.37	-3.95	-0.03	-0.01

Table 15-7 Variation in stage for sensitivity tests (mAOD)

Cross Section	Baseline	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_062	403.812	+0.03	-0.04	+0.03	-0.04	0.00	0.00
SLO_XS_061	400.013	+0.02	-0.02	+0.34	-0.17	0.00	0.00
SLO_XS_061A	399.916	+0.00	0.00	+0.40	-0.39	0.00	0.00
SLO_XS_060A	398.676	+0.34	-0.20	+0.32	-0.21	0.00	0.00
SLO_XS_060	398.577	+0.48	-0.26	+0.51	-0.29	0.00	0.00
SLO_XS_059A	398.633	+0.48	-0.42	+0.54	-0.48	0.00	0.00
SLO_XS_058A	397.15	+0.12	-0.10	+0.15	-0.10	0.00	0.00
SLO_XS_058	397.075	+0.16	-0.09	+0.20	-0.12	0.00	0.00
SLO_XS_057	396.944	+0.20	-0.18	+0.29	-0.19	0.00	0.00
SLO_XS_057A	396.815	+0.24	-0.18	+0.38	-0.29	0.00	0.00
SLO_XS_056A	396.224	+0.08	-0.10	+0.18	-0.13	0.00	0.00
SLO_XS_056	396.132	+0.07	-0.08	+0.22	-0.15	0.00	0.00
XS_056DUMMY	396.038	+0.07	-0.06	+0.27	-0.19	0.00	0.00
SLO_XS_055	396.002	+0.06	-0.04	+0.29	-0.20	0.00	0.00
SLO_XS_055A	396.024	+0.05	-0.03	+0.28	-0.20	0.00	0.00
SLO_XS_055B	395.636	+0.06	-0.05	+0.10	-0.09	0.00	0.00
SLO_XS_054A	395.599	+0.06	-0.06	+0.12	-0.11	0.00	0.00
054copy	395.551	+0.08	-0.11	+0.13	-0.12	0.00	0.00
SLO_XS_054U	395.546	+0.08	-0.11	+0.13	-0.12	0.00	0.00
SLO_XS_054D	395.546	+0.08	-0.11	+0.13	-0.12	0.00	0.00

Cross Section	Baseline	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
XS_054Dummy	395.041	+0.07	-0.07	+0.37	-0.13	0.00	0.00
SLO_XS_053	394.78	+0.08	+0.01	+0.67	-0.53	0.00	0.00
SLO_XS_053A	394.851	+0.06	+0.01	+0.62	-0.63	0.00	0.00
SLO_XS_052C	394.646	+0.07	+0.01	+0.62	-0.80	0.00	0.00
SLO_XS_052B	394.624	+0.07	+0.01	+0.62	-0.78	0.00	0.00
052copy	394.595	+0.08	+0.01	+0.64	-0.82	0.00	0.00
SLO_XS_052A	394.595	+0.08	+0.01	+0.64	-0.82	0.00	0.00
SLO_XS_051B	393.323	-0.05	+0.00	+0.20	-0.35	0.00	0.00
SLO_XS_051A	393.315	-0.05	+0.00	+0.20	-0.35	0.00	0.00
SLO_XS_050A	391.238	+0.11	-0.13	+0.07	-0.12	0.00	0.00
SLO_XS_050	390.987	+0.10	-0.13	+0.06	-0.12	0.00	0.00
SLO_XS_049U	384.754	-0.01	+0.00	+0.04	-0.08	0.00	0.00
SLO_XS_049D	382.76	-0.01	-0.00	+0.04	-0.08	0.00	0.00
SLO_XS_048U	362.084	+0.03	-0.06	+0.05	-0.09	0.00	0.00
SLO_XS_048D	362.084	+0.03	-0.06	+0.05	-0.09	0.00	0.00
SLO_XS_047	360.928	-0.05	+0.00	+0.17	-0.40	0.00	0.00
SLO_XS_046A	360.66	-0.05	+0.01	+0.19	-0.39	0.00	0.00
SLO_XS_044A	357.139	+0.52	+0.01	+0.69	-0.37	0.00	0.00
SLO_XS_044	357.594	+0.36	+0.01	+0.42	-0.56	0.00	0.00
SLO_XS_043	357.591	+0.36	+0.02	+0.42	-0.56	0.00	0.00
SLO_XS_43A	357.58	+0.37	+0.02	+0.42	-0.56	0.00	0.00
SLO_XS_042A	355.59	+0.09	-0.12	+0.07	-0.11	0.00	0.00
SLO_XS_042	355.321	+0.08	-0.10	+0.06	-0.09	0.00	0.00
SLO_XS_041	355.118	+0.08	-0.10	+0.06	-0.10	0.00	0.00
SLO_XS_040	354.906	+0.08	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_039	354.604	+0.07	-0.10	+0.06	-0.10	0.00	0.00
SLO_XS_038	354.029	+0.07	-0.09	+0.05	-0.08	0.00	0.00
SLO_XS_037	353.721	+0.07	-0.09	+0.05	-0.08	0.00	0.00
SLO_XS_036	353.488	+0.07	-0.10	+0.06	-0.09	0.00	0.00
SLO_XS_035	353.239	+0.08	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_034	352.711	+0.09	-0.11	+0.06	-0.11	0.00	0.00
SLO_XS_033	352.508	+0.08	-0.10	+0.06	-0.09	0.00	0.00
SLO_XS_032	352.184	+0.06	-0.08	+0.04	-0.07	0.00	0.00
SLO_XS_031	351.527	+0.03	-0.04	+0.02	-0.03	0.00	0.00
SLO_XS_030	351.245	+0.03	-0.04	+0.02	-0.04	0.00	0.00
SLO_XS_029	350.879	+0.02	-0.05	+0.03	-0.04	0.00	0.00

Cross Section	Baseline	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_028	350.804	+0.02	-0.06	+0.03	-0.04	0.00	0.00
SLO_XS_027	350.678	+0.04	-0.03	+0.03	-0.04	0.00	0.00
SLO_XS_026	350.622	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_025	350.091	+0.03	-0.04	+0.04	-0.06	0.00	0.00
SLO_XS_024	349.079	+0.03	-0.04	+0.04	-0.05	0.00	0.00
SLO_XS_023	348.798	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_022	348.524	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_021	348.251	+0.04	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS_020	347.76	+0.04	-0.06	+0.04	-0.05	0.00	0.00
SLO_XS_019	347.531	+0.05	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_018	347.282	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_017	346.898	+0.04	-0.06	+0.03	-0.05	0.00	0.00
SLO_XS_016	346.476	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_015	346.163	+0.04	-0.06	+0.04	-0.05	0.00	0.00
SLO_XS_014	345.887	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_013	345.606	+0.05	-0.06	+0.05	-0.06	0.00	0.00
SLO_XS012U	345.178	+0.06	-0.06	+0.06	-0.06	0.00	0.00
SLO_XS012D	345.178	+0.06	-0.06	+0.06	-0.06	0.00	0.00
SLO_XS_011	341.325	+0.05	-0.06	+0.06	-0.06	0.00	0.00
SLO_XS_010	341.118	+0.04	-0.05	+0.05	-0.06	0.00	0.00
SLO_XS_009	340.966	+0.06	-0.03	+0.05	-0.06	0.00	0.00
SLO_XSD008	340.91	+0.06	-0.07	+0.06	-0.06	0.00	0.00
SLO_XS_007	340.888	+0.05	-0.05	+0.06	-0.07	0.00	0.00
SLO_XS_006	340.863	+0.05	-0.05	+0.06	-0.06	0.00	0.00
SLO_XS_005	340.792	+0.06	-0.07	+0.05	-0.06	+0.01	-0.01
SLO_XS_004	340.726	+0.06	-0.08	+0.06	-0.06	+0.02	-0.02
SLO_XS_003	340.686	+0.06	-0.07	+0.06	-0.06	+0.02	-0.03
SLO_XS_002	340.673	+0.06	-0.06	+0.07	-0.06	+0.03	-0.03
SLO_XS_001	340.653	+0.06	-0.07	+0.07	-0.06	+0.03	-0.04

15.4.2 Overall, the results from the 1D sections show a relatively low sensitivity to the +/-20% variation in Manning's. However, the model shows variation of approximately than -0.80 m and 0.65 m through the structure sequence in the upper reaches of the model for +20% and -20% Manning's respectively.

15.4.3 The +/-20% variation in flow results for the reach show a variation in water levels of between 0.02 m and 0.69 m for +20% and -0.03m and -0.82m for -20%.

15.4.4 A large 0.69 m and -0.56 m change in water level occurs downstream of the A9 crossing but upstream of the access road crossing as a result of a +20% and -20% change in flow respectively. These results suggest that the structure capacity is hydraulically significant and sensitive to flow variation in the watercourse. However, the impact on water levels is muted elsewhere within the catchment, specifically the lower catchment.

15.4.5 The +/-20% variation in downstream boundary water level results for the 1D or ‘in channel’ sections show no significant change. These results suggest that the model is not sensitive to a reduction in downstream water levels.

15.4.6 The variation in simulated results is shown in Figures 15.3-15.5, this displays the longitudinal change in stage across the catchment for the sensitivity tests undertaken for roughness, flow and downstream boundary.

Figure 15-3 Modelled Long Section Sensitivity Results (Global Roughness)

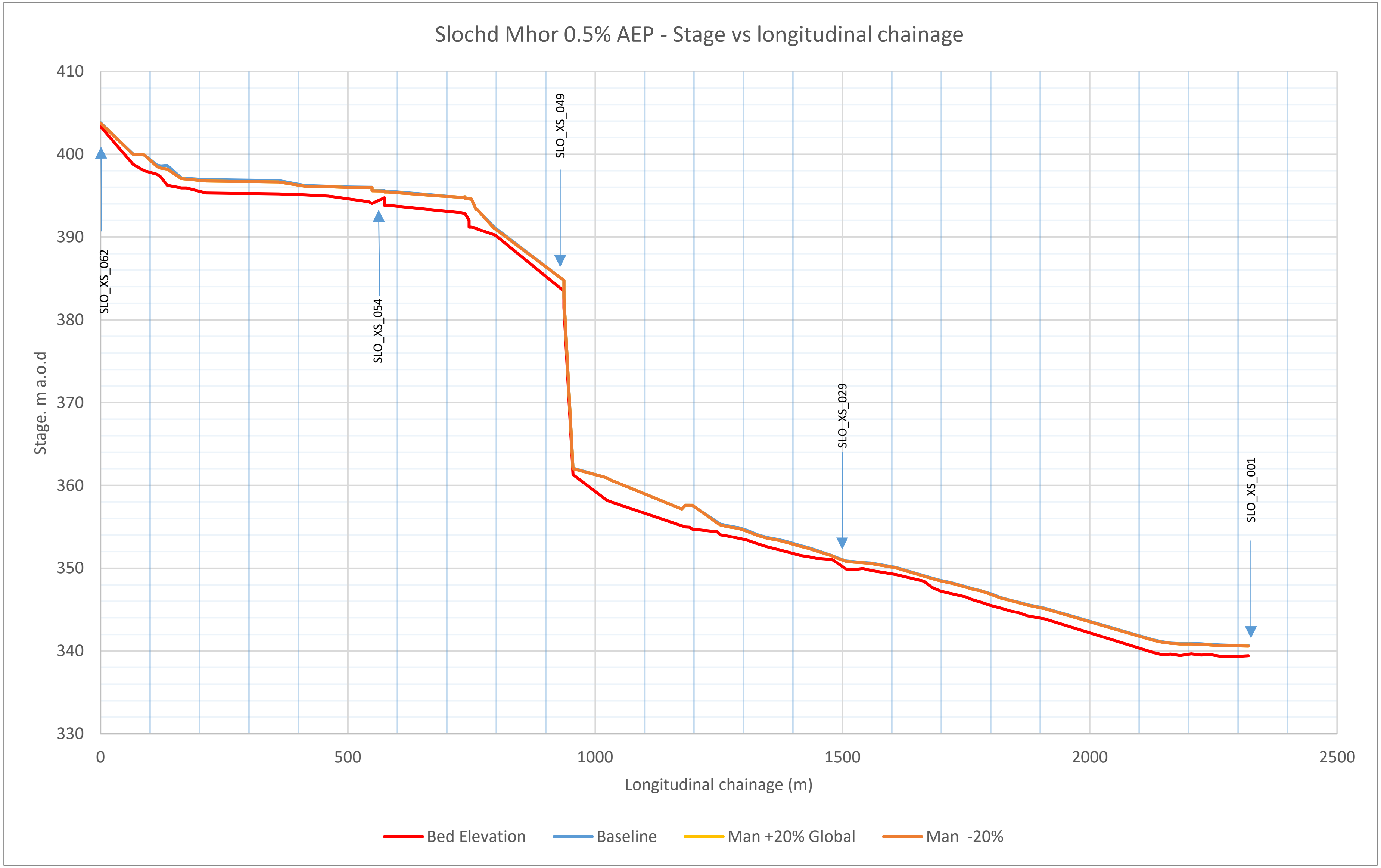


Figure 15-4 Modelled Long Section Sensitivity Results (Flow Variation)

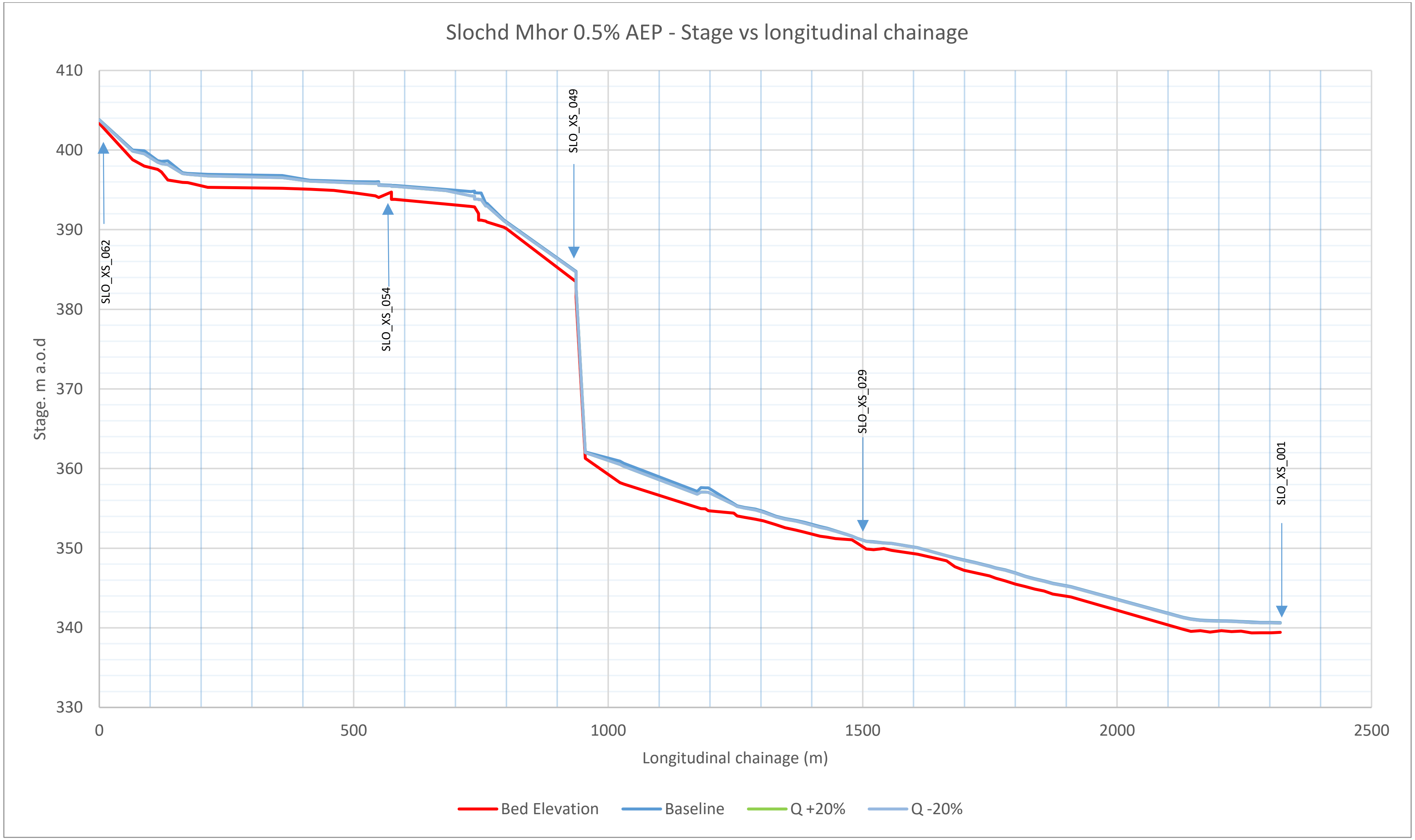
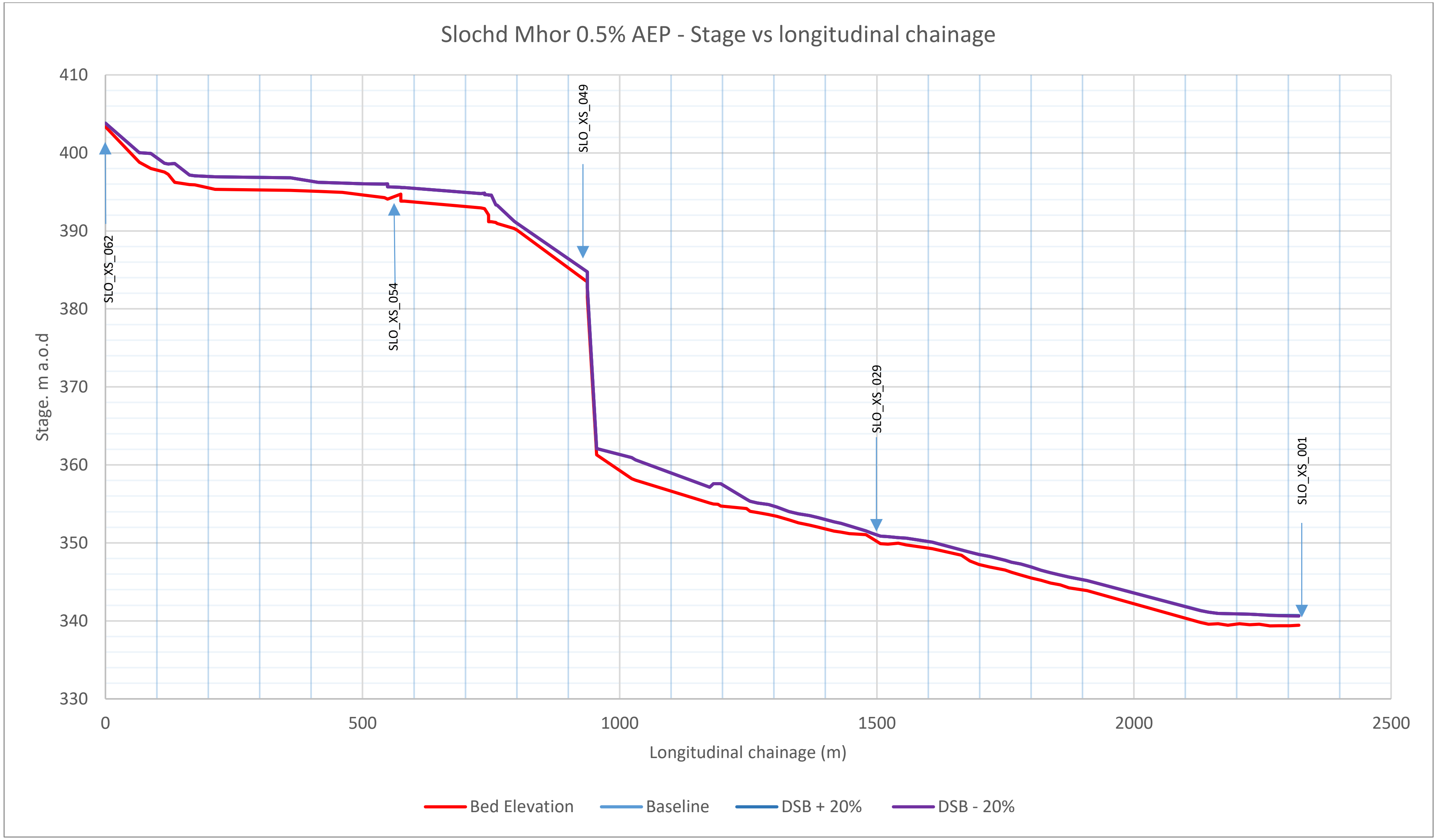


Figure 15-5 Modelled Long Section Sensitivity Results (DSB variation)



15.5 Proposed Model (with-scheme'modelling)

15.5.1 The proposed scheme modelling has been undertaking using data contained within Design Refresh 7a. Earthworks associated with the A9 scheme have resulted in a change in schematisation of the river network, this includes river realignment, infilling embankment and regrading of a cascade.

15.5.2 Proposed works which have been represented in the model are:

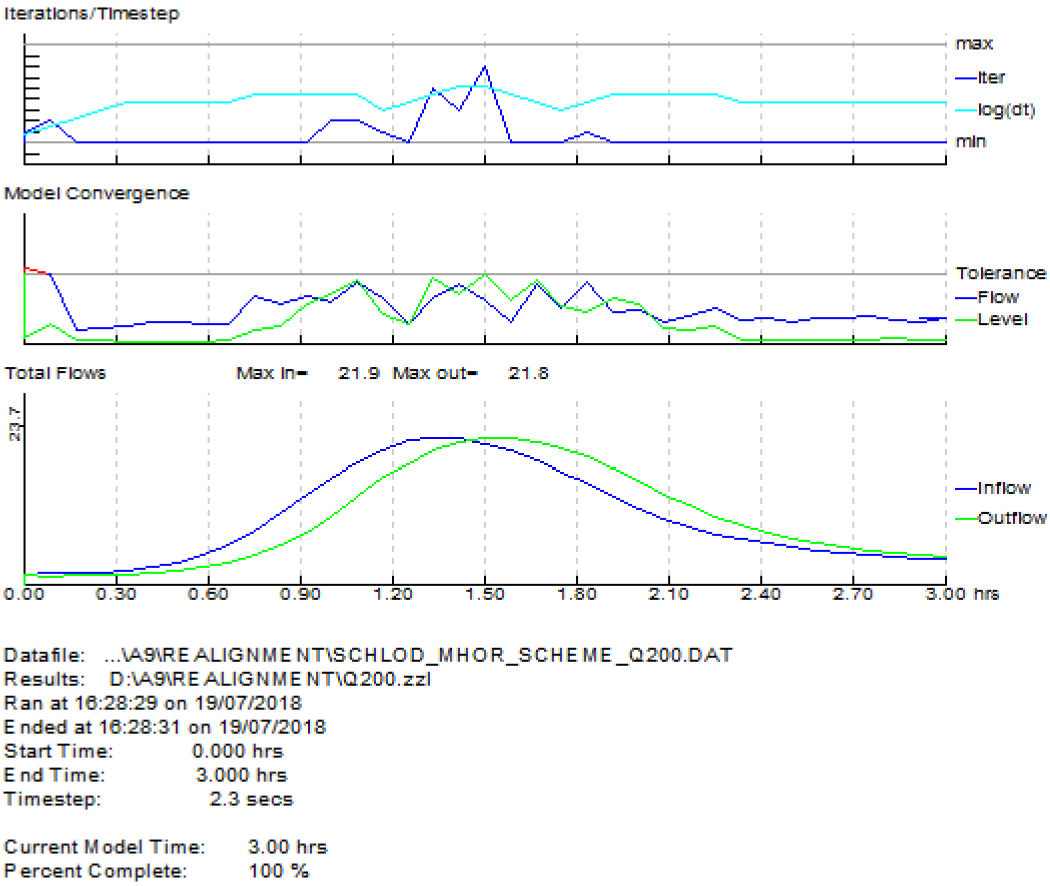
- The watercourse flows within the existing railway culvert and then forms part of a channel diversion with the watercourse proposed to flow adjacent to the railway in a 2m x 2m rectangular channel. This by-passes a sequence of existing A9 crossings with the watercourse remaining west of the current A9 footprint and ties back into the current alignment at the downstream railway culvert.
- A realignment is proposed which includes resizing of the culvert passing under the A9, the watercourse will then flow into a rock trap in a half hexagonal trapezoidal shape before flowing into a rectangular concrete channel. The watercourse will then pass back under the A9 through a culvert which includes a cycle path.
- Downstream of the cycle path culvert is a cascade, the existing ground levels include a 20m fall in elevation over a 20m reach. This has been re-graded as part of the upstream watercourse design. This has reduced the local gradient to approximately 25%. The watercourse initially maintains the slope from the upstream culvert (1%) for 40m. 60m of 25% gradient then takes the watercourse back to the original alignment.

15.5.3 Proposed levels and dimensions of culverts and watercourse design associated with the dualling of the A9 mainline are represented by including Design Refresh 7a information into Flood Modeller.

Scheme Model Performance

15.5.4 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. Over the duration of the flood event, model stability is generally good with no known periods of poor model convergence. Figure 15.6 shows model convergence for the 0.5% AEP event.

Figure 15-6 - 1D Model Convergence for the 0.5% AEP Event



Model Results Analysis

15.5.5 The following results tables provide comparisons between baseline and scheme models.

15.5.6 Table 15.8 provides maximum stage results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. In the upstream section there are cross sections for example, SLO_XS_060A, that display a significant change in level when comparing the proposed scheme arrangement to existing; however all flows are contained within the channel. The difference in levels represents the elevated realignment, which has included a change of ground levels. The location that provides a true comparison is observed downstream of the cascade where there is no change to the existing channel. The 0.5% return period comparison shows a negligible increase in water level of less than 10mm. This indicates that groundworks of the proposed realignment do not have any noticeable impact on downstream levels.

15.5.7 Table 15.9 provides peak flow results for the following AEP events: 50%, 3.33%, 1%, 0.5% and 0.5% + climate change. Peak flows vary when compared to the baseline model. Flow increases in the upper reaches, with flow increases of around 0.3 m^3/s observed for the 0.5% return period. This is due to the removal of two structures upstream causing a reduction in attenuation.

Table 15-8 1 D Model results - Baseline - Proposed Scheme Stage (mAOD) comparison across selected return periods

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
SLO_XS_062	403.85	403.85	0.00	403.81	403.81	0.00	403.78	403.78	0.00	403.74	403.74	0.00	403.63	403.63	0.00
SLO_XS_061	400.35	400.35	0.00	400.01	400.02	0.00	399.88	399.88	0.00	399.74	399.74	0.00	399.45	399.45	0.00
SLO_XS_061A	400.31	400.31	0.00	399.92	399.92	0.00	399.60	399.61	0.00	399.31	399.31	0.00	398.74	398.74	0.00
SLO_XS_060A	399.00	398.53	-0.47	398.68	398.38	-0.30	398.52	398.27	-0.24	398.35	398.13	-0.23	398.12	397.83	-0.28
SLO_XS_055A	396.31	396.59	0.28	396.02	396.06	0.03	395.88	395.90	0.02	395.67	395.69	0.01	395.30	395.31	0.00
SLO_XS_055B	395.74	395.89	0.16	395.64	395.65	0.02	395.57	395.58	0.01	395.49	395.50	0.00	395.27	395.27	0.00
SLO_XS_054A	395.72	395.89	0.17	395.60	395.62	0.02	395.52	395.53	0.01	395.42	395.42	0.00	395.20	395.20	0.00
054copy	395.68	395.87	0.19	395.55	395.57	0.02	395.47	395.48	0.01	395.34	395.35	0.01	394.99	395.00	0.01
SLO_XS_054U	395.68	395.87	0.19	395.55	395.57	0.02	395.46	395.47	0.01	395.33	395.34	0.01	394.99	394.99	0.01
SLO_XS_054D	395.68	395.87	0.19	395.55	395.57	0.02	395.46	395.47	0.01	395.33	395.34	0.01	394.99	394.99	0.01
XS_054Dummy	395.41	395.74	0.33	395.04	395.09	0.05	394.94	394.95	0.01	394.82	394.83	0.01	394.52	394.52	0.01
SLO_XS_053	395.45	395.77	0.31	394.78	394.95	0.17	394.32	394.34	0.02	393.96	393.98	0.02	393.50	393.51	0.00
SLO_XS_053A	395.48	395.78	0.31	394.85	395.00	0.15	394.34	394.36	0.02	393.89	393.92	0.02	393.24	393.24	0.00
SLO_XS_052C	395.26	395.59	0.33	394.65	394.79	0.14	394.04	394.06	0.02	393.47	393.49	0.01	393.13	393.13	0.00
SLO_XS_052B	395.25	395.58	0.33	394.62	394.76	0.14	394.02	394.03	0.02	393.41	393.42	0.01	392.93	392.94	0.01
052copy	395.24	395.57	0.33	394.60	394.74	0.14	393.96	393.98	0.01	393.26	393.09	-0.16	392.05	391.98	-0.07
SLO_XS_052A	395.24	395.57	0.33	394.60	394.74	0.14	393.96	393.98	0.01	393.25	393.09	-0.16	392.03	391.94	-0.09
SLO_XS_051B	393.52	392.74	-0.78	393.32	392.59	-0.73	393.07	392.42	-0.64	392.71	392.18	-0.53	391.93	391.61	-0.32
SLO_XS_051A	393.51	392.72	-0.79	393.32	392.57	-0.75	393.06	392.40	-0.66	392.70	392.16	-0.54	391.93	391.63	-0.30
SLO_XS_050A	391.31	391.25	-0.05	391.24	391.19	-0.05	391.15	391.11	-0.04	391.02	390.99	-0.03	390.72	390.70	-0.03
SLO_XS_43A	358.00	358.18	0.18	357.58	357.69	0.11	357.16	357.24	0.08	356.63	356.67	0.04	355.77	355.78	0.00
SLO_XS_042A	355.66	355.68	0.02	355.59	355.61	0.02	355.51	355.53	0.02	355.39	355.40	0.01	355.04	355.05	0.01

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
SLO_XS_042	355.38	355.40	0.02	355.32	355.34	0.01	355.25	355.27	0.01	355.15	355.16	0.01	354.85	354.86	0.00
SLO_XS_041	355.18	355.20	0.02	355.12	355.14	0.02	355.05	355.06	0.02	354.94	354.95	0.01	354.63	354.63	0.00
SLO_XS_040	354.97	354.99	0.02	354.91	354.92	0.02	354.83	354.85	0.02	354.71	354.72	0.01	354.38	354.38	0.00
SLO_XS_039	354.66	354.68	0.02	354.60	354.62	0.02	354.53	354.55	0.02	354.42	354.43	0.01	354.10	354.10	0.01
SLO_XS_038	354.08	354.10	0.02	354.03	354.04	0.01	353.97	353.98	0.01	353.87	353.87	0.01	353.58	353.58	0.00
SLO_XS_037	353.77	353.79	0.01	353.72	353.74	0.01	353.66	353.67	0.01	353.56	353.57	0.01	353.27	353.28	0.00
SLO_XS_036	353.54	353.56	0.02	353.49	353.50	0.01	353.42	353.44	0.01	353.32	353.33	0.01	353.00	353.01	0.00
SLO_XS_035	353.30	353.32	0.02	353.24	353.26	0.02	353.17	353.18	0.01	353.05	353.06	0.01	352.74	352.74	0.00
SLO_XS_034	352.78	352.80	0.02	352.71	352.73	0.02	352.64	352.65	0.02	352.52	352.53	0.01	352.21	352.22	0.00
SLO_XS_033	352.57	352.59	0.02	352.51	352.52	0.02	352.44	352.45	0.01	352.33	352.34	0.01	352.05	352.05	0.00
SLO_XS_032	352.23	352.24	0.01	352.18	352.20	0.01	352.13	352.14	0.01	352.05	352.06	0.01	351.84	351.84	0.00
SLO_XS_031	351.55	351.56	0.01	351.53	351.53	0.01	351.50	351.51	0.00	351.46	351.47	0.00	351.37	351.37	0.00
SLO_XS_030	351.27	351.27	0.01	351.25	351.25	0.00	351.22	351.22	0.00	351.18	351.18	0.00	351.08	351.08	0.00
SLO_XS_029	350.91	350.91	0.01	350.88	350.89	0.01	350.85	350.85	0.01	350.80	350.81	0.00	350.69	350.69	0.00
SLO_XS_028	350.83	350.84	0.01	350.80	350.81	0.01	350.77	350.78	0.01	350.73	350.73	0.00	350.61	350.61	0.00
SLO_XS_027	350.71	350.72	0.01	350.68	350.69	0.01	350.65	350.65	0.01	350.60	350.61	0.00	350.49	350.49	0.00
SLO_XS_026	350.66	350.67	0.01	350.62	350.63	0.01	350.58	350.59	0.01	350.53	350.53	0.01	350.38	350.37	-0.01
SLO_XS_025	350.13	350.14	0.01	350.09	350.10	0.01	350.05	350.06	0.01	349.99	350.00	0.00	349.82	349.82	-0.01
SLO_XS_024	349.12	349.12	0.01	349.08	349.09	0.01	349.05	349.05	0.01	349.00	349.00	0.00	348.86	348.85	-0.01
SLO_XS_023	348.84	348.84	0.01	348.80	348.81	0.01	348.77	348.77	0.01	348.72	348.72	0.00	348.50	348.49	-0.01
SLO_XS_022	348.56	348.57	0.01	348.52	348.53	0.01	348.49	348.50	0.01	348.43	348.44	0.01	348.22	348.21	-0.01
SLO_XS_021	348.29	348.29	0.01	348.25	348.26	0.01	348.21	348.22	0.01	348.14	348.15	0.01	347.97	347.96	-0.01
SLO_XS_020	347.80	347.81	0.01	347.76	347.77	0.01	347.72	347.73	0.01	347.66	347.67	0.01	347.52	347.51	-0.01

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
SLO_XS_019	347.57	347.58	0.01	347.53	347.54	0.01	347.50	347.50	0.01	347.44	347.45	0.01	347.31	347.30	-0.01
SLO_XS_018	347.32	347.33	0.01	347.28	347.29	0.01	347.25	347.25	0.01	347.20	347.20	0.01	347.05	347.04	-0.01
SLO_XS_017	346.93	346.94	0.01	346.90	346.91	0.01	346.86	346.87	0.01	346.80	346.81	0.01	346.65	346.64	-0.01
SLO_XS_016	346.52	346.52	0.01	346.48	346.48	0.01	346.44	346.45	0.01	346.38	346.39	0.01	346.23	346.21	-0.01
SLO_XS_015	346.20	346.21	0.01	346.16	346.17	0.01	346.12	346.13	0.01	346.07	346.07	0.00	345.93	345.92	-0.01
SLO_XS_014	345.93	345.93	0.01	345.89	345.90	0.01	345.85	345.86	0.01	345.79	345.80	0.01	345.65	345.63	-0.01
SLO_XS_013	345.65	345.66	0.01	345.61	345.62	0.01	345.56	345.57	0.01	345.50	345.51	0.01	345.34	345.32	-0.02
SLO_XS012U	345.24	345.24	0.00	345.18	345.18	0.00	345.13	345.14	0.00	345.07	345.07	0.00	344.91	344.89	-0.02
SLO_XS012D	345.24	345.24	0.00	345.18	345.18	0.00	345.13	345.14	0.00	345.07	345.07	0.00	344.91	344.89	-0.02
SLO_XS_011	341.38	341.38	0.00	341.33	341.33	0.00	341.28	341.28	0.00	341.21	341.21	0.00	341.03	341.00	-0.02
SLO_XS_010	341.17	341.17	0.00	341.12	341.12	0.00	341.08	341.08	0.00	341.01	341.01	0.00	340.85	340.83	-0.02
SLO_XS_009	341.02	341.02	0.00	340.97	340.97	0.00	340.93	340.93	0.00	340.87	340.87	0.00	340.76	340.75	-0.01
SLO_XSD008	340.97	340.96	-0.01	340.91	340.92	0.01	340.87	340.87	0.00	340.80	340.80	0.00	340.64	340.63	-0.01
SLO_XS_007	340.95	340.94	-0.01	340.89	340.89	0.01	340.84	340.85	0.00	340.77	340.77	0.00	340.59	340.58	0.00
SLO_XS_006	340.92	340.91	-0.01	340.86	340.87	0.01	340.82	340.82	0.00	340.75	340.75	0.00	340.57	340.56	-0.01
SLO_XS_005	340.84	340.84	0.00	340.79	340.80	0.01	340.75	340.75	0.00	340.68	340.69	0.00	340.50	340.50	0.00
SLO_XS_004	340.79	340.78	-0.01	340.73	340.73	0.01	340.68	340.69	0.00	340.61	340.62	0.00	340.42	340.42	-0.01
SLO_XS_003	340.75	340.74	-0.01	340.69	340.69	0.01	340.64	340.65	0.00	340.57	340.58	0.00	340.38	340.37	-0.01
SLO_XS_002	340.74	340.73	0.00	340.67	340.68	0.01	340.63	340.63	0.00	340.56	340.56	0.00	340.35	340.34	-0.01
SLO_XS_001	340.72	340.71	-0.01	340.65	340.66	0.01	340.61	340.61	0.00	340.54	340.54	0.00	340.33	340.32	-0.01

Table 15-9 1D model results- Baseline- Proposed scheme flow (m3/s) comparison across select return periods

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
SLO_XS_062	6.32	6.32	0.00	5.27	5.27	0.00	4.47	4.47	0.00	3.46	3.46	0.00	1.54	1.54	0.00
SLO_XS_061	6.32	6.32	0.00	5.27	5.27	0.00	4.48	4.48	0.00	3.47	3.47	0.00	1.53	1.54	0.01
SLO_XS_061A	6.30	6.30	0.00	5.27	5.28	0.01	4.49	4.49	0.00	3.47	3.47	-0.01	1.53	1.54	0.01
SLO_XS_060A	6.30	6.30	0.00	5.27	5.28	0.01	4.49	4.49	0.01	3.48	3.47	-0.01	1.53	1.54	0.01
SLO_XS_055A	5.83	6.19	0.35	5.12	5.27	0.15	4.39	4.49	0.09	3.41	3.48	0.07	1.53	1.55	0.02
SLO_XS_055B	5.83	6.19	0.35	5.12	5.27	0.15	4.39	4.49	0.09	3.41	3.48	0.07	1.53	1.55	0.02
SLO_XS_054A	5.84	6.12	0.28	5.13	5.26	0.13	4.40	4.48	0.08	3.41	3.48	0.06	1.53	1.54	0.02
054copy	5.84	6.12	0.28	5.13	5.26	0.13	4.40	4.48	0.08	3.41	3.48	0.06	1.53	1.54	0.02
SLO_XS_054U	5.86	6.11	0.25	5.13	5.26	0.12	4.40	4.48	0.08	3.42	3.48	0.06	1.53	1.54	0.02
SLO_XS_054D	9.68	10.33	0.65	8.53	8.82	0.29	7.29	7.51	0.22	5.68	5.82	0.14	2.54	2.58	0.04
XS_054Dummy	9.56	10.00	0.44	8.51	8.78	0.27	7.30	7.49	0.19	5.69	5.81	0.12	2.54	2.58	0.04
SLO_XS_053	9.39	9.82	0.43	8.43	8.67	0.24	7.29	7.48	0.20	5.69	5.81	0.12	2.54	2.57	0.04
SLO_XS_053A	9.40	9.80	0.40	8.43	8.66	0.23	7.29	7.48	0.19	5.69	5.81	0.12	2.54	2.57	0.03
SLO_XS_052C	9.40	9.80	0.40	8.43	8.66	0.23	7.29	7.48	0.19	5.69	5.81	0.12	2.54	2.57	0.03
SLO_XS_052B	9.40	9.78	0.38	8.43	8.65	0.22	7.28	7.46	0.18	5.69	5.81	0.12	2.54	2.57	0.03
052copy	9.40	9.78	0.38	8.43	8.65	0.22	7.28	7.46	0.18	5.69	5.81	0.12	2.54	2.57	0.03
SLO_XS_052A	9.33	9.76	0.43	8.43	8.64	0.21	7.27	7.46	0.19	5.68	5.80	0.12	2.53	2.57	0.04
SLO_XS_051B	9.33	9.76	0.43	8.43	8.64	0.21	7.27	7.46	0.19	5.68	5.80	0.12	2.53	2.57	0.04
SLO_XS_051A	9.33	9.76	0.43	8.43	8.64	0.21	7.27	7.46	0.19	5.68	5.80	0.12	2.53	2.57	0.04
SLO_XS_050A	9.33	9.76	0.42	8.43	8.64	0.21	7.27	7.47	0.19	5.68	5.80	0.11	2.54	2.57	0.03
SLO_XS_43A	11.21	11.68	0.47	10.02	10.34	0.32	8.66	8.94	0.28	6.77	6.94	0.16	3.06	3.08	0.02
SLO_XS_042A	11.21	11.68	0.47	10.02	10.34	0.32	8.66	8.94	0.28	6.77	6.94	0.17	3.04	3.08	0.04
SLO_XS_042	11.21	11.68	0.47	10.02	10.34	0.32	8.66	8.94	0.28	6.77	6.94	0.17	3.03	3.08	0.05
SLO_XS_041	11.22	11.68	0.46	10.02	10.34	0.32	8.66	8.94	0.28	6.77	6.94	0.17	3.04	3.08	0.04
SLO_XS_040	11.22	11.68	0.46	10.02	10.35	0.33	8.66	8.94	0.29	6.77	6.94	0.17	3.04	3.08	0.04

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
SLO_XS_039	11.22	11.68	0.45	10.01	10.35	0.34	8.66	8.94	0.28	6.78	6.94	0.16	3.04	3.08	0.03
SLO_XS_038	11.23	11.68	0.44	10.01	10.35	0.34	8.66	8.94	0.28	6.77	6.94	0.17	3.04	3.08	0.04
SLO_XS_037	11.24	11.68	0.44	10.01	10.35	0.34	8.66	8.94	0.28	6.78	6.94	0.16	3.05	3.08	0.03
SLO_XS_036	11.24	11.67	0.43	10.01	10.36	0.34	8.65	8.94	0.28	6.78	6.94	0.16	3.05	3.08	0.03
SLO_XS_035	11.25	11.67	0.42	10.01	10.36	0.35	8.66	8.94	0.28	6.77	6.94	0.17	3.05	3.08	0.03
SLO_XS_034	11.26	11.67	0.41	10.01	10.36	0.35	8.66	8.93	0.28	6.77	6.94	0.17	3.05	3.08	0.03
SLO_XS_033	11.25	11.67	0.42	10.02	10.36	0.34	8.66	8.93	0.28	6.77	6.94	0.17	3.05	3.08	0.03
SLO_XS_032	11.25	11.67	0.42	10.02	10.36	0.34	8.66	8.93	0.27	6.77	6.94	0.17	3.05	3.08	0.03
SLO_XS_031	11.26	11.67	0.41	10.03	10.36	0.33	8.67	8.93	0.26	6.77	6.94	0.17	3.07	3.07	0.00
SLO_XS_030	11.28	11.67	0.39	10.02	10.36	0.33	8.67	8.93	0.25	6.77	6.94	0.17	3.08	3.07	0.00
SLO_XS_029	11.28	11.66	0.39	10.03	10.35	0.33	8.67	8.92	0.25	6.77	6.94	0.18	3.10	3.07	-0.03
SLO_XS_028	11.29	11.67	0.38	10.03	10.35	0.31	8.69	8.92	0.23	6.77	6.94	0.17	3.14	3.07	-0.07
SLO_XS_027	11.27	11.66	0.39	10.03	10.33	0.30	8.69	8.92	0.23	6.78	6.93	0.15	3.13	3.07	-0.07
SLO_XS_026	11.35	11.67	0.32	10.03	10.32	0.29	8.72	8.94	0.22	6.79	6.94	0.14	3.18	3.07	-0.11
SLO_XS_025	15.33	15.78	0.46	13.33	13.84	0.51	11.50	11.92	0.42	9.03	9.27	0.24	4.30	4.10	-0.20
SLO_XS_024	16.49	16.98	0.50	14.31	14.82	0.52	12.32	12.77	0.45	9.68	9.93	0.25	4.55	4.39	-0.16
SLO_XS_023	17.78	18.36	0.58	15.41	15.96	0.55	13.30	13.75	0.45	10.46	10.69	0.23	4.95	4.73	-0.22
SLO_XS_022	17.78	18.36	0.58	15.39	15.95	0.56	13.29	13.75	0.45	10.45	10.69	0.24	4.97	4.73	-0.24
SLO_XS_021	17.85	18.36	0.52	15.40	15.94	0.54	13.30	13.74	0.44	10.42	10.69	0.27	4.99	4.73	-0.26
SLO_XS_020	17.81	18.36	0.55	15.43	15.94	0.51	13.30	13.74	0.44	10.40	10.69	0.30	5.00	4.73	-0.27
SLO_XS_019	17.81	18.35	0.54	15.42	15.93	0.51	13.30	13.74	0.43	10.40	10.69	0.29	5.01	4.73	-0.28
SLO_XS_018	17.85	18.36	0.50	15.42	15.93	0.50	13.31	13.73	0.43	10.41	10.69	0.28	5.02	4.73	-0.29
SLO_XS_017	17.85	18.36	0.51	15.42	15.92	0.50	13.32	13.73	0.41	10.41	10.69	0.28	5.03	4.73	-0.30
SLO_XS_016	17.87	18.36	0.49	15.43	15.92	0.48	13.33	13.72	0.40	10.40	10.68	0.28	5.04	4.73	-0.31
SLO_XS_015	17.88	18.35	0.47	15.44	15.91	0.48	13.33	13.72	0.39	10.40	10.68	0.28	5.05	4.73	-0.33
SLO_XS_014	17.90	18.34	0.44	15.43	15.91	0.47	13.33	13.71	0.38	10.40	10.68	0.27	5.04	4.73	-0.32

Cross-section	Q200+CC			Q200			Q100			Q30			Q2		
	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff	BL	Scheme	Diff
SLO_XS_013	17.91	18.34	0.43	15.44	15.90	0.46	13.34	13.71	0.37	10.41	10.67	0.26	5.07	4.72	-0.34
SLO_XS012U	17.97	18.32	0.35	15.44	15.88	0.45	13.34	13.69	0.35	10.42	10.66	0.24	5.08	4.72	-0.36
SLO_XS012D	23.05	22.95	-0.10	19.48	19.76	0.28	16.79	17.04	0.26	13.10	13.18	0.08	6.34	5.88	-0.46
SLO_XS_011	22.97	22.92	-0.06	19.49	19.77	0.28	16.83	17.00	0.17	13.13	13.18	0.05	6.46	5.87	-0.59
SLO_XS_010	22.99	22.92	-0.07	19.50	19.76	0.27	16.83	17.00	0.16	13.13	13.18	0.05	6.47	5.87	-0.60
SLO_XS_009	23.01	22.92	-0.09	19.50	19.77	0.27	16.83	16.99	0.16	13.14	13.18	0.04	6.49	5.87	-0.62
SLO_XSD008	23.81	23.67	-0.13	20.08	20.41	0.33	17.36	17.52	0.16	13.57	13.60	0.03	6.49	6.05	-0.45
SLO_XS_007	24.84	24.57	-0.27	20.77	21.16	0.39	17.95	18.15	0.19	14.05	14.10	0.04	6.59	6.26	-0.33
SLO_XS_006	25.71	25.37	-0.33	21.39	21.83	0.44	18.50	18.71	0.21	14.53	14.54	0.00	6.55	6.45	-0.10
SLO_XS_005	25.78	25.36	-0.41	21.38	21.82	0.44	18.48	18.71	0.22	14.46	14.53	0.07	6.60	6.45	-0.15
SLO_XS_004	25.73	25.36	-0.38	21.39	21.81	0.42	18.45	18.67	0.23	14.46	14.53	0.07	6.60	6.45	-0.15
SLO_XS_003	25.85	25.35	-0.50	21.39	21.80	0.40	18.43	18.66	0.23	14.44	14.52	0.07	6.61	6.45	-0.16
SLO_XS_002	25.71	25.34	-0.38	21.35	21.78	0.43	18.39	18.63	0.24	14.41	14.51	0.10	6.61	6.45	-0.16
SLO_XS_001	25.70	25.32	-0.38	21.34	21.76	0.43	18.41	18.65	0.24	14.35	14.49	0.14	6.67	6.45	-0.22

Sensitivity Analysis

15.5.8 Sensitivity analysis was undertaken for proposed scheme modelling using the same test scenarios as baseline modelling. The results have been compared against the scheme results, these are shown in Table 15.10 and 15.11. Figure 15.7 to 15.9 shows variation within the modelled long section.

15.5.9 Overall, the results from the 1D sections show a relatively low sensitivity to the +/-20% variation in Manning's. However, the model shows variation of approximately than 0.41 m at the bottom of the cascade before the watercourse enters the railway culvert.

15.5.10 The +/- 20% variation in flow results for the reach show a variation in water levels of between 0.04m and 0.81 m for +20% and -0.04m and -1.02m for -20%.

15.5.11 The largest change in water level occurs upstream of the A9 crossing as a result of a +20% and -20% change in flow respectively. These results suggest that the structure capacity is hydraulically significant and sensitive to flow variation in the watercourse. However, the impact on water levels is muted elsewhere within the catchment, specifically the lower catchment.

15.5.12 The +/-20% variation in downstream boundary water level results for the 1D or 'in channel' sections show no significant change. These results suggest that the model is not sensitive to a reduction in downstream water levels.

15.5.13 The variation in simulated results is shown in Figures 15.7-15.9, this displays the longitudinal change in stage across the catchment for the sensitivity tests undertaken for roughness, flow and downstream boundary.

Table 15-10 - Variation in stage for sensitivity tests (m AOD) - Proposed Scheme

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_062	403.81	+0.04	-0.04	+0.04	-0.04	0.00	0.00
SLO_XS_061	400.015	+0.02	-0.02	+0.34	-0.17	0.00	0.00
SLO_XS_061A	399.919	0.00	0.00	+0.39	-0.39	0.00	0.00
SLO_XS_060A	398.378	+0.14	-0.15	+0.15	-0.14	0.00	0.00
SLO_XS_055A	396.055	+0.14	-0.04	+0.53	-0.21	0.00	0.00
SLO_XS_055B	395.652	+0.07	-0.06	+0.24	-0.09	0.00	0.00
SLO_XS_054A	395.618	+0.08	-0.07	+0.27	-0.12	0.00	0.00
054copy	395.571	+0.09	-0.11	+0.30	-0.12	0.00	0.00
SLO_XS_054U	395.566	+0.09	-0.11	+0.30	-0.12	0.00	0.00
SLO_XS_054D	395.566	+0.09	-0.11	+0.30	-0.12	0.00	0.00
XS_054Dummy	395.09	+0.06	-0.07	+0.65	-0.17	0.00	0.00
SLO_XS_053	394.947	0.00	-0.01	+0.82	-0.68	0.00	0.00
SLO_XS_053A	394.997	0.00	-0.01	+0.78	-0.75	0.00	0.00
SLO_XS_052C	394.785	0.00	-0.01	+0.80	-0.99	0.00	0.00
SLO_XS_052B	394.764	0.00	-0.01	+0.81	-0.96	0.00	0.00
052copy	394.74	0.00	-0.01	+0.83	-1.02	0.00	0.00
SLO_XS_052A	394.739	0.00	-0.01	+0.83	-1.02	0.00	0.00
SLO_XS_051B	392.588	0.00	0.00	+0.15	-0.23	0.00	0.00

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_051A	392.568	0.00	0.00	+0.15	-0.23	0.00	0.00
SLO_XS_050A	391.187	+0.14	-0.14	+0.07	-0.11	0.00	0.00
SLO_XS_048U	385.817	+0.08	-0.08	+0.06	-0.08	0.00	0.00
SLO_XS_048D	380.443	-0.00	0.00	+0.05	-0.23	0.00	0.00
SLO_XS_044B	378.745	+0.13	-0.16	+0.09	-0.14	0.00	0.00
XS1_44	378.484	+0.14	-0.16	+0.09	-0.14	0.00	0.00
XS2_441	378.187	+0.14	-0.16	+0.10	-0.15	0.00	0.00
XS3_441	377.874	+0.16	-0.18	+0.11	-0.16	0.00	0.00
XS4_441	377.052	+0.16	-0.19	+0.12	-0.17	0.00	0.00
XS5_441	375.949	+0.13	-0.16	+0.09	-0.14	0.00	0.00
XS6_44	373.687	+0.12	-0.12	+0.08	-0.11	0.00	0.00
XS7_44	370.623	+0.14	-0.14	+0.09	-0.13	0.00	0.00
XS8_44	368.195	+0.14	-0.13	+0.09	-0.13	0.00	0.00
XS9_44	365.716	+0.14	-0.15	+0.09	-0.13	0.00	0.00
XS10_44	363.331	+0.14	-0.13	+0.09	-0.13	0.00	0.00
XS11_44	360.782	+0.14	-0.14	+0.09	-0.12	0.00	0.00
XS12_44	358.617	+0.20	-0.14	+0.15	-0.20	0.00	0.00
XS13_44	357.778	+0.28	-0.03	+0.25	-0.46	0.00	0.00
XS14_44	357.692	+0.51	-0.00	+0.49	-0.58	0.00	0.00
SLO_XS_43A	357.687	+0.51	0.00	+0.49	-0.60	0.00	0.00
SLO_XS_042A	355.609	+0.11	-0.12	+0.07	-0.11	0.00	0.00
SLO_XS_042	355.336	+0.09	-0.10	+0.06	-0.09	0.00	0.00
SLO_XS_041	355.135	+0.09	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_040	354.924	+0.09	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_039	354.619	+0.09	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_038	354.044	+0.08	-0.09	+0.05	-0.09	0.00	0.00
SLO_XS_037	353.736	+0.08	-0.09	+0.05	-0.09	0.00	0.00
SLO_XS_036	353.503	+0.09	-0.10	+0.06	-0.09	0.00	0.00
SLO_XS_035	353.257	+0.09	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_034	352.729	+0.10	-0.12	+0.07	-0.11	0.00	0.00
SLO_XS_033	352.524	+0.09	-0.11	+0.06	-0.10	0.00	0.00
SLO_XS_032	352.196	+0.07	-0.08	+0.05	-0.07	0.00	0.00
SLO_XS_031	351.533	+0.03	-0.04	+0.02	-0.04	0.00	0.00
SLO_XS_030	351.25	+0.03	-0.04	+0.02	-0.04	0.00	0.00
SLO_XS_029	350.887	+0.02	-0.05	+0.02	-0.05	0.00	0.00
SLO_XS_028	350.812	+0.03	-0.07	+0.02	-0.05	0.00	0.00
SLO_XS_027	350.686	+0.05	-0.03	+0.03	-0.04	0.00	0.00

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_026	350.633	+0.04	-0.05	+0.04	-0.06	0.00	0.00
SLO_XS_025	350.1	+0.03	-0.04	+0.04	-0.06	0.00	0.00
SLO_XS_024	349.087	+0.04	-0.04	+0.04	-0.05	0.00	0.00
SLO_XS_023	348.807	+0.04	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_022	348.532	+0.05	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_021	348.258	+0.05	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS_020	347.769	+0.05	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS_019	347.539	+0.05	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_018	347.29	+0.05	-0.05	+0.04	-0.05	0.00	0.00
SLO_XS_017	346.905	+0.04	-0.06	+0.03	-0.06	0.00	0.00
SLO_XS_016	346.484	+0.05	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS_015	346.17	+0.05	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS_014	345.895	+0.05	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS_013	345.615	+0.06	-0.06	+0.04	-0.06	0.00	0.00
SLO_XS012U	345.183	+0.06	-0.07	+0.05	-0.06	0.00	0.00
SLO_XS012D	345.183	+0.06	-0.07	+0.05	-0.06	0.00	0.00
SLO_XS_011	341.329	+0.06	-0.07	+0.05	-0.07	0.00	0.00
SLO_XS_010	341.122	+0.04	-0.05	+0.05	-0.06	0.00	0.00
SLO_XS_009	340.971	+0.06	-0.03	+0.05	-0.06	0.00	0.00
SLO_XSD008	340.916	+0.06	-0.07	+0.05	-0.06	0.00	0.00
SLO_XS_007	340.894	+0.05	-0.06	+0.05	-0.07	0.00	0.00
SLO_XS_006	340.869	+0.05	-0.05	+0.04	-0.07	0.00	0.00
SLO_XS_005	340.797	+0.06	-0.07	+0.04	-0.06	-0.01	+0.01
SLO_XS_004	340.732	+0.07	-0.09	+0.05	-0.07	-0.02	+0.02
SLO_XS_003	340.692	+0.07	-0.08	+0.05	-0.07	-0.03	+0.02
SLO_XS_002	340.679	+0.06	-0.07	+0.06	-0.07	-0.03	+0.03
SLO_XS_001	340.659	+0.06	-0.07	+0.05	-0.07	-0.03	+0.03

Table 15-11 Variation in flow for sensitivity tests (m^3/s) - Proposed Scheme

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_062	5.266	0.00	0.00	+1.05	-1.05	0.00	0.00
SLO_XS_061	5.273	0.00	0.00	+1.05	-1.06	0.00	0.00
SLO_XS_061A	5.28	0.00	0.00	+1.02	-1.06	0.00	0.00
SLO_XS_060A	5.28	+0.01	0.00	+1.02	-1.05	0.00	0.00
SLO_XS_055A	5.267	-0.02	0.00	+0.92	-1.03	0.00	0.00

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_055B	5.267	-0.02	0.00	+0.92	-1.03	0.00	0.00
SLO_XS_054A	5.258	-0.01	0.00	+0.87	-1.03	0.00	0.00
054copy	5.258	-0.01	0.00	+0.87	-1.03	0.00	0.00
SLO_XS_054U	5.256	-0.01	0.00	+0.85	-1.03	0.00	0.00
SLO_XS_054D	8.818	-0.02	0.00	+1.51	-1.74	0.00	0.00
XS_054Dummy	8.775	-0.01	-0.01	+1.22	-1.71	0.00	0.00
SLO_XS_053	8.67	+0.01	-0.02	+1.15	-1.62	0.00	0.00
SLO_XS_053A	8.659	+0.01	-0.01	+1.14	-1.61	0.00	0.00
SLO_XS_052C	8.659	+0.01	-0.01	+1.14	-1.61	0.00	0.00
SLO_XS_052B	8.648	+0.01	-0.01	+1.13	-1.61	0.00	0.00
052copy	8.648	+0.01	-0.01	+1.13	-1.61	0.00	0.00
SLO_XS_052A	8.637	0.00	-0.01	+1.12	-1.62	0.00	0.00
SLO_XS_051B	8.637	0.00	-0.01	+1.12	-1.62	0.00	0.00
SLO_XS_051A	8.636	0.00	-0.01	+1.12	-1.62	0.00	0.00
SLO_XS_050A	8.635	-0.01	-0.01	+1.12	-1.61	0.00	0.00
SLO_XS_048U	8.629	-0.03	0.00	+1.12	-1.60	0.00	0.00
SLO_XS_048D	10.317	-0.04	-0.01	+1.35	-1.91	0.00	-0.01
SLO_XS_044B	10.315	+0.04	0.00	+1.36	-1.88	0.00	0.00
XS1_44	10.314	+0.05	0.00	+1.36	-1.88	0.00	0.00
XS2_441	10.315	+0.06	0.00	+1.36	-1.88	0.00	0.00
XS3_441	10.316	+0.06	-0.01	+1.36	-1.88	0.00	-0.01
XS4_441	10.315	+0.07	0.00	+1.36	-1.88	0.00	0.00
XS5_441	10.311	+0.08	0.00	+1.36	-1.88	+0.01	0.00
XS6_44	10.305	+0.09	+0.01	+1.37	-1.87	+0.03	+0.01
XS7_44	10.308	+0.09	+0.01	+1.37	-1.87	+0.02	0.00
XS8_44	10.308	+0.09	+0.01	+1.37	-1.87	+0.02	0.00
XS9_44	10.312	+0.09	0.00	+1.37	-1.88	0.00	0.00
XS10_44	10.317	+0.09	0.00	+1.36	-1.88	-0.01	-0.01
XS11_44	10.319	+0.09	-0.01	+1.36	-1.88	-0.01	-0.01
XS12_44	10.32	+0.09	-0.01	+1.36	-1.88	-0.01	-0.01
XS13_44	10.322	+0.08	0.00	+1.36	-1.89	-0.01	-0.01
XS14_44	10.329	+0.05	0.00	+1.35	-1.89	-0.01	-0.01
SLO_XS_43A	10.335	+0.03	0.00	+1.34	-1.90	0.00	0.00
SLO_XS_042A	10.339	+0.02	0.00	+1.34	-1.90	0.00	0.00
SLO_XS_042	10.34	+0.02	0.00	+1.34	-1.90	0.00	0.00
SLO_XS_041	10.343	+0.01	0.00	+1.33	-1.91	0.00	0.00
SLO_XS_040	10.348	-0.01	0.00	+1.33	-1.91	0.00	0.00

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_039	10.35	-0.02	0.00	+1.33	-1.92	0.00	0.00
SLO_XS_038	10.352	-0.03	0.00	+1.32	-1.92	0.00	0.00
SLO_XS_037	10.354	-0.04	0.00	+1.32	-1.92	0.00	0.00
SLO_XS_036	10.357	-0.05	0.00	+1.32	-1.93	0.00	0.00
SLO_XS_035	10.358	-0.04	0.00	+1.31	-1.93	0.00	0.00
SLO_XS_034	10.359	-0.04	0.00	+1.31	-1.94	0.00	0.00
SLO_XS_033	10.359	-0.04	0.00	+1.31	-1.94	0.00	+0.01
SLO_XS_032	10.359	-0.04	+0.01	+1.31	-1.94	0.00	+0.01
SLO_XS_031	10.358	-0.04	+0.01	+1.31	-1.94	0.00	+0.01
SLO_XS_030	10.356	-0.04	+0.01	+1.31	-1.95	0.00	+0.01
SLO_XS_029	10.353	-0.03	+0.02	+1.31	-1.95	0.00	+0.01
SLO_XS_028	10.346	-0.02	+0.02	+1.32	-1.95	0.00	+0.01
SLO_XS_027	10.33	-0.00	+0.03	+1.33	-1.95	0.00	+0.01
SLO_XS_026	10.318	+0.02	+0.04	+1.35	-1.94	+0.01	+0.01
SLO_XS_025	13.838	-0.14	+0.05	+1.95	-2.65	0.00	-0.00
SLO_XS_024	14.82	-0.12	+0.06	+2.16	-2.85	+0.00	-0.01
SLO_XS_023	15.959	-0.12	+0.07	+2.41	-3.08	+0.01	0.00
SLO_XS_022	15.952	-0.11	+0.07	+2.41	-3.08	0.00	-0.01
SLO_XS_021	15.944	-0.11	+0.07	+2.42	-3.09	0.00	-0.01
SLO_XS_020	15.935	-0.11	+0.07	+2.42	-3.09	0.00	0.00
SLO_XS_019	15.932	-0.10	+0.07	+2.42	-3.10	0.00	-0.01
SLO_XS_018	15.927	-0.10	+0.07	+2.43	-3.10	0.00	0.00
SLO_XS_017	15.922	-0.10	+0.06	+2.44	-3.11	0.00	0.00
SLO_XS_016	15.915	-0.10	+0.07	+2.44	-3.12	+0.01	0.00
SLO_XS_015	15.91	-0.09	+0.07	+2.44	-3.11	+0.01	0.00
SLO_XS_014	15.905	-0.08	+0.06	+2.44	-3.09	+0.01	0.00
SLO_XS_013	15.899	-0.07	+0.07	+2.44	-3.08	+0.01	0.00
SLO_XS012U	15.882	-0.05	+0.07	+2.44	-3.06	+0.01	0.00
SLO_XS012D	19.759	+0.01	-0.01	+3.19	-3.78	+0.02	0.00
SLO_XS_011	19.765	-0.04	-0.01	+3.15	-3.80	+0.01	0.00
SLO_XS_010	19.764	-0.03	0.00	+3.16	-3.80	+0.01	0.00
SLO_XS_009	19.765	-0.02	0.00	+3.16	-3.80	0.00	0.00
SLO_XSD008	20.406	-0.06	0.00	+3.27	-3.93	0.00	0.00
SLO_XS_007	21.159	-0.11	+0.01	+3.41	-4.10	0.00	0.00
SLO_XS_006	21.826	-0.13	+0.01	+3.55	-4.25	0.00	0.00
SLO_XS_005	21.816	-0.13	+0.02	+3.55	-4.26	+0.01	0.00
SLO_XS_004	21.808	-0.12	+0.03	+3.55	-4.27	+0.01	-0.01

Cross Section	Proposed Scheme	Man +20% Global	Man - 20% Global	Q +20%	Q - 20%	DSB + 20% XSO2	DSB - 20% XSO2
SLO_XS_003	21.798	-0.10	+0.04	+3.55	-4.28	+0.01	-0.01
SLO_XS_002	21.778	-0.06	+0.05	+3.56	-4.29	+0.01	-0.02
SLO_XS_001	21.762	-0.04	+0.06	+3.56	-4.27	+0.01	-0.02

Figure 15-7 Modelling Long Section Sensitivity Results (DSB Variation)

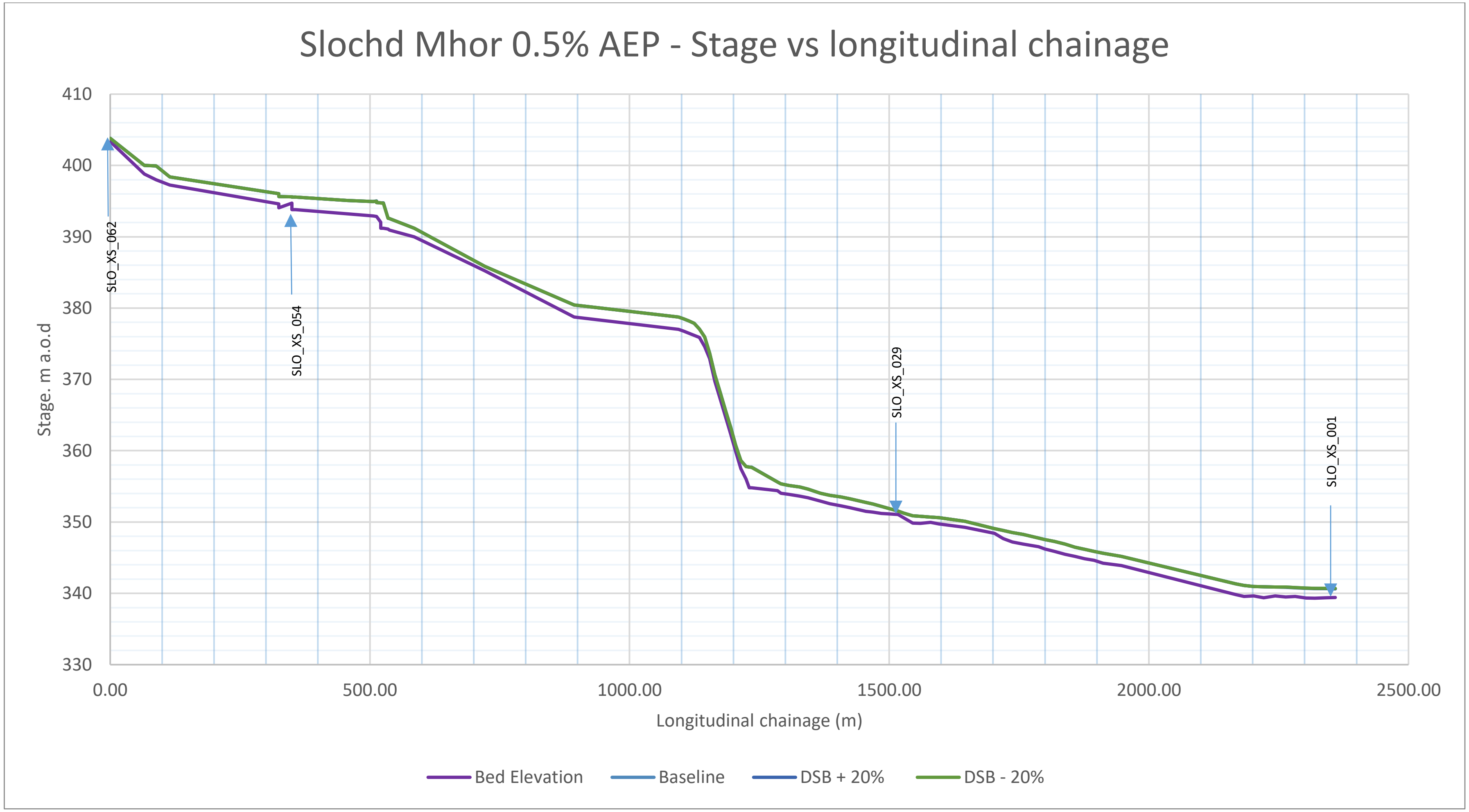


Figure 15-8 Modelled Long Section Sensitivity Results (Flow variation)

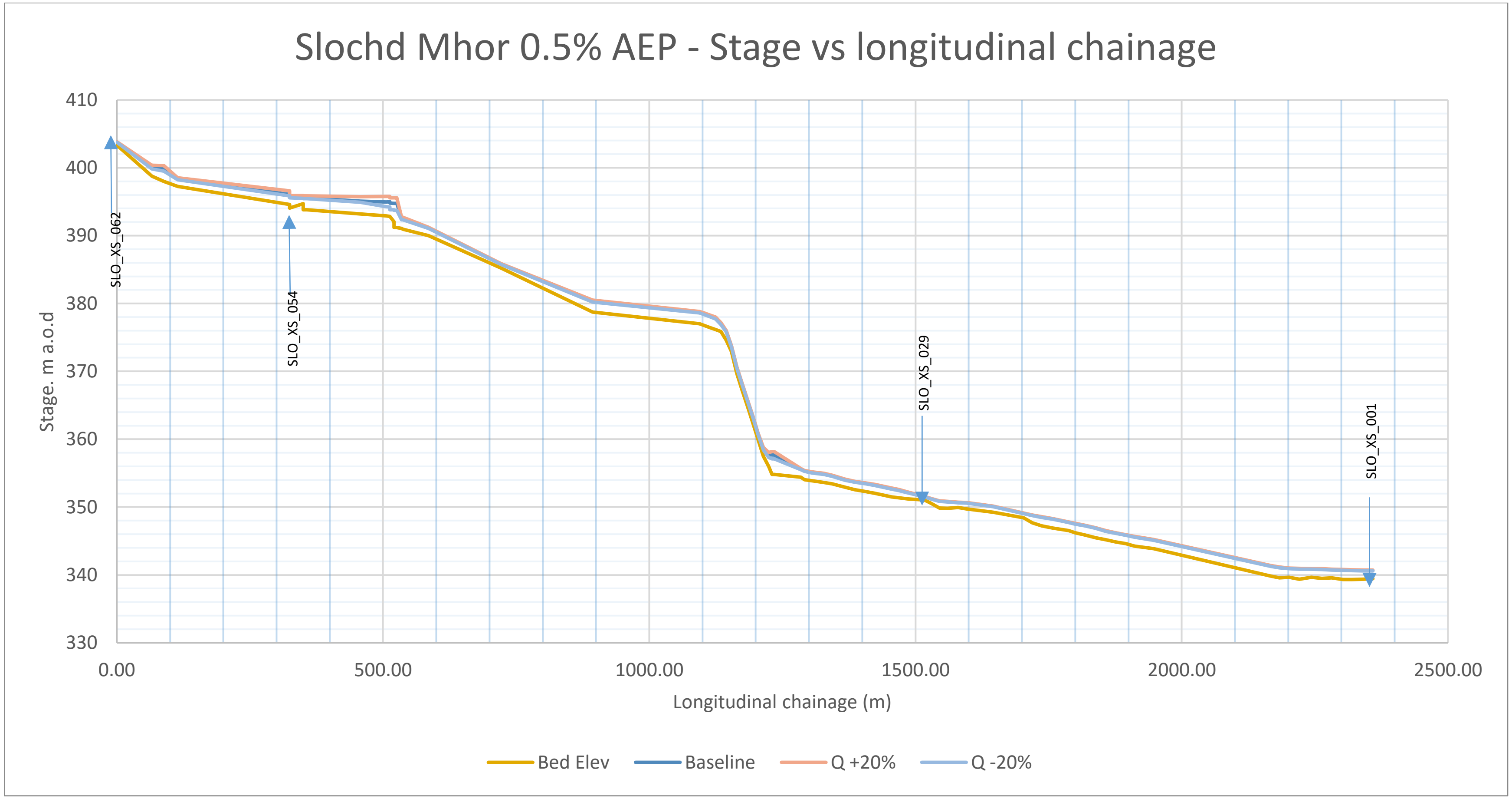
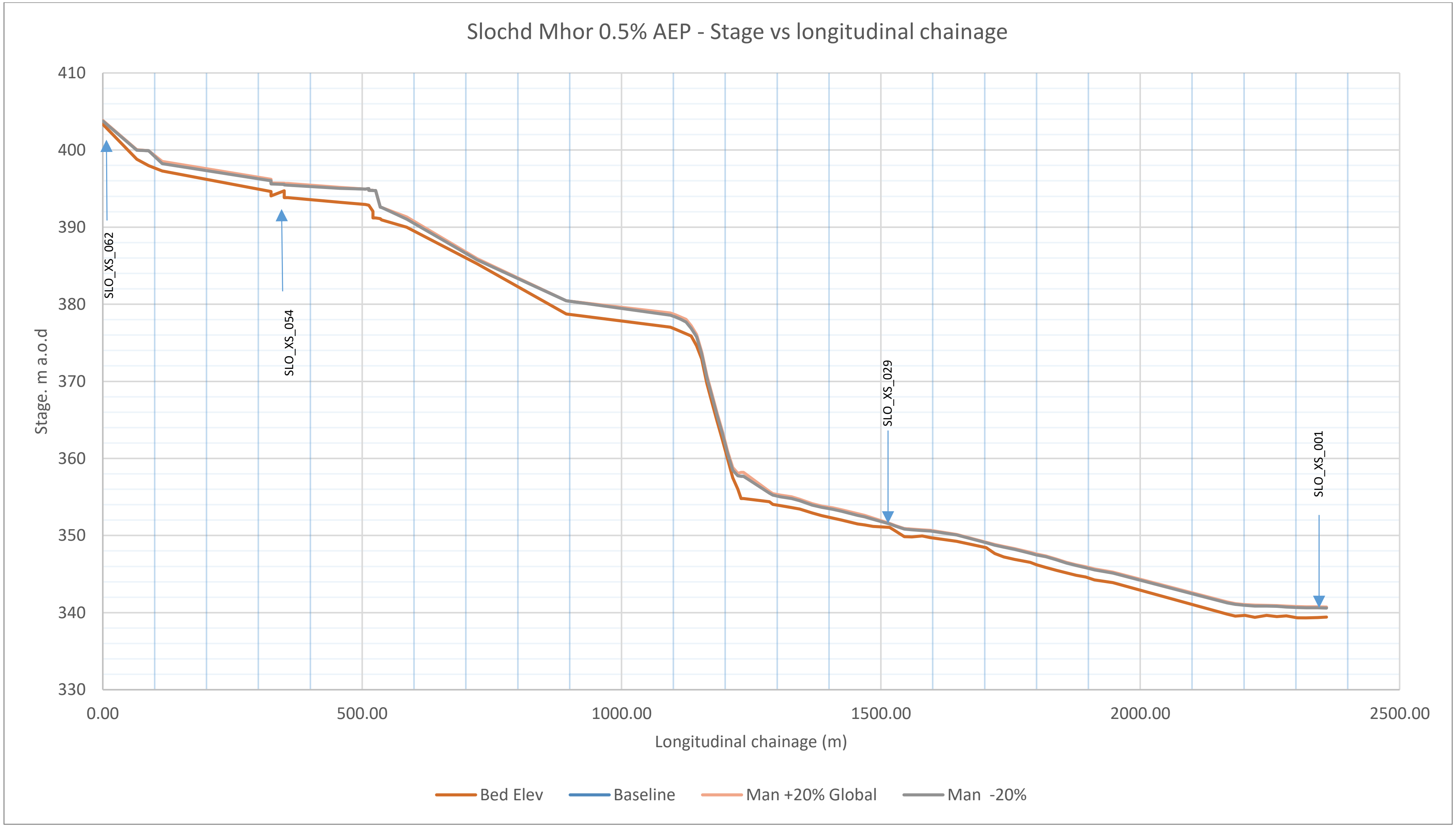


Figure 15-9 Modelled Long Section Sensitivity Results (Mannings variation)



15.6 Summary

15.6.1 The Slochd Mhor hydraulic model has been developed using a 1D ISIS Flood Modeller model, and includes the reach of the Slochd Mhor from source, upstream of the A9, and stretches 2.3km downstream.

15.6.2 The purpose of the Schlod Mhor hydraulic model was to support the design of the river diversion works and cascade.

15.6.3 The baseline model includes a series of existing A9 crossings as well as crossings of the adjacent railways alignment. There is no flood risk to the existing A9 or other receptors.

15.6.4 The proposed scheme modelling has been undertaking using data contained within Design Refresh 7a, including changes to the dimensions and design of the watercourse, this includes a realignment, resizing of culvert and regrading of cascade.

15.6.5 Results show there is an increase in water level as a result of the realignment of the Slochd watercourse which is associated with the change in ground level caused by the realignment and therefore does not provide a true comparison. All flows for the 0.5% AEP plus climate change remain within the new realigned channel.

15.6.6 The location that provides a true comparison is observed downstream of the cascade where there is no change to the existing channel. The 0.5% return period comparison shows a negligible increase in water level of less than10mm within a low sensitivity receptor. This indicates that groundworks of the proposed realignment do not have any noticeable impact on downstream levels.