A9.2: Flood Risk

1 Introduction

1.1.1 This appendix provides additional information relating to the flood risk impacts associated with the proposed A9 Dualling (Luncarty to Pass of Birnam) scheme, as reported in Chapter 9 (Road Drainage and the Water Environment).

1.1.2 As part of the consent application for the proposed scheme (Luncarty to Pass of Birnam) an Environmental Statement is required, including a Flood Risk Assessment. This appendix presents the Flood Risk Assessment for the A9 Dualling Luncarty to Pass of Birnam scheme.

1.1.3 The source of potential fluvial flooding local to the proposed scheme is from three principal watercourses, namely, Shochie Burn, Ordie Burn and Garry Burn together with a number of other minor watercourses, most of which drain into these three principal watercourses.

1.1.4 In particular, the Flood Risk Assessment has assessed the impact of the proposed scheme at the following locations:

- A9 crossing of the Shochie Burn (culvert extension).
- A9 crossing of the Ordie Burn (culvert extension).
- Ordie Burn at Newmill Junction (extension of the road embankment onto the functional flood plain).
- Garry Burn at Bankfoot Junction (extension of the road embankment onto the functional flood plain).

1.1.5 In addition to the above principal locations, an assessment of the impact on flood risk has also been undertaken at the minor watercourse crossings.

1.1.6 At each principal location, the assessment provides a commentary on the 'Proposed Works'; 'Impact on Flood Risk'; 'Climate Change Impact' and 'Proposed Mitigation / Flood Management Measures'.

1.1.7 The Flood Risk Assessment has been prepared with cognisance to 'Scottish Planning Policy' (February 2010) report and 'Technical Flood Risk Guidance for Stakeholders' SEPA (September 2013) report. As discussed with SEPA (27 January 2014), the philosophy adopted with regards to flood risk and flood risk management is as follows:

> ***'Where the propose scheme results in the loss of functional floodplain, the provision of upstream mitigation measures[1] will be considered, but where this is not possible due to either environmental, engineering or economic reasons or combination thereof, further justification will be provided. The impact on downstream flood risk will remain neutral'.***

[1] Mitigation Measures shall include the provision of compensatory storage as defined by Technical Flood Risk Guidance for Stakeholders, SEPA (September 2013) i.e. providing the same volume at the same level to that volume lost by development.

1.1.8 This report shall be read explicitly in conjunction with the Hydraulic Modelling Report, Final, February 2014 (Annex A) and also Appendix A9.1 (Surface Water Hydrology) of the Environmental Statement.

2 Estimation of Design Peak Flows

The locations of all 19 river crossings, including the catchment areas of the Shochie Burn, Ordie Burn, Garry Burn and other minor watercourses are shown on Figure 9.2 of the ES a copy of which is provided below as Figure 1 of this appendix. A fuller description of each watercourse can be found in ES Chapter 9 (Road Drainage and the Water Environment).

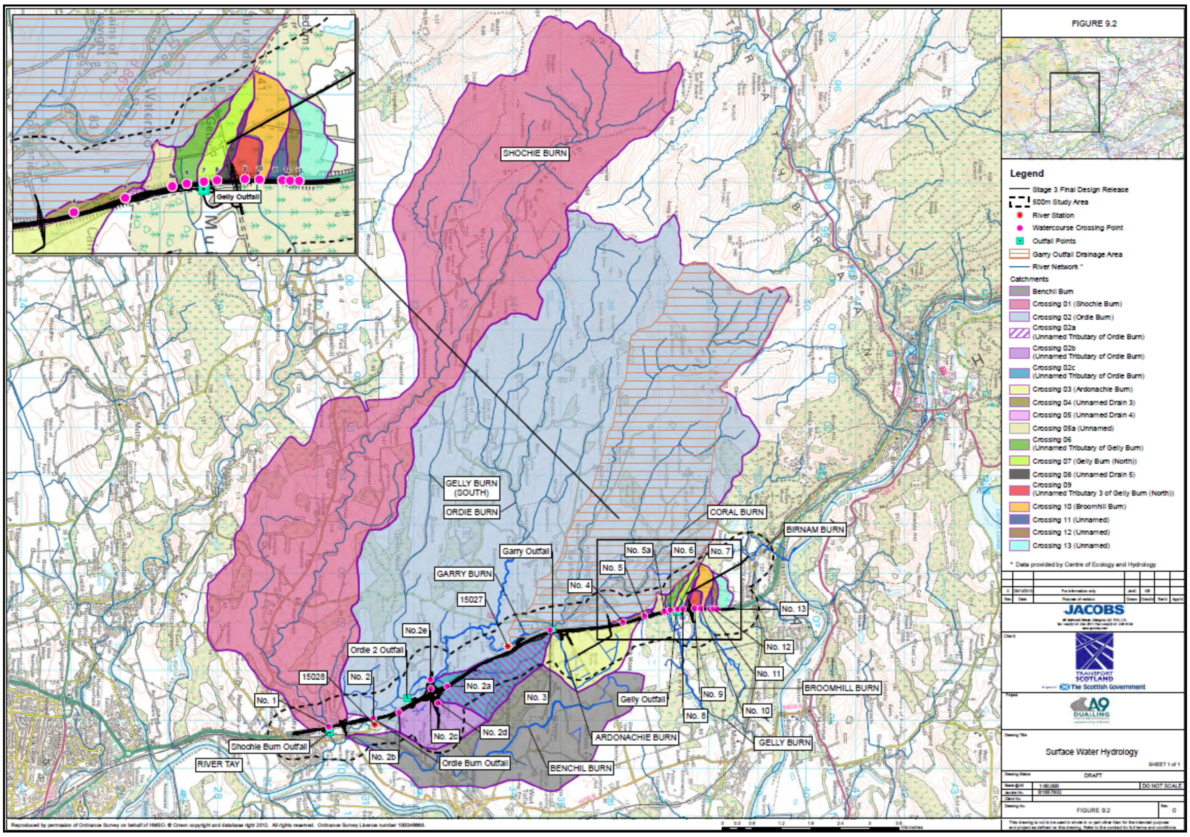

Figure 1: Location of the 19 watercourse crossings and contributing catchments

2.1.1 A detailed account of the methodology adopted to estimate the design peak flow for each of the impacted watercourses is given in the ES, Appendix A9.1 (Surface Water Hydrology), and is summarised below.

2.1.2 The design flows have been estimated using the industry standard Flood Estimation Handbook (FEH) pooling group methodology. This involves the estimation of the index flood (QMED) from FEH catchment descriptors; refinement of QMED using data transfers from local donor gauging stations where appropriate; estimation of flood growth curves using the FEH pooling group method; and finally the multiplication of the refined index flood by the appropriate growth factors to provide estimates of the design peak flow for each watercourse.

2.1.3 In addition, assessment of the catchment boundaries of those watercourses impacted by the proposed scheme have been based on delineation, using the 1m level contour derived from LiDAR imagery, together with further cross reference made using: watercourse observation from areal imagery; photographic evidence of flow and channels geometry matched to catchment areas; and watercourse mapping given on the SEPA 1:10,000 scale RBMP interactive map.

2.1.4 The predicted peak flow associated with the 0.5% AEP (1:200) design event for the Shochie Burn, Ordie Burn and Garry Burn at the Loakmill Gauging Station (15027) are presented in Table 1.

2.1.5 In accordance with DEFRA research (DEFRA, 2006), SEPA recommends that the impact of climate change is also considered by increasing the design peak flow by an additional 20% to reflect the predicted future impact of climate change on river flows.

Table 1: Design flood flows for the Shochie Burn, Ordie Burn, and the Garry Burn for both current and future scenarios.

AEP (Return Period)	Shochie Burn, A9 crossing (m^3/s)		Ordie Burn, A9 culvert (m^3/s)		Ordie Burn, Newmill culvert (m^3/s)		Garry Burn, Loakmill (m^3/s)	
	Present	Climate Change	Present	Climate Change	Present	Climate Change	Present	Climate Change
50% (1:2)	18.7	22.4	20.3	24.4	17.0	20.4	7.9	9.5
20% (1:5)	24.8	29.8	29.0	34.8	24.3	29.2	10.9	13.1
10% (1:10)	28.9	35.9	35.5	42.6	29.8	35.8	13.2	15.8
4% (1:25)	34.6	41.5	45.1	54.1	37.8	45.4	16.7	20.0
3.3% (1:30)	35.8	43.0	47.3	56.8	39.7	47.6	17.5	21.0
2% (1:50)	39.2	47.0	53.6	64.3	44.9	53.9	19.9	23.8
1% (1:100)	44.3	53.2	63.1	75.6	52.9	63.5	23.6	28.3
0.5% (1:200)	49.8	59.8	74.5	89.4	62.5	75.0	28.1	33.7
0.2% (1:500)	57.9	69.5	92.2	111.0	77.3	92.8	35.4	30.4

2.1.6 The predicted 0.5% AEP (1:200) plus climate change design event peak flows for the other minor watercourse crossings, are presented in Table A1 (Annex A).

2.1.7 The design event adopted for the proposed scheme is the predicted 0.5% AEP (1:200) peak flow.

2.1.8 In addition, the impact associated with the predicted 0.5% AEP (1:200) peak flow plus a 20% allowance to reflect the predicted future impact of climate change on peak river flow has also been assessed.

3 Mathematical Hydraulic Modelling of the Shochie Burn, Ordie Burn and Garry Burn

3.1 General

3.1.1 A fuller account of the hydraulic numerical modelling is given in the Hydraulic Modelling Report, (Final), February 2014 (Annex B), and is summarised below.

3.1.2 A 1-D hydraulic numerical model has been constructed to represent the Shochie Burn, Ordie Burn and Garry Burn impacted by the proposed scheme. The model has been extended sufficiently downstream to limit boundary effects on the model results at the point of interest.

3.1.3 The purpose of the numerical modelling is to predict the peak water level within the modelled river reach associated with the existing and design scenarios for the 0.5% AEP (1:200) design event and 0.5% AEP (1:200) plus climate change design event.

3.2 Model Construction

3.2.1 The 1-D hydraulic model of the Shochie Burn, Ordie Burn and Garry Burn (Figure 2) has been constructed using ISIS V3.6 river modelling software.

3.2.2 The model has been constructed as follows:

- The numerical model has been constructed based on surveyed cross sections of each watercourse within the modelled river reach.
- The hydraulic roughness coefficient (Manning's 'n') has been based on site photographs and with reference to standard guidance (refer to Hydraulic Modelling Report, Annex B).
- The river crossings have been represented using ISIS bridge units, culvert conduit sections, and orifice units, as considered appropriate.
- Floodplain storage has been modelled using ISIS 'reservoir units'. Where possible 'reservoir unit' geometry has been based on surveyed ground topography, supplemented with LIDAR derived digital terrain model data.
- All lateral and inline flood water spill profiles have been obtained from surveyed ground topography.
- A 1.5km reach of un-surveyed Ordie Burn watercourse between its confluence with the Garry Burn and 'Newmill' floodplain area was modelled using interpolated cross sections.

3.2.3 A 'normal depth' boundary unit, based on the upstream channel gradient has been applied as the downstream boundary for each model. This assumes a 'free flowing' condition at the downstream boundary.

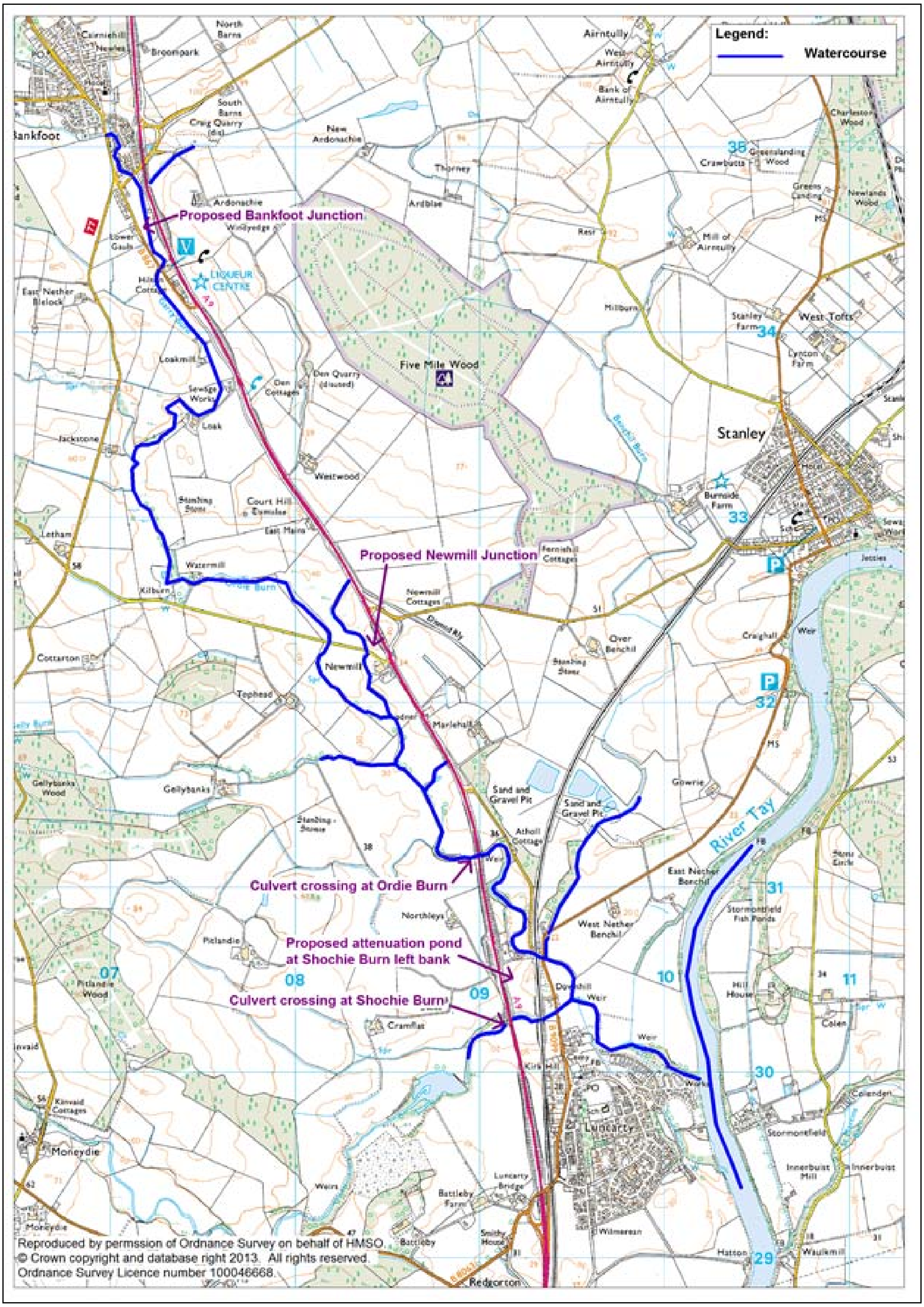

Figure 2: Study area with key scheme design features

3.3 Numerical Model Limitations

3.3.1 The following numerical model limitations should be noted.

- The numerical model is a 1-D ISIS model with floodplain areas represented as reservoir units. The representation of the watercourse and floodplain in 1-D is deemed to be appropriate for the study catchment as there does not appear to be any complex interactions between 'in-bank' and 'out-of-bank' flows and no complex flow splits within the floodplain, based on inspection of topographical survey plans.
- The Shochie Burn, Ordie Burn and Garry Burn model has not been quantitatively verified against gauge data. This is due to the lack of gauge data for the Shochie Burn and given the suspect quality of the high flow data associated with the Ordie Burn gauge at Luncarty (Station 15028, Ordie Burn). Although the quality of the high flow data for the Garry Burn gauge (Station 15027) is of a relatively good quality, it is considered that calibrating the Garry Burn model alone would not be advantageous to the calibration of the Ordie Burn and Shochie Burn models. In lieu of model calibration, sensitivity analysis of the principal model parameters (including roughness coefficient) has been undertaken.
- The results of the modelling are interpreted in the context of inherent modelling inaccuracies. On this basis, it is considered reasonable to interpret model results showing a change in water level of less than 10mm between the existing and design scenarios as being negligible.

3.3.2 The data from which the model is built, and the nature of the approach taken in its construction, are considered to be appropriate for producing a model which is sufficiently reliable for the purpose of assessing the impact of the proposed scheme on predicted water level within the modelled river reach.

4 Flood Risk

4.1 Introduction

4.1.1 The following sections provide an assessment of the flood risk at the following locations:

- A9 crossing of the Shochie Burn culvert.
- A9 crossing of the Ordie Burn culvert.
- Ordie Burn at Newmill.
- Garry Burn at Bankfoot.
- Crossing on other minor watercourses.

4.2 A9 Crossing of the Shochie Burn

<u>Proposed Works</u>

4.2.1 To accommodate widening of the A9 road corridor, the existing Shochie Burn A9 culvert will be extended upstream.

4.2.2 The existing culvert comprises a twin barrel box culvert (each barrel being 4.5m wide and 2.5m high) and 46m in length. This existing culvert will be retained and extended with a new culvert upstream by 20.6m. The extended culvert section will be formed with concrete side walls, concrete soffit (roof) and a natural bed underlain with a concrete base slab. The new culvert will be a single barrel of rectangular shape with opening dimensions of 9.5m wide by 2.5m high. The total length of the new A9 Shochie Burn culvert will be 66.6m.

Impact on Flooding

4.2.3 The predicted water level for the pre- and post-development condition at the 0.5% AEP (1:200) design event is presented in Table 2.

Table 2: Shochie Burn predicted water level for the 0.5% AEP (1:200) design event for both the existing and design scenarios.

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP (1:200), mAOD	Design Scenario 0.5% AEP (1:200), mAOD	Difference (m)
Upstream of A9 Culvert	SB_Sec2	19.768	19.735	-0.033
Downstream of A9 Culvert	A9_BC_D	19.130	19.130	0.000
At Ordie Burn confluence	SB_Sec9DS	17.073	17.069	-0.004

Note – a psotive value denotes an increase in water level, a negative value denotes a decrease in water level.

4.2.4 The modelling results presented in Table 2 suggest that proposed culvert extension will result in lower water level immediately upstream of the culvert i.e. 33 mm for the 0.5% AEP (1:200) flood event. This lower water level is attributed to improved culvert performance arising from the change to the hydraulic controls associated with introducing the new culvert (e.g. its shape and being a single barrel, dimensions, material, and improved inlet design reducing head losses).

4.2.5 The impact on the pass forward flow and predicted downstream water level for the 0.5% AEP (1:200) flood event is neutral.

4.2.6 The predicted flood extent envelop for the Shochie Burn local to the A9 Shochie Burn culvert is presented on Figure 3.

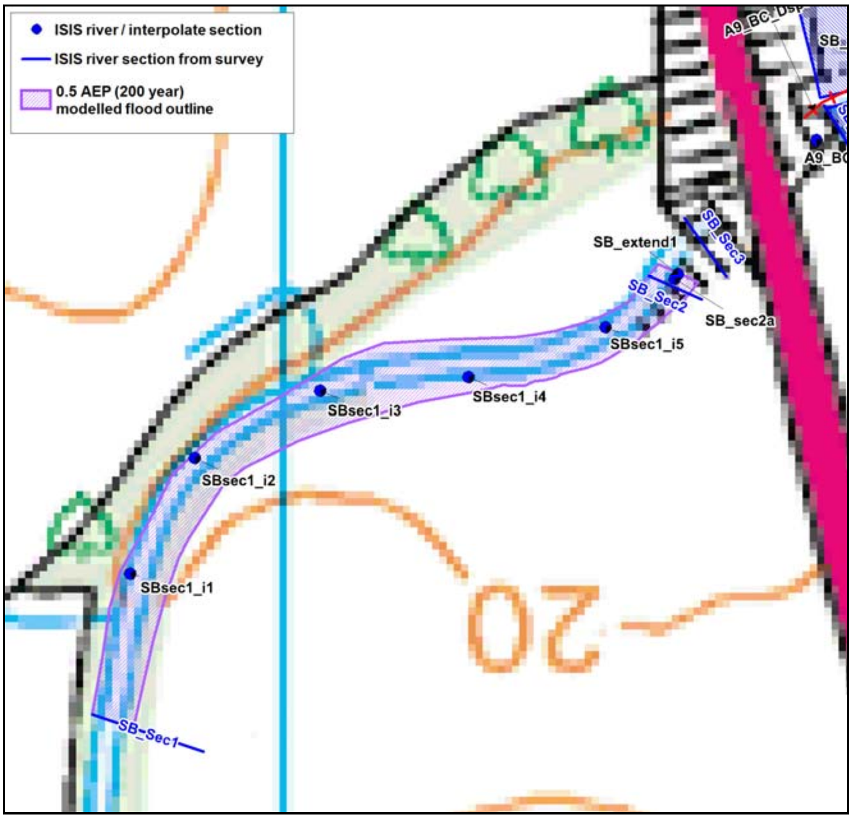

Figure 3 – Plan view: Shochie Burn model schematisation and modelled flood plain within vicinity of A9 crossing culvert. NB: There is no discernable change to the floodplain. Refer to the modelling report for further information.

Climate Change Impact

4.2.7 The predicted water level for the pre- and post-development scenario for the design 0.5% AEP (1:200) event including a 20% allowance for climate change is presented in Table 3.

Table 3: Predicted water levels along the Shochie Burn for the design 0.5% AEP (1:200) plus climate change event for the existing and design scenarios.

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP +CC event, mAOD	Design Scenario 0.5% AEP+CC event, mAOD	Difference (m)
Upstream of A9 Culvert	SB_Sec2	20.241	20.204	-0.037
Downstream of A9 Culvert	A9_BC_D	19.416	19.416	0.000
At Ordie Burn confluence	SB_Sec9DS	17.177	17.163	-0.014

Note: a positive value denotes an increase in water level, a negative value denotes a decrease in water level.

4.2.8 Climate change impact will result in water levels rising. For the design case the impact on the upstream water level is 436mm and a similar magnitude of increase is predicted downstream (refer to Figure 4).

4.2.9 Comparing the climate change impact for the existing and design scenarios as presented in Table 3 suggests that the proposed scheme will have a neutral impact on predicted water level both upstream and downstream.

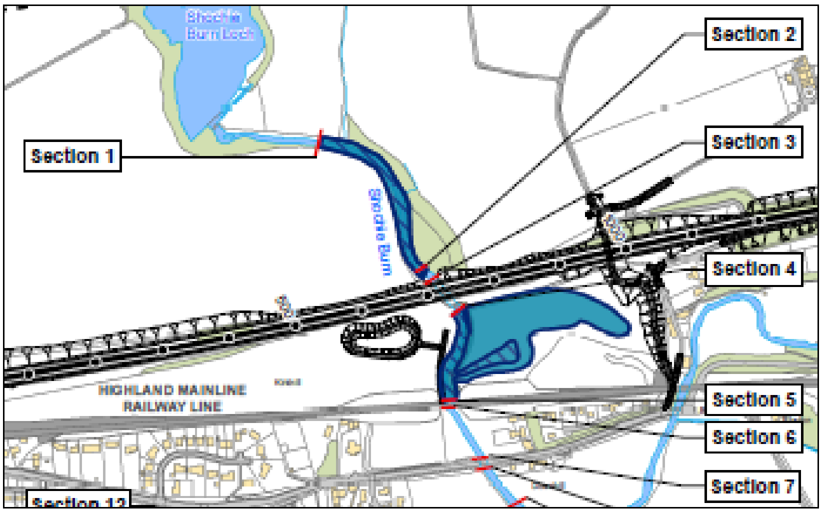

Figure 4: The flood extent for the 0.5% AEP (1:200) event (hatched) and the 0.5% AEP plus climate change event (un-hatched) in the vicinity of the A9 crossing on the Shochie Burn

Mitigation Measures / Flood Management

4.2.10 The model predicts that the 0.5%AEP (1:200) event design flow is largely contained within the channel, particularly at the entrance to the culvert, hence widening the road and projecting the road embankment in an upstream direction will not result in the loss of functional floodplain storage.

4.2.11 Modelling has demonstrated that the proposed scheme at the A9 crossing of the Shochie Burn will have a neutral impact on flood risk both upstream and downstream of the proposed culvert extension. Therefore the provision of flood mitigation measures is not required at this location.

4.3 A9 Crossing of the Ordie Burn

Proposed Works

4.3.1 To accommodate widening of the A9 road corridor the existing Ordie Burn A9 culvert will be extended upstream. In addition, widening the road corridor will result in projection of the new road embankment onto the functional floodplain on the upstream side of the Ordie Burn culvert. On average the embankment footprint will project onto the floodplain by 16m and a linear length of 100m.

4.3.2 The existing culvert comprises a twin barrel box culvert (each barrel being 4.5m wide and 2.5m high) and 30m in length. The existing culvert will be retained and a new culvert will be extended upstream by 15.6m. The extended culvert section will be formed with concrete side walls, concrete soffit (roof) and a natural bed underlain with a concrete base slab. The new culvert will be single barrel of rectangular shape with opening dimensions of 9.5m wide by 2.5m high. The total length of the new culvert will be 45.6m.

Impact on Flooding

4.3.3 The predicted water level for the 0.5% AEP (1:200) design event for the Existing and Design scenarios is provided in Table 4.

Table 4: Predicted water level along the Ordie Burn for the design 0.5% AEP (1:200) event for the Existing and Design scenarios

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP (1:200), mAOD	Design Scenario 0.5% AEP (1:200), mAOD	Difference (m)
U/S section	OB_add_4	27.410	27.408	-0.002
U/S section	OB_add_4ln1	26.533	26.559	0.026
U/S Section	OB_Sec 7	25.701	25.932	0.231
U/S of A9 – Ordie Burn Culvert	OB_Sec8	25.650	25.901	0.251
D/S of A9 – Ordie Burn Culvert	OB_A9d	24.198	24.192	-0.006

Note: a positive value denotes an increase in water level, a negative value denotes a decrease in water level.

4.3.4 The predicted flood extent map for the Ordie Burn for the 0.5% AEP (1:200) design event is presented on Figure 5.

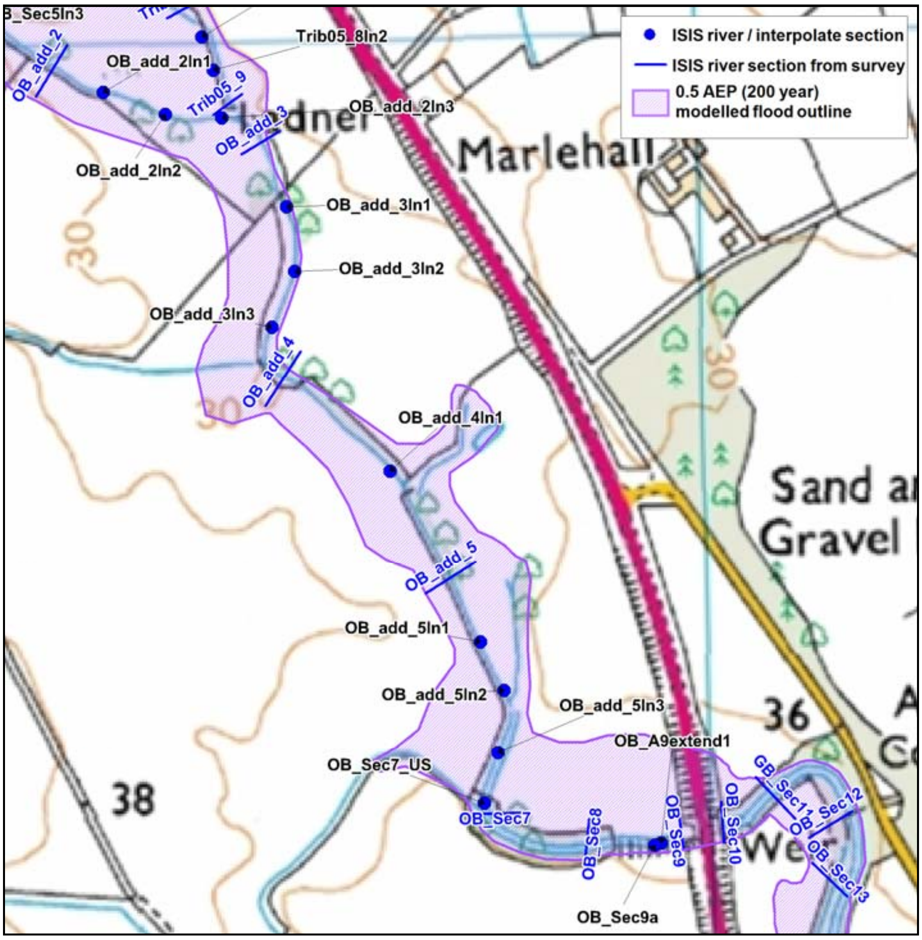

Figure 5: Plan view - Ordie Burn model schematisation and modelled flood plain within vicinity of A9 crossing culvert. NB: The increase in the flood outline associated with the culvert extension is minimal and therefore indiscernible on this plan view flood map. Refer the Modelling Report for further information.

4.3.5 The proposed scheme will result in raising water level immediately upstream of the culvert; by 251mm for the 0.5% AEP (1:200) flood event. The impact of raised water levels upstream will diminish moving upstream and the backwater effect is predicted to extend 550m upstream. The predicted volume of flood water displaced upstream for the design event is 1039m^3.

4.3.6 Given the topography of the river corridor which is constrained by a rising steep banks immediately beyond the right hand river bank and beyond the left hand flood plain, the increase in the width of flood extent immediately upstream of the culvert is predicted to be less than 4 m for the design event.

4.3.7 The predicted impact on pass forward flow and downstream water level for the 0.5% AEP (1:200) design event is neutral.

Climate Change Impact

4.3.8 The predicted water level for the existing and design scenarios for the 0.5% AEP (1:200) plus climate change design event are presented in Table 5.

Table 5: Predicted water levels along the Ordie Burn at the design 0.5% AEP plus climate change event for the pre- and post-development conditions

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP +CC, mAOD	Design Scenario 0.5% AEP + CC, mAOD	Difference (m)
U/S Section	OB_add_4	27.592	27.601	0.009
U/S Section	OB_add_4ln1	26.767	26.935	0.168
U/S Section	OB_Sec 7	26.396	26.720	0.351
U/S of A9 – Ordie Burn Culvert	OB_Sec8	26.348	26.708	0.360
D/S of A9 – Ordie Burn Culvert	OB_A9d	24.339	24.331	-0.008

Note: a positive value denotes an increase in water level, a negative value denotes a decrease in water level.

4.3.9 Climate change impact will result in a rise in predicted water level. For the design scenario the impact on upstream water level is a rise of 807mm. Downstream the water level is predicted to rise by 139mm.

4.3.10 Comparing the climate change impact for the existing and design scenarios as presented in Table 5 suggests that the rise in water level immediately upstream of the culvert will be 360mm but this impact will diminish moving upstream. The backwater impact is predicted to extend 890m upstream. The floodplain extent immediately upstream of the culvert is predicted to increase by 9m.

4.3.11 The impact on pass forward flow and downstream water level for the 0.5% AEP (1:200) plus climate change event is neutral.

Mitigation Measures / Flood Risk Management

4.3.12 Numerical modelling of the proposed A9 Ordie Burn culvert extension predicts that the flood risk upstream will increase, whilst the flood risk downstream will remain neutral.

4.3.13 Consideration has been given to provide mitigation to alleviate the increase in upstream flood risk with the provision of compensatory storage located on either the left or right hand bank local to A9 crossing.

4.3.14 The loss of functional flood plain storage due to the widening of the A9 road at this location is 2,592m^3 as given in Table 6.

Table 6: Flood Plain Storage lost at Ordie Burn Culvert.

Slice (mAOD)	Storage Lost (m^3)	
	Volume at Slice	Cumulative Volume
23.15 to 23.65	195	0
23.65 to 24.15	421	616
24.15 to 24.65	530	1146
24.65 to 25.15	609	1755
25.15 to 25.65	837	2592

4.3.15 Indicative areas considered to provide compensatory flood storage on a volume by volume, level by level basis is shown on Figure 6.

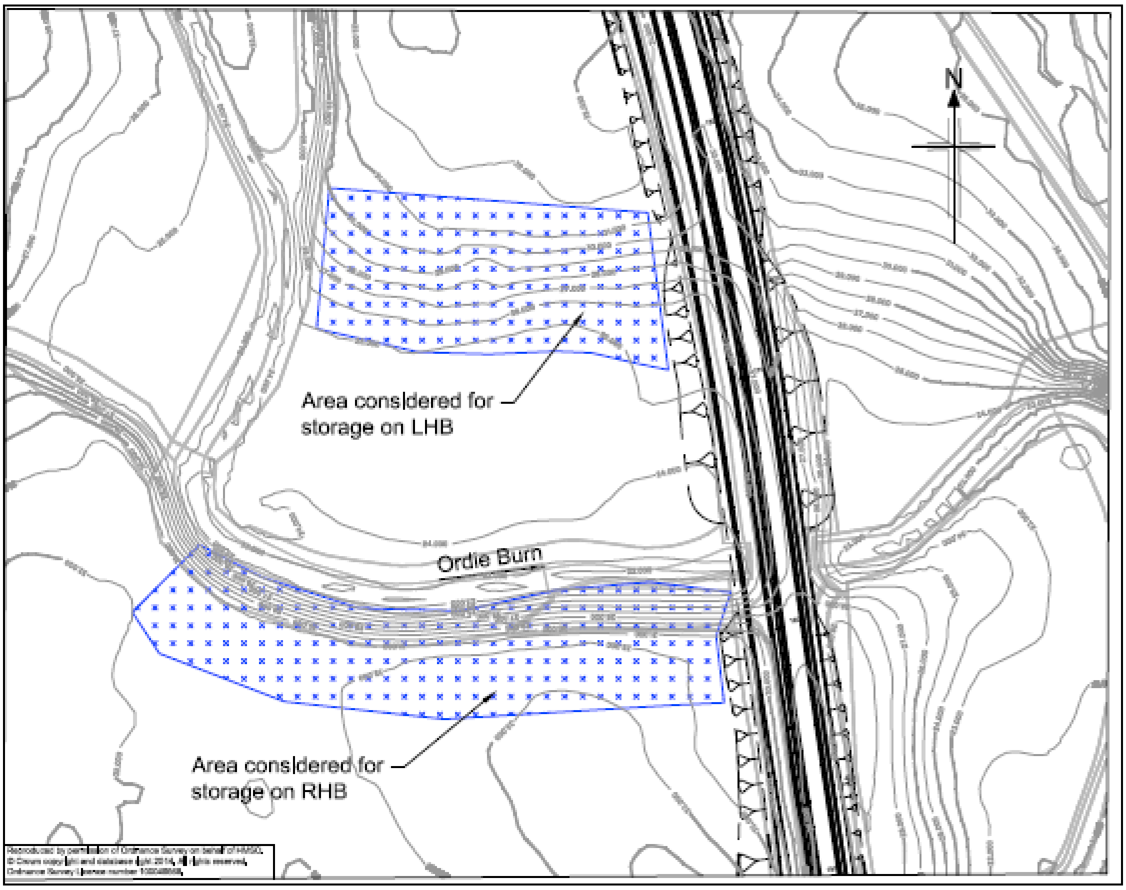

Figure 6 Indicative locations considered for compensatory flood storage

4.3.16 The river corridor immediately upstream of the Ordie Burn culvert comprises a relatively flat flood plain approximately 80m wide beyond the left hand bank before steeply sloping up, whereas the right hand bank rises relatively steeply with little functional floodplain.

4.3.17 The provision of compensatory storage to the right hand bank will result in a significant volume of material being excavated and removed from site. The Ordie Burn at this location is designated as part of the River Tay Special Area of Conservation (SAC) for otter, Atlantic salmon and lamprey species and provision of compensatory storage immediately on the right bank may have a detrimental impact on the qualifying species of the SAC, including:

- effects of elevated concentrations of suspended solids on migratory fish species and substrate habitats;
- noise and vibrations impacts associated with any earthworks in close proximity to the watercourse on migratory fish species; and
- fragmentation of otter commuting routes and adverse impacts on their food supply within the watercourse.

4.3.18 This option is therefore considered to be unfavourable.

4.3.19 Provision of compensatory storage beyond the left hand bank will require the re-grading of the steep slope located approximately 80m from the watercourse. The ‘cutting’ will occupy an area approximately 150m long by 45m wide and given its height and need to provide a stable and safe slope profile it will require a minimum of 12,000m^3 of excavated material to be removed from site at this location (approximately 1600 vehicle movements) with a capital cost in excess of £350k.

4.3.20 The excavation and removal of material may also have a detrimental impact of the adjacent SAC, with the risk of sediment being released into the watercourse during the construction phase, as highlighted above. In addition, acquisition of the land to accommodate the compensatory storage will double the 'land-take' in this area and have a greater impact on the landowner which is presently considered to be of 'slight' significance. Given these impacts, it is considered that this option is also unfavourable.

4.3.21 The increase in flood extent is not predicted to increase significantly (i.e. less than 4m) and the land is currently subjected to flooding with low impact on the current land use i.e. agricultural (grazing) land, with no other significant high risk flood receptors nearby. Allowing the land to continue to flood albeit to a greater depth and possibly greater frequency is considered to be the preferred option at this location as this approach would not adversely impact the SAC and would also have a positive economic and social benefit, with reduced impact to the landowner. Discussion with the landowner is proposed with a view of achieving an agreement in principal to accept the predicted impacts to his land. In addition, the area of land subjected to an increased risk of flooding for the design event will be included in the Compulsory Purchase Order.

4.4 Ordie Burn and its tributary at Newmill

Proposed Works

4.4.1 A new approach road is proposed to replace an existing road traversing the flood plain. The new approach road will join the A9 at Tullybelton Junction. In comparison to the existing approach road levels, the new road level will rise in elevation from right to left as it traverses the floodplain. As a consequence, the embankments forming the new road layout will traverse and project onto the functional floodplain at this location. A new bridge crossing the Ordie Burn will also be required. In addition, the culverted unnamed tributary (05) at Newmill will be re-aligned and culverted beneath the new road layout.

Impact on Flooding

4.4.2 The predicted water level for the 0.5% AEP (1:200) design event for the existing and design scenarios is provided in Table 7.

Table 7: Predicted water level along the Ordie Burn at Newmill area for the design 0.5% AEP (1:200) event for the Existing and Design scenarios

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP (1:200), mAOD	Design Scenario 0.5% AEP (1:200), mAOD	Difference (m)
U/S of Newmill Ordie culvert	OB_add_1	34.954	34.963	0.009
U/S of Newmill Ordie culvert	OB_Sec 1	33.136	33.457	0.321
U/S of Newmill Ordie culvert	OB_Sec 2	32.788	33.151	0.363
D/S of Newmill Ordie culvert	OB_Sec_4	31.888	31.888	0.000
D/S of Newmill Ordie culvert	OB_add 2	30.019	30.018	-0.001
D/S of Newmill Ordie culvert	OB_add_3	29.337	29.339	0.002

4.4.3 The predicted flood extent map for the Ordie Burn at Newmill during the 0.5% AEP (1:200) design event is presented on Figure 7.

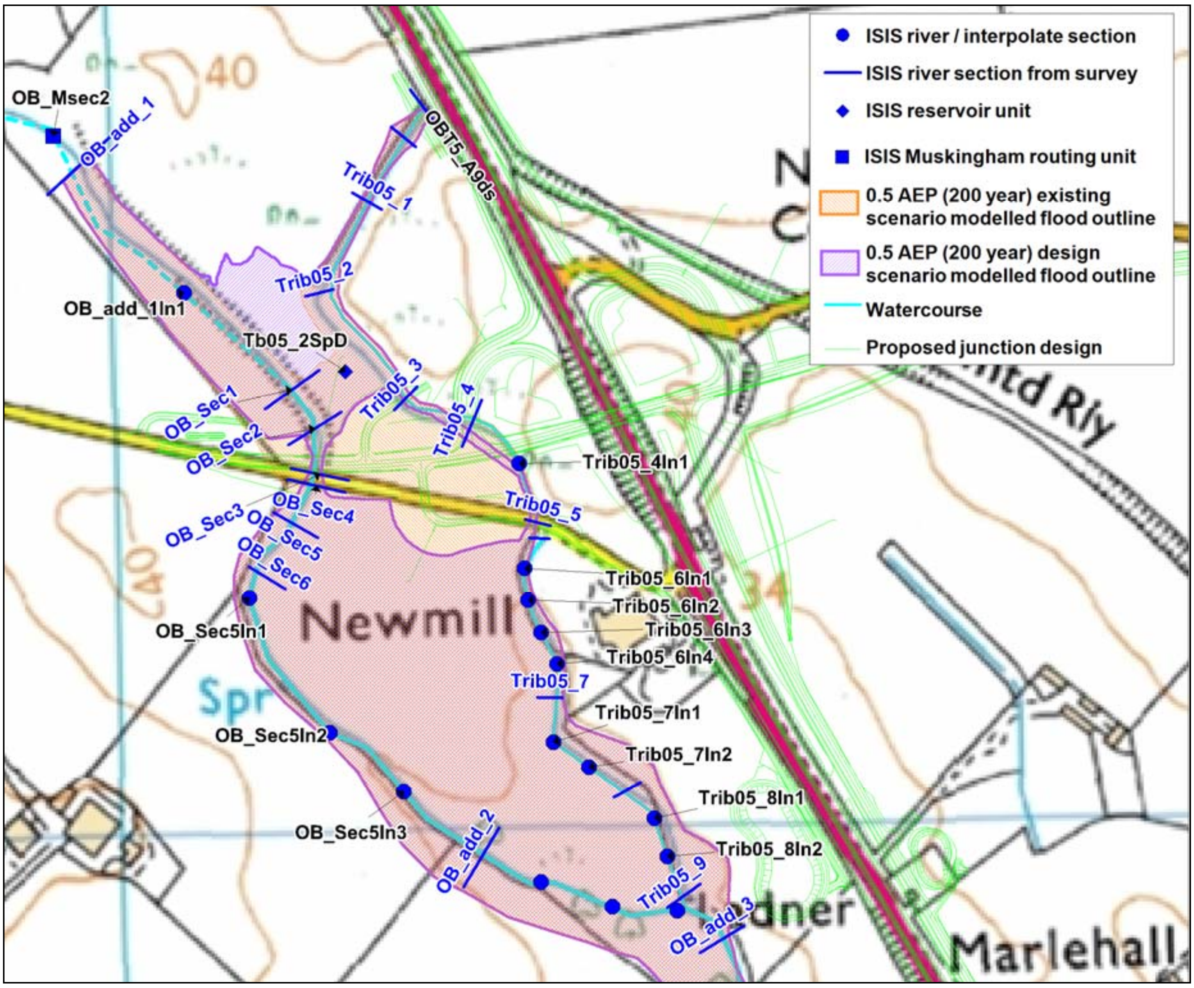

Figure 7: Model schematisation and mapped floodplain for the pre (existing) and post (design) scenario at the proposed Newmill Junction

4.4.4 The loss of functional floodplain to accommodate the new road layout will result in displacing flood water upstream, 'shifting' the functional floodplain northwards to extend over an area of land which is currently unaffected by flood water for the 0.5% AEP (1:200) design event. The predicted peak water level in the floodplain (Reservoir unit Tb05_2SpS) for the design event is 32.75m AOD for the existing scenario and 33.48mAOD for the design scenario. This represents a predicted 730mm rise in water level.

4.4.5 A low level embankment separates the unnamed tributary (05) with the Ordie Burn floodplain, however, during the design event this embankment is overtopped and the two watercourses are hydraulically connected. To control the pass forward flow through the unnamed tributary (05) culvert system, a 300mm orifice plate is proposed at the inlet to the upstream culvert on tributary (05). Although downstream water level in the unnamed tributary (05) is predicted to increase marginally (at most 72mm), the predicted increase in water level at the confluence between the unnamed tributary (05) and Ordie Burn (Cross section OB_add_3) is 2mm, which is considered to be negligible. The downstream flood risk is predicted to remain neutral.

4.4.6 The orifice plate will be housed in an appropriate chamber (including trash screen) at the inlet to the culvert system. The inlet structure will be maintained by an Operating Company who will maintain the road network on behalf of Transport Scotland.

Climate Change Impact

4.4.7 The predicted water level for the existing and design scenarios for the 0.5% AEP (1:200) plus climate change design event are presented in Table 8.

Table 8: Predicted water level along the Ordie Burn at Newmill area for the design 0.5% AEP (1:200) plus climate change event for the Existing and Design scenarios

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP (1:200), mAOD	Design Scenario 0.5% AEP (1:200), mAOD	Difference (m)
U/S of Newmill Ordie culvert	OB_add_1	35.131	35.131	0.000
U/S of Newmill Ordie culvert	OB_Sec 1	33.159	33.578	0.419
U/S of Newmill Ordie culvert	OB_Sec 2	32.825	33.319	0.494
D/S of Newmill Ordie culvert	OB_Sec_4	31.975	31.975	0.000
D/S of Newmill Ordie culvert	OB_add 2	30.094	30.095	0.001
D/S of Newmill Ordie culvert	OB_add_3	29.486	29.489	0.003

4.4.8 Climate change impacts will result in a rise in predicted water level. For the design case, the impact of climate change on predicted upstream water level in the functional floodplain is a rise of 150mm. immediately downstream the water level is predicted to rise by 87mm.

4.4.9 Comparing the climate change impact for the existing and design scenarios as presented in Table 8 suggests that the rise in water level within the upstream floodplain will be 780mm. Downstream, it is predicted that at the confluence of the Ordie Burn and the unnamed tributary (05) the impact on water level remain neutral for the 0.5% AEP (1:200) plus climate change design event.

Mitigation Measures / Flood Risk Management

4.4.10 The numerical model predicts that flood risk upstream of the proposed new road layout will increase, whereas the flood risk downstream will remain neutral.

4.4.11 The loss of functional flood plain storage at this location is 8,963m^3 as given in Table 9.

Table 9: Flood Plain Storage lost at Newmill

Slice (mAOD)	Storage Lost (m^3)	
	Volume at Slice	Cumulative Volume
31.25 to 31.75	246	246
31.75 to 32.25	2972	3218
32.25 to 32.75	5745	8963

4.4.12 Consideration has been given to provide mitigation to alleviate the increase in upstream flood risk with the provision of compensatory storage on a volume for volume, level for level basis.

4.4.13 Given that the topography is generally flat local to the Ordie Burn, the preferred location to provide compensatory storage on a volume by volume level by level basis is the ground located beyond the left hand floodplain as shown in Figure 8. Other areas considered include the area on the right hand bank and area upstream on the left hand bank.

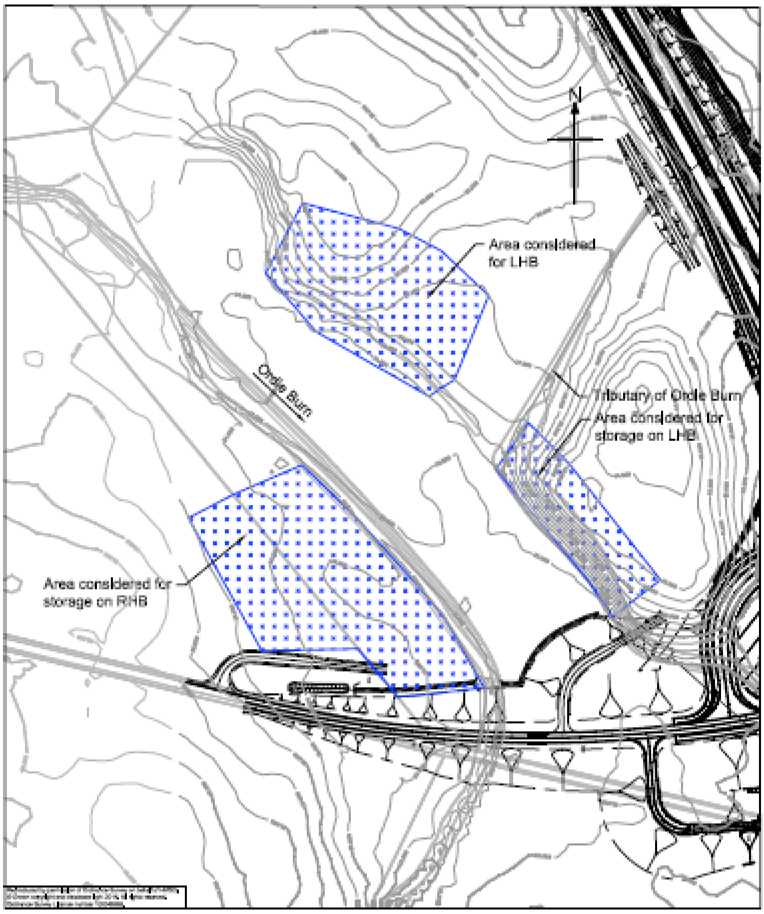

Figure 8: Indicative areas considered for compensatory flood storage

4.4.14 The areas located on the right hand bank and upstream left hand bank have been discounted as the topography is unfavourable to achieve volume by volume, level for level compensatory storage.

4.4.15 The area immediately upstream of the site and beyond the left hand bank has been considered further, however provision of compensatory flood storage at this location will require the re-grading of the unnamed tributary (05) i.e., lowering of its bed level along its reach at the toe of the hill. This may have a detrimental impact on the hydraulic performance of the new downstream culverts.

4.4.16 Similar to the impacts considered above, the provision of compensatory storage to the right hand bank and upstream left hand bank, will result in a significant volume of material being excavated and removed from site. Particularly in the storage area immediately on the right hand bank, there is a high risk of sediment being released into the SAC watercourse during construction. This could have detrimental impacts on the qualifying species of the SAC, including:

- effects of elevated concentrations of suspended solids on migratory fish species and substrate habitats;
- noise and vibrations impacts associated with any earthworks in close proximity to the watercourse on migratory fish species; and
- fragmentation of otter commuting routes and adverse impacts on their food supply within the watercourse.

4.4.17 The area of compensatory storage considered on the left hand bank of the tributary of Ordie Burn, will also result in a high risk of sediment release in the tributary, which considering the cumulative effect, would result in elevated concentrations in the Ordie Burn downstream. This option is therefore considered to be unfavourable.

4.4.18 In addition, given the height of the slope and need to maintain a safe and stable slope in excess of 55,000m^3 of material will need to be excavated and removed from site at an estimated cost of £1.1M. Also the impact of the scheme on the present landowner at this location is already considered to be substantial and provision of a compensatory storage would further increase this impact. Therefore, given these impacts and constraints, the provision of compensatory storage at this location is considered unfavourable.

4.4.19 The increase in flood extent is not predicted to increase significantly although a new area to the north will be at risk of flooding, as shown in Figure 7.

4.4.20 The volume of flood water stored in flood plain for the existing scenario is 8,600m^3. The total volume of flood water stored in flood plain for the design scenario, allowing for the loss of functional flood plain storage resulting from the new road layout is 8,435m^3, which is commensurate with volume of stored flood water for the existing scenario (8,600m^3) and also the estimated volume of lost functional flood plain (8,963m^3).

4.4.21 The land including the new flood risk area is currently used as agricultural (grazing) land and consequently the impact due to flooding is considered to be low. No other high risk flood receptors are nearby. Allowing the land to continue to flood albeit to a greater depth and possible with greater frequency is considered to be the preferred option at this location as this approach would not adversely impact at the unnamed tributary and have a positive economic and social benefit without increasing the impact on the present landowner which is already considered to be substantial. Discussion with the landowner is proposed with a view of achieving an agreement in principal to accept the predicted impacts to his land. In addition, the area of land subjected to an increased risk of flooding for the design event will be included in the Compulsory Purchase Order.

4.5 Garry Burn at Bankfoot Junction

Proposed Works

4.5.1 The new A9 Junction layout at Bankfoot requires a new road embankment which will project onto the functional floodplain.

Impact on Flooding

4.5.2 The predicted water level and flood extent for the 0.5% AEP (1:200) design event for the existing and design scenarios is provided in Table 10 and Figure 9, respectively.

Table 10: Predicted water levels along the Garry Burn for the 0.5% AEP (1:200) design event for the Existing and Design Scenarios

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP, mAOD	Design Scenario 0.5% AEP, mAOD	Difference (m)
U/S of Bankfoot Junction	GB_Sec17	58.801	58.801	0.000
Near Bankfoot Junction	GB_Sec18	57.008	57.008	0.000
Floodplain		56.570	56.570	0.000
U/S of Loakmill crossing	GB_Sec19	55.246	55.245	-0.001
U/S of Access track bridge	GB_Sec21	54.537	54.537	0.000

Note – a positive value denotes an increase in water level, a negative value denotes a decrease in water level.

4.5.3 It is recognised that the new road layout will result in the construction of a new embankment which will project onto the functional floodplain with a 600m^3 cumulative loss of floodplain volume, as presented in Table 11; however the model result suggests that the loss of functional floodplain will not impact on predicted peak water level both upstream and downstream of the site for the 0.5% AEP (1:200) design event.

Table 11: Flood Plain Storage lost at Gary Burn

Slice (mAOD)	Storage Lost (m^3)	
	Volume at Slice	Cumulative Volume
55 to 55.5	0	0
55.5 to 56	94	94
56 to 56.5	406	500
56.5 to 56.57	100	600

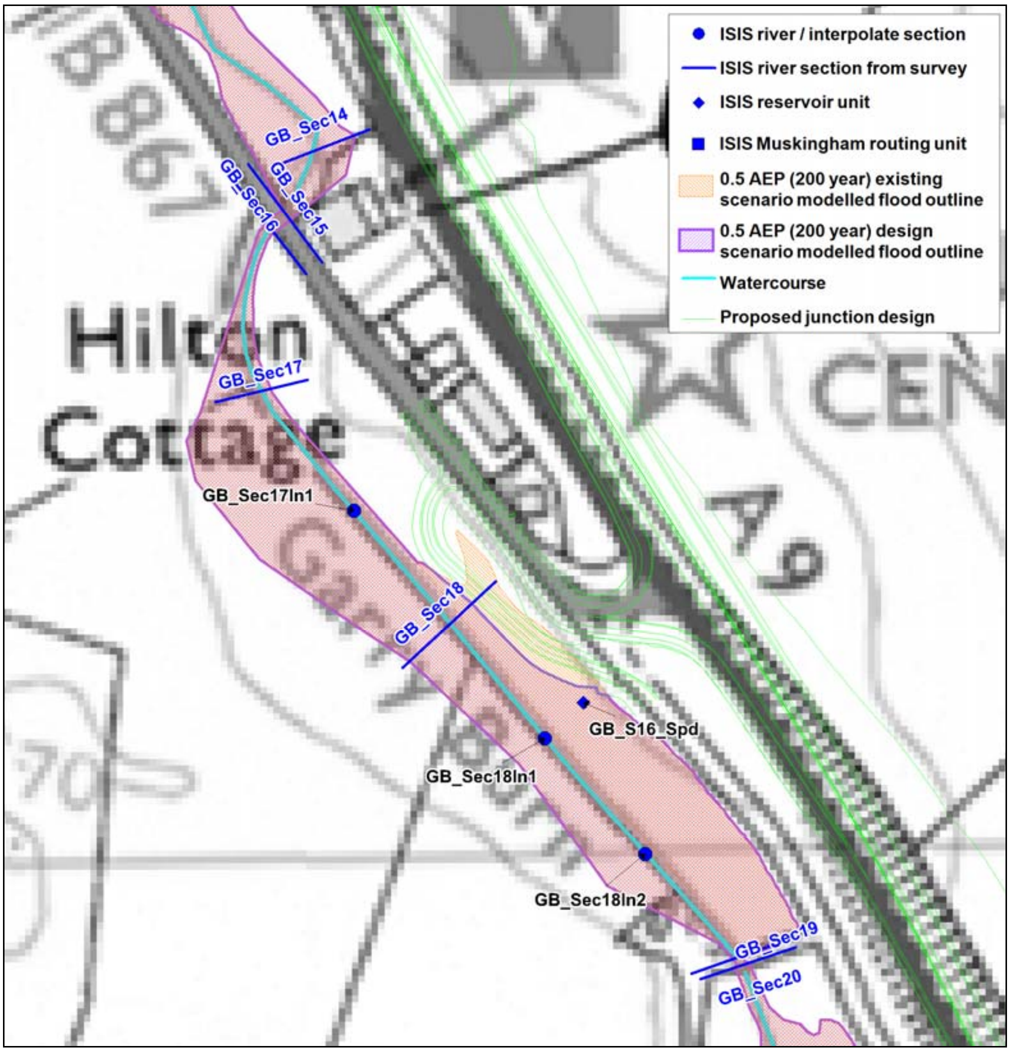

Figure 9: The 0.5% AEP (1:200) design event flood extent for the Garry Burn in the vicinity of the A9/B867 junction for the existing and design scenarios

4.5.4 The water level at this location is hydraulically controlled by downstream embankments, including an embankment carrying the Loakmill access path which traverses the flood plain (at cross section GB Sec19) and also an embankment forming the left hand channel bank. These embankments contain flood water within the flood plain and when overtopped they exert a hydraulic control on the pass forward flow.

4.5.5 At present during flood events water spills from the Garry Burn over a small embankment forming the left hand channel bank and into the functional floodplain. This flood water is then initially 'contained' by the downstream embankments until these are overtopped and flood water spills back into the Garry Burn and also downstream over the Loakmill access path.

4.5.6 When the downstream embankments are overtopped, the upstream water level is controlled by the 'head' required to pass the flow downstream and the loss of storage volume has no impact. Given that the geometry of the downstream embankments will remain unaffected by the proposed scheme, the hydraulic control on peak water level at this location will also remain unchanged.

Climate Change Impact

4.5.7 The predicted water level in the Garry Burn for the Existing and Design scenarios for the 0.5% AEP (1:200) plus climate change design event is presented in Table 12.

Table 12: Predicted water level along the Garry Burn for the 0.5% AEP plus climate change design event for the existing and design scenario

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP +CC event, mAOD	Design Scenario 0.5% AEP+CC event, mAOD	Difference (m)
U/S of Bankfoot Junction	GB_Sec17	58.870	58.870	0.000
Near Bankfoot Junction	GB_Sec18	57.045	57.045	0.000
Floodplain		58.870	58.870	0.000
U/S of Loakmill crossing	GB_Sec19	55.402	55.402	0.000
U/S of Access track bridge	GB_Sec21	54.648	54.648	0.000

4.5.8 Climate change impacts will result in a rise in predicted water level. For the design scenario the impact on upstream water level in the functional floodplain is a rise of 130mm.

4.5.9 Comparing the climate change impact for the existing and design scenarios as presented in Table 11 suggest no impact to predicted peak water level both upstream and downstream for the 0.5% AEP (1:200) plus climate change event.

Mitigation Measures / Flood Risk Management

4.5.10 The numerical model predicts a neutral impact with regards to flood risk both upstream and downstream of the proposed new road layout at Bankfoot. The loss of functional floodplain has no effect on the peak water level within the modelled reach, as the water level at this location is controlled by downstream embankments which will not be affected by the proposed scheme.

4.5.11 No flood risk management measures are proposed at this location.

4.6 Crossings over Other Watercourses

4.6.1 The proposed scheme between Luncarty and the Pass of Birnam has a total of 19 watercourse crossings. The location of these watercourse crossings is shown on Figure 1 and many of these watercourses are small tributaries / drainage ditches with design flows less than $1m^3/s$.

4.6.2 Further information relating to the nature of these minor watercourses can be found on Figure 9.1 of Chapter 9 (Road Drainage and the Water Environment).

4.6.3 At each of these minor crossings a flood risk assessment has been made with respect to:

- Assessment of the Hydraulic capacity of each crossing and new crossing (if appropriate).
- Assessment of the Flood Risk to the A9 road formation level.
- Assessment of the impact of the proposed scheme on flood risk local to each site.

4.6.4 The assessment of hydraulic capacity has been undertaken for both the 0.5% AEP (1:200) design event and the 0.5% AEP (1:200) plus climate change even and follows the methodology presented in 'Culvert Design and Operation Guide', CIRIA C689, 2010. The assessment has been based on deriving a 'free flowing' capacity, as presented in Table A1 (Annex A) and adoption of a Manning's 'n' value of 0.015 for the culvert roughness coefficient.

4.6.5 The flood risk to the A9 road formation level has been based on comparison between predicted upstream water level for the design event and proposed road formation level. The results are presented in Table A1 (Annex A).

4.6.6 The impact of the proposed scheme on local flood risk and identifying the need for further flood risk management measures has been based on determining the upstream channel flow regime (i.e. 'in bank' or 'out of bank') for the design event. Where an 'out–of-bank' flow condition is predicted and development (projection of the road embankment onto the functional floodplain) is proposed, the loss of flood plain storage has been estimated. The assessment has been based on applying Manning's equation together with typical channel cross sections based on photographic survey and photographic records. The assessment is tabulated in Table A2 (Annex A).

4.6.7 A summary of the assessment at each watercourse crossing is provided below.

<u>Crossing 2(a) – Unnamed Tributary 4/5 of Ordie Burn</u>

4.6.8 Crossing 2(a) conveys flow from an unnamed tributary of the Ordie Burn. The existing culvert has a diameter of 0.9m and is 35m long. The existing hydraulic capacity of the culvert, in a free flowing condition is 0.85m^3/s, which is less than the predicted 20% AEP (1:5) design event flow. This suggests that the culvert is likely to be surcharged for events rarer than the predicted 20% AEP (1:5) event, including the 0.5% AEP (1:200) design event.

4.6.9 To accommodate the proposed scheme, the length of the culvert will increase to 60m. To pass the design event, an upstream head water depth of 2.84m is required i.e. water level equal to 41.78mAOD. The available freeboard at this location to the A9 road formation level is 0.15m.

4.6.10 The height difference between the culvert soffit level and road formation level is 2m and a relatively narrow flood plain exists beyond both the left and right hand bank. Top of river bank level is 40.94mAOD, hence a significant head water depth (0.84m) would be required in the flood plain to drive the peak design flow through the culvert. The loss of functional flood plain storage is 215m^3. It is proposed that the existing channel will be widened to form a two stage channel to win the relatively small storage volume.

<u>Crossing 2(b) – Unnamed Tributary 3 of Ordie Burn</u>

4.6.11 The existing culvert at crossing 2(b) conveys flow from an unnamed tributary 3 of the Ordie Burn and has a diameter of 0.75m and is 50m long. To accommodate the A9 dualling the length of the culvert will be increased to 83m; with the extension projecting both upstream and downstream of the existing culvert.

4.6.12 Upstream of the A9 crossing the tributary is conveyed through a stone conduit (i.e. buried closed channel). The length of this conduit is approximately 300m and at its entrance a depression in the topography exists covering an area of 2.1Ha. This area, unaffected by the proposed scheme, is known to flood. A short 10m reach of open channel exists between the exit of the stone conduit and the entrance to the existing A9 culvert.

4.6.13 It has not been possible to determine the exact dimensions of the stone conduit, but survey records suggest that its height is 400mm. Its width is unknown, but given the channel bed is approximately 0.6m wide at its exit, it is unlikely the stone conduit will be wider than this. Hence the cross sectional area of the stone conduit is estimated as 0.24m^2. The existing A9 culvert crossing has a 0.75m diameter and cross sectional area of 0.44m^2, which is greater than the cross sectional area of the upstream stone conduit. Hence the stone conduit provides the hydraulic control at this location.

4.6.14 The hydraulic capacity of the stone conduit, based on upstream topography suggesting a gradient of 1 in 300 and equivalent pipe diameter of 600mm is estimated as $0.36m^3/s$.

4.6.15 The 0.5% AEP (1:200) design event ($1.99m^3/s$) exceeds the capacity of the stone conduit; hence the stone conduit will be surcharged at its entrance during this event with flooding of the upstream topographical depression. This flood mechanism will be unaffected by the proposed scheme.

4.6.16 Flooding local to the A9 culvert crossing is not likely given the hydraulic control provided by the stone conduit and flow remaining in-bank immediately upstream of the A9 culvert, hence no floodplain storage is lost as a result of the proposed culvert extension and road widening. To allow surface water runoff at the toe of the new road embankment to continue to drain into the unnamed tributary and A9 culvert a short 3m length of open channel will be maintained between the stone conduit exit and entrance to the new A9 culvert.

Crossing 2(c) – Unnamed Tributary 4/5 of Ordie Burn (by Newmill)

4.6.17 To the north-west of Newmill, an existing minor road crosses an unnamed tributary of the Ordie Burn. This culvert will be realigned as part of the proposed scheme.

4.6.18 The tributary was included in the Ordie Burn ISIS 1-D model. The hydraulic capacity of the culvert is estimated to be $0.28m^3/s$ which is less than predicted 50% AEP (1:2) event flow. Anecdotal evidence suggests that the area upstream of this culvert is flooded regularly, which could be due to the insufficient capacity of this culvert.

4.6.19 The new Tullybelton road layout will require realignment of this watercourse and provision of three culverts with a combined length of 165m. In order to maintain the existing flood regime downstream of the new culvert system, the flow into the culvert system will be controlled with inclusion of an orifice place with a diameter of 300mm.

Crossing (2d) – Newmill Cottage culvert

4.6.20 This culvert is located in an upstream reach of unnamed tributary 3 (a tributary of the Ordie Burn) near Newmill cottage. The existing box culvert is 0.8m wide, 0.9m high and 10m long. The existing culvert has a greater capacity than the 0.5% AEP (1:200) plus climate change event design flow of $1.00m^3/s$.

4.6.21 A new side road will be constructed as part of the proposed scheme which requires a new 65m long culvert near the downstream end of the existing culvert, separated by a 10m long open channel. It is proposed to provide a new culvert equalling the existing box culvert opening size, hence it is predicted that the new culvert will be able to freely pass the design 0.5% AEP (1:200) event.

4.6.22 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be ‘in-bank’. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing (2e) – Ordie Burn arch culvert at Newmill

4.6.23 This arch culvert is modelled as part as part of the Ordie Burn numerical model. This culvert is a 7.1m wide arch culvert and can freely pass the predicted 0.5% AEP (1:200) design event. The flood risk to the A9 road is considered to be negligible.

Crossing 3 - Ardonachie Burn

4.6.24 The A9 crosses the Ardonachie Burn at Crossing No. 3. The culvert is 0.9m diameter in diameter and 60m long. The existing hydraulic capacity of the culvert, in a free flowing condition is $0.70m^3/s$, which is less than the predicted 20% AEP (1:5) design event flow. The culvert will be surcharged for events rarer than the predicted 20% AEP (1:5) event including the 0.5% AEP (1:200) design event.

4.6.25 To accommodate the proposed scheme, the culvert length will be increased to 76m. The predicted 0.5% AEP (1:200) plus climate change event peak flow at this location is 2.51m^3/s. During this event the culvert inlet will be surcharged, however allowing for the required head of water at the culvert inlet to pass the peak flow the available freeboard to road level is 2.78m. Hence the flood risk to the A9 road is considered to be negligible.

4.6.26 It estimated that approximately 77m^3 of floodplain storage will be lost as a result of the culvert extension and road widening. It is proposed that the existing channel will be widened to form a two stage channel to win the relatively small storage volume.

Crossing 4 - Unnamed Drain 3

4.6.27 The existing culvert conveying unnamed drain 3 has a diameter of 0.6m and is 19m long. The free flowing hydraulic capacity of the culvert is 0.33m^3/s which is greater than the predicted 0.5% AEP (1:200) event peak flow.

4.6.28 To accommodate the scheme the existing culvert will be extended downstream with a total length of 35m. The free flowing capacity of the culvert will remain greater than the design event and the available freeboard between predicted upstream water level and proposed A9 road formation level is 0.51m; hence the flood risk to the A9 road is considered to be low.

4.6.29 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be ‘in-bank’, therefore no floodplain storage is lost as a result of the proposed culvert extension and road widening.

Crossing 5 – Unnamed Drain 4

4.6.30 The existing culvert at Crossing 5 conveys water from Unnamed Drain 4 and has a diameter of 0.6m and is 30m long. The free flowing hydraulic capacity of the culvert is 0.31m^3/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.31 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 55m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 2.14m; hence the flood risk to the A9 road is considered to be low.

4.6.32 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be ‘in-bank’. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 5a – Unnamed Tributary 1 of Gelly Burn

4.6.33 The existing culvert at Crossing 5a has a diameter of 0.6m and is 23m long. The free flowing hydraulic capacity of the culvert is 0.31m^3/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.34 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 55m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 0.55m; hence the flood risk to the A9 road is considered to be low.

4.6.35 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be ‘in-bank’. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 6 - Unnamed Tributary 2 of Gelly Burn

4.6.36 The existing culvert at Crossing 6 conveys water from a tributary of the Gelly Burn beneath the A9 road. The culvert has a diameter of 0.6m and is 25m long. The existing hydraulic capacity of the culvert, in a free flowing condition is 0.33m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.37 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 55m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 2.83m; hence the flood risk to the A9 road is considered to be low.

4.6.38 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be 'in-bank'. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 7 – Gelly Burn (North)

4.6.39 The two culverts in sequence at Crossing 7 each have a diameter of 0.9m and are 25m long. The existing hydraulic capacity of the culvert system, in a free flowing condition is 0.98m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.40 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 55m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 3.11m; hence the flood risk to the A9 road is considered to be low.

4.6.41 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be 'in-bank'. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 8 – Unnamed Drain 5

4.6.42 The culvert at Crossing 8 has a diameter of 0.6m and is 20m long. The existing hydraulic capacity of the culvert, in a free flowing condition is 0.33m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.43 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 30m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 1.05m; hence the flood risk to the A9 road is considered to be low.

4.6.44 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be 'in-bank'. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 9 – Unnamed Tributary 3 of Gelly Burn

4.6.45 The culvert at Crossing 9 has a diameter of 1.05m and is 27m long. The existing hydraulic capacity of the culvert, in a free flowing condition is 1.41m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.46 To accommodate the proposed scheme, the existing culvert will be extended downstream with a total length of 45m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 2.94m; hence the flood risk to the A9 road is considered to be low.

4.6.47 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be 'in-bank'. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 10 – Broomhill Burn

4.6.48 The existing culvert at Crossing 10 comprises twin 0.375m diameter culverts each 18m long. Their combined hydraulic capacity, in a free flowing condition is 0.18m³/s, which is less than the predicted 4% AEP (1:25) design event flow. This suggests that the culverts are likely to be surcharged for events rarer than the predicted 4% AEP (1:25) event including the 0.5% AEP (1:200) design event.

4.6.49 It is proposed to increase the diameter of the two culverts to 0.45m with a free flowing capacity of 0.33m³/s. This is required to reduce upstream water level and increase the available freeboard to the A9 road to 1.15m. In addition the channel upstream and downstream will be re-graded to accommodate the larger diameter culverts.

4.6.50 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be 'in-bank'. Therefore no floodplain storage is lost as a result of the proposed culvert extension and road widening.

4.6.51 The proposed re-grading of the Broomhill Burn will extend approximately 200m downstream of the proposed culvert extension and will have a flatter gradient compared to the existing channel gradient downstream of the culvert.

4.6.52 In addition, the new channel will have a larger cross sectional area when compared to the existing channel, to accommodate the depressed channel bed upstream of the culvert and will extend approximately 200m downstream. The existing channel downstream of the culvert has a volumetric capacity of approximately 120m³, and the new channel will double this volume to approximately 240m³. Given the small magnitude of the design flow, it is considered that the increase in channel volume will attenuate any marginal increase in pass forward flow at this location.

Crossing 11 – Unnamed Watercourse

4.6.53 The culvert at Crossing 11 has a diameter of 0.6m and is 25m long. The existing hydraulic capacity of the culvert, in a free flowing condition, is 0.31m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.54 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 38m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 1.15m; hence the flood risk to the A9 road is considered to be low.

4.6.55 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be 'in bank'. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 12 – Unnamed Watercourse

4.6.56 The culvert at Crossing 12 has a diameter of 0.6m and is 30m long. The existing hydraulic capacity of the culvert, in a free flowing condition is 0.30m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.57 To accommodate the proposed scheme the existing culvert will be extended downstream with a total length of 40m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 1.62m; hence the flood risk to the A9 road is considered to be low.

4.6.58 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be ‘in-bank’. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

Crossing 13 – Unnamed Watercourse

4.6.59 The culvert at Crossing 13 has a diameter of 1.05m and is 35m long. The existing hydraulic capacity of the culvert, in a free flowing condition is 1.48m³/s, which is greater than the predicted peak flow associated with the 0.5% AEP (1:200) design event.

4.6.60 To accommodate the proposed scheme, the existing culvert will be extended downstream with a total length of 45m. The free flowing capacity of the culvert will remain greater than the design event. The available freeboard between predicted upstream water level and proposed A9 road formation level is 2.32m; hence the flood risk to the A9 road is considered to be low.

4.6.61 Assessment of the upstream and downstream channel suggests that for the design event, the predicted water level will be ‘in-bank’. Therefore no floodplain storage lost as a result of the proposed culvert extension and road widening.

4.7 Downstream of Overall Scheme – Luncarty

4.7.1 The Garry Burn drains into the Ordie Burn which in turn drains into the Shochie Burn. All three watercourses flow through a predominantly rural landscape within the immediate vicinity of the Scheme, however downstream the Shochie Burn flows through the town of Luncarty.

Proposed Works

4.7.2 No construction activities will be required in the vicinity of the town of Luncarty as part of the proposed scheme.

Impact on Flooding

4.7.3 The predicted water level in the vicinity of town of Luncarty for the existing and design scenarios for the 0.5% AEP (1:200) design event (refer to Figure 10) is presented in Table 13.

Table 13: Shochie Burn predicted water level in the vicinity of Luncarty Town for the 0.5% AEP (1:200) design event for both the existing and design scenarios

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP (1:200), mAOD	Design Scenario 0.5% AEP (1:200), mAOD	Difference (m)
Upstream of Luncarty	SB_Sec10	15.448	15.446	-0.002
Upstream of Luncarty	SB_Sec11	14.805	14.803	-0.002
Upstream of Luncarty	SB_Sec12	14.763	14.761	-0.002
Upstream of Luncarty	SB_Sec13	14.438	14.436	-0.002

Note – a positive value denotes an increase in water level, a negative value denotes a decrease in water level.

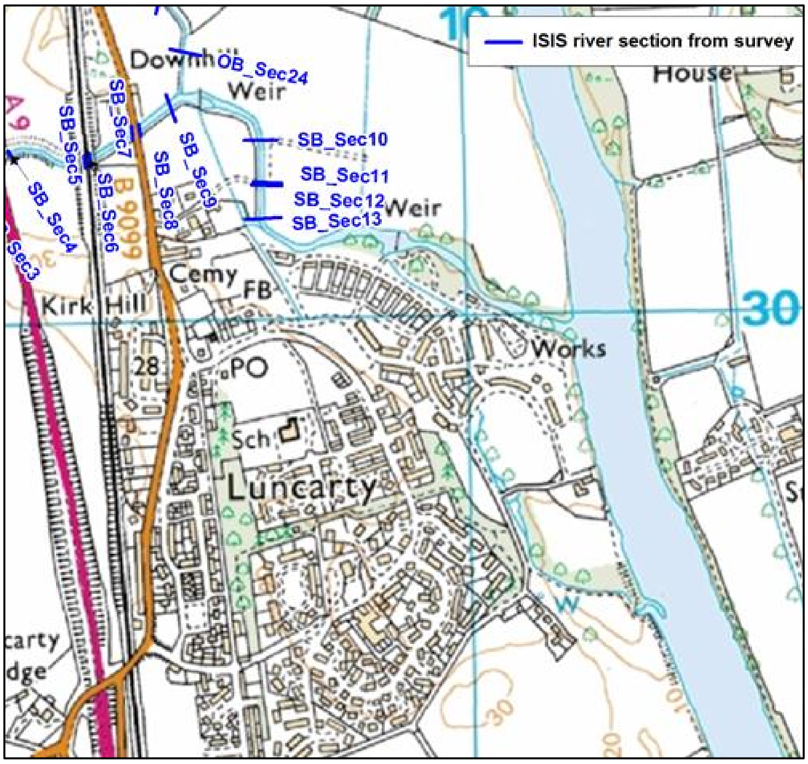

Figure 10: Schematisation of the downstream reach of the model within the vicinity of Luncarty

4.7.4 The modelling results indicate a neutral impact with respect to predicted water level for the design event.

Climate Change Impact

4.7.5 The predicted water level in the vicinity of the town of Luncarty for the pre- and post-development scenario for the design 0.5% AEP (1:200) event including a 20% allowance for climate change is presented in Table 14.

Table 14: Shochie Burn predicted water level in the vicinity of Luncarty for the 0.5% AEP (1:200) plus climate change event for both the existing and design scenarios

Locations	Cross section (ISIS Node)	Existing Scenario 0.5% AEP (1:200) + CC event, mAOD	Design Scenario 0.5% AEP (1:200) + CC event, mAOD	Difference (m)
Upstream of Luncarty	SB_Sec10	15.539	15.536	-0.003
Upstream of Luncarty	SB_Sec11	14.879	14.876	-0.003
Upstream of Luncarty	SB_Sec12	14.835	14.832	-0.003
Upstream of Luncarty	SB_Sec13	14.506	14.504	-0.002

Note: a positive value denotes an increase in water level, a negative value denotes a decrease in water level.

4.7.6 The modelling results indicate a neutral impact with respect to predicted water level for the design event plus climate change scenario, as shown in the above table.

Mitigation Measures / Flood Management

4.7.7 The model predicts a neutral impact with regards to predicted water level for the design event, both for the existing and climate change scenarios in the vicinity of the town of Luncarty. Therefore the provision of flood mitigation measures is not required at this location.

5 Summary and Conclusion

5.1.1 The impact on flood risk associated with the proposed scheme on 19 river crossings, including the Shochie Burn, Ordie Burn and Garry Burn and a number of other minor watercourses, has been undertaken.

5.1.2 The design event adopted is the 0.5% AEP (1:200) event. Consideration has also been given to the predicted impact of climate change.

5.1.3 The philosophy adopted with regards to flood risk and flood risk management is to maintain a neutral impact on downstream flood risk and where an increase to upstream flood risk is predicted to consider mitigation measures and where mitigation has not been possible to provide further justification.

5.2 A9 crossing of the Shochie Burn (culvert extension)

5.2.1 The proposed extension of the A9 Shochie Burn culvert will have a neutral impact on flood risk both upstream and downstream of the proposed culvert extension. Therefore the provision of flood mitigation measures is not required at this location.

5.3 A9 crossing of the Ordie Burn (culvert extension)

5.3.1 The proposed culvert extension and loss of 2,592m^3 functional flood plain storage will raise water level upstream by 251mm. The predicted impact on pass forward flow and downstream water level for the design event is neutral.

5.3.2 Consideration has been given to the provision of upstream compensatory storage, however these options have been considered to be unfavourable due to possible adverse impact on the SAC designated Ordie Burn, significant volume of material being excavated and removed from the site to ‘win’ the required storage volume and adverse impact on the landowner.

5.3.3 The preferred option is to allow the functional flood plain to continue to flood albeit to a greater depth and possibly greater frequency. This would not adversely impact the SAC and would also have a positive economic and social benefit, with reduced impact to the land owner. Discussion with the landowner is proposed with a view of achieving an agreement in principal to accept the predicted impacts to his land.

5.4 Ordie Burn at Newmill Junction (extension of the road embankment onto the functional flood plain)

5.4.1 The proposed new road layout and loss of 8,963m^3 of functional flood plain will raise water level upstream by 730mm. This will result in displacing flood water upstream, ‘shifting’ the functional floodplain upstream to extend over an area of land which is currently unaffected by flood water for the design event. Downstream flood risk is predicted to remain neutral for the design event.

5.4.2 Consideration has been given to the provision of upstream compensatory storage, however these options have been considered to be unfavourable due to possible adverse impact on the unnamed tributary SAC designated Ordie Burn, significant volume of material being excavated and removed from the site to ‘win’ the required storage volume and adverse impact on the landowner.

5.4.3 The preferred option is to allow the functional flood plain to continue to flood albeit to a greater depth and possibly greater frequency. This would not adversely impact the SAC and would also have a positive economic and social benefit, with reduced impact to the land owner. Discussion with the landowner is proposed with a view of achieving an agreement in principal to accept the predicted impacts to his land.

5.5 Garry Burn at Bankfoot Junction (extension of the road embankment onto the functional flood plain)

5.5.1 The loss of functional floodplain to accommodate the new road layout at this location has no impact on peak water level, as the water level is controlled by downstream embankments which will not be affected by the proposed scheme. As the impact on flood risk is neutral, there is no provision for any flood mitigation measures at this location.

5.6 Minor Watercourse Crossings

5.6.1 The flood risk at each of the minor watercourse crossings has been assessed using Manning's Equation. The flood risk impact of the proposed scheme at all locations is considered to be neutral apart from Crossing 2a and 3 where 215m^3 and 77m^3,of functional floodplain storage will be lost respectively. At these locations it is proposed to widened the existing channel (creating a two stage channel) to win the relatively small storage volumes.

5.7 Downstream of Overall Scheme – Luncarty

5.7.1 The model predicts a neutral impact with regards to predicted water level for the design event, both for the existing and climate change scenarios in the vicinity of Luncarty.

6 References

CIRIA (2004) Development and Flood Risk: Guidance for the Construction Industry, Report C624. Construction Industry Research and Information Association

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Scottish Planning Policy. February 2010 report.

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Annex A: Flood Risk Assessment of Minor Watercourses

Table 1A: Summary of results of culvert hydraulic assessment for the existing and design scenarios

Crossing	Culvert Details				Design Scenario			
	Diameter	Length	Culvert Capacity		Q200 + CC	Predicted upstream Water Level	Road Formation Level	Available Freeboard
	(m)	(m)	Q (m³/s)	T(yr)	(m³/s)	(mAOD)	(mAOD)	(m)
Crossing 1 – Shochie Burn	2Nrs 4.5m W *2.5mH	46 (66.6)	≈45	~ 100	59.8	20.20	27.30	7.10
Crossing 2 – Ordie Burn	2Nrs 4.5m W *2.5mH	30 (45.6)	≈25	<5	89.4	26.71	28.60	1.82
Crossing 2a (Unnamed Tributary of Ordie Burn)	0.9	35 (60)	0.85	<5	2.64	41.78	41.93	0.15
Crossing 2b (Unnamed Tributary of Ordie Burn)	0.75	50 (83)	0.47	<5	.1.99	30.448	33.24	2.79
Proposed Crossing 2c (Unnamed Tributary of Ordie Burn by Newmill)	0.9	7 (165)	0.28	<2	2.82	33.28	43	9.72
Crossing 2d (Newmill Cottage)	0.8m W *0.9m H	10 (65)	>1.0	>200	1.0	31.91	39.7	7.79
Crossing 2e (Ordie on side road)	Arch, 7.1m W		>66	>200	75.0	33.28	40.5	7.22
Crossing 3 (Ardonachie Burn)	0.9	60 (76)	0.70	<5	2.51	66.48	69.26	2.78
Crossing 4 (Unnamed Drain 3)	0.6	19 (35)	0.33	>200	0.11	115.69	116.20	0.51
Crossing 5 (Unnamed Drain 4)	0.6	30 (55)	0.31	>200	0.02	116.12	118.26	2.14

Crossing	Culvert Details				Design Scenario			
	Diameter	Length	Culvert Capacity		Q200 + CC	Predicted upstream Water Level	Road Formation Level	Available Freeboard
	(m)	(m)	Q (m^3/s)	T(yr)	(m^3/s)	(mAOD)	(mAOD)	(m)
Crossing 5a (Dry Channel) (Unnamed Tributary 1 of Gelly Burn)	0.6	23 (55)	0.31	>200	0.13	116.29	116.84	0.55
Crossing 6 (Unnamed Trib. 2 of Gelly Burn)	0.6	25 (55)	0.33	>200	0.22	112.93	115.76	2.83
Crossing 7 (Gelly Burn - North)	0.9	25 (55)	0.98	>200	0.27	113.21	116.32	3.11
Crossing 8 (Unnamed Drain 5)	0.6	20 (30)	0.33	>200	0.06	115.95	117.00	1.05
Crossing 9 (Unnamed Trib. 3 of Gelly Burn - North)	1.05	27 (45)	1.41	>200	0.14	115.86	118.80	2.94
Crossing 10 (Broomhill Burn)	0.375 x2 (0.45 x2)	18 (30)	0.18	<25	0.37	118.82	119.83	1.01
Crossing 11	0.6	25 (38)	0.31	>200	0.07	120.13	121.28	1.15
Crossing 12	0.6	30 (40)	0.30	>200	0.11	120.22	121.84	1.62
Crossing 13	1.05	35 (45)	1.48	>200	0.32	120.17	122.49	2.32

Note: Figures within brackets ( ) are for post development scenario

Table A2: Summary of flood risk assessment

Crossing	Description of Extension	Downstream condition			Upstream condition			Impact & Flood Risk Management (Comments)
		Water level*	Bank level*	Flow condition	Water level*	Bank level*	Flow condition	
		mOD	mOD	IB / OB	mOD	mOD	IB / OB	
Crossing 1 – Shochie Burn	Upstream only	19.42	22.72	IB	20.2	21.45	OB	Flow in-bank both upstream and immediately downstream of the culvert. Floodplain storage is not lost hence compensatory storage is not required.
Crossing 2 – Ordie Burn	Upstream only	24.32	24.21	OB	26.71	26.51	OB	Flow out-of-bank both upstream and downstream of culvert. Displaced volume of floodplain storage in the design scenario is 2,592m^3. The provision of compensatory storage is not feasible due to topography, environmental and economic reason.
Crossing 2a (Unnamed Tributary of Ordie Burn)	Upstream mainly and downstream	38.86	38.88	IB	41.78	40.44	OB	Culvert inlet surcharged with out-of-bank flow. Channel runs parallel to the A9. Loss of floodplain storage estimated to be 215m^3. Compensatory storage can be provided in-line by widening the channel and formation of a 2-stage channel.
Crossing 2b (Unnamed Tributary of Ordie Burn)	Upstream and downstream	27.396	27.416	IB	30.448	N/A	N/A	Flow in-bank downstream. Upstream reach is already culverted. To allow surface water runoff at the toe of the new road embankment to continue to drain into the unnamed tributary and A9 culvert a short 3m length of open channel will be maintained between the existing stone conduit exit and entrance to the new A9 culvert. No impact on flood risk.
Proposed Crossing 2c (Unnamed Tributary of Ordie Burn by Newmill)	Realigned	-	-	OB	-	-	OB	Functional floodplain storage lost is 8,963m^3. Flood water will be displaced upstream. No impact on downstream flood risk.
Crossing 2d (Newmill Cottage)	Upstream of side road	30.64	31.05	IB	31.91	32.04	IB	Flow in-bank both upstream and downstream. No impact on flood risk.
Crossing 2e (Ordie on side road)	New overbridge	-	-	OB	-	-	OB	Functional floodplain storage lost is 8,963m^3. Flood water will be displaced upstream. No impact on downstream flood risk.
Crossing 3(Ardonachie Burn)	Upstream only	63.04	63.32	IB	66.07	65.24	OB	Culvert inlet surcharged with out-of-bank flow. Loss of floodplain storage estimated as approximately 77m^3. Compensatory storage can be provided in-line by widening the channel and formation of a 2-stage channel.
Crossing 4 (Unnamed Drain 3)	Downstream only	115.39	115.95	IB	115.69	116.1	IB	Flow in-bank both upstream and downstream. No impact on flood risk.
Crossing 5 (Unnamed Drain 4)	D/S mainly - small section u/s approx 3m	115.71	116.23	IB	116.12	116.43	IB	Flow in-bank both upstream and downstream. No impact on flood risk.
Crossing 5a (Dry Channel) (Unnamed Tributary 1 of Gelly Burn)	Downstream only	115.91	116.43	IB	116.29	116.63	IB	Flow in-bank both upstream and downstream. No impact on flood risk
Crossing 6 (Unnamed Trib. 2 of Gelly Burn)	Downstream only	112.46	113.11	IB	112.93	113.33	IB	Flow in-bank both upstream and downstream. No impact on flood risk

Crossing	Description of Extension	Downstream condition			Upstream condition			Impact & Flood Risk Management (Comments)
		Water level*	Bank level*	Flow condition	Water level*	Bank level*	Flow condition	
		mOD	mOD	IB / OB	mOD	mOD	IB / OB	
Crossing 7 (Gelly Burn - North)	Downstream only	112.81	113.48	IB	113.21	113.67	IB	Flow in-bank both upstream and downstream. No impact on flood risk
Crossing 8 (Unnamed Drain 5)	Downstream only	115.23	115.93	IB	115.95	116.41	IB	Flow in-bank both upstream and downstream. No impact on flood risk
Crossing 9 (Unnamed Trib. 3 of Gelly Burn - North)	Downstream only	115.19	116	IB	115.86	116.43	IB	Flow in-bank both upstream and downstream. No impact on flood risk
Crossing 10 (Broomhill Burn)	Stream realigned vertically - downstream extension	118.44	118.49	IB	118.82	118.74	IB	In the existing scenario, flow in-bank downstream but 'out-of-bank' upstream. The existing culvert cross sectional area is to be increased by 44%, thus significantly improving its flow capacity and decreasing water level at the inlet thereby increasing the available freeboard and reducing the flood risk to the A9 Road level. Channel will be vertically re-graded and the channel cross section increased attenuating any marginal increase in downstream flow. No impact on flood risk both upstream and downstream.
Crossing 11	Downstream only	119.84	120.16	IB	120.13	120.29	IB	Flow in-bank both upstream and downstream. No impact on flood risk
Crossing 12	Downstream only	119.89	120.15	IB	120.22	120.32	IB	Flow in-bank both upstream and downstream. No impact on flood risk
Crossing 13	Downstream only	119.31	120.08	IB	120.17	120.62	IB	Flow in-bank both upstream and downstream. No impact on flood risk

Annex B: Hydraulic Modelling Report

JACOBS

A9 Dualling: Luncarty to Pass of Birnam

Hydraulic Modelling Report
Final

March 2014

JACOBS

Contents

1 Introduction

As part of the A9 Dualling: Luncarty to Pass of Birnam project a detailed Environmental Statement (ES) has been undertaken. This includes the assessment of fluvial flood risk associated with the proposed scheme, which has required detailed hydraulic and hydrological modelling. This document describes the river hydraulics modelling component of the work and forms an annex to the Flood Risk Assessment, which is Appendix A9.2 of the ES. The modelling work has also been used to inform wider project deliverables, for example the proposed drainage for the proposed scheme.

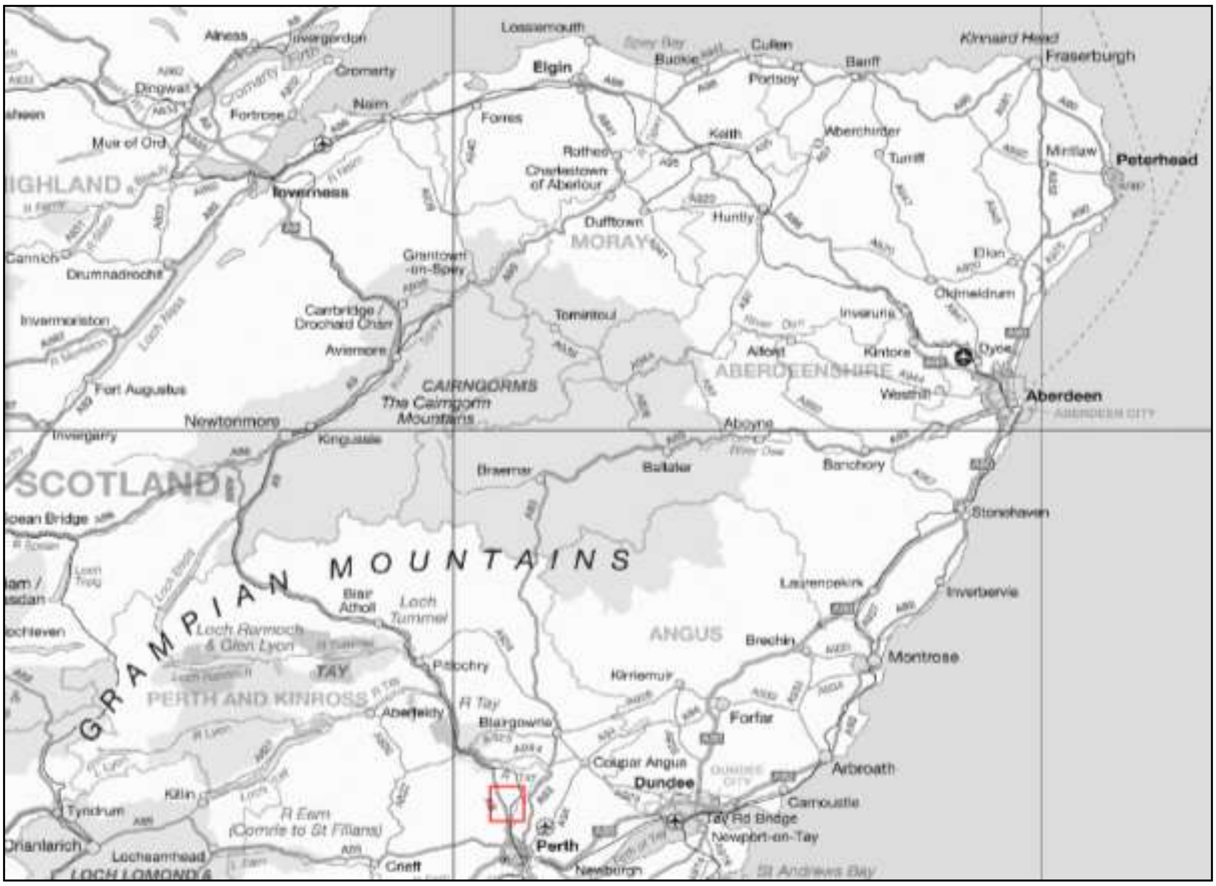
A separate hydrology report has been produced by Jacobs, which should be read in conjunction with this document; this is included in the ES as Appendix A9.1.

The ISIS model files and results files have been made available.

1.1 Background and Aims

The A9 is a major arterial road running from Dunblane to Inverness. Transport Scotland intends to upgrade the road from single to dual carriageway from Perth to Inverness. The work described in this report has been completed to support the assessment of the proposed scheme extending from Luncarty to Pass of Birnam, as shown on Figure 1.

Figure 1: Location of study area



To support the assessments reported in the ES and project design, a number of specific hydraulic and flood risk analysis tasks were required to be addressed by the modelling work, as follows:

a) Impact of extending A9 culvert crossings at Shochie Burn and Ordie Burn:

The A9 crosses two major Burns; Shochie Burn and Ordie Burn, which are culverted under the road immediately North of Luncarty. Modelling is required to determine the flood risk impact of the extension of the road culverts as well as provide the hydraulic profile for the culvert design.

b) Impact of proposed Tullybelton/Stanley Junction and Bankfoot Junction on fluvial floodplain:

The dual carriageway design includes a number of embanked junctions, two of which (Tullybelton/Stanley Junction and Bankfoot Junction) are situated within the functional floodplain of the fluvial system. The work is required to assess the flood risk impact of these two features and assess the need for and scope of potential flood mitigation options.

c) Design of proposed tributary culvert at Tullybelton/Stanley Junction:

At the proposed Tullybelton/Stanley *junction, a tributary of Ordie Burn (designated Tributary 05) runs through the footprint of the proposed junction. The modelling work is required to inform the hydraulic specification of the proposed culverted reaches of this tributary watercourse.*

d) Proposed attenuation pond at Shochie Burn left bank viability assessment:

Flood outline mapping is required to assess the viability of proposed locations of highway drainage retention ponds. There is one proposed retention pond which is within relatively close proximity of the watercourse and therefore warrants investigation in terms of assessing whether there are potential flood risk constraints associated with its location. This is the proposed pond in the area on the left bank of Shochie Burn downstream of the A9 crossing.

e) Input to highway drainage design:

The maximum water level at the 3.33%AEP (30 year) storm event is required at selected river locations to inform the design of highway drainage outfalls.

f) Flood risk downstream of overall scheme – Luncarty town:

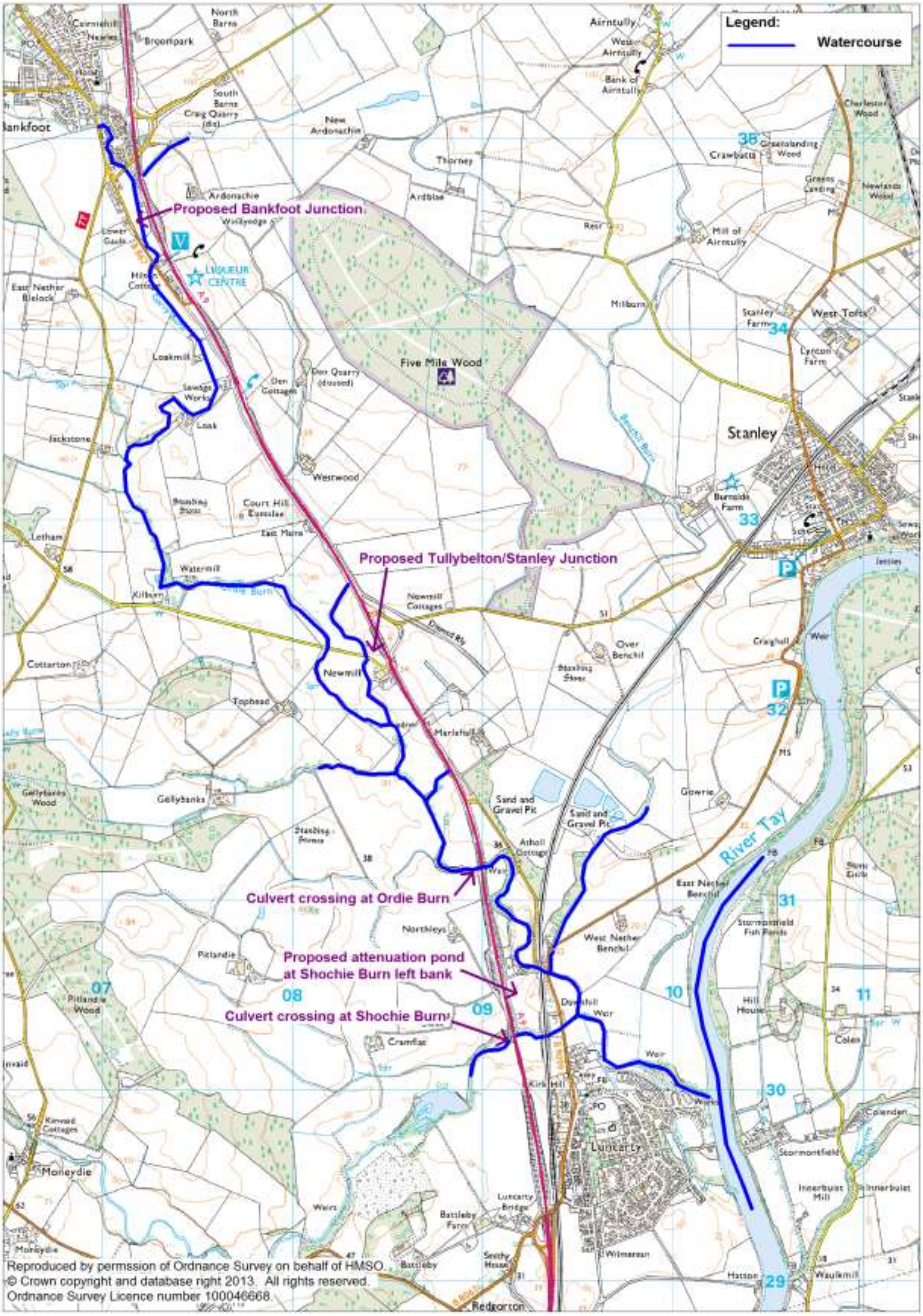
The watercourse through the study area flows through a predominantly rural landscape within the immediate vicinity of the proposed scheme. Downstream of the proposed scheme, however, the watercourse enters the town of Luncarty, which represents an area of vulnerable receptors (people/properties etc).The model is required to assess the impact of the proposed scheme on flood risk to the town of Luncarty.

g) Frequent event analysis:

Further model simulations for 50% AEP (2 year) storm events is required to assess scheme performance under more common flow conditions.

Figure 2 shows the location of the key areas within the proposed scheme described above.

Figure 2: Study area with key design scheme features



2 Methodology

2.1 Previous Studies

A flood protection scheme study was undertaken by Halcrow Consultants in 2010[1] for the town of Bankfoot. However this work does not cover any of the study extents of the present work and was not utilised beyond the initial review.

2.2 Hydrology

Design runoff from the catchment was provided by the Jacobs Hydrology team. The separate hydrology report (Appendix A9.1 of the ES) produced by Jacobs (20132) provides a detailed account of how the hydrological inputs to the hydraulic modelling were derived.

2.3 Model Extents

The model extends over a reach of the watercourse comprising: 1km of Shochie Burn, 5km of Ordie Burn and 2.4km of Garry Burn. The modelled reaches within the study area are shown on Figure 3. The model has been extended sufficiently downstream to prevent any boundary effect on the model results.

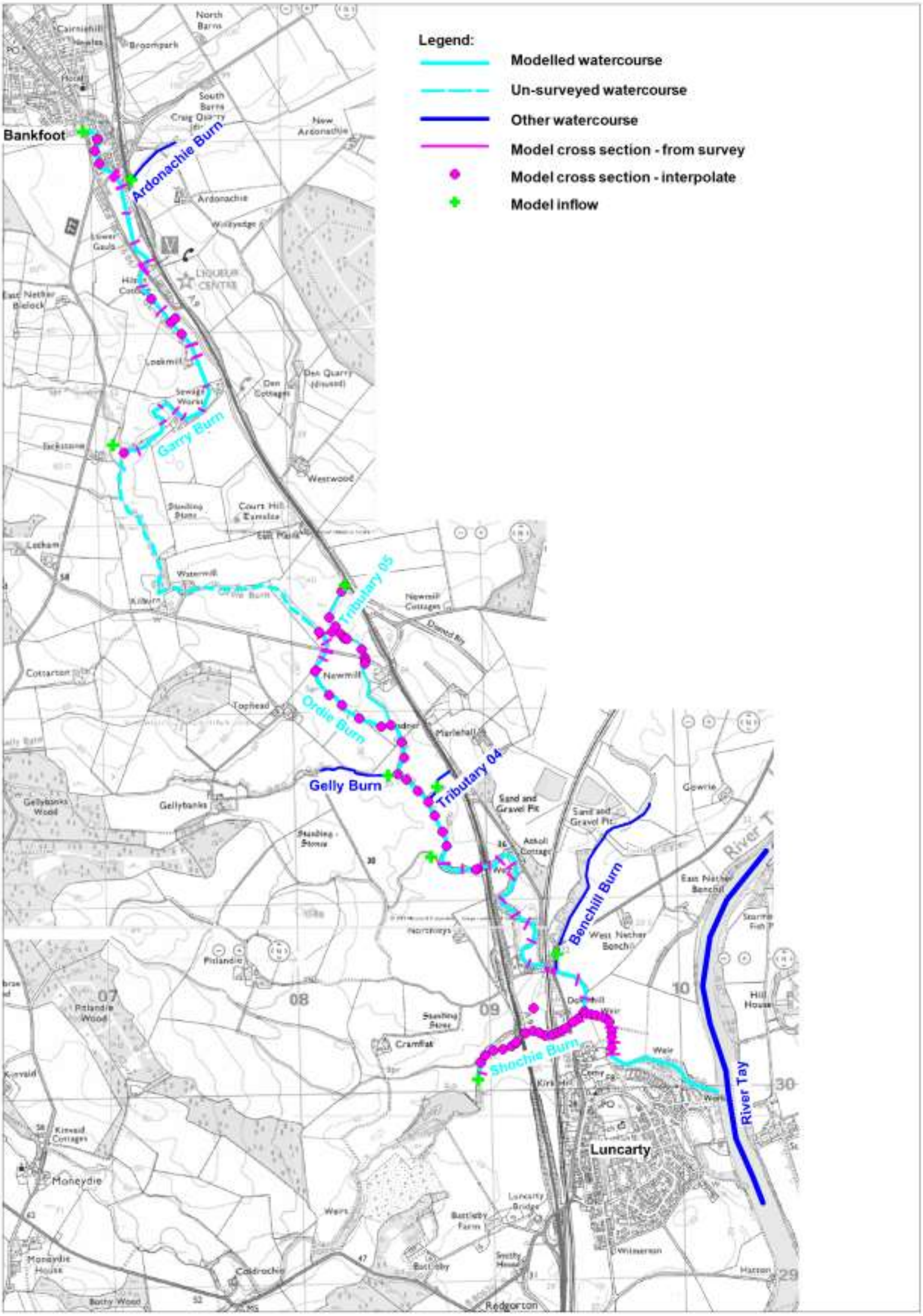
2.4 Model Schematisation – Existing situation

A 1D (One dimensional) hydraulic model of the Shochie, Ordie and Garry Burn Fluvial system (Figure 3) was constructed using ISIS V3.6 river modelling software (CH2MHill). The model was constructed as follows:

- The existing situation model was informed with cross section data collected by Jacobs Geomatics.
- Banktop markers were assigned to model sections.
- Hydraulic roughness coefficients were reviewed within the scheme reach using available site photographs as per the schedule provided in Table 1 with reference to standard guidance.
- Water course crossings were represented using ISIS bridge units, culvert conduit sections, and orifice units.
- Minor head losses within the model were reviewed using the ISIS guidance.
- Floodplain storage was modelled using ISIS reservoir units. Reservoir geometry was informed by surveyed topography where possible, and made use of the available 5 m DTM outside of the survey extents. The 5 m DTM has a coarser resolution and less vertical accuracy than the topographic survey, however its geographic coverage is greater; the topographic survey being limited to the immediate vicinity of the proposed design scheme features rather than the whole catchment area.
- Lateral and inline spill profiles were obtained from detailed topographic survey.
- 1.5 km of un-surveyed Ordie Burn watercourse from the Garry Burn Confluence to upstream of the floodplain near Newmill Farm was modelled using ISIS Muskingham routing sections.
- A Normal Depth Boundary boundary unit, based on the upstream bed profile, was implemented at the downstream extent of the model
- Model Inflows were provided by Jacobs Hydrology as FEH rainfall Runoff units. These were entered into the model at appropriate locations and flows were scaled to fit statistical runoff estimates at key watercourse locations.

[1] Halcrow (2010) Bankfoot Flood Protection Scheme. Stage 2 Report
[2] Jacobs (2013) A9 Luncarty to Birnam Hydrology Report

Figure 3: Modelled Watercourses



2.5 Model Roughness Coefficients

Following site inspection, the model roughness coefficients were reviewed within the scheme extents using the Manning's 'n' schedule outlined in Table 1.

Table 1: Manning's '*n'* baseline model roughness coefficients, values determined using CIRIA Guidance (R168).

Category	Baseline value	Notes
Existing concrete	0.015	Good Joints, rough finished walls
Existing out of bank scrub	0.060	Light Brush and Trees
Existing channel bed main Rivers	0.056	Cobbles and large boulders.
Existing channel bed Tributary	0.040	Steep, straight, submerged at high flows
Existing corrugated metal culvert	0.022	
Existing A9 culvert Bed	0.030	cobbled

2.6 Model Schematisation – Design situation

Updates were made to the existing situation model to represent the design situation as follows:

General:

- The design model was informed by drawings provided by the Jacobs design team.
- Design situation roughness coefficients were updated in line with the design specification.

Extending culvert A9 crossings at Shochie Burn and Ordie Burn:

- Additional culvert sections were added immediately upstream of the existing twin barrel culvert units as described in Table 2. The new extension is a single barrel culvert. Within the model, in the existing scenario, the reach immediately upstream of the culvert is included as open river sections representing the watercourse. In the design scenario, a length of this open channel reach (16m on the Ordie Burn culvert and 20m on the Shochie Burn culvert) is replaced with culvert sections representing the extension of the culvert into previously of open channel. The dimensions were informed by the topographic survey and the drawings provided by the Jacobs design team.

Table 2: A9 culvert crossing extensions: schematisation within design model. ('LH' denotes left hand, 'RH' denotes right hand).

	Shochie Burn A9 crossing			Ordie Burn A9 crossing		
	Existing LH culvert	*Existing RH culvert*	*Upstream extension culvert*	*Existing LH culvert*	*Existing RH culvert*	*Upstream extension culvert*
Inlet invert level (m AOD)	17.085	17.085	16.928 (ties in with upstream bed level)	21.851	21.590	21.651
Outlet invert level (m AOD)	17.036	17.036	17.085 (i.e. ties in with existing culvert inlet invert level)	21.546	21.520	21.651
Inlet soffit level (m AOD)	19.485	19.485	19.328	23.851	23.790	23.851
Outlet soffit level (m AOD)	19.436	19.436	19.485 (i.e. ties in with existing culvert inlet soffit level)	23.546	23.520	23.851(i.e. ties in with existing LH culvert inlet soffit level)
Length (m)	46	46	20	30	30	15.6
Width (m)	4.5	4.5	9.5	4.6	4.6	9.5
Headroom (m)	2.4	2.4	2.4	2	2.2	2.2

Incorporating proposed Tullybelton/Stanley Junction and Bankfoot Junction:

- The reservoir unit geometry was updated to reflect the change in ground levels associated with implementing new road embankment. Embankment levels supplied by the Jacobs design team were used to modify the existing situation DTM grid, interrogation of which was then undertaken in order to update the appropriate reservoir and spill units.
- At the Tullybelton/Stanley Junction, two additional circular culverts in sequence have been introduced on Tributary 05 to reflect required crossings under the new embankment. It is anticipated that the existing corrugated metal culvert will be replaced by a longer culvert spanning the width of the road embankment at this location. The dimensions of the culverts are informed by the Jacobs design team drawings. The diameter of the proposed culvert is 900 mm (as per the existing culvert).
- In order to achieve a neutral impact on pass forward flow and water level downstream of the proposed Tullybelton/Stanley Junction a flow control structure will be required on this reach. The model represents such a structure as a 300mm diameter orifice plate located at the inlet to the upstream culvert. The risk of blockage will be mitigated by constructing the orifice plate within a chamber with an appropriately design trash screen.
- The arch bridge span is moved to account for realignment associated with the proposed new junction.

2.7 Key Model Assumptions

The following assumptions were made in the modelling work:

- The model is a 1D ISIS model with floodplain areas represented as reservoir units. The representation of the watercourse and floodplain in 1D is deemed to be appropriate for the study catchment as, based on site inspection and topographical analysis, there is no complex interaction between in-channel and out-of-bank flows and there are no complex flow splits within the floodplain.
- The model has not been quantitatively verified against gauge data; given the suspect quality of the high flow data at the Ordie Gauging Station, it would not be appropriate to calibrate the model against this data set. Although the quality of the high flow data at the Garry Burn gauge is of a relatively good quality, it was considered that calibrating the Garry Burn model alone would not be advantageous to the calibration of the Ordie Burn model.
- The purpose of the modelling was to assess the impact of the design scheme on the fluvial hydrological regime of the study area and therefore the focus is on comparison of pre- and post-design flood risk at specific locations; those within the vicinity of the key design scheme features shown on Figure 2. The model at these key locations is considered to be sufficiently accurate for assessing the impact of the scheme and utilises a detailed schematisation based on good quality, accurate data. There are some locations within the study area which are not within immediate direct hydraulic connectivity with the proposed design scheme. On these reaches it has been considered appropriate to use a less detailed modelling approach, and a wider spacing of cross sections and simplistic schematisation - using Muskingham routing sections - has been adopted.
- The data from which the model is built, and the nature of the approach taken in its construction, are considered to be appropriate for producing a model which is sufficiently reliable for the purpose of meeting the specific objectives of the study.
- The results of the modelling are interpreted in the context of inherent modelling inaccuracies. On this basis, it is considered reasonable to interpret model results showing a change in water levels of less than 10mm between the existing and design scenarios as being negligible.

3 Model Results

3.1 Model Runs

In order to fully test the flood risk implications of the proposed scheme the following suite of model simulations were undertaken:

1. Baseline Existing Situation: 50% AEP (2 year); 3.33% AEP (30 year); 0.5% AEP (200 year); and 0.5%AEP (200 year) +20% Climate Change events.
2. Baseline Design Situation: 50% AEP (2 year); 3.33% AEP (30 year); 0.5% AEP (200 year); and 0.5%AEP (200 year) +20% Climate Change events.

The critical storm duration varies throughout the catchment as follows: Ordie Burn reach - critical storm duration = 12.1 hours; Shochie Burn reach - critical storm duration = 13.5 hours; Garry Burn reach - critical storm duration = 11.7 hours. As such, the model is run for each of these durations and the relevant results for the reach of interest is used in the analysis.

3.2 Model Outputs

The extents of the model are described in Section 2.3 and Figure 3. The full set of model results files have been provided along with the actual model files, therefore modelled outputs (e.g. stage; flow; velocity) at each model cross section/reach throughout the study area can be obtained through interrogation of these results files. For ease of reference and to aid discussion of the impact of the proposed scheme on flood risk, results at key locations are presented within the relevant sections of this report.

It was not within the scope of the study to produce mapped flood outlines throughout the whole modelled study area; rather, outlines were produced at key locations in order to inform the proposed scheme design and assessment of its effect on flood risk. The flood outlines have been mapped through applying modelled maximum flood levels - taken from the results of the ISIS model at the reservoir units representing the floodplain - to topographic survey data (or LIDAR data where coverage of topographic survey is limited) within the floodplain. These flood outlines are presented and described in the relevant sections below.

3.3 Key model tasks

The key tasks for the model were set out in Section 1 of this report. The following sections describe the model results for each of the tasks and demonstrate how the modelling objectives have been met.

a) <u>Impact of extending culvert crossings at Ordie Burn and Shochie Burn:</u>

The A9 crosses two major Burns; Shochie Burn and Ordie Burn, which are culverted under the road immediately North of Luncarty. Modelling is required to determine the flood risk impact of the extension of the road culverts as well as provide the hydraulic profile for the culvert design.

The behaviour of the hydraulic system within the vicinity of the A9 crossing culverts at Shochie Burn and Ordie Burn is captured by the model. The water level in the reach upstream and downstream of the culverts during extreme events is controlled by the design characteristics of the culverts. The nature of the design characteristics is the dominant exerting influence on the upstream water stage as they determine the head required to drive flows through the structure. The following variables (amongst others) can exert a control over the upstream and downstream levels:

- culvert dimensions (width/length);
- culvert shape;
- material from which the culvert is made (roughness); and
- entrance/exit design (type of wingwalls).

By extending the culverts upstream at Shochie Burn and Ordie Burn, the design characteristics of the culverts have changed which affects the hydraulic control on water levels upstream. In addition, a length (16m on the Ordie Burn culvert and 20m on the Shochie Burn culvert) of open watercourse immediately upstream of the existing culvert is no longer accessible to flows as it has been replaced by culvert. In the case of the Ordie Burn culvert extension, the open watercourse reach immediately upstream of the existing culvert comprises in-bank channel and vegetated out-of-bank. In the case of the Shochie Burn culvert extension, the open watercourse reach immediately upstream of the existing culvert comprises in-bank channel with minimum out-of-bank functional floodplain (a feature of the steep-sided banks in this location).

As a result of the changes described above, changes to the upstream stage have resulted, as observed in the modelling outputs and described in detail below.

(i) Ordie Burn

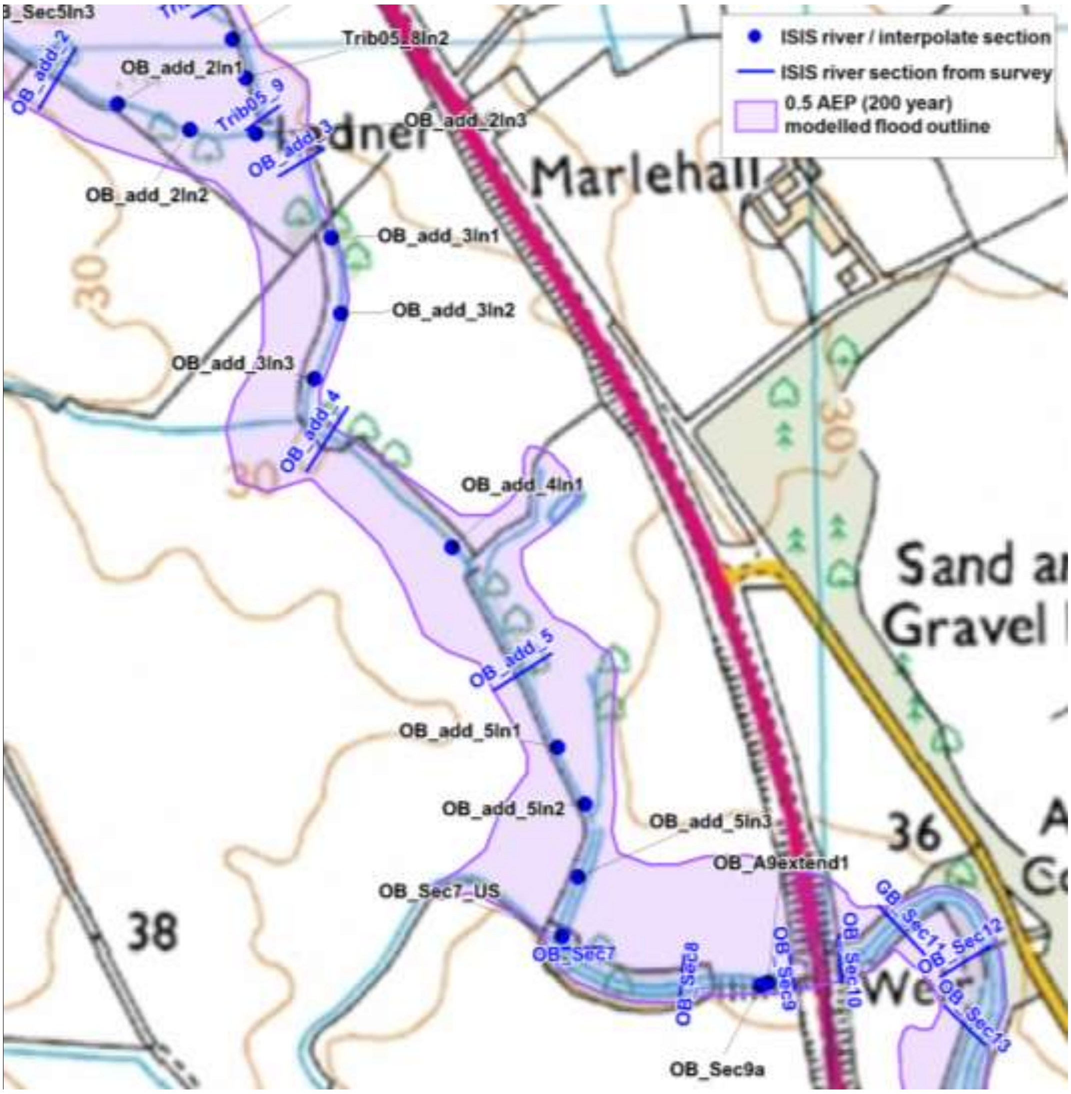
The results of the modelling demonstrate that the introduction of the proposed culvert extension upstream result in a slight increase in peak stage within the reach immediately upstream of the culvert entrance. In order to provide clarification on what the increase in stage associated with the proposed new culvert extension looks like in terms of area affected, the images included below demonstrate pre and post scenario flood risk:

- descriptively;
- plan view;
- cross section view;
- long profile view; and
- tabular view.

Box 1: Description of flood risk associated with Ordie Burn culvert extension

The proposed works will result in raising water level immediately upstream of the culvert; 251 mm for a 0.5% AEP (1:200) flood and 360 mm for a 0.5% AEP (1:200) flood including an allowance for the impact of climate change. The impact of raised water levels upstream will diminish, and extend 550 m and 890 m upstream of the culvert inlet respectively. This increase in stage over the length of reach affected is equivalent to 1,039 m^3 volume of water for the 0.5% AEP (1:200) event. The increase in the width of the flood envelope immediately upstream of the culvert associated with the implementation of the scheme is less than 4 m for a 0.5% AEP (1:200) flood and less than 9 m for a 0.5% AEP (1:200) flood including an allowance for the impact of climate change. Introducing the new culvert extension results in the pass forward flows through the overall structure slightly decreasing, producing a slight decrease in stage in the reach immediately downstream of the A9 culvert exit. This decrease is minimal and considered to be negligible (6 mm decrease for the 0.5% AEP (200 year) event and up to 8 mm for the 0.5% AEP (200 year) plus 20% climate change allowance event).

Figure 4: Plan view - Ordie Burn model schematisation and modelled flood plain within vicinity of A9 crossing culvert. NB: The increase in the flood outline associated with the culvert extension is minimal and therefore indiscernible on this plan view flood map. See Figures 5 to 7 and Tables 3 to 4 below for a detailed representation of the increase in upstream stage associated with the proposed scheme at this location.



Figures 5a to 5f : Cross section views - ISIS model screenshots of Ordie Burn reach upstream of A9 crossing culvert. (Existing scenario 0.5% AEP event = red line; Design scenario 0.5% AEP event = pink line; Existing scenario 0.5% AEP event with Climate Change = dark blue line; Design scenario 0.5% AEP event with Climate Change = light blue line)

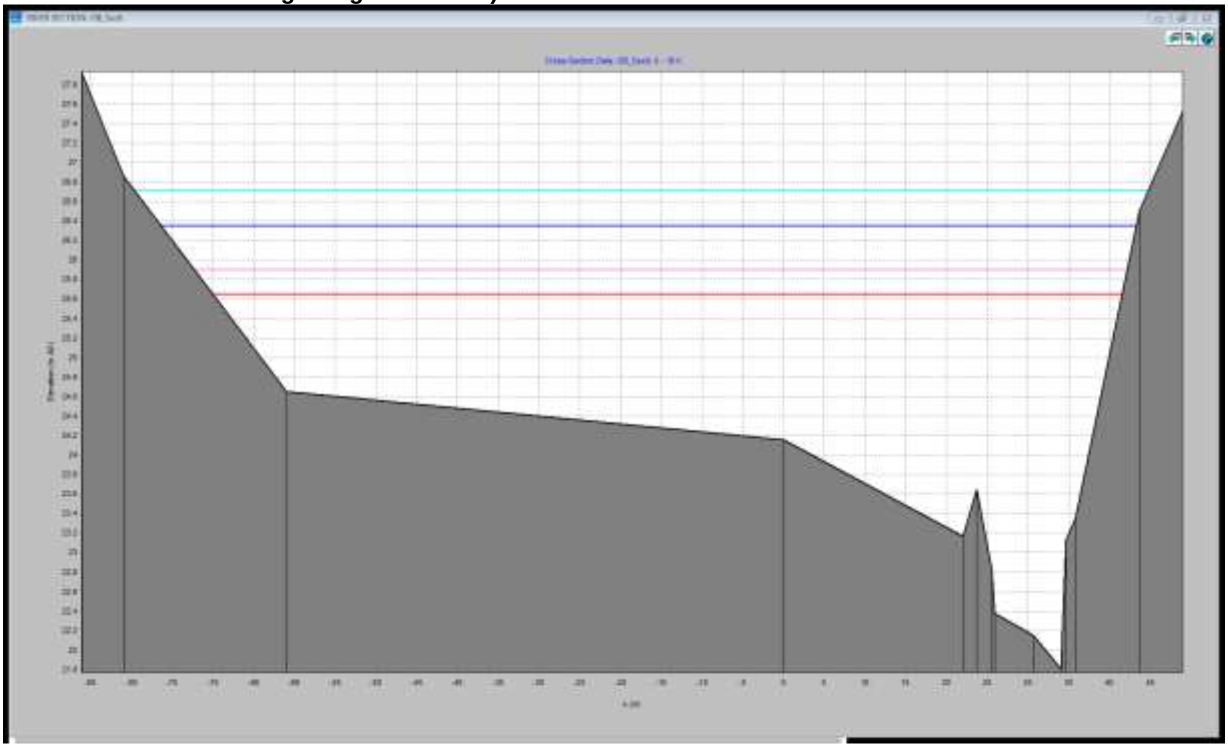


Figure 5a: Cross section OB_Sec8

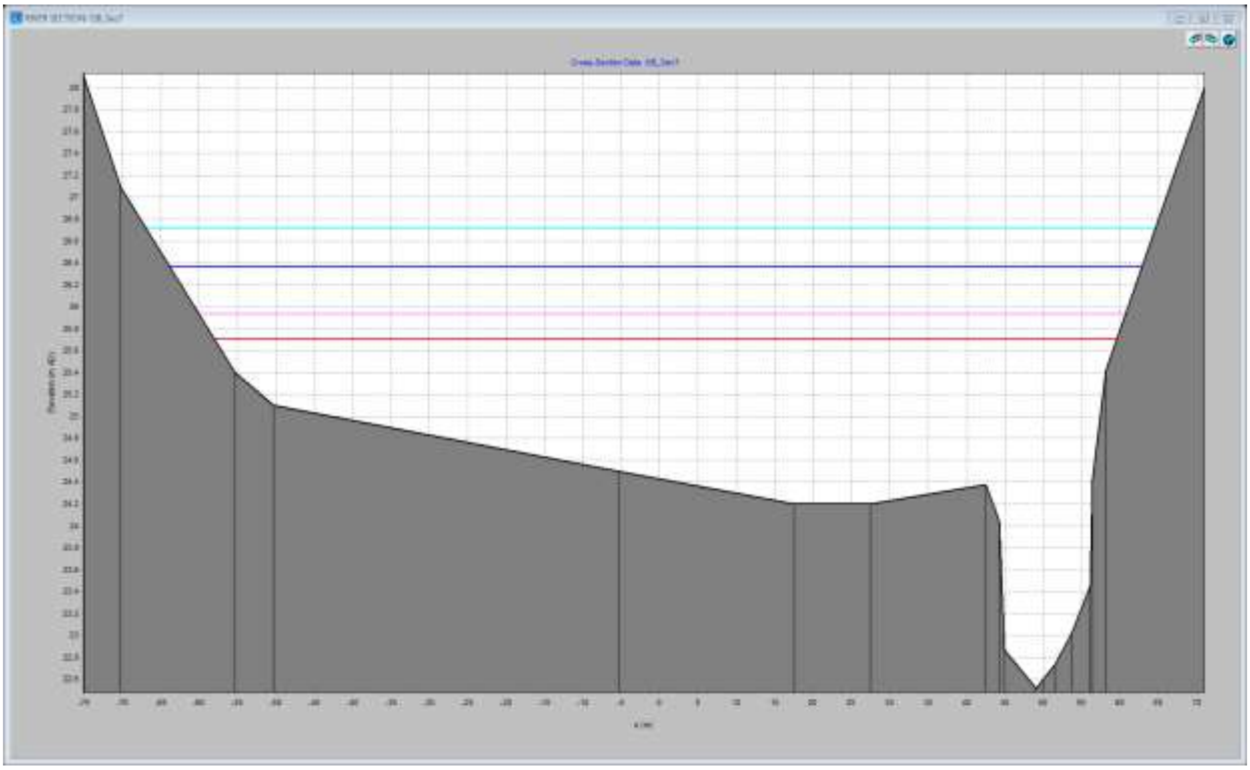


Figure 5b: Cross section OB_Sec7

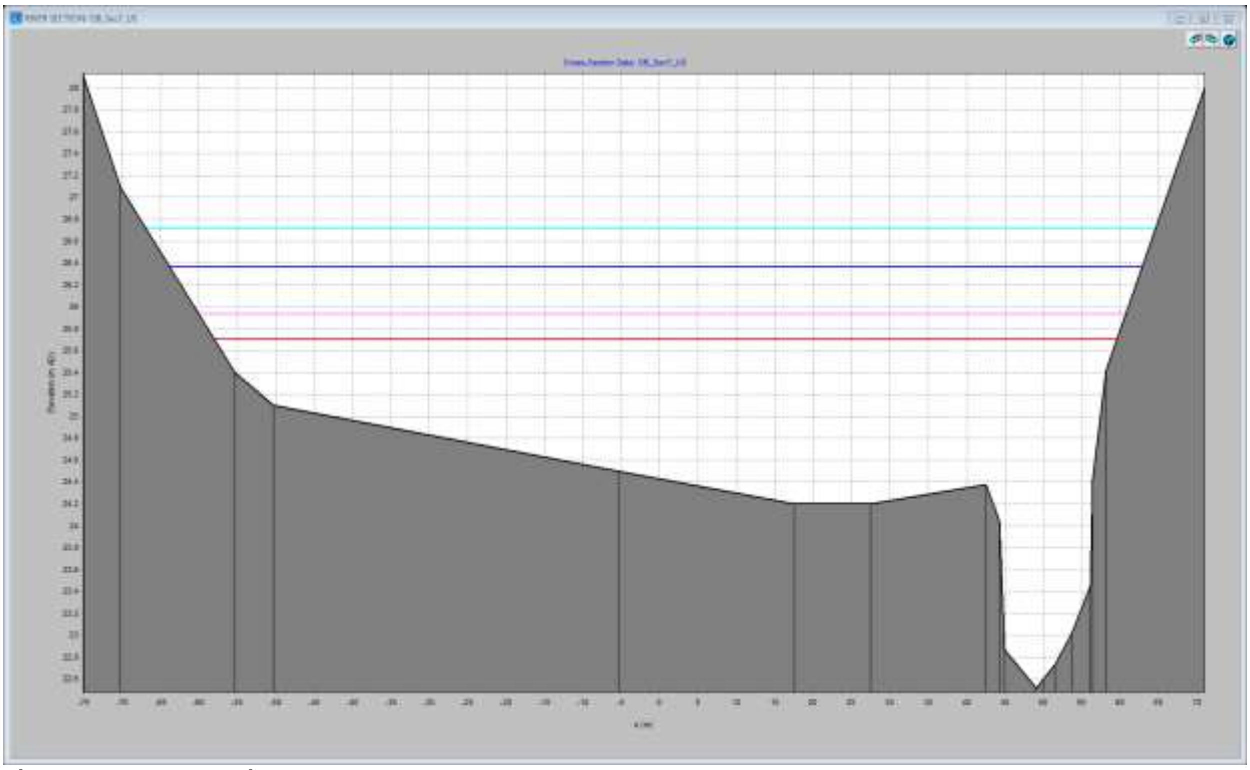


Figure 5c: Cross section OB_Sec7_US

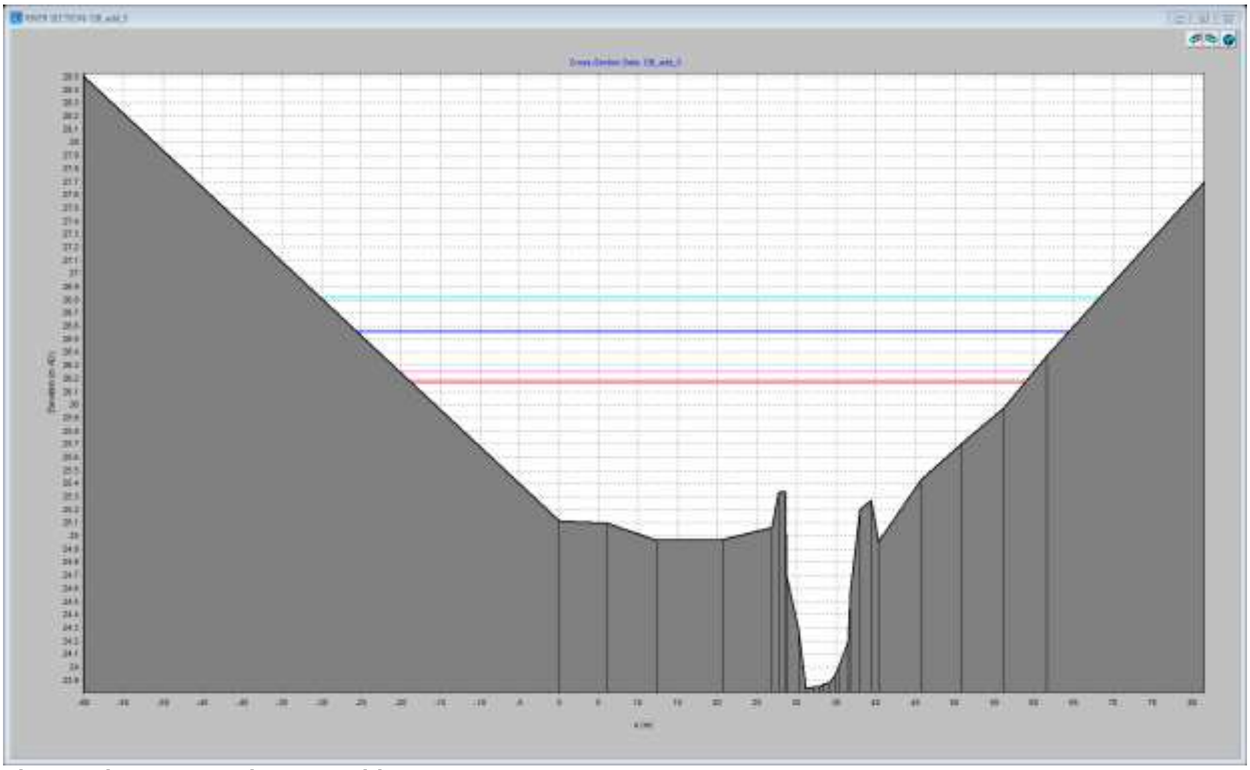


Figure 5d: Cross section OB_add_5

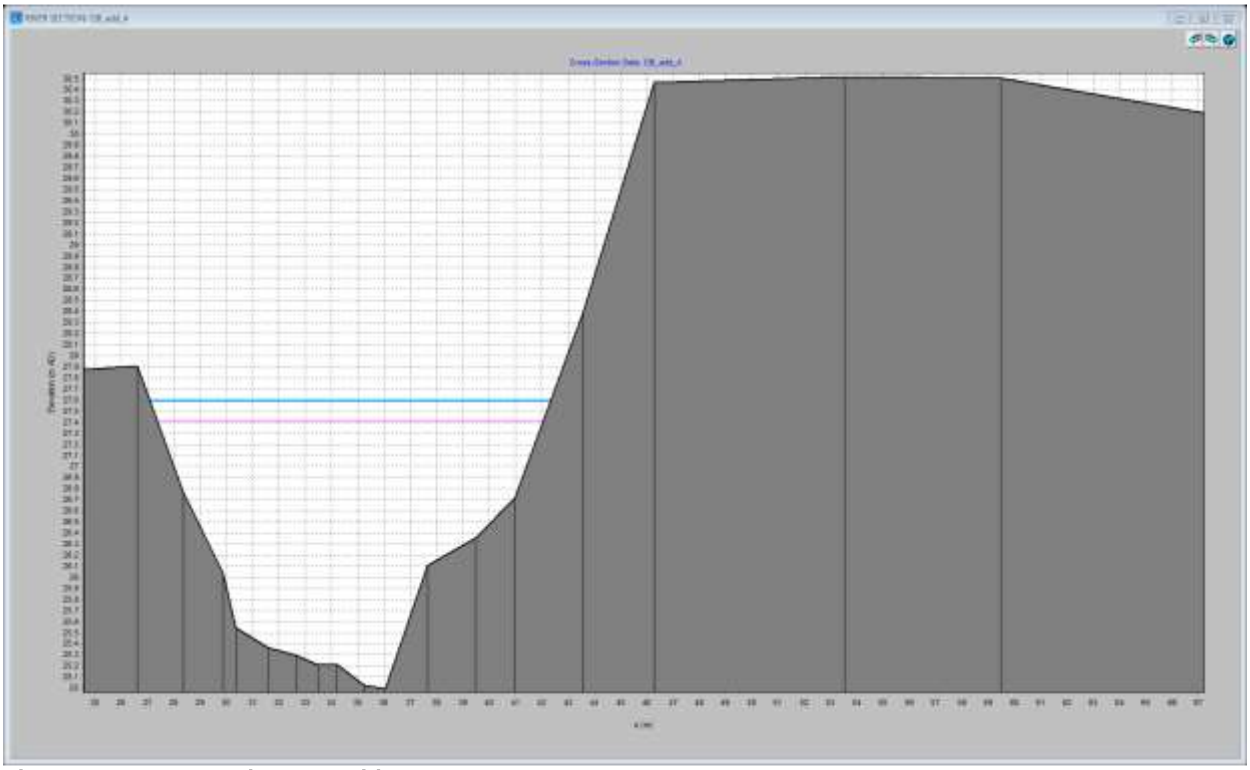


Figure 5e: Cross section OB_add_4

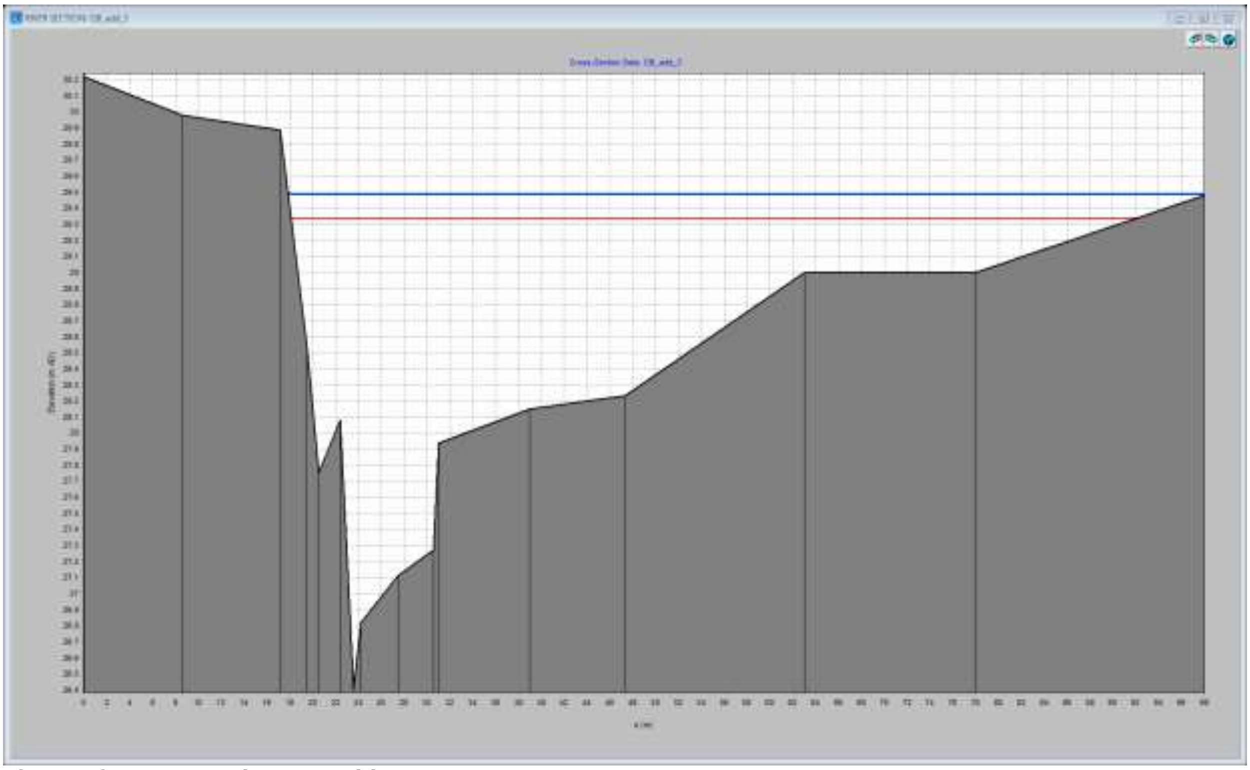


Figure 5f: Cross section OB_add_3

Figure 6: Long profile view: ISIS model screenshot of Ordie Burn long profile upstream of A9 crossing culvert. (Existing scenario 0.5% AEP event = red line; Design scenario 0.5% AEP event = pink line; Existing scenario 0.5% AEP event with Climate Change = dark blue line; Design scenario 0.5% AEP event with Climate Change = light blue line)

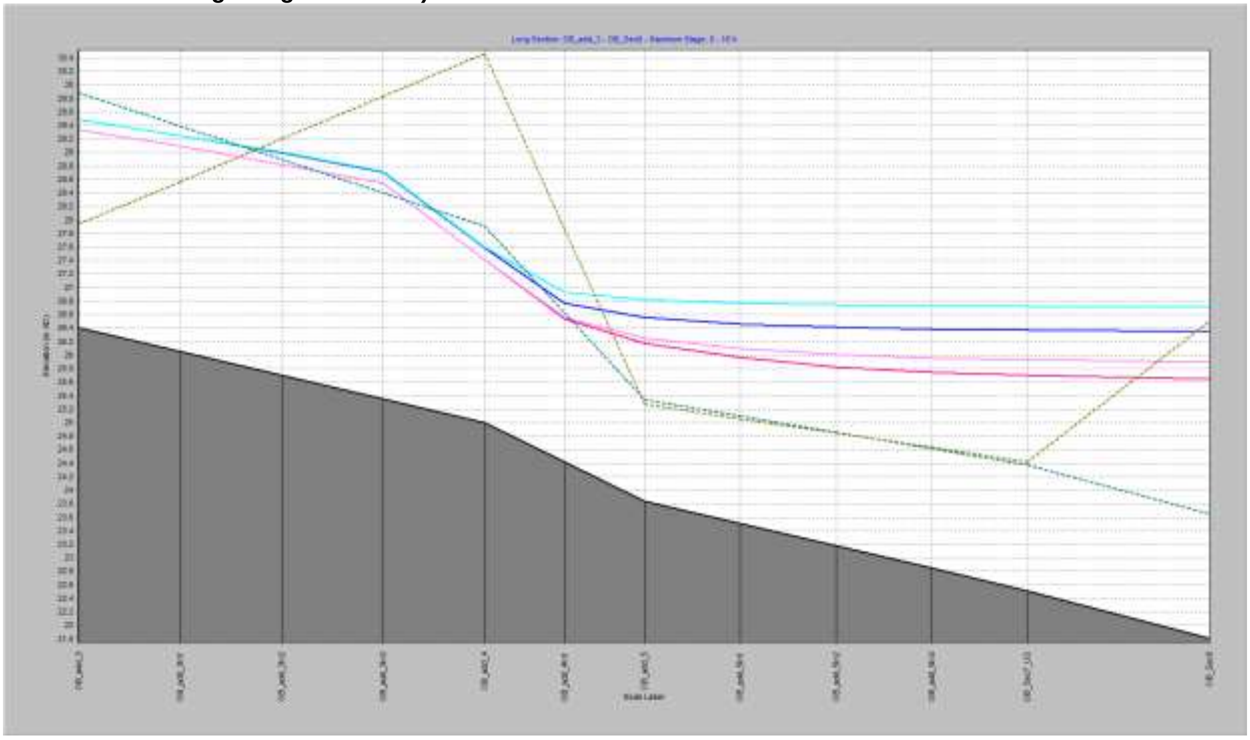


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Figure 7: Long profile view: Ordie Burn long profile within vicinity of A9 crossing culvert showing culvert position and downstream reach

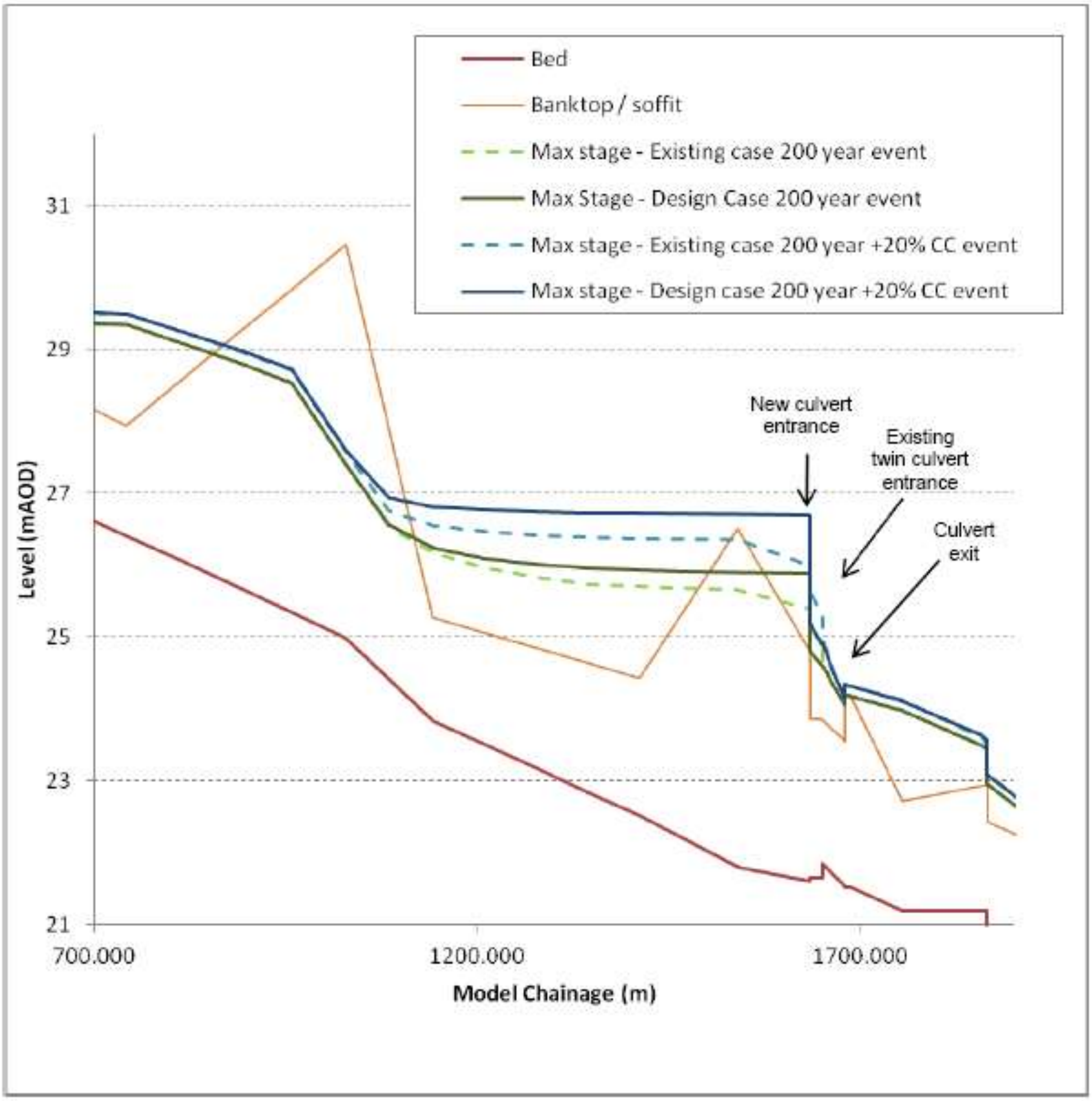


Table 3: Tabular view: 0.5% AEP (200 year) model results at Ordie Burn reach upstream of A9 crossing culvert

	Distance upstream from new culvert entrance (m)	Existing Scenario Max Stage 200 year (mAOD)	Design Scenario Max Stage 200 year (mAOD)	Difference in max stage (Design - Exist) (m)	Existing Scenario floodplain top width 200 year (m)	Design Scenario floodplain top width 200 year (m)	Difference in floodplain top width (Design - Exist) (m)
OB_add_4	605	27.410	27.408	-0.002	14.73	14.74	0.01
OB_add_4In1	549	26.533	26.559	0.026			
OB_add_5	492	26.174	26.247	0.073	77.60	80.00	2.40
OB_add_5In1	425	25.969	26.098	0.129			
OB_add_5In2	357	25.826	26.006	0.180			
OB_add_5In3	290	25.743	25.957	0.214			
OB_Sec7	222	25.701	25.932	0.231	117.50	120.70	3.20
OB_Sec8	94	25.650	25.901	0.251	111.68	114.49	2.81
OB_Sec9a	0						
OB_A9extend1	Start of New culvert						
OB_A9d	Open channel immediately downstream of existing culvert	24.198	24.192	0.006	87.40	87.40	0.00

Table 4: Tabular view: 0.5% AEP (200 year) with Climate Change allowance model results at Ordie Burn reach upstream of A9 crossing culvert

	Distance upstream from new culvert entrance (m)	Existing Scenario Max Stage 200 year +CC (mAOD)	Design Scenario Max Stage 200 year +CC (mAOD)	Difference in max stage (Design - Exist) (m)	Existing Scenario floodplain top width 200 year CC (m)	Design Scenario floodplain top width 200 year +CC (m)	Difference in floodplain top width (Design - Exist) (m)
OB_add_3	891	29.486	29.489	0.003			
OB_add_3In1	820	29.247	29.250	0.003			
OB_add_3In2	748	28.995	29.000	0.005			
OB_add_3In3	677	28.714	28.724	0.010			
OB_add_4	605	27.592	27.601	0.009	15.24	15.27	0.03
OB_add_4In1	549	26.767	26.935	0.168			
OB_add_5	492	26.553	26.816	0.263	89.80	98.40	8.60
OB_add_5In1	425	26.463	26.769	0.306			
OB_add_5In2	357	26.412	26.743	0.331			
OB_add_5In3	290	26.384	26.728	0.344			
OB_Sec7	222	26.369	26.720	0.351	126.75	131.55	4.80
OB_Sec8	94	26.348	26.708	0.360	119.60	124.30	4.70
OB_Sec9a	0						
OB_A9extend1	Start of New culvert						
OB_A9d	Open channel immediately downstream of existing culvert	24.339	24.331	0.008	90.52	90.30	0.22

(ii) Shochie Burn

The results of the modelling demonstrate that the introduction of the proposed culvert extension results in a slight decrease in peak stage within the reach immediately upstream of the culvert entrance. The images included below demonstrate pre and post scenario flood risk:

- descriptively;
- plan view;
- cross section view;
- long profile view; and
- tabular view.

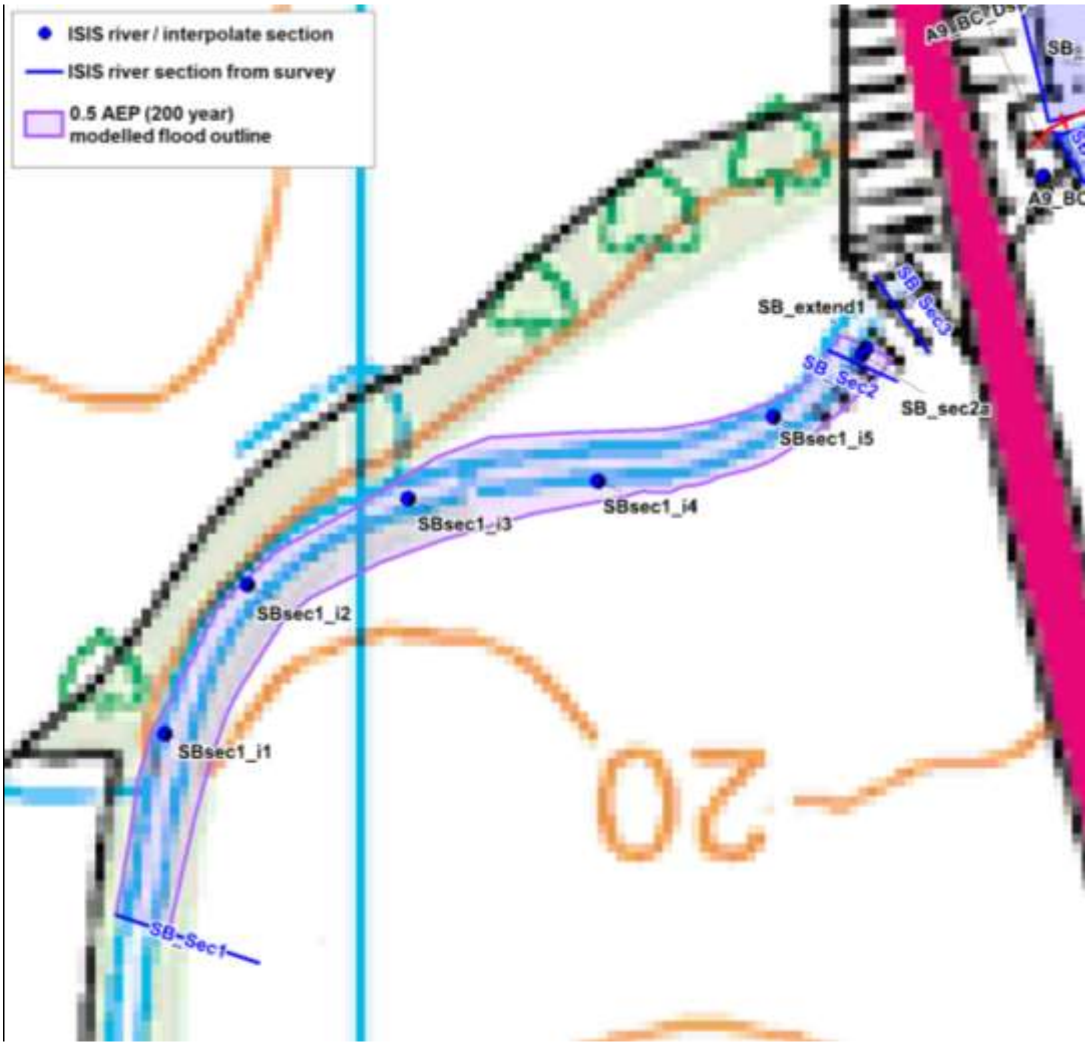
Box 2: Description of flood risk associated with Shochie Burn culvert extension

The proposed works will result in a decrease in water level immediately upstream of the culvert; 33 mm for a 0.5% AEP (1:200) flood and 37 mm for a 0.5% AEP (1:200) flood including an allowance for the impact of climate change. This decrease in water level is a result of improved culvert performance arising from the change to the hydraulic controls associated with introducing the new culvert (e.g. shape, dimensions, material, entrance design).

The impact on pass forward flow and downstream water level is predicted to be neutral.

Figure 8: Plan view - Shochie Burn model schematisation and modelled flood plain within vicinity of A9 crossing culvert.

NB: There is no discernable change to the floodplain. See Figures 9 to 10 and Tables 5 to 6 below for a detailed representation of the minor decrease in upstream stage associated with the proposed scheme at this location.



Figures 9a to 9b: Cross section views - ISIS model screenshots of Shochie Burn reach upstream of A9 crossing culvert.

(Existing scenario 0.5% AEP event = red line; Design scenario 0.5% AEP event = pink line; Existing scenario 0.5% AEP event with Climate Change = dark blue line; Design scenario 0.5% AEP event with Climate Change = light blue line)

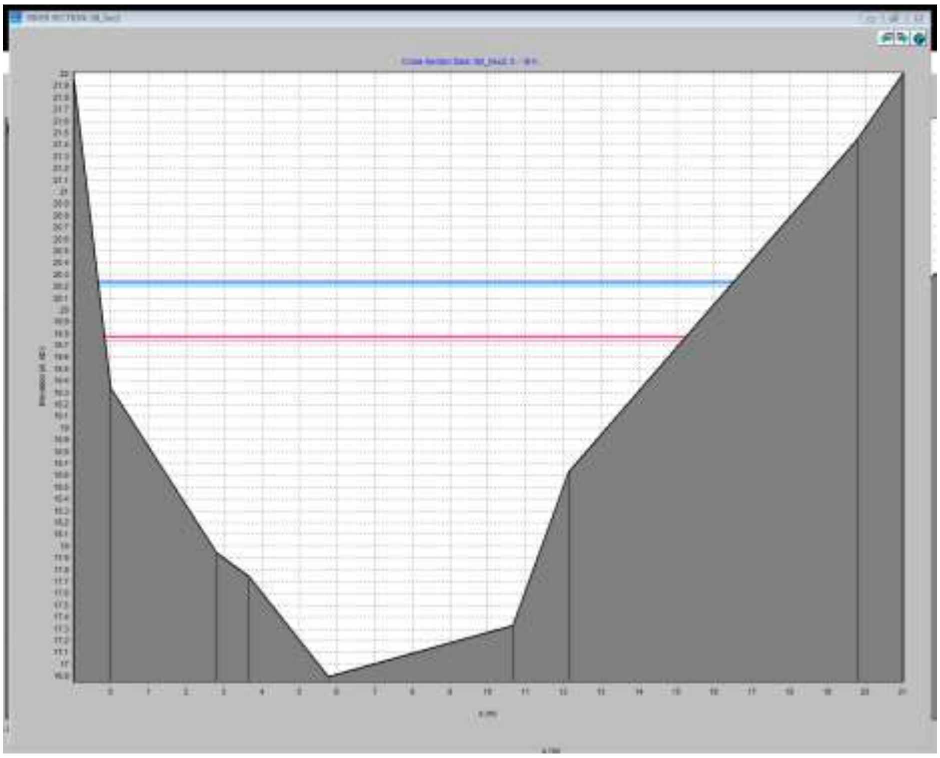


Figure 9a: Cross section SB_Sec2

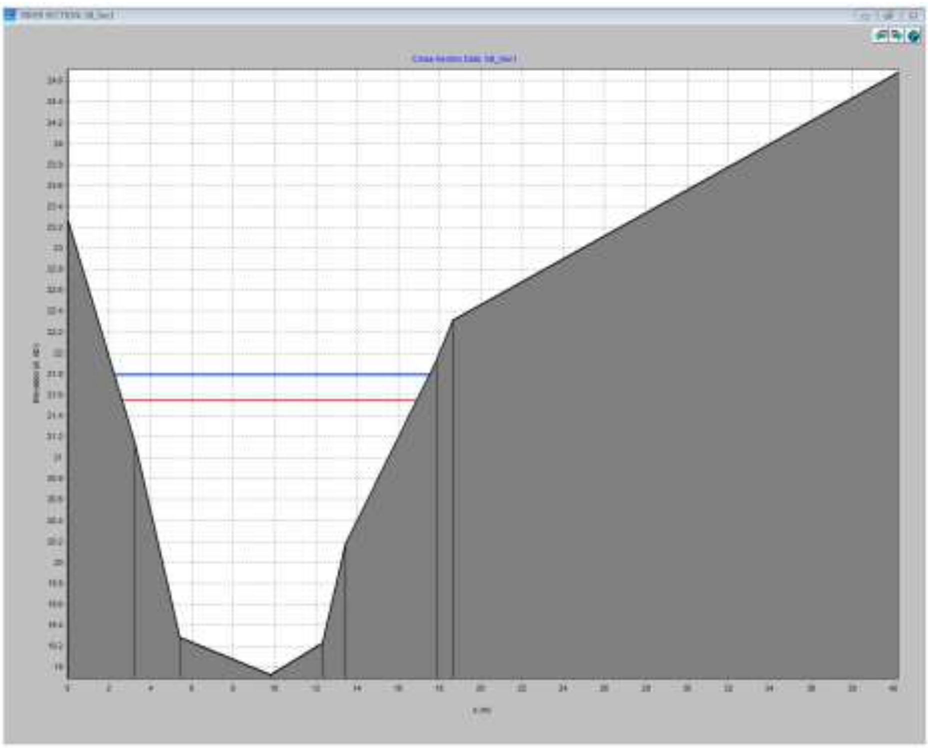


Figure 9b: Cross section SB_Sec1

Figure 10: Long profile view: Shochie Burn long profile within vicinity of A9 crossing culvert showing culvert position and downstream reach

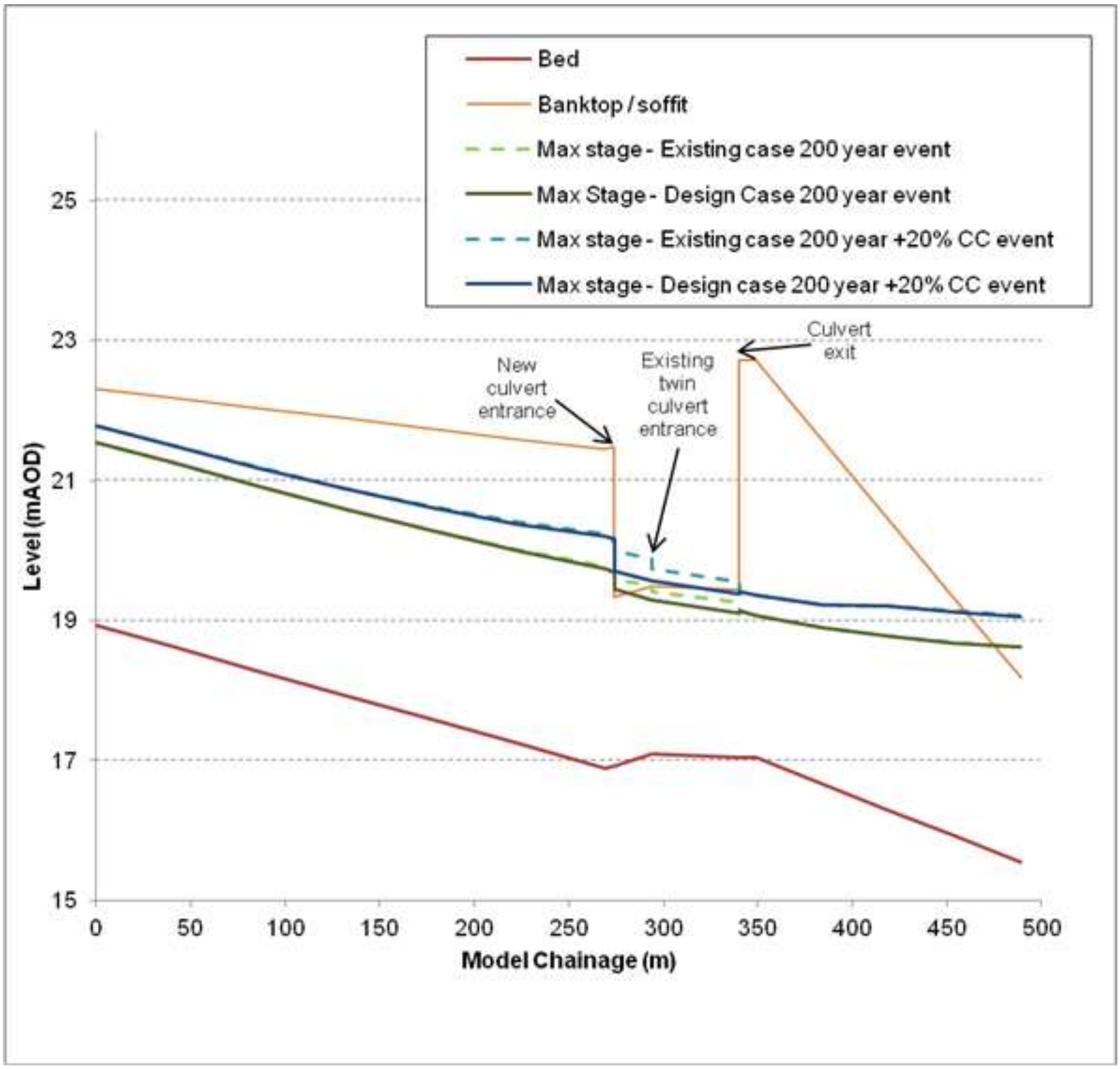


Table 5: Tabular view: Model results at Shochie Burn reach within vicinity of A9 crossing culvert

ISIS node label	Distance upstream from new culvert entrance (m)	Existing Scenario Max Stage 200 year (mAOD)	Design Scenario Max Stage 200 year (mAOD)	Difference (Design - Exist) (m)	Existing Scenario Max Stage 200 year +CC (mAOD)	Design Scenario Max Stage 200 year +CC (mAOD)	Difference (Design - Exist) (m)
SB_Sec1	274	21.545	21.544	-0.001	21.789	21.787	-0.002
SBsec1_i1	235	21.262	21.261	-0.001	21.510	21.507	-0.003
SBsec1_i2	189	20.931	20.929	-0.002	21.192	21.186	-0.006
SBsec1_i3	143	20.607	20.602	-0.005	20.894	20.884	-0.010
SBsec1_i4	97	20.296	20.285	-0.011	20.630	20.612	-0.018
SBsec1_i5	51	20.011	19.992	-0.019	20.410	20.383	-0.027
SB_Sec2	5	19.768	19.735	-0.033	20.241	20.204	-0.037
SB_Sec2a	0						
SB_extend1	Start of New culvert						
A9_BC_D	Open channel immediately downstream of existing culvert	19.130	19.130	0.000	19.416	19.416	0.000

b) Impact of proposed Bankfoot Junction and Tullybelton/Stanley Junction on fluvial floodplain:

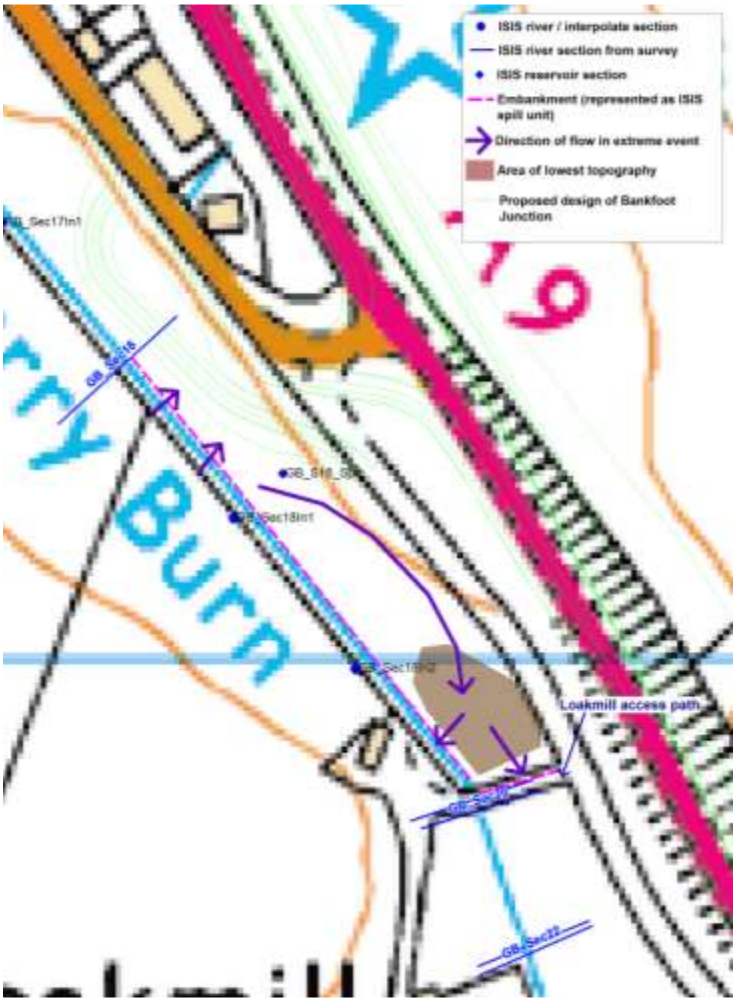
The dual carriageway design includes a number of embanked junctions, two of which (Tullybelton/Stanley Junction and Bankfoot Junction) are situated within the functional floodplain of the fluvial system. The work is required to assess the flood risk impact of these two features and assess the need for and scope of potential flood mitigation options.

(i) Bankfoot Junction

The behaviour of the hydraulic system in this area is captured by the model. This is schematised in Figure 11. During extreme events, the water level in the Gary Burn watercourse rises until it is at a level which allows it to spill over the left hand side embankment into the floodplain at its upstream end. In a 200 year event, the onset of this spilling occurs approximately 7.5 hours into the storm event. Once flood water has spilled onto the floodplain it is contained by the embankment forming the left hand channel bank and also the embankment carrying the Loakmill access path. The floodplain will continue to fill until the water level in the floodplain is greater than the embankment crest level at the downstream end. At this point flood water will spill back into the watercourse, as well as forwards over the Loakmill access path. For the 200 year event, the onset of this spill of flow from the floodplain back into the watercourse at the downstream end occurs approximately 9.25 hours into the storm event.

During high-stage events, the water level in the floodplain is determined by the driving head required to pass flow over the embankments. During these events, it is the embankments, rather than the amount of available storage in the floodplain, which is the dominant influencing factor on water levels. The embankment geometry will remain unchanged between existing and design scenarios, therefore the driving head required to pass given flows across them also does not change. Whilst the top-level storage volume does change in the design scenario, this does not affect water level, as storage volume in the floodplain is not hydraulically influential.

Figure 11: Schematisation of flooding mechanism at Bankfoot



The images included on the following pages demonstrate pre and post scenario flood risk:

- descriptively;
- plan view; and
- cross section view.

Box 3: Description of flood risk associated with Bankfoot Junction

The proposed works does not cause a change in maximum water level upstream or downstream of the proposed works. Maximum modelled 0.5% AEP (200 year) flood level within the ISIS reservoir unit representing the floodplain is 56.57 m AOD for the pre- and post- design scenario. Maximum modelled 0.5% AEP (1:200) flood level including an allowance for the impact of climate change is 56.70 m AOD for the pre- and post- design scenario.

The road embankment for the proposed junction cuts into the active floodplain at the upper water levels of extreme events causing the floodplain to be slightly 'squeezed'. Flows are no longer able to access the area of floodplain covered by the embankment footprint, however, no new areas are affected.

The total loss of floodplain volume within the floodplain is approximately 600 m^3. This loss has no effect on maximum water level within the floodplain or pass forward flows and levels downstream as these factors are controlled by the embankments, as described above. The embankments are not affected as part of the design works, therefore nor is the upstream head required to push flows across them.

Figure 12: ISIS model schematisation of the Garry Burn reach in the vicinity of the Bankfoot junction

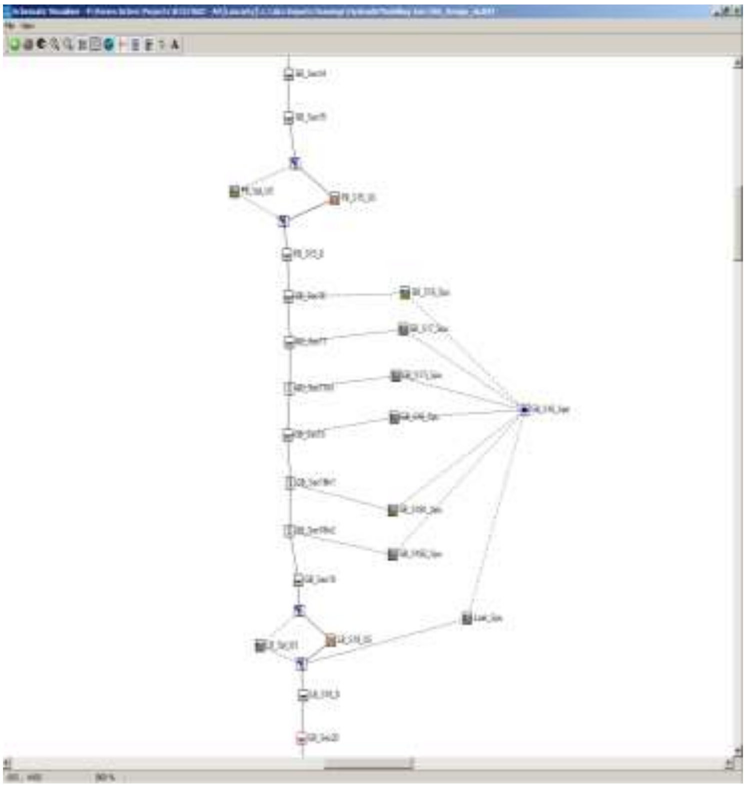


Figure 13: Model schematisation and mapped floodplain for the pre (existing) and post (design) scenario at the proposed Bankfoot Junction

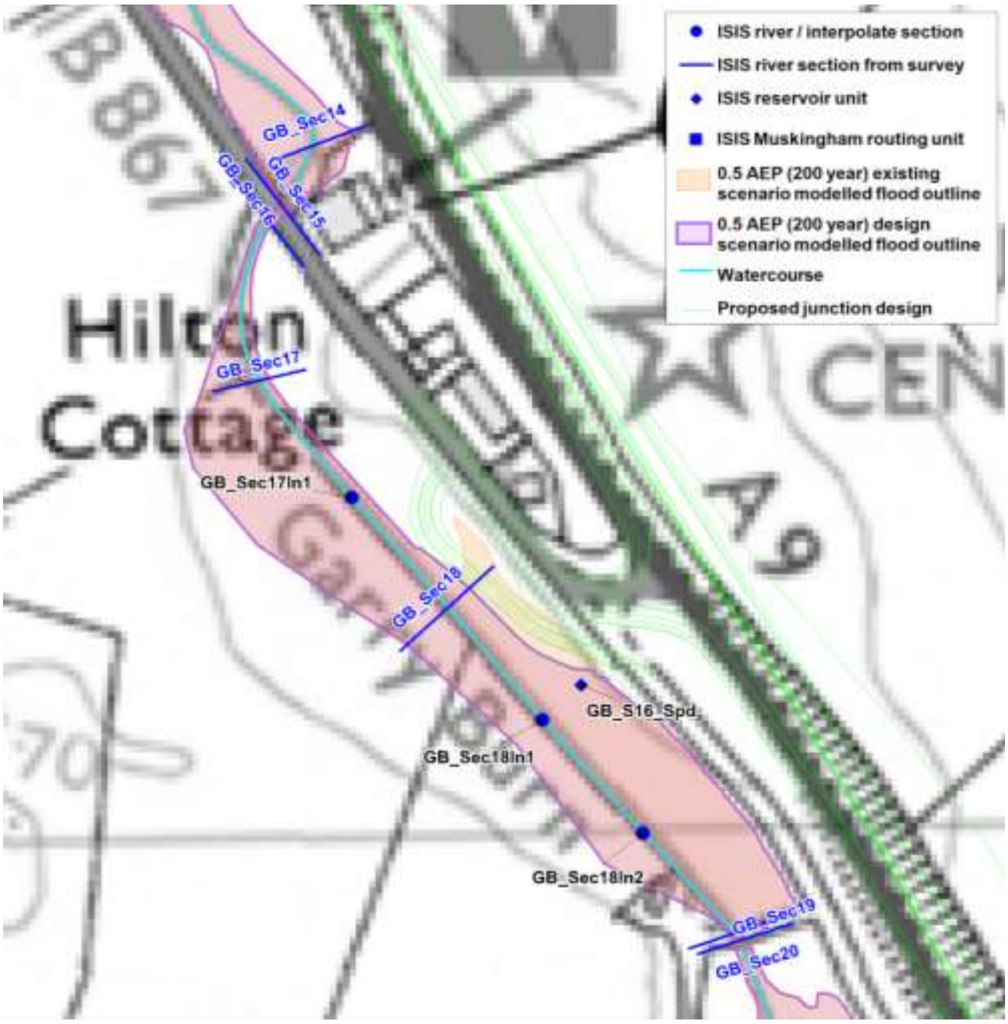


Figure 14: Modelled 0.5% AEP Stage Hydrograph within the ISIS reservoir unit ‘GB_S16_Spd’ representing the floodplain (Existing scenario = black line; Design scenario = pink line)

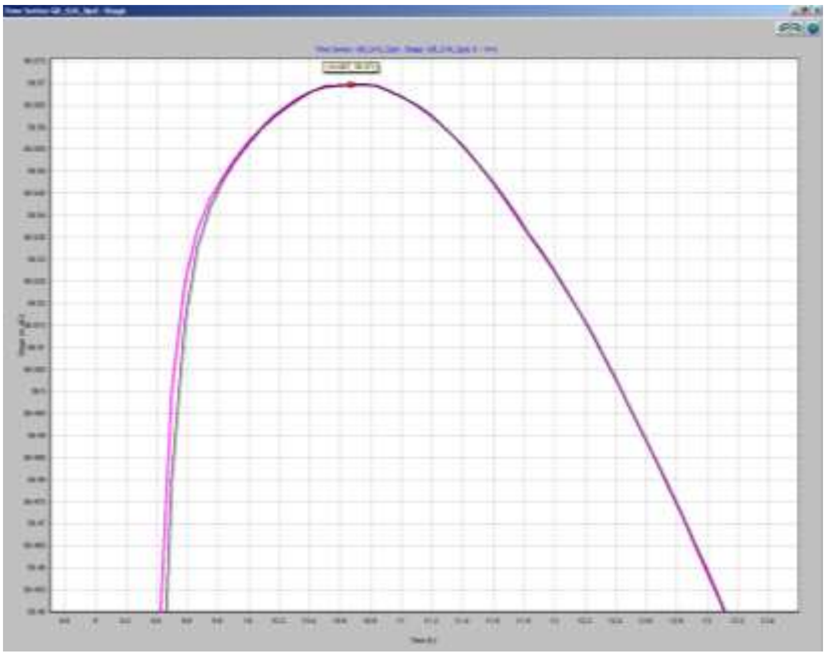
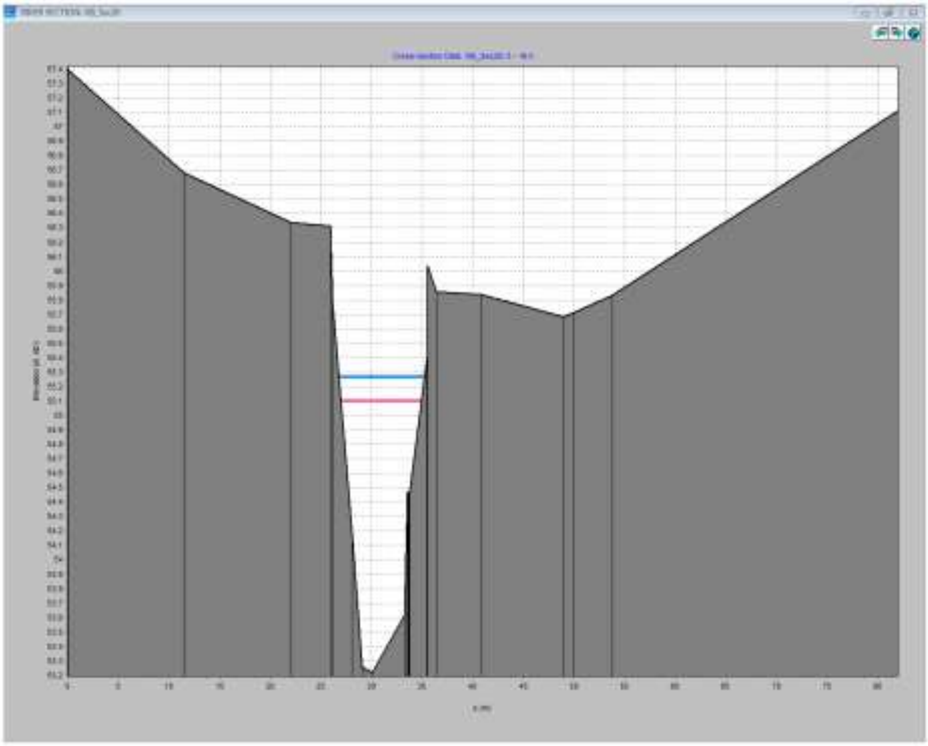


Figure 15: Cross section view: ISIS model screenshot of river unit 'GB_Sec20' immediately downstream of Bankfoot junction.

Existing scenario 0.5% AEP event = thick red line; Design scenario 0.5% AEP event = thin pink line (the results are the same hence the lines are indistinguishable); Existing scenario 0.5% AEP event with Climate Change = thick dark blue line; Design scenario 0.5% AEP event with Climate Change = thin light blue line (the results are the same hence the lines are indistinguishable)



(ii) Tullybelton/Stanley Junction

The behaviour of the hydraulic system in this area is captured by the model. In extreme events, the passage of flood water is controlled by the new road embankment.

The images included on the following pages demonstrate pre and post scenario flood risk:

- descriptively;
- plan view;
- cross section view; and
- tabular view.

Box 4: Description of flood risk associated with Tullybelton/Stanley Junction

The proposed works require construction of a new road with a footprint larger than the existing road. This will results in displacing flood water upstream, 'shifting' the active floodplain northwards to extend over a previously unaffected area of farmland.

The maximum modelled 0.5% AEP (200 year) flood level within the ISIS reservoir unit representing the floodplain is 32.75 m AOD for the existing scenario and 33.48 m AOD for the design scenario. The maximum modelled 0.5% AEP (200 year) plus Climate Change flood level within the ISIS reservoir unit representing the floodplain is 32.85 m AOD for the existing scenario and 33.63 m AOD for the design scenario.
The flow control structure at the inlet to the upstream culvert (as detailed previously in the 'model schematisation' section) restricts the magnitude of flows and predicted flow and stage immediately downstream of the new embankment are retained close to existing levels. At the confluence of the Tributary05 and the Ordie Burn (model section OB_add_3) the modelled magnitude of change in stage resulting from implementing the design scheme is 3 mm for the 0.5% AEP (200 year) +CC event.

Figure 16: ISIS model schematisation of the Ordie Burn and Tributary 05 reach in the vicinity of the Tullybelton/Stanley Junction

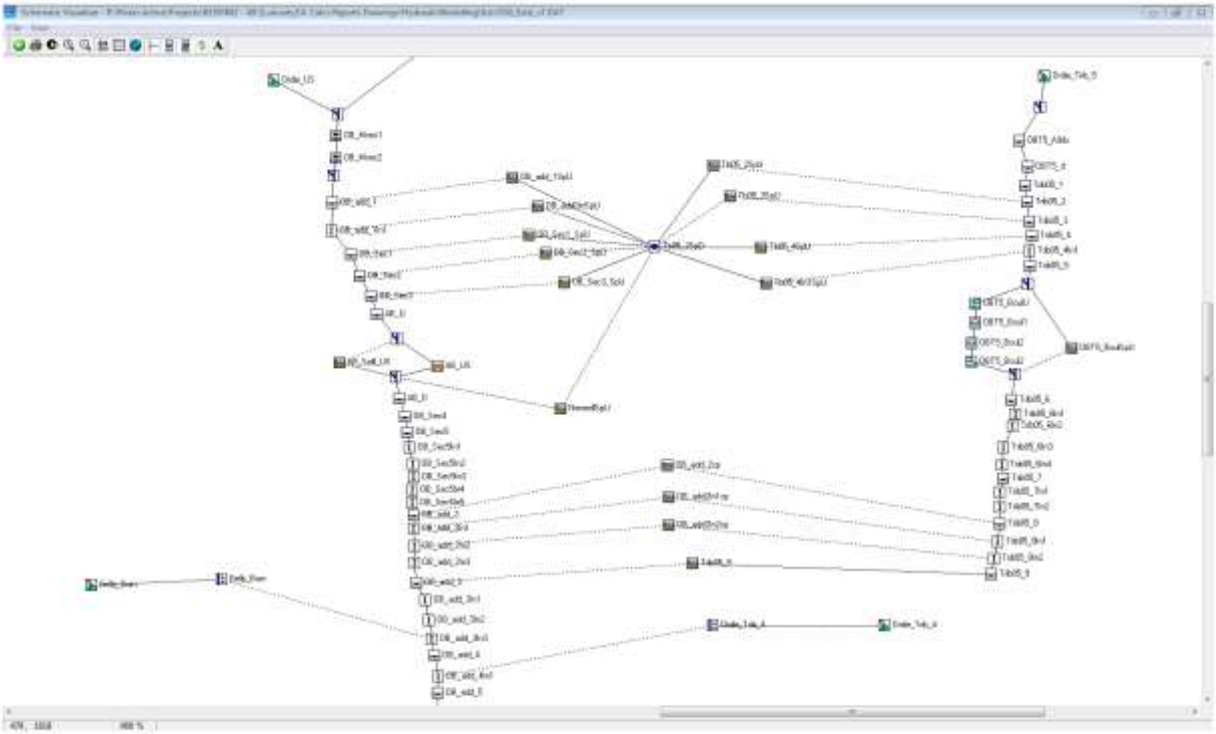


Figure 17: Model schematisation and mapped floodplain for the pre (existing) and post (design) scenario at the proposed Tullybelton/Stanley Junction

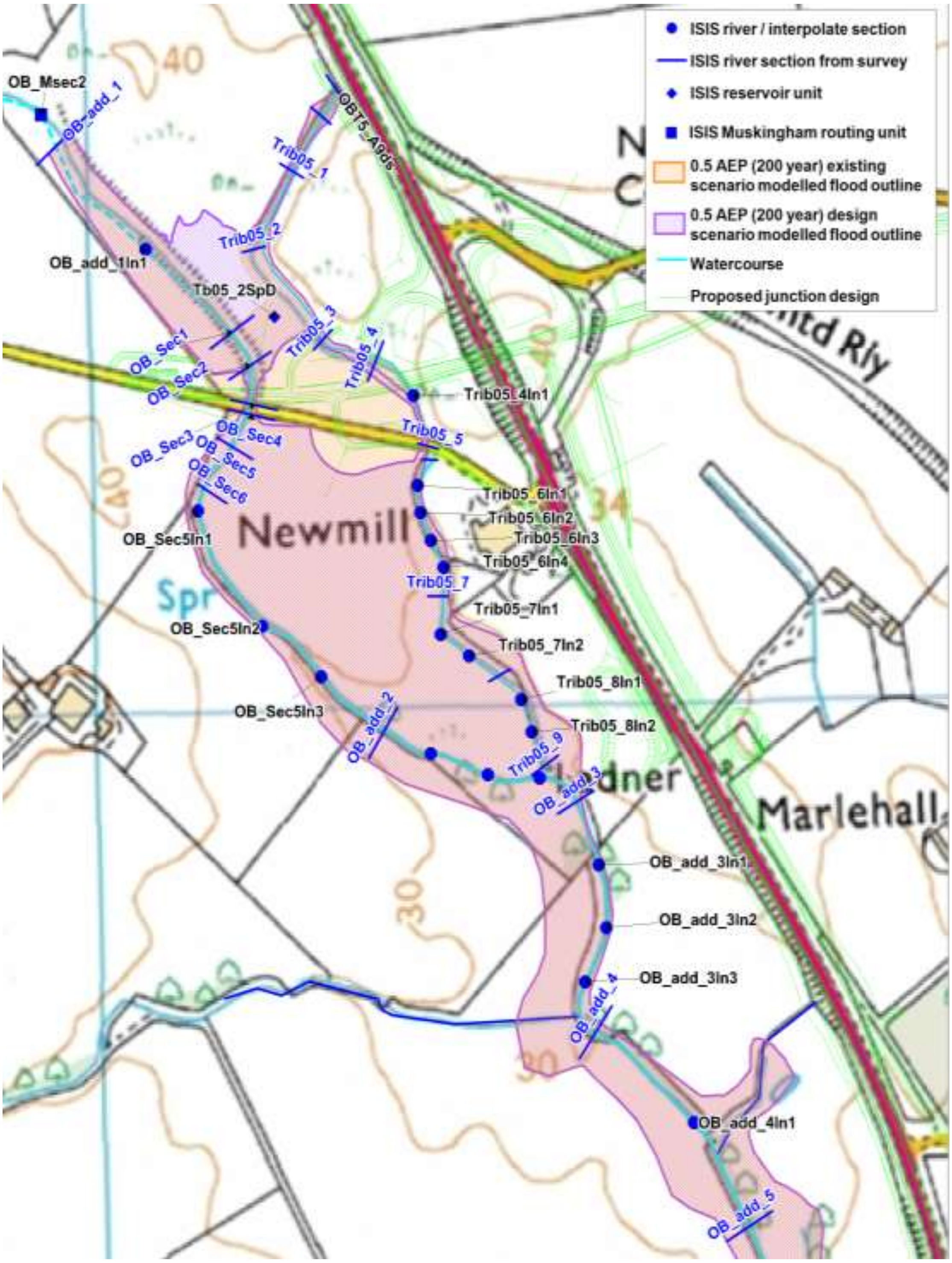


Figure 18: Modelled 0.5% AEP event flood levels within the ISIS reservoir unit representing the floodplain (Existing scenario = black line; Design scenario = pink line)

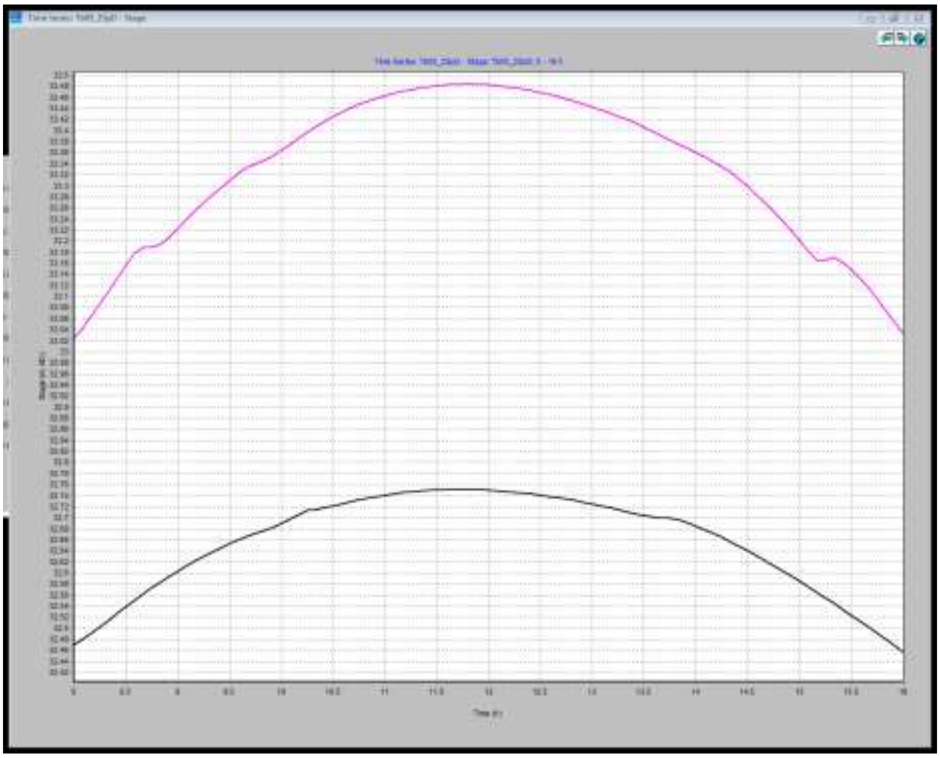


Figure 19: Cross section view: ISIS model screenshot of river unit 'OB_add_3' immediately downstream of confluence of Ordie Burn and Tributary05 channel downstream of the Tulleybelton/Stanley Junction.

Existing scenario 0.5% AEP event = thick red line; Design scenario 0.5% AEP event = thin pink line (magnitude of difference is only 2 mm hence the lines are indistinguishable); Existing scenario 0.5% AEP event with Climate Change = thick dark blue line; Design scenario 0.5% AEP event with Climate Change = thin light blue line (magnitude of difference is only 3 mm hence the lines are indistinguishable)

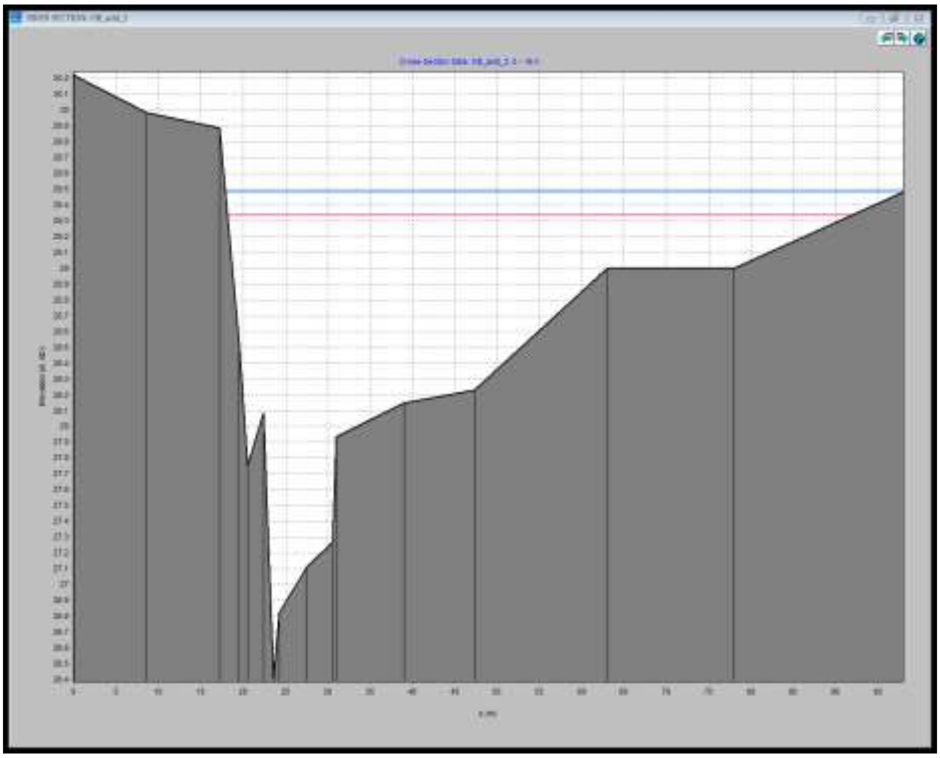


Table 6: Model results at Tributary05 and Ordie Burn reach downstream of the Tullybelton/Stanley Junction

	Existing Scenario Max Stage 200 year (mAOD)	Design Scenario Max Stage 200 year (mAOD)	Difference (Design - Exist) (m)	Existing Scenario Max Stage 200 year +CC (mAOD)	Design Scenario Max Stage 200 year +CC (mAOD)	Difference (Design - Exist) (m)
Tributary05 reach downstream of Tullybelton/Stanley Junction						
Trib05_6In1	31.965	31.983	0.018	31.965	31.983	0.018
Trib05_6In2	31.208	31.278	0.070	31.227	31.298	0.071
Trib05_6In3	30.516	30.552	0.036	30.516	30.552	0.036
Trib05_6In4	29.763	29.781	0.018	29.790	29.818	0.028
Trib05_7	29.435	29.491	0.056	29.590	29.660	0.070
Trib05_7In1	29.431	29.489	0.058	29.589	29.660	0.071
Trib05_7In2	29.430	29.488	0.058	29.588	29.660	0.072
Trib05_8	29.430	29.488	0.058	29.588	29.660	0.072
Trib05_8In1	29.425	29.478	0.053	29.582	29.643	0.061
Trib05_8In2	29.404	29.434	0.030	29.555	29.585	0.030
Trib05_9	29.294	29.338	0.044	29.447	29.493	0.046
Ordie Burn reach downstream of Tullybelton/Stanley Junction						
OB_Sec4	31.888	31.888	0.000	31.975	31.975	0.000
OB_Sec5	31.667	31.668	0.001	31.759	31.759	0.000
OB_Sec5In1	31.399	31.400	0.001	31.480	31.480	0.000
OB_Sec5In2	31.124	31.124	0.000	31.205	31.205	0.000
OB_Sec5In3	30.850	30.850	0.000	30.935	30.935	0.000
OB_Sec5In4	30.582	30.582	0.000	30.670	30.670	0.000
OB_Sec5In5	30.316	30.317	0.001	30.404	30.405	0.001
OB_add_2	30.019	30.018	-0.001	30.094	30.095	0.001
OB_add_2In1	29.674	29.680	0.006	29.763	29.776	0.013
OB_add_2In2	29.425	29.448	0.023	29.559	29.587	0.028
OB_add_2In3	29.360	29.377	0.017	29.510	29.528	0.018
Downstream of Tributary05 and Ordie Burn confluence						
OB_add_3	29.337	29.339	0.002	29.486	29.489	0.003

c) Design of proposed Tributary 05 culvert at Tullybelton/Stanley Junction:

At the proposed Tullybelton/Stanley junction, a tributary of Ordie Burn (designated Tributary 05) runs through the footprint of the proposed junction. The modelling work is required to inform the hydraulic specification of the proposed culverted reaches of this tributary watercourse.

The proposed alignment of the new Tributary 05 culverted sections, as provided by the Jacobs design team, has been incorporated into the model. The results of the modelling (presented in preceding sections concerned with the Tullybelton/Stanley junction) demonstrate that the culverts adequately convey flows through the junction and that the introduction of a control structure (300 mm diameter orifice plate) at the upstream culvert entrance results in a neutral impact on downstream water level and pass forward flow.

d) Proposed attenuation pond at Shochie Burn (left bank) viability assessment:

Flood outline mapping is required to assess the viability of proposed locations of highway drainage retention ponds. One retention pond is proposed in close proximity to Shochie Burn watercourse and therefore warrants investigation in terms of assessing whether there are potential flood risk constraints to its location.

The area of interest is that located downstream of the A9 crossing culvert and upstream of the viaduct. This is a reach approximately 150 m in length, characterised by relatively high banks on both sides, with the exception of a localised low point in the left bank close to the viaduct entrance. The model represents the fluvial system within the area as follows (see Figures 20 and 21): in-bank flow within the channel as ISIS river units; left bank as spill units which define the level at which water can pass out of the channel into the floodplain; the floodplain as a reservoir unit. All dimensions (elevations) have been informed by the topographic survey.

Figure 20: ISIS model schematisation of the Shochie Burn reach for the left bank potential attenuation pond location

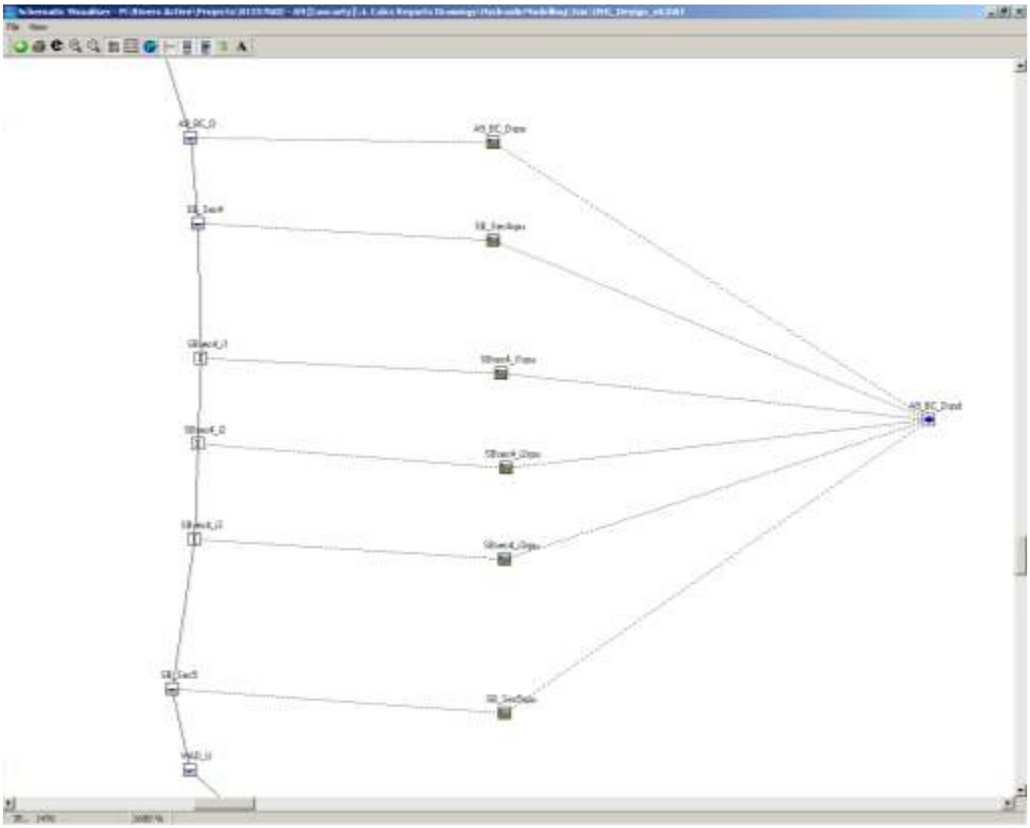
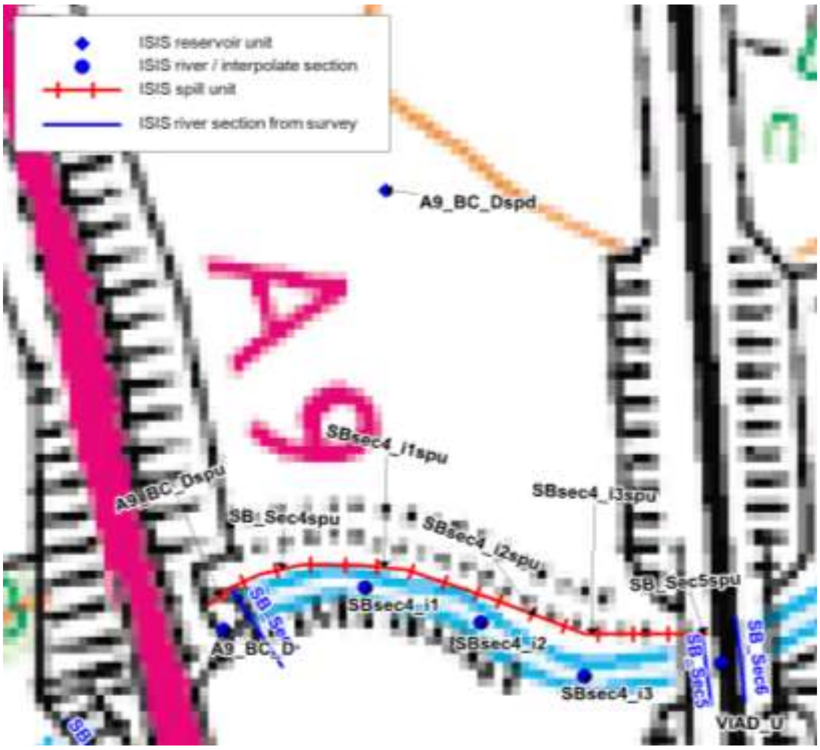


Figure 21: Schematisation of the Shochie Burn reach for the left bank potential attenuation pond location



The model results show that, for the 0.5% AEP (200 year) event, flows remain in-bank for the majority of the upper part of the reach. The banks here are higher than the peak in channel stage therefore water cannot spill into the floodplain. At the localised low point in the left bank (located approximately 30 m upstream of the viaduct opening) the peak in channel stage is higher than the bank level and therefore water spills over the bank and into the floodplain.

For the 0.5% AEP (200 year) plus climate change event, the maximum in-channel stage is higher than the left bank (allowing water to spill into the floodplain) along the majority of the reach. Tables 7 and 8 summarise the flood levels and flows within the area.

Table 7: 0.5% AEP (200 year) model results at Shochie Burn reach within vicinity of proposed attenuation pond

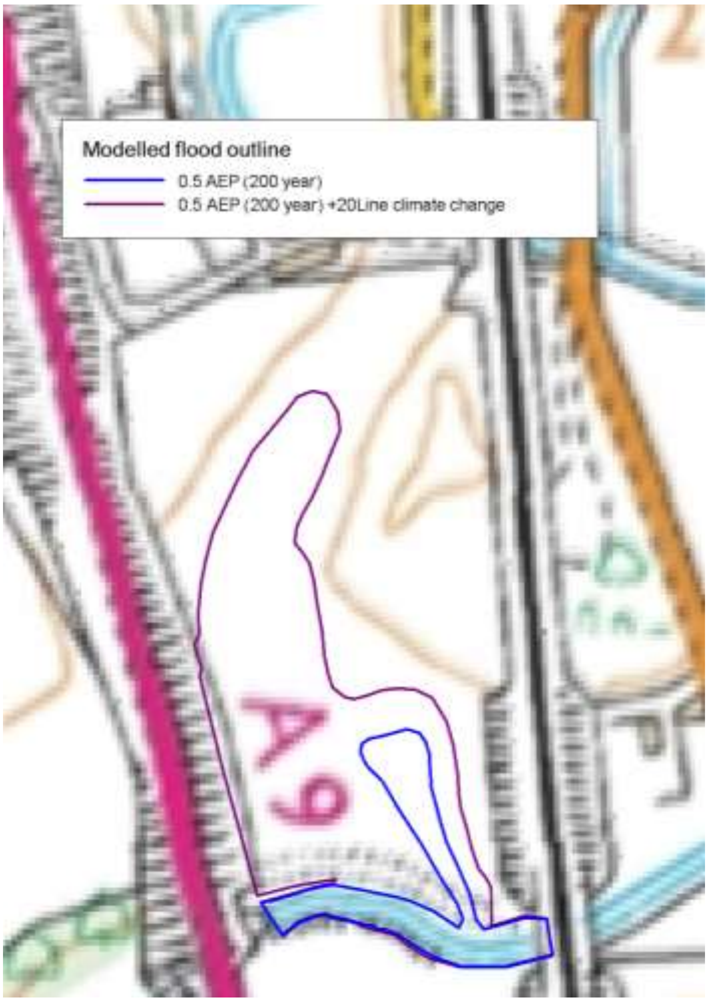
ISIS river node label	Max Stage 0.5% (200 year) (mAOD)	ISIS spill unit label	Elevation (upstream)	Elevation (downstream)	Max Flow across spill 0.5% (200 year) (cumecs)	ISIS reservoir unit label	Max Stage 0.5% (200 year) (mAOD)
A9_BC_D	19.13	A9_BC_Dspu	22.00	19.78	0.00	A9_BC_D spd	17.61
SB_Sec4	19.06	SB_Sec4spu	19.78	19.20	0.00		
SBsec4_i1	18.89	SB_Sec4_i1spu	19.20	18.85	0.00		
SBsec4_i2	18.77	SB_Sec4_i2spu	18.85	18.65	0.04		
SBsec4_i3	18.68	SB_Sec4_i3spu	18.65	22.00	0.01		
SB_Sec5	18.62	SB_Sec5spu	22.00	23.20	0.00		

Table 8: 0.5% AEP (200 year) +20% climate change model results at Shochie Burn reach within vicinity of proposed attenuation pond

ISIS river node label	Max Stage 0.5% (200 year) +20% CC (mAOD)	ISIS spill unit label	Elevation (upstream) (mAOD)	Elevation (downstream) (mAOD)	Max Flow across spill 0.5% (200 year) +20% CC (cumecs)	ISIS reser voir unit label	Max Stage 0.5% (200 year) +20% CC (mAOD)
A9_BC_D	19.42	A9_BC_Dspu	22.00	19.78	0.00	A9_B C_Ds pd	19.17
SB_Sec4	19.36	SB_Sec4spu	19.78	19.20	0.01		
SBsec4_i1	19.22	SB_Sec4_i1spu	19.20	18.85	7.42		
SBsec4_i2	19.20	SB_Sec4_i2spu	18.85	18.65	3.22		
SBsec4_i3	19.13	SB_Sec4_i3spu	18.65	22.00	0.75		
SB_Sec5	19.06	SB_Sec5spu	22.00	23.20	0.00		

The 0.5%AEP (200 year) and 0.5%AEP (200 year) plus 20% climate change allowance modelled flood extents are shown on Figure 22. As shown in the Flood Risk Assessment, the attenuation basin in this area will be located wholly outside of the 0.5%AEP (200 year) flood extent and therefore its implementation would not increase flood risk up to an event of this magnitude.

Figure 22: Modelled flood outline of the Shochie Burn reach for the left bank potential attenuation pond location



e) <u>Input to highway drainage design:</u>

Maximum water level at the 3.33%AEP (30 year) storm event is required at selected river locations to inform the design of highway drainage outfalls.

The Jacobs drainage engineer responsible for the design of the proposed drainage system for the scheme has been provided with 3.33% AEP (30 year) modelled maximum stage outputs at relevant locations. These are reported within the CAR (Controlled Activities Regulation, 2011) Application for the design scheme.

f) <u>Flood risk downstream of overall scheme – Luncarty town:</u>

The watercourse through the study area flows through a predominantly rural landscape within the immediate vicinity of the proposed scheme. Downstream of the proposed scheme, however, the watercourse enters the town of Luncarty, which represents an area of vulnerable receptors (people/properties etc).The model is required to assess the impact of the proposed scheme on flood risk to the town of Luncarty.

The model results predict a neutral impact with regards to predicted water level for the design event. Refer to Figures 23 and 24 and Table 9.

Figure 23: Schematisation of the downstream reach of the model within the vicinity of Luncarty

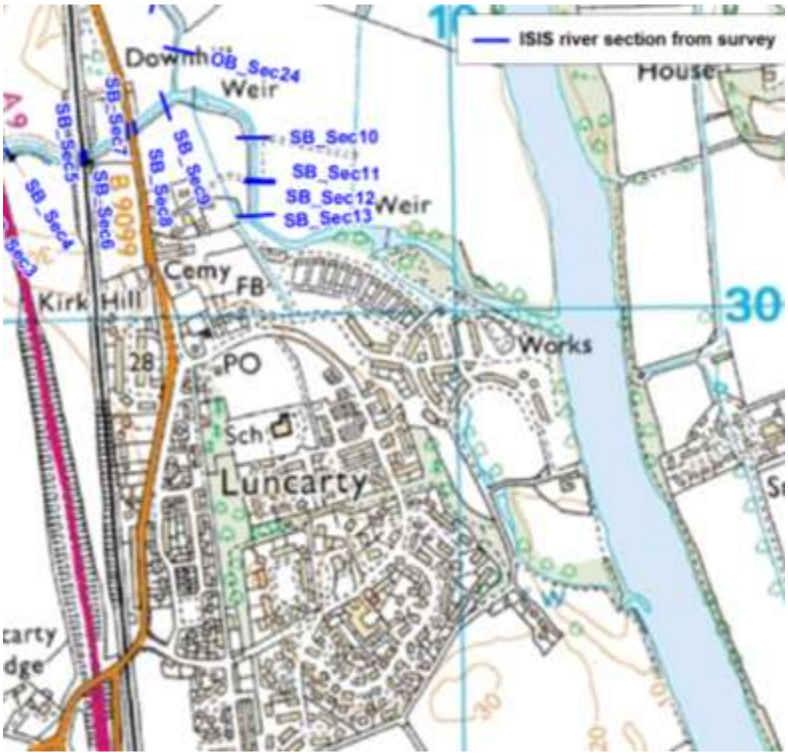


Figure 24: Long section view: ISIS model screenshot of downstream reach of the model within the vicinity of Luncarty.

Existing scenario 0.5% AEP event = thick red line; Design scenario 0.5% AEP event = thin pink line (the difference in the results is negligible hence the lines are indistinguishable); Existing scenario 0.5% AEP event with Climate Change = thick dark blue line; Design scenario 0.5% AEP event with Climate Change = thin light blue line (the difference in the results is negligible hence the lines are indistinguishable). Dashed lines are the bank levels.

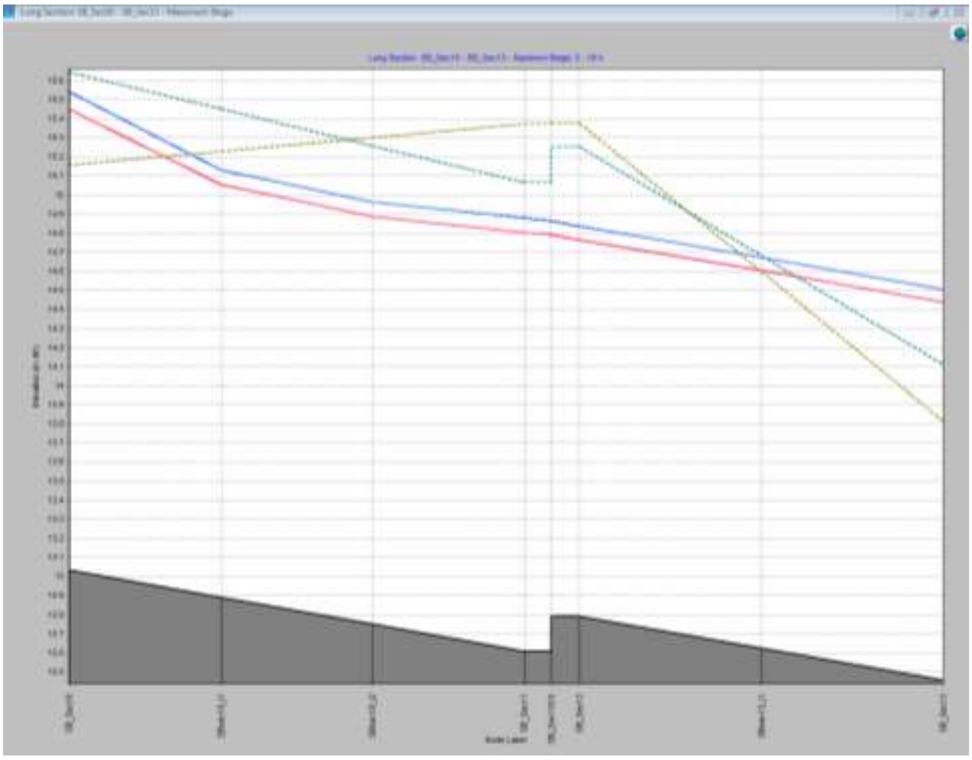


Table 9: Model results at downstream reach of the model within the vicinity of Luncarty.

	Existing Scenario Max Stage 200 year (mAOD)	Design Scenario Max Stage 200 year (mAOD)	Difference (Design - Exist) (m)	Existing Scenario Max Stage Max Stage 200 year +CC (mAOD)	Design Scenario Max Stage 200 year +CC (mAOD)	Difference (Design - Exist) (m)
SB_Sec10	15.448	15.446	-0.002	15.539	15.536	-0.003
SBsec10_i1	15.052	15.05	-0.002	15.129	15.126	-0.003
SBsec10_i2	14.887	14.885	-0.002	14.964	14.961	-0.003
SB_Sec11	14.805	14.803	-0.002	14.879	14.876	-0.003
SB_Sec11DS	14.79	14.788	-0.002	14.863	14.86	-0.003
SB_Sec12	14.763	14.761	-0.002	14.835	14.832	-0.003
SBsec12_i1	14.604	14.602	-0.002	14.673	14.67	-0.003
SB_Sec13	14.438	14.436	-0.002	14.506	14.504	-0.002

4 Conclusions

Hydraulic modelling work was undertaken to allow specific tasks required to support the consent application for the A9 Dualling Scheme from Luncarty to Birnam, to be undertaken. The outputs of the modelling feed into wider project deliverables, including: the Flood Risk Assessment elements of the detailed ES; design of culvert crossings associated with the proposed scheme; and design of the proposed highways drainage scheme.

A 1D ISIS model has been produced for the existing and proposed design scenario to allow an assessment of the impact on the proposed scheme on existing flood levels, flows and risks to be established. Interpretation of model results indicates that the impact of the proposed scheme on flood risk at identified key areas is as summarised in Table 10.

Table 10: Summary of modelling work findings

Key scheme area	Summary of model findings
Extending A9 culvert crossings at Shochie Burn	The introduction of the proposed culvert extension results in a slight decrease in peak stage (by up to 33 mm for the 0.5% AEP event and by up to 37 mm for the 0.5% AEP plus 20% climate Change allowance event) within the reach immediately upstream (extending approximately 225 m) of the culvert entrance. A slight decrease in stage is experienced in the reach immediately downstream of the A9 culvert exit.
Extending A9 culvert crossings at Ordie Burn	The introduction of the proposed culvert extension results in a slight increase in peak stage (by up to 251 mm for the 0.5% AEP event and by up to 360 mm for the 0.5% AEP plus 20% Climate Change allowance event) within the reach immediately upstream (extending approximately 550 m for the 0.5% AEP event approximately 890 m for the 0.5% AEP plus 20% climate Change allowance event) of the culvert entrance. A slight decrease in stage is experienced in the reach immediately downstream of the A9 culvert exit.
Tullybelton/Stanley Junction	The embankment for the proposed junction partially cuts into the 0.5% AEP (200 year) floodplain extent causing the floodplain to be 'shifted' northwards to extend over a previously unaffected area of farmland. There would be an insignificant impact on downstream flows and stage; the orifice plate located within the proposed culvert system restricts flows exiting the embankment to a magnitude which ensures flows downstream are retained at existing levels. The risk of blockage will be mitigated by constructing the orifice plate within a chamber with an appropriately design trash screen.
Bankfoot Junction	The embankment for the proposed junction partially cuts into the 0.5% AEP (200 year) floodplain extent causing the floodplain to be slightly 'squeezed'. The loss of floodplain volume has no effect on maximum water level within the floodplain or pass forward flows and levels downstream as the control on water levels in this area is the embankments over which water spills during flood events (the design of which remains unchanged in the design scenario).
Proposed attenuation pond at Shochie Burn left bank	The proposed attenuation pond is located entirely outside of the modelled 0.5% AEP (200 year) floodplain extent.
Overall flood risk within the study area	The proposed scheme results in an increase in water levels *upstream* of some of the key scheme locations, as detailed above, and throughout this report. The flood risk *downstream* of all key scheme locations has not increased. Importantly, there is no increase to flood risk to vulnerable receptors e.g. properties and people. The flood risk to the town of Luncarty, which is located downstream of the proposed scheme, does not increase through the implementation of the scheme.