JACOBS

A13.2.E River Nairn Hydraulic Modelling Report

1 Introduction

Purpose

1.1 This annex provides detailed information on the hydraulic modelling relevant to Appendix 13.2 (Flood Risk Assessment).

1.2 The A96 Dualling Inverness to Nairn (including Nairn Bypass) scheme comprises the provision of approximately 31km of new dual carriageway, achieved through offline construction (hereafter referred to as the proposed Scheme). The existing A96 single carriageway would be de-trunked and reclassified as a local road to maintain local access. Due to the size and layout of the proposed Scheme, there are a number of flood risks, which may place the road and its users at risk of flooding. The proposed Scheme also has the potential to impact the level of flood risk elsewhere.

1.3 The proposed Scheme starts east of the roundabout for Inverness Retail Park, approximately 850m east of Raigmore Interchange, and continues approximately 30km east and ends at Hardmuir, 3.5km to the east of Auldearn. The proposed Scheme would incorporate:

- 22 watercourse crossings;
- provision of shared use paths suitable for Non-Motorised Users (NMU), approximately 30km in length;
- six grade separated junctions;
- 24 principal structures including a crossing of the River Nairn and three structures over the Aberdeen to Inverness Railway Line;
- local road diversions and provision of new private means of access; and
- utility diversions including major diversions for Scottish Gas Networks (SGN) and CLH Pipeline Systems (CLH-PS).

1.4 For key watercourse crossings a Flood Risk Assessment (FRA) was required to meet relevant local and national planning legislation and inform the design and planning process. Hydraulic modelling was required to support the FRA. This took the form of computational hydraulic models with associated catchment hydrology. The impact of the proposed Scheme on water level both upstream and downstream and the associated flood envelope was determined for a range of storm flood events at each watercourse crossing.

1.5 The key watercourse crossings for which a hydraulic modelling was carried out to support the FRA are:

- Cairnlaw Burn crossing (Annex 13.2.B Cairnlaw Burn Hydraulic Modelling Report);
- Rough Burn crossing (Annex 13.2.C Rough Burn Hydraulic Modelling Report);
- Tributary of Ardersier Burn crossing (Annex 13.2.D Tributary of Ardersier Burn Hydraulic Modelling Report);
- River Nairn crossing (this report); and
- Auldearn Burn crossing (Annex 13.2.F Auldearn Burn Hydraulic Modelling Report).

1.6 This report details the methodology and the results of the hydraulic modelling carried out for the River Nairn crossing, for the baseline and 'with-scheme' situation. This is a technical report, focused on the hydraulic modelling, and therefore the intended audience is those with a reasonable understanding and knowledge of hydraulic modelling principles, although no specific knowledge of particular software is needed.

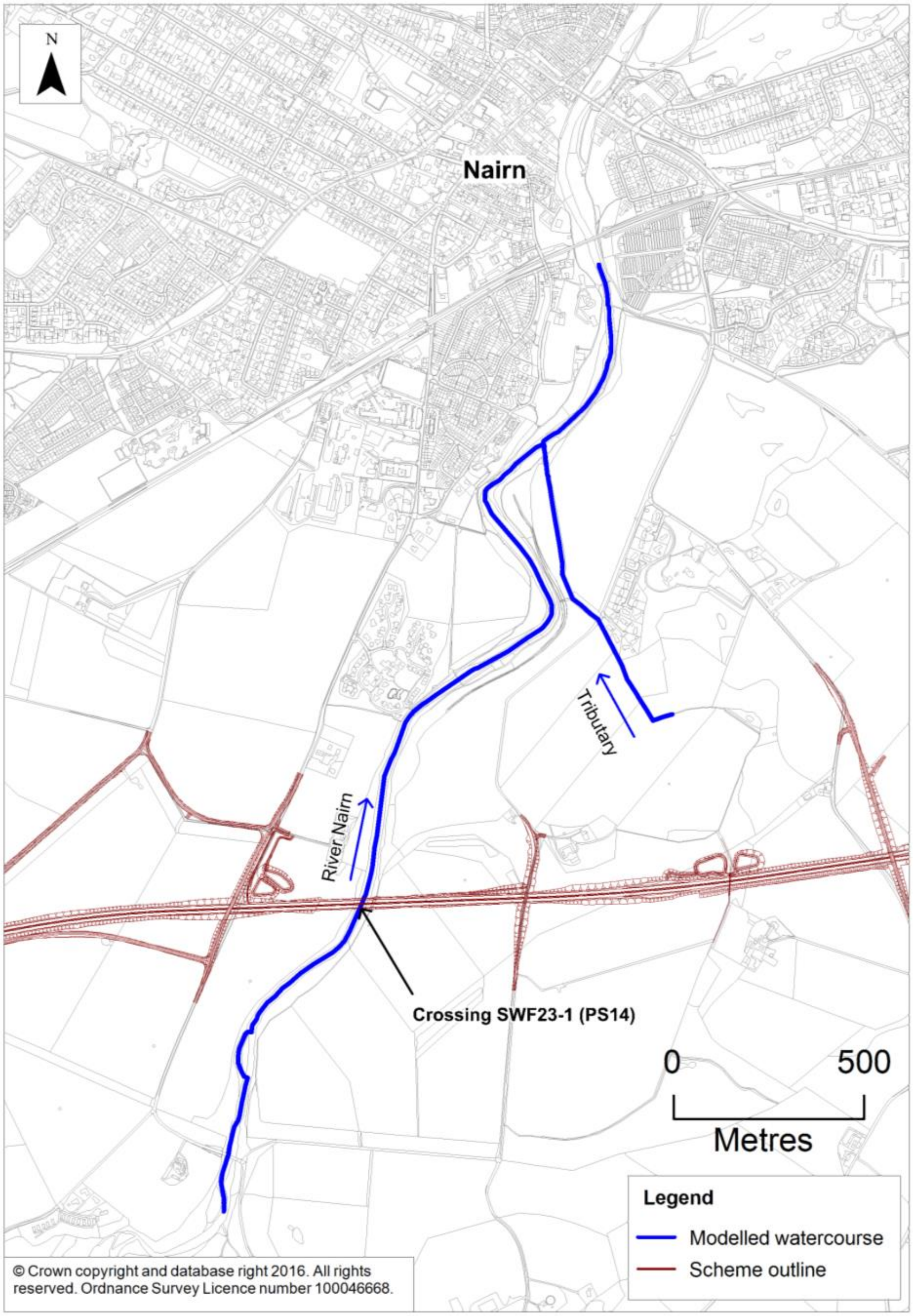
Methodology

1.7 The hydraulic model was built using a linked One-dimensional/Two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller Pro (version 4.1), and the 2D component was constructed using TUFLOW (version 2013-12-AE-iSP-w64).

Study Area

1.8 The proposed Scheme crosses the River Nairn 1.5km south of the town of Nairn. A new bridge at this location has been designated “Crossing SWF23-1 (PS14)”. The extent of the study area is shown in Diagram 1. The hydraulic model includes approximately 3km of the River Nairn and approximately 850m of an unnamed tributary. The confluence of the tributary with the River Nairn is towards the downstream end of the study area.

Diagram 1: River Nairn Study Area



2 Input Data

2.1 The data used to construct the hydraulic model for the River Nairn is summarised in Table 1.

Table 1: Data Used to Build the Hydraulic Model

Data	Description	Source
Photogrammetry	2009 2m horizontal resolution photogrammetry data. Used to represent the topography for the whole model extent See Section 4 (Flood Plain Schematisation - 2D domain)	Getmapping
OS maps	Mastermap data 1 to 10,000 Scale Raster	Transport Scotland
Channel survey	In-channel cross sections and hydraulic structures See Section 4 (Watercourse Schematisation - 1D Domain)	Jacobs Site survey 2015
Banktop survey	Survey of part of banktop for the River Nairn See Section 4 (Flood Plain Schematisation - 2D domain)	Jacobs Site survey 2015
Proposed Scheme topography	MXROAD ASCII grids	Jacobs 2016
Watercourse photographs	Site visit – in-channel watercourse photographs	Jacobs Site survey 2015 Site inspection 2015
Hydrological analysis	Hydrological analysis carried out for the River Nairn See Section 3 (Hydrology)	Jacobs 2016

3 Hydrology

3.1 The details of the analysis carried out to produce inflows for the hydraulic model are provided in a separate hydrology report (Annex 13.2.G (Surface Water Hydrology Report)), which was undertaken for the DMRB Stage 3 assessment.

3.2 There are two point inflows into the model. One at the upstream extent of the River Nairn and one at the upstream extent of the tributary (see locations in Diagram 2). For these locations inflows have been estimated for the 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1% Annual Exceedance Probability (AEP) flood events.

3.3 Peak inflows for the River Nairn are based on peak flows estimated from enhanced single site analysis at Firhall gauging station (7004). For the River Nairn the hydrograph shape is based on the July 1997 flood event from the gauging station. Peak inflows for the minor tributary were produced using the Flood Estimation Handbook (FEH) statistical method. The tributary hydrographs shape was derived using the FEH rainfall-runoff method for a critical storm duration of 18.25 hours, which is equivalent to the theoretical critical storm duration of the River Nairn at the gauging station.

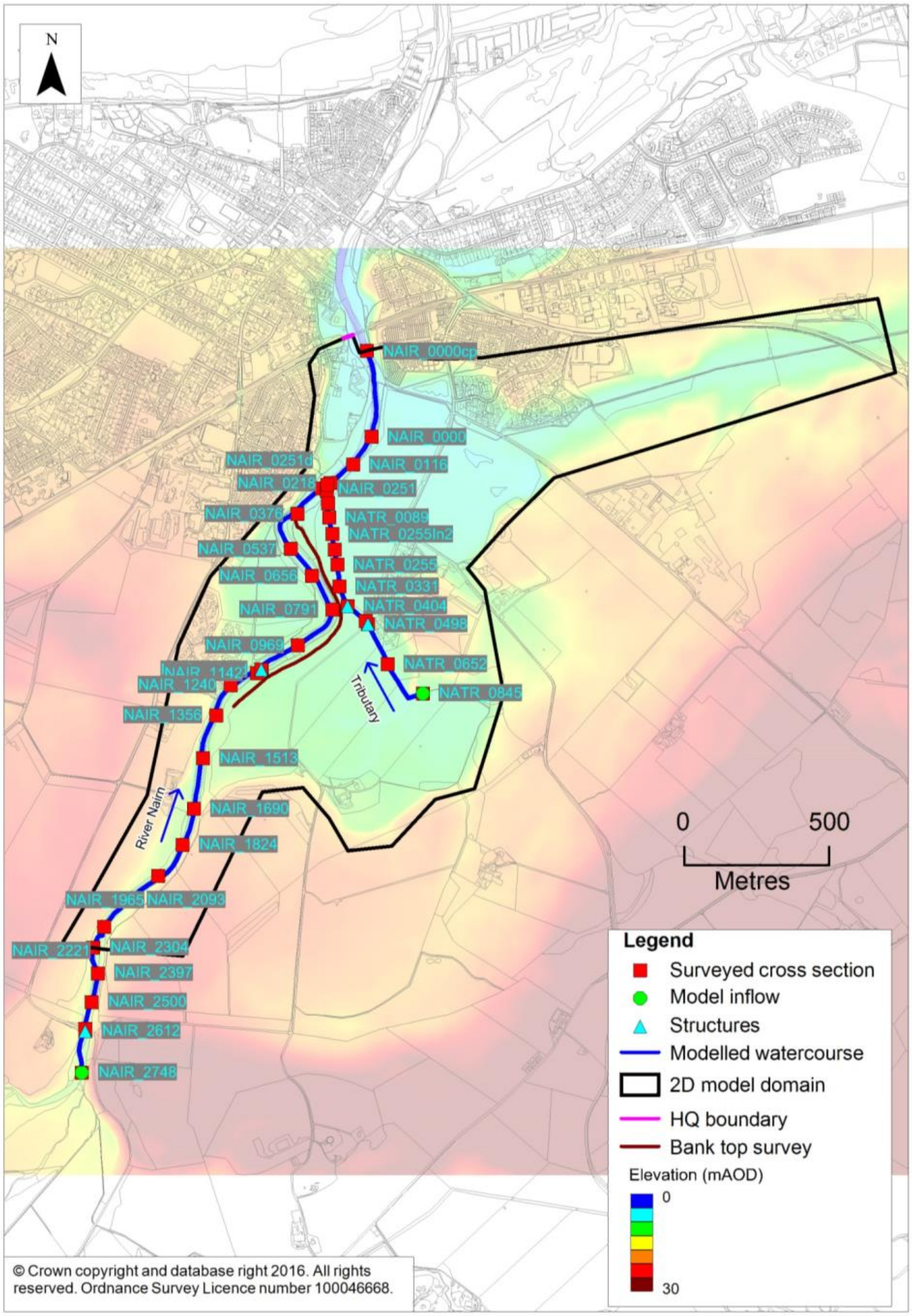
3.4 In order to assess the impact of Climate Change (CC), a 20% uplift of the hydrological inflows was applied on the 0.5% AEP event. This climate change uplift factor is based on current standard practice (SEPA 2015).

3.5 Peak inflows of the modelled watercourses are shown in Table 2 for all the events simulated.

Table 2: Hydrological Inflow Peak Values and Locations

Location	Peak Flow (m^3/s)								
	AEP 50%	AEP 20%	AEP 10%	AEP 3.33%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.5% + CC	AEP 0.1%
River Nairn upstream model extent	99	141	173	232	264	315	375	450	562
Tributary upstream model extent	0.20	0.28	0.34	0.45	0.51	0.60	0.71	0.85	1.05

Diagram 2: River Nairn Baseline Model Schematisation



4 Baseline Modelling

Watercourse Schematisation - 1D Domain

In-Channel Geometry

4.1 Surveyed cross section data has been used to inform the in-channel geometry of the modelled watercourses. The location of the surveyed cross sections is shown in Diagram 2. To aid model performance on the tributary, interpolated cross sections were added between the surveyed cross sections, at a spacing of approximately 50m. No interpolates where required on the River Nairn.

4.2 The first 445m of the modelled River Nairn are represented in 1D only. Therefore the cross sections in this location represent both the channel and the flood plain.

4.3 Table 3 shows the Flood Modeller nodes associated with the modelled watercourses.

Table 3: Flood Modeller Nodes

Reach	Upstream Node	Downstream Node
River Nairn 1D only	NAIR_2748	NAIR_2304
River Nairn 1D/2D	NAIR_2304	NAIR_0000cp
Tributary	NATR_0845	NATR_0000

In-Channel Hydraulic Friction

4.4 Hydraulic roughness (Manning's 'n' coefficient) values were determined primarily using the photographs taken during the survey. Generally, pebbles can be seen in the bed of the River Nairn, with trees on the bank. The bed of the tributary is either mud or vegetated. The banks of the tributary are covered by grass, bushes or trees. The Manning's 'n' coefficients used in the model are shown in Table 4. Roughness values adopted were taken from standard guidance (Chow 1959).

Table 4: Manning's 'n' Coefficients – 1D Domain

Flood Modeller Nodes	Bed Manning's 'n'	Bed Material	Banks Manning's 'n'	Banks Material
NAIR_2748 to NAIR_0000cp	0.05	Cobbles	0.10	Heavy vegetation/trees
NATR_0845 to NATR_0000	0.10 0.07 0.035	Heavy vegetation Vegetated channel Mud channel	0.10 0.07 0.035 0.035	Heavy vegetation/trees Medium vegetation Light vegetation Mud bank

In-Channel Hydraulic Structures

4.5 Four hydraulic structures were included in the model, two on the River Nairn and two on the tributary. Table 5 provides details regarding these structures. Their locations are shown in Diagram 2.

Table 5: In-Channel Hydraulic Structures

Watercourse	Structure	Flood Modeller node	Specification	
River Nairn	B9090 road crossing	NAIR_2612BRu	**Type:** **Left bed level:** **Right bed level:** **Width:** **Height:**	USBPR bridge unit. Two spans modelled 11.152mAOD 11.049mAOD 17m 5.14m
River Nairn	Footbridge	NAIR_1125BRu	**Type:** **Bed level:** **Width:** **Height:**	Arch Bridge (flat soffit) 6.734mAOD 41m 4m
Tributary	Culvert under road	NATR_0498u	**Type:** **Upstream bed level:** **Downstream bed level:** **Length:** **Diameter:**	Circular conduit 6.356mAOD 6.298mAOD 12.520m 0.890m
Tributary	Culvert through field	NATR_0404u	**Type:** **Upstream bed level:** **Downstream bed level:** **Length:** **Diameter:**	Circular conduit. 50% blockage unit added as described in paragraph 9.7 6.068mAOD 5.949mAOD 72.880m 1.000m

Boundary Conditions – 1D Domain

4.6 The upstream and downstream boundary conditions applied to the 1D domain are described in Table 6. Inflow locations are shown in Diagram 2.

Table 6: Boundary Conditions – 1D Domain

Type of Boundary	Flood Modeller Node	Description
Flow-Time Boundary	NAIR_2748	Based on historic event data. Applied at the upstream end of the River Nairn (see Section 3 (Hydrology)).
FEH Boundary	NATR_0845	Based on the FEH statistical method. Applied at the upstream end of the tributary (see Section 3 (Hydrology)).
Normal Depth Boundary	NAIR_0000cp	Normal depth boundary condition applied to the downstream end of the River Nairn

Flood Plain Schematisation - 1D domain

4.7 In the 1D only part of the model, the flood plain is represented by the surveyed cross sections. At some locations it was necessary to extend the cross sections using the 2m photogrammetry data. Hydraulic roughness values were assigned for grass (0.035) and trees (0.1) on the flood plain.

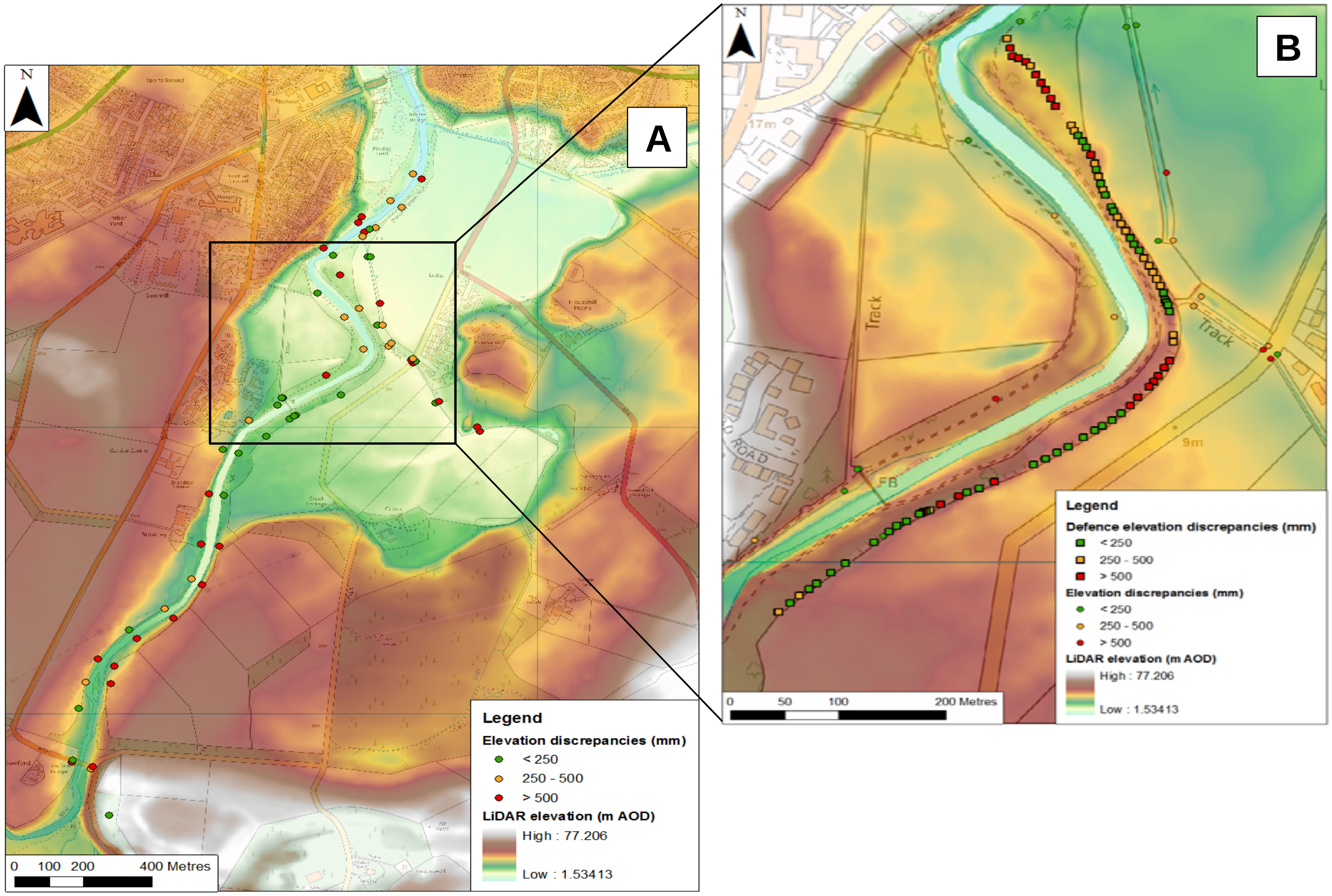
Flood Plain Schematisation - 2D domain

Flood Plain Topography

4.8 The 2D domain covers an area of 1.8km^2. The topography is represented using a 4m resolution square grid. The levels for the grid cells are based on a Digital Terrain Model (DTM) derived from 2m resolution photogrammetry data. The photogrammetry has been reviewed against the available survey, in as much detail as possible within the scope of the present study (Diagram 3). This work indicates that the data gives a good broad representation of the wider floodplain, with discrepancies mainly arising from the smoothing that is inherent in the coarser resolution DTM and also at steep hillside locations where small a shift in plan gives a large adjustment in vertical elevation. Appropriate use has been made of 2D breaklines (based on the available survey data), for 1D-2D banktop linkage and flood defence alignments. It is concluded that that the 2D model DTM is fully appropriate for the wider floodplain that extends considerably from the area of interest, and also provides an appropriate representation of the terrain local to the proposed scheme crossing for the explicit analysis of flood risk at that location.

4.9 A bank top survey was carried out for part of the River Nairn (Diagram 2). The banktop survey is on the right bank only. This was included as a breakline in the 2D model.

Diagram 3: Photogrammetry Elevation Discrepancies



(A) Channel cross section survey, bank top level comparison. **(B) Defence crest survey level comparison**

Flood Plain Hydraulic Friction

4.10 Hydraulic roughness coefficients are applied over each grid cell of the 2D domain, as shown in Table 7, depending on land use taken from OS Mastermap data. Roughness values adopted were taken from standard guidance.

Table 7: Manning's 'n' Coefficients – 2D Domain

Land use	Manning's n
Roads, tracks and paths	0.025
Rail	0.050
Buildings, manmade structures	1.000
Trees, rough grassland	0.100
Embankments, cliff	0.050
Open land, general surface	0.055
Water, inland water	0.020

Boundary Conditions – 2D Domain

4.11 No inflow has been applied directly in the 2D domain. Any flow across the 2D domain is as a result of the 1D channel being overtopped, simulating out of bank conditions. Table 8 describes the downstream boundary condition used in the 2D domain. Its location is shown in Diagram 2.

Table 8: Boundary Conditions - 2D Domain

Type of Boundary	TUFLOW Feature	Description
Stage-Discharge	HQ Boundary	Free flow boundary applied at the downstream extent of the model. This boundary assigns a water level to the 2D cells based on a stage–discharge curve generated using the ground slope.

1D/2D Linking

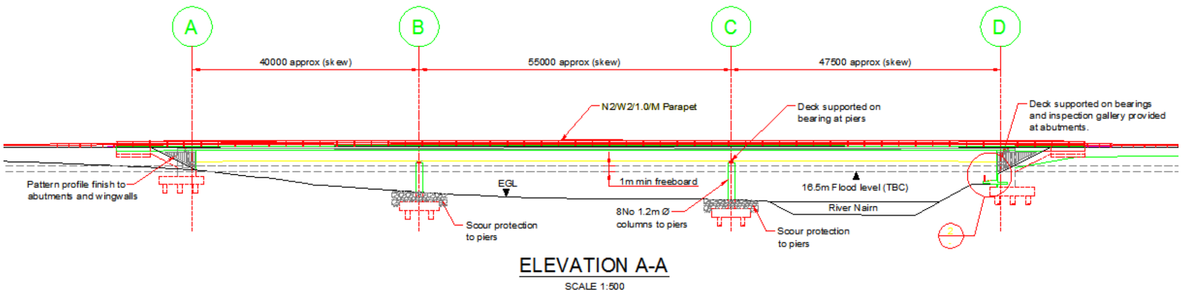
4.12 The link between the 1D and the 2D domains was defined along sections of the River Nairn and its tributary using the photogrammetry data. At the location of the banktop survey the 1D/2D link was informed with banktop survey data.

5 'With-Scheme' Modelling

Scheme Arrangement

5.1 There is a new crossing of the River Nairn for the proposed Scheme. The crossing is located 1.5km south of the town of Nairn. The crossing consists of a bridge with two piers in the flood plain. Each pier consists of a row of six circular columns, which support the bridge. The bridge is approximately 143m long and 31m wide. There will be a raised embankment on either side of the bridge. Diagram 4 shows the bridge arrangement. This is the only 'with-scheme' option which has been modelled.

Diagram 4: Proposed Scheme Bridge Side View



Modelling Approach

5.2 The soffit of the bridge is well above flood levels and has therefore no flood impact. The abutment and embankment were incorporated in the 2D domain topography. The bridge has two piers in the flood plain. Following standard guidance (Bradley 1978), the form loss associated with the piers was calculated as follows:

5.3 The fraction of blockage for two 1.2m wide piers within the 143m bridge opening was calculated to be 0.017.

5.4 From the guidance the fraction of blockage gives a form loss of 0.05, for a row of circular columns.

5.5 The form loss calculated is for the whole bridge opening. As shown in Diagram 5, the bridge opening spans the 1D and 2D model domains. Therefore updates where required in both components of the model.

<u>1D Model Updates</u>

5.6 A Flood Modeller general loss unit was added to the 1D model. The unit was added immediately upstream of the bridge. A loss coefficient of 0.05 was applied, as calculated in paragraph 5.2.3 above.

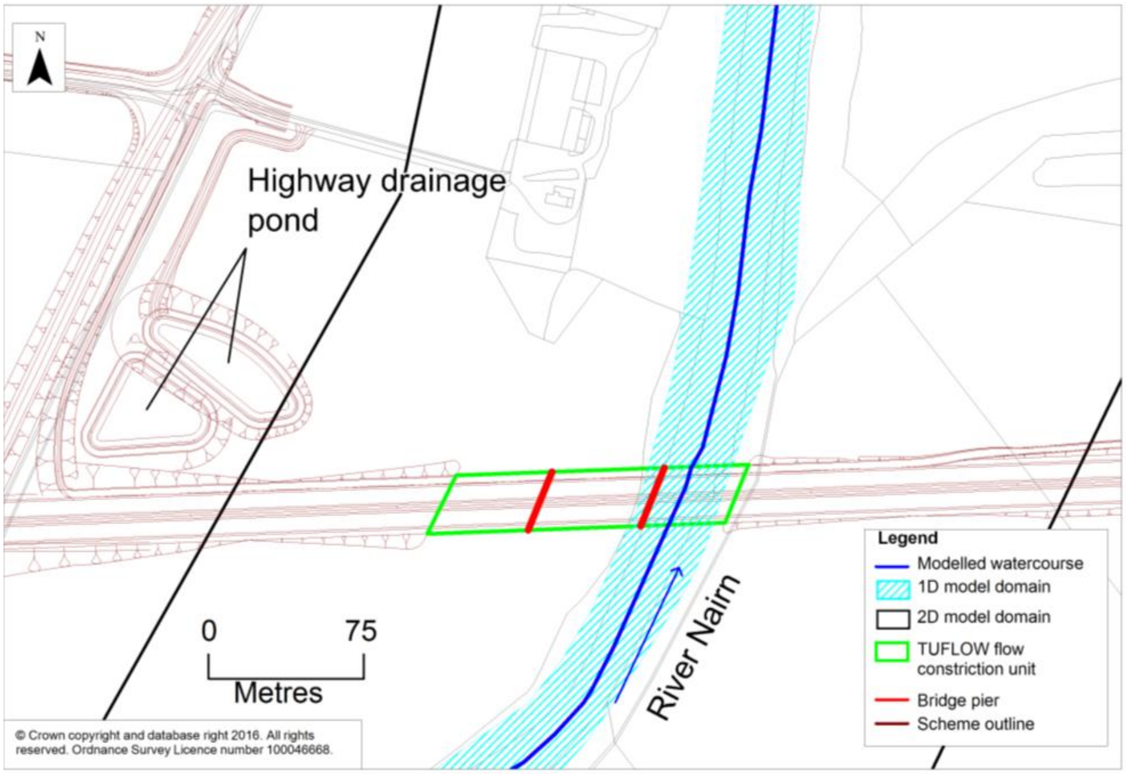
<u>2D Model Updates</u>

5.7 The proposed Scheme elevations were exported from the MXROAD software as ASCII grids, for inclusion in the hydraulic model. Within the proposed Scheme footprint, the ASCII grids replaced the ground elevation with the elevations for the road embankments. The surface roughness values within the proposed Scheme footprint were updated.

5.8 A flow constriction polygon was added to the 2D model to apply the form loss associated with the bridge piers. TUFLOW requires the form loss to be independent of the 2D cell size, therefore the form loss value (calculated in paragraph 5.2.3) was divided by the bridge width (31m). The form loss applied in the model was therefore 0.0016.

5.9 Diagram 5 shows that to the west of the River Nairn there are two highway drainage ponds. These were not included in the model as floodwater does not reach this location. No other features where required in the 2D model.

Diagram 5: River Nairn 'With-Scheme' Model Schematisation



6 Modelled events

6.1 Table 9 shows the AEP events and model scenarios that were simulated with the hydraulic model.

6.2 In order to test the model sensitivity to key hydraulic parameters, a series of simulations were undertaken for the baseline 0.5% AEP event. The assessed hydraulic parameters were: Manning's 'n' roughness coefficients, hydrological inflows and downstream boundary slope.

Table 9: Modelled Events

Scenario	AEP Event								
	50%	20%	10%	3.33%	2%	1%	0.5%	0.5% + CC	0.1%
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓
Roughness Sensitivity (1D and 2D)							✓		
Hydrological Inflow Sensitivity							✓		
Downstream Boundary Sensitivity (1D and 2D)							✓		
'With-Scheme'	✓	✓	✓	✓	✓	✓	✓	✓	✓

7 Model Proving

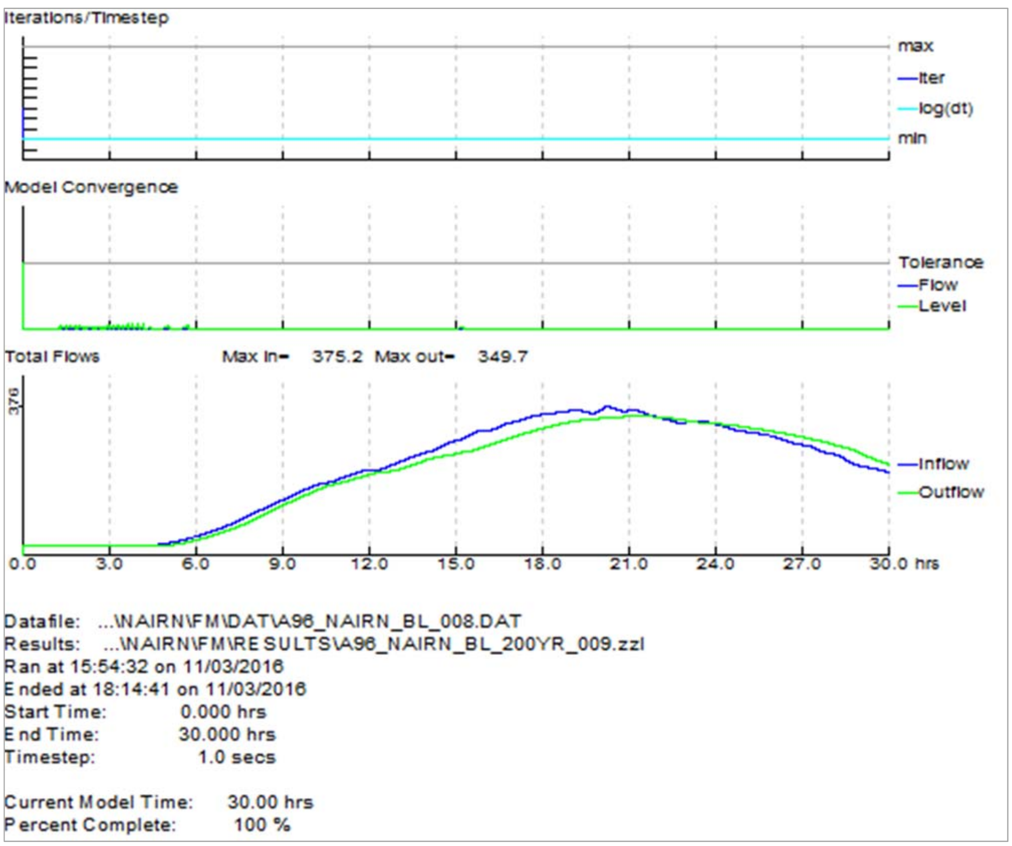
Introduction

7.1 The following sections discuss the model performance and the verification process. In addition, details relating to the additional runs carried out to test the sensitivity of the model to key variables are also discussed.

Model Performance

7.2 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure a suitable model convergence was achieved. Convergence refers to the ability of the modelling software to arrive at a solution that is close to the exact solution within a pre-specified error tolerance. The convergence of the 1D model was checked. As shown in Diagram 6, there are no 1D non-convergence issues. This convergence plot is generally typical for the events modelled. However some non-convergence occurs on the tributary for the 0.1% AEP event only. The non-convergence occurs immediately upstream of the tributary confluence with the River Nairn, which is 1.5km downstream of the proposed Scheme crossing. Checks have shown that the non-convergence does not affect water levels at the proposed Scheme location and is therefore deemed acceptable.

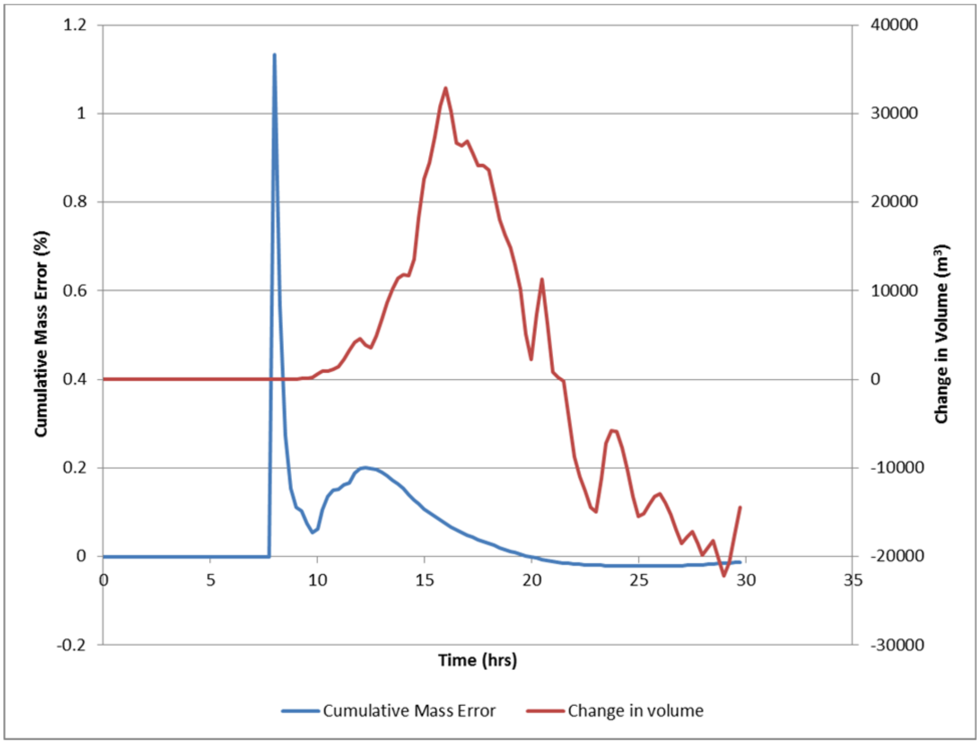
Diagram 6: 1D Model Convergence – 0.5 % AEP Event



7.3 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% Mass Balance error. The change in volume through the model simulation has also been checked and has been found to vary smoothly which is an indicator of good convergence of the 2D model.

7.4 Diagram 7 shows that for the 0.5% AEP event, the cumulative mass error is all less than 0.2%. There is a spike in the cumulative mass error which is outside of tolerance i.e. greater than 1% in absolute value. However, this spike occurs before there is significant volume of water in the model and is therefore deemed acceptable. This mass error diagnostic is typical for all events modelled, with a spike before the peak.

Diagram 7: 2D Cumulative Mass Error and Change in Volume – 0.5 % AEP Event



Calibration and Verification

Calibration

7.5 The records from the Firhall gauging station consist of high quality data, which could be used to inform the hydraulic model calibration. However, from the review of various reports and information on historic flooding in the vicinity of the modelled reach, no suitable flood level records were found along the modelled reach (other than at the gauge) to calibrate the hydraulic model (refer to Surface Water Hydrology Report). For this reason, a full hydraulic calibration of the River Nairn model was not possible. However, a high level verification of the model results has been undertaken and is detailed in the following sections.

Verification at Low Magnitude Events

7.6 The Firhall gauge data includes recorded annual maximum water levels with peak flows calculated from a rating curve. The rating curve for the Firhall gauge is shown on Diagram 8. Although a full calibration was not possible, it was possible to compare the model results at the gauge location to the annual maxima from the gauge. For events greater than the 3.33% AEP, the model results show that the gauge is bypassed by overtopping on the right bank, upstream of the gauge. Therefore, as expected the gauge data does not match the model results and cannot be used for verification for these high flow modelled events.

7.7 For the 50%, 20% and 10% AEP events the gauge is not bypassed. Therefore, a verification of the low magnitude events was carried out. Table 10 shows the peak flows predicted by the model and the closest equivalent annual maximum flows recorded by the gauge. The difference in water levels between the modelled data and the observed data ranges from approximately 45mm to 200mm. This shows that the modelled water levels are in good agreement with the recorded levels at the gauge. It should be noted that gauge flows, which are equivalent to a 20% and a 10% AEP event, are extrapolated from the rating curve. Therefore the gauge data for these events is likely to be less reliable, which may explain why the model fit is not as good as in the 50% AEP event.

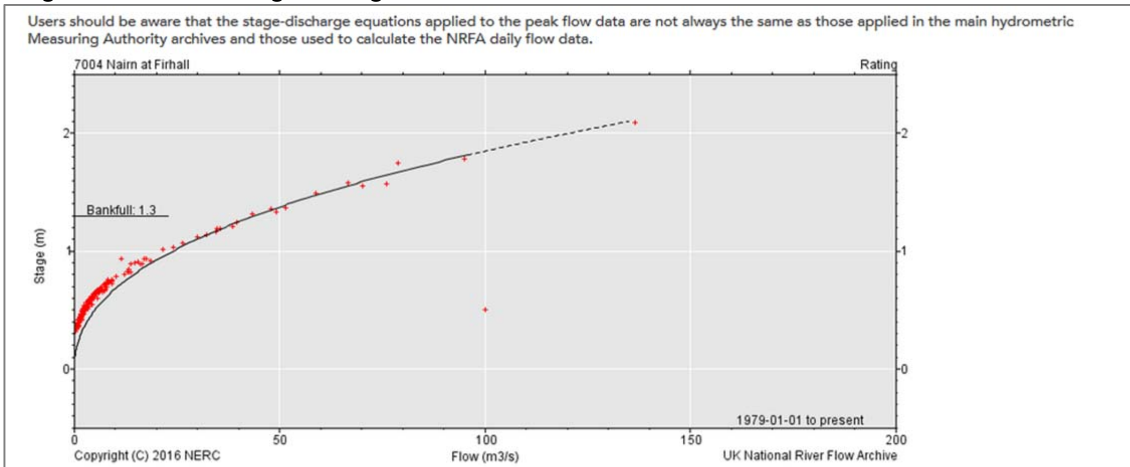
Table 10: Model Results vs. Gauge Maximums

Model Results at Node NAIR_1142			Gauge Annual Maximum			
Event (% AEP)	Stage (mAOD)	Flow (m^3/s)	Year	Stage (mAOD)	Flow (m^3/s)	Rating
50	8.971	98.44	1998-1999	9.017	98.58	In range
20	9.422	139.58	1984-1985	9.293	136.94	Extrapolated
10	9.706	171.13	1989-1990	9.499	170.488	Extrapolated

Table 11: Comparison of the Model Results with the Gauge Flows and Stages

	Flow		Stage	
Event (% AEP)	Difference (m^3/s)	Relative Difference	Difference (mm)	Relative Difference
50	-0.14	-0.1%	-46	-0.5%
20	2.64	1.9%	129	1.4%
10	0.64	0.4%	207	2.2%

Diagram 8: Firhall Gauge Rating Curve



Ref	Limb	Details	Equation	Start date	Max stage (m)	End date
1	a	SEPA highflow rating	Q = 21.233 * (h + 0.05400) ^ 2.412	01/01/1979	2.1	01/01/2100

<u>Verification Using Historic Data</u>

7.8 The verification exercise described in the section above was only suitable for low magnitude events. Historic flood incident data has been obtained in order to verify the model results for higher magnitude events.

7.9 Table 12 shows the data for the flood incidents within the Nairn model extent, along with a statement on the model verification. Diagram 9 shows the locations of the flood incidents. It should be noted that, as Auldearn Burn has not been modelled explicitly as part of the River Nairn model, the flooding originating from this watercourse (HIG1579, HIG1114 and HIG1833) is not accurately represented. In addition, Auldearn Burn is over 1.5km downstream from the proposed Scheme, and it has been shown that flood risk on this reach is not relevant for the flood risk assessment of the proposed Scheme crossing on the River Nairn. A separate model has been produced for the flood risk assessment of the proposed Scheme crossing on Auldearn Burn (see Annex 13.2.F (Auldearn Burn Hydraulic Modelling Report)).

7.10 This verification exercise shows that at most locations the model results are in agreement with the historic data. However it is acknowledged that there is a lack of good data for a full verification exercise.

Verification Using SEPA Flood Maps

7.11 Flood extent maps are available from the Scottish Environment Protection Agency (SEPA). These maps show the fluvial flood extent for different likelihoods of flooding (high, medium and low). The SEPA medium likelihood of flooding is equivalent to a 0.5% AEP event. Therefore a comparison has been made to the modelled baseline 0.5% AEP event flood extents (Diagram 10). The SEPA map shows a good match to the 0.5% AEP modelled event. Whilst this does not constitute a formal verification, it demonstrates that the modelling approach for this study confirms the less detailed model output from the SEPA national flood mapping. A difference between the two flood extents is noted at the Auldearn Burn watercourse location. With the present FRA model underestimating the flood outline compared to the published SEPA map. This difference occurs because Auldearn Burn is not represented explicitly within the River Nairn model. The inflow from this catchment was incorporated within the River Nairn model inflow arrangement. The confluence of Auldearn Burn and the River Nairn is approximately 2km downstream from the proposed Scheme location and the present model arrangement is considered appropriate.

Verification Conclusion

7.12 In conclusion the verification exercise has shown that, for the available data, the model results are generally in agreement with the verification data, indicating that the model results are realistic.

Table 12: Flood Incident Records

Reference	Easting	Northing	Date	Scale of Flooding	Description	Model Verification
HIG1579	289370	855960	7th Jan 2005	Street level	Flood water from Auldearn Burn adjacent to Balmakeith Park, Nairn putting houses at risk from flooding.	Model confirms flooding. Onset of flooding in 0.5% AEP event.
HIG1114	289301	855939	17th Jul 1997	Property level	Burn overflowed its banks, Balmakeith Park, Nairn	Model confirms flooding. Onset of flooding in 0.5% AEP event.
HIG1833	289200	855900	1st Jul 1997		High levels in Auldearn Burn resulted in flooding - Balmakeith Park Housing Estate	Model confirms flooding. Onset of flooding in 0.5% AEP event.
HIG1364	288530	856040	30th Jul 1956	Regional level	These properties were ultimately under water to a depth of approximately 2 ft. at one o clock	Model confirms flooding. These properties are first flooded in 0.5% AEP event.
HIG1365	288550	856140	30th Jul 1956	Regional level	These properties were ultimately under water to a depth of approximately 2 ft. at one o clock	Model confirms flooding. These properties are first flooded in 0.5% AEP event.
HIG1366	288650	856120	30th Jul 1956	Regional level	The Jubilee Bridge was brought down. The bridge appear to have been affected principally by trees carried by the flood waters	Bridge not in model.
HIG1367	288267	855082	30th Jul 1956	Regional level	The Firhall Suspension Bridge was brought down. The bridge appear to have been affected principally by trees carried by the flood waters	Bridge in model does not surcharge in any event. The bridge is likely to be a replacement for the Firhall Suspension Bridge, built at a higher level. A bridge spanning from banktop to banktop would surcharge in the 10% AEP event.
HIG1501	288470	855530	30th Jul 1956	Regional level	Major Fluvial Event	Model confirms flooding. Onset of flooding in 0.5% AEP event.
HIG1502	288670	856140	1956	Regional level	Major Fluvial Event	On edge of flooding in 0.5% AEP +CC event.
HIG1504	288260	855080	1956	Regional level	Major Fluvial Event	Model confirms flooding. Onset of flooding in 10% AEP event.
HIG1498	288650	856120	1915	Regional level	Major Fluvial Event	Model confirms flooding. Onset of flooding in 20% AEP event.
HIG1320	288120	855100	August 1829	Regional level	Heavy rain	No comparison made

Diagram 9: Location of Flood Incidents

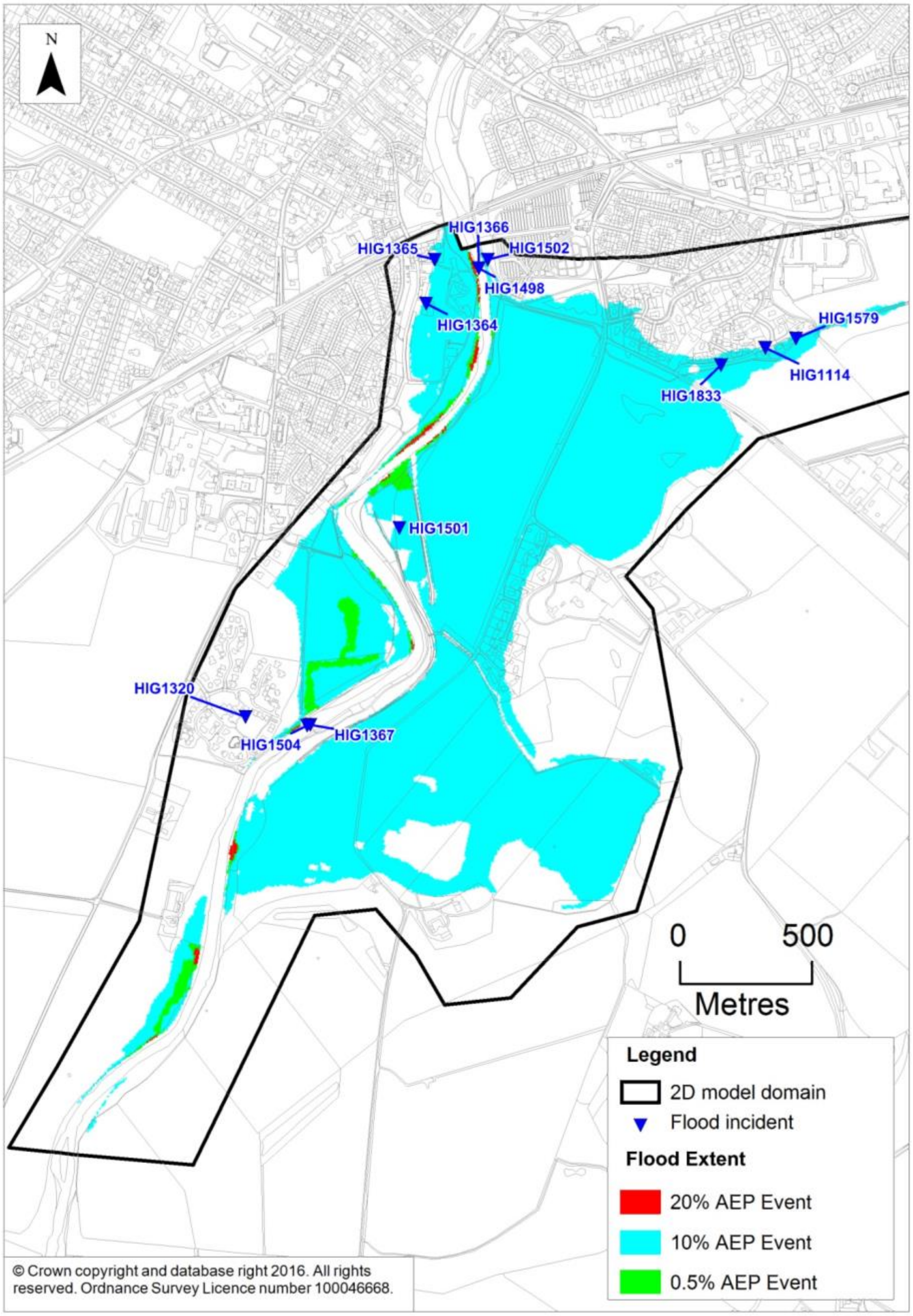
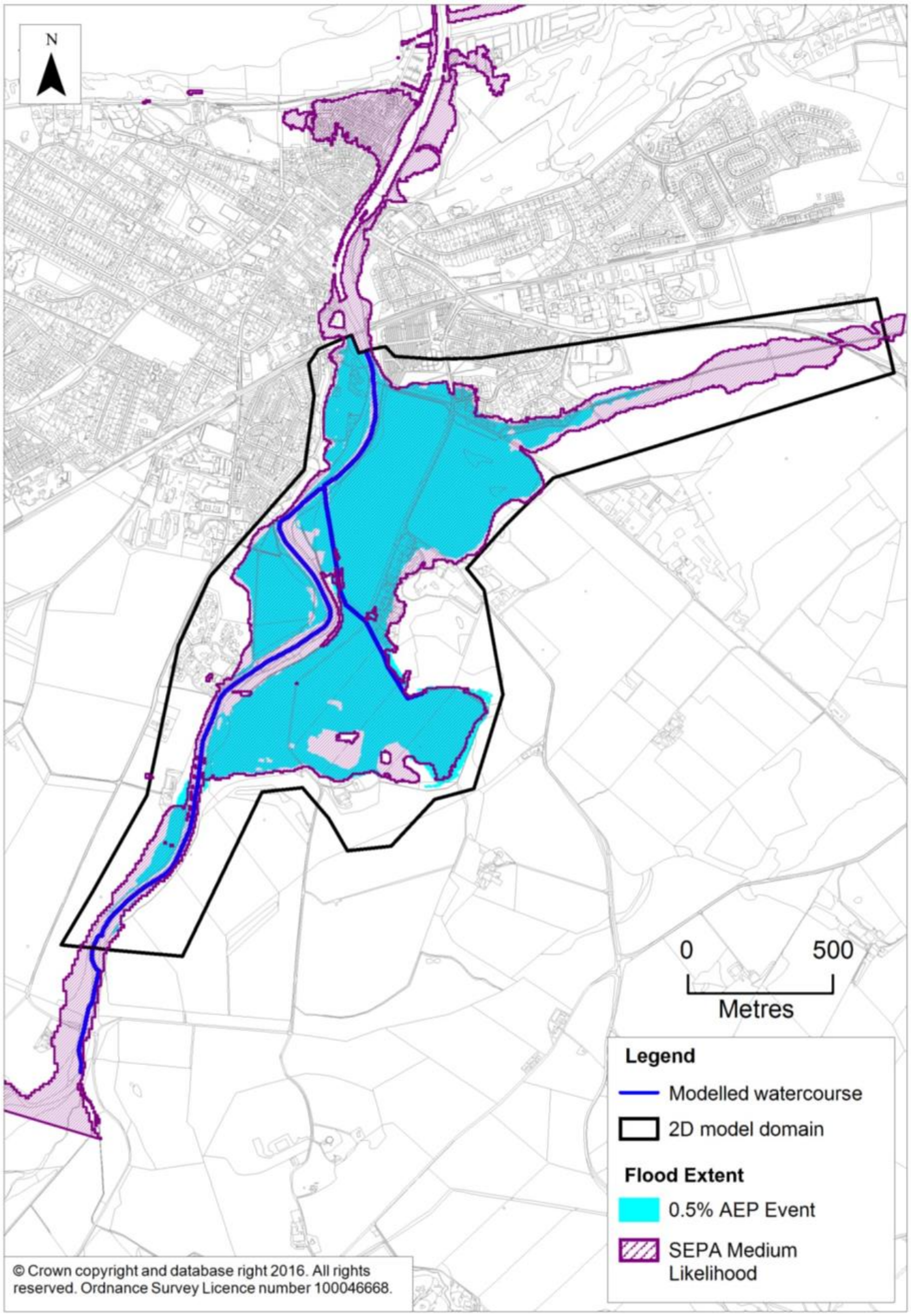


Diagram 10: Modelled 0.5 % AEP Event Flood Extent vs. SEPA Medium Likelihood Fluvial Extent



Sensitivity Analysis

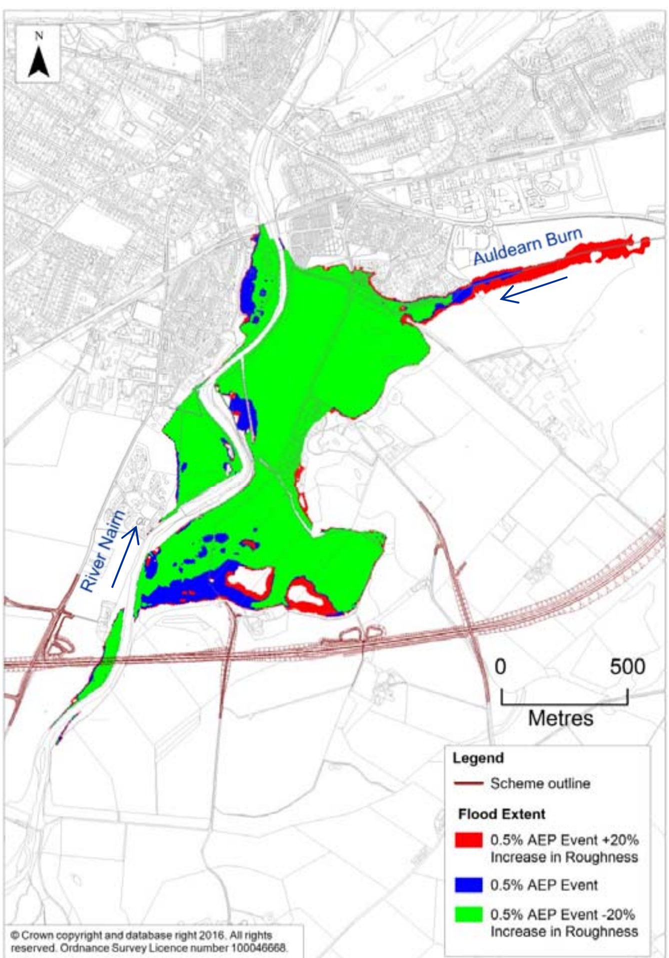
Roughness Sensitivity

7.13 In-channel and flood plain roughness coefficients (Manning's 'n') were changed by +20% and -20%. Table 13 shows the impact of changing the model roughness. Results are presented for the location along the whole of the River Nairn modelled reach (Flood Modeller Node NAIR_2748 to NAIR_0000cp) that shows the biggest magnitude of change in water level. The results show that the in-channel water levels are sensitive to changes in roughness. However, Diagram 11 shows that changes in flood extent as a result of changing the model roughness occur downstream (north) of the proposed Scheme location and changes close to the proposed Scheme are minimal. A large increase in flood extent is seen on Auldearn Burn as a result of increasing the roughness.

Table 13: Roughness Sensitivity Results

Sensitivity	Water Level Difference (m)			Water Level Difference at the Scheme (m)
	Max	Min	Average	NAIR_1824
+20% Roughness	0.430	0.023	0.253	0.292
-20% Roughness	-0.486	0.105	-0.231	-0.327

Diagram 11: 0.5 % AEP Event Roughness Sensitivity



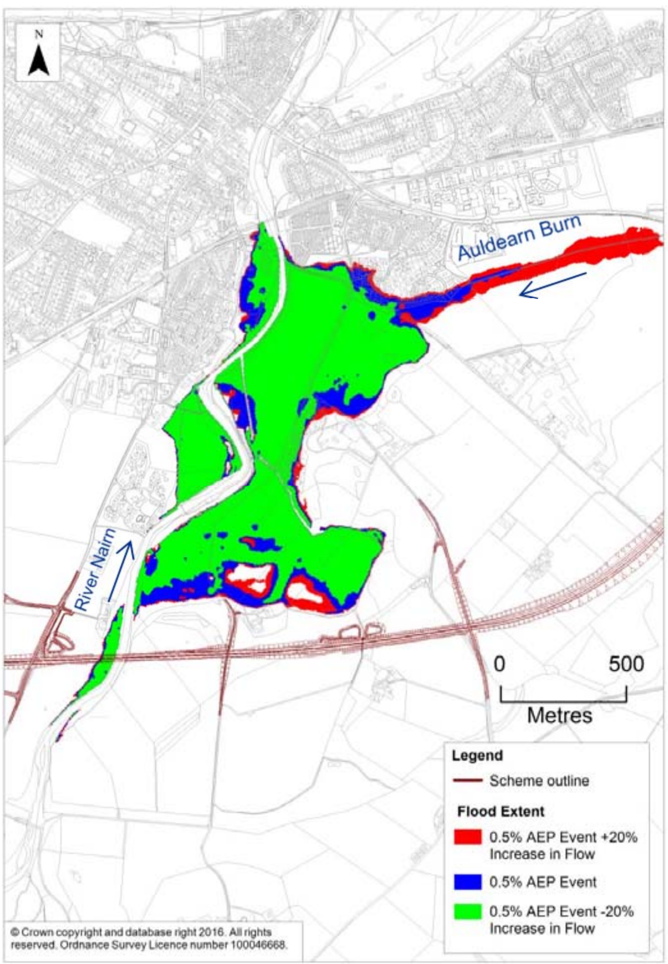
Hydrological Inflow Sensitivity

7.14 The flows into the model were adjusted by +20% and -20%. Table 14 shows the impact of changing the model inflows. Results are presented for the location along the whole of the River Nairn modelled reach (Flood Modeller Node NAIR_2748 to NAIR_0000cp) that shows the biggest magnitude of change in water level. The results show that the model is sensitive to changes in flow. Diagram 12 shows how the flood extent changes as a result of changing the model inflow. However, the results also show that at the proposed Scheme the changes are minimal, with the greatest changes seen downstream (north) of the proposed Scheme.

Table 14: Flow Sensitivity Results

Sensitivity	Water Level Difference (m)			Water Level Difference at the Scheme (m)
	Max	Min	Average	NAIR_1824
+20% Flow	0.525	0.053	0.279	0.335
-20% Flow	-0.620	-0.088	-0.306	-0.422

Diagram 12: 0.5 % AEP Event Flow Sensitivity



Downstream Boundary Condition Sensitivity

7.15 The slope of the downstream boundaries in the 1D and 2D models were adjusted by +20% and -20%. The results show that the changes to the downstream boundary only affect the downstream end of the model. Table 15 shows the response at the downstream of the model (Flood Modeller Node NAIR_0000cp). The location at which there is no change in water level as a result of changing the downstream boundary has been identified. Distances from this location, in relation to the downstream end of the model (tailwater distance) and in relation to the proposed Scheme, are shown in Table 15. This indicates that the proposed Scheme is at least 1286m upstream of the influence of the downstream boundary.

Table 15: Downstream Boundary Sensitivity Results

Sensitivity	Water Level Difference (m)		
	Water Level Difference (mAOD) at NAIR_0000cp (d/s Boundary)	Tailwater Distance (m)	Distance to Scheme (m)
+20% Downstream boundary slope	-0.232	833	1286
-20% Downstream boundary slope	0.245	833	1286

8 Model Results

Baseline Scenario

8.1 In-channel water levels have been inspected at key locations in relation to the proposed Scheme. Table 17 shows the 0.5% AEP event in-channel water levels. Table 18 shows in-channel water levels for the 0.5% AEP +CC. The in-channel water levels at key locations for all modelled events are shown in Section A.1 (Water Level Tables and Long Section).

8.2 Maps have been produced to show the baseline scenario flood extent for each modelled event, at the location of proposed Scheme and for the entire model extent (see Section A.2 (Flood Extent Maps)). For the 50% AEP event no out of bank flooding occurred, therefore no flood extent map was produced. Diagram 13 shows the main flood mechanisms for the 0.5% AEP +CC and has been analysed in conjunction with the extent maps to assess the baseline flooding (each area of flooding has been numbered to aid reporting):

8.3 Area 1 – Out of bank flooding on the left bank, first occurs in the 10% AEP event. Water flows downstream and returns to channel.

8.4 Area 2 – Water overtopping from the right bank of the River Nairn flows downstream and joins with flooding from the tributary. The onset of this flooding is the 3.33% AEP event. From the 2% AEP event flooding of this area extends further east, past the upstream modelled extent of the tributary.

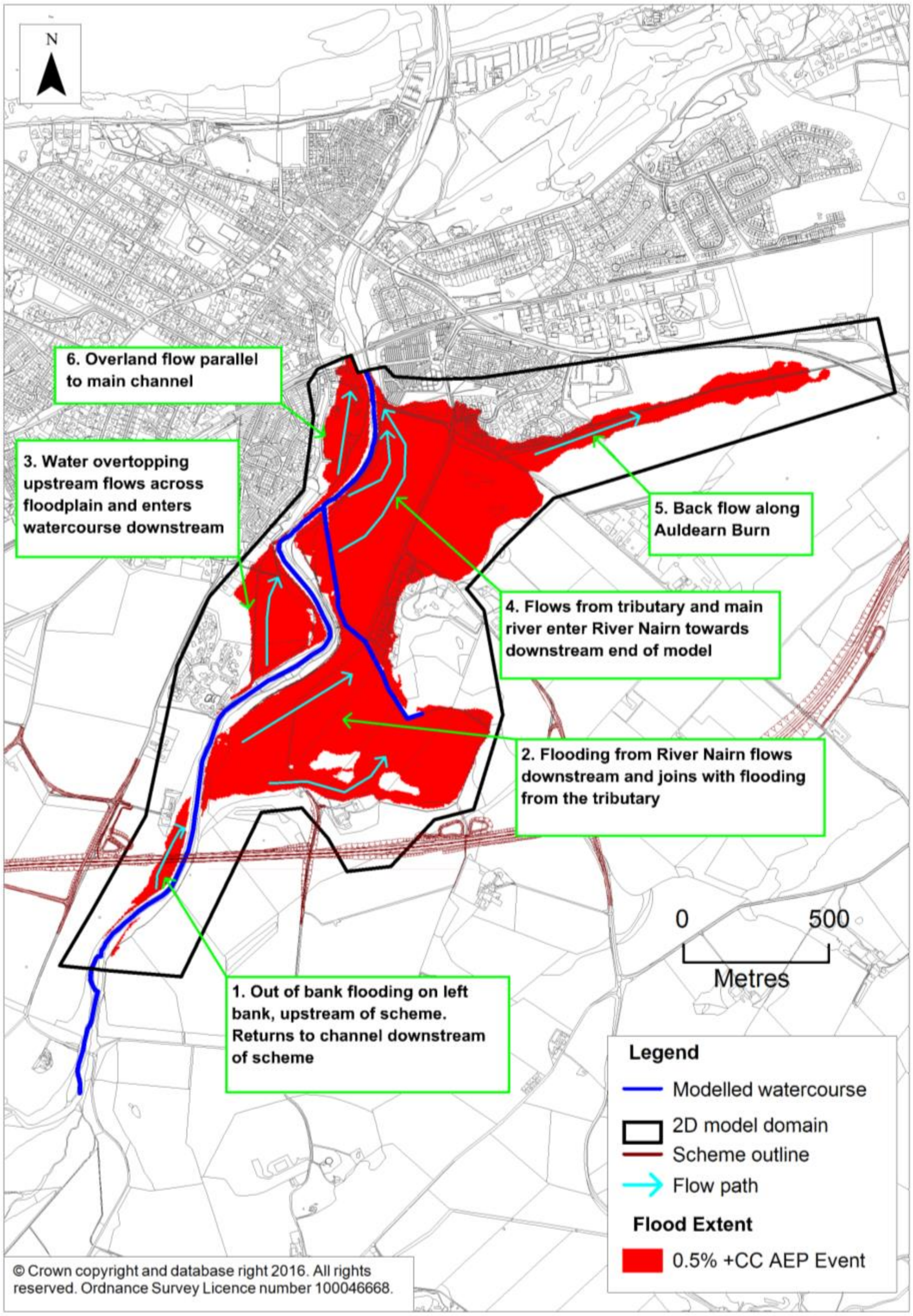
8.5 Area 3 – Overtopping on left bank first occurs here in the 10% AEP event. From the 3.33% AEP event flooding in this area re-enters the watercourse further downstream.

8.6 Area 4 – From the 3.33% AEP event water overtopping from the River Nairn right bank flows downstream and re-enters the watercourse towards the downstream extent of the model. From the 2% AEP event there is also out of bank flooding from the tributary.

8.7 Area 5 – Back flow along Auldearn Burn from the 0.5% AEP event onwards.

8.8 Area 6 – Out of bank flooding flows parallel to the main channel. This first occurs in the 10% AEP event.

Diagram 13: 0.5% AEP +CC Event Flood Mechanisms



Comparison of Baseline and 'With-Scheme' Scenarios

Differences in Maximum Flood Depths across the Flood Plain

8.9 In order to assess the impact of the proposed Scheme on the existing flood risk, the differences in maximum flood depths were calculated for the 3.33%, 0.5%, 0.5% +CC and 0.1% AEP events between the baseline and the 'with-scheme' scenarios. All the maps are shown in Section A.3 (Depth Change Maps). The impact on flood risk, whether adverse or beneficial, have been categorised in Table 16.

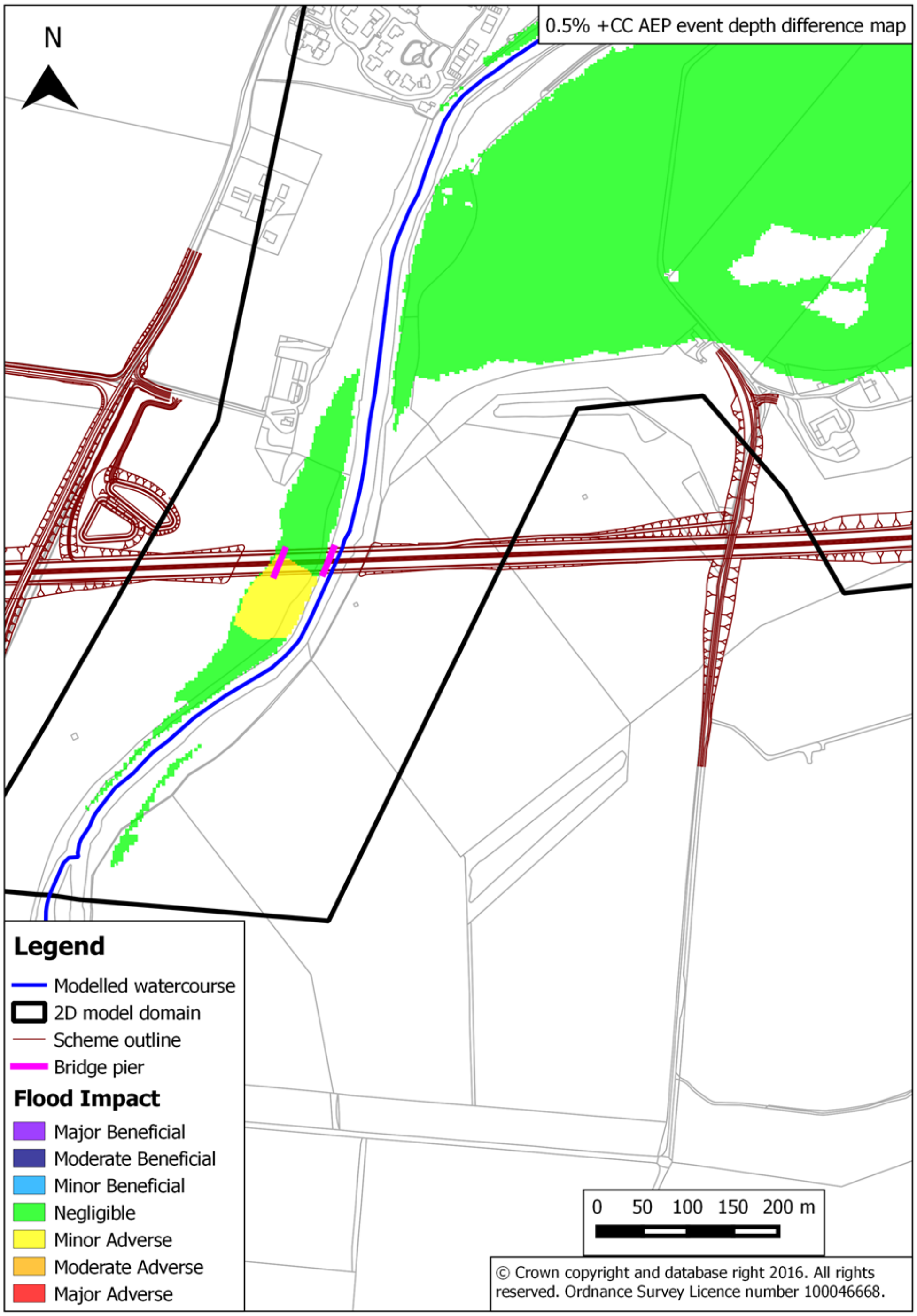
8.10 Diagram 14 below shows that for the 0.5% AEP +CC event, the change in flood depths in the flood plain between the baseline and the 'with-scheme' scenario is less than +/-10mm i.e. negligible (see Table 16). Only for a small area, from the proposed Scheme crossing up to 80m upstream of it, the difference in flood depths is less than 16mm. This is categorised as minor adverse. It is a consequence of the hydraulic loss introduced by the bridge piers. As this minor adverse impact occurs in agricultural land and as no sensitive receptors are present in the vicinity, it has been considered as acceptable. Therefore, no mitigation scenarios were carried out.

8.11 As shown on the depth change maps in Section A.3 (Depth Change Maps), for the four modelled events, the impact of the proposed Scheme on flood depths is categorised as minor adverse in the area from the proposed Scheme up to 80m upstream of it. Anywhere else across the River Nairn flood plain, the impact is negligible. For the 0.1% AEP event, a major adverse impact (increase in water level by maximum 460mm) is observable very locally downstream of the proposed Scheme, where the flood extent hit the base of the access road embankment.

Table 16: Categorisation of Difference in Flood Depths

	Potential Flood Impact	Criteria	Flood Risk
	Major Adverse	Results in loss of attribute and/ or quality and integrity of the attribute	Increase in peak flood depth >100 mm
	Moderate Adverse	Results in effect on integrity of attribute, or loss of part of attribute	Increase in peak flood depth 50-100 mm
	Minor Adverse	Results in some measurable change in attributes quality or vulnerability	Increase in peak flood depth 10-50 mm
	Negligible	Results in effect on attribute, but of insufficient magnitude to affect the use or integrity	Negligible change in peak flood depth <+/- 10 mm
	Minor Beneficial	Results in some beneficial effect on attribute or a reduced risk of negative effect occurring	Reduction in peak flood depth 10-50 mm
	Moderate Beneficial	Results in moderate improvement of attribute quality	Reduction in peak flood depth 50-100 mm
	Major Beneficial	Results in major improvement of attribute quality	Reduction in peak flood depth >100mm

Diagram 14: 0.5% AEP +CC Event Depth Difference Map



Differences in Maximum In-Channel Water Levels

8.12 Table 17 and Table 18 show the changes in in-channel peak water level between the baseline and the 'with-scheme' scenarios, for the 0.5% and the 0.5% AEP +CC events respectively. The results show that at the bridge crossing there is an increase in in-channel peak water level between the baseline and the 'with-scheme' scenarios. In the 0.5% AEP +CC event, the increase is 16mm at the bridge. At approximately 140m upstream of the bridge the increase between the baseline and the 'with-scheme' scenarios for the 0.5% AEP +CC event is 6mm.

8.13 Section A.1 (Water Level Tables and Long Section) shows the difference in in-channel water level at key locations for each modelled event. The results show that from the 10% AEP event onwards the increase in peak water level at the bridge is greater than 10mm; a minor adverse impact. Downstream of the bridge the increases in peak water level are less than 1mm or zero for all event modelled.

Table 17: In-Channel Water Level at Key Location for the 0.5% AEP Event

Model node	Description	Baseline Water Level (mAOD)	With-Scheme Water Level (mAOD)	Change in Water Level (m)
NAIR_2748	924m Upstream of Scheme crossing	16.174	16.174	0.000
NAIR_2304	480m Upstream of Scheme crossing	15.006	15.008	0.002
NAIR_1965	141m Upstream of Scheme crossing	13.962	13.966	0.004
NAIR_1824	At Scheme crossing	13.637	13.652	0.015
NAIR_1690	84m Downstream of Scheme crossing	13.114	13.114	0.000
NAIR_1125	472m Downstream of Scheme crossing	10.451	10.451	0.000

Table 18: In-Channel Water Level at Key Location for the 0.5% AEP +CC Event

Model node	Description	Baseline Water Level (mAOD)	With-Scheme Water level (mAOD)	Change in Water Level (m)
NAIR_2748	924m Upstream of Scheme crossing	16.626	16.627	0.001
NAIR_2304	480m Upstream of Scheme crossing	15.425	15.427	0.002
NAIR_1965	141m Upstream of Scheme crossing	14.282	14.288	0.006
NAIR_1824	At Scheme crossing	13.972	13.988	0.016
NAIR_1690	84m Downstream of Scheme crossing	13.416	13.416	0.000
NAIR_1125	472m Downstream of Scheme crossing	10.513	10.513	0.000

9 Model Assumptions and Limitations

Introduction

9.1 The accuracy and validity of the hydraulic model results is heavily dependent on the accuracy of the hydrological and topographic data included in the model. While the most appropriate available information has been used to construct the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

9.2 Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process. The assumptions made are considered to be generally conservative for modelled water levels at the proposed Scheme location and are therefore appropriate for the flood risk assessment. Additionally, the sensitivity analysis (presented in Section 7 (Sensitivity Analysis)) has quantified the magnitude of potential uncertainty, and the verification process described in Section 7 (Calibration and Verification) indicates that the modelling outputs are sensible.

9.3 The following sections summarise the key sources of uncertainty in addition to the limitations associated with the modelling undertaken for the River Nairn.

1D Domain

Cross Sections

9.4 Three surveyed cross sections, in the 1D part of the model, have been extended using photogrammetry data.

Channel Roughness

9.5 Channel roughness has been assigned using the best available information (site visit, survey data and aerial photographs). The roughness values used are based on available guidance (Chow 1959).

Representation of Structures

9.6 Hydraulic coefficients for structures have been applied using available guidance within the Flood Modeller software. The dimensions for structures have been based on detailed survey measurements.

9.7 A blockage factor of 50% has been applied to one of the culverts on the tributary (NATR_0404u). This allows for a build-up of sediment observed during the survey. This structure is approximately 1km downstream of the proposed Scheme location and therefore will not affect water levels at the proposed Scheme.

9.8 In order for the downstream extent of the 2D model to tie into high ground the model domain needed to be extended slightly beyond the available river survey. This required a copy section to be created in the 1D model, so that both components of the model finished at the same location. This extended the downstream end of the model past a footbridge, known as Jubilee Bridge. As this bridge was not included in the river survey, no dimension data was available for it. The bridge has therefore not been included in the model. The Jubilee Bridge is located over 2km downstream of the proposed Scheme crossing. During the site visit the bridge level was observed to be sufficiently high and, it is considered that the bridge will not have a significant hydraulic impact.

9.9 A 1D head loss has been calculated following standard guidance (Bradley 1978), to account for the proposed Scheme bridge piers.

Downstream Boundary Conditions

9.10 The downstream boundary is free discharge type without any downstream control; a normal depth boundary condition is applied. This is deemed appropriate as the boundary is approximately 2.1km downstream of the proposed Scheme location. In addition the sensitivity analysis has shown that changes to the downstream boundary only impact on water levels up to 800m upstream of the downstream model extent.

2D Domain

Flood Plain Topography

9.11 The photogrammetry data is assumed to appropriately represent the flood plain. A good match has been seen between banktop levels in the surveyed cross sections and photogrammetry.

Flood Plain Structures

9.12 A review of the flood plain using available aerial and road level photography, OS mapping and site inspection has shown that there are no existing flood plain structures that require modelling.

9.13 For the 'with-scheme' situation, a 2D form loss has been calculated following standard guidance (Bradley 1978), to account for the bridge piers.

9.14 Highway drainage ponds, which form part of the 'with-scheme' situation, have not been included in the model as floodwater does not reach them.

Grid Size

9.15 A 4m grid has been used. This is suitable to represent flood plain features to an appropriate level of detail.

DTM Modifications

9.16 Auldearn Burn joins the River Nairn towards the downstream end of the model. The runoff from for this tributary is included as a component of the main River Nairn inflow, rather than a point inflow at the tributary location. As such, in this model setup, floodwater from the River Nairn is able to propagate upstream along the Auldearn Burn valley. A test was carried out to block this flow path, removing the storage and simulating high water on Auldearn Burn. This highly conservative test showed no response at the proposed Scheme, and indicated that it was not necessary to include a discrete inflow for Auldearn Burn, or any more detailed representation of that channel in the hydraulic model.

9.17 Apart from a breakline for the banktop survey, no other modifications were made to the DTM. Site inspection and a check of aerial photographs established that no other breaklines were required for the existing situation.

9.18 For the 'with-scheme' situation, the existing ground levels were modified within the proposed Scheme footprint from the MXROAD software.

Blockage scenario

9.19 Considering the large size of the bridge openings, with minimum width between piers is 40m, it is considered unrealistic that this structure would experience blockage during flood event conditions. As such no blockage sensitivity scenarios were considered.

Model calibration

9.20 No calibration was carried out (see model Section 7 (Calibration and Verification)).

10 Conclusion

10.1 This report has detailed the modelling carried out to assess the baseline flood risk for the River Nairn with reference to the location of the proposed Scheme. A 3km reach of the River Nairn and 1km of unnamed tributary were represented in the model. A range of flood events from 50% to 0.1% AEP events were simulated.

10.2 The results of the baseline modelling have shown that in the vicinity of the proposed Scheme no properties are at risk of flooding.

10.3 The River Nairn crossing SWF23-1 (PS14) consists of a 143m width (perpendicular to the river) bridge supported by two piers. On either sides of the bridge, the proposed Scheme is embanked. The proposed Scheme has been incorporated into the design scenario to assess its impact on the baseline flood risk.

10.4 Results have shown that for the 0.5% AEP +CC event, change in water levels at the crossing location are less than 16mm both in-channel and in the flood plain. Flood impacts are categorised as minor adverse, up to 80m upstream of the proposed Scheme. This minor adverse impact occurs only in agricultural lands immediately adjacent to the proposed Scheme, it has been considered as acceptable. Anywhere else in the flood plain flood impacts are negligible.

12 References

Bradley (1978).Hydraulics of Bridge and Waterways

Chow, Ven Te (1959). Open-Channel Hydraulics. McGraw-Hill.

Scottish Environment Protection Agency (SEPA) (V9.1, 2015). Technical Flood Risk Guidance for Stakeholders (Ref SS-NFR-P_002)

A.1 Maximum Water Level Tables and Long Sections

	Baseline Water Levels (mAOD)					
Modelled Event	**Model Node**					
	NAIR_2748 (924m Upstream of Scheme crossing)	NAIR_2304 (480m Upstream of Scheme crossing)	NAIR_1965 (141m Upstream of Scheme crossing)	NAIR_1824 (At Scheme crossing)	NAIR_1690 (84m Downstream of Scheme crossing)	NAIR_1125 (472m Downstream of Scheme crossing)
50% AEP Event	13.940	12.578	11.789	11.321	10.861	8.961
20% AEP Event	14.370	13.129	12.332	11.819	11.370	9.439
10% AEP Event	14.671	13.489	12.684	12.141	11.709	9.758
3.33% AEP Event	15.165	14.025	13.158	12.696	12.238	10.187
2% AEP Event	15.415	14.276	13.366	12.968	12.484	10.294
1% AEP Event	15.778	14.631	13.661	13.309	12.808	10.385
0.5% AEP Event	16.174	15.006	13.962	13.637	13.114	10.451
0.5% AEP +CC Event	16.626	15.426	14.282	13.972	13.416	10.513
0.1% AEP Event	17.953	15.982	14.695	14.394	13.787	10.603

	With-Scheme Water Levels (mAOD)					
Modelled Event	**Model Node**					
	NAIR_2748 (924m Upstream of Scheme crossing)	NAIR_2304 (480m Upstream of Scheme crossing)	NAIR_1965 (141m Upstream of Scheme crossing)	NAIR_1824 (At Scheme crossing)	NAIR_1690 (84m Downstream of Scheme crossing)	NAIR_1125 (472m Downstream of Scheme crossing)
50% AEP Event	13.940	12.579	11.792	11.329	10.861	8.961
20% AEP Event	14.370	13.130	12.336	11.828	11.370	9.439
10% AEP Event	14.671	13.490	12.689	12.152	11.709	9.758
3.33% AEP Event	15.166	14.026	13.159	12.709	12.238	10.188
2% AEP Event	15.415	14.276	13.368	12.981	12.484	10.294
1% AEP Event	15.778	14.632	13.664	13.323	12.808	10.385
0.5% AEP Event	16.175	15.008	13.966	13.652	13.114	10.451
0.5% AEP +CC Event	16.627	15.427	14.288	13.988	13.416	10.513
0.1% AEP Event	17.954	15.984	14.702	14.413	13.788	10.603

	Change in Water Level (m)					
Modelled Event	**Model Node**					
	NAIR_2748 (924m Upstream of Scheme crossing)	NAIR_2304 (480m Upstream of Scheme crossing)	NAIR_1965 (141m Upstream of Scheme crossing)	NAIR_1824 (At Scheme crossing)	NAIR_1690 (84m Downstream of Scheme crossing)	NAIR_1125 (472m Downstream of Scheme crossing)
50% AEP Event	0.000	0.001	0.003	0.008	0.000	0.000
20% AEP Event	0.000	0.001	0.004	0.009	0.000	0.000
10% AEP Event	0.000	0.001	0.005	0.011	0.000	0.000
3.33% AEP Event	0.001	0.001	0.001	0.013	0.000	0.001
2% AEP Event	0.000	0.000	0.002	0.013	0.000	0.000
1% AEP Event	0.000	0.001	0.003	0.014	0.000	0.000
0.5% AEP Event	0.001	0.002	0.004	0.015	0.000	0.000
0.5% AEP +CC Event	0.001	0.001	0.006	0.016	0.000	0.000
0.1% AEP Event	0.001	0.002	0.007	0.019	0.001	0.000

Diagram A1: River Nairn Long Section – 0.5% AEP +CC Event - In-Channel Peak Water Levels

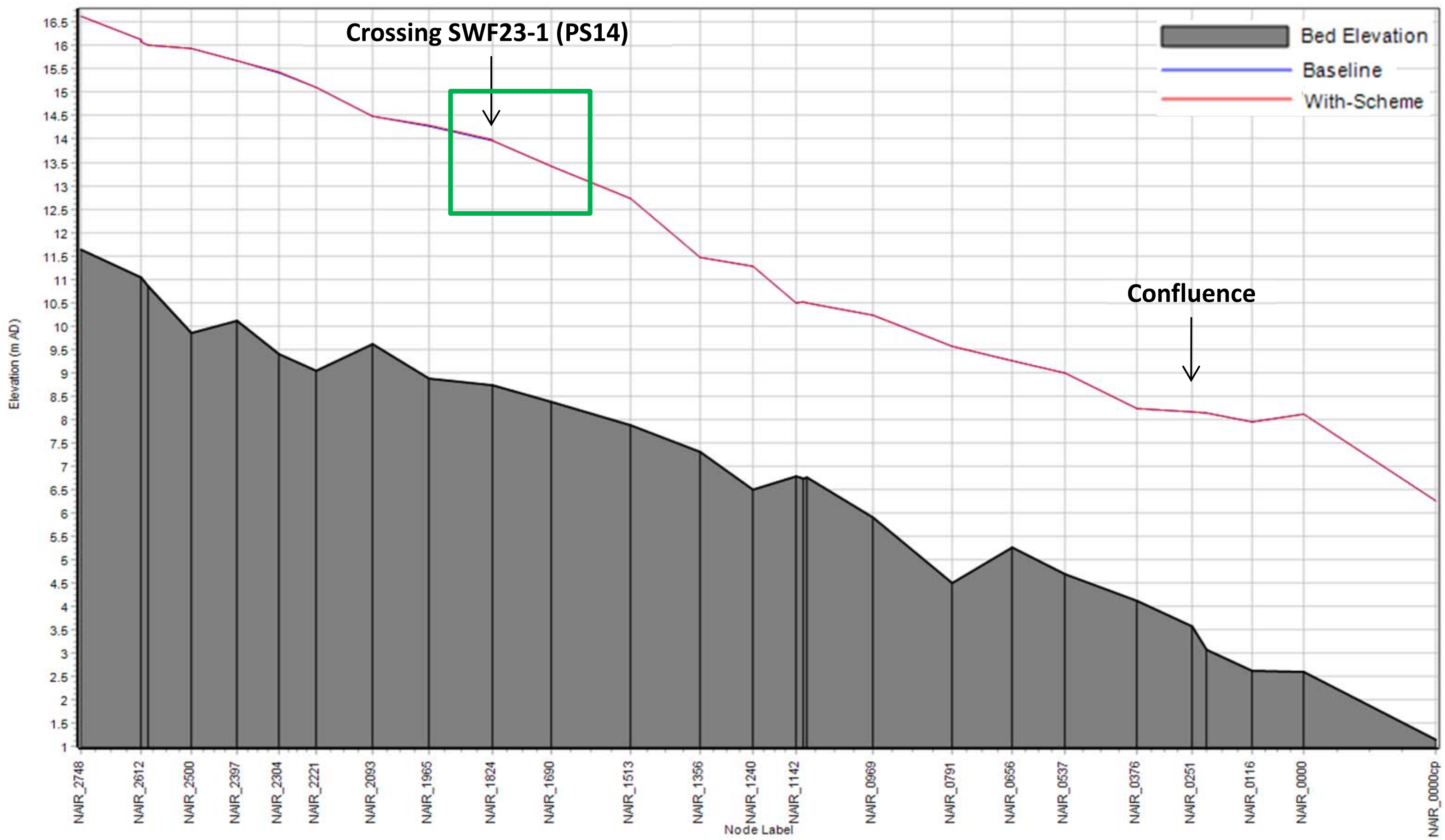
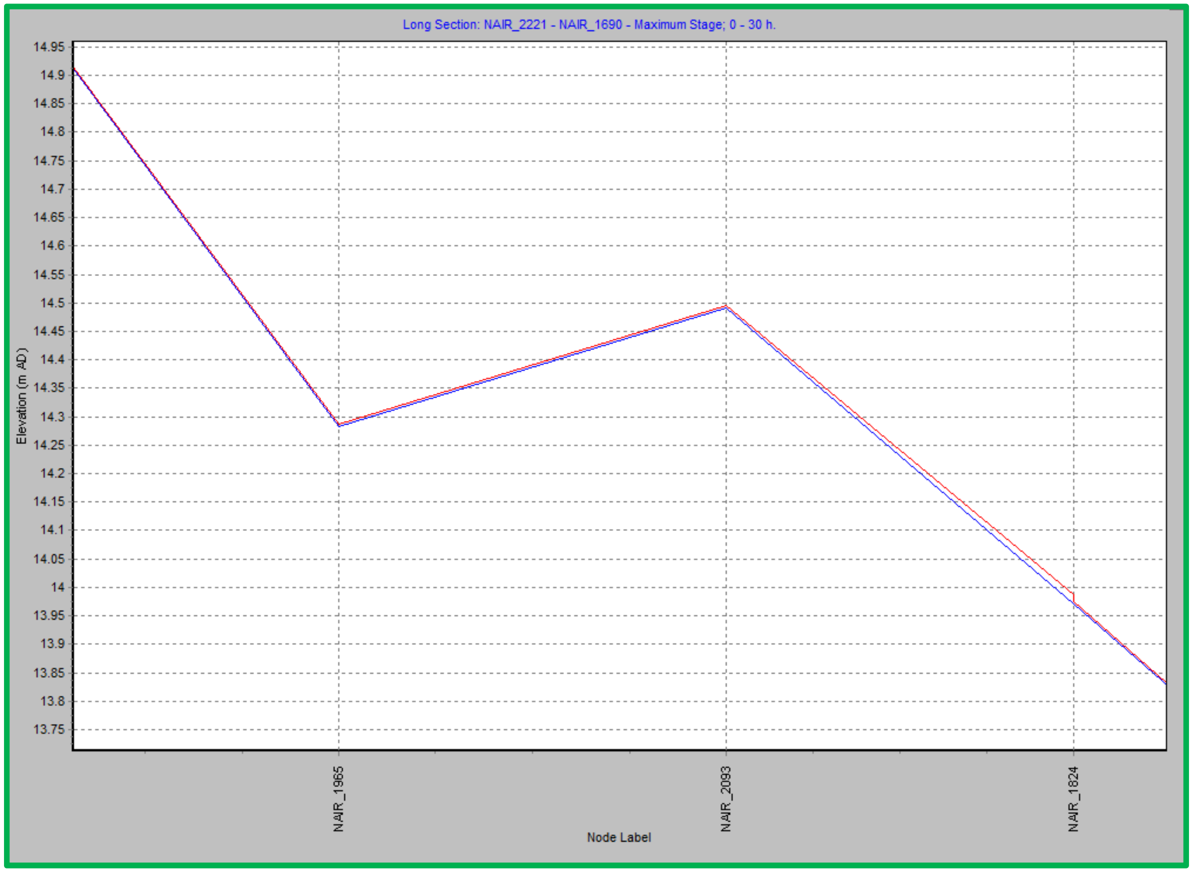


Diagram A2: River Nairn Long Section – 0.5% AEP +CC Event - In-Channel Peak Water Levels - Close up at Scheme Crossing



A.2 Flood Extent Maps

Diagram A3: Baseline Flood Extent for Entire Model Extent. 20%, 10%, 3.33% and 2% AEP Events

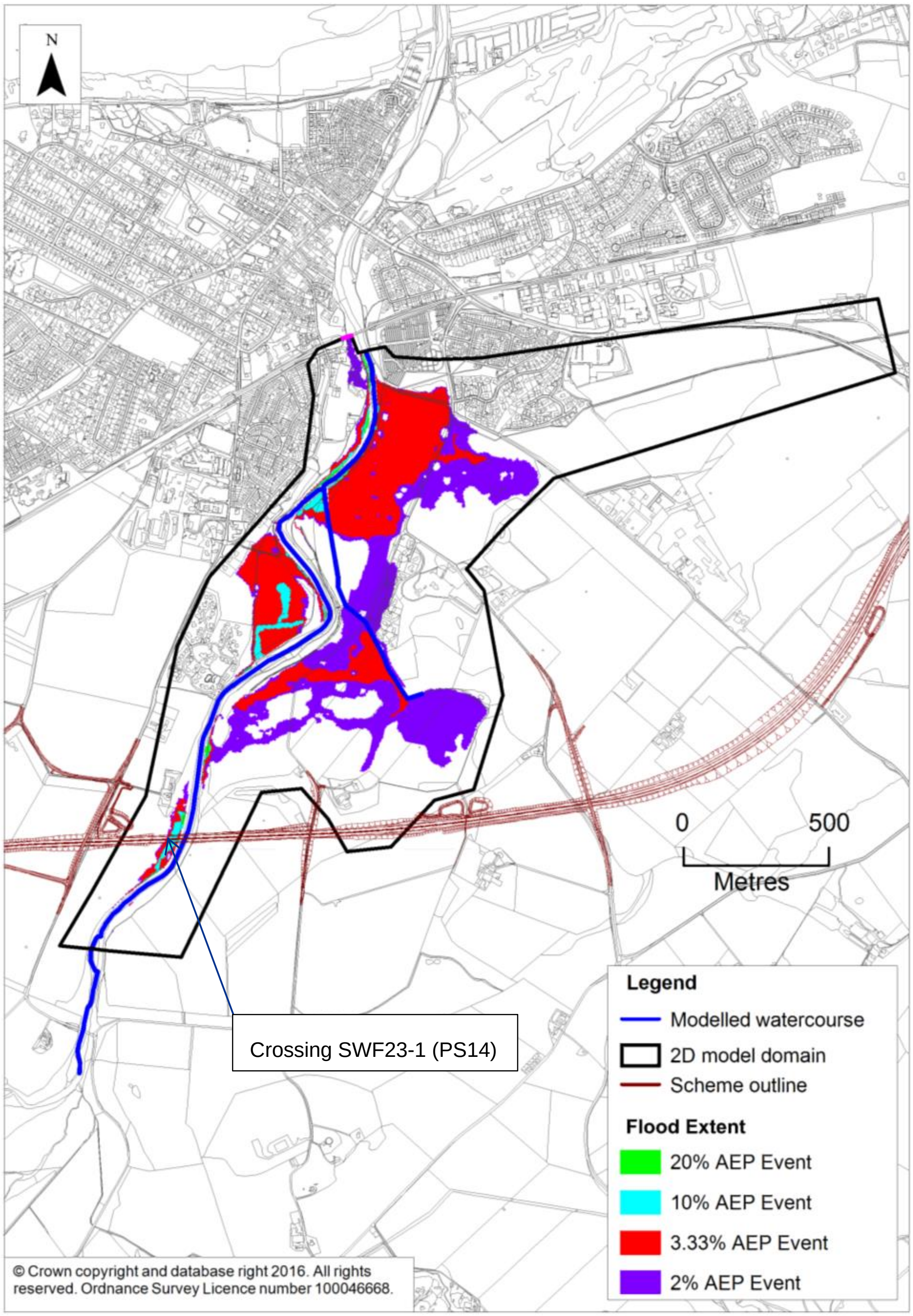


Diagram A4: Baseline Flood Extent for Entire Model Extent. 1%, 0.5%, 0.5% +CC and 0.1% AEP Events

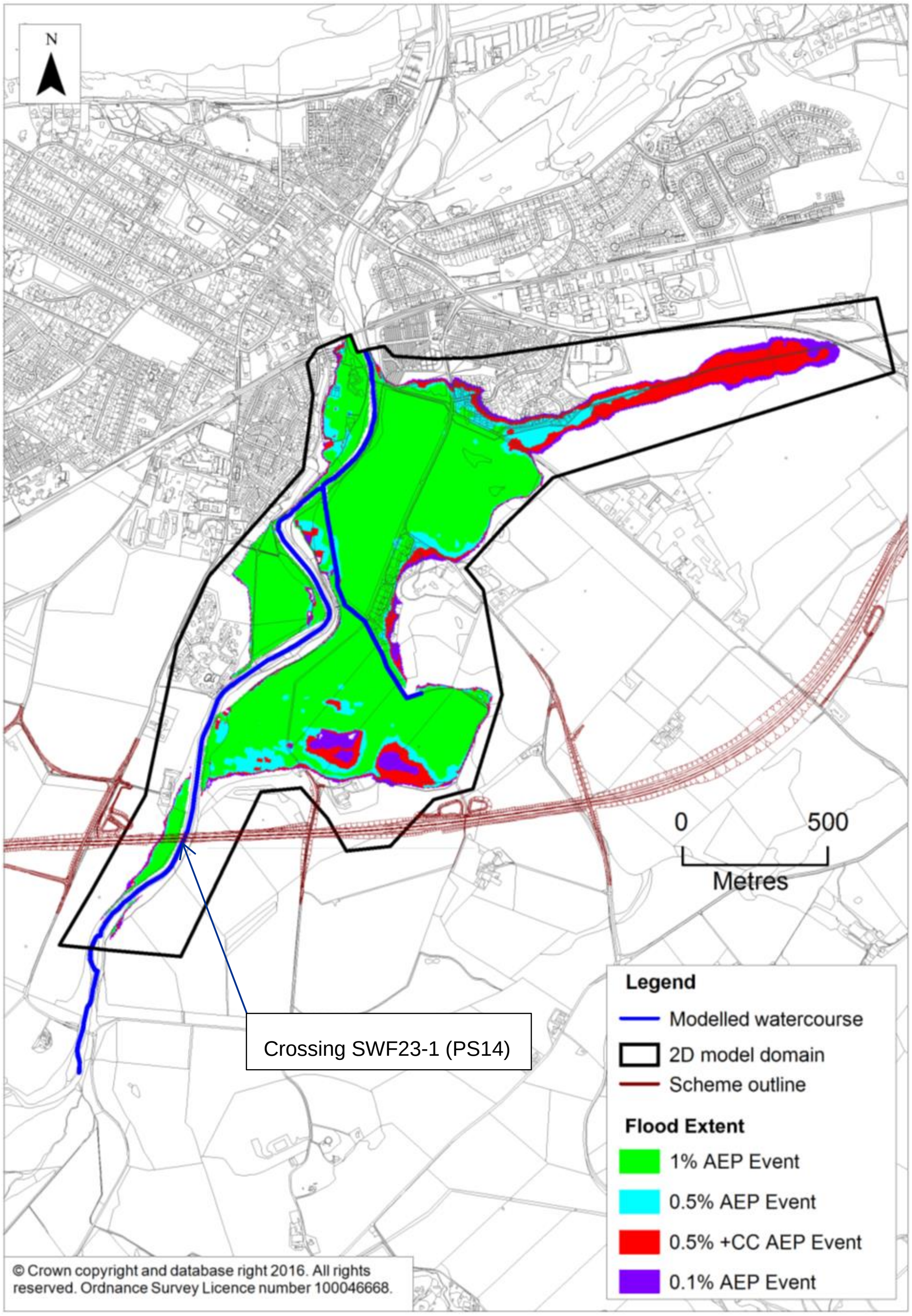


Diagram A5: Baseline Flood Extent at Scheme. 20%, 10%, 3.33% and 2% AEP Events

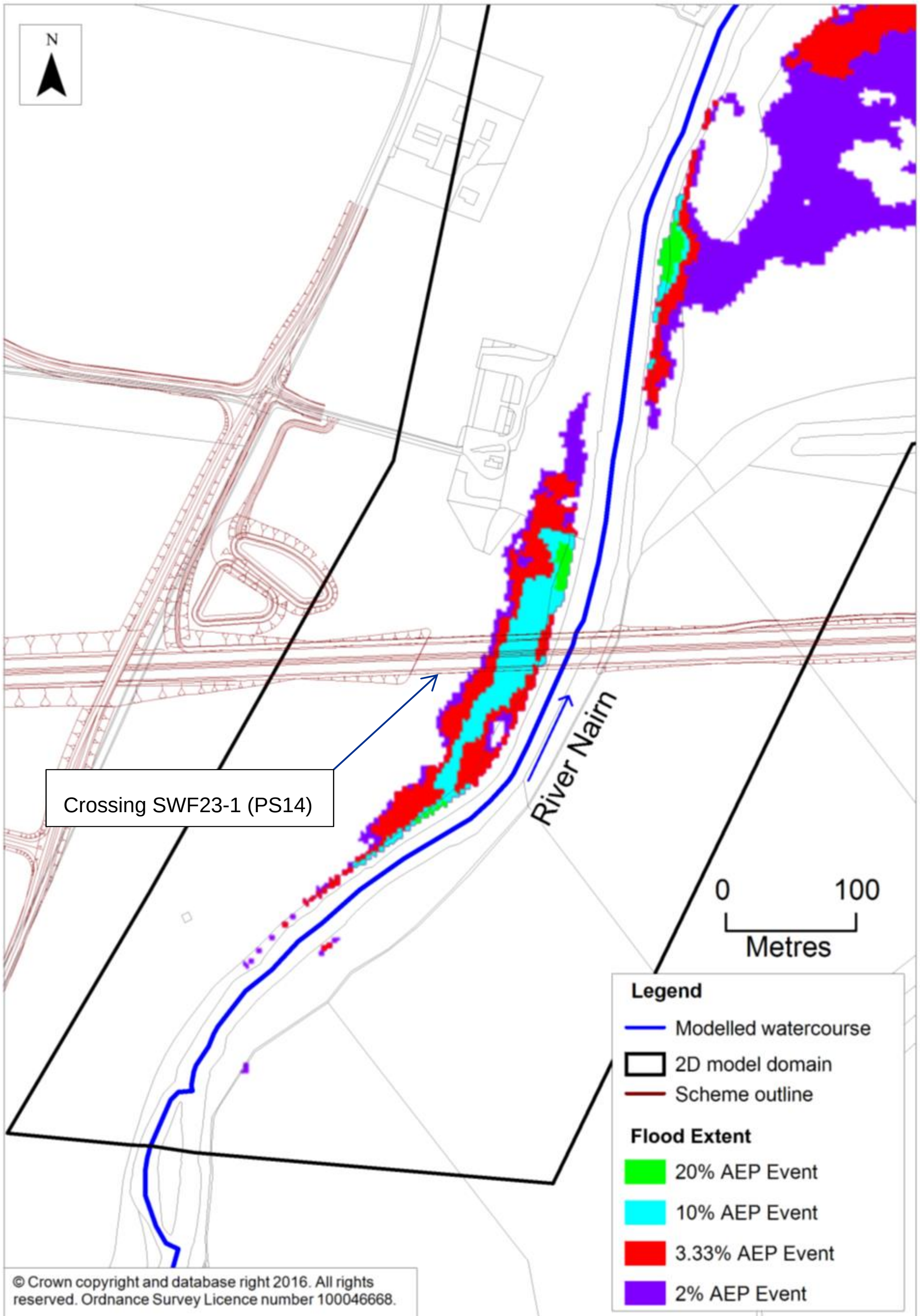
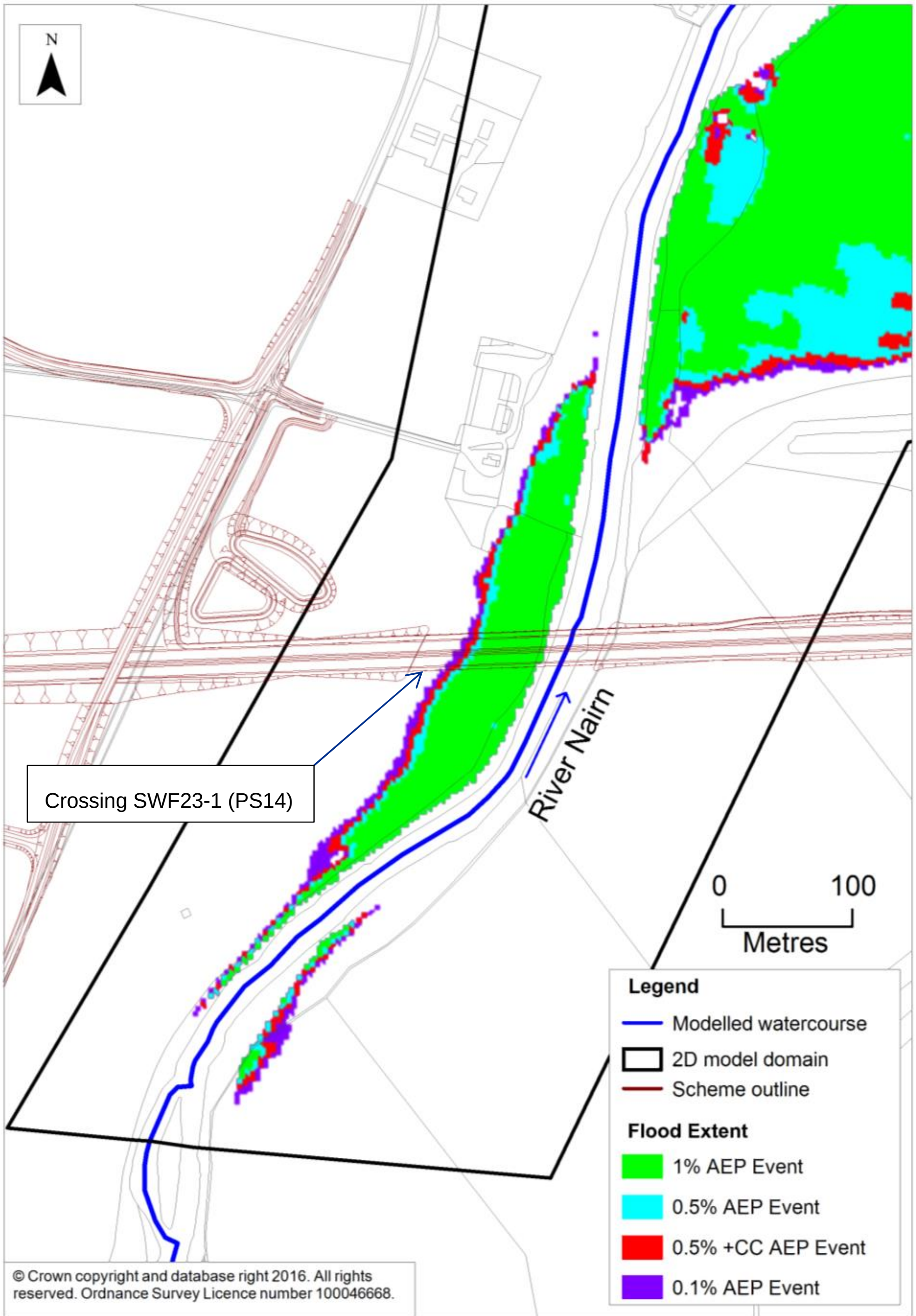


Diagram A6: Baseline Flood Extent at Scheme. 1%, 0.5%, 0.5% +CC and 0.1% AEP Events



A.3 'With-Scheme' Depth Change Maps

Diagram A7: 3.33% AEP Event Depth Difference Map

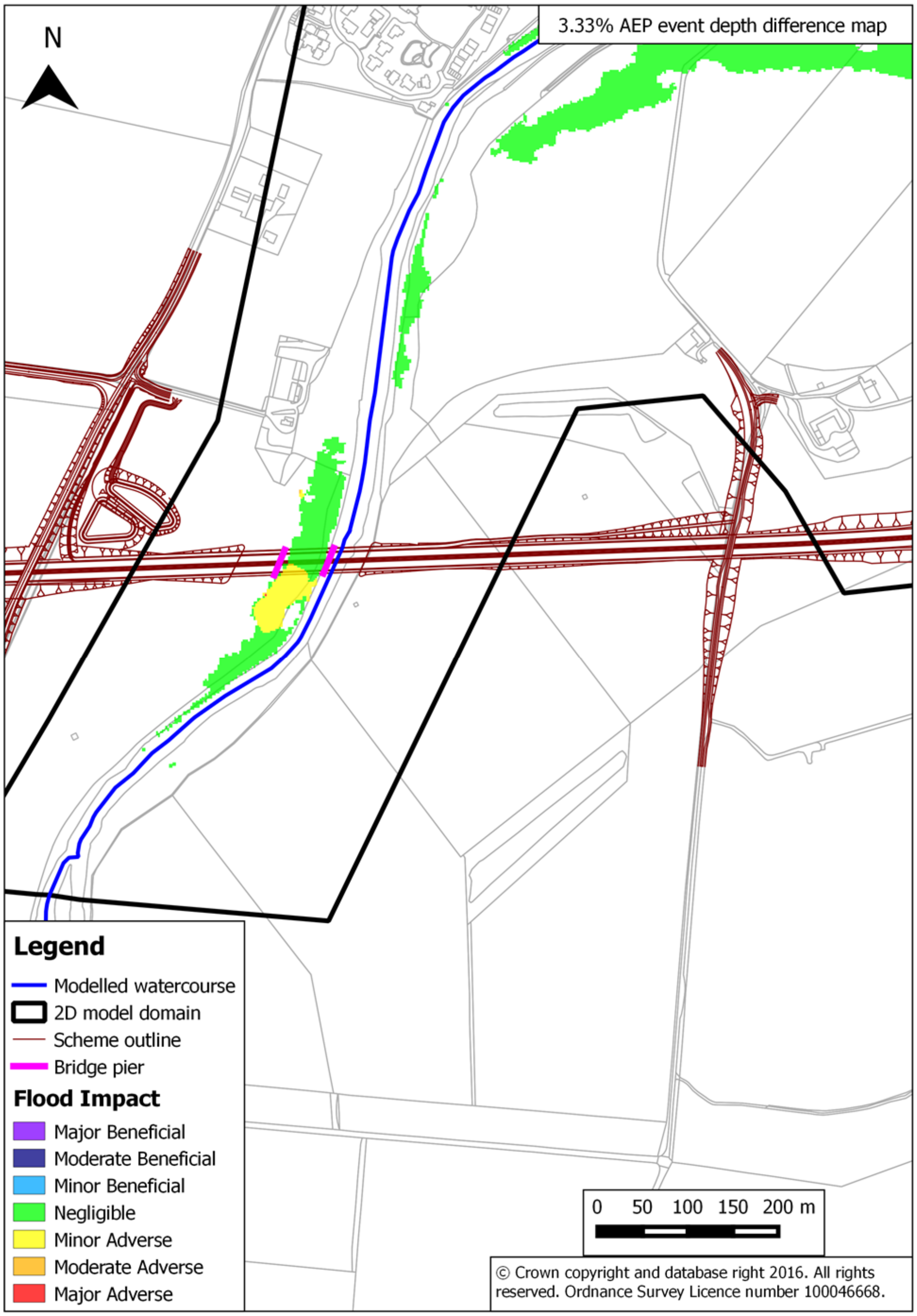


Diagram A8: 0.5% AEP Event Depth Difference Map

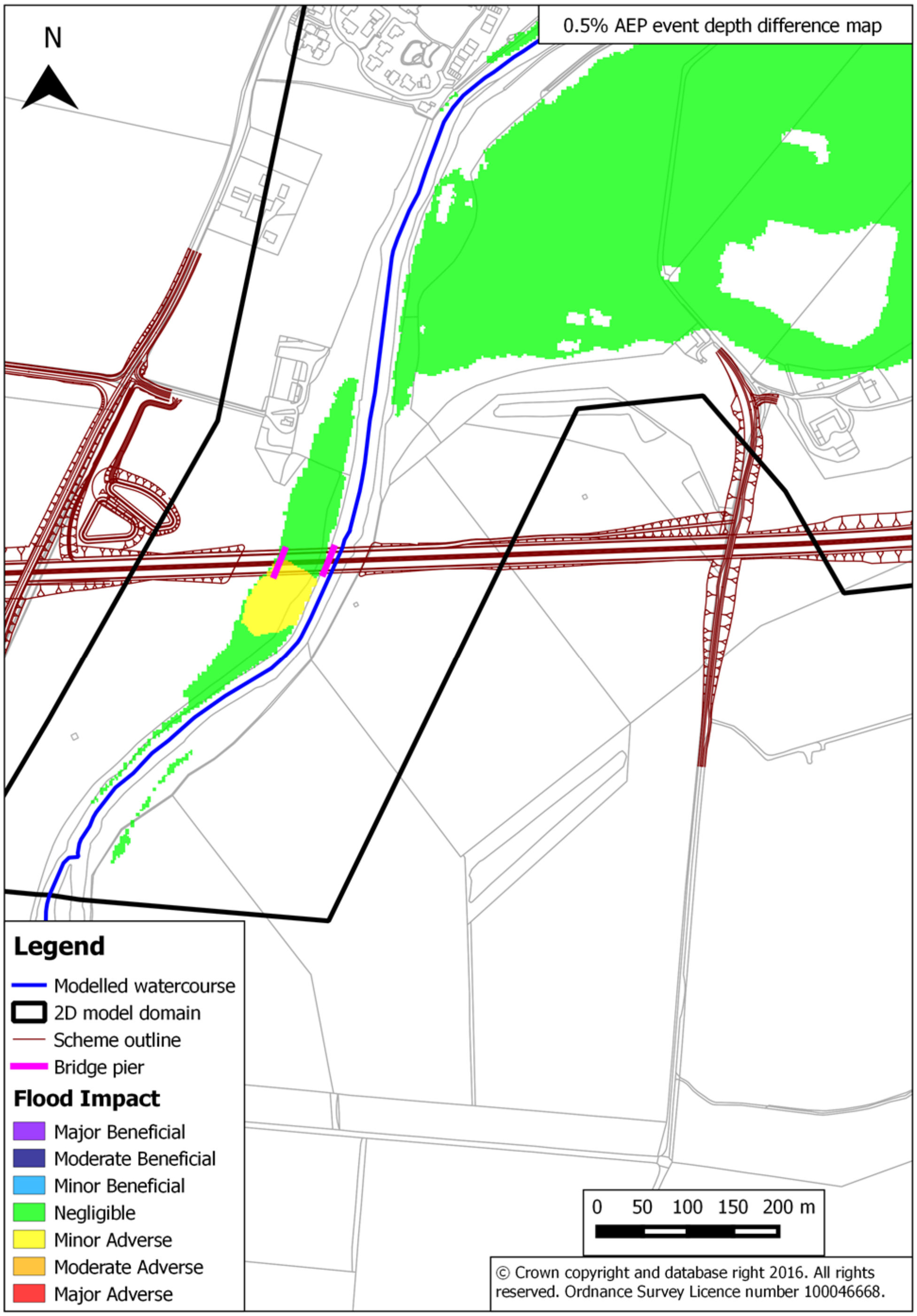


Diagram A9: 0.5% AEP +CC Event Depth Difference Map

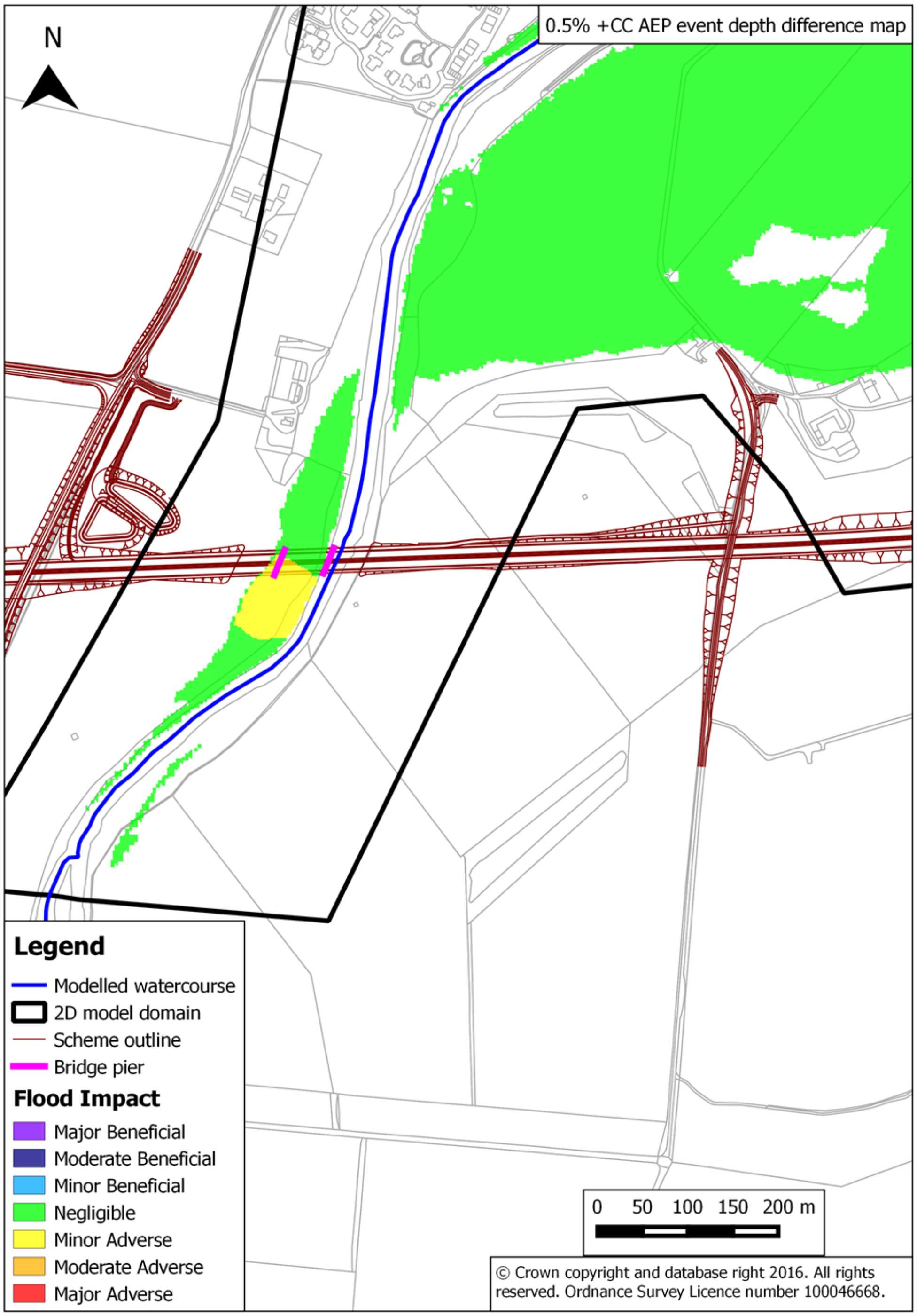
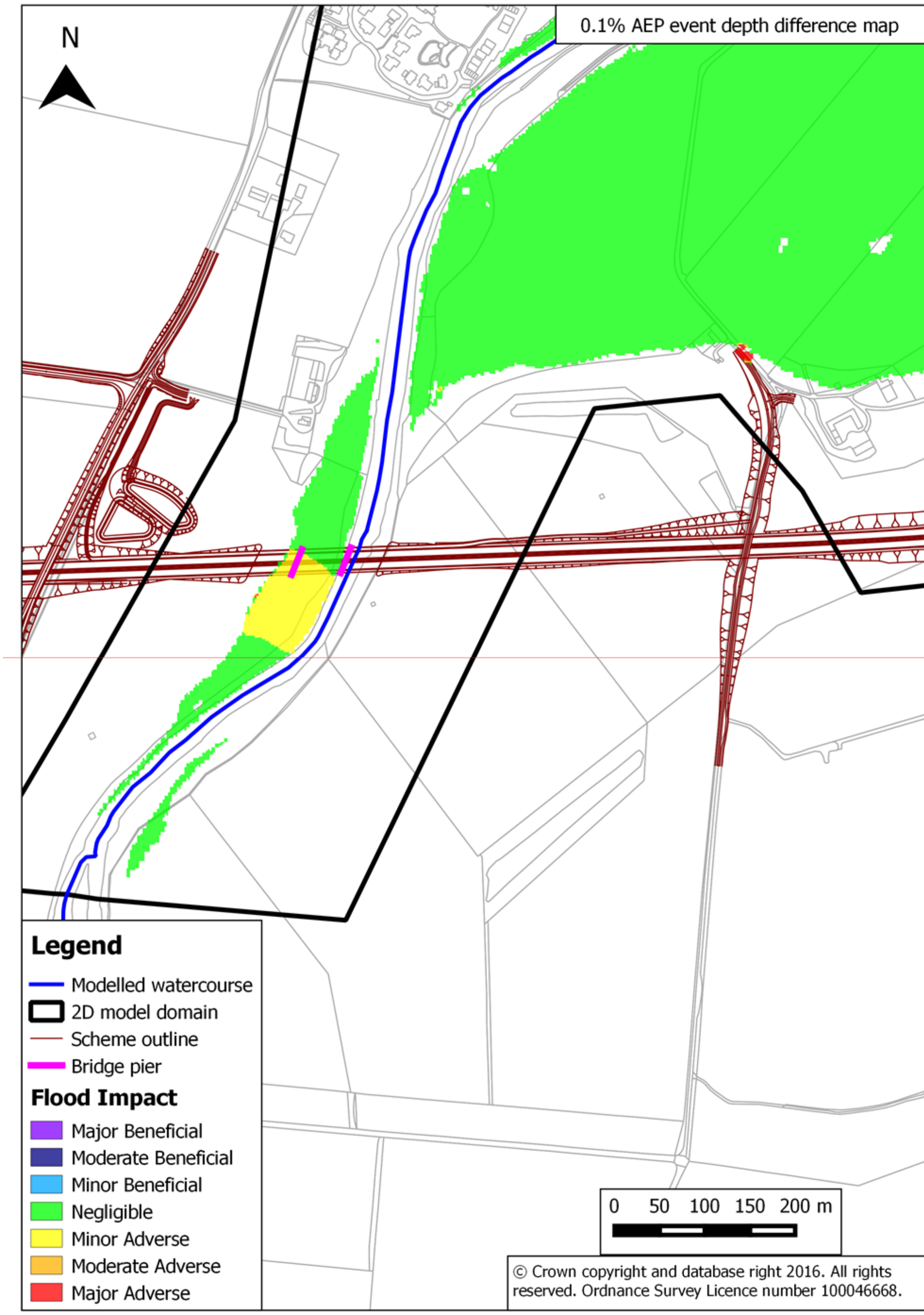


Diagram A10: 0.1% AEP Event Depth Difference Map



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A13.2.F Auldearn Burn Hydraulic Modelling Report

1 Introduction

Purpose

1.1 This annex provides detailed information on the hydraulic modelling relevant to Appendix 13.2 (Flood Risk Assessment).

1.2 The A96 Dualling Inverness to Nairn (including Nairn Bypass) scheme comprises the provision of approximately 31km of new dual carriageway, achieved through offline construction (hereafter referred to as the proposed Scheme). The existing A96 single carriageway would be de-trunked and reclassified as a local road to maintain local access. Due to the size and layout of the proposed Scheme, there are a number of flood risks, which may place the road and its users at risk of flooding. The proposed Scheme also has the potential to impact the level of flood risk elsewhere.

1.3 The proposed Scheme starts east of the roundabout for Inverness Retail Park, approximately 850m east of Raigmore Interchange, and continues approximately 30km east and ends at Hardmuir, 3.5km to the east of Auldearn. The proposed Scheme would incorporate:

- 22 watercourse crossings;
- provision of shared use paths suitable for Non-Motorised Users (NMU), approximately 30km in length;
- six grade separated junctions;
- 24 principal structures including a crossing of the River Nairn and three structures over the Aberdeen to Inverness Railway Line;
- local road diversions and provision of new private means of access; and
- utility diversions including major diversions for
- Scottish Gas Networks (SGN) and CLH Pipeline Systems (CLH-PS).

1.4 For key watercourse crossings a Flood Risk Assessment (FRA) was required to meet relevant local and national planning legislation and inform the design and planning process. Hydraulic modelling was required to support the FRA. This took the form of computational hydraulic models with associated catchment hydrology. The impact of the proposed Scheme on water level both upstream and downstream and the associated flood envelope was determined for a range of storm flood events at each watercourse crossing.

1.5 The key watercourse crossings for which a hydraulic modelling was carried out to support the FRA are:

- Cairnlaw Burn crossing (Annex 13.2.B Cairnlaw Burn Hydraulic Modelling Report);
- Rough Burn crossing (Annex 13.2.C Rough Burn Hydraulic Modelling Report);
- Tributary of Ardersier Burn crossing (Annex D Tributary Of Ardersier Burn Hydraulic Modelling Report);
- River Nairn crossing (Annex 13.2.E River Nairn Hydraulic Modelling Report); and
- Auldearn Burn crossing (this report).

1.6 This report details the methodology and the results of the baseline hydraulic modelling carried out for the Auldearn Burn crossing, for the baseline and ‘with-scheme’ situation. This is a technical report, focused on the hydraulic modelling, and therefore the intended audience is those with a reasonable understanding and knowledge of hydraulic modelling principles, although no specific knowledge of particular software is needed.

Methodology

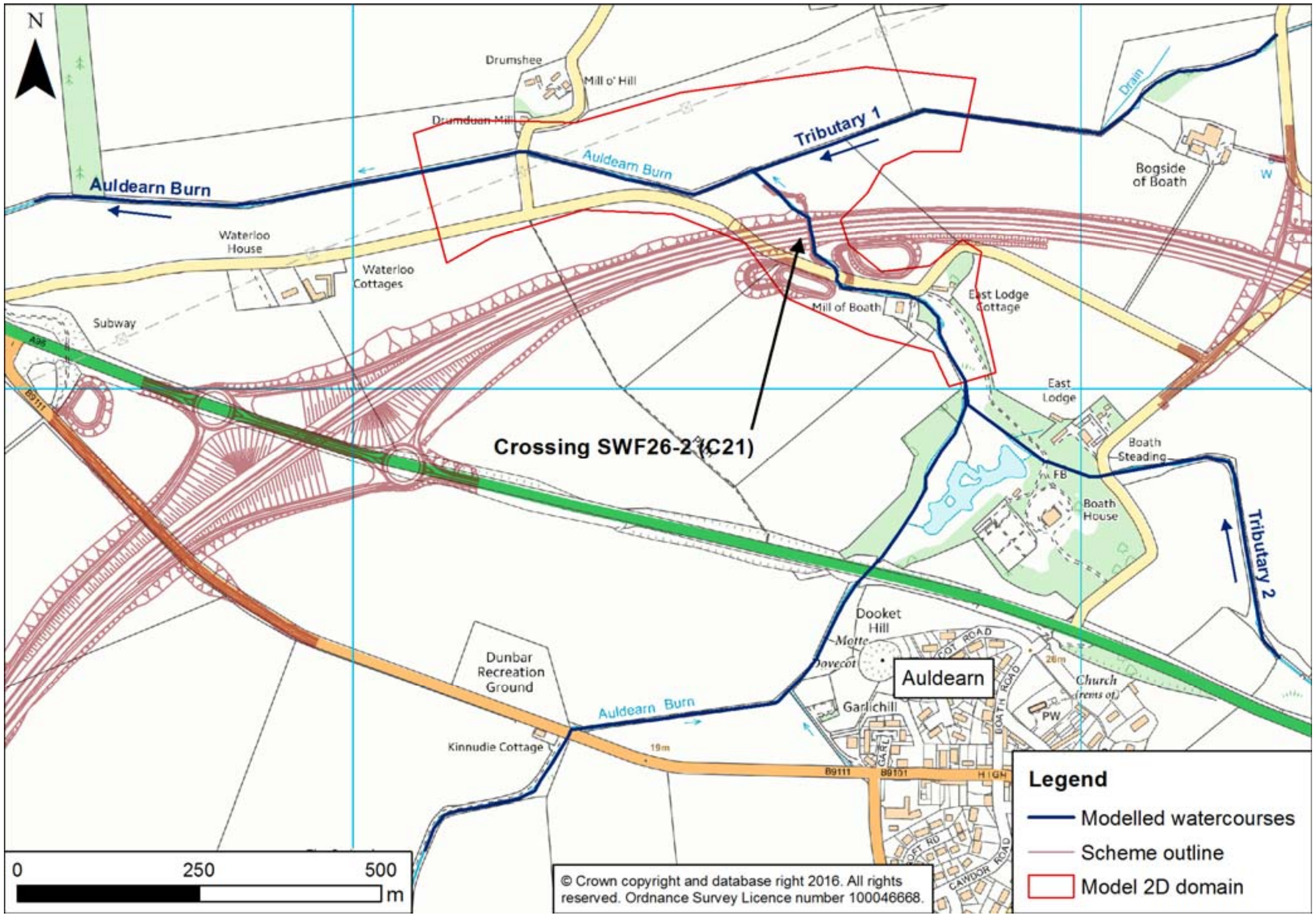
1.7 The hydraulic model was built using primarily a one-dimensional (1D) schematisation, representing the river channel and its adjacent flood plain. It was constructed using the river modelling package Flood Modeller Pro (version 4.1).

1.8 In the vicinity of the proposed Scheme, a linked One-dimensional/Two-dimensional (1D/2D) schematisation was used. The river channel is represented as a 1D component and is linked to the flood plain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller Pro (version 4.1), and the 2D component was constructed using TUFLOW (version 2013-12-AE-iSP-w64).

Study Area

1.9 The proposed Scheme crosses the Auldearn Burn watercourse north of the town of Auldearn. A new culvert at this location has been designated SWF26-2 (C21). The 1D model covers a 2.5km reach of Auldearn Burn, with 0.68km and 0.77km reaches of two of its tributaries (see Diagram 1). The 2D model extends from 130m upstream of Mill of Boath to 140m downstream of Drumshee and covers an area of approximately 0.2km^2 (see Diagram 1).

Diagram 1: Auldearn Burn Study Area



2 Input Data

2.1 The data used to construct the hydraulic model for Auldearn Burn are summarised in Table 1.

Table 1: Data Used to Build the Hydraulic Model

Data	Description	Source
Channel survey	In-channel cross sections and hydraulic structures See Section 4 (Watercourse Schematisation - 1D Domain)	Jacobs Site survey 2015
Photogrammetry/ LiDAR	2014 composite DTM: Car-based LiDAR data for existing A96 carriageway 10m horizontal resolution photogrammetry data See A96 Geodetic Survey Report_v1_0.pdf See Section 4 (Watercourse Schematisation - 2D Domain)	Blom Aerofilms
Proposed Scheme topography	MXROAD ASCII grids	Jacobs 2016
OS maps	Mastermap data 1 to 10,000 Scale Raster	Transport Scotland
Watercourse photographs	Site visit – in-channel watercourse photographs	Jacobs Site survey 2015/2016 Site inspection 2015
Hydrological analysis	Hydrological analysis carried out for Auldearn Burn See Section 3 (Hydrology).	Jacobs 2016

3 Hydrology

3.1 The details of the analysis carried out to produce inflows for the hydraulic model are provided in a separate hydrology report (Annex 13.2.G (Surface Water Hydrology Report)), which was undertaken for the DMRB Stage 3 assessment.

3.2 Four inflows have been applied at the boundaries of the 1D domain (see locations in Diagram 2):

- at the upstream extent of Auldearn Burn;
- at the upstream extent of Tributary 1; and
- at the upstream extent of Tributary 2.
- a lateral inflow in Auldearn Burn, which is distributed over 580m from downstream of the existing A96 to upstream of the proposed Scheme location.

3.3 The peak inflows have been estimated for the 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1% Annual Exceedance Probability (AEP) flood events.

3.4 The peak inflows were produced using the Flood Estimation Handbook (FEH) statistical method. The hydrograph shape was derived from the FEH rainfall-runoff model hydrograph shapes. These hydrographs used a theoretical critical storm duration of 9.8 hours calculated at the downstream extent of the hydrology model.

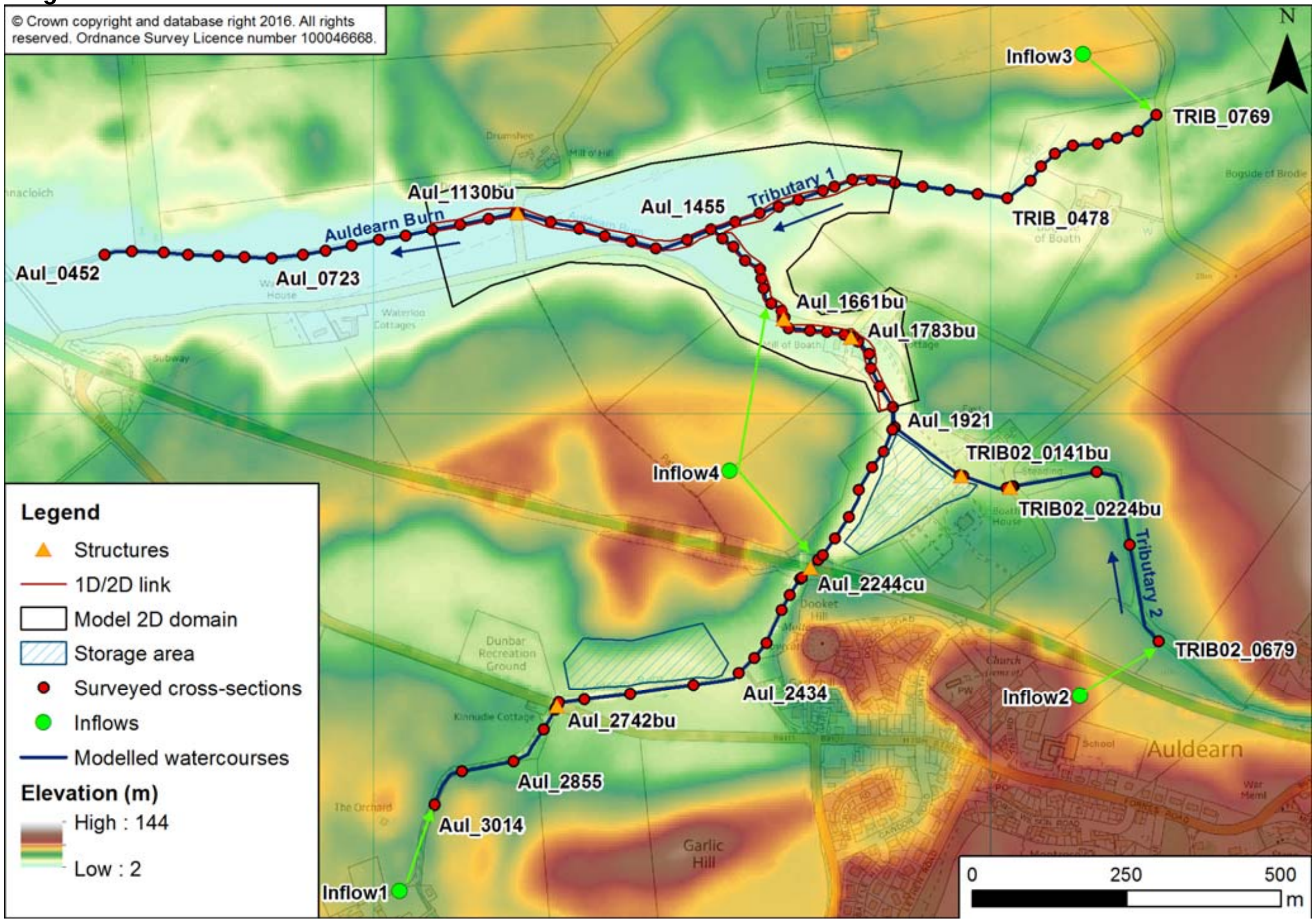
3.5 In order to assess the impact of Climate Change (CC), a 20% uplift of the hydrological inflows was applied on the 0.5% AEP event. This climate change uplift factor is based on current standard practice (SEPA 2015).

3.6 Peak inflows of the modelled watercourses are shown in Table 2 for all the events simulated.

Table 2: Hydrological Inflow Peak Values and Locations

Location	Peak Flow (m^3/s)								
	AEP 50%	AEP 20%	AEP 10%	AEP 3.33%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.5% + CC	AEP 0.1%
Auldearn Burn upstream model extent (Inflow 1)	1.36	1.90	2.32	3.08	3.50	4.15	4.91	5.89	7.24
Tributary 2 upstream model extent (Inflow 2)	1.06	1.48	1.80	2.40	2.72	3.23	3.82	4.58	5.64
Tributary 1 upstream model extent (Inflow 3)	0.92	1.29	1.58	2.09	2.37	2.82	3.34	4.00	4.92
Auldearn Burn lateral inflow (Inflow 4)	0.09	0.10	0.12	0.15	0.18	0.21	0.25	0.29	0.36

Diagram 2: Auldearn Burn Model Schematisation



4 Baseline Modelling

Watercourse Schematisation - 1D Domain

In-Channel Geometry

4.1 Surveyed cross section data has been used to inform the in-channel geometry of the modelled watercourses. The location of the surveyed cross sections is shown in Diagram 2. To aid model performance, interpolated cross sections were added between the surveyed cross sections as required, with spacing varying from 5m to 50m.

4.2 Table 3 shows the Flood Modeller nodes associated with the modelled watercourses, Auldearn Burn, Tributary 1 and Tributary 2.

Table 3: Flood Modeller Nodes

Reach	Upstream Node	Downstream Node
Auldearn Burn	Aul_3014	Aul_0452
Tributary 1	TRIB_0769	TRIB_0024
Tributary 2	TRIB02_0679	TRIB02_0000

In-Channel Hydraulic Friction

4.3 Hydraulic roughness (Manning's 'n' coefficient) values were determined primarily using the photographs taken during the survey. Generally, the channel beds of Auldearn Burn and its tributaries are clear or with some vegetation. Their banks are covered by high grass, bushes or trees. The Manning's 'n' coefficients used in the model are shown in Table 4. Roughness values adopted were taken from standard guidance (Chow 1959).

Table 4: Manning's 'n' Coefficients – 1D Domain

Watercourse	Flood Modeller Nodes	Bed Manning's 'n'	Bed Material	Banks Manning's 'n'	Banks Material
Auldearn Burn	Aul_3014 to Aul_1479	0.04	Clear bed	0.07	Medium vegetation
Auldearn Burn	Aul_1455u to Aul_1358	0.05	Vegetation	0.07	Medium vegetation
Auldearn Burn	Aul_1318 to Aul_0899	0.04	Clear bed	0.07	Medium vegetation
Auldearn Burn	Aul_0854 to Aul_0452	0.05	Vegetation	0.07	Medium vegetation
Tributary 2	TRIB02_0679 to TRIB02_0000	0.04	Clear bed	0.05	High grass
Tributary 1	TRIB_0769 to TRIB_0523	0.05	Vegetation	0.07	Medium vegetation
Tributary 1	TRIB_0478 to TRIB_0024	0.05	Vegetation	0.07	Medium vegetation

In-Channel Hydraulic Structures

4.4 Seven hydraulic structures on Auldearn Burn were included in the model. Table 5 provides details regarding these structures. Their locations are shown in Diagram 2.

Table 5: In-Channel Hydraulic Structures

Watercourse	Structure	Flood Modeller Node	Specification	
Auldearn Burn	Bridge under the B9111 road	Aul_2742bu	**Type:** **Bed level:** **Width:** **Springing height:** **Crown height:**	Arch Bridge 18.005mAOD 3.340m 0.900m 0.990m
Auldearn Burn	Culvert under the existing A96	Aul_2244cu	**Type:** **Upstream bed level:** **Downstream bed level:** **Length:** **Diameter:**	Circular conduit 16.273mAOD 15.821mAOD 38.533m 2.560m
Auldearn Burn	Access track bridge	Aul_1783bu	**Type:** **Bed level:** **Width:** **Springing height:** **Crown height:**	Arch Bridge 13.561mAOD 3.580m 0.637m 0.900m
Auldearn Burn	Bridge under a secondary road	Aul_1661bu	**Type:** **Bed level:** **Width:** **Springing height:** **Crown height:**	Arch Bridge 12.658mAOD 3.510m 0.702m 0.920m
Auldearn Burn	Bridge under a secondary road	Aul_1130bu	**Type:** **Bed level:** **Width:** **Springing height:** **Crown height:**	Arch Bridge 9.484mAOD 2.485m 1.376m 0.500m
Tributary 2	Access track bridge	TRI02_0224bu	**Type:** **Bed level:** **Width:** **Height:**	Arch Bridge (flat soffit) 17.068mAOD 2.636m 0.632m
Tributary 2	Bridge under a secondary road	TRI02_0141bu	**Type:** **Bed level:** **Width:** **Height:**	Arch Bridge (flat soffit) 16.419mAOD 2.583m 0.781m

Boundary Conditions – 1D Domain

The upstream and downstream boundary conditions applied to the 1D domain are described in

4.5 Table 6. Inflow locations are shown in Diagram 2.

Table 6: Boundary Conditions – 1D Domain

Type of Boundary	Flood Modeller Node	Description
FEH Boundary	Inflow1	Scaled FEH inflow boundary was applied at the upstream end of Auldearn Burn at node Aul_3014 (see Section 3 (Hydrology)).
FEH Boundary	Inflow2	Scaled FEH inflow boundary was applied at the upstream end of Tributary2 at node TRIB02_0679 (see Section 3 (Hydrology)).
FEH Boundary	Inflow3	Scaled FEH inflow boundary was applied at the upstream end of Tributary1 at node TRIB_0769 (see Section 3 (Hydrology)).
FEH Boundary	Inflow4	Scaled FEH lateral inflow boundary was distributed along Auldearn Burn between the nodes Aul_2205 and Aul_1621 (see Section 3 (Hydrology)).
Normal Depth Boundary	Aul_0452	Normal depth boundary condition applied to the downstream end of Auldearn Burn at node Aul_0452.

Flood Plain Schematisation – 1D Domain

4.6 To represent the flood plain of the modelled watercourses where a 1D schematisation is used, the surveyed cross sections were extended using a 5m resolution 2014 composite DTM dataset (car-based LiDAR and photogrammetry data).

4.7 The active flood plain area located between the existing A96 and the B9111, and the Boath House pond were both represented using 1D reservoir units (see Diagram 2).

Flood Plain Schematisation - 2D Domain

Flood plain Topography – 2D Domain

4.8 The 2D domain covers 0.2km^2 along Auldearn Burn and Tributary 1. The topography is represented using a 4m resolution square grid. The levels for the grid cells are based on the 2014 composite Digital Terrain Model (DTM).

4.9 Diagram 3 shows a comparison between the channel survey data and the 2014 photogrammetry data. In most places the discrepancy between the two datasets is less than 250mm. The higher discrepancies are generally in the upstream section of Auldearn Burn where the model is 1D only. In these locations only the channel survey data is used by the model.

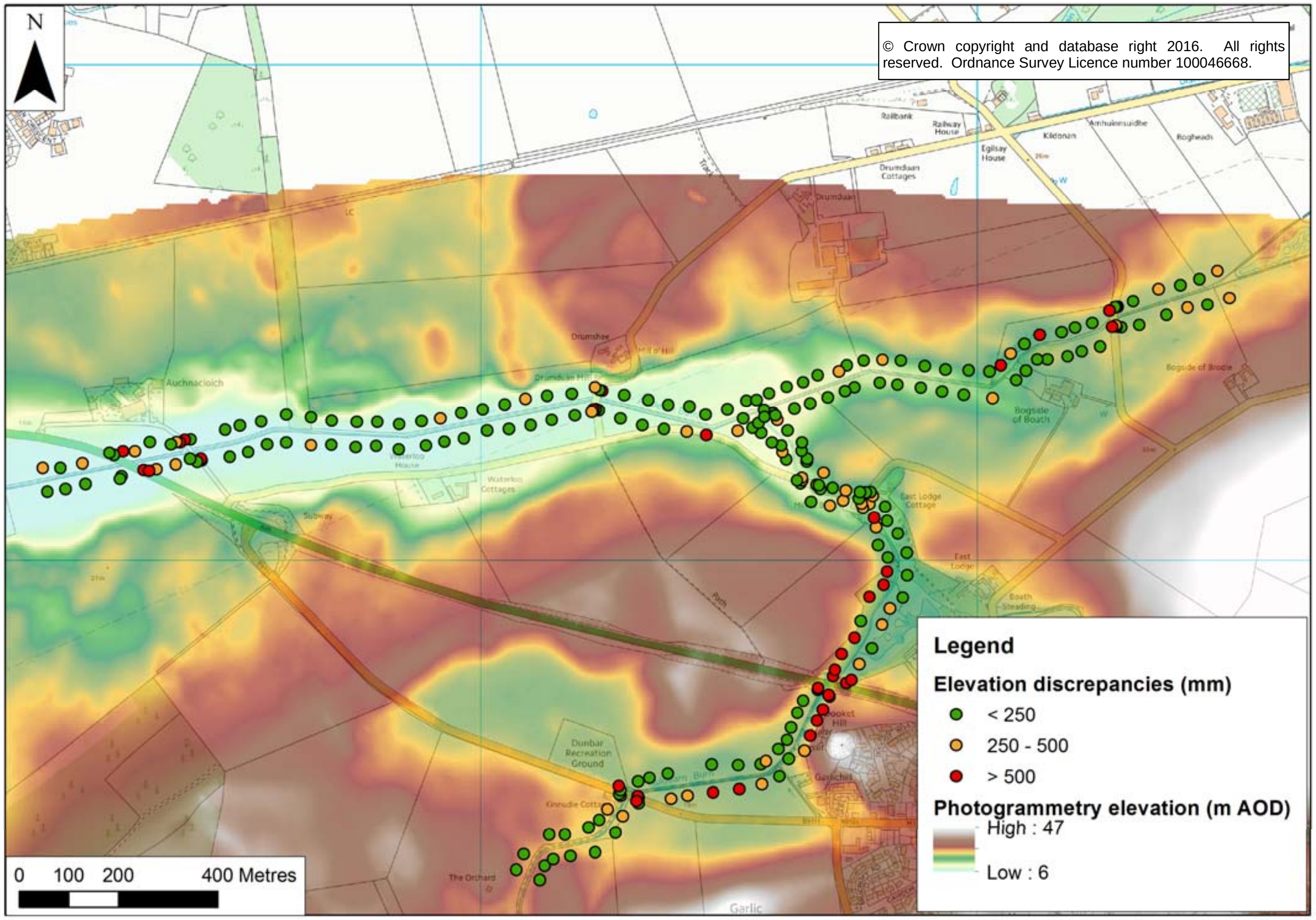
Flood Plain Hydraulic Friction – 2D Domain

4.10 Hydraulic roughness coefficients are applied over each grid cell of the 2D domain, as shown in Table 7, depending on land use taken from OS Mastermap data.

Table 7: Manning's 'n' Coefficients – 2D Domain

Land use	Manning's n
Roads, tracks and paths	0.025
Rail	0.050
Buildings, manmade structures	1.000
Land, trees, rough grassland	0.100
Land, cliff	0.050
Land, slope, manmade	0.050
Open land, general surface	0.050
Land, multi surface	0.055
Water, inland water	0.020

Diagram 3: Photogrammetry Elevation Discrepancies



1D/2D Linking

4.11 The link between the 1D and the 2D domains was defined along sections of Auldearn Burn and Tributary 1 using banktops from the surveyed cross section data. The location of the 1D/2D link is shown in Diagram 2.

4.12 The downstream boundary of the 2D domain is also linked to the 1D domain to ensure the connection between the 1D schematisation flood plain and the 2D schematisation flood plain.

5 'With-Scheme' Modelling

Scheme Arrangement

5.1 As shown in Diagram 4, from highway chainage 26600m to 26800m the proposed Scheme is crossing Auldearn Burn and its catchment approximately 150m downstream of Mill of Boath Hamlet. It consists of a new offline dual carriageway with associated infrastructure. Auldearn Burn crossing consists of a new culvert (SWF26-2 (C21)).

Modelling Approach

<u>1D Model Updates</u>

5.2 The culvert SWF26-2 (C21) under the proposed Scheme is 60m long (Flood Modeller node Aul_1601Cd). The culvert inlet and outlet tie into the toe of the embankment. The culvert has been assumed rectangular and to have a square headwall. The roughness within the culvert was set to a Colebrook - White Friction value of 0.001m (equivalent to a Manning's 'n' of 0.012) for the new concrete wall and soffit and to 1.360m (equivalent to a Manning's 'n' of 0.04) for the culvert invert to match the bed roughness.

5.3 The dimensions of the culvert were determined with this criterion: freeboard of 600mm within the culvert, above the 0.5% AEP + CC event maximum water level.

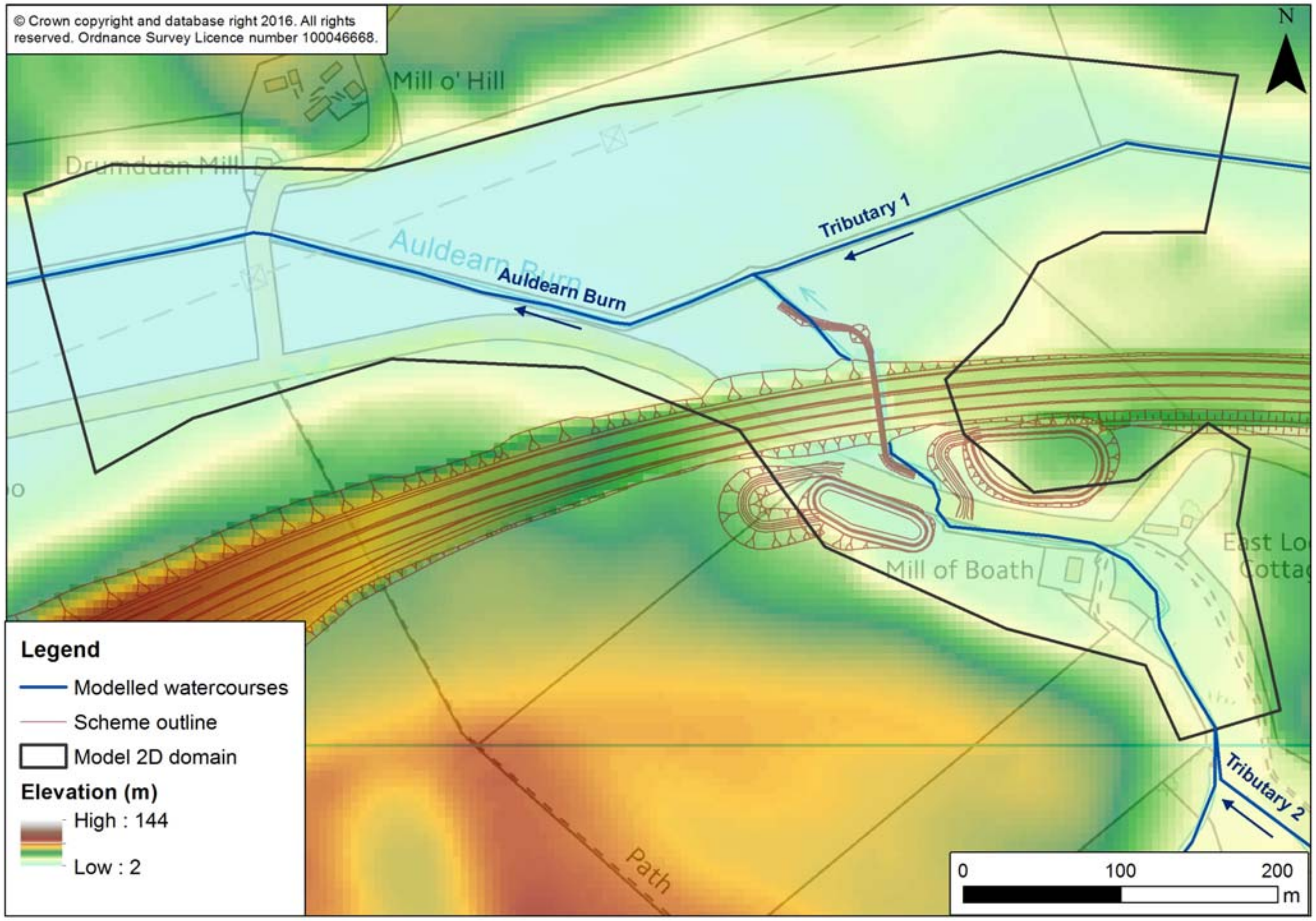
5.4 To achieve the criterion, the modelling results show that a culvert of 5m wide and 2m high would be required.

5.5 No mammal ledge was included in the culvert as a foot path is available nearby.

<u>2D Model Updates</u>

5.6 The DTM (Digital Terrain Model) was modified to represent the design features across Auldearn Burn flood plain in the 2D domain. The proposed Scheme elevations were exported from the MXROAD software as ASCII grid, for inclusion in the hydraulic model. Within the proposed Scheme footprint the ASCII grid replaced the existing ground elevation.

Diagram 4: Auldearn Burn Model Schematisation 'With-Scheme'



6 Modelled events

6.1 Table 8 shows the AEP events and model scenarios that were simulated with the hydraulic model.

6.2 In order to test the model sensitivity to key hydraulic parameters, a series of simulations were undertaken for the 0.5% AEP event in the baseline scenario. The assessed hydraulic parameters were: Manning's 'n' roughness coefficients, hydrological inflows and downstream boundary slope.

Table 8: Modelled Events

Scenario	AEP Event								
	50%	20%	10%	3.33%	2%	1%	0.5%	0.5% + CC	0.1%
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓
Roughness Sensitivity (1D and 2D)							✓		
Hydrological Inflow Sensitivity							✓		
Downstream Boundary Sensitivity (1D and 2D)							✓		
'With-Scheme'								✓	
'With-Mitigation' Measures				✓			✓	✓	✓

7 Model Proving

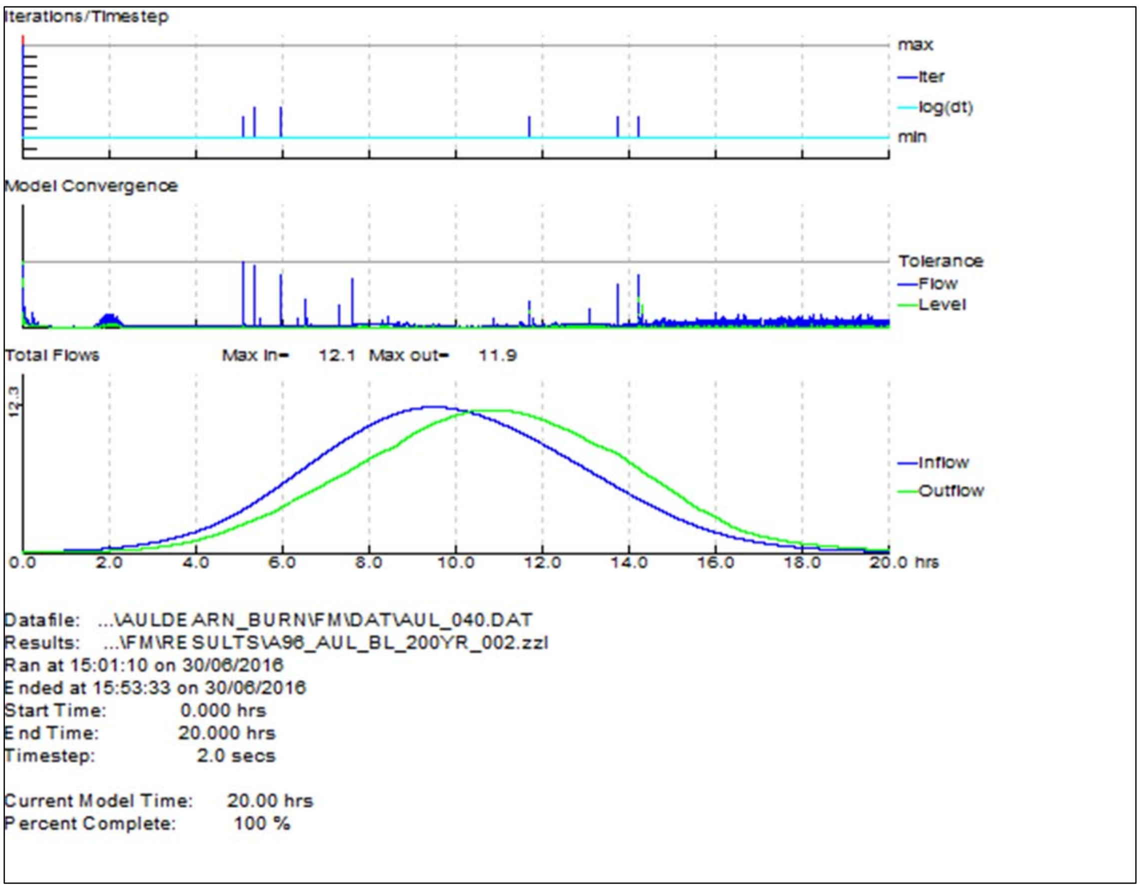
Introduction

7.1 The following sections discuss the model performance and the verification process. In addition, details relating to the additional runs carried out to test the sensitivity of the model to key variables are also discussed.

Model Performance

7.2 Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure a suitable model convergence was achieved. Convergence refers to the ability of the modelling software to arrive at a solution that is close to the exact solution within a pre-specified error tolerance. The convergence of the 1D model was checked as shown in Diagram 5 below and no poor convergence is evident. This convergence plot is generally typical for the events modelled.

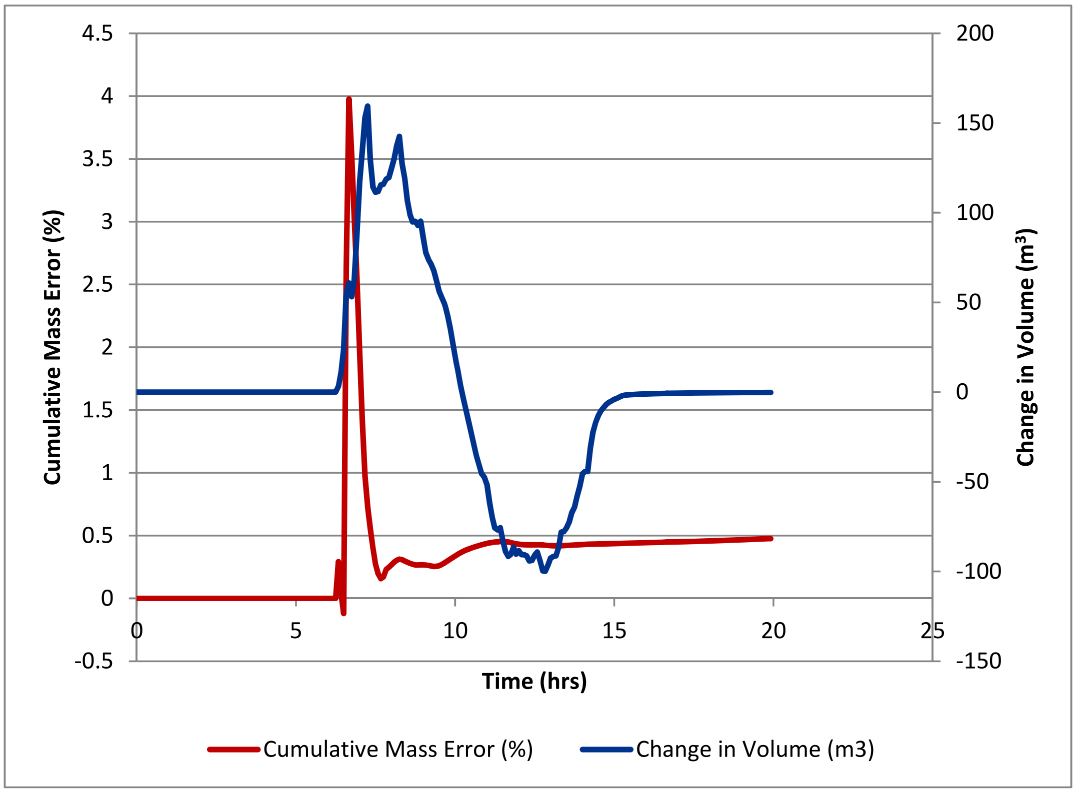
Diagram 5: 1D Model Convergence – 0.5 % AEP Event



7.3 The cumulative mass error reports output from the TUFLOW 2D model have been checked. The recommended tolerance range is +/- 1% Mass Balance error. The change in volume through the model simulation has also been checked and has been found to vary smoothly which is an indicator of good convergence of the 2D model.

7.4 Diagram 6 shows that for the 0.5% AEP event, the cumulative mass error is all less than 0.5%. There is a spike in the cumulative mass error which is outside of tolerance i.e. greater than 1% in absolute value. However, this spike occurs at the onset of flooding, before there is any significant volume of water in the model and is therefore deemed acceptable. This Mass Error diagnostic is typical for all the events modelled in which significant flooding occurs.

Diagram 6: 2D Cumulative Mass Error and Change in Volume – 0.5 % AEP Event



Calibration and Verification

7.5 No suitable historic flood record is available for a hydraulic model calibration. However, a high level verification was undertaken. Flood incident data, flood remarks and flood extent maps from the Scottish Environment Protection Agency (SEPA) are available.

<u>Verification Using Historic Data</u>

7.6 The flood incident data and the flood remark data are shown in Table 9 and in Table 12 respectively. Locations of the flood remark data are shown in Diagram 7. The modelling shows a good match with both flood remark and flood incident records.

Table 9: Flood Incident Records

Reference	Easting	Northing	Date	Scale of Flooding	Description	Model Verification
HIG1820	291800	856200	1st Jul 1997	Unknown	Mill of Boath, Auldearn	Matched by modelling: the property at Mill of Boath would flood from a 3.33% AEP event

Table 10: Flood Remark Data

ID	Comment	Model Verification
9	Ground water levels are high, garden around the tributary to Auldearn Burn floods yearly	Matched by modelling
10	Noted that property floods from burn. High water table	Matched by modelling: the property at Mill of Boath would flood from a 3.33% AEP event
12	Auldearn Burn to north of property flood yearly due to heavy rainfall	Matched by modelling
47	History of flooding. Dredging of burn reported as curing it	Matched by modelling
52	Vicinity prone to flooding. Drained quickly last year (2014)	Matched by modelling

<u>Verification Using SEPA Flood Maps</u>

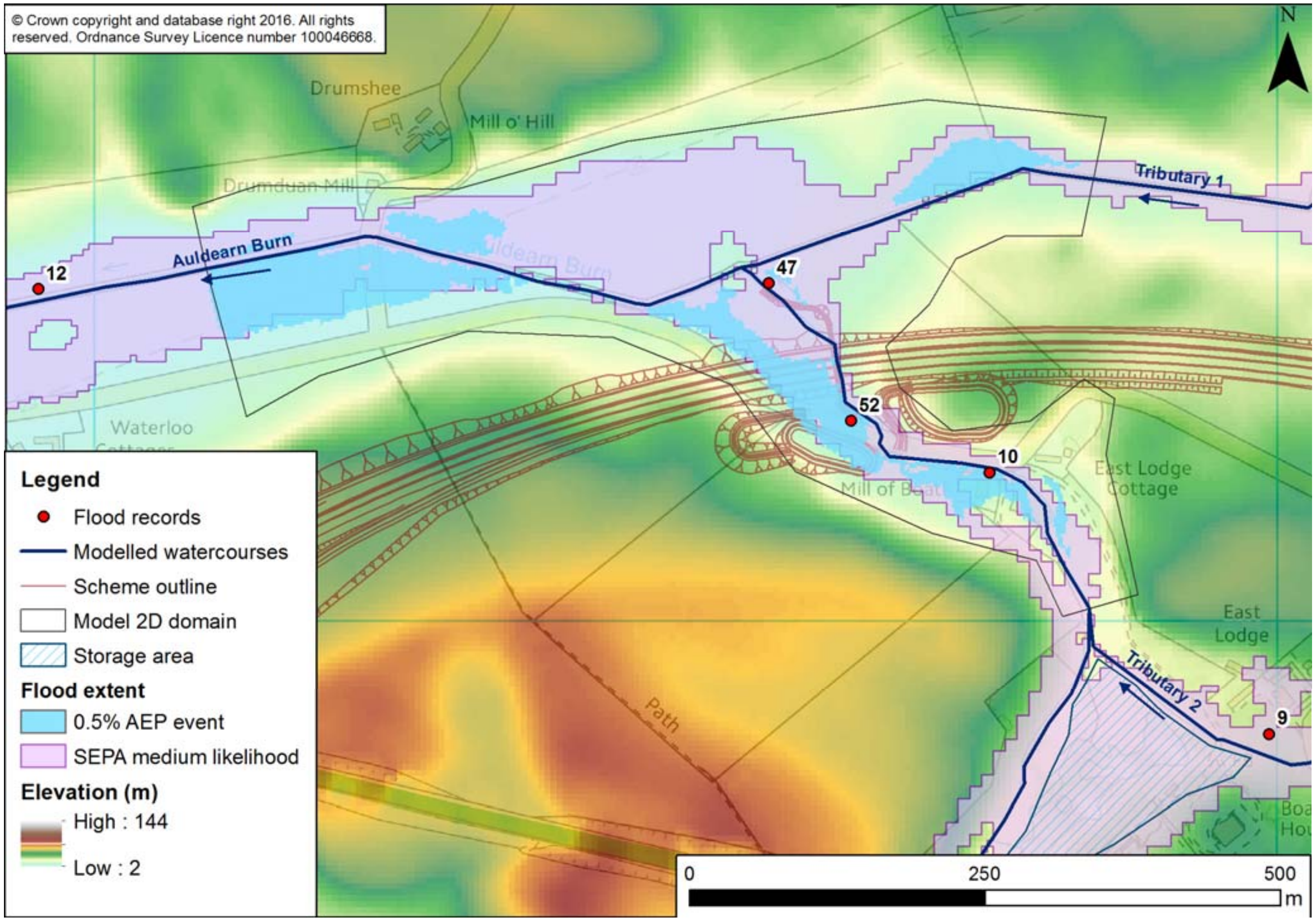
7.7 Flood extent maps from the Scottish Environment Protection Agency (SEPA) show the fluvial flood extent for different likelihoods of flooding (high, medium and low). The SEPA medium likelihood of flooding is equivalent to a 0.5% AEP event. Therefore a comparison has been made with the modelled baseline 0.5% AEP event flood extent (Diagram 7).

7.8 As shown in Diagram 7, the results for the 0.5% AEP event simulation show that the modelled flood extent in the vicinity of the proposed Scheme is generally smaller than the published flood map particularly at the confluence of Tributary 1 and Auldearn Burn. Such differences with the SEPA flood mapping are expected as the FRA modelling presented in this report is based on a finer level of detail along with refined catchment hydrology analysis.

<u>Verification Conclusion</u>

7.9 In conclusion the verification exercise has shown that, for the available data, the model results are generally in agreement with the verification data, indicating that the model results are realistic.

Diagram 7: Modelled 0.5 % AEP Event Flood Extent vs. SEPA Medium Likelihood Fluvial Extent



Sensitivity Analysis

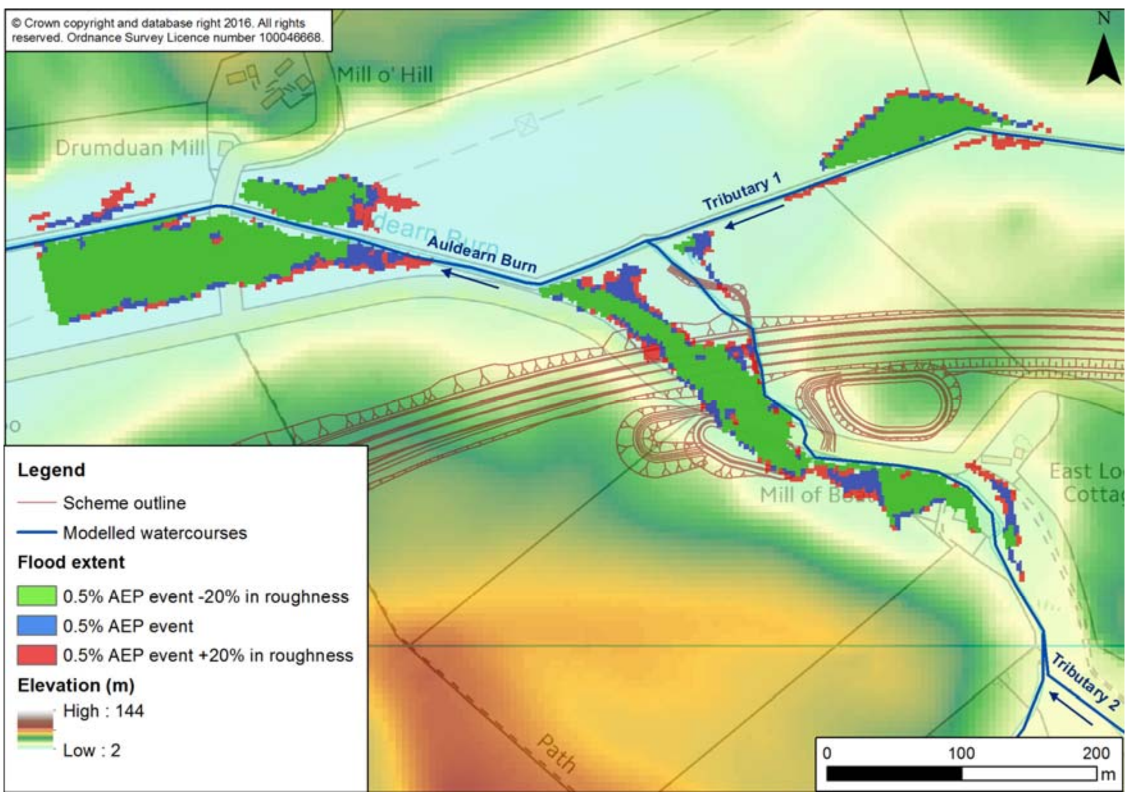
Roughness Sensitivity

7.10 In-channel and flood plain roughness coefficients (Manning's 'n') were changed by +20% and -20%. Table 11 shows the impact of changing the model roughness on in-channel water levels. The results show that the in-channel water levels are not sensitive to changes in roughness. Diagram 8 shows that changes in flood extent as a result of changing the model roughness are also minimal in the vicinity of the proposed Scheme.

Table 11: Roughness Sensitivity Results

Sensitivity	Water Level Difference (m)			Water Level Difference Immediately Upstream of the Scheme (m)
	Max	Min	Average	Aul_1621
+20% Roughness	0.157	-0.015	0.080	0.044
-20% Roughness	-0.199	0.004	-0.094	-0.182

Diagram 8: Change in the 0.5% AEP Event Flood Extent - Roughness Sensitivity



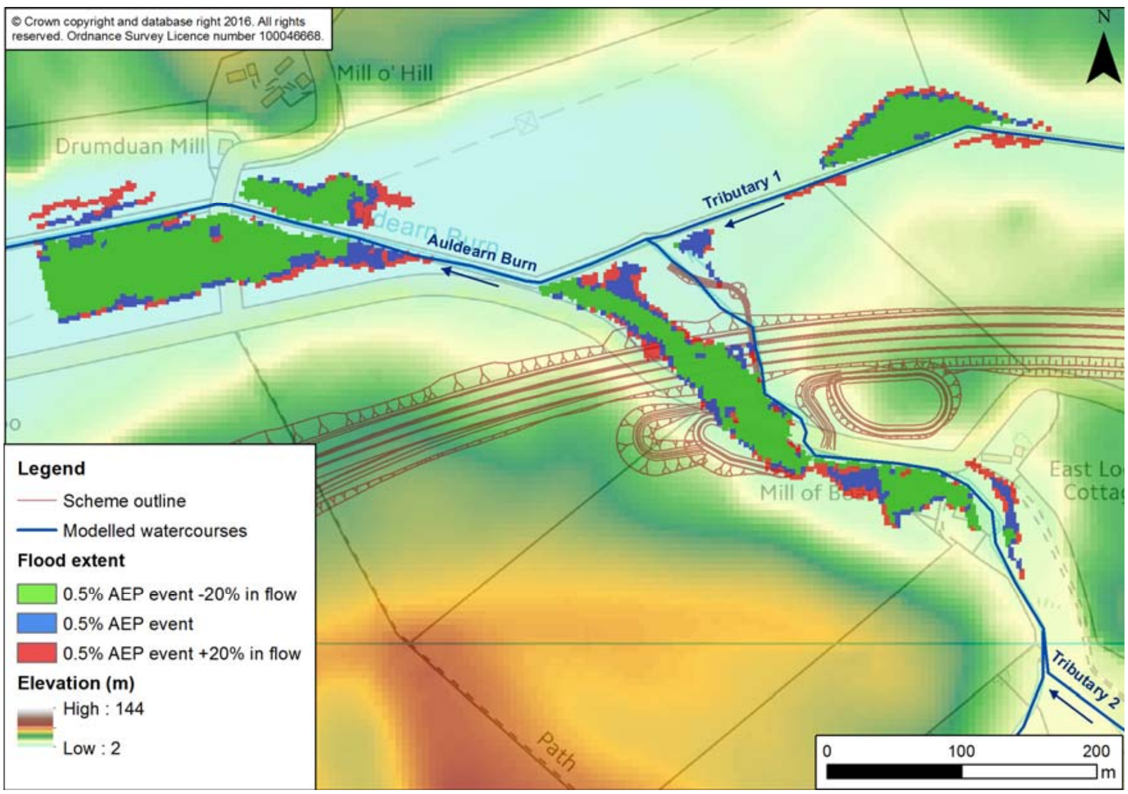
Hydrological Inflow Sensitivity

7.11 The flows into the model were adjusted by +20% and -20%. Table 12 shows the impact of changing the model inflows on in-channel water levels. The results show that the model is somewhat sensitive to changes in flow. Diagram 9 shows how the flood extent changes as a result of changing the model inflows. The results show that the flood extent is slightly affected at the location of the proposed Scheme.

Table 12: Flow Sensitivity Results

Sensitivity	Water Level Difference (m)			Water Level Difference Immediately Upstream of the Scheme (m)
	Max	Min	Average	Aul_1621
+20% Flow	0.296	0.024	0.096	0.042
-20% Flow	-0.258	-0.034	-0.115	-0.105

Diagram 9: Change in the 0.5% AEP Event Flood Extent - Inflow Sensitivity



Downstream Boundary Condition Sensitivity

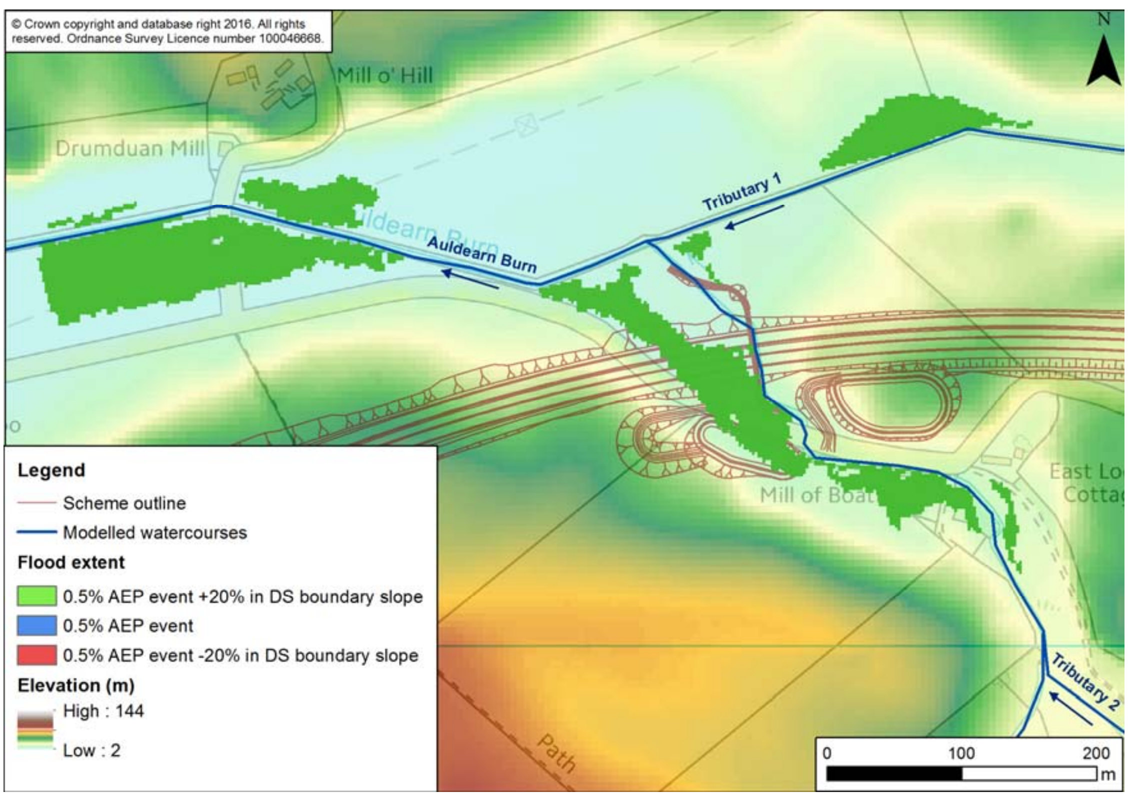
7.12 The slope of the downstream boundaries in the 1D and 2D models were adjusted by +20% and -20%. The results show that the changes to the downstream boundary only affect the downstream end of the model. Table 13 shows the response at the downstream end of the model (Flood Modeller Node Aul_0452). The location at which there is no change in water level as a result of changing the downstream boundary has been identified. Distances from this location, in relation to the downstream end of the model (tailwater distance) and in relation to the proposed Scheme, are shown in Table 13. This indicates that the proposed Scheme is at least 428m upstream of the influence of the downstream boundary.

7.13 Diagram 10 shows how the flood extent changes as a result of changing the slope of the downstream (DS) boundaries. The results show that the flood extent is not affected at the location of the proposed Scheme.

Table 13: Downstream Boundary Sensitivity Results

Sensitivity	Water Level Difference (m)		
	Water Level Difference (m) at Aul_0452	Tailwater Distance (m)	Distance to Scheme (m)
+20% Downstream boundary slope	-0.047	672	434
-20% Downstream boundary slope	0.057	678	428

Diagram 10: Change in the 0.5% AEP Event Flood Extent – Downstream Boundary Slope Sensitivity



8 Model Results – Baseline and 'With-Scheme'

Baseline Scenario

8.1 Maps have been produced to show the baseline scenario flood extent in the vicinity of the proposed Scheme for each modelled event in Section A.2 (Flood Extent Maps). For the 50%, 20% and 10% AEP events no out of bank flooding occurred in the vicinity of the proposed Scheme; therefore no flood extent map was produced. The in-channel water levels at key locations for all modelled events are shown in Section A.1 (Water Level Tables and Long Section).

8.2 To assess the baseline flooding, water levels have been inspected at key locations in relation to the proposed Scheme and the properties at risk of flooding. Diagram 11 shows the main flood mechanisms for the 0.5% AEP +CC event and has been analysed in conjunction with the extent maps (see Section A.2 (Flood Extent Maps)).

8.3 Upstream of the existing A96, no properties would be at risk of flooding.

8.4 One property at East Lodge would flood from a 1% AEP event (Flood Modeller node TRI02_0135). For a 0.5% AEP +CC event, maximum modelled water depth at this property is 142mm. The bridge under the road leading to the existing A96 is surcharged from the 10% AEP event (Flood Modeller node TRI02_0224bu) and the road floods from the 0.1% AEP event (Flood Modeller node TRI02_0224su). The bridge under the access track leading to Boath House is surcharged from the 20% AEP event (Flood Modeller node TRI02_0141bu) and the access track would be submerged from the 3.33% AEP event (Flood Modeller node TRIB02_0141su). The property at Boath House is not at risk of flooding.

8.5 The property at Mill of Boath would flood from the 3.33% AEP event, maximum modelled water depth at this location is between 500mm and 750mm for a 0.5% AEP +CC event. The bridge under the access track leading to Mill of Boath would be surcharged from a 0.5% AEP +CC event (Flood Modeller node Aul_1783bu) and the access track would flood from a 3.33% AEP event. This is because the channel has a lower capacity upstream of the bridge which would cause flooding on left bank prior to the bridge surcharging.

8.6 The road running along Auldearn Burn would flood from a 1% AEP event. The bridge under this road would be surcharged from the 0.5% AEP +CC event (Flood Modeller node Aul_1661bu).

8.7 Downstream of the proposed Scheme no properties are shown to be at risk of flooding. The road leading to Drumduan Mill would from a 3.33% AEP event (Flood Modeller node Aul_1130su).

8.8 The modelled flood mechanisms at the location of the proposed Scheme for a 0.5% AEP +CC event, show out of bank flooding on the left bank of Auldearn Burn from Mill of Boath location to the confluence with the tributary with flows running parallel to the channel. As shown in Diagram 12, maximum flood depths are at or below 500mm within the proposed Scheme footprint.

Diagram 11: 0.5 % +CC AEP Event Flood Mechanisms – Baseline Scenario

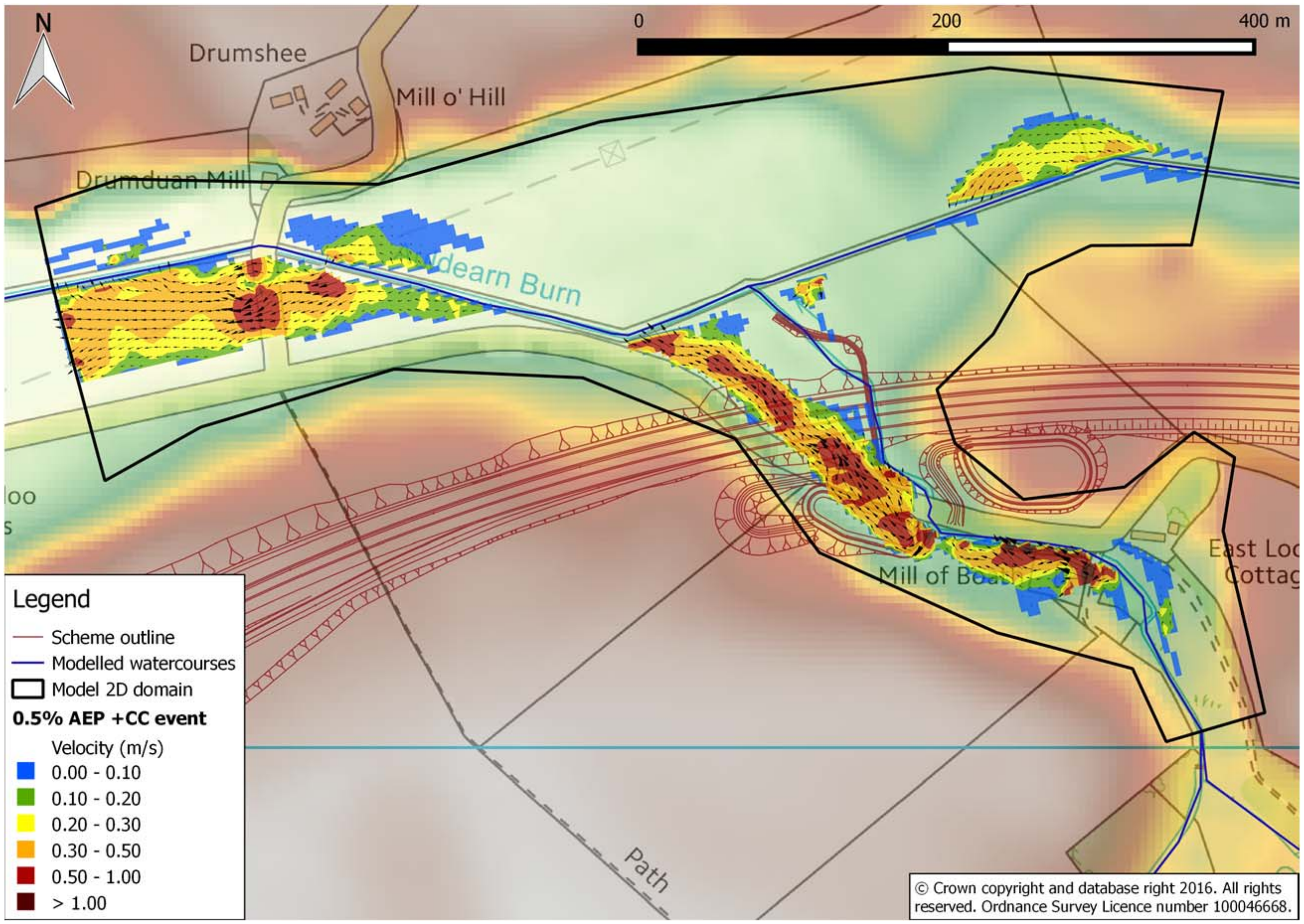
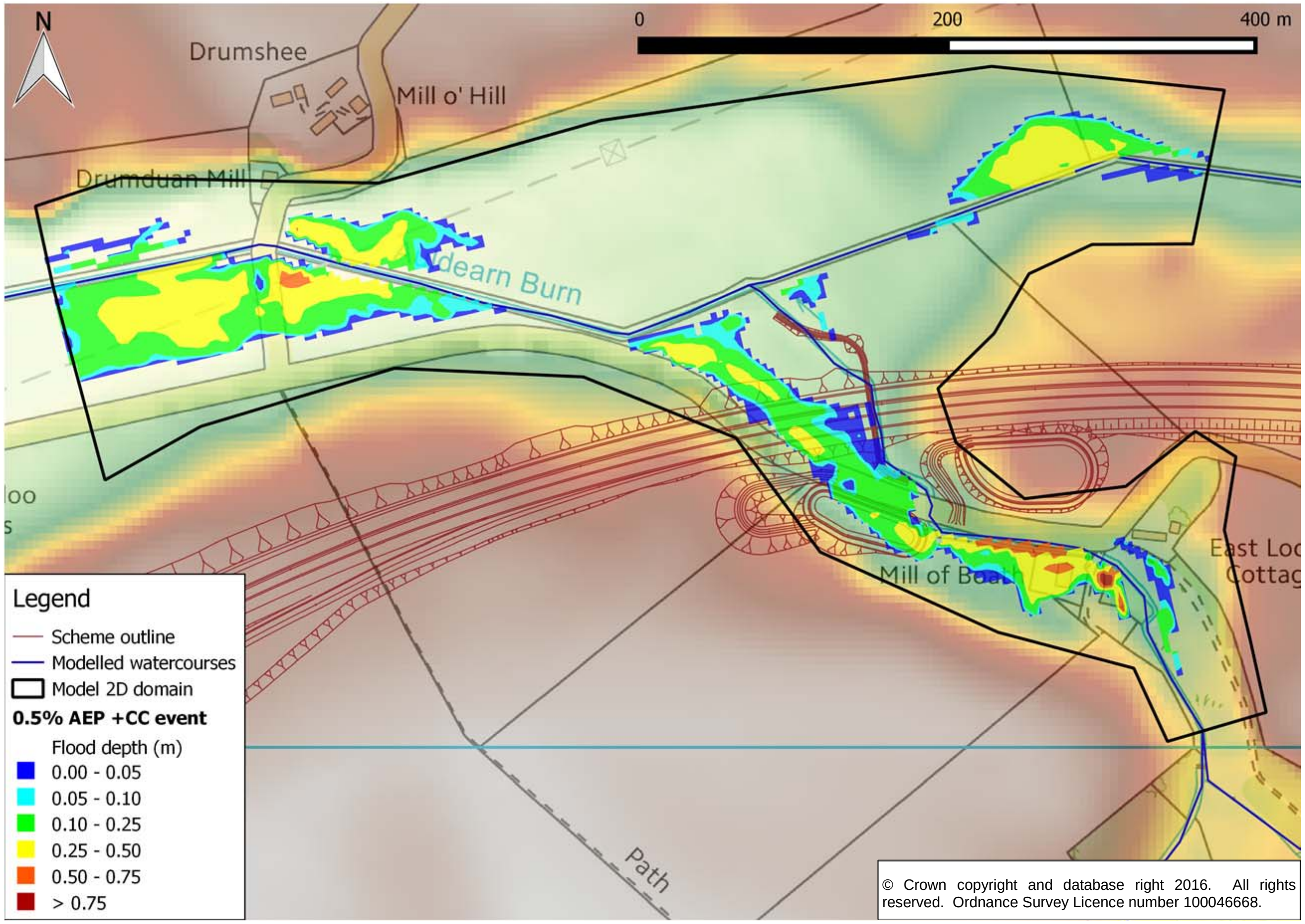


Diagram 12: 0.5 % +CC AEP Maximum Event Flood Depths – Baseline Scenario



'With-Scheme' Scenario

8.9 Diagram 13 and Diagram 14 below show respectively for the 'with-scheme' scenario, flood mechanisms and maximum flood depths for the 0.5% AEP +CC event.

8.10 Due to the proposed Scheme embankment, out of bank flooding on left bank of Auldearn is blocked. Therefore flows return into the channel and pass under the proposed Scheme through the culvert SWF26-2 (C21) (see Diagram 13 below). This contraction causes an increase in in-channel water levels from upstream of the proposed Scheme to Mill of Boath (i.e. 140m upstream of the proposed Scheme).

8.11 Upstream of Mill of Boath, the proposed Scheme has no flood impact.

8.12 Immediately downstream of the proposed Scheme, in-channel water levels increase due to the loss of the flood plain flow path resulting in more flow in the channel. This causes out of bank flooding on left bank of Auldearn Burn. Approximately 100m downstream of the confluence with Tributary 1, all out of bank flows re-enter into Auldearn Burn channel. The impact of the proposed Scheme on in-channel water levels is noticeable up to 220m downstream of the proposed Scheme.

Diagram 13: 0.5 % AEP +CC Event Flood Mechanisms – 'With-Scheme' Scenario

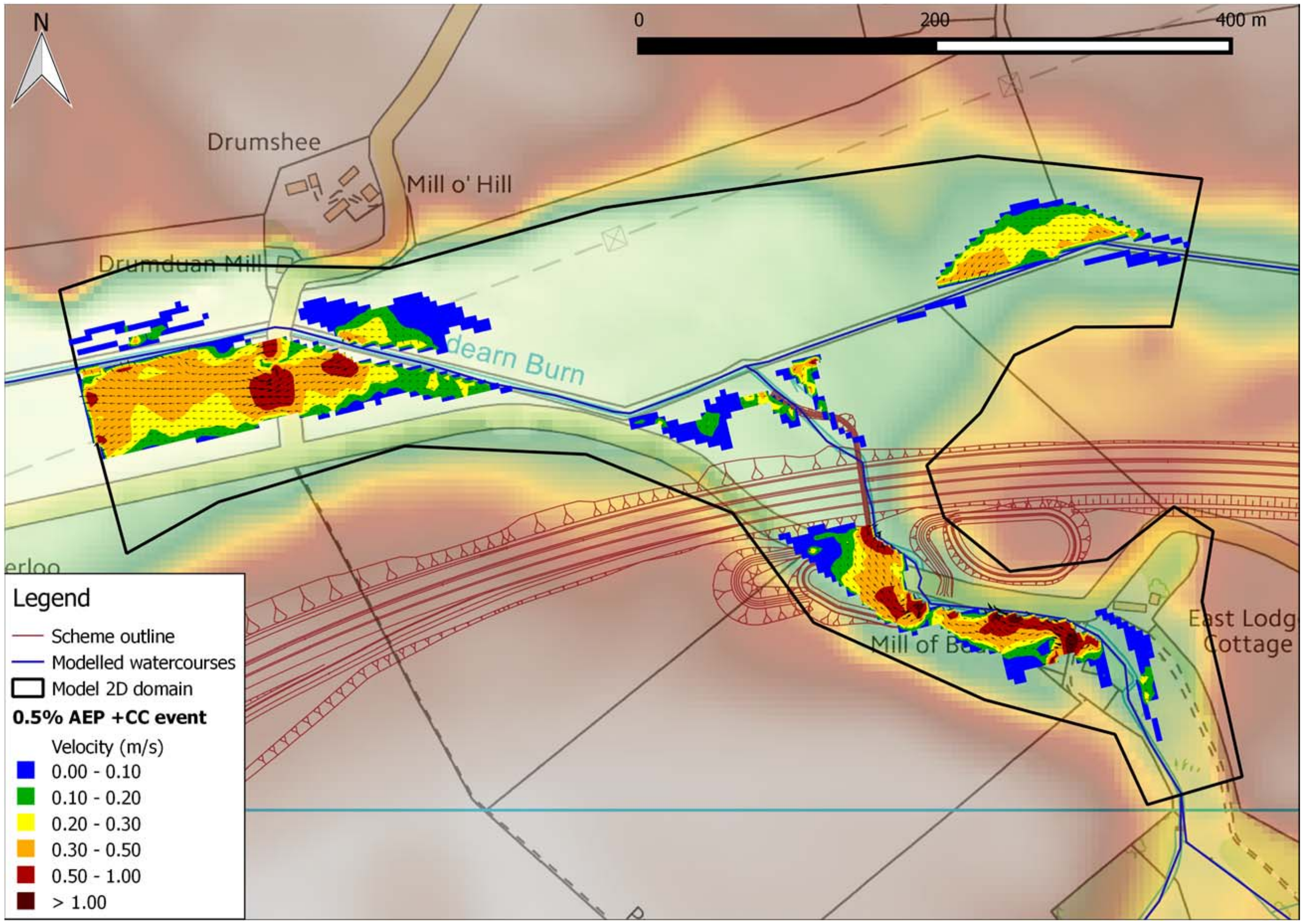
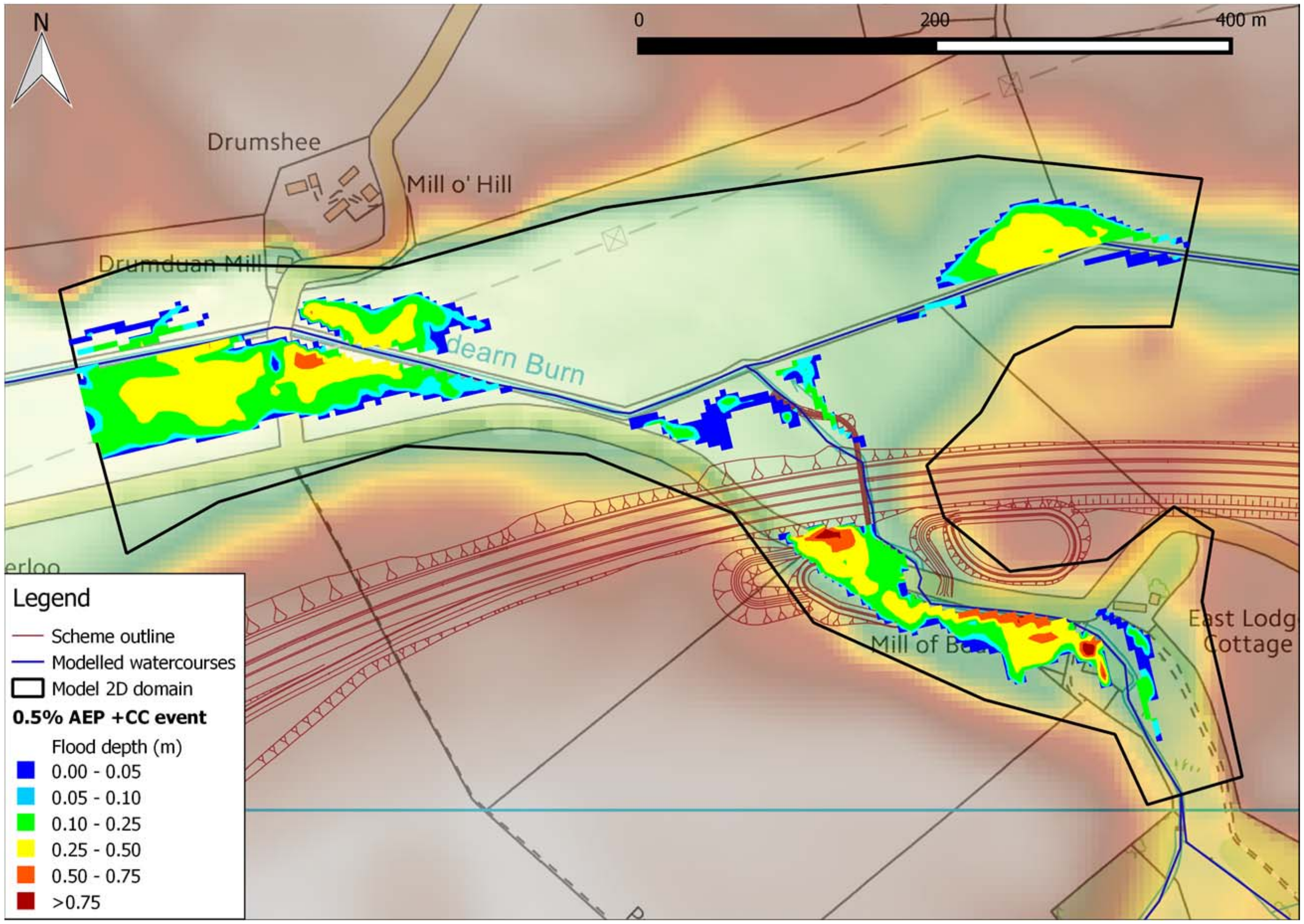


Diagram 14: 0.5 % AEP +CC Event Maximum Flood Depths – 'With-Scheme' Scenario



9 'With-Mitigation' Measures Modelling

9.1 'With-scheme' results show that the overland flow path is intercepted by the road embankment which causes an increase in water levels upstream of the proposed Scheme.

9.2 In order not to increase flood risk at the proposed Scheme and upstream of the proposed Scheme, mitigation measures are proposed. It is suggested to widen the channel up to 5-6m over a length of 44m upstream of the proposed Scheme culvert (Flood Modeller Nodes from Aul_1645 to Aul_1601).

9.3 Since the with-scheme scenario was modelled, a pedestrian access was added to the design. Therefore this feature was included in the with-mitigation model. The pedestrian access is 40m west and parallel to the proposed Scheme culvert. It is 3.5m wide, 2.7m high and 66m long. It was modelled as a 1D (Estry) element within the 2D model. The invert levels for the upstream and downstream were taken from the existing ground levels in the 2014 photogrammetry data. Standard values were used for the height and width contraction coefficients and the entry and exit loss coefficients (BMT WBM 2010). The roughness of the culvert internal surfaces were defined as new, smooth concrete with Manning's "n" = 0.013.

10 Model Results – 'With-Mitigation' Measures

'With-Mitigation' Measures Scenario

10.1 Diagram 15 and Diagram 16 show respectively the main flood mechanisms and maximum flood depths for the 0.5% AEP +CC event for the 'With-Mitigation' measures scenario.

10.2 Diagram 16 and Tables 15 and 16 shows that with this arrangement, upstream of the proposed Scheme in-channel water levels are lower than in the baseline scenario, which allows a decrease in flood depths in the flood plain. Immediately downstream of the proposed Scheme, in-channel water levels are higher, up to 104mm for the 0.5% AEP +CC event (Flood Modeller node Aul_1500), than in the baseline scenario due to the loss of flood plain flow path resulting in more flow in the channel. This causes out of bank flooding on left bank of Auldearn Burn. All flows are in-channel approximately 100m downstream of the confluence with Tributary 1.

Diagram 15: 0.5 % +CC AEP Event Flood Mechanisms - 'With-Mitigation' Measures

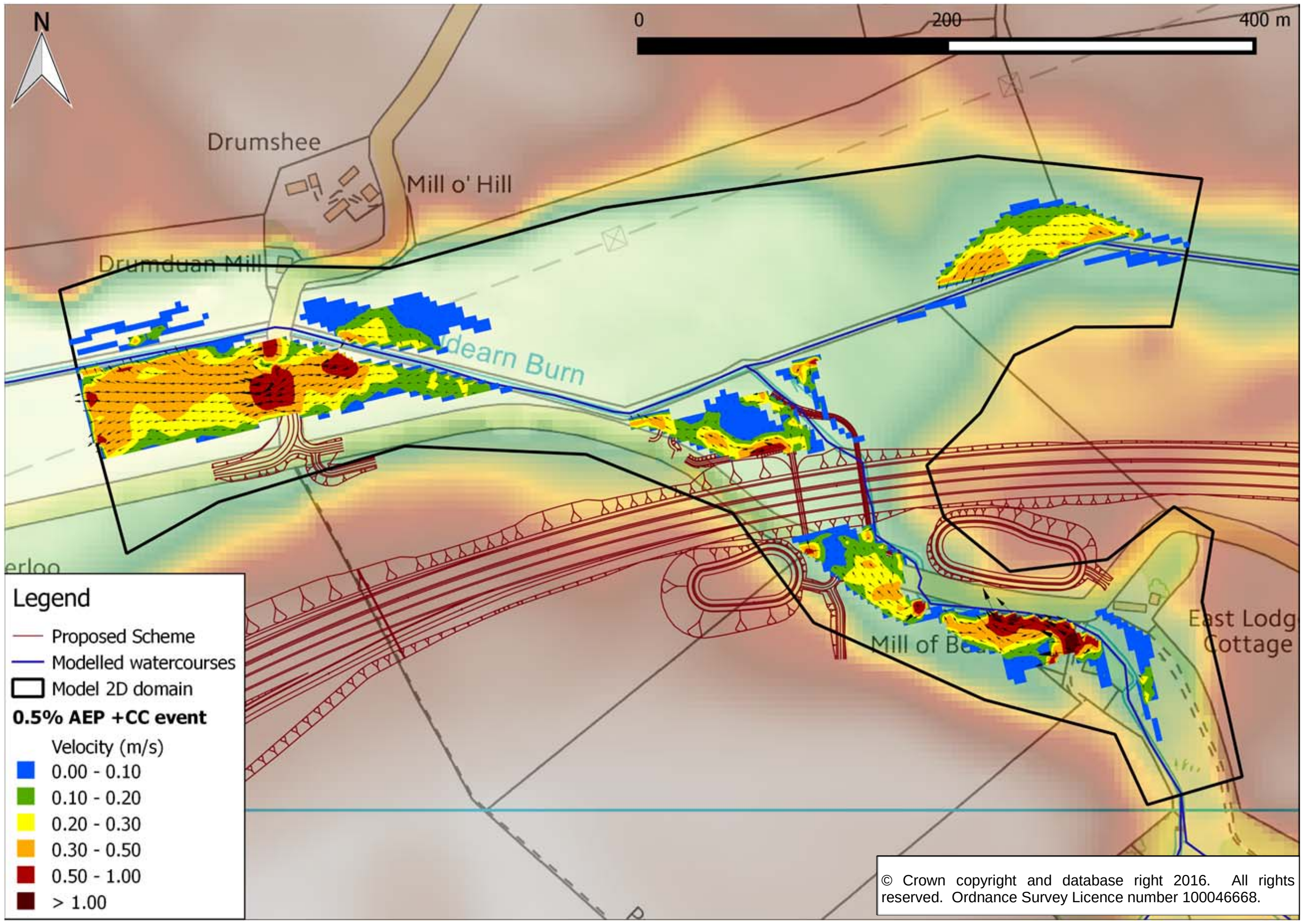


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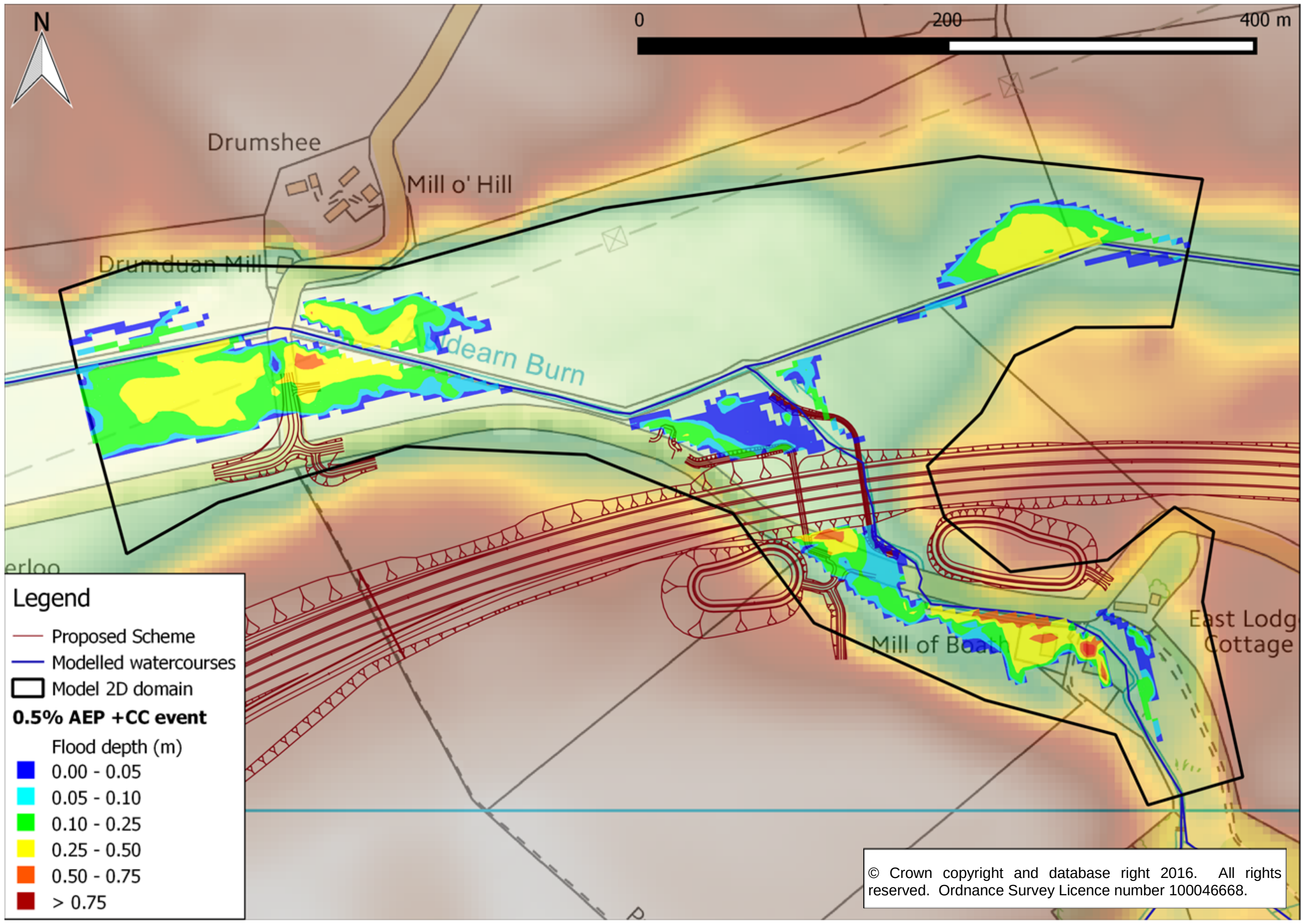
Diagram 16: 0.5 % +CC AEP Event Maximum Flood Depths – 'With-Mitigation' Measures



Comparison of Baseline and 'With-Mitigation' Scenarios

Differences in Maximum Flood Depths across the Flood Plain

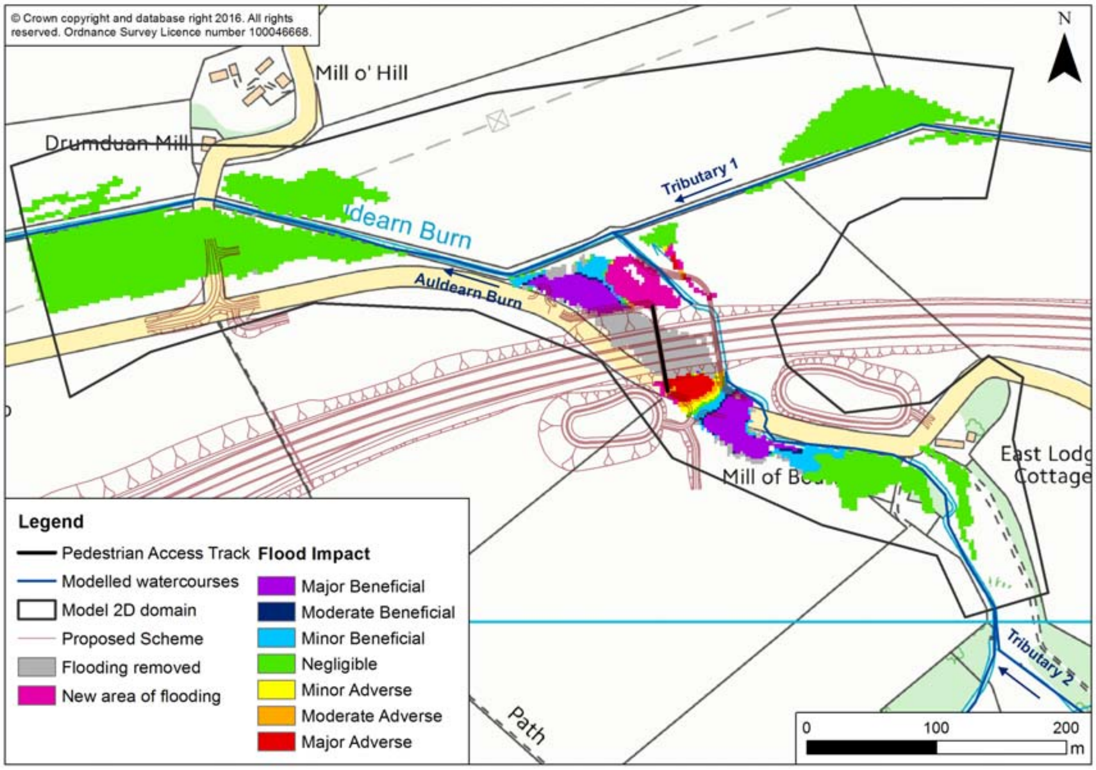
10.3 In order to assess the impact of the proposed Scheme on the existing flood risk, the differences in maximum flood depths were calculated for the 3.33%, 0.5%, 0.5% +CC and 0.1% AEP events between the baseline and the 'With-Mitigation' measures scenarios. All the change in depth maps are shown in Section A.3 (Depth Change Maps). The impact on flood risk, whether adverse or beneficial, have been categorised in Table 14.

10.4 Diagram 17 below shows the differences in maximum flood depths for the 0.5% AEP +CC event. For a 0.5% AEP +CC event, the difference in flood depths is major adverse immediately upstream of the proposed Scheme (i.e. up to 20m upstream of the proposed Scheme). The maximum depth increase is 634mm. From 30m to 120m upstream of the proposed Scheme, the impact is major beneficial to minor beneficial. Downstream of the proposed Scheme to the confluence with Tributary 1, the impact is major beneficial to minor beneficial. Immediately downstream of the Scheme there is also a new area of flooding. This is caused by the pedestrian access directing water to this area. Everywhere else in the flood plain the impact of the proposed Scheme is negligible.

Table 14: Categorisation of Difference in Flood Depths

	Potential Flood Impact	Criteria	Flood Risk
	Major Adverse	Results in loss of attribute and/ or quality and integrity of the attribute	Increase in peak flood depth >100 mm
	Moderate Adverse	Results in effect on integrity of attribute, or loss of part of attribute	Increase in peak flood depth 50-100 mm
	Minor Adverse	Results in some measurable change in attributes quality or vulnerability	Increase in peak flood depth 10-50 mm
	Negligible	Results in effect on attribute, but of insufficient magnitude to affect the use or integrity	Negligible change in peak flood depth <+/- 10 mm
	Minor Beneficial	Results in some beneficial effect on attribute or a reduced risk of negative effect occurring	Reduction in peak flood depth 10-50 mm
	Moderate Beneficial	Results in moderate improvement of attribute quality	Reduction in peak flood depth 50-100 mm
	Major Beneficial	Results in major improvement of attribute quality	Reduction in peak flood depth >100mm

Diagram 17: 0.5% AEP +CC Event Depth Difference Map



Differences in Maximum In-Channel Water Levels

10.5 Table 15 and Table 16 show the changes in in-channel water level between the baseline and the 'With-Mitigation' scenarios, for the 0.5% and the 0.5% AEP +CC events respectively. Where the proposed Scheme has removed the baseline nodes for the model, no comparison was made.

10.6 Table 15 and Table 16 show that 175m upstream of the proposed Scheme, the change in in-channel water levels is negligible for the 0.5% and the 0.5% AEP +CC event (1mm and 2mm respectively). 20m upstream of the proposed Scheme, there is a decrease in in-channel water level of 390mm and 318mm for the 0.5% and the 0.5% AEP +CC event respectively. This is due to the widening of the channel. Downstream of the proposed Scheme, more flows pass through the channel, in the mitigation scenario than in the baseline model. 12m downstream of the proposed Scheme, the increase in in-channel water level is of 38mm and 91mm for the 0.5% and the 0.5% AEP +CC event respectively. 223m downstream of the proposed Scheme the change in in-channel water levels is negligible.

Table 15: In-Channel Water Level at Key Locations for the 0.5% AEP Event

Model node	Description	Baseline Water Level (mAOD)	'With-Mitigation' Water Level (mAOD)	Change in Water Level (m)
Aul_1776	175m Upstream of Scheme crossing	14.881	14.880	-0.001
Aul_1739	138m Upstream of Scheme crossing	14.697	14.693	-0.004
Aul_1661	60m Upstream of Scheme crossing	14.255	14.138	-0.117
Aul_1655	54m Upstream of Scheme crossing	14.105	13.915	-0.190
Aul_1621	20m Upstream of Scheme crossing	13.954	13.564	-0.390
Aul_1601	At Scheme crossing	-	13.473	-
Aul_1529	12m Downstream of Scheme crossing	13.118	13.156	0.038
Aul_1479	62m Downstream of Scheme crossing	12.663	12.702	0.039
Aul_1318	223m Downstream of Scheme crossing	11.715	11.714	-0.001

Table 16: In-Channel Water Level at Key Locations for the 0.5% AEP +CC Event

Model node	Description	Baseline Water Level (mAOD)	'With-Mitigation' Water Level (mAOD)	Change in Water Level (m)
Aul_1776	175m Upstream of Scheme crossing	14.982	14.980	-0.002
Aul_1739	138m Upstream of Scheme crossing	14.845	14.842	-0.003
Aul_1661	60m Upstream of Scheme crossing	14.453	14.254	-0.199
Aul_1655	54m Upstream of Scheme crossing	14.135	13.989	-0.146
Aul_1621	20m Upstream of Scheme crossing	13.996	13.678	-0.318
Aul_1601	At Scheme crossing	-	13.587	-
Aul_1529	12m Downstream of Scheme crossing	13.142	13.233	0.091
Aul_1479	62m Downstream of Scheme crossing	12.728	12.806	0.078
Aul_1318	223m Downstream of Scheme crossing	11.824	11.824	0.000

Blockage of the Proposed Scheme Culvert

10.7 In order to assess the impact of the proposed Scheme culvert becoming obstructed, blockage sensitivity scenarios were modelled for the ‘with-mitigation’ situation for the 0.5% AEP +CC event. The scenarios consisted of a 50% and 90% blockage.

10.8 With a 50% blockage at the culvert there is an increase in water level of 299mm upstream of the Scheme culvert. This leads to an increase in flow through the pedestrian access from $0.43m^3/s$ to $0.99m^3/s$.

10.9 With a 90% blockage at the culvert there is an increase in water level of 1212mm upstream of the Scheme culvert. This leads to an increase in flow through the pedestrian access from $0.43m^3/s$ to $6.6m^3/s$.

11 Model Assumptions and Limitations

Introduction

11.1 The accuracy and validity of the hydraulic model results is heavily dependent on the accuracy of the hydrological and topographic data included in the model. While the most appropriate available information has been used to construct the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

11.2 Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process. The assumptions made are considered to be generally conservative for modelled water levels at the proposed Scheme and are therefore appropriate for the flood risk assessment. Additionally, the sensitivity analysis (presented in Section 7 (Sensitivity Analysis)) has quantified the magnitude of potential uncertainty, and the verification process described in Section 7 (Calibration and Verification) indicates that the modelling outputs are sensible. The sections below summarise the key sources of uncertainty in addition to the limitations associated with the modelling undertaken for Auldearn Burn.

1D Domain

Cross sections

11.3 Flood plain of the Auldearn Burn and its tributaries was represented by extending the surveyed cross-sections in the 1D domain, using the 2014 composite Digital Terrain Model (DTM) dataset. The grid of this dataset has a 5m resolution. This is deemed suitable to represent flood plain features to an appropriate level of detail.

Channel Roughness

11.4 Channel roughness has been assigned using the best available information (site visit, survey data and aerial photographs). The roughness values used are based on available guidance (Chow 1959).

Representation of In-Channel Structures

11.5 Hydraulic coefficients for structures have been applied using available guidance within the Flood Modeller software. The dimensions for structures have been based on detailed survey measurements.

Downstream Boundary Conditions

11.6 The downstream boundary is free discharge type without any downstream control; a normal depth boundary condition is applied. This is deemed appropriate as the downstream boundary is approximately 1106m downstream of the proposed Scheme location. In addition the sensitivity analysis has shown that changes to the downstream boundary only impact on water levels up to 678m upstream of the downstream model extent.

2D Domain

Flood Plain Topography

11.7 The flood plain topography in the 2D domain is based on the 2014 composite Digital Terrain Model (DTM) dataset. The grid of this dataset has a 5m resolution. This is deemed suitable to represent flood plain features to an appropriate level of detail.

Grid Size

11.8 A 4m grid has been used. This is suitable to represent flood plain features to an appropriate level of detail.

Flood Plain Structures

11.9 A review of the flood plain using available aerial photographs, OS mapping and site inspection has shown that there are no flood plain structures that require representation in the model.

DTM Modifications

11.10 No modifications were made to the DTM. Site inspection and a check of aerial photographs established that no breaklines were required.

Model calibration

11.11 No calibration was carried out as the modelled catchment is ungauged.

12 Conclusion

12.1 This report has detailed the modelling carried out to assess the baseline flood risk for Auldearn Burn and its tributaries with reference to the location of the proposed Scheme. A 2.6km reach of Auldearn Burn, 0.7km and 0.8km of its two tributary were represented in the model. A range of flood events from 50% to 0.1% AEP events were simulated.

12.2 The results of baseline modelling have shown that there are two properties at risk of flooding from Auldearn Burn and its tributary:

- one property at East Lodge would flood from a 1% AEP event; and
- one property at Mill of Boath would flood from a 3.33% AEP event.

12.3 Auldearn Burn crossing by the proposed Scheme consists of a new culvert SWF26-2 (C21). The proposed Scheme has been incorporated into the design scenario to assess its impact on the baseline flood risk. Results have shown that out of bank flows on the left bank of Auldearn Burn upstream of the proposed Scheme are blocked by the embankment, which causes increase in flood plain and in-channel water levels.

12.4 Therefore mitigation measures are proposed which consist of a widening of Auldearn Burn channel up to 44m upstream from the proposed Scheme crossing.

12.5 With the mitigation measures in place, in-channel water levels between Mill of Boath and the proposed Scheme crossing are lower than in the baseline scenario, therefore the impact on flood risk to Mill of Boath is beneficial. Immediately upstream of the proposed Scheme crossing, out of bank flows are impounded by the embankment. This causes an adverse flood impact within the flood plain up to 20m upstream of the proposed Scheme crossing.

12.6 Immediately downstream of the proposed Scheme, the loss of the flood plain flow path at the location of the proposed Scheme results in more flow in the channel, and therefore in higher in-channel water levels. There is also a new area of flooding caused by the pedestrian access directing water to this area. All flows are contained within the Auldearn Burn channel by approximately 100m downstream of the confluence with Tributary 1, and from this location the flood risk impact is negligible.

12.7 The proposed Scheme has no impact on flood risk with regard to the two properties at East Lodge and Mill of Boath, or to any other receptors.

13 References

BMT WBM (2010). TUFLOW User Manual: GIS based 2D/1D Hydrodynamic Modelling.

Chow, Ven Te (1959). Open-Channel Hydraulics. McGraw-Hill.

Scottish Environment Protection Agency (V9.1, 2015). Technical Flood Risk Guidance for Stakeholders (Ref SS-NFR-P_002)

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A.1 Maximum Water Level Tables and Long Sections

	Baseline Water Levels (mAOD)								
Modelled Event	**Model Node**								
	Aul_1776 (175m Upstream of Scheme crossing)	Aul_1739 (138m Upstream of Scheme crossing)	Aul_1661 (60m Upstream of Scheme crossing)	Aul_1655 (54m Upstream of Scheme crossing)	Aul_1621 (20m Upstream of Scheme crossing)	Aul_1601 (At Scheme crossing)	Aul_1529 (12m Downstream of Scheme crossing)	Aul_1479 (62m Downstream of Scheme crossing)	Aul_1318 (223m Downstream of Scheme crossing)
50% AEP Event	14.291	13.904	13.526	13.469	13.326	-	12.610	12.163	10.892
20% AEP Event	14.426	14.065	13.680	13.620	13.476	-	12.748	12.272	11.101
10% AEP Event	14.516	14.171	13.783	13.716	13.568	-	12.835	12.345	11.254
3.33% AEP Event	14.634	14.325	13.954	13.866	13.710	-	12.956	12.460	11.434
2% AEP Event	14.702	14.405	14.050	13.949	13.787	-	13.017	12.521	11.509
1% AEP Event	14.804	14.529	14.161	14.035	13.874	-	13.072	12.592	11.609
0.5% AEP Event	14.881	14.697	14.255	14.105	13.954	-	13.118	12.663	11.715
0.5% AEP +CC Event	14.982	14.845	14.453	14.135	13.996	-	13.142	12.728	11.824
0.1% AEP Event	15.042	14.851	14.560	14.187	14.061	-	13.195	12.827	11.929

	'With-Mitigation' Water Levels (mAOD)								
Modelled Event	**Model Node**								
	Aul_1776 (175m Upstream of Scheme crossing)	Aul_1739 (138m Upstream of Scheme crossing)	Aul_1661 (60m Upstream of Scheme crossing)	Aul_1655 (54m Upstream of Scheme crossing)	Aul_1621 (20m Upstream of Scheme crossing)	Aul_1601 (At Scheme crossing)	Aul_1529 (12m Downstream of Scheme crossing)	Aul_1479 (62m Downstream of Scheme crossing)	Aul_1318 (223m Downstream of Scheme crossing)
3.33% AEP Event	14.634	14.322	13.841	13.694	13.325	13.186	12.956	12.460	11.434
0.5% AEP Event	14.880	14.693	14.138	13.915	13.564	13.473	13.156	12.702	11.714
0.5% AEP +CC Event	14.980	14.842	14.254	13.989	13.678	13.587	13.233	12.806	11.824
0.1% AEP Event	15.041	14.874	14.502	14.040	13.824	13.689	13.313	12.914	11.930

	Change in Water Levels (m)								
Modelled Event	**Model Node**								
	Aul_1776 (175m Upstream of Scheme crossing)	Aul_1739 (138m Upstream of Scheme crossing)	Aul_1661 (60m Upstream of Scheme crossing)	Aul_1655 (54m Upstream of Scheme crossing)	Aul_1621 (20m Upstream of Scheme crossing)	Aul_1601 (At Scheme crossing)	Aul_1529 (12m Downstream of Scheme crossing)	Aul_1479 (62m Downstream of Scheme crossing)	Aul_1318 (223m Downstream of Scheme crossing)
3.33% AEP Event	0.000	-0.003	-0.113	-0.172	-0.385		0.000	0.000	0.000
0.5% AEP Event	-0.001	-0.004	-0.117	-0.190	-0.390		0.038	0.039	-0.001
0.5% AEP +CC Event	-0.002	-0.003	-0.199	-0.146	-0.318		0.091	0.078	0.000
0.1% AEP Event	-0.001	0.023	-0.058	-0.147	-0.237		0.118	0.087	0.001

Diagram A1: Auldearn Burn Long Section – 0.5% AEP +CC Event - In-Channel Peak Water Levels

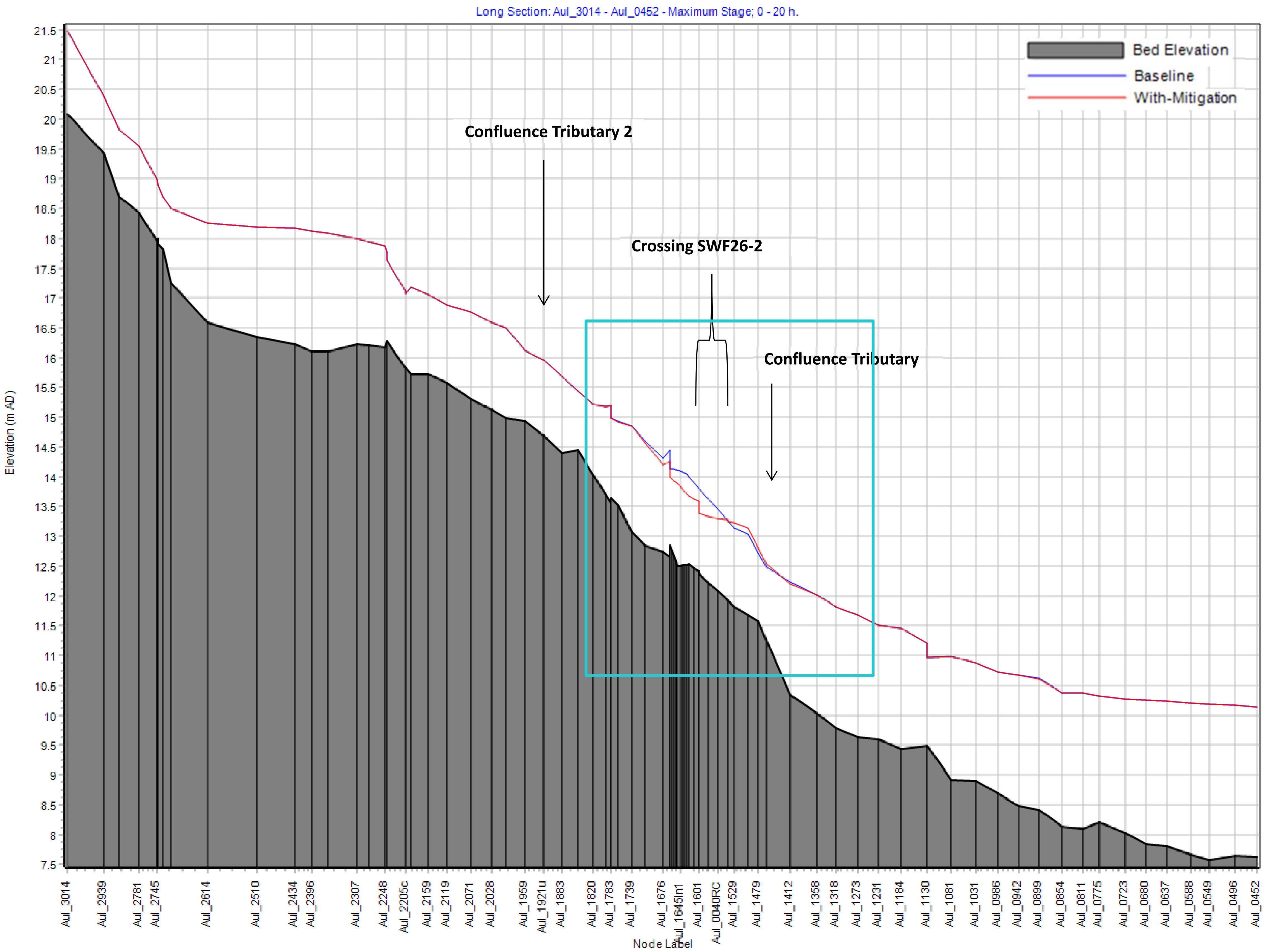
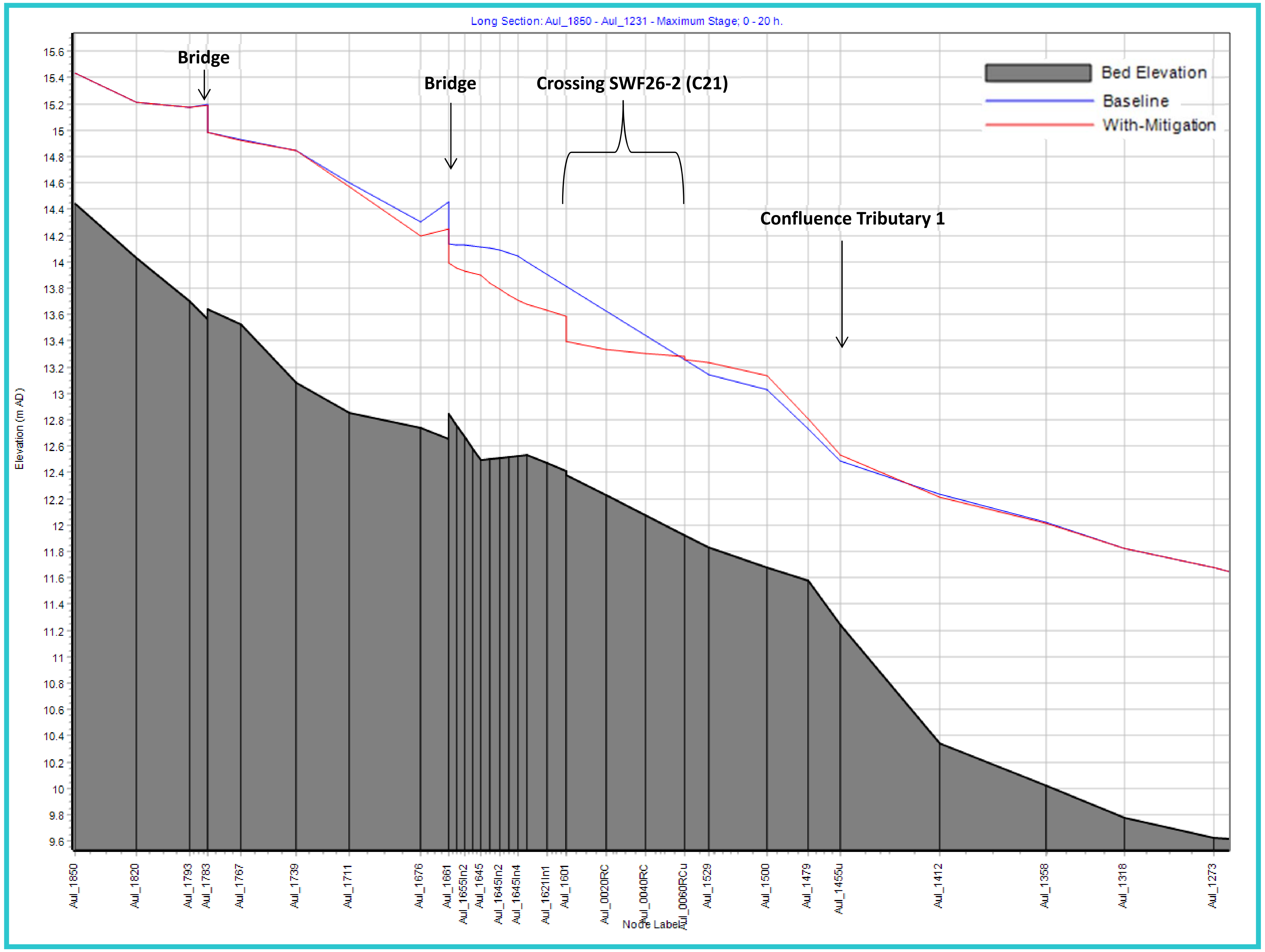


Diagram A2: Auldearn Burn Long Section – 0.5% AEP +CC Event - In-Channel Peak Water Levels - Close up



A.2 Flood Extent Maps

Diagram A3: Baseline Flood Extent for Entire Model Extent. 3.33%, 2%, and 1% AEP Flood Events

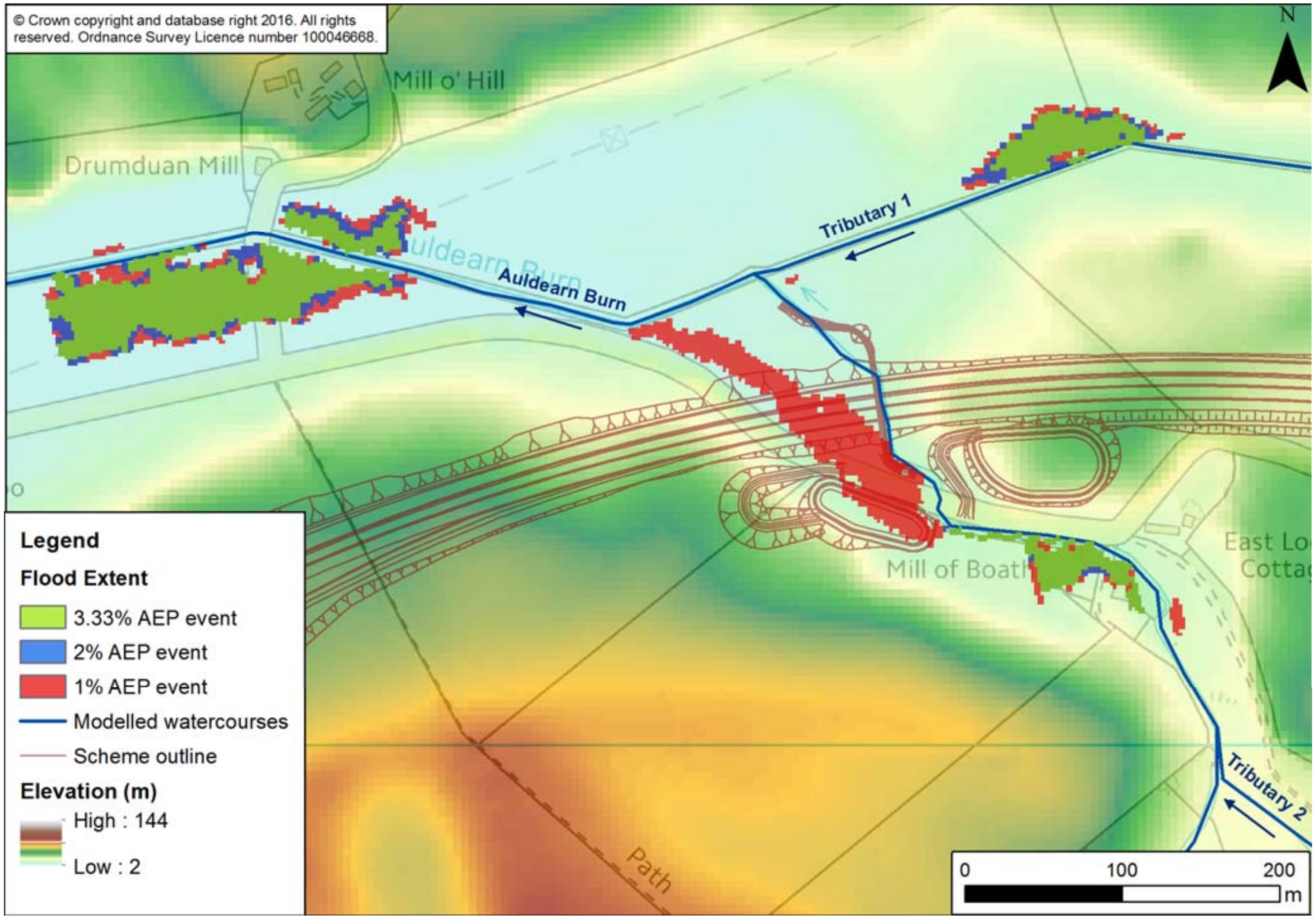
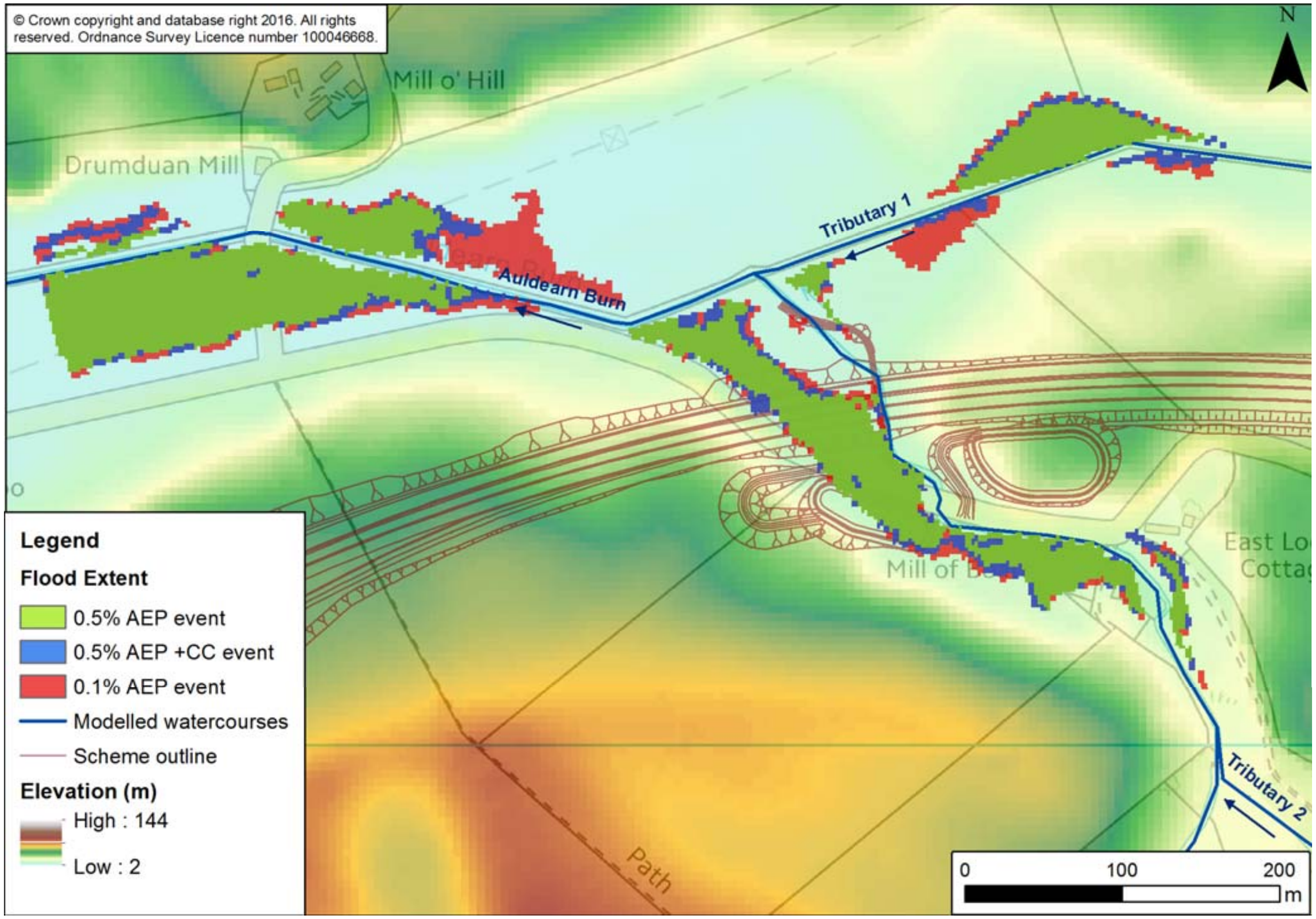


Diagram A4: Baseline Flood Extent for Entire Model Extent. 0.5%, 0.5% AEP +CC, and 0.1% AEP Flood Events



A.3 'With-Mitigation' Depth Change Maps

Diagram A5: 3.33% AEP Event Depth Difference Map

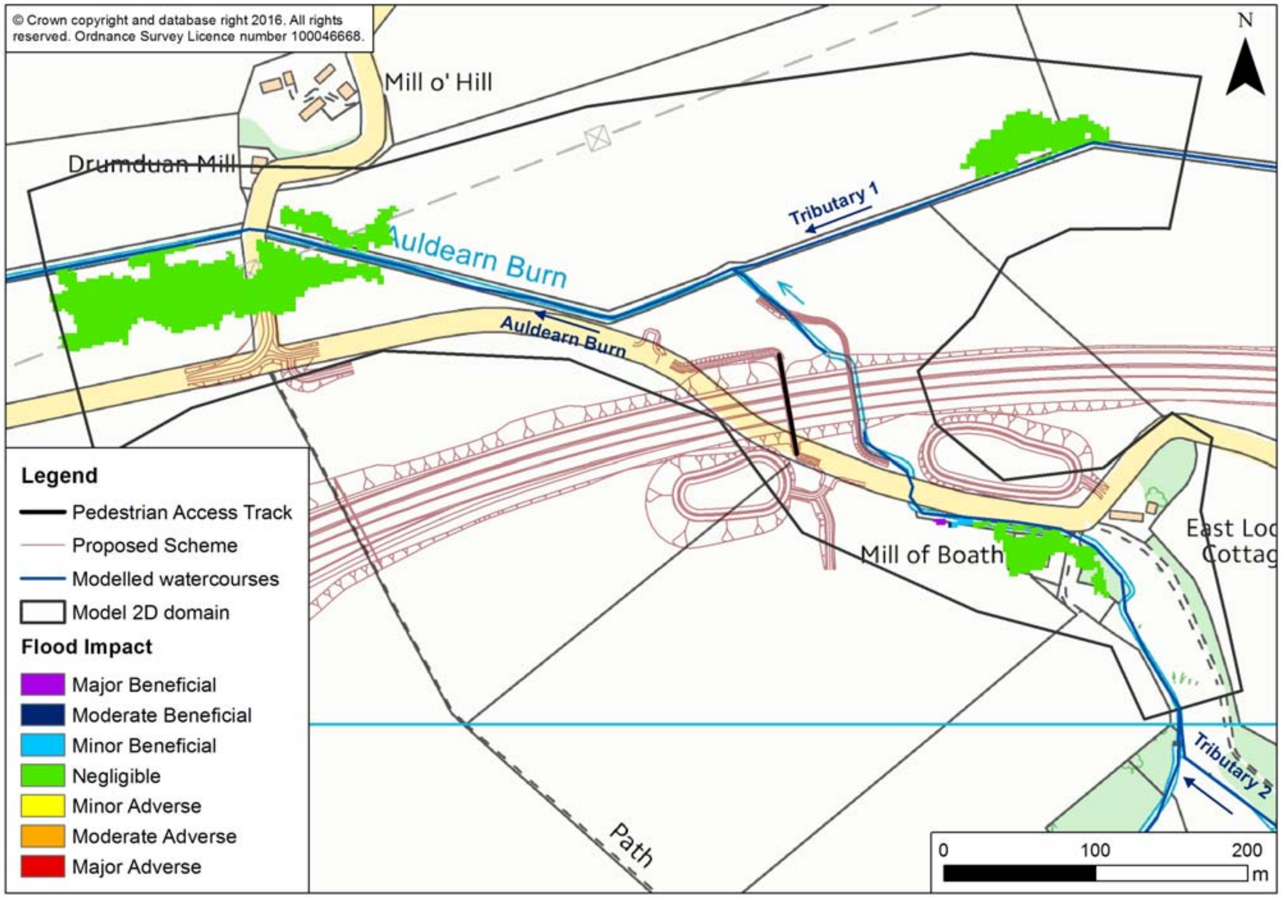


Diagram A6: 0.5% AEP Event Depth Difference Map

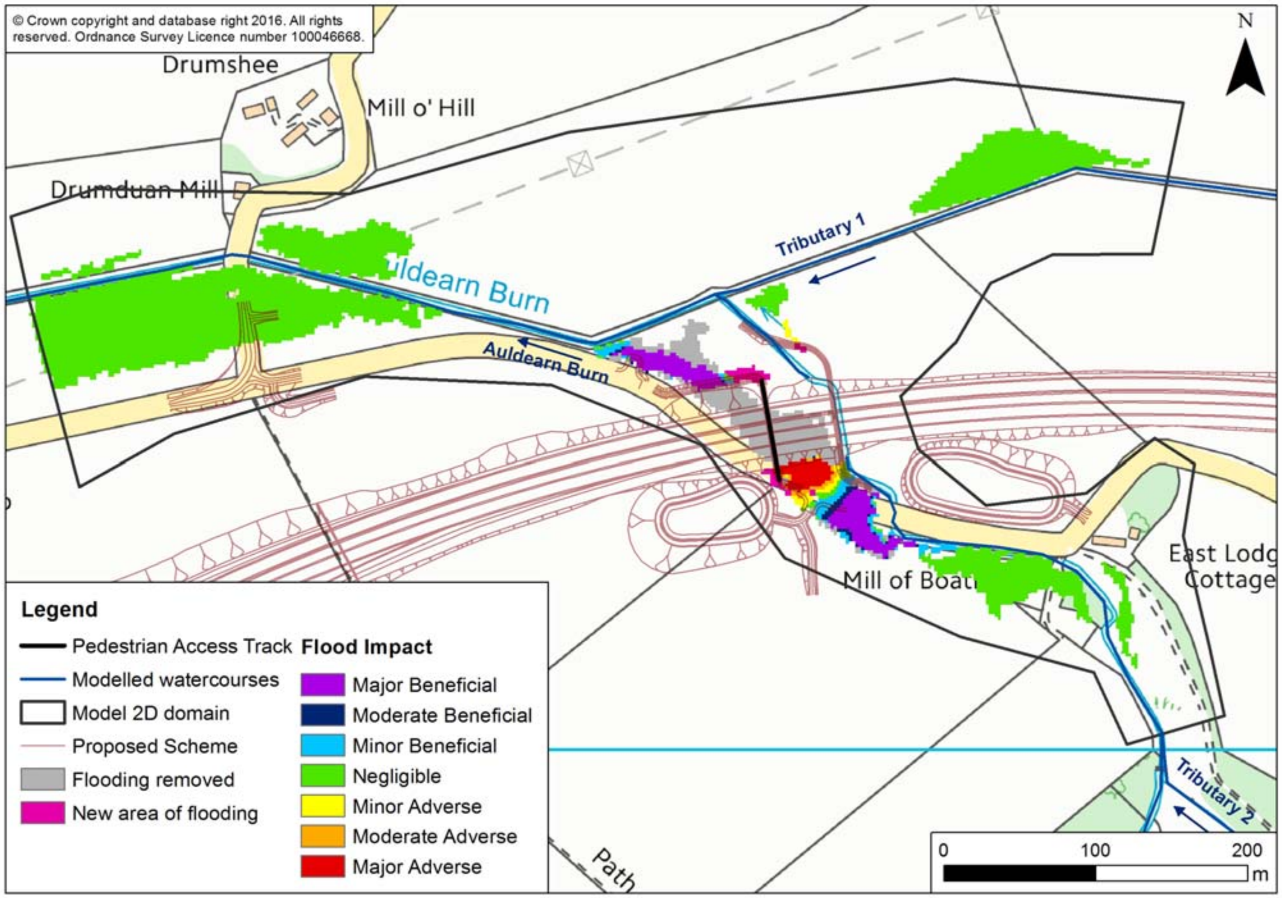


Diagram A7: 0.5% AEP +CC Event Depth Difference Map

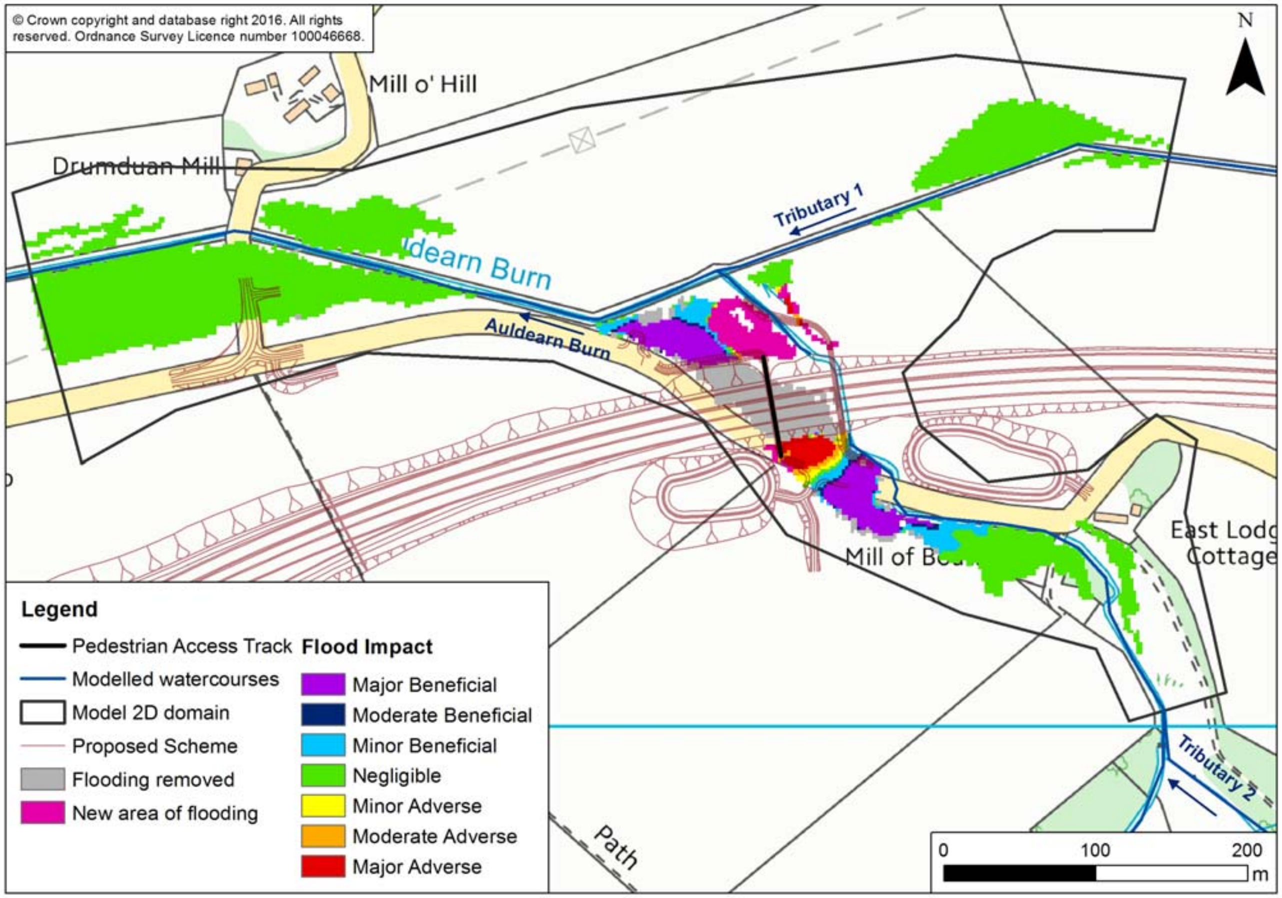
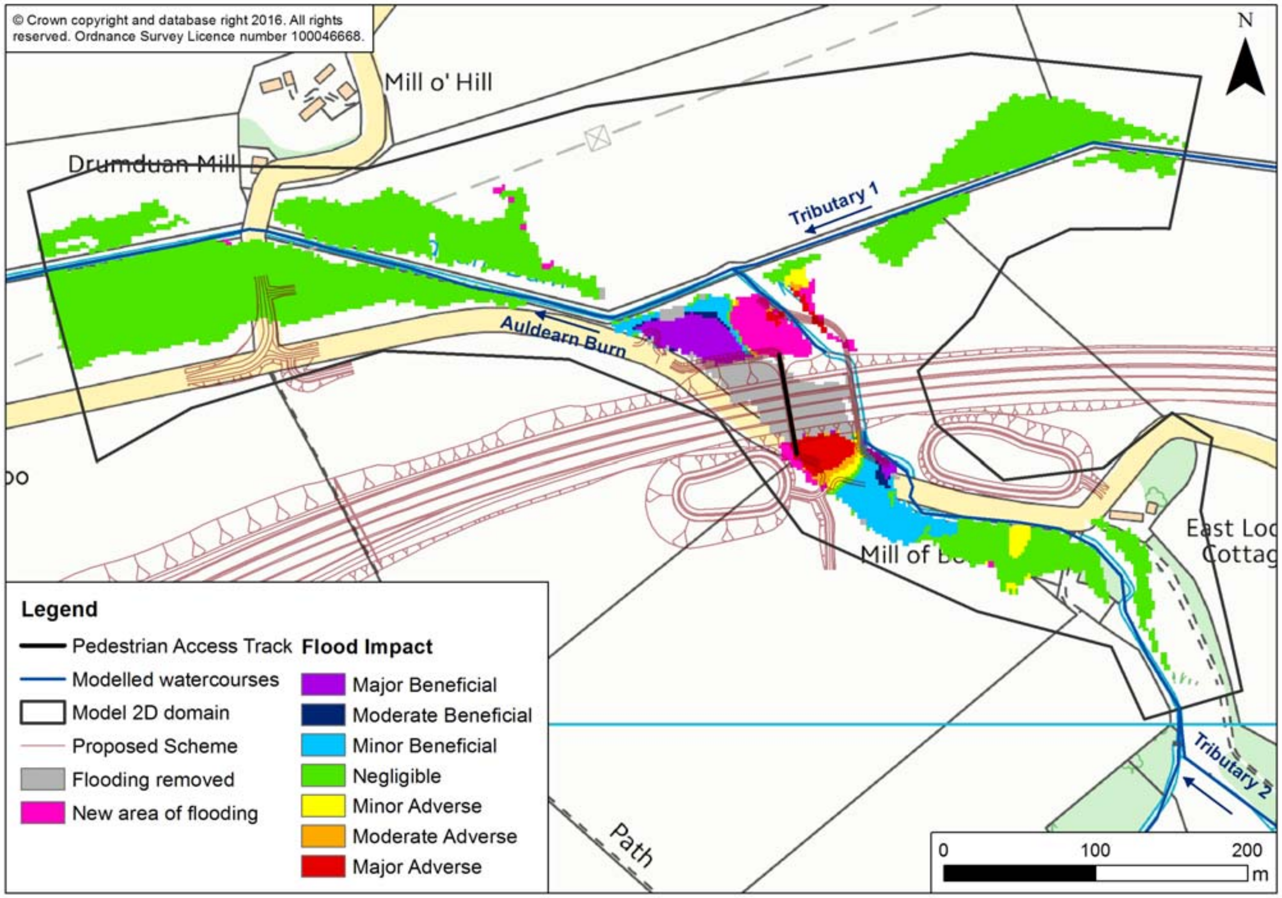


Diagram A8: 0.1% AEP Event Depth Difference Map



A13.2.G: Hydrology Report

1 Introduction

1.1 This annex provides detailed information on the hydrology relevant to Appendix 13.2 Flood Risk Assessment (FRA).

1.2 The A96 Dualling Inverness to Nairn (including Nairn Bypass) Scheme comprises the provision of approximately 31km of new dual carriageway, achieved through offline construction (hereafter referred to as the proposed Scheme). The existing A96 single carriageway would be de-trunked and reclassified as a local road to maintain local access to the proposed Scheme. Due to the size and layout of the proposed Scheme, there are a number of flood risks, which may place the road and its users at risk of flooding. The proposed Scheme also has the potential to impact the level of flood risk elsewhere.

1.3 Hydrological inputs are required for the Stage 3 DMRB assessment. This report specifically provides information on the methods and approach used to derive design peak flow estimates for the culvert assessments of the smaller ungauged catchments. Design peak flows along with inflow hydrographs have also been derived for the River Nairn and other tributaries which are identified for detailed hydraulic (numerical) modelling. It also provides information on the methods used to derive low flow estimates at the road drainage outfall locations for dilution calculations of the receiving watercourses. The design peak flow estimates, inflow hydrographs and low flow estimates are presented within this report for the watercourses which have the potential to be impacted by the proposed Scheme.

1.4 Within the proposed Scheme, a total of 27 watercourses have been identified as having the potential to be impacted by the proposed dualling of the A96 and associated infrastructure. These watercourses range in size from small drainage ditches to larger watercourses such as the River Nairn. Diagram A.1 in A.3 of this report shows the location of the watercourse crossing points of the proposed Scheme along with associated catchment areas.

2 Approach and Methods

General Approach

2.1 Design peak flows, inflow flood hydrographs and low flow estimates are required to be produced for this Stage 3 DMRB Assessment for watercourses/water features potentially impacted and/or crossed by the proposed Scheme. Flood event peak flows with appropriate allowance for climate change are required for all watercourse crossing locations for the following annual exceedance probability (AEP) events: 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1% (equivalent to the 2, 5, 10, 30, 50, 100, 200 and 1000-year return periods). For clarity, the notation used in this report, to describe for example the 0.5% AEP flood event, is 0.5%AEP (200-year). Inflow hydrographs are further required for the River Nairn and all other small watercourses identified for detailed hydraulic modelling. Low flow estimates such as Q95 and Qmean (average long-term flow) are also required for all road drainage outfall locations to assess the potential impacts of the proposed outfalls on the receiving watercourses. The hydrological methods and approaches used to derive this required information are presented in the sections below.

Review of Previous Work

2.2 As part of the initial assessment the following reports for the A96 Dualling were reviewed and relevant information extracted:

- A96 Dualling Inverness to Nairn (including Nairn Bypass) DMRB Stage 2 Scheme Assessment Report, Jacobs, 2014;
- A96 Dualling Inverness to Aberdeen Preliminary Engineering Assessment, Jacobs, 2015a
- A96 Dualling Inverness to Nairn (including Nairn Bypass), Environmental Impact Assessment Screening and Scoping Report; Jacobs (2015b)

- A96 Dualling Inverness to Aberdeen Strategic Environmental Assessment, Tier 2 Environmental Report, CH2M, 2015;
- Inverness to Aberdeen Corridor Study Strategic Business Case, Jacobs, 2014;

2.3 A review of any Potential Vulnerable Areas (PVA) within the project area and any historic flooding / culvert sizing issues / flood prone areas was also undertaken. SEPA Flood Maps were also reviewed to look for locations / properties at risk from flooding along the route.

Regional Hydrological Considerations

2.4 The proposed Scheme runs in close proximity to the Moray Firth and is bounded by the Grampian Mountains to the far south. The hills and mountains formed from relatively impermeable geology give way to notably more permeable soils near the road's corridor. This is indicated by higher BFIHOST values of the soils in this area suggesting relatively high percolation of the water into the soil and below.

2.5 The presence of snow within the catchments (most importantly for the River Nairn catchment) during the winter may be of significance: particularly snowmelt contributions to flood flows. The role of snow is however more complicated since precipitation falling above the snowline/freezing line will be stored rather than contribute to storm event flood flows within the watercourses.

2.6 These aspects make the estimation of design flood runoff particularly challenging (for example precipitation inputs to standard rainfall-runoff methods) and place extra emphasis on any gauged flow data within the region. In a few instances there is also attenuation of flows within some catchments due to the presence of lochs / reservoirs. These aspects influence the downstream flow regime, including both flood and low flow. Ideally these aspects need to be recognised when making hydrological estimates.

2.7 Further details are provided in the below sections as to how these issues have been catered for in the estimation of peak flows, inflow hydrographs and low flows for the catchments which have the potential to be impacted by the proposed Scheme.

Climate Change

2.8 Climate change considerations are required to be included as part of this assessment for design flood events. At present the general approach to climate change is to increase design floods by 20% in order to take into consideration the potential increase in flood flows that may occur in future as a result of a warming climate (SEPA 2015, Highways Agency 2009). This assessment follows standard practice and therefore an uplift factor of 20% has been applied to the design peak flow estimates.

2.9 No climate change adjustment factor has been applied to the low flows estimates.

Baseline Assessment

2.10 To undertake this assessment all watercourses, waterbodies and springs that could potentially be impacted by the proposed Scheme (including the main carriageway and associated ancillary roads) were identified and a list of these features compiled. This was undertaken using a GIS basemap and layers showing the current and proposed A96 development footprint. The list of watercourses, waterbodies and springs was then verified on site. This list of potentially impacted watercourses, waterbodies and springs formed the basis of the hydrological assessment.

2.11 The FEH CD-ROM v3 was used to derive catchment descriptors for all identified watercourses and waterbodies potentially impacted by the proposed Scheme. It should be noted that the FEH CD-ROM is not ideal at picking up small catchments and that a review of the derived catchment parameters was required. Catchment boundaries have been checked on Ordnance Survey maps supplemented with 2m LiDAR derived contour data and when required, via site investigation.

2.12 For a small number of catchments alterations to the FEH catchment were required and the catchment parameters have been adjusted using FEH methodologies. All catchments had their catchment boundaries reviewed, particularly when the catchments contained ambiguous flat areas or if a known artificial influence was present in the catchment. Some catchments within the route corridor were not picked up by the FEH CD-ROM due to the software imposing a minimum area of 0.5km². Where this was the case catchment descriptors have been borrowed (and areally adjusted) from either an adjacent catchment considered to share similar features or by extending the selection point further downstream to pick up the nearest catchment from within the FEH dataset catchment (if judged suitable). Standard FEH methodologies were used for specific parameters that can't be scaled based upon areal adjustment (e.g. DPLBAR, URBEXT and FARL).

2.13 A review of local gauged data within the identified catchments and within the vicinity of the proposed Scheme was then undertaken. Gauges were then reviewed and assessed for suitability for providing relevant high quality data to the project. This included assessment of the gauges performance in terms of both high and low flows. A desk based assessment of local flood histories was also undertaken using a combination of previous third party reports and local knowledge if readily available. A review of anthropogenic activity within the catchments was also undertaken and any notable impacts or activities highlighted.

2.14 All road drainage outfall locations were also identified based upon the preferred route since low flow estimates are required at these locations for dilution calculations. Additionally interaction with the hydraulic modelling team helped identify those watercourses requiring hydrological simulation within the detailed hydraulic (numerical) modelling.

Design Flood Flows

2.15 The level of detail required for peak flow estimates for watercourses within this project is generally based on the importance of the flow estimate and in particular whether the watercourse has been selected for hydraulic modelling. Larger watercourses and watercourses with known flood risk are more likely to require detailed numerical hydraulic modelling. Watercourses identified for detailed modelling require not only the peak flow but also the full inflow hydrograph.

2.16 The majority of watercourses within the proposed Scheme have small and ungauged catchments. Flow estimation for small, ungauged catchments is challenging and open to greater uncertainty than for larger catchments, where more relevant gauged data is likely to be available to aid flow estimation. Where flow data is available it has been used to aid the hydrological assessment. It should be noted though that within or in close proximity to the proposed Scheme there are a limited number of flow gauges which could be used. No return period peak flow estimates were supplied by SEPA for the River Nairn and therefore have not been referred to in our assessment.

2.17 Due to the different methodologies adopted for peak flow estimation for the smaller catchments to that adopted for the one large catchment (namely, the River Nairn); the following section has been split into two sub-sections.

<u>Design Peak Flow Estimation – Small Ungauged Catchments</u>

2.18 For all small ungauged catchments within the proposed Scheme the index flood (QMED) was initially derived from catchment descriptors for each target site. It should be noted that deriving QMED from catchments descriptors alone is subject to greater uncertainty than derivation using suitable local gauged data. Flow estimation is greatly improved by the use of local flow data, however, for these small catchments no direct flow gauging was available.

2.19 These initial QMED values were then adjusted for all ungauged catchments using a regionally derived QMED adjustment factor. The regional QMED adjustment factor has been used for all small ungauged catchments in the proposed Scheme and was derived based on a regional QMED assessment. For this purpose, all six high flow rated gauges in the Hydrometric Area 7 were analysed. Of the six peak-flow rated stations, one station (namely Station 70006 on Lossie @ Torwinny) was excluded as its AMAX data is not usable for either pooling group analysis or QMED (source: NRFA website). The ratio of station $QMED_{(observed)}/QMED_{(catchment\ descriptors)}$ values for the remaining five high flow rated stations varies from 1.51 to 2.46 and the geometric mean of the ratios is found to be 1.74, which was adopted as the regional QMED adjustment factor for all small ungauged catchments in the proposed Scheme.

2.20 To derive flood growth curves for each site the target watercourses were grouped into hydrologically similar groups based on the similarity of the following catchment descriptors: AREA, FARL, SAAR and FPEXT (the same attributes as used in the current FEH pooling approach) as well as catchment permeability (BFIHOST). Two groups were identified based on catchment area (one group for catchments with areas < 3km^2 and one group for catchments > 3km^2) as the other parameters were found to be in a similar range. FEH pooling group analysis was then undertaken on one representative target catchment from each group, but the resulting growth curve from both groups were not found to be significantly different from each other.

2.21 A sensitivity analysis was undertaken on the sites with FARL (Flood Attenuation due to Reservoirs and Lakes) values less than 1 (suggesting attenuation in the catchment) but growth curves were again not found to be significantly different to the other growth curves and therefore this analysis was not taken any further forward. Based on the analysis, a single growth curve was adopted for all ungauged watercourses in the proposed Scheme. The growth curve was then applied to the regionally adjusted QMED values allowing the derivation of the required design peak flows for the ungauged watercourses in the proposed Scheme.

2.22 For comparison both the FEH rainfall-runoff and the Revitalised Flood Hydrograph (ReFH2) methods were also applied to the small ungauged catchments. The ReFH2 model was applied using FEH13 rainfall.

Design Peak Flow and Inflow Hydrographs – Large / Modelled Catchments

2.23 The proposed Scheme crosses over one large watercourse, the River Nairn. Flow in the River Nairn is impacted by attenuation due to waterbodies within its catchment (predominantly Loch Duntelchaig), and snow/snow melt issues have the real potential to affect flood flows. These elements add some complexity into the peak flow estimation for the River Nairn. The River Nairn is, however, gauged just downstream of the proposed road crossing location at hydrometric station 7004. Flood frequency analysis at the Firhall gauging station should therefore provide reasonable estimates of design peak flows for the road crossing.

2.24 In order to avoid inconsistencies in peak flow estimation, SEPA was requested to provide not only the most up-to-date annual maximum series and 15-minute interval time series data but also their estimates of return period peak flows at the gauge. SEPA provide AMAX and 15 minute time series data for the Firhall station from November 1978 to September 2015 but no return period peak flow estimates were provided. A total of 36 years (1979 - 2014) AMAX data was provided from SEPA for the River Nairn at Firhall gauging station. SEPA consider the gauge to be a 'site of excellence' for flows as it has been gauged across a full range of flows including high flood flows. SEPA have reported it has been gauged up to 170.9m^3/s (i.e. 1.74 times QMED).

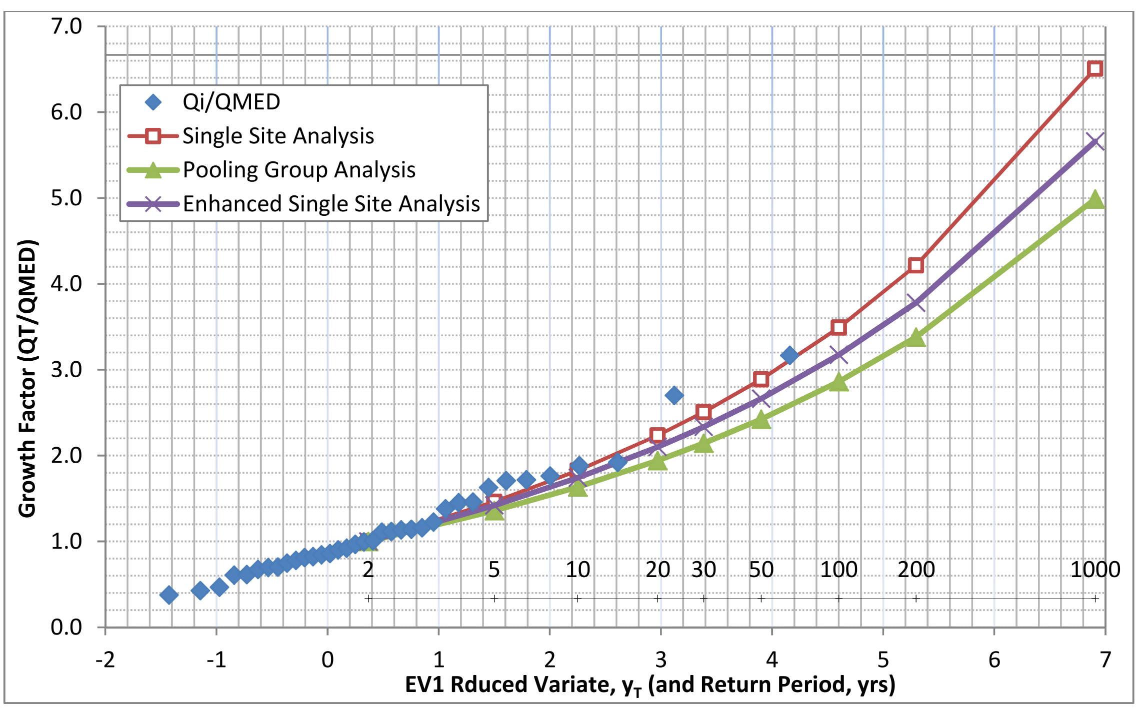
2.25 Flood frequency analyses were undertaken at Firhall gauging station involving both single site analysis and FEH pooling group analysis. However, the growth curve derived from single site analysis was found to have a much steeper slope than the growth curve from the FEH pooling group analysis. Enhanced single site analysis (Wallingford 2009) was also undertaken using the facility available in the WinFAP software package. The growth curves derived from the three methods (single site, enhanced single site and FEH pooling group) are presented in Diagram 1 and the return period flood estimates derived by these three methods are presented in Table 1.

Table 1: Peak flow estimates (m^3/s) for the River Nairn (station 7004 –Firhall) from various methods

Annual Exceedence Probability (%)	Return Period (yrs)	Single Site Analysis	Pooling Group Analysis	Enhanced Single Site Analysis*
50	2	99.2	99.2	99.2
20	5	145	135	141
10	10	181	162	173
5	20	222	193	208
3.33	30	249	213	232
2	50	286	240	264
1	100	346	284	315
0.5	200	418	335	375
0.1	1000	645	495	562

(*Note: According to Science Report SC050050 (The Environment Agency 2008), while conducting a pooling group analysis if data are available at a subject site, a special (large) weight is assigned to the at-site data (by using different sets of weights for L-CV and L-Skew of the at site data than the rest of the data in the pooling group) to emphasise the importance of at-site data compared to the other catchments in the pooling group. Version 3 of WinFAP (current version) includes this facility of assigning large weight to the subject site (gauged) during pooling group analysis and named this form of pooling group analysis as the 'Enhanced Single Site Analysis', although in essence, it is a special type of pooling group analysis.)

Diagram 1: River Nairn at Firhall (7004) Derived Growth Curves



2.26 The steepness of the growth curve produced from enhanced single site analysis at gauge 7004 lies between the growth curves produced by standard single site analysis and standard FEH pooling group analysis. The steepness of the growth curve produced by enhanced single site analysis at the Firhall gauge is also very similar to that of single site analysis based growth curves for hydrometric stations 7002 and 7003 (not shown in Diagram 1). Consequently the enhanced single site growth curve was used to represent the River Nairn.

2.27 The numerical modelling also required peak flows in an ungauged watercourse (a minor tributary of the River Nairn), which was obtained using the methodology described in paragraphs 2.18 to 2.22.

2.28 The hydrograph shape for the River Nairn was derived from the historic flood events recorded at the Nairn at Firhall gauge. A representative hydrograph shape was chosen from a comparison of the five largest flood events on record. The largest event on record (the July 1997 flood event) was selected as representing a typical hydrograph shape for the watercourse and taken forward for use in the River Nairn hydraulic model.

2.29 For the minor tributary included in the River Nairn model, the FEH rainfall-runoff based hydrograph shape was used for input into the hydraulic model. The storm duration adopted for generating the hydrograph shape for this tributary is similar to the theoretical storm duration of the River Nairn at Firhall station (i.e., 18.25 hrs), and not the shorter tributary specific design duration. However, for all other models involving small ungauged catchments, the catchment specific FEH rainfall-runoff based duration for the downstream extent of the model was used.

Low Flow Estimates

2.30 Low flow estimates [95-percentile flow (Q_{95}), mean flow (Qmean)] are required for all the proposed outfall locations for the Stage 3 DMRB assessment. These low flow estimates are required to support water quality, ecological and geomorphological assessments on the receiving watercourses. The following methodology has been used for deriving the low flow estimates.

2.31 Since the gauge on the River Nairn is located in the vicinity of the proposed road crossing the low flow statistics directly from this gauge are used for proposed outfall locations on this main waterbody (Table 2).

Table 2: Gauging station used to calculate low flows

Station Number	River Name	Station Name	Catchment Area (km^2)	Q_{95} (m^3/s)	Qmean (m^3/s)
7004	River Nairn	Firhall	313	0.88	5.55

2.32 For the smaller ungauged watercourses, the low flow estimates were derived based on Low Flows Enterprise (LFE) data. LFE datasets judged to be representative of the range of small catchments requiring estimates were obtained (Table 3). Areal scaling was applied to what was judged to be the most hydrologically similar LFE site in order to transpose the estimate to the target site.

Table 3: LFE gauges

Site	Catchment Area (km2)	Easting	Northing	Q95 (m3/s)	Qmean (m3/s)
1	3.08	292276	856494	0.003	0.023
2	4.39	276933	850754	0.008	0.041
3	5.85	285231	854279	0.009	0.045
4	1.45	288982	854525	0.002	0.010

Baseline Hydrology

2.33 Adopted catchment descriptors for each of the watercourses that could potentially be impacted by the proposed dualling of the A96 within the Inverness to Nairn Section (including the Nairn Bypass) are presented in Table 4. Manual adjustment of catchment descriptor values are discussed in further detail in A.2 (Amendments to Catchment Descriptors).

Table 4: Target site catchment descriptors

Watercourse / Structure Reference	OS Grid Reference	Catchment Area (km2)	SAAR 1961 -1990 (mm)	BFI-HOST	SPR-HOST (%)	FARL	URBEXT (2000)
SWF02-1	NH6990646015	7.20	741	0.764	25.4	1.000	0.037
SWF02-2	NH6989146042	7.20	741	0.764	25.4	1.000	0.037
SWF02-A	NH6981745966	7.20	741	0.764	25.4	1.000	0.037
SWF03-1	NH7045246148	5.19	772	0.606	32.4	0.972	0.073
SWF03-4	NH7071246620	6.04	760	0.626	32.4	0.976	0.074
SWF03-A	NH7067546680	6.04	760	0.626	32.4	0.976	0.074
SWF03-B	NH7066046715	6.04	760	0.626	32.4	0.976	0.074
SWF06-1	NH7086546829	5.69	729	0.679	33.3	1.000	0.076
SWF06-A	NH7151746683	5.38	729	0.679	33.3	1.000	0.079
SWF06-B	NH7133146781	5.46	729	0.679	33.3	1.000	0.078
SWF06-C	NH7083046830	5.69	729	0.679	33.3	1.000	0.076
SWF07-1	NH7143247212	0.63	694	0.744	27.9	1.000	0.056
SWF07-A	NH7131847304	0.93	694	0.744	27.9	1.000	0.046
SWF07-B	NH7163647432	0.25	694	0.743	27.9	1.000	0.025
SWF08-1	NH7281547672	1.56	697	0.762	26.3	1.000	0.131
SWF08-A	NH7278747851	1.75	697	0.762	26.3	1.000	0.131
SWF09-1	NH7413848558	2.83	705	0.692	32.3	1.000	0.014
SWF09-A	NH7407048700	3.06	704	0.699	31.7	1.000	0.013
SWF09-B	NH7401848384	2.13	706	0.685	32.9	1.000	0.018
SWF11-A	NH7422148394	0.43	703	0.705	31.2	1.000	0.000
SWF12-1	NH7525848699	6.29	743	0.533	46.0	0.979	0.009
SWF12-A	NH7529248786	6.34	743	0.533	46.0	0.979	0.009
SWF12-B	NH7527348833	6.34	743	0.533	46.0	0.979	0.009
SWF13-1	NH7599449863	1.21	674	0.817	21.7	1.000	0.004
SWF13-2	NH7608149674	1.07	674	0.817	21.7	1.000	0.004

Watercourse / Structure Reference	OS Grid Reference	Catchment Area (km2)	SAAR 1961 -1990 (mm)	BFI-HOST	SPR-HOST (%)	FARL	URBEXT (2000)
SWF13-A	NH7585950210	1.41	674	0.817	21.7	1.000	0.004
SWF14-1	NH7631950173	2.51	715	0.636	37.1	1.000	0.000
SWF14-A	NH7650049900	2.46	715	0.636	37.1	1.000	0.000
SWF15-1	NH7640850253	0.51	678	0.767	25.8	1.000	0.004
SWF15-A	NH7610050267	3.13	709	0.657	35.3	1.000	0.005
SWF15-B	NH7600950321	3.15	709	0.657	35.3	1.000	0.005
SWF15-C	NH7670050180	0.43	678	0.767	25.8	1.000	0.004
SWF16-1	NH7693150777	5.10	702	0.678	33.5	0.990	0.000
SWF16-2	NH7731850904	4.50	706	0.651	35.8	0.988	0.000
SWF16-A	NH7675750846	5.29	700	0.688	32.7	0.990	0.000
SWF16-B	NH7672950869	5.29	700	0.688	32.7	0.990	0.000
SWF17-1	NH7774451617	1.24	691	0.767	25.9	1.000	0.007
SWF17-A	NH7768751650	1.34	691	0.767	25.9	1.000	0.007
SWF18-1	NH7893651771	2.13	691	0.772	25.4	1.000	0.024
SWF18-2	NH7901651768	1.78	691	0.765	26.1	1.000	0.008
SWF18-A	NH7903452119	4.28	684	0.799	23.1	0.998	0.017
SWF18-B	NH7913951609	1.74	676	0.839	19.7	1.000	0.009
SWF18-C	NH7931251872	0.24	667	0.867	16.5	1.000	0.012
SWF19-1	NH8274353880	4.89	665	0.651	30.7	0.861	0.015
SWF19-2	NH8293153830	4.80	665	0.659	30.2	0.851	0.015
SWF19-A	NH8266153928	5.17	665	0.651	30.7	0.861	0.015
SWF19-B	NH8295653719	4.80	665	0.659	30.2	0.851	0.015
SWF22-1	NH8522454317	7.46	674	0.755	25.8	0.965	0.005
SWF22-A	NH8510954243	7.46	674	0.755	25.8	0.965	0.005
SWF24-1*	NH8898354525	2.19	672	0.874	17.6	1.000	0.000
SWF26-1	NH9027856194	24.6	687	0.732	28.9	0.999	0.003
SWF26-2	NH9163056217	19.3	698	0.75	27.6	0.998	0.004
SWF26-A	NH9041856233	24.6	687	0.732	28.9	0.999	0.003
SWF26-B	NH9123456335	23.6	687	0.732	28.9	0.999	0.003
SWF26-C	NH9166556158	19.3	698	0.75	27.6	0.998	0.004

Watercourse / Structure Reference	OS Grid Reference	Catchment Area (km2)	SAAR 1961 -1990 (mm)	BFI-HOST	SPR-HOST (%)	FARL	URBEXT (2000)
SWF26-D	NH9130155527	12.6	705	0.787	24.4	1.000	0.002
SWF26-E	NH9169955752	13.1	704	0.79	24.2	1.000	0.006
SWF34-1	NH9227556492	3.47	656	0.573	41.7	1.000	0.000
SWF23-1 (R. Nairn @ A96 crossing)	NH8801054495	303	942	0.587	41.3	0.923	0.001
R. Nairn (Gauge 7004)	NH8825055050	305	942	0.587	41.3	0.923	0.001

* SWF24-1 refers to the River Nairn tributary at the proposed A96 crossing

Flood Peak Flow Estimates – Small Ungauged Catchments

2.34 The peak flow estimates based upon the statistical FEH method for the following AEP events 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1% are presented below in Table 5. The 0.5% AEP estimate is also given including a +20% allowance for climate change.

Table 5: Peak Flow Estimates – FEH Statistical method (m^3/s)

Watercourse / Structure Reference	AEP 50%	AEP 20%	AEP 10%	AEP 3.33%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.5% + CC	AEP 0.1%
SWF02-1	1.18	1.65	2.02	2.68	3.04	3.60	4.27	5.12	6.30
SWF02-2	1.18	1.65	2.02	2.68	3.04	3.60	4.27	5.12	6.30
SWF02-A	1.18	1.65	2.02	2.68	3.04	3.60	4.27	5.12	6.30
SWF03-1	1.75	2.46	3.00	3.98	4.52	5.36	6.35	7.62	9.37
SWF03-4	1.83	2.56	3.12	4.15	4.71	5.59	6.61	7.94	9.76
SWF03-A	1.83	2.56	3.12	4.15	4.71	5.59	6.61	7.94	9.76
SWF03-B	1.83	2.56	3.12	4.15	4.71	5.59	6.61	7.94	9.76
SWF06-1	1.42	2.00	2.43	3.24	3.67	4.35	5.15	6.19	7.61
SWF06-A	1.35	1.89	2.30	3.06	3.47	4.11	4.87	5.84	7.19
SWF06-B	1.37	1.92	2.34	3.10	3.52	4.18	4.95	5.94	7.30
SWF06-C	1.42	2.00	2.43	3.24	3.67	4.35	5.15	6.19	7.61
SWF07-1	0.14	0.20	0.25	0.33	0.37	0.44	0.52	0.63	0.77
SWF07-A	0.19	0.27	0.33	0.44	0.50	0.60	0.71	0.85	1.04
SWF07-B	0.05	0.07	0.09	0.12	0.14	0.16	0.19	0.23	0.28
SWF08-1	0.38	0.53	0.64	0.85	0.97	1.15	1.36	1.63	2.01
SWF08-A	0.42	0.59	0.72	0.96	1.09	1.29	1.53	1.84	2.26
SWF09-1	0.59	0.82	1.00	1.33	1.51	1.79	2.12	2.54	3.13

Watercourse / Structure Reference	AEP 50%	AEP 20%	AEP 10%	AEP 3.33%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.5% + CC	AEP 0.1%
SWF09-A	0.63	0.89	1.08	1.43	1.63	1.93	2.28	2.74	3.37
SWF09-B	0.48	0.67	0.82	1.09	1.24	1.47	1.74	2.09	2.57
SWF11-A	0.09	0.12	0.15	0.20	0.23	0.27	0.32	0.39	0.47
SWF12-1	2.19	3.07	3.74	4.97	5.64	6.69	7.92	9.50	11.7
SWF12-A	2.19	3.07	3.74	4.97	5.64	6.69	7.92	9.50	11.7
SWF12-B	2.19	3.07	3.74	4.97	5.64	6.69	7.92	9.50	11.7
SWF13-1	0.14	0.19	0.24	0.31	0.36	0.42	0.50	0.60	0.74
SWF13-2	0.12	0.17	0.21	0.28	0.31	0.37	0.44	0.53	0.65
SWF13-A	0.16	0.23	0.27	0.36	0.41	0.49	0.58	0.70	0.86
SWF14-1	0.66	0.93	1.13	1.51	1.71	2.03	2.40	2.88	3.54
SWF14-A	0.65	0.91	1.11	1.48	1.68	1.99	2.36	2.83	3.48
SWF15-1	0.09	0.12	0.15	0.20	0.22	0.26	0.31	0.37	0.46
SWF15-A	0.73	1.02	1.25	1.66	1.88	2.23	2.64	3.17	3.90
SWF15-B	0.73	1.02	1.25	1.66	1.88	2.23	2.64	3.17	3.90
SWF15-C	0.07	0.10	0.12	0.16	0.19	0.22	0.26	0.31	0.38
SWF16-1	0.94	1.32	1.61	2.14	2.43	2.88	3.41	4.09	5.03
SWF16-2	0.95	1.34	1.63	2.17	2.46	2.92	3.45	4.14	5.10
SWF16-A	0.93	1.30	1.58	2.10	2.39	2.83	3.35	4.02	4.94
SWF16-B	0.93	1.30	1.58	2.10	2.39	2.83	3.35	4.02	4.94
SWF17-1	0.19	0.27	0.33	0.44	0.50	0.59	0.70	0.84	1.03
SWF17-A	0.21	0.29	0.36	0.48	0.54	0.64	0.76	0.91	1.12
SWF18-1	0.32	0.45	0.55	0.73	0.83	0.98	1.16	1.39	1.71
SWF18-2	0.27	0.38	0.46	0.61	0.69	0.82	0.97	1.16	1.43
SWF18-A	0.48	0.68	0.83	1.10	1.25	1.48	1.75	2.10	2.59
SWF18-B	0.17	0.25	0.30	0.40	0.45	0.53	0.63	0.76	0.93
SWF18-C	0.03	0.04	0.05	0.06	0.07	0.08	0.10	0.12	0.15
SWF19-1	0.56	0.78	0.96	1.27	1.44	1.71	2.03	2.43	2.99
SWF19-2	0.51	0.72	0.88	1.16	1.32	1.57	1.85	2.23	2.74
SWF19-A	0.59	0.82	1.00	1.33	1.51	1.80	2.13	2.55	3.14
SWF19-B	0.51	0.72	0.88	1.16	1.32	1.57	1.85	2.23	2.74
SWF22-1	0.77	1.09	1.32	1.76	2.00	2.37	2.80	3.36	4.14
SWF22-A	0.77	1.09	1.32	1.76	2.00	2.37	2.80	3.36	4.14
SWF24-1	0.16	0.23	0.28	0.37	0.43	0.50	0.60	0.72	0.88
SWF26-1	2.80	3.92	4.78	6.35	7.21	8.55	10.1	12.1	14.9

Watercourse / Structure Reference	AEP 50%	AEP 20%	AEP 10%	AEP 3.33%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.5% + CC	AEP 0.1%
SWF26-2	2.18	3.07	3.74	4.96	5.63	6.68	7.91	9.49	11.7
SWF26-A	2.80	3.92	4.78	6.35	7.21	8.55	10.1	12.1	14.9
SWF26-B	2.69	3.77	4.60	6.11	6.93	8.22	9.73	11.7	14.4
SWF26-C	2.18	3.07	3.74	4.96	5.63	6.68	7.91	9.49	11.7
SWF26-D	1.31	1.84	2.25	2.99	3.39	4.02	4.76	5.71	7.02
SWF26-E	1.36	1.90	2.32	3.08	3.50	4.15	4.91	5.89	7.25
SWF34-1	0.87	1.23	1.49	1.99	2.25	2.67	3.16	3.80	4.67

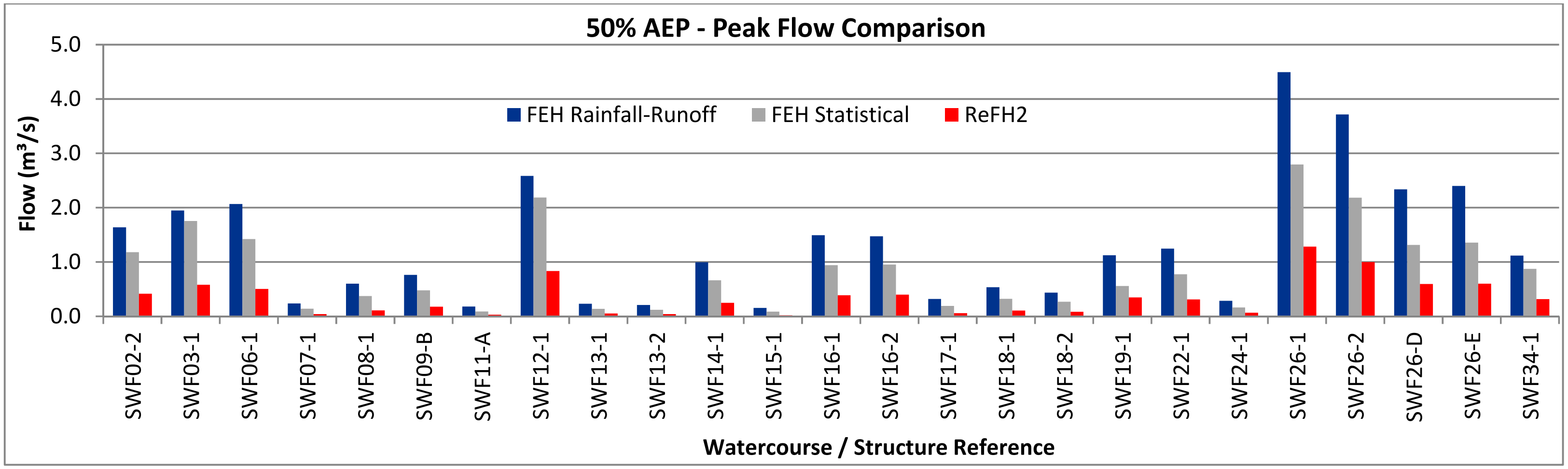
2.35 Table 6 presents both the FEH rainfall-runoff model and ReFH2 model produced peak flow estimates for the 50% and 0.5% AEP events for a sub-set of watercourses with catchment areas less than 25km^2. Diagram 2 compares the FEH statistical, FEH rainfall-runoff and ReFH2 produced 50% and 0.5% AEP event peak flow estimates.

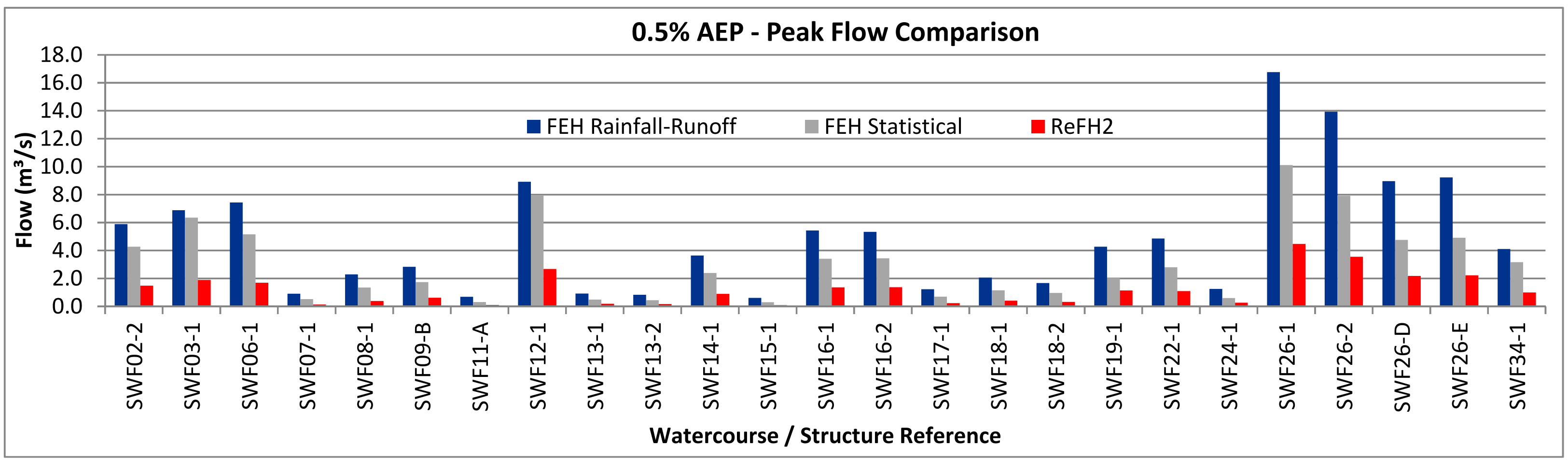
Table 6: Peak Flow Estimates (m^3/s) - FEH Rainfall-Runoff method vs ReFH2

Watercourse / Structure Reference	Catchment Area (km^2)	AEP 50%		AEP 0.5%	
		FEH R-R	ReFH2	FEH R-R	ReFH2
SWF02-2	7.20	1.64	0.42	5.89	1.48
SWF03-1	5.19	1.95	0.58	6.89	1.90
SWF06-1	5.69	2.07	0.51	7.44	1.70
SWF07-1	0.63	0.24	0.04	0.91	0.14
SWF08-1	1.56	0.60	0.11	2.30	0.39
SWF09-B	2.13	0.76	0.18	2.84	0.63
SWF11-A	0.43	0.18	0.03	0.69	0.11
SWF12-1	6.29	2.59	0.84	8.93	2.68
SWF13-1	1.21	0.23	0.05	0.92	0.19
SWF13-2	1.07	0.21	0.04	0.84	0.17
SWF14-1	2.51	1.00	0.25	3.65	0.90
SWF15-1	0.52	0.16	0.02	0.61	0.09
SWF16-1	5.10	1.49	0.39	5.43	1.37
SWF16-2	4.50	1.47	0.40	5.34	1.38
SWF17-1	1.24	0.32	0.06	1.23	0.23
SWF18-1	2.13	0.54	0.11	2.06	0.41
SWF18-2	1.78	0.44	0.08	1.67	0.32
SWF19-1	4.89	1.13	0.35	4.28	1.14
SWF22-1	7.46	1.247	0.31	4.86	1.09

Watercourse / Structure Reference	Catchment Area (km^2)	AEP 50%		AEP 0.5%	
		FEH R-R	ReFH2	FEH R-R	ReFH2
SWF24-1	2.19	0.29	0.07	1.25	0.27
SWF26-1	24.6	4.49	1.28	16.8	4.47
SWF26-2	19.3	3.72	1.00	13.9	3.55
SWF26-D	12.6	2.34	0.60	8.96	2.18
SWF26-E	13.1	2.40	0.60	9.22	2.24
SWF34-1	3.47	1.12	0.32	4.11	1.00

Diagram 2: Comparison of the FEH statistical, FEH Rainfall-Runoff model, and ReFH2 model peak flow estimates for a sub-set of watercourses with catchment areas <25km²





2.36 Diagram 2 shows that the peak flow estimates derived using the FEH statistical method are in general lower than the corresponding peak flow estimates derived using the FEH rainfall-runoff method for the majority of the watercourses for both the 50% and 0.5% AEP events. The comparison does, however, show that the rainfall-runoff method produces similar peak flow estimates to the statistical method for two watercourses, namely, SWF03-1 and SWF12-1.

2.37 The catchment descriptors for these two catchments have in general slightly lower permeability (BFIHOST <0.61, SPRHOST >32) than the rest of the catchments. In general, almost all watercourses under the proposed Scheme, except the River Nairn, are permeable in nature, with BFIHOST values between 0.6 and 0.8.

2.38 According to the FEH Volume 4 (Restatement and application of the Flood Studies Report rainfall-runoff method), the FSR Rainfall-Runoff method performed relatively badly on catchments with high proportions of permeable soils, and also that the conventional rainfall-runoff techniques, developed for less permeable catchments, such as the FSR rainfall-runoff method, may not adequately represent permeable catchments. This is because the response from permeable catchments under extreme conditions, particularly the surface response, is often complex and uncertain, and rarely captured in available records.

2.39 In addition to the permeable nature of the catchments some catchments have FARL values <1 (contributing to flow attenuation) which is to some degree taken into consideration by the QMED equation in the statistical method, but not taken into consideration by the FEH rainfall-runoff method, if routing is not undertaken separately.

2.40 Diagram 2 further shows that the peak flow estimates from the ReFH2 method are consistently lower (on average less than half) than those from the FEH statistical method; and also much lower (on average less than one third) than those from the FEH rainfall-runoff method.

2.41 In this study the FEH statistical method is favoured compared to the other two methods (ReFH2 and FEH rainfall-runoff) to represent the catchments for the following reasons:

- The recent Environment Agency study (Faulkner, Kieldsen, Packman, Stewart, 2012) undertaken by CEH Wallingford and JBA on flood estimation in small catchments across the UK concluded that "the FEH statistical method and the Revitalised Flood Hydrograph (ReFH1) event-based method both outperform the older methods" in the estimation of floods in small catchments.
- The FEH rainfall-runoff model has been shown to perform relatively badly on permeable catchments (Ref: Chapter 7, FEH Volume 4).
- There has been a long held belief within the industry that the default version of the FEH Rainfall-Runoff model has a general tendency to overestimate flows.
- For those catchments with open water bodies the FEH Statistical method does attempt to cater for this attenuating effect whereas the rainfall-runoff methods do not.
- The FEH statistical method has been refined to include an adjustment factor to its estimate of QMED based upon the regional picture of consistent underestimation of the FEH catchment descriptors QMED equation when compared against gauged data in this part of the country. The ReFH2 model has not been similarly refined.
- Snowmelt may be an important contributory factor in the flood characteristics of this area. Inclusion of snow in either of the rainfall-runoff models is not explicit and may be a weakness to such approaches. The use of a regionally derived QMED adjustment factor has the potential in the statistical approach to go some way to alleviating this problem.

Design Peak Flow and Inflow Hydrographs – Large / Modelled Catchments

Design Peak Flow

2.42 The proposed Scheme consists of a total of five numerical hydraulic models one each for the River Nairn (and its tributary), Rough Burn, Auldearn Burn, Cairnlaw Burn and Tributary of Ardersier Burn. The extents of the five hydraulic models are shown in Diagrams 3 to 7.

2.43 Design peak flow estimates described in Section 2.34 can be applied to four of the five models, with some adjustment. However, for the River Nairn, a detailed statistical analysis involving single site analysis, pooling group analysis and enhanced single site analysis was undertaken at Station 7004 (Firhall) on the River Nairn, involving the AMAX data received from SEPA (refer to Section 2).

2.44 The five models require design peak flow (target flow) at various locations as described below.

<u>Cairnlaw Burn Model</u>

- Inflow 1A – CBurn-01 (43.5% of the peak flow estimated at SWF03-1)
- Inflow 1B – C1Burn01 (56.5% of the peak flow estimated at SWF03-1)
- Inflow 2 – Residual flow between SWF3-1 and SWF3-4 applied at CBurn09.
- Inflow 3 – C2Burn01 (peak flow estimated at SWF03-4)
- Inflow 4 – C3Burn01 (peak flow estimated at SWF06-1)

<u>Rough Burn Model</u>

- Inflow 1 – RBurn01 (55.3% of the peak flow estimate at SWF12-1)
- Inflow 2 – RBurn03 (32.3% of the peak flow estimated at SWF12-1)
- Inflow 3 – Applied as a lateral flow between RBurn03 and the downstream model extent (12.3% of the peak flow estimated at SWF12-1)

<u>Tributary of Ardersier Burn</u>

- Inflow 1 – Drain04 (97% of the peak flow estimated at SWF16-2)
- Inflow 2 – Drain09 (3% of the peak flow estimated at SWF16-2)

<u>River Nairn Model</u>

- Inflow 1 – RNairn01 (the peak flow estimated at station 7004)
- Inflow 2 – R1Nairn01 (peak flow estimated at the minor tributary confluence with the River Nairn)

<u>Auldearn Burn Model</u>

- Inflow 1 – Auldearn Burn (peak flow estimated at SWF26-E)
- Inflow 2 – Tributary 2 (peak flow estimated at downstream extent)
- Inflow 3 – Tributary 1 (peak flow estimated at downstream extent)
- Inflow 4 – Lateral inflow applied between SWF26-E and SWF26-2 (Road Crossing)

Diagram 3: The Cairnlaw Burn model extent

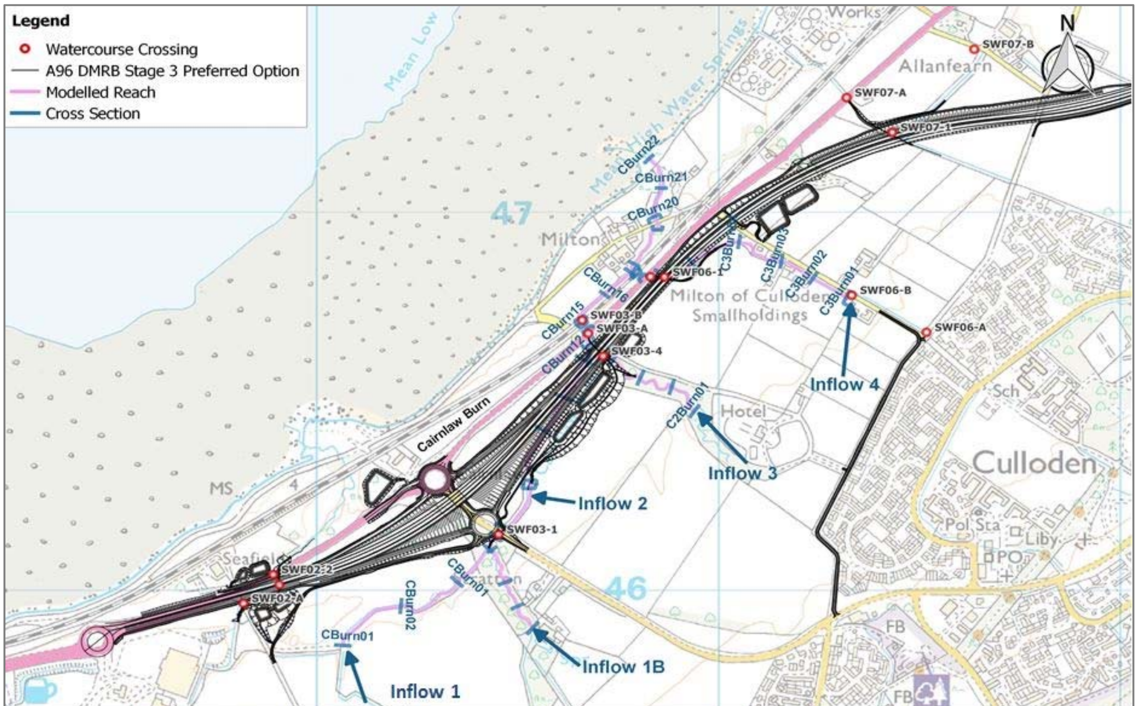


Diagram 4: The Rough Burn model extent

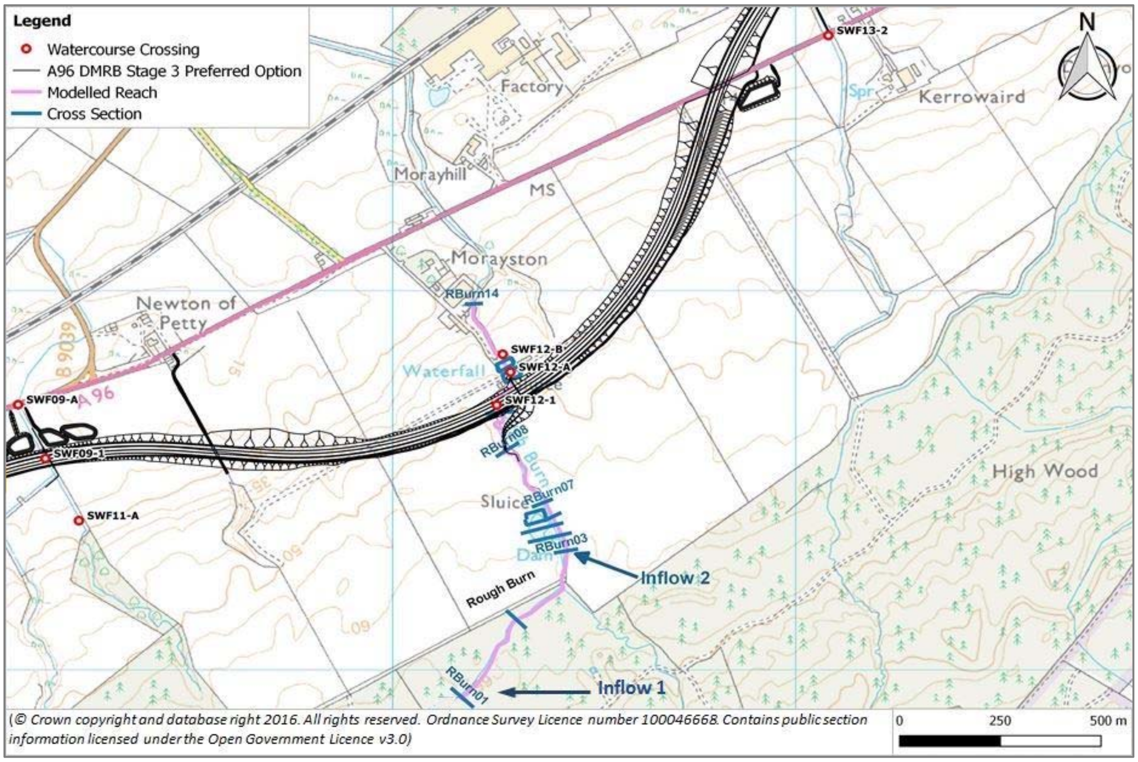


Diagram 5: Tributary of Ardersier Burn model extent

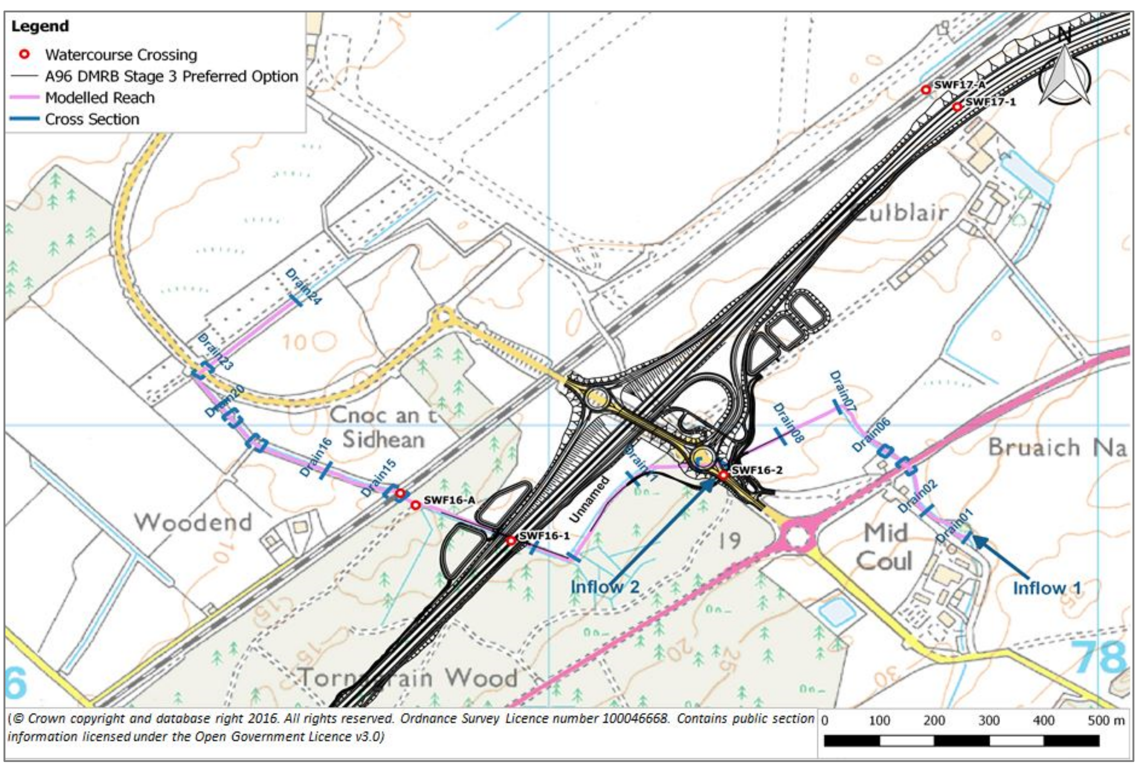


Diagram 6: The River Nairn model

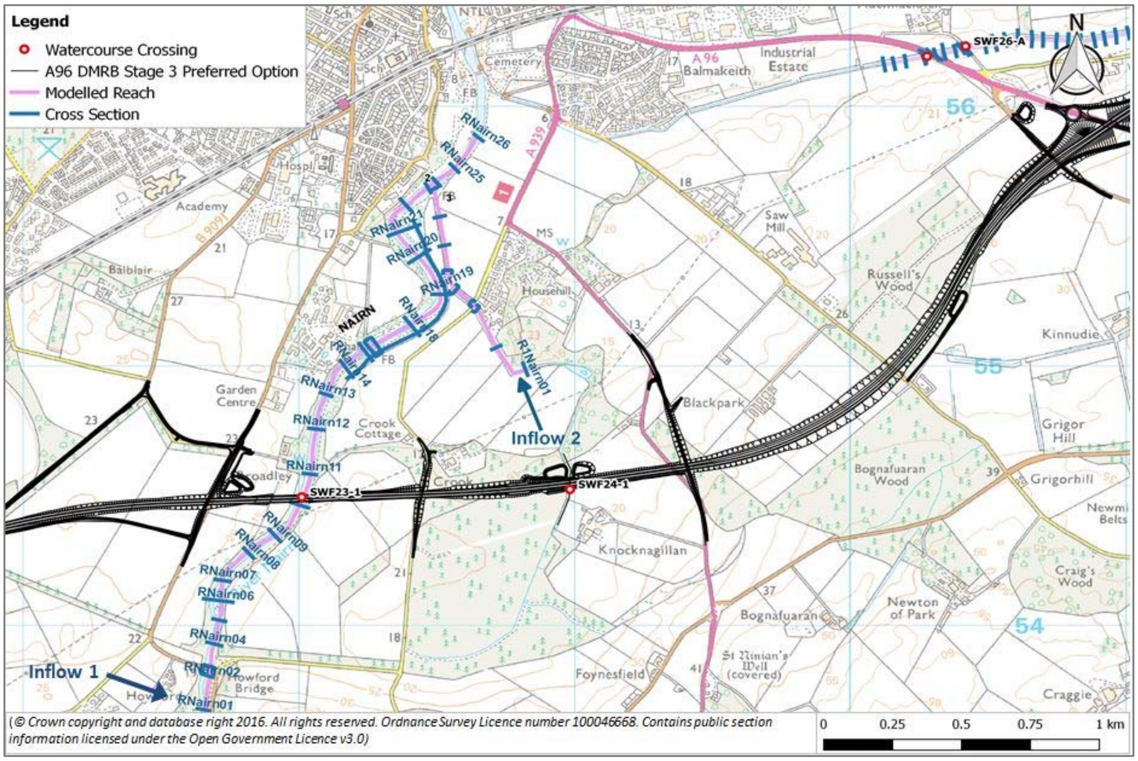
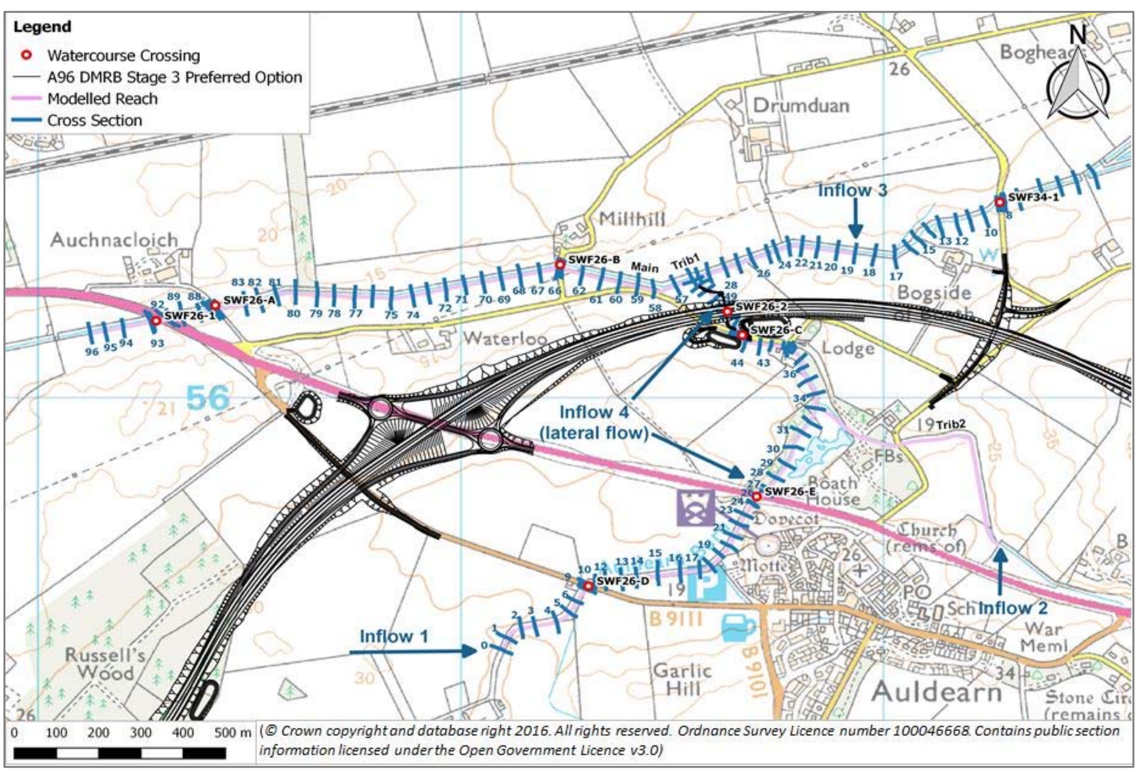


Diagram 7: The Auldearn Burn model extent



2.45 The peak flow estimates for the following AEP events 50%, 3.33%, 1%, 0.5% and 0.1% (equivalent to the 2, 30, 100, 200 and 1000-year design return periods) are presented in Table 7 for the five models. The 0.5% AEP estimate is also presented including a 20% allowance for climate change.

Table 7: Design peak flow estimates (m^3/s) for the five models at the inflow locations

Watercourse	AEP 50%	AEP 3.33%	AEP 1.0%	AEP 0.5%	AEP 0.5% + CC	AEP 0.1%
Rough Burn model						
Inflow 1 @ RBurn01	1.21	2.75	3.70	4.38	5.26	6.47
Inflow 2 @ RBurn03	0.71	1.61	2.16	2.56	3.07	3.78
Inflow 3 @ between RBurn03 and D/S model extent	0.27	0.61	0.82	0.97	1.17	1.44
Tributary of Ardersier Burn model						
Inflow 1 @ Drain04	0.93	2.10	2.83	3.35	4.02	4.94
Inflow 2 @ Drain09	0.03	0.07	0.09	0.10	0.12	0.15
Cairnlaw Burn model						
Inflow 1A @ CBurn-01	0.76	1.72	2.32	2.75	3.30	4.06
Inflow 1B @ C1Burn01	0.99	2.24	3.02	3.57	4.28	5.27
Inflow 2 @ between CBurn08 * CBurn09	0.20	0.46	0.62	0.73	0.88	1.08
Inflow 3 @ C2Burn01	0.08	0.18	0.25	0.29	0.35	0.43
Inflow 4 @ C3Burn01	1.42	3.22	4.33	5.12	6.15	7.56
Auldearn Burn model						
Inflow 1 @ model top	1.36	3.08	4.15	4.91	5.89	7.25
Inflow 2 @ tributary 2	1.06	2.40	3.23	3.82	4.58	5.64
Inflow 3 @ tributary 1	0.92	2.09	2.82	3.33	4.00	4.92
Inflow 4 @ residual flow	0.07	0.15	0.21	0.25	0.29	0.36
River Nairn model						
Inflow 1 @ RNairn01	99.2	232	315	375	450	562
Inflow 2 @ R1Nairn01	0.20	0.45	0.60	0.71	0.85	1.05

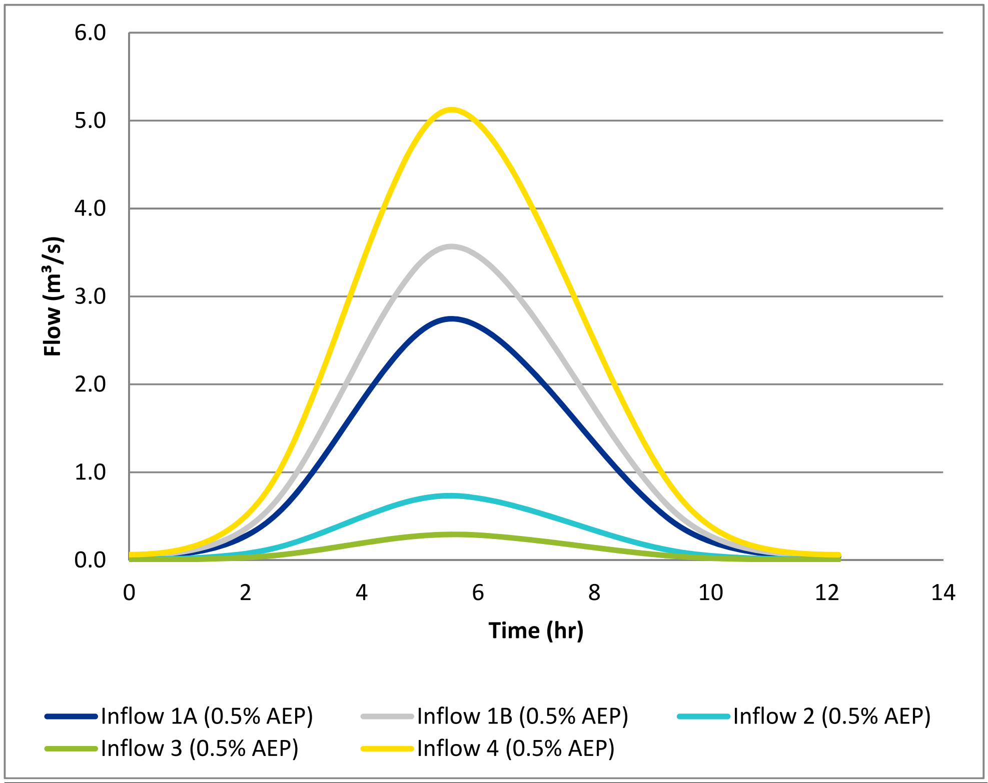
Inflow Hydrographs

2.46 The inflow hydrographs to be applied to the hydraulic models are derived for the 0.5% AEP event flood risk (the 200-year return period) along the watercourse main stem as well as for the tributary (if applicable). The derivation of design inflow hydrographs for the above five models are described in the following subsequent paragraphs.

Cairnlaw Burn model

2.47 Model inflows for Cairnlaw Burn are based on the peak flow in Table 7 and the hydrograph shapes based on the FEH rainfall-runoff model hydrograph shapes derived for the critical storm duration of 5.4 hours (a theoretical critical storm duration calculated at the downstream modelling extent and the same 5.4 hour duration was used to derive the inflow hydrograph shape for all tributaries). The design flows hydrographs thus obtained were applied to the five inflow locations as shown in Diagram 3. The inflow hydrographs for the 0.5% AEP event are presented in Diagram 8.

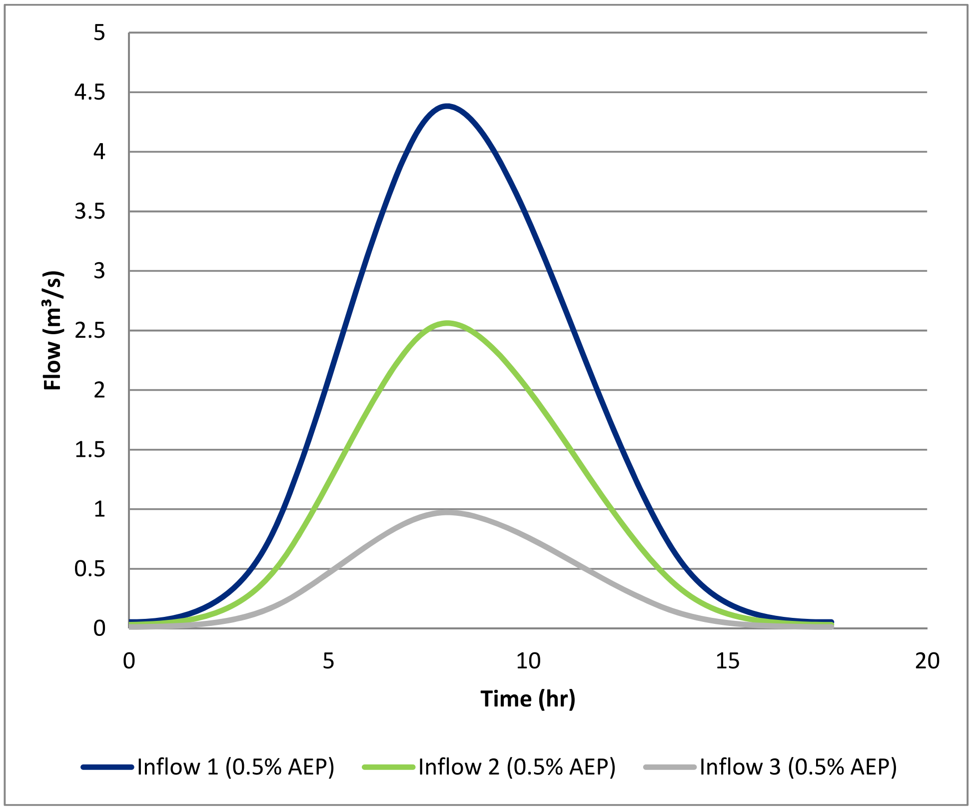
Diagram 8: The 0.5% AEP inflow hydrographs for the Cairnlaw Burn model



Rough Burn model

2.48 Model inflows for the Rough Burn are based on the peak flow in Table 7 and the hydrograph shape is based on the FEH rainfall-runoff model hydrograph shape derived for the critical storm duration of 7.4-hours (theoretical critical storm duration calculated at the target location of the downstream model extent). The inflow hydrographs thus obtained are applied to the three inflow locations shown in Diagram 4. The inflow hydrographs for the 0.5% AEP event are presented in Diagram 9.

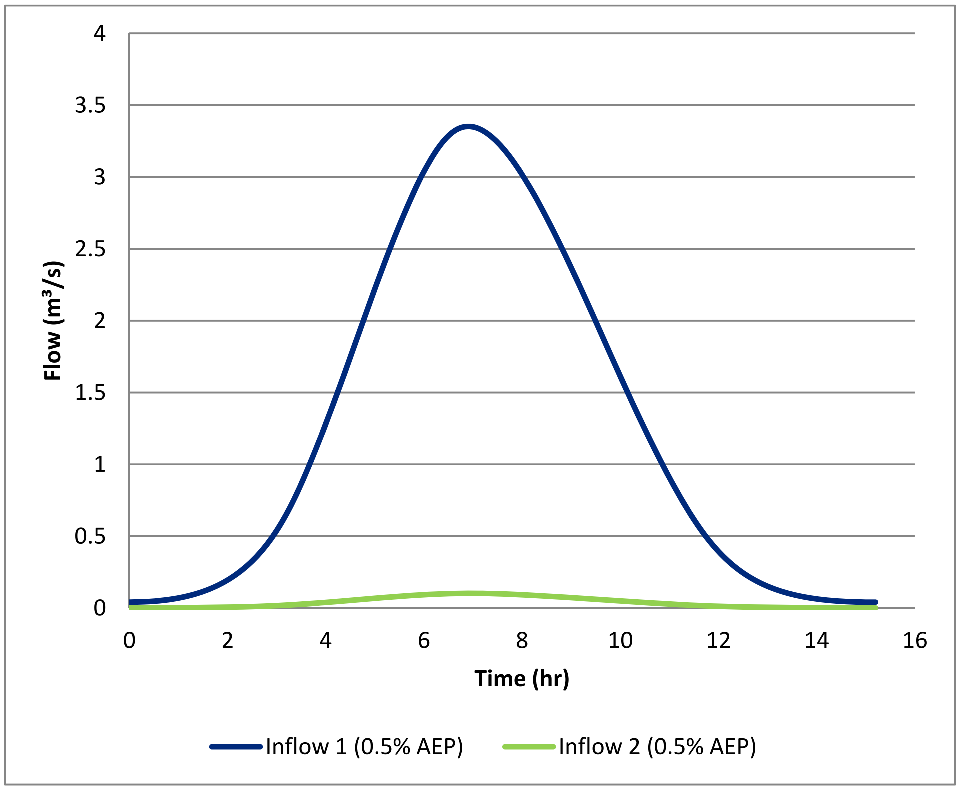
Diagram 9: The 0.5% AEP inflow hydrographs for the Rough Burn model



Tributary of Ardersier Burn model

2.49 Model inflows for Tributary of Ardersier Burn are based on the peak flow in Table 7 and the hydrograph shape based on the FEH rainfall-runoff model hydrograph shape derived for the critical storm duration of 6.6-hours (theoretical critical storm duration calculated at the downstream modelling extent). The inflow hydrographs thus obtained are applied to the two inflow locations shown in Diagram 5. The inflow hydrographs for the 0.5% AEP event are presented in Diagram 10.

Diagram 10: The 0.5% AEP inflow hydrographs for Tributary of Ardersier Burn model



River Nairn model

2.50 Model inflows for the River Nairn model are based on the peak flow estimated from enhanced single site analysis at Firhall station (7004) and from FEH statistical method at the Nairn confluence for the minor tributary, as shown in Table 7. The hydrograph shape for the River Nairn inflow is based on a historic flood event hydrograph shape for the July 1997 flood event at the Firhall gauging station. As the theoretical critical storm duration calculated at the River Nairn gauging station at Firhall is 18.25 hour, the tributary hydrograph shape is also derived using the FEH rainfall-runoff model using the theoretical critical storm duration of the River Nairn (i.e., 18.25 hour).

2.51 The inflow hydrograph of the 0.5% AEP event for the River Nairn and its minor modelled tributary are presented in Diagrams 11 and 12.

Diagram 11: The 0.5% AEP inflow hydrographs for the River Nairn

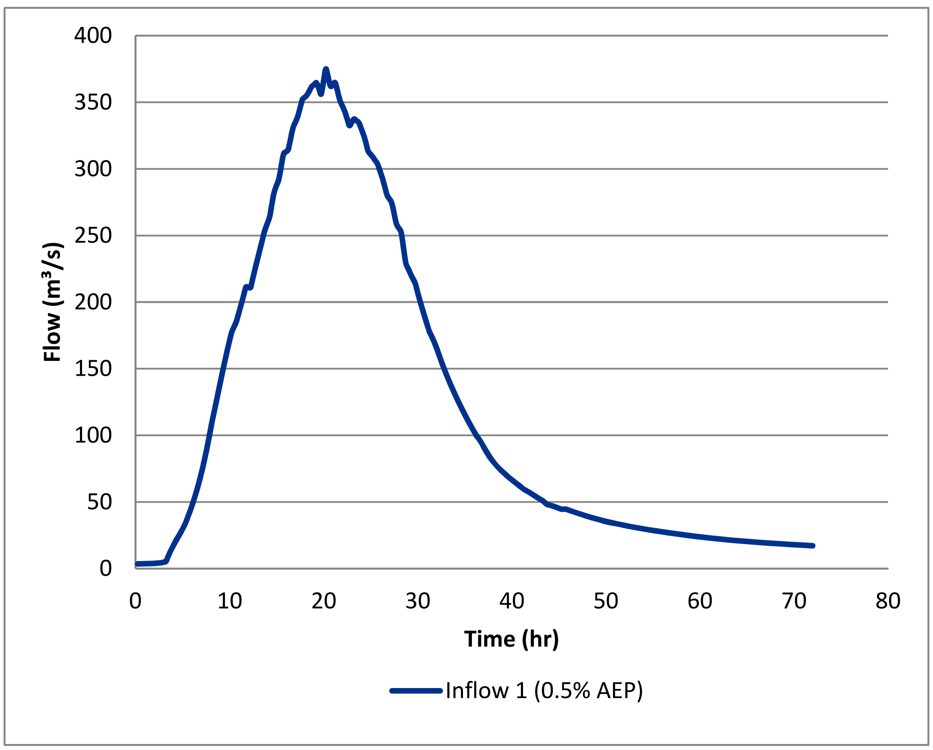
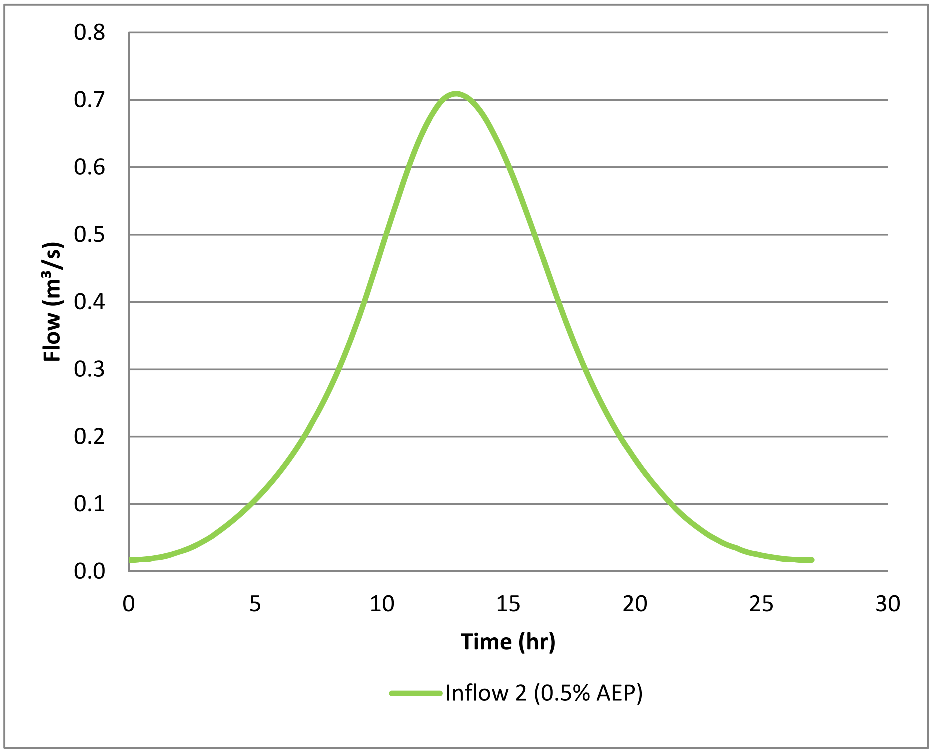


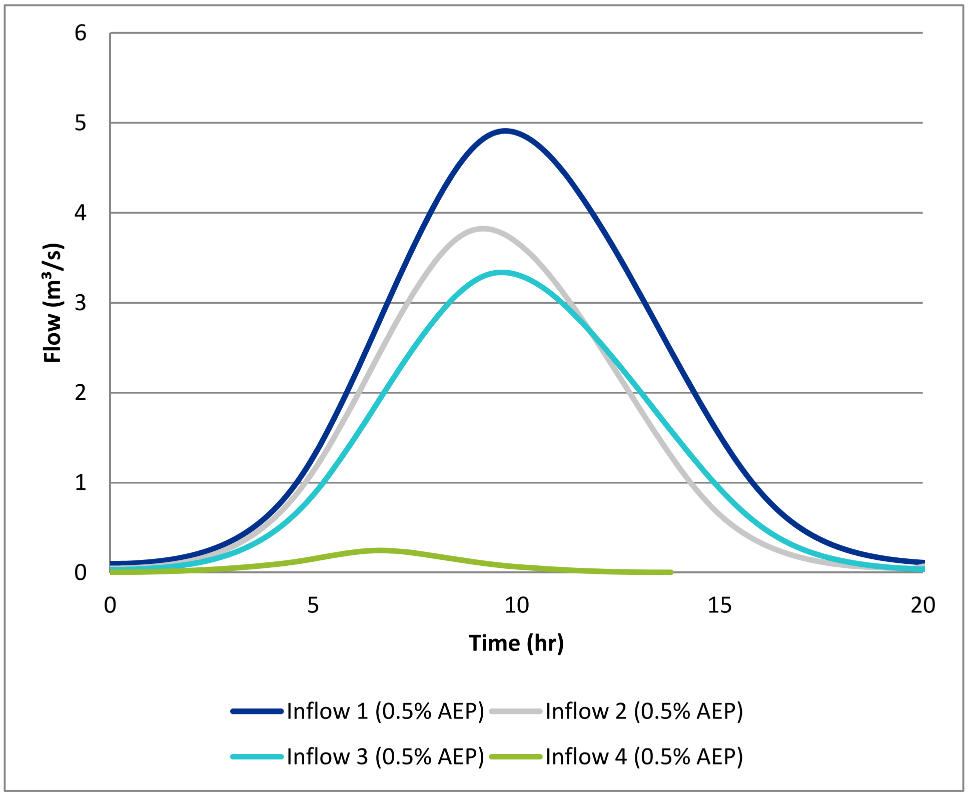
Diagram 12: The 0.5% AEP inflow hydrograph for minor tributary of the River Nairn



Auldearn Burn model

2.52 Model inflows for the Auldearn Burn are based on the peak flow in Table 7 and the hydrograph shapes based on the FEH rainfall-runoff model hydrograph shapes derived for the critical storm duration of 9.8 hours (theoretical critical storm duration calculated at the downstream modelling extent). The design flow hydrographs thus obtained were applied to the four inflow locations as shown in Diagram 7. The inflow hydrographs for the 0.5% AEP event are presented in Diagram 13.

Diagram 13: The 0.5% AEP inflow hydrographs for the Auldearn Burn model.



Hydrology for Hydraulic Model Calibration

2.53 Calibration of a hydraulic model requires historic flood hydrographs to inform the model inflow and records of historic flood levels in the vicinity of the model to compare against the model predicted water levels. There is one hydrometric station (Nairn at Firhall – gauge 7004) within the River Nairn model extent which is located in the vicinity of the road crossing. Flow data is therefore available for the calibration of this model to historic flood events if there are also corresponding flood level information from the events along the modelled reach. However, the other five models have no hydrometric stations in the model extents and hence cannot be calibrated/verified in this way.

Conclusions

2.54 This report presents the assessment methods used to derive design peak flows, inflow flood hydrographs and low flow estimates for watercourses within the proposed Scheme. Assessment methods have varied for catchments within this project based on a variety of factors such as catchment size, flood risk and the availability of gauged data. The River Nairn and the small ungauged watercourses which have been identified for detailed numerical hydraulic modelling, have undergone a more detailed assessment than those small ungauged watercourses not requiring detailed hydraulic modelling.

2.55 The following limitations should be noted when reviewing the findings from this report:

- Flow estimation is subject to some inevitable uncertainty. This is especially true of the flood estimates of the small catchments where appreciable differences among the three methods exist for those catchments with high permeability.
- The design flow in the River Nairn has been estimated from the statistical analysis of AMAX data provided by the SEPA using the FEH enhanced single site analysis. This is considered reasonably robust.
- The peak flood estimates (50% and 0.5% AEP) for the small watercourses were undertaken using three methods: FEH statistical, FEH rainfall-runoff method, and the ReFH2 method - enabling a comparison of the estimates to be made. Although none of the methods is ideal the strengths and weaknesses of the three approaches in this hydro-climatic region are presented and the statistical approach is favoured.
- A 20% climate change uplift factor has been applied to the design peak flow estimates based on current standard practice. It should be noted that climate change is an area of current research and therefore this uplift factor may be subject to change in the future based on the findings of evolving research.
- Low flow estimation on the River Nairn is based upon local gauged data provided by SEPA at the Firhall station (7004). For all other small ungauged watercourses, the Low Flow Enterprise (LFE) estimates provided by CEH Wallingford are assumed to be fit for purpose and have been used to derive low flow estimates.

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A.1 Abbreviations

ALTBAR – Mean catchment altitude (m above sea level)

AREA – catchment drainage area ($km^{2)}$

AEP – Annual Exceedance Probability

BFIHOST – Base flow index derived using the hydrology of soil types classification.

DPLBAR – Index describing catchment size and drainage path configuration (km)

DPSBAR – Index of catchment steepness (m / km)

FARL – Index of flood attenuation due to reservoirs and lakes

FEH – Flood Estimation Handbook

LDP – Longest drainage path (km)

LFE – Low Flows Enterprise

NRFA – National Rivers Flow Archive

PVA – Potential Vulnerable Area (in reference to flood risk)

SAAR – 1961 – 90 standard-period average annual rainfall (mm)

SFRA – Strategic Flood Risk Assessment

SPRHOST – Standard percentage runoff derived using the hydrology of soil types classification (%)

Q_{95} – The percentage of flow exceeded 95% of the time.

Q_{50} – The percentage of flow exceeded 50% of the time.

Qmean – Mean Flow

QMED – Median Annual Maximum Flood (a flood with a return period of 1:2 years)

URBEXT – FEH index of fractional urban extent

A.2 Amendments to Catchment Descriptors

2.56 In order to derive design peak flow estimates at each of the ungauged watercourses crossing the A96 carriageway, FEH catchment descriptors are required.

2.57 For watercourses draining an area >0.5km², catchment descriptors are extracted directly from the FEH CD-ROM and provide a starting point for the analysis. For each individual catchment lying within the Inverness to Nairn Section (including the Nairn Bypass) of the study area, the following catchment descriptors have been checked and where necessary, have been manually adjusted following guidelines presented in the FEH Vol.5:

- Catchment Area
- DPLBAR
- URBEXT
- FARL

2.58 **Catchment Area** – the catchment boundary for each watercourse (if available) was extracted from the FEH CD-ROM and checked for accuracy within a GIS application by:

- Plotting and comparing the location of the FEH derived catchment outflow against the supplied structure grid reference; and
- Comparison of the FEH derived catchment area against the surface water drainage network as interpreted from a 1:25,000 scale OS map and as observed on site.

2.59 For watercourses too small (i.e. <0.5km²) to be picked up by the FEH CD-ROM, catchment areas have been delineated manually using 1:25,000 scale OS mapping together with 2m LiDAR derived contour data and the boundary confirmed by a site walk over, if necessary.

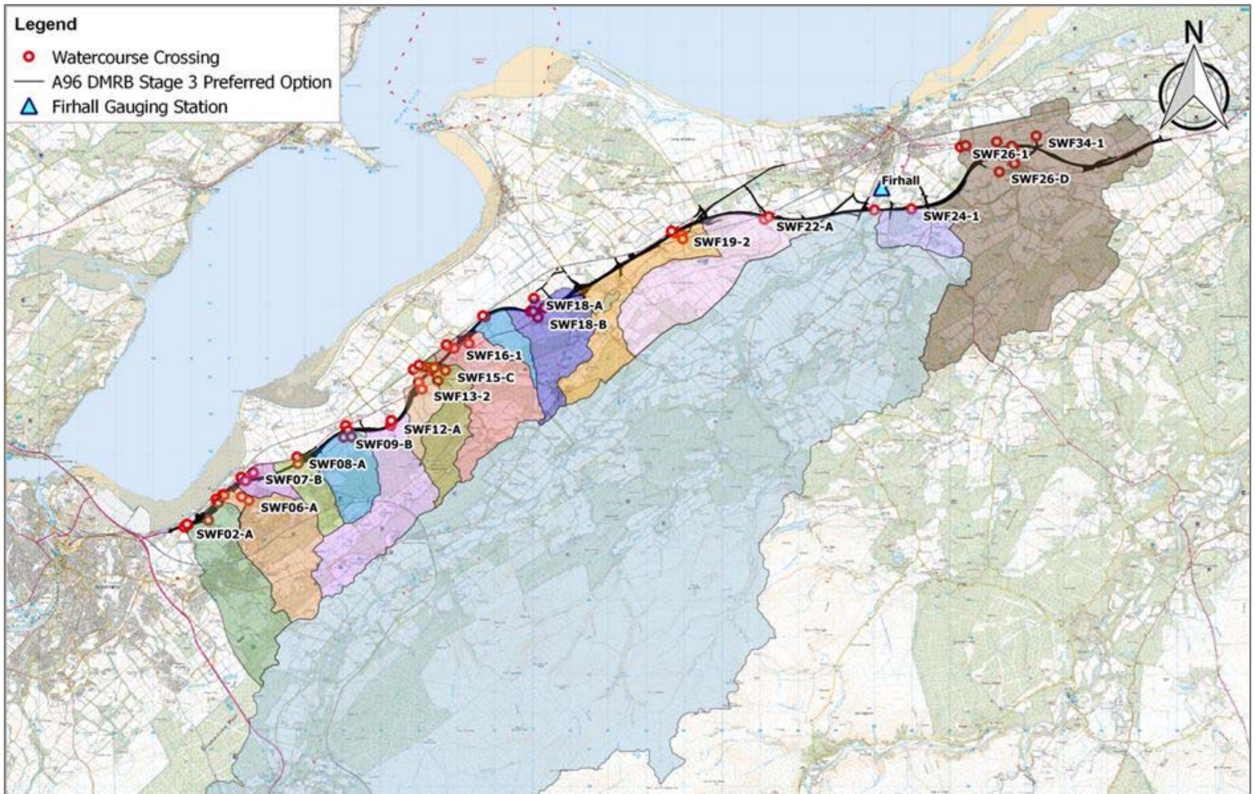
2.60 **DPLBAR** – where catchment boundaries required modification, the mean drainage path length was re-calculated using equation 7.1 presented in Volume 5 of the FEH (Bayliss, A.C. 1999).

2.61 **URBEXT** – The majority of catchments within the study area are rural in nature and as such have an URBEXT value of zero or very close to zero. Where a catchment is located within a particularly urban area and the catchment is too small to be included within the FEH software; catchment URBEXT was calculated manually from a 1:50,000 scale OS map and equation 6.2 presented in Volume 5 of the FEH and equation 5.4 presented in the Joint Defra/EA Technical Report (Bayliss, A.C., Black, K.B., Fava-Verde, A., Kjeldsen, T.R. 2006).

2.62 **FARL** – For the larger watercourses, catchment FARL values are derived directly from the FEH CD-ROM. However, for those catchments not included within the FEH CD-ROM (i.e. those having a catchment area <0.5km²), FARL is calculated manually following the methodology described within section 4.3 of the FEH Vol. 5.

A.3 Catchment Boundary Map

Diagram A1: Catchment Boundary Map



Annex A13.2.H Minor Watercourse Assessment

1 Introduction

Background Information

1.1 The A96 Dualling Inverness to Nairn (including Nairn Bypass) Scheme comprises the provision of approximately 31km of new dual carriageway, achieved through offline construction. The existing A96 single carriageway would be de-trunked and reclassified as a local road to maintain local access. Due to the size of the proposed Scheme, there are a number of flood risks, which may place the road and its users at significant risk of flooding. The proposed Scheme also has the potential to impact the level of flood risk elsewhere.

1.2 A Flood Risk Assessment (FRA) is required to demonstrate that the design meets the requirements of national and local planning policy and is considered appropriate from a flood risk perspective. As well as fluvial and coastal flooding, the FRA has also considered flood risk from other sources, including surface water, groundwater, and artificial drainage systems and infrastructure failure.

1.3 As part of the FRA, a baseline flood risk assessment has been carried out on existing culverts and watercourses that may be impacted by the Scheme.

1.4 There are a total of 59 watercourse crossings in the vicinity of the proposed Scheme. These include 22 new watercourse crossings (including a new bridge over the River Nairn) and 37 existing watercourse crossings (including one to be dismantled) within the vicinity of the proposed Scheme.

1.5 Detailed hydraulic assessment of these watercourse crossings has been undertaken by developing five numerical hydraulic models to evaluate the 24 watercourses crossings which were identified as being of the highest potential flood risk to the proposed Scheme. The hydraulic analysis of the remaining 34 minor watercourse crossings (excluding the one to be dismantled) has been undertaken using culvert assessment methodology from CIRIA report C689 (CIRIA 2010) and where necessary, through developing routing models in the Flood Modeller Pro software package. Table 1.1 shows the list of all 59 watercourses crossings and the type of assessment undertaken for each.

1.6 The following sections present the methodology of hydraulic analysis of the 34 minor watercourses and discuss the results of these assessments.

Table 1.1: Watercourse crossings requiring assessment

Structure Ref	New or Existing	Surface Water Feature	Easting	Northing	Calc Ref	Comments
C02	New	SWF02	269906	846015	SWF02-1	Mainline
C03	New	SWF03	270452	846148	SWF03-1	Numerical model
C04	New	SWF03	270712	846620	SWF03-4	Numerical model
C05	New	SWF06	270865	846829	SWF06-1	Numerical model
C06	New	SWF07	271432	847212	SWF07-1	Mainline
C07	New	SWF08	272815	847672	SWF08-1	Mainline
C08	New	SWF09	274138	848558	SWF09-1	Mainline
C09	New	SWF12	275258	848699	SWF12-1	Numerical model
C10	New	SWF13	275994	849863	SWF13-1	Mainline
C11	New	SWF14	276319	850173	SWF14-1	Mainline
C12	New	SWF15	276408	850253	SWF15-1	Mainline
C13	New	SWF16	276931	850777	SWF16-1	Numerical model
C14	New	SWF16	277318	850904	SWF16-2	Numerical model

Structure Ref	New or Existing	Surface Water Feature	Easting	Northing	Calc Ref	Comments
C22	New	SWF17	277744	851617	SWF17-1	Mainline
C15	New	SWF18	278936	851771	SWF18-1	Mainline
C16	New	SWF18	279016	851768	SWF18-2	Mainline
C17	New	SWF19	282743	853880	SWF19-1	Mainline
C23	New	SWF19	282931	853830	SWF19-2	New track culvert U/S of the Scheme
C18	New	SWF22	285224	854317	SWF22-1	Mainline
PS14	New	SWF23	288010	854495	SWF23-1	Numerical model
C19	New	SWF24	288983	854525	SWF24-1	Mainline
C21	New	SWF26	291630	856217	SWF26-2	Numerical model
	Existing	SWF26	269891	846042	SWF02-2	Existing A96 culvert D/S of the Scheme
	Existing	SWF26	270675	846680	SWF03-A	Numerical model
	Existing	SWF26	270660	846715	SWF03-B	Numerical model
	Existing	SWF26	271517	846683	SWF06-A	Numerical model
	Existing	SWF26	271331	846781	SWF06-B	Numerical model
	Existing	SWF26	270830	846830	SWF06-C	Numerical model
	Existing	SWF26	271318	847304	SWF07-A	Existing A96 culvert D/S of the Scheme
	Existing	SWF26	271636	847432	SWF07-B	Minor road culvert D/S of the Scheme
	Existing	SWF26	272787	847851	SWF08-A	Existing A96 culvert D/S of the Scheme
	Existing	SWF26	274070	848700	SWF09-A	Existing A96 culvert D/S of the Scheme
	Existing	SWF26	274018	848384	SWF09-B	Track culvert U/S of the Scheme
	Existing	SWF26	274221	848394	SWF11-A	Track culvert U/S of the Scheme
	Existing	SWF26	275292	848786	SWF12-A	Numerical model
	Existing	SWF26	275273	848833	SWF12-B	Numerical model
	Existing	SWF26	276081	849674	SWF13-2	Existing A96 culvert U/S of the Scheme
	Existing	SWF26	275859	850210	SWF13-A	Railway culvert D/S of the Scheme
	Existing	SWF26	276500	849900	SWF14-A	Existing A96 culvert U/S of the Scheme
	Existing	SWF26	276100	850267	SWF15-A	Track culvert D/S of the Scheme
	Existing	SWF26	276009	850321	SWF15-B	Railway culvert D/S of the Scheme
	Existing	SWF26	276700	850180	SWF15-C	Existing A96 culvert U/S of the Scheme
	Existing	SWF26	276757	850846	SWF16-A	Numerical model
	Existing	SWF26	276729	850869	SWF16-B	Numerical model
	Existing	SWF26	277687	851650	SWF17-A	Railway culvert D/S of the Scheme
	Existing	SWF26	279034	852119	SWF18-A	Local road culvert D/S of the Scheme
	Existing	SWF26	279139	851609	SWF18-B	Existing A96 culvert U/S of the Scheme
	Existing	SWF26	279312	851872	SWF18-C	Local road culvert D/S of the Scheme
	Existing	SWF26	282661	853928	SWF19-A	Existing A96 culvert D/S of the Scheme
	Existing	SWF26	282956	853719	SWF19-B	Railway culvert U/S of the

Structure Ref	New or Existing	Surface Water Feature	Easting	Northing	Calc Ref	Comments
						Scheme
	Existing	SWF26	285109	854243	SWF22-A	Local road culvert U/S of the Scheme
	Existing	SWF26	290418	856233	SWF26-A	Numerical model
	Existing	SWF26	291234	856335	SWF26-B	Numerical model
	Existing	SWF26	291665	856158	SWF26-C	Numerical model
	Existing	SWF26	291301	855527	SWF26-D	Numerical model
	New	SWF26	291699	855752	SWF26-E	Numerical model
	New	SWF26	290278	856194	SWF26-1	Numerical model
	Existing	SWF26	292275	856492	SWF34-1	Numerical model

Data

1.7 The following data has been used in this assessment:

- Design peak flow: For the 0.5% Annual Exceedance Probability (0.5% AEP (200 year)) design flood event plus 20% allowance for climate change was developed (Annex A13.2.G : Hydrology Report). Full hydrographs required for the culverts in which routing was required were obtained using the FEH rainfall-runoff model based hydrograph shape and scaled to peak flow derived from the statistical method.
- Culvert geometry, channel cross-sections and photographs (both looking upstream and downstream) of all minor watercourse crossings were obtained from topographic survey commissioned for this project.
- Digital Terrain Model (DTM): Derived on a 5m grid from photogrammetric data along the A96 corridor.
- Site visits: Culvert dimensions and other local information was collected during a site visit walkover undertaken between 21st and 25th September 2015. The survey team consisted of a hydrologist and hydraulic engineer.

2 Methodology

Design hydrology

2.1 The design flood event is the 0.5% AEP (200-year) flood event plus an allowance for climate change. This is represented by a 20% increase to the peak flow. This flood event is referred to as the 'design flood event' within this report, unless otherwise stated.

2.2 Annex A13.2.G (Hydrology Report) provides information on the methods and approaches used to derive the design peak flow estimates. For the smaller ungauged catchments the design peak flow estimates were based on the Flood Estimation Handbook (FEH) statistical method. When needed (i.e. additional routing assessment) the hydrograph shape was derived using the FEH rainfall runoff methodology, with peak flow scaled to the statistically derived flow. The design peak flows for a range of AEPs are provided in Annex A13.2.G (Hydrology Report).

Hydraulic Assessment

2.3 A number of watercourses have the potential to be impacted by the proposed road scheme. These watercourses range in size from small drainage ditches to larger watercourses such as the River Nairn. Hydraulic assessment of the minor watercourses includes the following activities.

2.4 The culvert capacity and stage/discharge relationship for all minor watercourses (not identified for detailed numerical modelling) were derived using the culvert analysis methodology presented within CIRIA C689.

2.5 The methodology calculates head water level upstream of the culvert for a range of discharges up to the design flood event and involved the following steps:

- Computation of average channel gradient and the culvert inlet/outlet levels using the topographic survey data
- Computation of average channel geometry downstream of the culvert, e.g., bottom width (b), top width (B), side slope using at least three channel cross sections downstream of the culvert using the topographic survey sections.
- Manning roughness 'n' for channel and culvert sections is based on the photographs taken by the surveyor from the site, information gathered during site visits and using CIRIA guidelines
- Culvert inlet/outlet and minor loss coefficients from CIRIA C689 guidelines

2.6 For those culverts where overbank flows occurred upstream of the culvert, flow routing was undertaken upstream of culvert using Flood Modeller Pro software package. The routing exercise included the following steps:

- Upstream surveyed cross-sections were used to derive a Triangulated Irregular Network (TIN) model of the channel. The TIN model was then used to derive an area/elevation relationship of the channel which was used as input into the 'reservoir unit' within Flood Modeller representing the channel.
- A small routing model was constructed within Flood Modeller to represent both the minor watercourse and floodplain. [Note: LiDAR was used to create an area.elevation relationship for input into the left and right bank floodplains].
- Surveyed bank levels were used to form lateral 'spill units' to link the channel and floodplain 'reservoir units'.
- The FEH rainfall-runoff boundary (scaled to statistical peak flow) was added to the routing model as an inflow whilst the stage/discharge relationship derived using C689 culvert methodology was connected to the channel 'reservoir unit' to represent the outflow from the system.
- A simulation was undertaken for the design flood event.
- Model inflow/outflow hydrographs, attenuation volume and live floodplain extent for the design flood event were extracted from the routing model.
- The design footprint of the proposed development was plotted on the live floodplain extent to calculate the compensatory storage volume requirement.

3 Results of Hydraulic Assessment

Culvert capacity assessment using CIRIA C689 methodology

3.1 Hydraulic analysis of all 34 minor watercourse crossings (including 14 proposed and 20 existing), not identified for detailed numerical modelling, was undertaken using the methodology suggested in CIRIA C689 Culvert Design and Operation Guide (CIRIA 2010). The output of this analysis is a stage/discharge relationship for each culvert up to the design flood event peak flow. The results of this study informed whether the design peak flow passing through the culvert would be free flowing or surcharged; and whether the flow regime upstream of the culvert will remain in-bank or out-of-bank. The results were also used to size the proposed new culverts.

3.2 The results of the CIRIA C689 method based assessment suggest that the peak flow associated with the design flood event will remain in bank for 18 of the 34 culverts, thus requiring further assessment as shown in Table 3.1.

Table 3.1: Watercourse crossings requiring assessment

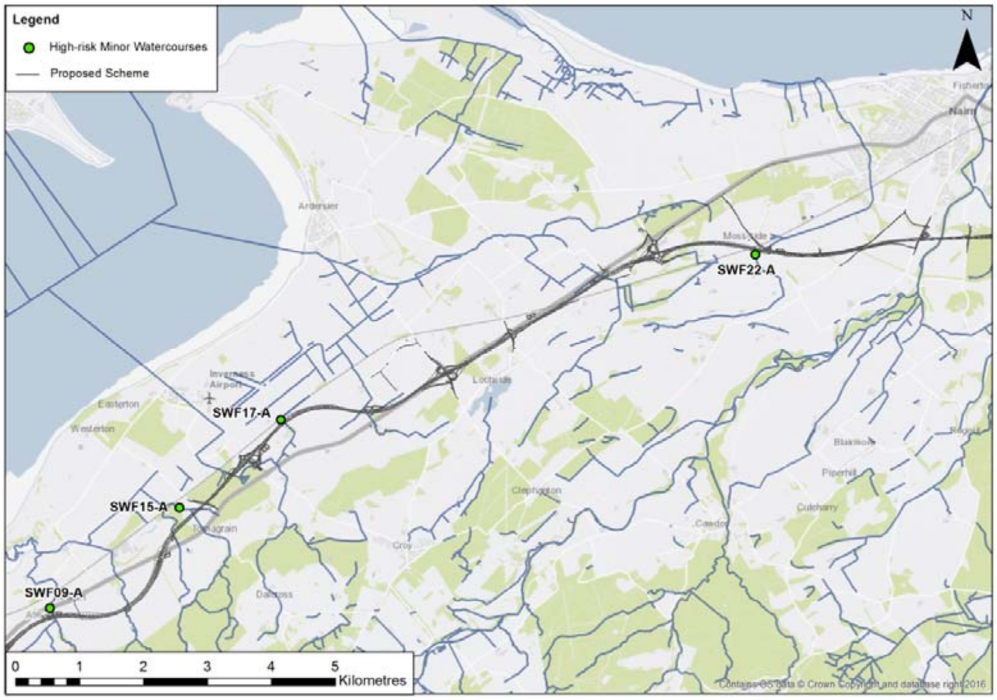
Structure No.	New or Existing	Water Feature	Inbank or out of bank @ 0.5% AEP (200-year)	Condition @ 0.5% AEP (200-year)	Routing required?
Watercourse crossings included in the proposed Scheme					
C02	New	SWF02-1	In bank	Free Flowing	No
C06	New	SWF07-1	In bank	Free Flowing	No
C07	New	SWF08-1	In bank	Free Flowing	No
C08	New	SWF09-1	Out of Bank	Free Flowing	Yes
C10	New	SWF13-1	In bank	Free Flowing	No
C11	New	SWF14-1	Out of Bank	Free Flowing	Yes
C12	New	SWF15-1	In bank	Free Flowing	No
C22	New	SWF17-1	Out of Bank	Free Flowing	Yes
C15	New	SWF18-1	In bank	Free Flowing	No
C16	New	SWF18-2	In bank	Free Flowing	No
C17	New	SWF19-1	In bank	Free Flowing	No
C23	New	SWF19-2	In bank	Free Flowing	No
C18	New	SWF22-1	In bank	Free Flowing	No
C19	New	SWF24-1	In bank	Free Flowing	No
Watercourse crossings in proximity to the proposed Scheme					
	Existing	SWF02-2	In bank	Free Flowing	No
	Existing	SWF07-A	Out of Bank	Surcharged	Yes
	Existing	SWF07-B	Out of Bank	Free Flowing	Yes
	Existing	SWF08-A	Out of Bank	Surcharged	Yes
	Existing	SWF09-A	Out of Bank	Surcharged	Yes
	Existing	SWF09-B	Out of Bank	Surcharged	Yes
	Existing	SWF11-A	Out of Bank	Surcharged	Yes
	Existing	SWF13-2	Out of Bank	Surcharged	Yes
	Existing	SWF13-A	In bank	Free Flowing	No
	Existing	SWF14-A	In bank	Surcharged	No
	Existing	SWF15-A	Out of Bank	Surcharged	Yes
	Existing	SWF15-B	In bank	Free Flowing	No
	Existing	SWF15-C	In bank	Free Flowing	No
	Existing	SWF17-A	Out of Bank	Surcharged	Yes
	Existing	SWF18-A	Out of Bank	Surcharged	Yes
	Existing	SWF18-B	In bank	Free Flowing	No
	Existing	SWF18-C	In bank	Free Flowing	No
	Existing	SWF19-A	Out of Bank	Surcharged	Yes
	Existing	SWF19-B	Out of Bank	Surcharged	Yes
	Existing	SWF22-A	Out of Bank	Surcharged	Yes

3.3 The initial assessment indicated that there may be a residual impact of flood risk at four watercourse crossings and these have been assessed in further detail. Those watercourse crossings are:

- SWF09-A: Tributary of Rough Burn;
- SWF15-A: Tributary of ‘Unnamed Burn - Castle Stuart to source (Tornagrain)’ (2);
- SWF17-A: Drains at Culblair; and
- SWF22-A: Alton Burn.

3.4 Diagram 3.1 illustrates the locations of these minor watercourses.

Diagram 3.1: Location of watercourse crossings requiring further assessment)



3.5 The following sections present the assessment for each watercourse in turn.

4 Results of Further Assessment

SWF09-A: Tributary of Rough Burn

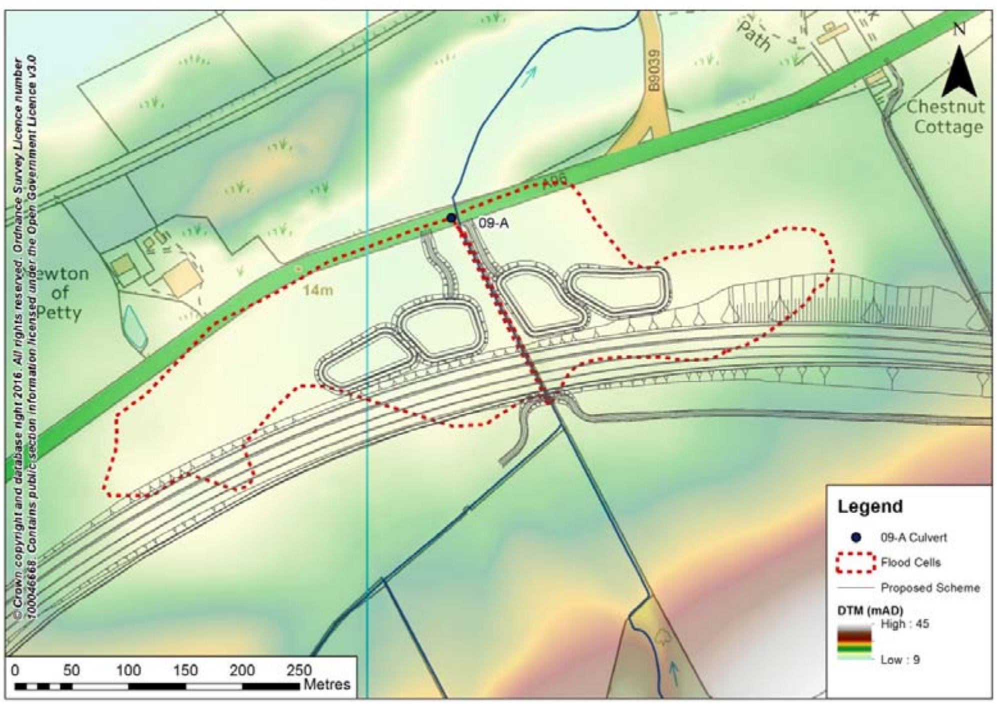
4.1 At Newton of Petty the proposed dual carriageway alignment traverses an area that is considered to be at risk of flooding following initial culvert analysis (using the CIRIA C689 methodology) since a culvert under the existing A96 (SWF09-A) is considered to be under capacity.

4.2 Further hydraulic assessment has been undertaken, to investigate the impact on flood risk due to constriction of the road embankment and Sustainable Drainage Systems (SUDS) basins on the flood plain. This has involved derivation of a simple routing model, based on an inflow hydrograph for the design flood event), representation of the ground topography and hydraulic control formed by the existing channel and culvert.

Ground Topography

4.3 The ground topography is based on a 5m grid photogrammetry survey which has then been sub-divided into flood cells representing 'basins' within the topography which are capable of containing floodwater. In this area, the flood cells are represented by the area immediately beyond the left and right hand bank, extending 380m on the left bank and 300m on the right bank (Diagram 4.1).

Diagram 4.1: Topography and Hydraulic Controls



4.4 The flood cells have been defined by the ground topography and the connection (spill) between adjoining cells is represented by the ground topography along the flood cell boundary.

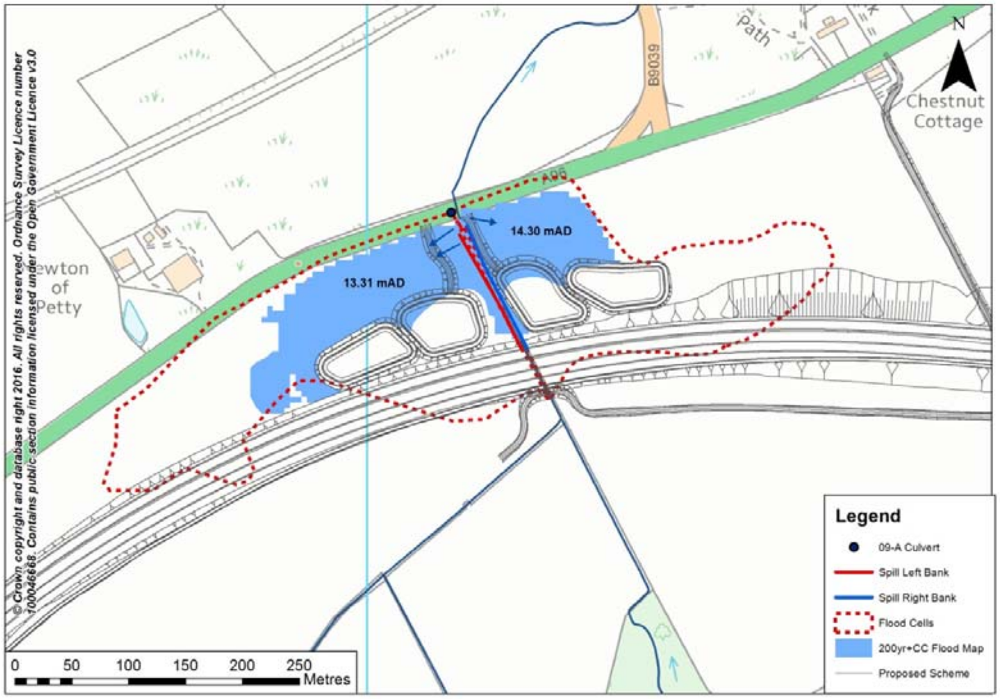
Hydraulic Controls

4.5 A site visit was undertaken to identify and map existing hydraulic controls local to the area of interest, as shown in Diagram 4.2.

Baseline Flood Risk and Flood Mechanisms

4.6 Diagram 4.2 indicates the area at risk of flooding associated with the design flood event. The peak flow associated with this event is 2.74m^3/s.

Diagram 4.2 : Baseline flood map for the design event (proposed Scheme design footprint and associated works shown for reference)



Note: PND_LB and PND_RB denotes the flood cells beyond the left and right banks, respectively.

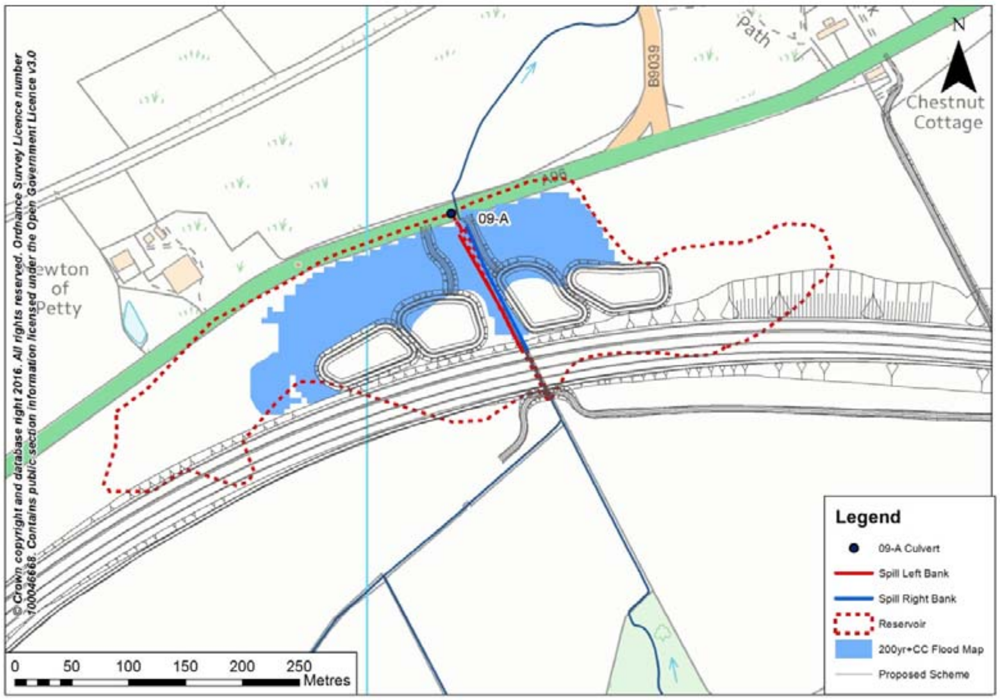
4.7 The forward passage of water is restricted by an existing downstream 1.35m diameter culvert, which results in floodwater spilling out of bank to both the left and right bank floodplains. The predicted peak water level within the channel and right bank flood plain is 14.301mAOD, whilst the left bank peak water level is predicted to be 13.310mAOD.

4.8 The forward flow of water is impounded by the existing A96. The minimum road level adjacent the left bank floodplain is 13.845mAOD, which is 535mm above the peak water level of 13.310mAOD. Whilst, the minimum road level adjacent the across the full length of inundation on the right bank floodplain is 14.394mAOD, which is 93mm above the peak water level of 14.301mAOD.

Scheme Flood Risk and Flood Mechanism

4.9 Diagram 4.3 shows the impact the proposed Scheme on flood risk associated with the design flood event.

Diagram 4.3 Scheme flood map for the Design flood event.



4.10 The proposed Scheme does not directly affect the hydraulic controls and flood mechanisms associated with the baseline case; however, the proposed Scheme design lies within an area predicted to flood thereby resulting in the displacement of floodwater. A new culvert (with dimensions 2.7m by 2.7m) is proposed to carry the dual carriageway alignment and to pass the design flood flow downstream. As with the baseline case, this will result in floodwater spilling from the left and right hand bank due to the restriction from the existing A96 culvert located immediately downstream.

4.11 As a result of the displaced floodwater, the peak water level immediately beyond the right hand bank is predicted to be 14.338mAD i.e. an increase of 0.037m when compared to the baseline case. The peak flood level beyond the left bank is 13.673mAOD i.e. an increase of 0.363m when compared to the baseline case.

4.12 In addition, the net pass forward flow i.e. the total flow passing through the existing culvert is 1.14m^3/s. This represents an increase of 1%, when compared to the baseline case.

4.13 It is estimated that the proposed road works will result in the displacement of approximately 1100m^3 of floodwater.

Mitigation Measures

4.14 The new dual carriageway alignment level is not considered to be at flood risk, as the proposed level is 1.64m above the predicted peak water level at this location. However, the proposed works will result in the displacement of flood water and the subsequent increase in water level will increase the flood risk to the existing A96 which will be retained.

4.15 To achieve a neutral flood risk impact, compensatory flood storage will be required to alleviate the increase in water level at this location. The estimated volume of floodwater displaced by the proposed Scheme design is $1100m^3$.

4.16 The ground topography bounded by the existing A96 to the north and new dual carriageway alignment to the south rises to both the east and west. Although the land is presently used for agriculture, it is proposed to 'win' compensatory storage from within these two areas.

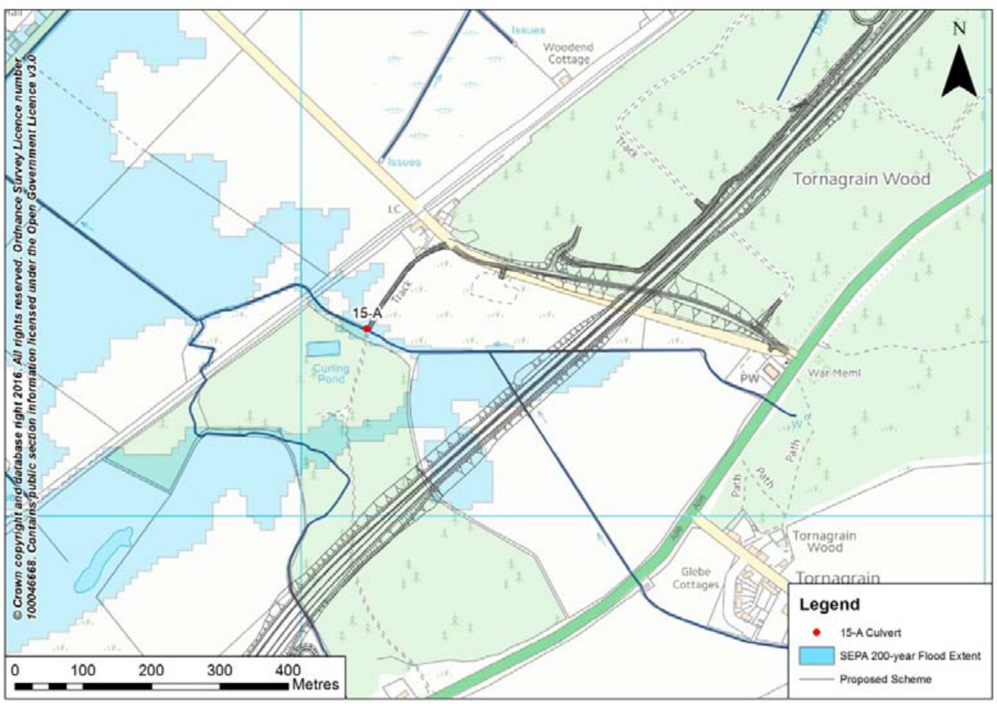
Summary

4.17 For the purposes of the DMRB Stage 3 Assessment SWF09-A has been identified as being of very high sensitivity. The proposed Scheme increases water levels by 0.363m, a major magnitude impact. This is an impact of Very Large significance. However with mitigation the magnitude of impact will be negligible hence the impact significance will be Neutral.

SWF15-A: Tributary of 'Unnamed Burn - Castle Stuart to source (Tornagrain)' (2)

4.18 At Tornagrain Wood the proposed dual carriageway alignment traverses a small area that is considered to be prone to flooding, as shown on SEPA's flood map (Diagram 4.4).

Diagram 4.4 SEPA flood extent (0.5 AEP (200 year)) at crossing 15A (proposed Scheme design footprint shown for reference)



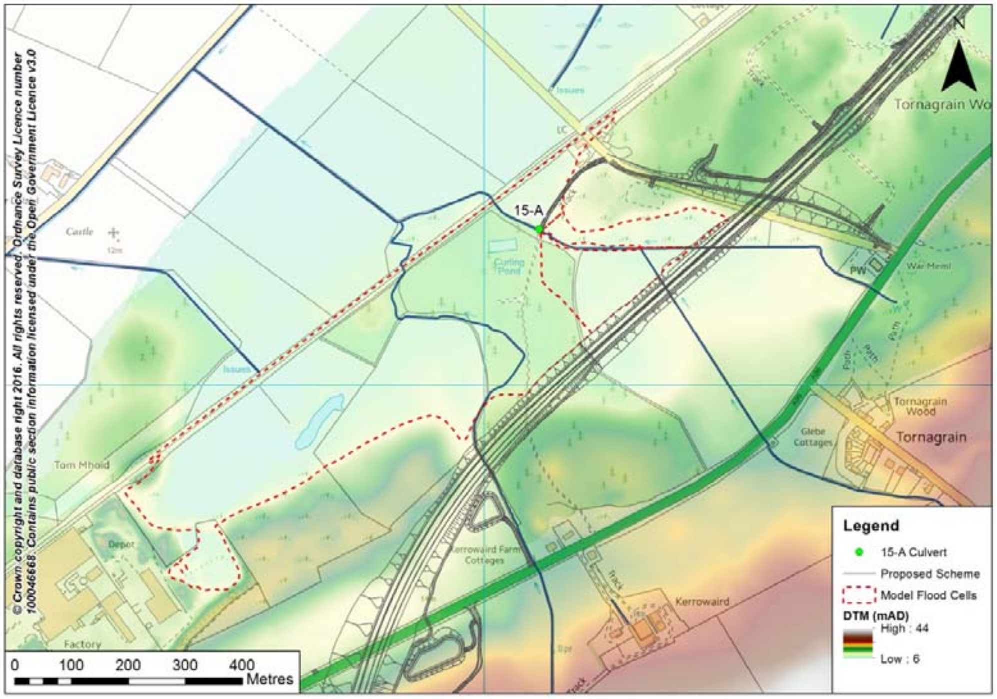
4.19 Further hydraulic assessment has been undertaken, to investigate the impact of road construction on existing flood risk. This has involved derivation of a simple routing model, based on an inflow hydrograph for the design flood event, representation of the ground topography and existing hydraulic controls.

Ground Topography

4.20 The ground topography is based on 5m grid photogrammetry survey which has been sub-divided into flood cells representing 'basins' within the topography which are capable of storing floodwater.

In this area, the flood cells are represented by the area immediately beyond the left and right hand bank and also an area of low ground located further to the west (Diagram 4.5).

Diagram 4.5: Topography and hydraulic controls



4.21 The flood cells have been defined by the ground topography and the connection (‘spill’) between adjoining cells is represented by the ground topography along the flood cell boundary.

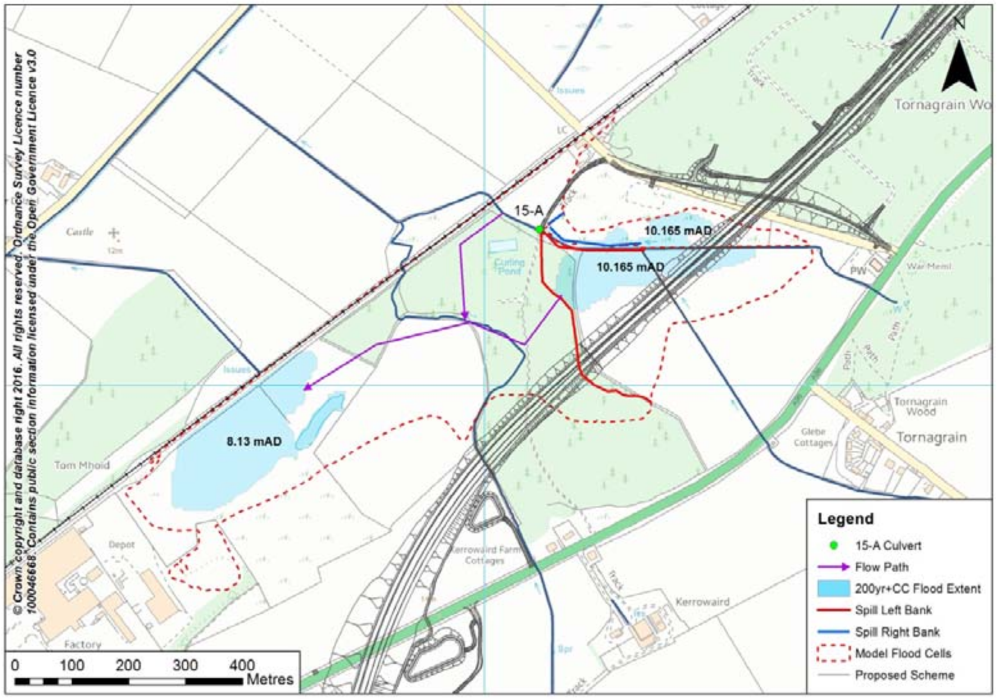
Hydraulic Controls

4.22 A site visit was undertaken to identify and map existing hydraulic controls local to the area of interest, as shown in Diagram 4.5.

Baseline Flood Risk and Flood Mechanisms

4.23 Diagram 4.6 indicates the area at risk of flooding associated with the design flood event.. The peak flow associated with this event is 3.14m^3/s.

Diagram 4.6: Baseline flood map for the design event (proposed Scheme design footprint shown for reference)



4.24 The forward passage of water is restricted by an existing downstream 0.4m diameter culvert, under an access track, which results in floodwater spilling out of bank to both the left and right hand floodplain. The predicted peak water level at this location is 10.17mAOD and the flood extent extends approximately 400m upstream. A ‘low spot’ in the topography exists at the location of the 0.4m diameter culvert and floodwater is predicted to overtop the culvert and pass forward towards the Aberdeen to Inverness Railway Line, where an existing arch culvert, with dimensions 1.4m wide by 2.5m high will convey floodwater downstream.

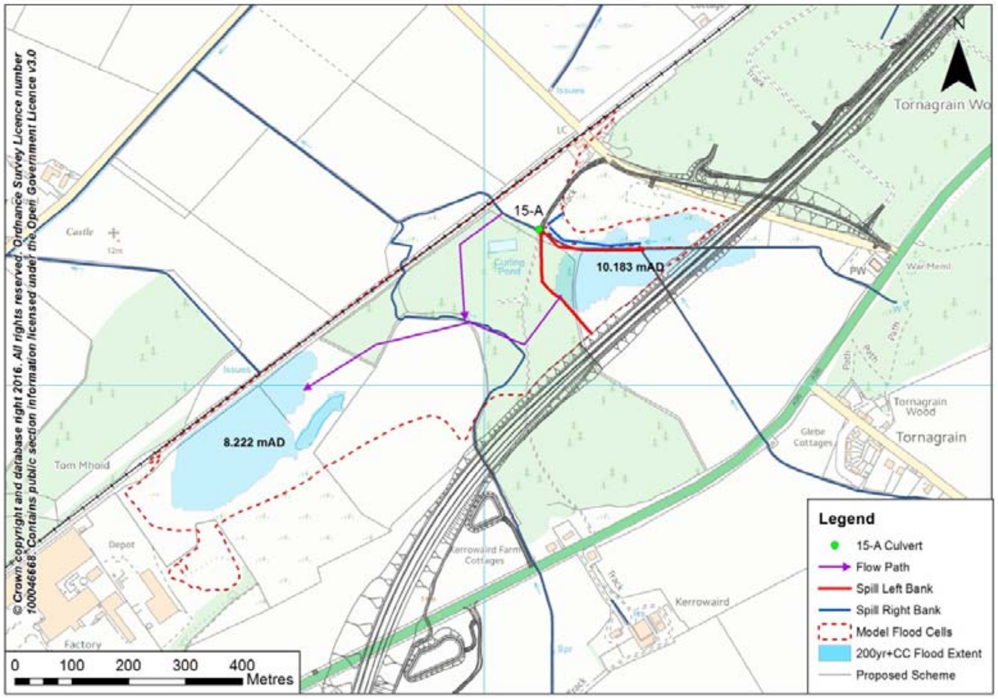
4.25 Floodwater spilling beyond the left hand bank is likely to result in overland flow to the west, as indicated by the flow path in Diagram 4.6. This flow path follows the contours of the topography and is likely to result in flooding of an area bounded by the railway line further to the west.

4.26 It is noticeable that the predicted areas of flooding and flow paths are similar to the flood extent presented in SEPA’s flood map.

Scheme Flood Risk and Flood Mechanism

4.27 Diagram 4.7 shows the impact of the proposed Scheme design on flood risk associated with the design flood event.

Diagram 4.7: Scheme flood map for the design flood event.



4.28 The hydraulic controls and flood mechanisms associated with the baseline case will be unaffected by the proposed Scheme, however the dual carriageway alignment lies within an area predicted to flood thereby displacing floodwater. A new culvert (with dimensions 1.8m by 1.8m) is required to pass the design flood flow downstream of the proposed Scheme, however this flow will be controlled by the existing 0.4m diameter culvert located under the access track approximately 400m downstream. As with the baseline case, this will result in floodwater spilling from the left and right hand bank and overland flow occurring further to the west.

4.29 The extent of flooding immediately beyond the right hand bank will be contained somewhat by the new road embankment. As a result of the displaced floodwater, the peak flood water level immediately beyond the left and right hand bank is predicted to be 10.183mAOD i.e. an increase of 0.018m when compared the baseline case.

4.30 In addition, the net pass forward flow i.e. the total flow passing through the existing 400mm culvert and peak flow passing over land is $3.16m^3/s$ as opposed to a pass forward flow of $3.14m^3/s$ for the baseline scenario. This represents an increase of 0.6%.

Mitigation Measures

4.31 The estimated volume of floodwater displaced by the proposed Scheme is $80m^3$, which results in a marginal increase in peak water level of 0.018m.

4.32 Two options present themselves;

- Provide compensatory storage to achieve a neutral impact. This needs to be provided close to the point of lost floodplain and ideally the same volume will be provided at the same level relative to the design flood level as that lost.

- Do nothing and allow a marginal increase in flood risk and pass forward flow at this location.

4.33 Both options are discussed further below.

4.34 The ground topography rises beyond the right hand bank, however this area forms part of the Tornagrain Wood, and excavation to ‘win’ compensatory storage will likely result in the loss of woodland habitat, which is considered to be detrimental. The land immediately beyond the left hand bank is presently used for agriculture. The total area of land bounded by the river, woodland and proposed Scheme is approximately 18,000m^2. Re-grading (lowering) of part of this land may ‘win’ the required compensatory flood storage, however it is recognised that this may not be ‘direct’ replacement of lost flood storage, which is not considered possible due to the generally flat topography at this location. In addition, continued agricultural working of the land may result in the future loss of this compensatory storage.

4.35 Alternatively, additional compensatory storage may be won, by increasing the size (sectional area) of the channel beyond the left hand bank encroaching into the agricultural land. This may result in the formation of a two stage channel.

4.36 The marginal increase in water level of 0.018m within the flood plain immediately beyond the left and right hand bank is unlikely to have any significant impact on the status of the woodland and use of the agricultural land. However, the increase in water level does result in a slight increase in the net pass forward flow and this may increase the flood risk immediately downstream, in particular to the railway line.

4.37 The greatest risk of flooding to the railway line is likely to occur to the west of the site, where floodwater is predicted to ‘pond’ against the railway embankment. This is also shown on the SEPA flood map. The simple hydraulic model employed in this assessment does not incorporate the railway culverts passing water downstream at this location, hence the predicted peak water level of 8.8mAOD (an increase of 0.092m against the baseline case) at this location is considered to be a conservative estimate. Numerical modelling possibly involving 2D modelling techniques to assess overland flow routes at this location should be considered if further detailed assessment is required.

4.38 The top level of the railway embankment at this location is 10.0mAOD, hence there is likely to be over 1.0m of freeboard, which is considered to be sufficient and not likely to compromise the operation of the railway.

4.39 Hence, given that loss of woodland is undesirable and the use of the agricultural land and operation of the railway are unlikely to be affected by a slight increase in water level and pass forward flow at this location, it is currently proposed that no further mitigation measures are proposed.

Summary

4.40 For the purposes of the DMRB Stage 3 Assessment SWF15-A has been identified as being of very high sensitivity due to the proximity of the railway and the proposed Scheme as flood receptors. The proposed Scheme increases in channel water levels by 0.80m at the proposed Scheme and 0.092m at the railway culverts. This would result in a moderate magnitude impact of Large significance, but the presence of 1m freeboard is sufficient to reduce the sensitivity of the receptor at this location. The DMRB Stage 3 Assessment is based on the 0.018m increase in water levels within the floodplain adjacent to the proposed Scheme, a minor magnitude impact. This is an impact of Moderate significance if judged against the proposed Scheme, but the baseline condition does not feature the proposed scheme, and the change is only experienced by the woodland area, which is of low sensitivity, resulting in an impact of Neutral significance.

SWF17-A: Drains at Culblair

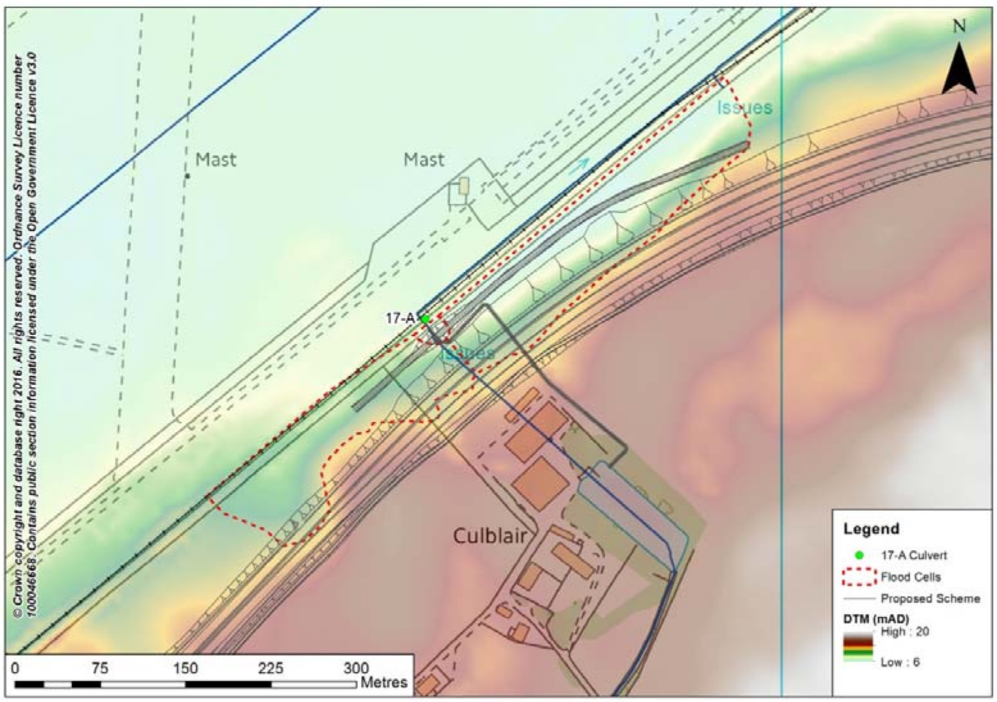
4.41 At Culblair the proposed Scheme traverses a small area that is considered to be at risk of flooding, based upon the initial baseline culvert assessment following the CIRIA C689 methodology.

4.42 Further hydraulic assessment has been undertaken, to investigate the impact of road construction on the flood plain. This has involved derivation of a simple routing model, based on an inflow hydrograph for the design flood event, representation of the ground topography and existing hydraulic controls.

Ground Topography

4.43 The ground topography is based on 5m grid photogrammetry survey which has been sub-divided into flood cells representing ‘basins’ within the topography which are capable of storing floodwater. In this area, the flood cells are represented by the area immediately beyond the left and right hand bank and also an area of low ground located further to the west.

Diagram 4.8 : Topography and Model flood cells (proposed Scheme design footprint shown for reference)



4.44 The flood cells have been defined by the ground topography and the connection (‘spill’) between adjoining cells is represented by the ground topography along the flood cell boundary.

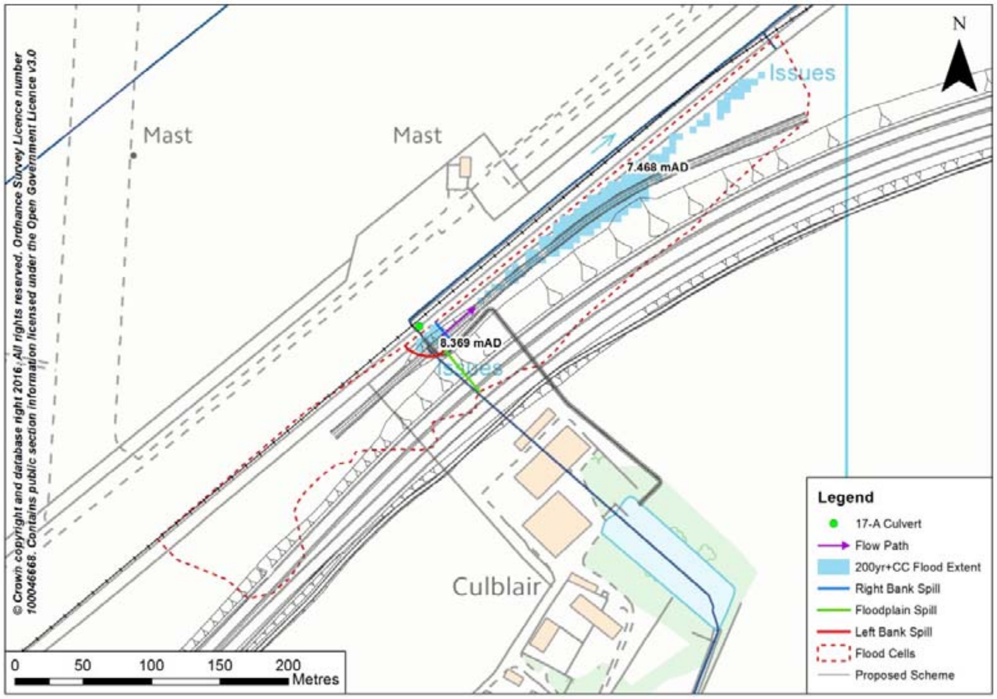
Hydraulic Controls

4.45 A site visit was undertaken to identify and map existing hydraulic controls local to the area of interest, as shown in Diagram 4.9.

Baseline Flood Risk and Flood Mechanisms

4.46 Diagram 4.9 indicates the area at risk of flooding associated with the design flood event. The peak flow associated with this event is $0.91m^3/s$.

Diagram 4.9: Baseline flood map for the design event (proposed Scheme design footprint shown for reference)

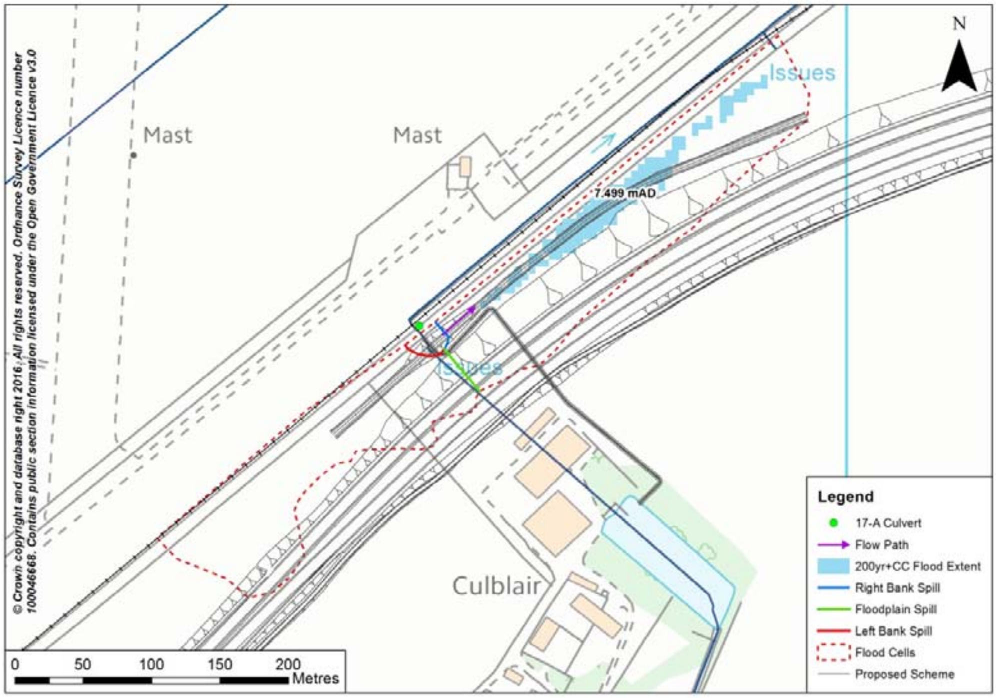


4.47 The forward passage of water is restricted by an existing downstream 0.7m x 0.9m box culvert, which results in floodwater spilling out of bank to the right hand floodplain. The predicted peak water level at this location is 7.47mAOD and the flood extent extends laterally parallel to the railway line for approximately 300m. The flood extent reaches the toe of the proposed road embankment.

Scheme Flood Risk and Flood Mechanism

4.48 Diagram 4.10 shows the impact of the proposed Scheme on flood risk associated with the design flood event.

Diagram 4.10: Scheme flood map for the design flood event



4.49 The hydraulic controls and flood mechanisms associated with the baseline case will be unaffected by the proposed Scheme, however the dual carriageway alignment will be constructed within an area predicted to flood thereby displacing a small amount of floodwater. Culvert 17-A passes under the Aberdeen to Inverness Railway Line and will not be altered during construction of the proposed Scheme. Therefore, as with the baseline case, this will result in floodwater spilling from the right hand bank and overland flow occurring parallel to the railway line.

4.50 The extent of flooding immediately beyond the right hand bank will be contained by the new road embankment displacing approximately 9m^3 of water. As a result of the displaced floodwater, the peak flood water level within the right hand bank is predicted to be 7.499mAOD i.e. an increase of 0.029m when compared the baseline case. There is no change to the peak pass forward flow for the baseline and proposed Scheme case.

Mitigation Measures

4.51 The estimated volume of floodwater displaced by the proposed Scheme design is 9m^3, which results in a marginal increase in peak water level of 0.029m.

4.52 The marginal increase in water level of 0.029m within the floodplain immediately along the right hand bank is unlikely to have any significant impact on the status of the land. The slight increase in water level does not increase the net pass forward flow.

The greatest risk of flooding to the railway line is likely to occur to the east of the site, where floodwater is predicted to surcharge against the railway embankment. The top level of the railway embankment at this location is 7.54mAOD, which is only marginally higher than the predicted peak water level by 0.041m. Given the small volume of flood water displaced by the proposed Scheme and confined area of flood risk, it is proposed that care is taken when locating the toe of the road embankment in relation to the railway embankment, such that the hydraulic connectivity in this area is not compromised and where possible the ground between the two embankments is lowered slightly to accommodate the small volume of displaced flood water.

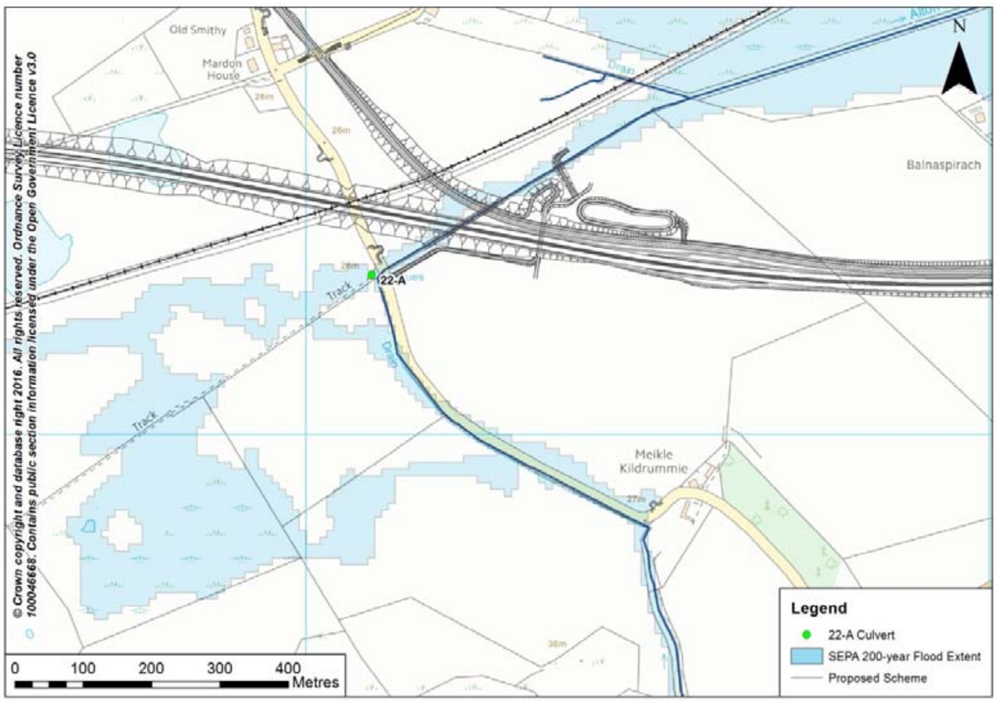
Summary

4.53 For the purposes of the DMRB Stage 3 Assessment SWF17-A has been identified as being of high sensitivity. The proposed scheme increases water levels by 0.779m within channel and 0.029m within the right bank floodplain, the latter considered to be a moderate magnitude impact. This results in an impact of moderate significance. Appropriate mitigation at detailed design is likely to remove this impact.

SWF22-A: Alton Burn

4.54 At the crossing of the Alton Burn the proposed Scheme road alignment traverses a small area that is considered to be prone to flooding, as shown on SEPA's flood map (Diagram 4.11), whilst initial culvert analysis (using the CIRIA methodology) also indicates that the existing culvert on the C1163 Delnies – Kildrummie – Howford Road is under capacity.

Diagram 4.11: SEPA flood extent (200-year) at crossing SWF22-A (proposed Scheme footprint shown for reference)

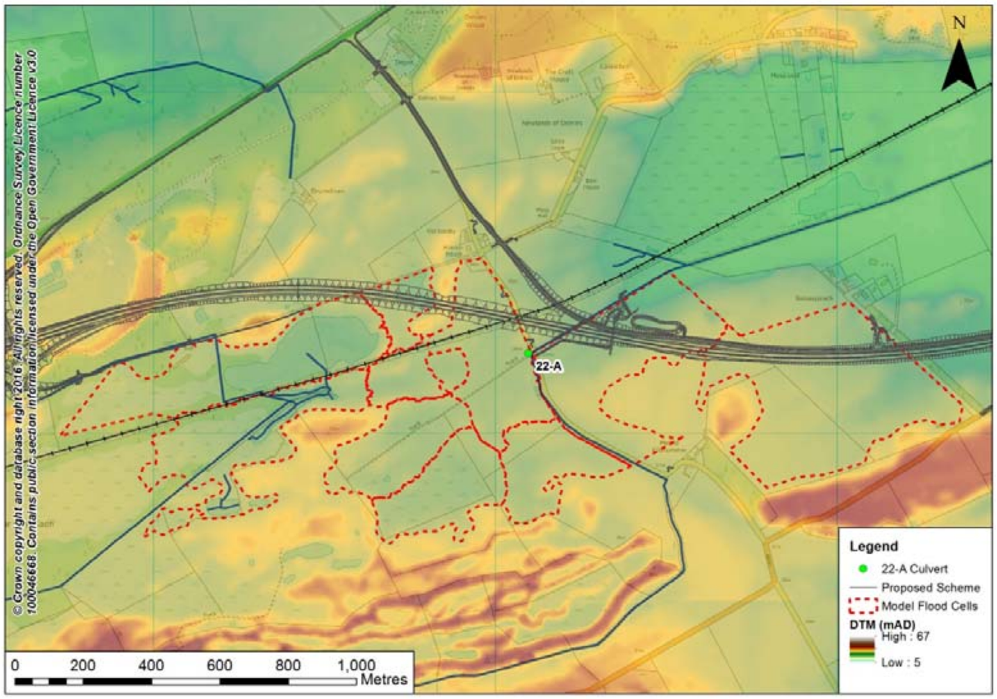


4.55 Further hydraulic assessment has been undertaken, to investigate the impact of road construction on flood risk. This has involved derivation of a simple routing model, based on an inflow hydrograph for the design flood event, representation of the ground topography and existing hydraulic controls.

Ground Topography

4.56 The ground topography is based on 5m grid photogrammetry survey which has been sub-divided into flood cells representing 'basins' within the topography which are capable of storing floodwater. In this area, the flood cells are represented by the area immediately beyond the left and right hand bank, extending 1.4km on the left bank and 1.2km on the left bank (Diagram 4.12).

Diagram 4.12: Topography and hydraulic controls



4.57 The flood cells have been defined by the ground topography and the connection (spill) between adjoining cells is represented by the ground topography along the flood cell boundary.

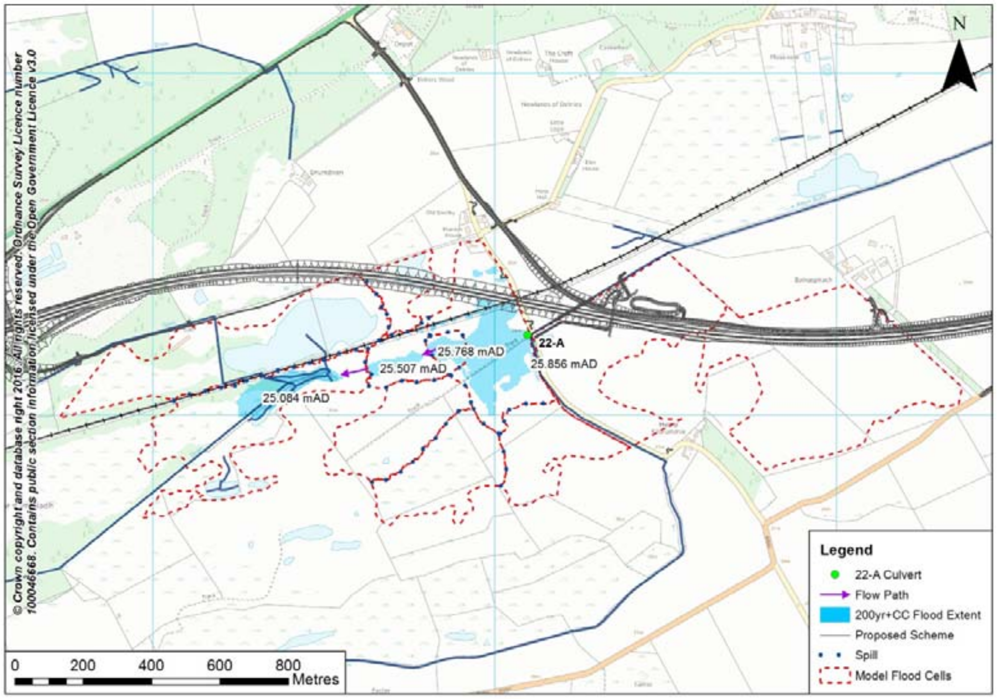
Hydraulic Controls

4.58 A site visit was undertaken to identify and map existing hydraulic controls local to the area of interest, as shown in Diagram 4.12.

Baseline Flood Risk and Flood Mechanisms

4.59 Diagram 4.13 indicates the area at risk of flooding associated with the design flood event. The peak flow associated with this event is $3.36m^3/s$.

Diagram 4.13: Baseline flood map for the design event (proposed Scheme design footprint shown for reference)



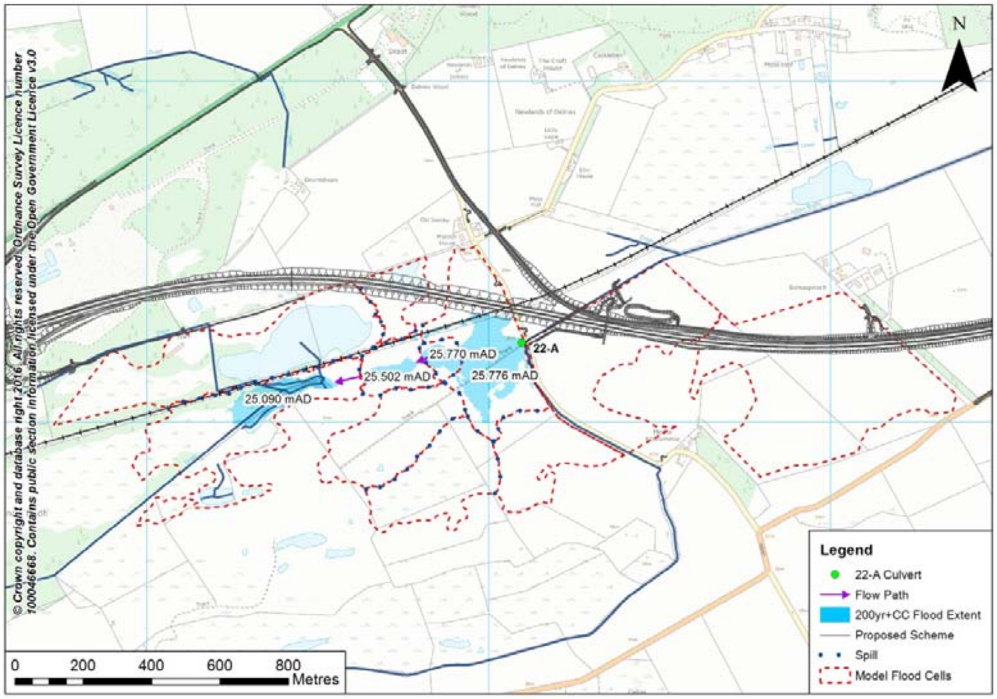
4.60 The forward passage of water is restricted by an existing downstream 0.48m diameter culvert under the C1163 Delnies – Kildrummie – Howford Road, which results in floodwater spilling out of bank to the left hand floodplain. The predicted peak water level at this location is 25.774mAOD and the flood extent extends approximately 100m upstream.

4.61 Floodwater spilling beyond the left hand bank is likely to result in overland flow to the west, as indicated by the flow path in Diagram 4.13. This flow path follows the contours of the topography and likely to result in flooding of an area bounded by the Aberdeen to Inverness Railway Line further to the west. The minimum elevation of the left bank spill unit is 25.423mAOD, and at approximately 6.6hrs, water within the channel begins to breach this spill unit and the water level rises to a peak of 25.856mAOD within the channel. During the flood event water flows in a westward direction. The floodwater eventually ponds in an area approximately 880m west of the channel.

Scheme Flood Risk and Flood Mechanism

4.62 Diagram 4.14 shows the impact of the proposed Scheme on flood risk associated with the design flood event.

Diagram 4.14: Scheme flood map for the design flood event.



4.63 The hydraulic controls and flood mechanisms associated with the baseline case will be unaffected by the proposed Scheme, however the dual carriageway alignment will be constructed within an area predicted to flood thereby displacing floodwater. A new culvert (with dimensions 2.7m by 2.7m) is required to pass the design flood flow downstream. As with the baseline case, this will result in floodwater spilling from the left and right hand bank and overland flow occurring further to the west.

4.64 As a result of the displaced floodwater, the peak flood water level immediately beyond the left hand bank is predicted to be 25.776mAOD i.e. an increase of 0.002m when compared the baseline case. In addition, the net pass forward flow is predicted to remain unchanged.

Mitigation Measures

4.65 The estimated volume of floodwater displaced by the proposed Scheme is 642m^3, which results in a marginal increase in peak water level of 0.002m.

4.66 The land affected by the increase in water level is used for agricultural purposes and it is considered unlikely that the use of the agricultural land will be affected by the 2mm increase in water level. In addition, this increase is unlikely to result a change in the operation of the Aberdeen to Inverness Railway Line. Currently there is a minimum of 0.167m freeboard at this location between the railway line level and peak water level.

Given that there is unlikely to be an impact on the use of the agricultural land and operation of the railway line due to a 0.002m increase in water level, no further mitigation measures are proposed at this location.

Summary

4.67 For the purposes of the DMRB Stage 3 Assessment SWF22 has been identified as being of very high sensitivity. The proposed scheme increases water levels by 0.190m within channel and 0.002m within the left bank floodplain. The changes in floodplain water level are considered most significant in terms of flood risk, and result in a negligible magnitude impact. This is an impact of Neutral significance.

Blockage Analysis

4.68 As part of the proposed scheme culvert analysis, a number of blockage scenarios were undertaken to determine the impact of such a blockage with the maximum head water level at the upstream of the culvert recorded. Table 4.1 below illustrates the change in upstream head water level for the various blockage scenarios for all proposed culverts (plus four existing culverts that impact upon the scheme).

Table 4.1: Culvert blockage results.

Water Feature	Culvert Type	Culvert Size (m)	TWL (m)	No Blockage	50% Blockage	90% Blockage
				HWL (m)	HWL (m)	HWL (m)
SWF02-1	Box	2.7m x 3.6m	0.730	1.510	2.130	5.670
SWF07-1	Box	1.8m x 1.8m	0.280	0.840	1.070	3.440
SWF08-1	Box	2.4m x 2.4m	0.395	1.226	1.465	4.617
SWF09-1	Box	2.7m x 2.7m	0.883	1.104	1.709	5.365
SWF13-1	Box	1.8m x 1.8m	0.340	0.715	1.226	3.565
SWF14-1	Box	2.1m x 2.7m	0.734	0.979	1.518	4.946
SWF15-1	Box	1.8m x 1.8m	0.318	0.25	0.40	1.20
SWF17-1	Box	2.4m x 2.4m	1.262	1.270	1.310	3.060
SWF18-1	Box	1.8m x 2.1m	0.645	0.776	1.127	3.162
SWF18-2	Box	1.8m x 2.1m	0.578	0.809	1.331	2.646
SWF19-1	Box	2.4m x 2.4m	0.660	1.001	1.632	4.054
SWF19-2	Box	1.8m x 2.1m	0.766	0.880	1.340	6.346
SWF22-1	Box	2.7m x 2.7m	0.867	1.320	2.279	4.858
SWF24-1	Box	1.5m x 1.8m	0.412	0.561	0.859	2.927
SWF09-A	Pipe	0.6m	N/A	2.552	2.620	2.713
SWF15-A	Pipe	0.45m	N/A	1.799	1.814	1.823
SWF17-A	Box	0.9m x 0.7m	N/A	1.190	1.318	1.585
SWF22-A	Pipe	0.81m	N/A	2.248	2.340	2.399

Impact Significance

4.69 Table 4.2 illustrates the impact significance of flooding at each of the 34 culvert crossings associated with the proposed A96 dualling. The tail water level (TWL) depth has been used, in cases where a new culvert is to be constructed, as an estimate of the existing water depth, whilst the head water level (HWL) depth is used as an estimate of the resultant change in peak water level as a result of a new structure. It should be noted that if the 0.5% AEP + CC flood event is retained within channel or there are no plans to replace an existing culvert the magnitude is deemed “Negligible”.

Table 4.2: Impact significance of flooding at each minor watercourse crossing.

Water Feature	Condition @ 0.5% AEP +CC	In/out of bank (following routing - where necessary)	TWL depth (m)	HWL depth (m)	Difference (mm)	Average depth on active floodplain (m)	Importance / Sensitivity	Magnitude	Significance
SWF02-1	Free Flowing	In-bank	0.73	1.51	780	N/A	Very High	Negligible	Neutral
SWF02-2	Free Flowing	In-bank	0.77	1.02	250	N/A	Very High	Negligible	Neutral
SWF07-1	Free Flowing	In-bank	0.28	0.84	560	N/A	Very High	Negligible	Neutral
SWF07-A	Surcharged	Out of bank	0.36	1.43	1069	0.02	Very High	Negligible	Neutral
SWF07-B	Free Flowing	Out of bank	0.16	1.31	1153	0.07	Very High	Negligible	Neutral
SWF08-1	Free Flowing	In-bank	0.4	1.23	831	N/A	Very High	Negligible	Neutral
SWF08-A	Surcharged	Out of bank	1.11	1.11	0	0.02	Very High	Negligible	Neutral
SWF09-1	Free Flowing	In-bank	0.88	1.10	221	0.00	Very High	Negligible	Neutral
SWF09-A	Surcharged	Out of bank	0.97	2.55	1578	0.43	Very High	Negligible	Neutral
SWF09-B	Surcharged	Out of bank	0.73	1.72	994	1.20	Very High	Negligible	Neutral
SWF11-A	Surcharged	Out of bank	0.31	0.91	597	0.08	Very High	Negligible	Neutral
SWF13-1	Free Flowing	In-bank	0.34	0.72	375	N/A	Very High	Negligible	Neutral
SWF13-2	Surcharged	Out of bank	0.27	1.42	1151	2.71	Very High	Negligible	Neutral
SWF13-A	Free Flowing	In-bank	0.63	0.79	160	N/A	Very High	Negligible	Neutral
SWF14-1	Free Flowing	In-bank	0.73	0.98	252	0.00	Very High	Negligible	Neutral
SWF14-A	Surcharged	In-bank	0.62	1.24	620	N/A	Very High	Negligible	Neutral
SWF15-1	Free Flowing	In-bank	0.32	0.32	0	N/A	Very High	Negligible	Neutral
SWF15-A	Surcharged	Out of bank	0.95	1.75	800	0.13	Watercourse is Very High, impacted	Minor	Neutral

Water Feature	Condition @ 0.5% AEP +CC	In/out of bank (following routing - where necessary)	TWL depth (m)	HWL depth (m)	Difference (mm)	Average depth on active floodplain (m)	Importance / Sensitivity	Magnitude	Significance
							receptor is Low (see 4.40)		
SWF15-B	Free Flowing	In-bank	1.35	1.48	130	N/A	Very High	Negligible	Neutral
SWF15-C	Free Flowing	In-bank	0.29	0.54	250	N/A	Very High	Negligible	Neutral
SWF17-1	Free Flowing	Out of bank	1.26	1.27	8	0.25	High	Negligible	Neutral
SWF17-A	Surcharged	Out of bank	0.42	1.20	779	0.25	High	Negligible	Neutral
SWF18-1	Free Flowing	In-bank	0.65	0.78	131	N/A	Very High	Negligible	Neutral
SWF18-2	Free Flowing	In-bank	0.58	0.81	231	N/A	Very High	Negligible	Neutral
SWF18-A	Surcharged	Out of bank	0.53	2.64	2109	0.79	Very High	Negligible	Neutral
SWF18-B	Free Flowing	In-bank	0.28	0.68	400	N/A	Very High	Negligible	Neutral
SWF18-C	Free Flowing	In-bank	0.26	0.31	50	N/A	Very High	Negligible	Neutral
SWF19-1	Free Flowing	In-bank	0.66	1.00	341	N/A	Very High	Negligible	Neutral
SWF19-2	Free Flowing	In-bank	0.77	0.88	110	N/A	Very High	Negligible	Neutral
SWF19-A	Surcharged	Out of bank	0.69	1.79	1100	0.00	Very High	Negligible	Neutral
SWF19-B	Surcharged	Out of bank	0.94	2.20	1260	0.12	Very High	Negligible	Neutral
SWF22-1	Free Flowing	In-bank	0.87	1.32	453	N/A	Very High	Negligible	Neutral
SWF22-A	Surcharged	Out of bank	0.79	2.25	1460	0.19	Very High	Negligible	Neutral
SWF24-1	Free Flowing	In-bank	0.41	0.56	140	N/A	Very High	Negligible	Neutral

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5 Conclusions

5.1 Following initial assessment of the minor watercourse crossings, further assessment was required at four locations.as the proposed Scheme design was considered likely to impact upon existing flood risk. These sites are at Tributary of Rough Burn (SWF09-A), Tributary of ‘Unnamed Burn - Castle Stuart to source (Tornagrain)’ (2 (SWF15-A), Drains at Culblair (SWF17-A) and Alton Burn (SWF22-A).

5.2 At SWF09-A the proposal is predicted to result in an increase in peak water level and displacement of 1100m^3 of floodwater. As a result, the increase in water level will increase the flood risk to the existing A96 which is being retained, albeit reclassified and this is considered undesirable. To achieve a neutral flood risk impact, it is proposed to provide compensatory flood storage from the adjacent agricultural land.

5.3 At SWF-15-A, the proposed dual carriageway alignment is predicted to result in an increase in peak water level and a displacement of 80m^3 of floodwater. This increases the flood risk to the Aberdeen to Inverness Railway Line downstream, however there is likely to be over 1m of freeboard, which is considered to be sufficient and not likely to compromise the operation of the railway. Given that the ecological status of the Tornagrain wood, use of the agricultural land and operation of the railway are unlikely to be affected by a marginal increase in water level and pass forward flow at this location, it is proposed that no further mitigation measures are proposed.

5.4 At SWF17-A the proposed dual carriageway alignment is predicted to result in an increase in peak water level and a displacement of 9m^3 of floodwater. This is predicted to pond against the railway line. Given the small volume of floodwater displaced by the proposed Scheme and confined area of flood risk, it is proposed that care is taken when locating the toe of the road embankment in relation to the railway embankment, such that the hydraulic connectivity in this area is not compromised and where possible, the ground between the two embankments is lowered slightly to accommodate the small volume of displaced flood water.

5.5 At SWF22, the proposed Scheme is predicted to result in an increase in peak water level and a displacement of 642m^3 of floodwater. The peak water level increases by 0.002m and it is considered unlikely that this will impact on the base of the agricultural land or the operation of the railway line. Therefore, no further mitigation measures are proposed at this location.

6 References

Scottish Environment Protection Agency (2015). Flood Maps [Online]: Available from www.map.sepa.org.uk/floodmap/map.htm [Accessed March 2016];

Balkham, M, Fosbeary, C, Kitchen, A, Rickard, C CIRIA C689 – Culvert Design and Operation Guide, CIRIA, 2010

Flood Estimation Guidelines (2015) – Technical guidance 197_08, Environment Agency, 2010

1 Background

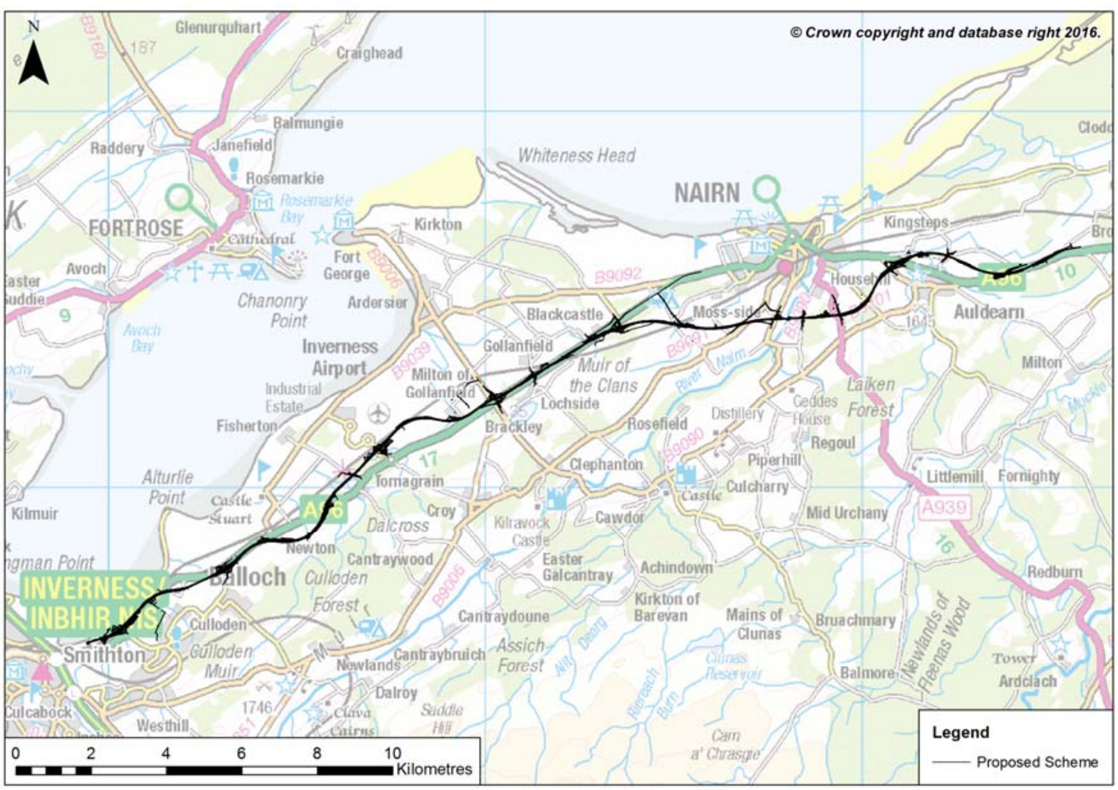
Background Information

1.1 This annex provides detailed information on the surface water impact assessment relevant to Appendix 13.2 (Flood Risk Assessment).

1.2 The A96 Dualling Inverness to Nairn (including Nairn Bypass) scheme comprises the provision of approximately 31km of new dual carriageway, achieved through offline construction. The existing A96 single carriageway would be de-trunked and reclassified as a local road to maintain local access the proposed Scheme. Due to the size of the proposed Scheme, there are a number of flood risks, which may place the road and its users at significant risk of flooding. The proposed Scheme also has the potential to impact the level of flood risk elsewhere. The outline of the proposed Scheme is presented in Diagram 1. A Flood Risk Assessment (FRA) is required to ensure the design meets the requirements of national and local planning policy and is considered appropriate from a flood risk perspective. As well as fluvial and coastal flooding, the FRA will also consider flood risk from other sources, including surface water, groundwater, and artificial drainage systems and infrastructure failure.

1.3 This assessment specifically focuses on the risk of surface water flooding both to and from the proposed Scheme and forms an annex to the main FRA report. Where adverse flood risk impacts are identified, this assessment proposes suitable mitigation to reduce these impacts.

Diagram 1: Location Plan



Aims and Objectives

1.4 The principal aim of this report is to assess the risk to and from the proposed Scheme from surface water flooding. This will be undertaken through completion of the following objectives:

- Identification of any significant surface water flowpaths and surface water ponding which could place the proposed Scheme at high risk.
- An investigation into the level of risk posed from the proposed Scheme to nearby sensitive receptors. This risk could occur by increased runoff from the highway, passing forward more flow in the watercourses or increased surface water ponding against proposed embankments.

2 Methodology

Introduction

2.1 This section of the report presents the methodology used to undertake the assessment. Two types of risk have been identified and included in the assessment; surface water ponding and surface water flow routes. Different methodologies have been used for each type of risk, and they are identified below.

Surface Water Flow Routes

2.2 The following sections describe the methodology for the surface water flow routes.

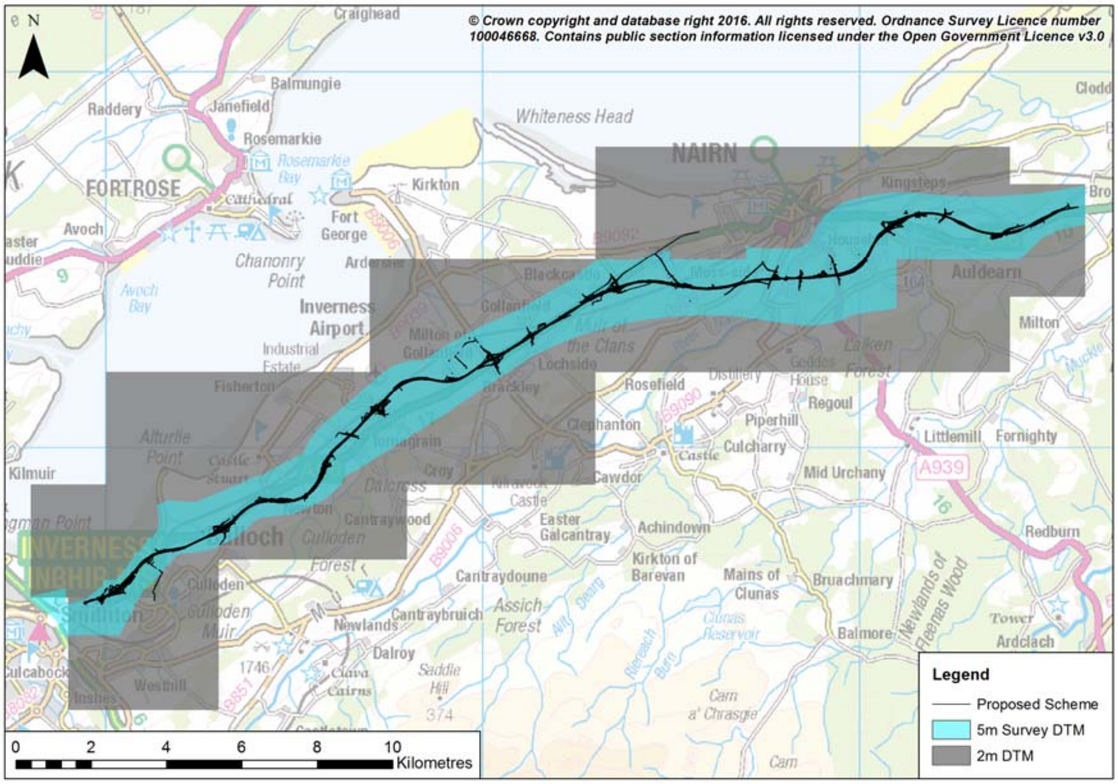
<u>DTM Available</u>

2.3 There were two Digital Terrain Models (DTMs) available for use within this assessment:

- 2m DTM – coverage based on photogrammetry data (2009)
- 5m Survey – route corridor based on photogrammetry data (2014) and wider coverage based on 10m spot levels, resampled at 5m.

2.4 Due to the wider available coverage and the finer resolution of cell size, the 2m DTM was chosen for use in the rolling ball analysis. The 5m Survey data provides better vertical accuracy close to the route of the proposed Scheme, but has insufficient spatial extent to support this analysis. Comparison of the spatial extents of the available data are shown in Diagram 2.

Diagram 2: DTM Coverage



<u>Baseline Rolling Ball Analysis</u>

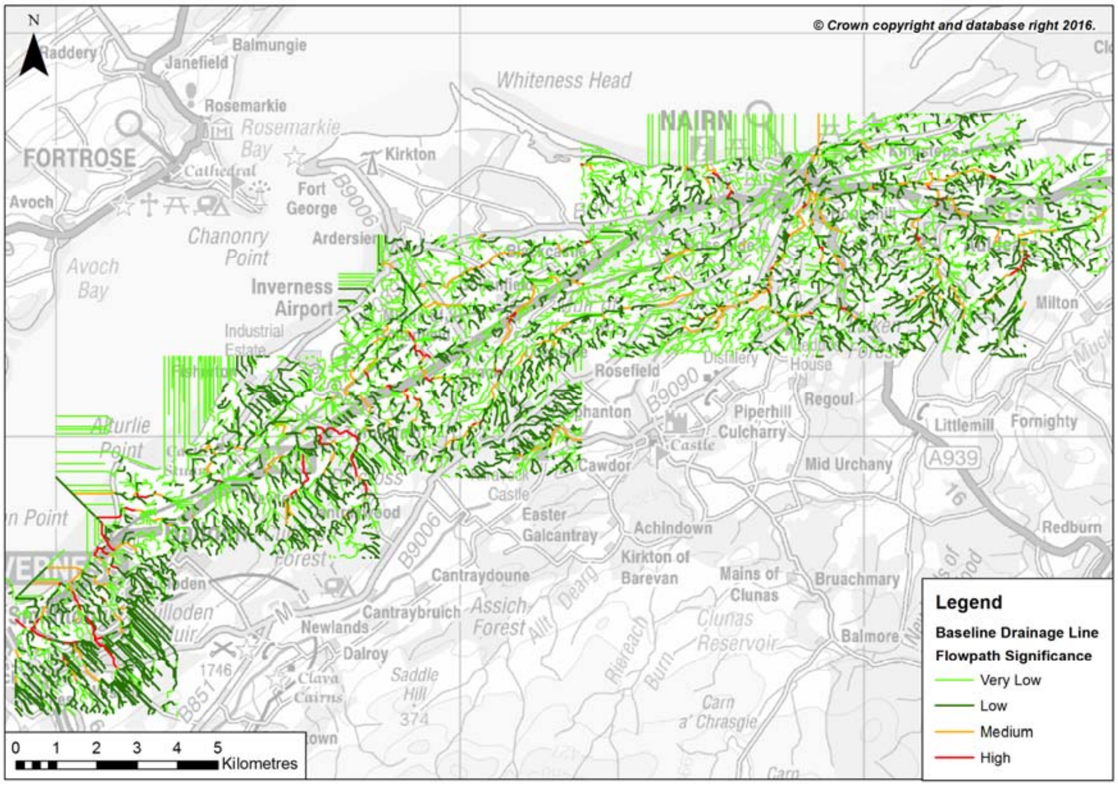
2.5 ArcGIS was used to undertake a ‘rolling ball’ analysis to identify overland flowpaths by using topographic data from DTM to predict the likely route of surface water runoff.

2.6 The method was chosen as it provides fine detail regarding the location of routing pathways and is one of four methods described in Defra’s Surface Water Management Plan Technical Guidance Guidance (Defra 2010).

2.7 The rolling ball technique produces a series of theoretical flowpaths, otherwise known as a surface water routing network; refer to Diagram 3. Essentially, the flow path generated represents the path of “low spots” over the ground along which water would flow if the ground was impermeable.

2.8 Based on catchment area and gradient the flowpaths can be scored, whereby a steep gradient and large catchment area results in a high flowpath significance (Diagram 3). The flowpath significance helps to determine the level of hazard that the surface water flow route may impose to a receptor.

Diagram 3: Rolling Ball Analysis



<u>Design Rolling Ball Analysis</u>

2.9 As part of the proposed Scheme, some re-profiling of the highway and surrounding areas is required. As such, a DTM has been created which depicts the ‘post scheme’ topographic profile, hereby referred to as the Design DTM.

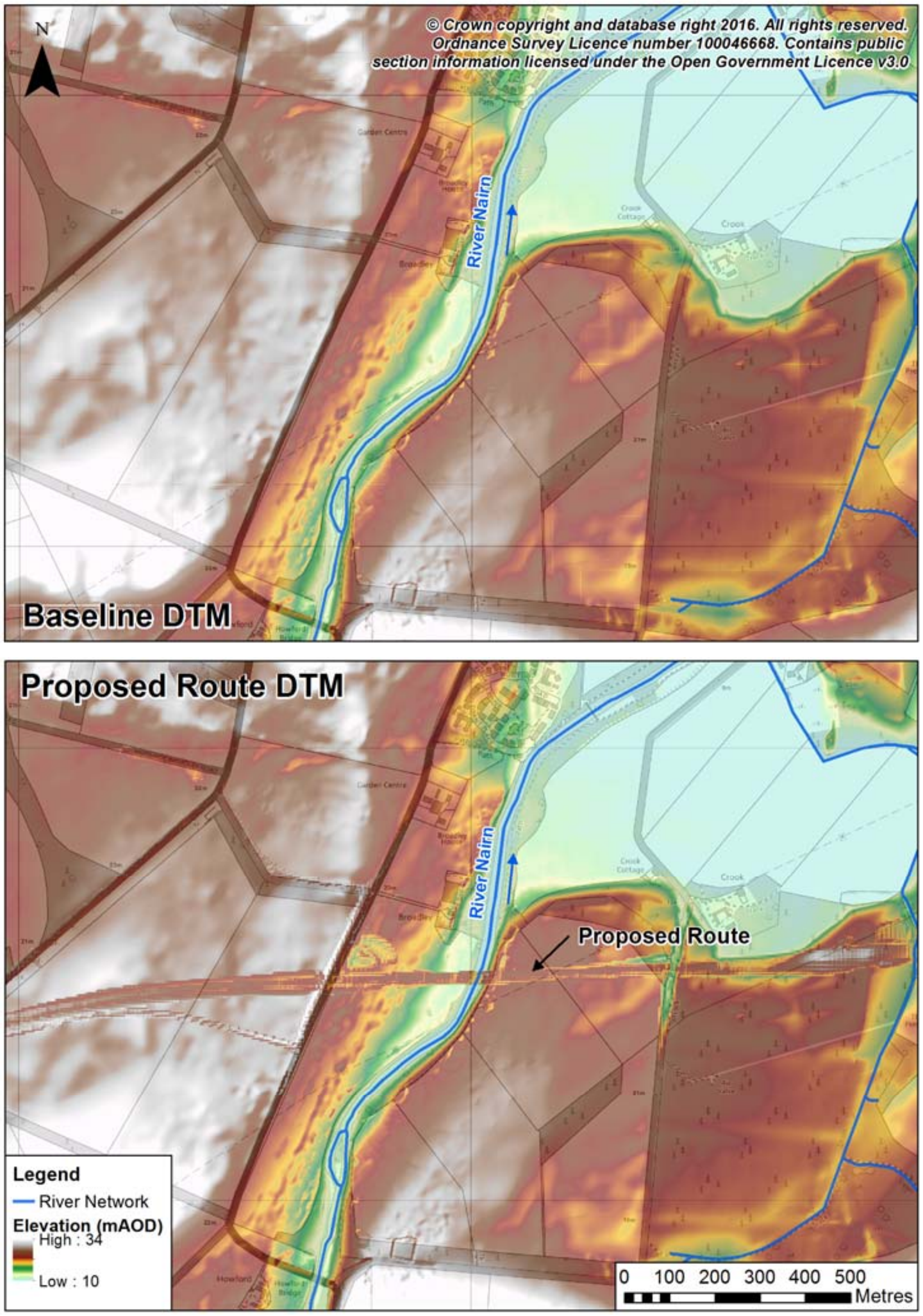
2.10 As mentioned above, two DTMs were available for the area surrounding of the Scheme. Whilst the 2m DTM was considered more appropriate for use within this rolling ball assessment, the road elevation was created using the 5m DTM, which has better vertical accuracy and was used in the design development. .

2.11 It was not possible to directly stamp the road elevation onto the 2m DTM due to discrepancies within the elevation data contained within the two datasets. Therefore, to produce the Design DTM, the height difference between the road elevation and the 5m DTM was stamped onto the 2m DTM.

2.12 The Design DTM was then used for the rolling ball analysis to determine how the proposed route might affect the existing surface water flow routes.

2.13 The difference between the baseline and proposed DTM (with the route stamped on) can be seen in Diagram 4 for an extract of the proposed Scheme.

Diagram 4: Baseline and Design DTM



Risk Assessment

2.14 The whole route will be assessed for surface water flood risk. The assessment will identify the flowpaths that meet the proposed route and will focus on the following:

- History of surface water flooding
- Presence of properties
- SEPA Surface water flood map
- Where the design route has significantly altered the existing overland flow route

- Watercourse crossings

2.15 Based on the available information, criteria to determine a level of risk has been developed, see Table 1.

Table 1: Risk Level

Criteria	Risk Level
• No properties at risk, no history of surface water flooding, no extent of surface water flood map and low flowpath significance • Where there is an existing watercourse, as all flows would be captured by the river network • Minor ponding against proposed embankment with earthwork ditches included in the design	Low
• Properties at risk of flooding located at existing watercourses • Proposed road cut into existing ground levels with small extent of surface water ponding • Small extent of surface water ponding with low flowpath significance	Moderate
• Properties at risk of flooding • Significant/frequent ponding on proposed route • Significant/frequent ponding with medium/high flowpath significance	High

Surface Water Ponding

2.16 SEPA's flood map (SEPA 2015) for surface water has been used for this assessment. The proposed route has been placed on top of the existing surface water ponding (as indicated by the flood outlines for different magnitude events on the SEPA surface water flood map), and where the route intersects with existing ponding, it has been identified in the assessment. The impacts of the ponding under the existing situation have been outlined in Section 3.

3 Impacts

Surface Water Flow Routes

3.1 Tables 2 to 13 overleaf list the flowpaths that meet the proposed route within each corresponding map, Diagrams 5 to 16, determined by the rolling ball analysis. An assessment of the impact of each flowpath has been made, based on the above criteria (in Table 1), and the assessment determines if any further consideration is required to reduce the level of surface water flood risk.

3.2 Further consideration required includes aspects such as:

- Identification of mitigation measures
- Where pre-earthwork drainage is required
- Where the collected water would discharge to (the Surface Water Feature (SWF) has been identified, where necessary)

3.3 It should be noted that a full detailed DTM was not available for the entire potential surface water catchment. However, the areas with poor coverage are in the extremities of the DTM and are unlikely to have a significant impact on the assessment. Furthermore, a conservative approach has been applied as every potential flowpath, regardless of hazard, has been investigated in more detail.

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Diagram 5: Map 1

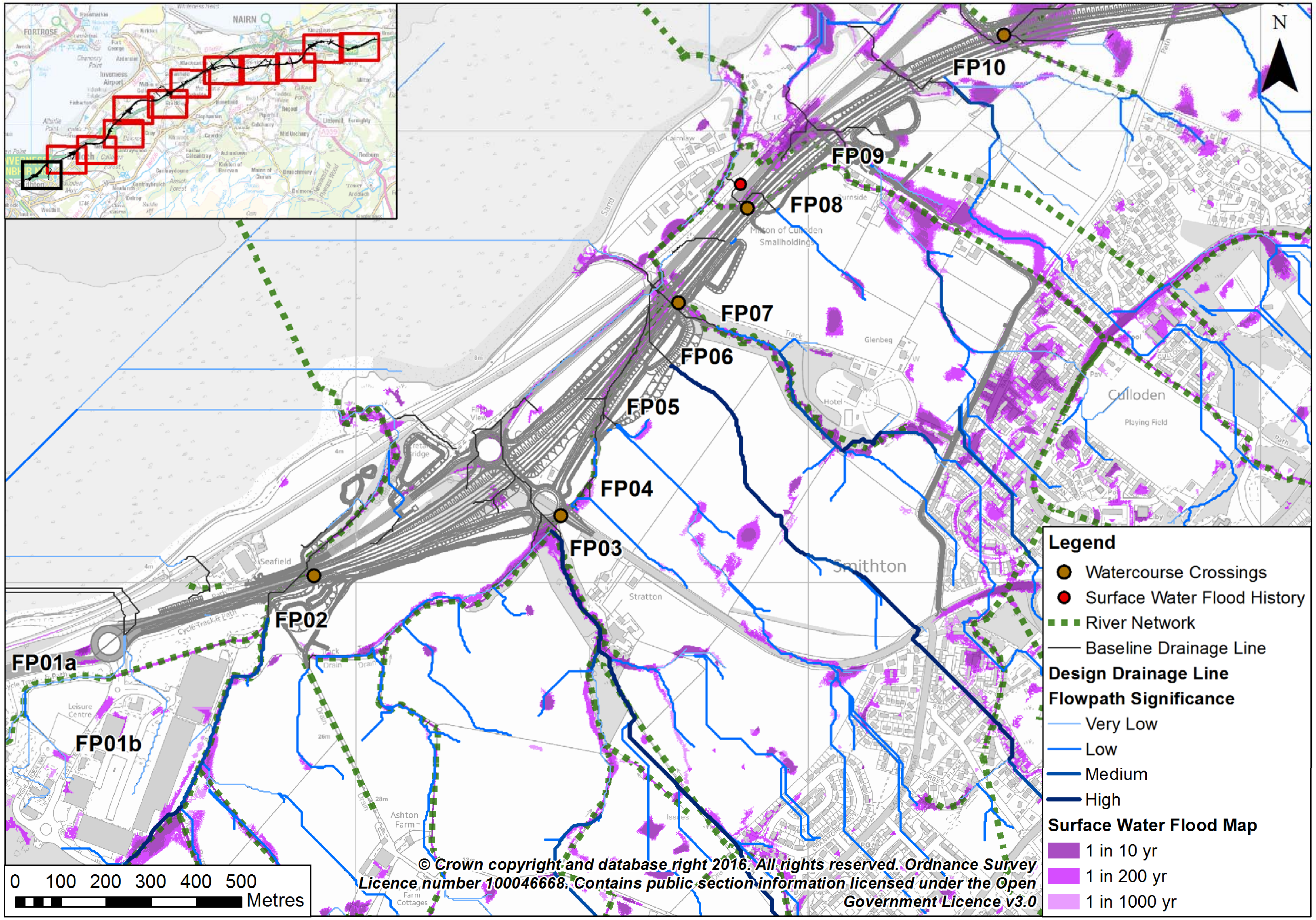

Table 2: Surface Water Risk Assessment – Map 1

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 1							
FP01a	Very Low	The flowpath is likely to discharge into existing watercourse	In-channel extent of 1 in 200yr with no history of surface water flooding	None. Properties located ~1m higher than flowpath	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Scretan Burn (C02)[1] needs to consider the additional surface water flow.
FP01b	Very Low	Local watercourse is culverted at this location, therefore flowpath is unlikely to discharge	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No, properties located ~1m higher than flowpath	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	N/A
FP02	Medium	The flowpath is likely to discharge into Scretan Burn	In-channel extent of 1 in 200yr with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Scretan Burn (C02) needs to consider the additional surface water flow.
FP03	High	The flowpath is likely to discharge into Cairnlaw Burn	There is a small extent of surface water flooding against the proposed route. There is no history of flooding.	No, properties upstream are located ~2m higher than flowpath	This flowpath is likely to increase flow to existing watercourse. Based on the SEPA flood maps, there is likely to be ponding against the proposed embankment.	LOW	Culvert capacity of Cairnlaw Burn (C03) needs to consider the additional surface water flow. Additional pre-earthwork drainage has been added to make sure there is sufficient capacity. This would outfall to Cairnlaw Burn.
FP04	Low	The flowpath is likely to discharge into Cairnlaw Burn	In-channel extent of 1 in 200yr with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Cairnlaw Burn (C04) needs to consider the additional surface water flow.
FP05	Low	The flowpath is likely to discharge into the realigned Cairnlaw Burn	In-channel extent of 1 in 200yr with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Cairnlaw Burn (C04) needs to consider the additional surface water flow.
FP06	High	The flowpath is likely to discharge into the realigned Cairnlaw Burn	In-channel extent of 1 in 200yr with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Cairnlaw Burn (C04) needs to consider the additional surface water flow.
FP07	Low	The flowpath is likely to discharge into the realigned watercourse	In-channel extent of 1 in 200yr with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Cairnlaw Burn (C04) needs to consider the additional surface water flow.
FP08	Low	The flowpath is likely to discharge into the realigned Milton Burn	Minimal ponding with one incident of surface water flooding where flash floods occurred due to unmaintained field drains. Not related to the highway.	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Milton Burn (C05) needs to consider the additional surface water flow.
FP09	Low	There is a culverted watercourse, flowpath is unlikely to discharge to the watercourse	Significant existing flow route and ponding against existing A96. No history of surface water flooding	Yes, properties at risk to the south of the flowpath	This flowpath is disrupted by the embankment to the detention ponds. As there is significant ponding against the existing A96, it is likely that this will occur upstream at the detention ponds. Due to the topography, the access track to the detention ponds could force water to the properties to the south of the flowpath.	MODERATE	The access track to the detention ponds has been lowered so not to increase risk to the properties.
FP10	Medium	No watercourses are nearby	Surface water ponding exists against the existing A96, no history of surface water flooding	No properties are located nearby	The proposed route is approximately 3m above the existing ground level. This is likely to lead to ponding against the proposed route embankment.	LOW	Sufficient pre-earth drainage has been incorporated into the design. Based on the fluvial results, a bypass channel has been included as a mitigation measure. This work is likely to allow the surface water flowpath to drain away before it reaches the Scheme.

[1] Structure number included in the design

Diagram 6: Map 2

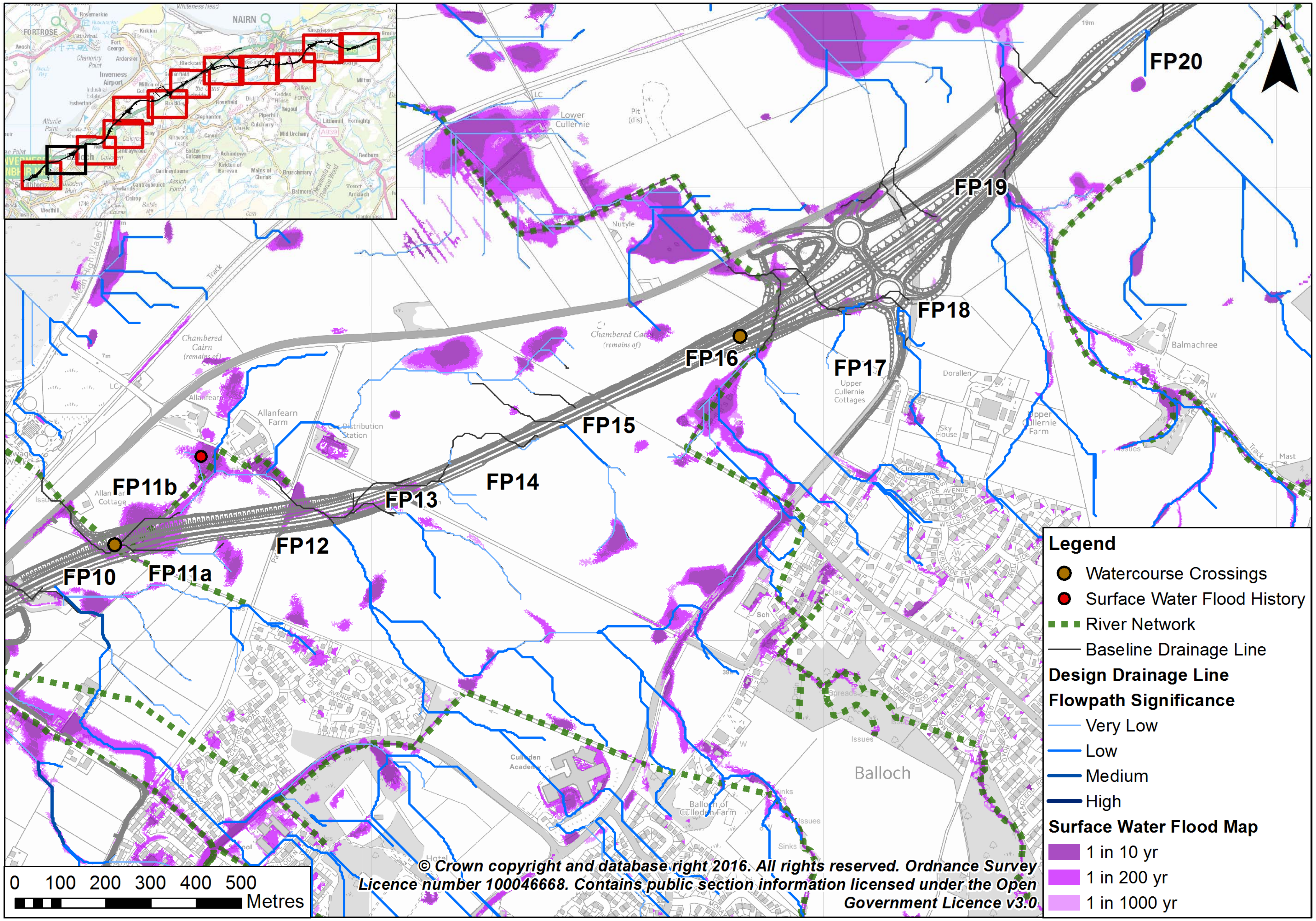

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Table 3: Surface Water Risk Assessment – Map 2

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 2							
FP11a	Very Low	The flowpath is likely to discharge into a local drain	Significant surface water ponding on the proposed route with no history of surface water flooding	No properties are located nearby	The surface water flow route would discharge into a local drain in the baseline scenario. However, the proposed route will disrupt the path. The proposed route is approximately 2.5m higher than the existing ground level. This would result in water ponding against the proposed embankment and possibly force the water west to the local drain.	LOW	The culvert capacity of the local drain (C06) needs to consider the additional surface water flow. In addition, there is sufficient pre-earthwork drainage incorporated into the design.
FP11b	Very Low	The flowpath is likely to discharge into a local drain	Significant surface water ponding on the proposed route with one incident of surface water flooding due to overland flow and flooded farmhouses and nearby land, upstream of the watercourse crossing	Farmhouses are located upstream and are situation approximately 1m higher than flowpath crossing level.	The existing local drain will be realigned as part of the works, however due to the significant amount of ponding, it is likely that ponding against the proposed embankment could occur. This could also have a negative impact on the properties located upstream.	HIGH	To reduce the flood risk to the nearby properties, it has been recommended to do minor landscaping and incorporate a bund around the area of Allanfearn Cottage to allow surface water to pond.
FP12	Low	No watercourses are nearby	The proposed route covers frequent surface water ponding against a footpath.	No properties are located nearby	The proposed route is approximately 1.5m above the existing ground level. This is likely to lead to ponding against the proposed route embankment.	MODERATE	To reduce the amount of surface water flooding on the footpath, additional pre-earthwork drainage has been incorporated into the design and will outfall to Allanfearn Drain (SWF07).
FP13	Very Low	No watercourses are nearby	There is surface water ponding where the proposed route disrupts the flow route	No properties are located nearby	The proposed footpath in this location is level with the existing ground level and the main carriageway is approximately 1m higher than the ground level. Based on the surface water flood map, the proposed route is likely to cause surface water ponding on the footpath.	MODERATE	To reduce the amount of surface water flooding on the footpath, additional pre-earthwork drainage has been incorporated into the design and will outfall to Allanfearn Drain (SWF07).
FP14	Very Low	No watercourses are nearby	There is a small extent of frequent surface water flooding, with no history of surface water flooding	No properties are located nearby	The main carriageway is approximately 1.2m higher than the ground level. Based on the surface water flood map, frequent surface water is likely to pond against the proposed embankment and due to similar ground levels, may affect the footpath to the west.	MODERATE	To reduce the amount of surface water flooding on the footpath, additional pre-earthwork drainage has been incorporated into the design and will outfall to Allanfearn Drain (SWF07).
FP15	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design and will outfall to Allanfearn Drain (SWF07).
FP16	Low	The flowpath is likely to discharge into Fiddler's Burn	There is a significant flow route of surface water flooding, both in-channel and within the floodplain	No properties are located nearby	This flowpath is likely to increase flow to the existing watercourse.	LOW	Culvert capacity of Fiddler's Burn (C07) needs to consider the additional surface water flow.
FP17	Low	No watercourses are nearby	There is a small extent of frequent surface water flooding, with no history of surface water flooding	No properties are located nearby	The proposed slip road in this location is below the existing ground level with the main carriageway approximately 5m higher than the ground level. Due to the surface water flood map, this is likely to result in frequent surface water ponding on the slip road.	MODERATE	To reduce the amount of surface water flooding on the slip road, additional pre-earthwork drainage has been incorporated into the design and will outfall to Fiddler's Burn (SWF08).
FP18	Low	No watercourses are nearby	There is a small extent of surface water ponding downstream, with no history of surface water flooding	No properties are located nearby	The proposed slip road is below the existing ground level. Due to the existing surface water ponding, it is likely that ponding occurs on the slip road.	MODERATE	To reduce the amount of surface water flooding on the slip road, a new culvert has been added to link the proposed pre-earthwork drainage and will outfall toFiddler's Burn (SWF08).
FP19	Medium	Newton Burn is located upstream, however it is unlikely that the flowpath will discharge into it.	There is a significant surface water flowpath that passes through the proposed route and ponds against the railway line.	Properties located upstream are ~15m higher than flowpath crossing level, therefore considered not at risk	The proposed slip road in this location is approximately 1m above the existing ground level with the main carriageway approximately 3m higher than the ground level. Due to the surface water flood map, the proposed route is likely to result in frequent surface water ponding on the slip road. The proposed route is also likely to force the water to the east, where the route cuts into the existing ground level. This could result in surface water flooding ponding on the main carriageway at this location.	HIGH	To reduce the amount of surface water flooding on the slip road and main carriageway, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Newton Burn (SWF09).

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 2							
FP20	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	At this location, the proposed route cuts into the existing ground level. This is likely to result in surface water ponding on the main carriageway.	MODERATE	To reduce the amount of surface water flooding on the road, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Newton Burn (SWF09).

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Diagram 7: Map 3

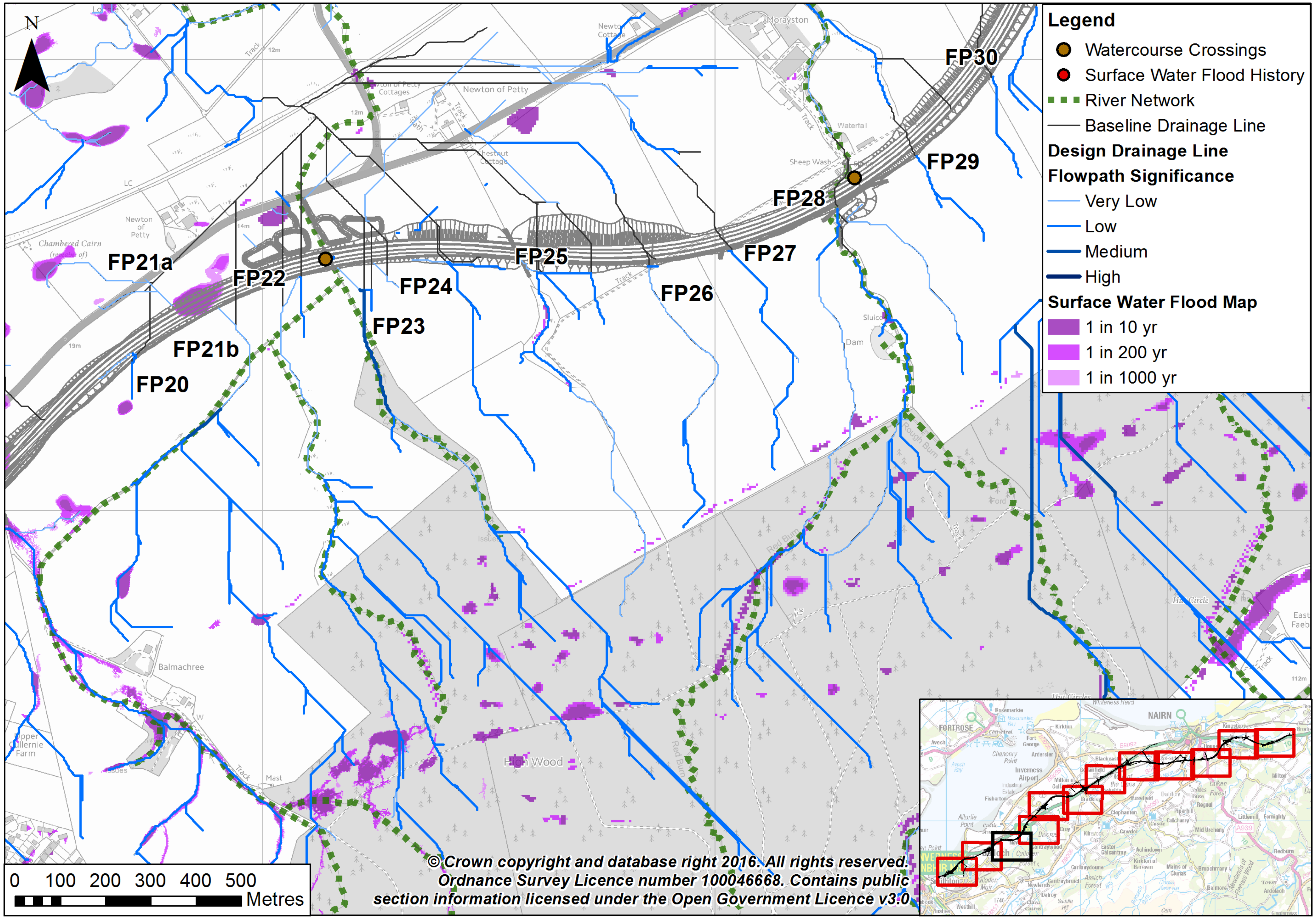

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Table 4: Surface Water Risk Assessment – Map 3

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 3							
FP21a	Very Low	No watercourses are nearby	There is frequent surface water ponding on the proposed route	No properties are located nearby	The proposed route is approximately 2m higher than the existing ground level. This is likely to result in frequent surface water ponding against the proposed embankment.	LOW	Additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Newton Burn (SWF09).
FP21b	Very Low	The flowpath is likely to discharge into Netwon Burn	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Newton Burn (C08) needs to consider the additional surface water flow.
FP22	Low	The flowpath is likely to discharge into Netwon Burn	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Newton Burn (C08) needs to consider the additional surface water flow.
FP23	Very Low	The flowpath is likely to discharge into Netwon Burn	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Newton Burn (C08) needs to consider the additional surface water flow.
FP24	Low	Newton Burn is located to the west	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	The proposed route is approximately 6m higher than the existing ground level. Any surface water flooding is likely to pond against the embankment. Based on LiDAR and the rolling ball analysis, it is likely that the proposed embankment could force the water to the west towards Newton Burn.	LOW	Additional pre-earthwork drainage has been incorporated into the design to allow water to flow towards Newton Burn (SWF09). Culvert capacity of Newton Burn therefore needs to consider the additional surface water flow.
FP25	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	The proposed route is approximately 8m higher than the existing ground level. Any surface water flooding is therefore likely to pond against the proposed embankment. The design includes an access track underneath the new road. It is likely that any surface water flooding would flow onto the access track.	LOW	To reduce the amount of surface water flooding on the access track, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Newton Burn (SWF09).
FP26	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Newton Burn (SWF09).
FP27	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Newton Burn (SWF09).
FP28	Low	The flowpath is likely to discharge into the realigned Rough Burn	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	This flowpath is likely to impact on the new culvert design.	LOW	Culvert capacity of Rough Burn (C09) needs to consider the additional surface water flow.
FP29	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to SWF13.
FP30	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to SWF13.

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Diagram 8: Map 4

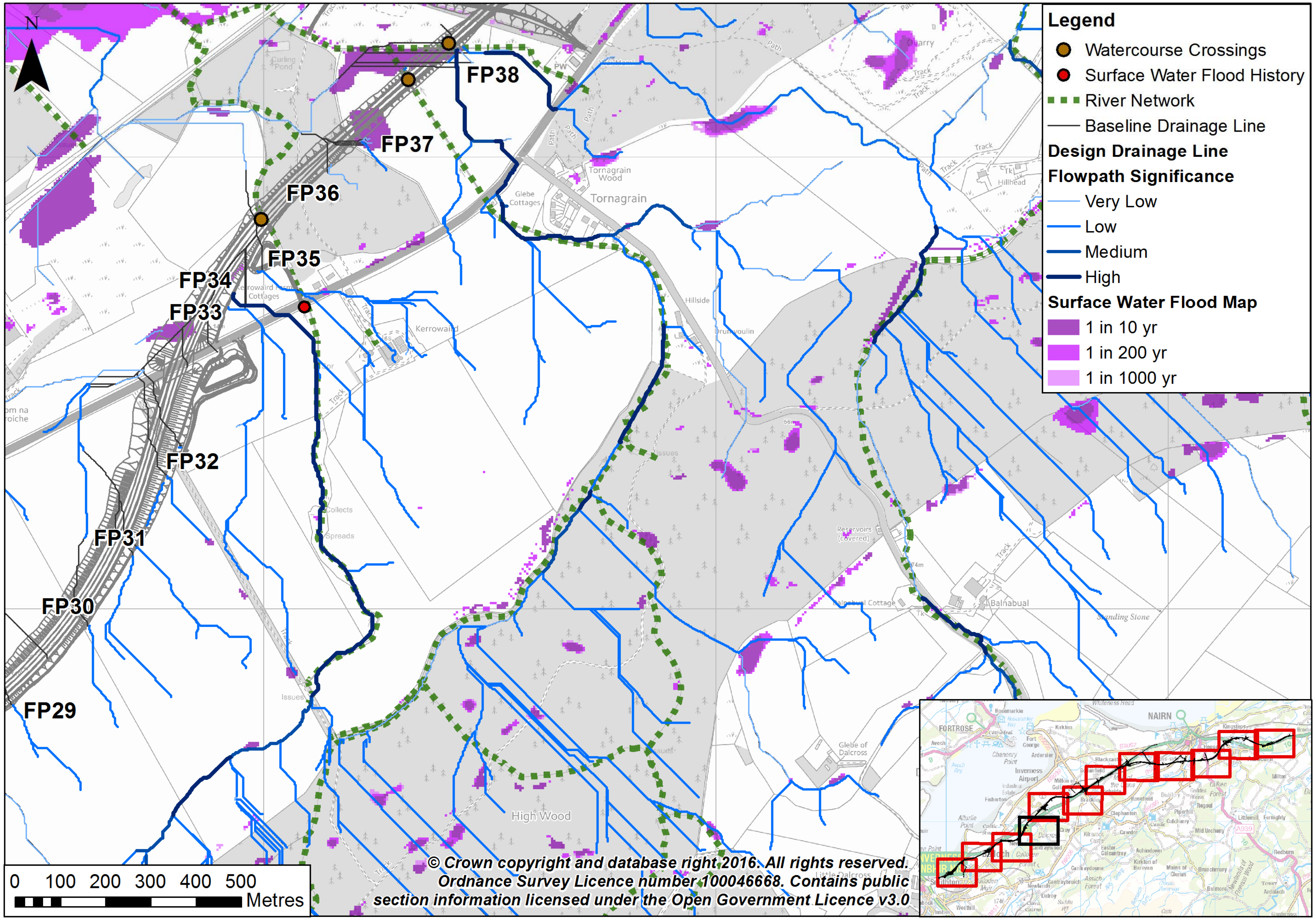

Table 5: Surface Water Risk Assessment – Map 4

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 4							
FP31	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design and will outfall toSWF13.
FP32	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design and will outfall toSWF13.
FP33	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	The new swale outfall from the detention pond will cut off this flowpath and will outfall toSWF13.
FP34	High	The flowpath is likely to discharge into Kerrowaird	There is no risk of surface water flooding in SEPA's flood map, but there is one incident of surface water flooding where there is occasional runoff onto the existing A96.	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse. With regards to the history of flooding, there is a detention pond proposed in the design, which should help reduce the occasional runoff flooding.	LOW	Culvert capacity of Kerrowaird (C10) needs to consider the additional surface water flow. The new swale outfall from the detention pond will cut off this flowpath and will outfall toSWF13.
FP35	Low	The flowpath is likely to discharge into Kerrowaird	There is no risk of surface water flooding in SEPA's flood map, but there is one incident of surface water flooding where there is occasional runoff onto the existing A96.	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Kerrowaird (C10) needs to consider the additional surface water flow.
FP36	Very Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design and will outfall toSWF14.
FP37	Low	No watercourses are nearby	The surface water flood map suggests frequent ponding at this location. However, there is no history of surface water flooding in this area.	No properties are located nearby	The proposed route is approximately 6m higher than the existing ground level. This is likely to result in frequent surface water ponding against the proposed embankment.	LOW	Additional pre-earthwork drainage has been incorporated into the design and will outfall toSWF14.
FP38	High	There is Tornagrain Farm to the west and Tornagrain Wood to the east. The flowpath is likely to discharge into both of these watercourses	There is significant frequent ponding of surface water in the SEPA flood map with no history of surface water flooding	No properties are located nearby	The proposed route is approximately 4m higher than the existing ground level. This is likely to result in frequent surface water ponding against the proposed embankment.	LOW	Culvert capacities of Tornagrain Farm (C11) and Tornagrain Wood (C12) need to consider the additional surface water flow.

Diagram 9: Map 5

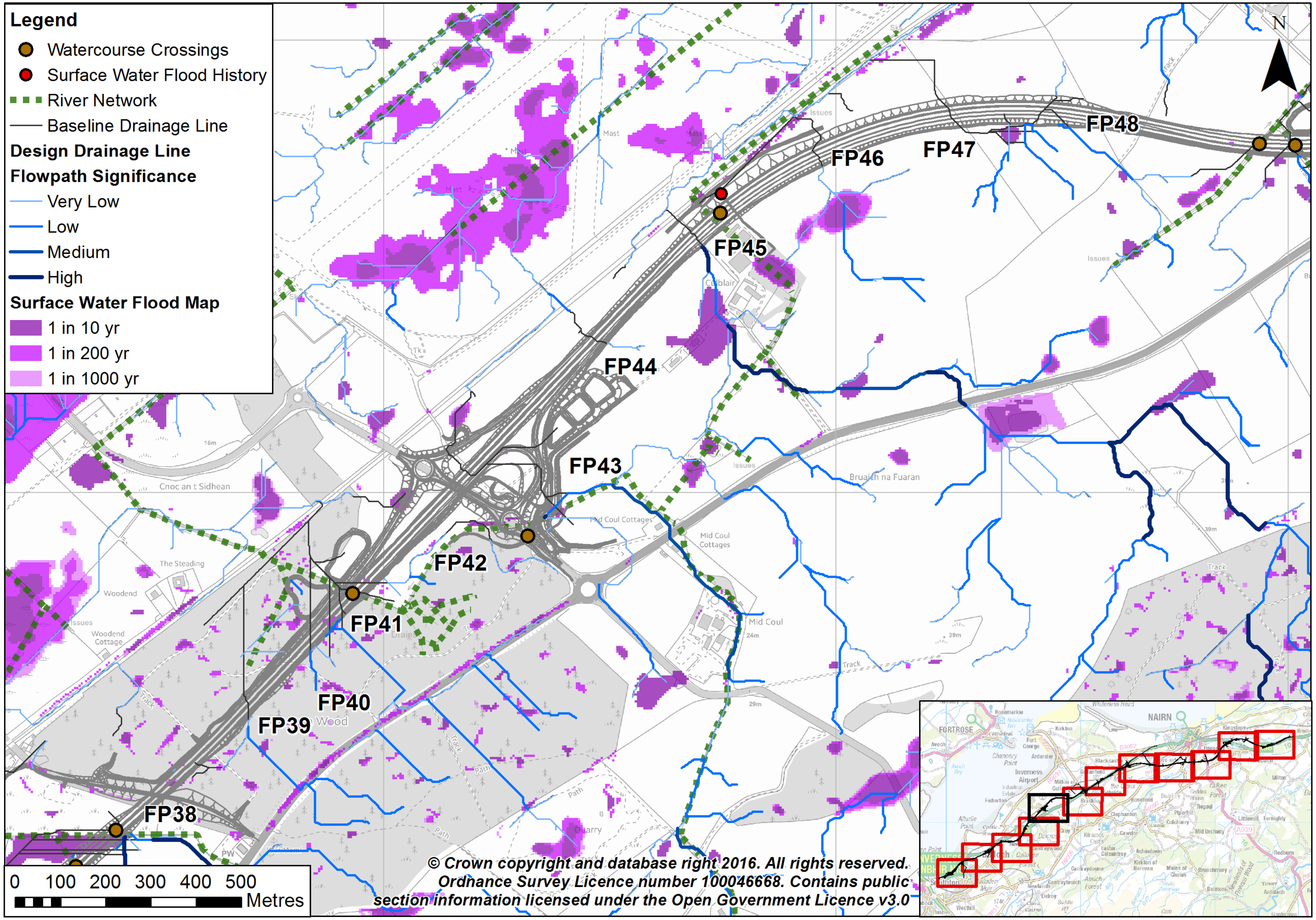

Table 6: Surface Water Risk Assessment – Map 5

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 5							
FP39	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Tributary of Ardersier Burn (SWF16).
FP40	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Tributary of Ardersier Burn (SWF16).
FP41	Low	No watercourses are nearby	There is a small extent of surface water ponding shown in SEPA's surface water flood map. However, there is no history of surface water flooding	No properties are located nearby	The proposed route is approximately 1.5m higher than the existing ground level. This is likely to result in surface water ponding against the proposed embankment.	LOW	Additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Tributary of Ardersier Burn (SWF16).
FP42	Very Low	Dalcross watercourse is in close proximity to the fowpath but it is unlikely that the two will intersect	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	N/A
FP43	Low	The flowpath is likely to discharge to the realigned Mid Coul watercourse	There is a small extent of frequent surface water ponding with no history of surface water flooding	No properties are located nearby	The proposed route is approximately 0.8m higher than the existing ground level. This is likely to result in surface water ponding against the proposed embankment.	LOW	To reduce the amount of surface water flooding, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to Tributary of Ardersier Burn (SWF16).
FP44	Very Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No, properties located upstream are ~1.5m higher than flowpath	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties at risk, it is considered there is a low impact from/on this flowpath.	LOW	Sufficient pre-earthwork drainage has been incorporated into the design.
FP45	High	The flowpath is likely to discharge into the Culblair watercourse before the watercourse goes into culvert	There is frequent surface water ponding upstream of the proposed route. However, there is no history of surface water flooding	No, properties located upstream are ~1m higher than flowpath crossing level	Should surface water flows overtop Culblair watercourse, where it meets the proposed route, the embankment is ~3m higher than existing ground level. This is likely to result in surface water ponding against the proposed embankment.	LOW	Additional pre-earthwork drainage has been incorporated into the design, which links to the existing culvert. The water collected will outfall to Culblair Farm drain (SWF36).
FP46	Very Low	No watercourses are nearby	There is frequent surface water ponding upstream of the proposed route. However, there is no history of surface water flooding	No properties are located nearby	The proposed route is approximately 4m higher than the existing ground level. This is likely to result in surface water ponding against the proposed embankment.	LOW	Additional pre-earthwork drainage has been incorporated into the design, which links to the existing culvert. The water collected will outfall to Culblair Farm drain (SWF36).
FP47	Low	No watercourses are nearby	There is frequent surface water ponding adjacent to the proposed route, with no history of surface water flooding	No properties are located nearby	The proposed route is approximately 5m higher than the existing ground level. This is likely to result in surface water ponding against the proposed embankment.	LOW	Additional pre-earthwork drainage has been incorporated into the design, which links to the existing culvert. The water collected will outfall to Culblair Farm drain (SWF36).
FP48	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties at risk, it is considered there is a low impact from/on this flowpath.	LOW	Additional pre-earthwork drainage has been incorporated into the design, which links to the existing culvert. The water collected will outfall to Culblair Farm drain (SWF36).

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Diagram 10: Map 6

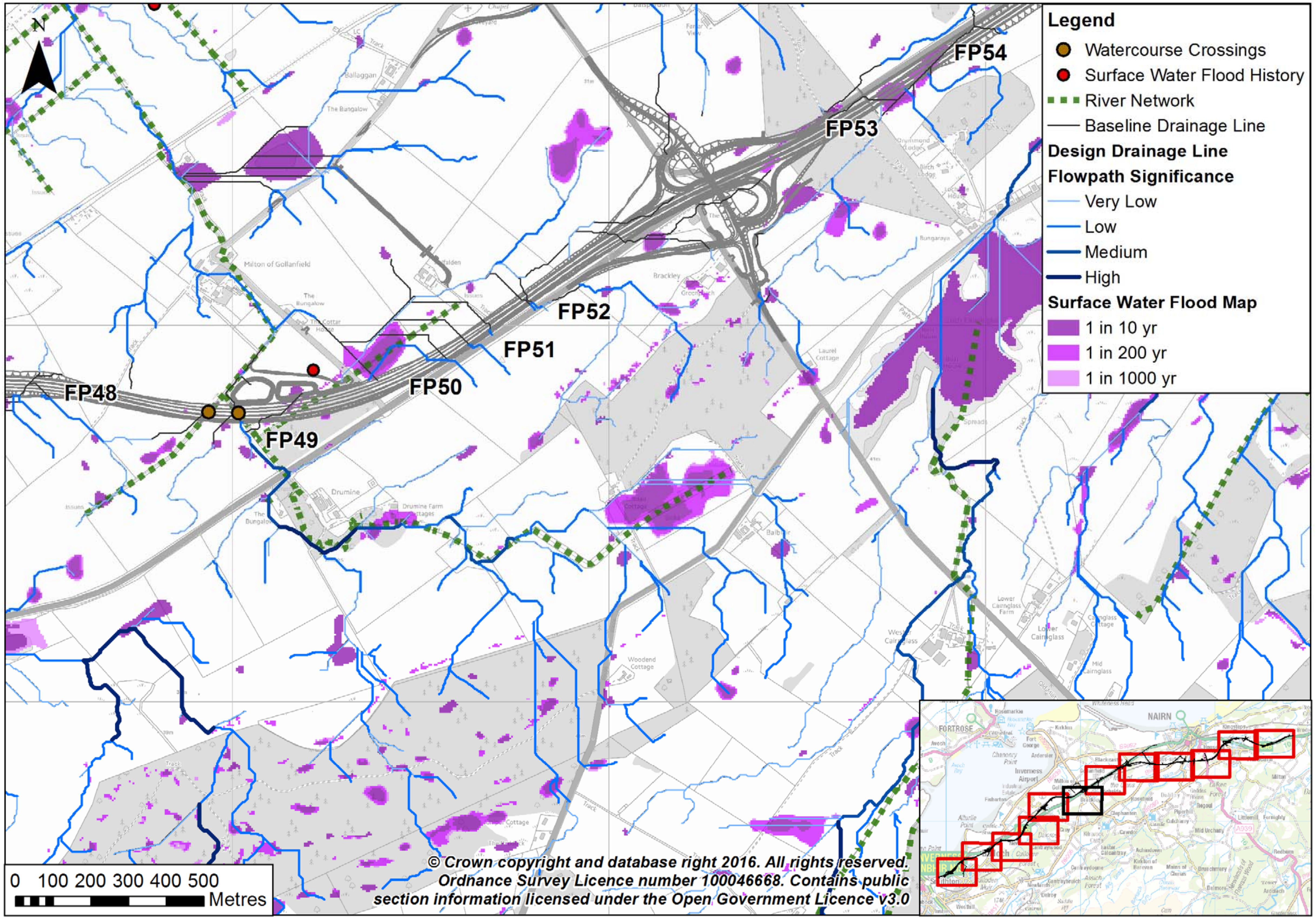

Table 7: Surface Water Risk Assessment – Map 6

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 6							
FP49	Low	The flowpath is likely to discharge into Drumine Burn	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of Drumine Burn (C16) needs to consider the additional surface water flow.
FP50	Low	A local drain is located downstream	There is frequent surface water ponding adjacent to the proposed route,. However, there is no history of surface water flooding	No properties are located nearby	The rolling ball analysis indicates that the flow route travels over the proposed route and will pond north of the new road. The proposed route is approximately 2m higher than the existing ground level at this location. This is likely to result in surface water ponding against the proposed embankment.	LOW	This flowpath would be intercepted by the existing A96 drainage network. Therefore, no further consideration is required.
FP51	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	This flowpath would be intercepted by the existing A96 drainage network. Therefore, no further consideration is required.
FP52	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	This flowpath would be intercepted by the existing A96 drainage network. Therefore, no further consideration is required.
FP53	Very Low	No watercourses are nearby	There is frequent surface water ponding adjacent to the proposed route, with no history of surface water flooding	No, properties located upstream are ~10m higher than flowpath crossing level	At this location, the proposed route cuts into the existing ground level. This is likely to result in frequent surface water ponding on the main carriageway.	HIGH	To reduce the amount of surface water flooding on the main carriageway, additional pre-earthwork drainage has been incorporated into the design, which links to the new culvert at FP55.
FP54	Low	No watercourses are nearby	There is frequent surface water ponding adjacent to the proposed route, with no history of surface water flooding	No properties are located nearby	At this location, the proposed route cuts into the existing ground level. This is likely to result in frequent surface water ponding on the main carriageway.	HIGH	To reduce the amount of surface water flooding on the main carriageway, additional pre-earthwork drainage has been incorporated into the design, which links to the new culvert at FP55.

Diagram 11: Map 7

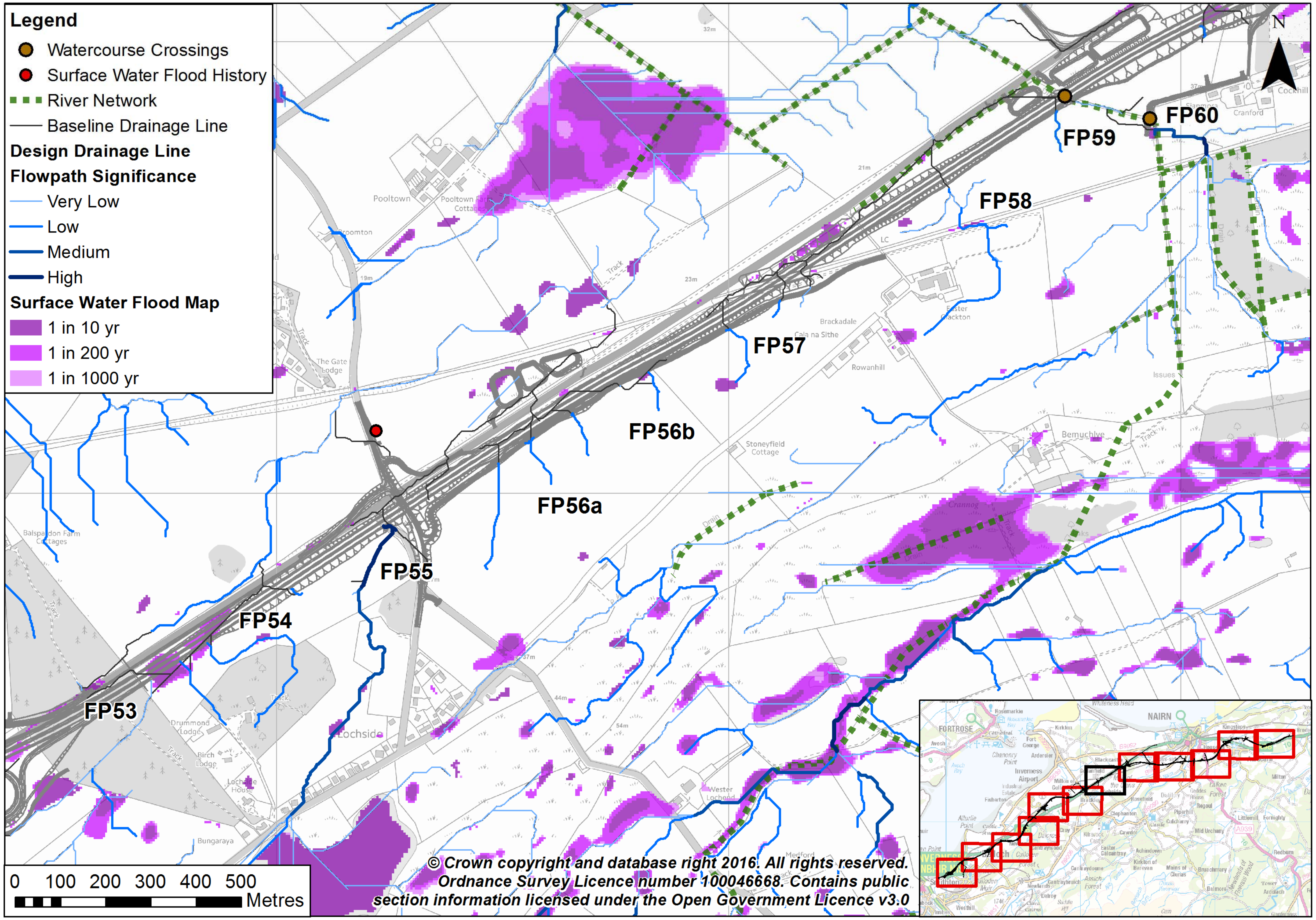

Table 8: Surface Water Risk Assessment – Map 7

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 7							
FP55	High	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	At this location, the proposed route cuts into the existing ground level. This is likely to result in frequent surface water ponding on the main carriageway.	HIGH	To reduce the amount of surface water flooding on the main carriageway, a new culvert has been incorporated into the design.
FP56a	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on these flowpaths.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to a soakaway.
FP56b	Low	No watercourses are nearby	There is frequent surface water ponding adjacent to the proposed route, with no history of surface water flooding	No properties are located nearby	At this location, the proposed route cuts into the existing ground level. This is likely to result in frequent surface water ponding on the slip road.	MODERATE	To reduce the amount of surface water flooding on the slip road, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to a soakaway.
FP57	Low	No watercourses are nearby	There is a small extent of frequent surface water ponding located upstream of the proposed route with no history of surface water flooding	No properties are located nearby	At this location, the proposed route cuts into the existing ground level. This is likely to result in surface water ponding on the main carriageway.	LOW	To reduce the amount of surface water flooding on the road, additional pre-earthwork drainage has been incorporated into the design. The water collected will outfall to a soakaway.
FP58	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	The existing railway drainage culvert in this location will likely to allow the surface water flowpath to drain away before it reaches the Scheme.
FP59	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the Alton Burn (SWF19).
FP60	Medium	The flowpath is likely to discharge into the Blackcastle watercourse	There is a small extent of frequent surface water ponding located on the proposed route with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacities of Blackcastle (C17 and minor road) needs to consider the additional surface water flow.

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Diagram 12: Map 8

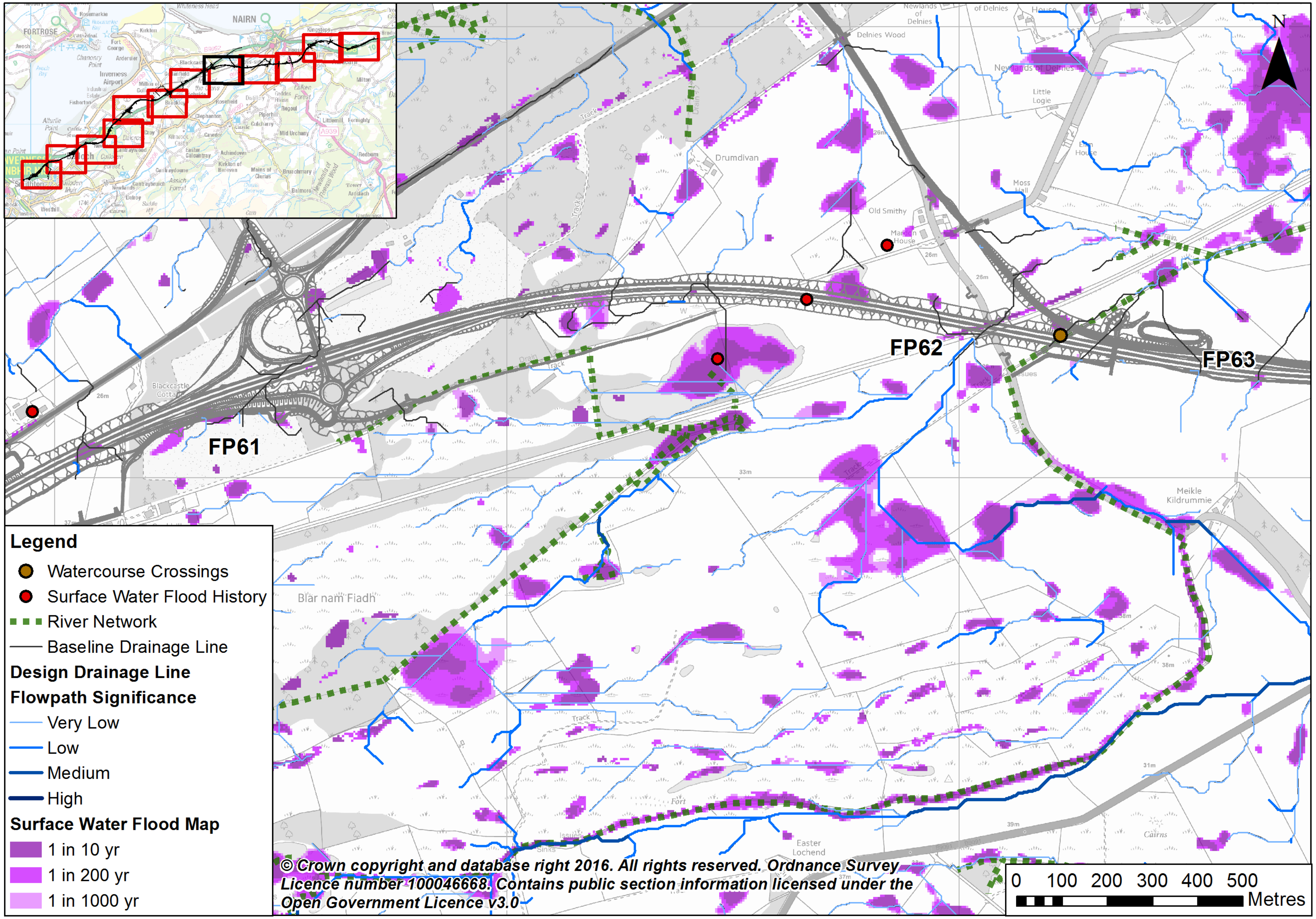

Table 9: Surface Water Risk Assessment – Map 8

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 8							
FP61	Very Low	No watercourses are nearby	There is a small extent of frequent surface water ponding located on the proposed route. However, there isno history of surface water flooding	No, properties located upstream are ~6m higher than flowpath crossing level	At this location, the proposed slip road is located level with the existing ground level, with the main carriageway 2m higher. This is likely to result in frequent surface water flooding on the slip road.	MODERATE	To reduce the amount of surface water flooding on the slip road, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the SWF21.
FP62	Low	No watercourses are nearby	There is a frequent surface water flow route along the existing railway line.	No properties are located nearby	At this location, the proposed route is ~10m higher than the existing ground level. The railway line is cut in below the proposed route and is an existing low spot in the area, where there is a surface water flow route. The proposed route is unlikely to increase the risk of surface water flooding to the railway line.	LOW	Additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the Alton Burn (SWF22).
FP63	Very Low	No watercourses are nearby	There is a small extent of surface water ponding located on the proposed route with no history of surface water flooding	No properties are located nearby	At this location, the proposed route is 0.5m higher than the existing ground level. Due to the very low flowpath significance, small extent of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the Alton Burn (SWF22).

Diagram 13: Map 9

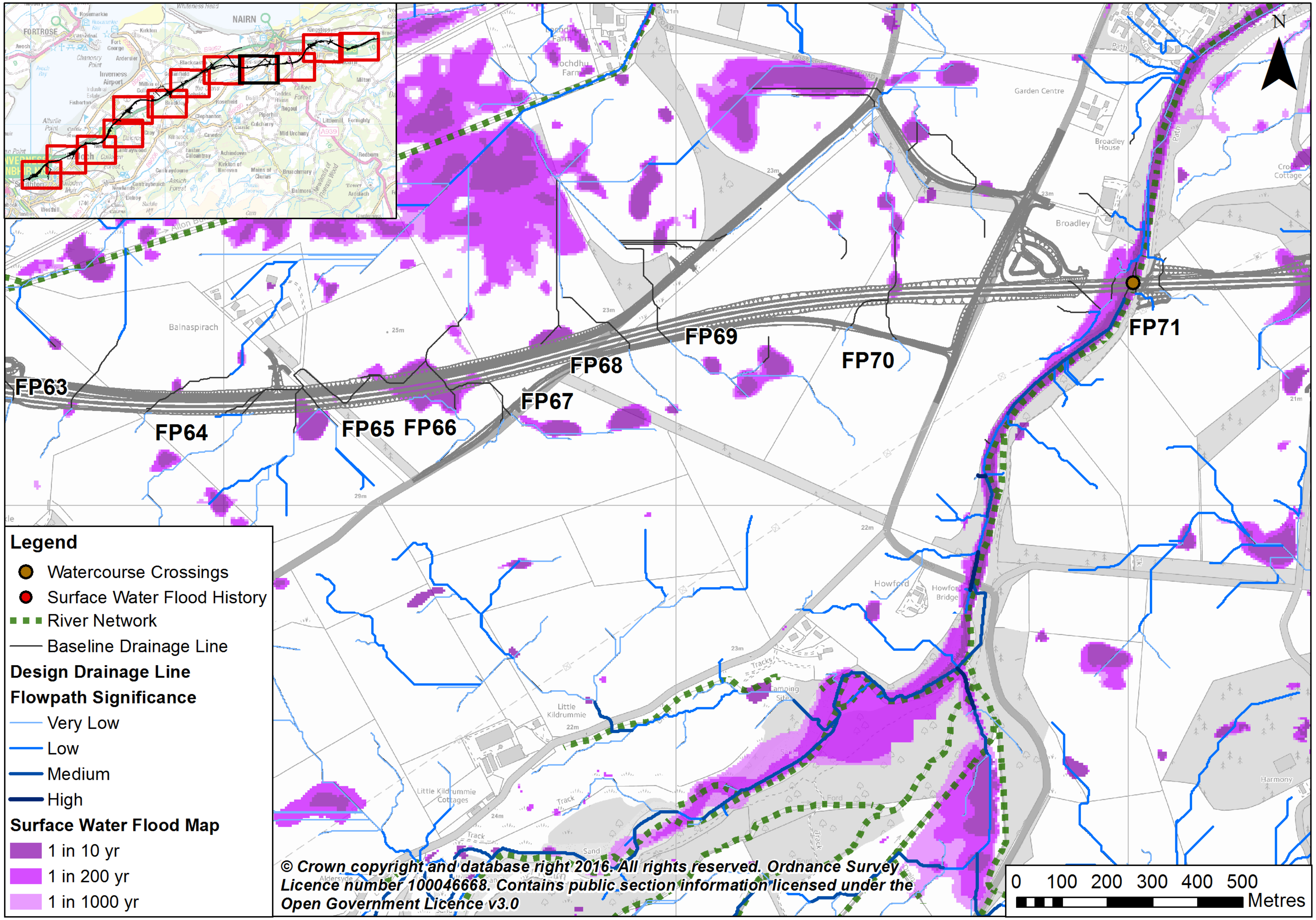

Table 10: Surface Water Risk Assessment – Map 9

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 9							
FP64	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP65	Very Low	No watercourses are nearby	There is a small extent of frequent surface water ponding located on the proposed route with no history of surface water flooding	No properties are located nearby	The proposed route is ~3m higher than the existing ground level. Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	Additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP66	Very Low	No watercourses are nearby	There is a significant frequent surface water ponding on the proposed route with no history of surface water flooding	No properties are located nearby	The proposed route is ~5m higher than the existing ground level. The proposed embankment is likely to force surface water to pond against the route, however this may have negative impact on the proposed slip road located to the south.	MODERATE	To reduce the amount of surface water flooding on the slip road, additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP67	Very Low	No watercourses are nearby	There is a small extent of frequent surface water ponding upstream of the proposed slip road with no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, the location of the potential surface water ponding and no properties in close proximity, it is unlikely that the proposed slip road is at risk or increases the risk of surface water flooding.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP68	Very Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP69	Very Low	No watercourses are nearby	There is a small extent of frequent surface water ponding upstream of the proposed slip road with no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP70	Very Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. Connection to infiltration is awaiting ground investigation results.
FP71	Medium	The flowpath is likely to discharge into the River Nairn	In-channel extent of 1 in 30yr and floodplain extent of the 1 in 200yr with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of River Nairn (PS14) needs to consider the additional surface water flow.

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Diagram 14: Map 10

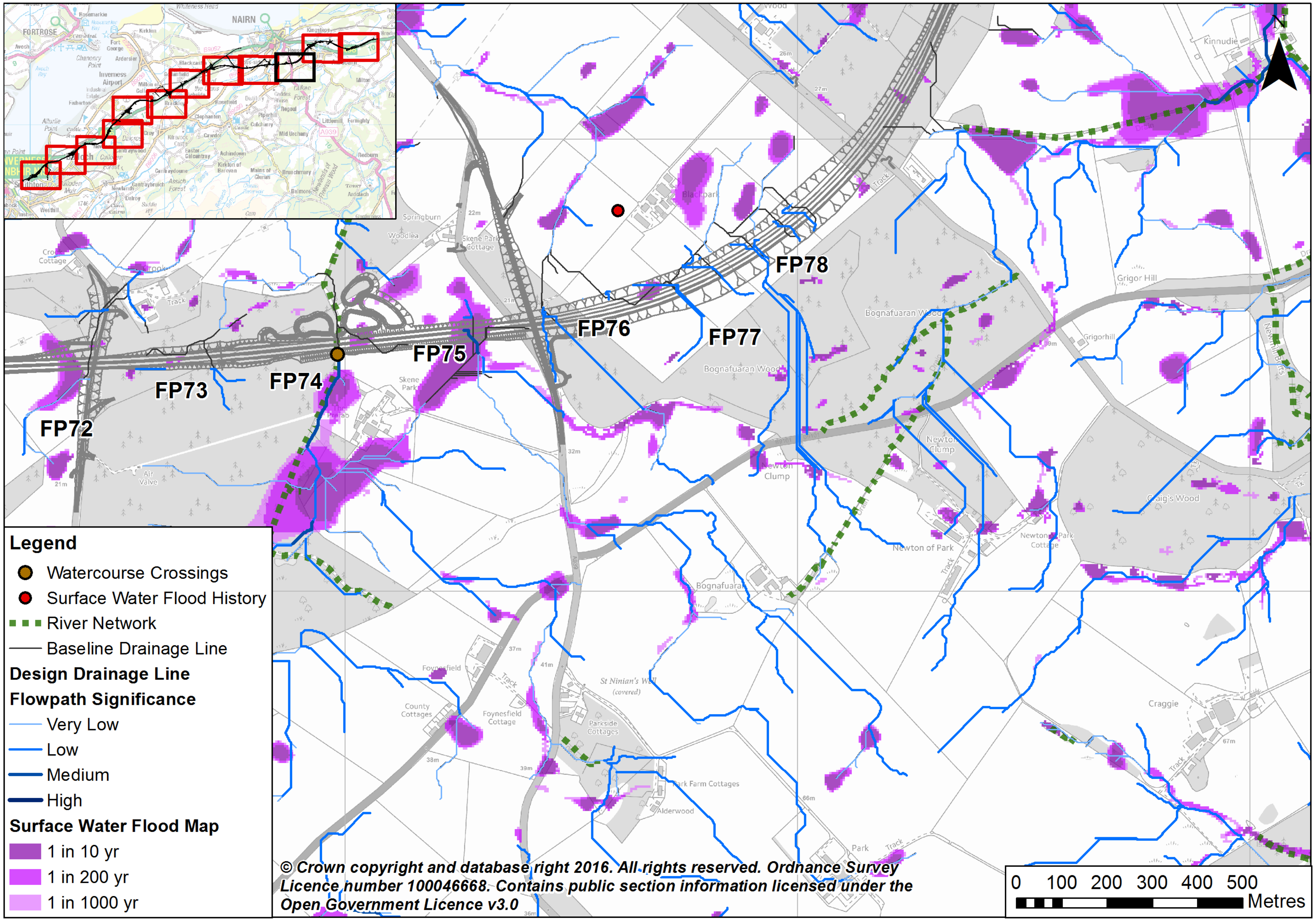

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Table 11: Surface Water Risk Assessment – Map 10

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 10							
FP72	Very Low	No watercourses are nearby	There is a significant frequent surface water ponding on the proposed route. However, there is no history of surface water flooding	No properties are located nearby	At this location, the proposed route is ~0.5m above the existing ground level. An additional road runs perpendicular to the main carriageway. In the design, this road is modified to cut into the existing ground level. The proposed main carriageway is likely to force frequent surface water ponding on the perpendicular road.	HIGH	To reduce the amount of surface water flooding on the perpendicular road, it has been recommended to place a bund on the adjacent land to the west to store water and slowly release the water into the pre-earthwork drainage and outfall at SWF24.
FP73	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the SWF24.
FP74	Medium	The flowpath is likely to discharge into the Knocknagillan watercourse	There is a significant extent of frequent surface water ponding upstream of the proposed route with no history of surface water flooding	No properties are located nearby	This flowpath is likely to increase flow to existing watercourse.	LOW	Culvert capacity of River Nairn (C19) needs to consider the additional surface water flow.
FP75	Medium	No watercourses are nearby	There is a significant extent of frequent surface water ponding upstream of the proposed route with no history of surface water flooding	No, properties located upstream are ~1m higher than the crossing level	At this location, the proposed route cuts into the existing ground level. This is likely to result in frequent surface water ponding on the proposed road. Upstream of this location, the flowpath travels over a perpendicular road. This road is proposed to be level with the existing ground levels, therefore, the existing surface water flowpath will not be impeded by the design.	HIGH	To reduce the amount of surface water flooding on the proposed route and the perpendicular road, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the SWF24.
FP76	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the SWF24.
FP77	Low	No watercourses are nearby	There is a small extent of frequent surface water ponding located on the proposed route with no history of surface water flooding	No properties are located nearby	At this location, the proposed route cuts into the existing ground level. This is likely to result in frequent surface water ponding on the proposed road.	MODERATE	To reduce the amount of surface water flooding on the proposed route, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the SWF24.
FP78	Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	There are a number of flow routes at this location and the proposed route cuts into the existing ground level. Therefore, this is likely to result in frequent surface water ponding on the proposed road.	MODERATE	To reduce the amount of surface water flooding on the proposed route, additional pre-earthwork drainage has been incorporated into the design. The water collected will be discharged to the SWF24.

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Diagram 15: Map 11

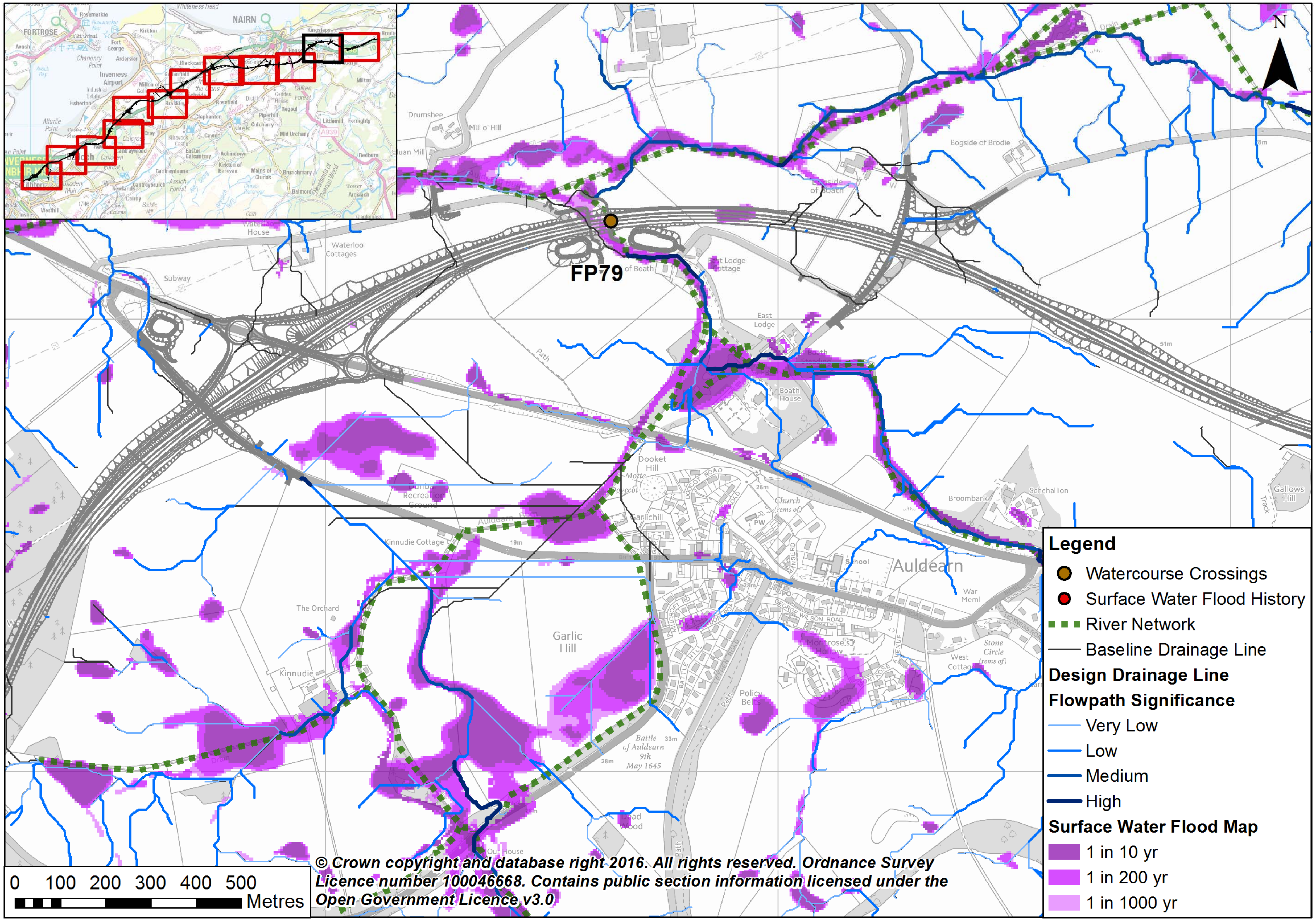

Table 12: Surface Water Risk Assessment – Map 11

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 11							
FP79	High	The flowpath is likely to discharge into the realigned Auldearn Burn	In-channel extent of 1 in 200yr with no history of surface water flooding	Yes, properties are located either side of Auldearn Burn are at similar level to the existing ground level.	This flowpath is likely to increase flow to existing watercourse.	MODERATE	Culvert capacity of Auldearn Burn (C21) needs to consider the additional surface water flow so that the proposed route does not increase the risk to the surrounding properties.

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Diagram 16: Map 12

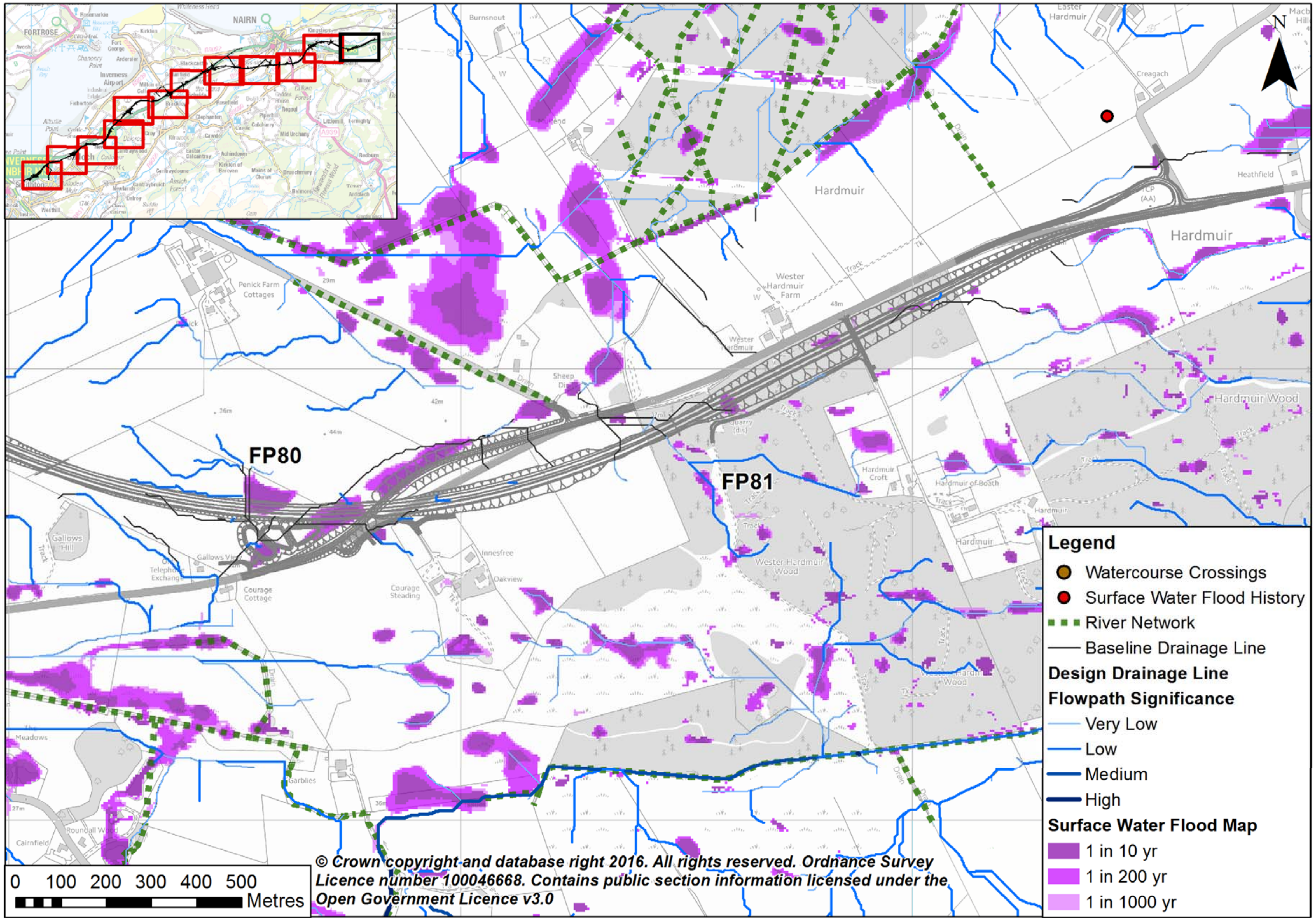

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Table 13: Surface Water Risk Assessment – Map 12

Flowpath ID	Flowpath Significance	Existing Watercourse	Surface Water Flooding	Receptors at risk	Impact	Risk	Further Consideration
Map 12							
FP80	Low	No watercourses are nearby	There is frequent surface water ponding upstream of the proposed slip road with no history of surface water flooding	No properties are located nearby	The proposed route is approximately 2m higher than the existing ground level. However, the proposed embankment is likely to force water onto the road further downstream.	HIGH	Additional pre-earthwork drainage has been incorporated into the design, which will connect to a new culvert at this location. The water collected will be discharged to the SWF35.
FP81	Very Low	No watercourses are nearby	There is no risk of surface water flooding in SEPA's flood map and no history of surface water flooding	No properties are located nearby	Due to the very low flowpath significance, no risk of surface water flooding from SEPA's flood map and no properties in close proximity, it is considered there is a low impact from/on this flowpath.	LOW	As a precautionary measure, additional pre-earthwork drainage has been incorporated into the design and will drain to the nearby detention ponds.

Surface Water Ponding

3.4 There are some locations where, based on SEPA's flood map for surface water, small extents of surface water ponding are not associated with the surface water flow routes calculated from the rolling ball analysis. Therefore, they have not been included in the assessment outlined in Table 3.1. However, surface water flood risk at these locations is addressed in the drainage design.

3.5 Where ponding is located where the proposed route is cut in, it is recommended that the capacity of the proposed highway drainage includes these additional flows. If ponding occurs where the proposed route will be raised, it is likely that the surface water extent will be forced to pond against the proposed embankment. Where this occurs, sufficient toe drainage needs to be included in the design, with discharge into a nearby watercourse (or joining with another natural flow path) to allow the flow to the passed under the highway via a culvert.

4 Conclusions and Recommendations

4.1 A rolling ball analysis was undertaken as part of this assessment to estimate overland flow routes. This technical note assessed each of these overland flowpaths (Tables 2 to 3.13) to determine if the proposed route was at risk of surface water flooding or if it would increase the risk of surface water flooding elsewhere.

4.2 Through the assessment, it was determined that there are a number of existing or new culverts where surface water flows would need to be included in the culvert capacity to allow conveyance of these flows in addition to the runoff generated from the highway. As the design hydrology flood flows was calculated at each of these locations, it has been assumed that these surface water flows are included in the inflows and therefore have already been considered in the culvert capacity calculations and hydraulic modelling.

4.3 There are some locations where water is likely to pond against the proposed embankments. New culverts or additional pre-earthwork drainage have been incorporated into the design to make sure that the water can drain away appropriately and will not increase the flood risk downstream.

4.4 Where the proposed route cuts into the existing ground level in a location that could intersect a surface water flow path, an increase in surface water flooding to the road is likely. Where necessary, additional pre-earthwork drainage has been included in the design to allow surface water to drain away before affecting the road.

4.5 There are a few locations where surface water ponding has not be assessed in Tables 2 to 13 as they were not associated with the flowpaths identified by the rolling ball analysis. However, it has been assumed that the surface water flood map has been considered in the drainage assessment prior to this work, and therefore at these locations indicated by the SEPA flood map, suitable drainage arrangements are in place.

5 References

Defra (2010). Surface Water Management Plan Technical Guidance [Online] Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69342/pb13546-swmp-guidance-100319.pdf [Accessed 5 August 2016]

Scottish Environment Protection Agency (2015). Flood Maps [Online]: Available from www.map.sepa.org.uk/floodmap/map.htm [Accessed March 2016]

1 Methodology

1.1 A high-level qualitative screening assessment was undertaken to determine if the proposed Scheme would be at risk if an existing structure downstream became blocked.

1.2 This assessment focused on existing structures 1km downstream of the proposed Scheme. The invert outlet levels of the proposed culverts were used to compare to the crest level of the existing structures. Where the crest level of the existing structures were below the invert level of the proposed culverts, the assessment assumed that a blockage of this structure would not have a back water affect that could impact on the proposed Scheme.

1.3 However, where the existing structure crest levels were above the proposed invert levels, further analysis was undertaken. This further analysis included the following tasks:

- Elevation data was investigated to determine if there was another route for the water to go, indicating that it was unlikely that the proposed Scheme would be affected.
- In locations where the water could not go anywhere else, an analysis on whether the blockage would occur at the existing structure or if a structure upstream of this would be the blockage control, reducing the risk of blockage at that particular structure.
- If the existing structure was still imposing a risk to the proposed Scheme, an analysis on volume available was undertaken. Based on elevation data of where water would pond, it was determined if there was sufficient volume naturally available, so that the proposed Scheme would not be affected.

1.4 Table 1 illustrates the results of this screening assessment.

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Table 1: Screening Assessment Results

Watercourse Crossing	Culvert Number	Structure	Proposed Outlet Invert Level (mAOD)	Existing Structure "Crest" Level (mAOD)	Difference (m)	Flowpath Analysis Required (Yes/No)	Is there another route for the water? (Yes/No)	Comments	Further Analysis Required (Yes/No)	Volume Available	Detailed modelling required?
SWF02-1	C02	Railway	12.03	7.95	*-4.08*	NO	N/A		NO	N/A	N/A
		Access Track	12.03	5.25	*-6.78*	NO	N/A		NO	N/A	N/A
SWF03-1	C03	Pipe crossing	12.96	13.89	*0.93*	YES	No	If the pipe crossing was to become blocked, water is likely to back up and pond in the natural floodplain. There is likely to be significant volume available upstream of the pipe crossing and upstream of Barn Church Road without impacting the proposed Scheme as the route is approximately 7m higher than existing ground levels.	YES	YES	NO
SWF03-4	C04	Road	6.67	9.38	*2.71*	YES	No	If the minor road was to become blocked, water is likely to back up and pond in the natural floodplain upstream. There is likely to be significant volume available without impacting the proposed Scheme as the route is approximately 7m higher than existing ground levels at the minor road.	YES	YES	NO
		Railway	6.67	9.57	*2.90*	YES	No	Culvert C04 is located upstream of the railway line. Due to the size of the proposed culvert (1.5m x 1.25m), it is likely that the culvert C04 becomes blocked before the railway line.	No	N/A	N/A
		Existing A96	6.67	9.02	*2.35*	YES	No	Culvert C04 is located upstream of the existing A96. Due to the size of the proposed culvert (1.5m x 1.25m), it is likely that the culvert C04 becomes blocked before the existing A96.	No	N/A	N/A
SWF06-1	C05	Road	10.37	9.38	*-0.99*	NO	N/A		NO	N/A	N/A
SWF07-1	C06	Existing A96	15.20	16.27	*1.07*	YES	Yes	If the existing A96 was to become blocked, water is likely to overtop the road at a low spot along the road. This low spot is lower than the proposed outlet invert level, and therefore a blockage at the existing A96 is unlikely to impact on the proposed Scheme at this location.	NO	N/A	N/A
		Railway	15.20	13.57	*-1.63*	NO	N/A		NO	N/A	N/A
SWF08-1	C07	Existing A96	21.65	19.94	*-1.71*	NO	N/A		NO	N/A	N/A
		Road	21.65	16.34	*-5.31*	NO	N/A		NO	N/A	N/A
		Railway	21.65	15.53	*-6.12*	NO	N/A		NO	N/A	N/A
SWF09-1	C08	Existing A96	13.25	13.94	*0.69*	YES	Yes	If the existing A96 was to become blocked, water is likely to overtop the road at a low spot along the road. This low spot is lower than the proposed outlet invert level, and therefore a blockage at the existing A96 is unlikely to impact on the proposed Scheme at this location.	NO	N/A	N/A
		B9039	13.25	11.13	*-2.12*	NO	N/A		NO	N/A	N/A
		Railway	13.25	10.50	*-2.75*	NO	N/A		NO	N/A	N/A
		B9039	13.25	8.18	*-5.07*	NO	N/A		NO	N/A	N/A
SWF12-1	C09	Access Track	41.11	42.97	*1.86*	YES	No	If the access track was to become blocked, water is likely to back up through the proposed Scheme culvert. Based on the blockage assessment through hydraulic modelling, it was determined that with the proposed culvert blocked, water would overtop the right bank and flow away from Rough Burn along the toe of the embankment. The proposed Scheme is approximately 2m above the existing ground levels and is considered out of flood risk.	YES	YES	NO
		Access Track	41.11	40.69	*-0.42*	NO	N/A		NO	N/A	N/A
		Access Track	41.11	20.73	*-20.38*	NO	N/A		NO	N/A	N/A
		Existing A96	41.11	19.26	*-21.85*	NO	N/A		NO	N/A	N/A
		Access Track	41.11	10.58	*-30.53*	NO	N/A		NO	N/A	N/A
		Railway	41.11	12.77	*-28.34*	NO	N/A		NO	N/A	N/A
SWF13-1	C10	Railway	11.65	9.04	*-2.61*	NO	N/A		NO	N/A	N/A
SWF14-1	C11	Access Track	9.35	9.91	*0.56*	YES	No	If the access track was to become blocked, water is likely to back up and pond upstream of the proposed Scheme. There is likely to be significant volume available upstream of the proposed Scheme without impacting the Scheme as the route is approximately 5m higher than existing ground levels. In addition, the existing A96 (located upstream of the proposed Scheme) is 1m higher than the proposed Scheme, and is unlikely be affected if the track was to become blocked and water ponded upstream of the proposed Scheme.	YES	YES	NO
		Railway	9.35	9.50	*0.15*	YES	Yes	The access track culvert has a diameter of 0.45m, whereas the railway line culvert has a height of 1.40. As the access track is upstream of the railway line, it is likely that the track becomes blocked first before the railway line.	NO	N/A	N/A

Watercourse Crossing	Culvert Number	Structure	Proposed Outlet Invert Level (mAOD)	Existing Structure "Crest" Level (mAOD)	Difference (m)	Flowpath Analysis Required (Yes/No)	Is there another route for the water? (Yes/No)	Comments	Further Analysis Required (Yes/No)	Volume Available	Detailed modelling required?
SWF15-1	C12	Access Track	8.95	9.91	*0.96*	YES	No	As SWF14-1 and SWF15-1 join upstream of the access track, if the access track was to become blocked, water is likely to back up in both watercourses and pond upstream of the proposed Scheme. There is likely to be significant volume available upstream of the proposed Scheme without impacting the Scheme as the route is approximately 5m higher than existing ground levels. In addition, the existing A96 (located upstream of the proposed Scheme) is 1m higher than the proposed Scheme, and is unlikely be affected if the track was to become blocked and water ponded upstream of the proposed Scheme.	YES	YES	NO
			8.95	9.50	*0.55*	YES	Yes	The access track culvert has a diameter of 0.45m, whereas the railway line culvert has a height of 1.40. As the access track is upstream of the railway line, it is likely that the track becomes blocked first before the railway line.	NO	N/A	N/A
SWF16-1	C13	Railway	8.05	8.60	*0.55*	YES	Yes	Based on hydraulic modelling, other flow routes have determined. If the railway line was to become blocked, water would overtop the right bank and flow over a low spot along the railway line. Therefore, this structure is unlikely to impact on the proposed Scheme.	NO	N/A	N/A
		Access Track	8.05	7.90	*-0.15*	NO	N/A		NO	N/A	N/A
		Road	8.05	8.60	*0.55*	YES	Yes	Based on hydraulic modelling, other flow routes have determined. If the road to the airport was to become blocked, the left bank would overtop and pond in the marsh land to the south west. Therefore, this structure is unlikely to impact on the proposed Scheme.	NO	N/A	N/A
		Road	8.05	8.00	*-0.05*	NO	N/A		NO	N/A	N/A
SWF17-1	C22	Railway	7.17	8.24	*1.07*	YES	Yes	If the railway was to become blocked, water is likely to back up and pond in the low spot, as indicated by the flow route in the figure to the right. The proposed Scheme is approximately 5m higher than this low spot, and is therefore unlikely to be affected by the railway culvert being blocked.	NO	N/A	N/A
SWF18-1	C15	Road	20.45	16.21	*-4.24*	NO	N/A		NO	N/A	N/A
		Road	20.45	12.35	*-8.10*	NO	N/A		NO	N/A	N/A
		Railway	20.45	9.04	*-11.41*	NO	N/A		NO	N/A	N/A
		Dismantled railway	20.45	4.83	*-15.62*	NO	N/A		NO	N/A	N/A
SWF18-2	C16	Road	20.38	16.21	*-4.17*	NO	N/A		NO	N/A	N/A
		Road	20.38	12.35	*-8.03*	NO	N/A		NO	N/A	N/A
		Railway	20.38	9.04	*-11.34*	NO	N/A		NO	N/A	N/A
		Dismantled railway	20.38	4.83	*-15.55*	NO	N/A		NO	N/A	N/A
SWF19-1	C17	Existing A96	18.99	21.72	*2.73*	YES	No	If the existing A96 was to become blocked, water is likely to back up and pond upstream of the proposed Scheme. There is likely to be significant volume available upstream of the proposed Scheme without impacting the Scheme as the route is approximately 4m higher than existing ground levels.	NO	N/A	N/A
		Road	18.99	18.05	*-0.94*	NO	N/A		NO	N/A	N/A
SWF19-2	C23	Existing A96	22.35	21.72	*-0.63*	NO	N/A		NO	N/A	N/A
		Road	22.35	18.05	*-4.30*	NO	N/A		NO	N/A	N/A
SWF22-1	C18	Bridge	20.92	20.58	*-0.34*	NO	N/A		NO	N/A	N/A
		Railway	20.92	19.99	*-0.93*	NO	N/A		NO	N/A	N/A
		Road	20.92	19.91	*-1.01*	NO	N/A		NO	N/A	N/A
		Road	20.92	18.78	*-2.14*	NO	N/A		NO	N/A	N/A
SWF23-1	PS14	Footbridge	8.74	10.74	*1.99*	YES	No	Due to the height and span of the footbridge (3m x 40m), it is considered unlikely to block.	NO	N/A	N/A
SWF24-1	C19	Road	13.88	8.05	*-5.83*	NO	N/A		NO	N/A	N/A
		Access Track	13.88	8.38	*-5.50*	NO	N/A		NO	N/A	N/A
		Footpath	13.88	7.06	*-6.82*	NO	N/A		NO	N/A	N/A
SWF26-2	C21	Road	11.92	11.42	*-0.50*	NO	N/A		NO	N/A	N/A

2 Conclusions and Recommendations

2.1 A high-level qualitative screening assessment was undertaken to determine if the proposed Scheme would be at risk if an existing structure downstream became blocked.

2.2 This assessment focused on existing structures 1km downstream of the proposed Scheme. The invert outlet levels of the proposed culverts were used to compare to the crest level of the existing structures.

2.3 After this screening assessment, it was determined that none of the existing structures would impose a risk to the proposed Scheme, if they were to become blocked.