Appendix A19.2: Flood Risk Assessment

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1.1 Introduction

Background

1.1.1 This Flood Risk Assessment (FRA) has been prepared as a Technical Appendix to Chapter 19 (Road Drainage and the Water Environment) of the Environmental Impact Assessment Report (EIAR) for the A9 Dualling Programme. The A9 Dualling Programme involves upgrading the A9 to dual carriageway standard between Perth and Inverness. This FRA covers the Pass of Birnam to Tay Crossing section of the A9 Dualling Programme, as shown on Figure A19.2.1, hereafter referred to as the ‘proposed scheme’.

1.1.2 The assessment has been undertaken in accordance with the Design Manual for Roads and Bridges (DMRB) and other relevant guidance, legislation, and planning policy extant in March 2025. In accordance with the DMRB Scheme Assessment Reporting (TD37/93), the Pass of Birnam to Tay Crossing section of the A9 Dualling Programme has been progressed through the DMRB Stage 1 and Stage 2 assessment processes and is currently at DMRB Stage 3 ‘Detailed Assessment’.

1.1.3 At the DMRB Stage 2 assessment, multiple route options were considered and a DMRB Stage 2 FRA was provided to the Scottish Environment Protection Agency (SEPA) and other statutory consultees for information and for comment. This DMRB Stage 3 FRA report has been completed for the preferred route option and with reference to comments provided by SEPA and other relevant stakeholders on the Pass of Birnam to Tay Crossing scheme.

Figure A19.2-1: Location of Pass of Birnam to Tay Crossing Section within extent of A9 Dualling Programme

Purpose

1.1.4 This DMRB Stage 3 FRA report provides detailed information on the assessment of all sources of flood risk relevant to the proposed scheme. The purpose of this FRA is to:

- investigate baseline (existing) flood risk;
- identify potential flood risk impacts associated with the proposed scheme; and
- where necessary, provide details of appropriate flood mitigation and flood management measures.

Context

1.1.5 The A9 road corridor between Perth and Inverness covers a total length of 177 kilometres (km). This consists of approximately 48km of existing dual carriageway and 129km of single carriageway, which will be upgraded to dual carriageway status.

1.1.6 The majority of the A9 road corridor traverses a hilly and mountainous environment and runs alongside and crosses some of the largest rivers in Scotland, with several significant tributaries and numerous smaller watercourses flowing beneath the existing carriageway. Many of these watercourses are considered to be of high ecological value, including nature conservation designations at both the national and international level.

1.1.7 Consequently, not only is the existing and proposed A9 route corridor at risk of flooding, but the proposed scheme has the potential to alter baseline hydrological regimes and flood mechanisms. This could potentially result in undesirable ecological, social and economic impacts, which would need to be mitigated through the design process.

Flood Risk Assessment Approach

1.1.8 This FRA has been developed with reference to the following key legislation, policy and guidance:

- Flood Risk Management (Scotland) Act 2009 (Scottish Government, 2009).
- National Planning Framework 4 (NPF4) (Scottish Government, 2023).
- Technical Flood Risk Guidance for Stakeholders SEPA (2022).
- Flood Risk and Land Use Vulnerability Guidance, SEPA (2024a)
- Climate change allowances for flood risk assessment in land use planning SEPA (2024b)
- DMRB LA 113 'Road Drainage and the Water Environment', Revision 1 (Highways England et al., 2020).

1.1.9 Throughout this report flood events are presented as Annual Exceedance Probability (AEP) events such as 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1%, which are equivalent to the 2, 5, 10, 30, 50, 100, 200 and 1000-year return period respectively. AEP refers to the chance that a flood of a particular magnitude is experienced or exceeded during any one year. For clarity, the notation used in this report, to describe for example the 0.5% AEP flood event, is '0.5% AEP (200-year) flood event'.

1.1.10 The DMRB Stage 3 assessment takes cognisance of the latest SEPA climate change guidance (SEPA, 2024b). Current guidance (as of August 2024) advises a peak river flow allowance of +53% and a peak rainfall intensity allowance of +39% to be applied for the Tay River Basin Region.

1.1.11 NPF4 states that development proposals at risk of flooding or in a flood risk area will only be supported if they constitute essential infrastructure where the location is required for operational reasons. Given the scale of the A9 Dualling Programme and the surrounding topography, impacts on areas currently at risk of flooding are unavoidable.

1.1.12 However, it must be designed and constructed to:

- remain operational and safe for users during times of flood;
- results in no reduction in floodplain capacity;
- not impede flows; and
- not increase flood risk elsewhere.

1.1.13 In order to demonstrate that the proposed scheme has considered flood risk at all stages of the design process, DMRB LA 113 advocates a staged approach to the evidence-based assessment. Table A19.2-1 presents the adopted process of assessing flood risk within the context of the DMRB assessment and how this relates to SEPA's technical requirements as a statutory consultee.

Table A19.2-1: Flood risk assessment stages

Stage	Assessment Detail	Purpose	Alignment with the requirements of SEPA Technical Guidance
DMRB Stage 1 Scoping Assessment	The 'Scoping Assessment' uses readily available information to: ▪ highlight potential sources of flood risk; and ▪ identify and establish areas and flood sources that require further detailed assessment. This includes high-risk sources of flooding as identified in the route-wide Strategic Flood Risk Assessment including rivers, small watercourses and existing A9 water-crossings.	To scope the DMRB 2 'Simple Assessment'.	Identification of sources and types of flooding.

Stage	Assessment Detail	Purpose	Alignment with the requirements of SEPA Technical Guidance
DMRB Stage 2 Simple Assessment	The 'Simple Assessment' aims to assess and compare flood risks between alternative alignment route options by: ▪ providing a description of the baseline conditions; ▪ identifying receptors sensitive to flooding; ▪ assessing the impacts of the proposed scheme route options; and ▪ assessing the importance of the impact i.e. magnitude of the impact against the sensitivity of the receptor.	To inform the selection of a preferred route option and the Stage 2 assessment Environmental Report.	Assessment of design flows. Identification of the plan extents of flooding. Describe the proposed structure/changes and impacts on predicted water level. Assessment of climate change impacts.
DMRB Stage 3 Detailed Assessment	The 'Detailed Assessment' will focus on potential effects of the preferred alignment route option and where necessary consider appropriate flood mitigation measures to achieve a neutral flood risk.	To inform the scheme design and the Environmental Statement.	Provide details of proposed flood mitigation measures. Provide an assessment of any displaced floodwater on sensitive receptors. Provide reference to any other impact on the river environment.

1.1.14 This DMRB Stage 3 FRA documents the findings of the assessment undertaken for the preferred route option based on the current scheme design. For full details of the scheme design see Chapter 6: The Proposed Scheme.

1.1.15 The DMRB Stage 3 FRA has adopted a range of assessment techniques to quantify the existing risk of flooding and potential impact of the proposed scheme on baseline flood risk. This has included hydraulic calculations to quantify the hydraulic performance of individual culverts located on minor watercourses to detailed hydraulic modelling of principal and minor watercourses.

1.1.16 Further detail of the hydrological and hydraulic modelling assessments undertaken at DMRB Stage 3 are contained within Annex D (Surface Water Hydrology) and Annex E (Hydraulic Modelling Report) respectively. Where necessary, to aid understanding, the FRA includes a brief overview of the hydrological and hydraulic modelling assessments undertaken.

1.1.17 Where the FRA has identified potential flood risk impacts, flood mitigation measures (either embedded in design or standalone) have been considered to minimise the overall impact on flood risk. At locations where the proposed scheme may have an impact, a range of measures have been explored with the aim of achieving a neutral effect on that source of flood risk.

Sources of Flooding

1.1.18 The assessment of flood risk has considered all sources of flooding, specifically:

- Fluvial (Principal Watercourses): Flooding originating from principal watercourses, including the River Tay, River Braan, Inchewan Burn and the Mill Stream at Inver, which have the potential to pose the most significant flood risks within the study area (see Section 1.3: Principal Watercourses).
- Fluvial (Minor Watercourses): Flooding originating from minor watercourses, with localised or less significant flood risk issues (see Section 1.4: Minor Watercourses).
- Surface Water (Pluvial): Urban or rural flooding resulting from high intensity rainfall travelling overland and ponding in local topographic depressions before the runoff enters a watercourse, drainage system or sewer (see Section 1.5: Surface Water).
- Groundwater: Flooding due to the groundwater table rising above the surface, normally due to prolonged and heavy rainfall over a sustained period of time (see Section 1.6: Groundwater).
- Sewers and Water Mains: Flooding due to exceedance of the capacity of man-made drainage systems. A review undertaken as part of the A9 Strategic Flood Risk Assessment (SFRA) indicated that the A9 is within an essentially rural area and that the extent and coverage of the existing sewer network in this area is limited. The proposed scheme would not result in additional flow being discharged into the existing sewers or affect the water supply networks. It is therefore anticipated that the risk of flooding is unlikely to change and consequently this source of flooding has only been briefly discussed (see Section 1.7: Failure of Water Retaining Infrastructure).
- Land Drainage and Artificial Drainage: Failure of land drainage infrastructure such as drains, channels and outflow pipes, which is most commonly the result of obstructions, poor maintenance and/or blockages. For the proposed scheme, a like for like replacement would be undertaken where this infrastructure is affected. Therefore, the risk of flooding is unlikely to change and consequently the FRA has not considered this source of flooding further.
- Failure of Water Retaining Infrastructure: Flooding due to the collapse and/or failure of man-made water retaining features such hydropower-dams, water supply reservoirs, canals, flood defences structures, underground conduits, and water treatment tanks or pumping stations (see Section 1.7: Failure of Water Retaining Infrastructure).
- Coastal: Flooding originating from the sea where water levels exceed the normal tidal range and flood onto the low-lying areas that define the coastline. At an elevation of 50mAOD or above, the proposed scheme does not traverse areas considered to be at risk of coastal flooding and would not increase the risk of coastal flooding. Therefore, the FRA has not considered this source of flooding further.

- Construction Risks: Risk associated with all sources of flooding listed above, during the construction phase (see Section 1.8: Construction Phase).

1.1.19 This DMRB Stage 3 FRA adopts the SEPA Flood Maps (SEPA 2024c) as one of a number of sources of information used to assess the risk of both fluvial and surface water flooding. For each source of flooding, the maps illustrate flood extents for a Low, Medium and High probability of flooding, which refer to the 0.1% AEP (1,000-year), 0.5% AEP (200-year) and 10% AEP (10-year) flood events respectively. This information has been supplemented by detailed hydraulic modelling.

1.1.20 The functional floodplain is defined by SEPA as the 0.5% AEP (200-year) flood extent. It should be noted that the SEPA flood mapping can be indicative in nature. Consequently, the 0.5% AEP (200-year) flood extent outline indicates the areas considered to be at flood risk at the present time. Where detailed hydraulic modelling has been undertaken for this FRA, it will supersede the published SEPA Flood Map as the assessment of baseline (existing) flood risk.

1.1.21 The FRA has considered the potential impact of climate change on fluvial flood depths and extents in line with current SEPA guidance for applying climate change allowances for flood risk assessment in land use planning (SEPA 2024b). Peak flow estimates for the 0.5% AEP (200-year) flood event have been increased by 53% and, where appropriate, design peak rainfall estimates increased by 39%. The uplifted 0.5% AEP (200-year) event is denoted by 0.5% AEP (200-year) plus CC. This has been adopted as the ’design flood event’.

1.2 Pass of Birnam to Tay Crossing Study Area

Location

1.2.1 The Pass of Birnam to Tay Crossing section of the A9 Dualling Programme commences at the northern extent of existing dual carriageway that extends from Perth to the Pass of Birnam. The section extends approximately 8.4km, bypassing the towns of Birnam, Little Dunkeld and Dunkeld, to the east, and Inver and the Hermitage to the west. The tie-in point with the following (northern) section, Tay Crossing to Ballinluig, is approximately 0.75km north of the current River Tay Crossing. The project location is shown on Figure A19.2-2.

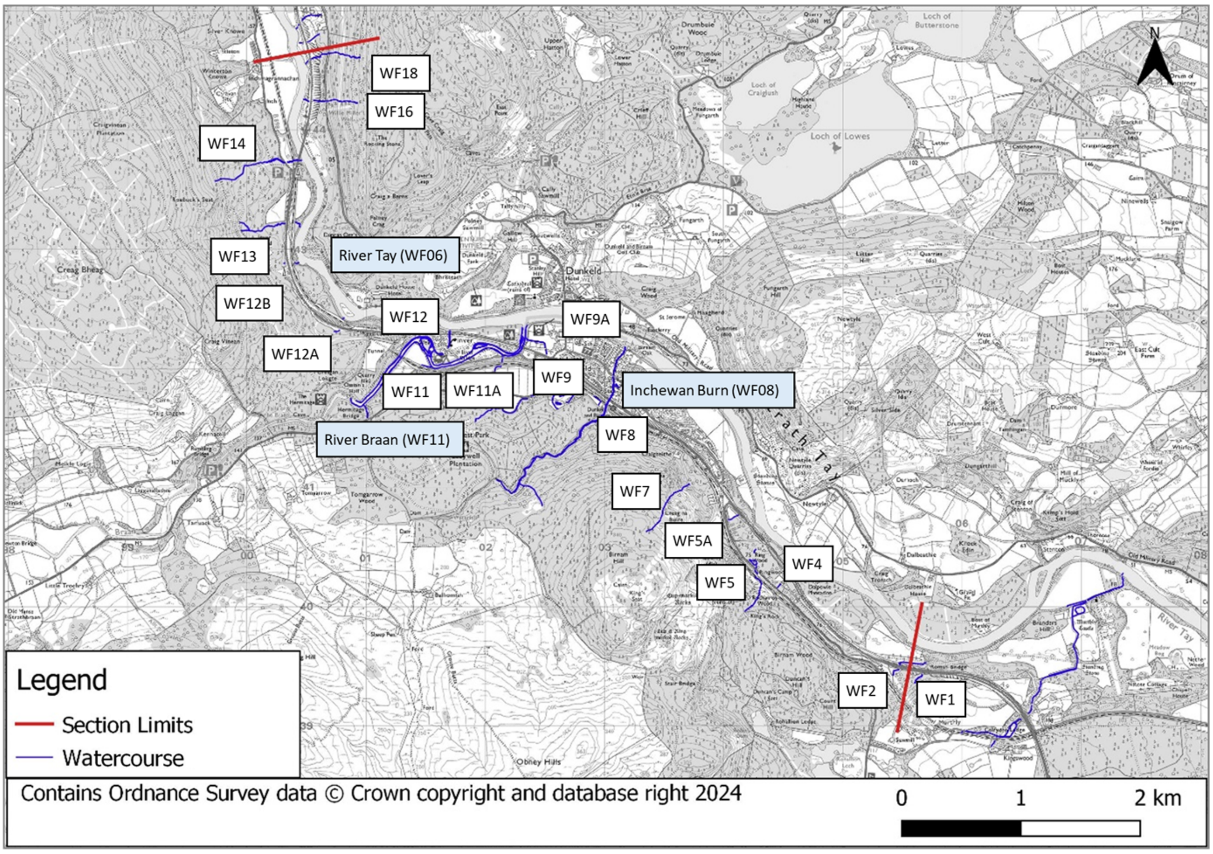


Figure A19.2-2: Location Plan Showing, Pass of Birnam to Tay Crossing Section and Watercourses

Watercourses in Study Area

1.2.2 Within the extents of the study area, the A9 and side roads cross four principal watercourses, Inchewan Burn, River Braan, Mill Stream and the River Tay, as well as 12 minor watercourses at 13 crossings (one minor watercourse is crossed twice). The River Tay runs parallel and in close proximity to the road for much of the section. The A9 crosses the River Tay near the northern extent and crosses the River Braan approximately 190m upstream of its confluence with the River Tay.

1.2.3 The locations of all principal watercourses (with river names) and minor watercourse crossings (with crossing numbers only) are shown previously on Figure A19.2-2 and listed in Table A19.2-2. Further information on the watercourse crossings which form part of the proposed scheme are outlined in Appendix 19.3 Watercourse Crossings Report.

Table A19.2-2: Details of Watercourse Crossings in Study Area

Water Feature	Watercourse	Principal or Minor Watercourse	Easting	Northing
WF01	Birnam Burn	Minor	305668	739430
WF02	Unnamed	Minor	305469	739476
WF04	Ephemeral	Minor	304529	740242

Water Feature	Watercourse	Principal or Minor Watercourse	Easting	Northing
WF05	Unnamed	Minor	304312	740583
WF05A	Unnamed	Minor	304121	740771
WF07	Ephemeral	Minor	303910	741083
WF08	Inchewan Burn	Principal	303038	741734
WF09	Unnamed	Minor	302532	742073
WF11	River Braan	Principal	302298	742176
WF11A	Braan Tributary	Minor	302127	742027
WF12	Mill Stream	Principal	301705	742288
WF12A	Unnamed	Minor	300775	742320
WF12B	Unnamed	Minor	300317	742919
WF13	Unnamed	Minor	300327	743218
WF14	Unnamed	Minor	300435	743748
WF16	Unnamed	Minor	300561	744247
WF18	Unnamed	Minor	300556	744343

1.2.4 Within the study area, there are intermittent channels subject to ephemeral flow conditions which do not exhibit any clear hydrological connection to the existing A9. The watercourse crossings marked as 'Ephemeral' indicate that no visible watercourse was identified and/or no hydraulic structure located.

Development Constraints

1.2.5 There are a number of natural environmental and man-made engineering constraints within the Pass of Birnam to Tay Crossing section.

Environmental Constraints and Designations

1.2.6 At Dunkeld and Birnam the A9 passes through the steep sided, narrow River Tay valley, with the topography rising steeply to the west and with the floodplain associated with the River Tay to the east. At the southern extent, the existing A9 is surrounded by Ancient Woodland that forms part of the Murthly Castle Gardens, Birnam Wood, Rochanroy Wood and Ring Wood to the immediate west.

1.2.7 To the east of the A9, the floodplain opens out and the settlements of Little Dunkeld and Birnam are located on the west bank of the River Tay, which is a Special Area of Conservation (SAC). A further small settlement, Inver, is located to the immediate west of the A9 between the River Braan and River Tay on a low-lying area of land. The Hermitage, which is a National Trust for Scotland (NTS) protected site, is also to the west of the A9 and offers attractive woodland walks.

1.2.8 Within the extents of the Pass of Birnam to Tay Crossing section, the existing A9 trunk road is mainly outside floodplain areas, apart from short sections of the A9 that span the Inchewan Burn, the River Braan and the River Tay.

Man-Made Engineering Constraints

1.2.9 The route of the current A9 interfaces with the local road network operated and maintained by Perth & Kinross Council, including the B898, B867, Perth Road, A923 and A822 which follows the route of General Wade's Old Military Road, originally constructed in the 18th Century.

1.2.10 Access tracks, many of which form direct junctions with the current A9, provide access to land adjacent to the road. In total, there are 13 direct accesses on the current A9.

1.2.11 The Highland Main Line railway is in close proximity to the A9 at Birnam and Dunkeld and passes under the A9 carriageway approximately 1.5km west of the A822 junction, and immediately south of the River Tay Crossing. The route is predominantly single track through this area, with a short section of double track creating a passing loop at the Dunkeld & Birnam Station.

1.2.12 Dunkeld & Birnam Station is located immediately to the west of the A9. The station is located on a section of passing loop and has platforms in both directions. Presently vehicular access to the station is from the A9. The station building is Category A Listed, and the listing includes the pedestrian footbridge. The signal box at the station is Category B Listed.

1.2.13 There are a number of residential areas in the locality of the existing A9, including Birnam, Little Dunkeld, Dunkeld and Inver that use the local road network to access the A9. Birnam, Little Dunkeld and Dunkeld can be accessed using either the existing left/right staggered priority junction with the B867 and Perth Road at Birnam, or the existing right/left staggered priority junction with the A923 and A822 at Dunkeld. Inver can be accessed using the A822.

1.2.14 There are several business properties in the locality of the existing A9 between the Pass of Birnam and Tay Crossing which are accessed via the A9 and the existing local road network. The Birnam Industrial Estate is located immediately east of the A9 and comprises of several business units. This industrial estate is in Birnam and can be accessed via Perth Road utilising the junctions at Birnam or Dunkeld.

1.2.15 Ladywell Landfill, which is monitored by Perth & Kinross Council, is located immediately to the south of the Highland Main Line railway and approximately 0.2km to the west of the Inchewan Burn.

The Proposed Scheme

1.2.16 The proposed scheme between the Pass of Birnam and the Tay Crossing is an online option and includes widening the existing single carriageways along with junction, access road and drainage improvements. When completed, the Pass of Birnam and the Tay Crossing will have a 10.2km continuous section of dual carriageway, incorporating the existing dual carriageway at Pass of Birnam.

1.2.17 The subsequent subsections provide an overview of the key features of the proposed scheme as pertaining to flood risk. Chapter 6 (The Proposed Scheme) contains a full description of the proposed scheme. The proposed scheme is shown on Figure 6.1 of Chapter 6 (The Proposed Scheme).

A9 Dualling, Junctions, Access Roads and Tracks

1.2.18 The proposed scheme involves widening of the existing A9 alignment as well as short sections of realignment at Birnam Junction (Ring Wood) and Dalguise Junction. This widening would involve new cuttings into steep hillside and widening of existing embankments on both the north and southbound carriageways.

1.2.19 The proposed scheme includes the provision of modified local access arrangements to the B867 to Waterloo and Bankfoot, Perth Road to Birnam and Little Dunkeld, the A923 to Little Dunkeld, the A822 to Milton, the unnamed access road from the A822 to Inver and the B898 (Dalguise Road). The proposed scheme would also include an additional bridge across the River Tay (immediately adjacent to the existing bridge) and a widened replacement bridge across the River Braan and Inchewan Burn. Other surfaced access roads or unsurfaced access tracks to be modified or provided by the proposed scheme include new access roads for Sustainable Drainage System (SuDS) features and access tracks serving a small number of properties and agricultural land.

Minor Watercourse Crossings

1.2.20 The existing A9 carriageway crosses four principal watercourses and 12 minor watercourses within the study area. Many of these crossings consist of simple culverts draining small open channels. The proposed scheme includes the extension, replacement and/or enlargement of these culverts.

1.2.21 The design process for the minor watercourse crossings takes account of a range of design criteria and constraints to develop the most appropriate crossing for each watercourse. The factors that influence the culvert design include:

- horizontal and vertical alignment of the proposed scheme, specifically the influence on online construction and the level of the road drainage to avoid clashes with the watercourse crossing;
- maintenance requirements to meet DMRB standards;
- ecological considerations, such as the need to provide adequate mammal passage through culverts;
- geomorphological considerations related to potential erosion and sedimentation issues upstream and downstream of the watercourse crossings; and
- existing flood risks and the potential impact on upstream and downstream flood sensitive receptors in the event that a culvert is either extended (based on current geometry) or enlarged.

1.2.22 For all areas, these influencing factors need to be considered collectively on a case-by-case basis to develop the most appropriate culvert design for each crossing. The decision-making hierarchy adopted during the design process was, where possible, to retain the existing culvert or to extend the culvert on a 'like-for-like' basis to accommodate the proposed scheme. Only where this was not possible, due to flood risk, engineering or environmental constraints, would the existing culvert be replaced with a new culvert.

1.2.23 The design of all new culverts will be in accordance with DMRB CD 529 Design of Outfall and Culvert Details (Highways England et al., 2021). There are a number of locations where the proposed scheme will result in earthworks 'cut' into the adjacent hillside or where the invert of the new watercourse crossing will need to be lowered to pass beneath the proposed road drainage system. In both cases this will result in a steepened watercourse requiring a 'cascade' to safely convey the design flood event without compromising the integrity and existing landform of the hillside and/or operation of the proposed scheme. Appendix A19.3 (Watercourse Crossing Report) contains further detail and justification for the design of each structure.

Surface Water Drainage

1.2.24 The proposed scheme includes the construction of new drainage features to treat and attenuate surface water runoff to ensure no detrimental impact upon flood risk and water quality. This will include Pre-Earthwork Drainage (PED), road drainage networks including SuDS features with associated outfall structures and access tracks.

Proposed Scheme Design Principles and Standards

1.2.25 The design of the proposed scheme has developed over the three DMRB assessment stages and is cognisant of a range of design principles and standards and a full range of locational and environmental issues. Table A19.2-3 provides a list of flood risk design principles and standards considered during the development of the proposed scheme to minimise potential flood risk impacts.

Table A19.2-3: Proposed scheme flood risk design principles and standards

Proposed Scheme	Design Principles and Standards	Description
Mainline A9 Dualling, Junctions, Access Roads and Tracks	▪ 0.5% AEP (200-year) Functional Floodplain ▪ 0.5% AEP (200-year) plus CC flood event plus 600mm freeboard	Avoid locating the proposed scheme and any associated works within the functional floodplain. Set the mainline, junctions and surfaced access roads above the design flood event level. Unsurfaced access tracks would remain unchanged from existing elevations and as a result could have lower flood design standards.

Proposed Scheme	Design Principles and Standards	Description
Principal Watercourse Crossings	▪ 0.5% AEP (200-year) Functional Floodplain ▪ 0.5% AEP (200-year) plus CC flood event plus 600mm freeboard	Avoid locating the proposed scheme and any associated works including bridge piers and abutments within the functional floodplain. Where the proposed scheme intends to replace existing structures, soffit levels are set above the design flood event level.
Minor Watercourse Crossings	<u>New (or replaced) mainline and access road culverts</u> ▪ 0.5% AEP (200-year) plus CC flood event plus appropriate freeboard <u>New (or replaced) unsurfaced track culverts</u> ▪ 2% AEP (50-year) flood event plus appropriate freeboard <u>Freeboard</u> Culvert freeboard requirements are as follows: ▪ for culverts between 0.45m and 1.2m barrel diameter/height, a minimum freeboard of D/4 shall be provided, where D is the culvert internal diameter or culvert height for a box culvert; ▪ for culverts between 1.2m to 1.8m barrel diameter/height, a minimum freeboard of D/6 shall be provided, where D is the culvert internal diameter or culvert height for a box culvert; and ▪ for culverts of over 1.8m barrel diameter/height, 0.3m to 0.6m freeboard shall be provided.	In line with DMRB, all new (or replacement) mainline and access road culverts are designed to freely pass the 1% AEP (100-year) design flood event plus climate change allowance (with appropriate freeboard within the culvert barrel). In line with DMRB, all new (or replaced) unsurfaced track culverts are designed to freely pass the 2% AEP (50-year) design flood event (with appropriate freeboard within the culvert barrel). The flood design standard for unsurfaced access track culverts is lower than for mainline culverts as these tracks have a low traffic volume, and thus limited consequences in the case of flooding. Unsurfaced access tracks are also to be set at existing ground level (which may be elevated above surrounding ground levels), to avoid changing the local risk of flooding. The impact of the proposed scheme on flooding has been assessed against the design flood event. Within the study area, all but one of the new mainline and access

Proposed Scheme	Design Principles and Standards	Description
		road culverts have been designed to pass the 0.5% AEP (200-year) plus CC event due to their location and proximity to the A9. There is one new unsurfaced track culvert which has been designed to the lower standard.
Pre-earthwork Drainage (PED)	▪ 1% AEP (100-year) rainfall runoff flood event	In line with DMRB, PED are designed to capture and convey surface water runoff from the catchment they would be intercepting and discharge into the nearest watercourse.
Road drainage system	▪ 100% AEP (1-year) rainfall flood event, without surcharging ▪ 20% AEP (5-year) rainfall flood event, plus a 39% allowance for climate change, without exceeding the chamber cover	As per DMRB CG 501 (2022), the design of the road drainage system would accommodate a short duration, high intensity rainfall event, without surcharging.
SuDS Features	▪ 0.5% AEP (200-year) Functional Floodplain	Where possible, avoid developing SuDS in the functional floodplain. If this is the only available open space provide mitigation for increase in flood risk caused by any loss of floodplain capacity where practicable. In accordance with guidance in the CRDM (2015) SuDS Manual (Section 8.8.2), where SuDS in the floodplain cannot be avoided, they will be constructed without loss of floodplain storage, e.g. access tracks will be at existing ground levels and bunds will be avoided. Surface discharge from SuDS will be dispersed (i.e. allowed to shed off as sheet flow) with point discharges minimised or eliminated.

Proposed Scheme	Design Principles and Standards	Description
	▪ 3.33% AEP (30-year) flood event	SuDS features not to be inundated with floodwater during the fluvial event
	▪ 0.5% AEP (200-year) rainfall flood event, plus an allowance for climate change and appropriate freeboard where practicable and at least the 3.33% AEP (30-year) flood event.	SuDS features to treat and attenuate the peak flow from the proposed road drainage system.
	▪ 50% AEP (2-year) 'greenfield' runoff rate where practicable and no greater than existing 50% AEP (2-year) runoff where not.	SuDS features to discharge into the nearest watercourse at a controlled rate.
Compensatory Flood Storage	▪ Same volume to be provided at the same level relative to the design flood event, which is the 0.5% AEP (200-year) flood event.	Compensatory flood storage should be provided close to the point of lost floodplain and provide the same volume at the same level relative to the design flood level as that lost. In designing compensatory flood storage, the impacts of the measure will be tested against a range of flood events up to the design flood event.

Flood History

1.2.26 Historical incidences of flooding are informed through a range of sources including SEPA, the A9 Dualling Programme Strategic Flood Risk Assessment (SFRA) (Halcrow, 2014), the Chronology of British Hydrological Events and a web-based search of internet news articles. Historical incidences of flooding are collated in Table A19.2-4.

1.2.27 In addition to those sources of information named, anecdotal evidence provided by local residents has been collated and information relevant to the Pass of Birnam to Tay Crossing section is reproduced in Table A19.2-5.

A9 Dualling Programme Strategic Flood Risk Assessment

1.2.28 A route-wide Strategic Flood Risk Assessment (SFRA) Report (Transport Scotland, 2014) was produced as an addendum to the A9 Dualling Programme Strategic Environmental Assessment (SEA), for the A9 corridor between Perth and Inverness. The SFRA considers route-wide flood history, identifies key areas of flood risk to the A9 dualling and areas where the proposed dualling may have an impact on flooding.

1.2.29 The SFRA reports historical incidences of flooding however included only one record in the study area of the proposed scheme. This was reported as a landslide on 4th April 2011 and occurred along the stretch of the A9 just north of the Tay crossing, near the northern boundary of the proposed scheme area. The SFRA notes that due to its rural setting many flood events may not be recorded.

1.2.30 The Strategic Environmental Assessment (SEA) Statement identified that at the local and route wide scales, the A9 dualling could potentially present major adverse effects.

SEPA Potentially Vulnerable Areas (PVAs)

1.2.31 Potentially Vulnerable Areas (PVAs) are areas where significant flood risk exists at present or is likely to occur in the future. PVAs are updated every six years with the latest published in December 2024 for the flood risk management planning cycle 2028-2034.

1.2.32 The settlements of Dunkeld and Birnam form a PVA (Target Area 225) under the Tay Local Plan District (SEPA, 2021). The main source of flooding in the area is river flooding from the River Tay. It is estimated that there are approximately 104 homes and businesses currently at risk of flooding. This is likely to increase to 149 homes and businesses by the 2080s due to climate change.

Historical Flood Records

1.2.33 A review of historical flood records indicates that there have been a number of flood events that have occurred within the study area, predominantly within the floodplain of the principal watercourses and/or from exceedance of minor watercourses, away from the existing A9 route corridor. Where the source of flooding is provided, incidences of historic flooding are generally caused by exceedance flows (fluvial), heavy rainfall (pluvial) or rapid snow melt.

1.2.34 Significant flooding from the principal watercourses within the project area has been recorded up to 2015 when during December 2015 and January 2016, Storms Desmond and Frank caused prolonged rainfall throughout Perth and Kinross.

1.2.35 Details of historic incidences of flooding within the Pass of Birnam to Tay Crossing study area are provided in Table A19.2-4.

Table A19.2-4: Historic Flood Events

Date	Location	Source	Further details
07 October	015 - Tay	Chronology of British	1847 October 7 Level at Smeaton's Bridge in Perth 6.11 metres (rank 2 of 20 flood levels in

1847		Hydrological Events	this reference between 1814 and 1990 inclusive). "excessive rainfall coupled with a S.E. wind. Rained from 8p.m. Tues. to 5 p.m. Thurs. Areas affected in Perth: North Port, South Inch, Princes St., Charlotte St., Rose Terrace. Inundation and damage in Dunkeld district, Dalguise, Dalmarnock."
29 January 1892	015 - Tay	Chronology of British Hydrological Events	1892 January 29 Observer at Dunkeld (Inver Braan) noted p[35] "Very severe, snow and ice lying on the ground up to the 27th, when a strong W. gale sprang up, and by 29th the snow and ice were all gone. The sudden freshet which followed raised the rivers to a great height, and the Tay was higher than it had been for 30 years. Around Guay and Dalguise, roads were torn up, whole fields of soil washed away, and one man lost more than 100 tons of potatoes. Cows, sheep and pigs, and great quantities of fencing &c., were seen floating past Dunkeld."
31 January 1903	015 - Tay	Chronology of British Hydrological Events	1903 January 31 Level at Smeaton's Br 5.64 metres (rank 13 of 20 flood levels in this reference between 1814 and 1990 inclusive) "Heavy rains and strong gales. Heavy rain and snowmelt from the Grampians... Perth: North and South Inches, Rose Terr, North Port, Lower Commercial St., Princes St., Nelson St., Scott St., James St., King St., Edinburgh Rd, Marshall Pl, Moncrieff Island all flooded. Nearly all cellars in the city flooded. Meikleour, Dunkeld, Pitlochry, Ballinluig, Dalguise affected. Many roadways impassable".
21 December 1912	015 - Tay	Chronology of British Hydrological Events	1912 December 21 Level at Smeaton's Bridge in Perth 5.68 metres (rank 10 of 20 flood levels in this reference between 1814 and 1990 inclusive). "Heavy rain, snowmelt. River Tay was abnormally high for 2 weeks before floods. Incoming tides increased flooding. Perth: North and South Inches, Marshall Pl (from James to Princes St.) McQuibbans Bldgs, Moncrieff Island, Commercial St. Bridgend, Edinburgh Rd., North Port, Tay St, George Hotel's stables and kitchens all flooded. Lower Strathern, Dunkeld, Dalguise, Aberfeldy, Castle Menzies, Weem Mid Atholl

			District, Logierait, Moulinearn, Blairgowrie District, St Fillians, Crieff, Tay Farm, Delvine House, Pitlochry, Meikle Fardle."
22 January 1928	015 - Tay	Chronology of British Hydrological Events	1928 January 22 Level at Smeaton's Bridge in Perth 5.77 metres (rank 8 of 20 flood levels in this reference between 1814 and 1990 inclusive) "Wettest January on record. Snowmelt. Perth: flooding at Commercial St., Bridgend, basements in Marshall Pl, cellars in the vicinity of North Inch, Barossa Pl, Shore Road, Mun Golf Course. Outside Perth: Flooding at Strathearn, Comrie, Crieff, Aberfeldy, Logieriate, Dowally, Caputh, Meikle Fardle, Pitlochry, Meikleour, Strathblane, Dalguise, Meigle, Blairgowrie."
January 1993	Logierait to Dalguise	SEPA	Rapid snow melt and heavy rain resulting in widespread flooding within the area. Dunkeld Perthshire A822 flooded near Dunkeld and flooding to the rear of TA Hall.
August 2004	Perth to Pitlochry	SEPA	Intense heavy rainfall resulting in widespread flooding within the area. Flooding was noted at Inver and Invermill Caravan site.
2004 (month not known)	Dunkeld	SEPA	A9 landslide engulfed a car and closed the A9 north of Dunkeld
January 2005	Guay to Dalguise	SEPA	Heavy rain resulting in widespread flooding to agricultural land. The River Tay was bankfull at Dunkeld and flooding occurred to agricultural land near Newtyle, Littleton and a small piece of land flooded by Dunkeld Bridge on the north bank of the Tay.
December 2006	Logierait to Tay Crossing	SEPA	Large flows in the Middle and Lower River Tay resulting in flooding to properties and the railway and B898 becoming impassable in places.
January 2008	Dalguise	SEPA	Heavy rain resulting in widespread flooding from the River Tay.
January 2014	Dowally to Tay Crossing	SEPA	Heavy rain resulting in widespread flooding from the River Tay.
January 2015	Logierait to Tay Crossing	SEPA	Widespread flooding throughout the area.
February 2020	Dunkeld	Perth & Kinross	Properties in Dunkeld threatened by flooding or were flooded from small watercourses

		Council	(Sawmill Brae and Spoutwell Burn)

Local Resident Feedback

1.2.36 Following community engagement through public exhibition events, local residents were asked to provide feedback to Transport Scotland in relation to flooding. This feedback has been collated and those records affecting the Pass of Birnam to Tay Crossing study area are summarised in Table A19.2-5.

Table A19.2-5: Local resident feedback

Date	Location	Source	Further details
Meeting notes 10th Oct 2013	Highland Mainline Railway / General	Meeting between MP (Jacobs), Atholl Estates, Private Landowner RL	“In the past 20 years the River Tay has flooded four times with the water level rising up to 15ft (4.5m) above the normal river level.” “During a flood event the Highland Mainline Railway, which links Perth and Inverness, acts as a barrier. However, all of the existing underpasses are flooded. It is not uncommon for the flood waters to reach the level of the railway tracks, which are on embankment through this section.”
Public exhibition feedback	N/A	(names omitted for privacy protection)	Expression of concerns and request for political reflection on the A9 proposal. Raises flood risk as a general point of consideration. No location-specific information on flood risk provided.
Public exhibition feedback	B898	(names omitted for privacy protection)	Comment in favour of Option 1 (two junctions at Dunkeld): “We … would be very concerned in particular to see more traffic sent along the Dalguise road which … is also prone to flooding and often blocked with snow.”
Email feedback 5th Sep 2016	Railway underpass, east of Dunkeld and Birnam Station.	(names omitted for privacy protection)	“You asked for the grid reference of flooding at the railway underpass east of Dunkeld and Birnam Station. This is caused by a stream which has never been culverted. The reference is NO411039*.” “There is another problem stream which has never been culverted at NN511988*. This is opposite a building currently used by House of Bruar”

*Note 1: Grid references NO411039 and NN511988 are both not in the project area. Reversing northing and eastings corrects the problem: NO039411 and NN988511 are both in the expected locations. NO039411 is within the proposed scheme area (WF7) and NN988511 is in the Tay Crossing to Ballinluig section (WF51).

1.3 Principal Watercourses

Introduction

1.3.1 Within the context of this FRA, principal watercourses are categorised as those having the potential to pose the most significant flood risk along the existing A9 corridor. These include the River Tay and its tributaries the River Braan and Inchewan Burn. A short channel connecting the Rivers Braan and Tay at Inver, the Mill Stream, is considered a principal watercourse in this assessment, as flooding from it is driven by high water levels on the Rivers Braan and Tay.

1.3.2 Based on the SEPA fluvial Flood Maps, an approximately 650m section of the existing A9 from the River Braan crossing to the Mill Stream crossing is located in the floodplain of the River Tay and River Braan. The SEPA Flood Maps suggest this section would be overtopped in a 0.5% AEP (200-year) flood. Elsewhere within the study area, the existing A9 is not indicated by the SEPA Flood Maps to encroach into the 0.5% AEP (200-year) functional floodplain.

1.3.3 Given the limitations of the SEPA Flood Map, which are based on high level hydraulic modelling, and the proximity of the proposed scheme to the floodplain; a detailed assessment has been undertaken to investigate the risk of flooding to the proposed scheme and the impact from the proposed scheme upon flood risk elsewhere.

Assessment Approach

1.3.4 To undertake assessment of flood risk, a hydraulic model has been developed for the proposed scheme study area. The model adopts a linked one-dimensional/two-dimensional (1D/2D) approach, whereby the river channel is represented as a 1D component within Flood Modeller (v7.1) software, which is linked dynamically to the floodplain, which is represented in 2D, using TUFLOW (2020-10-AF) software. The hydraulic model includes a representation of the River Tay, River Braan, the Mill Stream and Inchewan Burn.

1.3.5 It should be noted that the hydraulic modelling software has a numerical convergence tolerance of +/- 10 millimetres (mm) on water levels and that there are further uncertainties within the survey data and hydrological and hydraulic parameters used to construct the model. Further details are available within Annex D (Surface Water Hydrology) and Annex E (Hydraulic Modelling Report). These uncertainties are applicable to both the baseline and proposed scheme modelling and are therefore not considered to impact the assessment of flood risk to the scheme unduly. The inherent uncertainties are addressed via the incorporation of freeboard within the proposed scheme design. Throughout this FRA, modelling results are reported to the nearest mm to allow for the comparison of baseline and proposed scheme modelling, but it is emphasised that they are subject to these uncertainties.

1.3.6 To assess existing flood risk and the potential impact of the proposed scheme, the modelling considers a range of flood events for three scenarios: the 'baseline (existing A9) scenario'; the 'proposed scheme (without mitigation) scenario'; and a third modelling scenario, the 'proposed scheme (with mitigation) scenario' which was developed to identify methods of mitigating any adverse impacts.

1.3.7 By way of a summary, modifications to the baseline model to represent the proposed scheme include:

- horizontal and vertical changes to the existing A9 and embankments to accommodate the new carriageway, which includes embedded mitigation to prevent the carriageway from flooding;
- modifications to existing A9 structures and inclusion of new hydraulic structures (bridges and culverts) in the river channel; and
- inclusion of proposed scheme features within the floodplain, including junctions, access roads and tracks, and road drainage features, such as SuDS features.

1.3.8 Model scenarios were simulated for a range of flood events including the 0.5% AEP (200-year) plus CC design flood event. Peak flows on each of the principal watercourses are included in Table A19.2-6. Annex D (Surface Water Hydrology) provides further details of the flood hydrology.

Table A.19.2-6: Peak flows (m^3/s) on modelled watercourses

Watercourse	50% AEP (2-year)	3.33% AEP (30-year)	0.5% AEP (200-year)	0.5% AEP CC (200-year) CC
River Tay at Inver	803	1,473	2,120	3,243
Inchewan Burn at A9	2.97	6.76	10.61	16.23* 15.56**
River Braan at A9	125	287	472	722

*Model Run 1: Climate change uplift (53%) based on the peak river flow allowance for the Tay river basin region as per SEPA climate change allowance guidance for catchments larger than $50km^2$.
**Model Run 2: Climate change uplift (39%) based on peak rainfall intensity allowance for the Tay river basin district as per SEPA climate change allowance for catchments less than $30km^2$.

1.3.9 Flood maps illustrating modelled flood extents under the baseline scenario and the proposed scheme (no mitigation) scenario during the 0.5% AEP (200-year) plus CC design flood event, are presented in Annex C (Flood Risk Assessment Figures). The mapping also illustrates the impacts on maximum flood level difference categorised using Table A.19.2-7. Annex E (Hydraulic Modelling Report) includes peak water levels for each model cross-section.

Table A.19.2-7: Fluvial flood risk impacts

Potential flood impact		Change in Peak Flood Level for the Design Flood Event
	Major Adverse	Increase in peak flood level >100mm

Potential flood impact		Change in Peak Flood Level for the Design Flood Event
	Moderate Adverse	Increase in peak flood level >50mm
	Minor Adverse	Increase in peak flood level >10mm
	Negligible	Negligible change in peak flood level <+/- 10mm
	Minor Beneficial	Reduction in peak flood level >10 mm
	Moderate Beneficial	Reduction in peak flood level >50mm
	Major Beneficial	Reduction in peak flood level >100mm

Baseline Fluvial Flood Risk

1.3.10 The baseline fluvial flood risk identified by the hydraulic model, is shown on Figure A19.2-4 to Figure A19.2-6 for the 0.5% AEP (200-year) plus 53% CC scenario. The flood extents shown, and the accompanying discussion of the modelled baseline flood risk are for model Run 1, which represents the critical flood event on the River Tay with a less severe flood on the Braan and Inchewan Burn. Model results are shown for Run 1 as this represents the critical flood scenario i.e., the greatest flood extents and depths. Annex D (Surface Water Hydrology) provides further details of the flood hydrology.

1.3.11 An alternative modelled scenario, referenced as Run 2, represents the critical flood event on the River Braan and Inchewan Burn with minor flooding (taken as the estimated QMED flow) on the River Tay.

1.3.12 Where reference is made to left bank or right bank, this is relative to the perspective of looking downstream.

<u>Chainage 1700 – 4300 (Birnam to Dunkeld)</u>

1.3.13 Between Ring Wood, at road chainage 1750 (NGR NO 04331 40642), to Oak Avenue, located on the right bank of the Inchewan Burn at road chainage 3450 (NGR NO 03084 41971); the hydraulic modelling predicts that the right bank of the River Tay would be inundated. The average modelled flood depth is approximately 1.7m however maximum flood depths greater than 5.0m are predicted for example, to the south of the sewage works at NGR NO 04235 40845 and NO 04174 40914. North of the sewage works, i.e. towards the settlement of Birnam, flood depths generally decrease and at Torlee Road, the average modelled flood depth is approximately 1.2m and maximum modelled flood depths are approximately 1.7m. With the exception of properties on Torlee Road, the settlement of Birnam is predicted to be largely unaffected by flooding from the River Tay. Flood water is generally confined to the low-lying floodplain, although properties located on Oak Road and Oak Avenue are predicted to be impacted from the combined influence of elevated river levels in the River Tay and the Inchewan Burn. Flood water is shown to extend upstream of the confluence of the River Tay and Inchewan Burn to Tayburn House at NGR NO 03084 41975. The average modelled flood depth is approximately 0.6m and maximum modelled flood depths of approximately 3.5m are predicted over ground to the east of Tayview Cottage at NGR NO 03271 42108.

1.3.14 Flooding is also predicted to inundate the left bank of the River Tay and from NGR NO 03389 42236 to NGR NO 03214 42301 the A984 is predicted to be impacted with average flood depths of approximately 1.8m and a maximum flood depth of approximately 3.2m at NGR NO 03259 42285. At Eastwood NGR NO 03512 42133, flood depths of up to approximately 2.7m are predicted.

1.3.15 Between the left bank of the Inchewan Burn at road chainage 3500 (NGR NO 03143 42128) i.e., near Burnmouth Road, and the confluence of the River Tay and River Braan at road chainage 4300, located by Dunkeld and Birnam Recreation Club (NGR NO 02340 42314), the hydraulic model predicts that the right bank of the River Tay would be inundated. The average modelled flood depth is approximately 1.3m however maximum flood depths greater than 7.0m are predicted, although confined to the bankside of the River Tay. The footpath between NGR NO 02980 42287 to NO 03082 42244 for example, is inundated to depths greater than 6.0m.

1.3.16 Flood depths are also predicted to be significant in the area of Burnmouth Road with an average predicted flood depth of approximately 3.4m and a maximum depth of approximately 5.9m at NGR NO 03160 42173. Flood depths decrease with distance from the River Tay and at the termination of Burnmouth Road, i.e., at No. 10 Burnmouth Rd, flood depths are approximately 1.5m increasing to >5m at No. 1 Burnmouth Rd.

1.3.17 Within the wider area of Little Dunkeld, the area to the east of the A923 crossing of the River Tay, north of Perth Road, i.e., properties in the Willow Bank area for example, are predicted to be impacted by flooding, with average predicted flood depths of approximately 1.2m. To the west of the A923 River Tay crossing to the confluence of the River Braan and River Tay, i.e., Bruce Gardens and the area occupied by Dunkeld and Birnam Recreation Club, average predicted flood depths are approximately 1m.

1.3.18 Flood water from the River Tay is also predicted to inundate the left bank and from the junction of the A923 crossing and A984 at NGR NO 02678 42577 eastwards to NGR NO 03197 42306, the A984 is predicted to be flooded to a maximum depth of approximately 3.7m at NGR NO 02915 42477. Properties along Bridge Street and Tay Terrace, Dunkeld i.e., Atholl Arms Hotel and Tay house are predicted to be impacted with flooding predicted to extend northward as far as the Royal British Legion Club at NGR NO 02644 42804.

1.3.19 Much of lower Dunkeld is predicted to be impacted, for example the High Street and Cathedral Street are completely inundated with maximum flood depths of approximately 5m predicted although on average flood depths are predicted to be approximately 1.9m.

<u>Chainage 4350 – 7400 (Inver)</u>

1.3.20 At Inver, located on the right bank of the River Tay, widespread flooding is predicted from the combined influence of elevated river levels in the River Tay and flows in the River Braan. The existing A9 is inundated along an approximately 600m stretch from NGR NO 02285 42185 to NO 01687 42310 (between road chainage 4350 and 4950) and the extent of flooding is broadly consistent with the 0.5% AEP (medium likelihood) flood extent shown by the SEPA Flood Maps.

1.3.21 Inver Mill Holiday Park at NGR NO 01985 42116 is completely inundated with average flood depths of approximately 2.5m and a maximum flood depth of approximately 3.7m predicted. Properties on the left bank of the River Braan including Inver Park and the settlement of Inver itself are predicted to be impacted with flood inundation shown to extend up to the Old Inn around NGR NO 01654 42211 where maximum flood depths are predicted to be greater than 2m.

1.3.22 Between road chainage 5300 and 7400, flooding over the right bank of the River Tay is less significant with no properties or critical infrastructure predicted to be impacted.

1.3.23 Flooding on the left bank of the River Tay extends westward to NGR NO 00856 42617 (road chainage 5800) near Dunkeld House Hotel and land occupied by the Tennis Courts. The Hotel is not shown to be impacted by flooding however the Tennis Court and nearby buildings are shown to be impacted.

Chainage 7500 – 8400 (Inchmagrannachan)

1.3.24 From NGR NO 00365 43870 to NO 00232 44469 (road chainage 7600 to 8200) the right bank of the River Tay is inundated with an average flood depth of approximately 4.6m and maximum flood depths of approximately 7.0m. The B898 and railway are overtopped.

1.3.25 From NGR NO 00539 44259 to NO 00516 44603 (road chainage 8000 to 8400) the A9 is flooded from the Tay left bank for a length of approximately 290m and area of approximately 4,000m^2 with an average depth of approximately 0.3m and maximum flood depth of approximately 1.1m predicted.

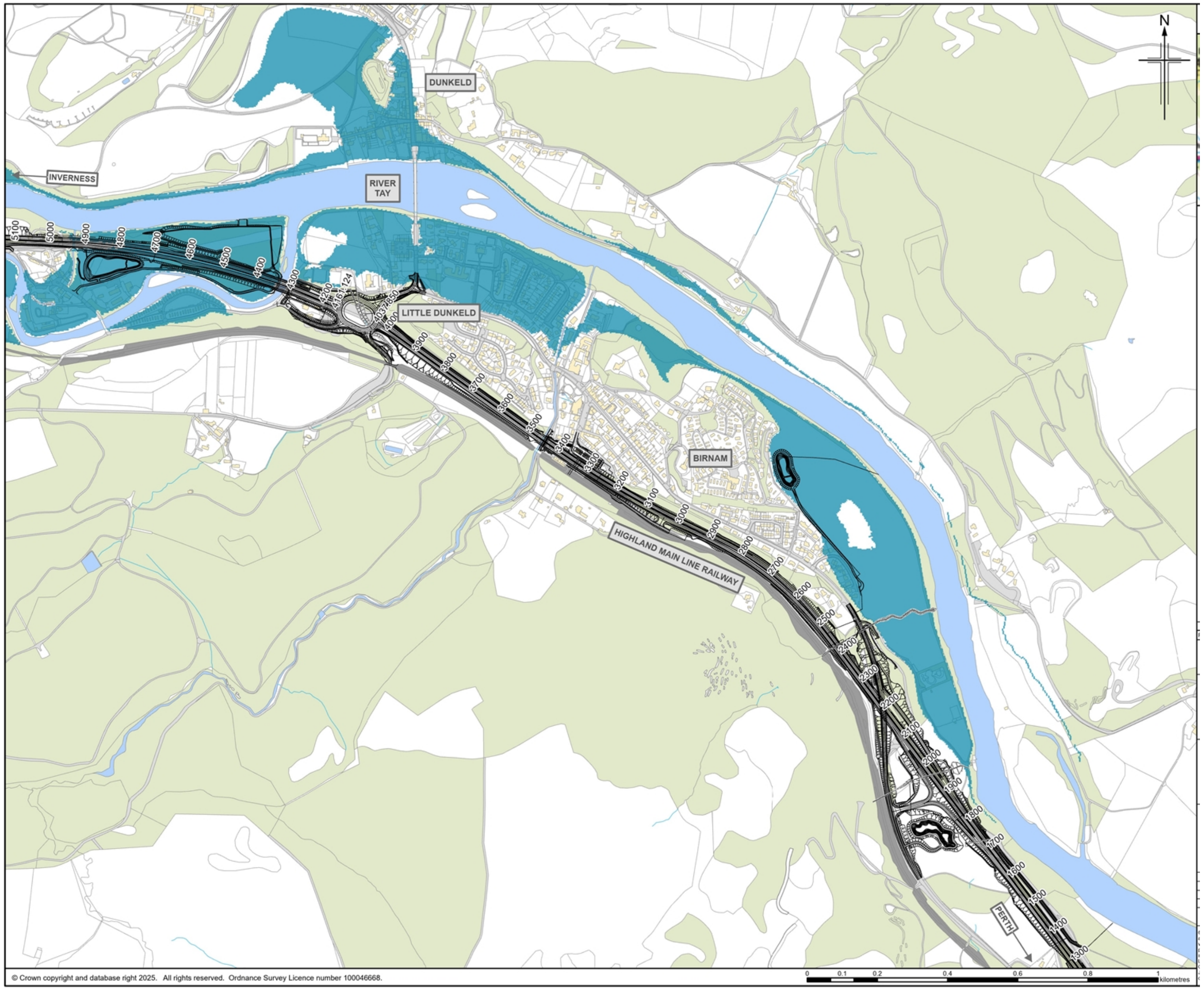


Figure A19.2-4: Run 1 Baseline – Flood Extent Map for the 0.5% AEP plus 53% Climate Change Event (ch 1700 - 5100)

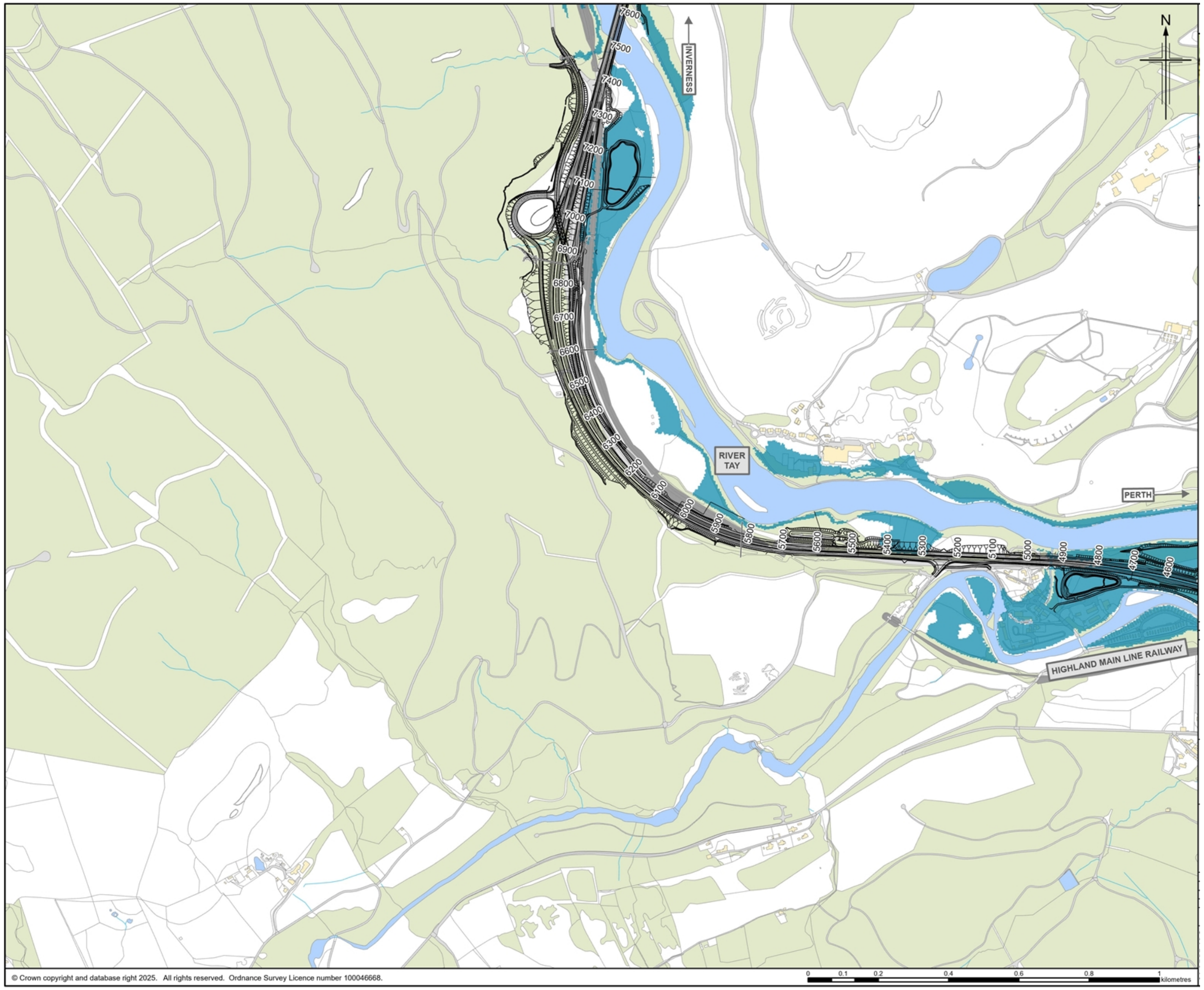


Figure A19.2-5: Run 1 Baseline – Flood Extent Map for the 0.5% AEP plus 53% Climate Change Event (ch 4600 - 7500)

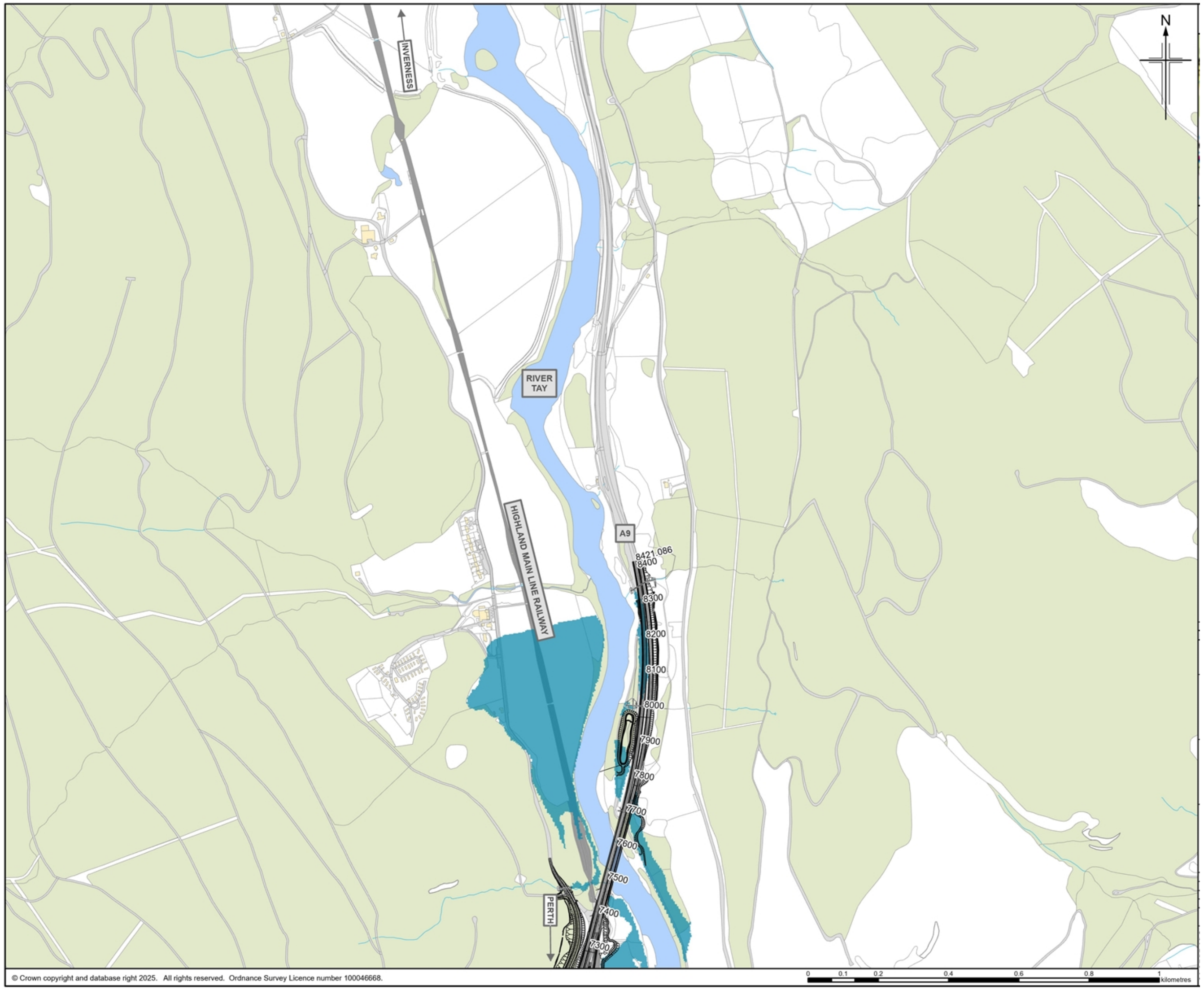


Figure A19.2-6: Run 1 Baseline – Flood Extent Map for the 0.5% AEP plus 53% Climate Change Event (ch 7300 - 8400)

Potential Pre-Mitigation Impacts

1.3.26 This section provides an overview of the impact of the proposed scheme upon fluvial flood risk in the absence of essential mitigation but includes embedded mitigation. Embedded mitigation are measures included as part of the scheme design process, for example, avoidance and re-locating scheme elements out of the floodplain. The proposed scheme includes raising the road profile above the 0.5% AEP (200-year) plus climate change peak water level. A minimum freeboard of 600mm has been provided above this level as per SEPA Technical Flood Risk Guidance (SEPA 2022). Embedded mitigation is detailed further below in section 1.3.50.

1.3.27 The following descriptions detail the flood mechanism and impacts in the key reaches (as provided in the baseline section) and highlights both adverse and beneficial magnitude of impact.

<u>Chainage 1700 – 4300 (Birnam to Dunkeld)</u>

1.3.28 There is no change is this reach with the proposed scheme impacts remaining similar to the baseline scenario with negligible changes in flood depth.

<u>Chainage 4350 – 7400 (Inver)</u>

1.3.29 On the banks of the River Tay there are some small areas of adverse impact directly opposite the confluence with the River Braan, however there are minor to major beneficial reductions in flood depth in the floodplain which extend some distance upstream.

1.3.30 The area of Inver between the right bank of the Tay and the left bank of the Braan (from chainage 4370 to 5000) is split by the existing A9. The proposed scheme will have a higher vertical alignment and this has the effect of preventing flooding from the River Braan overtopping towards the River Tay. The areas of beneficial impact on the right-bank of the River Tay upstream of the Braan confluence reflect this reduction in flow via this overtopping mechanism. Conversely, due to the increased impoundment, there are large areas of minor and moderate adverse impact on the River Braan floodplain as the overtopping flood mechanism is prevented. This area of adverse impact extends upstream on the River Braan to Inver Bridge and extends along the Mill Lade with moderate adverse impact with changes in depths of up to 128mm to sensitive receptors.

1.3.31 The proposed scheme incorporates a newly constructed crossing of the River Braan which has a widened bridge span and an increased height, relative to the existing bridge structures. In the baseline the main road bridge is being significantly surcharged with a peak water level of 53.356mAOD well above the 51.385mAOD soffit level during the design event. In the proposed design, the soffit has been increased significantly to 54.276mAOD to mitigate this. The peak water level is reduced from the baseline to 53.245mAOD and thus freely passes beneath the new bridge.

1.3.32 As the current structures crossing the River Braan both surcharge and overtop during the baseline design flood, they act as a significant throttle to flows, reducing conveyance in this reach and bringing the peak flows of the two rivers closer together (when compared with the proposed scheme with no mitigation). This throttle behaviour and high River Tay water levels backs-up the River Braan into the floodplain and eventually reaches levels where the road embankment overtops. This does not happen in the proposed scheme as the vertical alignment of the carriageway has been elevated to keep the highway flood-free; and allow sufficient freeboard for the peak water levels to the Braan crossing soffit level (approximately 1.03m freeboard provided). This leads to greater depths in the Inver area than the baseline with minor to moderate adverse impacts.

1.3.33 The hydrographs representing the River Braan and Inchewan Burn are set to peak around 6.9 hours before the River Tay to reflect a time lag observed in historic floods. Historic flood hydrographs on the Rivers Tay and Braan show that the Braan tends to peak earlier than the Tay, see Annex D: Surface Water Hydrology. During the 20 largest historic events, the Braan on average peaked 6.9 hours before the Tay, with a standard deviation of 4.6 hours. As a consequence of the larger bridge opening in the with-scheme condition, the flood hydrograph from the River Braan reaches the confluence with the River Tay slightly earlier than in the baselinethis results in the Braan contributing less to the peak flow and water level on the River Tay. This has a beneficial impact not just on flooding along the River Tay, but also on flooding in the downstream part of the River Braan floodplain, where backwater effects from floods on the Tay are the dominant cause of flooding. Upstream of Inver Bridge there is a small area of minor beneficial impact with slight improvements in flood depth but largely flooding is in line with the baseline scenario with no properties nor critical infrastructure predicted to be impacted by the proposed scheme.

<u>Chainage 7500 – 8400 (Inchmagrannachan)</u>

1.3.34 There is a Minor Beneficial reduction (10-50mm) in water levels on the right bank of the Tay and for much of the left bank, likely due to the SuDS pond at NGR NO 00498 44167. However, the wider road design at this location allows further encroachment of the flooding across the carriageway.

Encroachment into the floodplain

1.3.35 There are five areas where the scheme encroaches into the floodplain of the River Tay and River Braan and these are discussed in the following sections.

<u>Inver</u>

1.3.36 The proposed scheme encroaches into the 0.5% AEP (200-year) plus CC flood extent on both the north and south sides of the main alignment through this section from the Braan Crossing at road chainage 4300 to the Mill Lade culvert at road chainage 4950m.

1.3.37 To the north, the raised and widened embankment would reduce the floodplain available within the area between the main alignment and the River Tay. This is currently an area of scrub and woodland which runs along the existing A9 embankment. On this side of the proposed scheme, the encroachment would be limited by use of retaining walls rather than embankments.

1.3.38 On the south side of the main alignment there would be a loss floodplain as a result of the widened embankment for the mainline which is more pronounced on this southern side due to the provision of additional new lanes and associated earthworks for pedestrian access to the Braan Crossing. The construction of a SuDS pond and access road within the floodplain would be below existing ground or at current grade and has been designed to have a neutral impact on floodplain loss. The increased embankments, SuDS pond and access road are all fully located within the design event flood extent and constitute a significant volume of floodplain loss, with approximately 24,016m^3 of flood plain storage loss to the River Tay floodplain and 28,931m^3 loss to the River Braan floodplain during the 0.5% AEP (200-year) plus CC event. This gives a total of 52,946m^3 loss in the Inver area.

1.3.39 During the 0.5% AEP (200-year) event there is a 4,602m^3 loss to the River Tay floodplain and a 12,468m^3 loss to the River Braan floodplain.

Hermitage Junction

1.3.40 The proposed scheme footprint would encroach onto the 0.5% AEP (200-year) plus CC flood extent on the north side of the main alignment at Hermitage Junction. This reduces the floodplain available between the main highway and the River Tay, with 3,833m^3 of storage lost over an area of 3,900m^2. There is no detectable change in the hydraulic modelling results due to this floodplain loss.

1.3.41 During the 0.5% AEP (200-year) event there is no loss of floodplain storage in this area.

Dalguise Junction

1.3.42 To the west side of Dalguise Junction, the main alignment has a limited footprint within the 0.5% AEP (200-year) plus CC flood extent, with the main highway and its embankments clear and only a small section of the eastern slip road within the floodplain at a very shallow depth. The inclusion of a SuDS pond and associated access tracks and NMU is the primary loss of floodplain storage in this area and 1,357m^3 is lost over around 250m of embankment at the edge of the flood extent. There is no detectable change in the hydraulic modelling results from the baseline due to this floodplain loss.

1.3.43 During the 0.5% AEP (200-year) event there is a 198 m^3 loss of floodplain storage in this area.

Birnam Junction (Sewage Treatment Works Access)

1.3.44 The proposed scheme has a limited footprint within the floodplain in this area, with road infrastructure located primarily outside the 0.5% AEP (200-year) plus CC flood extents. Small sections of embankments for the side roads would encroach into the floodplain with a loss of 302m^3, having a negligible impact on flood risk.

1.3.45 A proposed SuDS pond also located in this area would be placed within the flood extent, with only minor sections of its earthworks and the western tip of the access road from Torlee Road falling within the flood event extents. This will have a minor impact on floodplain loss and is unlikely to increase flood risk.

1.3.46 During the 0.5% AEP (200-year) event there is a 79m^3 loss of floodplain storage in this area.

Tay Crossing Left Bank Abutment and NMU provision

1.3.47 The proposed scheme has a wider carriageway on the east side of the crossing at the Tay left bank, encroaching into the floodplain. There is also a SuDS pond to the north of the crossing and an NMU track leading from the east of the crossing to the Tay bank, leading to a loss of 3,011 m^3 of floodplain storage during the 0.5% AEP (200-year) plus CC event.

1.3.48 During the 0.5% AEP (200-year) event there is a 825m^3 loss of floodplain storage in this area.

Summary

1.3.49 The impact of the unmitigated scheme on floodplain storage loss has been summarised in Table A19.2-8. The major loss is in the Inver area and here the embankment is fully submerged during the design flood event in the baseline, with the new embankment raised and the footprint widened to accommodate the proposed scheme.

Table A19.2-8: Impact of proposed scheme upon 0.5% AEP (200-year) +CC fluvial flood risk

Location	Chainage	Approximate Volume of Floodplain Lost (m^3)
Inver	5000 - 4300	52,946
Hermitage Junction	5300 - 5400	3,833
Dalguise Junction	6900 - 7100	1,357
Tay Crossing Left Bank Abutment and NMU provision	7600	3,011
Birnam Junction (Sewage Treatment Works Access)	2300	302
Total	**-**	**61,451**

Mitigation Measures

1.3.50 The hydraulic model predicts that without mitigation the proposed scheme would increase peak water levels locally within the River Braan floodplain. Mitigation measures to prevent these increases have therefore been considered and are discussed in more detail in the following sections.

Embedded Mitigation

1.3.51 Initially, potential changes in the proposed scheme design to reduce the impact on flood risk were considered. The embedded mitigation options considered and whether they have been incorporated are included in Table A19.2-9. It should be noted that the volumes of floodplain lost due to the proposed scheme are included in Table A19.2-8.

Table A19.2-9: Embedded mitigation measures considered

Measure	Flood Risk Benefit	Incorporation in Proposed Scheme
Relocate scheme outside floodplain	Would prevent loss of floodplain storage on the River Tay.	A multi-disciplinary technical study looking at potential alternative routes was undertaken at DMRB Stage 2. Routes that completely removed the proposed scheme from the floodplain were considered less favourable due to greater potential environmental impacts and considerably greater cost. At the Birnam Junction, the junction design originally encroached into the floodplain. This was redesigned to be outside the floodplain, resulting in no floodplain loss. The access track to the STW was also moved southwards to reduce floodplain loss, although a small amount of loss (at the transition from high ground to low ground at floodplain level) could not be avoided. Compensatory flood storage very close to the scheme has been incorporated in the scheme to fully offset this small loss.
Reduce extent of scheme within floodplain	Would reduce loss of floodplain storage on the River Tay.	A desire to reduce impact on the floodplain was one of the primary reasons for southbound widening. Where possible, side roads have been relocated to be outside the functional floodplain. When considering options for the location of the overbridge, areas of lower flood risk have been considered in preference to areas of higher risk. Embankment slopes within the floodplain have been steepened to minimise encroachment where this is considered a sustainable solution in liaison with landscape and ecology specialists. Cantilever structure at Mill Stream extending to the beginning of proposed embankments. Where possible have access and tracks at or near grade where the floodplain interacts with the proposed scheme infrastructure.
Remove raised elements of SuDS ponds within the floodplain	Would reduce loss of floodplain storage on the River Tay.	Raised SuDS ponds removed from functional floodplain such as at Inver and Dalguise where raised bunds have been removed. Where ponds are within the floodplain they are below existing ground level.
Birnam Junction (Sewage Treatment	Reduce the impact of floodplain loss as much as possible	Northern section of the proposed new access road alignment has been moved westwards away from Tay floodplain. Southern section of road is in floodplain and designed to be level with existing ground levels. Where

Measure	Flood Risk Benefit	Incorporation in Proposed Scheme
Works Access Track)	without impacting too much on ancient woodland	the northern section and southern section meet, the road drops to floodplain level, causing a minimal residual floodplain loss of 76m^3. This is discussed in the Flood Risk Mitigation section below. To remove this impact requires further widening into the existing slope, creating large earthworks and loss of ancient woodland.

Flood Risk - Specific Mitigation

1.3.52 Where it has not been possible to prevent the scheme from impacting on the functional floodplain by embedding mitigation within the design, the initial measure considered for standalone mitigation has been the provision of compensatory flood storage (CFS) that, in accordance with SEPA guidance, should be provided on a 'like for like' basis i.e., compensatory storage must become effective at the same point in a flood event, as the lost storage would have been (SEPA 2022). It is also a DMRB Standard that a road scheme should result in no net loss of floodplain volume.

1.3.53 There are limited areas of high ground close to the areas of loss that can be used to provide direct storage at Inver to compensate for the 0.5%AEP (200-year) plus CC event. There are also ecological, environmental and land constraints to the provision of CFS within the proposed scheme area. The River Tay floodplain is relatively constrained close to the main channel banks with various landscape designations and sensitive habitats limiting the available area to provide CFS.

1.3.54 These constraints have been taken into account as part of the assessment of mitigation measures and compensatory storage area screening is detailed in Annex E. A detailed description of the options considered for the Inver area to mitigate flood risk are presented in Annex F. Engineered solutions are not considered to be viable (e.g. viaduct options or extensive and high retaining walls) due to impacts to other sensitive environmental receptors and significant cost.

1.3.55 The primary aim in mitigation design and assessment has been to achieve a neutral impact on flood risk as a result of the proposed scheme. Where this has been identified as impracticable due to local constraints, prevention of increase in flood risk to sensitive receptors such as buildings and local infrastructure has been prioritised over water level increases to agricultural and other undeveloped land within the existing floodplain.

1.3.56 The process for identifying potential flood mitigation has generally been as follows:

- Identify areas of floodplain loss as a result of the proposed scheme and identify and characterise the flood mechanism where adverse impacts are noted;
- Develop a long-list of potential mitigation options, including areas of potential level for level (direct) compensation and measures to improve conveyance or reinstate flood mechanisms that are changed by the proposed scheme;
- Identify candidate sites for compensatory storage and testing of flood mitigation measures leading to a short-list for more detailed consideration; and

- Detailed analysis of shortlisted options, generally including iterative hydraulic modelling to refine mitigation measures and determine hydraulic performance and effectiveness.

1.3.57 The following sections set out the mitigation that has been selected within the proposed scheme extents. The mitigation options considered have been assessed for their effectiveness both to mitigate changes in flood risk locally and as part of a wider range of measures to consider the wider floodplain. Shortlisted mitigation options located within the proposed scheme area are included in Table A19.2-10.

Table A19.2-10: Shortlisted mitigation measures and selection.

Location	Mitigation measures shortlisted	Effectiveness and mitigation selection
River Tay/ River Braan Confluence	▪ Compensatory storage area on the River Tay at the Braan confluence (Ch 4350-4700)	▪ Effective - included as CFS Area 1. Provides like for like, level for level compensatory storage for the 0.5%AEP event on the Tay side. Indirect storage in this location also helps to negate any increases in flood level due to improved conveyance at the Braan crossing.
Inver Floodplain	▪ Flood relief culverts reducing flood depth to the Mill lade area (Ch 4890)	Effective - 3no. 1.5m diameter Flood Relief Culverts proposed to convey additional floodwater within the Inver floodplain through the A9 carriageway into the River Tay.
Inver Floodplain	▪ Flood relief culverts in the A9 embankment at to replicate the overtopping mechanism from the River Braan to the River Tay (Centred on Ch 4500)	▪ Effective - 14no. 3.6m x 1.2m Flood Relief Culverts constructed through proposed embankment (level of culverts set to existing carriageway level – 52.1mAOD). The culverts will only operate during the Run 1 0.5% AEP + CC flood event, replicating the existing flood path over the A9 carriageway.
Inver Floodplain	▪ Compensatory storage area on the River Tay at the Braan confluence (Ch 5280-5500)	▪ Was not effective for the design event as only indirect storage was feasible. Indirect storage tested increased flood extents and depths locally causing detriment to the left-bank. This was due to the storage area introducing recirculatory flows which create a localised increase in water level and increase flood extent and depth.
North of the Tay Crossing	▪ Area of flooding at chainage 8300-8400	▪ Ineffective - although technically feasible it has been considered impractical to construct a c.1200-2600 mm flood wall

Location	Mitigation measures shortlisted	Effectiveness and mitigation selection
	north of the Tay Crossing	(including 600mm freeboard) that would be required to protect the proposed scheme from flooding at Chainage 8300-8400. ▪ Impractical - Tay Crossing to Ballinluig section, to which this section of the route ties-in, is designed and consented to the 0.5%AEP plus 20%CC event. This FRA demonstrates that this section of the road remains operational for the same event, therefore it is considered impractical to raise the road elevation due to the highway geometry. ▪ It is considered proportionate to manage this limited flooding at the design event rather than mitigate given the challenges of a flood defence solution and tie-in requirements of the proposed scheme with the Tay Crossing to Ballinluig section.

1.3.58 With the exception of the Inver area, the losses of floodplain storage due to the proposed scheme are very small when compared to the flooded area and capacity of the River Tay floodplain adjacent to the areas of loss. The displacement leads to very small changes in water levels locally and no detectable downstream impacts to the hydrograph or stage level are shown in the hydraulic modelling. It is not considered to be proportionate to mitigate for these losses due to the negligible impacts to areas with no sensitive flood receptors. Any floodplain storage provision would result in other environmental impacts and cost with no measurable benefit to flood risk. The losses described are only relevant to the most extreme events.

1.3.59 At Inver, for the 0.5%AEP (200-year) plus CC event it is not feasible to provide direct replacement for the proposed scheme losses. The only available high ground is generally occupied or adjacent to infrastructure (e.g. the Inver access road and the Highland Mainline railway) or residential or commercial properties. Several areas are also sensitive habitats or have landscape designations precluding land lowering. The proposed CFS area at the Braan confluence provides some direct compensatory storage at the 0.5% AEP (200-year) event level on the River Tay side but no areas were considered to be viable for the River Braan floodplain.

1.3.60 At Inver, the primary pre-mitigation impacts were moderate adverse changes in flood level in the Braan floodplain of 18-128mm at sensitive receptors, primarily due to the raised level of the proposed scheme changing the baseline overtopping mechanism to the River Tay. Any impact from the loss of floodplain storage appears to be largely mitigated by improved conveyance at the Braan Crossing. Downstream of the Braan Crossing, there is a small area of riparian woodland within the Cathedral Historic Monument which shows a minor adverse impact due to the improved conveyance. As velocities are low, there is no increased erosion risk that could change the character of the receptor no further mitigation is proposed.

1.3.61 At Inver, localised impacts to sensitive receptors would be mitigated by 3no. flood relief culverts adjacent to the Mill Lade culvert. The wider impacts to the floodplain would be mitigated through the inclusion of 14no. flood relief culverts with invert level at the existing A9 road level, replicating the overtopping mechanism in the baseline.

1.3.62 As demonstrated in this FRA, a 53% climate change uplift applied as the design event would result in flooding north of the Tay Crossing at the interface with the proposed scheme and the A9 Dualling: Tay Crossing to Ballinluig section which was designed and consented to a 20% uplift for climate change. It should be noted that, as demonstrated in this FRA, the entire A9 mainline within the proposed scheme extents would remain operational during the 0.5%AEP (200-year) plus 20% for climate change flood event.

1.3.63 The area of flooding to the proposed scheme to the north of the Tay Crossing was investigated and flood wall options were examined. Although a wall is feasible to construct it would be challenging due to the limited space and necessity to accommodate an access road. As the flooding is limited to the A9 and the northern section of the road has to tie into the A9 Dualling: Tay Crossing to Ballinluig section which is designed to a 20% uplift for climate change, it is considered to be proportionate to manage this limited flooding at the design event rather than mitigate.

1.3.64 Given the B898 would be flooded at Inchmagarrachan in the design flood event, it is considered that this would not present a suitable alternative route and access at the Dalguise Junction would therefore also require to be managed. The flooding to the proposed scheme occurs at the very peak of the flood hydrograph and would be passable to emergency vehicles able to traverse depths of 300-600mm. The limited extent and volume (circa 2000m^3) could also be managed by emergency pumping to limit the flood depth and extent.

Summary of proposed mitigation for Principal Watercourses

1.3.65 The assessment set out above demonstrates that multiple mitigation options have been considered and explains the process through which selection of effective mitigation has been made. The proposed mitigation measures adopted are:

- P02-W37 - Compensatory Flood Storage Area (CFSA 1)
- P02-W38 - Mill Lade Flood Relief Culverts
- P02-W39 - Embankment culverts to replicate current A9 overtopping
- P02-W41 – Emergency Response Plan

1.3.66 The volume of compensatory storage provided by the proposed mitigation is summarised in Table A19.2-11. Although the constraints to provision of compensatory storage have prevented no net loss, the proposed CFSA1 area close to the Brann crossing is effective in providing some benefit in combination with the improved conveyance of the widened Braan Bridge crossing, the Mill Lade flood relief culverts and the embankment flood relief culverts which replicate the existing overtopping mechanism. This suite of mitigation has resulted in minor to moderate beneficial impacts in the Inver area compared with the baseline.

1.3.67 There is a small 600m^2 area of riparian woodland within the Cathedral Historic Monument boundary, which shows a minor adverse impact with an increase of c.21mm due to improved conveyance at the Braan confluence and as a result of the Essential Mitigation designed to counter the increased flooding upstream on the River Braan. Velocities in this area are low (<1.5m/s) and there is no additional erosion risk that could change the landscape character of the designated site. The area is flooded for about 36 hours in both Baseline and Design scenarios with very little difference in the depth profiles except for the small peak increase. Given this very small area of minor adverse impact and limited impact on the sensitive receptor, no further mitigation is proposed for this impact.

1.3.68 The deficit in compensatory storage is therefore considered to be acceptable as it has been demonstrated that the proposed mitigation measures are effective and that overall, the proposed scheme achieves a neutral impact to flooding with some beneficial reductions in depth and extent for the design flood event.

Table A19.2-11: Volume of compensatory storage compared with storage lost due to the proposed scheme during the 0.5% AEP (200-year) plus CC event.

Storage Area	Compensatory Storage Volume (m^3)
CFSA1 Volume (Indirect storage)	31,198
Total Storage Lost	61,451
Total floodplain storage loss	**30,253**

<u>Impact of Scheme with Proposed Mitigation</u>

1.3.69 The proposed scheme has been modelled with all the proposed mitigation included to identify any residual impact of the scheme. The impact of the scheme has been investigated over a range of flood events (50% AEP (2-year), 3.33% AEP (30-year), 0.5% AEP (200-year) and 0.5% AEP (200-year) plus CC) and the impact of the scheme on peak depths and flows has been considered.

<u>Peak Flood Depth at Receptors</u>

1.3.70 Key receptors included in this discussion are properties within the modelled flood extents for the design flood event and a selection of points within the general floodplain. The points selected are identified on Figure A19.2-7. The change from the baseline in peak flood depth at a range of receptors in the unmitigated scenario is presented in Table A19.2-12. Figures stated are Run 1 unless there is a worse case for Run 2, in which case the Run 2 figures are stated.

1.3.71 The change from the baseline in peak flood depth at a range of receptors for the mitigated proposed scheme is provided in Table A19.2-13. The negligible changes in flood depth at these receptors as a result of the proposed scheme (with mitigation) means that there would also be negligible change to the threshold, extent and frequency of flooding as a result of the proposed scheme.

1.3.72 The results presented within Table A19.2-13 and within Annex D demonstrate that any change as a result of the mitigated proposed scheme is negligible or beneficial at sensitive receptors. Post mitigation there is an increase of 5mm at Torlee Road. The encroachment of the access road to the SuDS pond and to the sewerage works does result in a 76m^3 loss in flood storage but given the water depths at these sensitive receptors of between 1.0-1.6m depth it is considered to be a negligible change and no mitigation is proposed.

1.3.73 All other sensitive receptors show no change or minor to moderate beneficial impacts of the proposed scheme.

1.3.74 Run 2, where the River Braan flood is dominant, does display very small pockets of minor to major adverse upstream of the Braan Confluence on both banks of the River Tay, extending towards the top of the modelled extents. This is likely due to the improved conveyance of the Braan Crossing and the converging flows creating a very minor backwater effect on the River Tay, slightly increasing marginal flood extents on the river banks. This has not been considered further for mitigation as there are no sensitive receptors impacted and this is a much less severe event than Run 1, where there are largely beneficial impacts in these areas.

1.3.75 Figures A19.2.8 to A19.2.13 show the water level differences between the mitigated proposed scheme and the baseline and demonstrate along the scheme the water level difference with the baseline is mainly negligible or beneficial. The Braan floodplain is mainly beneficial with the mitigation measures in place.

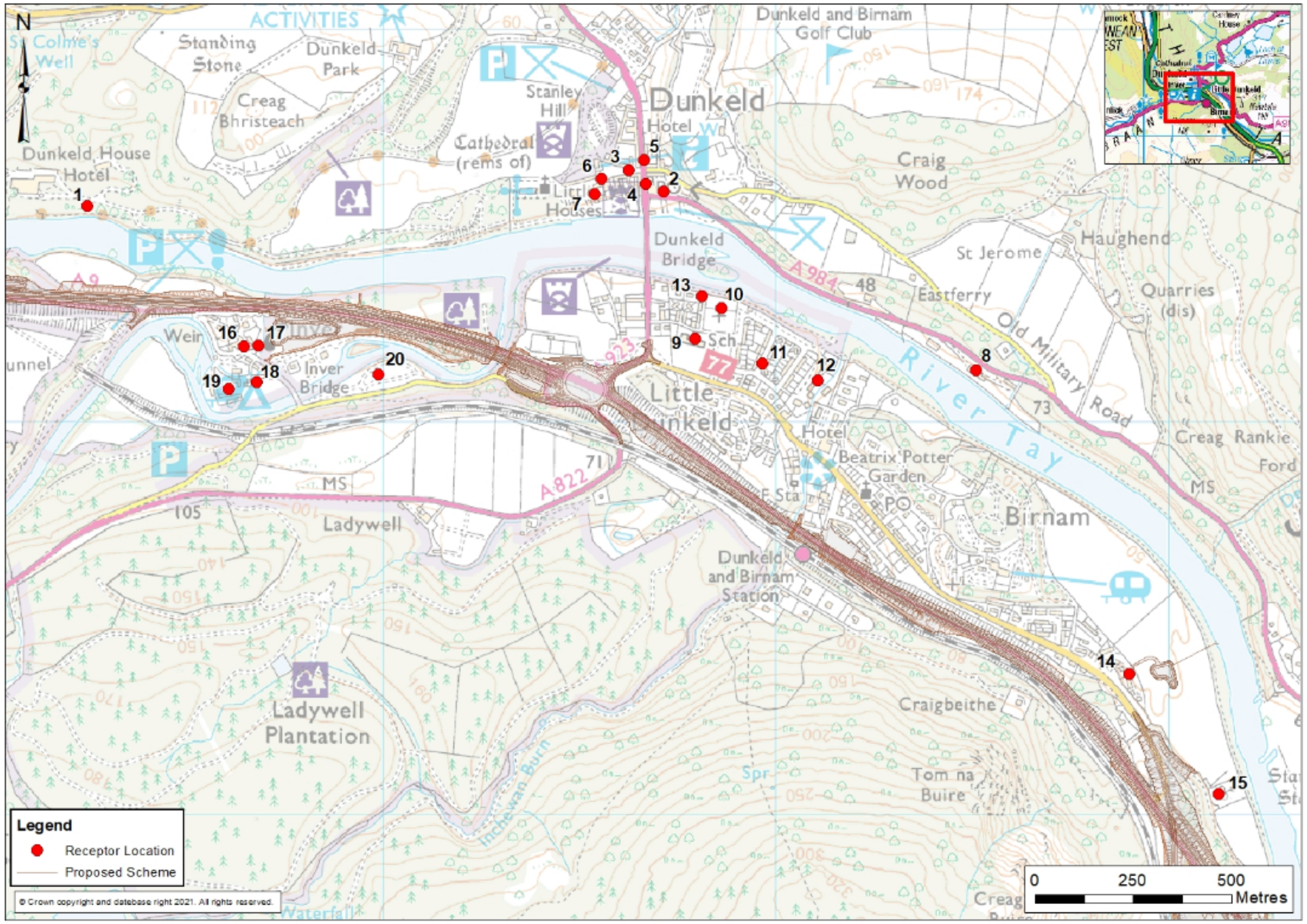


Figure A19.2-7: Receptor Locations

Table A19.2-12: Change in Flood Depth with unmitigated scheme

No.	Receptor Name	3.33% AEP (30yr)				0.5% AEP (200yr)				0.5% AEP (200yr) + CC			
		Baseline		No Mitigation		Baseline		No Mitigation		Baseline		No Mitigation	
		Level[1] (mAOD)	Depth (m)	Level[1] (mAOD)	Change (m)	Level[1] (mAOD)	Depth (m)	Level (mAOD)	Change (m)	Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)
Key Receptors- River Tay													
1	Sewage Treatment Plant close to Dunkeld House Hotel	-	0.000	-	0.000	-	0.000	-	0.000	54.689	1.743	54.619	-0.070
2	Tay House	-	0.000	-	0.000	-	0.000	-	0.000	52.780	1.719	52.778	-0.002
3	High Street (approx.7 properties)	-	0.000	-	0.000	50.940	0.268	50.939	-0.001	53.089	2.417	53.087	-0.002
4	Bridge Street (A923) (approx.10 properties)	-	0.000	-	0.000	-	0.000	-	0.000	53.086	0.879	53.084	-0.002
5	Athol Street (A923) (approx.7 properties)	-	0.000	-	0.000	-	0.000	-	0.000	53.089	1.045	53.087	-0.002
6	Cathedral Street (approx..7 properties)	-	0.000	-	0.000	-	0.000	-	0.000	53.082	1.549	53.080	-0.002

No.	Receptor Name	3.33% AEP (30yr) Baseline Level[1] (mAOD)	3.33% AEP (30yr) Baseline Depth (m)	3.33% AEP (30yr) No Mitigation Level[1] (mAOD)	3.33% AEP (30yr) No Mitigation Change (m)	0.5% AEP (200yr) Baseline Level[1] (mAOD)	0.5% AEP (200yr) Baseline Depth (m)	0.5% AEP (200yr) No Mitigation Level (mAOD)	0.5% AEP (200yr) No Mitigation Change (m)	0.5% AEP (200yr) + CC Baseline Level (mAOD)	0.5% AEP (200yr) + CC Baseline Depth (m)	0.5% AEP (200yr) + CC No Mitigation Level (mAOD)	0.5% AEP (200yr) + CC No Mitigation Change (m)
7	Water Wynd (approx.3 properties)	-	0.000	-	0.000	50.937	0.234	50.936	-0.001	53.057	2.311	53.054	-0.003
8	Eastwood House	-	0.000	-	0.000	49.504	0.612	49.503	-0.001	51.312	2.420	51.311	-0.001
9	Royal School of Dunkeld	-	0.000	-	0.000	-	0.000	-	0.000	52.431	1.114	52.430	-0.001
10	Little Dunkeld Kirk	-	0.000	-	0.000	50.426	0.345	50.425	-0.001	52.580	2.480	52.578	-0.002
11	Willowbank (approx. 75 properties)	-	0.000	-	0.000	-	0.000	-	0.000	52.206	1.266	52.205	-0.001
12	Burnmouth Road (approx.8 properties)	48.644	0.82	48.644	0.000	50.077	2.252	50.076	-0.001	52.014	4.190	52.013	-0.001
13	Cottages along East Bank of River Tay in Little Dunkeld (approx.17 properties)	-	0.000	-	0.000	50.588	0.065	50.587	-0.001	52.644	2.122	52.643	-0.001

No.	Receptor Name	3.33% AEP (30yr)				0.5% AEP (200yr)				0.5% AEP (200yr) + CC			
		Baseline		No Mitigation		Baseline		No Mitigation		Baseline		No Mitigation	
		Level[1] (mAOD)	Depth (m)	Level[1] (mAOD)	Change (m)	Level[1] (mAOD)	Depth (m)	Level (mAOD)	Change (m)	Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)
14	Torlee Road, Birnam (approx. 8 properties)	-	0.000	-	0.000	-	0.000	-	0.000	49.902	1.360	49.906	0.004
15	STW, Dunkeld	46.479	1.124	46.481	0.002	47.951	2.597	47.951	0.000	49.824	4.469	49.823	-0.001
Key Receptors - River Braan													
16	Old Inn	-	0.000	-	0.000	52.354 [B]	0.016 [B]	52.354 [B]	0.000 [B]	53.413	1.069	53.541	0.128
17	Ladeside Cottages	-	0.000	-	0.000	52.020 [B]	1.161 [B]	51.802 [B]	-0.218 [B]	53.396	2.537	53.491	0.095
18	Inver Mill Farm	52.531 [B]	0.069 [B]	52.530 [B]	-0.001 [B]	53.320 [B]	0.855 [B]	53.317 [B]	-0.003 [B]	53.903	1.437	53.963	0.060
19	Inver Mill Caravan Site	53.164 [B]	0.054 [B]	53.163 [B]	-0.001	53.574 [B]	0.465 [B]	53.574 [B]	0.000 [B]	54.395	1.286	54.413	0.018
20	Inver Mill Holiday Park (approx. 70 properties) *	51.069 [B]	0.473 [B]	50.999 [B]	-0.070 [B]	51.934 [B]	1.338 [B]	51.654 [B]	-0.280 [B]	53.380	2.784	53.452	0.072

*Maximum level difference of properties within the same location taken

[1]No flooding is shown as blank.

[B]Proposed scheme increase in flood level is predicted for Run 2 (Braan dominant flooding).

Negligible	(No change or less than +/- 0.010m)	Level in mAOD

Betterment	(Greater than or equal to 0.010m)	Change in m
Increase	(Greater than or equal to 0.010m)	Flood Depth in m

Table A19.2-13: Change in Flood Depth with mitigated scheme

No.	Receptor Name	30yr Baseline Level (mAOD)	30yr Baseline Depth (m)	30yr With Mitigation Level (mAOD)	30yr With Mitigation Change (m)	200yr Baseline Level (mAOD)	200yr Baseline Depth (m)	200yr With Mitigation Level (mAOD)	200yr With Mitigation Change (m)	200yr+CC Baseline Level (mAOD)	200yr+CC Baseline Depth (m)	200yr+CC With Mitigation Level (mAOD)	200yr+CC With Mitigation Change (m)
Key Receptors – River Tay													
1	Sewage Treatment Plant close to Dunkeld House Hotel	-	0.000	-	0.000	-	0.000	-	0.000	54.689	1.743	54.652	-0.037
2	Tay House	-	0.000	-	0.000	-	0.000	-	0.000	52.780	1.719	52.779	-0.001
3	High Street (approx.7 properties)	-	0.000	-	0.000	50.940	0.268	50.940	0.000	53.089	2.417	53.088	-0.001
4	Bridge Street (A923) (approx.10 properties)	-	0.000	-	0.000	-	0.000	-	0.000	53.086	0.879	53.084	-0.002
5	Athol Street (A923) (approx..7 properties)	-	0.000	-	0.000	-	0.000	-	0.000	53.089	1.045	53.088	-0.001

No.	Receptor Name	30yr				200yr				200yr+CC			
		Baseline		With Mitigation		Baseline		With Mitigation		Baseline		With Mitigation	
		Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)	Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)	Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)
6	Cathedral Street (approx..7 properties)	-	0.000	-	0.000	-	0.000	-	0.000	53.082	1.549	53.081	-0.001
7	Water Wynd (approx..3 properties)	-	0.000	-	0.000	50.937	0.234	50.937	0.000	53.057	2.311	53.054	-0.003
8	Eastwood House	-	0.000	-	0.000	49.504	0.612	49.503	-0.001	51.312	2.420	51.311	-0.001
9	Royal School of Dunkeld	-	0.000	-	0.000	-	0.000	-	0.000	52.431	1.114	52.431	0.000
10	Little Dunkeld Kirk	-	0.000	-	0.000	50.426	0.345	50.426	0.000	52.580	2.480	52.579	-0.001
11	Willowbank (approx. 75 properties)	-	0.000	-	0.000	-	0.000	-	0.000	52.206	1.266	52.205	-0.001
12	Burnmouth Road (approx.8 properties)	48.644	0.820	48.644	0.000	50.077	2.252	50.077	0.000	52.014	4.190	52.014	0.000

No.	Receptor Name	30yr				200yr				200yr+CC			
		Baseline		With Mitigation		Baseline		With Mitigation		Baseline		With Mitigation	
		Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)	Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)	Level (mAOD)	Depth (m)	Level (mAOD)	Change (m)
13	Cottages along East Bank of River Tay in Little Dunkeld (approx.17 properties)	-	0.000	-	0.000	50.588	0.065	50.587	-0.001	52.644	2.122	52.643	-0.001
14	Torlee Road, Birnam (approx. 8 properties)	-	0.000	-	0.000	-	0.000	-	0.000	49.902	1.360	49.907	0.005
15	STW, Dunkeld	46.479	1.124	46.481	0.002	47.951	2.597	47.951	0.000	49.824	4.469	49.823	-0.001
Key Receptors – River Braan													
16	Old Inn	-	0.000	-	0.000	52.338 B	0.006 B	52.337 B	-0.001 B	53.413	1.069	53.411	-0.002
17	Ladeside Cottages	-	0.000	-	0.000	52.043 B	1.184 B	51.711 B	-0.332 B	53.396	2.537	53.385	-0.011
18	Inver Mill Farm	52.531 B	0.069 B	52.530 B	-0.001 B	53.262 B	0.797 B	53.258 B	-0.004 B	53.910 B	1.445 B	53.886 B	-0.024 B

		30yr				200yr				200yr+CC			
		Baseline		With Mitigation		Baseline		With Mitigation		Baseline		With Mitigation	
No.	**Receptor Name**	**Level (mAOD)**	**Depth (m)**	**Level (mAOD)**	**Change (m)**	**Level (mAOD)**	**Depth (m)**	**Level (mAOD)**	**Change (m)**	**Level (mAOD)**	**Depth (m)**	**Level (mAOD)**	**Change (m)**
19	Inver Mill Caravan Site	53.164 B	0.054 B	53.163 B	-0.001 B	53.479 B	0.369 B	53.479 B	0.000 B	54.463 B	1.353 B	54.446 B	-0.017 B
20	Inver Mill Holiday Park (approx. 70 properties)*	51.069 B	0.473 B	50.998 B	-0.071 B	52.015 B	1.418 B	51.678 B	-0.337 B	53.380	2.784	53.360	-0.020

*Maximum level difference of properties within the same location taken
[1]No flooding is shown as blank.
[B]Proposed scheme increase in flood level is predicted for Run 2 (Braan dominant flooding).

Negligible	(No change or less than +/- 0.010m)	Level in mAOD
Betterment	(Greater than or equal to 0.010m)	Change in m
Increase	(Greater than or equal to 0.010m)	Flood Depth in m

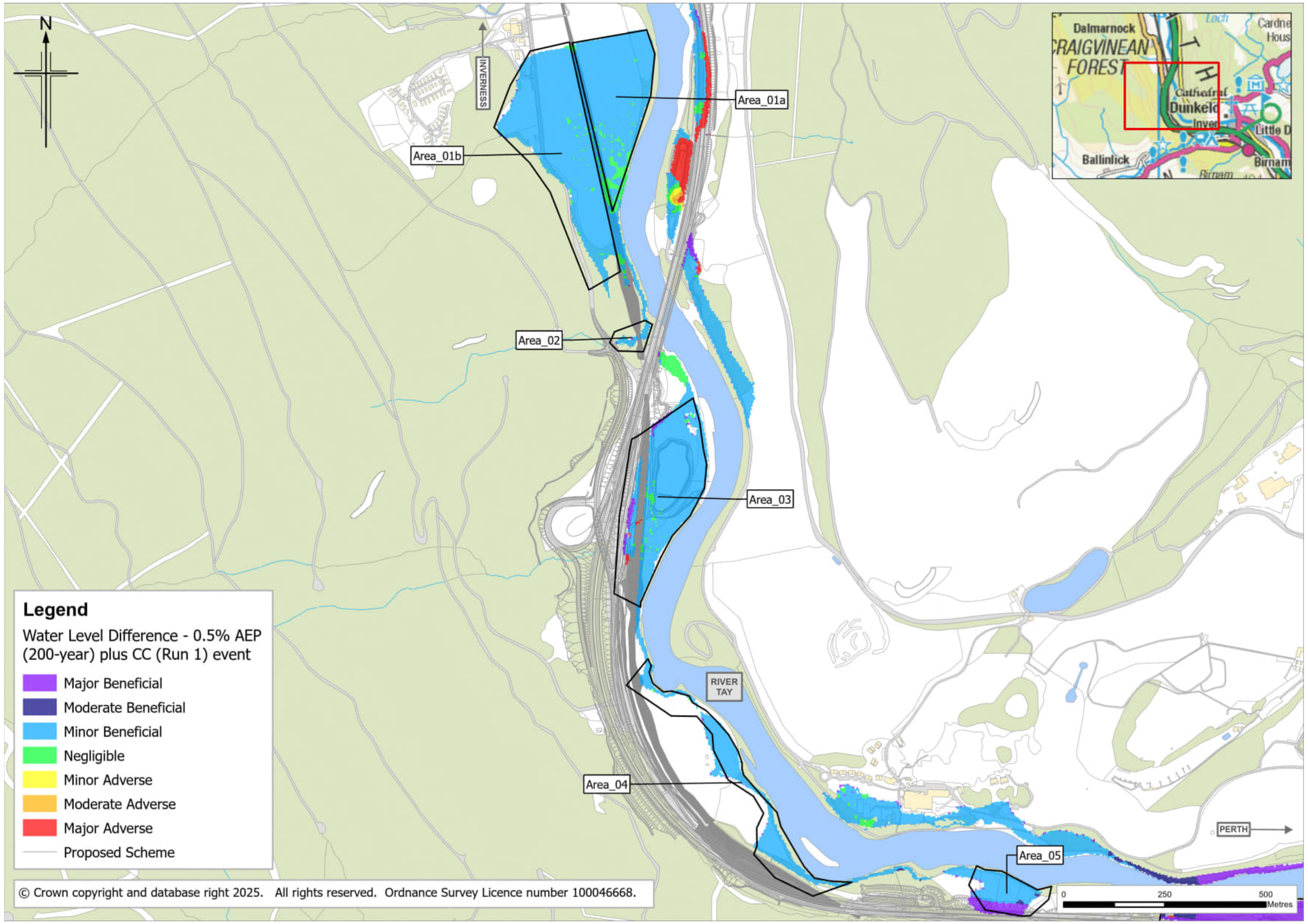


Figure A19.2-8: Area of peak water level difference in 0.5% (200-year) plus CC event on the River Tay (Run 1) (Areas 01 – 04)

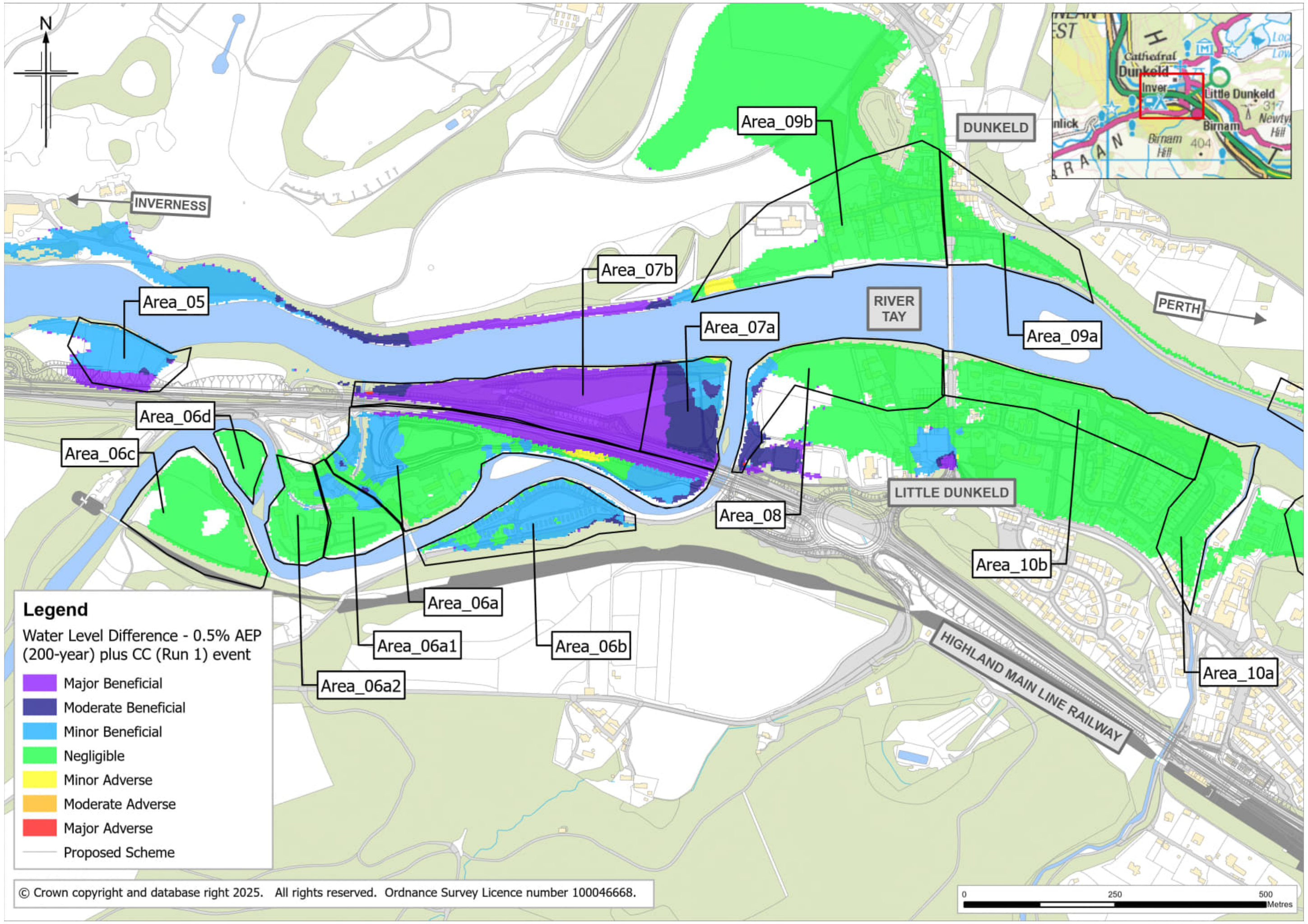


Figure A19.2-9: Area of peak water level difference in 0.5% (200-year) plus CC event on the River Tay (Run 1) (Areas 05 – 10)

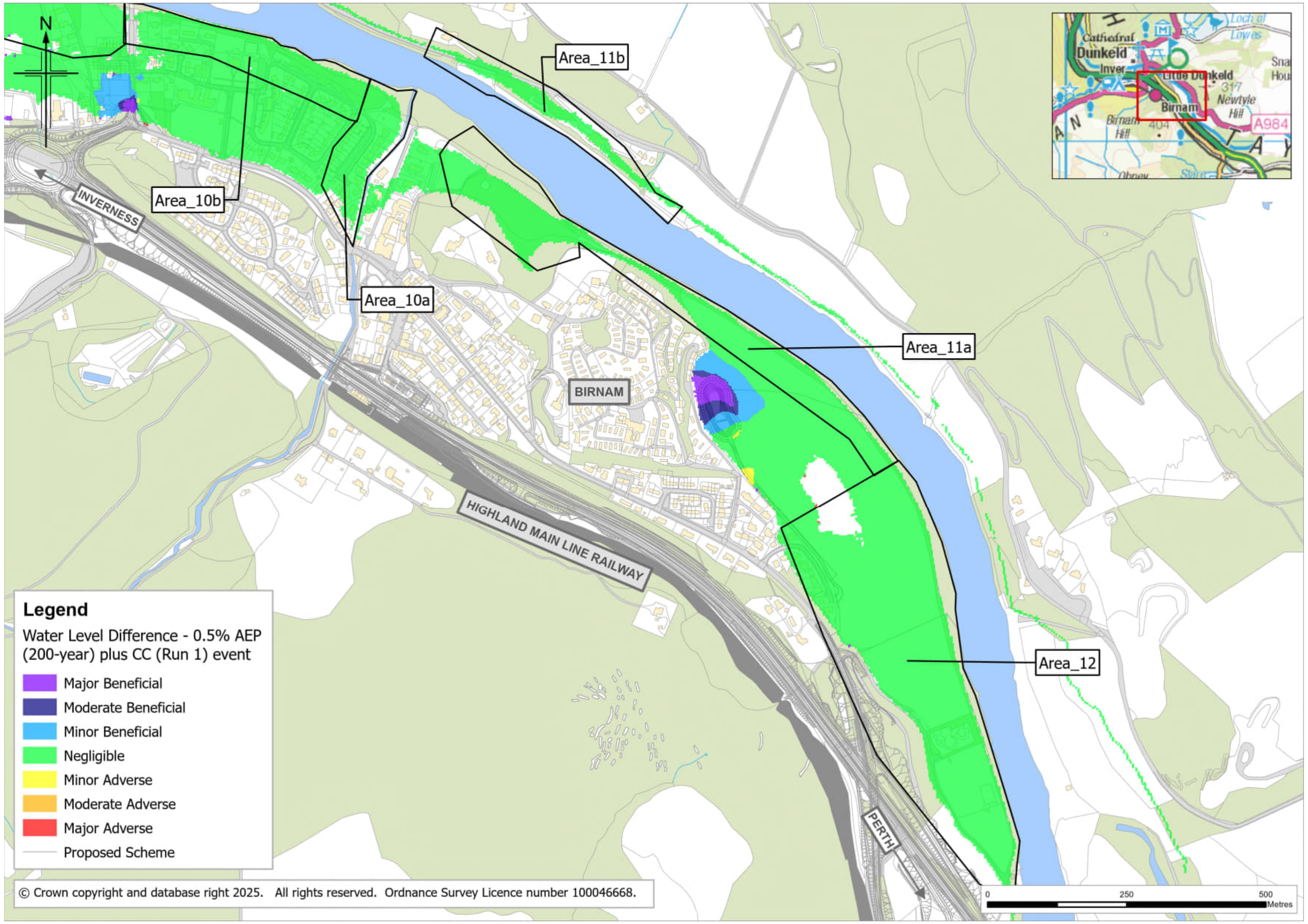


Figure A19.2-10: Area of peak water level difference in 0.5% (200-year) plus CC event on the River Tay (Run 1) (Areas 11 – 12)

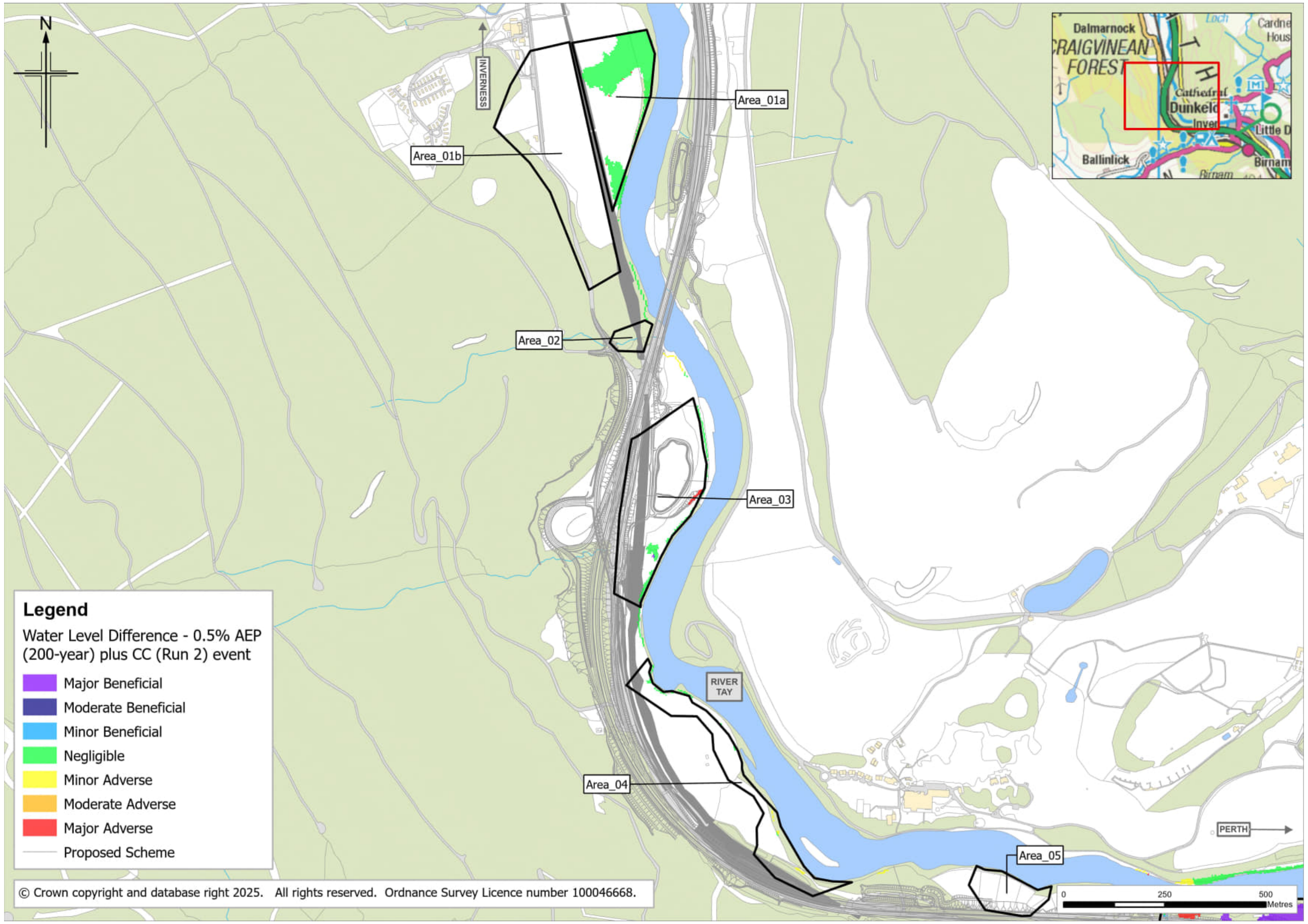


Figure A19.2-11: Area of peak water level difference in 0.5% (200-year) plus CC event on the River Braan (Run 2) (Area 01 – 04)

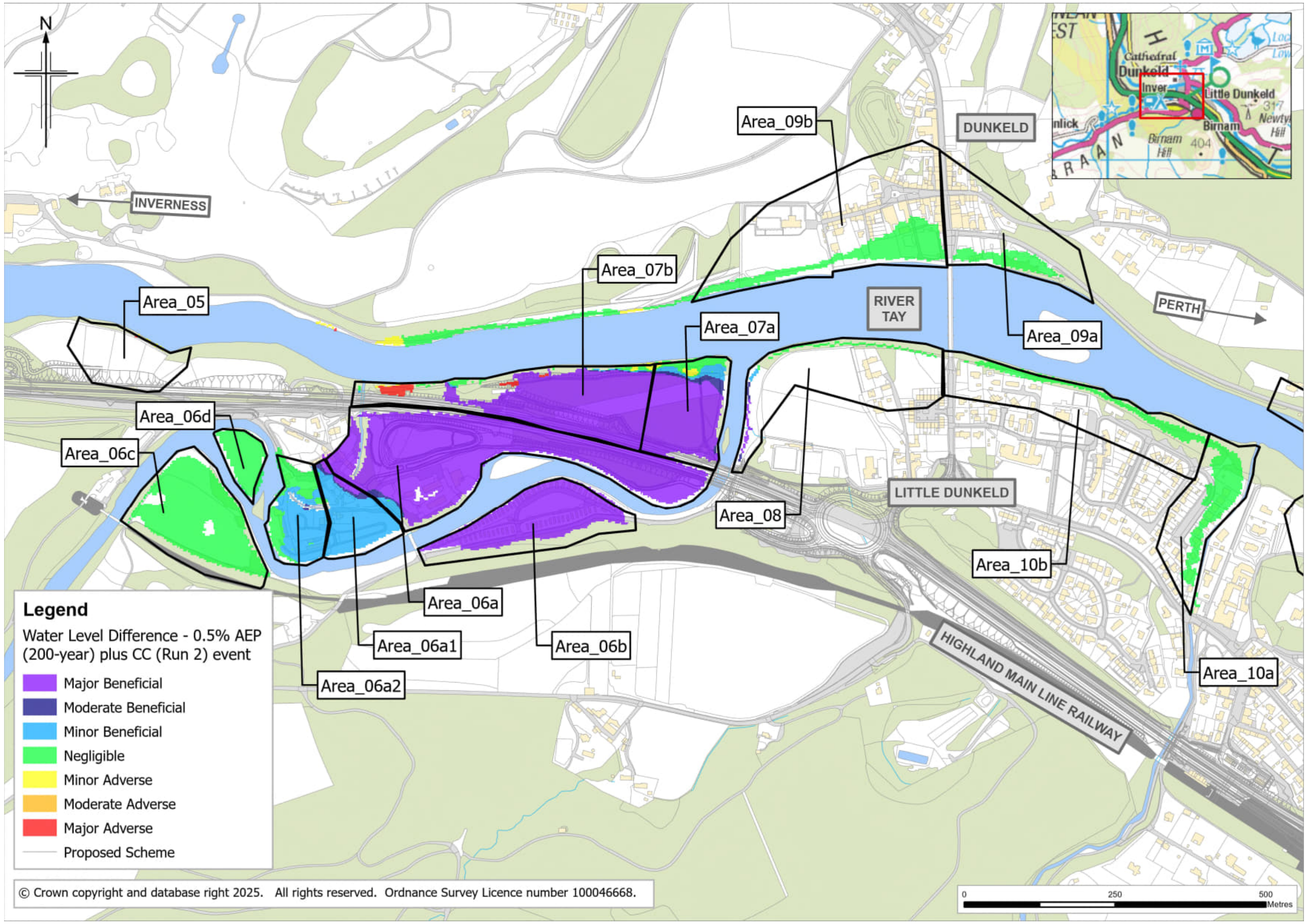


Figure A19.2-12: Area of peak water level difference in 0.5% (200-year) plus CC event on the River Braan (Run 2) (Area 04 – 10)

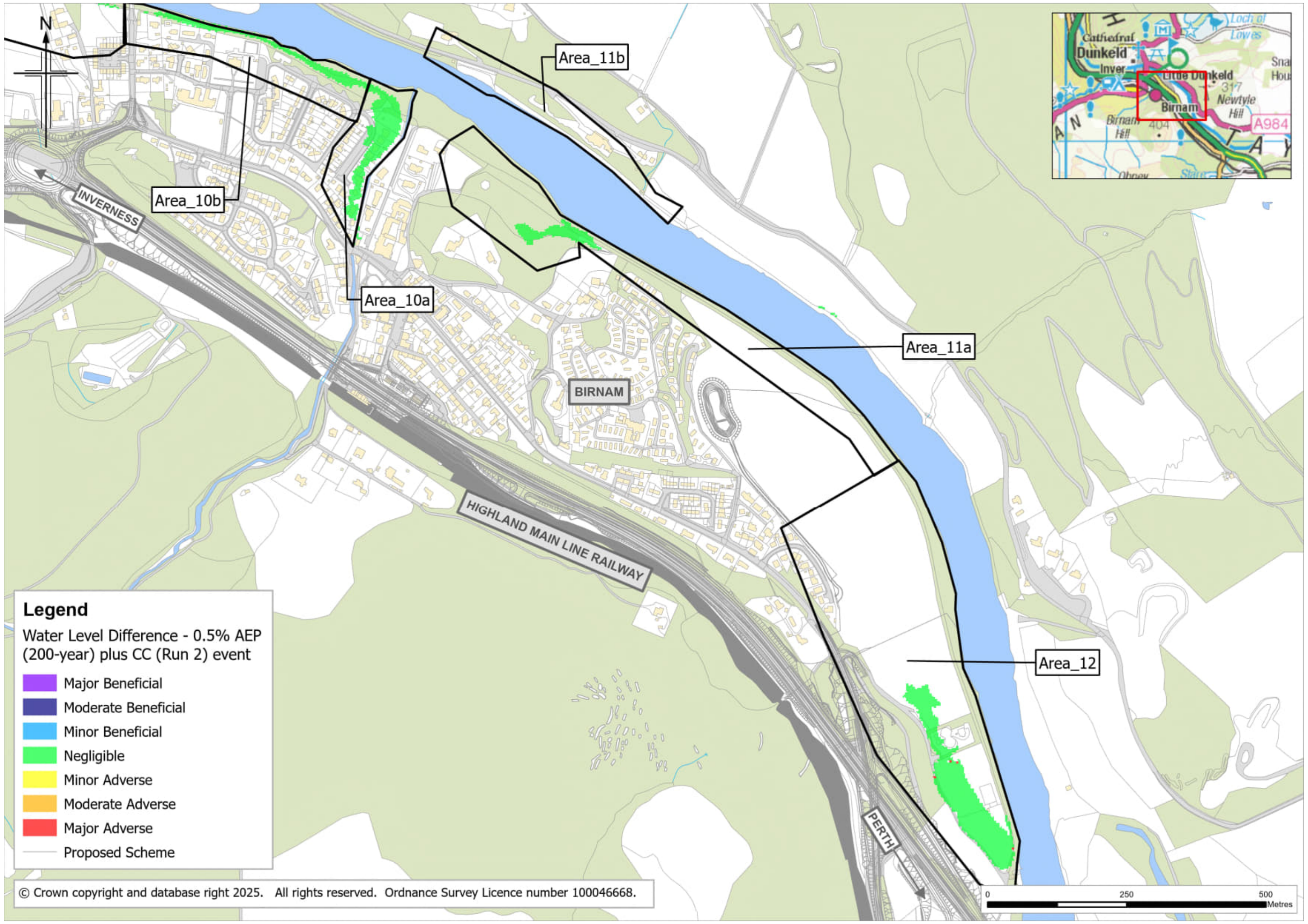


Figure A19.2-13: Area of peak water level difference in 0.5% (200-year) plus CC event on the River Braan (Run 2) (Area 11 – 12)

Impacts Downstream

1.3.76 The impact of the proposed scheme on receptors downstream of the project area has also been assessed by considering any changes in conditions at the downstream end of the hydraulic model. This is to identify any potential cumulative impacts that the proposed scheme may contribute to. The result of this assessment is included in Table A19.2-14 and Table A19.2-15.

Table A19.2-14: Downstream extent of model – River Tay peak flow rates

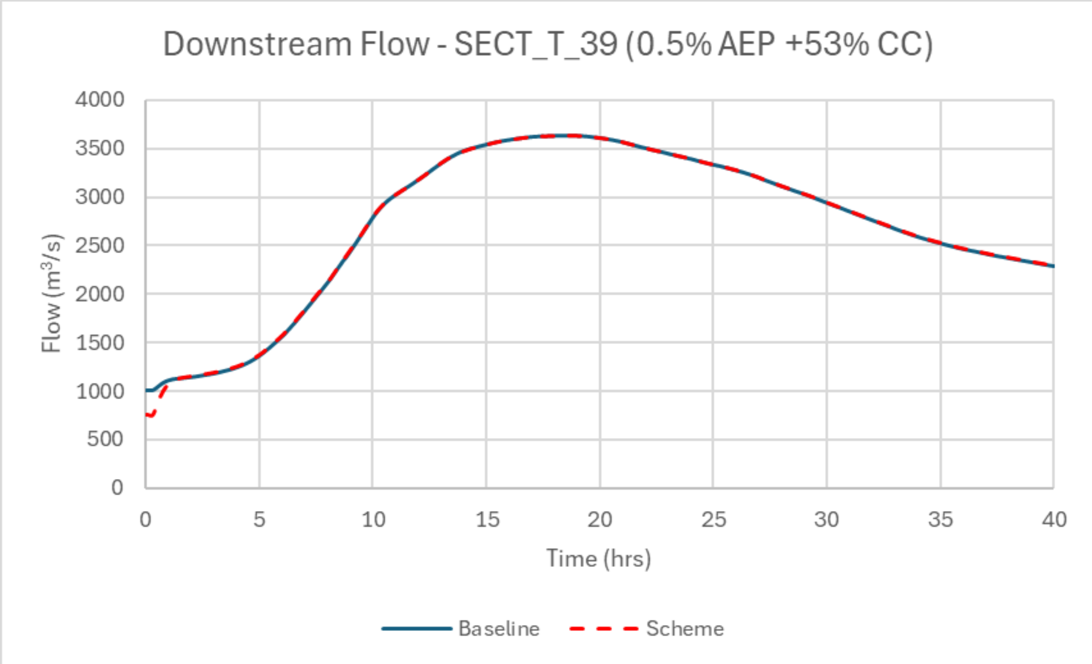
Model	3.33% AEP (30-year)	0.5% AEP (200-year)	0.5% AEP (200-year) +CC
	Standard Run (Run 1)		
Baseline (Existing) (m^3/s)	1628.1	2375	3633.6
With-Scheme (mitigated) (m^3/s)	1628	2334.5	3633.6
Change (m^3/s)	-0.10	-0.50	0.00
% Change	0.00	0.02	0.0

Table A19.2-15: Downstream extent of model – River Tay water level

Model	3.33% AEP (30-year)	0.5% AEP (200-year)	0.5% AEP (200-year) +CC
	Standard Run (Run 1)		
Baseline (Existing) (mAOD)	44.988	46.463	48.509
With-Scheme (mitigated) (mAOD)	44.993	46.463	48.509
Change (m)	0.005	0.000	0.000

1.3.77 Table A19.2-14 demonstrates very small changes in peak flow across all the return periods considered in comparison to the total flow within the River Tay at downstream extent of the model. The 0.5% AEP and 0.5% AEP+CC events show a neutral or beneficial impact. The 0.5% AEP event shows a decrease in flow of 0.02% while the 3.33 AEP event shows a minor increase of 5mm in water level as shown in Table A19.2-15. This negligible impact is also demonstrated in the flow hydrographs for the River Tay presented on Diagram 19.2-1.

Diagram 19.2-1: River Tay flow hydrograph for 0.5% (200-year) AEP plus CC event: baseline, proposed scheme – downstream extent of hydraulic model



1.3.78 These results indicate that despite some net loss of floodplain storage, the proposed scheme does not substantially affect the flood mechanisms in terms of conveyance or in terms of flow rates and volumes into and out of the floodplain.

1.3.79 The negligible changes seen across all modelled events from the 50% AEP to the 0.5% AEP plus CC events further indicates no impacts on flood frequency. This is due to there being fundamentally no change in the timing of the flows through this reach, no substantial change in peak flows and levels experienced and no increase in the extent of flooding, despite the loss of floodplain storage. Consequently, it is concluded that there will be no areas within the modelled reach and downstream which will experience a measurable change in the frequency of flooding.

1.3.80 The flows and levels at the downstream model boundary have been shown to be virtually unaffected, with any minor impacts remaining close to the source and dissipating within the modelled reach. It is concluded that the proposed scheme will not result in a cumulative impact downstream along the River Tay beyond the model boundary.

Impact of Other Development on the Assessment

1.3.81 This assessment has been undertaken based on existing conditions in the project area and upstream. There is therefore a risk that any significant development upstream could impact on the hydrology of the area and alter the assessment undertaken. Key development planned upstream of the proposed scheme that could have a material impact on the assessment undertaken has therefore been considered:

- A9 Dualling, Project 7 (Glen Garry to Dalwhinnie): The Environmental Statement for this scheme states that the 'results of the Enhanced 2D models do not indicate a material change in flood risk passed downstream' (Transport Scotland, 2017a).

- A9 Dualling Project 5: (Killiecrankie to Glen Garry): Section 3.1.45 of the Flood Risk Assessment for this scheme (Transport Scotland, 2017b) demonstrates that the total impact on peak flow at the downstream point of the modelled reach is an additional $0.52m^3/s$ during the 0.5% AEP + CC event. This represents a 0.04% increase in peak flow on the River Garry. This negligible additional flow would flow into Loch Faskally and would be attenuated here and therefore be unlikely to have a notable impact downstream.
- A9 Dualling Project 4: (Pitlochry to Killiecrankie): The change in peak flow at the downstream end of the River Tummel hydraulic model developed for Project 4 during the design event is $0.63m^3/s$, which represents an increase of 0.04%. This negligible change results in a maximum increase in peak water level of 1mm.
- A9 Dualling Project 3: (Tay Crossing to Ballinluig): The change in peak flow at the downstream end of the hydraulic model developed for Project 3 during the 0.5% AEP + CC event is $1.3m^3/s$, which represents an increase of 0.05%. This negligible change results in a maximum increase in peak water level of 2mm.

1.3.82 The changes upstream are therefore considered negligible and would have no impact on the assessment undertaken for the proposed scheme.

Erosion Risk

1.3.83 The proposed scheme has the potential to impact on velocities within the affected watercourses and the floodplain. Any increase in velocity has the potential to increase the risk of erosion whilst any decrease could potentially lead to an increase in sediment deposition. The geomorphology of the area is covered in more detail in Appendix A19.3 (Watercourse Crossing Report) and Annex A19.3A (Hydromorphology Baseline).

1.3.84 The hydraulic model has been used to assess the impact of the proposed scheme on peak flow velocities within the floodplain. Across the majority of the floodplain the change in velocity as a result of the scheme would be +/-0.1m/s, which is considered negligible. The locations where the change in velocity is greater than 0.1m/s are within or in close proximity to compensatory flood storage areas or diverted minor watercourses. The change in velocity at these locations is a result of the changes in flows associated with the storage areas. The small changes in flood velocity are on areas of agricultural land and would not be anticipated to result in additional erosion or sediment deposition. It is anticipated that these changes would not result in additional erosion or sediment deposition.

Residual Risks

1.3.85 As reported in Section 1.3.60, there will be flooding of the proposed scheme for a short period (10-11 hours) during the 0.5% AEP (200-year) plus CC event north of the Tay Crossing. For reasons outlined in Table A19.2-10, this will be managed through an Emergency Response Plan (Mitigation Item P02-W41).The remainder of the proposed scheme has been designed including sufficient freeboard to ensure it is not at risk of flooding during the design flood event, a residual risk remains that it could flood from a more extreme event than the design flood event.

1.3.86 There is a residual risk to side roads and drainage infrastructure within the floodplain which have been designed to a lower design standard to ensure functionality. For example, side roads to properties that are within the floodplain cannot be designed to the same design flood event as the main alignment as this would result in access routes at higher levels than the properties or infrastructure they serve.

1.4 Minor Watercourses

Introduction

1.4.4 Between the Pass of Birnam and the Tay Crossing 13 watercourse crossings over 12 minor watercourses have been identified, see Figure A19.2.2. Minor watercourses WF05A and WF09 cross the proposed scheme twice. These minor watercourses are typically small unnamed streams, confined to narrow, often incised channels with relatively small catchment areas (less than $4.5km^2$). The majority of these watercourses flow beneath the existing A9 through circular culverts ranging from 0.6m diameter to 1.8m in diameter. During the 0.5% AEP (200-year) plus CC design flood event, the peak flow estimates for these watercourses range from $0.1m^3/s$ up to $3.44m^3/s$.

1.4.5 The risk of flooding from these watercourses is typically low as they usually flow through rural areas away from flood sensitive receptors. The greatest risks associated with the watercourse crossings are usually to the proposed scheme, especially in those cases where the existing capacity of the culvert impedes flood flow, combined with limited upstream storage for floodwater, which could place neighbouring receptors (including the existing A9) at risk of more significant flooding.

1.4.6 The proposed scheme includes modifications to existing watercourse crossings where the main alignment embankments would be widened to accommodate the dual carriageway. The proposed scheme would also include new watercourse crossings where localised offline realignment is required and where new access roads and access tracks are proposed.

1.4.7 It is generally considered that the proposed scheme would have a negligible impact on flooding at these watercourse crossings and in fact could have a beneficial impact where culverts are to be replaced based on DMRB design criteria to pass the design flood event. This results in increased flow through the culvert, reducing flood risk upstream and increasing pass forward flows. Where these flows are directly into the River Tay, without impacting on potential flood receptors, the flood risk downstream is not considered to be increased as the size of the flows is negligible when compared to the flows in the River Tay and the peak of the flood event on the minor watercourse is unlikely to coincide with the peak flood event on the River Tay. However, there is also potential for the proposed scheme to have an adverse impact. For example, changing the culvert geometry and building within the floodplain could increase water levels upstream of the proposed scheme, reduce floodplain storage volume or pass additional flood flow to downstream flood receptors, increasing the risk of flooding. This has the potential to be a significant issue if there are flood sensitive receptors nearby and this risk is therefore investigated as part of this FRA.

Assessment Approach

Assessment criteria

1.4.8 Table A19.2-16 details the importance criteria considered for flood risk which draws upon the SEPA land use vulnerability guidance (SEPA, 2024a) classifications.

1.4.9 The categories outlined in Table A.19.2-7 have been used to assess the magnitude of flood risk impact relating to predicted flood water levels associated with each watercourse/structure.

Table A19.2-16: Receptor Importance as defined in Criteria for Minor Watercourses SEPA's land use vulnerability guidance (SEPA, 2024a)

Importance	Criteria
Very High	Most Vulnerable Land Uses
High	Highly Vulnerable Land Uses
Medium	Least Vulnerable Land
Low	Water Compatible Land Uses

1.4.10 The output of the assessment in terms of flood risk impact significance is the product of the assessed impact magnitude and the importance of receptors. Table A19.2-17 presents the matrix for determining significance from the receptor importance and magnitude of impact. Where there are two alternatives provided in the table such as 'slight /moderate', a single significance rating is chosen based on professional judgement. It is emphasised that whilst the minor watercourses are much smaller than the principal watercourses, a major flood event on one of these watercourses could have a significant impact, and therefore, they need careful consideration with regard to impact and mitigation.

Table A19.2-17: Flood Risk Impact Significance

Magnitude / Importance	All Beneficial	Negligible	Minor Adverse	Moderate Adverse	Major Adverse
Very High	Beneficial	Neutral	Moderate / Large	Large / Very Large	Very Large
High	Beneficial	Neutral	Slight / Moderate	Moderate / Large	Large / Very Large
Medium	Beneficial	Neutral	Slight	Moderate	Large
Low	Beneficial	Neutral	Neutral	Slight	Slight / Moderate

1.4.11 The FRA Flood Maps (Annex C) illustrate the distribution of minor watercourses and the location of existing A9 watercourse crossings (e.g. bridges, culverts, pipes etc.). Each watercourse has been given a unique water feature reference number (e.g. WF09,) as many of the watercourses are unnamed. Where multiple scheme crossings exist on one minor watercourse, the additional crossings may be named with endings a, b, etc. (e.g. WF05A and Watercourse Crossings 9 and 9a on WF09A).

1.4.12 The SEPA Flood Map (SEPA, 2024c) does not show flood risk on watercourses or ditches with a drainage catchment area are less than 0.5km². Whilst it might be possible to infer their flood flow paths and extent using the SEPA Surface Water Map, there is a lack of baseline information available to assess the risk of flooding from these watercourses and structures, in the level of detail suitable for this FRA. A staged approach to the assessment of flood risk on such watercourses has been adopted.

1.4.13 Estimations of the peak design flow were generated using the Flood Estimation Handbook (FEH) Statistical method for ungauged catchments and the FEH Rainfall-Runoff method for each minor watercourse. The method which presented the highest design flow was selected in order to be conservative. At all but one crossing the FEH Rainfall-Runoff method gave the highest flow. Annex D (Surface Water Hydrology) provides further details of this approach and results.

1.4.14 Following the methodology presented in CIRIA's Culvert Design and Operation Guide (CIRIA, 2010) and detailed in Annex B (Hydraulic Performance Assessment), a preliminary assessment was adopted for each of the watercourse crossing structures, with the aim of assessing for both the baseline and the proposed scheme considering:

- flow condition of the existing watercourse crossing structures (i.e. free-flow or surcharged); and
- upstream headwater level (HWL) required to pass the steady-state design flow through the structure.

1.4.15 The preliminary assessment assumed the structure conveying the minor watercourse would be extended to accommodate the mainline of the proposed scheme. Whilst the CIRIA approach is likely to estimate a conservative upstream HWL (e.g. it does not take into account flood hydrograph shape, flood volume, local topography and attenuation provided by adjacent floodplain), by comparing results, it does provide a useful initial tool in which to assess existing flood risks and the potential flood impacts of the proposed scheme at these locations.

1.4.16 Following completion of the preliminary assessment, its findings, along with a wide range of design criteria, environmental and ecological constraints were considered to inform the initial design of the watercourse crossing including the like-for-like extension or replacement of the structure.

1.4.17 Where the preliminary assessment suggested a low risk of flooding or low impact, that watercourse crossing was not considered further, as the approach is sufficiently robust so as not to require a more detailed hydraulic assessment.

1.4.18 Where the preliminary assessment suggested that the initial design could have an adverse flood impact, either by increasing upstream HWL or by-passing additional flow downstream, the hydraulic analysis of these watercourse crossings was considered in further detail through 1D/2D hydraulic modelling. This also included further analysis of potential flow paths to better define baseline flood risks and potential impacts.

1.4.19 The findings of the detailed assessment were then used to refine the final design of the watercourse crossing and to assess the need for specific mitigation measures. The design of culverts to pass the design flood event is considered to be embedded mitigation. Where standard culvert design cannot meet with the required hydraulic performance for flood risk management, specific mitigation would be required, for instance flood bypass culverts or storage techniques.

Preliminary Hydraulic Assessment - Results

1.4.20 Table A19.2.18 below sets out the key parameters and hydraulics for each minor watercourse crossing showing the change between baseline scenario and the proposed developed case.

1.4.21 The preliminary assessment identifies that all but four of the existing A9 watercourse crossings have adequate capacity with sufficient freeboard. Four crossing culverts (crossings WF7, WF9, WF9a, WF12b) are under capacity and potentially pose a risk of flooding to the existing A9 in the baseline. It should be noted that while the estimated upstream HWL is conservative, due to local topography which generally slopes down towards the existing A9, any out of bank flow originating from the culvert inlet could potentially place the existing A9 at risk of flooding.

Table A19.2-18: Minor Watercourse Preliminary Hydraulic Assessments

Water-course Crossing	Design Flow (m3/s)	Baseline Structure Details				Developed Case Structure Details					Baseline Hydraulics		Developed Case Hydraulics	
		Diameter (m)	Length (m)	Road Level (mAOD)	Bank Level* (mAOD)	Proposal	Diameter (m)	Length (m)	Road Level (mAOD)	Bank Level* (mAOD)	Headwater Level (mAOD)	Flow Condition	Headwater Level (mAOD)	Flow Condition
WF1	3.44	1.8	63.2	78.21	71.79	Retain with extension	1.8	69.16	78.25	71.93	71.5	In Bank	71.67	In Bank
WF2	0.88	0.72	40.6	74.40	71.56	Retain existing	0.72	40.6	75.32	71.57	72.0	Out of Bank	Identical to baseline	
WF5	1.11	0.6	47.6	62.65	56.28	Retain with extension	0.6	74.2	63.25	56.32	56.91	Out of Bank	57.51	Out of Bank
WF5a	1.45	1.0	54	62.41	53.21	Retain with extension	1.0	103.67	64.06	53.53	54.01	Out of Bank	54.43	Out of Bank
WF5b	1.45	1.0	56.8	76.07 (rail level)	71.56	Retain with downstream extension	1.0	70.67	76.07 (rail level)	71.56	66.38	Out of Bank	Identical to baseline	
WF7	2.32	0.6 (unconfirmed)	unconfirmed	68.10	64.72	New culvert and downstream open channel	1.8	152.55	69.66	64.72	77.54	Out of Bank	62.34	In bank
WF9	2.072	0.6	51.72	56.99	57.372	New culvert	1.8	18.1	60.482	60.38	57.725	Out of Bank	59.67	In Bank
WF9a	2.072	0.6	23.7	54.68	54.171	Retain with extension	0.6	55.25	59.307	55.97	54.277	Out of Bank	54.99	In Bank
WF12a	1.3	1.05	99.3	70.42	62.38	Retain existing	1.05	99.3	71.55	62.38	62.21	In Bank	Identical to baseline	
WF12b	1.41	1 (variable)	90.0	63.61	64.5	New culvert	1.8	131.47	72.98	67.50	64.2	In Bank	67.56	Out of Bank
WF13	3.3	1.05	45	61.16	56.13	New culvert	1.8 x 2.7 box	174.4	63.1	60.85	58.57	Out of Bank	61.73	Out of Bank
WF14a	1.97	1.2	24.4	60.21	57.63	Retain with extension	1.2	28.4	60.39	57.78	58.29	Out of Bank	58.44	Out of Bank
WF16	1.19	1.02	43.8	57.86	60.33	New culvert	1.2	41.2	58.75	57.75	57.11	In Bank	56.2	In Bank
WF18	1.21	0.77	75.5	57.83	62.99	New culvert	1.5 x 1.8 box	43.2	58.13	59.45	55.92	In Bank	55.408	In Bank

*Note that bank levels have not yet been confirmed at this stage and bank levels may differ in the developed case.

1.4.22 From a flood management perspective, the aim was to retain the flow regime of the existing culvert to maintain the balance between flood risk locally to the watercourse crossing and downstream receptors. For that reason, retaining the existing culvert without amendments or like-for-like culvert extension/replacement is the preferred option for the proposed scheme. Taking these into account, the proposed scheme includes - out of 14 minor watercourse crossings:

- 2No with culverts retained without amendments (crossings WF02 and WF12a) and no change to the baseline flood risk;
- 6No with like-for-like (i.e. same dimensions and gradient) culvert extensions either upstream, downstream or both; crossings WF01, WF05, WF05A, WF5B, WF09, WF14); and
- 6No with replaced culverts designed as per DMRB guidance (crossings WF07, WF09, WF12B, WF13, WF16 and WF18).

1.4.23 The new culvert crossings are designed to freely pass (i.e. without surcharging) the peak flow during the 0.5% AEP (200-year) plus climate change flood event plus appropriate internal culvert freeboard. New access track crossings have been designed to freely pass the peak flow during the 0.5% AEP (200-year) flood event.

1.4.24 To assess the potential impacts on flooding, the hydraulic performance of each crossing was tested against the design flood event. Table A19.2-19 provides an overview of the proposed scheme assessment.

Table A19.2-19: Proposed scheme hydraulic performance (counts) for 0.5% AEP (200-year) + CC flood event

Minor Watercourse Crossings	Increased Pass-Forward Flow	Downstream Flood Receptors potentially at risk[2]	Headwater Level > Bank Level	Road potentially at risk[1]
14	6	0	5	0

[1] Road considered at risk when out of bank flow is predicted and the HWL is within 600mm of the road level

[2] Downstream flood receptors considered at risk when pass forward flows increase in the proposed scheme and potential flood receptors are present downstream of the crossing near the watercourse banks

Change in Head Water Level

1.4.25 Although the proposed scheme reduces the risk of flooding to the A9 overall, 8 of the 14 watercourse crossings would result in an increase in upstream head water level (HWL). However, these impacts do not result in a new risk to the road, i.e. where the freeboard to the road in the 0.5% AEP (200-year) plus CC peak water level is less than 600mm.

1.4.26 For WF07, there is a risk of flooding for the design event at the inlet during the baseline scenario. As the dimensions and condition of the existing crossing infrastructure have not been validated as a worst-case scenario it has been considered to be under sized and therefore subject to flooding due to lack of capacity.

1.4.27 At WF09, there is flooding to the A9 in the baseline scenario for the 0.5%AEP plus 39% Climate change event. This represents a major adverse impact if not mitigated in the proposed scheme design.

1.4.28 Watercourse crossing WF12b is at a location along the A9 where the road is in cutting. The watercourse bed and banks upstream of the A9 are therefore raised above the A9. The watercourse drains to a drop structure before passing under the A9. In the proposed scheme this arrangement will be reproduced and hence cause no detriment to flood risk on the A9. This option is therefore not subjected to any further detailed assessment.

Change in Pass Forward Flow

1.4.29 Downstream of the watercourse crossings, the proposed scheme has the potential to increase flows as a result of enlarging an existing culvert that may have been inhibiting flows during the baseline scenario.

1.4.30 The preliminary assessment identified three watercourses (WF09, WF13 and WF16) where peak flows may increase downstream when compared to the baseline scenario (i.e. the culvert now conveys the design flood event). Of these, only for WF09 and WF13 were there downstream flood sensitive receptors identified and therefore the impact of the proposed scheme at all other watercourses is considered to be low. The watercourse crossings on WF09, WF13 and WF16 were examined through more detailed hydraulic modelling assessments.

<u>Detailed Assessment</u>

Increase in Downstream Flows

1.4.31 The preliminary assessment identified four culverts that require replacement as a result of the proposed scheme. These have the potential to pass increased flows, potentially increasing flood risk downstream of the proposed scheme.

1.4.32 Where the watercourse discharges directly into the River Tay downstream of the proposed scheme, no further assessment has been completed because the increase in flows from the minor watercourse is considered to be negligible when compared to the flow on the River Tay (range approximately 862m^3/s to 3,479m^3/s). The rainfall events that would produce the peak flood event on the River Tay and minor watercourses are different and therefore are unlikely to occur simultaneously on the different watercourses. Further information is included in Annex D – Surface Water Hydrology.

1.4.33 The size and length of the existing culvert on WF7 is unconfirmed. However, it is suspected highly likely that the existing culvert arrangement is insufficient to pass the required design flow at this location of 2.32m^3/s. The best estimate available is that the existing culvert is a 0.6m diameter pipe, if true this pipe would only have a flow capacity of approximately 0.7m^3/s based on typical design of the other culverts in the area and thus would be undersized by 1.62m^3/s.

1.4.34 The proposed solution at this location is an upsized pipe which has been designed to freely pass the design flow and thus would result in an increase in pass forward flows at this location of 1.62m^3/s. There are no downstream receptors at risk and the flow would be passed forward in open channel over an agricultural field and to the River Tay via a series of step pools.

1.4.35 A summary of the watercourses with an increase in downstream flows is included in Table 19.2-20.

Table 19.2-20: Culverts with increased downstream flows (all figures for 0.5% AEP (200yr) +39% design event)

Watercourse Crossing	Water Feature baseline flow (m^3/s)	A9 crossing baseline capacity (m^3/s)	Increase in flows with scheme (m^3/s)	Downstream receptors	Proposed Action
WF9	2.86	0.51	2.35	A9	Hydraulic modelling
WF13[1]	3.30	3.30	0	None	Hydraulic modelling
WF16[1]	1.06	1.06	0	None	Hydraulic modelling

[1] Stability issues with dynamic runs meant that steady state model runs were carried out instead. There is no difference in peak flows between baseline and proposed scheme flows for such runs, regardless of the changes in culvert dimensions and arrangement. As in the proposed scheme no out of bank flooding is expected upstream of the scheme (and hence no significant flood routing), the peak flow from the steady state run is expected to be a good approximation of the peak flow achieved with dynamic runs. In the baseline some out of bank flow and floodplain flooding is expected. Therefore, for the baseline condition flood routing may result in a reduced flood peak compared to that reported here.

1.4.36 WF09, WF13 and WF16 required further assessment with a hydraulic model and the findings and options considered are discussed below.

<u>WF09</u>

1.4.37 WF09 originates in hills to the south of the River Tay and Dunkeld. It flows mostly as an informal ditch before following the right side of the A822 and entering culvert and passing along and beneath the road toward the A9 and passing beneath the Highland Main Line. It emerges just to the south of the existing A9 in ditch before passing under the A9 in a 0.6m diameter culvert.

1.4.38 The existing culvert is surcharged during the design flood event i.e. 0.5% AEP (200-year) plus CC event. Flooding is recorded on the upstream side of the A9 and flows into the area to the west which includes a residential property and a storage yard for a builders merchants. The downstream channel shows no flooding in the baseline scenario.

1.4.39 Model runs for an upsized culvert (1.8m diameter) confirms that this resolves the out of bank flooding upstream. However, this passes forward higher flows to downstream receptors on the right bank with a flow route possible due to a 20m length of the right bank of the channel being at a lower level. Additional modelling was undertaken to demonstrate that by modifying the land in this area, flood risk could be managed and passed to the Braan. The existing 600mm culvert that discharges to the open channel has very limited cover to the access road level and any upsized culvert would require complete re-sectioning of the downstream watercourse to achieve suitable cover under this access road. This was not considered to be feasible and therefore specific mitigation was required to manage flood risk and conveyance of the design event.

1.4.40 Due to constraints and the potential for major adverse impacts a flood bypass solution was investigated. The maintenance of the existing watercourse flows, ecology and processes of the open channel could only be achieved by connecting into the existing 600mm culvert and this provides the basis for flows up to the 10%AEP (10-year) storm event to flow via the watercourse to the River Braan. Flows up to the design event would be required to bypass this route. A flood bypass culvert to the River Braan was examined. The identified solution comprises a 1.2m x 1.0m box culvert installed in the headwall, which begins to bypass flows as the 600mm pipe begins to surcharge. This solution is considered effective in ensuring the flood risk is managed. Further details are outlined in Appendix 19.3: Watercourse Crossing Report. The flood bypass channel mitigation solution has been assigned specific mitigation code: P02-W40 – Flood bypass channel.

<u>WF13</u>

1.4.41 WF13 is a deeply incised watercourse that flows through woodland (Inver Wood) with dense undergrowth. It meanders its way from west to east before crossing an abandoned section of General Wade’s Military Road and the A9 through a 1m diameter culvert. During multiple visits both culverts were observed to be subject to heavy blockage of up to an estimated 70% of the culvert opening. Flooding from this watercourse onto the adjacent agricultural land to the north of the watercourse has been observed during at least two independent site visits, most recently on 24 February 2021. Neither event appears to have caused flooding of the A9.

1.4.42 It is proposed that the culvert is replaced by a 1.8m by 2.7m square box culvert. To allow it to cross the proposed Dalguise Junction (which features an underpass) the watercourse would be diverted southwards to cross the A9 to the south of the existing crossing. This requires the open watercourse to be diverted over a length of about 50m upstream of the existing A9 culvert inlet. Downstream of the proposed A9 and access road the watercourse would be routed back northwards to its original crossing with the railway line. The majority of the realigned section upstream of the A9 crossing would be open watercourse, whilst that downstream of the A9 and access road would need to be culverted for some of its length to overcome level gradients. The culvert length would increase from 45m in the existing condition to 143m in the proposed condition.

1.4.43 The existing culvert is surcharged during the design flood event i.e. 0.5% AEP (200-year) plus CC. However, the watercourse is well below the existing road level and there are no other sensitive receptors upstream of the crossing. The existing A9 is therefore not considered to be at flood risk during the design flood event, with 2.6m existing freeboard available.

1.4.44 In the proposed condition, the available flood freeboard between headwater level and the road level would be 1.62m, hence the proposed scheme is not considered to be at flood risk during design flood event. Without other sensitive receptors, no further mitigation measures are considered necessary upstream of the A9.

1.4.45 Downstream flood risk is potentially increased by the proposed scheme, as the increased capacity of the culvert will result in increased flow downstream of the A9. There is a single sensitive flood receptor downstream of the crossing, the Highland Mainline Railway. The increase in flows downstream is small in comparison to the receiving watercourse (River Tay) and any exceedance will result in shallow depths of flooding within the existing floodplain, at far lower depths than occurs during even a 3.33% (30-year) event on the River Tay, therefore the increase in flood risk is considered negligible.

WF16

1.4.46 Watercourse WF16 drains the steep hillside on the east of the A9 north of the Tay crossing. It drains down the steep cutting adjacent to the A9 in a deep channel before spilling into a concrete drop structure. WF16 is culverted beneath the existing A9 via a 1m diameter concrete culvert. The existing culvert inlet is set back from the carriageway close to existing and proposed A9 road levels.

1.4.47 The proposed scheme will result in the A9 footprint at this location being widened on both the upstream and downstream sides to accommodate the scheme. The proposed widening on the downstream side (northbound carriageway) is included within the Tay Crossing to Ballinluig scheme, whereas the upstream (southbound carriageway) widening is included within the Dunkeld to Tay Crossing Scheme. Additionally, a new road drainage treatment basin on the downstream side clashes with the location of the existing culvert outlet.

1.4.48 The proposed culvert would replace the existing culvert on a new plan alignment with a new culvert inlet location at a lower level than the existing. This will require the culvert invert to be set at a lower level and the channel gradient immediately upstream of the culvert entrance to be steeper; hence a new cascade feature will be required to convey the flow of water to the culvert entrance. A new culvert outlet is proposed to the north of the new drainage basin. The proposed new culvert will have a 1.2m internal diameter and will be approximately 41m in length.

1.4.49 Although both the existing culvert and the proposed new culvert are expected to surcharge under the 0.5% AEP plus climate change design condition, flows remain in-bank. Furthermore, the freeboard below the road level increases from 0.75m to 3.51m.

Summary of flood risk from Minor Watercourses

1.4.50 A summary of the flood risk impacts is provided in Table A19.2-21. With the exception of WF9, all watercourse flood impacts are considered to be Slight, Neutral or Beneficial following the application of embedded mitigation as part of the proposed scheme design.

1.4.51 For WF9, there are flooding impacts to local sensitive receptors in the baseline scenario, it has not feasible to manage this through standard design considerations. An effective solution has been identified in the form of a bypass culvert (P02-W40) which becomes active when the existing 600mm culvert starts to surcharge. This mitigation solution manages the existing flood risk and results in beneficial impacts to the downstream sensitive receptors.

Residual Risks

1.4.52 The residual flood risks from minor watercourses will include:

- Blockages of culverts by large debris that reduce its capacity to convey flows. This FRA confirms that the scheme is robust to reduced flows, but flooding of sensitive receptors including the proposed scheme could occur if a blockage is excessive; and
- Severe flood events which exceed the design capacity of the culverts. It has been confirmed that all minor watercourse culverts in the proposed scheme will not cause flooding of the main alignment for floods up to the 0.5% AEP (200-year) plus CC design event, but some flooding from minor watercourses could occur for exceedance events.

1.4.53 It will be important that the relevant operating company carry out routine inspection and ongoing maintenance of the culverts. The information contained in this FRA will be used to identify the sensitive locations and prioritise any inspection schedule within the A9 operation and maintenance plan.

Table A19.2-21: Minor Watercourses Impact Assessment – Baseline and proposed scheme impacts on flood risk

Crossing	Receptors*	Importance	Baseline	Post Development	Potential Impact Magnitude	Potential Impact Significance
WF01	▪ A9 Road ▪ Woodland	Low	Headwater level in bank	**Short culvert extension upstream**. >100mm Headwater level increase but >600mm of freeboard to road	Major Adverse	Slight
WF02	▪ A9 Road ▪ Woodland	Low	Headwater level out of bank	**No works to culvert required**. No change from baseline	Negligible	Neutral
WF05	▪ A9 Road ▪ Woodland	Low	Headwater level out of bank	**Upstream extension**. >100mm Headwater level increase but >600mm of freeboard to road	Major Adverse	Slight
WF05A	▪ A9 Road ▪ Woodland	Low	Headwater level out of bank	**Upstream and downstream extension and formation of new channel section to downstream reach**. >100mm Headwater level increase but >600mm of freeboard to road	Major Adverse	Slight
WF05B	▪ B876 Road ▪ HML railway ▪ Woodland	Low	Headwater level out of bank	**No works to culvert required**. No change from baseline	Negligible	Neutral

Crossing	Receptors*	Importance	Baseline	Post Development	Potential Impact Magnitude	Potential Impact Significance
WF07	▪ A9 Road ▪ Perth Road ▪ HML railway ▪ Woodland ▪ Residential properties in Birnam downstream	Very High	Headwater level above Existing Road Level. Unconfirmed culvert route to River Tay with likely undersized culvert	**New culvert.** Designed to pass design flow without surcharging which discharges to an open channel and floodplain wetland section to the River Tay.	Major Beneficial	Beneficial
WF09 & WF09A	▪ A9 Road ▪ A923 Road ▪ Residential and commercial properties in Little Dunkeld	Very High	Headwater level out of bank	**New culvert (WF9)** Designed to pass design flow without surcharging. >100mm Headwater level increase but >600mm of freeboard to road. **Culvert extension (WF9A) to existing and Specific Mitigation (P02-W40)** Constrained in conveying design flow via existing route and extension to 600mm culvert required. Flood bypass culvert to Braan conveys flows >10%AEP flow.	Beneficial following application of P02-W40 – Flood Bypass Culvert	Beneficial
WF12A	▪ A9 Road	Low	Headwater level in bank	**No works to culvert required**. No change from baseline.	Negligible	Neutral

Crossing	Receptors*	Importance	Baseline	Post Development	Potential Impact Magnitude	Potential Impact Significance
	▪ HML railway ▪ Woodland					
WF12B	▪ A9 Road ▪ HML railway ▪ Woodland	Very High	Headwater level in bank	**New culvert** Designed to pass design flow without surcharging. >100mm Headwater increase but >600mm of freeboard to road.	Major Beneficial	Beneficial
WF13	▪ A9 Road ▪ HML railway ▪ Woodland ▪ Agricultural land	Low	Headwater level out of bank	**New culvert** Designed to pass design flow without surcharging. >100mm Headwater increase but >600mm of freeboard to road.	Major Beneficial	Beneficial
WF14	▪ B898 Road ▪ HML railway ▪ Woodland	Low	Headwater level out of bank	**Upstream extension of existing culvert** >100mm Headwater level increase but >600mm of freeboard to road	Major Adverse	Slight
WF16	▪ A9 Road ▪ Woodland	Low	Headwater level in bank	**New culvert** Designed to pass design flow without surcharging. >100mm Headwater increase but >600mm of freeboard to road	Major Beneficial	Beneficial

Crossing	Receptors*	Importance	Baseline	Post Development	Potential Impact Magnitude	Potential Impact Significance
WF18	▪ A9 Road ▪ Woodland	Low	Headwater level in bank	**New culvert** Designed to pass design flow without surcharging. >100mm Headwater level decrease but >600mm of freeboard to road	Major Beneficial	Beneficial

*Some minor watercourses cross 'Essential transport infrastructure' (roads and railway). These are considered flood receptors because the watercourses have the potential to flood these during extreme events. However, where the hydraulic assessment (see Table A19.2-18: Minor Watercourse Preliminary Hydraulic Assessments) indicates that the infrastructure embankment would not flood with sufficient freeboard, i.e. the headwater level of the 0.5% AEP plus allowance for climate change is at least 600mm below existing road level, the Importance and impact significance have been assessed without considering that essential infrastructure flood receptor.

1.5 Surface Water

Introduction

1.5.1 Surface water (pluvial) flooding results from rainfall-generated overland flow before the runoff enters any watercourse, drainage system or sewer or when the infiltration capacity of the ground surface is exceeded during extreme rainfall events. Excessive surface water runoff itself may pose a flood risk especially if flowing at high velocity. Localised depressions in the ground topography may result in the ponding of water, sometimes to a significant depth.

1.5.2 The antecedent conditions, permeability of the soil type or geology can affect the volume of runoff, whist the capacity and condition of the drainage network can affect how much water remains on the surface. The topography of the land and location of urban features such as buildings and road networks would also influence surface water flood risk by increasing the velocity of overland flow and depth of ponding.

Baseline Risks

1.5.3 The existing A9 follows the valley of the River Tay, which generally has steep hillsides sloping down towards the road. As a result, the hillsides are likely to generate significant volumes of runoff during high intensity rainfall events that would flow towards the existing A9.

1.5.4 As part of a typical carriageway design, roadside filter drains or Pre-Earthworks Drainage (open ditches) adjacent to earthworks or the mainline collect surface water runoff from hillsides. Therefore, incidences of surface water flooding on the existing A9 tie in closely with existing road drainage efficiency (associated with capacity exceedance and blockages). The existing A9 would also form an obstruction to natural overland flow routes where raised embankments would prevent surface water runoff draining through the usual routes and into nearby watercourses.

1.5.5 This FRA has adopted a preliminary assessment to identify areas along the existing A9 at risk of surface water flooding using the following information and methodology:

- **SEPA Surface Water Flood Map** – the mapping identifies areas with a high (10% AEP (10-year)), medium (0.5% AEP (200-year)) or low (0.1% AEP (1,000-year)) probability of surface water flooding.
- **Overland Flowpath Analysis** – the analysis has used a ‘rolling ball’ technique based on topographic data from a Digital Terrain Model (DTM) to produce a series of theoretical surface water flowpaths. Essentially, the flowpath generated represents the path of ‘low spots’ over the ground along which water would flow if the ground was impermeable. The analysis identifies areas at particularly high surface water flood sensitivity based upon the catchment area and the gradient of the flowpaths within that location, with those flowpaths associated with large catchments and/or steep gradients resulting in high flowpath significance.
- **Historical Flood Incidents** – records provided by Transport Scotland indicate that surface water flooding has occurred on the existing A9 in areas close to Dunkeld.

1.5.6 The preliminary assessment concludes that the majority of the existing A9 between the Pass of Birnam and the Tay Crossing is on a raised embankment, which reduces the risk of the road becoming flooded by surface water. In these cases, the SEPA Surface Water Flood Map and the overland flowpath analysis identifies surface water ponding against the embankment, or the embankment directing overland flow routes to the nearest minor watercourse, as listed in Table A19.2-22. The areas of surface water flooding are mainly associated with flooding along minor watercourses rather than direct surface water runoff. Since both the SEPA Surface Water Flood Map and the overland flowpath analysis do not take into account existing drainage features such as the existing A9 road drainage or culverts running underneath the existing A9, the flood mapping is likely to provide a conservative estimate of risk. Based upon the information presented above, this FRA concludes that there is an existing low risk of surface water flooding along the A9 corridor.

Table A19.2-223: Locations of potential surface water flooding (baseline scenario)

A9 Chainage	Description
ch450 – ch550	The SEPA Flood Map identifies surface water ponding on the downstream side of the existing A9 embankment and on the eastern side of the carriageway. The risk of ponding was confirmed by GIS flowpath analysis undertaken as part of this assessment. The existing A9 is on very low embankments at this location and so risk to the road is possible, however as pre-earthworks drainage is not represented within SEPA’s surface water model and the road is raised above the area of flooding in the field, the risk of flooding to the existing A9 is considered to be low.
ch900 – ch950	The SEPA Flood Map identifies surface water ponding on the existing A9. The risk of ponding is confirmed by GIS flow path analysis. As pre-earthworks and highway drainage is not represented within the SEPA surface water model, the risk of flooding to the existing A9 is considered to be low.
ch1000 – ch1080	The SEPA Flood Map identifies surface water ponding in a local depression on the northern side of the existing A9. No sensitive receptors have been identified within this vicinity, although ponding here may spill onto the A9 carriageway. As pre-earthworks drainage upstream of the A9 is not represented within SEPA’s surface water model, it is likely that the flooding predicted along the existing A9 is overestimated, with the risk to the existing A9 considered to be low. The GIS flow path analysis does not indicate any flow paths to the ponding identified in this depression. Differences between the two methods may be due to the DTMs used, with the GIS analysis considered more accurate. The risk of ponding is therefore expected to be small.
ch1100 – ch1200	The SEPA Flood Map identifies surface water flooding on the existing A9 carriageway, in an area of cutting. The predicted flooding is immediately up against the cutting and is likely to be due to ponding of water against the cut slopes. The extent of flooding is small and just to the edge of the

A9 Chainage	Description
	carriageway and is likely to be overestimated as the influence of road drainage in the location will not have been included in SEPA's model. The GIS flow path analysis does not indicate any flow paths in this location. However, it does show a flow path crossing the A9 at approx. ch1300. This flow path may result in the flooding shown in the SEPA Flood Map, with discrepancies down to the DTM used.
ch1400 – ch1450	The SEPA Flood Map identifies surface water ponding on the downstream side of the existing A9 embankment and on the northern side of the carriageway. The northern side of the existing A9 is on an embankment at this location and so risk to the road is possible, however as pre-earthworks drainage is not represented within SEPA's surface water model and the road is raised above the area of flooding, the risk of flooding to the existing A9 is considered to be low. No flow paths have been identified in a GIS surface water flow path analysis.
ch2000 – ch2100	The SEPA Flood Map identifies surface water ponding on the upstream side of the existing A9 embankment. No sensitive receptors have been identified immediately upstream of the A9 and the A9 does not appear to be at risk due to its raised position on high embankments.
ch2100 – ch2300	The SEPA Flood Map identifies surface water flooding on the existing A9 carriageway, in an area of cutting. The risk of ponding is confirmed by GIS flow path analysis. The predicted flooding is along the existing carriageway but is likely constrained by the cut slopes downstream of the existing A9. The extent of flooding is small although occurs over a long stretch of the carriageway between 2 junctions and is likely to be overestimated as the influence of road drainage in the location will not have been included in SEPA's model.
ch2400 – ch2600	The SEPA Flood Map identifies surface water flooding on the south side of the existing A9, between the road embankment and the railway embankment. The risk of ponding is confirmed by GIS flow path analysis. The area of flood is relatively small, and as the existing A9 is on an embankment at this location, the flood risk is considered to be low.
ch3000 - ch3100	The SEPA Flood Map identifies surface water ponding on the south side of the existing A9, adjacent to Peth Road, between the road embankment and the railway embankment. The risk of ponding is confirmed by GIS flow path analysis. The area of ponding is relatively small, and as the existing A9 is on an embankment at this location, the flood risk is considered to be low.
ch3600 – ch4000	The SEPA Flood Map identifies surface water ponding along the existing A9 carriageway, in Little Dunkeld, in an area where the carriageway is in cutting and is likely due to the ponding of water against the southern slope. The risk of ponding is confirmed by GIS flow path analysis. The extent of flooding is small and likely to be overestimated as the

A9 Chainage	Description
	influence of the highway drainage in the location will not have been taken into account in SEPA's model.
ch4450 – ch4550	The SEPA Flood Map identifies surface water ponding along the existing A9 carriageway. In this location the existing A9 carriageway is raised above the surrounding land on an embankment. The extent of flooding is small and is likely to be overestimated as the influence of the highway drainage will not have been taken into account in SEPA's model. The GIS flow path analysis does not indicate any flow paths to the ponding identified in this area. Differences between the two methods may be due to the DTMs used, with the GIS analysis considered more accurate. The risk of ponding is therefore expected to be small.
ch4750 – ch4800	The SEPA Flood Map identifies surface water ponding along the southbound carriageway in an area where the existing A9 is raised above the surrounding ground on an embankment. As pre-earthworks and highway drainage is not represented within the SEPA surface water model, the risk of flooding to the existing A9 is considered to be low. The GIS flow path analysis does not indicate any flow paths to the ponding identified in this area. Differences between the two methods may be due to the DTMs used, with the GIS analysis considered more accurate. The risk of ponding is therefore expected to be small.
ch5450 – ch5750	The SEPA Flood Map identifies surface water flooding on the existing A9 carriageway, in an area of cutting. The risk of ponding is confirmed by GIS flow path analysis. The predicted flooding is along the carriageway and is likely to be due to ponding of water against the cut slopes. The extent of flooding is small and is likely to be overestimated as the influence of road drainage in the location will not have been included in SEPA's model.
ch5850 – ch6080	The SEPA Flood Map identifies surface water ponding on the upstream side of the existing A9 embankment, between the embankment and the railway line, just upstream of Inver. The risk of ponding is confirmed by GIS flow path analysis. The existing A9 is on very high embankments at this location. Pre-earthworks drainage is not represented within SEPA's surface water model and the road is raised above the area of flooding in the field, the risk of flooding to the existing A9 is considered to be low.
ch6250 – ch6350	The SEPA Flood Map identifies surface water ponding on the downstream side of the existing A9 embankment, between the embankment and the railway line. The risk of ponding is confirmed by GIS flow path analysis. The existing A9 is on very low embankments at this location and so risk to the road is possible, however as pre-earthworks drainage is not represented within SEPA's surface water model and the road is raised above the area of flooding, the risk of flooding to the existing A9 is considered to be low.

A9 Chainage	Description
ch6450 – ch6500	The SEPA Flood Map identifies surface water ponding on the downstream side of the existing A9 with a small area of flooding to the carriageway. The risk of ponding is confirmed by GIS flow path analysis. The existing A9 is on a very low embankment at this location and so the risk to the road is possible, however as pre-earthworks drainage is not represented within SEPA's surface water model and the road is raised above the area of flooding in the field, the risk of flooding to the existing A9 is considered to be low.
ch7000 - ch7150	The SEPA Flood Map identifies extensive surface water ponding against the upstream embankment of the existing A9 at Dalguise Junction, within an area of farmland to the west of the A9, which has a steep hillside sloping up away from it to the west. There are no sensitive receptors in this location, and the existing A9 embankment is moderately high, exposing the A9 to a minimal amount of risk. As pre-earthworks drainage upstream of the A9 is not represented within SEPA's surface water model, it is likely that the flooding predicted along the A9 embankment is overestimated. Flooding in this field was observed on 24 February 2021, a day after very heavy rainfall.

Summary

1.5.7 Surface water flooding to the existing A9 is predicted in isolated areas along the length of the study area including; adjacent to Dalpowie Plantation and the Birnam Sewage Treatment Works and north of the A9 Inver Rail crossing, south side of the existing A9 adjacent Peth Road between the road embankment and the railway embankment, in Little Dunkeld along the existing A9 carriageway in an area where the carriageway is in cutting, just upstream of Inver on the upstream side of the existing A9 embankment between the embankment and the railway line. Extensive surface water ponding is expected against the upstream embankment of the existing A9 at Dalguise Junction, within an area of farmland to the west of the A9, which has a steep hillside sloping up away from it to the west.

Potential Impacts

1.5.8 The proposed scheme has the potential to impact existing surface water flood risk, by:

- constructing new features over existing overland flow paths, which could impede the movement of water causing local changes to catchment drainage patterns and consequently flood risk; and
- altering run-off rates from areas impacted by the proposed scheme, with potential for compaction of ground, altering existing gradients and changes in vegetation levels. These could increase or decrease run-off rates locally, however the impact on any receiving watercourse is anticipated to be low and would be expected to be negligible in the context of flows from a significant storm event.

Surface Water Drainage

1.5.9 There is potential for an increase in flood risk as a result of dualling existing single carriageways and the construction of new roads and junctions, which would result in a greater area of paved surface. Without storage and attenuation of the additional runoff it could increase the rate at which runoff reaches receiving watercourses. While the increase from one drainage outfall alone may not make a significant difference to the receiving watercourse, the cumulative effect of all the outfalls in the proposed scheme, or the effects of its construction, may affect flood risk elsewhere in the catchment, increasing fluvial flood risk. Surface water flood risk could also be increased locally by the increase in impermeable surfacing and potential for new surface water flow paths to be formed as a result of the works. The proposed scheme therefore includes surface water drainage features used to manage the risk of surface water flooding along the proposed scheme carriageway and the impact of the proposed scheme on flood risk elsewhere. These features are summarised below.

Pre-Earthworks Drainage

1.5.10 Pre-Earthworks Drainage (PED) is permanent drainage infrastructure located where there is a risk of surface water runoff affecting the earthworks or adjacent land. It is designed to collect hillside runoff at the toe of road embankments where the adjacent land falls towards the earthworks and where there would be a risk of ponding around the scheme footprint. PED is also located at the top of cut slopes where the adjacent land falls towards the slope to prevent runoff flowing down the cut and compromising its structural integrity.

1.5.11 In both cases, PED is usually located in catchments without defined watercourses, where the proposed scheme would intercept overland flow prior to it making its way to a nearby watercourse. The PED would then ensure drainage towards an open watercourse, which would help minimise alterations to local hydrological regimes.

1.5.12 In accordance with DMRB, the design of PED would convey the 1.3% AEP (75-year) rainfall runoff event from the intercepted catchment, which is usually adopted for catchments without defined watercourses. Whilst this is not the case along large stretches of the proposed scheme and large numbers of minor watercourses are present, it would be used along the length of the A9 Dualling Programme for consistency. PED would be designed to ensure flows would not be transferred to another catchment.

1.5.13 Where PED is located at the top of cut slopes, there is the potential for water to overspill down the earthworks towards the proposed scheme during events greater than the 1.3% AEP (75-year) event. However, where practicable, the sizing of PED at the top of the cuttings should be increased to accommodate the design flood event to minimise the risk of overtopping and flood risk to the road. Furthermore, the design of these slopes would ensure that there would be a degree of infiltration into the slope and verge to minimise the volume running onto the mainline of the proposed scheme and into the proposed scheme road drainage network. Measures to encourage infiltration on the cut slope would also limit the potential for erosion. Potential catchment areas flowing into the PED are generally small and therefore any exceedance flows are likely to be small. Any areas where flows could present a risk to the A9 will be considered further at detailed design. As a result, the risk of flooding to the proposed scheme from rainfall runoff is considered low.

Road Drainage

1.5.14 In accordance with DMRB, the design of the road drainage system would accommodate a short duration, high intensity 100% AEP[1] (1-year) rainfall event, without surcharging. The design would also ensure the 20% AEP (5-year) rainfall event would not flood the carriageway. This would include a 39% uplift allowance for predicted impact of climate change.

Sustainable Drainage Systems

1.5.15 All runoff from the proposed scheme carriageways would be collected and treated via SuDS features, which are likely to include filter drains, swales and wetlands, as well as underground storage, prior to discharging to a watercourse via an outfall. These SuDS features have been designed to provide an improvement when compared to the existing drainage network, with discharge rates from storms up to the 0.5% AEP (200-year) plus climate change event restricted to the 50% AEP (2-year) greenfield runoff rate where possible and to at least below the 50% AEP (2-year) pre-development discharge rate where it has not been possible to achieve the 50% AEP (2-year) greenfield runoff rate.

1.5.16 Where the proposed scheme includes SuDS, they have been designed with the following design principles in mind:

- As a minimum, all SuDS features are designed to treat and attenuate the peak flow from the new road drainage system for a range of floods up to a 3.33% AEP (30-year) rainfall event, including an allowance for climate change. Where practicable (without increasing footprint of the scheme within the floodplain), features have been designed to attenuate peak flows up to the 0.5% AEP (200-year) rainfall event, including an allowance for climate change;
- Where practicable, SuDS features have been located outwith the functional floodplain (0.5% AEP (200-year) flood extent;
- Where practicable, SuDS features located within the functional floodplain are located outside of the 3.33% AEP (30-year) fluvial flood extent;
- A 300mm freeboard depth over and above the design peak water level has been used to set the attenuation basin spill level height for the features designed to the 0.5% AEP (200-year) event. Where features are within the functional floodplain, spill levels have been set at existing ground levels so as not to reduce floodplain storage;
- If practicable, outfall levels from the SuDS ponds have been set above the 3.33% AEP (30-year) peak water level in the receiving watercourse. Where it has not been possible to achieve this, they have been kept as high as possible; and
- In order to provide sufficient attenuation, the outfall peak flow rate is controlled to the 50% AEP (2-year) ‘greenfield’ runoff rate where practicable. Where it has not been possible to achieve this without increased impact on the floodplain, outfall peak flow rate is controlled to the 50% AEP (2-year) pre-development runoff rate.

[1] the AEP convention here is used for convenience. The actual AEP for the 1-year event is approximately 63%.

1.5.17 There are conflicting design priorities between sizing the SuDS and under road storage features, sizing the embankment to prevent overtopping and minimising (if possible) the flood impact of the feature whilst considering a wider range of spatial and environmental constraints. The SuDS design process has therefore been an iterative one.

1.5.18 This FRA has informed the SuDS design process by providing modelled baseline flood extents and peak water levels for the design flood event.

1.5.19 Table 19.2-23 contains a full list of SuDS features and outfall levels along with associated peak fluvial flood levels (extracted from hydraulic model results).

1.5.20 Whilst it has been possible to locate the majority of the SuDS features outwith the fluvial functional floodplain, three SuDS features are to be located within this zone due to other overriding design considerations. During the design event on the River Tay these three SuDS features would become inundated with flood water. Given the volume of flood water within the floodplain in the design flood event, the impact of the SuDS features becoming inundated on flood risk is considered negligible.

Downstream Impacts

1.5.21 Downstream impacts of the proposed scheme include online dualling with existing road levels largely retained or increased and is therefore unlikely to increase surface water flows downstream of the road embankment. The proposed scheme also interacts with a considerable number of minor watercourses. Where possible, PED and road drainage catchments would discharge to the nearest watercourses to mirror natural flow routes and would therefore not be likely to alter existing surface water catchments.

1.5.22 The attenuation volumes provided in the form of SuDS features would also ensure that there is no increase in flood risk downstream along the receiving watercourse because of an increase in runoff rates and volumes due to the extended area of impermeable surfaces. By following the overarching design principles where possible and ensuring flood risk has been considered at all stages of the design process, the impact of the proposed scheme on surface water flooding is considered negligible.

Table 19.2-23: SuDS basins and outfall levels

Drainage Catchment	Mainline Chainage (start / end)		Attenuation Storage	Discharge Location	Discharge Rate (QMED) at outfall (l/s)	Outfall Level (mAOD)	SuDS within 3.33% AEP (30-year) Floodplain	Peak 3.33% AEP (30-year) Floodplain Water Level (mAOD)	SuDS within 0.5% AEP (200-year) plus CC Floodplain	Peak 0.5% AEP (200-year) plus CC Floodplain Water Level (mAOD)
Run A	0	885	Filter Drain and Detention Basin	River Tay	12.7	41.36	NO	45.239	NO	48.905
Run B1	885	2,200	Filter Drain and Detention Basin with Wet Pond	River Tay	27.4	57.95	NO	46.273	NO	49.68
Run B2	2200	2650-	Filter Drain and Detention Basin	River Tay	14.8	39.72	NO	47.319	YES	50.098
Run C1	2,650	3,350	Filter Drain, Geocellular Storage and Vortex Separator	Inchewan Burn	7.4	58.91	NO	58.761	NO	59.551
Run C2	3,350	3,450	Filter Drain and Dry Swale	Inchewan Burn	1.0	59.61	NO	58.761	NO	59.551
Run D	3,460	4,330	Filter Drain and Detention Basin	River Tay	18.3	50.15	NO	49.856	NO	53.244
Run E	-	-	Filter Drain and Swale (outfalls to existing drainage network)	Existing Drainage Network	N/A	50.47	N/A	N/A	N/A	N/A
Run F	4,330	5,490	Filter Drain and Detention Basin	Inver Mill Lade	17.8	49.54	YES	50.393	YES	53.376
Run G	5,490	6,300	Filter Drain, Detention Basin and Swale/Open Channel	River Tay	13.7	64.10	NO	51.077	NO	54.577
Run H	6,300	7,350	Filter Drain and Detention Basin	River Tay	43.2	52.63	NO	52.649	YES	56.181
Run I	7,350	8,421	Filter Drain and Wetland	River Tay	13.1	49.56	NO	53.421	YES	57.344

Mitigation Measures

1.5.23 This FRA considers that, with the surface water drainage systems in place as part of the proposed scheme, no additional mitigation measures are required. Since no additional mitigation measures are proposed, the surface water risks and impacts would remain unchanged from that described under Potential Impacts.

Residual Risks

1.5.24 In the context of the proposed scheme, the residual surface water risks would include:

- severe runoff events as a result of intense rainfall or rapid snow melt, which exceed the design capacity of the PED (greater than 1.33% AEP (75-year)), road drainage (greater than 20% AEP (5-year)) or SuDS features (greater than 3.33% AEP (30-year) or 0.5% AEP (200-year) plus climate change);
- blockages within the drainage infrastructure that reduce its capacity to convey flows from adjacent land and the carriageway or from SuDS features into receiving watercourses; and
- the failure of proposed SuDS features (embankment failure), which could result in a sudden release of water and flooding of receptors downstream.

1.5.25 In the event of extreme events or blockages causing the drainage system to surcharge, the geometry of the mainline of the proposed scheme has been designed in such a way as to shed runoff from the edges of the road and to avoid ponding on the mainline itself ensuring that disruption to traffic is minimised.

1.5.26 The design of SuDS features outwith the functional floodplain also includes a 300mm freeboard of additional storage above the peak attenuated water level to manage the residual risk of blockages and to provide additional storage capacity should it be required. There is also an overflow facility provided in each of the outlet controls, again to provide resilience to the design should any blockages occur. The residual risk posed by these two scenarios is therefore considered to be low.

1.5.27 A high-level assessment of the impact of failure or overtopping of the SuDS ponds has been undertaken, the results of which are included in Table 19.2-24. In the vast majority of cases, SuDS features are located in close proximity to watercourses or within the River Tay or River Braan floodplain, with no sensitive receptors between the two. In these cases, should the SuDS feature embankment fail, the water would flow on to the floodplain or directly into the watercourse. The volume of water flowing into large watercourses, such as the River Tay, would be insignificant in comparison to average flows and would have a negligible impact on flood risk downstream.

Table 19.2-24: SuDS Ponds – risk of embankment failure, overtopping and exceedance pathways

SuDS Feature	Impact of failure/overtopping	Residual Risk
A	The pond is slightly raised above the surrounding land to the south east and any failure mechanism is unlikely to result in the release of a significant volume. Any exceedance or flooding would follow a depression to the River Tay through Dalpowie Plantation to the north-east.	Low – flooding of plantation woodland. No sensitive receptors downstream.
B1	The pond is raised above the surrounding land at the eastern extent. If the embankment was to fail or capacity was exceeded, then flooding would pond against the proposed scheme embankment and drain down via the PED and to the outfall to the River Tay.	Low – flooding of Ring Wood in close proximity to the SuDS pond where water would be retained. No sensitive receptors downstream.
B2	Flooding of field in surrounding area due to overtopping during exceedance. No risk of embankment failure as SuDS pond is below the existing ground level.	Low - No sensitive receptors in close proximity to the SuDS pond.
D	Flooding to the River Braan due to overtopping during exceedance. No risk of embankment failure as SuDS pond is below the existing ground level.	Low - No sensitive receptors in close proximity to the SuDS pond.
F	Exceedance flows would flood to the north and west to the River Tay. No risk of embankment failure as SuDS pond is below the existing ground level.	Low - No sensitive receptors in close proximity to the SuDS pond.
G	SuDS pond SuDS pond below current ground level. Exceedence pathway to the north east to the River Tay	Low - No sensitive receptors in close proximity to the SuDS pond.
H	SuDS pond below current ground level. Exceedence pathway to the south east to the River Tay	Low - No sensitive receptors in close proximity to the SuDS pond.
I	SuDS pond below current ground level. Exceedance pathway to the south east to the River Tay	Low - No sensitive receptors in close proximity to the SuDS pond.

1.6 Groundwater

Introduction

1.6.1 Groundwater flooding occurs where water levels, beneath the ground, rise above the ground surface. In some instances, groundwater can emerge at surface level following heavy rainfall events and contribute to existing flooding from other sources. Alternatively, a greater risk can be presented if construction works or long-term, large-scale developments, such as road schemes, intersect areas with shallow groundwater levels or create pathways for deeper confined artesian pressures, which can be released at ground level and cause widespread flooding.

1.6.2 In order to develop a conceptual understanding of groundwater flooding associated with the proposed scheme, groundwater level data from 150 borehole-monitoring installations along the proposed scheme corridor has been collated and reviewed. The number of monitored locations and duration of monitoring varied by phase of GI with data available from 55 locations from the most recent 2023 phase of GI which included logger data from 9 boreholes. Further details are provided in Chapter 13 (Geology and Soils) Table 13.8.

1.6.3 By assessing recorded groundwater levels along the scheme corridor, a screening assessment was carried out to identify those areas at greatest risk of groundwater flooding, potential scheme impacts and to identify where potential mitigation may be required. This included a detailed review of all parts of the proposed scheme that would involve excavations below existing ground level, including cuttings and the locations of proposed detention basins. Chapter 13 (Geology and Soils) undertakes this screening and fully assesses groundwater issues in relation to the proposed scheme.

Baseline Risks

1.6.4 Superficial deposits are recorded as alluvium, alluvial fan deposits, river terrace deposits, glaciofluvial deposits and Devensian – Diamicton glacial till (BGS 2024). Throughout the proposed scheme area the total thickness of superficial materials ranged from locally absent in an area west of Inver (around ch5580) to 79.5 mbgl to the north of the River Tay Crossing (ch7690). Superficial deposits comprise glacial till underlying the hillsides of the River Tay valley, with alluvium and glaciofluvial deposits in the valley bottoms. Generally, the existing A9 corridor lies to the west of the River Tay, at the boundary of the alluvium and glaciofluvial deposits.

1.6.5 The bedrock geology underlying the majority of the study area is low grade metamorphic bedrock of Dalradian age, belonging to the Southern Highland Group (SHG) and is comprised of interbedded pelites, semipelites, psammities and metasandstones.

Groundwater in the Superficial Deposits

1.6.6 The glacial till is typically comprised of poorly sorted sands and gravels within a clay matrix, and is generally considered to have low permeability. As a result, recharge rates into the underlying bedrock aquifer in these locations are likely to be low. After periods of intense or prolonged rainfall, this is likely to contribute to significant waterlogging and surface water ponding in low lying areas and enhanced run-off in other areas.

1.6.7 In valley floor areas, underlain by alluvium and river terrace deposits, groundwater levels may emerge at ground level because of rising groundwater levels in the superficial deposits. In the vicinity of watercourses, there may also be a connection between surface water and groundwater and rising surface water levels may contribute to locally increasing groundwater levels, and vice versa.

1.6.8 The A9 development corridor is linear and consequently the ground investigations cannot fully define groundwater flow directions across the surrounding area. However, the groundwater flow within the superficial deposits is expected to broadly follow the topography and, at the shallow, local scale, this would be towards the River Tay. The direction of groundwater flow within the bedrock is unknown

1.6.9 Ground investigation data, obtained from the 150 monitoring installations along the A9 corridor, indicates maximum groundwater level to be typically in excess of 5mbgl, although there was a large degree of variation across the study area with levels ranging from surface level to over 30 mbgl. Three locations recorded maximum groundwater levels in excess of 30 mbgl, the deepest at 38 mbgl in proximity to the existing A9 at Dunkeld Railway Station (ch3200).

1.6.10 Shallow groundwater levels were typically encountered close to surface water features (the River Tay and River Braan) and in areas where especially thin superficial deposits lie upon the low permeability metamorphic bedrock. Four locations recorded maximum groundwater levels within the top 1 m, three of which were in proximity to surface water features or shallow superficial deposits.

Bedrock Groundwater

1.6.11 Groundwater flow in the bedrock metamorphic rocks will occur primarily through fractures. Permeability is expected to be low and variable, dependent on the density and interconnection of fracture networks. Recharge rates into the bedrock may also be low and variable, due to the low bedrock permeability and may contribute to the development of waterlogging and surface water ponding in low lying areas and enhanced run-off in other areas.

1.6.12 Four boreholes are screened within the bedrock and data collected from these locations indicates that maximum groundwater level is typically within 5m of ground surface.

1.6.13 Based on these groundwater monitoring results and the local geology (highly permeable sands and gravels overlying low permeability bedrock) groundwater flow is expected to be predominantly within the immediate overlying superficial deposits (typically sands and gravels) and the uppermost weathered section of bedrock (if present). The consequence of this is that the depth to groundwater and groundwater flow is highly variable across the project area and can be dependent upon the depth to bedrock.

Limitations

1.6.14 It should be noted that geological and hydrogeological information obtained from the GI phases have been used for this assessment although coverage is not total, both laterally and vertically. Limited data is available from the bedrock and in areas where no groundwater level data were available, the nearest geological and hydrogeological information was extrapolated from the wider available dataset.

Potential Impacts

1.6.15 As the proposed scheme is located at, or below ground level (cuttings) in several locations, there is a risk that groundwater flooding could affect the proposed scheme during both its construction and operational phases, if not managed. The key element of the design of relevance to groundwater flooding is the deep excavations required where new road cuttings are proposed.

1.6.16 A separate road cutting screening exercise has been undertaken in Chapter 13 (Geology and Soils), which has identified 11 cuttings which are likely to intercept groundwater. Of particular relevance are the four areas where shallow groundwater conditions have been recorded. These areas are summarised in Table A19.2-25.

Table A19.2-25: Summary of shallow groundwater levels recorded

Borehole Reference	Chainage	Maximum Recorded Groundwater Level (m bgl)
BHBT114	3700	0.34
BHBT141	4350	0.17
BTB4001	900	0.55
BTB4007A	1950	0.73

1.6.17 In addition, construction of sheet pile retaining walls could also affect existing groundwater flow paths and groundwater levels. The length of the currently proposed sheet pile walls range from 30 to 350m in length and would extend down to a maximum depth of 19m bgl. However, it is likely that the sheet pile walls would not represent significant barriers to groundwater movement as water could divert around the proposed structures. Any increase in groundwater level is likely to be relatively minor and given that the depth to groundwater at these locations is relatively significant (circa 10m bgl) an increased risk of groundwater flooding is not anticipated.

Mitigation Measures

1.6.18 It is considered that groundwater flood risk can be mostly managed through mitigation embedded into the design of the proposed scheme. Table A19.2-26 details the embedded mitigation measures likely to be incorporated into the proposed scheme. With these in place, the impact of the proposed scheme on groundwater flood risk is considered low.

Table A19.2-26: Groundwater mitigation measures

Embedded Mitigation Measures	Description
Dewatering of cuttings	During the construction phase, the proposed scheme would include standard excavation dewatering practices involving passive and/or active dewatering, as required. It would protect construction personnel, works, plant and machinery associated with the new cuttings. The potential volume of groundwater drainage would be considered in the context of potential groundwater abstraction CAR licences prior to works commencing.
Drainage of cuttings	To protect flood sensitive receptors from groundwater flooding during the operational phase, groundwater seepage would be collected by the proposed road drainage system.
Pre-earthworks drainage	Pre-earthworks drainage should be sized appropriately to intercept and accommodate all shallow groundwater flows entering the works area to protect flood sensitive receptors.

1.6.19 Other than at cuttings, it is considered unlikely that groundwater flooding will pose a significant issue along the proposed scheme. It may however contribute to surface water flooding in some areas, as noted above. It is considered that embedded mitigation proposed as part of the proposed scheme would be sufficient to manage the groundwater flooding issues identified above.

1.6.20 However, due to the presence of deep cuttings and the remaining uncertainties associated with the existing ground investigation data to date, it is recommended that a groundwater level monitoring programme is implemented before and during construction to identify any potential future groundwater flood risk issues.

Residual Risks

1.6.21 There is a low, residual groundwater flood risk that temporary drainage systems would be unable to cope with the groundwater flows that could emerge as a result of localised drainage of groundwater at deep cuttings. It is assumed that the contractor is aware of these possible groundwater releases, and as such, would design any future drainage systems to accommodate any potential groundwater flows.

1.7 Failure of Water Retaining Infrastructure

Introduction

1.7.4 Flooding due to the collapse and/or failure of man-made water-retaining infrastructure such as a dam, water supply reservoirs, canals, flood defences, underground conduits (e.g. sewers), and water treatment tanks or pumping station is considered to be a residual risk.

1.7.5 It is not possible to attach a probability of collapse and/or failure to water-retaining infrastructure, as it would be dependent on the combined effect of a number of factors such as their condition, existing maintenance regimes and other outside influences. However, it would be significantly lower than the design flood event, which is used to assess the risk of fluvial and pluvial flooding.

1.7.6 However, a collapse and/or failure could potentially result in a large volume of water suddenly being released at potentially extremely high velocities, resulting in potentially catastrophic consequences. Released water would follow local topography towards low-lying areas or into nearby watercourses. As the existing A9 crosses the valley floodplain and spans a number of watercourses, the proposed scheme is potentially at risk from this source of flooding and could potentially alter these flow paths.

1.7.7 A preliminary assessment has been undertaken to identify the location of water-retaining infrastructure and assess the potential for the proposed scheme to affect residual risks associated with infrastructure failure.

Baseline Risks

Reservoirs

1.7.8 The project area is downstream of a number of reservoirs, failure of which could result in flood risk to the existing A9 and other receptors within the project area. These include Loch Tummel, Loch Rannoch, Errochty Reservoir, Loch Garry, Loch Faskally, Glen Lyon, Loch Ericht and Loch an Daimh. These reservoirs are located upstream along the River Tummel or River Tay and failure of any of these reservoirs could result in flooding to the existing A9 within the project area.

1.7.9 The normal operation of these dams poses a negligible risk to the existing A9. The failure of dams associated with these reservoirs is likely to result in the inundation of large extents of the existing A9 as illustrated by SEPA’s Reservoir Flood Maps (2023b). It should be noted that the reservoirs listed are regulated under the Reservoirs (Scotland) Act 2011 and therefore the risk of failure is considered low as a result of the monitoring regime the owners have to comply with.

Sewers

1.7.10 Scottish Water records indicate that there are no sewers or watermains in the project extent that could pose a flood risk to the proposed scheme.

Potential Impacts

1.7.11 The proposed scheme will not alter or affect any of the infrastructure described above. The flood risk to the proposed scheme from this source of flooding is therefore considered to be low and no mitigation is proposed.

1.7.12 The impact of the proposed scheme on flood risk from these sources has also been considered. The raising of the main alignment, increased embankment footprint and new side roads has the potential to alter flows from any of these sources, potentially increasing flood risk, however the risk is considered to be negligible and therefore no mitigation is proposed.

1.8 Construction Phase

Introduction

1.8.4 This section of the FRA provides an overview of potential flood risks for the Main works Contractor to consider during the construction phase, to set out high-level requirements with respect to managing flood risk, and to provide general guidance to assist.

Potential Short-term Impacts

1.8.5 Temporary works can themselves be at risk of flooding and have the potential to impact flood risks both to work areas and to receptors beyond the work site. Critically, there is a risk to life from flooding to those working on site, and the construction works also have the potential to affect the existing risk to life from flooding beyond the construction site. The design of the temporary works therefore needs to consider these factors.

1.8.6 Table 19.2-27 outlines the construction elements of temporary works required during the construction phase and highlights the key potential impacts of the temporary works with respect to flooding.

Table 19.2-27: Summary of short-term construction impacts

Temporary Works	Description	Potential Short-Term Impacts
Temporary earthworks	Due to the difference in levels between the existing and proposed levels of the carriageway and in order to aid construction of some structures there is a requirement to construct temporary carriageways to the side of the existing A9.	Excavation works could result in the pooling of pluvial runoff, the emergence of groundwater, the creation of an impounded body of water or a water mains strike. Works associated with filling could result in the diversion of overland flow routes, a reduction in floodplain storage, impacts on floodplain conveyance, and increased volumes of surface water runoff.

Temporary Works	Description	Potential Short-Term Impacts
	Some of these sections occur from ch 750-1000, ch2100 – 2300, ch 3900 – 4900 and ch 5800 – 7400.	
Temporary drainage	Including site compound drainage (to facilitate the use of cabins), temporary road drainage, pre-earthworks drainage	Temporary drainage could increase both the rate and volume of pluvial runoff to a receiving watercourse or sewer, and has the potential to transfer sediment to the receiving watercourse or sewer (potentially affecting the flooding mechanisms of the watercourse).
Works within or adjacent to watercourses	Including temporary river works, such as at the River Braan bridge where a new temporary alignment may be needed for utilities as well as a temporary crash deck for demolition of the existing bridge.	Temporary work located within or adjacent to watercourses could affect the frequency, depth, extent and duration of fluvial flooding.
General site activities	Including site compounds and the storage of construction materials and equipment; and works traffic	The location of site compounds and the storage of construction materials and equipment on site could potentially reduce floodplain storage and divert flood flow routes in many of the locations initially chose as possible locations. Placing working sites within the floodplain could also place human life at risk. Works traffic could also damage existing sewers or land drains, and could also compact ground, which could increase surface water runoff.

1.8.7 The Main works Contractor should ensure that the temporary works are protected from flooding during a high-risk event undertaken during the construction phase and that the temporary works do not increase the risk of flooding beyond the site during a similar event.

1.8.8 The overall guiding principle should be to avoid any temporary works within the functional floodplain: the 0.5% AEP (200-year) extent, where possible. Where it is not practical to avoid temporary works in areas at risk of flooding, the Main works Contractor should take into account the depth of flooding, potential floodplain flows and local site conditions to place more vulnerable works in lower risk areas. The Main works Contractor must also provide measures to mitigate the risk of flooding using the below mitigation principles as a starting point.

Mitigation Principles

General Guidance

1.8.9 The Main works Contractor should follow the following general guidance concerning the management of flood risk during the construction period of the proposed scheme:

- Prepare a Flood Response Plan. This should include due consideration of the requirements of businesses, residents and livestock within the project area;
- Sign up to the Floodline, Scotland's flood warning service provided by SEPA, and also be responsible for monitoring forecasts and weather conditions on site;
- Consult with SEPA when working within a river or within 50m of bank top is proposed and ensure the activities are licensed under the Water Environment (Controlled Activities) Regulations (CAR), if applicable;
- Monitor water levels when working within or near rivers;
- Prepare emergency evacuation plans for each construction area given issue of a Flood Warning or following rapid rises in river level or continuous heavy rainfall, identifying safe access and egress routes and refuge points;
- Provide standby pumping equipment to remove any surface water runoff that enters the working area;
- Ensure site drainage is not discharged to a local sewer; and
- Contact SEPA during a flooding event greater in magnitude than the temporary works are designed to, particularly where receptors could be at increased risk of flooding.

Temporary Work Guidance

1.8.10 The Main works Contractor should also follow the following guidance regarding to temporary works and flood risk:

Temporary Earthworks

- Review local groundwater data prior to extensive excavations;
- Where dewatering of excavations is undertaken, discharge overland or to a watercourse (with appropriate treatment where necessary) at the relevant greenfield runoff rate;
- Undertake initial desk-based services searches before digging on site. The Contractor should also undertake appropriate survey (CAT scans, GPR survey, etc.) on site to verify the location or presence of underground services before digging;
- Avoid trafficking areas with known vulnerable services. Assess ground loading in these areas and provide additional cover protection if necessary. Close co-ordination with utility owners is required. Plan abnormal load routes;

- Locate stockpiles outside of areas susceptible to prominent surface water flows. Where this is not possible, stockpiles should be constructed with regular spaces between heaps (with each stockpile not exceeding 25m in length) to preserve existing low points and flow paths, and to prevent surface water backing up behind the structure and being re-directed elsewhere;
- Store excavated materials outside of the floodplain. Excavated material should only be placed in 'at risk areas' when required for use;
- Construct haul roads and access roads as close to ground level as possible when crossing the floodplain; and
- Construct temporary drainage measures along access road / temporary diversion edges and around stockpiles to collect runoff and direct to treatment facilities.

Temporary Drainage

- Assess requirements for discharge rate control and treatment as part of the construction works; and
- Drainage receiving runoff, which is expected to contain sediment, should be directed towards a suitable sized temporary settlement pond that provides sufficient treatment before being discharged to a watercourse.

Works within or adjacent to Watercourses

- Design temporary river works, which involve the diversion of a watercourse (e.g. fluming or over-pumping), to convey the design flood event to be agreed with SEPA. A lower standard may be acceptable if the works would be in place for a shorter period than the overall construction phase;
- Design temporary works, such as a diversion and crash deck associated with the replacement of the River Braan crossing to be single span as not to affect the river flow or risk of flooding;
- Where temporary access crossings include the use of a culvert, design to convey the peak flow during the design flood event, to be agreed with SEPA. Multiple pipes should not be used, where reasonably practicable, to reduce the risk of blockage; and
- Where temporary access crossings include the use of bridges, such as the River Braan bridge crossing , design the soffit above the peak water level during the design flood event plus 600mm freeboard to be agreed with SEPA. Bridge piers should not be located within the watercourse.

General Site Activities

- Minimise trafficking and loading of unprotected site areas. Consider protecting large site areas subject to heavy traffic loads and methods to alleviate soil compaction post works, as soil compaction may lead to an increased runoff rate;
- Avoid trafficking areas with known vulnerable services. Assess ground loading in these areas and provide additional cover protection if necessary. Plan abnormal load routes;

- Store construction materials outside of the floodplain. Construction material should only be placed in 'at risk areas' when required for use; and
- Raise offices and other site facilities outwith the functional floodplain. Where not suitable, raise offices above the peak water level for the chosen design flood event to be agreed with SEPA. Facilities could be elevated on stilts, or in some cases, located on the higher areas of the compound.

Residual Risks

1.8.11 Given that the Main works Contractor follows and correctly implements the principles outlined in this section of the report, the main residual flood risks during the construction phase of the proposed scheme are considered to be:

- fluvial or surface water events, which exceed the design standard of the temporary works or general site work;
- blockages within temporary surface water drainage; and
- failure (including blockage) of temporary works within watercourses.

1.8.12 In the event of flood events of greater magnitude than the design standard, or blockages causing temporary drainage systems to surcharge, flooding within construction areas could occur. The main risk is likely to be to the site operatives in this event; however, assuming that conditions on site, weather forecasts, flood warnings and river levels are monitored appropriately, and site evacuation plans are in place, the residual risk is considered low.

1.8.13 In the majority of cases, failure of temporary works within watercourses is unlikely to result in a significant detrimental impact to the flood risk on the watercourse affected, as flows are unlikely to be impacted. Again, the main risk is likely to be to site operatives in this event; however, assuming that the Main works Contractor has emergency plans in place given failure of works where operatives are at significant risk, then the residual risk is considered low.

1.9 Conclusions

1.9.4 Where achievable, the proposed scheme has a neutral or better effect on overall flood risk. However, where this has not been possible taking cognisance of environmental, engineering and economic constraints, additional mitigation measures have been proposed, or justification as to why potential flood impacts are acceptable when considering the potential consequence of that impact.

Impact of the Proposed Scheme

1.9.5 The proposed scheme results in a net loss of floodplain storage due to the very limited opportunities for compensatory flood storage areas in the landscape. Some indirect flood storage provision, in combination with additional mitigation measures has resulted in very limited and small localised areas of minor adverse impacts close to the river bank. These are minor changes in flood depth and extent; largely within the site of the proposed scheme or in areas of riparian woodland. It has been demonstrated that there are no adverse impacts to sensitive receptors.

1.9.6 Table 19.2-28 to Table 19.2-32 provide a summary of the FRA findings.

Table 19.2-28: Principal watercourses summary

Risk	Summary
Baseline	Extensive flooding at Inver on the River Braan and River Tay at Dunkeld and Little Dunkeld, with overtopping of the existing A9 at Inver and flooding of the A9 at the northern extent.
Potential Impacts	The proposed scheme has been shown to have both beneficial and potentially adverse flood impacts during the design flood event. **Beneficial flood impacts**: ▪ The proposed scheme mainline has been raised above the design flood event and as a result, would largely remain safe and operational during times of flood. **Negligible flood impacts:** ▪ Local loss of 250m length of floodplain storage is predicted at Dalguise Junction , 150m at Hermitage Junction and at the Tay Crossing but has been shown to have negligible flood impacts across the wider floodplain within the scheme area and downstream. ▪ Minor adverse changes to bank full extents away from sensitive receptors or within the scheme CPO. ▪ Torelee Road issue – 5mm increase **Adverse flood impacts:** ▪ The proposed scheme results in a loss of 70,000m^3 of floodplain storage at the design flood event principally at Inver. There are very limited opportunities to replace this directly

Risk	Summary
	▪ Unmitigated, the proposed scheme would increase the risk of flooding to flood sensitive receptors including residential properties in the Braan floodplain. ▪ Flooding at the northern extent of the proposed scheme which will be managed rather than defended
Mitigation Measures	• Compensatory flood storage has been proposed at one location within the project area, CSFA1 to mitigate some limited direct loss of floodplain storage due to the proposed scheme. • 3 culverts to relieve flooding on the Mill Lade. • 14 culverts through proposed embankments to replicate baseline flood mechanisms
Residual Risks	The residual fluvial flood risks remaining are associated with flood events of greater magnitude than the design standard of the proposed scheme or blockage of any of the culverts that connect floodplain areas on the east of the A9 with the main floodplain. A freeboard allowance has been included in the design to reduce these risks to the A9. The risk of blockage of the culverts is reduced by the flow generally being in the opposite direction during a major flood event to what occurs in general day to day flows from minor watercourses. This risk will be further managed by the maintenance regime for the culverts.

Table 19.2-29: Minor watercourses summary

Risk	Summary
Baseline	According to the preliminary assessment carried out for all existing A9 mainline crossings of minor watercourses, during the design flood event: ▪ 3 of the 13 existing A9 mainline watercourse crossings have adequate capacity or surcharge at levels that do not pose a potential risk to the A9; and ▪ 10 of the 13 existing A9 mainline watercourse crossings are under capacity and pose a potential risk of flooding to the existing A9.
Potential Impacts	The proposed scheme has been shown to have both beneficial and adverse flood impacts during the design flood event. **Beneficial flood impacts**: - Benefits are seen at WF09 where surcharged out of bank flows previously flooding properties and the A9 are now conveyed in culvert. **Adverse flood impacts:** ▪ 8 watercourses have an increased HWL as a result of the proposed scheme.
Specific	Mitigation measures proposed for minor watercourses are:

Risk	Summary
Mitigation Measures	▪ WF09 – Filling in of approximately 100m length of right bank low-section downstream of new culverts to prevent out of bank flooding in design event
Residual Risks	Residual flood risks along minor watercourses are primarily associated with: ▪ Culvert blockage; and ▪ Flood events greater than the design capacity of the watercourse crossing.

Table 19.2-30: Surface water summary

Risk	Summary
Baseline	Generally, the preliminary assessment identifies a low risk of flooding to the existing A9. The SEPA Flood Map shows several locations where direct runoff ponds against the existing A9 embankment, ponds on the surface of the A9, or flows across the A9. However, the mapping is likely to be conservative as it does not take into account the road drainage or minor watercourse crossings.
Potential Impacts	As the proposed scheme is an online dualling option, existing surface water flow paths and areas of ponding within fields either side of the main alignment are likely to remain unchanged in most locations. The proposed scheme would include new surface water drainage features including PED, road drainage and SuDS, to manage the risk of surface water flooding along the proposed scheme carriageway and the impact of the proposed scheme on flood risk elsewhere. These would provide a beneficial impact on surface water flooding when compared to the baseline scenario.
Mitigation Measures	Additional mitigation measures beyond that provided within the proposed scheme are not recommended.
Residual Risks	Generally, residual surface water risks are considered low and include: Severe rainfall events, which exceed the capacity of the PED, road drainage or SuDS features; and blockages within the drainage infrastructure or SuDS features. In the event of extreme events or blockages, the geometry of the proposed road surface has been designed in such a way as to shed runoff from the edges of the road and to avoid ponding on the carriageway itself ensuring that disruption to traffic is minimised. Where SuDS features are outside the functional floodplain, the design includes a 300mm freeboard above the peak attenuated water level to manage the residual risk of blockages and to provide some additional storage capacity should it be required. Where in the functional floodplain, any exceedance or blockage would result in flooding within the floodplain and eventually flow into local watercourses. If this occurs during a River Tay flood event the impact would be negligible and outside of flood events the depth of flooding would be anticipated to be significantly lower than in a Tay flood. Therefore, there would be no increase

Risk	Summary
	in flood risk to sensitive receptors. There is also an overflow facility provided in each of the outlet controls, again to provide resilience to the design should any blockages occur. Ongoing routine inspection and maintenance of the SuDS features would reduce the likelihood of failure.

Table 19.2-31: Groundwater summary

Risk	Summary
Baseline	Along the existing A9 corridor, there is a risk of groundwater flooding from valley alluvium and river terrace deposits, which could contribute to, and extend the duration of other sources of flooding, such as surface water or fluvial flooding in low-lying areas. However, data collected at this stage does not provide any evidence of shallow groundwater flooding significantly contributing to flooding in the area of interest.
Potential Impacts	The proposed scheme has the potential to be at risk of groundwater flooding during both construction and operation phase, especially where excavations are proposed for new road cuttings. Where excavations are proposed to bedrock there are no known confined artesian or sub-artesian bedrock groundwater pressures and therefore groundwater flood risk from the bedrock is considered low. However, eight cuttings are likely to intercept groundwater within superficial deposits. Negligible flood impacts: It is anticipated that groundwater flood risk can be mostly managed through typical best practice road design and mitigation embedded into the design. As a result, the proposed scheme is considered to have a negligible impact on groundwater flooding.
Mitigation Measures	It is recommended that a groundwater level-monitoring programme be implemented before and during construction, allowing potential impacts to be eliminated through additional mitigation if they arise.
Residual Risks	There is a low residual groundwater flood risk that temporary drainage systems would be unable to cope with the groundwater flows that could emerge as a result of localised drainage of groundwater at deep cuttings. It is assumed that these risks will be managed by the contractor.

Table 19.2-32: Failure of water-retaining infrastructure summary

Risk	Summary
Baseline	The risk of flooding to the existing A9 from reservoirs and sewers is considered to be low.
Potential Impacts	Negligible flood impacts: The proposed scheme would not include any works that would alter or affect water-retaining infrastructure and as a result the impact of the proposed scheme is considered to be negligible.

Mitigation Measures	No additional mitigation measures are proposed.
Residual Risks	The residual risk of flooding from water-retaining infrastructure would remain unchanged from the baseline scenario and no additional mitigation measures are proposed.

1.9.7 There are also likely to be a number of activities during the construction phase of the proposed scheme that could affect flood risks and potential mitigation measures that have been identified. However, the detailed assessment of the risks and appropriate mitigation measures would be best identified and managed by the Contractor on a case-by-case basis depending upon the construction techniques to be used and the location.

1.9.8 The potential impacts as a result of multiple sources of flooding occurring simultaneously have been considered. The most significant event in terms of flood depth and risk to receptors is the design event on the River Tay. The rainfall event that would cause this is very different from the storm event that would result in peak surface water or minor watercourse flooding. The risk of these events coinciding is therefore considered to be low. Groundwater levels would often be expected to respond more slowly to rainfall events than river or surface water flooding, however the response may vary with antecedent conditions. Localised flooding through alluvial deposits hydraulically linked to the River Tay is possible and could occur in a similar timeframe to flooding on the River Tay. Given the hydraulic connectivity, this would not be anticipated to significantly alter peak flood levels in comparison to an event on the River Tay and therefore would not result in increased flood risk to the proposed scheme. The proposed scheme would not be expected to cause a change from the existing risk of groundwater emergence in combination with a fluvial flood event and therefore would not cause an increase in flood risk to other sensitive receptors. Combined flood events that do not include the design event on the River Tay result in reduced flood depths in comparison to Tay flood events. The proposed scheme is therefore considered to have a negligible impact on flood risk from combined events.

1.9.9 Localised flooding through alluvial deposits hydraulically linked to the River Tay is possible and could occur in a similar timeframe to flooding on the River Tay. Given the hydraulic connectivity, this would not be anticipated to significantly alter peak flood levels in comparison to an event on the River Tay and therefore would not result in increased flood risk to the proposed scheme. The proposed scheme would not be expected to cause a change from the existing risk of groundwater emergence in combination with a fluvial flood event and therefore would not cause an increase in flood risk to other sensitive receptors. Combined flood events that do not include the design event on the River Tay result in reduced flood depths in comparison to Tay flood events. The proposed scheme is therefore considered to have a negligible impact on flood risk from combined events.

1.9.10 The potential for cumulative impacts as a result of multiple A9 proposed schemes has been considered. The assessment shows that there is negligible impact on the Project 02 scheme area from upstream proposed schemes, and negligible impact downstream of Project 02. The assessment shows that across a range of flood events from the 50% AEP (2-year) to the 0.5% AEP (200-year) plus CC event, the increase in peak flow at the downstream limit of the reach is a maximum of 0.01% compared to the baseline, and the decrease in water level is a maximum of 1mm compared to the baseline. It is concluded that the cumulative impact is therefore negligible.

Standard of protection and resilience to climate change

1.9.11 This FRA demonstrates that the proposed scheme design has adequately addressed any local flood risk issues and that the entire A9 mainline would remain operational during the 0.5%AEP (200-year) plus 20% for climate change flood event; as per the northern dualling sections.

1.9.12 As demonstrated in this FRA, a 53% climate change uplift applied as the design event results in flooding north of the Tay Crossing at the interface with the Tay Crossing t oBallinluig section. The flooding occurs very close to the peak of the hydrograph and would be one of the last sections to become inundated and with a relatively small volume and extent. This residual flood risk at the design event will be managed through Emergency Response Planning.

1.9.13 Although the proposed scheme has a neutral impact on flood risk, it does result in a net loss of floodplain storage. This does not comply with DMRB Standard and as such a Departure from Standard will be required from Transport Scotland as the competent authority. SEPA guidance also looks to the provision of compensatory flood storage as the primary mitigation measure for encroachment into the floodplain. Due to the over-riding constraints presented in this FRA it has not been possible to fully achieve this objective. With these exceptions, it is concluded that the proposed scheme would meet relevant planning and design standards in terms of flood risk.

1.9.14 In summary, a comprehensive assessment of the flood risk to and from the proposed scheme has been undertaken. Mitigation measures to manage any identified flood risks have been proposed such that flood risk is managed appropriately up to the design flood event.

1.10 References

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Annex A: Impact Assessment Criteria

Sensitivity

1.10.1 The sensitivity of water features associated with the existing risk of flooding or its hydrological importance.

1.10.2 This FRA considers the existing A9 as a flood sensitive receptor. This approach differs from that approach presented in the EIA, which considers the impact of the proposed scheme on other sensitive flood receptors, assuming that the proposed scheme is not a sensitive flood receptor, as it would ultimately be designed to be operational during the design flood event.

1.10.3 This is important because it allows the focus of the EIA to be on the surrounding area rather than considering the impact of the proposed scheme on the A9 itself. However, from a flood risk perspective, the mainline of the proposed scheme must be considered as a sensitive receptor so that it can be designed to remain operational and safe for users during times of flood.

Table A19.2-A1: Hydrology and flood risk sensitivity criteria

Sensitivity	Criteria
Very High	Water feature with direct flood risk to the adjacent populated areas, with greater than 100 residential properties at risk or critical social infrastructure units such as the existing A9, hospitals, schools, safe shelters or other land use of great value at risk. Water feature with hydrological importance to: i) sensitive and protected ecosystems of international status; ii) critical economic and social uses (e.g. water supply, navigation, recreation, amenity).
High	A water feature with direct flood risk to the adjacent populated areas, with between 1 and 100 residential properties and/or more than 10 industrial premises at risk from flooding. Water feature with hydrological importance to: i) national designation sensitive and protected ecosystems; ii) locally important economic and social uses (e.g. water supply, navigation, recreation, amenity).
Medium	A water feature with a possibility of direct flood risk to less populated areas without any critical social infrastructure units such as hospitals, schools, safe shelters and/or utilisable agricultural fields. A water feature with some but limited hydrological importance to: i) sensitive or protected ecosystems; ii) economic and social uses; iii) the flooding of 10 or fewer industrial properties.
Low	A water feature passing through uncultivated agricultural land. A water feature with minimal hydrological importance to: i) sensitive or protected ecosystems; ii) economic and social uses; iii) with a low probability of flooding of residential and industrial properties.

Magnitude of Impact

1.10.4 The impact magnitude influenced by the timing, scale, size and duration of change to the baseline conditions, as well as likelihood of occurrence of the potential impact. For flood risk, this is assessed based on the increase in flood level during the design flood event.

Table A19.2-A2: Hydrology and flood risk magnitude of impact criteria

Sensitivity		Criteria
	Major Adverse	Increase in peak flood level 0.5% AEP (200-year) greater than 100 mm
	Moderate Adverse	Increase in peak flood level 0.5% AEP (200-year) 50 - 100 mm
	Minor Adverse	Increase in peak flood level 0.5% AEP (200-year) 10 - 50mm
	Negligible	Negligible change in peak flood level 0.5% AEP (200-year) less than +/- 10 mm
	Minor Beneficial	Reduction in peak flood level 0.5% AEP (200-year) 10 - 50mm
	Moderate Beneficial	Reduction in peak flood level 0.5% AEP (200-year) 50 - 100mm
	Major Beneficial	Reduction in peak flood level 0.5% AEP (200-year) greater than100mm

Impact Significance

1.10.5 The significance of impact is determined as a function of the sensitivity of the water feature and the magnitude of impact.

Table A19.2-A3: Hydrology and flood risk impact significance matrix

Magnitude / Sensitivity	Negligible	Minor	Moderate	Major
Very High	Neutral	Moderate/Large	Large/Very Large	Very Large
High	Neutral	Slight/Moderate	Moderate/Large	Large/Very Large
Medium	Neutral	Slight	Moderate	Large
Low	Neutral	Neutral	Slight	Slight /Moderate

1.10.6 Note that even though the resulting impact significance may not be considered significant in the context of the EIA Regulations mitigation may still be proposed to address any increase in water levels.

Annex B: Hydraulic Performance Assessment

Approach

1.10.7 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.

1.10.8 The methodology calculates the upstream headwater level (HWL) at 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; and
- culvert inlet/outlet and minor loss coefficients from CIRIA C689 guidelines

1.10.9 The results of the minor watercourse crossing hydraulic performance assessment for both the baseline and proposed scheme (no mitigation) scenarios are contained within a spreadsheet provided outside of this FRA report. The spreadsheet includes the crossing location, diameter, soffit level, invert level, upstream bank level and existing and proposed A9 level, peak flow during the 0.5% AEP (200-year) plus climate change event (the design flood event) and derived HWL. When compared, the data helps identify:

- free-flow or surcharged conditions;
- in-bank or out-of-bank flow;
- locations where the A9 is at risk of overtopping (HWL > A9 level – 600mm freeboard); and
- impacts of the proposed scheme.

Assumptions & Limitations

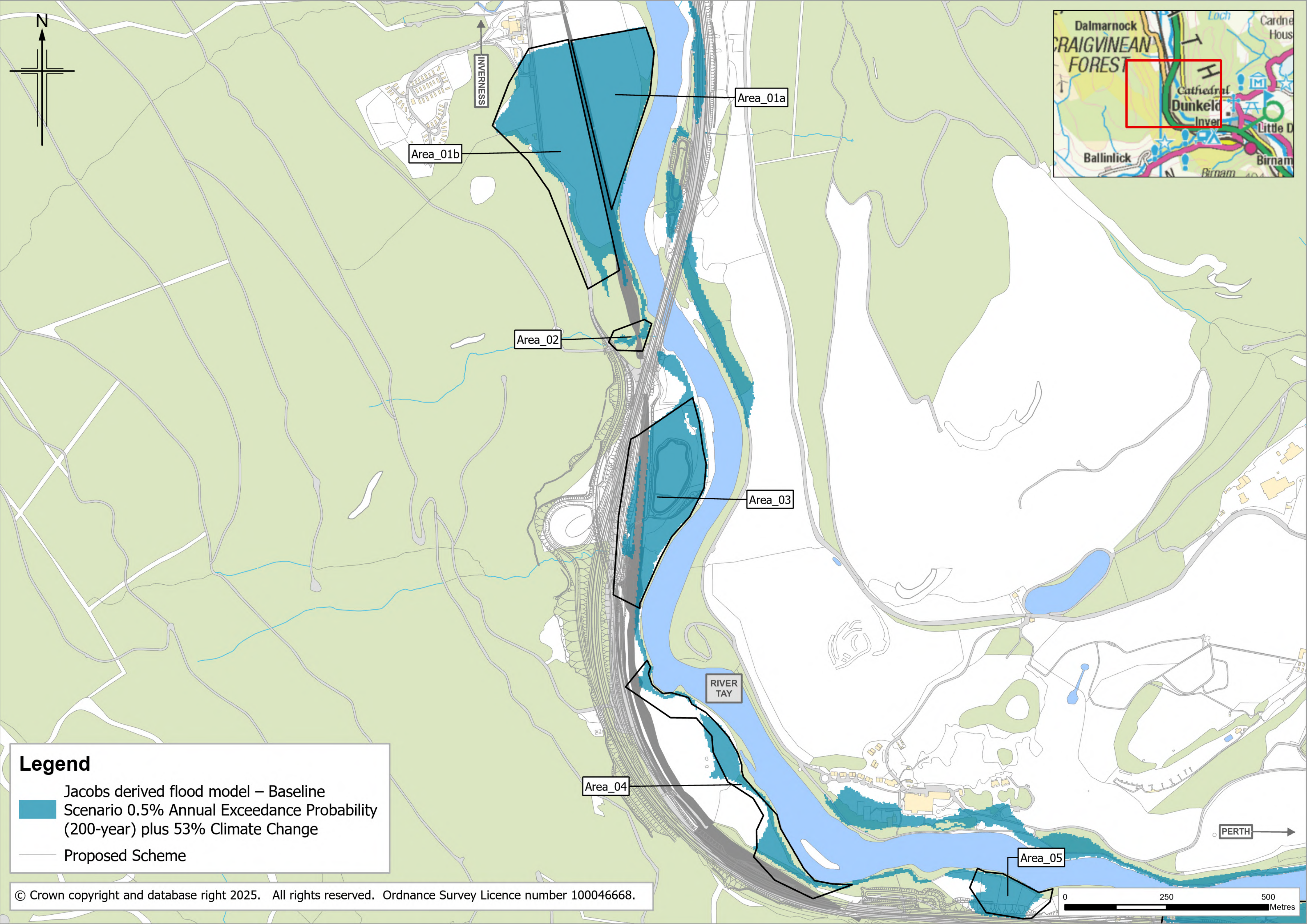
1.10.10 The preliminary assessment is based on the following assumptions:

- the methodology adopted to estimate HWLs is presented in CIRIA's Culvert Design and Operation Guide.
- both upstream and downstream channel cross-sections are identical based on a simplified trapezoidal representation of the observed geometry.
- all structures are considered free of debris, straight, in good operational order and culvert inlets and outlets are designed appropriately to minimise hydraulic head loss.
- the Manning's roughness coefficients for the culvert and channel section are based on available guidance in Chow, 1959.

- the assessment assumes that the tailwater level (TWL) immediately downstream of the culvert is determined by the downstream channel using ‘normal’ water depth calculated using Manning’s equation. The impact of any other downstream structure exerting a hydraulic control on the culvert has not been considered; and
- where the predicted HWL exceeds the channel level or structure diameter/height, in particular for small diameter culverts, the predicted HWL is likely to be conservative estimate as the upstream channel cross sectional area is confined to the channel width. No account is taken regarding the shape of the design hydrograph and consequently the flood volume, or the attenuation afforded by flood storage on adjacent floodplain or overtopping of the carriageway. These assumptions make the preliminary assessment a conservative estimate of water levels.

Annex C: Flood Risk Assessment Figures

- Figure A19.2-C.1: Fluvial Flood Depth Map Baseline Scenario
- Figure A19.2-C.2: Fluvial Flood Depth Impact Map with Scheme (with Mitigation) Run 1
- Figure A19.2-C.3: Fluvial Flood Depth Impact Map with Scheme (with Mitigation) Run 2



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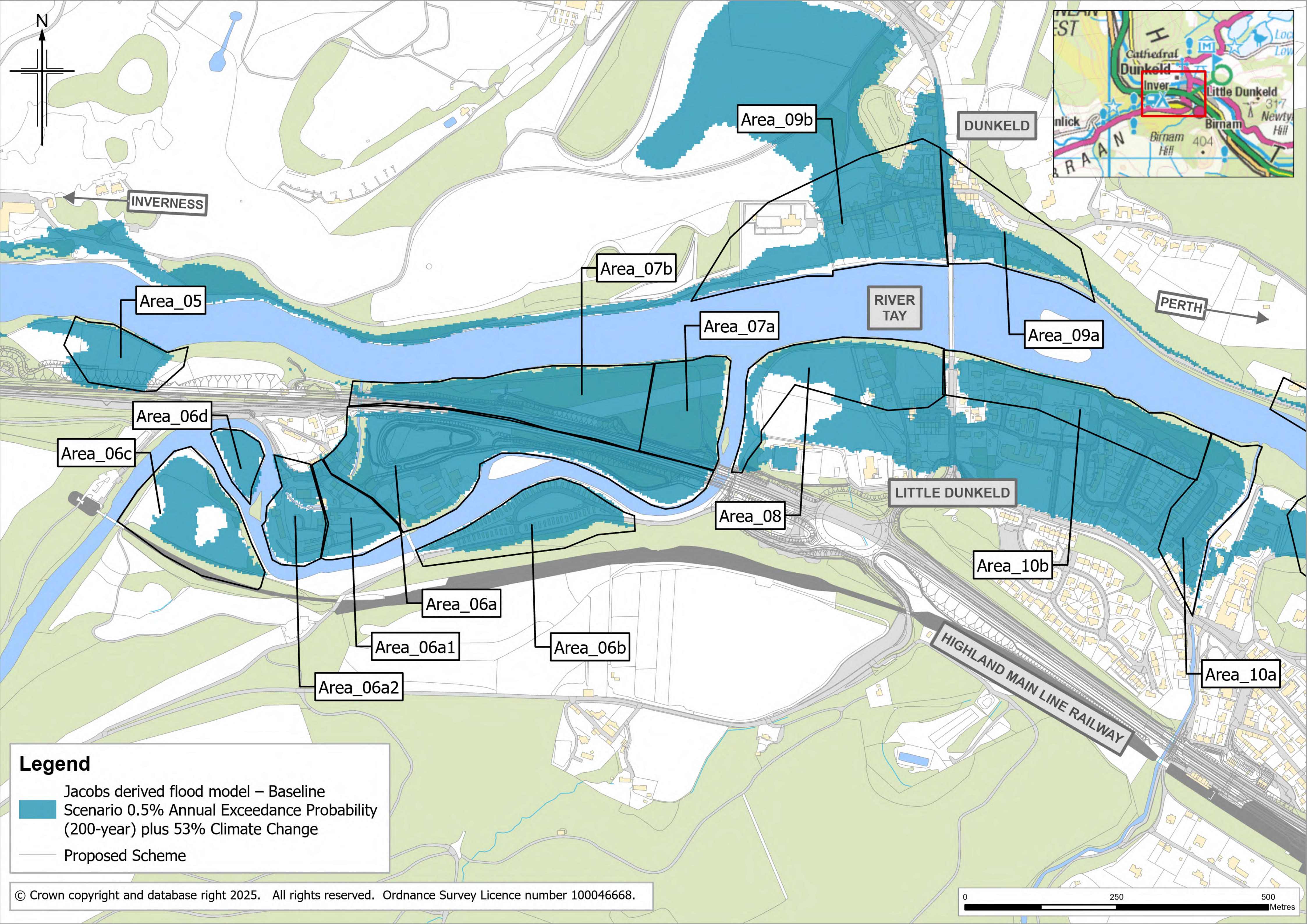

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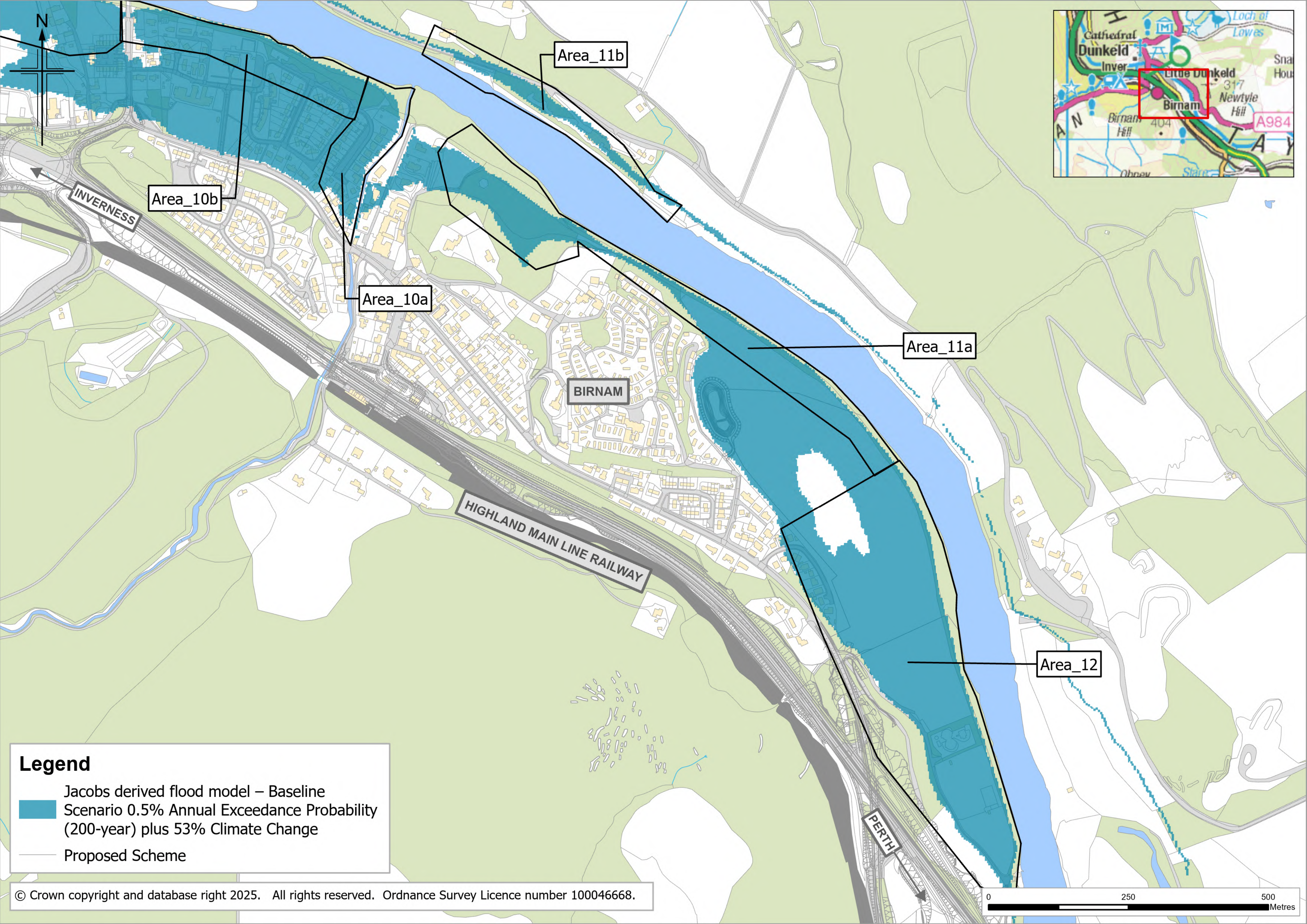
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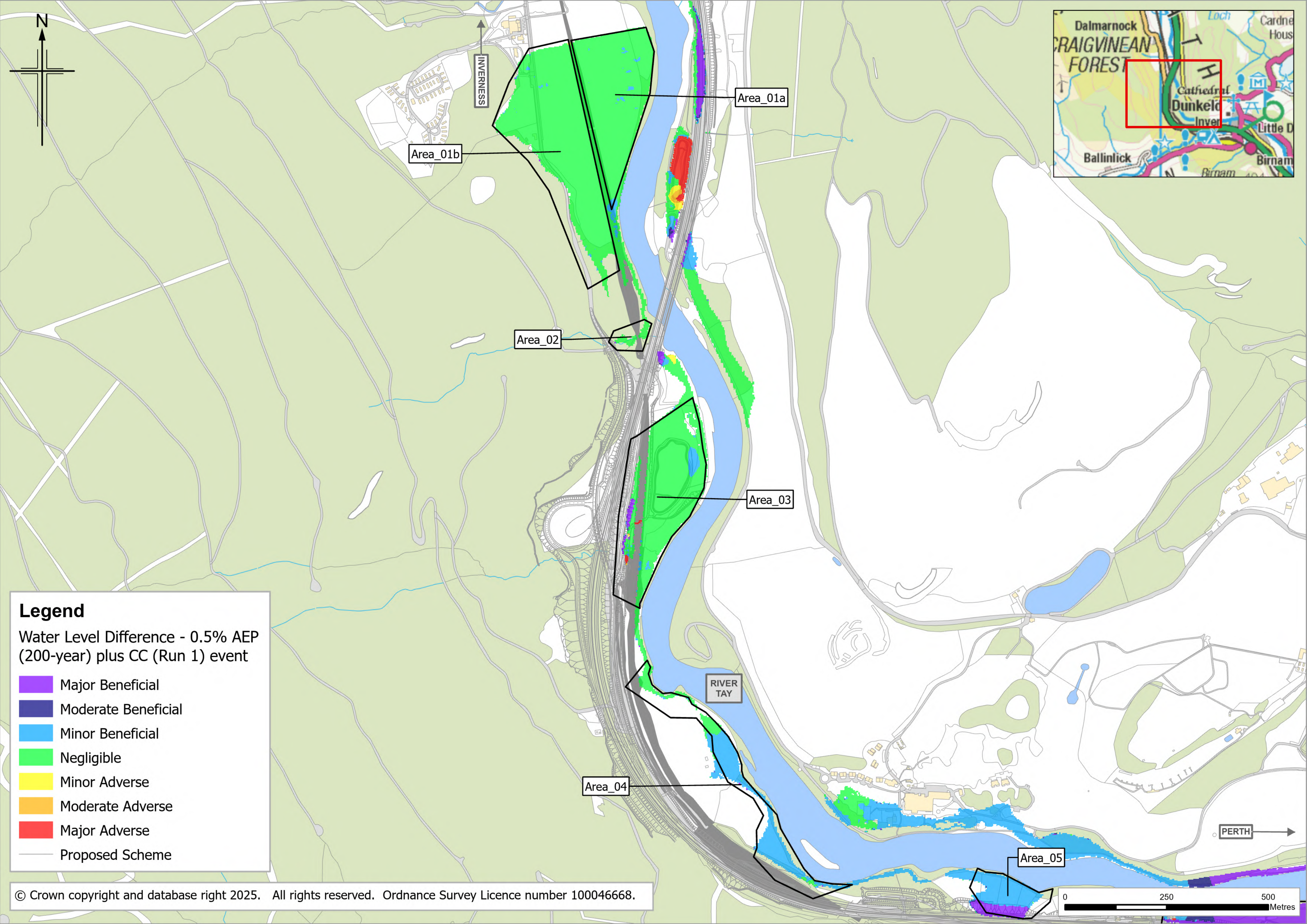

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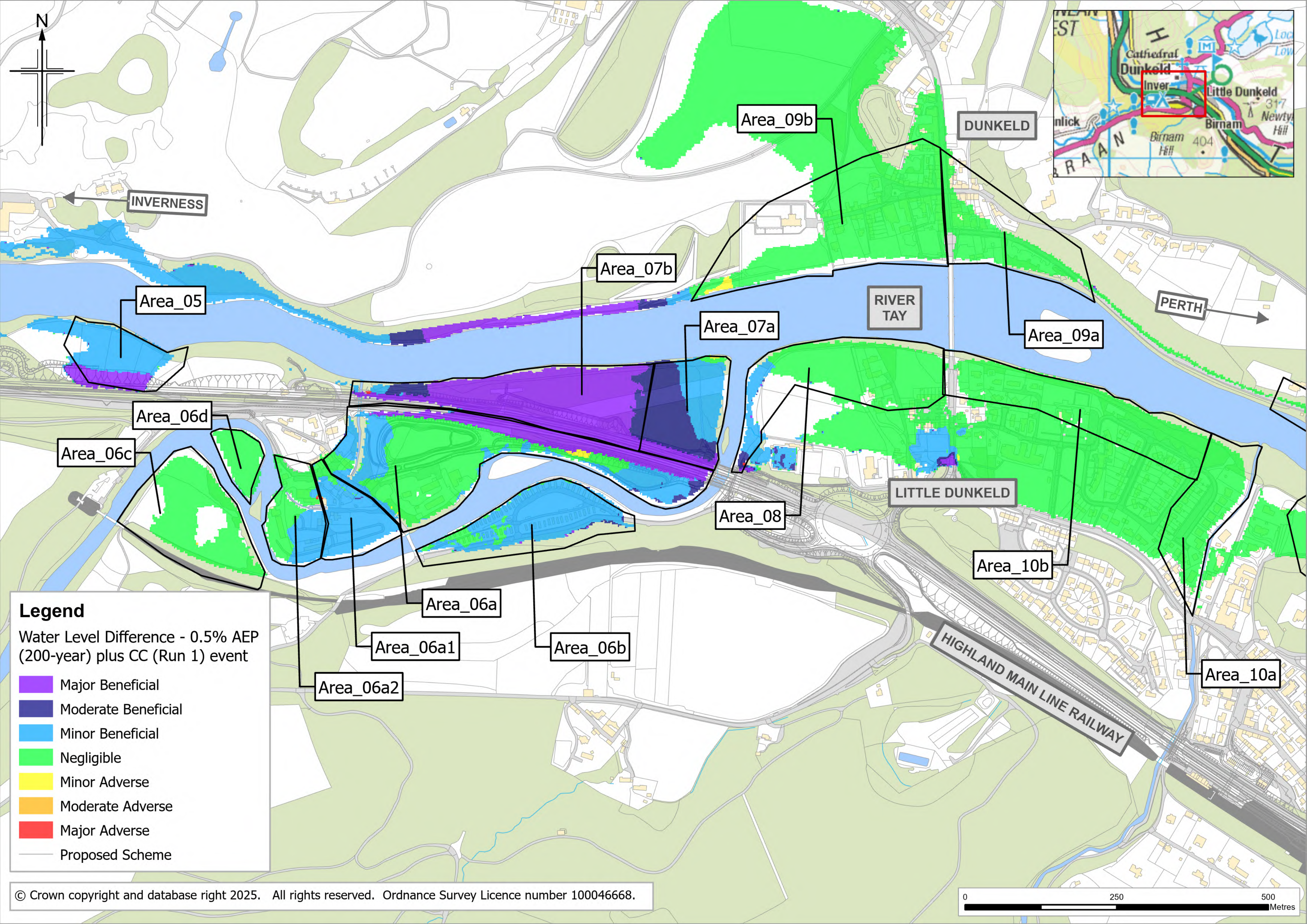
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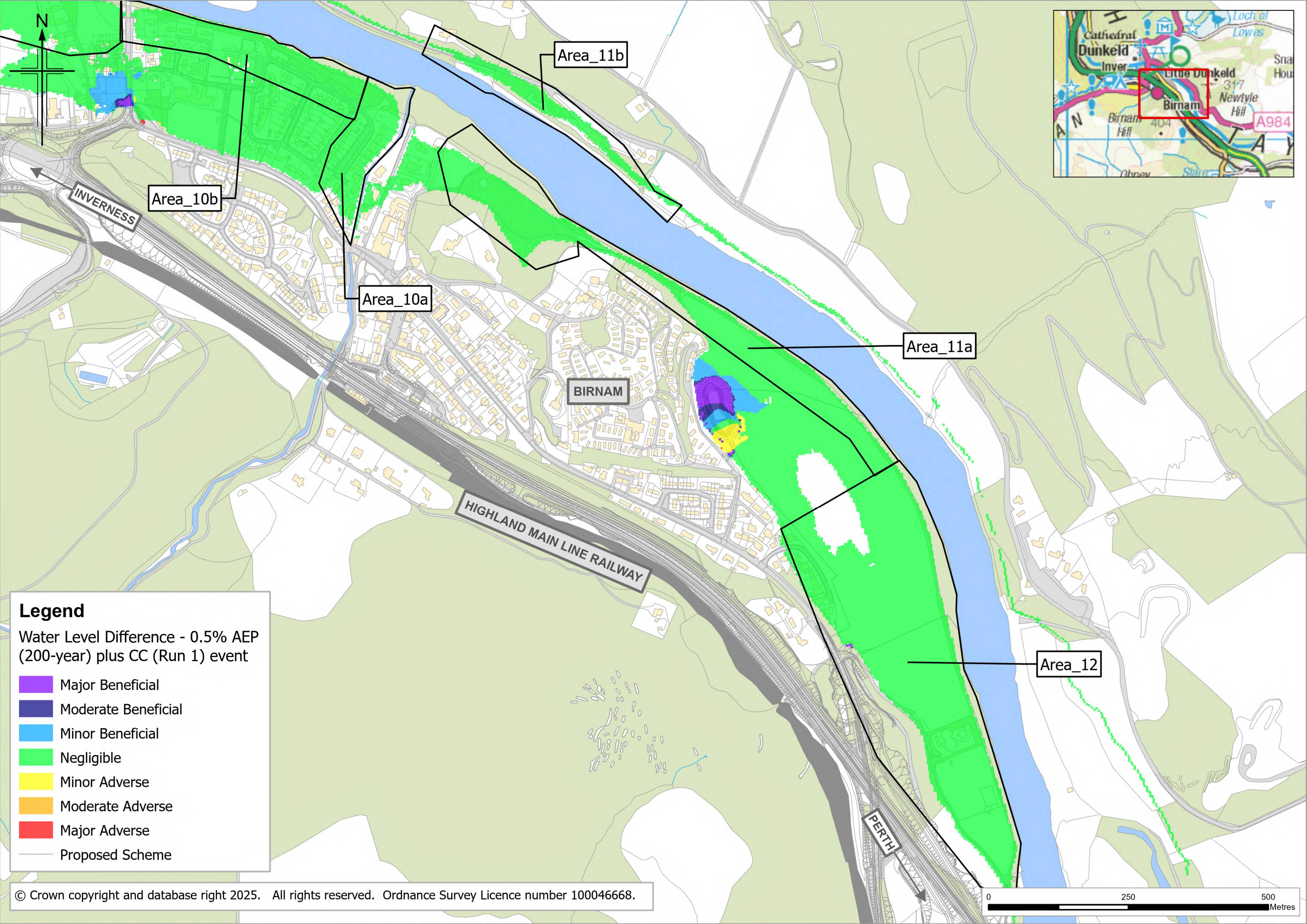

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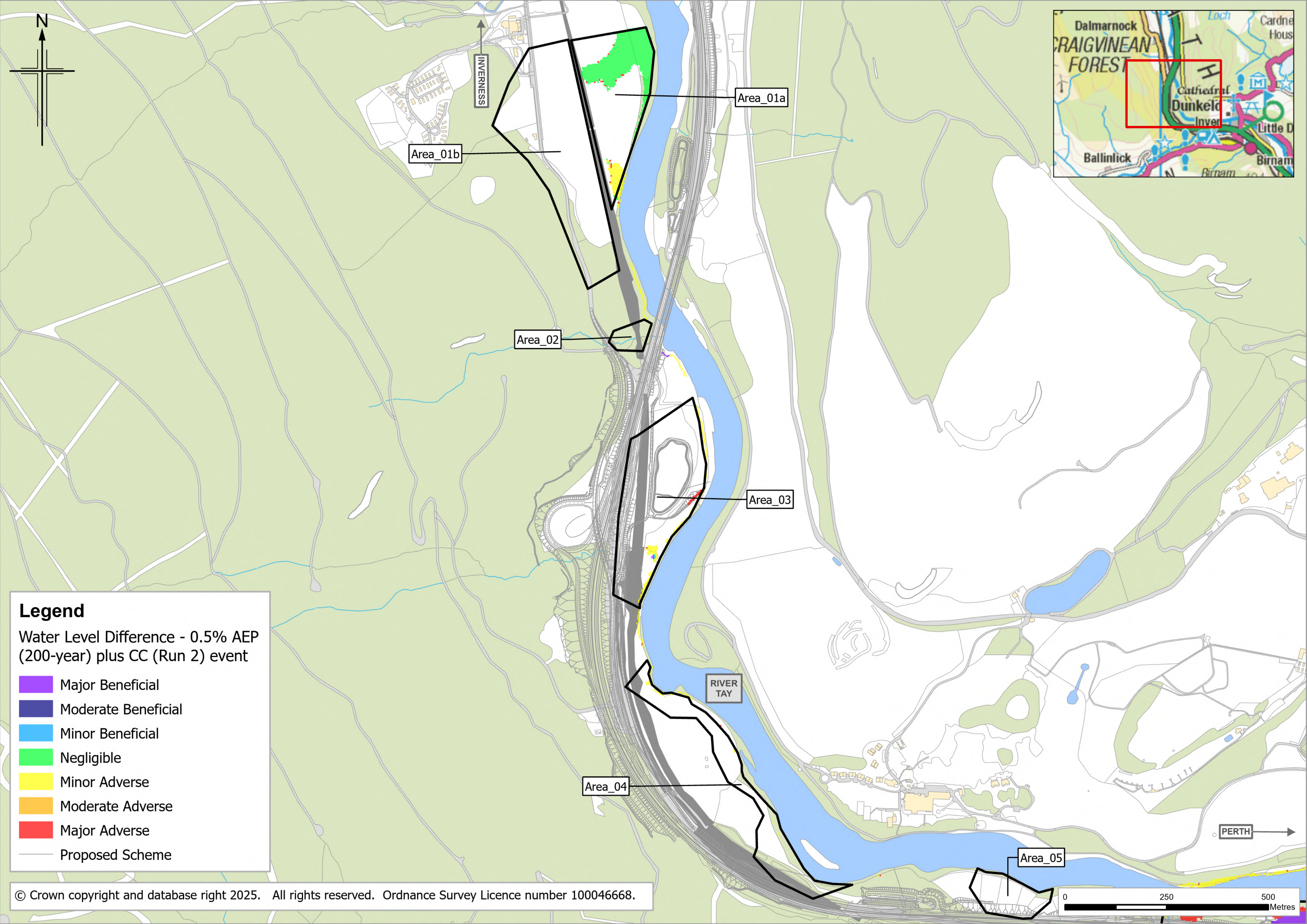

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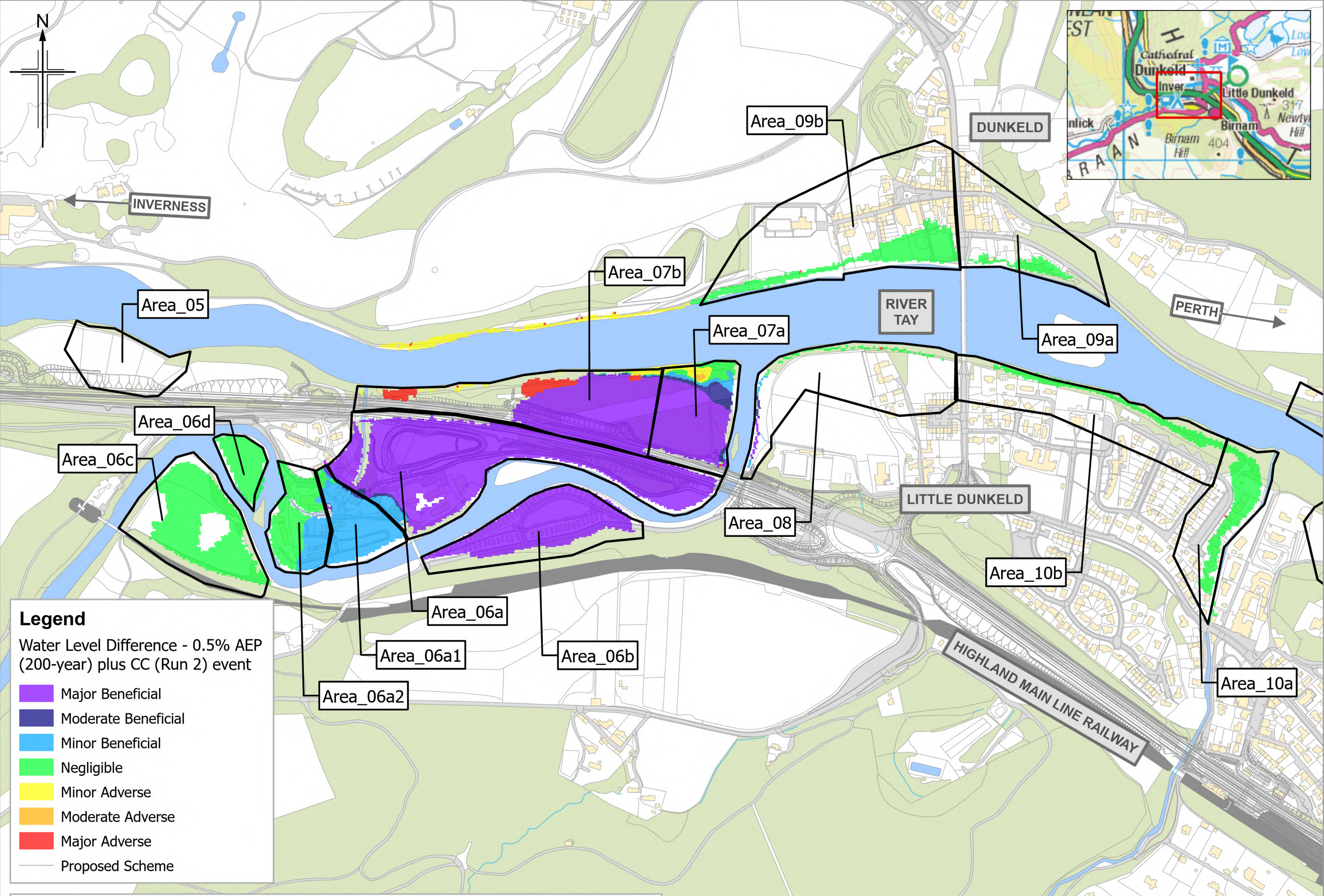
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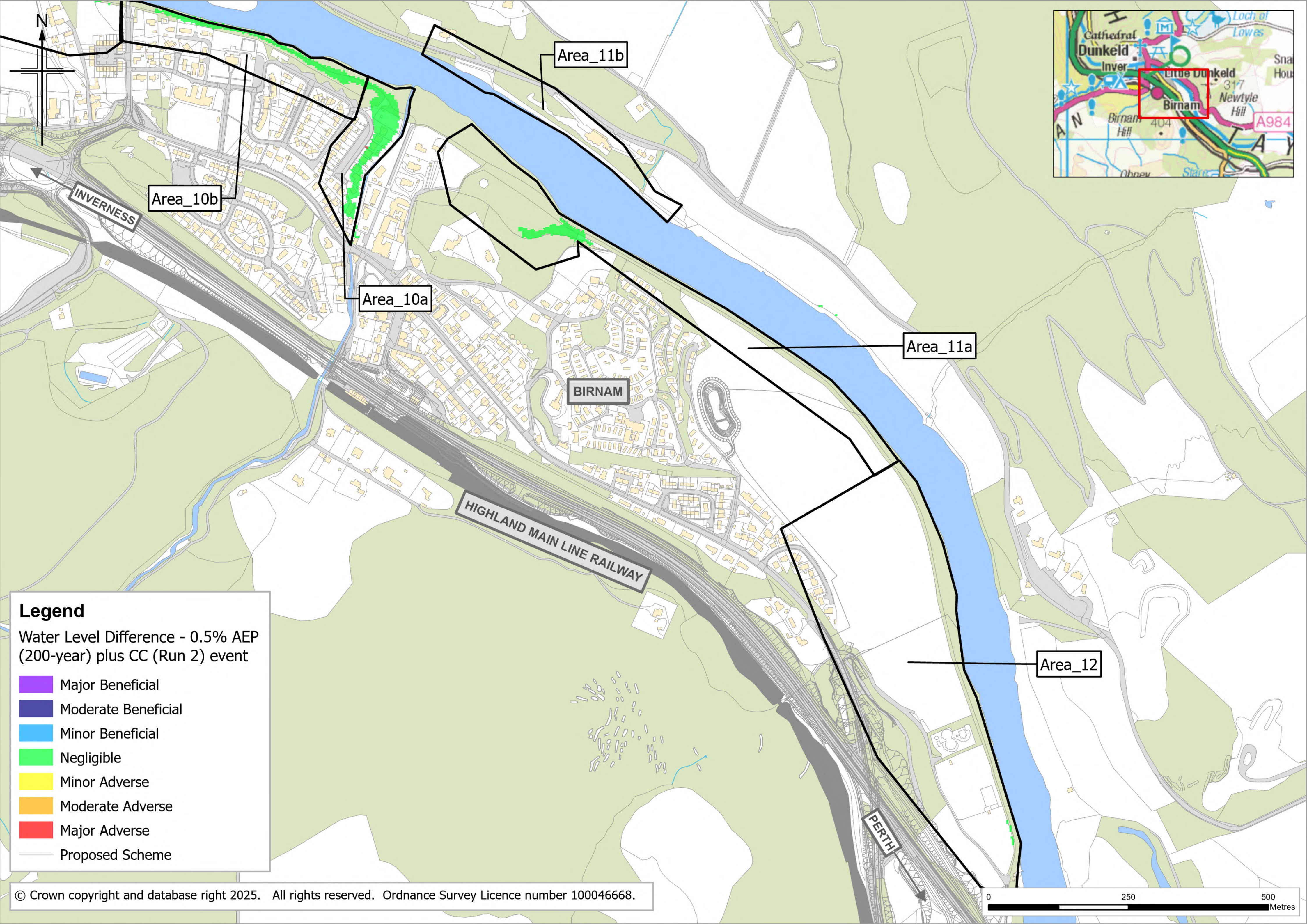

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Annex D: Surface Water Hydrology

Annex D: Surface Water Hydrology

Introduction

1.1.1 This Annex provides detailed information on the hydrological analyses relevant to Appendix A19.2 (Flood Risk Assessment) for the Pass of Birnam to Tay Crossing section of the A9 Dualling Programme.

1.1.2 Consultation comments provided by SEPA, following submission of the Pass of Birnam to Tay Crossing DMRB Stage 2 Flood Risk Assessment (FRA), have been acknowledged and the adopted peak flood flow estimates revised. These estimates underpin hydraulic modelling, watercourse crossing design and flood risk assessment of the proposed scheme. An update to the River Braan peak flood flow estimates was also undertaken in February 2025 following SEPA feedback received after a project meeting on 21st January 2025.

1.1.3 The proposed scheme (Pass of Birnam to Tay Crossing section) crosses both large, gauged rivers (such as the River Tay and the River Braan) and small ungauged watercourses, some with catchment areas <0.5km^2. The impacts of the proposed scheme on the large watercourses are assessed using one numerical hydraulic model (Model II) for the River Tay and its tributaries, the River Braan (WC11) and the Inchewan Burn (WC8). The impact of the proposed scheme on the small ungauged watercourses are assessed either through analyses by Jacobs using the in-house spreadsheet or by developing individual watercourse numerical hydraulic model. This annex reviews the design peak flow estimates for both the larger modelled watercourses (River Tay, River Braan and Inchewan Burn) and the small ungauged watercourses.

Requirements for flood estimates

1.1.4 A total of 20 catchments have been identified as having the potential to be impacted by the proposed scheme. These watercourses range in size from small drainage ditches to large watercourses such as the River Tay and the River Braan.

1.1.5 Peak flood flow estimates are required for all watercourse crossing locations for the following annual exceedance probability (AEP)[1] 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).

1.1.6 Whilst not required for the purpose of flood risk assessment, low flow statistics such as the Q95 and Qmean flow are also required at all road drainage outfall locations to assess the potential impacts of the proposed outfalls on the receiving watercourses.

1.1.7 The location of catchments with the potential to be affected by the proposed scheme are shown on Figure A19.2-D.1.

[1] Annual Exceedance Probability (AEP) refers to the chance that a flood of a particular size is experienced or exceeded during any year. The notation used in this report to describe for example the 0.5% AEP flood event, is ‘0.5%AEP (200-year)’.

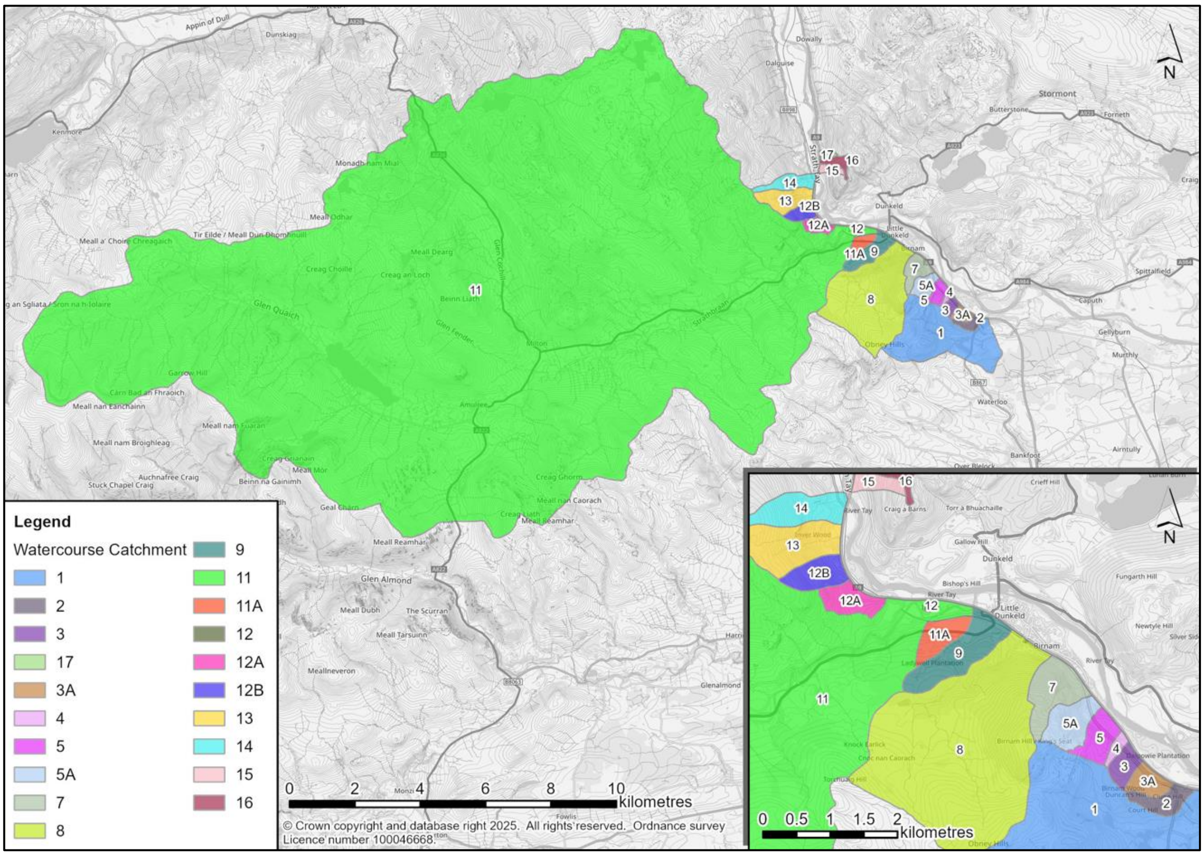


Figure A19.2-D.1 - Catchment boundary maps for the tributaries of the River Tay

Previous Studies

1.1.8 Following consultation comments provided by SEPA on the DMRB Stage 2 Flood Risk Assessment (FRA) and following further comments received from SEPA regarding the River Braan on 21st January 2025, peak flood flow estimates have been revised. Peak flood flow estimates presented herein, supersede those reported in:

- A9 Dualling – Pass of Birnam to Tay Crossing DMRB Stage 2 Assessment Flood Risk Assessment (Transport Scotland, 2023).

Approach and Methodology

Regional Hydrological Considerations

1.1.9 The A9 forming the focus of this work runs through the southern portion of the Grampian Mountains. Hills and mountains formed from relatively impermeable geology form the landscape surrounding the road's corridor and have a dominating influence on the hydrological characteristics of the streams and rivers. The steepness of the land coupled with the lack of permeability tends to promote fast responding watercourses.

1.1.10 Orographic uplift of the rainfall is less than further west however the presence of snow within the catchments during the winter is of significance particularly snowmelt contribution to flood flows, an example of which would be the extreme January 1993 flood within the Tay Basin. However, the role of snow is more complicated than this since precipitation falling above the snowline\freezing line will be stored rather than contribute to storm event flood flows within the watercourses. 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 this upland region.

1.1.11 There is also notable attenuation and diversion of flows within a number of catchments in the area as a result of the development of hydropower (most notably the Tummel Valley hydropower scheme) and due to the numerous lochs/reservoirs (some of which are involved in the holding of water as part of the hydropower schemes). These aspects can influence the downstream flow regime, including both floods and low flows.

Catchment Delineation

1.1.12 Catchment descriptors for all watercourses potentially impacted by the proposed scheme were obtained through the Flood Estimation Handbook (FEH) Web Service Portal[2] or the National River Flow Archive (NRFA)[3] where available. The FEH catchment boundaries were checked against Ordnance Survey (OS) mapping and where required via site investigation.

1.1.13 Due to the minimum area of 0.5km² imposed by the FEH, catchments with contributing areas <0.5km² are not available through the FEH Web Service. Where this is the case, catchment descriptors have been 'borrowed' (and adjusted where appropriate) from either an adjacent/donor catchment, considered to share similar hydrological features, or by extending the selection point further downstream to obtain the nearest catchment from within the FEH catchment dataset.

1.1.14 For this assessment all small ungauged watercourses in the scheme were divided into five groups based on the availability of FEH CDs and perceived similarity of catchments to the five donor watercourses, as was undertaken for the previous Stage 2 DMRB assessment. The FEH CDs for all other minor watercourse with catchment area <0.5km^2 were derived from the corresponding hydrologically similar neighbouring donor catchment(s). The five donor watercourses are as follows:

- Donor 1 (WC1) Birnam Burn (305650 739450) adopted for WC1 – Birnam Burn only.
- Donor 2 (WC7) (303950 741650) – used as a donor for WC7 and WC9 (both with area >0.5km^2), as well as for WC2, WC3, WC4, WC5 and WC12 (all with area <0.5km^2).
- Donor 3 (WC13) Inver Wood Burn (300300 743200) – used for WC13 (area >0.5km^2), WC12A and WC12B (both with areas <0.5km^2).
- Donor 4 (WC14) (300400 743750) - used for WC14 only (area >0.5km^2)

[2] FEH Web Service Portal. Accessed at: https://fehweb.ceh.ac.uk
[3] National River Flow Archive. Accessed at: https://nrfa.ceh.ac.uk/data

- Donor 5 (302300 743250) – used for WC15, WC16 and WC17 (all three with area <0.5km^2).

1.1.15 Where donor catchments have been used catchment descriptors have been borrowed (and areally adjusted where appropriate). Standard FEH methodologies were used for specific parameters that can't be scaled based upon areal adjustment alone (e.g. DPLBAR, URBEXT and FARL).

Subject Site Catchment Descriptors – Small Ungauged watercourses

1.1.16 Catchment descriptors, including any amendments, are presented in Table A19.2-D.1 for the small ungauged watercourses potentially impacted by the proposed scheme.

Table A19.2-D.1: FEH Catchment Descriptors as used in assessment

Watercourse	Grid Reference	AREA(km^2)*	FARL	SAAR 1961-1990 (mm)	BFIHOST19	SPRHOST (%)	URBEXT 1990 (updated to 2024)***	URBEXT $_{2000}$ (updated to 2024)***
1 - Birnam Burn	305693, 739462	4.378	0.804	944	0.609	29.65	0.000	0.000
2 - Birnam Burn Tributary	305454, 739520	0.245	1.000	951	0.661	30.77	0.000	0.000
3A- Unnamed	305125, 739625	0.212	1.000	951	0.661	30.77	0.000	0.000
3 - Unnamed	304620, 740098	0.195	1.000	951	0.661	30.77	0.000	0.000
4 - Unnamed	304529, 740242	0.074	1.000	951	0.661	30.77	0.005	0.007
5 - Unnamed	304341, 740550	0.319	1.000	951	0.661	30.77	0.000	0.000
5-A - Unnamed	304143, 740783	0.432	1.000	951	0.661	30.77	0.000	0.000
7 - Unnamed	303910, 741083	0.588	1.000	951	0.661	30.77	0.000	0.000
9 - Unnamed	302529, 742085	0.755	1.000	951	0.661	30.77	0.002	0.002
11A – Braan Tributary**	302127, 742026	0.314	1.000	951	0.661	30.77	0.000	0.000
12 - Mill Stream	301702, 742282	0.024	1.000	951	0.661	30.77	0.028	0.036
12A - Unnamed	300768, 742354	0.327	1.000	1065	0.495	31.05	0.000	0.000
12B - Unnamed	300328, 742858	0.364	1.000	1065	0.495	31.05	0.000	0.000

Watercourse	Grid Reference	AREA(km^2)*	FARL	SAAR 1961-1990 (mm)	BFIHOST19	SPRHOST (%)	URBEXT 1990 (updated to 2024)***	URBEXT $_{2000}$ (updated to 2024)***
13 - Unnamed	300325, 743218	0.967	1.000	1065	0.495	31.05	0.000	0.000
14 - Unnamed	300425, 743747	0.643	1.000	1047	0.570	28.63	0.000	0.000
15 - Unnamed	300524, 744108	0.176	1.000	975	0.539	33.70	0.000	0.000
16 - Unnamed	300565, 744247	0.290	1.000	975	0.539	33.70	0.000	0.000
17 - Unnamed	300556, 744343	0.107	1.000	975	0.539	33.70	0.000	0.000

* The catchment areas for the previous Jacobs (2018) assessment have been adopted.
** WC11-A, a minor tributary of the Braan, does not cross the existing/proposed A9 route alignment but only the side road.
*** URBEXT has not been updated for WC4/WC9/WC12 as it was calculated using mapping data for previous Jacobs 2018 assessment.

Subject Site Catchment Descriptors – Large modelled watercourses

1.1.17 The impact of the proposed scheme (A9 Birnam to Tay Crossing is assessed using one hydraulic model (Model II) for the River Tay and its tributaries the River Braan (WC11) and Inchewan Burn (WC8). The model requires design peak flow estimates at various locations as described below and as shown in Figure A19.2-D.2:

- River Tay u/s extent of Model II
- River Tay d/s extent of Model II
- River Braan inflow location to model
- Inchewan Burn inflow location to model

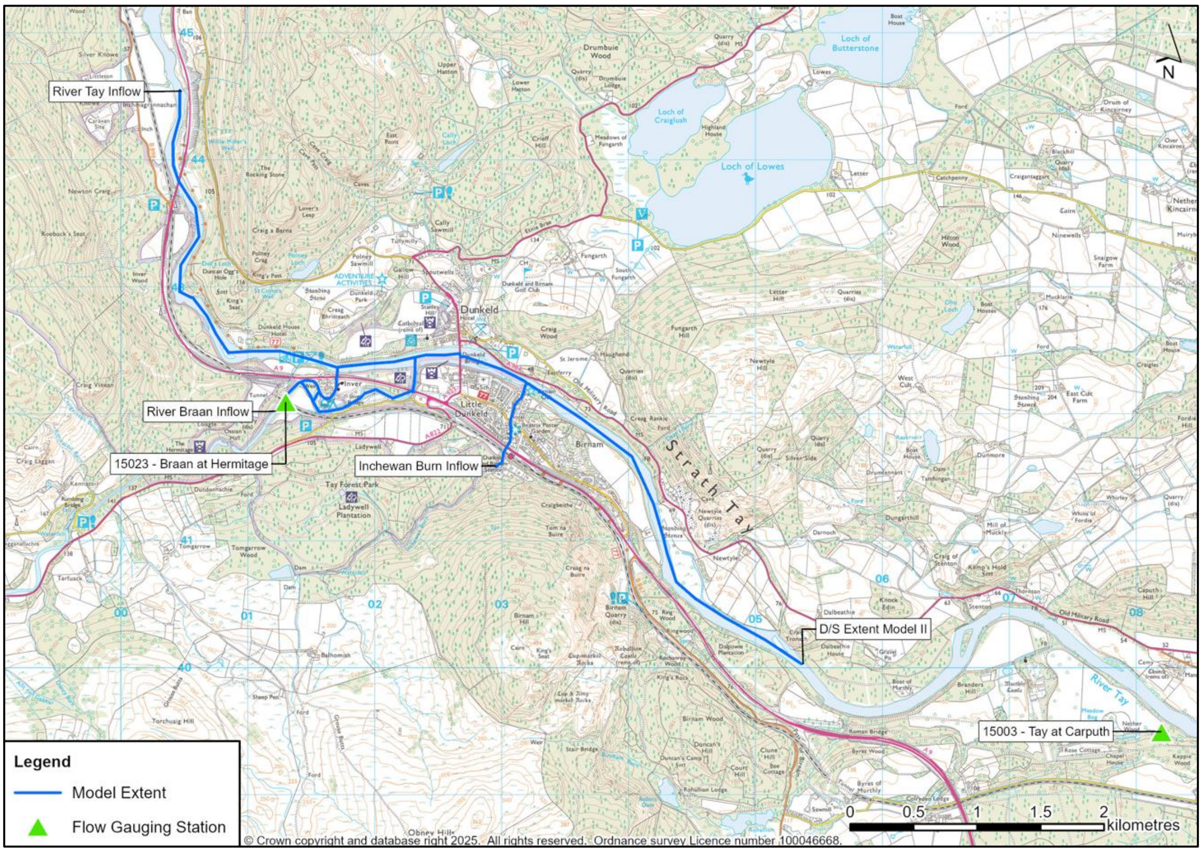


Figure A19.2-D.2 – Model extent together with flow estimation locations

1.1.18 For the large modelled watercourses the FEH CDs were extracted from the NRFA dataset for the gauged catchment (River Tay @ Caputh and the River Braan @ Hermitage). The FEH Web Service was alternatively used to derive FEH CDs for the ungauged Inchewan Burn. The FEH CDs for the large / modelled watercourses are presented in Table A19.2-D.2.

Table A19.2-D.2 - FEH CDs Large / Modelled Watercourses

Watercourse	Grid Reference	Catchment Area (km^2)	SAAR 1961-1990 (mm)	BFIHOST19	SPRHOST (%)	FARL	URBEXT 2000 (updated to 2024)
River Tay @ Caputh	308289 739575	3211	1609	0.41	45.36	0.807	0.0007
River Tay @ Model II inflow	302200 742400	2982*	1609**	0.41**	45.36**	0.807**	0.0007**
River Tay @ Model II d/s extent	305350 740000	3199*	1609**	0.41**	45.36**	0.807**	0.0007**
River Braan @	301320	211	1326	0.429	39.88	0.929	0.0001

Hermitage (WC11)	742158						
Inchewan Burn (WC8)	303150 742200	5.8	993	0.49	32.87	0.985	0.0078

* Area adopted from previous assessment
**River Tay @ Caputh FEH CDs adopted.

Source of Flood Peak Data

1.1.19 The hydrological analyses reported here adopted the most up to date flow data at the time of assessment (summer 2024) from the National River Flow Archive (NRFA), SEPA Time series data service (API)[4] where available and any information on recent flood events suggested by SEPA. The latest versions of WINFAP (Version 5) and the NRFA Peak Flow dataset (Version 12.1 released 2nd November 2023), that includes flow data up to water year 2021/22, have been adopted. For the River Braan 2025 update SEPA provided an extended AMAX sequence for the River Brann at Hermitage from water year (WY) 1981 to 2023 (for further details refer to Annex D.1).

Initial Choice of Approach

1.1.20 As notes previously the majority of watercourses within the study area drain small, ungauged catchments. Flow estimation for small[5], ungauged catchments is open to greater uncertainty than for larger catchments, where gauged data is likely to be available to aid design flow estimates. Where flow data is available it has been used to refine the hydrological assessment.

Small Ungauged Catchments

1.1.21 At the onset of the previous study, the ReFH2 rainfall-runoff method was not widely adopted for use in Scottish catchments. Therefore, the peak flood flow estimates for the small ungauged catchments were derived using two methods only, the FEH Statistical method and the FEH Rainfall–Runoff method (with FEH99 rainfall). The larger of the two estimates (generally from FEH rainfall-runoff method) was adopted as the design peak flood flow estimate. A sensitivity analysis was undertaken using the ReFH2 method towards the end of the previous study as it was becoming more widely adopted. ReFH2 was applied to a representative small ungauged watercourse in the scheme. This analysis showed that ReFH2 produced the smallest peak flow estimate among the three methods.

1.1.22 The DMRB Stage 3 hydrology presented herein, compares peak flood flow estimates derived using all three methods, the FEH Statistical, the FEH Rainfall-Runoff and the ReFH2.3 methods. Other notable changes in the hydrology are as follows:

[4] SEPA Time series data service (API) https://timeseriesdoc.sepa.org.uk/api-documentation/api-function-reference/#WalkThrough
[5] Catchments with areas <25km^2 are considered to be small catchments in this discussion.

- The previous study used a global QMED adjustment factor of 1.24 for all small ungauged watercourses, derived from the peak flow rated gauges within Hydrometric Area 15. However, this DMRB Stage 3 analysis derived QMED adjustment factors, for all five donor catchments, using a single, local donor gauge (River Braan), as recommended by the small catchment flood estimation guidelines (2024)[6].
- The growth curves for the small ungauged watercourses have been derived for the selected two donor watercourses (WC1 / WC13) using the methodology available within WinFAPv5 for small ungauged catchments and using the Peak Flow dataset version 12.1.
- The 0.1% AEP (1,000-year return period) FEH Statistical peak flow estimate has been derived using a hybrid method, in which the FEH Statistical 0.5% AEP (200-year return period) peak flow estimate is multiplied by the ratio of ReFH2.3 0.1% AEP and 0.5% AEP peak flow estimates.
- The FEH Rainfall-Runoff peak flood flow estimates are derived using default catchment descriptors and adopting FEH22 rainfall (as a sensitivity check).
- The ReFH2.3 peak flow estimates are derived for a rural catchment (using FEH22 rainfall), as suggested by the Environment Agency (2024) research ‘Estimating flood peaks and hydrographs for small catchments’.

1.1.23 The peak flow estimates for all small ungauged watercourses with catchment area >0.5km^2 were derived using the above three methods and compared with the peak flow estimates from the previous DMRB Stage 2 assessment (2018). The peak flow estimates for all watercourses with a catchment area <0.5km^2 were derived using areal scaling of peak flow estimates of the corresponding donor catchment, from the adopted method.

Large Gauged Catchments

1.1.24 The proposed scheme crosses two large gauged watercourses, namely the River Tay, and the River Braan.

1.1.25 The River Tay is gauged at Caputh (Station 15003) and the River Braan at Hermitage (Station 15023). Both stations are classified by the NRFA as being suitable for QMED and Pooling Group analysis. Hence, QMED and flood growth curves have been estimated using the gauged AMAX record for the River Tay at Caputh and for the River Braan at Hermitage and the estimates transferred to the location(s) of the flood estimation points i.e., the model inflow locations.

FEH Statistical Peak Flow Estimates – Small Ungauged Watercourses

1.1.26 The majority of the small ungauged watercourses have catchment areas less than 0.5km^2 and as such QMED has been estimated for six watercourses within the scheme area with catchment area >0.5km^2.

[6] Environment Agency, Department for Environment Food & Rural Affairs, Natural resources Wales, Welsh Government (2024). Estimating flood peaks and hydrographs for small catchments, March 2024.

1.1.27 The estimate of QMED for the six catchments was initially derived from FEH CDs and adjusted using the River Braan at Hermitage as a donor catchment. An overview of the QMED adjustment process for each of the six watercourses with a catchment area greater than $0.5km^2$ is presented in Table A19.2-D.3.

Table A19.2-D.3: QMED estimates for watercourses with catchment area >$0.5km^2$.

Watercourse (WC)	Area (km^2)	$QMED_{CD}$ (m^3/s)	QMED adjustment factor	$QMED_{RURAL}$ Adjusted (m^3/s)	UAF	$QMED_{URBAN}$ Adjusted (m^3/s)	QMEDadj rural/Area ($m^3/s/km^2$)
WC1 (Donor 1)	4.378	0.604	1.150	0.695	1.000	0.695	0.159
WC7 (Donor 2*)	0.588	0.192	1.154	0.222	1.000	0.222	0.377
WC9 (Donor 2*)	0.755	0.237	1.154	0.274	1.004	0.275	0.363
WC13 (Donor 3)	0.967	0.654	1.169	0.764	1.000	0.764	0.790
WC14 (Donor 4)	0.643	0.350	1.167	0.409	1.000	0.409	0.636
Donor 5	0.503	0.277	1.158	0.320	1.000	0.320	0.638

*Donor 2 (WC7) is also used as a donor for WC9 to derive key FEH CDs.
**Donor 5 is used as a donor for WC15, WC16 and WC17 which all have an area less than $0.5km^2$.

1.1.28 The QMED estimates for all minor watercourses i.e., those with a catchment area <$0.5km^2$, were derived by scaling of the QMED estimates of the corresponding donor catchment by the ratio of catchment areas.

1.1.29 Two sets of growth curves, one for WC1 (with FARL = 0.804) and the other for WC13 (which was used for all other small ungauged watercourse as FARL = 1), were derived using the small catchment methodology included in WinFAPv5 and using version 12.1 of the NRFA peak flow dataset. The resulting growth curves are presented in Table A19.2-D.4 and the final pooling groups adopted are presented in Annex D1.2, Table A19.2-D1.2.1 and D.1.2.2 respectively.

Table A19.2-D.4: Growth Curves for pooling group 1 (FARL = 0.804) and pooling group 2 (FARL = 1)

Pooling Group	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.3% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.1% AEP (1000-year)
Group 1 (WC1)	1.000	1.427	1.744	2.282	2.554	2.948	3.376	4.519

Group 2 (WC13)	1.000	1.372	1.667	2.230	2.550	3.060	3.677	5.664

1.1.30 It should be noted that the pooling group for Group 1 (WC1) does not include selection based on FARL. A sensitivity test was undertaken where sites were excluded from the pooling group based on FARL. This resulted in an approximate 10% reduction in design peak flow estimate for the 0.5% AEP (200-year return period) event, however, this also resulted in the exclusion of around 200 gauges with other similar catchment characteristics to the target site.

1.1.31 The resulting FEH Statistical peak flow estimates for the six ungauged watercourses with catchment area >0.5km^2 are presented Table A19.2-D.5.

Table A19.2-D.5: Peak flow estimates from FEH Statistical method (m^3/s)

Watercourse	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.3% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.1% AEP (1000-year)
1 (Donor 1)	0.695	0.991	1.211	1.585	1.774	2.048	2.345	3.139
7 (Donor 2)	0.222	0.304	0.370	0.494	0.565	0.678	0.815	1.256
9 (Donor 2)	0.275	0.377	0.459	0.613	0.701	0.842	1.011	1.558
13 (Donor 3)	0.764	1.048	1.273	1.704	1.948	2.338	2.809	4.327
14 (Donor 4)	0.409	0.561	0.682	0.912	1.043	1.252	1.504	2.317
Donor 5	0.320	0.440	0.534	0.715	0.817	0.981	1.178	1.815

* All watercourses use Group 2 growth curve excluding WC1 which has its own derived growth curve (Group 1).

FEH Rainfall Runoff (R-R) method peak flow estimates – small ungauged watercourses

1.1.32 Peak flow estimates for the six small ungauged watercourse with catchment area >0.5km^2 were also derived from FEH Rainfall-Runoff method using the FEH R-R tool available in Flood Modeller Pro software package. The default FEH99 design rainfall in the FEH R-R model was replaced by the corresponding design rainfall depths extracted from FEH22 DDF rainfall model (refer to Annex D1.3 Table A19.2-D1.3.1). The resulting peak flow estimates from the FEH R-R method derived using FEH22 rainfall data, for the ungauged watercourses with catchment area >0.5km^2 are presented in Table A19.2-D.6.

Table A19.2-D.6: Peak flow estimates derived using FEH Rainfall-Runoff method / FEH 22 rainfall data (m^3/s)

Watercourse	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.3% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.1% AEP (1000-year)
1 (Donor 1)	2.058	3.065	3.707	4.858	5.426	6.119	6.899	9.046
7 (Donor 2)	0.462	0.745	0.895	1.160	1.303	1.474	1.664	2.190
9 (Donor 2)	0.594	0.958	1.150	1.491	1.674	1.893	2.138	2.813
13 (Donor 3)	0.846	1.381	1.659	2.164	2.416	2.717	3.046	3.928
14 (Donor 4)	0.525	0.857	1.029	1.350	1.512	1.702	1.912	2.478
Donor 5	0.488	0.807	0.976	1.264	1.416	1.596	1.793	2.332

*It is noted that these peak flood estimates are very conservative.

ReFH2.3 peak flow – small ungauged watercourses

1.1.33 Peak flow estimates for the six small ungauged catchment with area >0.5km^2 were also derived using the ReFH2.3 model, which incorporates FEH22 rainfall data, and the results are presented in Table A19.2-D.7.

Table A19.2-D.7: Peak flow estimates derived using ReFH2.3 method / FEH 22 rainfall data (m^3/s)

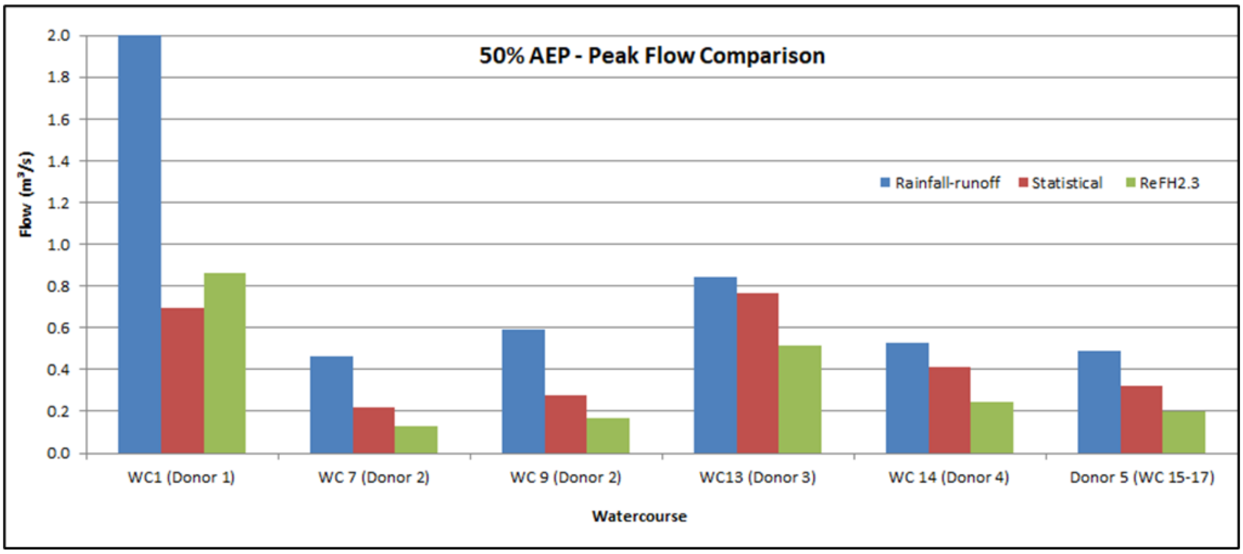
Watercourse	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.3% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.1% AEP (1000-year)
1 (Donor 1)	0.861	1.194	1.446	1.884	2.112	2.452	2.836	3.909
7 (Donor 2)	0.130	0.188	0.233	0.309	0.349	0.406	0.471	0.650
9 (Donor 2)	0.165	0.240	0.297	0.394	0.444	0.517	0.600	0.827
13 (Donor 3)	0.514	0.750	0.924	1.211	1.355	1.558	1.781	2.354
14 (Donor 4)	0.242	0.355	0.439	0.580	0.651	0.753	0.864	1.158
Donor 5	0.198	0.292	0.363	0.480	0.539	0.625	0.717	0.965

Comparison of peak flow estimates from FEH Statistical, FEH R-R and ReFH2.3 methods

1.1.34 Design peak flood flow estimates for the six small ungauged watercourses with catchment area >0.5km^2, derived using the FEH Statistical, FEH R-R and ReFH2.3 methods, for the 50% and 0.5% AEP (2-year and 200-year return period) events are compared in Table A19.2-D.8 and Figure A19.2-D.3.

Table A19.2-D.8: Comparison of Peak flow Estimates (m^3/s)

Watercourse (WC)	FEH Statistical		FEH Rainfall Runoff		ReFH2.3	
	50% AEP (2-year)	0.5% AEP (200-year)	50% AEP (2-year)	0.5% AEP (200-year)	50% AEP (2-year)	0.5% AEP (200-year)
1 (Donor 1)	0.695	2.345	2.058	6.899	0.861	2.836
7 (Donor 2)	0.222	0.815	0.462	1.664	0.130	0.471
9 (Donor 2)	0.275	1.011	0.594	2.138	0.165	0.600
13 (Donor 3)	0.764	2.809	0.846	3.046	0.514	1.781
14 (Donor 4)	0.409	1.504	0.525	1.912	0.242	0.864
Donor 5	0.320	1.178	0.488	1.793	0.198	0.717



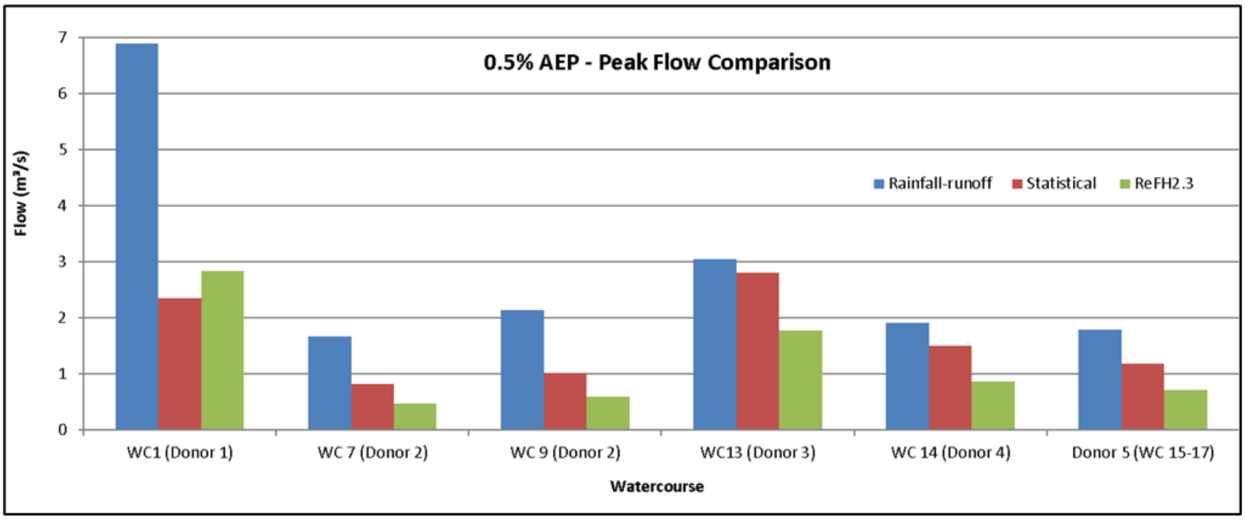


Figure A19.2-D.3: Comparison of peak flow estimates for the 50% AEP and 0.5% AEP events

*Donor 2 (WC7) is also used as a donor for WC9 to derive key FEH CDs.

1.1.35 It is shown by Table A19.2-D.8 and Figure A19.2-D.3 that the FEH Rainfall-Runoff method using the FEH22 rainfall data produces the largest peak flow estimates for all watercourses with an area >0.5km^2, whereas the ReFH2.3 method which also uses FEH22 rainfall produces the lowest peak flow estimates on average. The FEH Statistical method produced peak flow estimates higher than those from the ReFH2.3 method but lower than those from the FEH Rainfall-Runoff method, except for WC1 for which the FEH Statistical method produced the lowest peak. This is due to the FEH Statistical method being the only method which takes into consideration attenuation within the target catchment.

Climate change allowance for small ungauged watercourses

1.1.36 The Jacobs 2018 assessment used an initial climate change (CC) uplift factor of 20%, which was subsequently updated to 35%, and again in 2024, updated to 39% to be applied to rainfall intensity. Therefore, for this update, the latest SEPA climate change guidance[7] has been adopted, which specifies that CC allowance of 39% should be applied to the peak rainfall intensity for watercourses with catchments area less than 30km^2. As all small watercourses have catchment area <30km^2 the CC allowance was applied directly to rainfall intensity within the ReFH2.3 model, which indicates an equivalent CC allowance of 1.46 to 1.50 to be applied to the peak flow estimates.

Comparison of design peak flow estimates (0.5% AEP+CC) from previous and current methods for all small ungauged watercourses

1.1.37 In this assessment, the peak flow estimates were derived using three methods (FEH R-R /FEH 22 rainfall; ReFH2.3/FEH22 rainfall and FEH Statistical using the small catchment method) for the watercourse with catchment >0.5km^2. For minor watercourses with catchment area < 0.5km^2, the peak flow estimates were derived by areal scaling the corresponding donor catchment peak flow estimates. To derive the design peak flow estimates, the 0.5% AEP (200-year return period) peak flow estimates were uplifted by equivalent CC allowance, as mentioned above. Table A19.2-D.9 compares the design peak flow estimates (0.5% AEP +CC) adopted for the previous study and the 0.5% AEP +CC peak flow estimates from all three methods derived as part of this assessment.

Table A19.2-D.9: Comparison of design peak flow estimates (0.5% AEP+CC) of the 2018 study with those from the 2024 study (m^3/s)

Watercourse	Area (km^2)	2018 design 0.5% AEP +CC	FEH R-R (2024 study)		FEH Statistical (2024)		ReFH2.3 (2024)	
			0.5% AEP +CC	% difference	0.5% AEP +CC	% difference	0.5% AEP +CC	% difference
WC1	4.378	3.743			3.496	-6.6		
WC2	0.245	0.954	1.039	8.9	0.509	-46.6	0.294	-69.2

[7] SEPA (2023) Climate change allowances for flood risk assessment in land use planning, Version 4. Accessible at: climate-change-allowances-guidance-v4-final_nov23.pdf (sepa.org.uk)

Watercourse	Area (km^2)	2018 design 0.5% AEP +CC	FEH R-R (2024 study)		FEH Statistical (2024)		ReFH2.3 (2024)	
			0.5% AEP +CC	% difference	0.5% AEP +CC	% difference	0.5% AEP +CC	% difference
WC3	0.195	0.794	0.829	4.5	0.406	-48.8	0.235	-70.4
WC3A	0.212	0.847	0.899	6.2	0.441	-48.0	0.255	-69.9
WC4	0.074	0.359	0.316	-12.0	0.156	-56.4	0.089	-75.1
WC5	0.319	1.211	1.355	11.8	0.664	-45.2	0.383	-68.3
WC5A	0.432	1.582	1.834	16.0	0.899	-43.2	0.519	-67.2
WC7	0.588	2.064	2.496	20.9	1.223	-40.8	0.706	-65.8
WC9	0.755	2.546	3.205	25.9	1.516	-40.4	0.899	-64.7
WC11A	0.314	1.195	1.332	11.5	0.653	-45.4	0.377	-68.4
WC12	0.024	0.112	0.102	-8.5	0.053	-52.5	0.029	-74.1
WC12A	0.327	1.410	1.501	6.5	1.384	-1.8	0.878	-37.8
WC12B	0.364	1.538	1.672	8.8	1.542	0.3	0.978	-36.4
WC13	0.967	3.597	4.443	23.5	4.098	13.9	2.597	-27.8
WC14	0.643	2.140	2.833	32.4	2.229	4.1	1.280	-40.2
WC15	0.176	0.845	0.924	9.3	0.607	-28.2	0.369	-56.3
WC16	0.290	1.295	1.518	17.2	0.997	-23.0	0.607	-53.1
WF 17	0.107	0.556	0.559	0.7	0.368	-33.9	0.224	-59.7

1.1.38 A comparison of the adopted design peak flow estimates (0.5% AEP+CC) from the 2018 study and the corresponding peak flow estimates from the three methods used in this review study (refer to Table A19.2-D.9) indicates that:

- The ReFH2.3/FEH22 rainfall method produced peak flow estimates for this study which are approximately 28% to 75% smaller than the design peak flow estimates from the 2018 study.
- The FEH Statistical peak flow estimates (derived using the small catchment method) for this review study are approximately 2% to 56% smaller than the design peak flow estimates from the 2018 study except for WC12B (which is approximately 0.3% higher), WC13 (approximately 14% higher) and WC14 (approximately 4% higher).

- The FEH R-R/FEH22 rainfall method produced peak flow estimates for this study which are approximately 1% to 32% larger than the 2018 design peak flow estimates except for WC4 and WC12 for which the FEH R-R peak flow estimates are slightly reduced (12% and 8.5 % respectively). The increase in peak flow from FEH R-R method during this review study is attributed to the increase in rainfall depth (approximately 21 – 24%) from FEH22 DDF rainfall model in comparison to FEH99 DDF model rainfall (default in FEH R-R method) adopted in the 2018 study; whereas the reduction in peak flow in two minor WCs seems to be due to adoption of areal scaled peak flow estimates for very small catchments (area <0.1km^2).

1.1.39 Based on the above findings, it is considered that the DMRB Stage 2 (2018) design peak flow estimates for the small ungauged watercourses are still appropriate as conservative peak flow estimates (in comparison to the peak flows derived in 2024 study from the FEH Statistical and ReFH2.3 methods) except for WC13 and WC14 for which the 2018 design peak flow has been replaced by the 2024 study FEH Statistical peak flow estimates (which are approximately 14% and 4% higher respectively). Given WC12B 2024 study FEH Statistical peak flow estimate is within 0.3% of the 2018 FEH design peak flow estimate, the 2018 design peak flow estimate have been retained.

Peak Flow Estimation – Large Modelled Watercourses

1.1.40 At the time of assessment (summer 2024) the latest version of WINFAP (Version 5) and the NRFA Peak Flow dataset (Version 12.1) released 2nd November 2023, were adopted for this study to derive revised peak flow estimates for the River Tay, River Braan and Inchewan Burn.

1.1.41 The River Tay @ Caputh (15003) and the River Braan @ Hermitage (15023) are both large, gauged watercourses classified by the NRFA as suitable for both QMED and Pooling Group analysis. Single Site (SS) and Enhanced Single Site (ESS) analysis have therefore been undertaken for both gauges to derive updated growth curves. QMED has been estimated using the gauged AMAX record for the River Tay @ Caputh and for the River Braan @ Hermitage. An additional water year (WY) 2022 (extracted from SEPA API portal) was added to the NRFA AMAX sequence for the River Tay @ Caputh for SS, ESS and QMED estimation. For the River Braan @ Hermitage two additional years of AMAX data (WY 2022 from SEPA API portal and WY2023 indicated by SEPA during consultation) were initially added to the NRFA AMAX sequence and used for SS and ESS growth curves and QMED estimation. Following the 21st January 2025 project meeting SEPA provided an extended AMAX record for the River Braan @ Hermitage (refer to Annex D1.1) for the purposes of SS analysis. The extended AMAX record was from WY1981 to WY2023 and included an additional 10 years of AMAX data.

1.1.42 The Inchewan Burn is a small ungauged watercourse and therefore FEH Statistical Pooling Group analysis has been undertaken for this watercourse. QMED has been derived for the Inchewan Burn using the FEH catchment descriptors equation (using BFIHOST19 instead of BFIHOST) with donor adjustment applied using the single closest donor (15023 River Braan @ Hermitage) as per recent guidance for small catchments[8].

1.1.43 A total of 72 year of annual maxima data has been used in the FEH Statistical analysis for the River Tay at Caputh (15003) and a total of 33 annual maxima was used for the statistical analysis for the River Braan at Hermitage. A further FEH Single Site (SS) Statistical analysis and QMED estimation were undertaken for the River Braan at Hermitage using the SEPA provided extended AMAX sequence (provided February 2025) which has a total of 43 annual maxima.

1.1.44 The QMED estimates for the large modelled watercourses (River Tay and River Braan) and Inchewan Burn are presented in Table A19.2-D.10.

Table A19.2-D.10: QMED estimates for large modelled watercourses.

Watercourse (WC)	Area (km^2)	$QMED_{OBSVD}$ (m^3/s)	$QMED_{CD}$ (m^3/s)	QMED Adjustment factor
River Tay at Caputh	3211	865	710	1.218
River Braan at Hermitage (33 years AMAX data)	211	127*	84.7	1.502
River Braan at Hermitage (43 years AMAX data)	211	125**	84.7	1.477
Inchewan Burn at Tay confluence	5.77	-	2.56	1.159***

*Derived using 33 years of annual maxima data as per NRFA / SEPA API / additional WY2023.
**Derived using 43 years of annual maximum data provided by SEPA February 2025.
***Donor River Braan at Hermitage (QMED adjustment derived using 33 years AMAX data) with standard distance adjustment.

1.1.45 For the River Tay and River Braan, Single Site (SS), Enhanced Single Site (ESS) and simple Pooling Group (P) analysis have been undertaken within WINFAPv5 to derive peak flow estimates. The resulting flood growth curves for the River Tay at Caputh and the River Braan at Hermitage plotted against GL reduced variate are plotted in Figures A19.2-D.4 and A19.2-D.5 For the River Braan @ Hermitage this analysis includes the initial 2024 SS and ESS analysis growth curves including 33 years of AMAX data and the update 2025 SS analysis using the SEPA provided AMAX sequence which includes 43 years of AMAX data.

[8] FCERMRDP and EA (2024) Review of methodology for estimating flood peaks and hydrographs for small catchments. Accessible at: Review of methodology for estimating flood peaks and hydrographs for small catchments - GOV.UK (www.gov.uk)

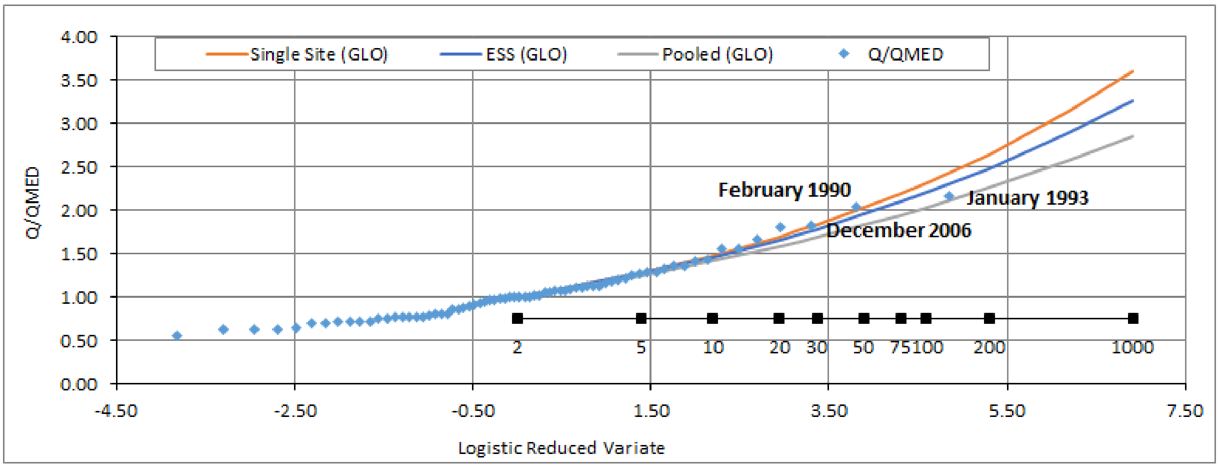


Figure A19.2-D.4: Growth Curve - River Tay at Caputh gauge

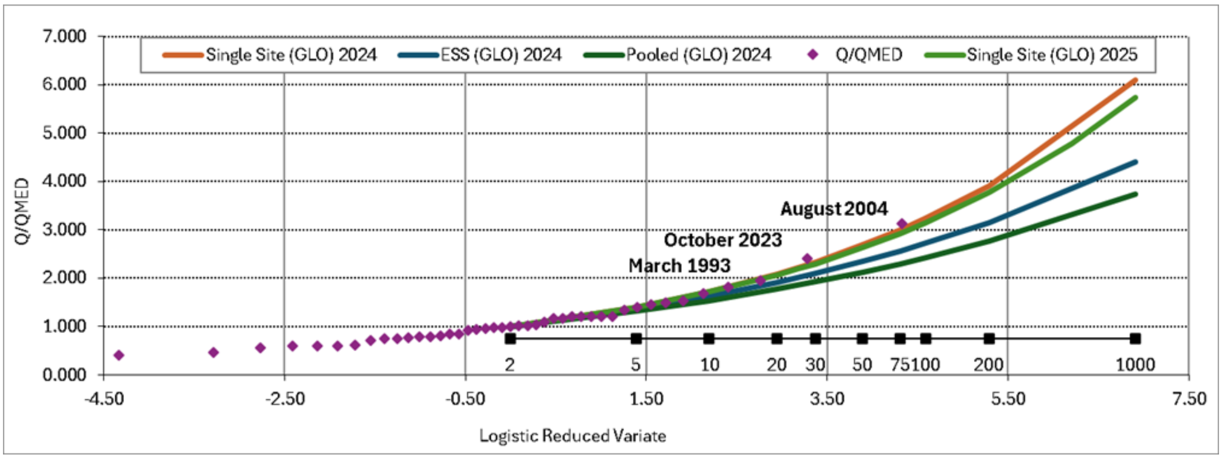


Figure A19.2-D.5: Growth Curve - River Braan at Hermitage gauge

1.1.46 A single site analysis has been adopted as the preferred method for the River Tay at Caputh, which is consistent with the approach adopted at the DMRB Stage 2 FRA study. Figure A19.2-D.4 shows that the largest flood recorded on the River Tay at Caputh (January 1993) has an estimated rarity of approximately 1.33% AEP (75- year return period) based on the single site growth curve and 1% AEP (100-year return period) based on the enhanced single site growth curve. The growth curve derived by Pooling Group analysis, places the January 1993 flood event as having an estimated rarity of 0.67% AEP (150-year return period).

1.1.47 Figure A19.2-D.5 shows that the largest event on the River Braan (August 2004) has a rarity of approximately 1.18% AEP (85-year return period) based on the updated 2025 SS growth curve, whereas its rarity is approximately 1.25% AEP (80-year return period) based on the 2024 Single Site Analysis growth curve. It is noted that, in agreement with SEPA, the DMRB Stage 2 assessments adopted the August 2004 peak flow as the design 0.5% AEP (200-year return period), and the corresponding design growth curve was equivalent to the average of the single site and pooling group growth curves. Thus, using the updated 2025 SS as the preferred growth curve, the rarity of the August 2004 is reduced from 0.5% AEP (200-year return period) in 2018 study, to approximately 1.18% AEP (85-year return period) in this study. Adopting the 2025 SS growth curve for the River Braan at Hermitage is the preferred SEPA approach.

1.1.48 For the Inchewan Burn, as it is an ungauged watercourse, FEH Statistical pooling group analysis has been undertaken to derive the growth curve using the latest peak flow dataset at the time of assessment in summer 2024 (NRFA dataset version 12.1 released 2nd November 2023).

1.1.49 For details of the FEH Statistical analysis including final pooling groups refer to Annex D1.4.

Climate Change Large Modelled Watercourses

1.1.50 During the DMRB Stage 2 design assessment process, SEPA issued revised climate change guidance which increased the suggested peak river flow and peak rainfall intensity climate change allowances from +20% to +35% for the Tay River Basin. This was applied to the 0.5% AEP (200-year return period) peak flow estimates for Run 1 for all watercourses (Tay, Braan and Inchewan Burn).

1.1.51 For this assessment the latest SEPA climate change guidance has been adopted. The current SEPA guidance specifies that climate change allowance should be applied to peak river flow for catchments larger than 50km^2 and to peak rainfall intensity for catchments less than 30km^2. For Run 1 the SEPA climate change allowance for the Tay river basin district (53% uplift) was applied to the peak river flow for all modelled watercourses. For Run 2 the climate change allowance was based on peak rainfall intensity for the Inchewan Burn as its catchment is less than 30km^2. As uplift to peak rainfall intensity can't be applied directly to the FEH Statistical peak flow estimate, ReFH2.3 was used to derive a scaling factor. This was undertaken by applying the peak rainfall intensity allowance for the Tay river basin district (39% uplift) to the Inchewan Burn 0.5% AEP (200-year return period) event within ReFH2.3. A scaling factor was then derived using the ReFH2.3 0.5% AEP (200-year return period) and 0.5% AEP (200-year return period) + climate change peak flow estimates. The revised scaling factor was then applied to the FEH Statistical 0.5% AEP (200-year return period) peak flow to derive the 0.5% AEP (200-year return period) plus climate change peak flow estimate.

Results of the Hydrological Analysis: Large Modelled Watercourses

1.1.52 Results of the hydrological analysis of the large, modelled catchment, including Inchewan Burn, along with the results of previous DMRB Stage 2 study (2018), are presented in Table A19.2-D.11.

Table A19.2-D.11: Previous Study and 2024 Updated Design Peak Flow Estimates (River Tay, River Braan and Inchewan Burn)

Watercourse	Study	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.33% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.5% AEP (200-year) + 53% CC uplift	0.1% AEP (1000-year)*****
Tay @ Caputh	Jacobs Previous Study	838	1040	1210	1575	1720	2017	2328	3562	3265
	Jacobs 2024 update - SS Analysis (GL) (adopted)	**865**	**1104**	**1278**	**1586**	**1750**	**1998**	**2283**	**3493**	**3117**
	Jacobs DMRB Stage 3 – PG Analysis (GL)	865	1078	1222	1462	1582	1758	1950	2983	2470
	Jacobs DMRB Stage 3 - ESS Analysis (GL)	865	1099	1262	1542	1688	1903	2144	3281	2824
Braan (WC11)	Jacobs DMRB Stage 2	122	161	191	246	277	325	390**	597	570
	Jacobs 2024 DMRB Stage 3 - SS Analysis (GL)	127	179	219	297	342	413	498	763	775
	Jacobs 2024 DMRB Stage 3 – PG Analysis (GL)	127	167	196	245	270	309	352	538	475
	Jacobs 2024 DMRB Stage 3 – ESS Analysis	127	174	208	267	299	346	401	613	560

Watercourse	Study	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.33% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.5% AEP (200-year) + 53% CC uplift	0.1% AEP (1000-year)*****
	(GL)									
	Jacobs 2025 DMRB Stage 3 –SS Analysis (GL) – SEPA updated AMAX sequence (adopted)	**125**	**175**	**214**	**287**	**329**	**394**	**472**	**722**	**613**
Inchewan Burn (WC8)	Jacobs Previous Study	3.2	4.4	5.3	6.9	7.9	9.4	11.3**	17.2	16.3
	Jacobs 2024 update – PG Analysis (KAP3)	**2.97**	**4.16**	**5.09**	**6.76**	**7.66**	**9.03**	**10.61**	**Run 1: 16.23*** Run 2: 15.56********	**15.24**

*Area scaled using Tay @ Caputh peak flow estimates.
**SEPA suggested 0.5% AEP (200-year) peak flow for River Braan and Inchewan Burn, which were close to Jacobs previous estimates and adopted.
***Climate change uplift based on the peak river flow allowance for the Tay river basin region as per SEPA climate change allowance guidance for catchments larger than 50km^2.
****Climate change uplift based on peak rainfall intensity allowance for the Tay river basin district as per SEPA climate change allowance for catchments less than 30km^2.
*****2024 0.1% AEP peak flow estimate from FEH Statistical method (before applying ReFH2.3 ratio).

Final Design Peak Flow Estimates

Minor Watercourses

1.1.53 As part of this DMRB Stage 3 assessment, peak flow estimates for all small ungauged watercourses were derived using three methods and compared with the design peak flow estimates (0.5% AEP +CC) of the DMRB Stage 2 (2018) assessment. The results show ReFH2.3/FEH22 rainfall method peak flow estimates are much small than the corresponding 2018 design peak flow estimates for all watercourses. The FEH Statistical method peak flow estimates are also smaller for all watercourses except WC12B, WC13 and WC14 and FEH R-R/FEH22 rainfall peak flow estimates are generally higher than 2018 design peak flow estimates. The 2018 design peak flow estimates were largely generated using the FEH R-R method (with FEH99 rainfall dataset).

1.1.54 Given the FEH R-R/FEH22 peak flow estimates are very conservative (and the FEH R-R method is an older method with the newer FEH22 dataset), it is concluded that the 2018 design peak flow estimates for the minor watercourses can still be adopted as conservative design peak flow estimates (in comparison to FEH Statistical and ReFH2.3 methods) for most watercourses. The exception to this is for WC13 and WC14 for which the 2018 design peak flow estimates are required to be replaced by the 2024 study FEH Statistical peak flow estimates (which are approximately 14% and 4% higher). Given WC12B FEH Statistical peak flow estimate is within 0.3% of the 2018 study design peak flow estimate, the 2018 design peak flow estimate can be retained.

1.1.55 The final adopted peak flow estimates are presented in Table A19.2-D.12.

Table A19.2-D.12: Final peak flow estimates (m^3/s) for ungauged minor watercourse

WC	50% (2-year)	20% (5-year)	10% (10-year)	3.3% (30-year)	2% (50-year)	1% (100-year)	0.5% (200-year)	0.1% (1000-year)***	0.5% +CC (200yr+CC)
WC1 *	0.703	0.974	1.185	1.504	1.795	2.138	2.546	3.510	3.743
WC2*	0.192	0.282	0.339	0.439	0.492	0.561	0.649	0.989	0.954
WC3*	0.160	0.212	0.254	0.327	0.366	0.416	0.540	0.744	0.794
WC3A*	0.171	0.250	0.301	0.390	0.437	0.498	0.576	0.879	0.847
WC4*	0.071	0.105	0.127	0.165	0.186	0.212	0.244	0.369	0.359
WC5*	0.242	0.354	0.425	0.550	0.616	0.701	0.824	1.244	1.211
WC5A*	0.316	0.460	0.552	0.711	0.796	0.904	1.076	1.614	1.582
WC7*	0.412	0.598	0.716	0.921	1.031	1.179	1.404	2.097	2.064
WC9*	0.509	0.739	0.884	1.138	1.272	1.454	1.732	2.586	2.546
WC11A *	0.239	0.350	0.420	0.542	0.608	0.691	0.813	1.227	1.195
WC12*	0.022	0.033	0.040	0.052	0.058	0.066	0.076	0.115	0.112
WC12A *	0.283	0.415	0.500	0.647	0.726	0.836	0.959	1.457	1.410
WC12B	0.309	0.453	0.545	0.705	0.791	0.901	1.046	1.591	1.538

WC *	50% (2-year)	20% (5-year)	10% (10-year)	3.3% (30-year)	2% (50-year)	1% (100-year)	0.5% (200-year)	0.1% (1000-year)***	0.5% +CC (200yr+CC)
WC13**	0.764	1.048	1.273	1.704	1.948	2.338	2.809	3.713	4.098
WC14**	0.409	0.561	0.682	0.912	1.043	1.252	1.504	2.017	2.229
WC15*	0.168	0.249	0.300	0.391	0.439	0.501	0.575	0.878	0.845
WC16*	0.258	0.379	0.456	0.592	0.664	0.757	0.881	1.333	1.295
WC17*	0.109	0.162	0.196	0.256	0.288	0.329	0.378	0.573	0.556

*From 2018 study (WC1- FEH Statistical, other WCs - FEH RR with default rainfall data, 200+CC uses latest CC allowance).

**FEH Statistical (2024 study, 200+CC uses latest CC allowance).

*** 0.1% AEP FEH Statistical peaks (WC1, WC13 & WC14) are from ReFH2.3 ratio.

<u>Large Modelled Watercourses</u>

1.1.56 For the large / modelled watercourses (River Tay, River Braan and Inchewan Burn) the Stage 3 DMRB assessment adopts the most up to date design peak flow estimates. This is due to the increased availability of flow data for this assessment and due to the updates to WINFAP, the NRFA peak flow dataset and FEH CDs since the previous DMRB Stage 2 hydrology was undertaken in 2018. The final revised peak flow estimates and the corresponding difference (%) from the DMRB Stage 2 (2018) assessment are presented in Table A19.2-D.13. The results in Table A19.2-D.13 show that the changes in peak flow are within 10% for the River Tay and Inchewan Burn. For the Inchewan Burn the design peak flow estimates all decreased, mainly due to adoption of a single donor (River Braan) for QMED adjustment, as per the guidance for small catchment. For the River Braan the changes in peak flow estimates are within 21%. This is due to the adoption of the relatively conservative 2025 SS growth curve as requested by SEPA.

Table A19.2-D.13: Final peak flow estimates (m^3/s) Jacobs (2024) and relative % change from Jacobs (2018)

WC	Study	50% AEP (2-year)	20% AEP (5-year)	10% AEP (10-year)	3.33% AEP (30-year)	2% AEP (50-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.5% AEP (200-year) + 53% CC uplift**	0.1% AEP (1000-year)****
River Tay, upstream model inflow*	Jacobs (2018)	783	966	1124	1462	1598	1873	2162	3307	3032
	Jacobs (2024) update	**803**	**1025**	**1187**	**1473**	**1625**	**1855**	**2120**	**3243**	**2733**
	Difference (%)	*+2.6*	*+6.1*	*+5.6*	*+0.7*	*+1.7*	*-0.9*	*-1.9*	*-1.9*	*-9.9*
River Tay, downstream model inflow*	Jacobs (2018)	835	1036	1206	1569	1714	2009	2319	3548	3253
	Jacobs (2024) update	**862**	**1100**	**1274**	**1580**	**1743**	**1991**	**2274**	**3479**	**2932**
	Difference (%)	*+3.2*	*+6.1*	*+5.6*	*+0.7*	*+1.7*	*-0.9*	*-1.9*	*-1.9*	*-9.9*
River Braan (WC11)	Jacobs (2018)	122	161	191	246	277	325	390	597	570
	Jacobs (2025) update	**125**	**175**	**214**	**287**	**329**	**394**	**472**	**722**	**613**
	Difference (%)	+2.6	+8.8	+12.2	+16.7	+18.7	+21.0	+20.9	+20.9	+7.6
Inchewan Burn (WC8)	Jacobs (2018)	3.19	4.36	5.26	6.92	7.85	9.37	11.25	17.22	16.33
	Jacobs (2024) update	2.97	4.16	5.09	6.76	7.66	9.03	10.61	Run 1: 16.23 Run 2 ***: 15.56	14.20
	Difference (%)	*-7.0*	*-4.5*	*-3.3*	*-2.31*	*-2.45*	*-3.6*	*-5.7*	*Run 1: -5.7* *Run 2 ***: -9.6*	*-13.1*

*Area scaled using Tay @ Caputh peak flow estimates.
**Climate change uplift based on the peak river flow allowance for the Tay river basin region as per SEPA climate change allowance guidance for catchments larger than 50km^2.
***Run 2 Climate change uplift based on peak rainfall intensity allowance for the Tay river basin district as per SEPA climate change allowance for catchments less than 30km^2.
****2024 0.1% AEP peak flow estimates from ReFH2.3 ratio (0.1% AEP / 0.5% AEP) multiplied by FEH Statistical 0.5% AEP peak.

Limitations

Large modelled watercourses

1.1.57 Given the Inchewan Burn is an ungauged catchment, inherent uncertainties are likely to exist with flow estimation for small ungauged catchments. The River Tay @ Caputh gauge has 72 years of AMAX data, and the Single Site growth curve has been adopted as per the 2018 study. The River Braan @ Hermitage has 43 years of AMAX data and the Single Site growth curve has been adopted as requested by SEPA. It should therefore be noted that higher return period peak flow estimates are subject to greater uncertainty.

Small ungauged catchments

1.1.58 Flow estimation for small ungauged Scottish catchments is subject to greater uncertainty than for larger gauged catchments.

1.1.59 The results of the present (2024) study involving FEH R-R (FEH22 rainfall), ReFH2.3 (FEH22 rainfall) and FEH Statistical (applying the small catchment method) suggest that the DMRB Stage 2 (2018) design peak flow estimates derived using FEH R-R method with default FEH99 rainfall data are largely conservative in comparison to the peak flow estimates derived using the ReFH2.3 and FEH Statistical methods for all watercourses except WC12B, WC13 and WC14. The FEH R-R / FEH22 rainfall method, however, result in very conservative peak flow estimates for these small ungauged Scottish catchments in comparison to the ReFH2.3/FEH22 rainfall and FEH Statistical method for small watercourses and therefore has not been taken forward.

1.1.60 The DMRB Stage 2 (2018) design peak flow estimates are considered conservative for these small ungauged watercourses and have therefore been taken forward for all watercourses except WC13 and WC14, for which the 2024 study FEH Statistical peak flow estimates are recommended. For WC1 (derived for 2018 study using FEH Statistical methods), WC13 and WC14, the 0.1% AEP (1000-year) peak flow estimates derived using the FEH Statistical method have been replace by the ratio of ReFH2.3 peaks at the 0.1% AEP / 0.5% AEP event multiplied by the FEH Statistical 0.5% AEP peak flow. This is due to inherent uncertainties in FEH Statistical estimates for higher return periods.

Inflow Hydrographs

1.1.61 The inflow hydrograph shape adopted by Jacobs for the DMRB Stage 2 assessment were based on typical flood hydrographs obtained from the local gauge records (Tay at Caputh and Braan at Hermitage). The inflow hydrograph shapes from the DMRB Stage 2 assessment have been accepted as suitable to use for this DMRB Stage 3 assessment as they are believed to be a good representation of the typical flood responses of these catchments for the River Tay and the River Braan.

1.1.62 The following two hydraulic model runs were used to examine flood risk across the modelled reaches:

- Run 1 – to determine the 0.5% AEP (200-year return period) event flood risk along the River Tay main stem. The typical Tay hydrograph shape was based on an assessment of historical events and the December 2006 hydrograph shape selected. This was then scaled to the required design flow on the Tay based on statistical analysis. The typical Braan hydrograph shape was also based on an assessment of historic events (the March 1993 shape selected) and this was then scaled to the required design flow. The required flow in the Braan was determined from a pseudo-calibration of the FEH rainfall-runoff model to the statistical peak flow - targeting the Braan catchment by itself. The required scaling factor was retained within the rainfall-runoff model and then the much longer critical storm duration rainfall for the Tay catchment – estimated to be about 25 hours – was applied to this pseudo-calibrated rainfall-runoff model. The resulting peak flow (which is less than the statistical estimate of peak flow of the Braan catchment) was then taken to be the required design flow in the Braan in the Run 1 Scenario. The general time lag between the arrival of the Tay hydrograph peak to that of the Braan hydrograph peak was used in the hydraulic model as an initial offset of the two hydrographs. Similar principles were used for the Inchewan Burn simulation.
- Run 2 – to determine the 0.5% AEP (200-year) event flood risk along the River Braan and the Inchewan Burn reaches. The River Braan hydrograph shape was based on the analysis of historic events from which the March 1993 shape was selected. This was then scaled to the predetermined design peak flow (based on statistical analysis). The Inchewan Burn hydrograph shape was based on the design run of the FEH rainfall-runoff model using a critical duration of 6.5 hours. The simulated hydrograph was then scaled to the predetermined design flow of the watercourse. In the hydraulic model representation of these events the inflows were coupled with the 50% AEP (2-year) event peak flow occurring on the River Tay main stem.

1.1.63 For further details on the hydrograph shape and hydraulic model runs refer to the DMRB Stage 2 Assessment: A9 Dualling – Pass of Birnam to Tay Crossing: Flood Risk Assessment (Transport Scotland, 2023). This Appendix also contains additional information on the assessment of coincident flood flows on the River Tay and River Braan and a review of the high/low flow performance of the gauges.

Hydrology for Hydraulic Model Calibration

1.1.64 Calibration of a hydraulic model requires accurate recorded flood flows with which to run the model and observed level data from the event to compare the model predicted water levels to.

1.1.65 The Caputh gauging station on the River Tay is located 2km downstream from the bottom end of the model is well placed to provide flows for the River Tay. The Hermitage gauging station on the River Braan is also located within the modelling extent. As such, flood hydrographs of the historic events at these two gauges can be used to calibrate the hydraulic model, if good quality flood levels are available along the modelling reach.

1.1.66 15-minute interval flow data at the Caputh and Hermitage gauging stations was obtained from SEPA for the winter 2015/2016 period. Some flood wrack information from the 2015/16 winter was collected by Jacobs in early 2016. This information was used in the calibration of the hydraulic model.

1.1.67 Some information on the January 2006 and December 2006 historic flood events is available in the council's Biennial Incidence of Flooding Report (Perth & Kinross Council 2008). The associated flow hydrographs at the Caputh and Hermitage stations for these two events were also supplied so that the feasibility of using this information to verify the model could be investigated.

1.1.68 For further details of the hydraulic model calibration refer to Annex E Hydraulic Model Report.

Low Flow Estimates

1.1.69 Low flow estimates such as Q95 and mean flow (Qmean) are required for all road drainage 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 was used for deriving these flow estimates.

1.1.70 Where an adequate flow gauge exists the low flow values are based directly on the gauge record. The flow gauges considered are given in Table A19.2-D.14.

Table A19.2-D.14: Gauging station Q_{95} flow

Station Number	River Name	Station Name	Catchment Area (km^2)	Q_{95} (m^3/s)*
15007	Tay	Pitnacree	1149	12.95
15003	Tay	Caputh	3210	36.23
15023	Braan	Hermitage	210	0.612

*Q95 values calculated in 2020

1.1.71 To estimate Q95 flows for locations along the major watercourses (viz: River Tay and River Braan) the estimates derived at the gauge location are transposed to the outfall location based on catchment areal scaling.

1.1.72 For the smaller ungauged watercourses, Q95 flows were estimated using the UK Centre for Ecology & Hydrology (UKCEH) Low Flows Enterprise (LFE) software. Estimates of river flows were derived at six locations, judged to be representative of the range of small catchments considered in this assessment. The Q95 flows obtained at the six locations were used to estimate Q95 flows at the target locations based on hydrological similarity defined by BFIHOST19 and simple areal scaling. Table A19.2-D.15 presents the LFE estimates used for this analysis.

Table A19.2-D.15: LFE calculation locations

Location	Area (km^2)	Easting	Northing	Q_{95} (m^3/s)
Inchewan Burn	5.6	303018	741731	0.025
Kindallachan Burn	18.8	299400	749841	0.092
Allt Bhaic (WF115)	10.7	284543	765604	0.036
Allt a' Chrombaidh (WF142)	10.8	278925	766592	0.042
Unnamed Watercourse (WF151)	0.2	277250	768350	0.0005
Allt Anndeir (WF158)	61.6	275536	769635	0.350

1.1.73 Figure A19.2-D.6 identifies the locations requiring low flow estimates and Table A19.2-D.16 presents the estimates.

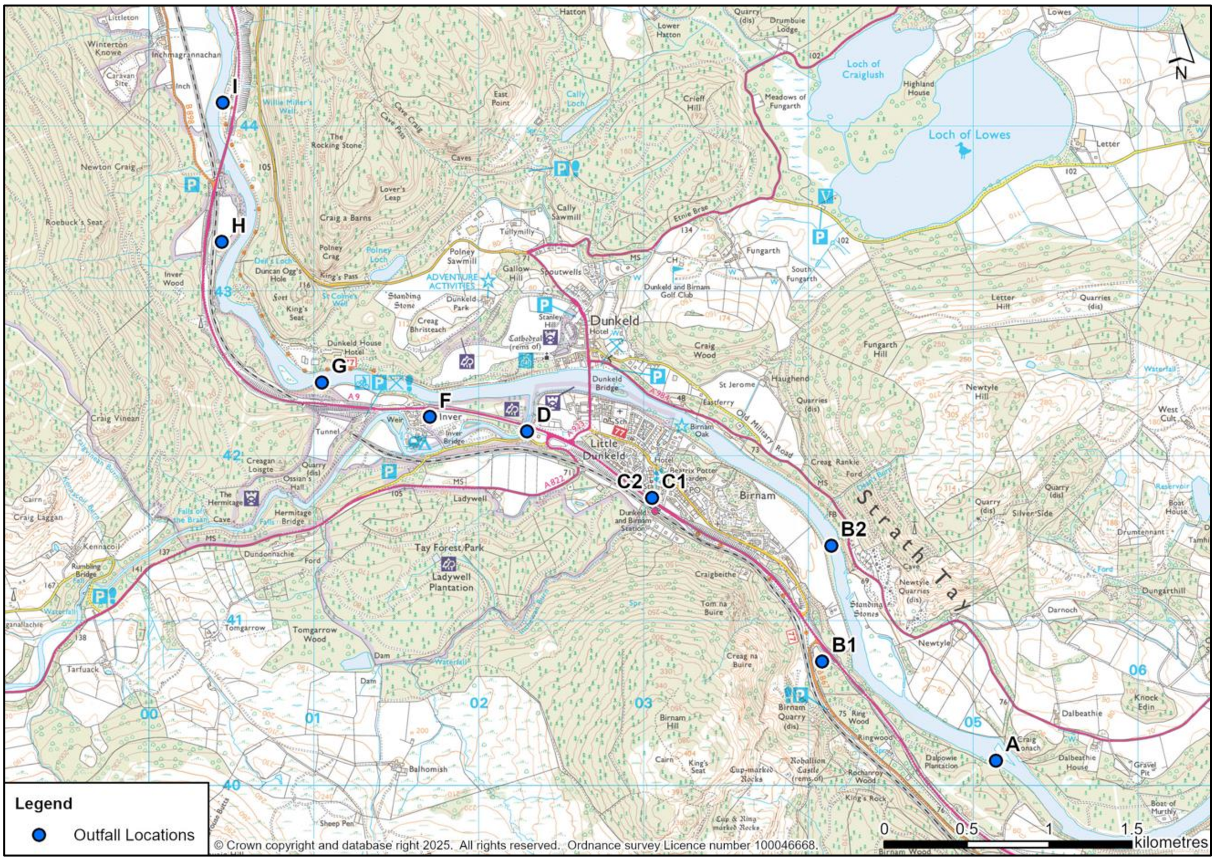


Figure A19.2-D.6: Outfall locations

Table A19.2-D.16: LFE calculation locations

Watercourse	Outfall*	Grid Reference	Catchment Area (km^2)	Q95 (m^3/s)	Mean Flow (m^3/s)
River Tay	A	305139, 740151	3198	36.10	141.11

Watercourse	Outfall*	Grid Reference	Catchment Area (km^2)	Q95 (m^3/s)	Mean Flow (m^3/s)
WF5A	B1	304086, 740753	0.432	0.002	0.010
River Tay	B2	304140, 741455	3195	36.06	141.0
Inchewan Burn	C1	303053, 741744	5.77	0.026	0.128
Inchewan Burn	C2	303053, 741744	5.77	0.026	0.128
River Braan	D	302296, 742148	211	0.616	7.02
Inver Mill Lade	F	301705, 742235	0.024	0.000	0.001
River Tay	G	301050, 742445	2971	35.27	133.36
River Tay	H	300444, 743296	2969	35.25	133.25
River Tay	I	300448, 744141	2967	35.22	133.17

Conclusions

1.1.74 This report has presented the assessment methods used to derive design peak flows, flood inflow hydrographs, and low flow estimates for watercourses within the proposed scheme. Assessment methods have varied for catchments within this study area based on a variety of factors such as catchment size, flood risk and the availability of gauged data. Larger watercourses which are identified for detailed numerical hydraulic modelling have undergone a more detailed assessment than small ungauged watercourses.

1.1.75 The following limitations and comments should be noted when reviewing the findings from this report:

- Flow estimation is subject to some inevitable uncertainty and therefore the results presented within this report should be considered with this in mind. The design flow estimates / inflow hydrographs / low flow estimates presented within this report have been derived using standard methods and adjusted when appropriate.
- The peak flood estimates for the small watercourses (catchment area <25km^2) were undertaken using FEH statistical, ReFH2.3 and the FEH rainfall-runoff methodologies. This enabled a conservative peak flow to be selected for each watercourse. For larger catchments (catchment area >25km^2), the design flows are based solely on the statistical methods.

- The latest climate change uplift (at the time of assessment) has been applied to the 0.5% AEP (200-year return period) design peak flow estimates for large modelled watercourses and applied to the peak rainfall intensity for the small ungauged watercourses (all with catchment area less than 30km^2) to take into consideration the impacts of changing climates. SEPA provided an extended AMAX sequence for the River Braan at Hermitage in February 2025 which has been used to derive an updated SS growth curve for the River Braan.
- Low flow estimates on the larger rivers are based upon local gauged data, where available, otherwise Low Flow Enterprise (LFE) estimates provided by CEH Wallingford have been used to derive estimates.

Annex D1.1 - SEPA Provided AMAX data River Braan @ Hermitage (15023)

The SEPA provided AMAX data for the River Braan at Hermitage (15023) received on the 25th February 2025 is provided below.

Table A19.2-D1.1 - SEPA River Braan @ Hermitage AMAX Data

Water Year	Date	Flow (m^3/s)
1981	28-Sep-82	73.533
1982	01-Oct-82	98.272
1983	20-Dec-83	50.286
1984	27-Nov-84	136.632
1985	09-Jan-86	89.837
1986	10-Dec-86	122.107
1987	01-Sep-88	92.896
1988	01-Oct-88	190.263
1989	05-Feb-90	149.809
1990	04-Mar-91	96.344
1991	12-Nov-91	69.514
1992	29-Mar-93	244.188
1993	04-Mar-94	126.001
1994	02-Feb-95	75.861
1995	08-Jan-96	114.563
1996	19-Feb-97	180.985
1997	20-Nov-97	106.417
1998	20-Sep-99	146.628
1999	19-Sep-00	150.213
2000	09-Oct-00	104.633
2001	20-Oct-01	173.756
2002	02-Nov-02	117.169

Water Year	Date	Flow (m^3/s)
2003	10-Aug-04	390.621
2004	10-Jan-05	121.643
2005	24-Oct-05	130.278
2006	03-Dec-06	151.109
2007	26-Jan-08	101.764
2008	15-Jan-09	76.773
2009	01-Nov-09	127.299
2010	15-Jan-11	97.489
2011	27-Aug-12	119.282
2012	22-Dec-12	125.076
2013	23-Feb-14	147.267
2014	17-Jul-15	166.631
2015	30-Dec-15	209.908
2016	26-Feb-17	57.651
2017	24-Jan-18	93.784
2018	18-Dec-18	151.951
2019	15-Feb-20	228.030
2020	23-Feb-21	187.697
2021	31-Oct-21	75.691
2022	18-Nov-22	151.641
2023	20-Oct-23	300.009

Annex D.1.2 – Final pooling groups for the small ungauged watercourses with area >0.5km^2

Table A9.2-D.1.2.1 – Final pooling group for small ungauged catchment – Group 1 (FARL =0.804)

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST 19	SPRHOST
27051 (Crimple @ Burn Bridge)	0.570	8.172	855	0.013	1.000	0.006	0.329	40.77
45816 (Haddeo @ Upton)	0.792	6.808	1210	0.011	1.000	0.005	0.535	31.27
76011 (Coal Burn @ Coalburn)	0.891	1.63	1096	0.074	1.000	0.000	0.274	58.93
25019 (Leven @ Easby)	1.046	15.088	830	0.019	1.000	0.004	0.495	38.58
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	1.069	16.08	1044	0.023	0.991	0.006	0.562	31.92
28033 (Dove @ Hollinsclough)	1.119	7.915	1346	0.007	1.000	0.000	0.347	42.5
27010 (Hodge Beck @ Bransdale Weir)	1.161	18.82	987	0.009	1.000	0.001	0.303	50.58
47022 (Tory Brook @ Newnham Park)	1.441	13.432	1403	0.023	0.942	0.014	0.353	44.18
25011 (Langdon Beck @ Langdon)	1.515	12.787	1463	0.012	1.000	0.001	0.264	58.21
72014 (Conder @ Galgate)	1.629	28.992	1183	0.082	0.975	0.006	0.427	35.96
73015 (Keer @ High Keer Weir)	1.632	30.043	1158	0.074	0.976	0.003	0.455	35.79
41020 (Bevern Stream @ Clappers Bridge)	1.665	35.48	886	0.076	0.993	0.013	0.362	43.25
18014 (Bannock Burn @ Bannockburn)	1.706	25.372	1333	0.054	0.893	0.011	0.407	39.35

A sensitivity analysis was also undertaken where FARL was used to remove sites from the pooling group. This resulted in around 200 gauges being removed in total from the pooling group. The results of this analysis indicated that the 0.5% AEP (200-year return period) peak flow estimate reduced by approximately 10%.

Table A19.2-D1.2.2 – Final pooling group for small ungauged catchments – Group 2 (FARL =1)

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST 19	SPRHOST
76011 (Coal Burn @ Coalburn)	0.421	1.63	1096	0.074	1.000	0.000	0.274	58.93
45816 (Haddeo @ Upton)	1.587	6.808	1210	0.011	1.000	0.005	0.535	31.27
28033 (Dove @ Hollinsclough)	1.793	7.915	1346	0.007	1.000	0.000	0.347	42.5
27051 (Crimple @ Burn Bridge)	1.802	8.172	855	0.013	1.000	0.006	0.329	40.77
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.225	16.08	1044	0.023	0.991	0.006	0.562	31.92
25011 (Langdon Beck @ Langdon)	2.236	12.787	1463	0.012	1.000	0.001	0.264	58.21
25019 (Leven @ Easby)	2.288	15.088	830	0.019	1.000	0.004	0.495	38.58
27010 (Hodge Beck @ Bransdale Weir)	2.359	18.82	987	0.009	1.000	0.001	0.303	50.58
71003 (Croasdale Beck @ Croasdale Flume)	2.506	10.71	1882	0.016	1.000	0.000	0.283	54.51
206006 (Annalong @ Recorder)	2.527	14.438	1704	0.023	0.981	0.000	0.267	51.72
25003 (Trout Beck @ Moor House)	2.566	11.395	1905	0.041	1.000	0.000	0.255	59.86
27032 (Hebden Beck @ Hebden)	2.622	22.245	1433	0.021	0.997	0.000	0.272	57.36
48009 (St Neot @	2.699	22.973	1511	0.023	0.982	0.002	0.388	39.93

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST 19	SPRHOST
Craigshill Wood)								

Annex D1.3 - FEH22 rainfall used in FEH R-R analysis

Table A19.2-D1.3.1: FEH22 rainfall depth used in the FEH R-R model (mm)

Flood return period	Storm duration (hour)	2-year	5-year	10-year	30-year	50-year	100-year	200-year	1000-year
Rainfall return period		2	8	17	50	81	140	247	1000
WC1 (Donor 1)	5.1	23.4	35.6	42.2	52.6	57.6	63.6	70.2	87.8
WCs 7 & 9(Donor 2)	2.3	17.5	28.6	34.5	43.4	47.6	52.6	58.1	72.9
WC13 (Donor 3)	2.3	17.9	29.7	35.8	45.0	49.1	54.1	59.4	73.3
WC14 (Donor 4)	2.3	18.0	29.9	36.0	45.2	49.5	54.5	59.9	73.9
Donor 5	2.1	17.1	28.5	34.6	43.5	47.7	52.7	58.1	72.3

Annex D1.4 Final pooling group for the River Tay, River Braan and Inchewan Burn

Table A19.2-D1.4.1: River Tay @ Caputh Single Site (SS was adopted)

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19	SPRHOST
15003* (Tay @ Caputh)	0.000	3211.225	1609	0.041	0.807	0.001	0.411	45.36

Table A19.2-D1.4.2: River Tay @ Caputh ESS Pooling Group

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19	SPRHOST
15003* (Tay @ Caputh)	0.000	3211.225	1609	0.041	0.807	0.001	0.411	45.36
8006 (Spey @ Boat o Brig)	1.205	2852.39	1119	0.052	0.959	0.001	0.438	43.98
76007 (Eden @ Sheepmount)	1.340	2276	1182	0.074	0.971	0.008	0.493	37.8
55002 (Wye @ Belmont)	1.391	1894.257	1230	0.069	0.967	0.003	0.421	39.67
21021 (Tweed @ Sprouston)	1.398	3345.765	1014	0.046	0.978	0.004	0.44	38.7
23001 (Tyne @ Bywell)	1.425	2172.36	1016	0.05	0.961	0.003	0.342	48.19
54005 (Severn @ Montford)	1.522	2026.77	1147	0.092	0.977	0.004	0.444	38.49
12002 (Dee	1.549	1833.213	1080	0.048	0.98	0.002	0.455	39.69

@ Park)								

Table A19.2-D1.4.3: River Tay @ Caputh Simple Pooling Group

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19	SPRHOST
8006 (Spey @ Boat o Brig)	1.205	2852.39	1119	0.052	0.959	0.001	0.438	43.98
76007 (Eden @ Sheepmount)	1.340	2276	1182	0.074	0.971	0.008	0.493	37.8
55002 (Wye @ Belmont)	1.391	1894.257	1230	0.069	0.967	0.003	0.421	39.67
21021 (Tweed @ Sprouston)	1.398	3345.765	1014	0.046	0.978	0.004	0.44	38.7
23001 (Tyne @ Bywell)	1.425	2172.36	1016	0.05	0.961	0.003	0.342	48.19
54005 (Severn @ Montford)	1.522	2026.77	1147	0.092	0.977	0.004	0.444	38.49
12002 (Dee @ Park)	1.549	1833.213	1080	0.048	0.98	0.002	0.455	39.69

Table A19.2-D1.4.4: River Braan @ Hermitage SS details

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19
15023 (Braan @ Hermitage)	0.000	210.715	1326	0.034	0.929	0	0.429

Table A19.2-D1.4.5: River Braan @ Hermitage ESS Pooling Group

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19
15023 (Braan @ Hermitage)	0.000	210.715	1326	0.034	0.929	0	0.429
27053 (Nidd @ Birstwith)	0.205	219.305	1218	0.029	0.913	0.004	0.365
69017 (Goyt @ Marple Bridge)	0.337	184.232	1152	0.03	0.918	0.025	0.464
25018 (Tees @ Middleton in Teesdale)	0.344	242.012	1533	0.034	0.939	0.001	0.31
46014 (Teign @ Chudleigh)	0.366	232.275	1228	0.027	0.976	0.005	0.54
49001 (Camel @ Denby)	0.367	209.942	1338	0.034	0.987	0.012	0.481
84040 (Clyde @ Abington)	0.398	251.805	1540	0.043	0.937	0.001	0.32
66006 (Elwy @ Pont-y-Gwyddel)	0.411	191.355	1185	0.032	0.98	0.001	0.425
8013 (Feshie @ Feshie Bridge)	0.434	229.627	1286	0.041	0.993	0	0.385
24003 (Wear @ Stanhope)	0.446	173.49	1279	0.019	0.978	0.002	0.305
47006 (Lyd @ Lifton Park)	0.453	220.387	1228	0.035	0.996	0.002	0.448
54080 (Severn @ Dolwen)	0.459	174.42	1611	0.029	0.928	0.003	0.406
76021 (Eden @ Great Musgrave Bridge)	0.47	223.025	1270	0.047	0.997	0.004	0.414
54038 (Tanat @ Llanyblodwel)	0.473	241.125	1274	0.038	0.996	0.001	0.427

Table A19.2-D1.4.6: River Braan @ Hermitage Simple Pooling

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST 19
27053 (Nidd @ Birstwith)	0.205	219.305	1218	0.029	0.913	0.004	0.365
69017 (Goyt @ Marple Bridge)	0.337	184.232	1152	0.03	0.918	0.025	0.464
25018 (Tees @ Middleton in Teesdale)	0.344	242.012	1533	0.034	0.939	0.001	0.31
46014 (Teign @ Chudleigh)	0.366	232.275	1228	0.027	0.976	0.005	0.54
49001 (Camel @ Denby)	0.367	209.942	1338	0.034	0.987	0.012	0.481
84040 (Clyde @ Abington)	0.398	251.805	1540	0.043	0.937	0.001	0.32
66006 (Elwy @ Pont-y-Gwyddel)	0.411	191.355	1185	0.032	0.98	0.001	0.425
8013 (Feshie @ Feshie Bridge)	0.434	229.627	1286	0.041	0.993	0	0.385
24003 (Wear @ Stanhope)	0.446	173.49	1279	0.019	0.978	0.002	0.305
47006 (Lyd @ Lifton Park)	0.453	220.387	1228	0.035	0.996	0.002	0.448
54080 (Severn @ Dolwen)	0.459	174.42	1611	0.029	0.928	0.003	0.406
76021 (Eden @ Great Musgrave Bridge)	0.47	223.025	1270	0.047	0.997	0.004	0.414
54038 (Tanat @	0.473	241.1	1274	0.038	0.996	0.001	0.427

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST 19
Llanyblodwel)		25					

Table A19.2-D1.4.7: Inchewan Burn Revised Pooling Group

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST19	SPRHOST
27051 (Crimple @ Burn Bridge)	0.507	8.172	855	0.013	1.000	0.006	0.329	40.77
45816 (Haddeo @ Upton)	0.580	6.808	1210	0.011	1.000	0.005	0.535	31.27
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	0.819	16.08	1044	0.023	0.991	0.006	0.562	31.92
28033 (Dove @ Hollinsclough)	0.906	7.915	1346	0.007	1.000	0.000	0.347	42.5
25019 (Leven @ Easby)	0.914	15.088	830	0.019	1.000	0.004	0.495	38.58
27010 (Hodge Beck @ Bransdale Weir)	0.931	18.82	987	0.009	1.000	0.001	0.303	50.58
76011 (Coal Burn @ Coalburn)	1.043	1.63	1096	0.074	1.000	0.000	0.274	58.93
47022 (Tory Brook @ Newnham Park)	1.193	13.432	1403	0.023	0.942	0.014	0.353	44.18
25011 (Langdon Beck @ Langdon)	1.274	12.787	1463	0.012	1.000	0.001	0.264	58.21
72014 (Conder @ Galgate)	1.368	28.992	1183	0.082	0.975	0.006	0.427	35.96
73015 (Keer @ High	1.374	30.043	1158	0.074	0.976	0.003	0.455	35.79

Station	Distance (SDM)	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOS T19	SPRHO ST
Keer Weir)								
41020 (Bevern Stream @ Clappers Bridge)	1.470	35.48	886	0.076	0.993	0.013	0.362	43.25
28041 (Hamps @ Waterhouses)	1.489	37.04	1085	0.033	1.000	0.004	0.311	47.08

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SEPA Time series data service (API). Accessed 2024 at: https://timeseriesdoc.sepa.org.uk/.

Annex E: Hydraulic Modelling Report

1. Introduction

1.1 Purpose

1.1.1 This annex provides detailed information on the hydraulic model build process undertaken to assess the risk of fluvial flooding from the River Tay, and a number of its tributaries, to the Pass of Birnam to Tay Crossing section (proposed scheme) of the A9 Dualling Programme.

1.1.2 This annex supports the hydraulic modelling results presented in Appendix A19.2 (Flood Risk Assessment) in Chapter 19 Road Drainage and the Water Environment (RDWE) of the Environmental Impact Assessment Report (EIAR).

1.1.3 The main body of this annex covers the hydraulic modelling of the main rivers (i.e. River Tay, River Braan and Inchewan Burn). Annex E3 (Minor Watercourse Modelling) presents additional hydraulic modelling undertaken for three minor watercourses respectively named as MWC09, MWC13 and MWC16[1].

1.1.4 In accordance with the DMRB, the proposed scheme development is currently at DMRB Stage 3 'Detailed Assessment'. This report documents the modelling undertaken on the DMRB Stage 3 only.

1.2 Modelling Approach

1.2.1 The hydraulic model was built using a linked One-Dimensional/Two-Dimensional (1D/2D) technique, where the river channel is represented as a 1D component using Flood Modeller (FM) software (Version 6.1) and the floodplain is represented in 2D using TUFLOW 2020-10-AF-iDP-w64 software. The linked 1D/2D modelling approach means that the model dynamically transfers the water between the watercourses and the floodplain.

1.2.2 Since 2015, the original baseline model of the River Tay, River Braan and Inchewan Burn built by URS in 2013 has been updated by Jacobs at Stage 2 of the DMRB process. The Stage 2 model updates are summarised in Annex E1 of this Annex.

1.2.3 The hydraulic modelling aimed to predict the peak water levels within the modelled river reach and the floodplain for the 50% AEP (2-year), 3.33% AEP (30-year), 0.5% AEP (200-year) and 0.5% AEP (200-year) plus an allowance for climate change (plus CC) flood events for both the baseline and proposed scheme scenarios. These were then used to understand the existing fluvial flood risk and assess the potential impacts of the proposed scheme on flooding. Subsequently, the hydraulic model was used to test options to mitigate these impacts.

1.2.4 Throughout this document climate change is represented as a +53% uplift on flows in accordance with the revised Scottish Environmental Protection Agency (SEPA) guidance (November 2023). The guidance recommends that for a river catchment with an area greater

[1] Also referred to as WF09, WF13 and WF16 respectively, in Appendix A19.2 (Flood Risk Assessment)

than 50km² in the Tay River Basin region, the climate change allowance for peak flow should be +53%, and the climate change allowance for peak rainfall should be +39%.

1.3 Modelled Area

1.3.1 Figure A19.2-E.1 illustrates the proposed scheme footprint and watercourses modelled between Pass of Birnam and Tay Crossing. The model covers three principal watercourses: the River Tay, the River Braan (a tributary of the River Tay that flows north east to its confluence with the Tay) and the Inchewan Burn (a key tributary flowing north between Little Dunkeld and Birnam). Three minor watercourses (MWC09, MWC13 and MWC16) crossing the proposed scheme have also been modelled separately. Details associated with the modelling of these minor watercourses are presented in Appendix C of this report.

1.3.2 The model extents were chosen based on the key locations where the River Tay and its tributaries are close to the existing A9 and could potentially influence the flood risk to and from the road in both baseline and proposed scheme scenarios.

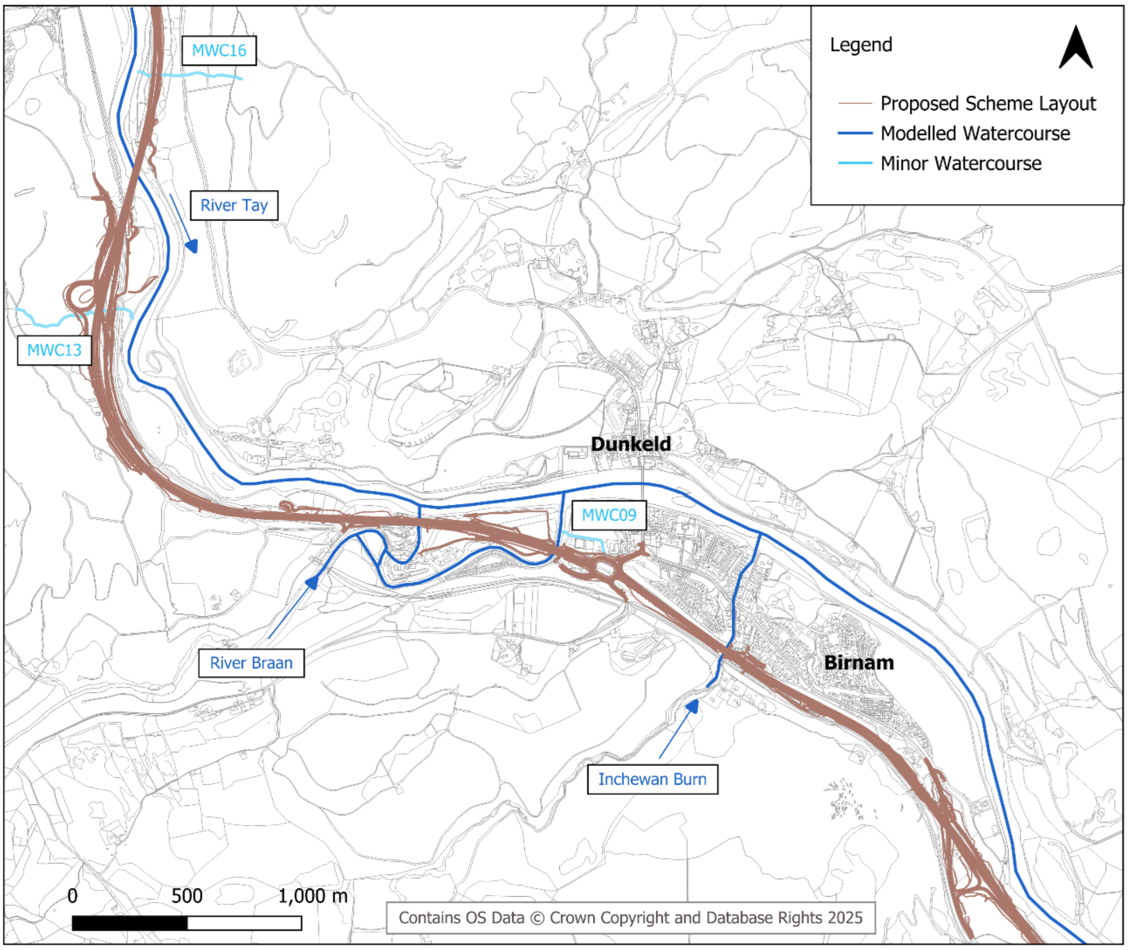


Figure A19.2-E.1: Modelled Area

2. Input Data

2.1.1 The data sets used to build the hydraulic model are summarised in Table A19.2-E.1.

Table A19.2-E.1: Data used to build the Hydraulic Model

DATA	DESCRIPTION	SOURCE
EXISTING HYDRAULIC MODEL	Existing Hydraulic Model of the River Tay, River Braan and Inchewan Burn developed by URS in 2013 using ISIS-Tuflow. See Section 4	Transport Scotland
1M DIGITAL TERRAIN MODEL (DTM)	1m horizontal resolution DTM (2018). See Section 4.3	Transport Scotland
OS MAPS	Background maps and Master Map data. See Section 4.3	Ordnance Survey
HYDROLOGICAL ANALYSIS	Hydrological analysis carried out as discussed in Section 3.	Jacobs 2015-2025
SEPA FLOOD MAPS	Flood maps showing the fluvial flood extent for medium likelihood of flooding. See Section 8.2.8	SEPA
TOPOGRAPHIC SURVEYS	• Cross section survey upstream of railway line and downstream of Perth Road along Inchewan Burn. • Topographical surveys at Dunkeld and Birnam in the Tay floodplain. See Section 4.2 and Section 4.3	Jacobs 2019-2020
WATERCOURSE PHOTOGRAPHS	Site visit in-channel watercourse photographs	Jacobs 2015 - 2020

DATA	DESCRIPTION	SOURCE
	See Section 4.2.3.	
PROPOSED SCHEME TOPOGRAPHY – ROAD VERTICAL AND HORIZONTAL ALIGNMENTS	ASCII grid of the road alignment that includes drainage ponds across the floodplain. The most up to date version at time of writing this report is Stage 3 Design Fix 8 See Section 5.1	Jacobs 2025
PROPOSED SCHEME STRUCTURE DETAILS	Design drawings for proposed structure modifications: watercourse crossings, drainage ponds and side roads. See Section 5.2	Jacobs 2025

3. Hydrology

3.1.1 The details of the analysis carried out to produce design inflows for the hydraulic model are provided in Annex D of Appendix A19.2 (Flood Risk Assessment). Inflows have been provided for the 50% AEP (2-year), 3.33% AEP (30-year), 0.5% AEP (200-year) and 0.5% AEP (200-year) plus CC flood events. For each of these events the estimated peak flow near the downstream end of the model has also been provided.

3.1.2 As discussed in the Hydrology report, two sets of hydrological inflows were simulated, referred to as Run 1 and Run 2.

- Run 1 – The purpose of this run was to determine the flood risk from the main river and hence the critical storm duration of the River Tay (25 hours) was used. The tributary inflows were adjusted consistently to the main river storm duration of 25 hours.
- Run 2 – The purpose of this run was to determine flood risk along the River Braan and the Inchewan Burn, with the inflows corresponding to their critical storm duration (6.5 hours for the Inchewan Burn and 15 hours for the River Braan). A constant QMED flow was applied to the River Tay.

3.1.3 Hydrograph shapes for the River Tay and River Braan inflows were derived from historic flood events and for the Inchewan it takes the form a typical FEH (Flood Estimation Handbook) hydrograph.

3.1.4 The derived peak inflows for Run 1 and Run 2 are shown in Table A19.2-E.2, along with the locations where they were estimated. The inflow locations are shown in Figure A19.2-E.2.

3.1.5 Full hydrographs are shown in Figure A19.2-E.3 (Run 1) and Figure A19.2-E.4 (Run 2). These flows have been used as inflows to the Flood Modeller component of the model.

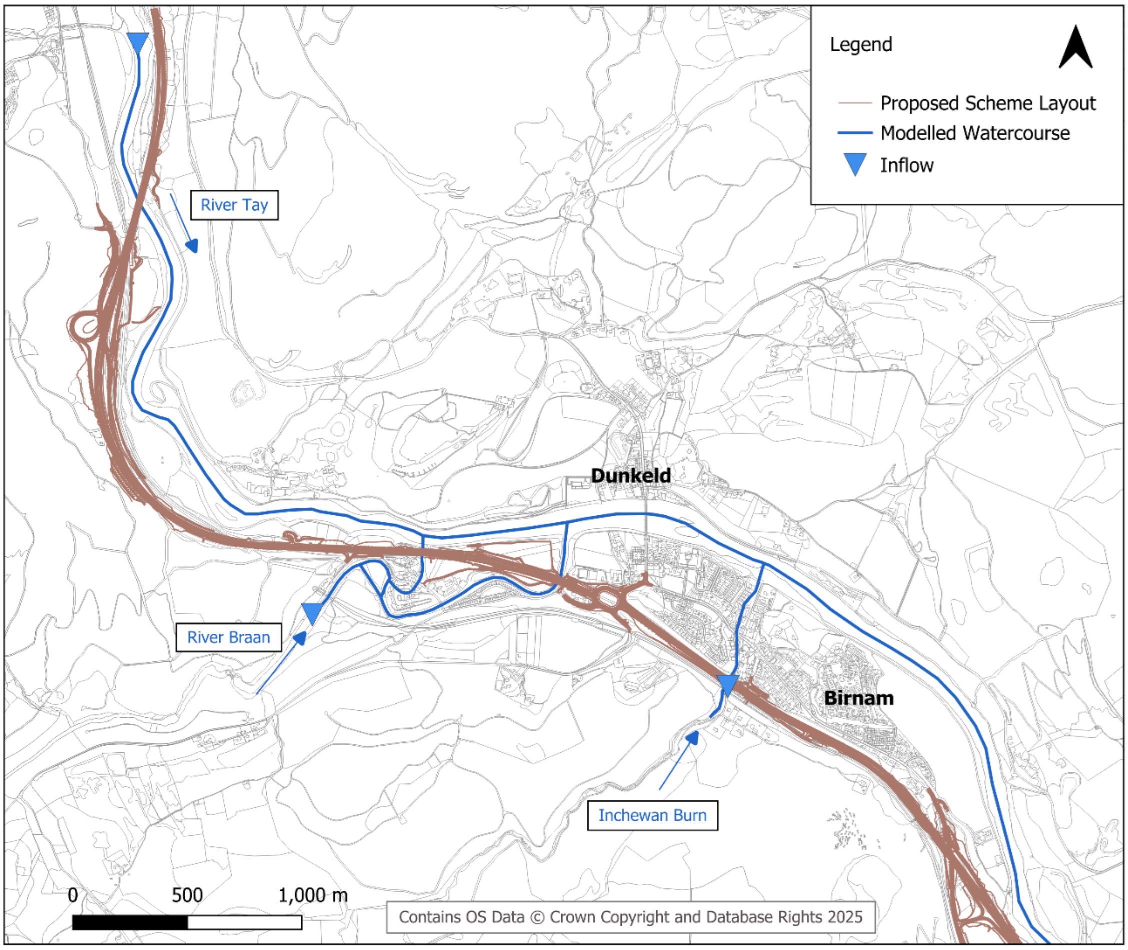
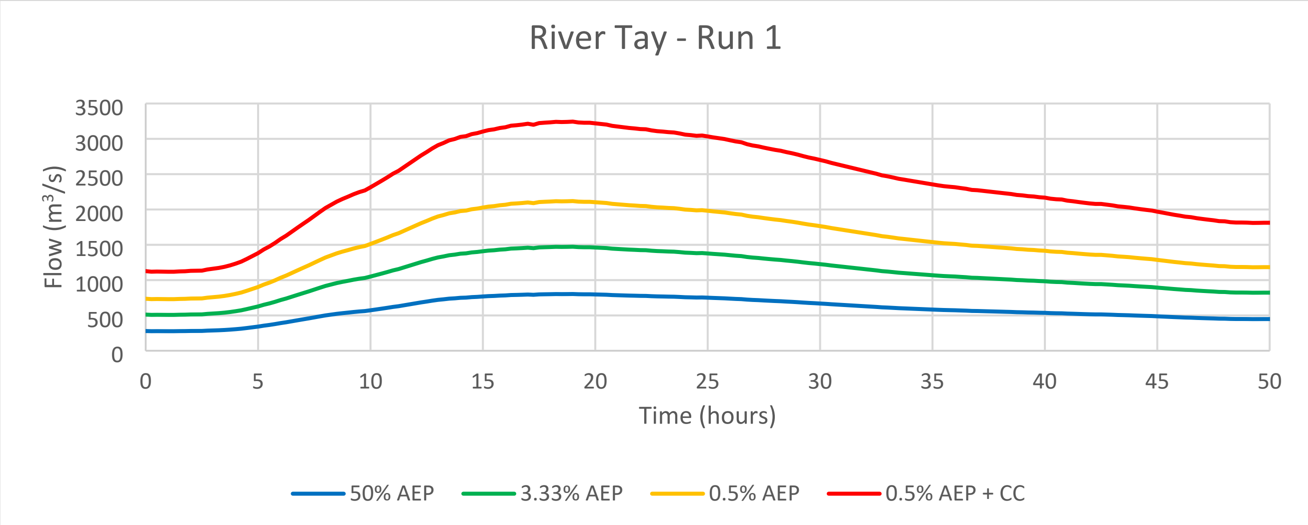
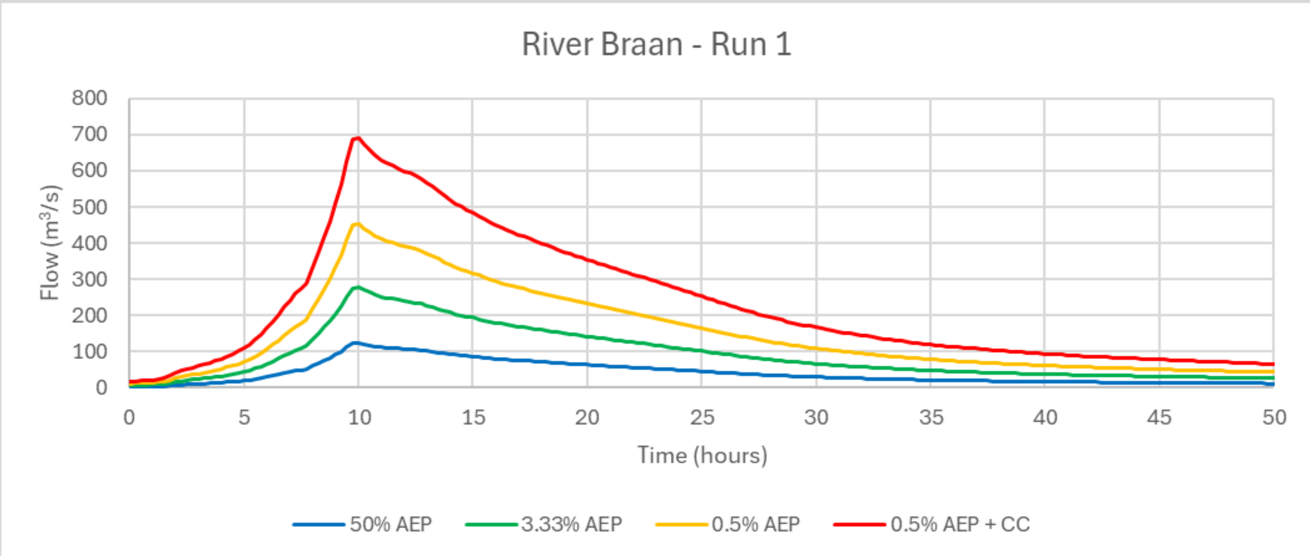


Figure A19.2-E.2: River Tay, River Braan and Inchewan Burn Inflows

Table 19.2-E.2: Peak Hydrological Inflows at Key Locations

LOCATION	DESCRIPTION	PEAK FLOW (M^3/S)							
		RUN 1				RUN 2			
		AEP 50%	AEP 3.33%	AEP 0.5%	AEP 0.5% + CC	AEP 50%	AEP 3.33%	AEP 0.5%	AEP 0.5% + CC
RIVER TAY	Peak flow at the upstream end of the modelled reach, at Inchmagrannachan, 725m upstream of the existing A9 crossing, at National Grid Reference (NGR) 300459, 744541	803	1473	2120	3243	803	803	803	803
RIVER BRAAN	Peak flow at the upstream end of the modelled reach, 100m upstream of the railway bridge (NGR 301,225, 742,030)	124	277	452	691	125	287	472	722
INCHEWAN BURN	Peak flow at the upstream end of the modelled reach, 128m upstream of the railway bridge (NGR 302,960, 741,581)	2.37	5.33	8.12	12.43	2.97	6.76	10.61	15.56





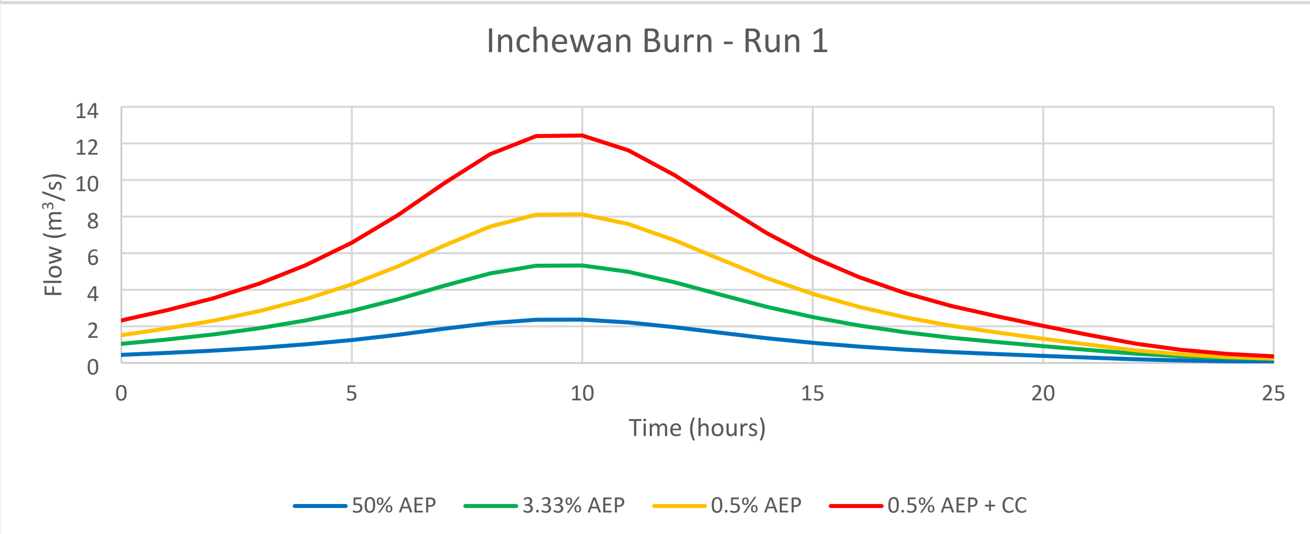
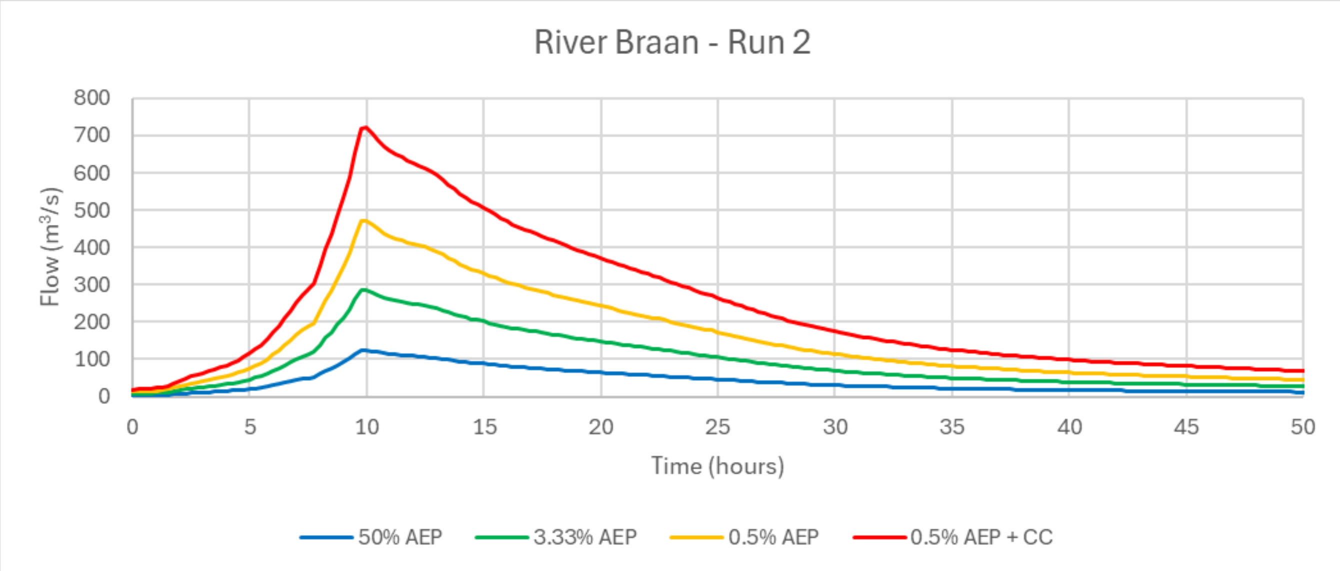


Figure A19.2-E.3: Inflow hydrographs (Run 1)



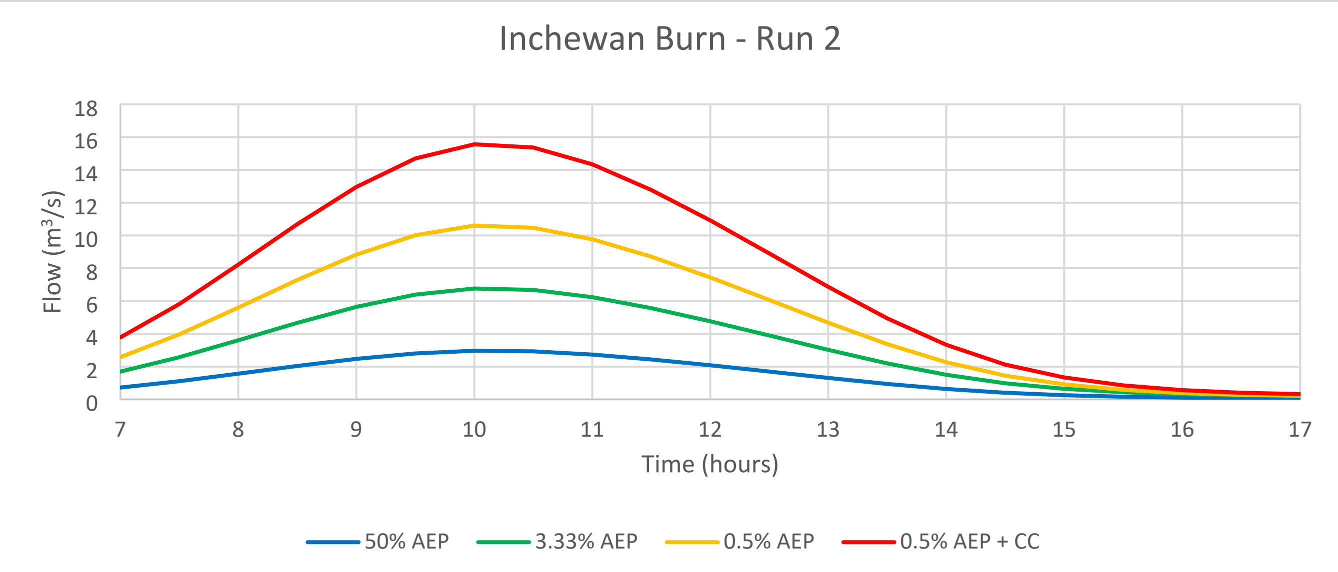


Figure A19.2-E.4: Inflow hydrographs (Run 2)

3.1.6 Run 1 modelled flows at the downstream end of the model were reconciled with the target flows provided by the hydrology team applying scaling factors to the model inflows. The results of the reconciliation process are reported in Table A19.2-E.3.

Table A19.2-E.3: Flow Reconciliation

LOCATION	DESCRIPTION	PEAK FLOW (M^3/S)			
		AEP 50%	**AEP 3.33%**	**AEP 0.5%**	**AEP 0.5% + CC**
RIVER TAY (MODELLED FLOWS)	Peak flow at the downstream end of the model (NGR 305,368, 740,036), used for the reconciliation of the routed flow through the model	873	1628	2375	3634
RIVER TAY (TARGET FLOWS)	Tay at Downstream End of the model	862	1580	2274	3479
DIFFERENCE (%)		**+1**	**+3**	**+4**	**+4**

4. Baseline Modelling

4.1 General

4.1.1 The baseline model comprises of channels and structures represented within Flood Modeller and the 2D schematisation of the floodplain represented in TUFLOW.

4.2 Watercourse Schematisation – Flood Modeller (1D)

4.2.1 Three principal watercourses have been modelled in 1D using Flood Modeller: River Tay, River Braan and the Inchewan Burn (refer back to Figure A19.2-E.1 for locations).

In-Channel Geometry

4.2.2 Surveyed river cross section data (mostly inherited from the URS 2013 model) has been used to inform the in-channel geometry of the watercourses modelled in Flood Modeller. The locations of the surveyed river cross sections are shown in Figure A19.2-E.5. To aid model performance interpolated cross sections were added between the surveyed cross sections where needed.

4.2.3 Table A19.2-E.4 shows the upstream and downstream Flood Modeller nodes associated with the modelled watercourses. Node labels at key locations are provided in Figure A19.2-E.5.

Table A19.2-E.4: Upstream and downstream Flood Modeller nodes for each watercourse

WATERCOURSE	UPSTREAM NODE	DOWNSTREAM NODE	DOWNSTREAM NODE LOCATION
RIVER TAY	SECT_T_1	SECT_T_39	At the model downstream boundary
RIVER BRAAN	BR_1	BR_33_CON	Confluence with the River Tay
INCHEWAN BURN	IN_0.1	IN_23	Confluence with the River Tay
MILL LADE	BR_36	BR_45A	Downstream end of culvert discharging into to the River Tay

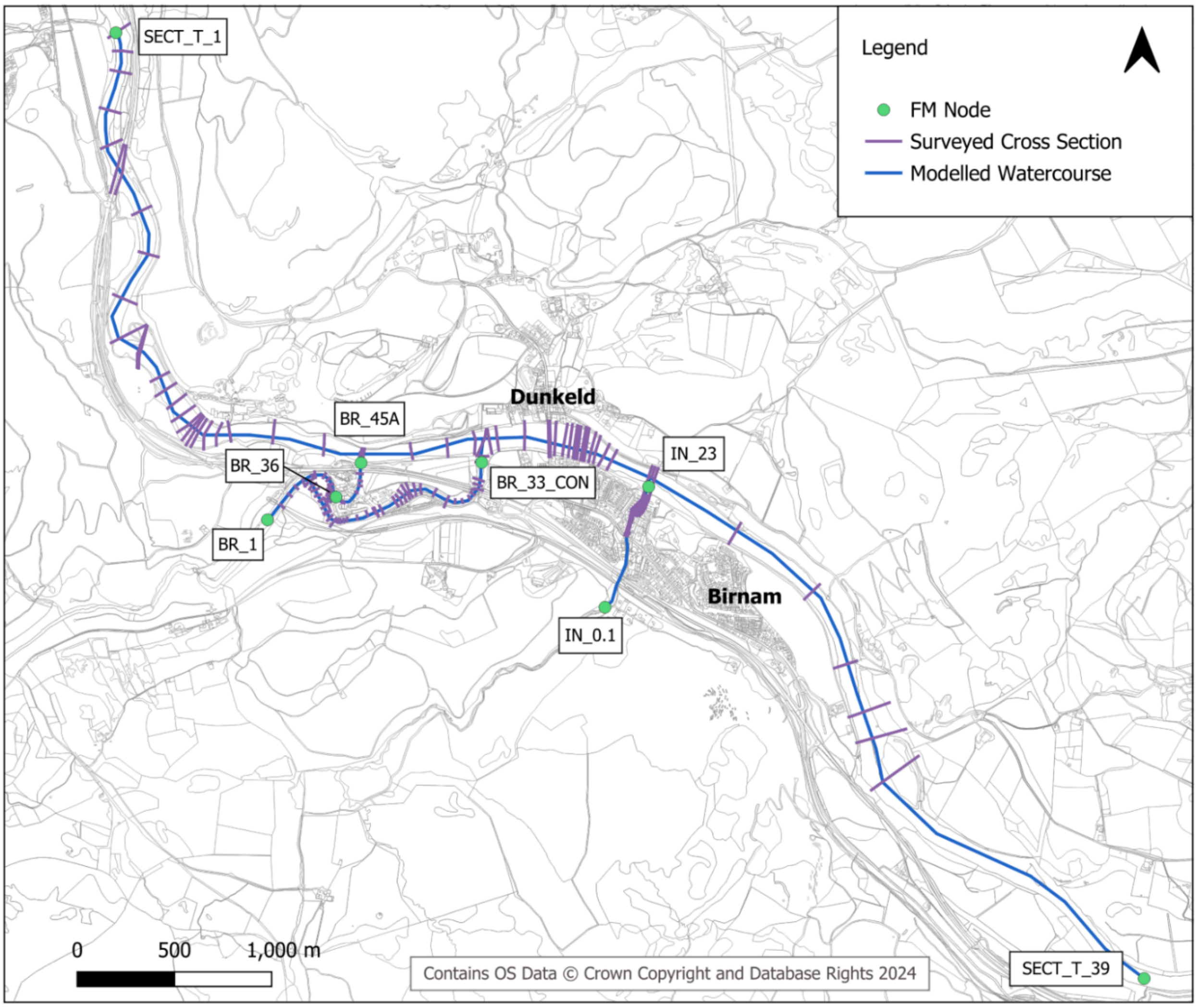


Figure A19.2-E.5: Flood Modeller nodes at key locations and surveyed cross sections

In-Channel Hydraulic Friction

4.2.4 Hydraulic roughness (Manning's 'n' coefficient) values were determined primarily using photographs taken during a site visit. Typical photos for each watercourse are shown in Figure A19.2-E.6. The in-channel coefficients used are shown in Table A19.2-E.5. Roughness values adopted were taken from standard guidance (Chow, 1959).

Figure A19.2-E.6: Channel Material for the Inchewan Burn (top left), River Braan (top right) and River Tay (bottom left)

Table A19.2-E.5: In-Channel Manning's 'n' Coefficients

WATERCOURSE	MANNING'S 'N'	BED MATERIAL
RIVER TAY	0.035	Large river with straight reaches. River bed with gravels, cobbles, and few boulders.
RIVER BRAAN	0.040	Main channel slightly meandering with some pools and shoals. River bed with gravels and cobbles.
INCHEWAN BURN	0.050	Mountain stream, no vegetation in channel, banks usually steep. River bed with gravels and few boulders.

In-Channel Hydraulic Structures

4.2.5 The in-channel hydraulic structures included in the 1D model extent are specified in Table A19.2-E.6 and locations are shown by reference number in Figure A19.2-E.7.

Table A19.2-E.6: In-channel Hydraulic Structures (Represented in Flood Modeller)

REFERENCE NO.	WATERCOURSE	STRUCTURE	FLOOD MODELLER NODE	DESCRIPTION
1	River Tay	River Tay Bridge	TAY_BR_US	Type: USBPR Spans: 3 Total Width: 224.7m Soffit Level: 58.46 mAOD
2	River Tay	Dunkeld Bridge	DUN_BR_US	Type: Arch Spans: 7 Total Width: 167.3m Lowest Soffit Level: 54.34 mAOD
3	River Braan	Braan Rail Bridge	RAILBR_1	Type: Arch Spans: 4 Total Width: 85.7m Lowest Soffit Level: 60.25 mAOD
4	River Braan/Mill Stream	Mill Lade Stream Conduit (1)	LADECUL1_0	Type: Sprung Arch Conduit Length: 5m Width: 2.9m Height: 0.98m Upstream Invert Level: 52.63 mAOD Downstream Invert Level: 52.71 mAOD
5	River Braan/Mill Stream	Mill Lade Stream Conduit (2)	LADECUL2_0	Type: Sprung Arch Conduit Length: 68.3m Width: 2.9m Height: 1.36m Upstream Invert Level: 48.51 mAOD Downstream Invert Level: 48.34 mAOD
6	River Braan/Mill Stream	Mill Lade Stream Conduit (3)	A9CUL1_0	Type: Rectangular Length: 40.6m Width: 3.5m Height: 1.997m

REFERENCE NO.	WATERCOURSE	STRUCTURE	FLOOD MODELLER NODE	DESCRIPTION
				Upstream Invert Level: 47.94 mAOD Downstream Invert Level: 47.65 mAOD
7	River Braan	Inver Bridge	INVER_BR	Type: Arch Spans: 2 Total Width: 30.8m Lowest Soffit Level: 55.02 mAOD
8	River Braan	Footbridge	FOOT_BR	Type: Arch Spans: 3 Total Width: 38.3m Lowest Soffit Level: 49.35 mAOD
9	River Braan	A9 Bridge	A9_BRAAN	Type: USBPR Spans: 1 Total Width: 29.0m Soffit Level: 51.39 mAOD
10	Inchewan Burn	Bridge (1)	IN_4_BR_U	Type: Arch Spans: 2 Total Width: 12.3m Lowest Soffit Level: 65.38 mAOD
11	Inchewan Burn	Bridge (2)	IN_6_BR_U	Type: Arch Spans: 2 Total Width: 31.2m Lowest Soffit Level: 64.95 mAOD
12	Inchewan Burn	Conduit (1)	IN_13_CUL_1	Type: Rectangular Length: 20.3m Width: 3.9m Height: 1.90m Upstream Invert Level: 50.93 mAOD Downstream Invert Level: 50.66 mAOD

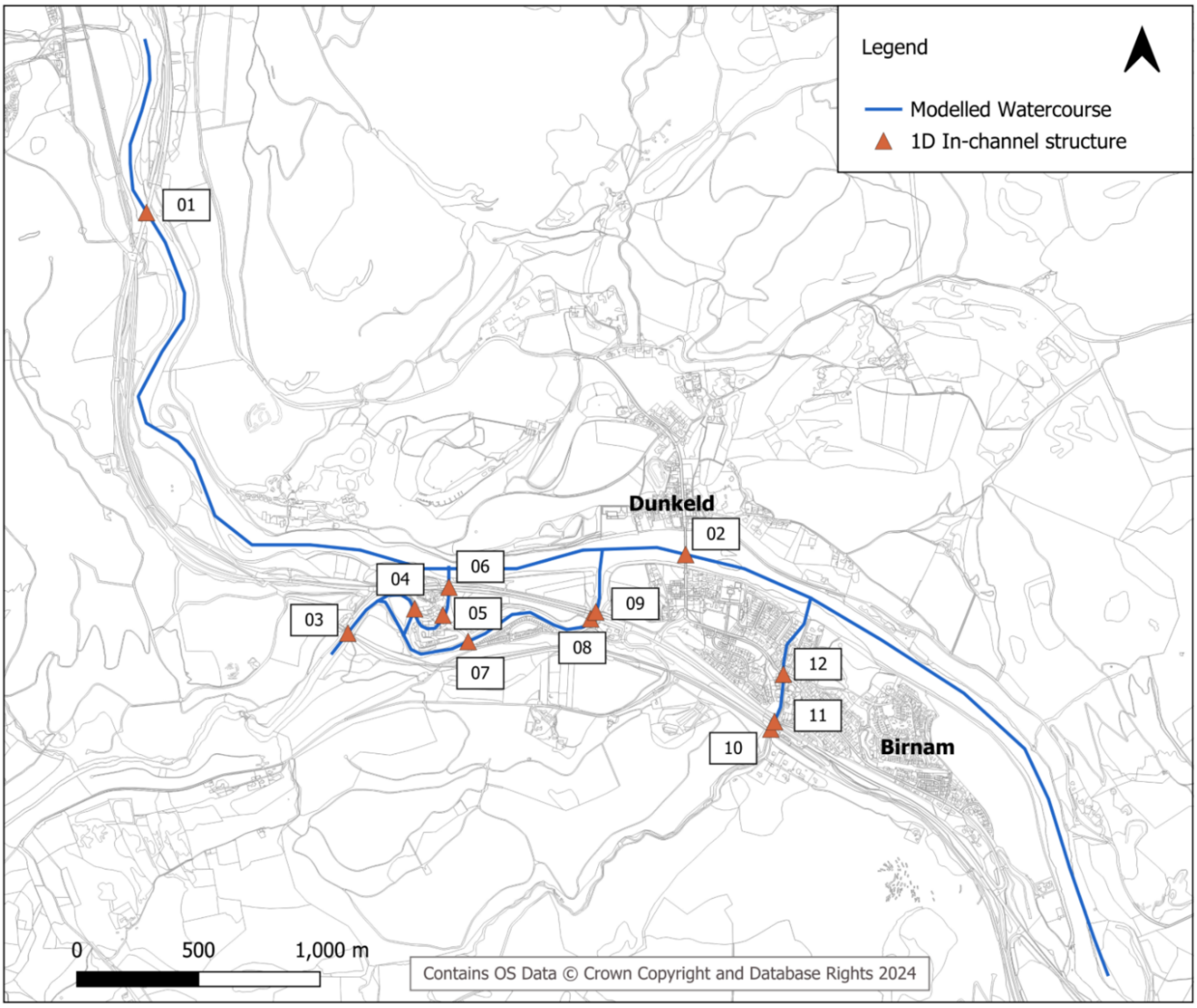


Figure A19.2-E.7: In-Channel Hydraulic Structures (Represented in Flood Modeller), Reference numbers provided in Table A19.2-E.6.

Boundary Conditions – 1D Domain

4.2.6 The upstream and downstream boundary conditions applied to the 1D domain for each modelled reach are described in Table A19.2-E.7 (refer back to Figure A19.2-E.2 for locations).

Table A19.2-E.7 Boundary Conditions in 1D Domain

TYPE OF BOUNDARY	FLOOD MODELLER NODE	DESCRIPTION
FLOW-TIME BOUNDARY	SECT_T_1	Hydrological inflow applied at the upstream end of the model on the River Tay
FLOW-TIME BOUNDARY	BR_1	Hydrological inflow applied at the upstream end of the model on the River Braan
FLOW-TIME BOUNDARY	IN_0.1	Hydrological inflow applied at the upstream end of the model on the Inchewan Burn
NORMAL DEPTH BOUNDARY	SECT_T_39	Downstream end of the model on the River Tay

4.3 Floodplain Schematisation – TUFLOW (2D)

4.3.1 Most of the floodplain areas have been represented in 2D using TUFLOW except for a couple of sections of the River Tay and River Braan where a 1D representation has been adopted using extended river cross-sections in the 1D Flood Modeller model. These are:

- River Tay both left and right floodplain, from model node SECT_T_35d to model node SECT_T_39 (downstream end of the model).
- The right bank of a 175m reach of the River Braan immediately upstream of the Braan Bridge is not connected to the 2D domain. This is because the right bank along this reach is particularly high preventing any out of bank flooding into the right-hand flood plain.

Floodplain Topography

4.3.2 The 2D domain covers an area of 4.23 km^2 as shown in Figure A19.2-E.8. The topography is represented using a 4m resolution square grid. The levels for the topography grid cells are based on a 1m resolution Digital Terrain Model (DTM) derived from LiDAR 2018.

4.3.3 Appropriate use has been made of 2D breaklines and elevation polygons (z-shapes) to accurately represent roads, drains and ridges where they have a significant impact on flow across the floodplain.

4.3.4 Table A19.2-E.8 summarises all the model layers used to modify the floodplain topography.

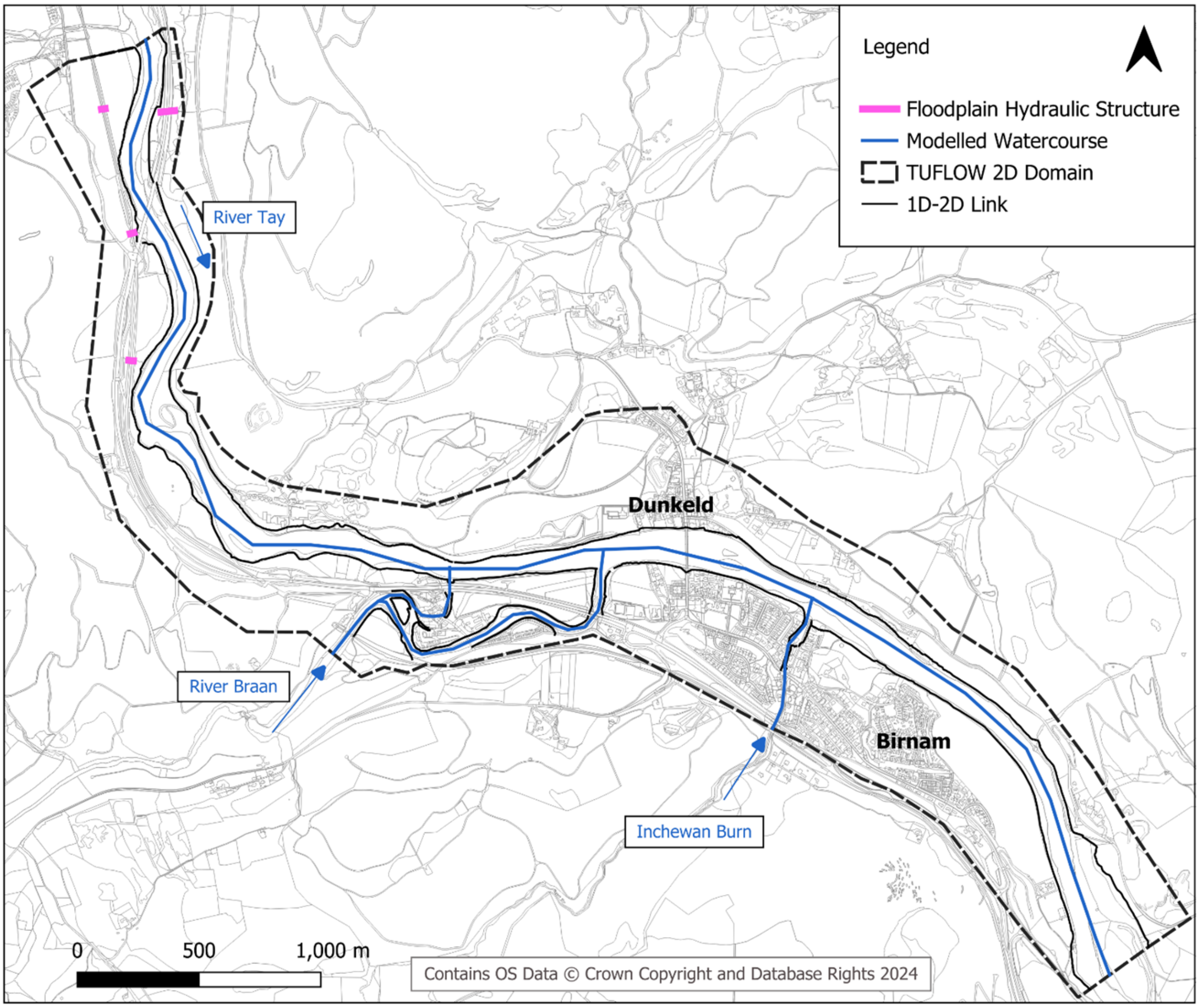


Figure A19.2-E.8: TUFLOW Baseline Schematisation

Table A19.2-E.8: GIS layers used to inform the 2D model with floodplain topography

MODEL LAYER	COMMENT
DTM_1M_MERGED_TRIM.ASC	Digital Terrain Model
2D_ZPATCH_BUILDINGS.MIF	To 'fill in' bridge decks which have a non-variable level, i.e. single level to represent deck
2D_ZLINE_BRAAN_BANK_02.MIF 2D_ZLINE_DRAIN.MIF 2D_ZLINE_LADESPILLS_01.MIF 2D_ZLINE_TAY_BANK_02.MIF 2D_ZLINE_TAY_UNSURV_BANKTOPS_V10.MIF 2D_ZLINE_BRAAN_UNSURV_BANKTOPS_V3.MIF 2D_ZLINE_INCH_UNSURV_BANKTOPS_V4.MIF 2D_ZLINE_INCH_ISIS_BANKTOPS_V4.MIF	Reinforcing top of banks along the watercourses modelled in 1D
2D_ZSH_MINORWC_001.MIF	Reinforcing bed levels of some minor watercourses
2D_ZTIN_ISLAND.MID 2D_ZTIN_EXISTINGA9.MID 2D_ZTIN_PATCH_01.MID 2D_ZTIN_INCHEWAN_01.MID	Defining 3D shapes for changing the elevation based on collected topographic survey data

Floodplain Hydraulic Roughness

4.3.5 Hydraulic roughness coefficients are applied across each cell of the 2D domain depending on land use taken from OS Mastermap data, as shown in Table A19.2-E.9.

4.3.6 Roughness values adopted were taken from standard guidance (Chow, 1959).

Table A19.2-E.9: Manning's 'n' Coefficients – 2D Domain

LAND USE	MANNING'S 'N'
WATER BODIES	0.020
ROADS, TRACKS AND PATHS	0.020
INLAND WATER	0.035
WOODLAND	0.100
GLASSHOUSES	0.300

LAND USE	MANNING'S 'N'
RAILWAY	0.040
GENERAL GREEN AREAS	0.055
BUILDINGS	1.000
UNCLASSIFIED	0.040

Floodplain Hydraulic Structures

4.3.7 Hydraulic structures in the floodplain (2D) were included where they were considered important for flow connectivity and flood risk using 1D ESTRY culverts. Details are provided in Table A19.2-E.10. Dimensions and levels for these structures have been informed by either survey data or site visit notes.

Table A19.2-E.10: Floodplain Hydraulic Structures Represented in ESTRY

MODEL ID	TYPE	DIMENSIONS (M)	LENGTH (M)	UPSTREAM INVERT LEVEL (MAOD)	DOWNSTREAM INVERT LEVEL (MAOD)
RLW7	R	2.75 x 2.95	4	52.27	52.25
RLW_WC13	R	3.20 x 3.00	13	51.75	51.15
RLW_WC14	R	1.80 x 2.00	11	52.50	52.08
RLW_WC16	C	1.20	47.46	54.27	52.50

Boundary Conditions – 2D Domain

4.3.8 No inflow has been applied directly to the 2D domain. Any flow across the 2D domain is a result of the 1D channel being overtopped. No 2D boundaries have been applied at the downstream end of the 2D domain as all flow returns to the 1D domain.

1D/2D Linking

4.3.9 The link between the 1D and the 2D domains was defined along the banks of the watercourses represented in Flood Modeller using HX connections.

4.3.10 SX links were also used to connect the 1D ESTRY components for the floodplain structures to the 2D domain.

5. Proposed Scheme

5.1 Proposed Scheme Arrangement

5.1.1 Figure A19.2-E.9 shows the layout of the proposed scheme. The modifications to the baseline model for the inclusion of the proposed scheme include the widening of the existing A9 from single to dual carriageway standards over the entire length of the section; additional road side junctions updates to the road elevations and roughness values along the scheme footprint; inclusion of Sustainable Drainage System (SuDS) features within the floodplain; updates to the dimensions, lengths and invert levels for the existing A9 culverts; updates to the dimensions of existing A9 bridges; and the removal of an existing footbridge.

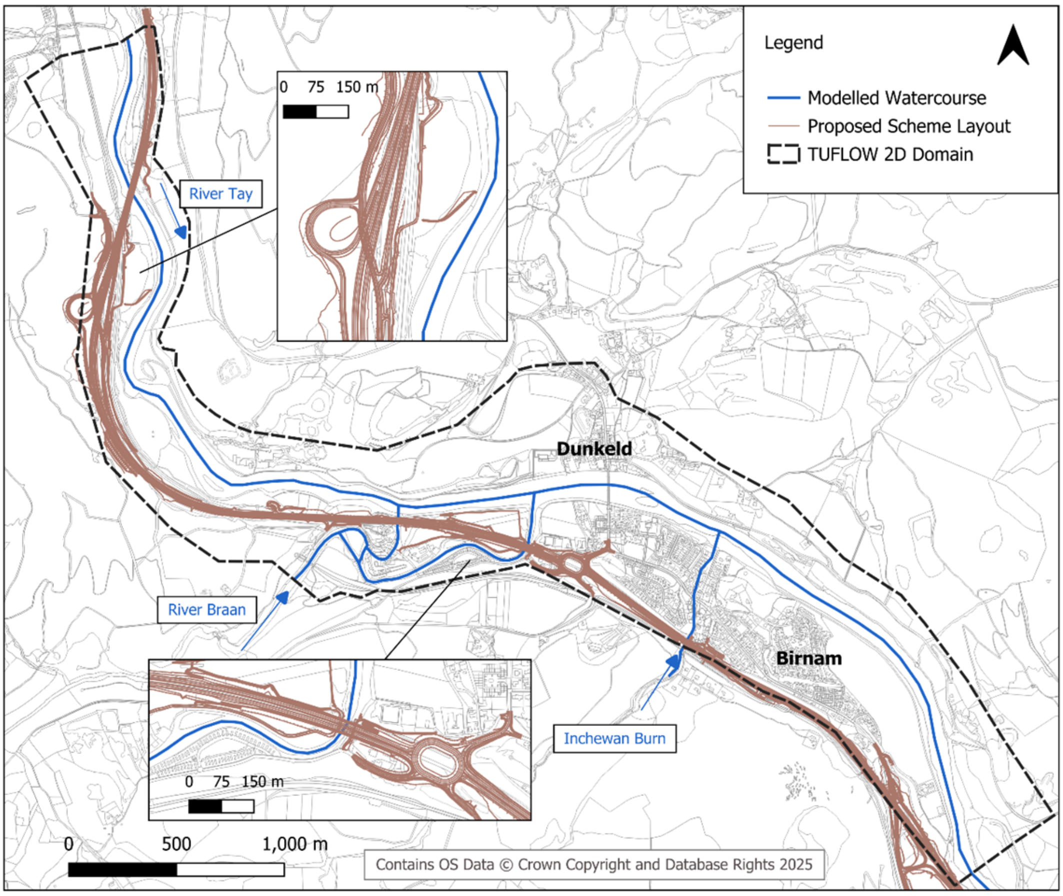


Figure A19.2-E.9: Stage 3 Design Fix 8 Proposed Scheme Alignment

5.2 Flood Modeller Updates

5.2.1 The proposed scheme crosses each of the three main watercourses. At each of these crossings, the existing hydraulic structures have been modified to fit the widened road footprint. The modifications at these structures are provided in Table A19.2-E.11.

Table A19.2-E.11: Flood Modeller Hydraulic Structure Updates

WATERCOURSE	STRUCTURE	FLOOD MODELLER NODE	MODIFICATIONS
RIVER TAY	A9 Bridge (North)	TAY_BR_US	The existing A9 Bridge is retained to carry the proposed northbound carriageway and a new structure added to provide the southbound carriageway. The existing bridge unit in the 1D model has been amended to account for both bridges. The representation of the new bridge assumes a total span of 224.7m and a soffit level of 57.57mAOD.
MILL STREAM	Culvert	A9CUL1_0	The 3.5 wide x 2m high box culvert under the A9 has been extended to 42.6m to accommodate the wider road embankment.
RIVER BRAAN	A9 Bridge	A9_BRAAN	The existing A9 Bridge will be demolished and replaced by a new structure. The 1D structure representing the bridge has been amended to a single span of 52.83m and a soffit level of 54.28mAOD
RIVER BRAAN	Footbridge	FOOT_BR	The existing structure is to be removed entirely. The 1D model component representing the footbridge has been removed.
INCHEWAN BURN	Bridge	-	The existing bridge on the Inchewan Burn is to be demolished and replaced by a new two-span structure which spans the Birnam Glen Road and the Inchewan Burn: 8.0m & 18.8m, respectively. The proposed structure sits clear of the flood levels so there is no need to represent it in the 1D model of the watercourse.

5.3 TUFLOW Updates

5.3.1 The proposed scheme elevations were exported from the Civil 3D software as raster grids (GeoTIFF), for inclusion in the hydraulic model. Within the footprint of the proposed scheme these raster grids replaced the ground elevation with the elevations for the road embankments (as ASCII raster). The surface roughness values within the proposed scheme footprint were also updated.

5.3.2 Eight SuDS ponds are included in the proposed scheme with the size, shape and position of the ponds as per Design Fix 8 of the DRMB Stage 3 process. These have been included in the model with no initial water level set such that the ponds are empty at the start of the simulation. A sensitivity check was carried out with the SuDS ponds full at the start of the simulation which demonstrated no impact on the water level difference grids. The detention ponds were designed to be fully floodable above a 3.33% AEP event.

5.3.3 The proposed road embankment impinges on the edge of the floodplain at Birnam, where amendments are required to accommodate the sewage treatment works access road, and to the north of the Hermitage Junction. In addition, the existing road embankment at Inver is to be raised and widened, reducing the storage in the existing floodplain. The 2D hydraulic model domain has been adjusted to model the effects of these three areas of floodplain loss.

6. With Mitigation Modelling

6.1.1 The proposed scheme was found to increase flood risk in a number of locations, as presented in Appendix A19.2(Flood Risk Assessment). Multiple mitigation options have been tested to try and reduce flood risk in these areas back to baseline flood levels. The following section discusses the final options which have been incorporated into the proposed scheme. A full list of the tested options can be found in Annex E2.

6.1.2 Table A19.2-E.12 lists the locations where increased flood risk has been identified and the consequent mitigation measures which have been incorporated into the proposed scheme model in order to resolve these issues. The locations are shown in Figure A19.2-E.10.

Table A19.2-E.12: Locations with increased flood rick and the proposed mitigation measures

LOCATION	EVENT	CHANGE IN FLOOD RISK	PROPOSED MITIGATION MEASURE
INVER FLOODPLAIN	Run 1 - 0.5% AEP + CC	Increased road footprint encroaches on floodplain for water spilling out of the River Braan whilst increased height of proposed carriageway prevents overtopping, leading to increased water levels within Inver floodplain.	14no. 3.6m x 1.2m Flood Relief Culverts constructed through proposed embankment (level of culverts set to existing carriageway level – 52.1mAOD). The culverts will only operate during the Run 1 0.5% AEP + CC flood event, replicating the existing flood path over the A9 carriageway. These have been modelled as 14no. separate culverts using Tuflow 1d_nwk.
UPSTREAM OF TAY BRIDGE	Run 1 - 0.5% AEP + CC	Increased road footprint results in loss of functional flood plain, leading to increased flood water depth upstream of the Tay Bridge on the left bank of the River	Although feasible it has been considered impractical to construct a c.1200-2600 mm flood wall (including 600mm freeboard) required to protect the

LOCATION	EVENT	CHANGE IN FLOOD RISK	PROPOSED MITIGATION MEASURE
		Tay. Flood water overtops the existing carriageway under the baseline scenario 0.5% AEP + CC flood event.	scheme from flooding at this location. As Project 03 (A9 from Dowally Junction to Ballinluig) is designed to the 0.5%AEP plus 20%CC event, the road will be closed to north and southbound traffic during the design event. It is impractical to raise the road elevation due to the highway geometry and tie in with the Tay Crossing. Given the challenges of a flood defence solution and the necessary closure of the northern section of the A9 from Dowally Junction to Ballinluig, it has been considered appropriate to mitigate this risk through a Road Closure Plan.
UPSTREAM BRAAN BRIDGE	Run 2 – 3.33% AEP	Increased road footprint results in loss of functional floodplain, leading to increased flood water depth immediately upstream of the Braan Bridge (left bank).	Currently no mitigation incorporated into the design since adverse flood impact is located within the CPO boundary and no receptors are at risk.
DOWNSTREAM BRAAN BRIDGE	Run 2 – 0.5% AEP + CC	Increased road footprint results in loss of functional floodplain, leading to	Compensatory Flood Storage proposed between right bank of River Tay and A9

LOCATION	EVENT	CHANGE IN FLOOD RISK	PROPOSED MITIGATION MEASURE
		increased flood water depth immediately downstream of the Braan Bridge (left bank).	Carriageway to mitigate loss of functional floodplain.
MILL LADE	Run 1 – 0.5% AEP + CC	Increased road footprint results in loss of functional floodplain, leading to increased flood water depth on both left and right bank of the Mill Lade upstream of the A9 carriageway.	3no. 1.5m diameter Flood Relief Culverts proposed to convey additional floodwater within the Inver floodplain through the A9 carriageway into the River Tay.

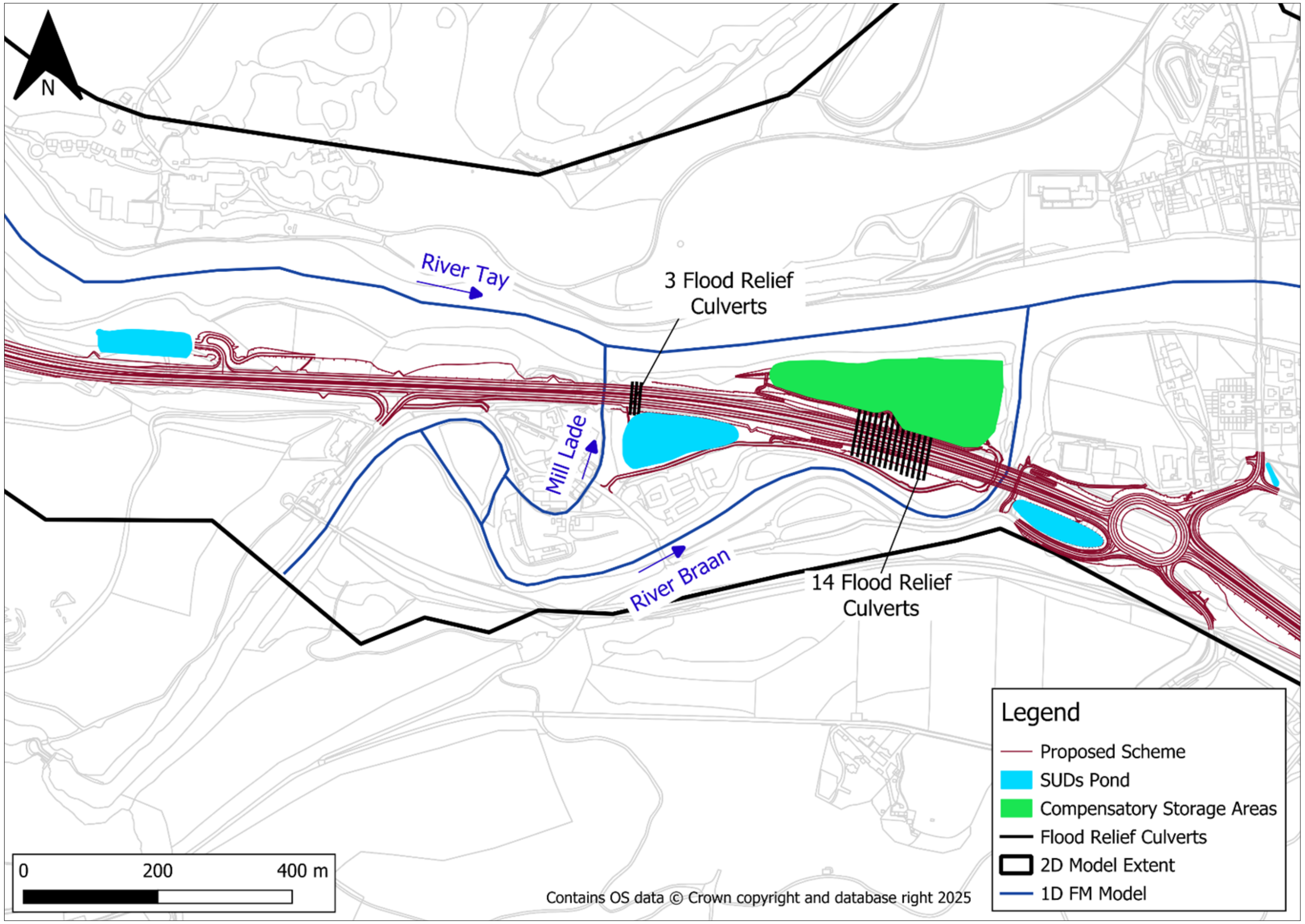


Figure A19.2-E.10: Proposed mitigation measures

7. Modelled Events

7.1.1 Table A19.2-E.13 shows the AEP flood events and model scenarios that were simulated with the hydraulic model. The table shows the final model scenarios only and does not include the large number of mitigation tests which have been completed. These are summarised in Annex E2.

Table A19.2-E.13: Modelled Events

SCENARIO	AEP EVENT			
	50% (2-YEAR)	3.33% (30-YEAR)	0.5% (200-YEAR)	0.5% (200-YEAR) + CC
BASELINE – RUN 1 HYDROLOGY	x	x	x	x
BASELINE – RUN 2 HYDROLOGY	x	x	x	x
ROUGHNESS SENSITIVITY +/-20%			x	
HYDROLOGICAL INFLOW SENSITIVITY +/-20%			x	
DOWNSTREAM BOUNDARY SENSITIVITY +/-20%			x	
PROPOSED SCHEME – RUN 1 HYDROLOGY		x	x	x
PROPOSED SCHEME – RUN 2 HYDROLOGY		x	x	x
WITH MITIGATION – RUN 1 HYDROLOGY	x	x	x	x
WITH MITIGATION – RUN 2 HYDROLOGY	x	x	x	x

8. Model Proving

8.1 Model Performance

8.1.1 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 for which the variation of the found solution between successive iterations is either zero or negligibly small and lies within a pre-specified tolerance limit.

8.1.2 It was found to be necessary to adjust some of the Flood Modeller Advanced Parameters to allow completion of the simulations for the large magnitude events such as the 0.5% AEP (200-year) plus CC (+53% allowance) event. These were dflood, minitr, and maxitr, and justification for their changes is given in Table A19.2-E.14.

Table A19.2-E.14: Advanced Parameter changes

PARAMETER	DEFAULT VALUE	BASELINE 0.5% AEP PLUS CC VALUE	SCHEME 0.5% AEP PLUS CC VALUE	JUSTIFICATION
DFLOOD	3	15	10	Significant transfer of water from 1D to 2D domain with rapidly rising water levels and maximum depths
MINITR	3	4	4	Small increase due to initial model instabilities
MAXITR	11	31	29	Large increase to due to considerable model instabilities detailed below

8.1.3 High flows associated with the Run 1 0.5% AEP (200- year) plus CC event caused model instabilities in baseline and proposed scheme scenarios from the confluence of the Rivers Tay and Braan, to Dunkeld Bridge. This resulted in rapidly oscillating water levels which gave erroneous water level difference results between baseline and proposed scheme. To rectify this a roughness patch with a value 0.5 was placed at the instability location on the left bank of the Tay which solved the issue.

8.1.4 As shown in Figure A19.2-E.11, Run 2 baseline 1D model convergence is good. However, the Run 1 baseline 0.5% AEP (200-year) plus CC (+53% allowance) model simulation experiences poor model convergence for approximately 16 hours. The poor model convergence was investigated and was attributed to the small footbridge located upstream of the Braan Bridge which is surcharged during the flood event. Sensitivity tests were carried out in which model schematisation was slightly amended in the vicinity of the foot bridge. These concluded that the poor model convergence is very localised to the small footbridge on the River Braan and has a negligible impact on peak water levels within the floodplain. Therefore, this was deemed acceptable.

8.1.5 Figure 19.2-E.12 and Figure 19.2-E.13 illustrate the model performance for the Baseline 0.5% AEP (200-year) flood event and Proposed Scheme (with mitigation) 0.5% AEP (200-year) plus CC. The model performance across these simulations is good, with isolated timesteps where poor model convergence is observed.

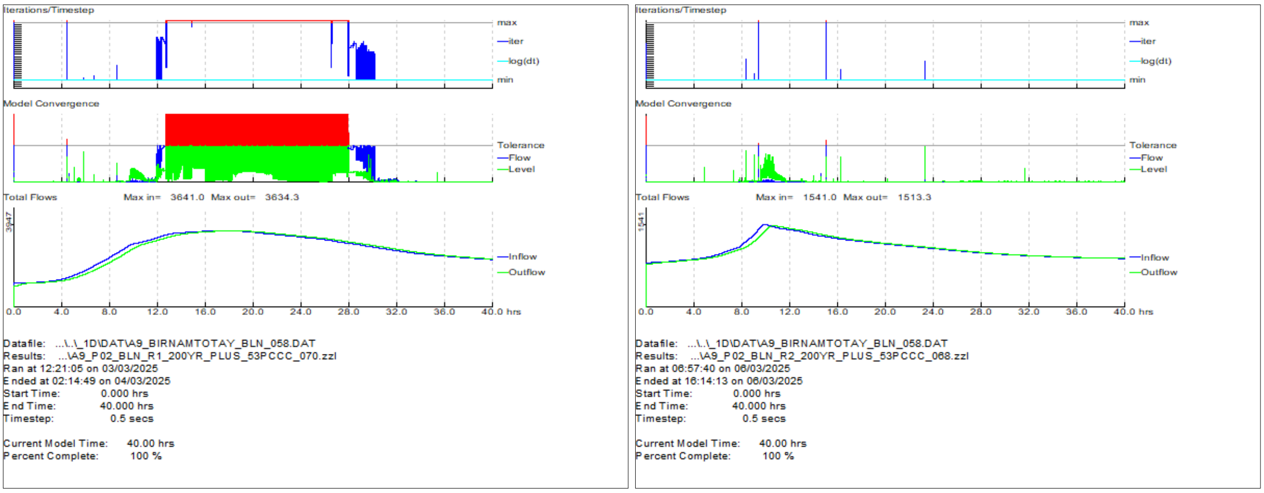


Figure A19.2-E.11: Flood Modeller 1D Model Convergence Plots for the Baseline Run 1 – 0.5% AEP plus CC Event (left) and Run 2 – 0.5% AEP plus CC Event (right)

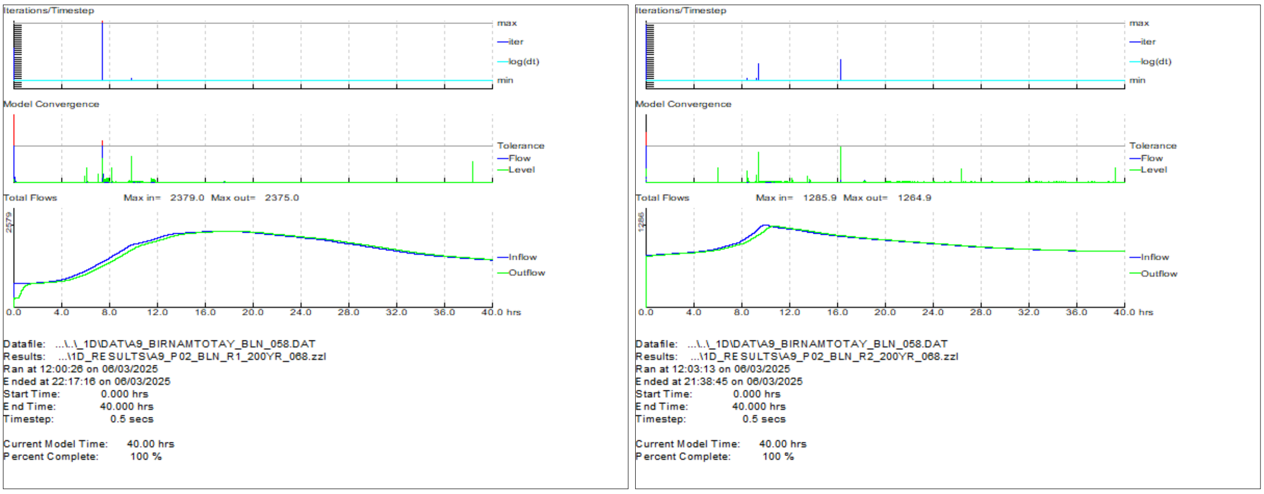


Figure A19.2-E.12: Flood Modeller 1D Model Convergence Plots for the Baseline Run 1 – 0.5% AEP Event (left) and Run 2 – 0.5% AEP Event (right)

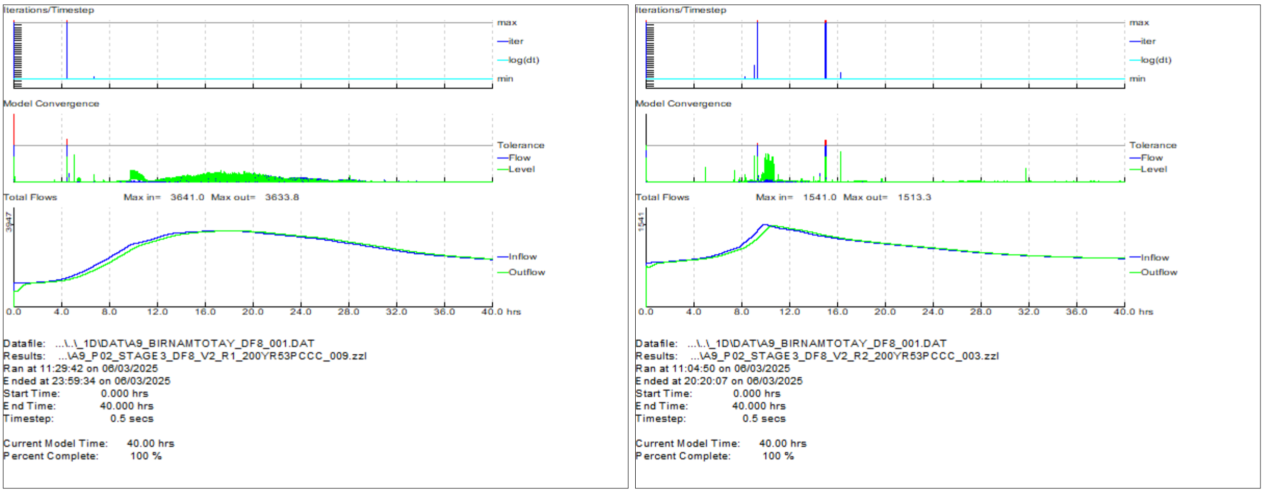


Figure A19.2-E.13: Flood Modeller 1D Model Convergence Plots for the Scheme Run 1 – 0.5% AEP +CC Event (left) and Run 2 – 0.5% AEP + CC Event (right)

8.1.6 The cumulative mass error reports output from the TUFLOW 2D model have been checked for all simulated events. The accepted tolerance range recommended by the software manual is +/- 1% mass balance error. Figure A19.2-E.14 shows that for both Run 1 and Run 2 0.5% AEP (200-year) plus CC flood event, the cumulative mass error is well within the tolerance range for the duration of the run. This mass error diagnostic is typical for all events simulated.

8.1.7 Smooth variation of the change in volume through the model simulation can be another indicator of good convergence of the 2D model, however Figure A19.2-E.14 shows that in this model there is considerable fluctuation in the change in volume. This effect is actually caused by fluctuations in the hydrological inflow hydrographs as a result of using a hydrograph shape based on a historic flood event and is not related to the model numerical performance.

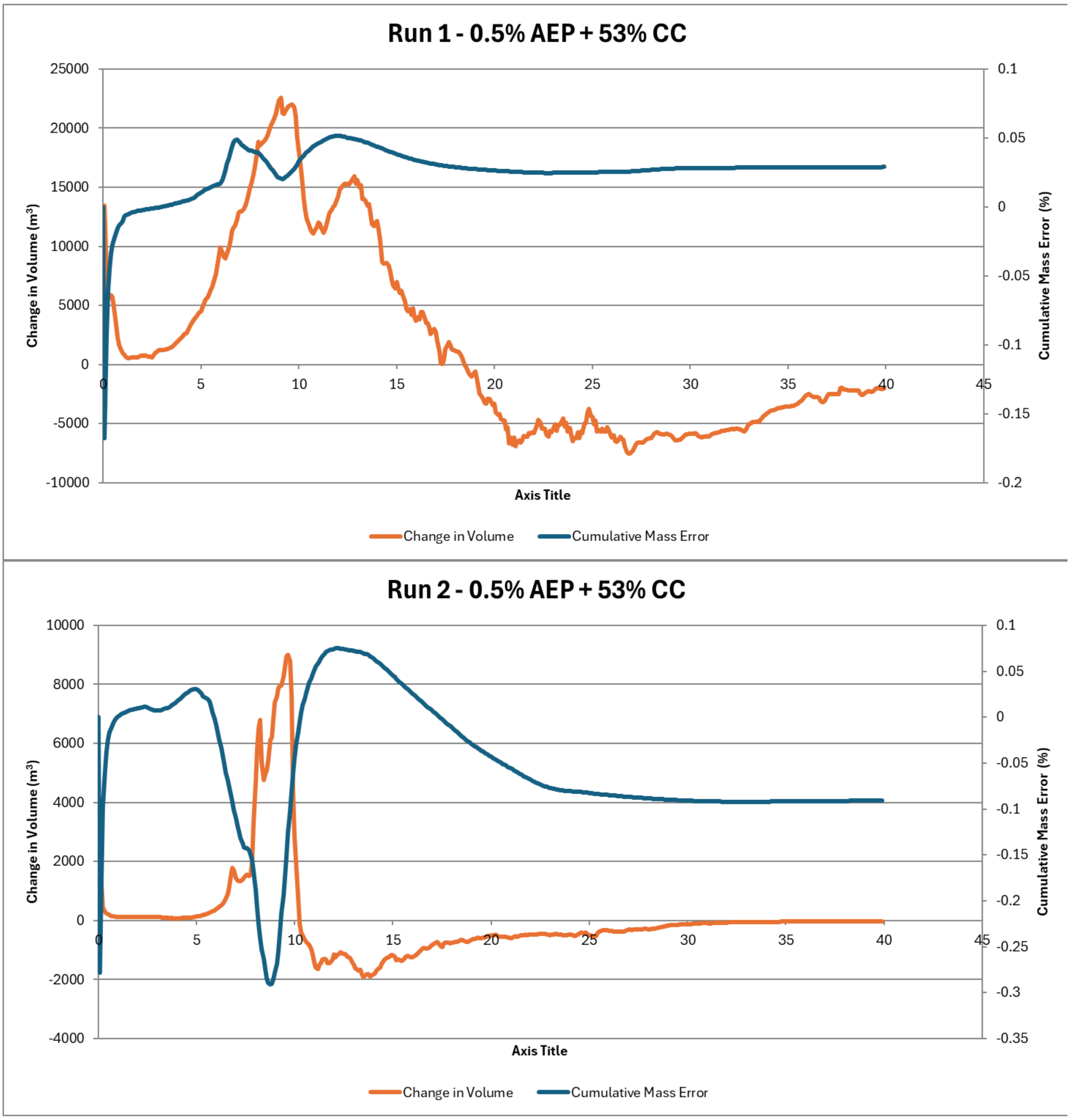


Figure A19.2-E.14: Cumulative Mass Error Reports from TUFLOW 2D Model for the 0.5% AEP +CC Event for Run 1 (top) and Run 2 (bottom)

8.2 Calibration and Verification

8.2.1 Calibration of a hydraulic model requires accurate recorded flood flows with which to run the model and observed level data from the event to compare the model predicted water levels to. However, insufficient gauge data was available to calibrate the hydraulic model. A high-level verification was therefore carried out based on collected wrack mark levels and historical records for three past flood events: 14th December 2006, 25th January 2008 and 30th December 2015.

Inflow time series for these events were obtained from two gauging stations: Tay at Caputh (15003) and Braan at Hermitage (15023).

8.2.2 The Caputh gauge is located downstream of the model extent; as such it includes flow from the River Braan. To estimate the River Tay model inflow (located upstream of the confluence between the Tay and the Braan), the flow hydrograph of the River Braan at Hermitage was subtracted from the hydrograph of the Tay recorded at Caputh. Allowances were made for the travel times between the gauges and the confluence between the River Braan and River Tay during this calculation.

8.2.3 As no gauge data was available for the Inchewan Burn, the 3.33% AEP event inflow was used for all events. This was considered appropriate as flooding along Inchewan Burn is dominated by the effects of the River Tay.

8.2.4 Hydrological peak inflows from the Caputh gauge and full hydrographs are shown in Table A19.2-E.15 and Figure A19.2-E.15.

Table A19.2-E.15: Hydrological Peak Inflows (Verification Events)

FLOOD EVENT	PEAK FLOW (M^3/S)
30TH DECEMBER 2015	1442.60
25TH JANUARY 2008	1282.14
14TH DECEMBER 2006	1479.25

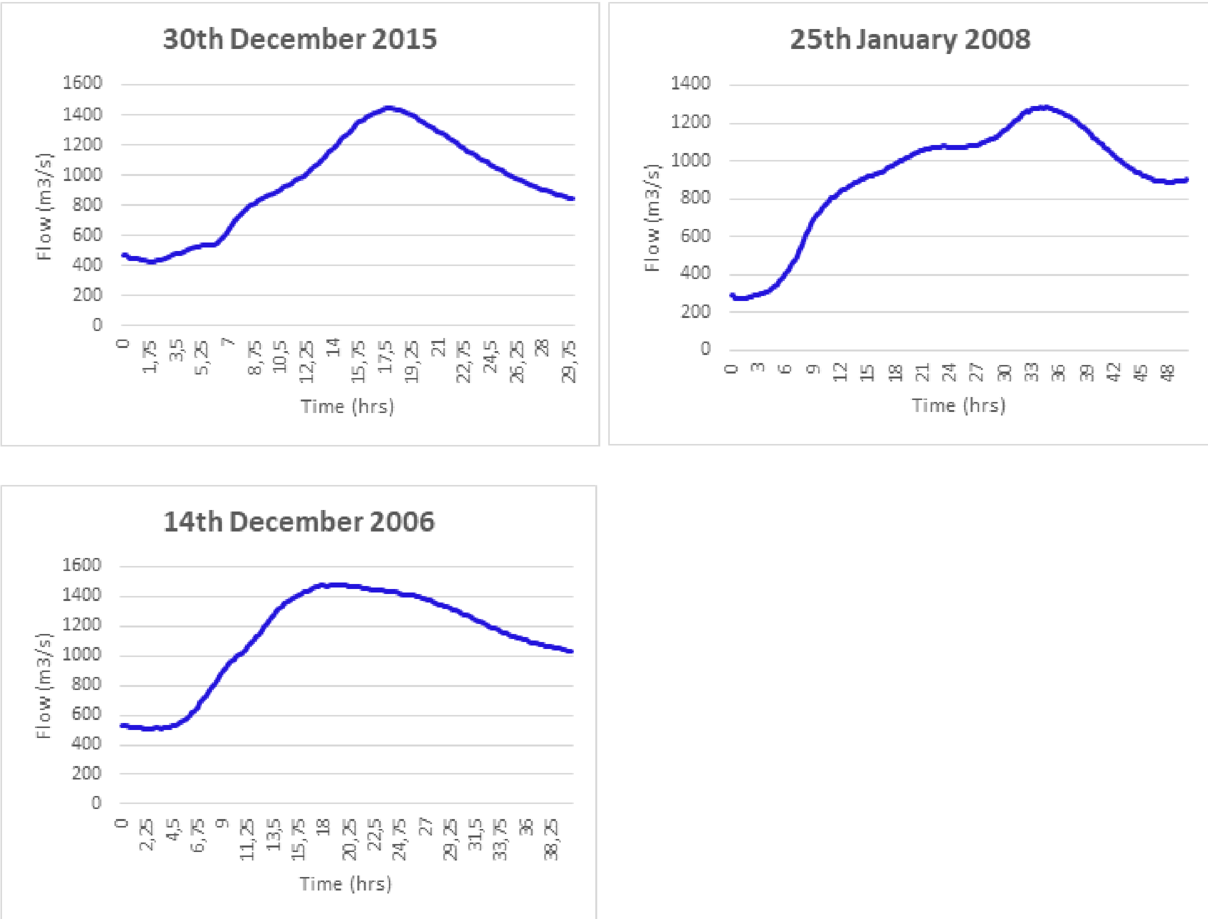


Figure A19.2-E.15: Full Hydrographs (Verification Events)

Flood Event 1: 30th December 2015

8.2.5 Maximum water levels for the 30th of December 2015 event have been estimated at a few locations throughout the modelled area from wrack mark observations collected following the event. These locations are shown in Figure A19.2-E.16 and a summary of the estimated levels compared with the model results is shown in Table A19.2-E.16.

8.2.6 Overall, the model results match reasonably well with the wrack mark levels at most locations. At some locations there is too much uncertainty in the wrack mark levels to compare the modelled water levels against them.

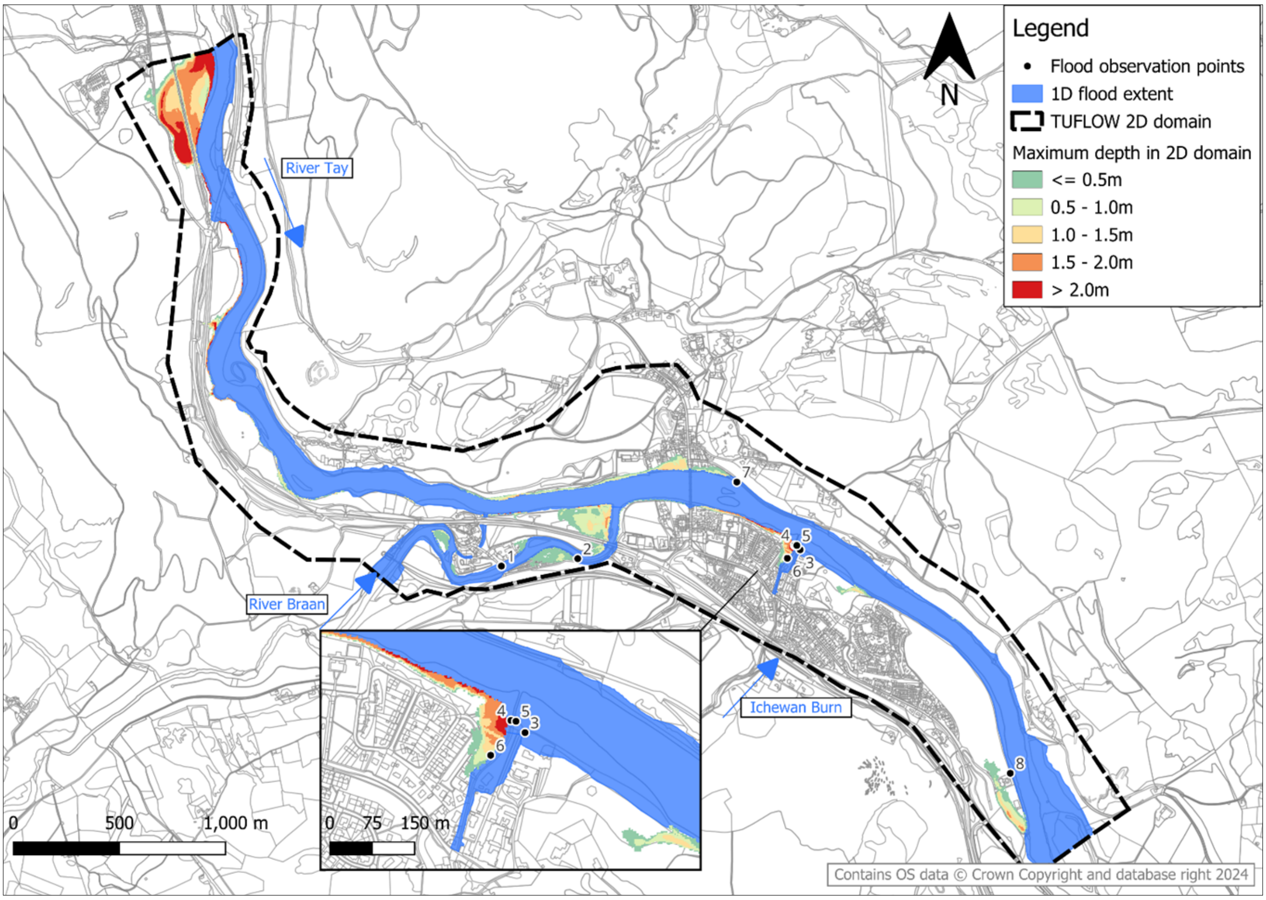


Figure A19.2-E.16: Modelled Flood Depths for the 30th December 2015 Verification Event

Table A19.2-E.16: Summary of Model Verification Results for the 30th December 2015 Event

ID	LOCATION	ESTIMATED WRACK MARK LEVEL (MAOD)	MAXIMUM MODELLED WATER LEVEL (MAOD)	DIFFERENCE (M)	COMMENT
1	Inver Bridge	51.40	51.55	0.15	Model within 150mm of estimated wrack mark level
2	Near Inver Caravan Park	49.77	49.70	-0.07	Model results are a good match but there is a lot of uncertainty in the estimated

ID	LOCATION	ESTIMATED WRACK MARK LEVEL (MAOD)	MAXIMUM MODELLED WATER LEVEL (MAOD)	DIFFERENCE (M)	COMMENT
					level at this location
3	Birnam Oak	48.10	48.46	0.36	Considering the good match to the wrack mark levels on the opposite bank and the uncertainty at the estimated level at this bank we can considered this discrepancy acceptable.
4	Inchewan Burn Foot Bridge (Left Bank)	48.50	48.46	-0.04	Model results are a good match with the observed level
5	Inchewan Burn Foot Bridge (Upstream Right Bank)	48.48	48.46	-0.02	Model results are a good match with the observed level
6	Burnmouth Road	48.58	48.47	-0.11	Model results are a good match with the observed level
7	Carpark off of Boat Road, Dunkeld	48.59	48.92	0.33	Too much uncertainty in the estimated wrack mark level to be conclusive. Reasonably good match in terms of flood extent.

ID	LOCATION	ESTIMATED WRACK MARK LEVEL (MAOD)	MAXIMUM MODELLED WATER LEVEL (MAOD)	DIFFERENCE (M)	COMMENT
8	By sewage works	46.38	46.54	0.16	Model within 160mm of estimated level

Flood Event 2: 26th January 2008

8.2.7 For the 26th of January 2008 event, flood extent records were obtained from Appendix 4 of "PERTH AND KINROSS COUNCIL Environment Committee – 30th January 2009 BIENNIAL REPORT ON FLOOD PREVENTION RESPONSIBILITIES 2009 Report by the Executive Director (Environment) 08/41".

8.2.8 It was recorded that the carriageway flooded on the A984 Boat Road at Dunkeld due to the River Tay bursting its banks. The corresponding model results estimate flooding up to 1m deep on the road in this location.

Flood Event 3: 14th December 2006

8.2.9 For the 14th of December 2006 event, historic flood event data was provided by SEPA, listing three locations where flooding was observed. These locations and the associated model results are shown in Figure A19.2-E.17 and Table A19.2-E.17.

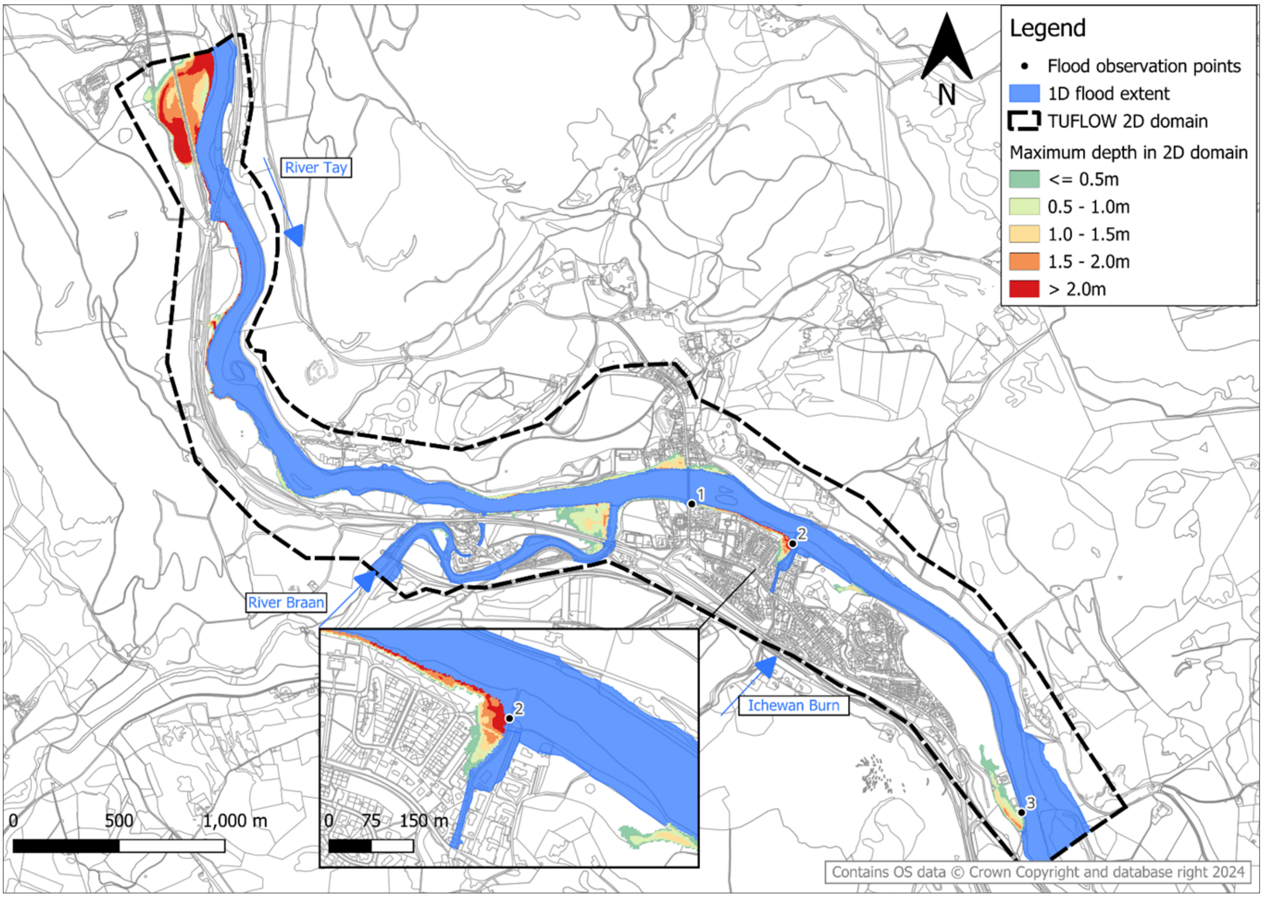


Figure A19.2-E.17: Modelled Flood Depths for the 14th December 2006 Verification Event

Table A19.2-E.17: Summary of Model Verification Results of the 14th December 2006 Event

LOCATION	WATERCOURSE	SOURCE	MODEL RESULTS
GARDENS BACKING ONTO TAY BY DUNKELD BRIDGE	River Tay	SEPA Post flood survey - aerial photo 14/12/2006	Model results show flooding in this location
BURNMOUTH ROAD (NORTHERN EXTENT)	River Tay	SEPA Post flood survey - aerial photo 14/12/2007	Model results show flooding in this location
DUNKELD AGRICULTURAL LAND AROUND NEWTYLE FISHING BEAT (AND HUT/FARMERS SHED (RIGHT BANK)	River Tay	SEPA Post flood survey - aerial photo 14/12/2006	Model results show flooding in this location

Verification Using SEPA Maps

8.2.10 Flood extent maps are available from SEPA showing 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.

8.2.11 Figure A19.2-E.18 shows a comparison of the 0.5% AEP event flood extent predicted by the hydraulic model with the medium likelihood flood extent from the SEPA flood maps.

8.2.12 The model results show smaller flood extents than the SEPA maps along reaches downstream of the River Braan, however, upstream of the Braan the results compare well with the SEPA maps. This difference can be attributed to the more detailed representation of the modelled area as well as differences in the hydrology.

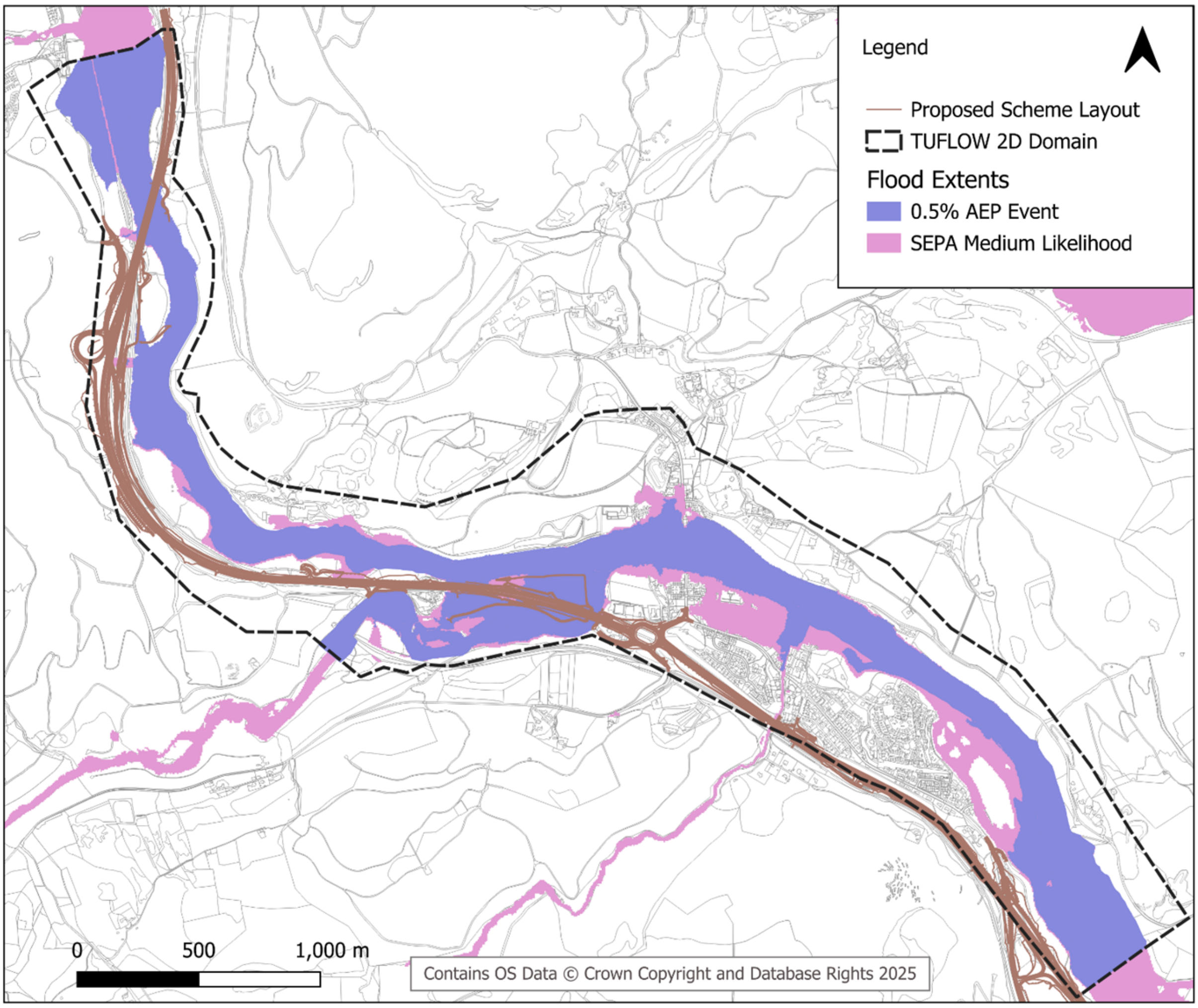


Figure A19.2-E.18: Modelled 0.5% AEP Event Flood Event vs. SEPA Medium Likelihood Fluvial Extent

8.3 Sensitivity Analysis

8.3.1 In order to test the model sensitivity to key hydraulic parameters a series of simulations were undertaken for the 0.5% AEP event under the baseline scenario (Run 1). The assessed hydraulic parameters were Manning's 'n' roughness coefficients, hydrological inflows and downstream boundary slope.

Roughness Sensitivity

8.3.2 In-channel and floodplain roughness coefficients (Manning's 'n') were changed by +20% and -20%. Table A19.2-E.18 shows the impact of changing the model roughness on the 1D in-channel water levels across the entire baseline model and in key locations which are near the proposed scheme. The results show that the in-channel water levels are highly sensitive to changes in roughness coefficients.

8.3.3 Figure A19.2-E.19 shows the impact on the 2D maximum flood extents. The 2D flood extents are sensitive in two areas relevant to the scheme: at Birnam Junction and between Inver Mill Lade and the River Braan.

Table A19.2-E.18: Roughness Sensitivity Results

SENSITIVITY	WATER LEVEL DIFFERENCE (M)			WATER LEVEL DIFFERENCE AT THE SCHEME (M)		
	MAX	MIN	AVERAGE	RIVER TAY A9 BRIDGE	RIVER BRAAN A9 BRIDGE	INCHEWAN BURN A9 CULVERT
+20% ROUGHNESS	0.914	-0.302	0.306	0.707	0.908	0.074
-20% ROUGHNESS	0.147	-0.965	-0.409	-0.791	-0.743	-0.047

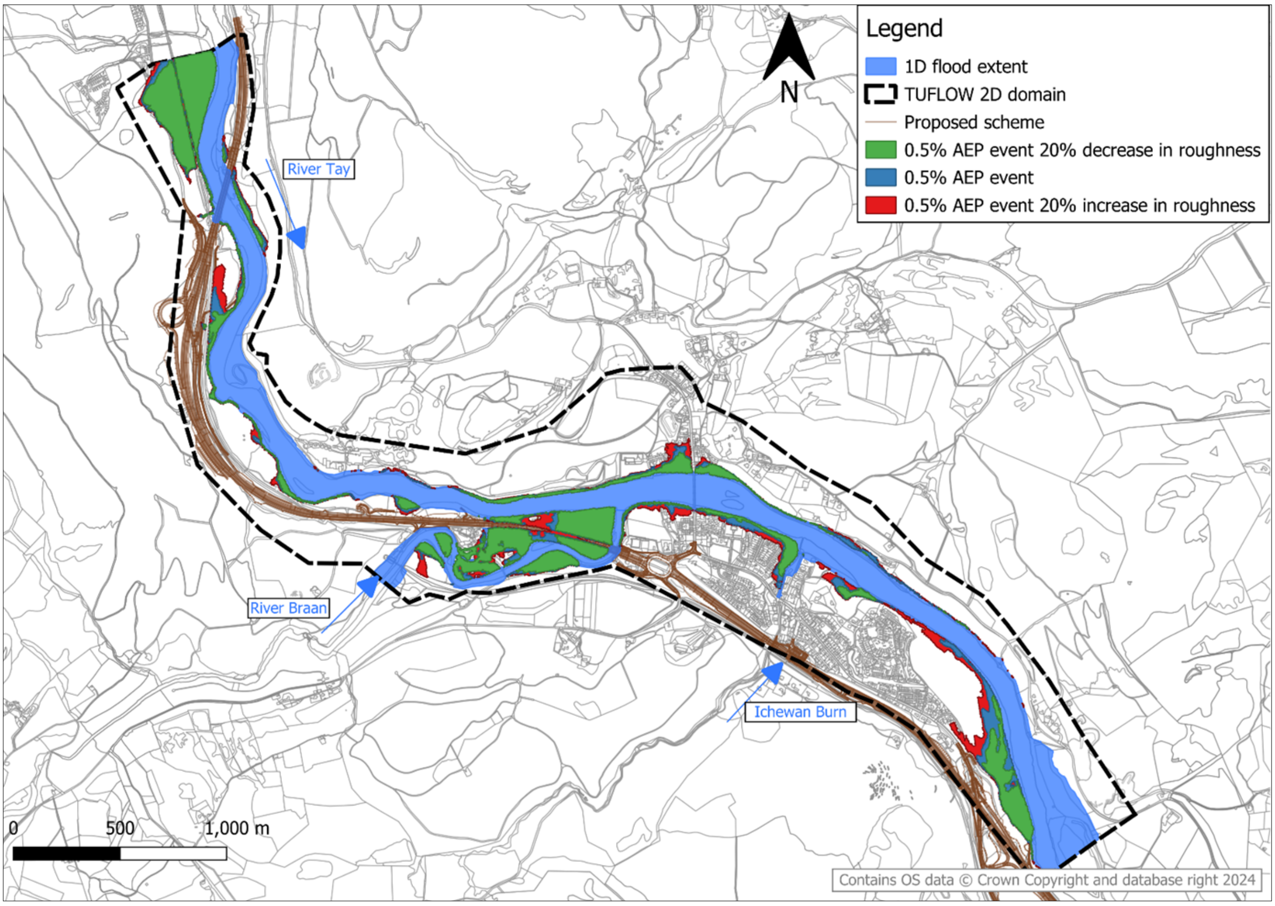


Figure A19.2-E.19: Change in the 0.5% AEP Event Flood Extent – Roughness Sensitivity

Hydrological Inflow Analysis

8.3.4 The flows into the model were adjusted by +20% and -20%. Table A19.2-E.19 shows the impact of changing model inflows on the 1D in-channel water levels and the 2D maximum flood extents are shown in Figure A19.2-E.20. The model responses are found to be highly sensitive to changes in flow.

Table A19.2-E.20: Flow Sensitivity Results

SENSITIVITY	WATER LEVEL DIFFERENCE (M)			WATER LEVEL DIFFERENCE AT THE SCHEME (M)		
	MAX	MIN	AVERAGE	RIVER TAY A9 BRIDGE	RIVER BRAAN A9 BRIDGE	INCHEWAN BURN A9 CULVERT
+20% FLOW	1.314	0.041	0.677	0.894	1.060	0.136
-20% FLOW	-0.036	-0.989	-0.512	-0.964	-0.858	-0.131

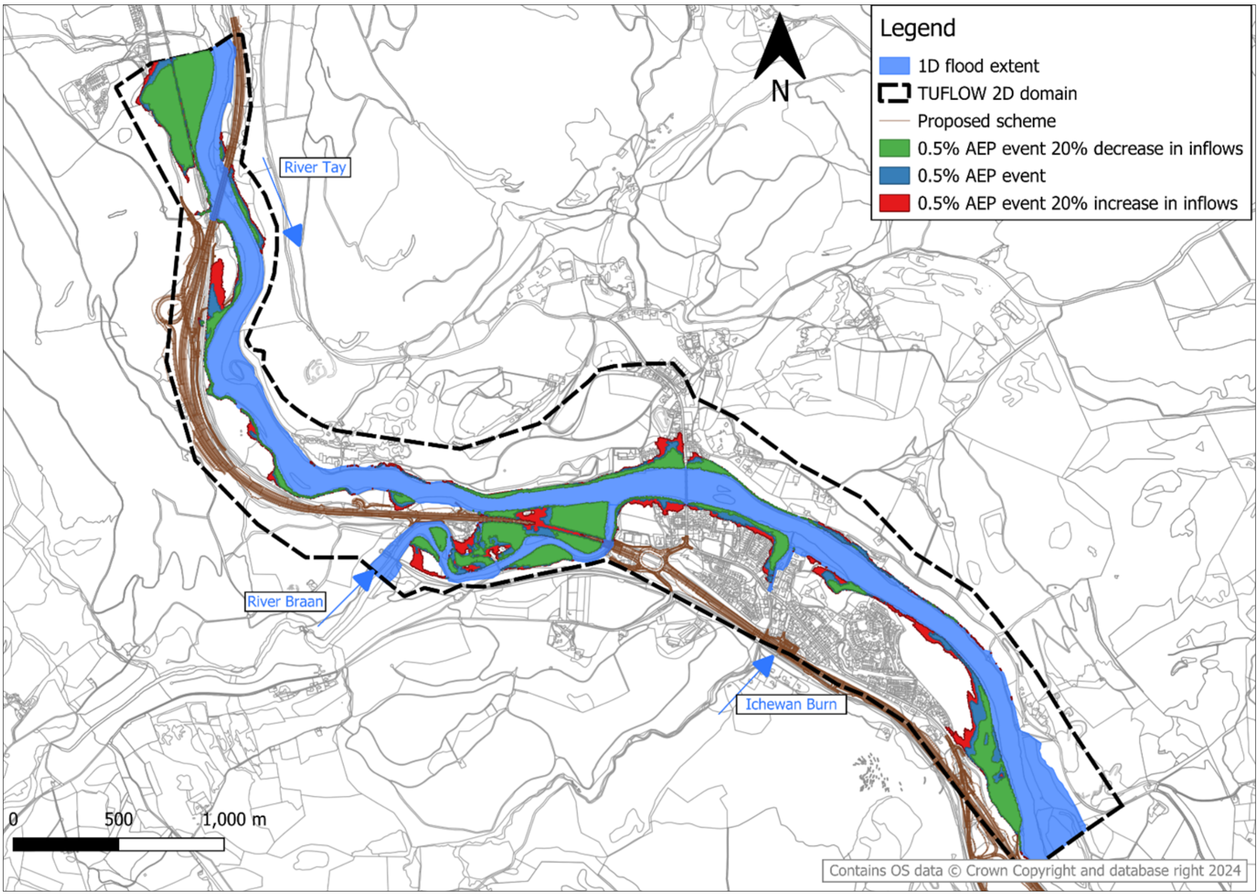


Figure A19.2-E.20: Change in the 0.5% AEP Event Flood Extent – Inflow Sensitivity

Downstream Boundary Condition Sensitivity

8.3.5 To test the model sensitivity to the downstream boundary condition, 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 have an influence extending approximately 6500m upstream along the River Tay, 570m up the River Braan from the confluence, 220m up Inver Mill Lade and 250m up Inchewan Burn. Table A19.2-E.20 shows the response at the downstream boundary and at the proposed scheme. Figure A19.2-E.21 shows the impact on the 2D maximum flood extents. It can be seen that the influence of the downstream boundary at the proposed scheme locations is insignificant.

Table A19.2-E20: Downstream Boundary Sensitivity Results

SENSITIVITY	WATER LEVEL DIFFERENCE (M) AT THE DOWNSTREAM BOUNDARY (SECT_T_39)	WATER LEVEL DIFFERENCE AT THE SCHEME (M)		
		RIVER TAY A9 BRIDGE	RIVER BRAAN A9 BRIDGE	INCHEWAN BURN A9 CULVERT
+20% DOWNSTREAM	-0.380	-0.002	-0.016	0.000

SENSITIVITY	WATER LEVEL DIFFERENCE (M) AT THE DOWNSTREAM BOUNDARY (SECT_T_39)	WATER LEVEL DIFFERENCE AT THE SCHEME (M)		
		RIVER TAY A9 BRIDGE	RIVER BRAAN A9 BRIDGE	INCHEWAN BURN A9 CULVERT
BOUNDARY SLOPE				
-20% DOWNSTREAM BOUNDARY SLOPE	0.492	0.004	0.031	0.000

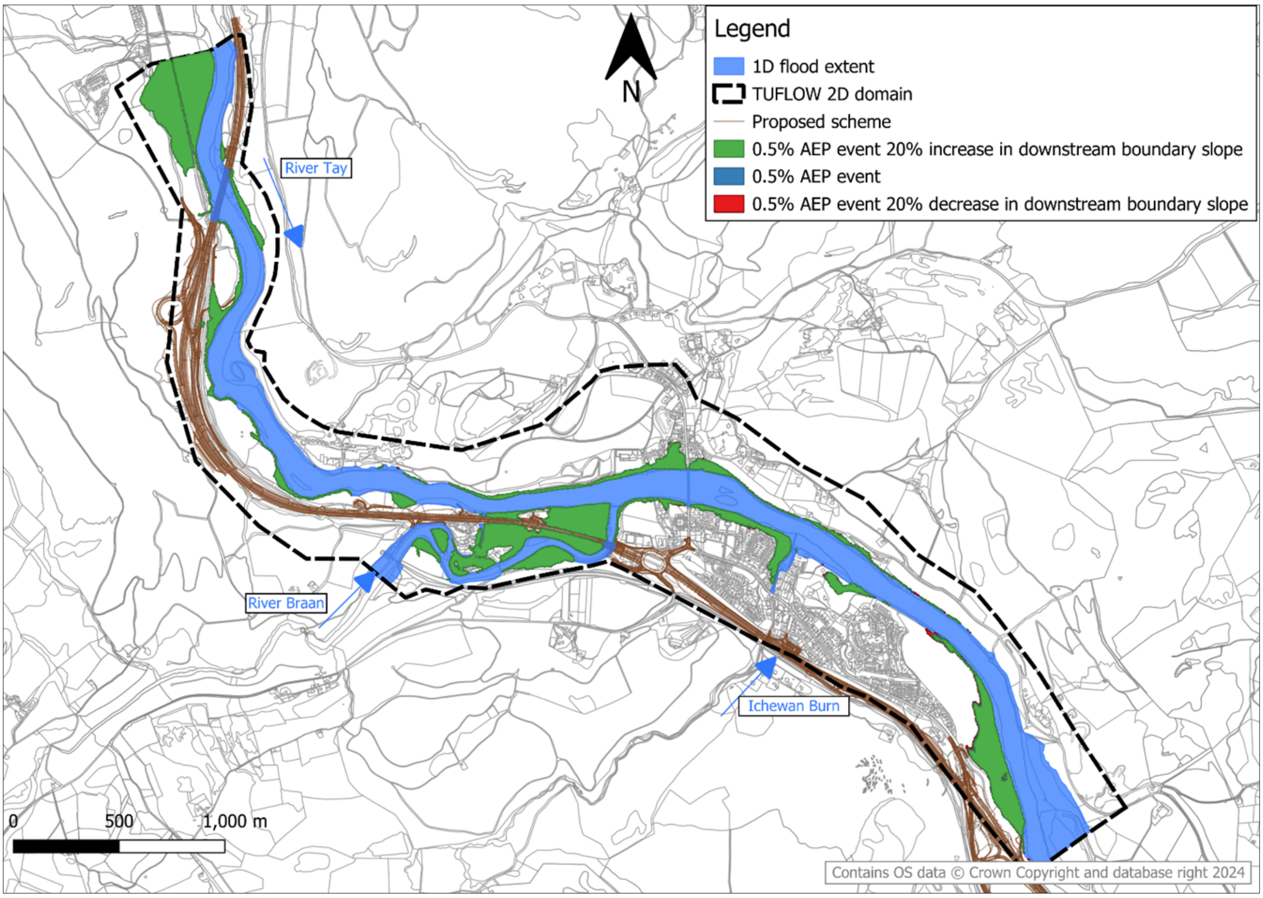


Figure A19.2-E.21: Change in the 0.5% AEP Event Flood Extent – Downstream Boundary Sensitivity

9. Model Assumptions and Limitations

9.1 Introduction

9.1.1 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.

9.1.2 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 has quantified the magnitude of potential uncertainty, and the calibration and verification process indicates that the modelling outputs are sensible.

9.1.3 The following sections summarise the key sources of uncertainty in addition to the limitations associated with the modelling.

9.2 1D Domain

Watercourse Schematisation

9.2.1 Cross sections of the River Tay, River Braan and Inchewan Burn (from downstream of the proposed A9 crossing to the confluence with the River Tay) were inherited, unchanged from the 2013 URS model. Only the Inchewan Burn, from the location of the proposed A9 crossing to approximately 90m upstream of the Railway crossing and downstream of Perth Road, was covered in 2018 Jacobs surveys. It was assumed that the URS river survey was of adequate quality and as such no check survey was undertaken. According to the “A9 Birnam to Tay Crossing –Flood Risk Assessment” report (URS, 2013, paragraph 2.3A) a detailed topographic survey of the river, site and surrounding land was used to build the original model. Although rivers’ tops of banks from the existing URS model were generally found in good agreement with the 2018 1m LiDAR DTM, the URS survey was not included in the documentation provided to Jacobs, hence it was not possible to carry out a cross section check.

9.2.2 The 30th of December 2015 flood event (see Calibration and Verification – Section 8.2) may have affected the river channel morphology. As such any cross-section data used within the model using pre-December 2015 survey data may have changed slightly following the flood event, however, for this study it is assumed the channel morphology remains unchanged following the 2015 flood event.

Channel Roughness

9.2.3 Channel roughness has been assigned using the best available information (site visit, survey data and aerial photographs). The roughness values are based on industry standard guidance (Chow 1959). Sensitivity tests have been carried out to quantify the sensitivity to this parameter.

Representation of Structures

9.2.4 Hydraulic coefficients for structures have been applied using available guidance within the Flood Modeller and TUFLOW software. The dimensions for watercourse structures have been based on detailed survey measurements for the baseline scenario and using the detailed structural drawings for the proposed scheme.

9.3 2D Model Domain

Floodplain Topography

9.3.1 The floodplain topography has been represented using 1m resolution LiDAR data. A 4m grid resolution has been used in the 2D domain, which samples the 1m LiDAR DTM data every 4m. This lowers the resolution of the representation of the ground model but is suitable to represent most of the floodplain features across the model extents to an appropriate level of detail to support the Flood Risk Assessment of the Stage 3 of the DMRB process.

9.3.2 Breaklines and elevation polygons have been used as required to better represent topographic features. Elevations for these features have been informed by the LiDAR or survey data.

9.3.3 Bank heights along the 1D/2D link have been defined using a combination of LiDAR and survey data as the top of bank was well represented in the DTM for the River Tay and River Braan but not very well represented for the smaller watercourses.

Floodplain Hydraulic Friction

9.3.4 Hydraulic roughness coefficients across the 2D domain have been defined based on OS Mastermap land use data and standard guidance.

Floodplain Structures

9.3.5 Floodplain structures have only been included where they were considered to have an impact on flood mechanisms. Levels and dimensions have come from survey data as much as possible, however some assumptions have had to be made based on LiDAR 2018 and site visit information.

9.4 Model Calibration

9.4.1 Due to the unavailability of adequate gauge data, a standard model calibration exercise was not possible. A high level verification exercise was instead undertaken using collected wrack mark levels and historical records for three past flood events. Simulation outputs indicated that the model matched the observed levels well (see Calibration and Verification - Section 8.2).

9.5 Model Tolerance

9.5.1 For the above uncertainties and limitations, the comparison between the baseline and proposed scheme scenarios can be considered to be a like for like comparison. However, there is still a degree of uncertainty due to the inherent assumptions inside the Flood Modeller and TUFLOW software's solution schemes, such as the diffusion terms and other coefficients applied in the models. In particular, it is worth noting the water level convergence tolerance used within Flood Modeller is 10 millimetres. As the scale of change that is being used as a measure of flood risk impact is in the order of millimetres, any interpretation at this order should be treated with caution.

10. Conclusions

10.1.1 In order to support the development of a Flood Risk Assessment for the Environment Statement of Stage 3 of the DMRB process, a hydraulic model was constructed to establish a baseline scenario for the flood risk along the River Tay between Pass of Birnam to Tay Crossing. A 9km long reach of the River Tay was represented along with the two key tributaries, namely the River Braan and Inchewan Burn, and a number of minor watercourses which cross the proposed scheme.

10.1.2 Three minor watercourses crossing the proposed scheme have been modelled separately. Details can be found in Annex E3 of this report.

10.1.3 The 50% AEP, 3.33% AEP, 0.5% AEP and 0.5% AEP + CC events were simulated using the model.

10.1.4 The baseline model was then adapted to represent the proposed scheme scenario in order to assess the impact of the proposed scheme on the flood risk. Where increases to flood risk were identified, mitigation measures were developed and incorporated into the proposed scheme and tested with hydraulic model simulations.

10.1.5 The assumptions and limitations associated with the hydraulic modelling are discussed in Section 9 of this report, which should be considered for any future use of the hydraulic model.

10.1.6 Model results have been used to inform Appendix 19.2: Flood Risk Assessment.

11. References

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

URS (2014) A9 Birnam to Tay Crossing – Flood Risk Assessment – Stage 2 DRMB

SEPA (2023) Climate change allowances for flood risk assessment in land use planning, Version 4. Accessible at: climate-change-allowances-guidance-v4-final_nov23.pdf (sepa.org.uk)

Annex E1: DMRB Stage 2 Model Updates

1D Model Updates

- The Inchewan Burn was extended upstream using Jacobs cross-section survey undertaken in 2018. The new survey covered the following reach of the Inchewan Burn: 42m downstream of the existing A9 Bridge to 145m upstream of the Railway Bridge;
- Following a site visit, Manning's 'n' roughness values in the 1D domain were reviewed based on the guidance available in the literature:
    - along the Inchewan Burn bed roughness was increased from 0.04 to 0.05;
    - along the River Tay bed roughness was increased from 0.03 to 0.035 and spatial distribution of roughness across the floodplain was reviewed;
- The weir coefficient was decreased from 1.7 to 1.2 at Weir_2 (weir adjacent to the inlet culvert of the Mill Lade) to better represent the material and profile of the weir crest;
- At various spill units representing drops along the river bed, weir coefficients were reviewed to better represent material and profile of the bed;
- Orifice mode was activated at the A9 footbridge and A9 Bridge on the River Braan to better represent flow through the bridges in surcharged conditions.
- Outlet units were added at culverts where they were previously missing to represent exit losses.
- Arch Bridge Units at A9 Bridge on the River Tay and A9 Braan Bridge updated to USBPR units. The cross sections at the A9 Bridge on the River Tay were also found to be skewed at a 40 degree angle to the perpendicular and were adjusted accordingly and a skew angle was applied to the bridge unit.
- A comparison between the model representation and site visit photos at the footbridge on the River Braan found that the model was excluding a significant area of the left bank. Corrections were made by extending both the left and right bridge spans to meet the banks, using an average soffit level to represent the sloping levels. Increased roughness values were applied to the upstream and downstream cross sections to represent the trees and bridge posts on the left bank. The spill across the bridge was also extended to match the extended bridge.

2D Model Updates

- The 2D domain was extended upstream, for around 2,460m, from the Hermitage Junction to the top end of the 1D model, around 700m upstream of the A9 crossing on the River Tay; Similarly, the 2D domain was extended 1,450m further downstream from SECT_T_30 to SECT_T_35, to improve representation of the floodplain near the proposed A9 scheme at Birnam Junction.
- Within the 2D domain, 2m and 5m horizontal resolution DTM (Digital Terrain Model) were replaced with 1m LiDAR DTM obtained in 2018. Zlines and 1D-2D boundary layers were updated accordingly;
- Railway underpasses in the area of the extended 2D domain were inserted in the floodplain;
- Jacobs topographical survey (undertaken in 2018) of the Inchewan Burn, covering a new residential area downstream of Perth Road, was also incorporated in the 2D model.
- The model DTM was found to be in good agreement with the topographical surveys at Dunkeld and Birnam in the Tay floodplain and no changes were required.
- Roughness values in the 2D domain were assigned based on Mastermap coverage where they had previously been assigned based on 10k Ordnance Survey maps.
- The connectivity between 1D and 2D domain was improved by finding a better correspondence between 1D top of bank levels and LiDAR DTM levels. This action also helped to improve model convergence.
- In the original URS model, the top of bank elevations were intermittently reinforced with zlines informed by elevations from the cross-sectional survey undertaken for that study. In the areas where these zlines were missing, ground levels were reinforced with zlines with point elevations extracted from the LiDAR DTM.
- From model nodes IN_16 to IN_20 on the Left Bank of the Inchewan Burn, since it was not possible to establish a good correspondence between the 1D bank top levels (as part of the cross-section data) and 2D DTM, an additional zline with elevations taken from the top of banks of the surveyed cross sections was created.
- The other zlines and ztins present in the original URS model were retained.
- After implementing the actions described above, roughness patches added to improve model stability in the URS model were found unnecessary and were removed.

ANNEX E2: Log of Mitigation Tests

Table E2.1 below lists all the mitigation measures which were tested using the hydraulic model to determine the final mitigation measures which have been incorporated into the proposed scheme and are discussed in Section 6 of the main report. Further details can also be found in Appendix A19.2 (Flood Risk Assessment).

Table E2.1: List of modelled mitigation measures

Location	Design Fix	Mitigation Measure
Mill Lade Culvert	DF6 – DF8	Flood Relief Culverts located immediately to the right of the Mill Lade at the proposed A9 Carriageway. Various number of culverts, sizes and invert levels were tested.
Tay Floodplain	DF6 – DF8	Compensatory Flood Storage areas of varying sizes and shapes have been tested within this floodplain area.
Hermitage	DF6 – DF8	Compensatory Flood Storage areas of varying sizes and shapes have been tested within this floodplain area. As a result of widening and raising the soffit of the Braan Bridge, a CFS is no longer required in this location.
Inver floodplain	DF6 – DF8	Flood Relief Culverts located west of the Braan Bridge. These operate during the 0.5% AEP + 53% CC flood event only to replicate the existing flow path of water across the A9 carriageway. Numerous variations of number, size, location and invert level of FRCs were tested, with 14 being the current preferred mitigation solution.
Right bank of Tay upstream of Tay Bridge	DF7 – DF8	No flood wall to be constructed as detailed in Table A19.2-E.12. Road closure in event of flooding.

ANNEX E3: Minor Watercourse Modelling

General

To better define the baseline flood risks at key locations, standalone models of selected minor watercourses located in the area of the proposed scheme (MWC09, MWC13 and MWC16) were built for the baseline scenario. The three watercourses and their node layout plans are shown in Figure E3.1 to Figure E3.6.

MWC13 and MWC16 were modelled in 1D only, whereas the MWC09 floodplain was modelled in 1D/2D.

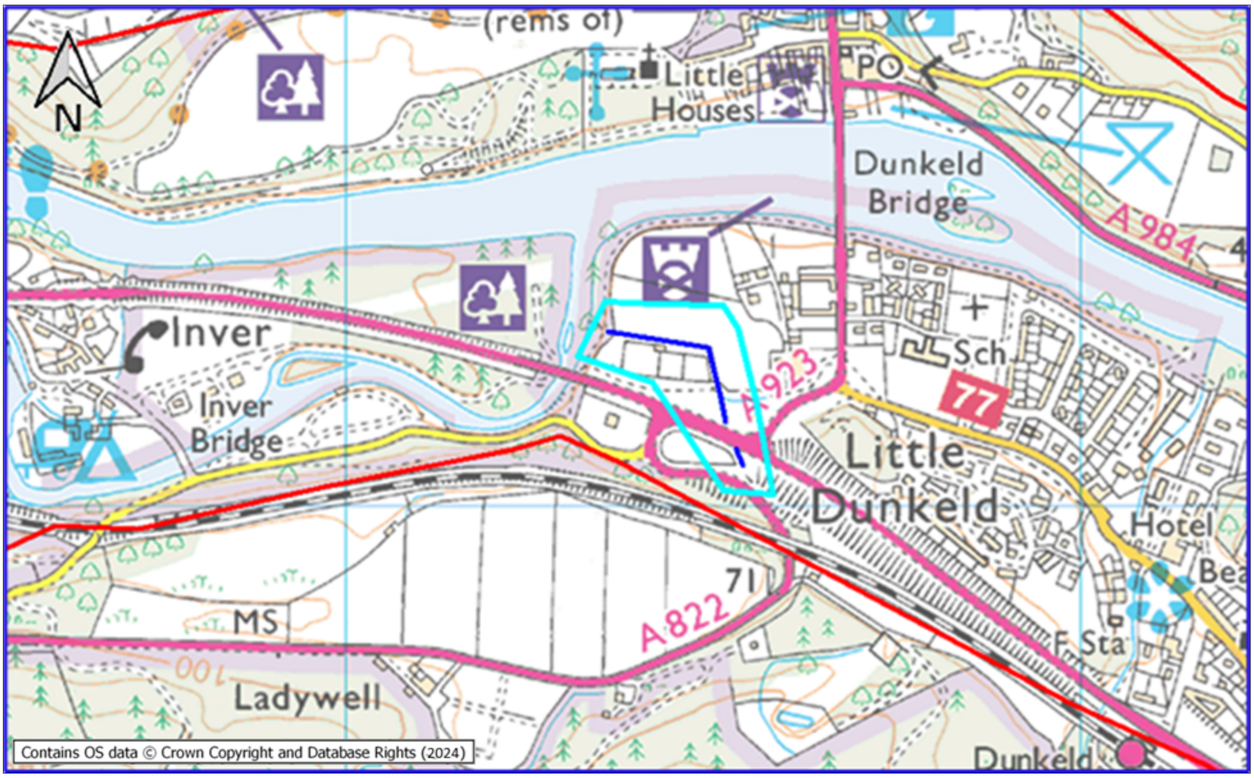


Figure E3.1: Minor Watercourse 09 (MWC09)

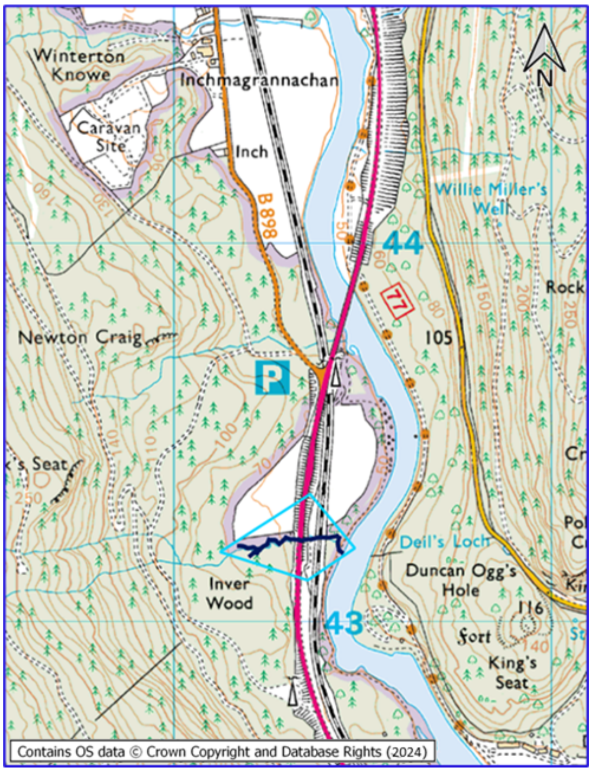


Figure E3.2: Minor Watercourse 13 (MWC13)

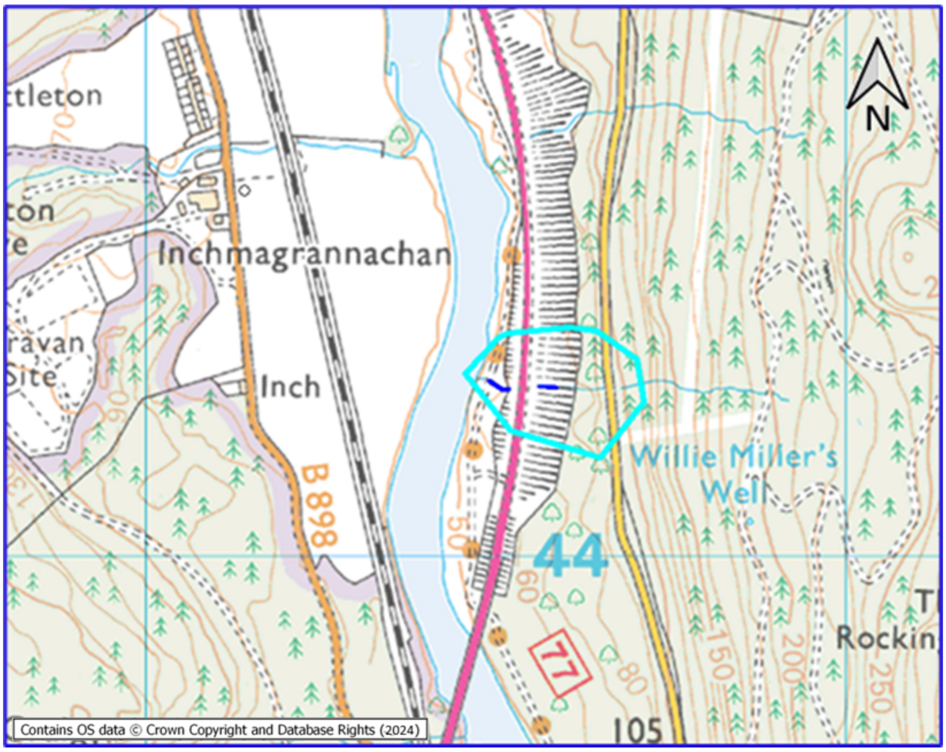


Figure E3.3: Minor Watercourse 16 (MWC16)

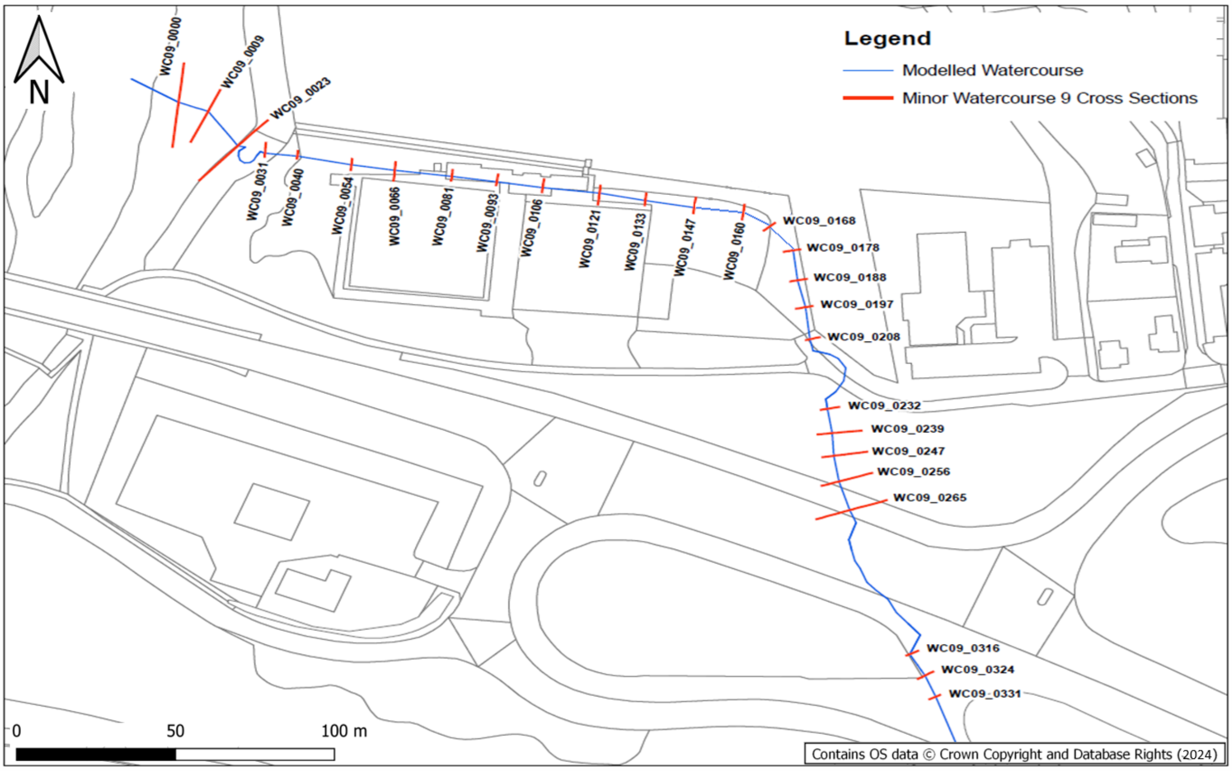


Figure E3.4: Flood Modeller Nodes on Minor Watercourse 9

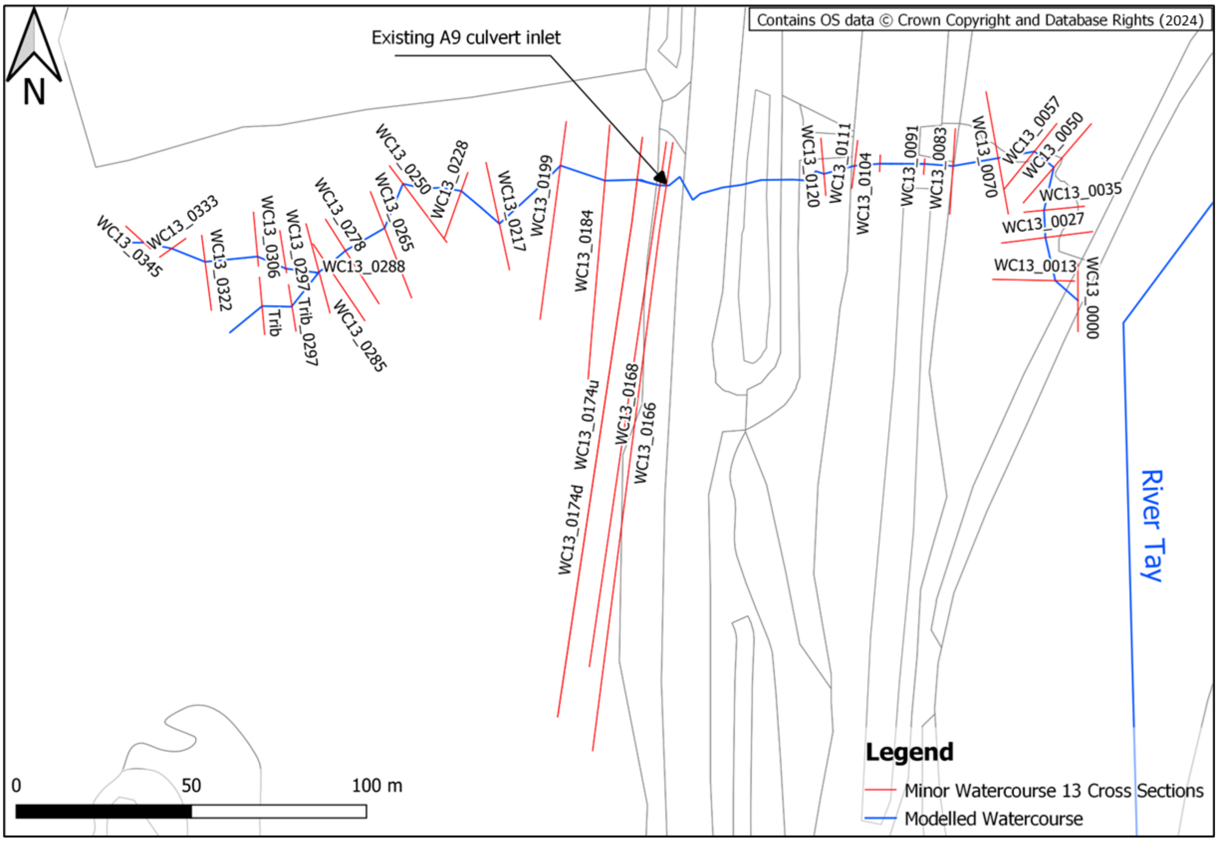


Figure E3.5 Flood Modeller Nodes on Minor Watercourse 13

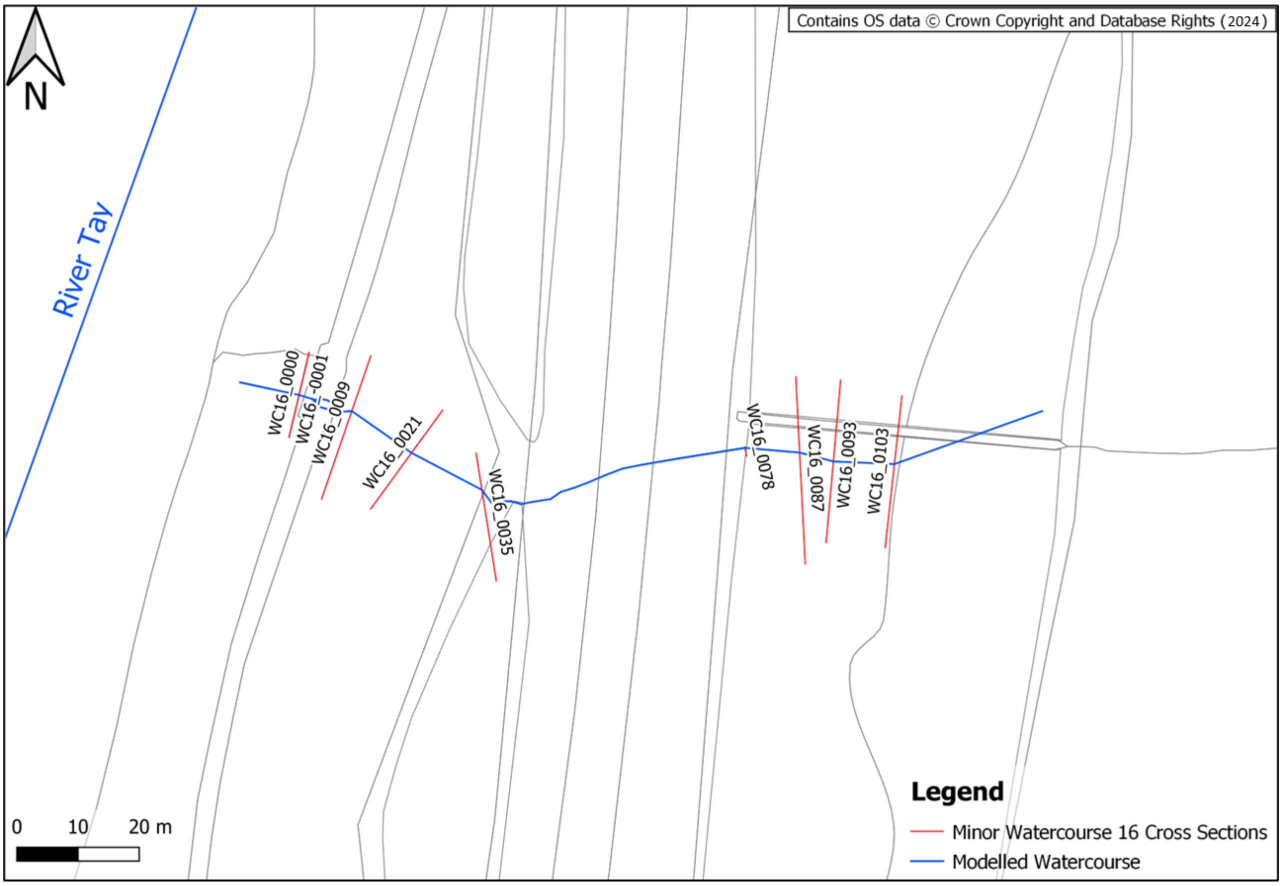


Figure E3.6: Flood Modeller Nodes on Minor Watercourse 1

Input Data

The data used to construct the hydraulic models of the minor watercourses is summarised in Table E3.1 below:

Table E3.1: Data Used to Build the Hydraulic Models for the Minor Watercourses

Data	Description	Source
1m DTM	1m horizontal resolution DTM (2018)	Transport Scotland
OS Maps	Background maps and Master Map data	Ordnance Survey
Hydrological Analysis	Hydrological analysis carried out as discussed in Section 0.	Hydrological Analysis
Topographic Surveys	Cross section survey of the three watercourses	Jacobs 2018 Jacobs 2024

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Hydrology

The minor watercourses models were run for two hydrological scenarios: Run 1 (inflow hydrographs with the same critical storm duration as the River Tay) and Run 2 (inflow hydrographs with critical storm durations specific to each minor watercourse catchment). MWC13 baseline and proposed scheme scenarios as well as MWC16 were simulated using steady state solver under peak flows for each respective event listed in Table E3.2.

A summary of the two scenarios is given below. Inflows and downstream boundaries used are given in Table E3.2 and Table E3.3. Full inflow hydrographs for events simulated with unsteady flows (MWC09 only) are shown in Figure E3.7.

Table E3.2: Hydrological Peak Inflows into Minor Watercourses

Location	Description	Peak Flows (m^3/s)					
		Run 1			Run 2		
		AEP 3.3%	AEP 0.5%	AEP 0.5% + CC	AEP 3.3%	AEP 0.5%	AEP 0.5% + CC
MWC09	Peak flow at the upstream end of the modelled reach, 14m upstream of the existing A9 crossing, at National Grid Reference (NGR) 302,538, 742,058	0.64	0.94	1.13	1.14	1.73	2.55
MWC13	Peak flow at the upstream end of the main MWC13 modelled reach, 170m upstream of the existing A9 crossing (NGR 300,178, 743,200)	0.74	-	-	1.48	2.44	3.57
MWC13	Peak flow at the tributary, 120m upstream of the existing A9 crossing (NGR 300 203, 743 174)	0.11	-	-	0.22	0.37	0.53
MWC16	Peak flow at the upstream end of the modelled reach, 25m upstream of the existing A9 crossing (NGR 300,586, 744,246)	0.28	0.40	0.59	0.59	0.88	1.30

Table E3.3: Downstream Boundaries Used in Minor Watercourses Models

Location	Description	Scenario	Water Levels (m AOD)					
			Run 1			Run 2		
			AEP 3.3%	AEP 0.5%	AEP 0.5% + CC	AEP 3.3%	AEP 0.5%	AEP 0.5% + CC
MWC09	Confluence with River Braan (at cross section BR_32 from Main Model)	BLN	49.75	51.14	53.50	48.42	48.42	48.42
		DES	49.79	51.16	53.50	48.43	48.43	48.43
MWC13	Confluence with River Tay (at cross section SECT_T_9 from Main Model)	BLN/DES	52.56	-	-	50.71	50.71	50.71
MWC16	Confluence with River Tay (at cross section SECT_T_2 from Main Model)	BLN/DES	53.63	55.16	57.39	51.58	51.58	51.58

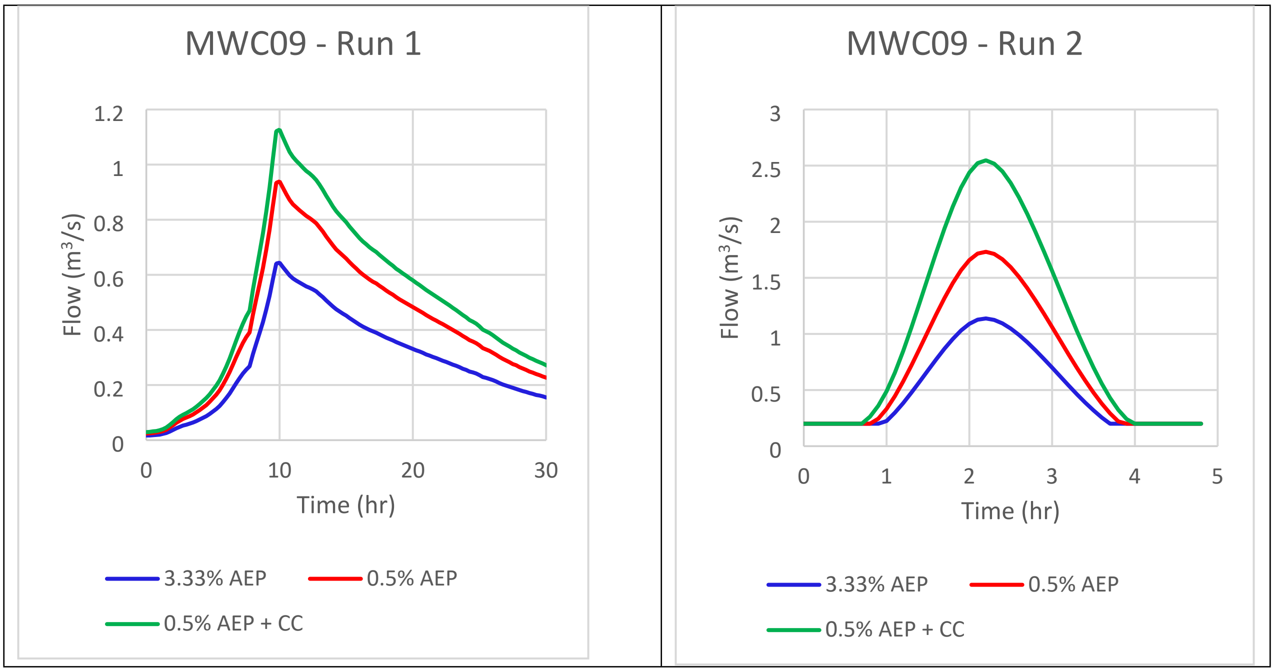

Figure E3.7: MWC09 Inflow Hydrographs

Minor Watercourse 9

Run1:

- Inflows at MWC09 are the 3.3% AEP and 0.5% AEP hydrographs with a 25h storm duration (critical storm duration for the River Tay). Peaks along the minor watercourse occur at 10h (same as on the River Braan and the Inchewan Burn, 8h earlier than on the Tay, as in the main model Run 1 inflows). Of note, the 0.5% AEP +CC event (Run 1) was not simulated with MWC09 since during this event, flood risk is dominated by water coming from the main watercourses and the floodplain area between the A9 and the right banks of the River Braan and River Tay is fully submerged;

- Downstream boundaries are the 3.3% AEP and 0.5% AEP maximum water levels on the River Braan from the main model Run 1 results;

Run2:
- Individual storm duration flow hydrographs along MWC09 for the 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events;

- Downstream boundary is fixed to the maximum water level on the River Braan from the main model Run 1 results for a 50% AEP event;

Minor Watercourse 13

Run1:
- Only the 3.3% AEP was modelled, using steady state solver with the peak inflow from the 25h storm duration hydrograph (critical storm duration for the River Tay). An 87:13 ratio has been applied to split the flows between the main channel and the tributary.

- Downstream boundary is the 3.3% AEP peak water level on the River Tay from the main model Run 1 results.

Run2:
- Peak inflows from individual storm duration flow hydrographs along MWC13 for the 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events. An 87:13 ratio has been applied to split the flows between the main channel and the tributary,

- Downstream boundary is fixed to the maximum water level on the River Tay from the main model Run 1 results for a 50% AEP event.

Minor Watercourse 16

Run1:
- For both baseline and scheme scenarios, peak inflows associated with the 3.3% AEP, 0.5% AEP and 0.5% AEP + CC event with a 25h storm duration (critical storm duration for the River Tay) have been applied.

- Downstream boundaries are the 3.3% AEP, 0.5% AEP and 0.5% AEP + CC maximum water levels on the River Tay from the main model Run 1 results.

Run2:
- Peak inflows from individual storm duration flow hydrographs along MWC16 for the 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events,

- Downstream boundary is fixed to the maximum water level on River Tay from the main model Run 1 results for a 50% AEP event.

Minor Watercourse 9 Modelling

Structures

Hydraulic structures along MWC09 were modelled as shown in Table E3.4.

Table E3.4: Modelled Structures Along MWC09

Structure	Modelling Approach
A9 crossing (WC09_0316c - WC09_0265c)	600mm circular conduit. Orifice schematising drop of bed level and culvert entrance. Bridge deck represented in 2D
Culvert under Little Dunkeld (WC09_0232c - WC09_0208c)	600mm circular conduit. Bridge deck represented in 2D
Culvert under footpath (WC09_0031c - WC09_0023c)	600mm circular conduit. 1.1m bottom slot added to improve model stability. Bridge deck represented in 2D.

Hydraulic Friction

Manning's 'n' coefficient values were determined using survey and site visit photos as well as aerial imagery and are reported in Table E3.5.

Table E3.5: MWC09 - Roughness Coefficients

Cross sections in 1D Domain	In-Channel Manning's 'n'
WC09_0331- WC09_0000	0.05 for bed; 0.055 to 0.1 for banks
Material in 2D Domain	**Out of banks Manning's 'n'**
Buildings	1
Water	0.02
Glasshouse	0.3
Inland Water	0.035
Wood land	0.1
Path	0.02
Rail	0.04
Road or track	0.02
Unclassified	0.04
General green areas (default)	0.055
Default	0.055
Short grass (Tennis courts etc.)	0.025

2D Domain

In the 2D domain:

- A 3m grid was used (the main model used a 4m grid – the grid was reduced to improve model convergence);
- It was not possible to establish a good correspondence between 1m DTM and bank tops from survey, so the bank levels in 2D were reinforced with bank levels from the cross-section survey collected in May 2024;
- For Run 2, a free flow (QH) boundary was added to the border of the 2D domain aligned with the River Braan to avoid glass walling. For Run 1, a fixed HT boundary was used informed with water level in the River Braan extracted from the main model results.

Proposed Scheme Modelling

Figure E3.8 shows the layout of the proposed scheme as per Design Fix 8 of the DRMB Stage 3 process. The modifications to the baseline model for the inclusion of the proposed scheme include:

- 26m long 1.8m diameter culvert under proposed roundabout;
- Drainage ditch across roundabout island;
- 55m long 0.6m diameter culvert under little Dunkeld connecting to the existing channel supplemented by a 1.5m x 1m Flood Relief Culvert (FRC) discharging into the Braan;

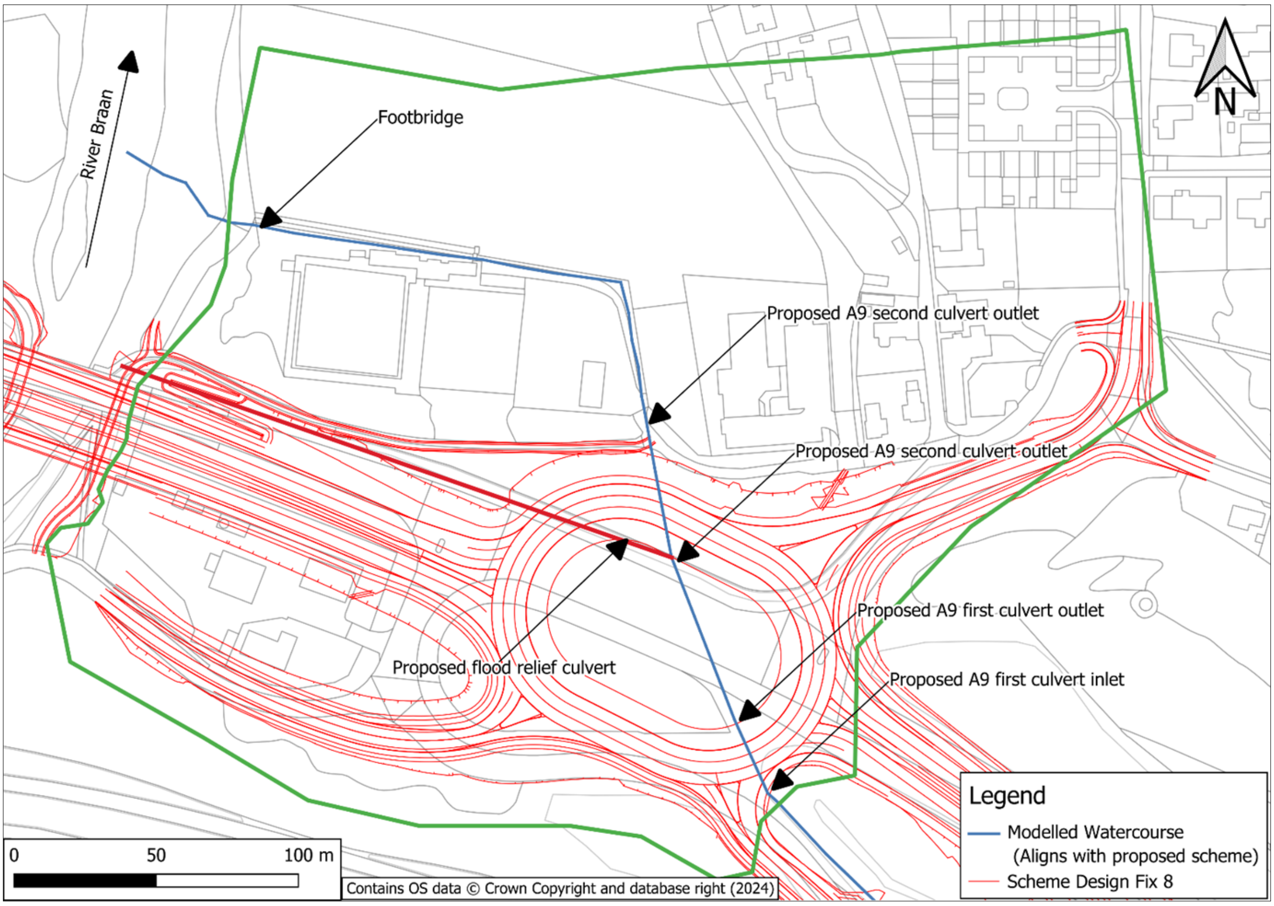

Figure E3.8: MWC9 scheme scenario schematisation

<u>Baseline Results</u>

1D and 2D domain modelling results for both Run 1 and Run 2 baseline scenarios are shown in Figure E3.9 to Figure E3.12. Baseline results indicate that the current 0.6m diameter A9 culvert does not have sufficient capacity to accommodate any of the modelled flows which results in significant water volume backing up at the upstream face of the structure leading to overtopping of the headwall. Baseline results show significant flood risk between the existing A9 culvert and River Braan along the A9 current alignment. In addition, flooding also occurs downstream around Dunkeld and Birnam Bowling Club due to limited open channel capacity.

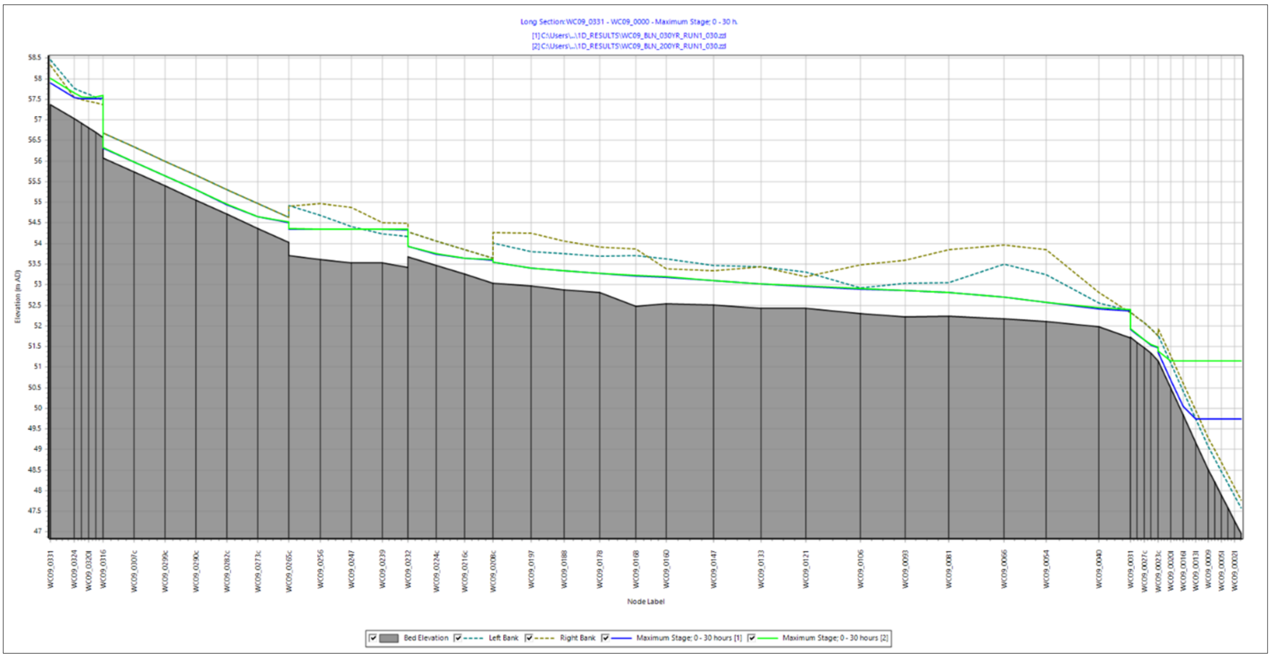

Figure E3.9: Baseline Scenario Maximum Water Levels Along MWC09 (Run 1 - 3.3% AEP and 0.5% AEP events)

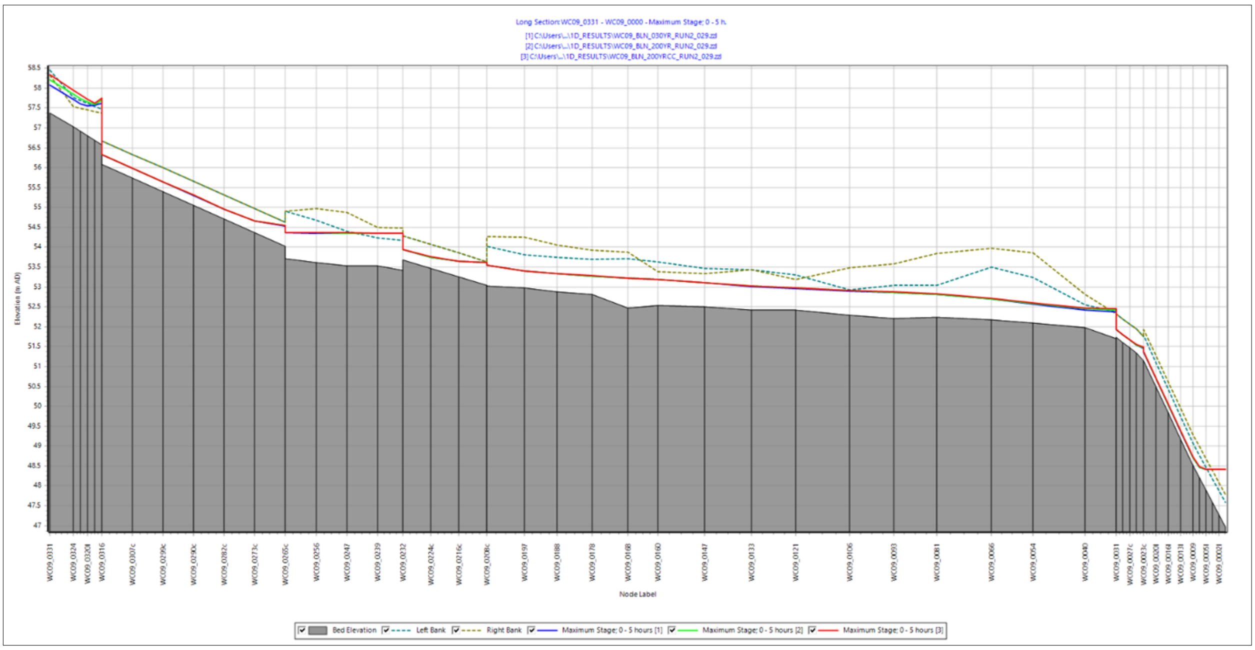

Figure E3.10: Baseline Scenario Maximum Water Levels Along MWC09 (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

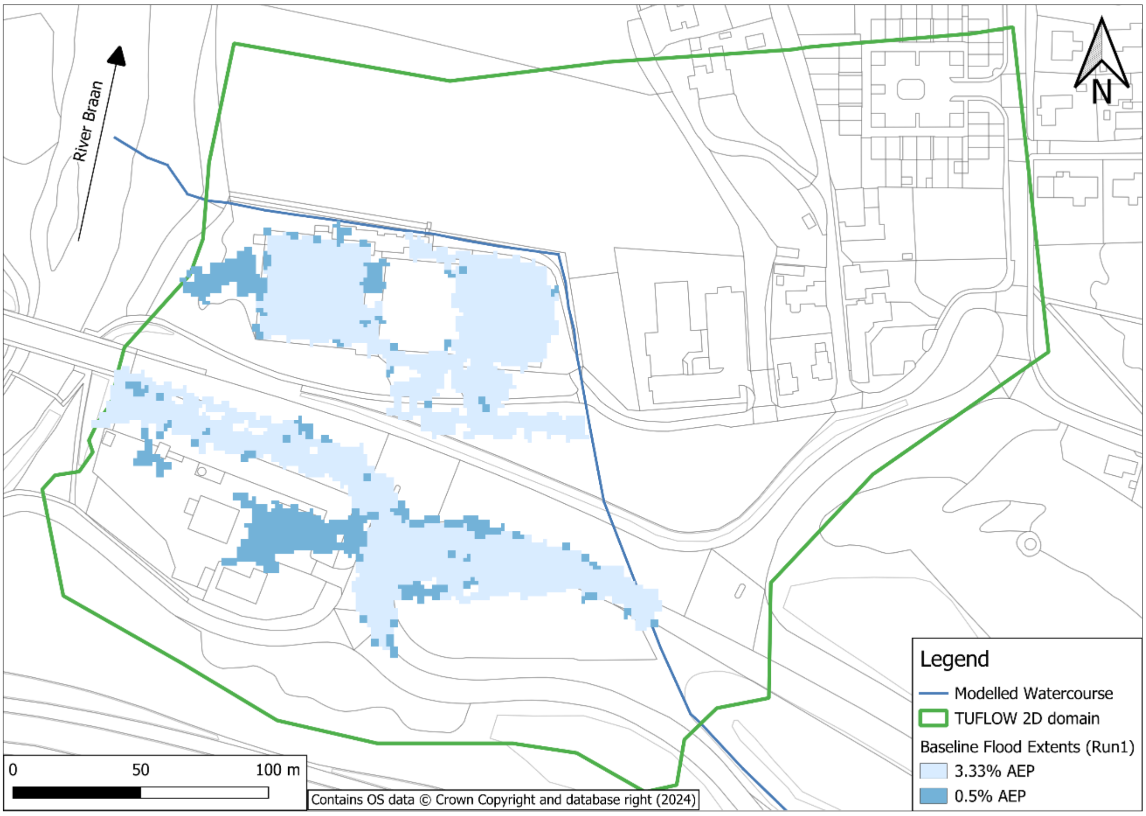

Figure E3.11: Maximum Flood Extent for the MWC09 Baseline Scenario (Run 1 - 3.3% AEP and 0.5% AEP events)

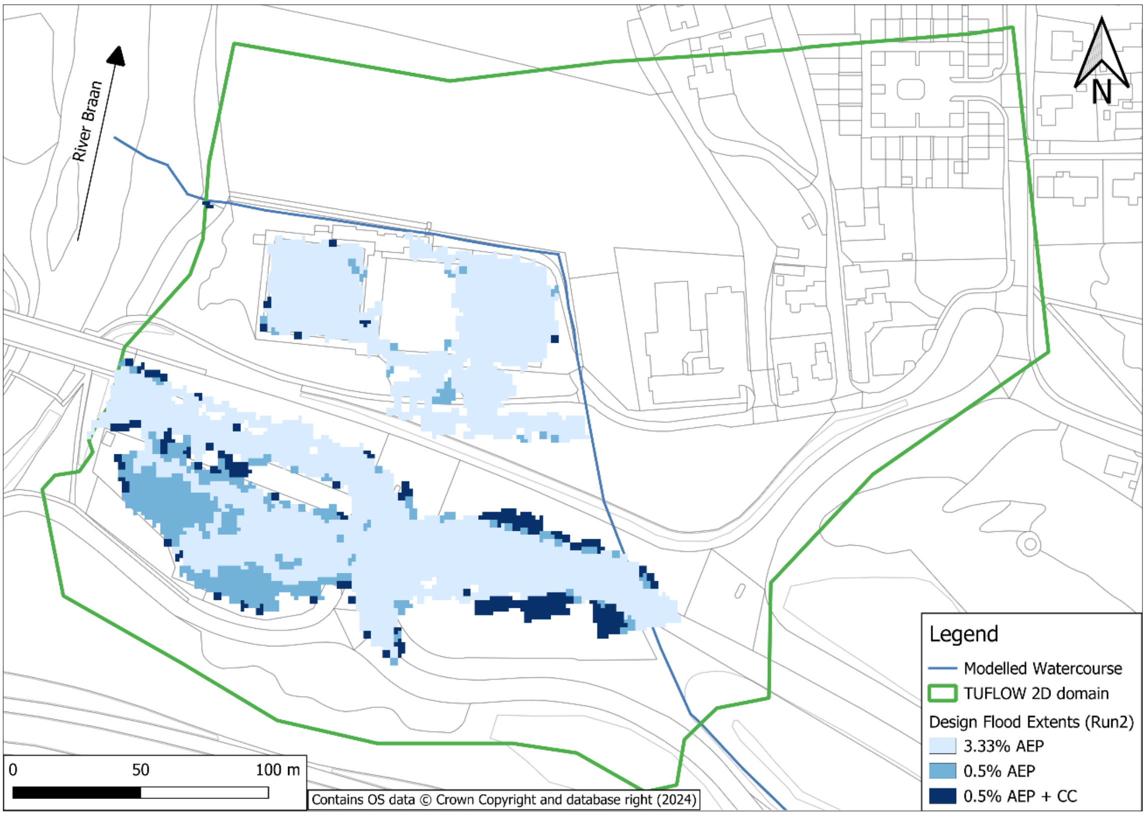

Figure E3.12: Maximum Flood Extent for the MWC09 Baseline Scenario (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

Scheme Results

Modelling results for both Run 1 and Run 2 proposed scheme scenarios are shown in Figure E3.13 to Figure E3.16 and further discussed in Appendix A19.2 (Flood Risk Assessment) in Chapter 19 Road Drainage and the Water Environment (RDWE) of the Environmental Impact Assessment Report (EIAR).

It can be seen that upsizing the first A9 culvert to a 1.8m diameter pipe prevents flooding of the A9 due to surcharging of the culvert as seen in the baseline results. However, as a result of increased capacity of the first culvert there is an increase in pass-forward flow downstream which is mitigated by the provision of the flood relief culvert set at the inlet of the second A9 culvert. As pass-forward flow is controlled by the second culvert (0.6m diameter pipe), the open channel downstream can accommodate the remaining flows that are not directed through the FRC and there is no longer flooding around Dunkeld and Birnam Bowling Club.

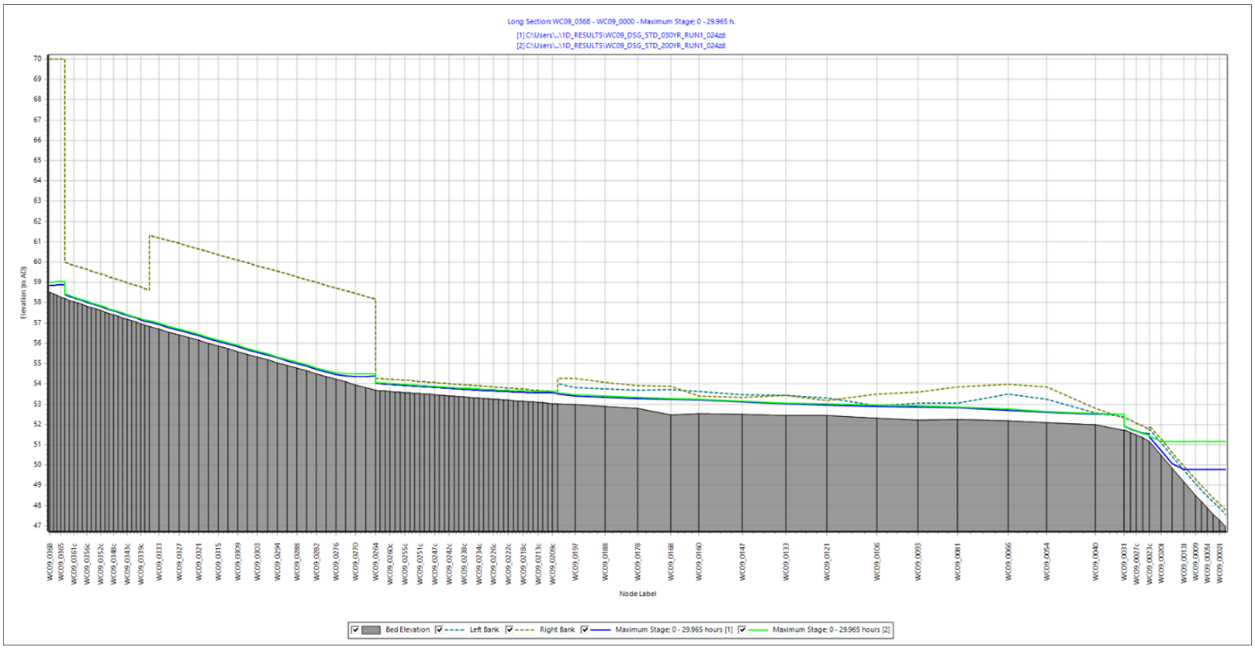

Figure E3.13: Design Scenario Maximum Water Levels Along MWC09 (Run 1 - 3.3% AEP, 0.5% AEP events)

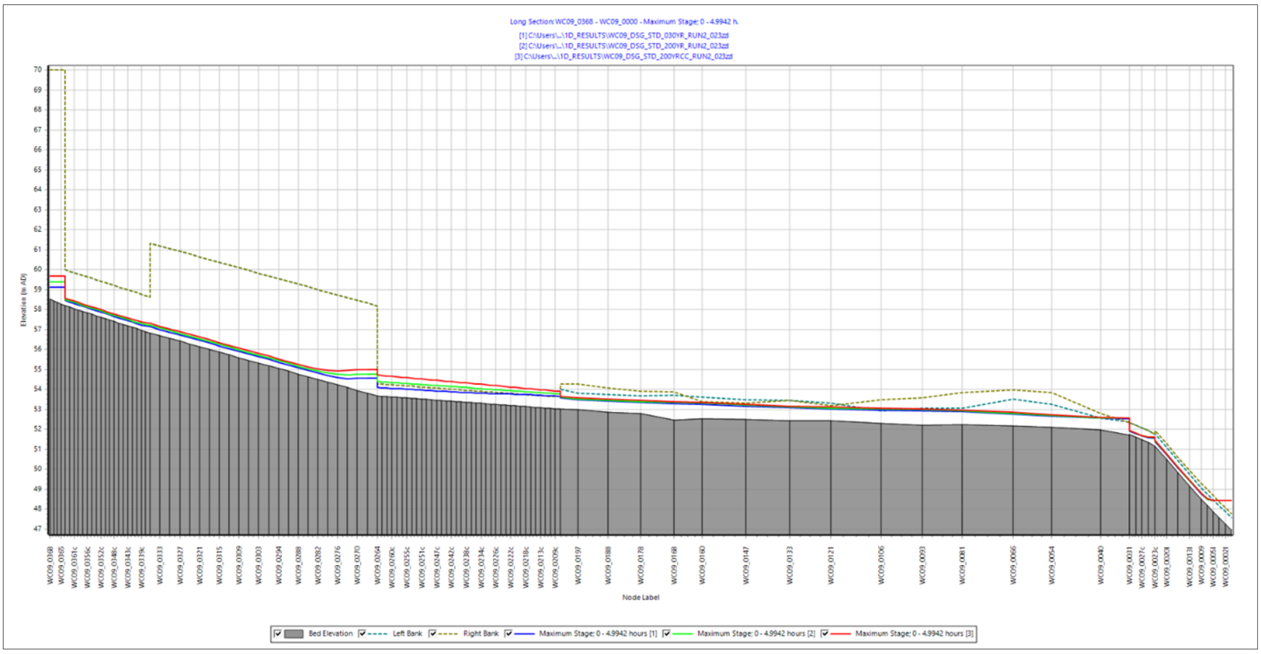

Figure E3.14: Design Scenario Maximum Water Levels Along MWC09 (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

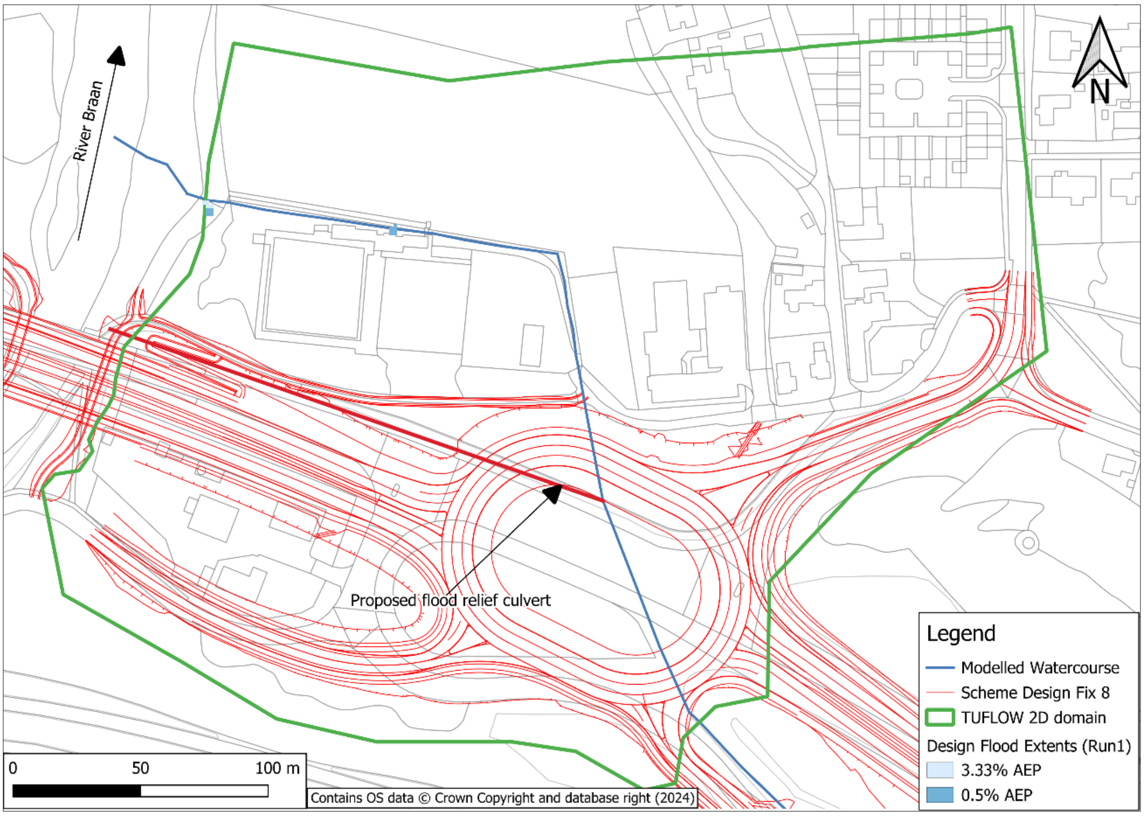

Figure E3.15: Maximum Flood Extent for the MWC09 Design Scenario (Run 1 - 3.3% AEP and 0.5% AEP events)

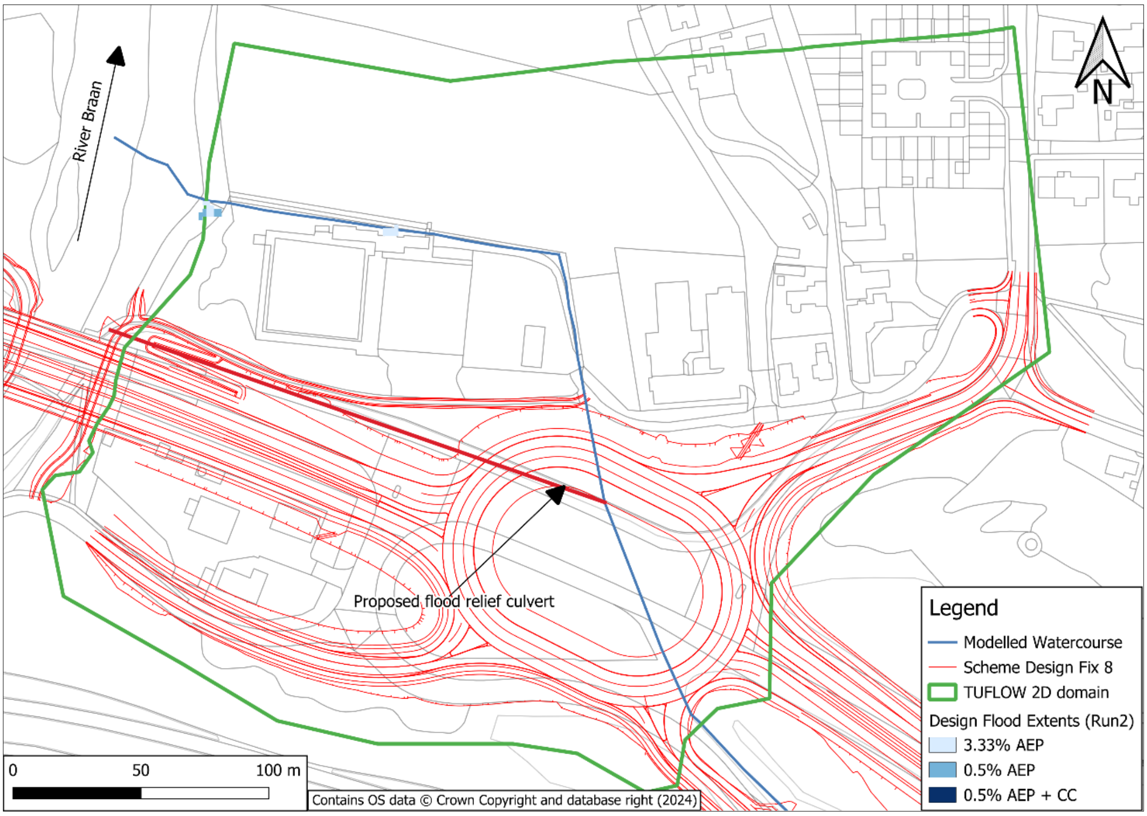

Figure E.16: Maximum Flood Extent for the MWC09 Design Scenario (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

Minor Watercourse 13 Modelling

The MWC13 has been modelled using a 1D approach using Flood Modeller (FM) software (version 7.0).

Due to steepness of the modelled channel, the use of the unsteady solver to run the model simulations was deemed inappropriate, and instead Flood Modeller's steady state transcritical method was utilised.

Preliminary model runs have shown that the water levels on River Tay have no effect on the peak water levels calculated at the A9 culvert inlet (in both baseline and proposed scenarios). Therefore, for Run 1, only the 3.3% AEP event was simulated.

Structures

Baseline structures along MWC13 were modelled as shown in Table E3.6.

Table E3.6: Modelled Structures along MWC13 in the baseline scenario

Structure	Modelling Approach
Minor road (WC13_0174bu)	Arch bridge. Deck represented with spill unit

A9 crossing (WC13_0166c – WC13_0120c)	1000mm circular conduit. Deck represented with spill unit. Used 0.1m Top Slot used to improve stability. Survey photos show the entrance of this culvert totally blocked with silt.
Railway Crossing (WC13_0104c – WC13_0091c)	Sprung arch conduit 3.2m wide, 3.37m high. Deck not represented.

Although survey photos show that the entrance of the culvert at the A9 crossing is totally blocked with silt, the baseline model was run assuming the culvert entrance free from blockages.

Immediately upstream of the A9 crossing (from cross section WC13_0217 to WC13_0168), floodplain on the left bank was modelled with spills and reservoir and floodplain on the right bank was modelled with extended cross sections.

Hydraulic Friction

Manning's 'n' coefficient values were determined using survey and site visit photos as well as aerial imagery and are reported in Table E3.7.

Table E.7: MWC13 - Roughness Coefficients

Cross Sections	Manning's 'n'	
	In-Channel	Out of banks
WC13_0345 - WC13_0166	0.07	0.1
WC13_0120- WC13_0000	0.05	0.07

In the baseline scenario it was deemed appropriate to set the bottom roughness of the culverts to the riverbed roughness as a conservative approach.

Proposed Scheme Modelling

Figure E3.17 shows the layout of the proposed scheme as per Design Fix 8 of the DRMB Stage 3 process. The modifications to the baseline model for the inclusion of the proposed scheme include:

- a realignment of almost the entire channel approximately 50m to the south (see Figure E3.18 for an example of cross-section shape of the realigned channel),
- changes in roughness for the realigned cross-sections (0.05 for the channel, 0.07 for the banks),
- widening of the existing A9 section from single to dual carriageway and a new rectangular culvert. The existing minor road bridge is assumed to be demolished (WC13_0174bu), whilst the railway bridge remains as it is.

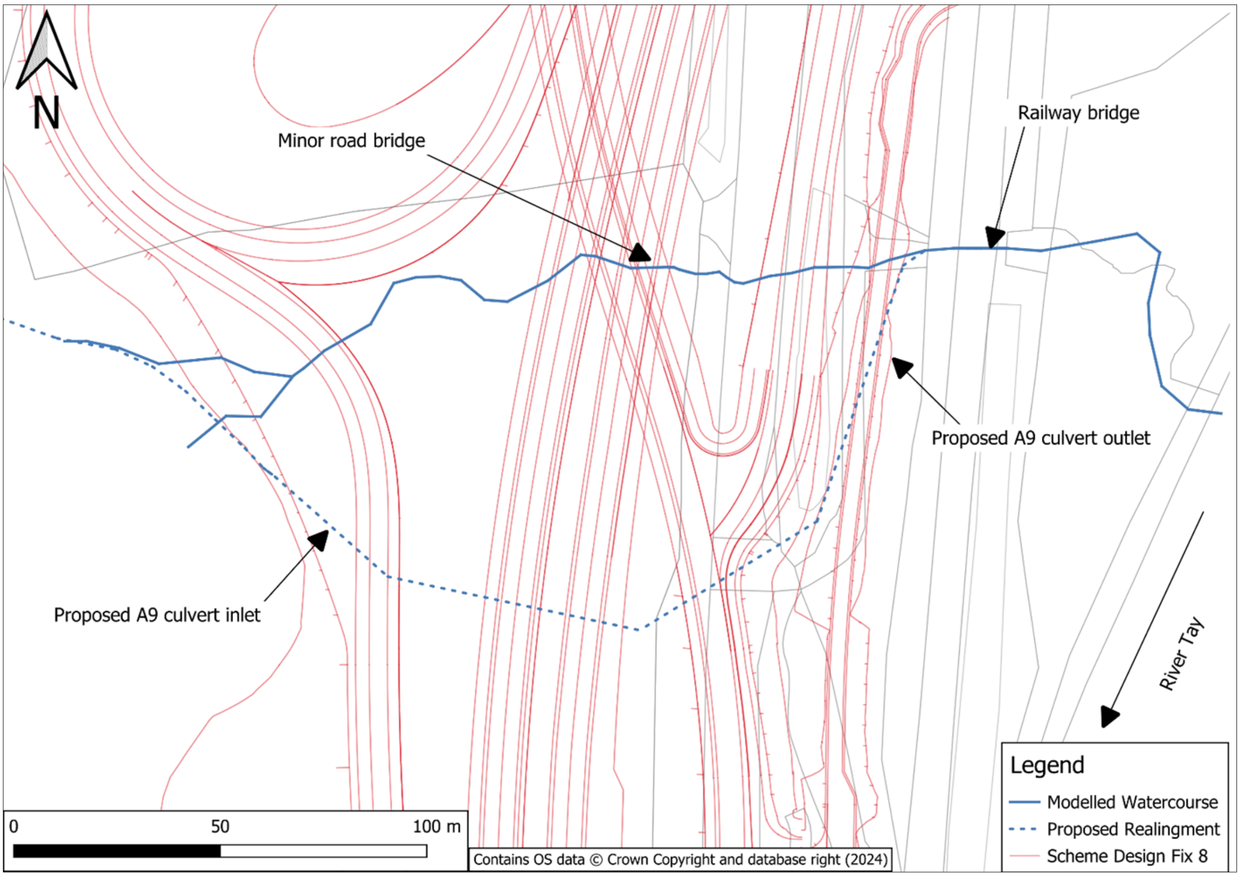

Figure E3.17: MWC13 scheme scenario schematisation

Table E3.8 lists all modelled structures in the proposed scheme scenario.

Table E3.8: Modelled structures along MWC13 in the proposed scheme scenario

Structure	Modelling Approach
A9 crossing (R1_XS10 – R2_XS01)	Symmetrical rectangular conduit 2.70m wide, 1.8m high.
Railway Crossing (WC13_0104i – WC13_0091c)	Sprung arch conduit 3.2m wide, 3.37m high. Deck not represented. No change from the baseline.

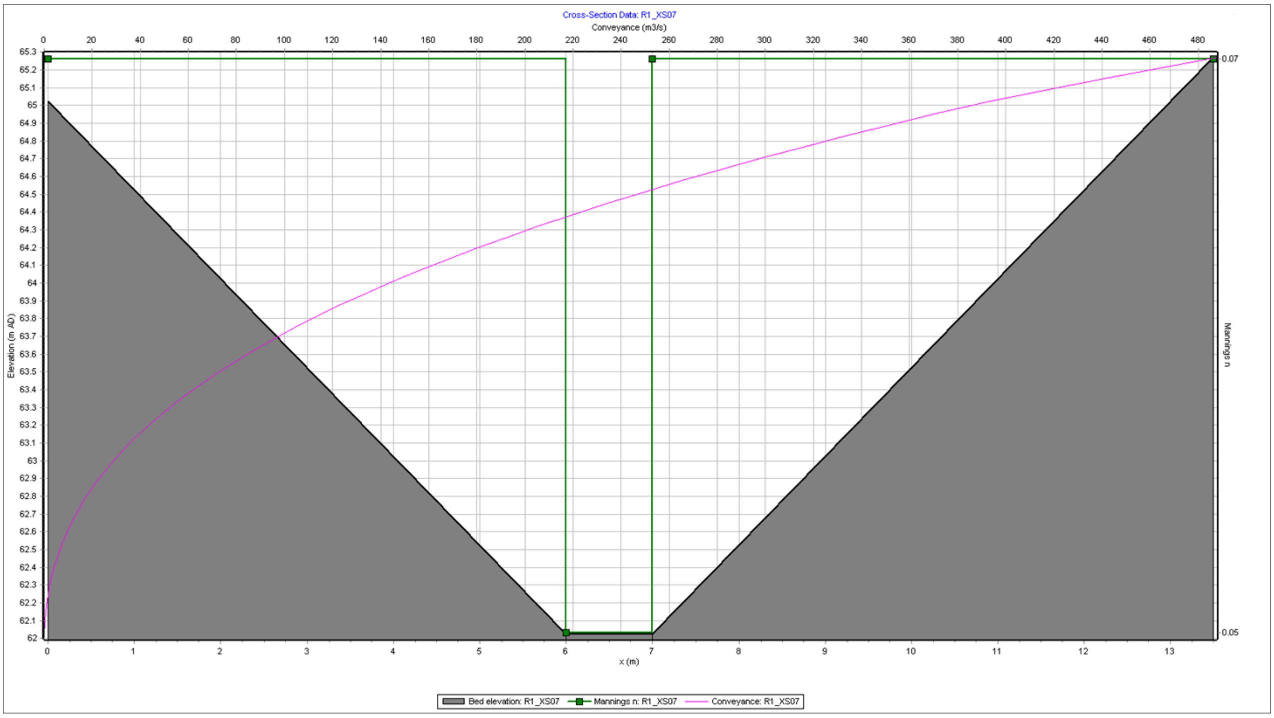

Figure E3.18: MWC13 typical cross-section of the realigned channel

Baseline Results

Modelling results for the Baseline scenario (Run 1 and Run 2) are shown in Figure E3.19 and Figure E3.20.

Model results show that for Run 1 – 3.3% AEP event the existing A9 culvert is not surcharged, and the watercourse remains in bank upstream of the A9.

In Run 2, the A9 culvert starts surcharging from a 3.3% AEP event and out of bank flooding occurs from a 0.5% AEP event. However, the A9 road embankment is sufficiently high for the road to remain free of flooding up to and including the 0.5% AEP plus climate change event.

The model is glass walling downstream of the A9 for Run 1 and Run 2 due to high levels driven by the River Tay as set in the downstream boundary. However, the floodplain is swamped and the water velocity at these locations is very low (<=0.2m/s), so the glass walling is deemed acceptable.

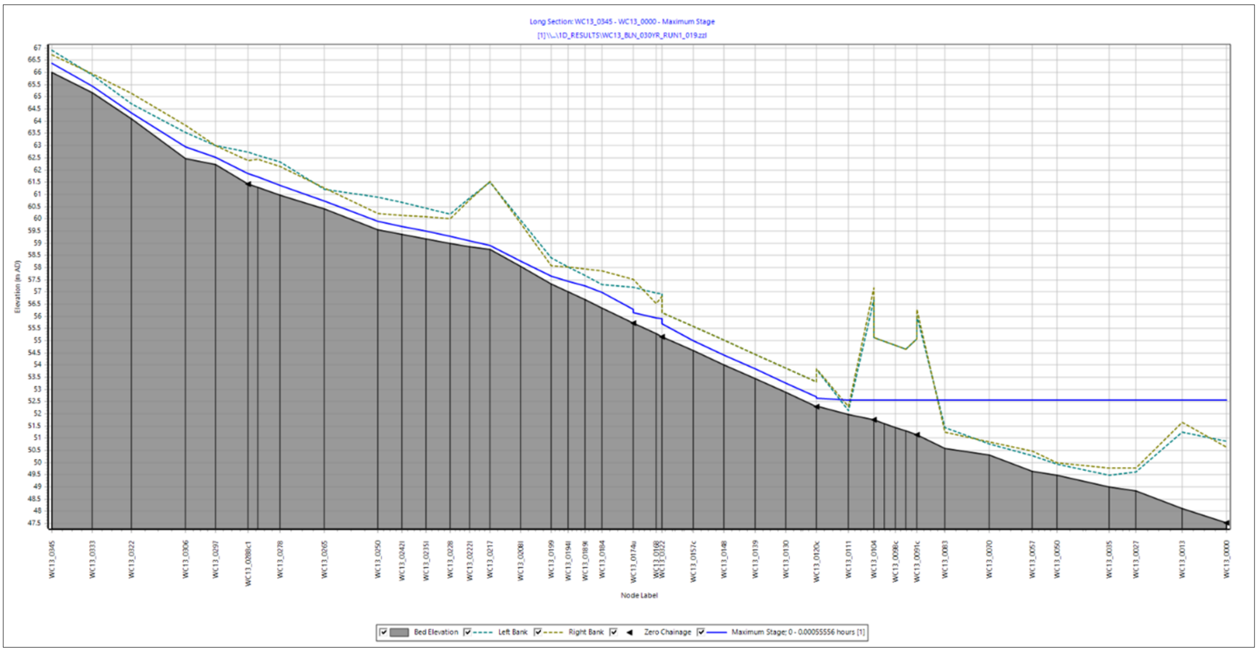

Figure E3.19: Baseline Scenario Maximum Water Levels Along MWC13 (Run 1 – 3.3% AEP event)

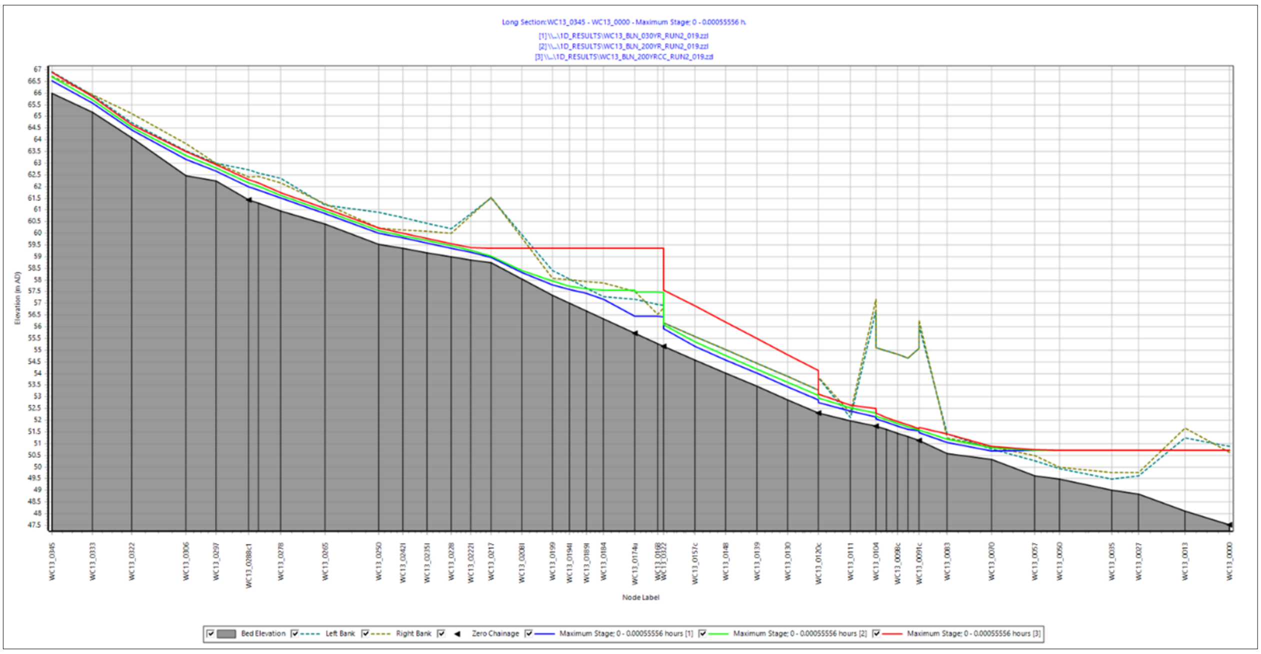

Figure E3.20: Baseline Scenario Maximum Water Levels Along MWC13 (Run 2 – 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

Scheme Results

Modelling results for the Scheme scenario (Run 1 and Run 2) are shown in Table E3.9 and in Figure E3.21 and Figure E3.22. These are further discussed in Appendix A19.2 (Flood Risk Assessment) in Chapter 19 Road Drainage and the Water Environment (RDWE) of the EIAR.

For all modelled events, the proposed A9 culvert runs under inlet control i.e. its discharge capacity is determined by the inlet to the structure. Model results show the inlet is no longer submerged even for the Run 2 -0.5% AEP + CC event and there is 560mm of available freeboard to soffit for this event. However, the sudden change in slope part-way through the culvert barrel results in a reduced capacity and surcharging occurs in the Run 2 -0.5% AEP + CC event from 40m downstream of the inlet to the outlet. However, predicted peak water levels remain well below road level.

Downstream flood risk is not affected by the proposed culvert as it is determined by the water levels on the River Tay. Based on Run 1 results, the realigned sections of the channel, between the new culvert outlet and existing railway bridge contains maximum water levels associated with a 3.33% AEP event in the River Tay. For this event, the River Tay driven flooding only occurs downstream of the existing railway bridge, where part of the access track is located.

In summary the model suggests that the proposed A9 scheme is not at risk of flooding from MWC13, and no further mitigation measures are necessary.

Table E3.9: Freeboard at the proposed MWC13 culvert under Run 2 – 0.5 % AEP + CC event

Proposed culvert	Culvert invert (mAOD)	Culvert soffit (mAOD)	Proposed road level (mAOD)	Run 2 - 0.5% AEP + CC		
				Maximum water level (mAOD)	Available freeboard to soffit (m)	Freeboard to road level (m)
R1_XS10cu	60.04	61.84	62.90	61.28	0.56	1.62

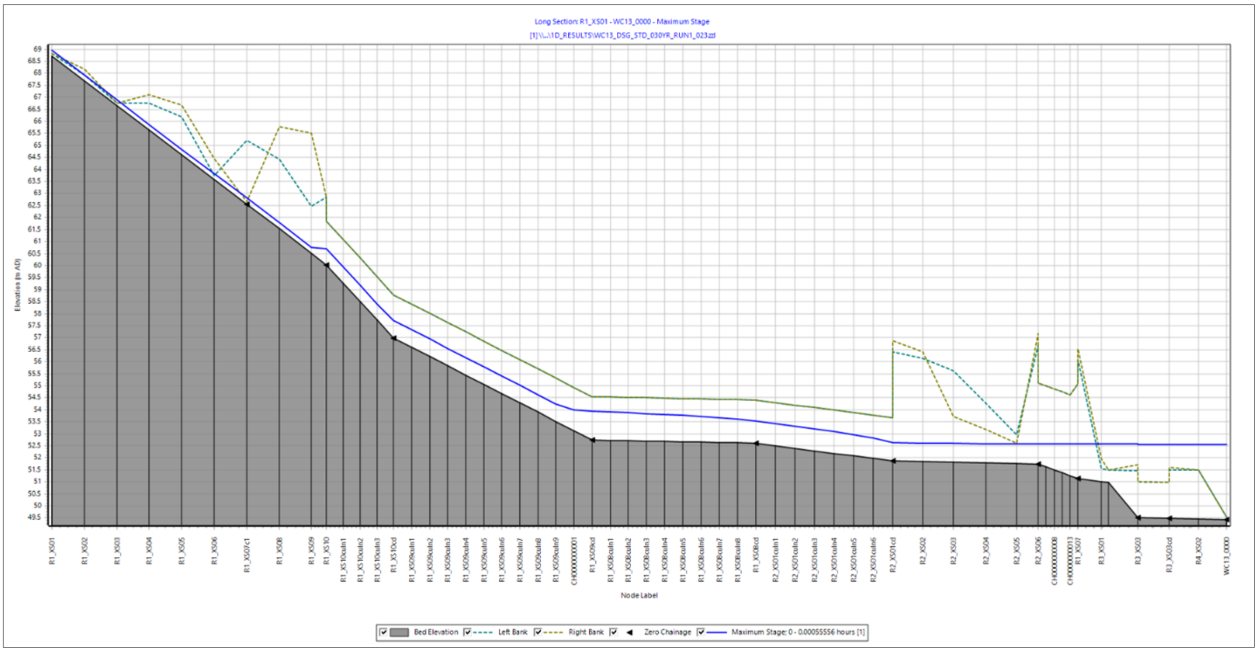

Figure E3.21: Scheme Scenario Maximum Water Level Along MWC13 (Run 1 – 3.3% AEP event)

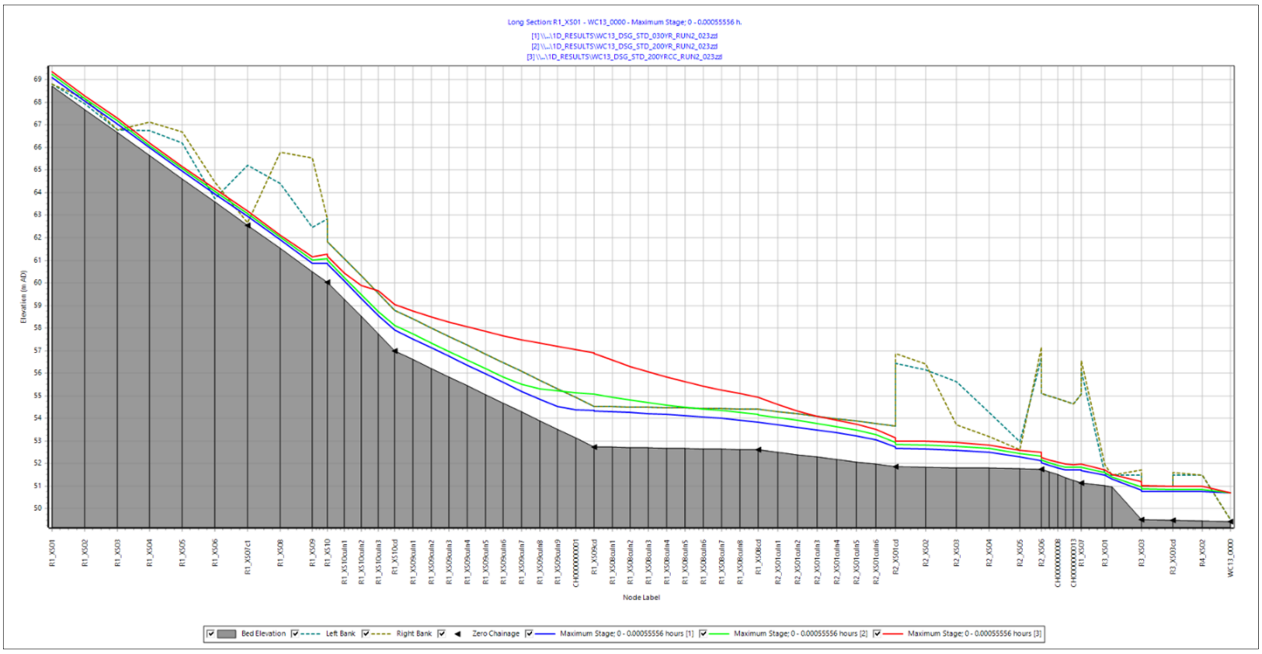

Figure E3.22: Scheme Scenario Maximum Water Level Along MWC13 (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

Minor Watercourse 16 Modelling

The MWC16 has been modelled using a 1D approach using Flood Modeller (FM) software (version 7.0).

Due to steepness of the modelled channel, the use of the unsteady solver to run the model simulations was deemed inappropriate, and instead Flood Modeller's steady state transcritical method was utilised.

Structures

Baseline structures along MWC16 were modelled as shown in Table E3.10.

Table E3.10: Modelled Structures along MWC16 in the baseline scenario

Structure	Modelling Approach
A9 crossing (WC16_0078c – WC16_0035c)	1100mm circular conduit. Entrance represented with an orifice unit. Deck not represented.
Small path crossing (WC16_0009c – WC16_0000c)	Sprung arch conduit 1.1m wide, 1.46m high. Deck represented with spill unit with 1.1 weir coefficient.

Hydraulic Friction

Manning's 'n' coefficient values were determined using survey and site visit photos as well as aerial imagery and are reported in Table E3.11.

Table E3.11: MWC16 - Roughness Coefficients

Cross-Sections	Manning's 'n'	
	In-Channel	Out of banks
WC16_0103 - WC16_-0001	**0.05**	**0.1**

Proposed Scheme Modelling

Figure E3.23 shows the layout of the proposed scheme as per Design Fix 8 of the DRMB Stage 3 process. The modifications to the baseline model for the inclusion of the proposed scheme include:

- a realignment of the entire modelled channel approximately 10m to the north (see Figure E3.24 for an example of cross-section shape of the realigned channel),
- changes in roughness for the realigned cross-sections (0.011 for the channel, 0.07 for the banks),

- widening of the existing A9 section from single to dual carriageway and a new 1200mm circular culvert. The existing small path crossing at the downstream of the model remains as it is.

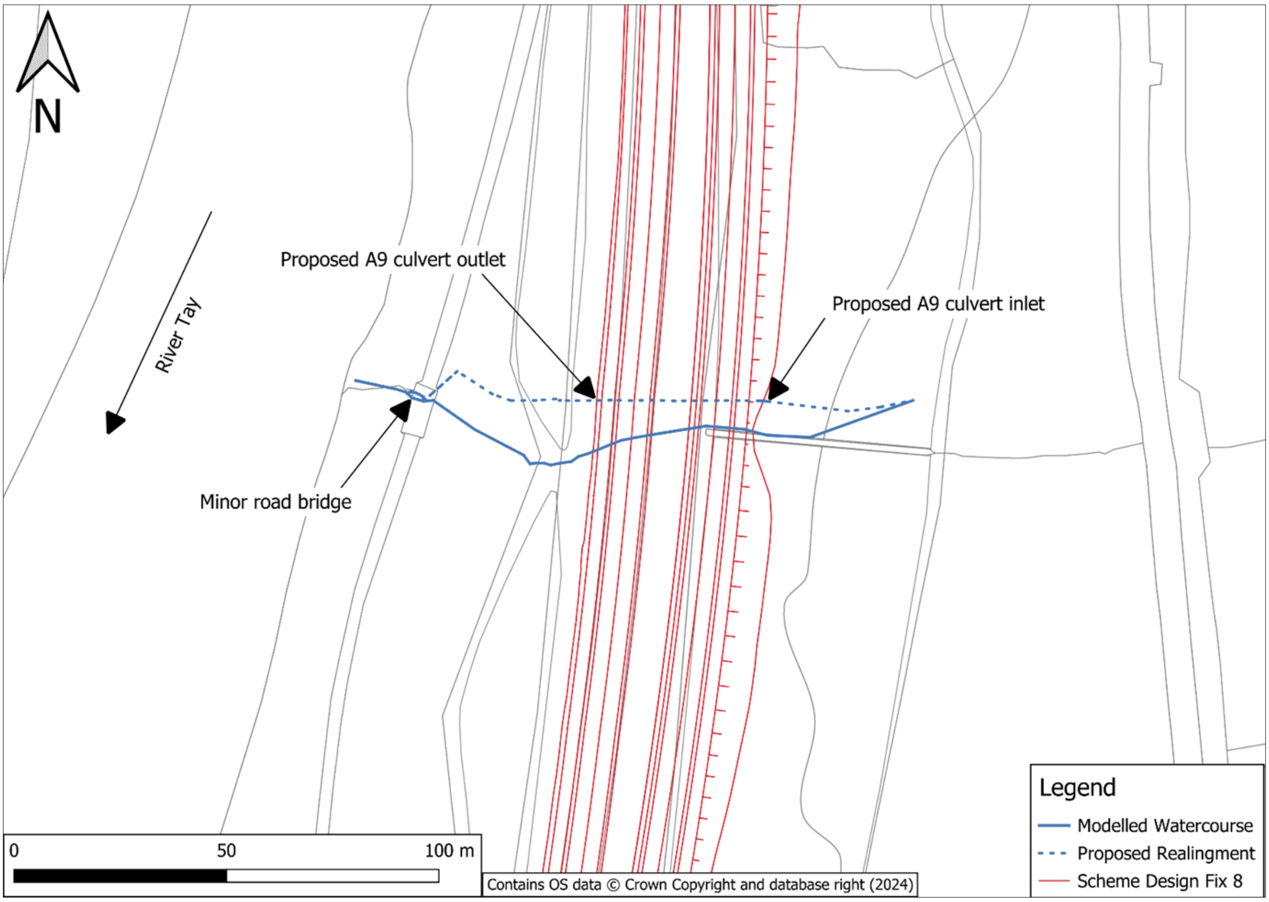

Figure E3.23: MWC16 scheme scenario schematisation

Table E3.12 below lists all modelled structures in the proposed scheme scenario.

Table E3.12: Modelled structures along MWC16 in the proposed scheme scenario

Structure	Modelling Approach
A9 crossing (WC16_0082-WC16_0035)	Circular conduit, 1200mm diameter. Entrance/exit represented with culvert inlet/outlet units. Deck not represented
Small Path Crossing (WC16_0009-WC16-0000)	Sprung arch conduit 1.1m wide, 1.46m high. Deck represented with spill unit with 1.1 weir coefficient. No change from baseline.

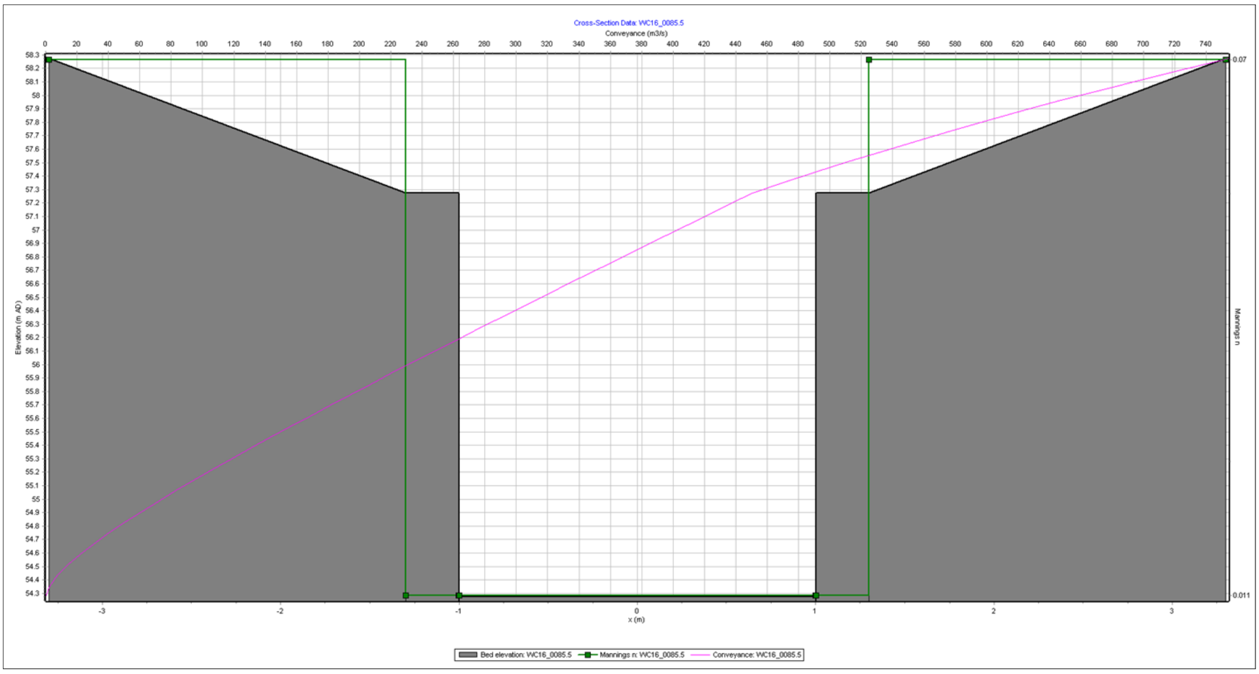

Figure E3.24: MWC16 typical cross-section of the realigned channel

Baseline Results

Modelling results for the Baseline scenario (Run 1 and Run 2) are shown in Figure E3.25 and Figure E3.26. These are further discussed in Appendix A19.2 (Flood Risk Assessment) in Chapter 19 Road Drainage and the Water Environment of the EIAR.

Under the baseline Run 1 scenario, due to high water levels driven by the downstream boundary, the model is glass walling on all events. Minor flooding can be expected at the downstream end of the model for a 3.33% and 0.5% AEP events. The model predicts significant changes in downstream driven flood risk due to climate change. Assuming a 53% increase in flows, the entire channel downstream of the existing A9 embankment is submerged; however, the A9 road embankment at the MWC16 crossing is sufficiently high for the road to remain free of flooding up to and including the 0.5% AEP plus climate change event.

Under baseline Run 2 scenario, peak water levels are contained within the existing channel for all events simulated. The A9 culvert operates in state of inlet control however peak water levels rise above culvert soffit by about 10mm during the 0.5% AEP plus Climate change event.

In conclusion, water levels along River Tay are the main driver of flood risk at MWC16. Current flood risk is low but is expected to be greatly impacted by the climate change.

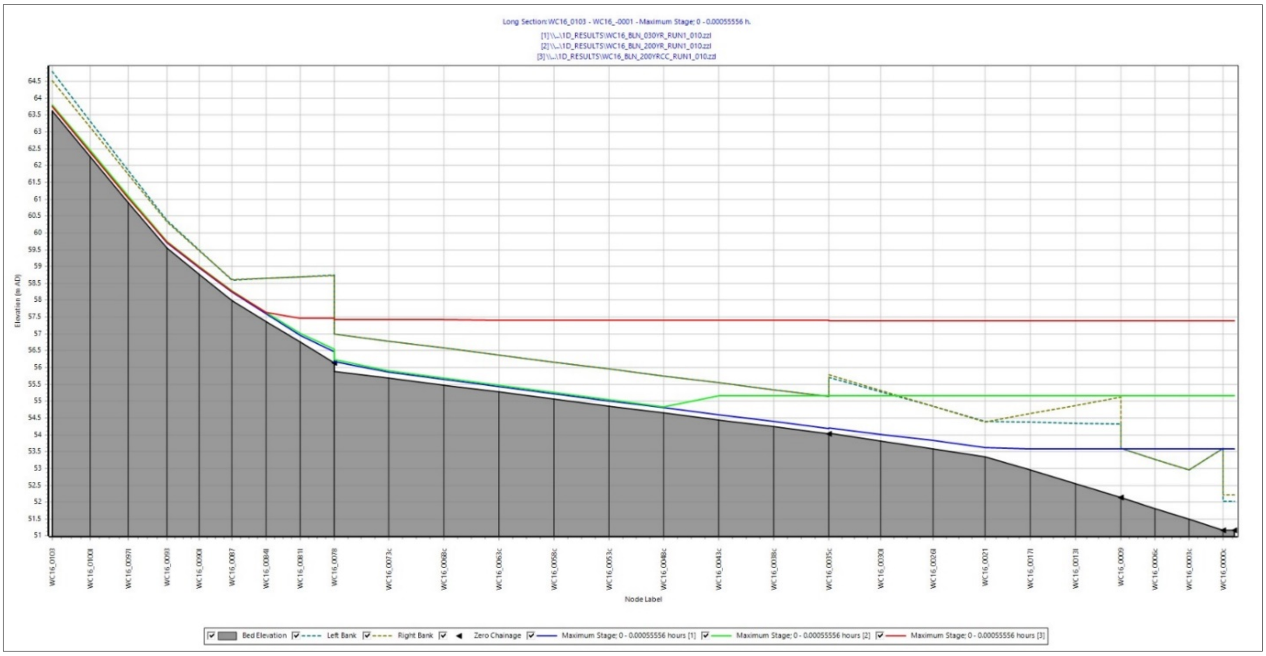

Figure E3.25: Baseline Scenario Maximum Water Levels Along MWC16 (Run 1 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

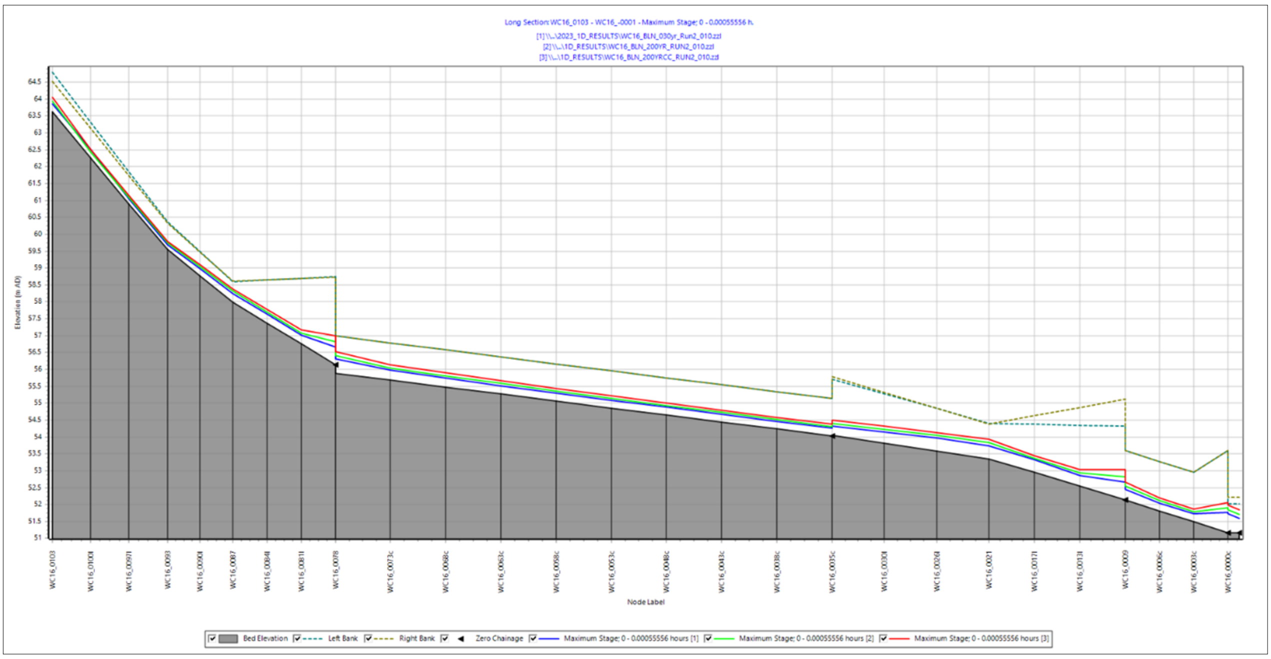

Figure E3.26: Baseline Scenario Maximum Water Levels Along MWC16 (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

<u>Design Results</u>

Modelling results for the Scheme scenario (Run 1 and Run 2) are shown in Table E3.13 and in Figure E3.27 and Figure E3.28. These are further discussed in Appendix A19.2 (Flood Risk Assessment) in Chapter 19 Road Drainage and the Water Environment of the EIAR.

As for the baseline scenario, the main driver of flood risk is the River Tay. Under Run 1 case, flow conditions similar to the baseline scenario are predicted at the small path crossing. Upstream of that crossing however, peak water levels are contained within the channel of the proposed realignment. Considering that the proposed road level is at 58.75m AOD, model results show that the proposed scheme is not at risk of flooding from the River Tay.

Under Run 2 scenario, model results also show that the proposed scheme is not at risk of flooding. The realigned channel contains peak water levels associated with the 0.5% AEP+CC event. The proposed A9 culvert runs in inlet control and peak water levels at the inlet maintain 240mm of freeboard to soffit level during the 0.5% AEP+CC event.

Table E3.13: Freeboard of the proposed MWC16 culvert under Run 2 – 0.5 % AEP + CC event

Proposed culvert	Culvert invert (mAOD)	Culvert soffit (mAOD)	Proposed road level (mAOD)	Run 2 - 0.5% AEP + CC		
				Maximum water level (mAOD)	Available freeboard to soffit level (m)	Freeboard to road level (m)
WC16_0082c	54.28	55.48	58.75	55.24	0.24	3.51

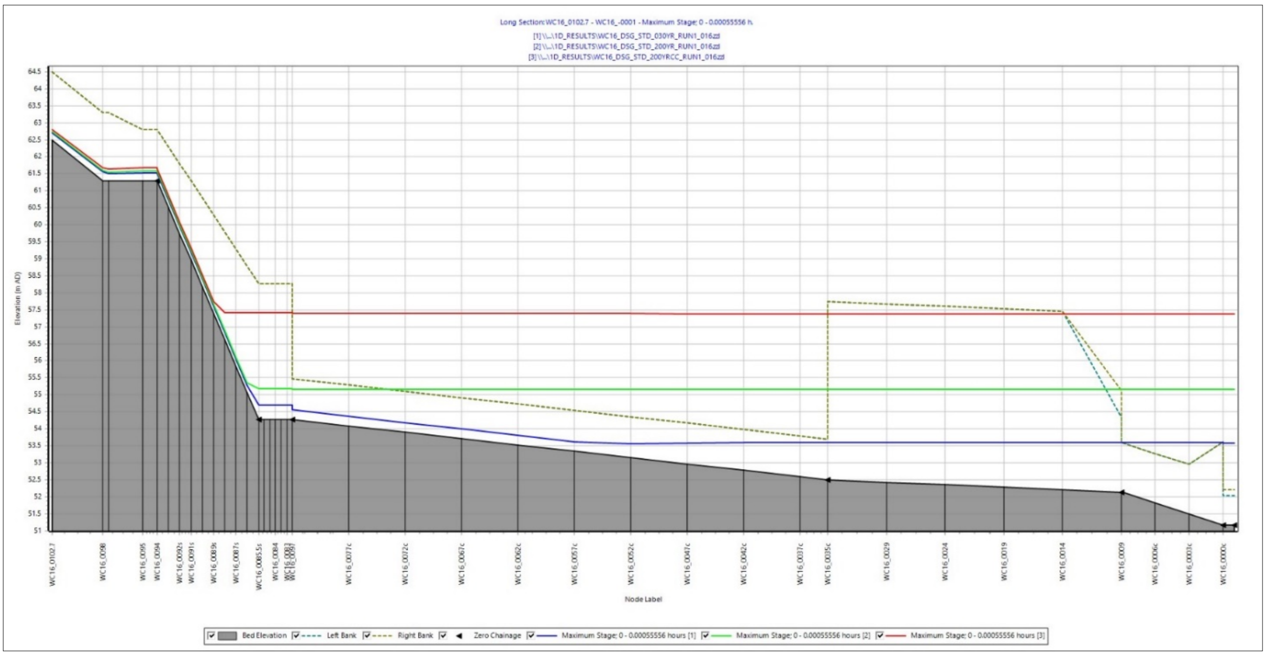

Figure E3.27: Scheme Scenario Maximum Water Levels Along MWC16 (Run 1 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

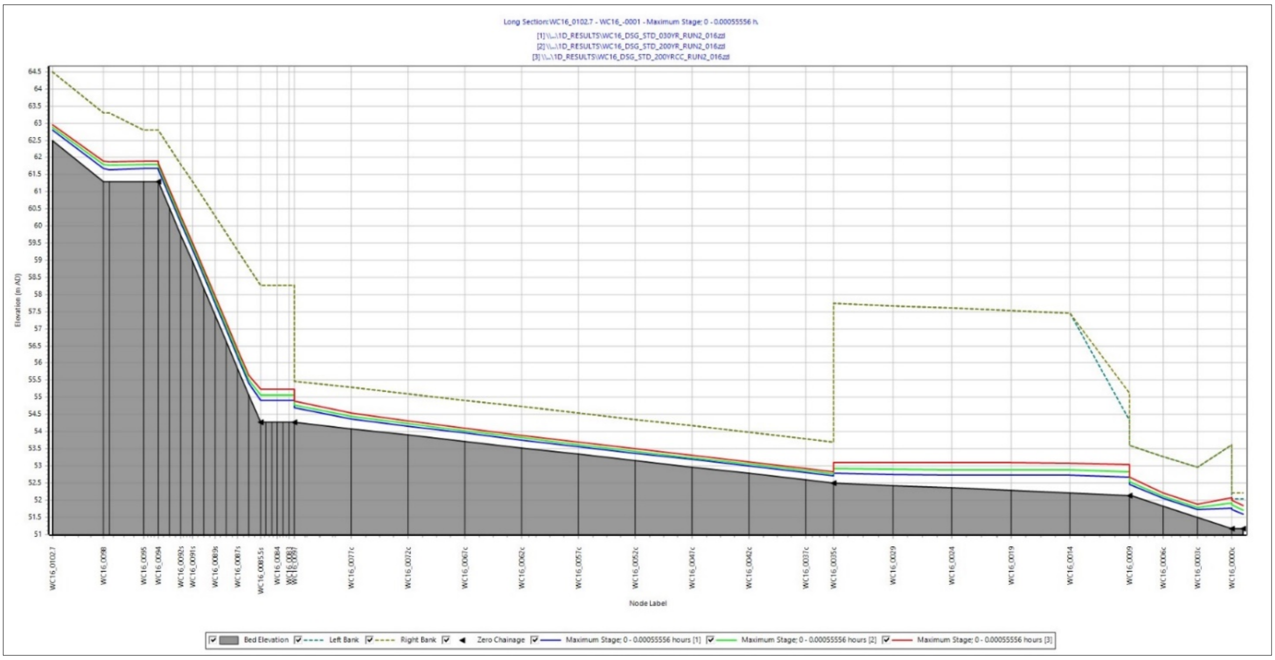

Figure E3.28: Scheme Scenario Maximum Water Levels Along MWC16 (Run 2 - 3.3% AEP, 0.5% AEP and 0.5% AEP + CC events)

Annex F: Compensatory flood storage screening

Technical Note

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Subject	**Compensatory Flood Storage Areas – Environmental Screening**	**Project Name**	A9 Dualling Pass of Birnam to Tay Crossing
		Project No.	B2140002
Date	09/05/2025	**Status**	S3
Document Number	A9P02-JAC-EGN-D_ZZZZZ_ZZ-TN-EN-0003	**Revision**	P01
Originator	PG	**Checker**	GK
Reviewer	GK	**Approver**	EM

Introduction

The flood risk team has provided a GIS layer showing the areas that are technically suitable for Compensatory Flood Storage Areas (CFSA). The purpose of this Technical Note is to document the environmental constraints in these areas so as to identify areas that would be suitable as CFSA, taking into account the potential for likely significant effects.

In the event that some areas identified by the flood risk team are unsuitable for Compensatory Flood Storage (CFS) due to the potential for significant environmental effects, and the level for level replacement required by SEPA cannot be met, this document would support the flood risk team in discussions with SEPA to explain why certain areas were excluded.

The areas proposed for this screening exercise are on Track Record Maps in the layer titled 'P2 Preliminary Screening of Flood Compensation Areas'. There are 19 locations identified (labelled as A to P2):

Methodology

- Step 1: Areas provided by the flood risk team were screened by specialist teams to identify if they could be screened in, partially screened in or screened out of future assessment. This is presented in Section 3: Screening Assessment.
- Step 2: Areas provided by the flood risk team split into smaller areas to apply 'Red, Amber, Green' (RAG) criteria as follows (Section 4);
  - **Red:** Due to the potential for additional significant impacts which cannot be mitigated, and the strong likelihood of objections being raised, these areas should be excluded from further consideration.
  - **Amber:** Due to the potential for additional significant impacts and the strong likelihood of objections being raised, these areas should be considered only if additional flood risk to key receptors is identified through modelling and it would have to be clearly demonstrated that no other options for the siting of FSC areas were available. Special consideration will need to be made with regards to consultation and mitigation in these areas.

- **Green:** These areas can be considered as any additional environmental impacts can be mitigated.

Limitations/Additional considerations

Northern bank of River Tay

No surveys have been undertaken on the northern bank of the River Tay so there is potential for further impacts that have not yet been identified. If any areas on the north bank are screened in, surveys will need to be conducted to understand the potential impacts and mitigation required.

Ecological Field Surveys

Biodiversity surveys have not yet been undertaken in many of the potential CFSA areas, particularly north of the River Tay. Therefore, local ecological constraints such as bat roosts and otter holts will not be used to screen these areas. A full suite of Biodiversity surveys will be required to cover any selected CFSA area and determine likely impacts and required mitigation.

Freshwater Pearl Mussel

Freshwater pearl mussels (FWPM) are protected under the Wildlife and Countryside Act (1981) Schedule 5 and as such it is illegal to disturb, injure, take, or kill a FWPM. They are also listed on Annex 2 and Annex 5 of the Habitats Directive as a non-priority species whose conservation requires the designation of special areas of conservation. They are classified as Critically Endangered under International Union for Conservation of Nature 2001 guidelines. Furthermore, FWPM are listed on the Scottish Biodiversity List and are a key species listed in the Tayside Biodiversity Action Plan.

The presence of FWPM adjacent to proposed CFSA will not be a criterion for screening an area in or out, but any hard infrastructure proposed as part of CFS in the vicinity of FWPM will need to be assessed by the Biodiversity team.

Unknown archaeological remains

Within any of the CFSA identified there is the potential for unknown archaeological remains, however, any significant impacts are likely to be reduced by mitigation.

Designated Areas

There are multiple environmental constraints in the area surrounding Project 02: Pass of Birnam to Tay Crossing. These constraints include international, national and local designations. This section explains the reasons for excluding certain designated areas from being made available for CFS.

Ancient Woodland Inventory (AWI)

Scottish Planning Policy identifies ancient woodland as an important and irreplaceable resource that should be protected and enhanced. The document *Scottish Government's Policy on Control of Woodland Removal: Implementation Guidance* (2019) requires a strong presumption against removal of ancient semi-natural woodland, and of long-established woodlands of plantation origin with significant biodiversity interest. Scottish Natural Heritage's Ancient Woodland Inventory (AWI) is a map-based tool that highlights areas of ancient woodland and long-established woodlands of plantation origin. It is recognised that there could be areas of ancient woodland that exist outside of the sites identified in the AWI; however, in the absence of survey data, the AWI will be used for this initial screening assessment.

The proposed scheme is currently anticipated to remove approximately 17.5ha of ancient woodland habitat directly underneath the footprint of the design. Any area of CFS anticipated to remove or otherwise negatively impact ancient woodland habitat shall be screened out; however, where only part of a CFSA impacts ancient woodland habitat the remainder of the CFSA could still be utilised where identified in Section 3. Where CFSA are proposed in the vicinity of ancient woodland habitat, a 15m protection zone should be established to protect ancient woodland features.

Native Woodland

The document *Scottish Government's policy on control of woodland removal: implementation guidance* (2019) requires a strong presumption against removal of UK Biodiversity Action Plan (BAP) priority woodland types, including well-established semi-natural priority woodlands. The Native Woodland Survey of Scotland provides information on native woodland types and can be used to screen proposed CFSA in the absence of survey data.

Due to the limited available area to mitigate, or compensate, for the loss of native woodland, any area of CFS anticipated to remove or otherwise negatively impact UK BAP priority woodland types shall be screened out. However, where only part of a CFSA impacts UK BAP priority woodland the remainder of the CFSA could still be utilised where identified in Section 3.

River Tay Special Area of Conservation

The statutory designated site River Tay Special Area of Conservation (SAC) is designated for its biological interest and supports qualifying interests including Atlantic salmon, otter, and lamprey species. Whilst the majority of the SAC boundary is aquatic habitat, there are also sections of bankside terrestrial habitat within the designation boundary. Construction and creation of CFSA in the vicinity of the River Tay SAC could lead to sedimentation impacts or bank instability of the River Tay; it is therefore advised that a minimum of 15m protection zone should be established around the River Tay SAC boundary.

Craig Tronach Site of Special Scientific Interest

The statutory designated site Craig Tronach Site of Special Scientific Interest (SSSI) is designated for its biological interest and is important for the regionally rare fern: the forked spleenwort. Any area of CFS anticipated to remove or otherwise negatively impact the SSSI shall be screened out. However, where only part of a CFSA impacts the SSSI the remainder of the CFSA could still be utilised where identified in Section 3.

Scheduled Monuments

CFSA 'I' would remove part of the scheduled area of Dunkeld Cathedral Scheduled Monument as defined by Historic Environment Scotland (HES) resulting in a significant impact to Dunkeld Cathedral Scheduled Monument. This would not align with Policy 145 of the Scottish Planning Policy (SPP) and Policy 26 of the Perth & Kinross Council (PKC) Local Development Plan 2 (see Appendix A) and is likely that the location of the FSC within the scheduled area would be considered unacceptable by statutory consultees, unless it could be clearly evidenced that the need to locate the FSC within the scheduled area was an '*exceptional circumstance*', in this case through exhaustively demonstrating that all other options had been explored and that no alternative options were available.

While there is the potential for the CFSA identified to result in impacts on Scheduled Monuments due to changes to their setting it is unlikely that these impacts would be significant.

Listed Buildings

CFSA 'A', 'F2', 'N' and 'I' have the potential to result in significant impacts on Listed Buildings due to their physical loss, and for CFSA 'E1' due to changes to the setting of a Listed Building. This does not align with SPP Policy 141 or PKC Local Development Plan 2 (PKC LDP2) Policy 27B (see Appendix A). It is likely that this would not be considered acceptable by the statutory consultees unless it could be clearly demonstrated that the proposed scheme required the demolition of these Listed Buildings in order to deliver '*significant benefits to economic growth or the wider community'*.

There is the potential for additional impacts on other Listed Buildings through changes to their setting resulting from the CFSA identified, however it is unlikely that these impacts would be significant.

Conservation Areas

There is the potential for significant impacts on Birnam Conservation Area from CFSA 'E2' and Dunkeld Conservation Area from the location of CFSA 'F1' and 'G' resulting from changes to their character. The CFSA 'E2', 'F1' and 'G' would not '*preserve or enhance the character and appearance'* of Birnam Conservation Area (E2) and Dunkeld Conservation Area (F1 and G) and would result in the loss of trees within Birnam Conservation Area and would therefore not align with SPP Policies 143 and 144 or PKC Policies 28A or 40A (see Appendix A). Statutory consultees are likely to object to the location of CFSA within either of the Conservation Areas identified above.

Inventory Gardens and Designed Landscapes

Murthly Castle, Dunkeld House and The Hermitage are gardens and designed landscapes (GDL) recorded in the Inventory of Gardens and Designed Landscapes. The location of FSC Areas 'B' and 'D' within Murthly Castle (GDL) and FSC Areas 'I', 'L' and 'N' within Dunkeld House GDL would result in significant impacts due to physical changes within the Inventory site boundary affecting their key landscape features and special features identified in the Inventory site descriptions. While FSC Area 'J' is partly located within the Inventory site boundary of The Hermitage GDL, this is unlikely to result in a significant impact. The location of CFSA within these GDLs do not align with SPP Policy 148 and PKC Local Development Plan 2 Policy 29 and therefore are highly unlikely to be acceptable to HES and PKC. The requirements of *Managing Change in the Historic Environment: Gardens and Designed Landscapes* (HES, 2020) are that developments within a GDL should '*avoid, minimise and mitigate detrimental impacts*', and it would have to be clearly demonstrated that no other options for the siting of FSC areas were available.

Inventory Battlefields

Dunkeld Battlefield is recorded on the Inventory of Historic Battlefields which is compiled and maintained by HES. The location of CFSA I and F1 within the Inventory site boundary identified for Dunkeld Battlefield would have a significant impact on the Inventory battlefield resulting from direct impacts on the battlefields special qualities and changes to key landscape characteristics. This would not align with SPP Policy 149 or PKC Local Development Plan 2 Policy 30 (see Appendix A) and therefore is highly unlikely to be acceptable to HES or PKHT. The requirements of *Managing Change in the Historic Environment: Historic Battlefields* (HES, 2020) is to '*avoid impacts that compromise factors that were among the reasons for including the battlefield in the Inventory*', and it would have to be clearly demonstrated that no other options for the siting of FSC area with the Dunkeld Battlefield are available.

Open Space

The PKC LDP2 identifies Sports Pitches, Parks and Open Space which has value to the community for either recreational or amenity purposes. There is the potential for significant potential impacts arising from land-take on designated Open Space from CFSA 'E2', 'F1', 'F2' and 'G'. This would not align with Policy 14 (Open Space Retention and Provision) and accompanying supplementary guidance 'Open Space Provision for New Developments'.

Prime Agricultural Land

SPP Policy 80 states that *"development on prime agricultural land, or land of lesser quality that is locally important should not be permitted except where it is essential: ….. for example for essential infrastructure, where no other suitable site is available"*. For the purposes of this assessment it is assumed that through mitigation and the design of the flood compensatory storage areas, they would not preclude the continued use as agricultural land (subject to burdens on future land use and development) nor would they change the LCA Class. Therefore, whilst there would be land-take of prime agricultural land associated with CFSA 'B', 'C', 'D', 'I', 'O', 'P1', and 'P2' there would not in effect be a loss of prime agricultural land.

National Scenic Areas (NSAs)

The whole area is within the River Tay NSA and would result in removal of managed plantation woodland and important riparian trees along both sides of the River Tay. Small non-wooded areas may have potential for a CFSA without significant impact e.g. agricultural land in the east north of the Tay and open rough grassland/scrub in northwest. Site surveys would be needed to confirm potential impacts.

Screening Assessment

This table considers each area (A to P2) proposed for the initial screening to determine whether each should be screened in as a potential location or screened out and excluded from consideration.

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
A	Biodiversity	AWI SAC Native Woodland	Partially screened out to avoid ancient woodland, SAC, and native woodland habitats.	The southern bank of the River Tay in CFSA A is entirely listed on the AWI and partially within the River Tay SAC and should, therefore, be avoided. Half of CFSA A to the north of the River Tay is comprised of UK BAP native pine woodland, with areas to the north listed on the AWI which should be avoided. The north-west of CFSA A can be utilised, with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	Listed Buildings	Screen out areas that may affect the Listed Building. Screen in areas that would not impact in Listed Buildings.	Potential for significant impacts to a Listed Building. Please refer to page 4, section headed 'Listed Buildings' for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area is within NSA and would result in removal of managed plantation woodland and important riparian trees along both sides of the River Tay. Small non-wooded areas may have potential for CFS without significant impact: agricultural land in the east north of the Tay and open rough grassland/scrub in northwest. Site survey needed to confirm.
	WCH	None	Screened in	No WCH routes within CFSA A.
	Land Use	None	Screened in	Commercial plantation on Murthly Estate. Land-take of this area alone unlikely to have potential for significant effects.
B	Biodiversity	AWI SAC SSSI	Partially screened out to avoid ancient and native woodland, SAC, and SSSI habitat.	The northern bank of the River Tay in CFSA B is predominantly listed on the AWI and partially within the Craig Tronach SSSI which should be avoided. The corner of the arable field on the northern bank can still be utilised with a 15m protection zone around the SAC and AWI. Half of CFSA B to the south of the River Tay is listed on the AWI, includes an area of UK BAP upland oakwood habitat, and is partially within the River Tay SAC. These areas should be avoided; however, the remainder of the area to the south can be utilised with a 15m protection zone around the SAC and

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
		Native Woodland		AWI.
	Cultural Heritage	Inventory Gardens and Designed Landscape	Screened out	Whole of CFSA B is within Murthly Castle GDL. Please refer to page 4, section headed 'Inventory Gardens and Designed Landscape' for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole of CFSA B is within NSA and would result in removal of woodland and scattered trees. Small section of scrub/rough grassland in the west of CFSA B may have potential for CFS without significant impact. Potential for adverse visual impacts for Greystones and Boat of Murthly on the north bank of the Tay. Site survey needed to confirm.
	WCH	Local Path 15	Screened in	Approximately 137m of Local Path 7 within CFSA B.
	Land Use	Prime agricultural land	Screened in	Whilst there is a presumption against development on prime agricultural land it is assumed that the design of the CFSA B would not preclude its continued use as agricultural land nor change its LCA Class. Areas of woodland assumed to be relatively young natural regeneration on previous plantation site. Arb surveys required to determine quality of trees.
C	Biodiversity	AWI SAC Native Woodland	Partially screened out to avoid ancient and native woodland, and SAC habitats	The southern bank of the River Tay in CFSA C is entirely listed on the AWI and partially within the River Tay SAC. One area of CFSA C to the north of the River Tay is listed on the AWI and is UK BAP wet woodland habitat. These areas shall be avoided; however, the majority of the arable fields could be utilised with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	None	Screened in	There are unlikely to be any significant impacts on cultural heritage resources.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area is within NSA and would result in removal of important riparian trees along both sides of the River Tay. Large areas of open agricultural land north of Tay may have potential for CFS without significant impacts, provided woodland and trees are avoided. Potential for visual impact at Newtyle Farm, Deans Park and A984. Wooded area south of Tay should be avoided.
	WCH	None	Screened in	No WCH routes within CFSA C.
	Land Use	Prime agricultural land	Partially screened out to avoid woodland	Refer to Biodiversity assessment for potential impacts on AWI. Whilst there is a presumption against development on prime agricultural land it is assumed that the

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
				design of the CFSA C would not preclude its continued use as agricultural land nor change its LCA Class.
D	Biodiversity	AWI SAC Native Woodland	Partially screened out to avoid ancient and native woodland, and SAC habitats	The northern bank of the River Tay in CFSA D is entirely listed on the AWI, partially within the River Tay SAC, and includes areas of UK BAP upland oakwood habitat. Therefore, the entire northern bank of CFSA D should be screened out. The part of CFSA D to the south of the River Tay is predominantly an area of arable field; however, a strip of ancient woodland on the AWI runs along the bank of the River Tay which should be avoided. The part of CFSA D that is in the arable field can be utilised from an Biodiversity perspective with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	Inventory Gardens and Designed Landscape	Screened out	Whole area is within Murthly Castle GDL. Please refer to page 4, section headed ‘Inventory Gardens and Designed Landscape’ for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area is within NSA. Large area of open agricultural land south of Tay may have potential for CFS without significant impact, provided riparian trees/ woodland along both sides of the River Tay are avoided. Potential visual impact for various properties in Birnam and Core paths DUNK/10/4 and DUNK/10/5. Wooded area north of Tay should be avoided.
	WCH	Core Path 24 and Right of Way (RoW)	Screened in	Approximately 1.26km of Core Path and RoW within CFSA D.
	Land Use	Prime agricultural land	Partially screened out to avoid woodland	Refer to Biodiversity assessment for potential impacts on AWI. Whilst there is a presumption against development on prime agricultural land it is assumed that the design of CFSA D would not preclude its continued use as agricultural land nor change its LCA Class.
E1	Biodiversity	AWI SAC Native Woodland	Partially screened out to avoid ancient and native woodland, and SAC habitats	The eastern half of CFSA E1 is listed on the AWI, partially within the River Tay SAC, and includes an area of UK BAP upland oakwood habitat. The eastern half of CFSA E1 should, therefore, be avoided; however, the western half of CFSA E1 could be utilised with a 15m protection zone around the SAC and AWI. Due to the protection zones, the available area is minimal.
	Cultural Heritage	Listed Building	Screen out areas that my affect the Listed Building Screen in areas that would not	Potential for significant impacts to a Listed Building due to changes to its setting. Please refer to page 4, section headed ‘Listed Buildings’ for further information.

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
			impact in Listed Buildings	
	Landscape and Visual	NSA	Screen out trees/woodland and formal gardens associated with Eastwood House	Whole area is within NSA and would result in removal of important riparian trees and policy woodland including parkland trees along north side of the River Tay. Small areas of open ground appear to be formal gardens associated with Eastwood House. Potential visual impacts on Eastwood House and nearby cottages. Unlikely that area has potential for CFS without significant impacts.
	WCH	None	Screened in	No WCH routes within CFSA E1.
	Land Use	None	Partially screened out to avoid woodland	Potential for trees to be of high quality. Arboriculture surveys required to determine quality of trees.
E2	Biodiversity	AWI SAC	Partially screened out to avoid ancient woodland and SAC habitats	CFSA E2 is mostly listed on the AWI and within the River Tay SAC. These areas shall be avoided; however, the remainder of CFSA E2 can be utilised with a 15m protection zone around the SAC and AWI. Due to the protection zones, the available area is minimal.
	Cultural Heritage	Conservation Area	Screened out	Whole area is within Birnam Conservation Area. Please refer to page 4, section headed 'Conservation Areas' for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland and Beatrix Potter Garden	Whole area is within NSA and would result in loss of important riparian trees, woodland and large mature trees along the south side of the River Tay. Small areas of open ground (open space and children's play area) may have potential for CFS without significant impacts. Site survey needed to confirm. Potential visual impact at properties in Birnam and Core paths DUNK/56/2 and DUNK/10/3. Includes Beatrix Potter garden, which should be avoided.
	WCH	None	Screened in	No WCH routes within CFSA E2.
	Land Use	Open Space Conservation Area	Screened out	Whole area is designated Open Space in the PKC LDP2. If land-take necessary would potentially require exchange land. There are culturally significant ancient trees adjacent to river (including Birnam Oak) and trees of potentially high quality at the Playground in Birnam.
F1	Biodiversity	AWI SAC Native Woodland	Partially screened out to avoid ancient and native woodland, and SAC habitat	CFSA F1 is partly listed on the AWI and includes an area of UK BAP upland oakwood habitat. These areas shall be avoided; however, other locations could be utilised with a 15m protection zone around the SAC and AWI. Due to the protection zones, the available area is minimal.

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
	Cultural Heritage	Conservation Area Inventory Battlefield	Screen out areas that are within the Conservation Area and Inventory Battlefield	Area partly located within Dunkeld Conservation Area. Please refer to page 4, section titled 'Conservation Area' for further information. Area partly located within Dunkeld Battlefield. Please refer to page 4, section titled 'Inventory Battlefields' for further information.
	Landscape and Visual	NSA	Partially screened out to avoid trees/woodland	Whole area is within NSA and would result in loss of important riparian trees alongside the River Tay, woodland on the north side of the A984 and large mature trees in open space west of Atholl Street. Also, loss of public open space play area and allotments. Potential visual impact at properties in Dunkeld along Tay Terrace, Boat Brae, Atholl Street, High Street and Cathedral Street, allotments, play area and local NMU routes.
	WCH	None	Screened in	No WCH routes within CFSA F1.
	Land Use	Open Space	Partially screened out to avoid Open Space and trees/woodland	Area to the west is designated Open Space in PKC LDP2 and is screened out. If land-take necessary would potentially require exchange land. Area to the east is not designated Open Space and there would likely be no potential for significant impact to open space/community land and assets. There are some moderate or above quality trees located around peripherals of car park and along river bank.
F2	Biodiversity	AWI SAC	Partially screened out to avoid ancient woodland and SAC habitats	A small area of CFSA F2 is listed on the AWI and within the River Tay SAC. These areas shall be avoided; however, the majority of CFSA F2 could be utilised with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	Listed Buildings	Screen out areas that would result in the loss of the Listed Building	Potential for significant impacts to Listed Buildings. Please refer to page 4, section titled 'Listed Buildings'. for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Area west of A923 is community Orchard and areas east of A923 are cemetery, school playing field with associated trees and public open space. Potential for visual impacts on neighbouring properties in Birnam and users of NMU routes and open space areas. Potential for area of public open space between Royal School of Dunkeld and Willowbank to be lowered with limited long impacts. Area of trees around war memorial should be avoided if possible.
	WCH	None	Screened in	No WCH routes within CFSA F2.
	Land Use	Open Space	Screened out	Whole area is designated Open Space in the PKC LDP2. If land-take necessary would potentially

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
				require exchange land. There are some moderate or above quality trees located adjacent to the river and moderate or above quality trees in areas around town including Royal School of Dunkeld and the Birnam playground.
G	Biodiversity	SAC	Partially screened out to avoid SAC habitat	A small area of CFSA G is within the River Tay SAC. This area will be avoided; however, the majority of CFSA G could be utilised with a 15m protection zone around the SAC. There are very small areas to the south of CFSA G that are within AWI and UK BAP upland oakwood habitat – it is assumed that these areas will not be used and are a mapping error.
	Cultural Heritage	Conservation Area	Screen out areas within the Conservation Area	Area partly located within Dunkeld Conservation Area. Please refer to section 2.6 for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS with limited impacts within open space areas, provided riparian woodland along Rivers Braan and Tay and boundary trees are avoided. Potential for visual impacts on users of the recreation area, Core Path DUNK10/6, tennis and bowling club and adjacent properties.
	WCH	Core Path 24 and Row	Screened in	Approximately 150m of Core Path and RoW within area G.
	Land Use	Open Space	Screened out within Open Space and to avoid woodland	Whole area is designated Open Space in the PKC LDP2. If land-take necessary would potentially require exchange land. There are high quality trees located along the river bank which should be avoided.
H	Biodiversity	AWI SAC	Partially screened out to avoid ancient woodland and SAC habitats	The section of CFSA H to the south of the River Braan is listed on the AWI and areas are within the River Tay SAC. These areas shall be avoided; however, the majority of CFSA H could be utilised with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	None	Screened in	There are unlikely to be any significant impacts on cultural heritage resources.
	Landscape and Visual	NSA	Partially screened out to avoid ancient woodland	Whole area within NSA. Potential for CFS in large triangle between the A9 and River Tay with limited impacts within area of newly planted woodland, provided woodland is replaced and riparian woodland along Rivers Braan and Tay and trees south of Inver Caravan park are avoided. Potential for visual impacts on users of the recreation area, Core Paths DUNK/137/1 and 2.
	WCH	Core Path 35	Screened in	Approximately 105m of Core Path within area H.

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
	Land Use	None	Partially screened out to avoid ancient woodland	Recently planted saplings (refer to Landscape and Biodiversity assessments).
I	Biodiversity	AWI	Partially screened out to avoid ancient woodland and SAC habitats.	The section of CFSA I along the northern bank of the River Tay is listed on the AWI and partially within the River Tay SAC. This area shall be avoided; however, areas of open land habitat could be utilised with a 15m protection zone around the SAC and AWI.
		SAC		
	Cultural Heritage	Scheduled Monument	Screened out	Area is partly located with the scheduled area for Dunkeld Cathedral Scheduled Monument. Please refer to section 2.4 for further information.
		Listed Building		Potential for significant impacts to a Listed Building. Please refer to section 2.5. for further information.
		Inventory Garden and Designed Landscape		Whole area is located within Dunkeld House GDL. Please refer to section 2.7 for further information.
		Inventory Battlefield		Whole area is located within Dunkeld Battlefield. Please refer to section 2.8 for further information.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS within open space areas provided woodland west of Dunkeld Cathedral, along the River Tay and in the north and east is avoided.
	WCH	Core Path 40	Screened in	Approximately 220m of Core Path within area I.
		Core Path 38		Approximately 695m of Core Path within area I.
	Land Use	Prime agricultural land	Partially screened out to avoid woodland	Whilst there is a presumption against development on prime agricultural land it is assumed that the design of the flood compensatory storage areas would not preclude its continued use as agricultural land nor change its LCA Class. High quality trees located to east of Dunkeld House Hotel track road.
J	Biodiversity	AWI	Partially screened out to avoid ancient and native woodland, and SAC habitats	Small areas of ancient woodland habitat, areas of UK BAP upland mixed ashwood habitat, and areas within the River Tay SAC in CFSA J, mostly along the River Braan, should be avoided; however, the majority of CFSA J can be utilised with a 15m protection zone around the SAC and AWI.
		SAC		
		Native Woodland		
	Cultural Heritage	Inventory Garden and Designed Landscape	Screen out the areas located within the Inventory site boundary	The area is partly located within The Hermitage GDL. Please refer to section 2.7 for further information.

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS within large area of open space area provided boundary woodland and riparian trees are retained
	WCH	None	Screened in	No WCH routes within area J.
	Land Use	None	Partially screened out to avoid woodland	Young deciduous trees along river bank and some scattered in open fields.
K	Biodiversity	AWI SAC	Partially screened out to avoid ancient woodland and SAC habitats	The western end of CFSA K is listed on the AWI and the eastern end is within the River Tay SAC. These areas shall be avoided; however, areas of open land habitat could be utilised with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	None	Screened in	While not designated this area includes Neil Gow's tree and there is potential for significant impacts on this cultural heritage resource.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS within area of open space area provided riparian trees and woodland to the west are retained. Visual impact on users of Core Path DUNK/23/2.
	WCH	Core Path 35	Screened in	Approximately 520m of Core Path within area K.
	Land Use	None	Partially screened out to avoid woodland	Culturally significant tree located along river bank SE of Dunkeld House Hotel (Niel Gows Oak) so this immediate area to be avoided. Potential for other high quality trees along this bank.
L	Biodiversity	AWI SAC	Mostly screened out to avoid ancient woodland and SAC habitats	The majority of CFSA L is listed on the AWI (including plantation on ancient woodland site) and partially within the River Tay SAC. These areas shall be avoided; however, areas of open land habitat could be utilised with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	Inventory Garden and Designed Landscape	Screened out	Whole area is within Dunkeld House GDL. Please refer to section 2.7 for further information. Potential for non-significant impacts to Listed Buildings and Dunkeld Battlefield.
	Landscape and Visual	NSA	Mostly screened out to avoid ancient woodland and SAC habitats	Whole area within NSA. Potential for CFS within open areas (formal parkland surrounding the hotel and chalets) provided trees are avoided. Visual impacts on users of Core Path DUNK/145/1, Dunkeld House Hotel and chalets.
	WCH	NCR77 & Core Path 38	Screened in	Approximately 940m of NCR and Core Path 38 within area L.
	Land Use	None	Mostly screened out to avoid woodland	Contains areas of AWI. Trees situated outwith AWI on Dunkeld House Hotel grounds are high quality. Potential for significant impacts on tourism/accommodation provider.

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
M	Biodiversity	AWI SAC	Screened out	The entirety of CFSA M is either listed on the AWI or within the River Tay SAC, or immediately adjacent to such habitats and, therefore, should be entirely screened out.
	Cultural Heritage	None	Screened in	There are unlikely to be any significant impacts on cultural heritage resources.
	Landscape and Visual	NSA	Screened out	Whole area within NSA. Area entirely wooded and CFS likely to have significant landscape impact. Visual impact on users of Core Path DUNK/23/2.
	WCH	Core Path 35	Screened in	Approximately 175m of Core Path within area M.
	Land Use	None	Screened out	Refer to Biodiversity assessment.
N	Biodiversity	AWI	Screened out	The majority of CFSA N is listed on the AWI. The remaining part of CFSA N is woodland habitat surrounded by ancient woodland. Removal of the non-ancient woodland habitat would likely still impact the surrounding ancient woodland; therefore, CFSA N should be entirely screened out.
	Cultural Heritage	Inventory Garden and Designed Landscape	Screened out	Whole area is within Dunkeld House GDL. Please refer to section 2.7 for further information.
	Landscape and Visual	NSA	Screened out	Whole area within NSA. Area entirely wooded and CFS likely to have significant landscape impact. Visual impact on users of Core Path DUNK/145/1.
	WCH	None	Screened in	No WCH routes within area N.
	Land Use	None	Screened out	Refer to Biodiversity assessment.
O	Biodiversity	AWI SAC	Mostly screened out to avoid ancient woodland and SAC habitats	The majority of CFSA O is listed on the AWI, with a small area within the River Tay SAC. These areas shall be avoided; however, the arable field could be utilised with a 15m protection zone around the AWI.
	Cultural Heritage	None	Screened in	There are unlikely to be any significant impacts on cultural heritage resources.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS within open field area with limited impacts, provided woodland is retained.
	WCH	Core Path 35	Screened in	Approximately 510m of Core Path within area O.
	Land Use	Prime agricultural land	Partially screened out to avoid woodland	Refer to Biodiversity assessment. Whilst there is a presumption against development on prime agricultural land it is assumed that the

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
				design of the flood compensatory storage areas would not preclude its continued use as agricultural land nor change its LCA Class.
P1	Biodiversity	SAC Native Woodland	Mostly screened out to avoid SAC and native woodland habitats	The majority of CFSA P1 is comprised of either UK BAP wet woodland and upland birchwood habitat or is within the River Tay SAC. These areas will be avoided; however, small areas to the south of CFSA P1 can be utilised with a 15m protection zone around the SAC.
	Cultural Heritage	None	Screened in	There are unlikely to be any significant impacts on cultural heritage resources.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS within open space areas around the Tay crossing but avoiding riparian trees and woodland. Visual impact on users of Core Path DUNK/145/3, DUNK/100/1, and potentially for properties at Inchmagrannchan if woodland removed between A9 and River Tay
	WCH	NCR77	Screened in	Approximately 320m of NCR within area P1.
	Land Use	Prime agricultural land	Partially screened out to avoid woodland	Refer to Biodiversity assessment. Some trees are of moderate and above quality. Whilst there is a presumption against development on prime agricultural land it is assumed that the design of the flood compensatory storage areas would not preclude its continued use as agricultural land nor change its LCA Class.
P2	Biodiversity	AWI SAC Native Woodland	Partially screened out to avoid ancient and native woodland, and SAC habitats	An area to the south of CFSA P2 is listed on the AWI and includes an area of UK BAP upland mixed ashwood habitat. Additionally, parts of CFSA P2 along the River Tay are within the River Tay SAC. These areas shall be avoided; however, the rest of CFSA P2 can be utilised with a 15m protection zone around the SAC and AWI.
	Cultural Heritage	None	Screened in	There are unlikely to be any significant impacts on cultural heritage resources.
	Landscape and Visual	NSA	Partially screened out to avoid woodland	Whole area within NSA. Potential for CFS within open space agricultural areas avoiding boundary riparian woodland/trees.
	WCH	None	Screened in	No WCH routes within area P2.
	Land Use	Prime agricultural land	Partially screened out to avoid woodland	Refer to Biodiversity assessment. Some trees are of high quality. Whilst there is a presumption against development on prime agricultural land it is assumed that the

CFSA	Environmental Topic	Environmental Designations present within area	Screened in or out of further CFSA assessment	Justification for screening in/out (Also highlight any potential difficulties that may be encountered)
				design of the flood compensatory storage areas would not preclude its continued use as agricultural land nor change its LCA Class.

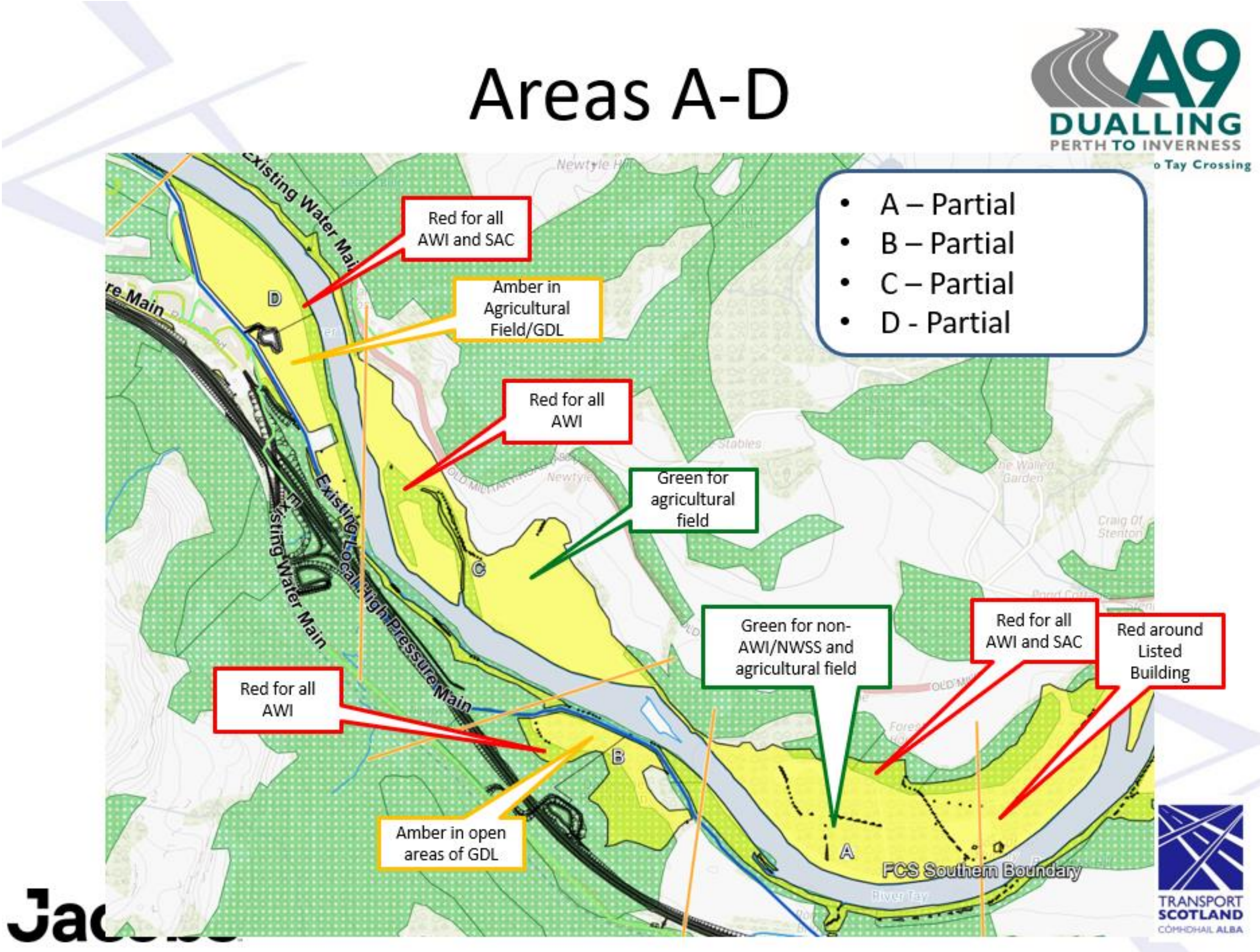
Red/Amber/Green Assessment

The following criteria were used to identify Red/Amber/Green areas.

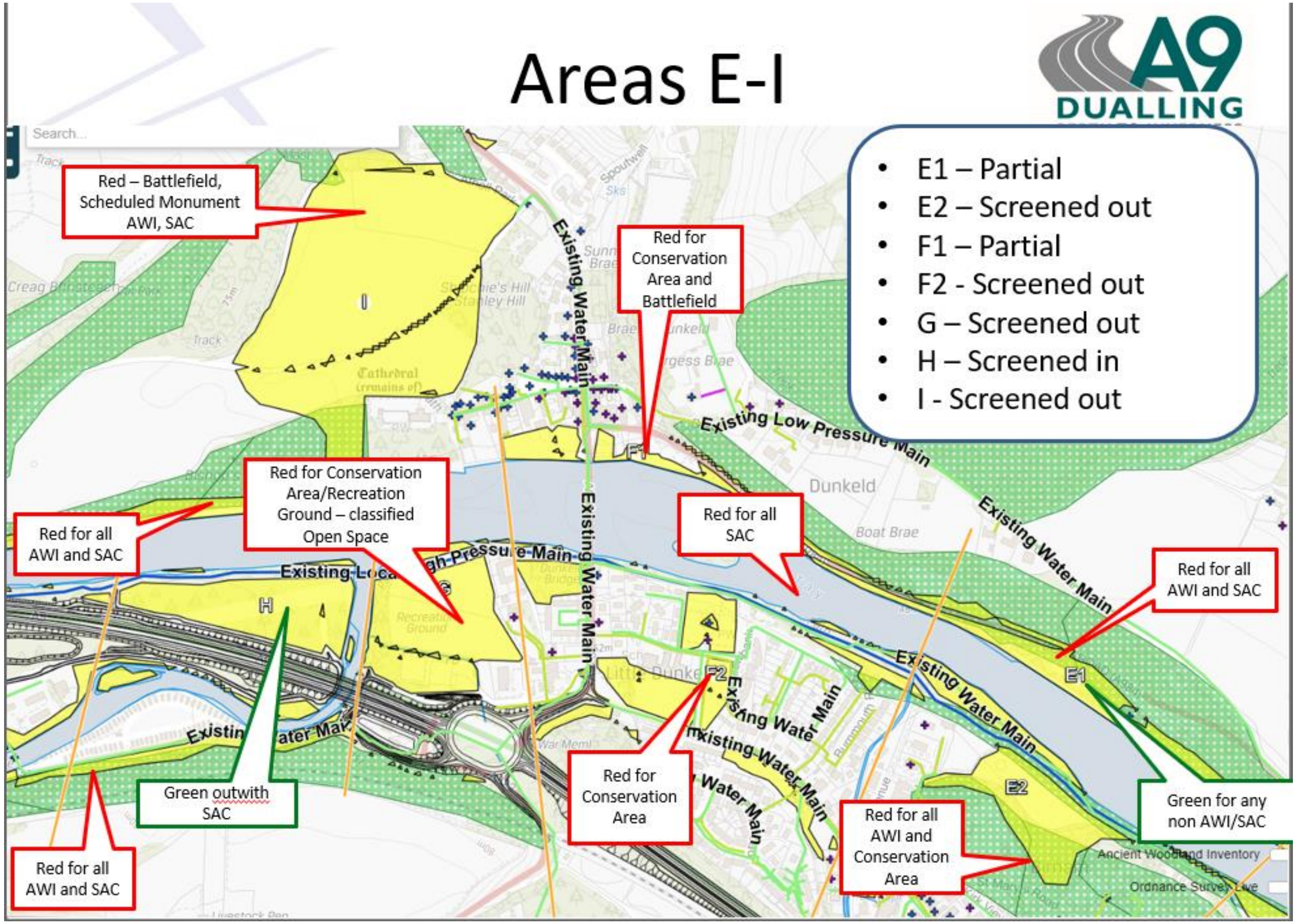
- **Red:** Due to the potential for additional significant impacts which cannot be mitigated, and the strong likelihood of objections being raised, these areas should be excluded from further consideration.

- **Amber:** Due to the potential for additional significant impacts and the likelihood of objections being raised, these areas should be considered only if additional flood risk to key receptors is identified through modelling and it would have to be clearly demonstrated that no other options for the siting of FSC areas were available. Special consideration will need to be made with regards to consultation and mitigation in these areas.

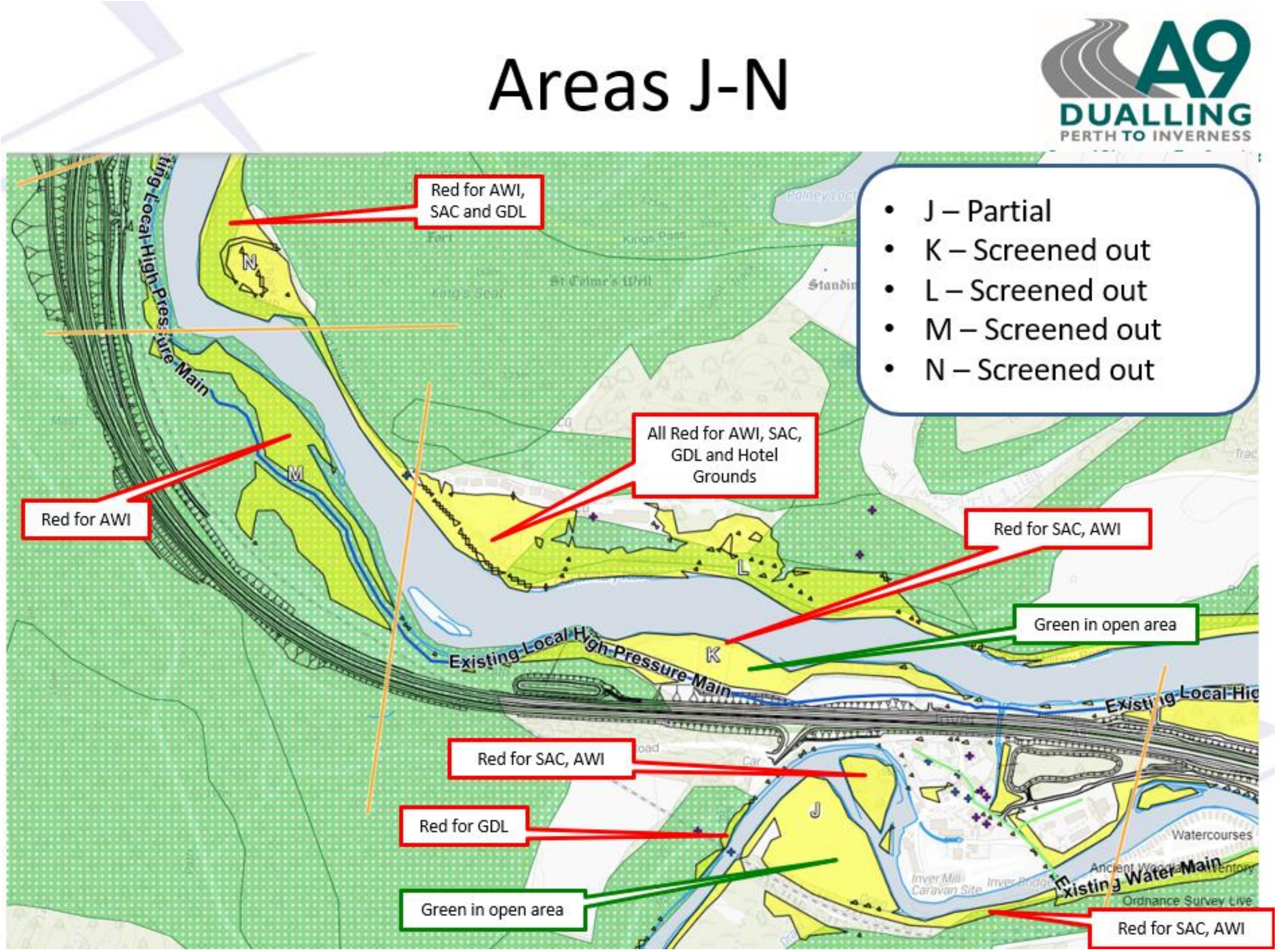
- **Green:** These areas can be considered as any additional environmental impacts can be mitigated.



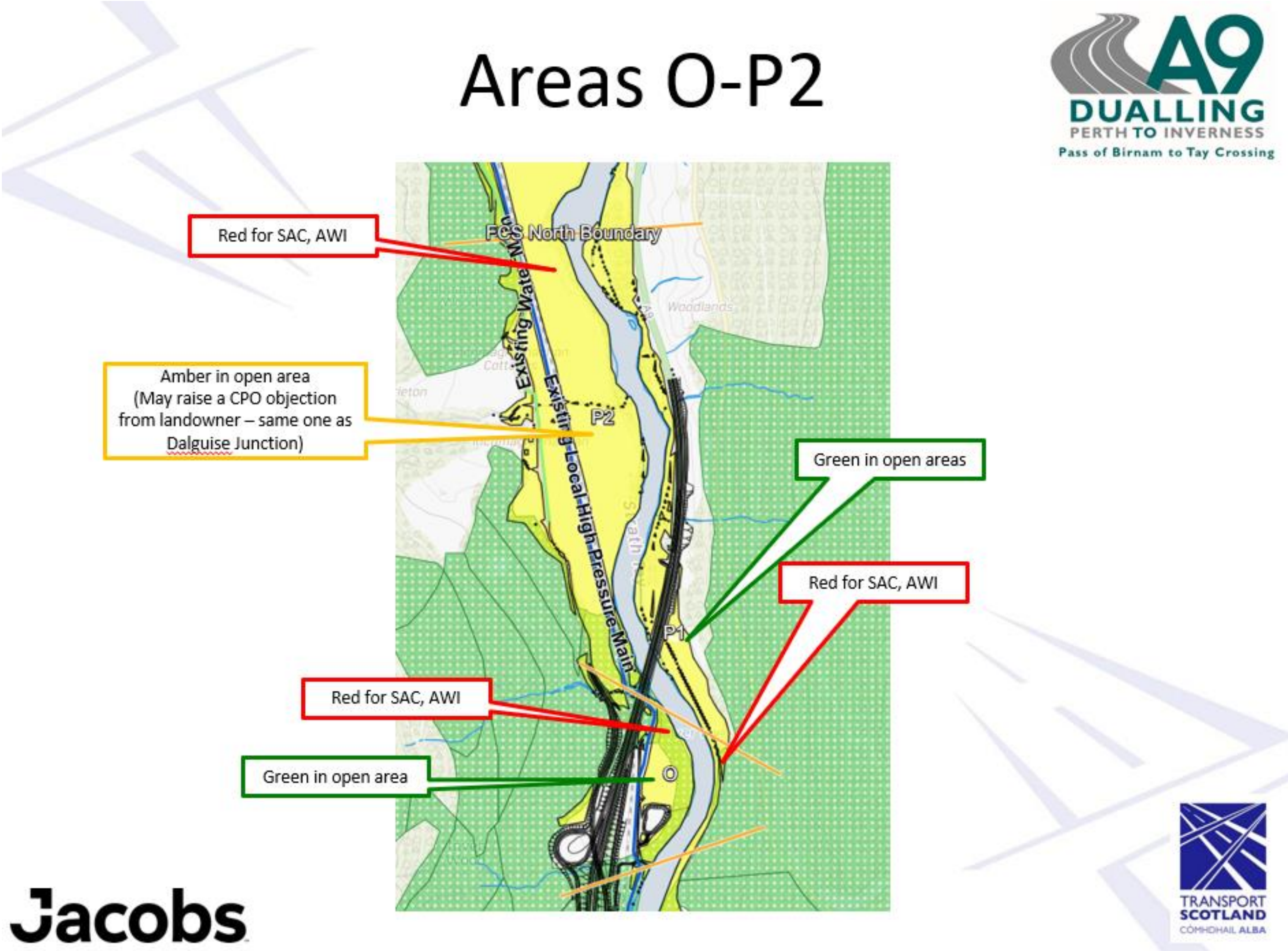
Areas A-D
A9 DUALLING
PERTH TO INVERNESS
A – Partial
B – Partial
C – Partial
D - Partial
Red for all AWI and SAC
Amber in Agricultural Field/GDL
Red for all AWI
Green for agricultural field
Green for non-AWI/NWSS and agricultural field
Red for all AWI and SAC
Red around Listed Building
Red for all AWI
Amber in open areas of GDL
Existing Water Main
Existing Local High Pressure Main
Existing Water Main
FCS Southern Boundary
D
C
B
A
TRANSPORT SCOTLAND
COMHDHAIL ALBA



Areas E-I
A9 DUALLING
E1 – Partial
E2 – Screened out
F1 – Partial
F2 - Screened out
G – Screened out
H – Screened in
I - Screened out
Red – Battlefield, Scheduled Monument AWI, SAC
Red for Conservation Area and Battlefield
Red for Conservation Area/Recreation Ground – classified Open Space
Red for all AWI and SAC
Red for all SAC
Red for all AWI and SAC
Green outwith SAC
Red for Conservation Area
Red for all AWI and Conservation Area
Green for any non AWI/SAC
Red for all AWI and SAC
Existing Water Main
Existing Low Pressure Main
Existing Water Main
Dunkeld
Boat Brae



Areas J-N
A9
DUALLING
PERTH TO INVERNESS
J – Partial
K – Screened out
L – Screened out
M – Screened out
N – Screened out
Red for AWI, SAC and GDL
Red for AWI
All Red for AWI, SAC, GDL and Hotel Grounds
Red for SAC, AWI
Green in open area
Red for SAC, AWI
Red for GDL
Green in open area
Red for SAC, AWI
Existing Local High Pressure Main
Existing Water Main
Watercourses
J
K
L
M
N



Areas O-P2
A9 DUALLING
PERTH TO INVERNESS
Pass of Birnam to Tay Crossing
Red for SAC, AWI
FCS North Boundary
Existing Water Main
Existing Local High Pressure Main
Amber in open area
(May raise a CPO objection
from landowner – same one as
Dalguise Junction)
P2
Green in open areas
Red for SAC, AWI
P1
Red for SAC, AWI
Green in open area
O
Jacobs
TRANSPORT
SCOTLAND
CÒMHDHAIL ALBA

Appendix A: Cultural Heritage Legislation and Policy

Designation	Legislation	Scottish Planning Policy (SPP)	Perth & Kinross Council (PKC) Local Development Plan 2 Policy
Scheduled Monuments	Scheduled Monuments are, by definition, of national importance and are protected by law under the Ancient Monuments and Archaeological Areas Act 1979 (as amended by the Historic Environment Scotland Act 2014). It is a criminal offence to damage a Scheduled Monument, and Scheduled Monument Consent must be obtained from Historic Environment Scotland before any works affecting a Scheduled Monument may take place.	Policy 145 states that '*where there is potential for a proposed development to have an adverse effect on a Scheduled Monument or on the integrity of its setting, permission should only be granted where there are exceptional circumstances*' (Scottish Government, 2014).	Policy 26: Scheduled Monuments and Archaeology states that '*there is a presumption against development which would have an adverse effect on the integrity of a Scheduled Monument and its setting, unless there are exceptional circumstances*' (PKC, 2019).
Listed Buildings	Listed Buildings are protected under the Planning (Listed Buildings and Conservation Areas) (Scotland) Act 1997 (as amended by the Historic Environment Scotland Act 2014) and are recognised to be of special architectural or historic interest. Under Section 59 of the Act, in considering whether to grant planning permission for a development which affects a Listed Building or its setting, a planning authority or the Secretary of State (as the case shall be) shall have special regard to the desirability of preserving the building or its setting, or any features of special architectural or historic interest which it possesses. Listed Building Consent is required before undertaking alteration or demolition of a Listed Building.	Policy 141 states that Listed Buildings should be protected from demolition or other work that would adversely affect it or its setting (Scottish Government, 2014).	Policy 27B: Demolition of Listed Buildings states that there is a presumption against the demolition of Listed Buildings and identifies the circumstance under which permission may be granted including if '*the demolition of the building is essential to delivering significant benefits to economic growth or the wider community*' (PKC, 2019).
Conservation	The Planning (Listed Buildings and	Policy 143 states that proposals for development within	Policy 28A: New Development requires that a development within a

Designation	Legislation	Scottish Planning Policy (SPP)	Perth & Kinross Council (PKC) Local Development Plan 2 Policy
Areas	Conservation Areas) (Scotland) Act 1997 (as amended by the Historic Environment Scotland Act 2014) imposes a duty on local planning authorities to designate and protect the historic character and appearance of some areas through their designation as Conservation Areas. These are areas of special architectural or historic interest, the character or appearance of which it is desirable to preserve or enhance. The main implication of this designation is that consent would be required for specific types of development that would not otherwise require it, such as Conservation Area Consent for applications to demolish unlisted buildings in Conservation Areas.	Conservation Areas which will impact on its appearance, character or setting should preserve or enhance the character and appearance of a Conservation Area; and Policy 144 identifies that proposed works to trees in Conservation Areas require prior notice to the planning authority (Scottish Government, 2014).	Conservation Area must preserve or enhance its character and appearance; and Policy 40A: Forestry, Woodland and Trees part (e) identifies that PKC is required to safeguard trees in Conservation Areas (PKC, 2019).
Inventory Gardens and Designed Landscapes	The Ancient Monuments and Archaeological Areas Act 1979 (as amended by the Historic Environment Scotland Act 2014) requires Historic Environment Scotland to compile and maintain an Inventory of Gardens and Designed Landscapes. When a garden and designed landscape is included on the Inventory it becomes a material consideration in the planning process. Under the Town and Country Planning (Development Management Procedure) (Scotland) Regulations 2013, local authorities are required to consult Scottish Ministers on development proposals that may affect an Inventory Garden or	Policy 148 states that planning authorities should protect and, where appropriate, seek to enhance gardens and designed landscapes included in the Inventory of Gardens and Designed Landscapes (Scottish Government, 2014).	Policy 29: Gardens and Designed Landscapes states that PKC will '*seek to manage change in order to protect and enhance the integrity of those sites included on the current Inventory of Gardens and Designed Landscapes*' (PKC, 2019).

Designation	Legislation	Scottish Planning Policy (SPP)	Perth & Kinross Council (PKC) Local Development Plan 2 Policy
	Designed Landscape.		
Inventory Battlefields	The Ancient Monuments and Archaeological Areas Act 1979 (as amended by the Historic Environment Scotland Act 2014) requires HES to compile and maintain an Inventory of Historic Battlefields. Under the Town and Country Planning (Development Management Procedure) (Scotland) Regulations 2013, local authorities are required to consult Scottish Ministers on development proposals that may affect a battlefield included on the Inventory of Historic Battlefields.	Policy 149 states that '*Planning authorities should seek to protect, conserve and, where appropriate, enhance the key landscape characteristics and special qualities of sites in the Inventory of Historic Battlefields*' (Scottish Government, 2014).	Policy 30: Protection, Promotion and Interpretation of Historic Battlefields states that PKC will seek to '*protect, conserve and, where appropriate, enhance the key landscape characteristics and special qualities of those battlefields listed on the Inventory of Historic Battlefields*' (PKC, 2019).

References

Ancient Monuments and Archaeological Areas Act 1979 (as amended by the Historic Environment Scotland Act 2014).

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Planning (Listed Buildings and Conservation Areas) (Scotland) Act 1997 (as amended by the Historic Environment Scotland Act 2014).

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Town and Country Planning (Development Management Procedure) (Scotland) Regulations 2013.

Annex G: Road design and options considered at Inver

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Technical Note

Subject	**Inver/Braan Flood Relief Culvert Highways Design Options**	**Project Name**	A9 Dualling Pass of Birnam to Tay Crossing
		Project No.	B2140002
Date	27/02/25	**Status**	S2
Document Number	A9P02-JAC-HGN-D_ZZZZZ_ZZ-TN-RD-0004	**Revision**	P01
Originator	AB	**Checker**	DK
Reviewer	DK	**Approver**	MP

1. Interaction of flood relief culverts and highways design

At DMRB Stage 3, the guidance from the Scottish Environmental Protection Agency (SEPA) on climate change allowance to be included in the design was revised, increasing the peak river flow allowances (used in the river flood modelling) to 53%. The effect of this increase required the vertical level of the proposed A9 mainline carriageway to be raised in the locality of the River Braan to avoid flood water overtopping the proposed A9 carriageway. To mitigate the increased flood risk from the River Braan to the surrounding properties at Inver, a number of flood relief culverts are proposed.

2. Design Fix 7A

2.1 Highways design

Through design development from Design Fix 7 (DF7) to DF7A (Interim Design Fix 2), the footprint of the highways mainline alignment and the walking, cycling and horse-riding (WCH) design increased in the locality of the River Braan and the flood relief culverts to the north of the River Braan crossing were incorporated. In Figure 1, shown below, the difference in design footprints between design fixes is visible.

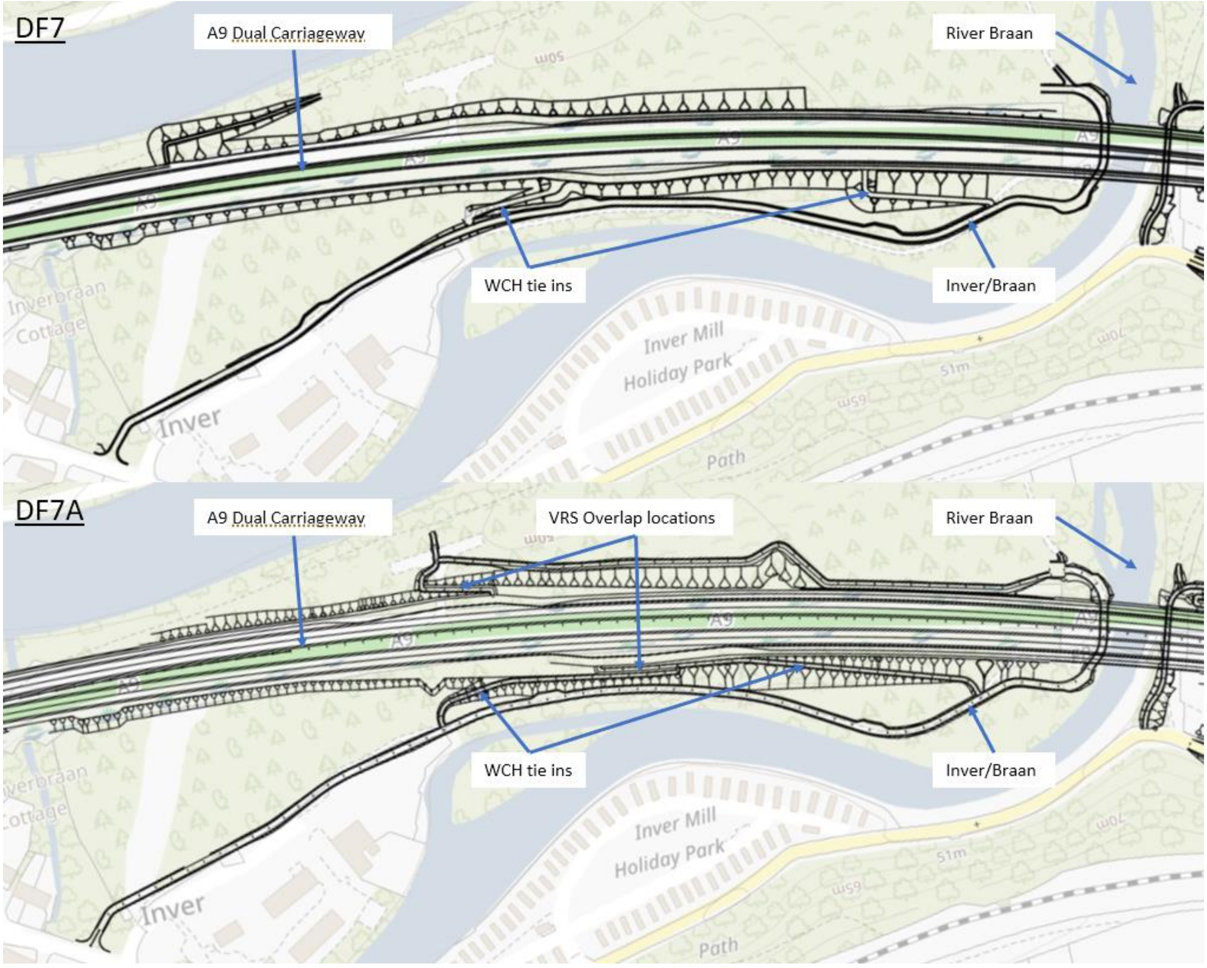

Figure 1 - DF7 vs DF7A scheme footprint north of the River Braan crossing.

The footprint increase from DF7 to DF7A is a result of the highways, WCH, and flood relief culverts designs being completed independently of each other in DF7 but in conjunction in DF7A. The approach taken on DF7 resulted in two main concerns. The first being the proposed Vehicle Restraint System (VRS) did not account for the need to provide access between the WCH provision on the northbound verge of the mainline and the Inver/Braan access track below. The second being the WCH routes crossed through a number of the proposed flood relief culverts. To rectify this during DF7A, a number of changes were made, including:

- The required overlap detail for the VRS (see Figure 2 below) was incorporated into the design to facilitate the movements of WCH users. By incorporating this detail into the DF7A design, the mainline verge was increased to accommodate the VRS provision using the standard 1:16 taper.
- Due to the VRS overlap, the design rationalised the tie-ins of the two WCH routes in the northbound mainline verge to a single tie-in at the back of the northbound bus layby resulting in only one section of VRS overlap being required.
- To resolve the clashes between the WCH routes and culverts, the profile of the two WCH routes from the back of the northbound bus layby was updated from a 5% gradient along their full

lengths, to both continue at carriageway level until a point to the east and west of the first and last culvert respectively, then the 5% gradient down to Inver/Braan access track.

The combination of changes resulted in an increased mainline verge width, increased length of both WCH routes from the northbound verge of the mainline, and subsequently increased the height and width of the proposed earthworks embankments in this area.

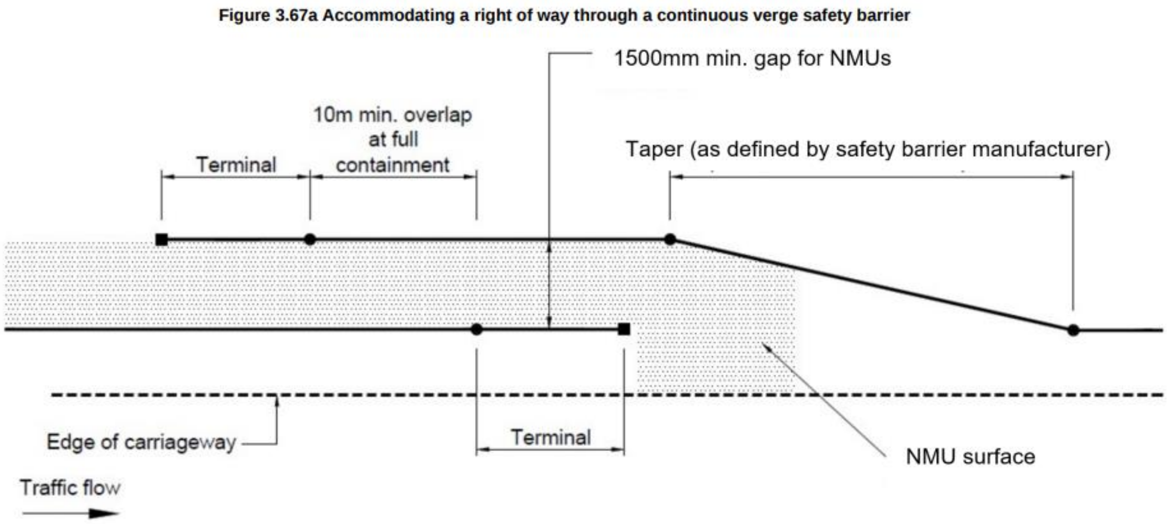

Figure 2 - DMRB CD377 VRS overlap detail.

To reduce the overall verge width, a departure from standard could be applied to remove the overlap detail and provide a short gap in the proposed VRS. However, this option is not being considered at this time, but could be considered at a later stage if required.

2.2 Sustainable Drainage System feature design

The proposed Sustainable Drainage System (SuDs) attenuation feature at Inver is located within the River Tay floodplain. Due to a number of constraints including existing topography and presence of public utility apparatus, it is considered the most viable location. The SuDS feature is designed not to be surrounded by an earthwork bund (i.e. at or below existing ground level) and as such would be inundated during a flood event. This allows the area to remain part of the functional floodplain and further compensatory flood storage would not be required.

2.3 Flood modelling results

Figure 3, provided below, shows the comparison of Design and Baseline maximum water levels for the Run 1 (critical storm event on River Tay) 200 year + 53% Climate Change event. The figure shows water levels in the Braan floodplain increasing by at least 10mm (Minor Adverse effect) in the Design scenario compared to the Baseline. This is attributed to the A9 carriageway width having increased from DF6 (Interim Design Fix 1) and therefore reducing the floodplain volume available. The three culverts under the A9 carriageway at Inver, presented in DF6, are no longer sufficient to convey enough water to mitigate this adverse effect and these additional flood relief culverts further south, closer to the River Braan structure (as shown below) would need to be assessed.

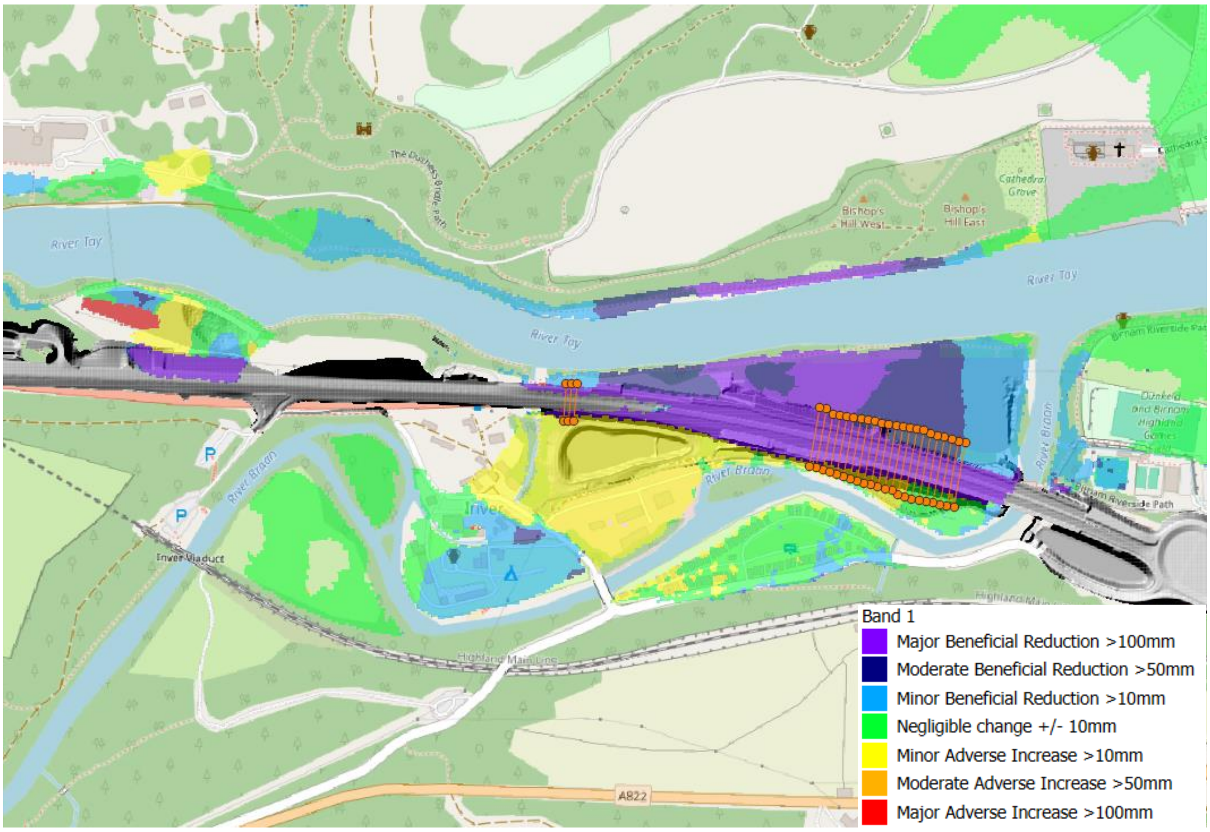

Figure 3 - DF7A scheme water level results Design vs Baseline for Run 1 200yr + 53% Climate Change event

3. Alternative options to minimise flooding

Following the flooding assessment of the DF7A design model, the results were found to be "Notably worse" than the previous DF6 model that was assessed. To alleviate this increased flooding risk, the following alternative options were developed and assessed from a highways and flooding perspective, with the aim of reducing the footprint of the scheme and thus reducing the impact on the anticipated flooding extents.

3.1 Revised SuDS design

During the DF7A design the SuDS basin at Inver was raised and minor embankment slopes were created around the SuDS feature. This negatively impacted the flood modelling in this location and therefore the model was reinstated at/below the existing ground level as per the previous design.

3.2 Reduce mainline embankment/remove WCH route

To help reduce the scheme footprint and the impact of the anticipated flooding, the option of removing the eastern WCH route between the northbound mainline verge and Inver/Braan access track was assessed as shown in Figure 4 below.

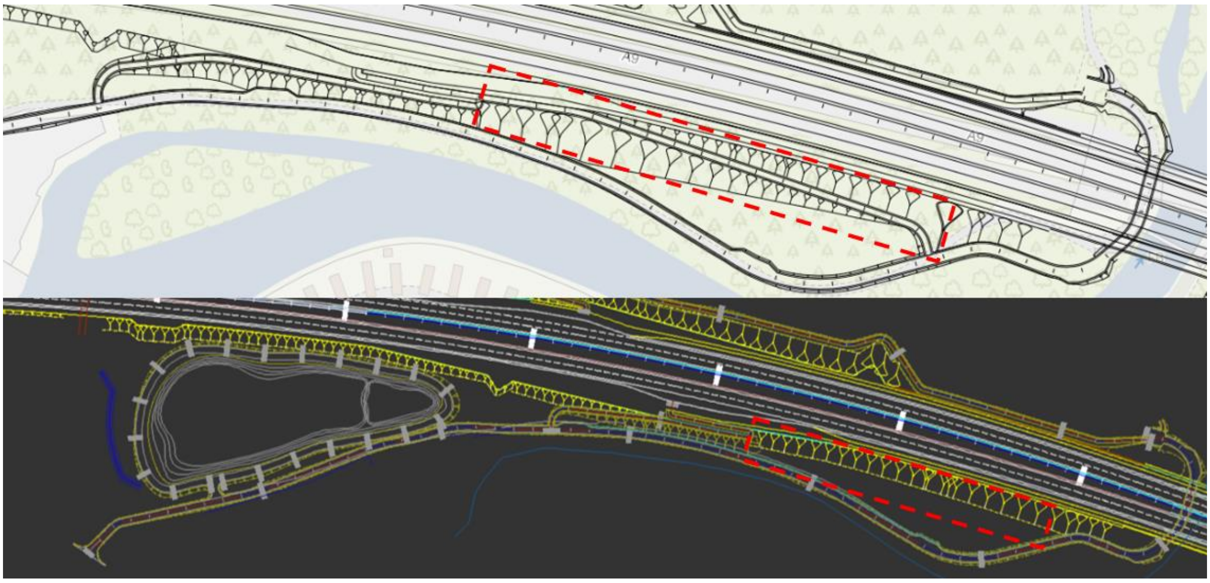

Figure 4 - Alternative option removing eastern WCH link

Removing this link from the design increased the length a WCH user would have to travel by approximately 400m, if travelling from Dunkeld along the northbound mainline verge to get to the riverside paths on the western bank of the River Tay. It should be noted that there is an alternative route available on the southbound side of the carriageway that would be considerably shorter for getting to the same location. Refer to Figure 5 below for the difference in routes.

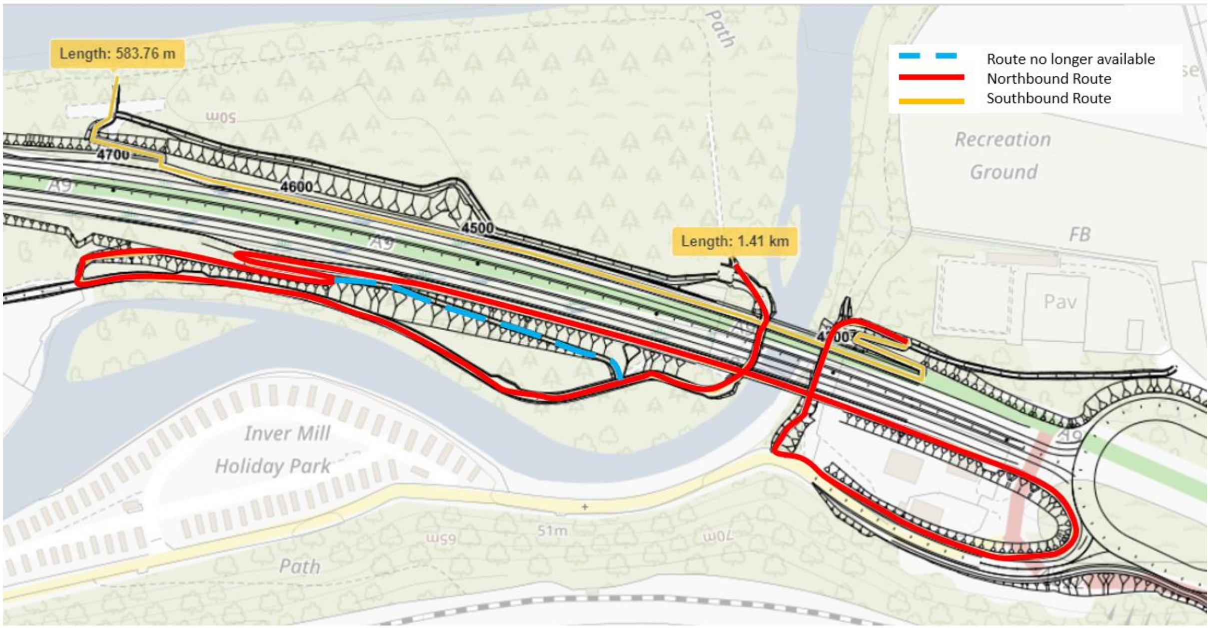

Figure 5 - Alternative WCH routes

Another aspect of this option was to realign and reprofile the western WCH route from the northbound mainline verge to Inver/Braan access track. In DF7A, the profile of this route remained at carriageway level until approximately ch4660, then ramped down at 5% to the Inver/Braan access track. To reduce the length of this route – and the length and height of associated earthworks – the start of the 5% gradient was moved south to approximately ch4625, allowing the WCH route to tie into Inver/Braan access track further south. This has reduced both the length and height of the embankment between Inver/Braan access track and this WCH tie-in, without the WCH tie-in clashing with the northern most flood relief culvert.

The result of the changes in this option from DF7A is a significantly reduced earthwork embankment on the northbound side of the mainline in this area. The widest part of the embankment in DF7A, approximately ch4540. was in the region of 17m, and is reduced to approximately 9.5m. Overall this reduction in earthworks, in combination with the proposed flood relief culverts, proved sufficient to rectify the flooding issues associated with DF7A.

3.3 Flood modelling results

Following the hydrology assessment of the alternative option for the SuDS pond and WCH routes the results were found to be "notably improved" when compared to the recent DF7A assessment. Figure 6, below, shows the water level difference between Design and Baseline with the updates, which include the Braan Bridge being widened, increased soffit level and greater bridge span. This results in a greater conveyance of water along the River Braan, reducing the adverse effect on the River Braan floodplain. Such is the benefit of this increased conveyance that only 14 additional culverts around Ch. 4500 are required from the Braan to the Tay floodplains.

An area of compensatory flood storage, which was considered to the east of the proposed A9 carriageway in the field opposite the Hermitage Junction, has been removed as flood modelling showed this was causing eddies in the flow which led to water being passed back upstream and resulted in a minor adverse increase of water levels across the Tay at the Dunkeld House Hotel.

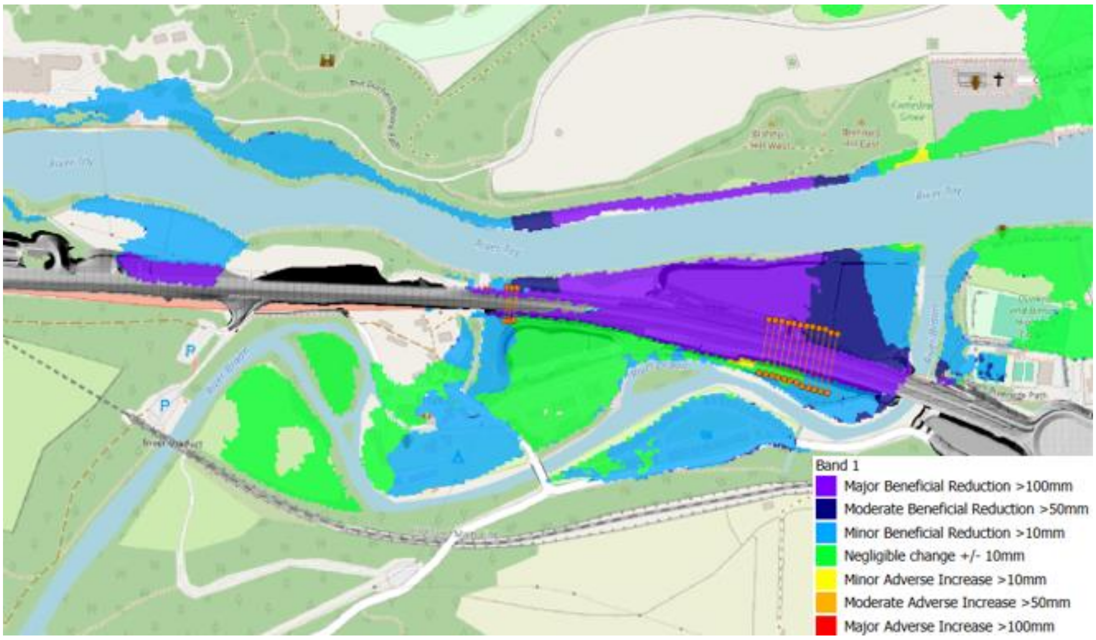

Figure 6 – Updated scheme water level results Design vs Baseline for Run 1 200yr + 53% Climate Change event

4. Summary

As the alternative options considered for the WCH route and SuDS pond, together with the inclusion of the flood refiled culverts, rectified the flooding issue, no further alternatives were assessed. However, it is worth noting that an additional WCH option was considered that removed both WCH tie-ins from the northbound verge, and rerouted WCH users further north to connect into Inver. This has not been assessed by the flood modellers at this time as a working solution had been found, however could be considered at a later stage if required.

Further refinements may be considered in this area as part of the DMRB Stage 3 Design Fix to further reduce the scheme footprint, and subsequently the impact of the anticipated flooding. These include:

- Possible removal of the southbound mainline bus lay-by. The removal of this lay-by would reduce the width of the verge by a minimum of 3.5m.

- The proposed WCH route on the southbound side is currently located in the mainline verge over the Inver Mill Culvert. It is expected that if the route is removed from the mainline, the verge width could be reduced and the existing route along the river edge could be retained. It is expected that the footprint could be reduced by a minimum of 1.5m from approximately ch4750 – 5050, and the WCH tie in at ch5050 could also be removed.