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Chipping WWTW Maintenance

United Utilities

Hydraulic Modelling Report

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1. Introduction

United Utilities are planning an expansion to the Chipping Waste Water Treatment Works (WWTW) site and the construction of a new access bridge. Following the delivery of the Level 1 Flood Risk Assessment (FRA), United Utilities commissioned Jacobs to build a linked 1-dimensional/2-dimensional (1D/2D) hydraulic model to determine the:

1) Existing flood risk (extents and depths) in the Chipping Brook floodplain; and the
2) Maximum in-channel water levels for the 1% Annual Exceedance Probability (AEP) and the 1% AEP plus Climate Change flood events at the new proposed bridge location.

The complete model has been handed over to United Utilities Design and Build contractor for them to use to carry out their design and FRA. Figure 1-1 shows the coverage of the hydraulic model and the location of the Chipping WWTW site. The model represents Chipping Brook from downstream of Chipping Village to approximately 200m upstream of its confluence with the River Loud, an unnamed tributary of Chipping Brook (right bank) and the surrounding floodplain areas. The model was built using Flood Modeller[1] (1D) and TUFLOW[2] (2D) software.

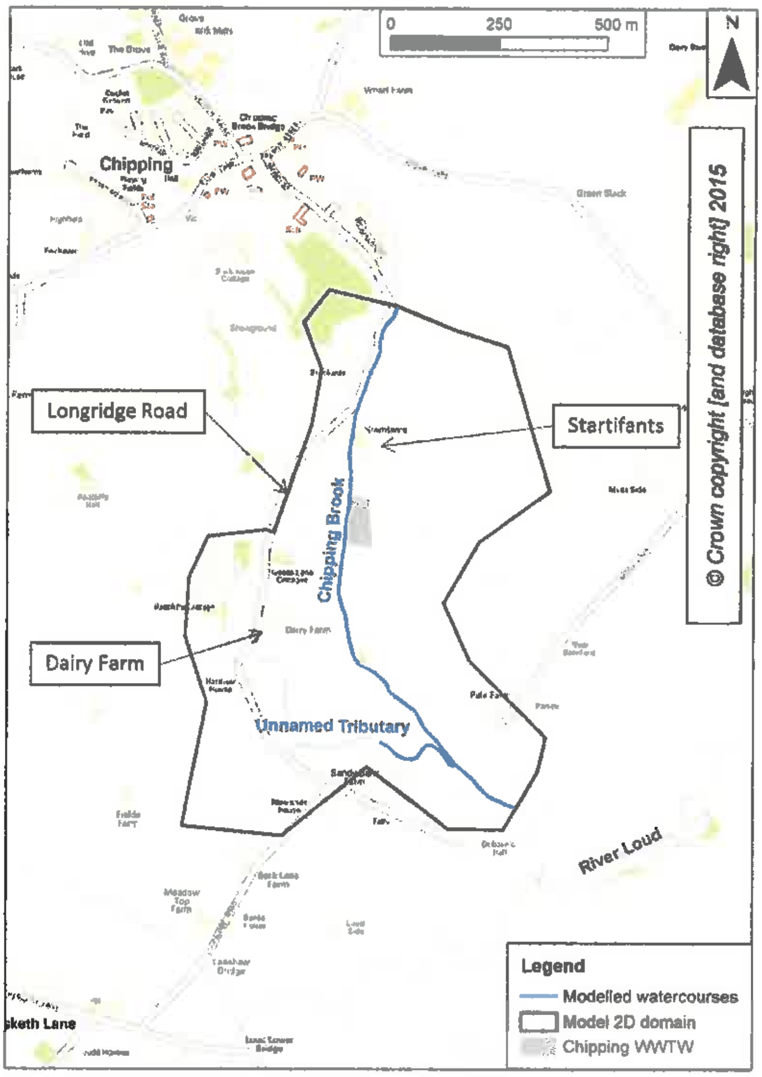


Figure 1-1: Chipping WWTW Site Location

[1] Flood Modeller Pro v4 by CH2M HILL (2015)
[2] TUFLOW Build 2013-12-AE by BMT WBM (2013)

2. Input Data

The data used to construct the hydraulic model are summarised in Table 2-1.

Table 2-1: Data used to build the hydraulic model

Data	Description	Source
Topographic survey data	In channel cross sections and hydraulic structures. See Section 2.1.1.	RPS
LiDAR	LiDAR (Light Detection And Ranging) data: 2m horizontal resolution. See Section 2.1.2.	Environment Agency
Hydrological Inflows	Hydrological analysis carried out for Chipping Brook. See Section 2.3.	Jacobs
OS Mapping	Mastermap data and 1 to 10,000 Scale Raster	United Utilities

2.1 Topography

2.1.1 Topographic survey

River cross sections and in-channel structures were surveyed by RPS (August 2015) to inform the hydraulic model with in-bank topographic details of Chipping Brook and one of its unnamed tributary (see Figure 1-1). The cross section information was provided by the surveyors in standard Flood Modeller format and CAD drawings. Photographs of the watercourses and the structures were also provided for the surveyed reaches. The modelled reach of Chipping Brook is 1350m long and the modelled reach of the unnamed tributary is 220m long. A total of 26 cross sections were surveyed for these reaches. Survey was also provided for three bridges along Chipping Brook.

Figure 2-1 shows the location of the surveyed cross sections. Surveyed cross-sections show that Chipping Brook is perched at cross-sections CH01_0629 and CH01_0512.

2.1.2 LIDAR

LiDAR data (2008) was used to inform the hydraulic model with floodplain topography. Filtered LiDAR data with 2m horizontal resolution was used in which the vegetation and buildings have been removed from the topography in order to model the overland flow routes. Figure 2-2 shows the digital terrain model (DTM) used for modelling. As shown by the surveyed cross-sections, LiDAR data confirms that a section of Chipping Brook is perched over the floodplain from approximately the WWTW site to the confluence with the unnamed tributary.

2.2 Hydrology

Inflows at the upstream ends of the modelled watercourses (see locations in Figure 2-3) have been estimated for the 50%, 20%, 10%, 5%, 2% and 1% AEP flood events.

The Flood Estimation Handbook (FEH) statistical method along with the Revitalised Flood Hydrograph Method (ReFH1) was used to derive the inflow hydrographs that were applied to the model. The methodology used to determine these inflow hydrographs is further detailed in Appendix C of this report.

In order to calculate the impact of climate change, a 20% uplift of the hydrological inflows was applied on the 1% AEP event. This climate change uplift factor is based on the latest Environment Agency Guidance[3]. Table 2-2 shows the estimated inflow peak flows in the modelled watercourses for all the AEP events simulated.

[3] Environment Agency (2011) Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities

Table 2-2: Estimated peak flows in m³/s for all locations

Hydrological Inflow	Peak Flow (m3/s)						
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1% AEP + Climate Change
CB01	11.9	15.9	18.9	22.2	27.3	31.8	38.2
TRIB	2.8	3.8	4.5	5.2	6.4	7.5	9.0

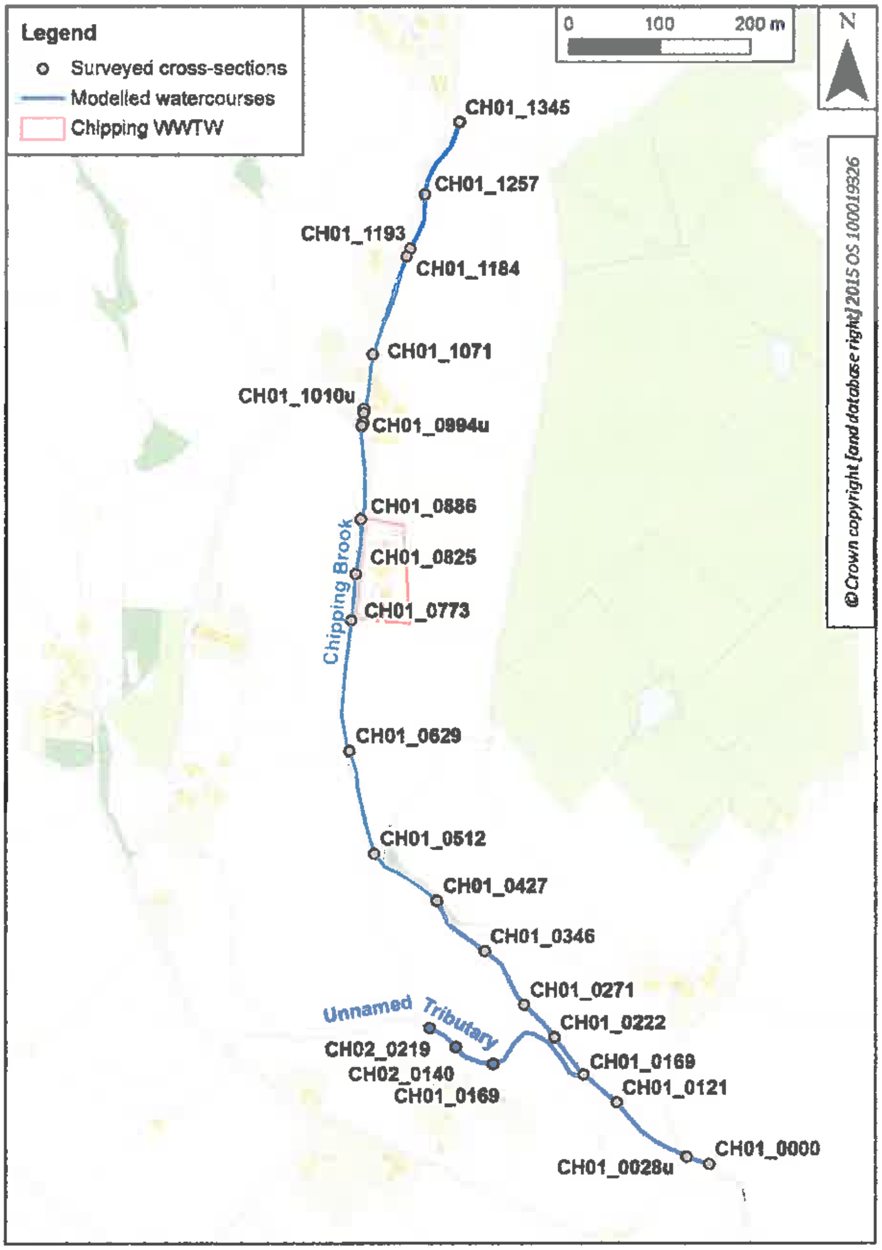


Figure 2-1: Location of surveyed cross-sections used for modelling in-channel watercourses

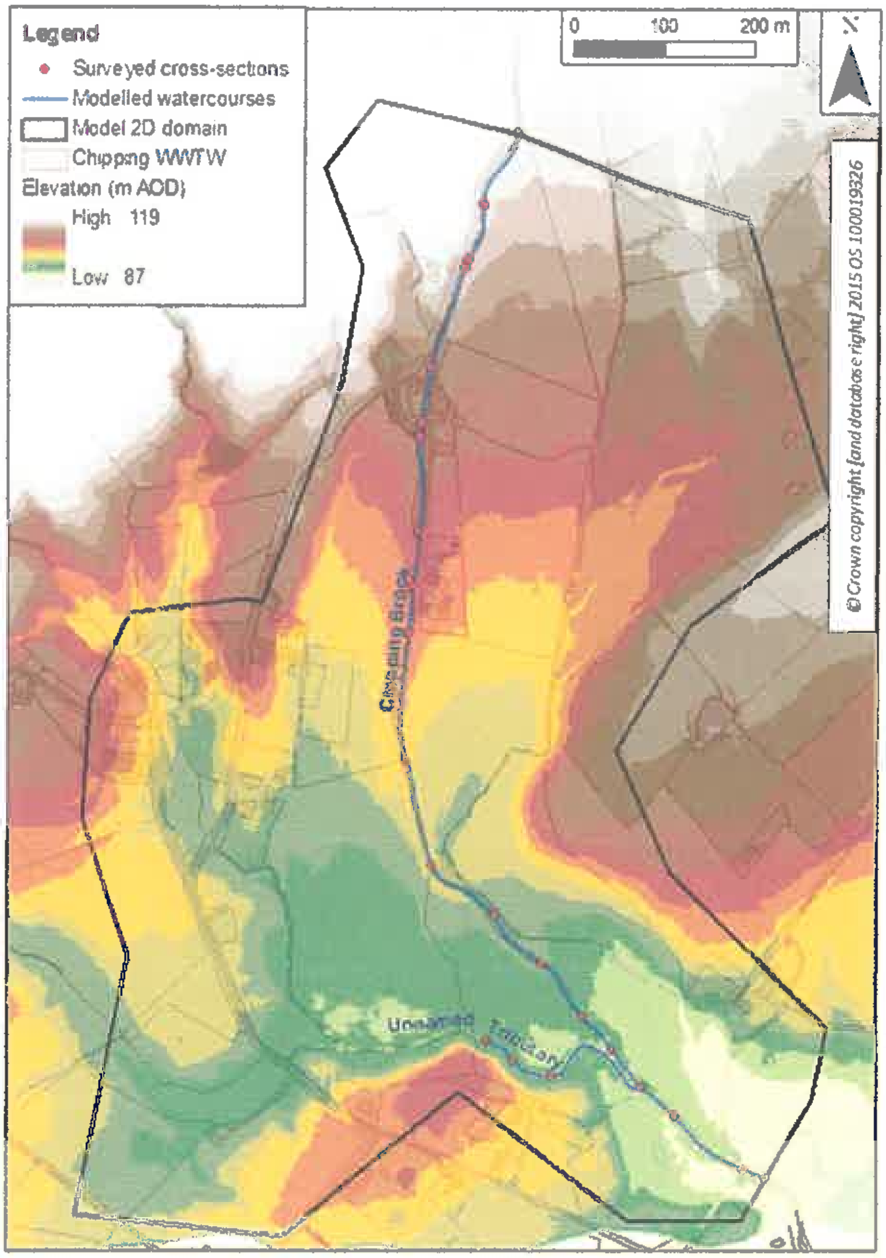


Figure 2-2: LiDAR data used for modelling floodplain topography

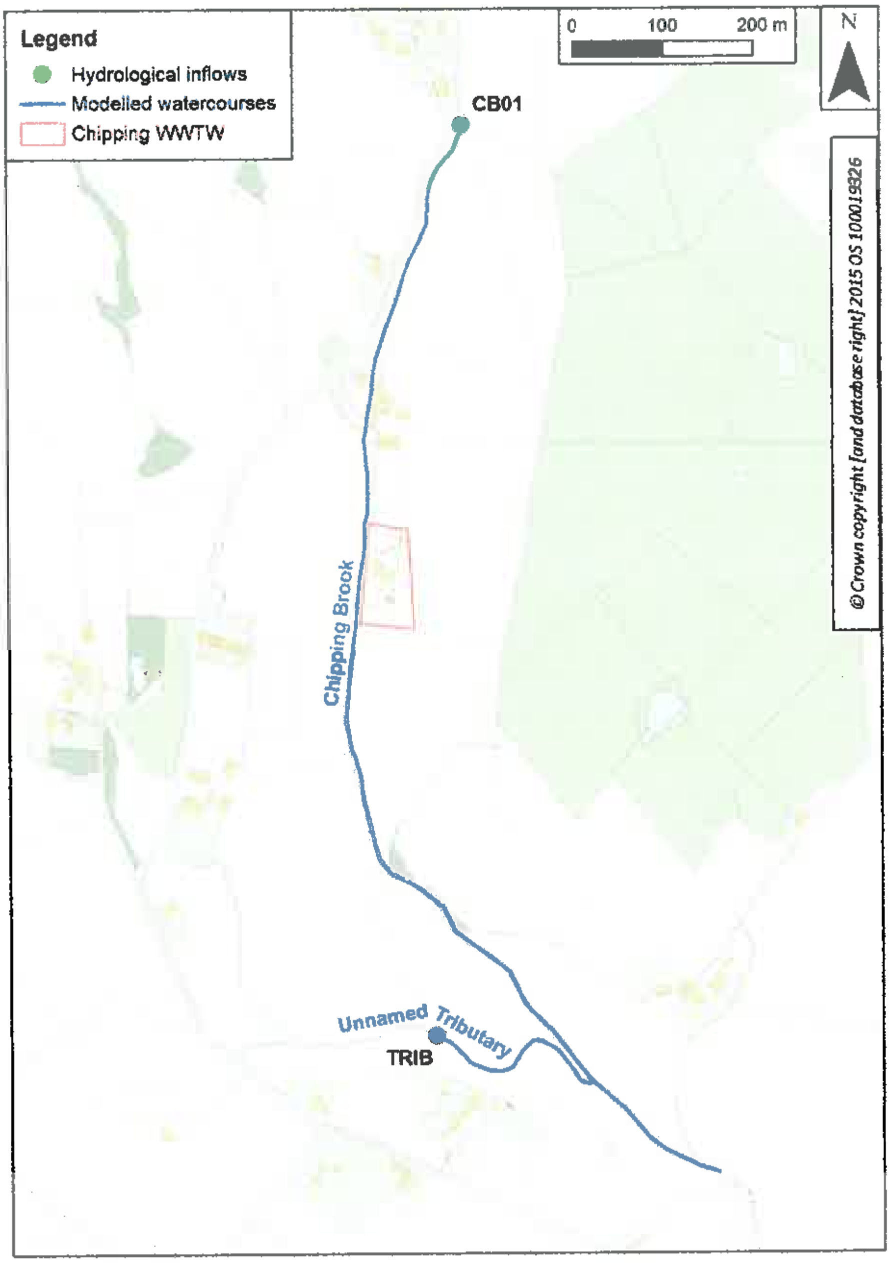


Figure 2-3: Location of hydrological inflows to the hydraulic model

3. Hydraulic Model

3.1 Methodology

A hydraulic model has been constructed using the ISIS-TUFLOW link based on the combination of the one dimensional (1D) river modelling package Flood Modeller Pro (version 4.1) and the two dimensional (2D) modelling software TUFLOW (version 2013-12-AE-iDP-w64).

The methodology adopted for the hydraulic modelling of the river system is based on the approaches described by the TUFLOW modelling manual[4]. The user sets up a model as a combination of 1D network domain representing the river channels, dynamically linked to a 2D TUFLOW domain representing the adjacent floodplain, using the hydrodynamic programme to form one model.

The 1D model covers a 1350m reach of Chipping Brook and a 220m reach of its unnamed tributary (see Figure 2-1). The 2D model extends from downstream of Chipping village to 200m upstream of River Loud and covers an area of approximately 0.7km^2 (see Figure 2-2).

3.2 Watercourses Schematisation

3.2.1 In-channel geometry

Surveyed cross section data has been used to inform the modelled watercourses with in-channel geometry. The location of the surveyed cross-sections is shown in Figure 2-1. A few interpolated cross sections were also created to ensure stability of the model. Table 3-1 shows the Flood Modeller nodes associated with Chipping Brook and the unnamed tributary.

Table 3-1: Flood Modeller nodes

Reach	Upstream Node	Downstream Node
Chipping Brook	CH01_1345	CH01_0000 (200 m upstream of River Loud confluence)
Unnamed Tributary	CH02_0219	CH02_0000 (confluence with Chipping Brook at CH01_0169)

3.2.2 In-channel roughness

Hydraulic roughness (Manning's 'n' coefficient) values were determined primarily using the photographs taken during the survey. Information was also taken from Google Earth and Street View mapping and guidance (Chow, 1959). The Manning's 'n' coefficients used in the model are shown in Table 3-2.

Table 3-2: Manning's 'n' coefficients – 1D domain

Flood Modeller nodes	Bed Manning's 'n'	Banks Manning's 'n'
CH01_1345 to CH01_0773	0.05	0.025 to 0.10
CH01_0629	0.04	0.04 to 0.10
CH01_0512	0.05	0.10
CH01_0427	0.04	0.06
CH01_0346	0.05	0.06
CH02_0271 to CH02_0000	0.04	0.06

[4] TUFLOW User Manual, GIS based 2D/1D Hydrodynamic Modelling, BMT WBM November 2010

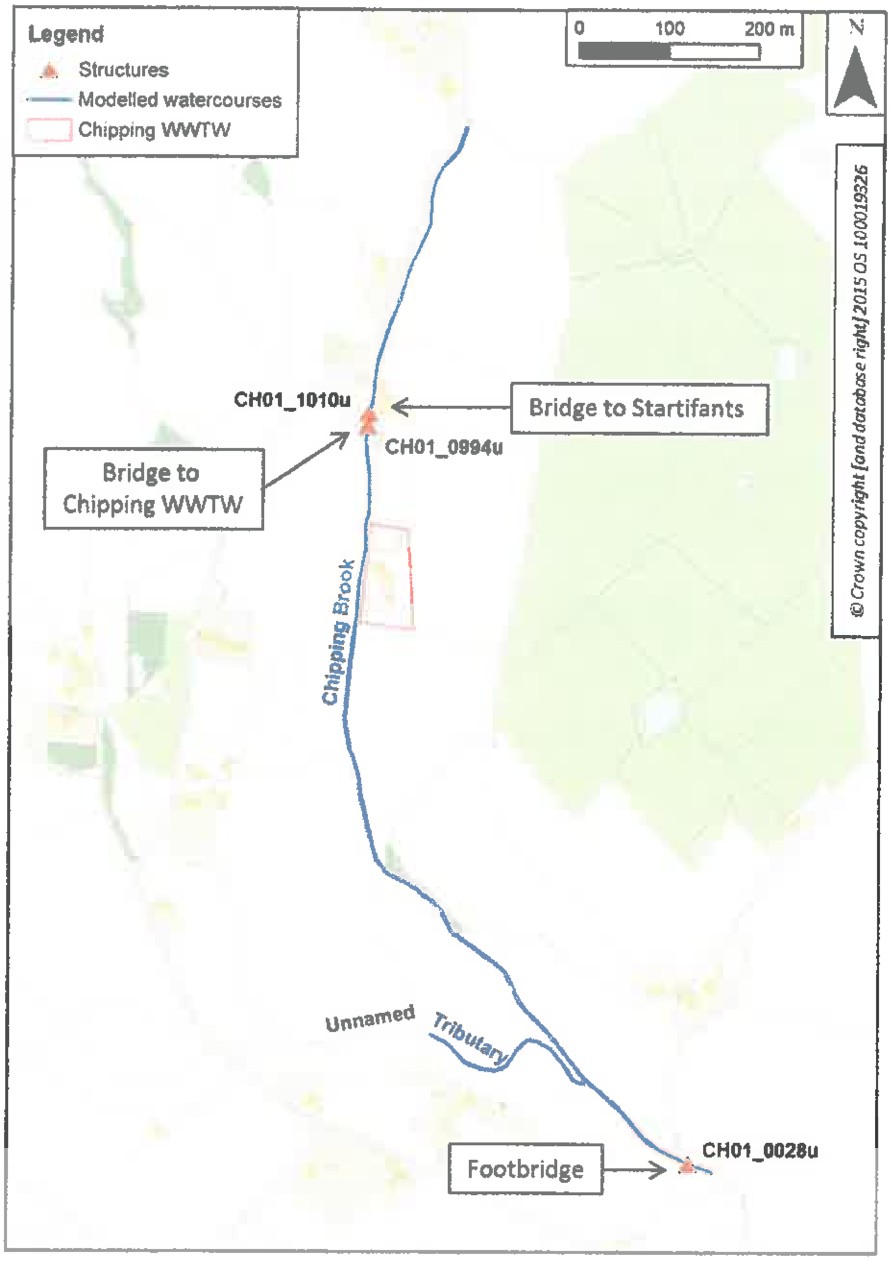


Figure 3-3: Location of modelled hydraulic structures

Figure 3-4: Bridge to Startifants

Figure 3-5: Bridge to Chipping WWTW

Figure 3-6: Footbridge

3.2.4 Boundary conditions – 1D Domain

The upstream and downstream boundary conditions applied to the 1D domain are described in Table 3-4. The use of a Normal Depth Boundary as downstream conditions implies that the influence of the River Loud on Chipping Brook is not considered in this study. Sensitivity tests were carried out to ascertain that any change in the downstream boundary conditions will not impact the water levels predicted by the model near the area of interest i.e. Chipping WWTW (see Section 4.4.1).

Table 3-4: Boundary conditions – 1D domain

Type of Boundary	Flood Modeller Node	Description
ReFH Boundary	CB01	CB01 ReFH inflow boundary was applied at the upstream end of Chipping Brook at node CH01_1345 (see Section 2.3).
ReFH Boundary	TRIB	TRIB ReFH inflow boundary was applied at the upstream end of unnamed tributary at node CH02_0219 (see Section 2.3).
Normal Depth Boundary	CH01_0000	Normal depth boundary condition applied to the downstream end of Chipping Brook at node CH01_0000

3.3 Floodplain Schematisation

3.3.1 Floodplain topography

The topography is represented using a 4m resolution square grid. The levels for the grid cells are based on a Digital Terrain Model (DTM) derived from Light Detection and Ranging (LiDAR) data with a 2m horizontal resolution. Floodplain topography is shown in Figure 2-2.

Breaklines were used in the 2D domain to accurately represent geographical features that have a significant impact on the propagation of flow across the floodplain. It is particularly useful where the TUFLOW fixed grid discretisation (in our case 4m) does not guarantee that the elevations along a key feature are picked up from the LiDAR data, for example along a narrow ditch.

The link between the 1D and the 2D domains was defined along Chipping Brook and the unnamed tributary with a breakline using the bank top levels from the surveyed cross-sections. In particular, a wall along Chipping Brook right bank from cross-section CH01_1345 to cross-section CH01_0990 was included in the model.

The breaklines included in the 2D domain are summarised in Table 3-5 below.

Table 3-5: Breaklines – 2D domain

Break Line Type	Geographical Feature
Bank top	Right and left bank levels along the modelled watercourses using bank top data from the surveyed cross-sections
Drains	Drains / ditches running in the modelled area and not implemented in the 1D domain have been represented using breaklines to create continuous flow paths

3.3.2 Floodplain roughness

A hydraulic roughness coefficient is applied at each cell of the 2D domain depending on land use. The coefficients (Manning's 'n') used in the model are given in Table 3-6.

Table 3-6: Manning's 'n' coefficients – 2D domain

Land Use	Manning's N
Roads, tracks and paths	0.025
Buildings, manmade structures	1.000
Multiple surface (garden), orchard	0.050
Manmade surface or step	0.030
Natural surface	0.035
Non coniferous trees	0.100
Rough grassland	0.055
Marsh reeds or saltmarsh	0.055
Land unclassified	0.035

Remark:

It should be noted that the use of filtered LiDAR data to inform the 2D model DTM means that buildings are not inherently represented in the grid. Given the fact that any building is an obstruction to the flow and would have a major impact on the overland flow routes, a very high roughness value has been attributed to each building/house within the study area to model the effect of the obstruction.

3.3.3 Floodplain structures

Where identified, hydraulically significant structures in the floodplain have been embedded inside the TUFLOW 2D domain as ESTRY elements. ESTRY is the 1D component of TUFLOW software. The locations of these floodplain structures have been informed through examination of preliminary model results and Google Earth, Street View and OS mapping. The dimensions for these structures were assumed (1m diameter circular pipes with invert levels taken from DTM) as no survey data was available for them.

Three culverts under Longridge Road have been included in the model. Their locations are shown on Figure 3-7.

3.3.4 Boundary condition – 2D Domain

No inflows have been applied directly in the 2D domain. Table 3-7 describes the downstream boundary condition used in the 2D domain. Its location is shown in Figure 3-7.

Table 3-7: Boundary Condition - 2D domain

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

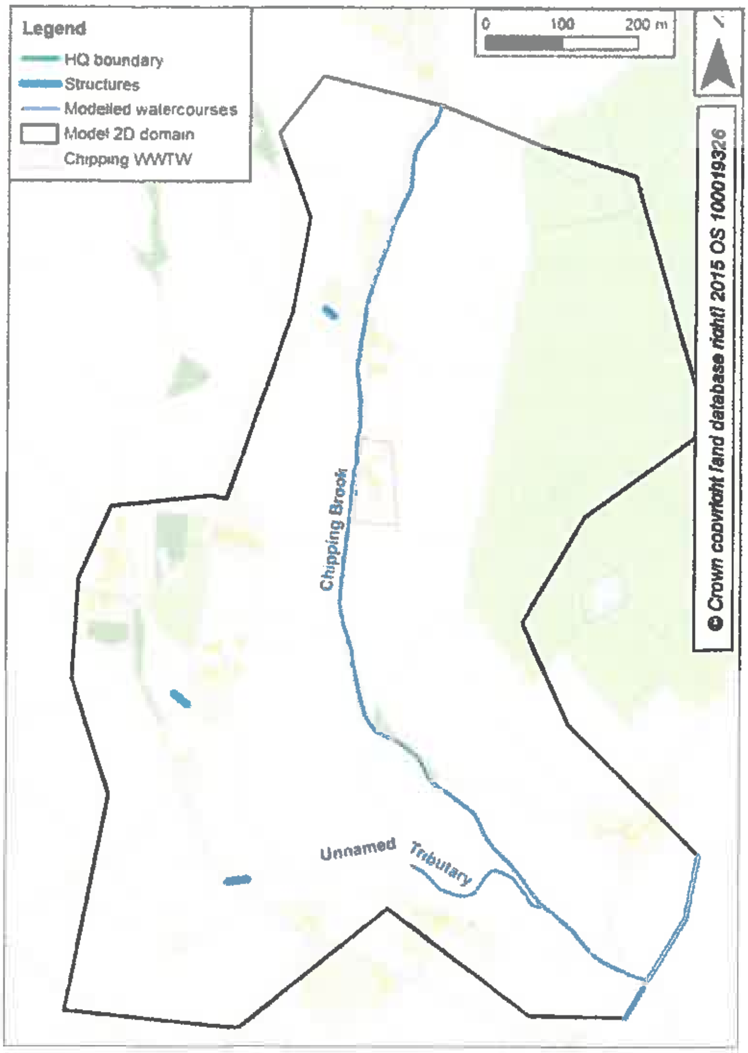


Figure 3-7: Structures in flow path

3.4 Modelled Events

Table 3-8 shows the AEP events that were simulated with the hydraulic model in the existing scenario. In order to test the model sensitivity to key hydraulic parameters, a series of simulations were undertaken for the 1% AEP event. The assessed hydraulic parameters were: Manning's n roughness coefficients, hydrological inflows and downstream boundary slope.

Table 3-8: Modelled events

Model	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1% AEP + Climate Change*
Existing Scenario	✓	✓	✓	✓	✓	✓	✓
Roughness Sensitivity						✓	
Hydrological Inflow Sensitivity						✓	
Downstream Boundary Sensitivity						✓	

*Climate change scenario for which a 20% uplift of the hydrological inflows to the model is considered.

4. Model Results

The following sections discuss the model results for the existing scenario simulations as well as the results for the sensitivity test simulations.

4.1 Model Verification & Flow Reconciliation

Chipping Brook is an ungauged catchment therefore no gauge data was available in the modelled area to carry out any calibration. As a verification exercise, flood extent maps for the 50%, 20% and 10% AEP events were sent to the United Utilities site team of the Chipping WWTW for review. The feedback was that the predicted flood extents looked reasonable and the areas where channel banks were overtopped were accurate.

In order to check consistency of the hydraulic model results with the flood frequency curve predicted by the hydrological analysis, the flows routed through the hydraulic model were compared with the peak flow estimates from the hydrological analysis at the downstream end of the model.

The comparison showed that the differences between peak flows ranged from -1.4% in the 20% AEP event to 1.1% in the 2% AEP event. As such, no adjustment of hydrological inflows to the model was required.

4.2 Model Performance

Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure the optimum model convergence was achieved. In the 1D model the convergence plots produced as .bmp files were checked. As shown in Figure 4-1 below, there are no non-convergence issues with the 1D model.

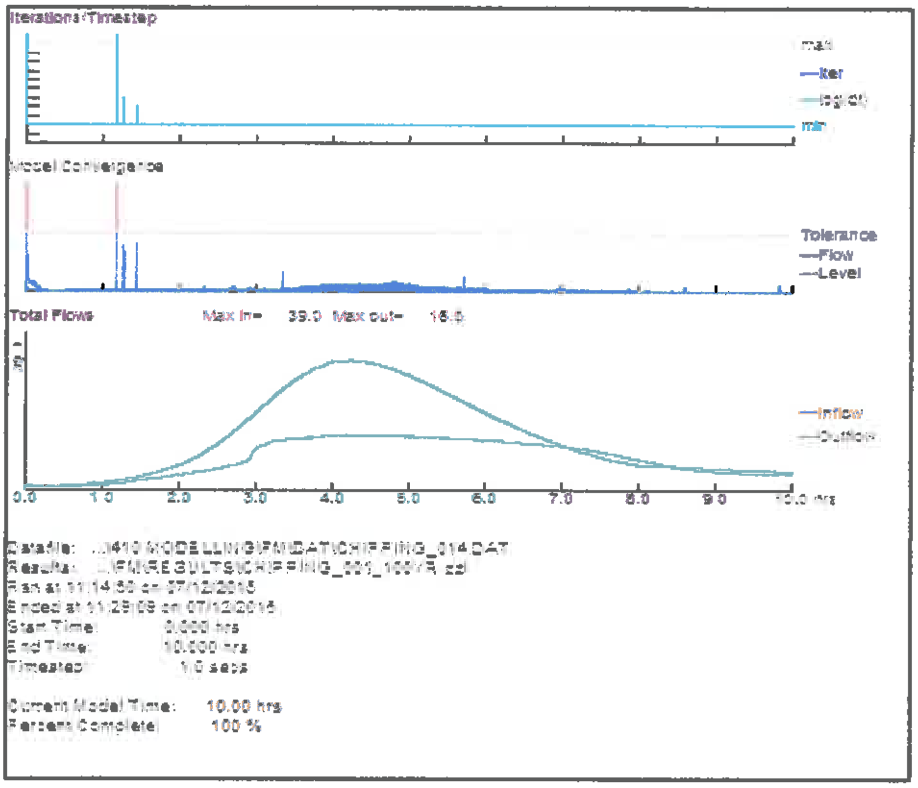


Figure 4-1: 1D model convergence – 1 % AEP event

The cumulative mass error reports output from the TUFLOW 2D model have been also checked. The recommended tolerance range is +/- 1% Mass Balance error. The change in volume through the model simulation has also been checked.

Figure 4-2 shows that the cumulative mass error is within the tolerance range for most part of the simulation. The change in volume curve shows a smooth increase, which is another indicator of stable computation during the simulation process.

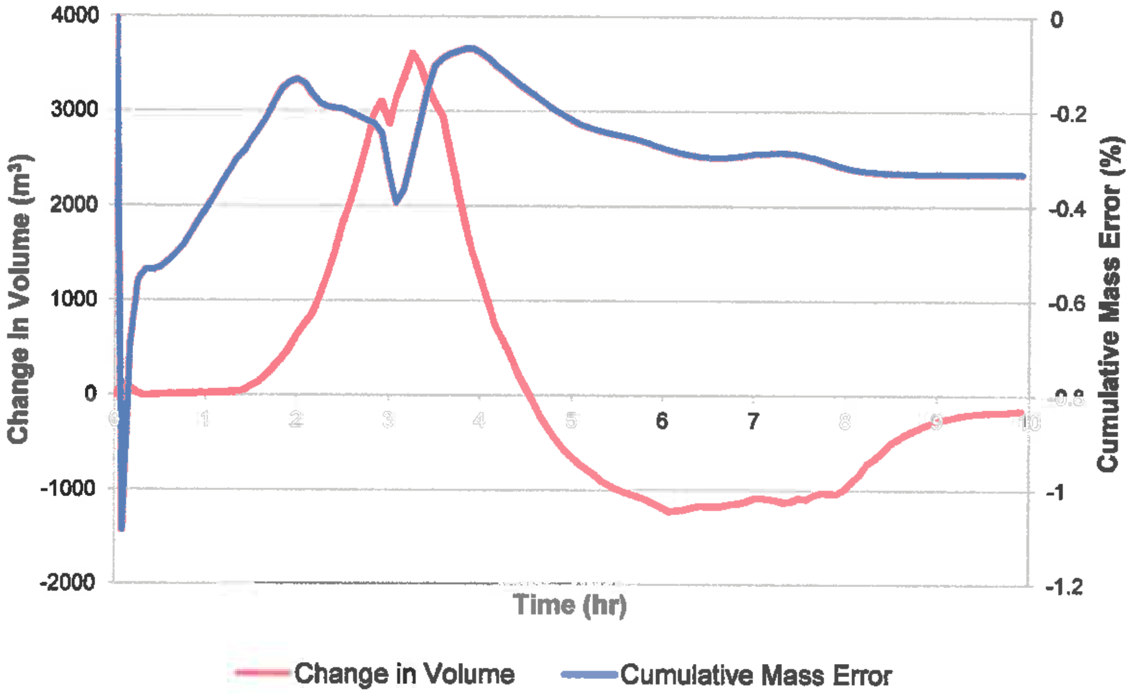


Figure 4-2: 2D cumulative mass error and change in volume – 1 % AEP event

4.3 Model Results

4.3.1 Model outputs

Maximum water levels have been extracted at each model node of the 1D domain for all simulated events. These are provided in Appendix A of this report. Maximum flood depth maps were produced for all the simulated events and they are provided in Appendix B of this report.

4.3.2 Existing scenario flood risk

This section summarises the key findings from the model simulations.

- The model simulation results for the 50% AEP event show that the flow begins to spill into the floodplain via a small drain that meets Chipping Brook around cross-sections CH01_0427 and CH01_0512 (approximately 380m downstream of the WWTW). The water then spills out of Chipping Brook on both banks where the watercourse is perched (node CH01_0629). At peak flow, the water overtops just upstream of the WWTW site (node CH01_0886) on both banks, as well as over the left bank immediately upstream of Startifants (node CH01_1071).
- The 50% AEP results show significant flooding in the modelled area especially near the unnamed tributary modelled. Due to the topography of the area, the flood water originating from Chipping Brook flows south and ponds near the unnamed tributary (left bank). Here, predicted water depth is as high as 750mm.
- The simulation results for the 20% AEP event show that, in addition to flooding described above for the 50% AEP event, the water also spills over the right bank of Chipping Brook at the location of Startifants.

The results for the 10% AEP and higher order events show that water overtops the left bank of Chipping Brook near the upstream end of the model as well.

- Simulation results show that flood water from Chipping Brook is transferred upstream through the modelled floodplain culverts for almost all the modelled AEP events.
- Longridge Road is overtopped west of the modelled unnamed tributary during the 1% AEP event plus climate change with approximately 100mm of water depth.
- The bridge leading to Startifants is surcharged during the 20% AEP event. The bridge leading to the WWTW site is not surcharged for any of the simulated AEP events.
- A few properties in Startifants get flooded for the 20% and higher order AEP events with maximum flood depths greater than 100mm.
- The Chipping WWTW site is partially flooded (north side) for all the simulated AEP events. The maximum water depth is generally less than 100mm and only a local depression shows depths ranging from 500mm to 750mm. Figure 4-3 shows predicted maximum flood depths in the vicinity of WWTW site for the 1% AEP event.

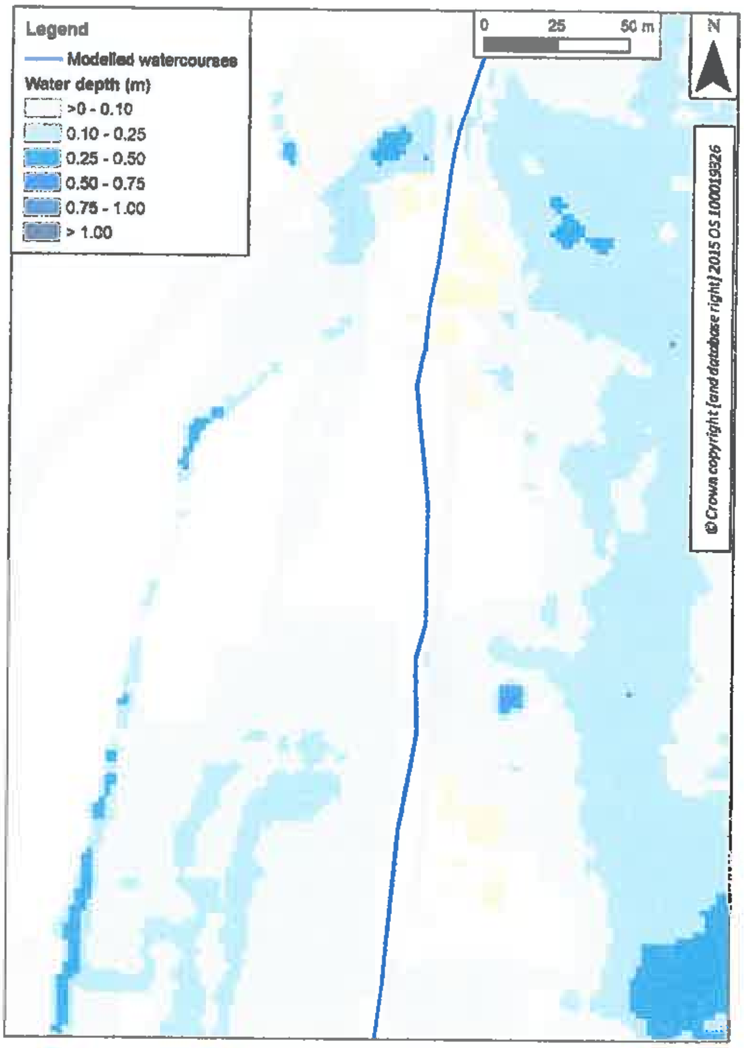


Figure 4-3: Predicted Maximum Flood depth - 1 % AEP event

4.3.3 Peak river water levels at the new proposed bridge location

Chipping WWTW site is located on Chipping Brook left bank between cross-sections CH01_0886 and CH01_0773 in the hydraulic model. A new access bridge is proposed in place of the existing access bridge, which is located approximately 110m upstream of the northern end of the site (node CH01_0994u). Table 4-1 below provides peak river water level for all the simulated events at the new proposed bridge location.

Table 4-1: Peak river water level for all the simulated events at the new proposed bridge location

Node	Existing Scenario Maximum Water Level (m AOD)						
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 % AEP + Climate Change
CH01_0994u	98.55	98.64	98.68	98.69	98.71	98.72	98.73

4.4 Sensitivity Analysis

In order to test the model sensitivity to key hydraulic parameters, a series of simulations were undertaken for the 1% AEP event. These tests were carried out for the 1D and 2D domain. Table 4-2 provides a summary of the sensitivity runs results. These are discussed in the following sections. The analysis gives an indication of the level of confidence that can be placed in the water levels predicted by the model for the existing scenario.

Table 4-2: Summary of results for the sensitivity test runs

Sensitivity Test	Average Water Level Difference (mm)	Maximum Water Level Difference (mm)	Cross Section where the Maximum Difference Occurs
Downstream Boundary's Slope -20 %	0	-37	CH01_0000
Downstream Boundary's Slope +20 %	0	43	CH01_0000
Roughness - 20%	18	-176	CH01_0427
Roughness + 20%	3	-126	CH01_1010u
Inflow - 20 %	26	-95	CH01_0427
Inflow + 20 %	-30	51	CH01_0427

4.4.1 Downstream boundary conditions sensitivity test

The effect of the downstream boundary's slope on the water levels in the Chipping Brook was tested by increasing and decreasing the existing scenario's slope by 20%.

For both cases, the effect of modifying the slope remains local to the downstream end of the model. The effect of the changes only extends approximately 30m from the downstream boundary. Therefore, it can be concluded that the hydraulic model results are not sensitive to the downstream boundary conditions of the model.

4.4.2 Roughness sensitivity test

Manning's 'n' roughness coefficients were sensitivity tested for a 20% increase and a 20% decrease in value for the full modelled reaches of the watercourses and their floodplain (1D and 2D domain).

The 1D results suggest that the model is not sensitive to changes in roughness. For both cases, the average change in water levels in Chipping Brook is less than +20mm. For the 2D floodplain model, the roughness makes a small difference to the flood extent. Figure 4-4 shows the changes in flood extent as a result of the roughness sensitivity testing.

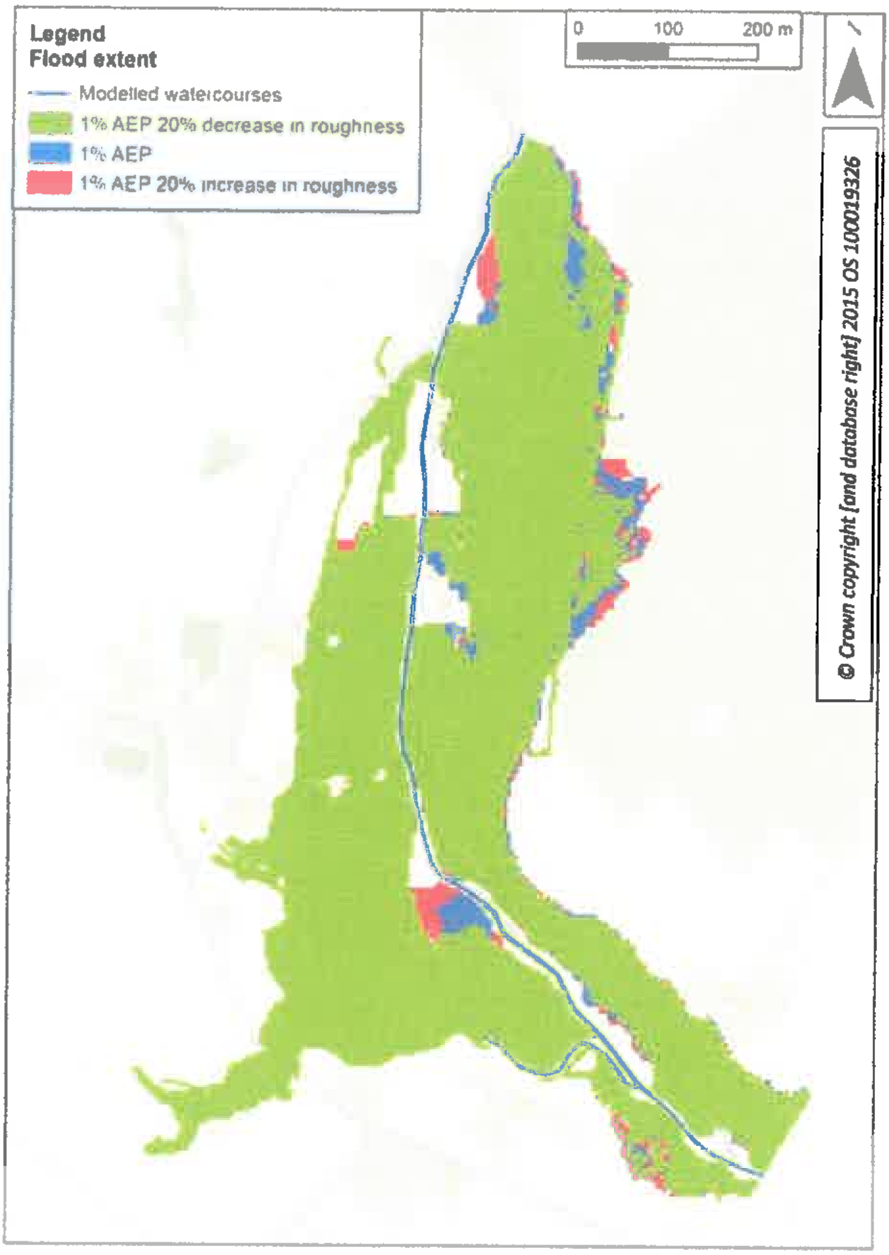


Figure 4-4: Flood extents - roughness sensitivity testing

4.4.3 Inflow sensitivity test

All hydrological inflows included in the model were tested for a 20% increase and a 20% decrease in peak flows. The hydrograph profile shape was not changed but scaled to the corresponding peak flows.

The 1D results suggest that the model is not sensitive to changes in peak flow. For both cases the maximum change in water is less than +/-50mm. For the 2D floodplain model, the inflow makes a small difference to the flood extent. Figure 4-5 shows the changes in flood extent as a result of the inflow sensitivity testing.

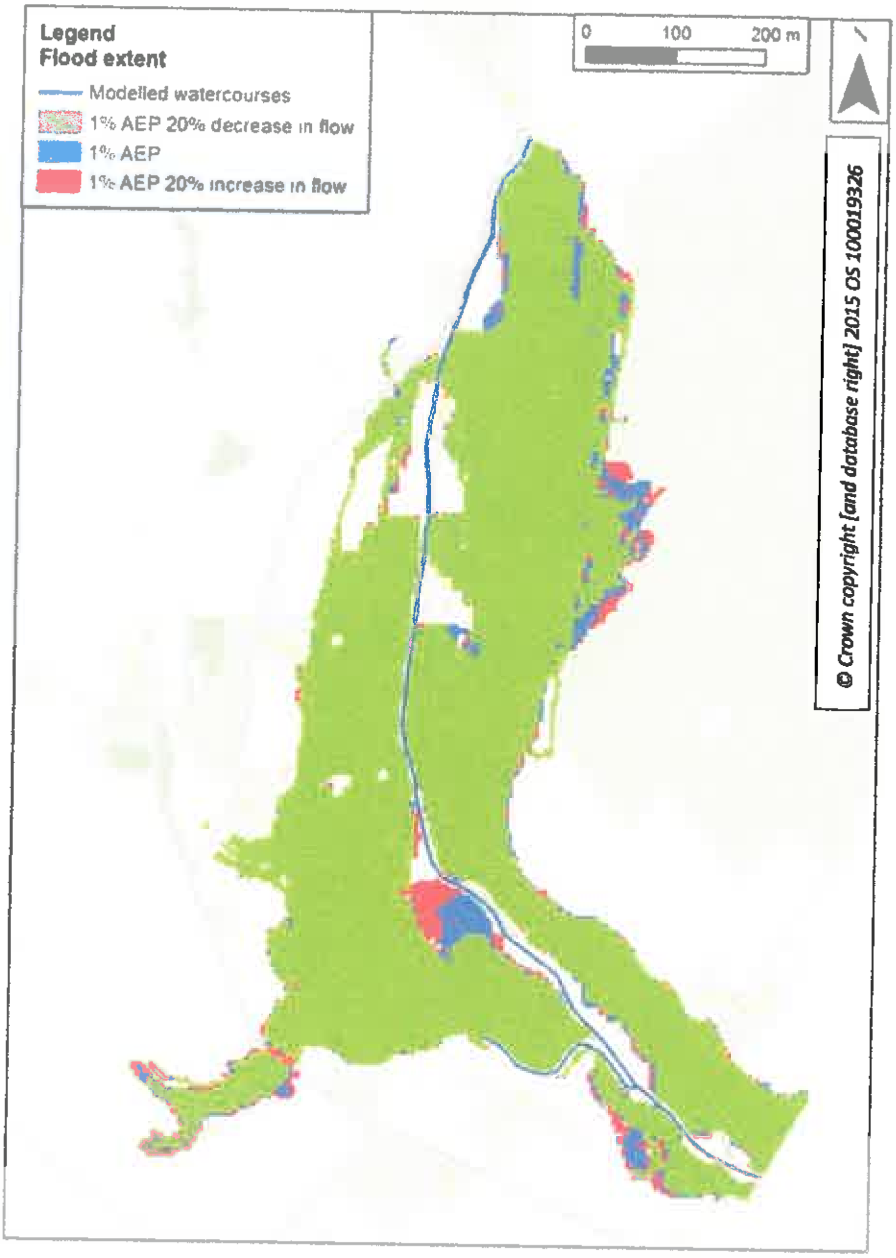


Figure 4-5: Flood extents - flow sensitivity testing

4.4.4 Sensitivity test results at the new proposed bridge location

This section discusses the sensitivity test results for the 1% AEP event specifically at the upstream face of the existing access bridge to the WWTW:

- A 20% decrease in inflows for 1% AEP event results in a 14mm lowering of water levels at the upstream face of the bridge and a 20% increase in inflows results in 12mm increase in maximum water level at the upstream face of the bridge.
- A 20% decrease in roughness results in a 58mm lowering of water levels at the upstream face of the bridge and a 20% increase in roughness results in negligible change in maximum water level at the upstream side of the bridge.
- The sensitivity tests for the downstream boundary show no impact on the water levels at the upstream face of the existing access bridge to WWTW.

5. Assumptions & Limitations

The accuracy and validity of the model results is heavily dependent on the accuracy of the hydrological, surveyed and topographic data included in the model. While the most appropriate available information has been used to construct the model, there are assumptions and limitations associated with the model. These are listed below:

1) The LiDAR data used to inform the 2D model domain with ground elevation information has a horizontal resolution of 2m. In the 2D model, this was further resampled using a 4m square grid in TUFLOW. This resolution is appropriate for predicting the flooding mechanism in the modelled area;
2) The model has not been quantitatively calibrated as the Chipping Brook catchment is ungauged. However, model performance has been checked as well as the consistency of model results;
3) Culverts in floodplain, included in the 2D domain as ESTRY 1D elements, were not surveyed. Their dimensions have been estimated using Google Earth, Street View and OS mapping. However considering the extensive flooding in the floodplain it is considered that model results are not sensitive to these assumptions.
4) The downstream boundary of the model assumes free flow and the impact of River Loud on the downstream boundary is not considered. However, sensitivity tests have demonstrated that model predictions at Chipping WWTW are not influenced by the downstream boundary conditions.

6. Conclusions

A linked 1-dimensional / 2-dimensional (1D/2D) hydraulic model has been built to represent Chipping Brook, one of its unnamed tributary and their floodplain using Flood Modeller Pro (1D) and TUFLOW (2D) software.

The key conclusions from the hydraulic modelling carried out are the following:

- The modelled flood extents are significant during the 50% AEP event due insufficient capacity of the river channels and the topography of the floodplain areas that allow widespread flooding.
- Chipping WWTW site is partially flooded, in the northern part of the site, for all the modelled AEP events, including the 50% AEP event. For all the modelled events, maximum flood depths are generally less than 100mm and very locally (in topographic depressions) reach values as high as 750mm.
- A few properties in Startifants get flooded for the 20% and higher order AEP events with maximum flood depths greater than 100mm.
- The new access bridge will replace the existing bridge. At this location, maximum river water level for the 1% AEP event is 98.72m AOD and for the 1% AEP plus climate change event, it is 98.73m AOD.

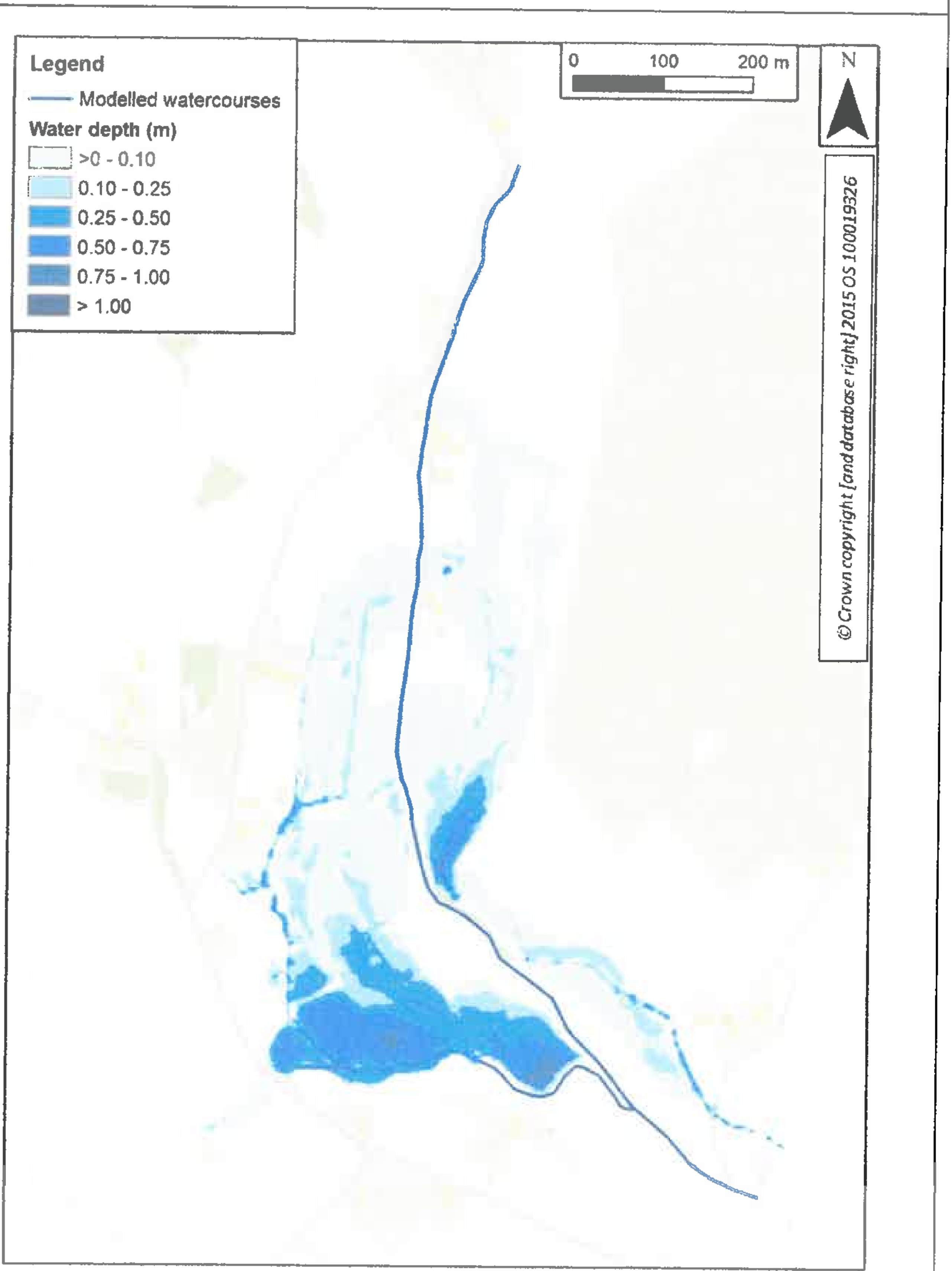
Appendix A. Maximum River Water Levels

Node	Chipping Brook - Existing Scenario Maximum Water Level (m AOD)						
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 % AEP + Climate Change
CH01_1345	101.94	102.16	102.28	102.34	102.38	102.41	102.45
CH01_1257	100.98	101.18	101.29	101.35	101.42	101.45	101.49
CH01_1193	100.40	100.54	100.55	100.55	100.56	100.57	100.60
CH01_1184	100.25	100.29	100.30	100.31	100.32	100.32	100.33
CH01_1071	99.32	99.44	99.48	99.50	99.51	99.52	99.54
CH01_1010u	98.67	99.08	99.14	99.17	99.19	99.21	99.24
CH01_1007	98.65	98.72	98.75	98.77	98.78	98.79	98.80
CH01_0994u	98.55	98.64	98.68	98.69	98.71	98.72	98.73
CH01_0990	98.55	98.64	98.68	98.69	98.71	98.72	98.73
CH01_0886	97.51	97.52	97.52	97.52	97.53	97.53	97.53
CH01_0825	96.76	96.79	96.80	96.80	96.80	96.80	96.81
CH01_0773	96.12	96.14	96.15	96.16	96.18	96.18	96.19
CH01_0629	94.81	94.81	94.81	94.81	94.81	94.81	94.81
CH01_0512	93.49	93.52	93.54	93.57	93.64	93.67	93.72
CH01_0427	92.74	92.79	92.81	92.86	92.95	93.01	93.06
CH01_0346	92.06	92.11	92.15	92.20	92.25	92.28	92.32
CH01_0271	91.43	91.58	91.67	91.75	91.80	91.82	91.86
CH01_0222	91.18	91.28	91.33	91.36	91.40	91.43	91.47
CH01_0170	91.05	91.15	91.17	91.18	91.21	91.24	91.27
CH01_0169	91.05	91.15	91.17	91.18	91.21	91.24	91.27
CH01_0121	90.83	90.98	91.01	91.03	91.04	91.06	91.07
CH01_0028u	90.13	90.18	90.21	90.22	90.25	90.28	90.32
CH01_0026	90.13	90.18	90.21	90.22	90.25	90.28	90.32
CH01_0000	90.09	90.16	90.19	90.20	90.22	90.24	90.27

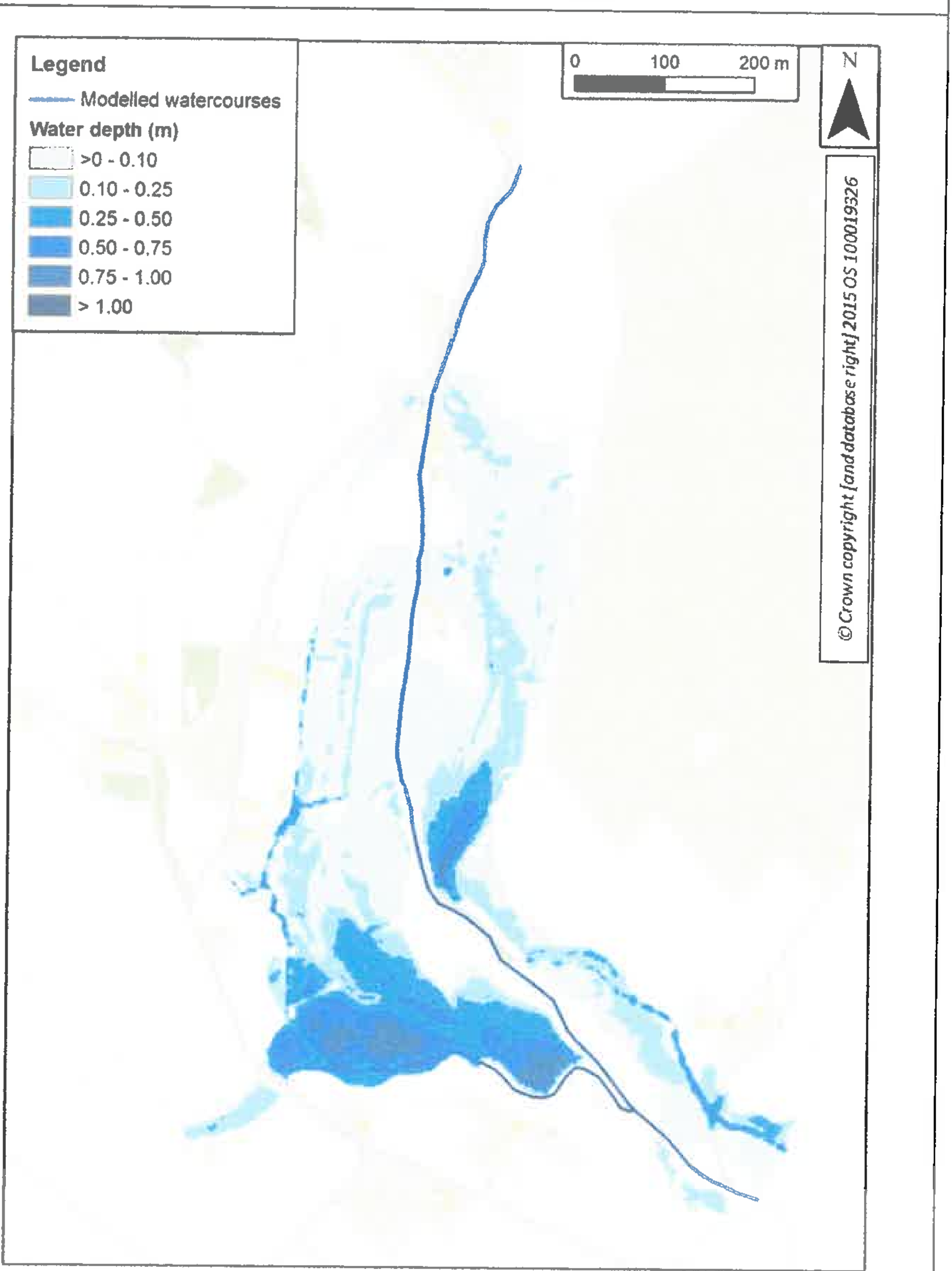
Node	Unnamed Tributary - Existing Scenario Maximum Water Level (m AOD)						
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 % AEP + Climate Change
CH02_0219	91.65	91.74	91.78	91.80	91.84	91.87	91.93
CH02_0183	91.64	91.74	91.78	91.81	91.85	91.88	91.97
CH02_0140	91.64	91.70	91.72	91.73	91.74	91.74	91.75
CH02_0000	91.05	91.15	91.17	91.18	91.21	91.24	91.27

Appendix B. Flood Maps

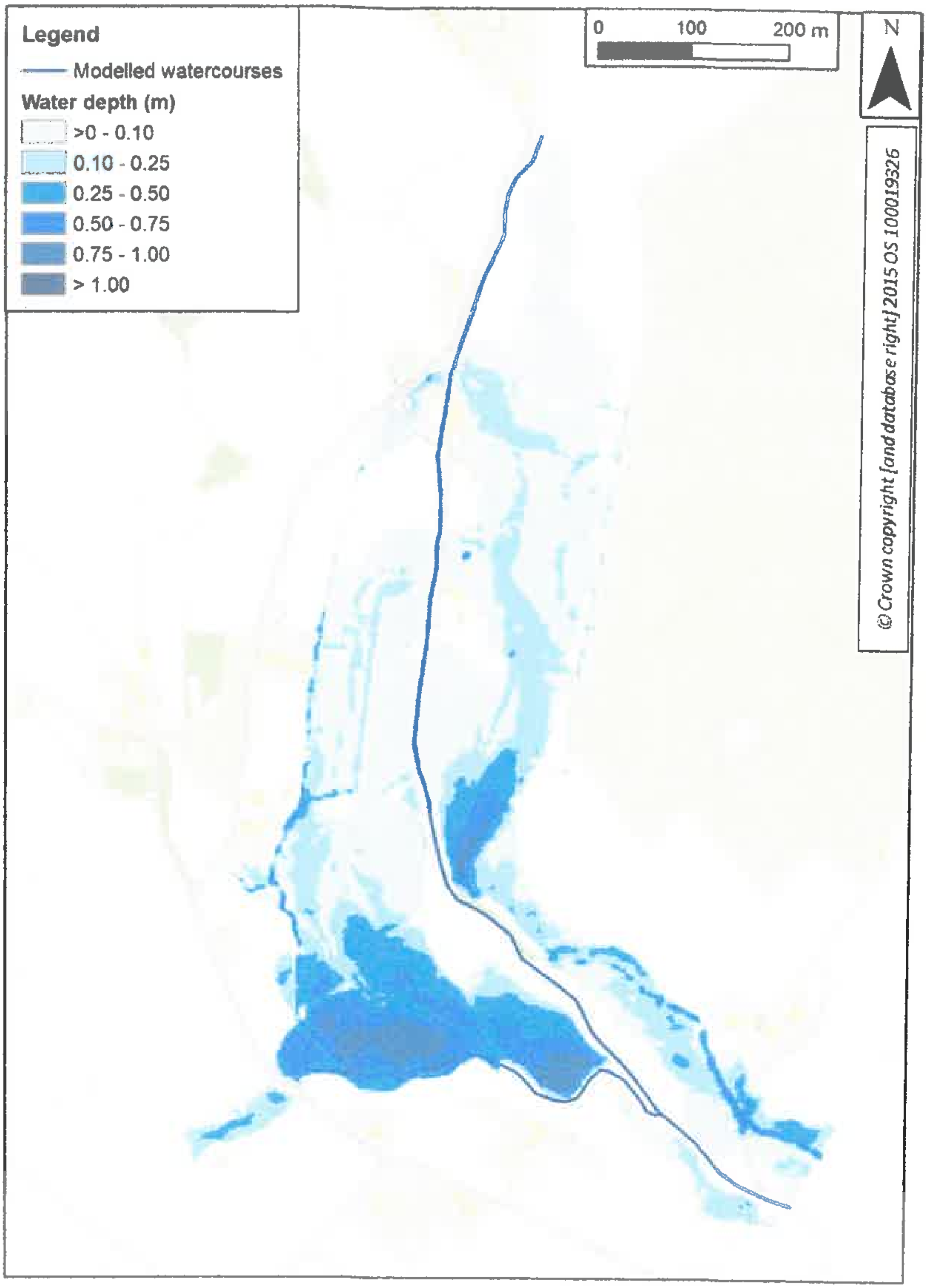
Maximum Flood Depth – 50 % AEP Event



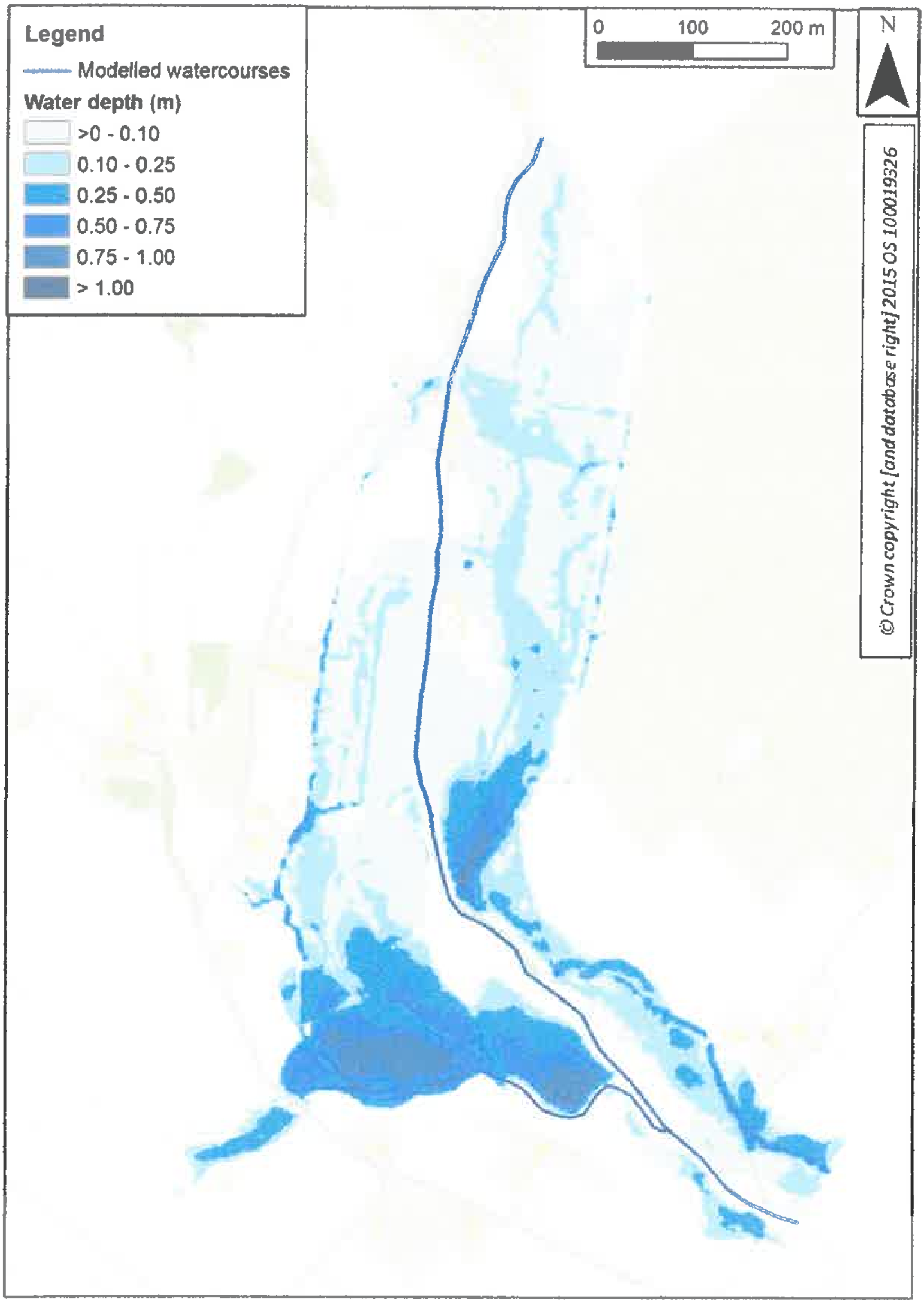
Maximum Flood Depth – 20 % AEP Event



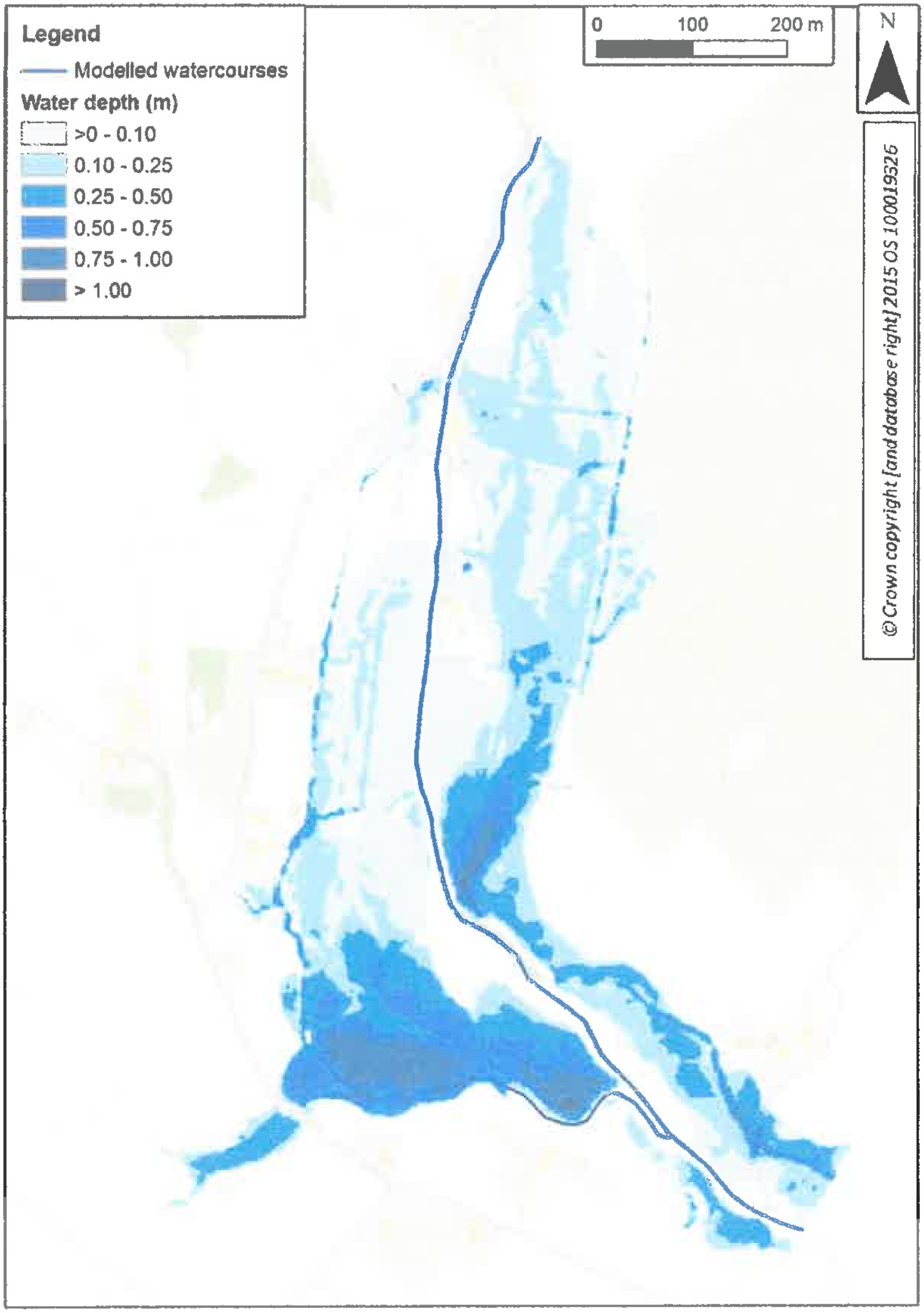
Maximum Flood Depth – 10 % AEP Event



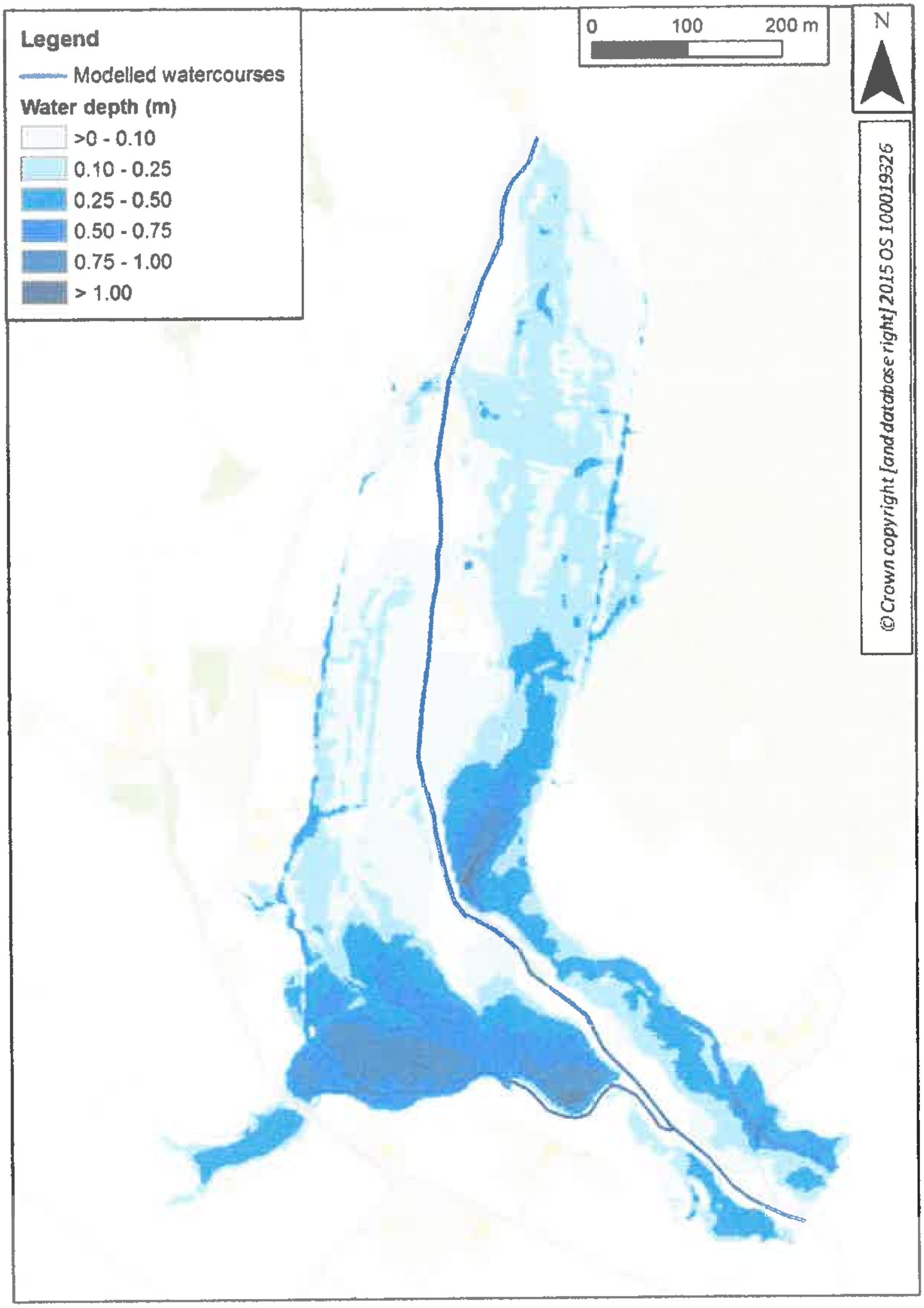
Maximum Flood Depth – 5 % AEP Event



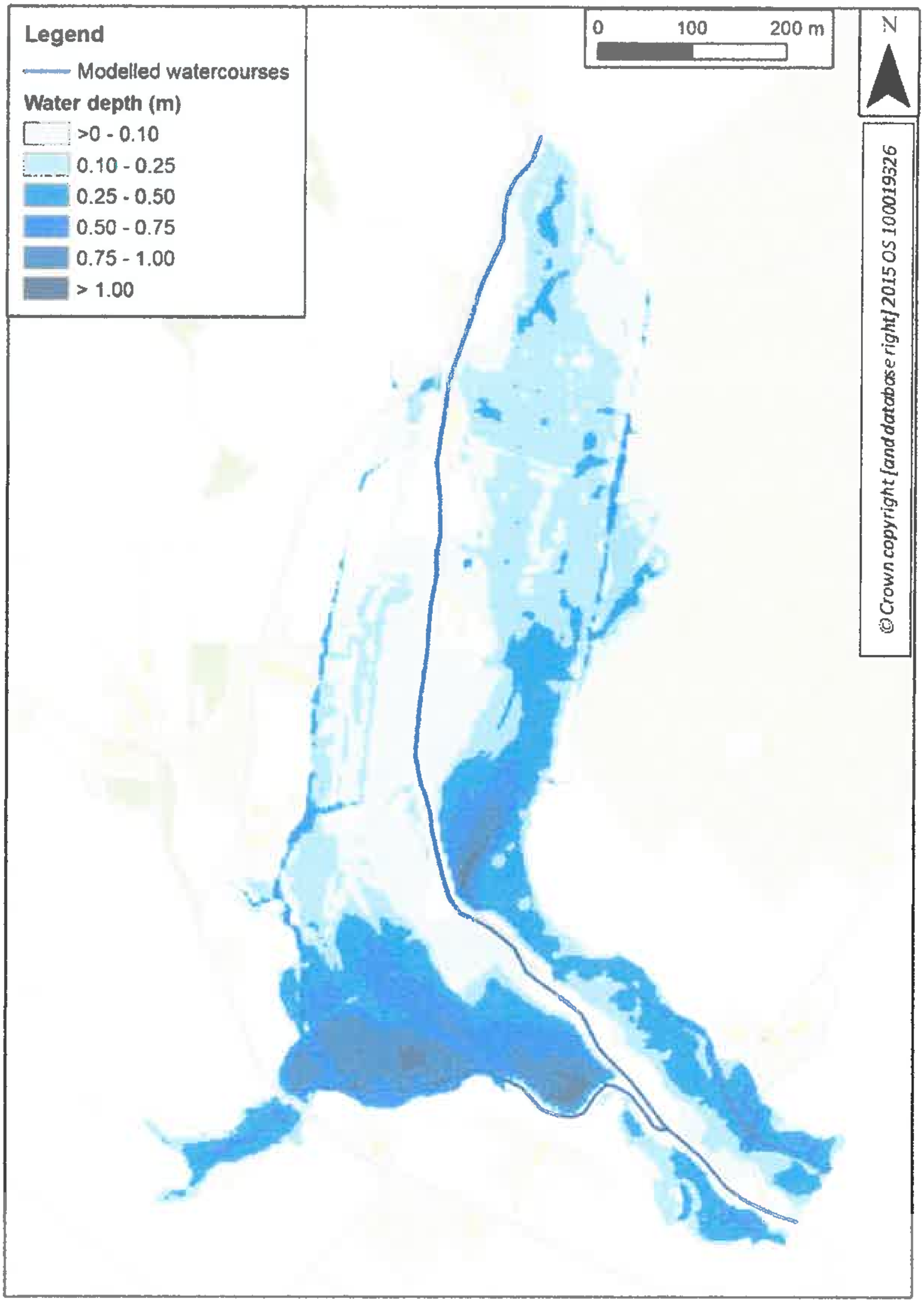
Maximum Flood Depth – 2 % AEP Event



Maximum Flood Depth – 1 % AEP Event



Maximum Flood Depth – 1 % AEP plus Climate Change Event



Appendix C. Chipping Brook Hydrology

C.1 Objectives

As an input to the hydraulic model, hydrological assessments are required to determine the design flows for the 20%, 10%, 5%, 2%, 1% and 1% plus climate change AEP at specified locations on the Chipping Brook and its tributary.

C.2 Catchment Description

Chipping Brook is located in Lancashire and originates on the hills in the Forest of Bowland (Figure C.1). The Brook drains an area of approximately 10.8km^2 to its confluence with the River Loud. The catchment is predominately rural with the main area of settlement being Chipping village, located in the lower half of the catchment.

$URBEXT_{2000}$ values are up to 0.0097 immediately downstream of the Chipping at location CB01. The brook flows south east through Chipping before joining the River Loud. There is an unnamed tributary which joins the brook from the right bank approximately 1km downstream of Chipping village at NGR SD626419 (Figure C.1).

Soils within the catchment are classed as slowly permeable, seasonally wet acid loamy and clayey soils. The bedrock of the catchment is Bowland High Group and Craven (Mudstone, Siltstone and Sandstone) and the superficial geology comprises a combination of Till-Diamicton and Alluvium (Clay, Silt and Sand) with areas of Peat in the upper reaches of the catchment. The SPRHOST value ranges from 35.59% to 47.06%. The BFIHOST value is between 0.323 and 0.367.

The topography of the catchment ranges from 520m AOD in the upper reaches to 90m AOD at the confluence with the River Loud (i.e. location CB02). The standard average annual rainfall (SAAR) of the catchment ranges from 1381mm to 1592mm.

C.3 Flow Estimation Locations

Flow estimates were required at three locations in the Chipping Brook catchment. These are shown in Table C.1 below and mapped on Figure C.1.

Table C.1 : Locations of flow estimates

Flow Estimation Point	Description	Grid Reference	Catchment Area (km^2)
CB01	Chipping Brook approximately 500m downstream of Chipping Brook Bridge.	SD625429	8.45
CB02	Chipping Brook upstream of the confluence with River Loud	SD628417	10.79
TRIB	Unnamed tributary upstream of the confluence with Chipping Brook.	SD625419	2.14

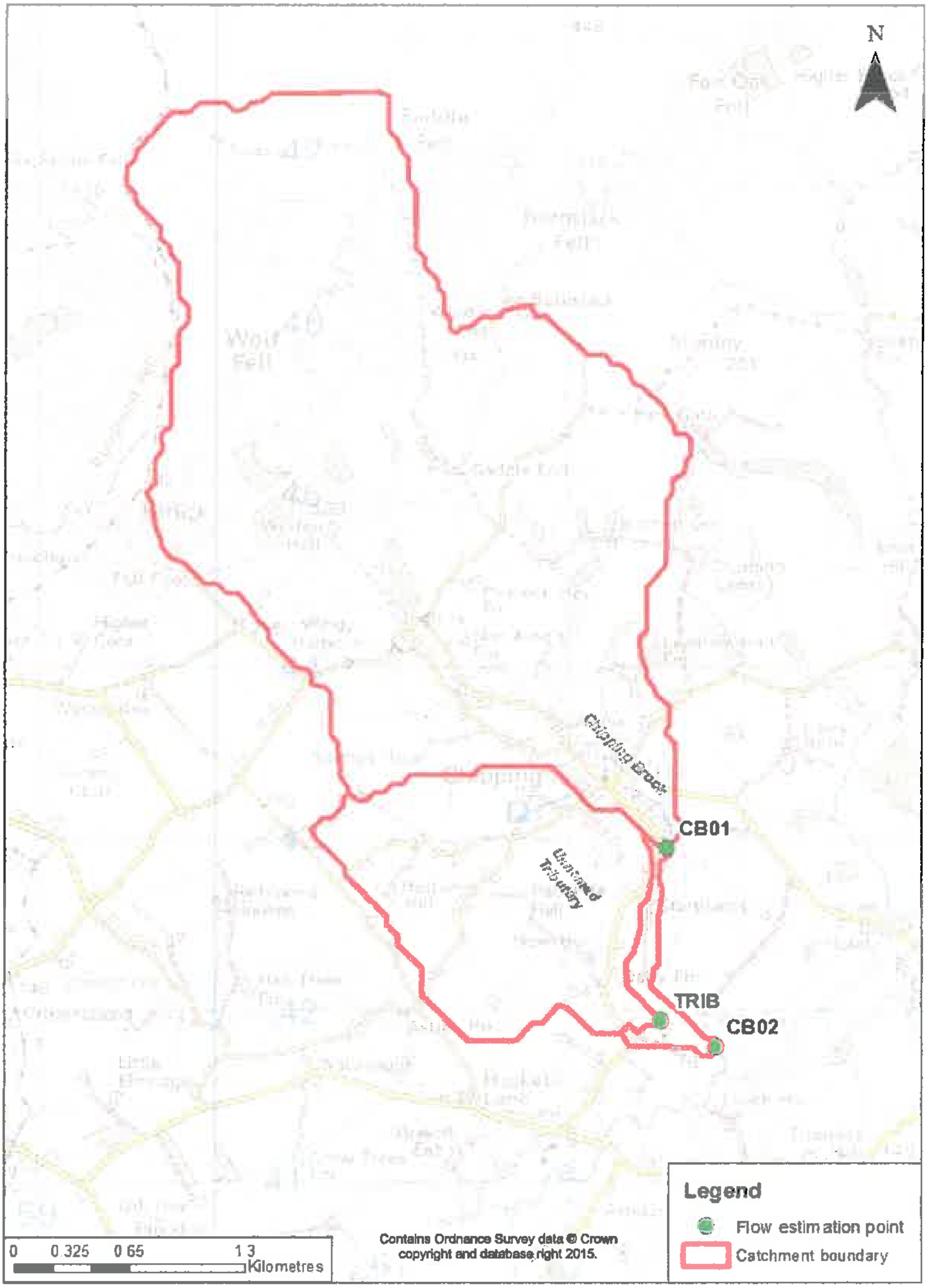


Figure C.1 : Locations of flow estimates

C.4 Methodology

The following bullet points details the methodology used for this assessment.

- Catchment areas were extracted from the FEH CD-ROM Version 3.0 (2009) for the three locations listed in Table C.1 and checked against the 1:50,000 OS mapping and contours. No amendments were required to the catchment AREAs.
- The median annual maximum flow (QMED) was calculated from the Flood Estimation Handbook (FEH) catchment descriptors. Gauging station 72007 was identified as a reliable donor catchment for a data transfer in the calculation of QMED. The data transfer was implemented for both the Chipping Brook catchment and its tributary.
- The catchments in the study are classed as "*essentially rural*" therefore no urban adjustment was made to QMED.
- A statistical pooling group analysis was undertaken using WINFAP-FEH Version 3.0.003 (2009). The Jacobs WINFAP-FEH database currently uses Peak Flow data version 3.3.4 dated August 2014, published on the Centre for Hydrology and Ecology (CEH) website.
- The whole river catchment (CB02) was used to generate a pooling group and the resultant growth curve applied to all locations.
- Revitalised Flood Hydrograph ReFH1 boundary units were set up in ISIS v3.7.0.233 for all catchments using a catchment-wide design storm duration of 4.4 hours.
- Revitalised Flood Hydrograph ReFH2 analysis was undertaken for all three catchments using a catchment-wide design storm duration of 4.75 hours. Resultant flows were compared with the flows produced using ReFH1.

A climate change adjustment, based on the Environment Agency's Adoption for Climate Change guidance of 20% in the North West England was applied[5] to the 1% AEP event flows.

C.5 Results

The following section provides a summary of the results of the hydrological assessment. The detailed analyses are described in the audit trail in Appendix D.

C.5.1 QMED results

Table C.2 shows the QMED values calculated for all three locations calculated using the FEH statistical analysis with a data transfer from gauging station 72007.

Table C.2 : Catchment QMED values from FEH statistical method

Flow Estimation Point	QMED Catchment Descriptors (m^3/s)	QMED with Data Transfer from 72007 (m^3/s)
CB01	11.42	11.87
CB02	13.32	13.85
TRIB	2.70	2.81

C.5.2 FEH pooling analysis

Table C.3 shows the growth factors determined using a pooling group of hydrologically similar catchments at CB02 and estimated peak flows for all three catchments.

[5] Environment Agency (2011) Adapting to Climate Change Advice for Flood and Coastal Erosion Management Authorities

Table C.3 : Growth factors and flow estimates at locations CB01-02 and TRIB using the pooling group method

AEP Event	Growth Factors CB02	FEH - Estimated Peak Flows (m^3/s)		
		CB01	CB02	TRIB
20%	1.337	15.9	18.5	3.8
10%	1.590	18.9	22.0	4.5
5%	1.868	22.2	25.9	5.2
2%	2.297	27.3	31.8	6.4
1%	2.680	31.8	37.1	7.5
1% + Climate Change	–	38.2	44.6	9.0

C.5.3 Calculated flows for catchment using ReFH1 method

ReFH1 analysis was undertaken at all three locations using a catchment-wide design storm of 4.4 hours. Results are shown in Table C.4 below.

Table C.4 : ReFH1 results at CB01-02 and TRIB

AEP Event	ReFH1 - Estimated Peak Flows (m^3/s)		
	CB01	CB02	TRIB
20%	14.0	15.9	3.5
10%	16.9	19.1	4.2
5%	19.9	22.6	4.9
2%	24.8	28.1	6.0
1%	29.3	33.2	7.1
1% + Climate Change	35.1	39.8	8.5

C.5.4 Calculated flows for catchments using ReFH2 methods

Results of ReFH2 analysis undertaken at all three locations are shown in Table C.5 using a catchment-wide design storm of 4.75 hours.

Table C.5 : ReFH2 results at CB01-02 and TRIB

AEP Event	ReFH2 - Estimated Peak Flows (m^3/s)		
	CB01	CB02	TRIB
20%	12.5	14.3	3.2
10%	14.9	17.0	3.8
5%	17.4	19.8	4.4
2%	20.8	23.7	5.3
1%	26.7	26.9	6.0
1% + Climate Change	32.0	32.3	7.2

C.5.5 Comparison of calculated flows using FEH and ReFH methods

Different formulae are used in the calculation of the catchment storm duration at CB02 for both methodologies. 4.4 hours and 4.75 hours were calculated using ReFH1 and ReFH2 respectively. Results at CB02 show higher flows for all return periods using the FEH approach in comparison to the ReFH methods for all return periods. This is detailed in Table C.6 below.

Table C.6 : Results at CB02 using all methods

AEP Event	CB02 - Estimated Peak Flows (m³/s)		
	FEH Pooling	ReFH1	ReFH2
20%	18.5	15.9	14.3
10%	22.0	19.1	17.0
5%	25.9	22.6	19.8
2%	31.8	28.1	23.7
1%	37.1	33.2	26.9
1% + Climate Change	44.6	39.8	32.3

C.6 Conclusions and Recommendation

The hydrological analysis has been undertaken using the FEH pooling group and ReFH methodologies. The results show higher flows using the FEH pooling group method for all return periods for the Chipping Brook. However, for the smaller catchment, location TRIB, flows were similar for both methods with an average of 5% difference for the 1% AEP event.

Catchments within the study area are ungauged. No allowances have been made within ReFH to amend model parameters based on recorded data. Flows are estimated solely based on catchment descriptors.

The Environment Agency guidelines state that, the use of FEH statistical pooling analysis is essential for ungauged sites[6]. The pooling group uses gauged data from hydrologically similar stations in the construction of a growth curve. The approach also allows for the improvement of QMED value by the use of a donor catchment. For this study, the estimation of QMED was improved by using gauged data from a neighbouring catchment, improving the reliability of assessment using the statistical pooling group method.

The FEH approach is therefore deemed appropriate and recommended for use for this study.

[6] Environment Agency (2015) Flood Estimation Guidelines, Technical Guidance 197_08

Appendix D. Chipping Brook Hydrology – FEH Audit Trail

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

Contents

Approval

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:		Agnes Adjei	
Calculations checked by:		Alison Janes	
Calculations approved by:		Phil Raynor	

Environment Agency competence levels are covered in Section 2.1 of the flood estimation guidelines:

- Level 1 – Hydrologist with minimum approved experience in flood estimation
- Level 2 – Senior Hydrologist
- Level 3 – Senior Hydrologist with extensive experience of flood estimation

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations • Approx. time available	Proposed expansion works are required to the United Utility Chipping Waste Water Treatment Works (WWTW) site located in Lancashire. As part of the planning application process a hydraulic mode is required to determine the level of flood risk to surrounding area and properties. As an input to this model, hydrological assessments were required to determine the design flows for the following Annual Exceedance Probability 20%, 10%, 5%, 2%, 1% and 1% plus climate. Estimated flows are required at these locations: • Chipping Brook approximately 500m downstream of Chipping Brook Bridge. • Unnamed Tributary upstream of confluence with Chipping Brook. • Chipping Brook upstream of confluence with River Loud.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	Chipping Brook drains an area of approximate 10.8km^2 to its confluence with the River Loud. The catchment is predominately rural with the only area of settlement being the Chipping town located in the lower half of the catchment. The Brook runs from the hills in the Forest of Bowland then flows south easterly in the River Loud. There is an unnamed Tributary that joins the Brook approximately 1km downstream of Chipping town on the right bank. Soils within the catchment as classed as slowly permeable, seasonally wet acid loamy and clayey soils. The bedrock of the catchment is Bowland High Group and Craven-Mudstone, Siltstone and Sandstone. The superficial geology mainly comprises of a combination of Till-Diamicton and Alluvium (Clay, Silt and Sand) with areas of Peat in the upper reaches of the catchment. The topography of the catchment ranges from 520 mAOD in the upper reaches to 90 mAOD downstream of catchment.

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.3.4 downloaded August 2014

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
Brock	U/S A6		72007	SD512405	32.0	Broad crested weir	1978 - 2014

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
U/S A6	1978-2011	N	Y	Y	N	Yes - Gauged to within 20% of AMAX3. No bypassing reported
Give link/reference to any further data quality checks carried out						

1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
N/A	Single rating for the period of record based on current meter gaugings	N	

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
CB01	Chipping Brook	Chipping Brook approximately 500m downstream of Chipping Brook Bridge.	362550	442900	8.45	-
CB02	Chipping Brook	Unnamed Tributary upstream of confluence with Chipping Brook.	362850	441750	10.79	-
TRIB	Unnamed Tributary	Chipping Brook upstream of confluence with River Loud.	362550	441900	2.14	-
Reasons for choosing above locations		Locations requested by modelling team.				

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

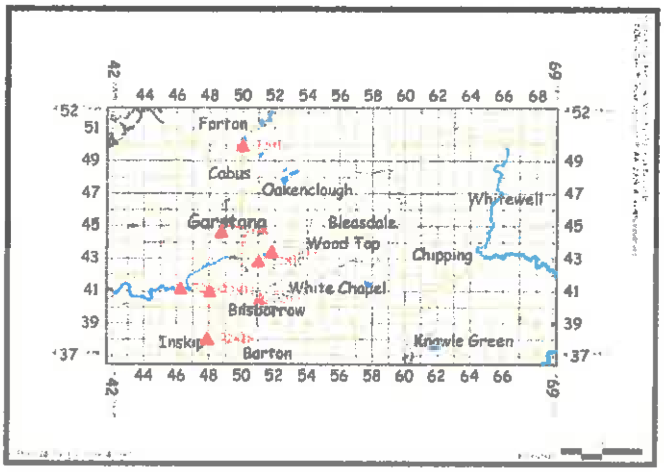
Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT	FPEXT
CB01	1.000	0.6	0.323	3.87	137.6	1592	47.06	0.0065	0.0283
CB02	1.000	0.6	0.332	4.50	117.8	1545	44.66	0.0097	0.0541
TRIB	1.000	0.6	0.367	1.56	52.3	1381	35.59	0.0064	0.1014

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchment boundaries were checked with the 1:50,000 OS mapping and contours. No changes made.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	N/A
Source of URBEXT	URBEXT1990 / URBEXT2000 Updated URBEXT 2000 to 2015 CB01 — 0.0067 — Essentially rural CB02 — 0.0100 — Essentially rural TRIB — 0.0066 — Essentially rural
Method for updating of URBEXT	CPRE formula from FEH Volume 4 / CPRE formula from 2006 CEH report on URBEXT2000

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	Station 72007 drains the neighbouring River Brock catchment to the subject site was identified as suitable donor for the Chipping Brook and unnamed tributary catchment. The following are the characteristics of donor site. AREA = 31.53 FARL = 1.00 URBEXT = 0 (essentially rural) SPRHOST = 49.42 BFIHOST = 0.319 

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjust-ment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)
72007	Accepted for QMED adjustment to Chipping Brook and Unnamed Tributary	AM	N	31.41	28.90	1.09

Which version of the urban adjustment was used for QMED at donor sites, and why? Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).	WINFAP-FEH v3.0.003 / Kjeldsen (2010) / other (delete as applicable)

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED (m^3/s)	Data transfer						Final estimate of QMED (m^3/s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d_{ij} (km)	Power term, a	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor		
							Weight	Weighted average adjustment factor	
CB01	DT	11.42	72007	4.62	0.48	1.04	N/A	N/A	11.87
CB02	DT	13.32	72007	4.70	0.48	1.04	N/A	N/A	13.85
TRIB	DT	2.70	72007	5.61	0.45	1.04	N/A	N/A	2.81

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	
Which version of the urban adjustment was used for QMED, and why?	WINFAP-FEH v3.0.003 / Kjeldsen (2010) / other (delete as applicable)

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.

When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added.

When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050[Error! Bookmark not defined.] should be used. If the original FEH equation has been used, say so and give the reason why.

The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data.

The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is $(A/B)^a$ times the initial estimate from catchment descriptors.

If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

3.4 Derivation of pooling groups

The composition of the pooling groups is given in the Annex. Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
CB-02.feh	CB02	Ungauged	Discordant station; 48009 Stations removed; 49006 short record years 47022, FARL<0.95 54022, 57017, SAAR>2100 Stations added to increase pooling group to target years 27010, 27051	L-CV = 0.208 L-Skew = 0.228

Notes

Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). Amend if not applicable.

The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (3.4)	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 100-year return period
CB_02	P	CB_02.feh	GL distribution generally recommended for the UK	N/A	Location = 1.000 Shape = -0.228 Scale = 0.207	2.680

Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Growth curves were derived using the revised procedures from Science Report SC050050 (2008). Amend if not applicable.

Any relevant frequency plots from WINFAP-FEH, particularly showing any comparisons between single-site and pooled growth curves (including flood peak data on the plot), should be shown here or in a project report.

3.6 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	5	**10**	**20**	**50**	**100**	**100+20%cc**
Growth Factors	1.337	1.590	1.868	2.297	2.680	-
CB01	15.9	18.9	22.2	27.3	31.8	38.2
CB02	18.5	22.0	25.9	31.8	37.1	44.6
TRIB	3.8	4.5	5.2	6.4	7.5	9.0

4 Revitalised flood hydrograph (ReFH) method

4.1 Parameters for ReFH1 model

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
CB01	CD	1.512	230.538	25.541	0.921
CB02	CD	1.711	236.636	26.247	0.949
TRIB	CD	1.149	260.275	22.410	1.057

Brief description of any flood event analysis carried out (further details should be given below or in a project report)	

4.2 Design events for ReFH method

ReFH1

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
CB01	Rural	Winter	4.4	8.45
CB02	Rural	Winter	4.4	10.79
TRIB	Rural	Winter	4.4	2.14

Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?	

ReFH2

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
CB01	Rural	Winter	4.75	8.45
CB02	Rural	Winter	4.75	10.79
TRIB	Rural	Winter	4.75	2.14

Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?	

4.3 Flood estimates from the ReFH method

ReFH 1

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	5	10	20	50	100	100+20%cc
CB01	14.0	16.9	19.9	24.8	29.3	35.1
CB02	15.9	19.1	22.6	28.1	33.2	39.8
TRIB	3.5	4.2	4.9	6.0	7.1	8.5

ReFH2

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	5	10	20	50	100	100+20%cc
CB01	12.5	14.9	17.4	20.8	23.6	28.3
CB02	14.3	17.0	19.8	23.7	26.9	32.3
TRIB	3.2	3.8	4.4	5.3	6.0	7.2

5 FEH rainfall-runoff method

5.1 Parameters for FEH rainfall-runoff model

Methods:
FEA : Flood event analysis
LAG : Catchment lag
DT : Catchment descriptors with data transfer from donor catchment
CD : Catchment descriptors alone
BFI : SPR derived from baseflow index calculated from flow data

Site code	Rural (R) or urban (U)	Tp(0): method	Tp(0): value (hours)	SPR: method	SPR: value (%)	BF: method	BF: value (m^3/s)	If DT, numbers of donor sites used (see Section 5.2) and reasons

5.2 Donor sites for FEH rainfall-runoff parameters

No.	Watercourse	Station	Tp(0) from data (A)	Tp(0) from CDs (B)	Adjustment ratio for Tp(0) (A/B)	SPR from data (C)	SPR from CDs (D)	Adjust-ment ratio for SPR (C/D)
1								
2								

5.3 Inputs to and outputs from FEH rainfall-runoff model

Site code	Storm duration (hours)	Storm area for ARF (if not catchment area)	Flood peaks (m^3/s) or volumes (m^3) for the following return periods (in years)							
			2							

Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?	

6 Discussion and summary of results

6.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 5 years			Return period 100 years		
	ReFH1	ReFH2	FEH	ReFH1	ReFH2	FEH
CB01	14.0	12.5	15.9	29.3	26.7	31.8
CB02	15.9	14.3	18.5	33.2	26.9	37.1
TRIB	3.5	3.2	3.8	7.1	7.2	9.0

6.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The estimated flows using the FEH statistical method is recommended for use for this study. This approach is suitable for ungauged catchment and allows QMED from catchment descriptors to be improved through the use of data transfer from a donor site. A suitable donor site from a neighbouring rural catchment was identified and used to improve the estimation of QMED, thereby, improving the reliability of the assessment using FEH statistical approach.

6.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The donor catchment for QMED estimation is sufficiently similar to the study catchment that it has similar hydrological response
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	N/A
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	CB_01: 68% confidence interval = (7.98, 16.34) 95% confidence interval = (5.58, 23.38) CB_02: 68% confidence interval = (9.31, 19.06) 95% confidence interval = (6.50, 27.28) TRIB: 68% confidence interval = (1.89, 3.89) 95% confidence interval = (1.32, 5.53)
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	N/A
Give any other comments on the study, for example suggestions for additional work.	N/A

6.4 Checks

Are the results consistent, for example at confluences?	The sum of flows from catchments CB01 and TRIB are roughly equal to the estimate at catchment CB02.
What do the results imply regarding the return periods of floods during the period of record?	N/A
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	The 100 year growth factor is 2.680. This is within the typical guidance range.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	N/A
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	The 2 year runoff rate for CB02 from the FEH pooling group method equates to13 l/s/ha. This is felt to be a high value but within published guidance.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	N/A
Are the results compatible with the longer-term flood history?	N/A
Describe any other checks on the results	N/A

6.5 Final results

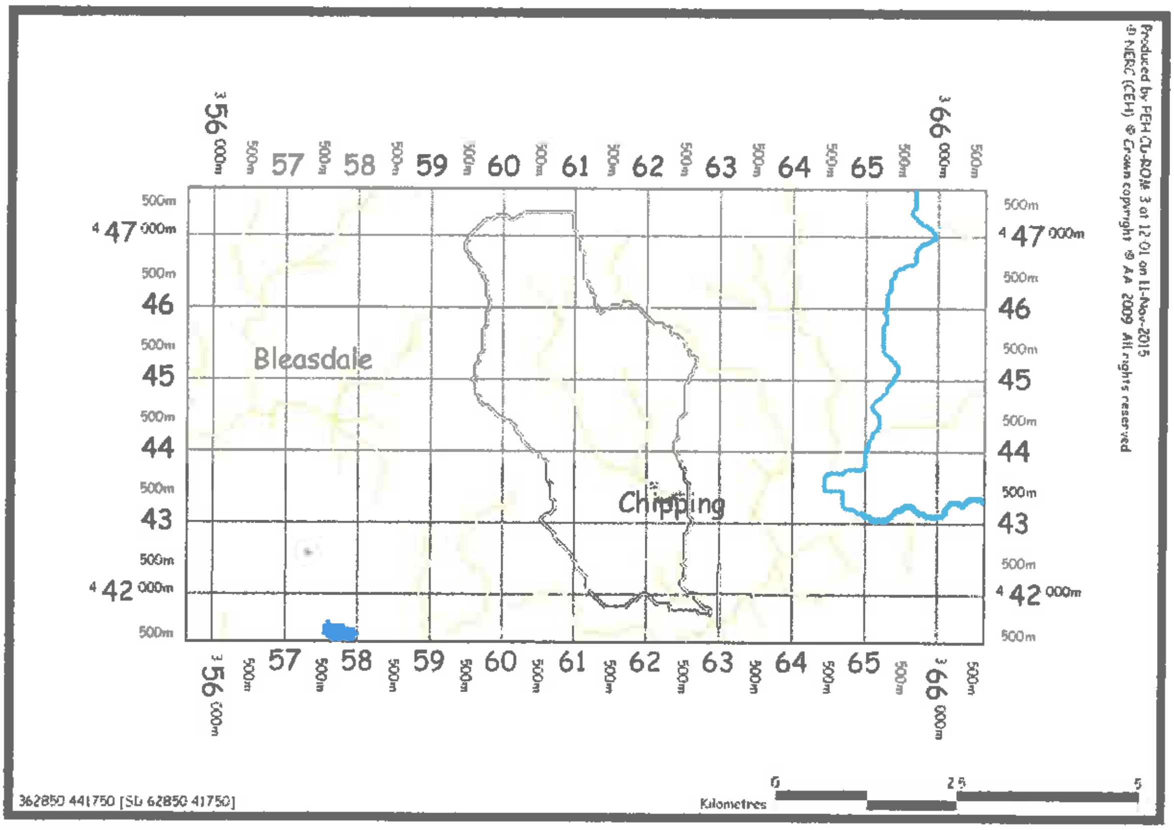
Site code	Flood peak (m^3/s) for the following return periods (in years)					
	5	10	20	50	100	100+20%cc
CB01	15.9	18.9	22.2	27.3	31.8	38.2
CB02	18.5	22.0	25.9	31.8	37.1	44.6
TRIB	3.8	4.5	5.2	6.4	7.5	9.0

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	

7 Annex - supporting information

7.1 Pooling group composition

Location of CB_02 Catchment



Pooling Group – AM Data Table

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
25003 (Trout Beck @ Moor House)	0.433	39	15.164	0.176	0.291	0.630
206006 (Annalong @ Recorder)	0.532	48	15.330	0.189	0.052	2.063
25011 (Langdon Beck @ Langdon)	0.533	26	15.878	0.241	0.326	0.833
28033 (Dove @ Hollinsclough)	0.725	33	4.666	0.266	0.415	0.905
45816 (Haddeo @ Upton)	0.927	19	3.456	0.324	0.434	0.732
49003 (de Lank @ de Lank)	0.982	46	13.559	0.232	0.241	0.161
51002 (Horner Water @ West Luccombe)	1.070	31	8.354	0.382	0.326	1.401
27032 (Hebden Beck @ Hebden)	1.085	46	4.082	0.211	0.258	0.368
48009 (st Neot @ Craigshill Wood)	1.117	12	8.469	-0.245	-0.373	3.614
46005 (East Dart @ Bellever)	1.176	48	38.510	0.162	0.082	0.935
25012 (Harwood Beck @ Harwood)	1.209	43	33.265	0.189	0.251	0.902
48004 (Warleggan @ Trengoffe)	1.222	43	9.799	0.268	0.287	0.589
27010 (Hodge Beck @ Bransdale Weir)	1.261	41	9.420	0.224	0.293	0.179
27051 (Crimple @ Burn Bridge)	1.281	40	4.539	0.222	0.149	0.687
Total		515				
Weighted means				0.208	0.228	

Pooling Group - Catchment Descriptors

Station	Distance SDM	AREA	SAAR	FPEXT	FARL	URBEXT 2000
25003 (Trout Beck @ Moor House)	0.433	11.460	1904	0.041	1.000	0.000
206006 (Annalong @ Recorder)	0.532	13.660	1720	0.024	0.980	0.000
25011 (Langdon Beck @ Langdon)	0.533	12.790	1463	0.013	1.000	0.001
28033 (Dove @ Hollinsclough)	0.725	7.930	1346	0.007	1.000	0.000
45816 (Haddeo @ Upton)	0.927	6.810	1210	0.011	1.000	0.005
49003 (de Lank @ de Lank)	0.982	21.610	1628	0.064	0.998	0.000
51002 (Horner Water @ West Luccombe)	1.070	20.380	1485	0.003	0.978	0.000
27032 (Hebden Beck @ Hebden)	1.085	22.200	1433	0.021	0.997	0.000
48009 (st Neot @ Craigshill Wood)	1.117	22.910	1512	0.022	0.982	0.002
46005 (East Dart @ Bellever)	1.176	22.270	2095	0.042	1.000	0.000
25012 (Harwood Beck @ Harwood)	1.209	24.580	1577	0.021	1.000	0.000
48004 (Warleggan @ Trengoffe)	1.222	25.260	1445	0.035	0.978	0.003
27010 (Hodge Beck @ Bransdale Weir)	1.261	18.840	987	0.009	1.000	0.001
27051 (Crimple @ Burn Bridge)	1.281	8.150	855	0.013	1.000	0.006