Bradford Beck Hydraulic Modelling Report



SWECO

Ver	Date	Description of the change
01	24/01/2025	For Review and Comment
02	23/04/2025	For Review and Comment
03	01/06/25	Draft
04	05/07/25	Draft
05	22/07/25	For EA Review
06	27/10/2025	For EA Review
07	19/12/2025	For EA Review
08	05/03/2026	Issue to CBMDC

Sweco UK Limited	2888385
Project Name	Bradford Beck Hydraulic Modelling
Project Number	65206733
Client	City of Bradford Metropolitan District Council
Date	2023-08-10
Document reference	Bradford Beck Hydraulic Modelling Report v08

Executive Summary

City of Bradford Metropolitan District Council commissioned Sweco UK Ltd to undertake fluvial modelling of the Bradford Beck to gain an updated understanding of the present day and future flood risk.

The works undertaken for this fluvial flood risk investigation comprise:

- Modelling a baseline scenario for the whole catchment with all key hydraulic structures included.
- Using the most up to date hydrology to accurately assess the current and potential flood risk from fluvial flooding including the impact of climate change.
- Inclusion of up to date survey of key structures and sections of watercourse.
- Modelling of a range of design events with the inclusion of predicted impacts of climate change.
- Modelling of sensitivity tests to understand the impact of minor changes to the model.

Glossary

Term	Definition
Annual Exceedance Probability	Annual Exceedance Probability (AEP) represented as a % (e.g. 1 in 100 year flood event = 1% AEP, a 1% change of that flood event happening in a given year)
Areal Reduction Factor	The Areal Reduction Factor (ARF) is the ratio of the rainfall depth over an area to the rainfall depth of the same duration and return period at a representative point in the area.
Climate Change	Long term variations in global temperature and weather patterns caused by natural and human actions.
Culvert	A channel or pipe that carries water below the level of the ground.
Digital Elevation Model	Digital Elevation Model (DEM): a topographic model consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. DEM is often used as a global term to describe DSMs (Digital Surface Model) and DTMs (Digital Terrain Models).
Department of Environment, Food and Rural Affairs	UK government department responsible for natural environment, food, farming and rural economies. Defra is the principal sponsoring department of the Environment Agency.
Depth-duration-frequency curves	Depth-duration-frequency (DDF) curves describe rainfall depth as a function of duration for given return periods
Depth Discharge Curve	The relationship between depth over a gully pot to discharge into the sewer network.
Depth to Groundwater	Depth to Groundwater (dGW)
Digital Surface Model	Digital Surface Model (DSM): a topographic model of the bare earth/underlying terrain of the earth's surface including objects such as vegetation and buildings.
Digital Terrain Model	Digital Terrain Model (DTM): a topographic model of the bare earth/underlying terrain of the earth's surface excluding objects such as vegetation and buildings. DTMs are usually derived from DSMs.
Environment Agency	Environment Agency, Government Agency reporting to DEFRA charged with protecting the environment and managing flood risk in England.
Flood defence	Mitigations measures to protect an area against flood risk. These include hard (i.e. flood walls and embankments) solutions and soft (i.e. catchment/ land management) solutions.
Flood Estimation Handbook	The Flood Estimation Handbook (FEH) and its related software offer guidance on rainfall and river flood frequency estimation in the UK. Flood frequency estimates are required for the planning and assessment of flood defences, and the design of other structures such as bridges, culverts and reservoir spillways
Hyetograph	A graphical representation of the variation of rainfall depth or intensity with time.
Integrated Urban Drainage	Integrated Urban Drainage (IUD); a concept which aims to integrate different methods and techniques, including sustainable drainage, to effectively manage surface water within the urban environment.

Term	Definition
Lead Local Flood Authority	A Lead Local Flood Authority (LLFA) is a Local Authority responsible for taking the lead on local flood risk management. The duties of LLFAs are set out in the Floods and Water Management Act.
LiDAR	Light Detection And Ranging, a technique to measure ground and building levels remotely from the air, LiDAR data is used to develop DTMs and DEMs (see definitions above).
Flood Defence Grant in Aid	The funding from central government for managing flood risk in England is known as Flood Defence Grant in Aid or FDGiA.
Main River	Main rivers are a statutory type of watercourse in England and Wales, usually larger streams and rivers, but also include some smaller watercourses. A main river is defined as a watercourse marked as such on a main river map and can include any structure or appliance for controlling or regulating the flow of water in, into or out of a main river. The Environment Agency's powers to carry out flood defence works apply to main rivers only.
Partner	A person or organisation with responsibility for the decision or actions that need to be taken.
Risk	In flood risk management, risk is defined as a product of the probability or likelihood of a flood occurring, combined with the consequence of the flood.
Risk of Flooding from Surface Water	Risk of Flooding from Surface Water (RoFfSW) is a national map produced in 2013 showing the risk of flooding from surface water.
Standard Average Annual Rainfall	Average annual rainfall in the standard period (1961-1990) in millimetres.
Seasonal Correction Factor	Seasonal Correction Factor (SCF); Transforms annual maximum rainfall to seasonal maximum rainfall.
Surface Water Flooding	Surface water flooding happens when rainwater does not drain away through the normal drainage systems or soak into the ground, but lies on or flows over the ground instead.
Sewer flooding	Flooding caused by a blockage or overflowing in a sewer or urban drainage system.
Stakeholder	A person or organisation affected by the problem or solution, or interested in the problem or solution. They can be individuals or organisations, includes the public and communities.

Table of contents

Executive Summary 3
Glossary 4
1 Introduction 10
1.1 General 10
1.2 Study Area 10
1.3 Previous studies 12
1.4 Historic flood information 13

2 Hydraulic model build 15
2.1 Software selection 15
2.2 Existing Model Data 15
2.3 Climate Change 16
2.4 Model Simulation 16
2.5 Model Extent 17
2.6 Cell Size 17
2.7 Topography 19
2.7.1 Topographic Modifications 19
2.7.2 Building Representation 20
2.7.3 Survey 20
2.8 West Brook Catchment 23
2.9 Outflow 28
2.10 Channel Representation 29
2.11 Model Roughness 29
2.12 1D structures 31
2.12.1 Culvert Roughness 33
2.12.2 1d to 2d connections 34
2.13 Inflows 34

3 Baseline model results 37
3.1 Baseline model results 37
3.2 Validation 47
3.2.1 Flood Extent Comparison 47
3.2.2 Flow Reconciliation 49
3.3 Model Health 50
3.3.1 Timestep 50
3.3.2 Model checks & warnings 51
3.3.3 Time to Max Depth 54
3.3.4 Mass Balance 55
3.3.5 Negative Depths 56
3.3.6 Nu Output 56
3.4 Sensitivity Analysis 57

4 Assumptions & Limitations 62
5 Conclusion 63

Table of Figures

Figure 1-1 – Bradford Beck Catchment with Environment Agency Detailed River Network ..11
Figure 1-2 - Previous Modelling Results ..12
Figure 1-3 – Environment Agency Flood Risk from Rivers and Sea Risk Map ..13
Figure 1-4 – EA Historic flood map ..14
Figure 2-1 – Supplied culvert data used within model. ..16
Figure 2-2 – Bradford Beck Hydraulic Model Extent ..17
Figure 2-3 – Grid Check File showing Flexible Mesh. ..18
Figure 2-4- Flexible mesh grid with Nesting Layer. ..18
Figure 2-5 – Bradford Beck Catchment Topography ..19
Figure 2-6 – OS MasterMap Buildings ..20
Figure 2-7 – Survey Location 1 ..21
Figure 2-8 – Survey Location 2 ..21
Figure 2-9 – Survey Location 3 ..22
Figure 2-10 – Survey Location 4 ..22
Figure 2-11 – Survey Locations 5 ..23
Figure 2-12: Survey Locations 6 ..23
Figure 2-13 – West Brook Open Channel Sections ..24
Figure 2-14 – West Brook channel looking south west (October 2025) ..25
Figure 2-15 – West Brook Channel looking north west (October 2025) ..26
Figure 2-16 – Topographic survey of West Brook adjacent to Tumbling Mill Street, Planning application 07/02743/REM ..27
Figure 2-17 – Extract of West Brook Open channel section at confluence with Bradford Beck, Plan SE1533, 1957 ..27
Figure 2-18 – Downstream Boundary Location ..28
Figure 2-19 – Land Cover Classifications across the Bradford Beck catchment ..30
Figure 2-20 – Land Cover classification areas surrounding Middlebrook and Bradford Beck31
Figure 2-21 – All Modelled Culverts ..32
Figure 2-22 – Upper Catchment Culvert Locations ..32
Figure 2-23 – Downstream Culvert Locations ..33
Figure 2-24 – Structure 8 Photograph ..34
Figure 2-25 – Structure 17 Survey Photograph ..34
Figure 2-26 – Bradford Beck catchments ..35
Figure 2-27 – Locations of 1d inflows. ..36
Figure 3-1 - 1% AEP + Higher Climate Change Maximum Depth Results Full Catchment ...37
Figure 3-2 – 1% AEP Maximum Depth Results Full Catchment ..38
Figure 3-3 – 3.33% AEP Maximum Depth Results Full Catchment ..38
Figure 3-4 – 1% AEP + Climate Change Maximum Depth Results, Western Catchment ..39
Figure 3-5 - 1% AEP + Higher Climate Change Maximum Depth Results, Central Catchment ..40
Figure 3-6 – 1% AEP + Higher Climate Change Maximum Depth Results, West Brook Catchment ..41
Figure 3-7 – Flows upstream of Bradford Beck flood relief tunnel ..42
Figure 3-8 – Bradford Beck flood relief tunnel flow ..42
Figure 3-9 – Flows immediately downstream of flood relief tunnel junction ..43
Figure 3-10 - 1% AEP + Higher Climate Change Maximum Depth Results, Northern Catchment ..44
Figure 3-11 – Bradford Beck at Polar Road ..44
Figure 3-12 - 1% AEP + Higher Climate Change Maximum Velocity Results, Full Catchment ..45
Figure 3-13 - 1% AEP + Higher Climate Change Maximum Velocity Results, Full Catchment ..46

Figure 3-14 - 1% AEP + Higher Climate Change Maximum Hazard Results, Full Catchment 46
Figure 3-15 - 1% AEP + Higher Climate Change Higher Maximum Hazard Results, Zoom..47
Figure 3-16 – 0.1% AEP Comparison to Flood Zone 2 48
Figure 3-17 – 1% AEP Comparison to Flood Zone 3 48
Figure 3-18 – Reporting Line 30 Location 49
Figure 3-19 - Reporting Line 30 Flow 49
Figure 3-20 Timestep in 1% AEP simulation 50
Figure 3-21 – Timestep (dt) map 51
Figure 3-22 – Time to Maximum, 1% AEP + Climate Change Scenario 55
Figure 3-23 – Cumulative Mass Error , 1% AEP 55
Figure 3-24, dvol Output, 1% AEP 56
Figure 3-25 – Nu Output, 1% AEP 57
Figure 3-26 – Downstream Boundary Sensitivity Test, 1% AEP. 58
Figure 3-27 – Downstream boundary sensitivity test, downstream area results. 58
Figure 3-28 – 20% Roughness Increase Sensitivity Test, 1% AEP 59
Figure 3-29 - 20% Roughness Increase Sensitivity Test, 1% AEP 60
Figure 3-30 - 50% Culvert Blockage Sensitivity Test, 1% AEP 60
Figure 3-31 – 20% decrease in inflows 61
Figure 3-32 – 20% Increase in inflows 61

1 Introduction

1.1 General

Sweco UK Ltd has been commissioned by the City of Bradford Metropolitan Borough Council (CBMDC) to update the Bradford Beck hydraulic model. The Bradford Beck has a documented history of flooding supported by both reported incidents and anecdotal evidence. Sweco were tasked with developing a fluvial hydraulic model to evaluate flood risk for a range of design flood events. The outputs of this study will inform the Bradford Strategic Flood Risk Assessment (SFRA).

1.2 Study Area

The Bradford Beck is a heavily culverted watercourse that flows through Bradford city centre. A map of the catchment with the Environment Agency Detailed River Network dataset indicating the location of watercourses and structures is shown in Figure 1-1. Much of the Bradford Beck was culverted during the industrial revolution in the 19th century. Its headwaters are more rural in nature and are located to the west of the Bradford urban area. Downstream of the city centre, it flows through a channelised open section before discharging into the River Aire at Shipley.

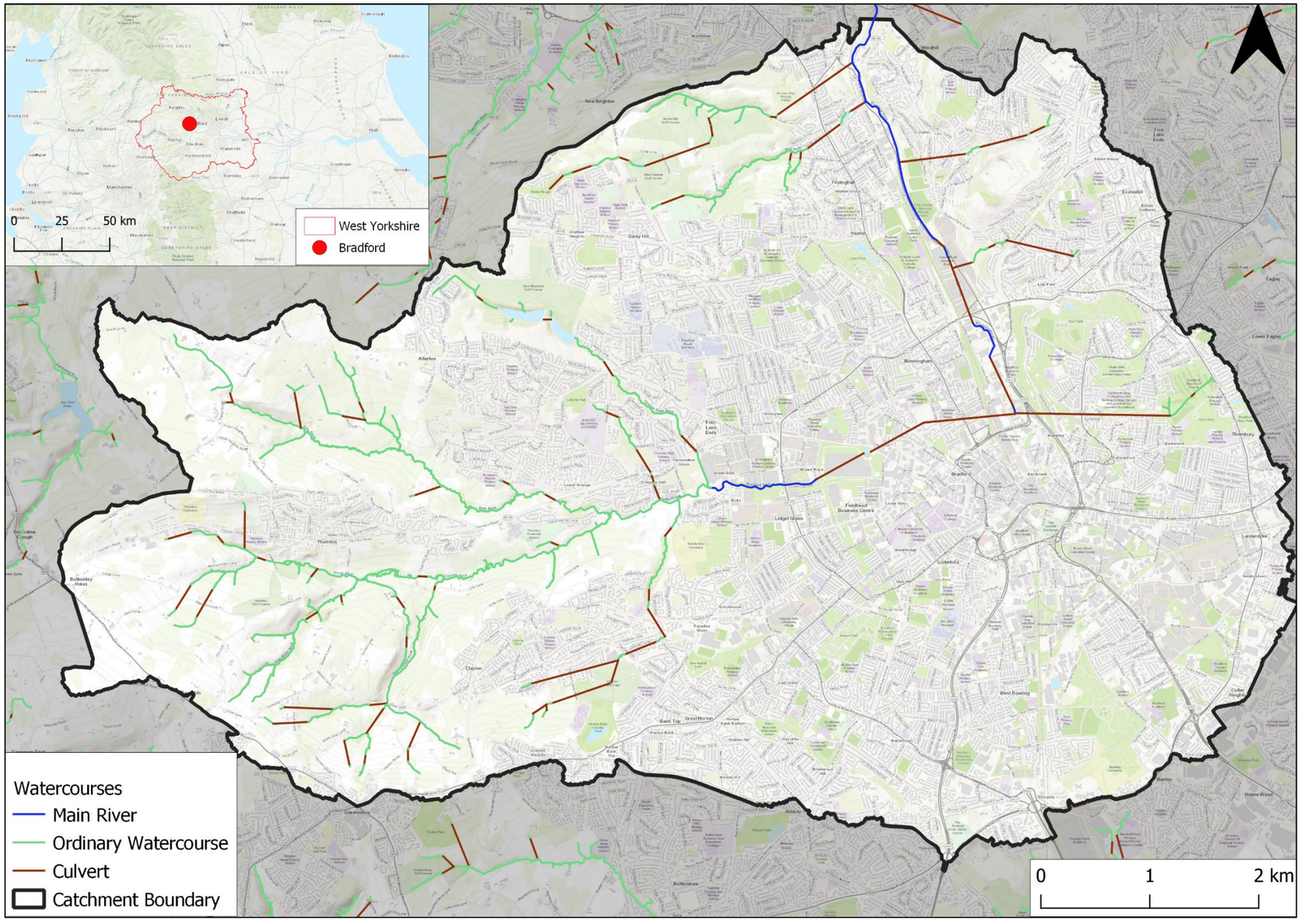


Figure 1-1 – Bradford Beck Catchment with Environment Agency Detailed River Network

1.3 Previous studies

A previous hydraulic model was undertaken by The University of Sheffield and the Pennine Water Group in October 2013[1]. The purpose of the previous modelling study was to update the Environment Agency flood maps which had been available since 2001. The hydraulic model was built using the Infoworks CS modelling package, which has since been replaced by Infoworks ICM. Results of the hydraulic model are shown in Figure 1-2. They show that the areas of greatest flood risk in the 5% Annual Exceedance Probability (AEP) event are generally in the upper catchment with some small areas in the centre. There are large areas of flooding following the course of the Beck predicted in the 0.1% AEP event. These results are comparable to the Environment Agency Risk of Flooding from Rivers and Sea[2] mapping shown in Figure 1-3.

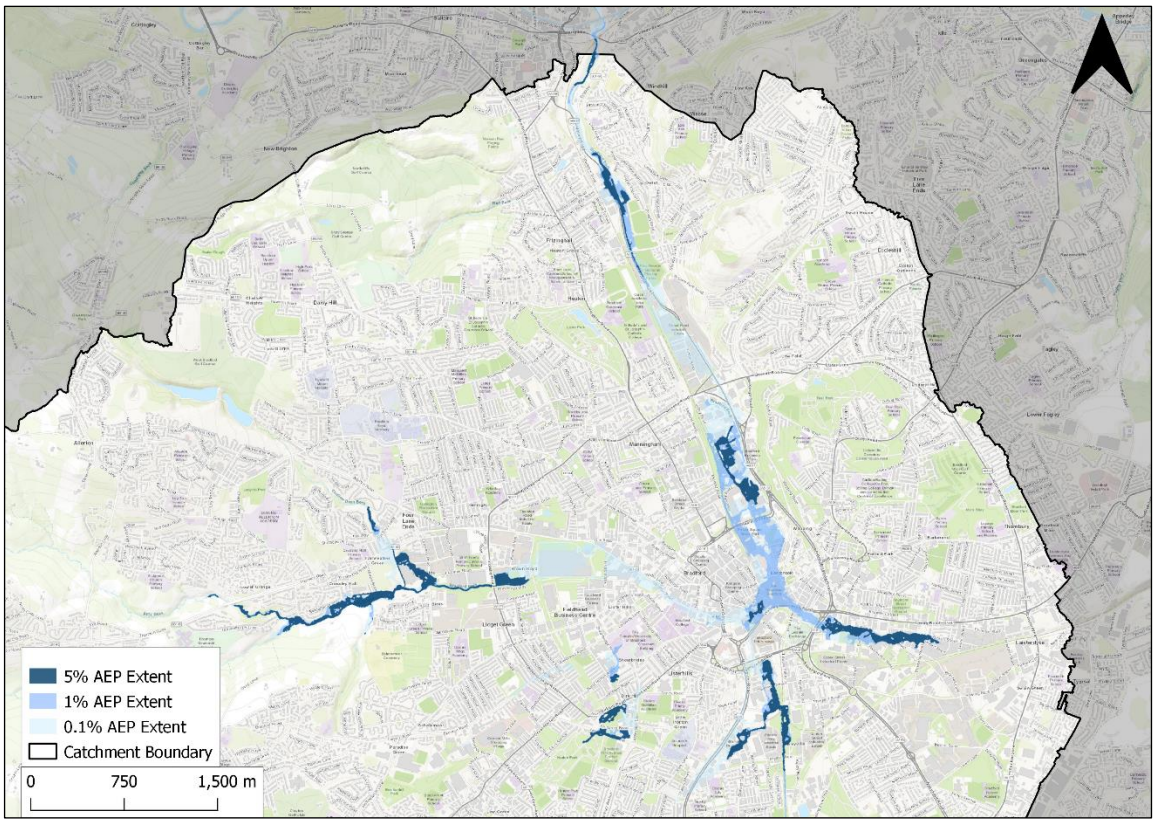


Figure 1-2 - Previous Modelling Results

[1] Bradford Beck Flood Modelling Developing an InfoWorks CS Model, The University of Sheffield, Pennine Water Group, October 2013

[2] Risk of Flooding from Rivers and Sea

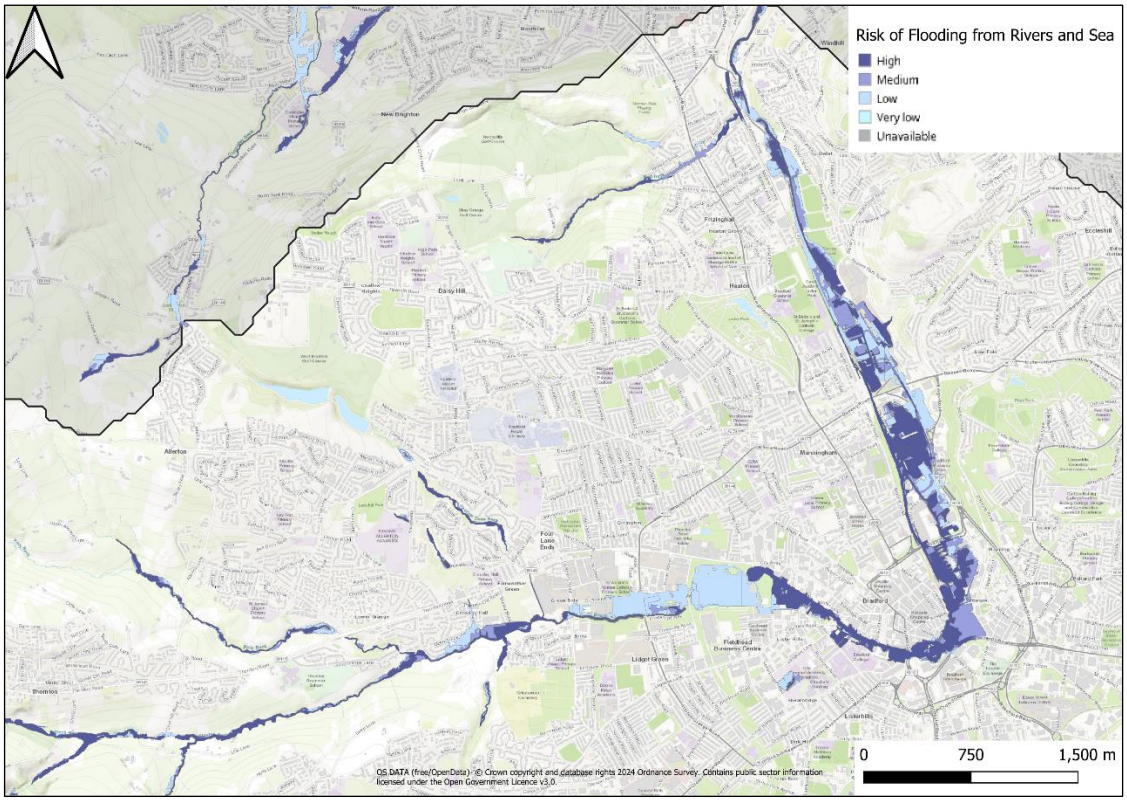


Figure 1-3 – Environment Agency Flood Risk from Rivers and Sea Risk Map

1.4 Historic flood information

The Environment Agency (EA) historic flood mapping[3] shows that there have not been any significant fluvial flood events recorded in the Bradford Beck catchment (Figure 1-4). The historical floods shown are primarily along the River Aire which is located downstream of the Bradford Beck. It is likely flood events may have not been added along sections for the Bradford Beck as the majority is not defined as a main river.

[3] Historic Flood Map - data.gov.uk

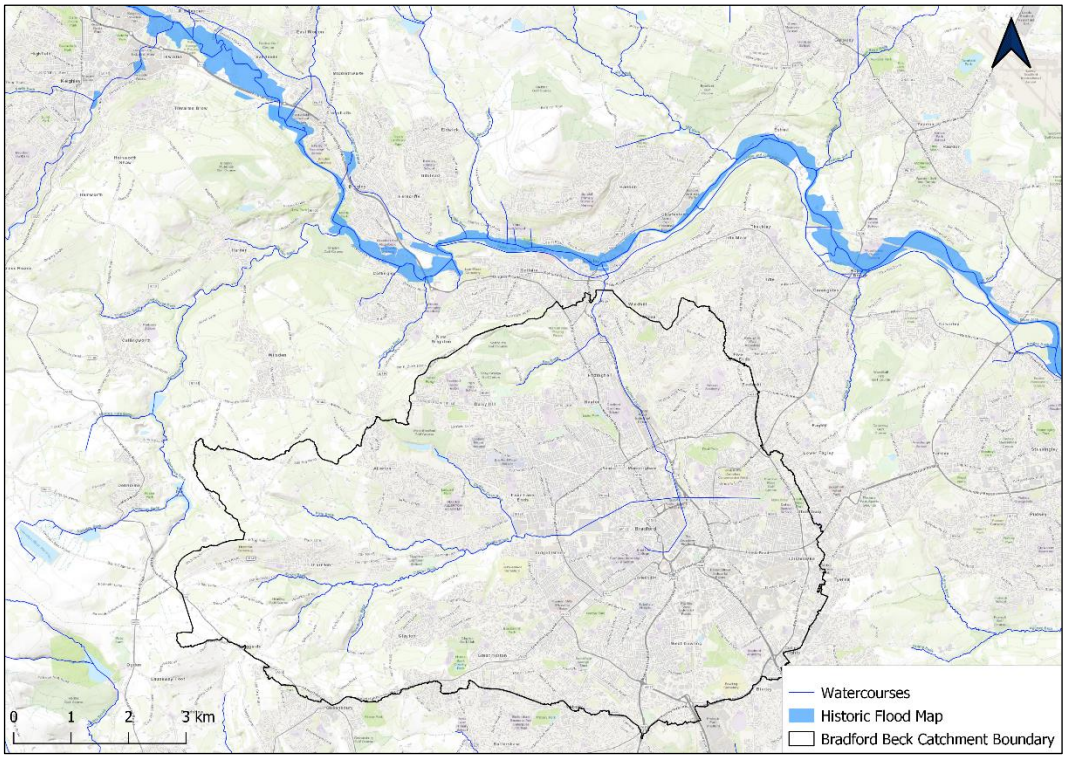


Figure 1-4 – EA Historic flood map

2 Hydraulic model build

This section describes the process undertaken to build the hydraulic model to assess fluvial flooding mechanisms in line with the latest modelling guidance[4].

2.1 Software selection

TUFLOW Heavily Parallelised Compute (HPC) was selected to undertake the Bradford Beck fluvial flood risk study based on the Infoworks CS package being discontinued combined with Sweco's knowledge of the software. The latest available version has been used (2025.0.0-iSP-w64).

TUFLOW HPC uses the power of Graphical Processing Units (GPU) and can simulate large models at a high resolution with improved simulation times. It is therefore suitable for assessing fluvial flood risk in urbanised areas where micro-topographic features influence flooding mechanisms.

The TUFLOW suite of products were benchmarked by the EA in 2010 and 2013. It represents industry standard software and is determined to be suitable for assessing fluvial water flood risk.

The use of TUFLOW also enabled the use of Sub Grid Sampling and Quadtree within the model build. Further details on these elements are provided in Section 2.6.

2.2 Existing Model Data

To minimise data collection costs and timescales, the data from the previous modelling study completed by Sheffield University in 2013 has been used to inform inverts and sizes of culverts. The culverts which have been retained from this study for use within this updated model are shown in Figure 2-1. These culverts are generally within the centre of Bradford where there are unlikely to have been changes made to the dimensions/inverts since the previous model was completed.

[4] River modelling: technical standards and assessment - GOV.UK

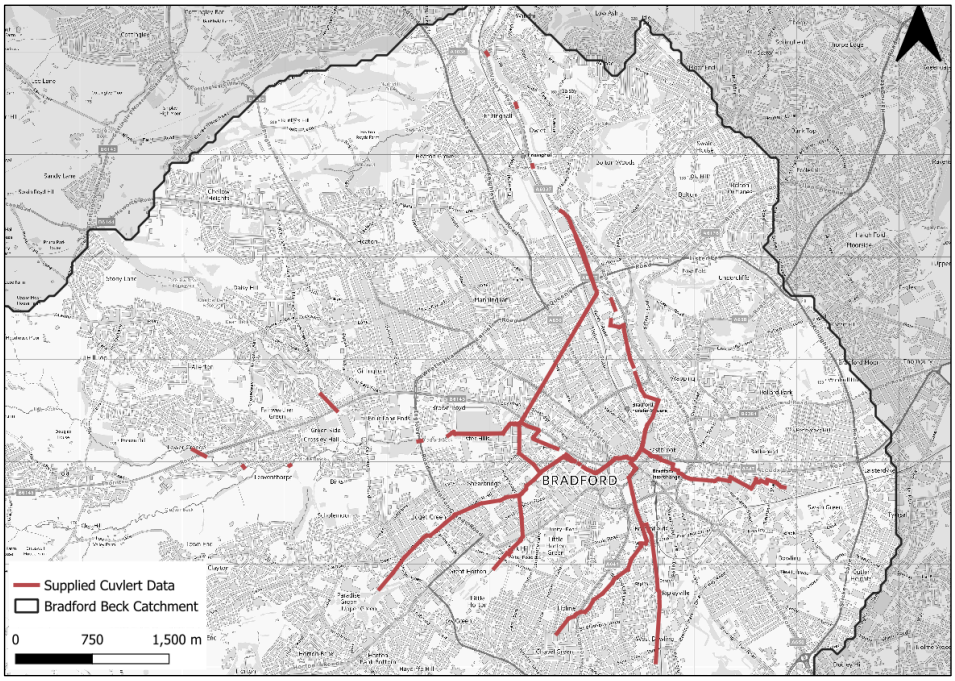


Figure 2-1 – Supplied culvert data used within model.

2.3 Climate Change

The latest Environment Agency guidance on climate change allowances for peak river flows was used to inform the climate change uplifts used.

The Central (23%) and Higher (31%) peak flow allowances for the Aire and Calder Management Catchment for the years 2070 to 2115 were applied to the 1 in 2 year, 1 in 20 year and 1 in 100 year event [5]. This was agreed with CBMDC at the project outset to aid with their SFRA requirements.

2.4 Model Simulation

The model was simulated for the following Annual Exceedance Probability (AEP) events to understand flood extents surrounding the Bradford Beck:

- 1 in 2 Year - 50% AEP
- 1 in 5 Year - 20% AEP
- 1 in 10 Year – 10% AEP
- 1 in 20 Year – 5% AEP
- 1 in 20 Year – 5% AEP + Climate Change Central
- 1 in 20 Year – 5% AEP + Climate Change Higher
- 1 in 30 Year - 3.33% AEP
- 1 in 75 Year – 1.33% AEP
- 1 in 100 Year – 1% AEP
- 1 in 100 Year – 1% AEP + Climate Change Central
- 1 in 100 Year – 1% AEP + Climate Change Higher
- 1 in 200 Year – 0.5% AEP
- 1 in 1000 Year – 0.1% AEP
- 1 in 1000 Year – 0.1% AEP + Climate Change Central

[5] Climate change allowances for peak river flow

- 1 in 1000 Year – 0.1% AEP + Climate Change Higher

2.5 Model Extent

A GIS analysis of the 1m Environment Agency National LiDAR Programme[6] Digital Terrain Model (DTM) was undertaken to determine the catchment of the Bradford Beck. After reviewing the initial model simulation, the boundary was refined to only include areas within or adjacent to the potential floodplain. The hydraulic model extent (2d_code) is shown within Figure 2-2. The model has incorporated the floodplain surrounding the Bradford Beck as well as its main tributaries including the Clayton and Pitty Beck in the headwaters of the catchment.

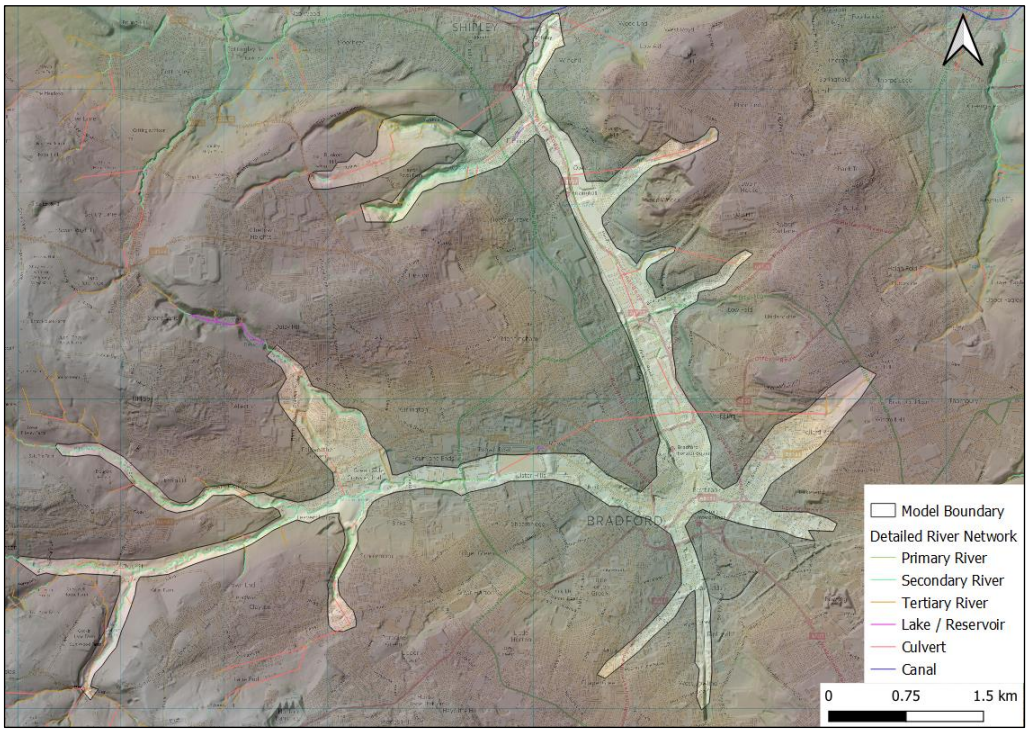


Figure 2-2 – Bradford Beck Hydraulic Model Extent

2.6 Cell Size

The flood hazard predictions in urban environments with complex flow paths can be sensitive to model grid resolution. Three to five grid cells are typically required across key flow paths to provide suitable representation of hydraulic features.

The model has benefitted from the use of Quadtree and Sub Grid Sampling to 1m to increase model resolution without extensive increase to simulation times. Quadtree enables a flexible mesh to be used so areas of higher importance can be simulated with a lower cell size. In this case the Bradford Beck channel has been modelled with a 1m cell size. The surrounding floodplain has a base 4m cell size but benefits from 1m Sub Grid Sampling which allows the underlying

[6] National LIDAR Programme

DTM to be sampled. The flexible mesh is shown in more detail in Figure 2-3 and Figure 2-4.

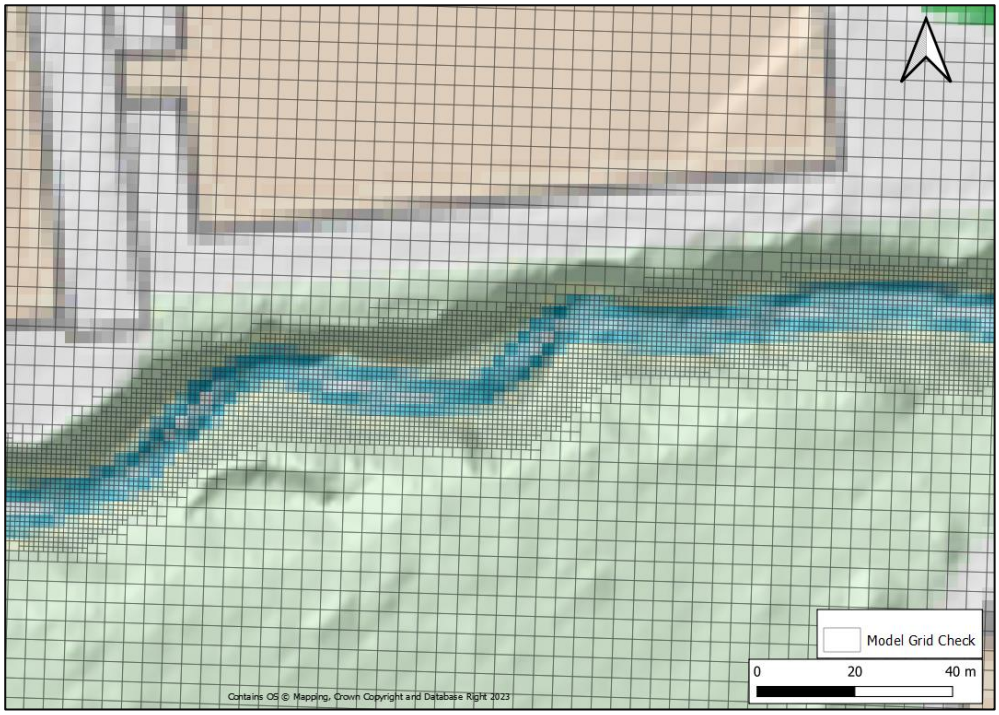


Figure 2-3 – Grid Check File showing Flexible Mesh.

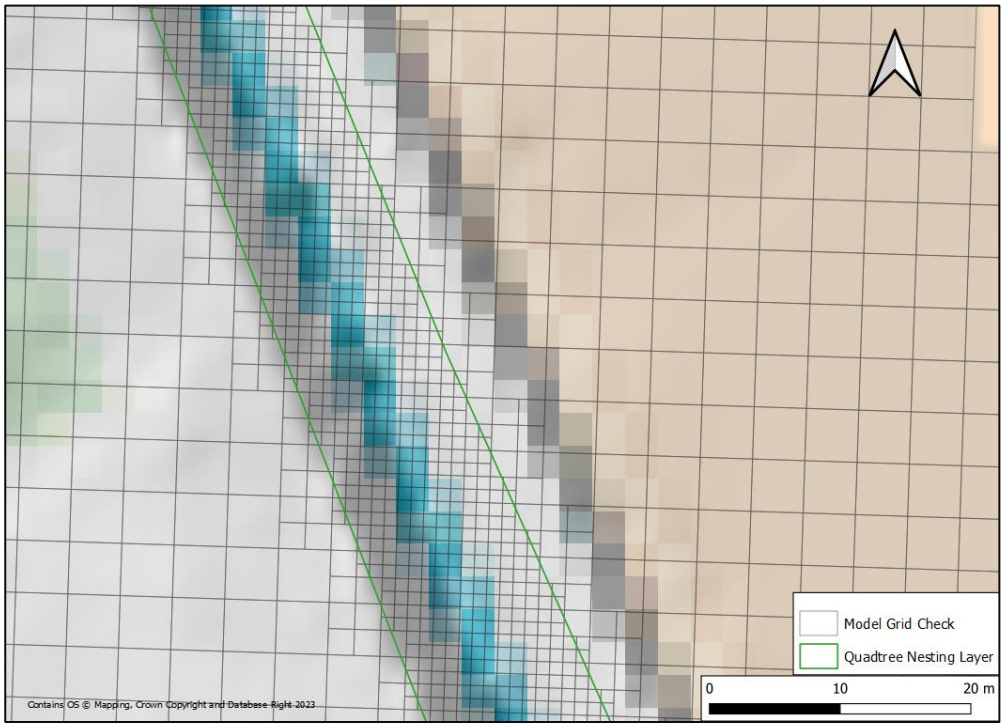


Figure 2-4- Flexible mesh grid with Nesting Layer.

2.7 Topography

The 2D model component requires representation of the underlying topographic surface from a DTM The accuracy of the ground model is therefore very important as it used to enable accurate derivation of flood depths and flow routing over the 2D model domain.

The elevations across the Bradford Beck catchment are shown in Figure 2-5. The areas with the highest elevations are to the west of the catchment, in places the elevation is up to 400mAOD. The Bradford Beck and its tributaries can be seen from the depression through the catchment, in a west to east direction then turning northwards after flowing through Bradford city centre. The lowest point of the catchment is where the Bradford Beck discharges into the Aire at Shipley which lies at around 95mAOD. The dataset shown in the figure and used within the model is the 1m Environment Agency National LiDAR Programme DTM flown in 2022[6].

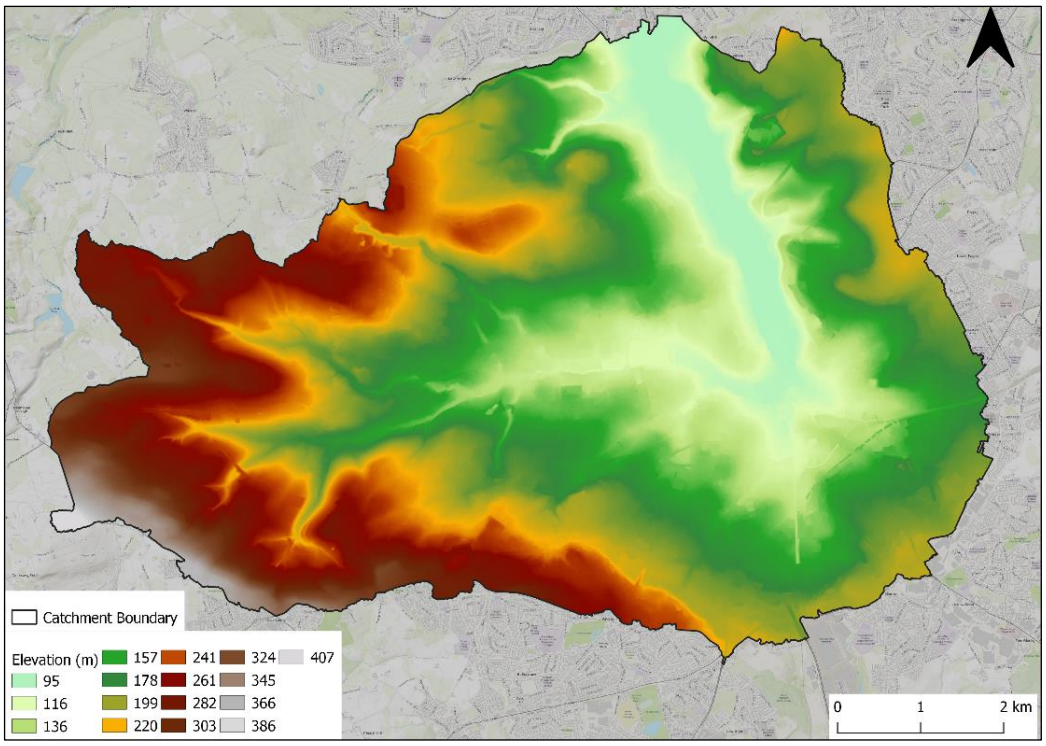


Figure 2-5 – Bradford Beck Catchment Topography

2.7.1 Topographic Modifications

Modifications have been made to the base DTM to better represent the complex nature of the topography surrounding the Bradford Beck. Examples of this are enforcing of road decks in locations where the watercourse flows beneath roads and the DTM does not represent accurately. Sections of the channel have also been cut through in the upper catchment to ensure water is able to pass through. This generally happens in areas where there is dense vegetation, and the channel is relatively narrow meaning the LiDAR may struggle to pick up the channel in detail.

2.7.2 Building Representation

Buildings have been represented in the model with depth varying roughness. Location of buildings has been taken from the Ordnance Survey MasterMap (OSMM) data (Figure 2-6). A depth varying Mannings n coefficient was applied to buildings between 0.15 and 0.5. The coefficient value is increased at greater depths to represent the likelihood of water to pond within buildings.

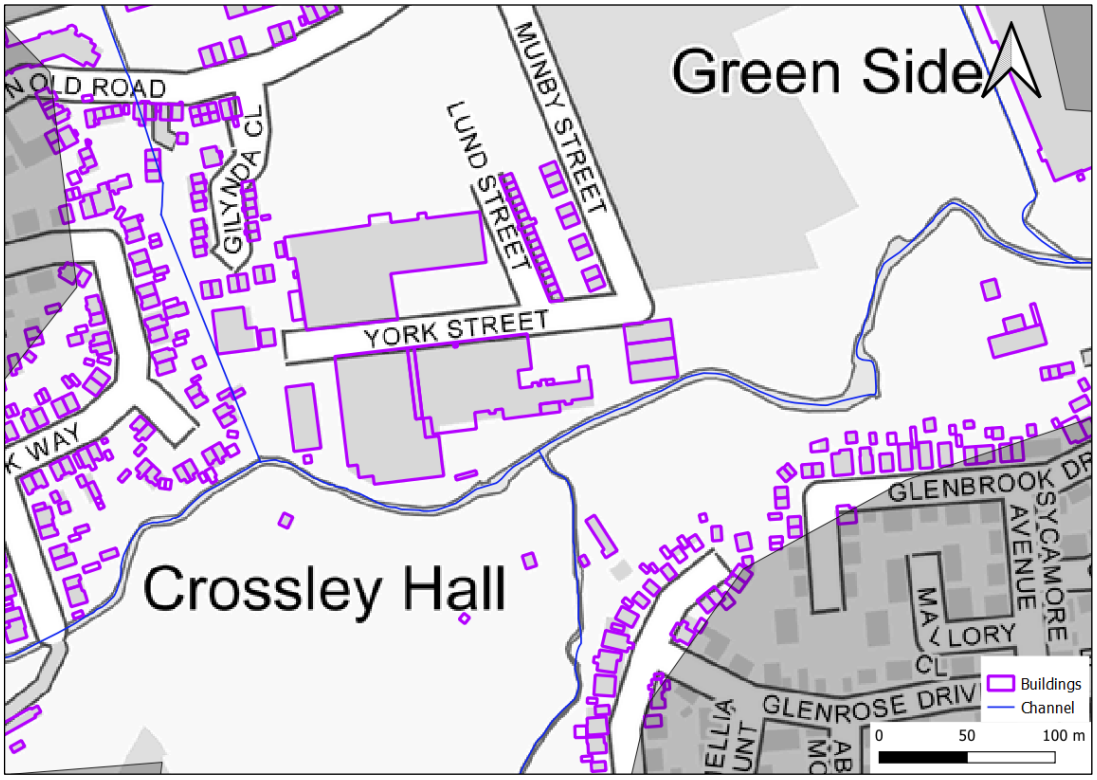


Figure 2-6 – OS MasterMap Buildings

2.7.3 Survey

Survey data was acquired for use within the hydraulic model. Not all survey data requested was able to be collected due to issues with access to the channel or structures. The locations where survey was received is shown within Figure 2-7 and Figure 2-8.

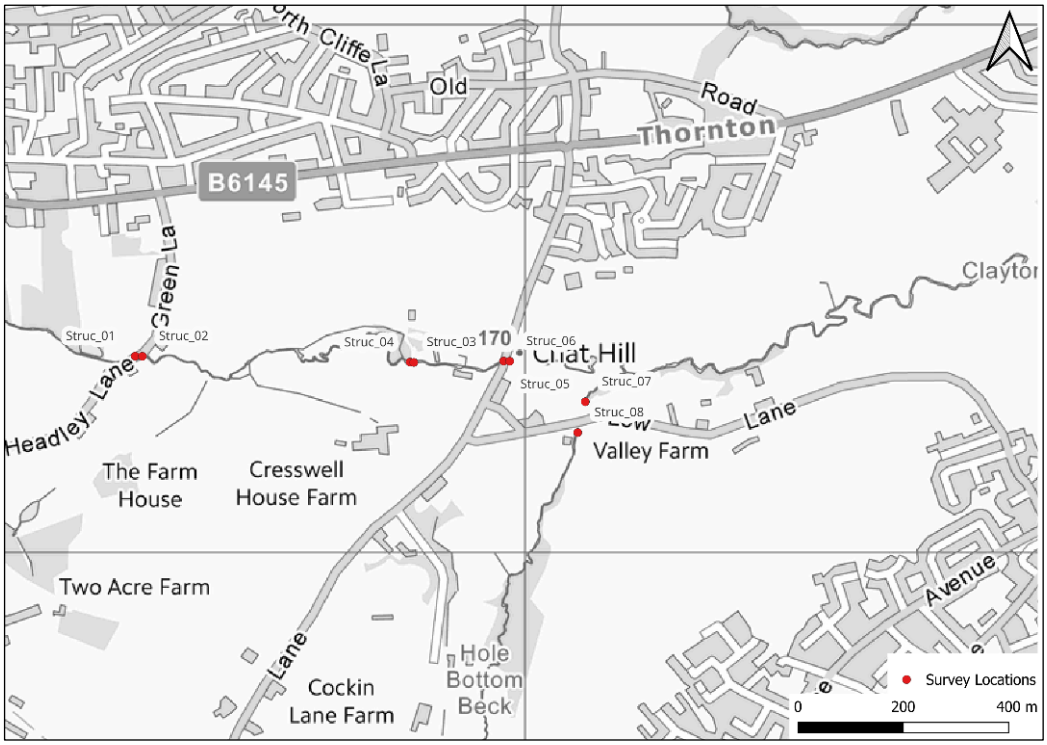


Figure 2-7 – Survey Location 1



Figure 2-8 – Survey Location 2



Figure 2-9 – Survey Location 3

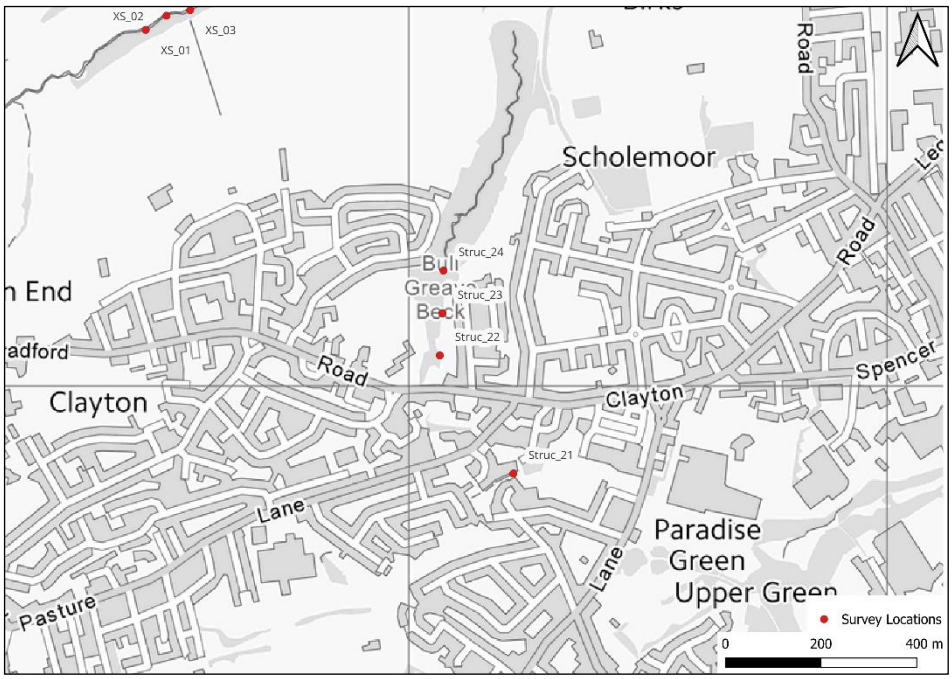


Figure 2-10 – Survey Location 4

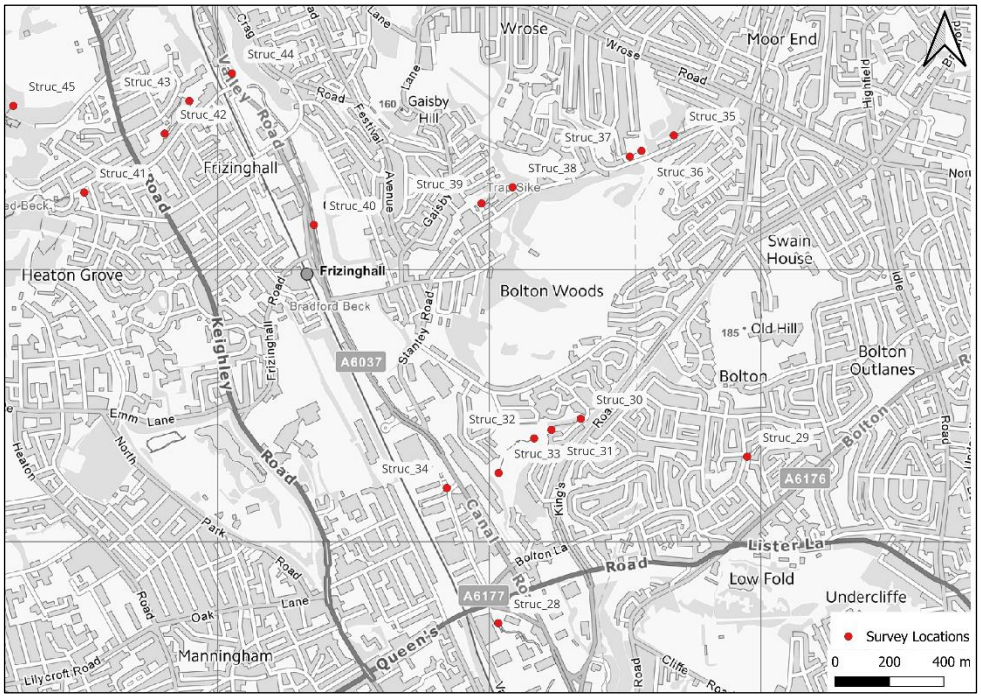


Figure 2-11 – Survey Locations 5

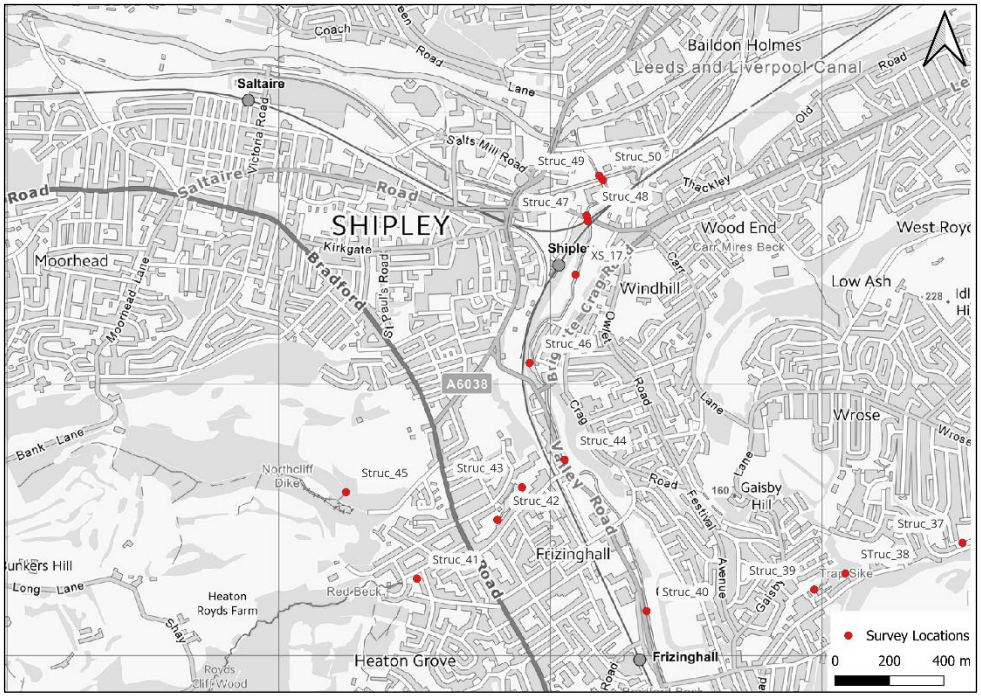


Figure 2-12: Survey Locations 6

2.8 West Brook Catchment

The West Brook is an ordinary watercourse to the south west of Bradford city centre. It is primarily culverted but has three short sections of open channel before it enters the Bradford Beck south of Thornton Road (Figure 2-13).

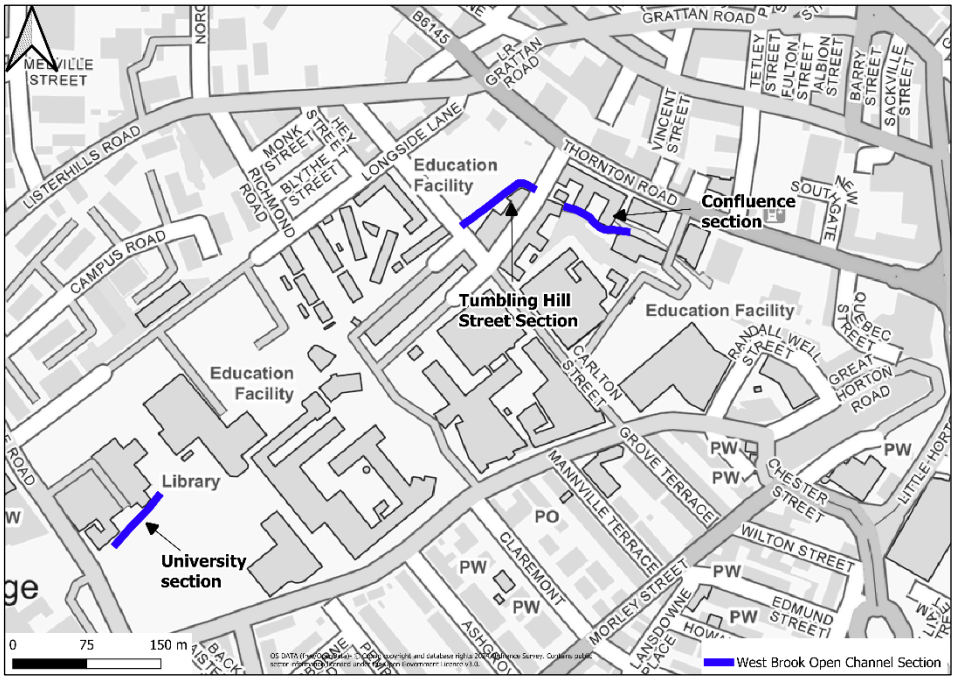


Figure 2-13 – West Brook Open Channel Sections

Following the publication of the updated Flood Maps as a result of the National Flood Risk Assessment 2, the Environment Agency requested that the West Brook watercourse was better represented in the model.

To aid this, a site visit was conducted in October 2025 to assess the condition of the watercourse and obtain measurements of the dimensions of the open channel section in the University of Bradford grounds. The open channel is located to the south west of the Pheonix Building (Figure 2-14 and Figure 2-15). The measurements taken on the site visit were added to the hydraulic model as 2d Z lines, the metal bars have not been represented as it is assumed it is unlikely they will have impact on water leaving the channel. It was estimated the average depth of the channel along this stretch is 1.6m, with a width of 2m. A 2d Z line has been added to this section to reduce the LiDAR elevations by 1.1m, this is because the underlying LiDAR already has a depression at the channel location of approximately 0.5m. Access to the other two sections of open channel was not possible, therefore dimensions of this section have been estimated as described below.



Figure 2-14 – West Brook channel looking south west (October 2025)



Figure 2-15 – West Brook Channel looking north west (October 2025)

The locations of the other two open channel sections (Tumbling Hill Street and Confluence) to the north of the University can be viewed in historic aerial imagery and mapping. There is also reference to them in topographic plans for planning application 07/02743/REM, extracts of these are shown in Figure 2-16 and Figure 2-17.

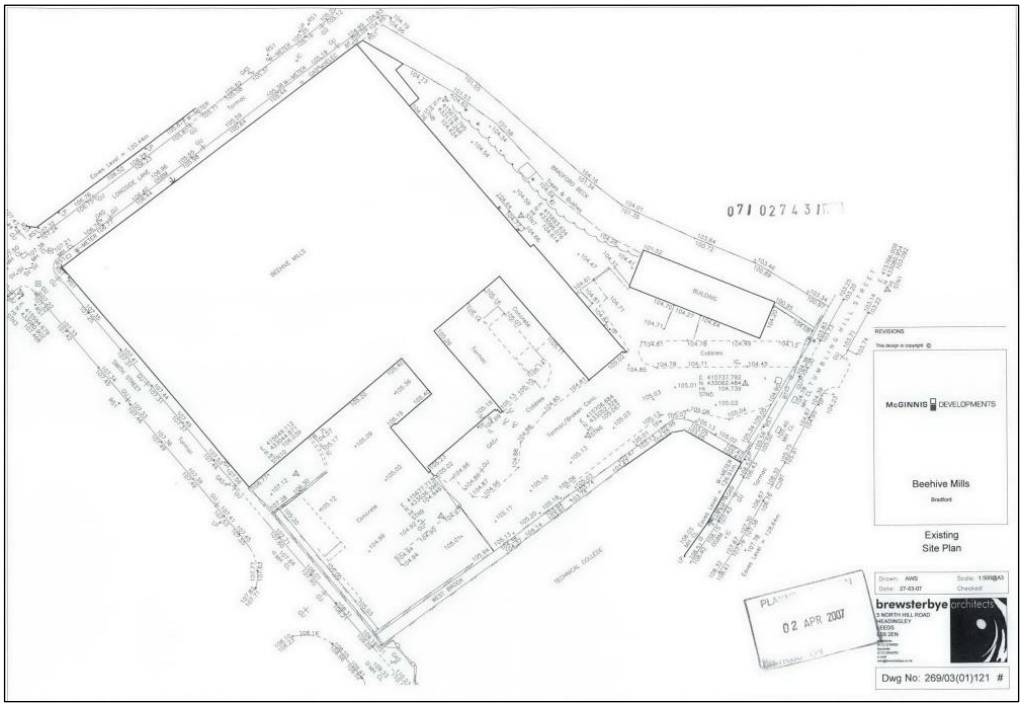


Figure 2-16 – Topographic survey of West Brook adjacent to Tumbling Mill Street, Planning application 07/02743/REM[7]

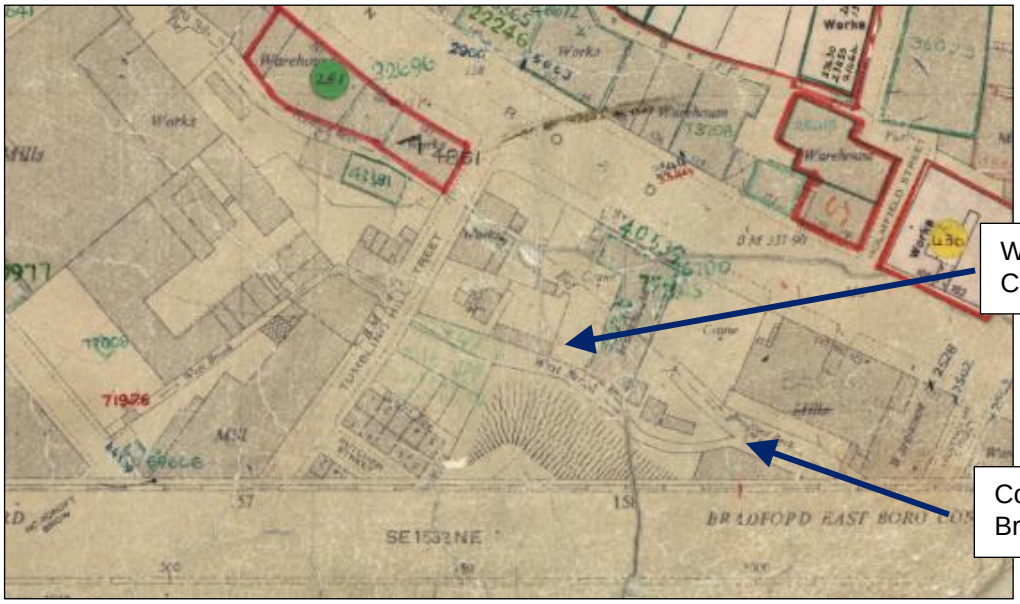


Figure 2-17 – Extract of West Brook Open channel section at confluence with Bradford Beck, Plan SE1533, 1957[8]

The sections within the area covered by planning application 07/02743/REM, to the west of Tumbling Hill Street, have been taken from the topographical survey which was submitted as part of the planning application for the site (Figure 2-16), access to this area is not possible as hoardings and vegetation have prevented access since 2008 (as shown by Google Street View images and

[7] 07_02743_REM-EXISTING_SITE_PLAN-720847.pdf
[8] SE_1533_SE_UNPR.jpg (7115×7102)

confirmed on site). The section immediately adjacent to its confluence with the Bradford Beck has been estimated from LiDAR data and assumptions based on the dimensions of the known channel sections upstream. These open channel sections have been included in the model as 2d Z Lines and associated points.

In the future, should further resolution be required (e.g. to support a Flood Risk Assessment for the development of the site), then site specific modelling studies will need to be undertaken. These will need to include detailed topographical and CCTV survey of the West Brook and Bradford Beck confluence to confirm the flood flow routes and extents. This site specific modelling would likely be used to define the flood extents for sequential testing and steering along with defining the floodplain and levels for masterplanning and planning purposes.

2.9 Outflow

A 2D stage discharge (HQ) boundary was used in one downstream boundary location, located to the south of the canal crossing at Shipley (Figure 2-18). This allows for the removal of water from the model preventing artificially elevated water levels within the areas of interest. The impact of downstream flow constrictions are not considered when using HQ boundaries. A sensitivity test has been completed to understand the impact of removing this downstream boundary from the model (Section 3.4).

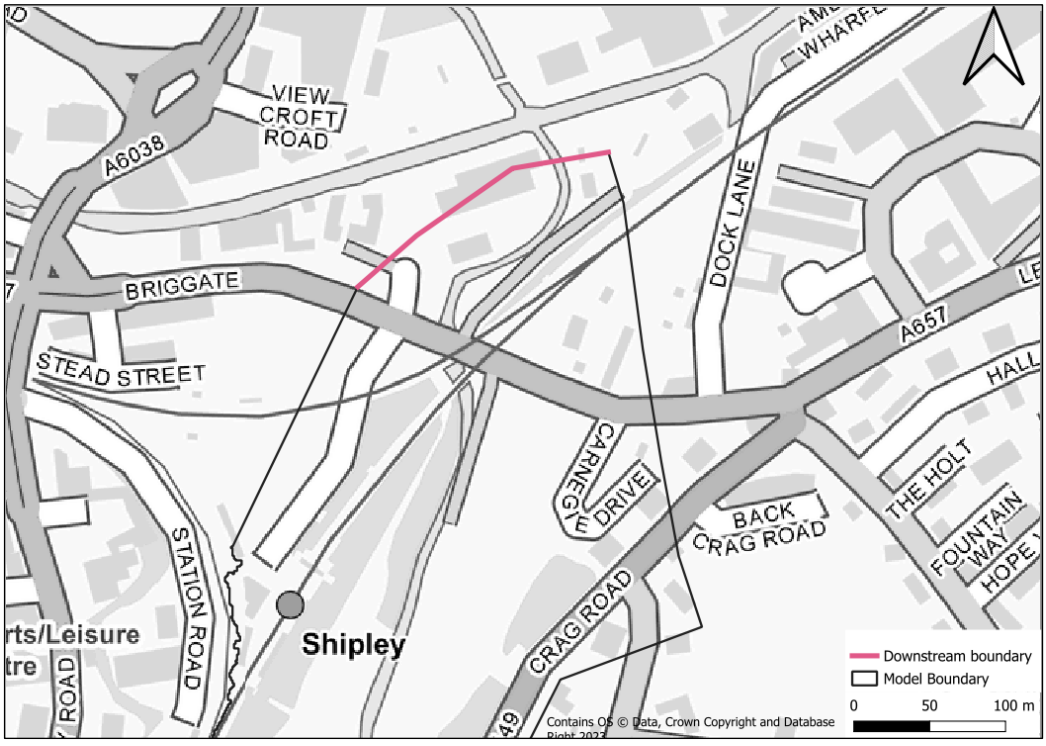


Figure 2-18 – Downstream Boundary Location

The HQ boundary uses the slope of the ground (m/s) to calculate a stage-discharge curve. Based on the upstream water level, the corresponding flow within the stage-discharge curve is used to determine the volume of water leaving the model from each boundary cell.

2.10 Channel Representation

The Bradford Beck channel, where it is not culverted, has been represented as a 2D open channel due to insufficient survey detail to define an accurate and detailed 1D channel. By using a flexible mesh approach, whereby the channel is represented by a 1m cell size, the 2D model can capture sufficient detail to accurately represent the flow dynamics within the channel. Outside of the flexible mesh zone sub grid sampling to 1m resolution has been utilised to ensure the 1m LiDAR data is still represented.

In the upstream catchment areas, where the channel is wider and vegetation may obscure the channel, 2D cuts have been added to ensure a constant flow path. In addition to this, checks have been made between the acquired survey data and LiDAR, and they are broadly similar. This further validates the approach to use the LiDAR to represent the majority of the channel area.

2.11 Model Roughness

Flow velocity depends on the amount of friction (resistance) between the water and the underlying surface. Smoother surfaces will have less friction and therefore, faster flow. Surface roughness contributes to turbulence, which dissipates energy and reduces flow velocity. The Manning's n coefficient (Table 2-1) represents the roughness of the land surfaces, or river channel, in the hydraulic model. OS MasterMap data was used to classify different land uses Figure 2-19 and Figure 2-20.

Table 2-1 – Land Use Roughness Coefficients

MM Code	OSMM Description	Manning's *n*
10021	Buildings	Depth Varying
10053	General Surface (Residential Yards)	0.04
10054	General Surface (Step)	0.025
10056	General Surface (Grass Parkland)	0.03
10062	Building (Glasshouse)	Depth Varying
10076	Land – Heritage and Antiques	0.5
10089, 10210	Water (Inland)	0.035
10099, 10111	Natural Environment (Coniferous/NonConiferous Trees)	0.1
10119	Roads Tracks and Paths (Manmade)	0.02
10123	Road Tracks Paths (Dirt Tracks)	0.025
10167	Rail	0.05
10172	Roads Tracks and Paths (Tarmac)	0.02
10183	Roads Tracks and Paths (Pavement)	0.02
10096	Roadside Structure	0.03
10185, 10193	Structures	0.03
10187	Structures (Generally on top of buildings)	0.5

MM Code	OSMM Description	Manning's *n*
10203	Water (Foreshore)	0.04
10217	Land (Unclassified)	0.035
99	Default (General Surface)	0.04
5	Concrete (unfinished)	0.017
2	Watercourse Channel	0.035
3	Floodplain	0.07

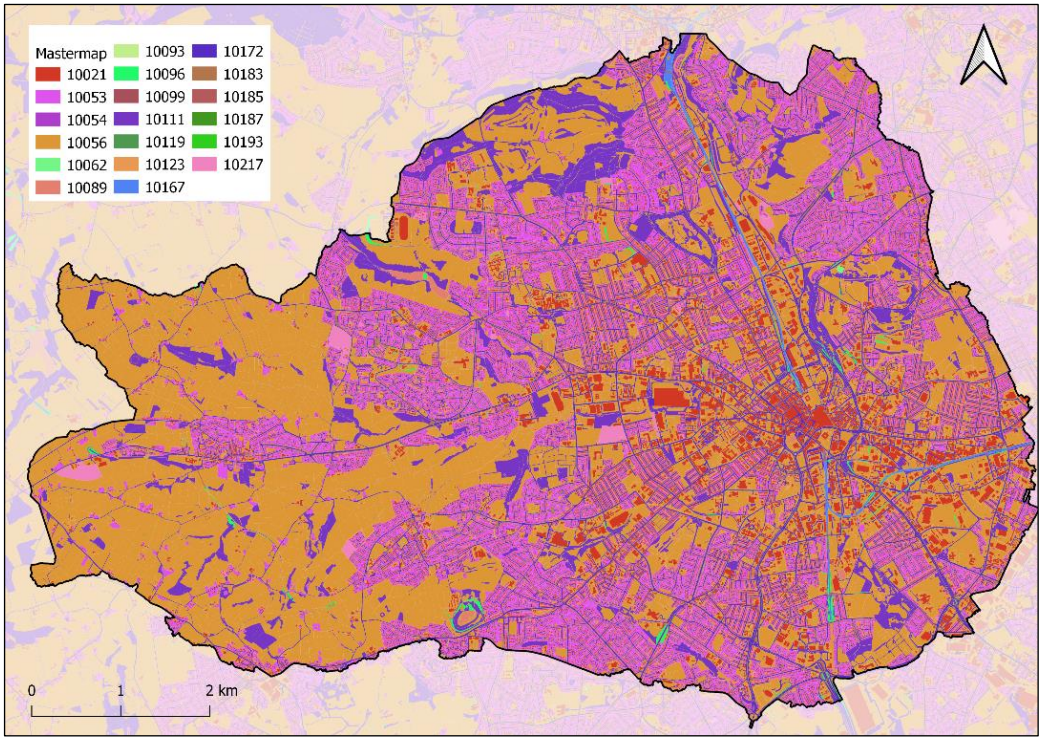


Figure 2-19 – Land Cover Classifications across the Bradford Beck catchment

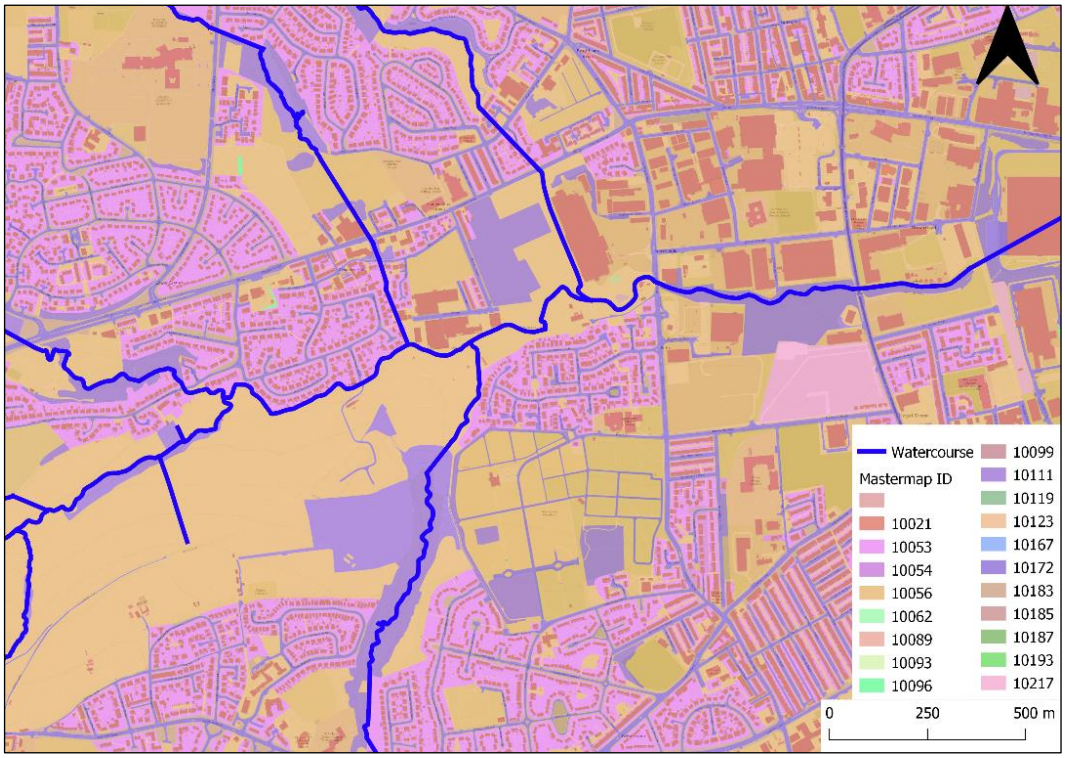


Figure 2-20 – Land Cover classification areas surrounding Middlebrook and Bradford Beck

2.12 1D structures

The culverts included within the model are shown in Figure 2-21. It shows there are large sections of culverted watercourse through the urban area of Bradford. There are fewer culverted sections in the upper catchment to the west of Bradford due to the less dense land use. Culverts have been modelled in the upper catchment where survey has been provided. The culverts within the centre of Bradford have kept the dimensions from the previous modelling study assuming no changes. If there was no available survey data or data from previous modelling, culvert locations have been assumed from the Environment Agency Detailed River Network and aerial imagery. These culverts were based on the adjacent channel widths and elevations. Further detail on the assumptions used for the culverted sections of the model can be found in appendix A.

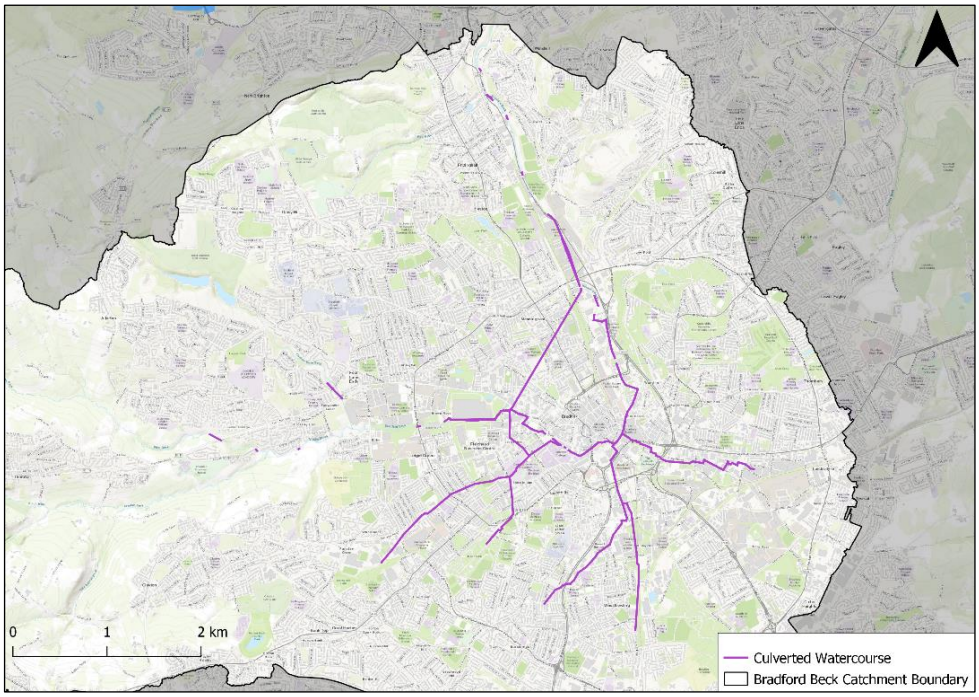


Figure 2-21 – All Modelled Culverts

The additional culverts included in this modelling study based on survey data and information from Bradford council are shown in Figure 2-22 and Figure 2-23.

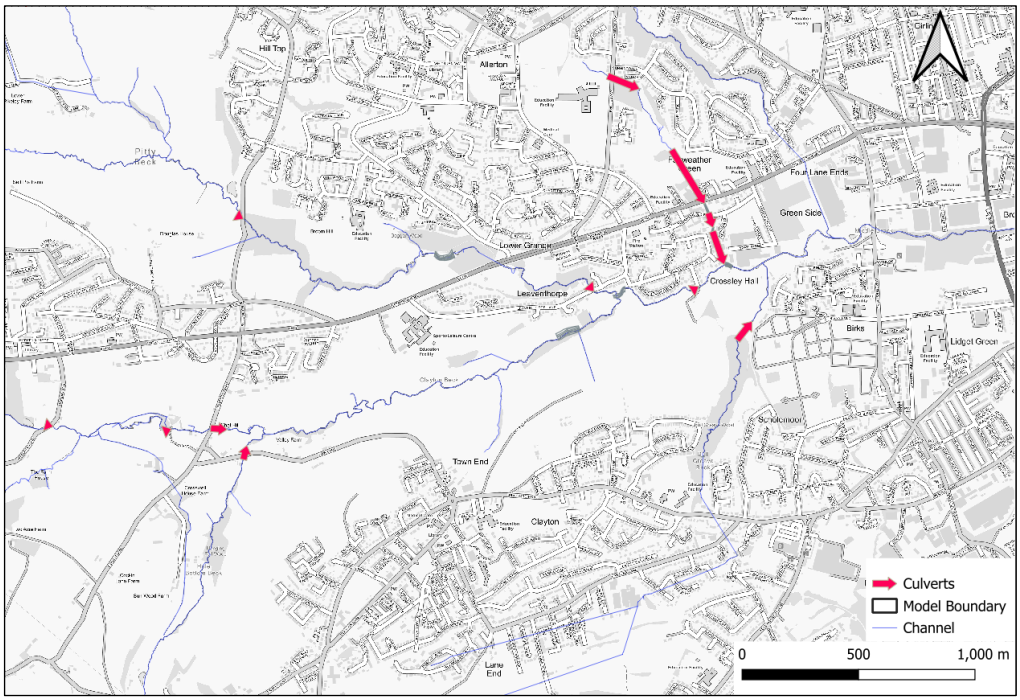


Figure 2-22 – Upper Catchment Culvert Locations

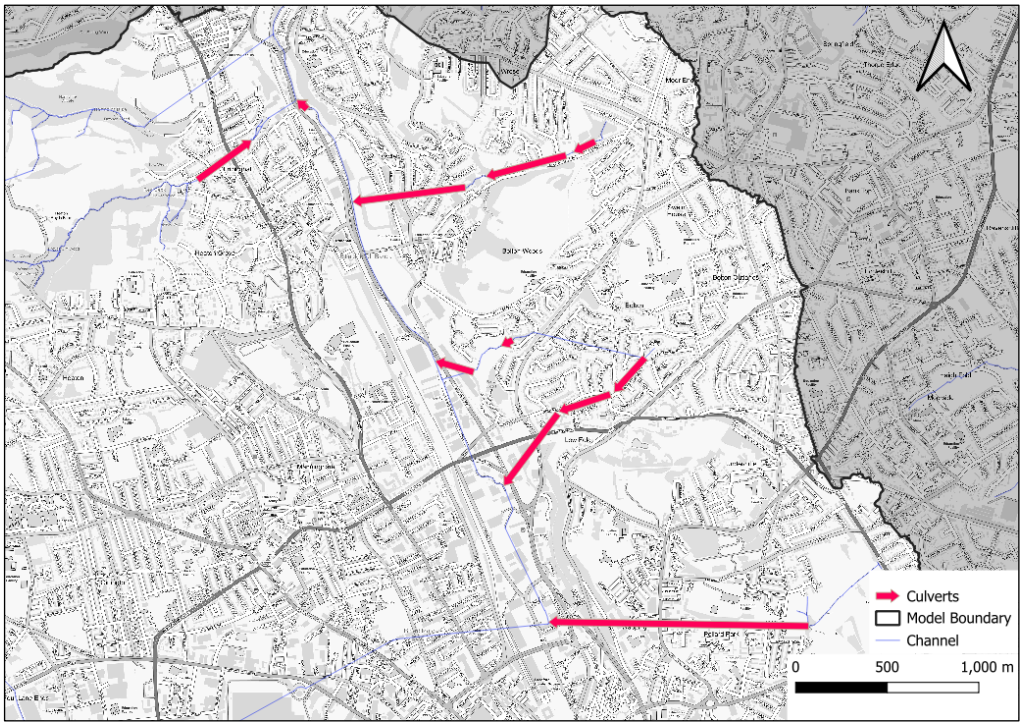


Figure 2-23 – Downstream Culvert Locations

2.12.1 Culvert Roughness

The roughness values for surveyed culverts are based on survey photographs. An example of the method to assign roughness values is described below. Structure 9 from the survey (Figure 2-24) shows the culvert has a corrugated metal lining which extends into the culvert bed. Therefore, the culvert has been modelled with a Mannings value of 0.019 (Chow 1959).



Figure 2-24 – Structure 8 Photograph

Structure 17 from the survey (Figure 2-25) shows a metal box culvert. Therefore, the culvert has been modelled with a Mannings value of 0.014 (Chow 1959).



Figure 2-25 – Structure 17 Survey Photograph

Survey photographs have not been provided for the majority of culverts. Therefore, they have been assigned a Mannings value of 0.015 which is the Mannings n for a *sewer with manholes, inlet, etc., straight* (Chow 1959).

2.12.2 1d to 2d connections

It has been ensured that an appropriate number of 2d cells have been selected to transfer water between the 1d and 2d sections of the model. In all instances the number of cells selected is equal to or greater than the width of the culvert. For example, a 2m wide culvert will have at least 2 x 1m wide model cells selected at the upstream and downstream inlet.

2.13 Inflows

Inflows have been added to the model for each of the sub catchments shown in Figure 2-26. This allows for accurate representation of hydrographs entering the Bradford Beck as the catchment size increases. Further detail on the hydrological analysis is found in Appendix B. In the upper catchment and areas where there is a clear open channel for flows to be added to these have been applied as 2d_sa streamlines.

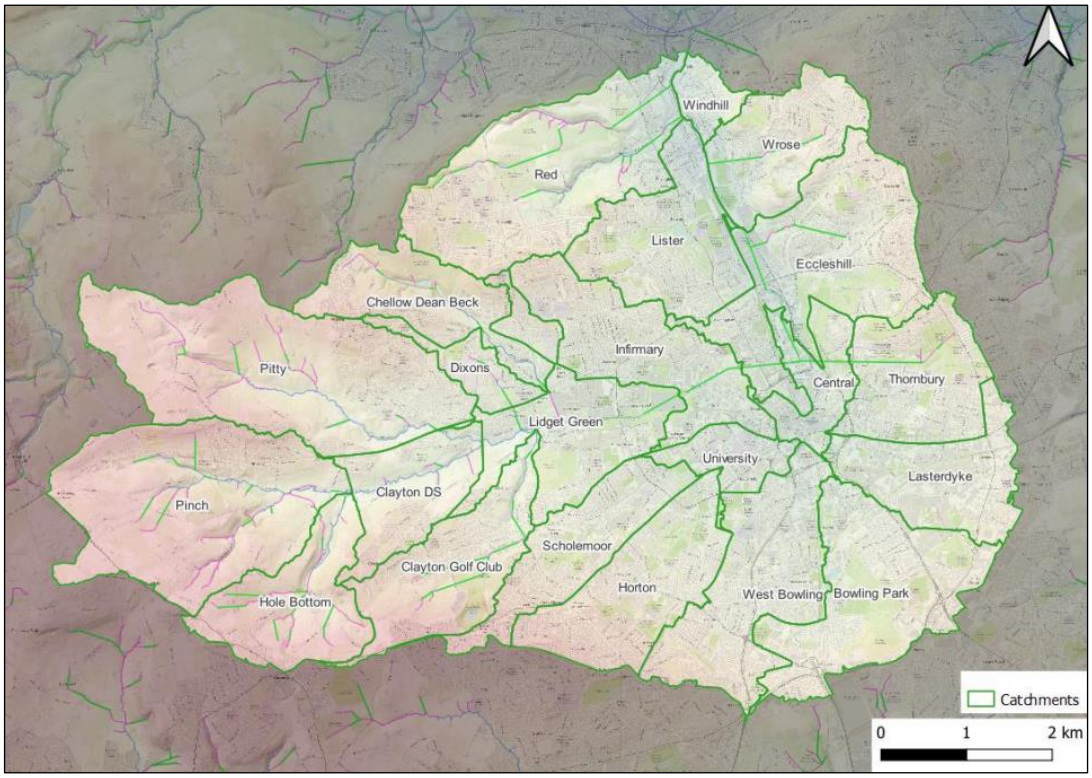


Figure 2-26 – Bradford Beck catchments

In the central area of Bradford where there are no obvious channels for 2d inflows to be added to the model in an appropriate location. Therefore, 1d inflows have been applied to culverts in appropriate locations. Inflows have been added as close as possible to where it is believed culverts would outfall into the main Bradford Beck culverted channel (Figure 2-27). For model stability reasons, some of these have had to be moved to more central locations on the Beck where the culverts have larger dimensions and have capacity to cope with the high volume of water. This still ensures an accurate representation of flood risk and representation of culvert flows within the centre of Bradford and further downstream. Details of how inflows have been calculated can be found in Appendix B.

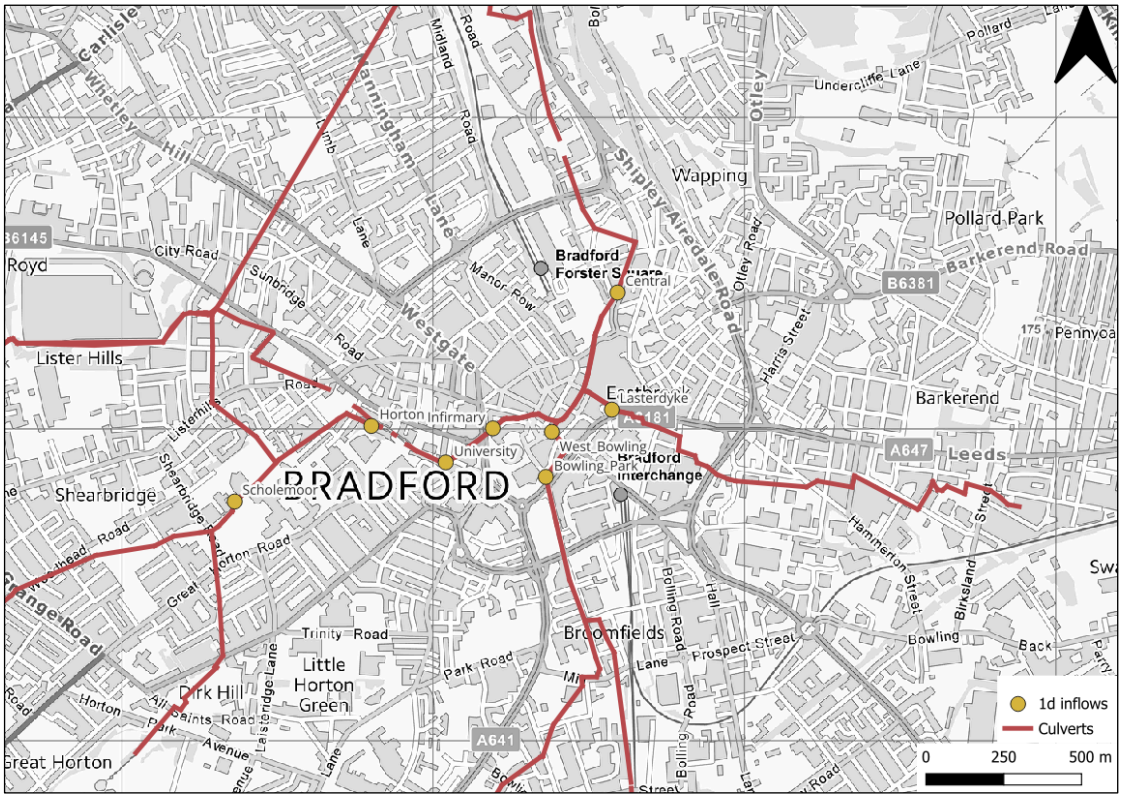


Figure 2-27 – Locations of 1d inflows.

3 Baseline model results

The results from the baseline modelling of the Bradford Beck are described in the below section. A suite of flood maps for all modelled events is included in Appendix C.

3.1 Baseline model results

The hydraulic model results for the full model extent for the 1% AEP + Higher climate change allowance, 1% AEP and 3.33% AEP are shown in Figure 3-1, Figure 3-2 and Figure 3-3. The results show the distinct flow path of the Bradford Beck flowing from west to east then north once it has passed through Bradford city centre. The flood extents increase as we move further downstream because of the greater number of contributing catchments joining the flow route. The extent and depths of the predicted flooding increases across modelled events.

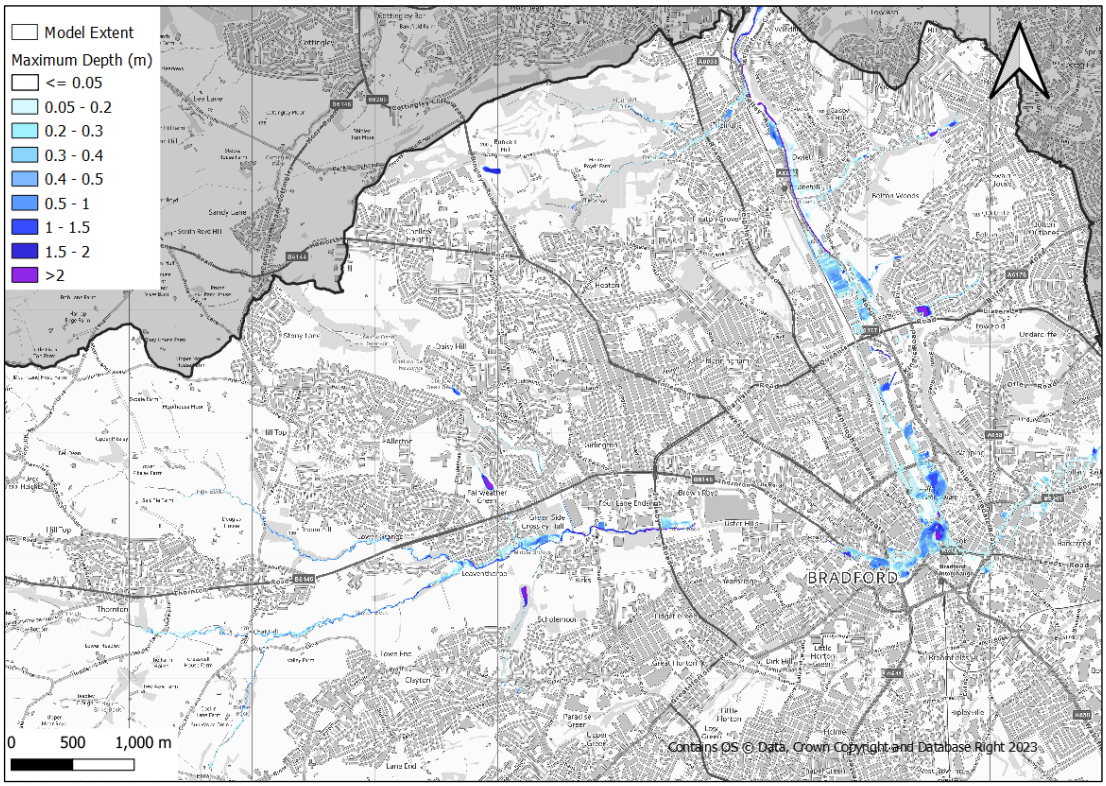


Figure 3-1 - 1% AEP + Higher Climate Change Maximum Depth Results Full Catchment

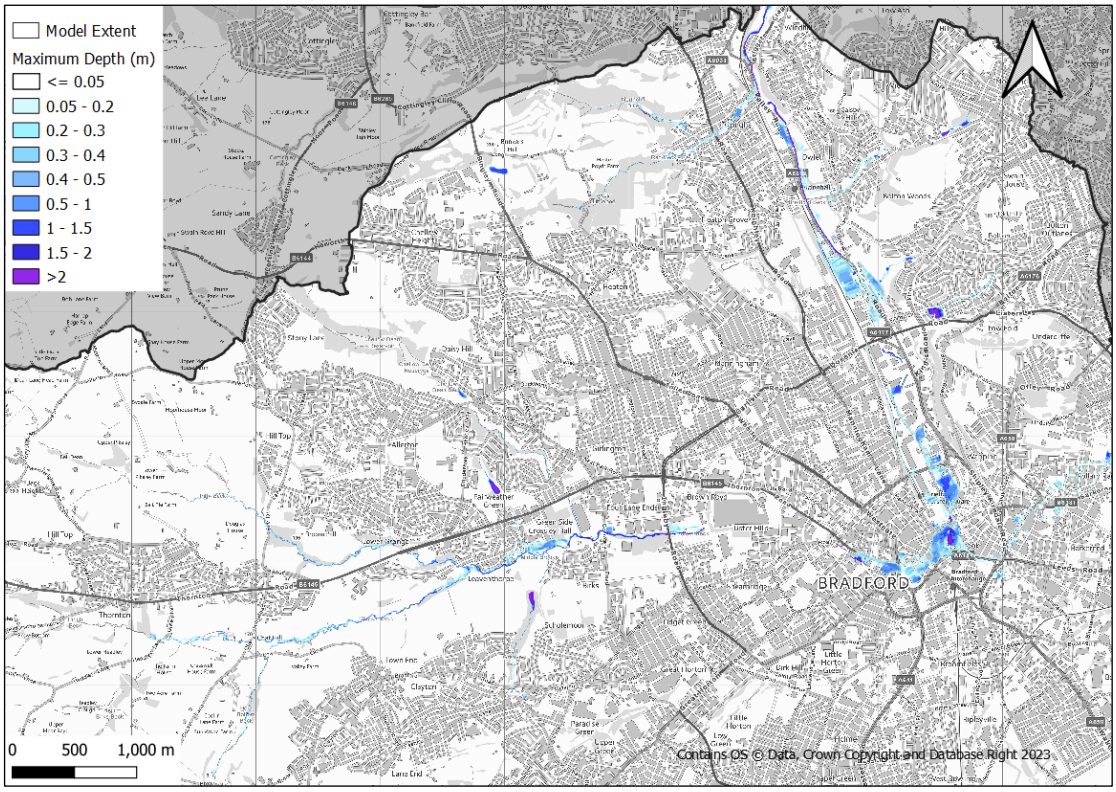


Figure 3-2 – 1% AEP Maximum Depth Results Full Catchment

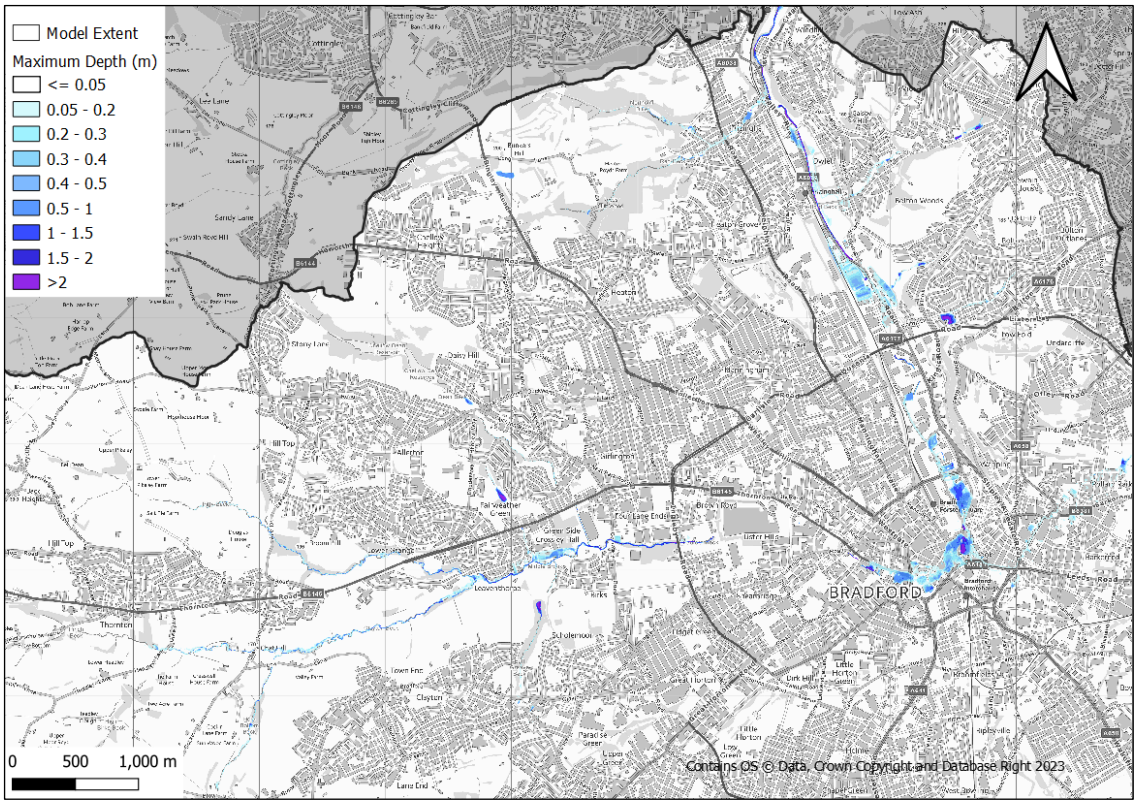


Figure 3-3 – 3.33% AEP Maximum Depth Results Full Catchment

Results for the western area of the catchment are shown in Figure 3-4. They show the sinuous tributaries of the Pitty Beck, Clayton Beck, Hole Bottom Beck and Middle Brook, as well as the Chellow Dean Beck which flows from the Chellow Dean Reservoir. The model results for the upper catchment show flow remains largely within the floodplain and there is limited predicted flooding to receptors. After the confluence of the Clayton and Pitty Beck there is the potential for out of bank flooding in the area surrounding Middlebrook Crescent and Middlebrook Way. There is further out of bank flooding predicted to the east of Middlebrook Walk impacting the industrial properties of York Street.

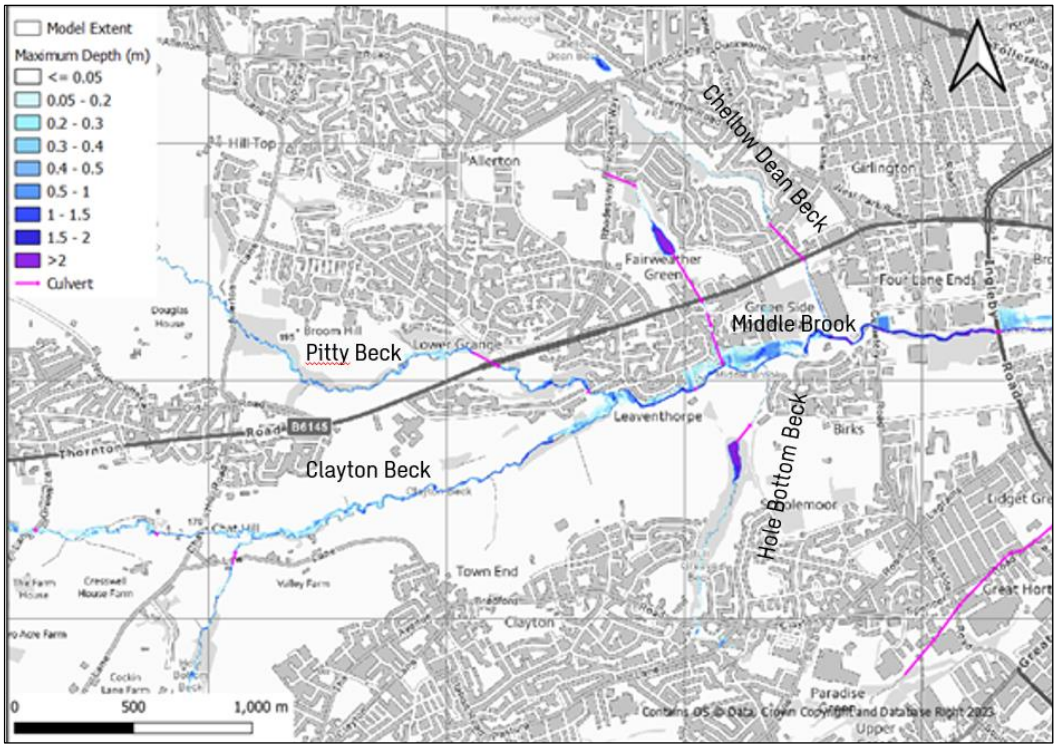


Figure 3-4 – 1% AEP + Climate Change Maximum Depth Results, Western Catchment

The 1% AEP + Climate Change results for the Central catchment (Figure 3-5) show greater potential for out of bank flooding in this area. Through this section the Beck runs predominately through culverted sections. The model shows flooding originates from the small sections of open channel which are able to overtop, as well as an overland flow route from the catchment including Pollard Park west of Killinghall Road. There is also shown to be overtopping of culverts for example in the vicinity of Byron Primary School where not all flow is able to enter the culvert and therefore forms a flow route towards Shipley Airedale Road.

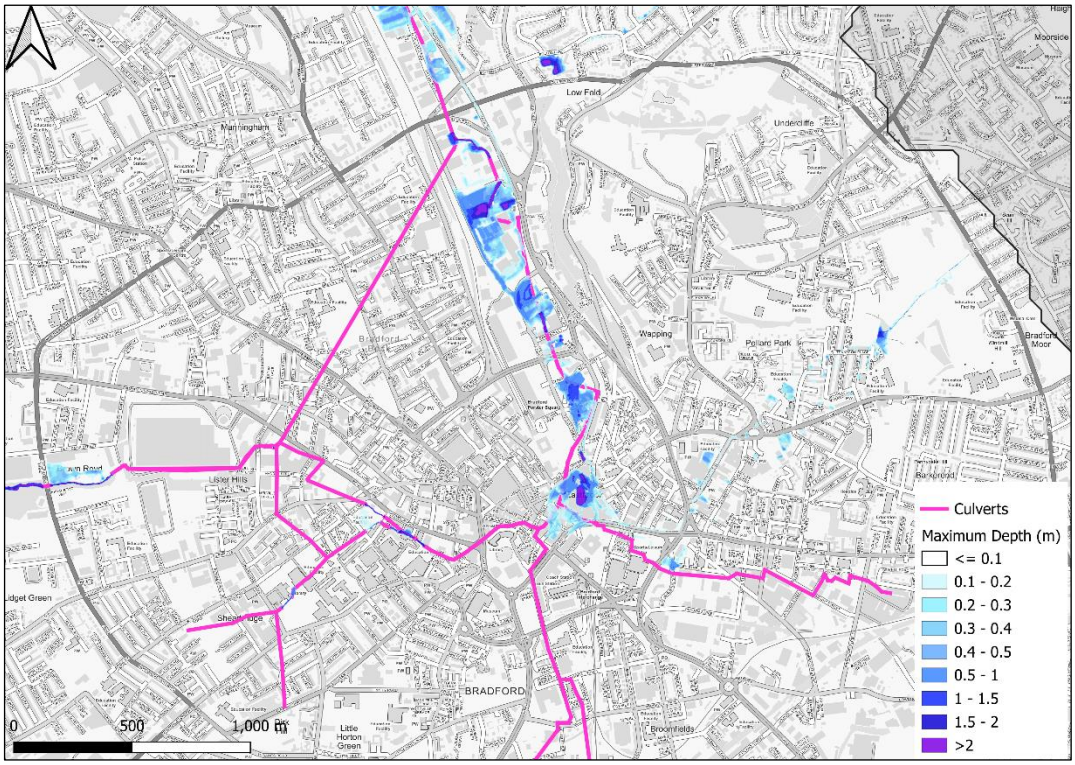


Figure 3-5 - 1% AEP + Higher Climate Change Maximum Depth Results, Central Catchment

To the south east of the City Centre is the West Brook catchment which contains a number of open channel sections shown in Figure 3-6 and described in section 2.8. The results for the 1% AEP + Higher Climate Change event indicate that flow will remain largely within the channel in the open channel section within the University grounds, with only minor overtopping into the grassed area to the north east of the downstream culvert inlet. Downstream at the site adjacent to Tumbling Mill Road there is out of bank flooding predicted within the currently unused land (planning application reference 07/02743/REM) of up to 170mm.

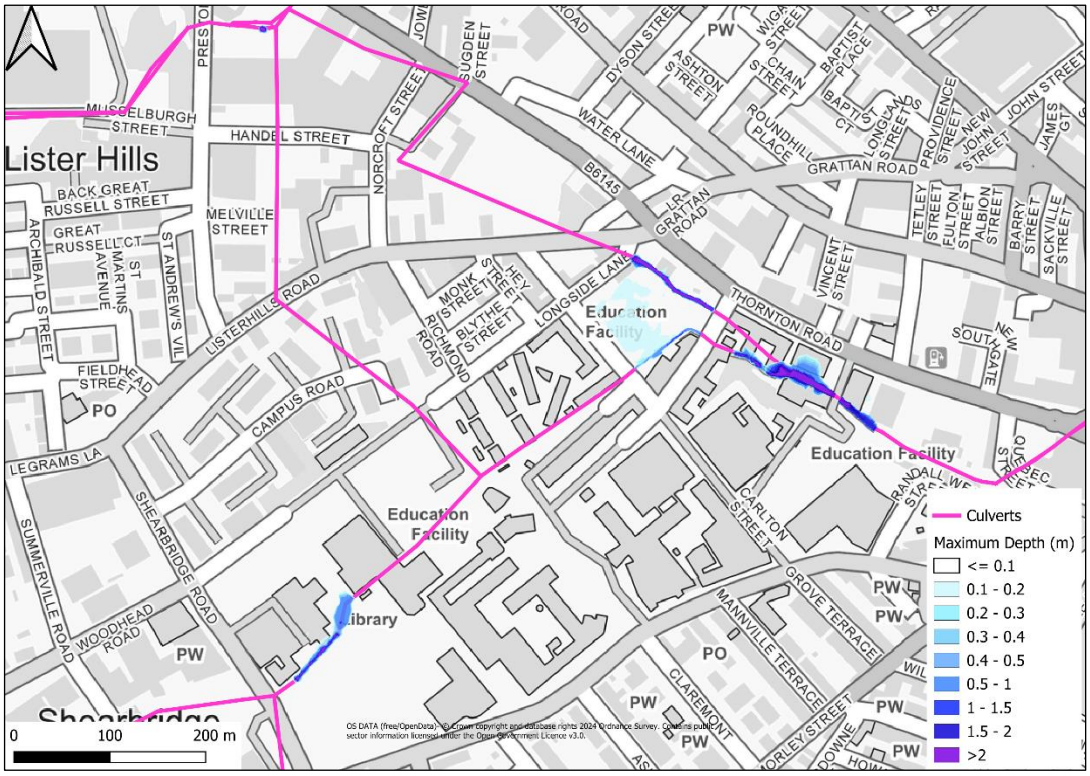


Figure 3-6 – 1% AEP + Higher Climate Change Maximum Depth Results, West Brook Catchment

Figure 3-7, Figure 3-8 and Figure 3-9 show the flows in the vicinity of the Bradford Beck flood relief tunnel for a selection of return periods from 50% AEP to 0.1% AEP.

The results show 13.9m^3/s flow through the flood relief tunnel in a 1% AEP + Higher climate change allowance event. There is 25.7 m^3/s passing through the culvert immediately upstream of here showing 59.6% of flow is predicted to enter the flood relief channel and bypass the centre of Bradford.

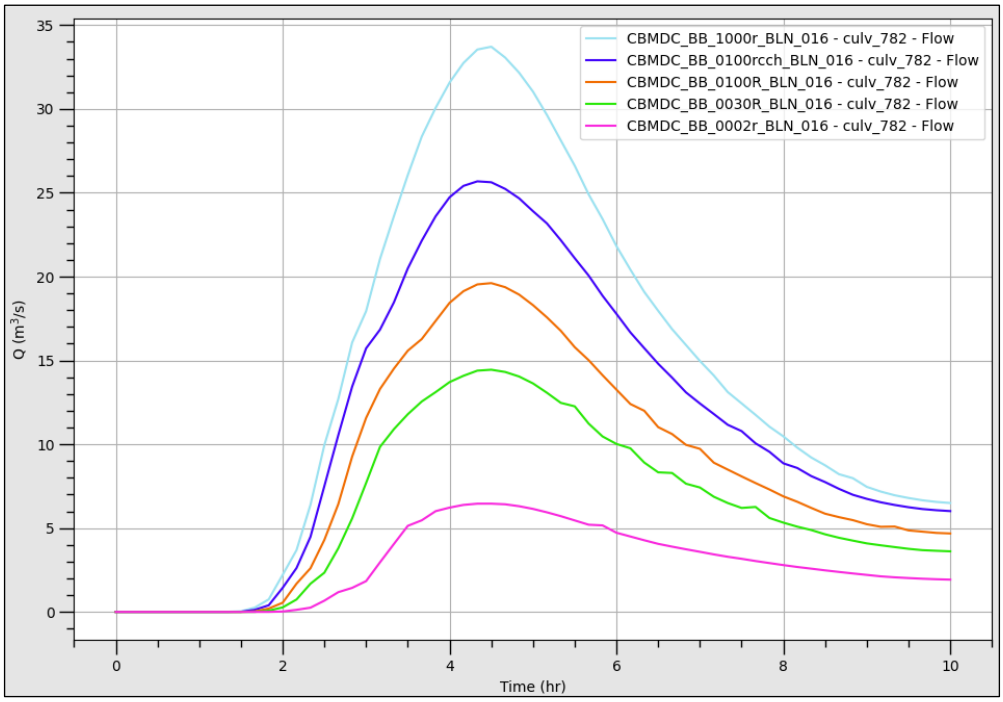


Figure 3-7 – Flows upstream of Bradford Beck flood relief tunnel

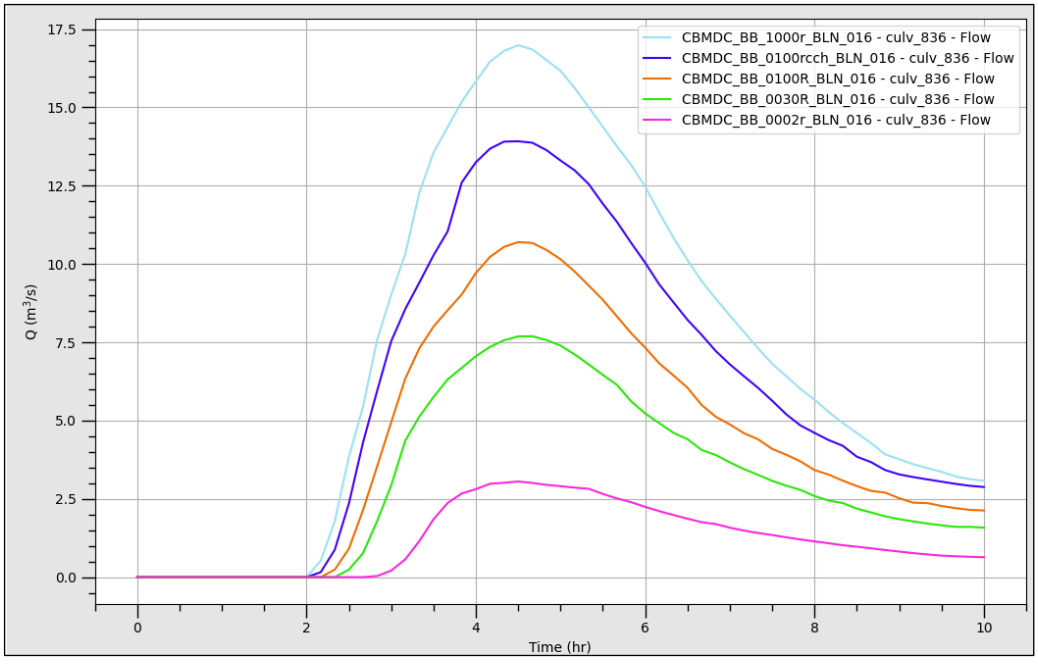


Figure 3-8 – Bradford Beck flood relief tunnel flow

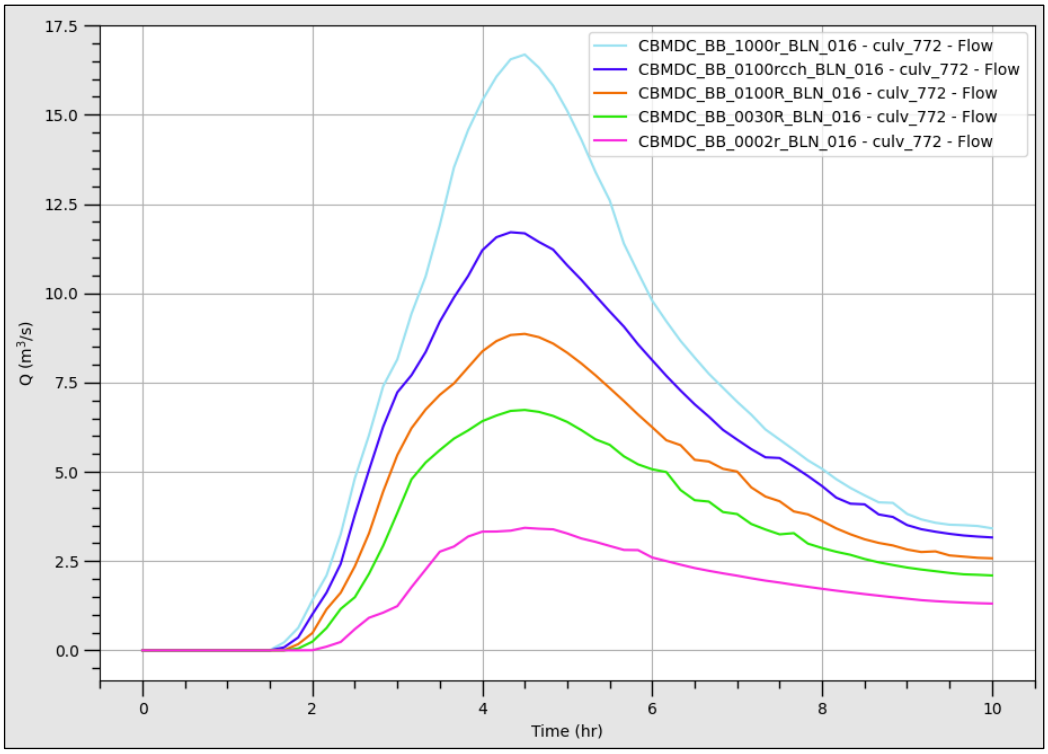


Figure 3-9 – Flows immediately downstream of flood relief tunnel junction

The results for the northern end of the catchment for the 1% AEP + Higher Climate change allowance are shown in Figure 3-10. The predicted out of bank flooding here generally impacts the commercial properties of Canal Road and Valley Road. There are minor overland flow routes shown through urban areas originating from the Red Beck and Trap Sike. Flow within the Bradford Beck stays predominately within the channel in the northern section due its defended nature lying within a deep concrete lined channel (Figure 3-11). There is also a flow route arising from the east of the main channel and overtopping/bypassing culverts to form a flow route adjacent to Gaisby Lane. This flow path enters the main Bradford Beck channel to the east of Frizinghall Station.

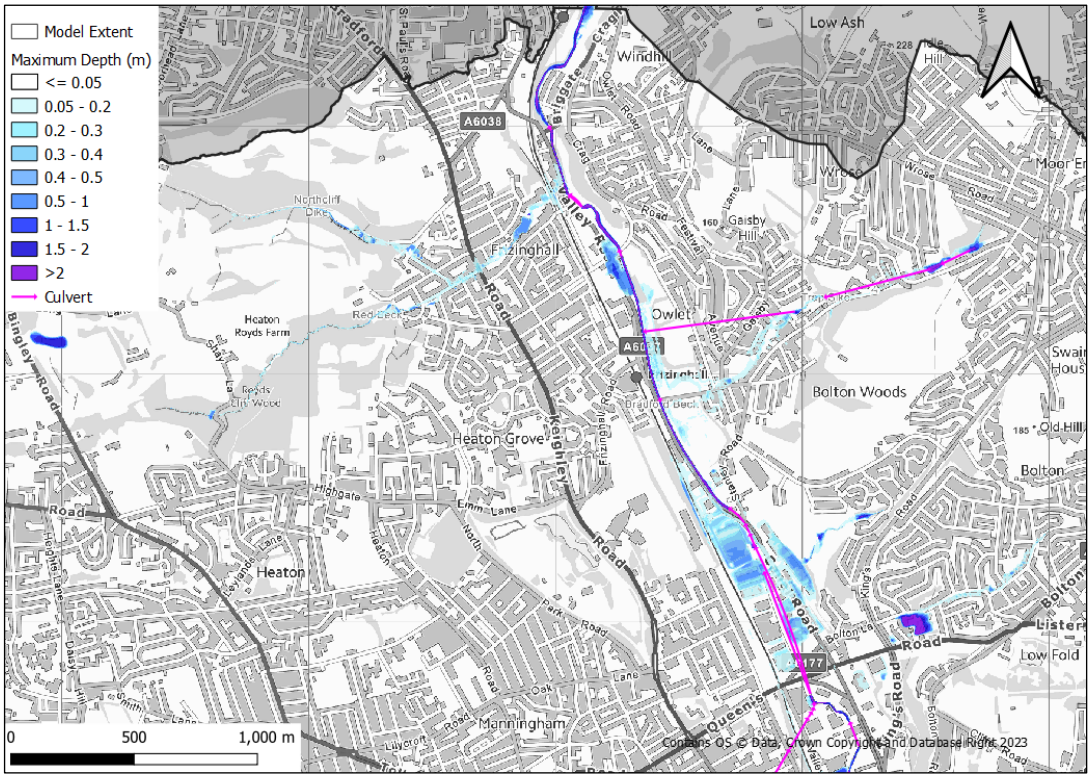


Figure 3-10 - 1% AEP + Higher Climate Change Maximum Depth Results, Northern Catchment



Figure 3-11 – Bradford Beck at Polar Road

The maximum velocity results are shown within Figure 3-12. As expected, this shows the areas of highest predicted velocity are within the fast flowing channel. The lowest velocities are shown within areas where ponding is predicted within the city Centre and upstream of culverts in the upper catchment.

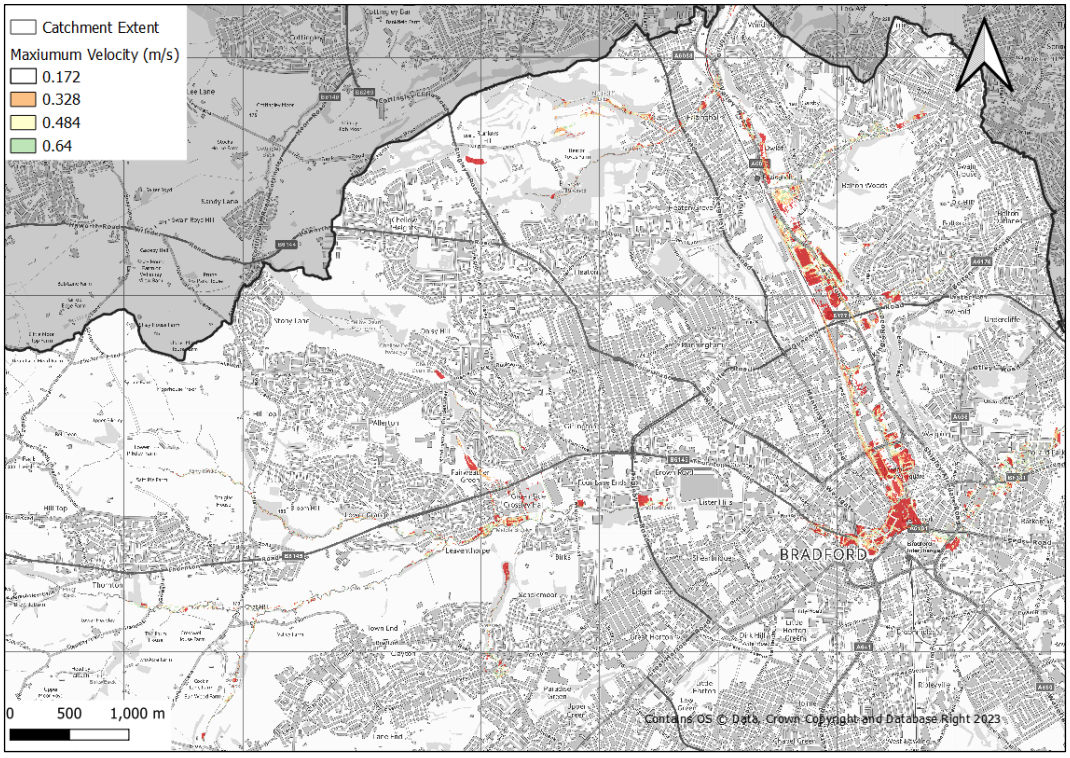


Figure 3-12 - 1% AEP + Higher Climate Change Maximum Velocity Results, Full Catchment

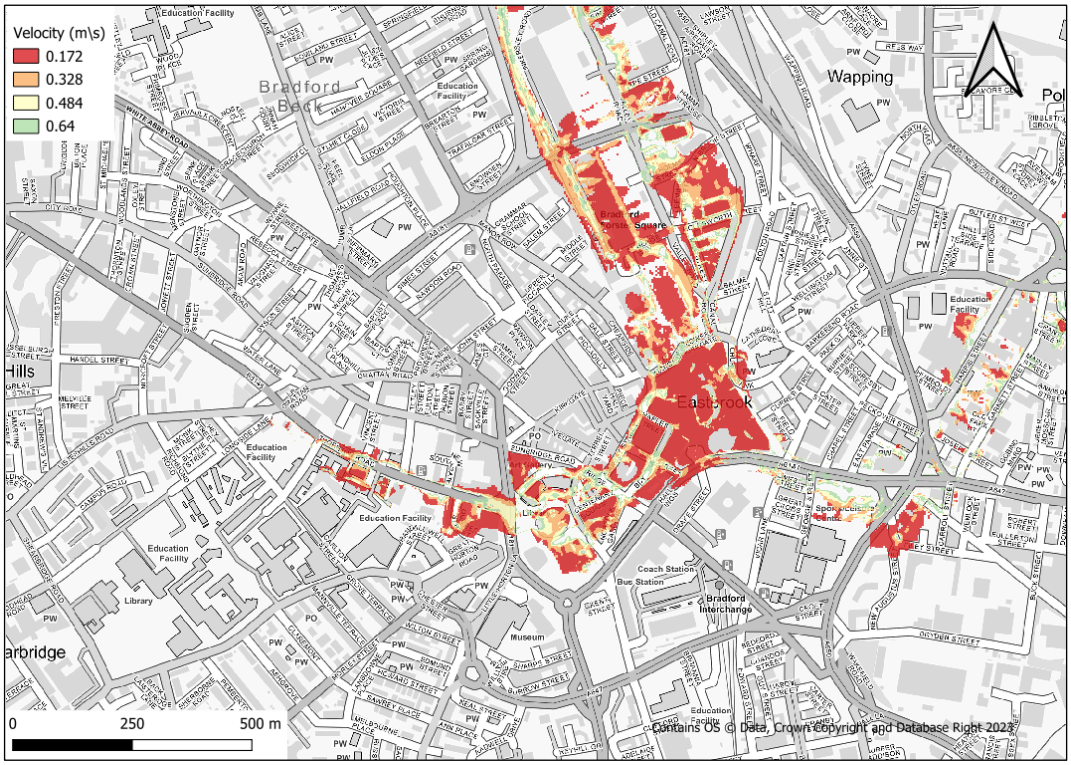


Figure 3-13 - 1% AEP + Higher Climate Change Maximum Velocity Results, Full Catchment

The hazard results for the 1% AEP + Higher Climate Change scenario are shown in Figure 3-14 and Figure 3-15. The results show there is a relatively small number of areas of high hazard within urban areas. This specifically occurs in Bradford Town Centre and surrounding industrial/commercial areas.

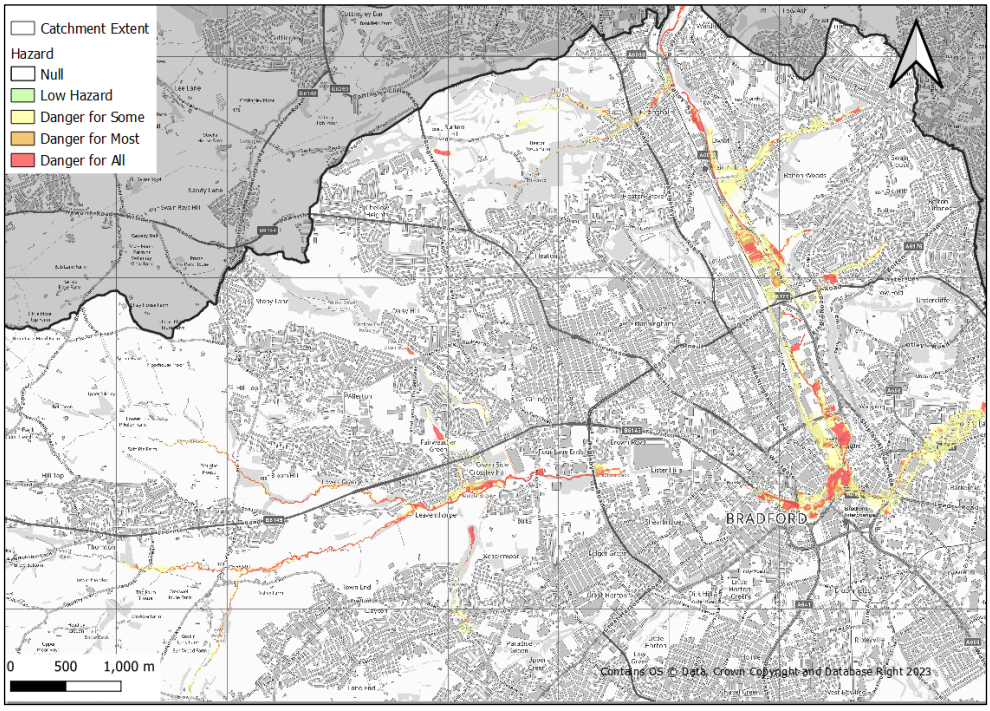


Figure 3-14 - 1% AEP + Higher Climate Change Maximum Hazard Results, Full Catchment

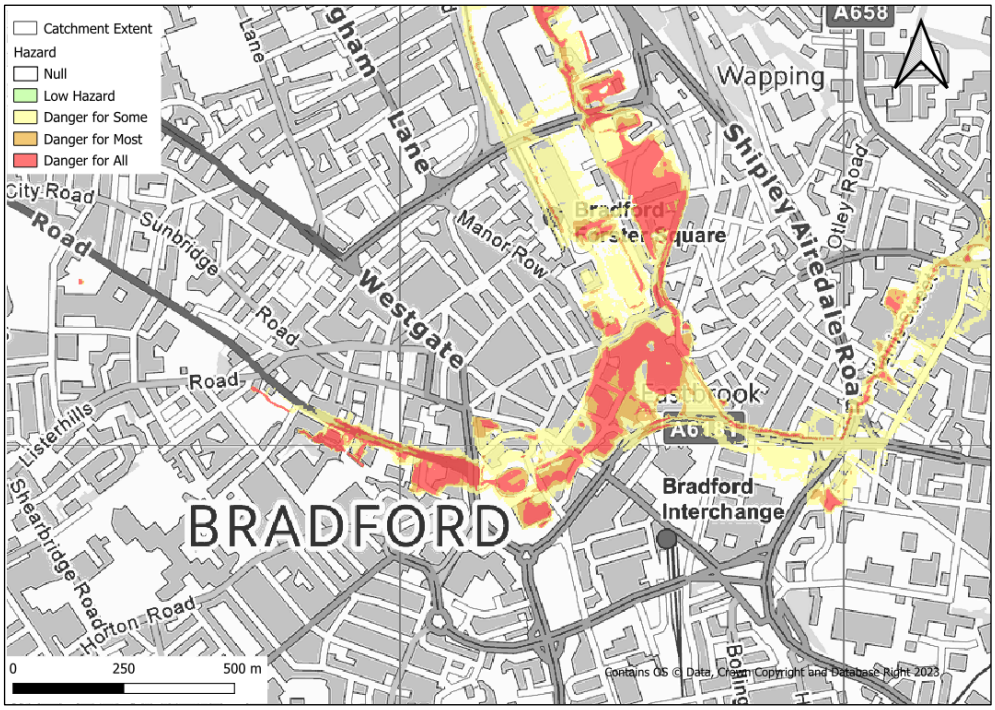


Figure 3-15 - 1% AEP + Higher Climate Change Higher Maximum Hazard Results, Zoom

3.2 Validation

3.2.1 Flood Extent Comparison

The below figures (Figure 3-16, Figure 3-17) show a comparison between the Environment Agency flood zones and the results of this study. It shows there are largely similar flood extents between the Flood Zones and outputs produced in this study. The reduced model cell size and detailed structure survey used in this study are likely to be the reason for the reduction in flood extent upstream of Bradford City Centre. As a result of these improvements, larger volumes of water are able to enter the culverted Bradford Beck sections which result in an increase in flood extent downstream of the city centre. Flood extents to the south of the city centre shown within the Flood Zone layers are represented as an inflow in the model used in this study.

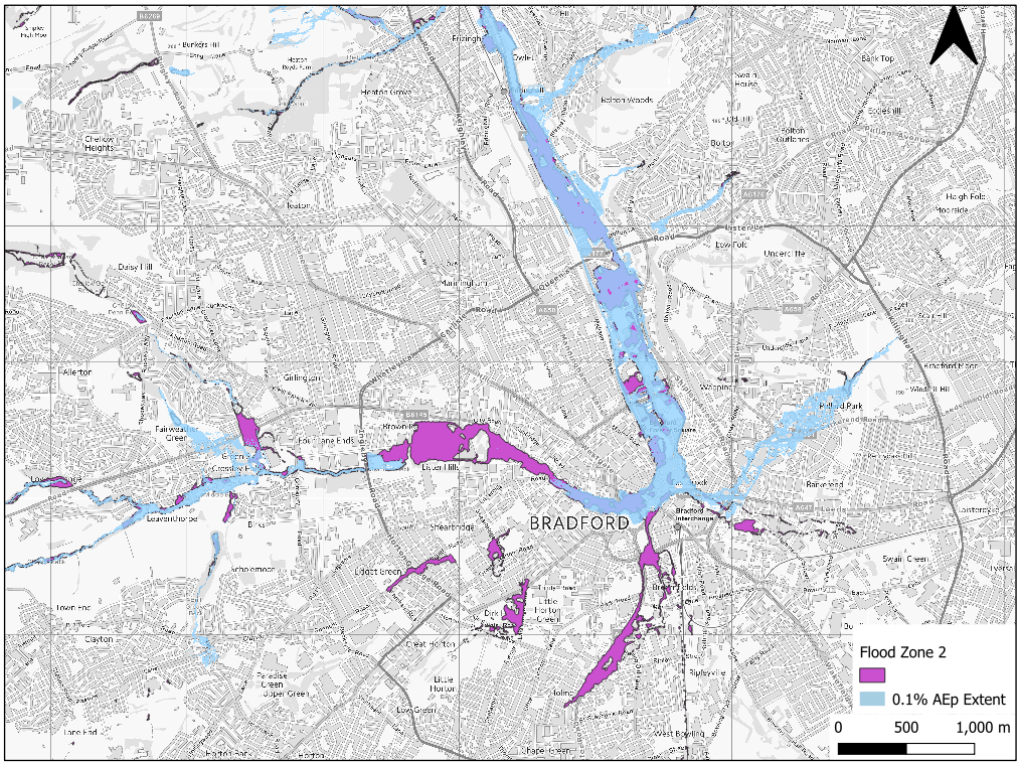


Figure 3-16 – 0.1% AEP Comparison to Flood Zone 2

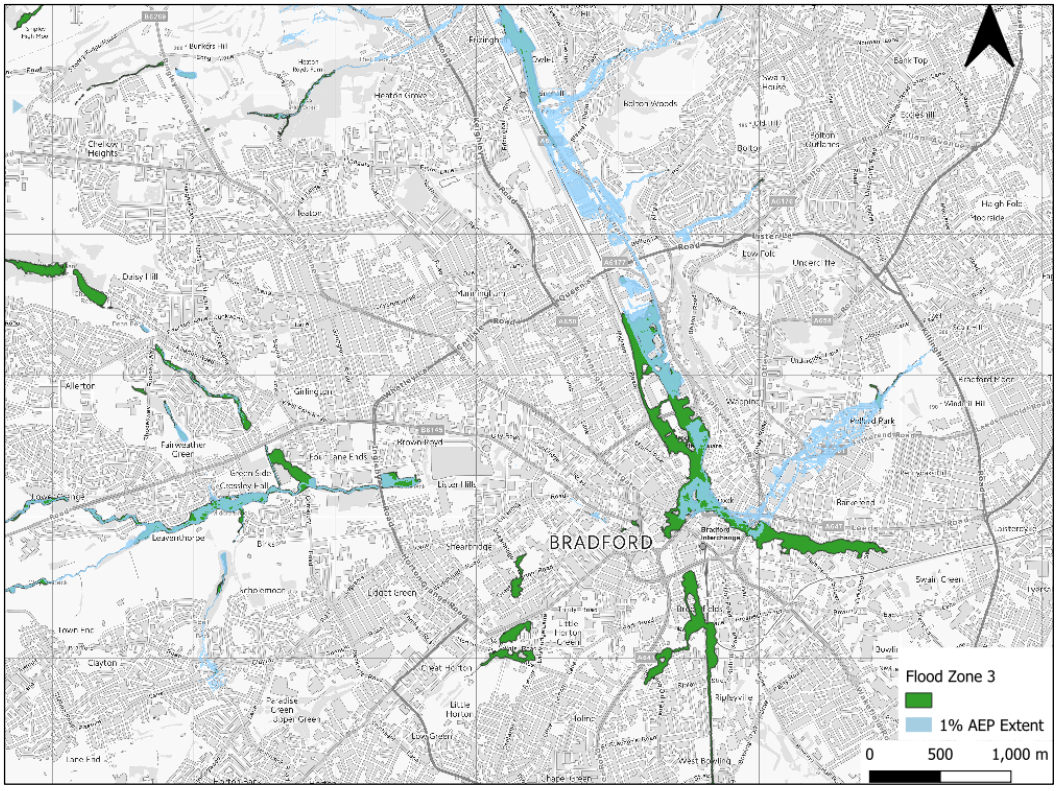


Figure 3-17 – 1% AEP Comparison to Flood Zone 3

3.2.2 Flow Reconciliation

A comparison of the inflows into the model compared to the modelled flows has been undertaken. Reporting Point 30 immediately upstream of the main culverted section of the Bradford Beck (Figure 3-18) has been chosen for this assessment. The volume of water passing through this line for the 1% AEP event is 320,888m^3. The combined upstream catchments draining to this location is 409,852m^3. Although this is a 20% difference in volume, this is likely due to additional volumes of water stored upstream at the end of the model simulation resulting in an underreporting of total volume at reporting point 30 when compared to the total catchment volumes.

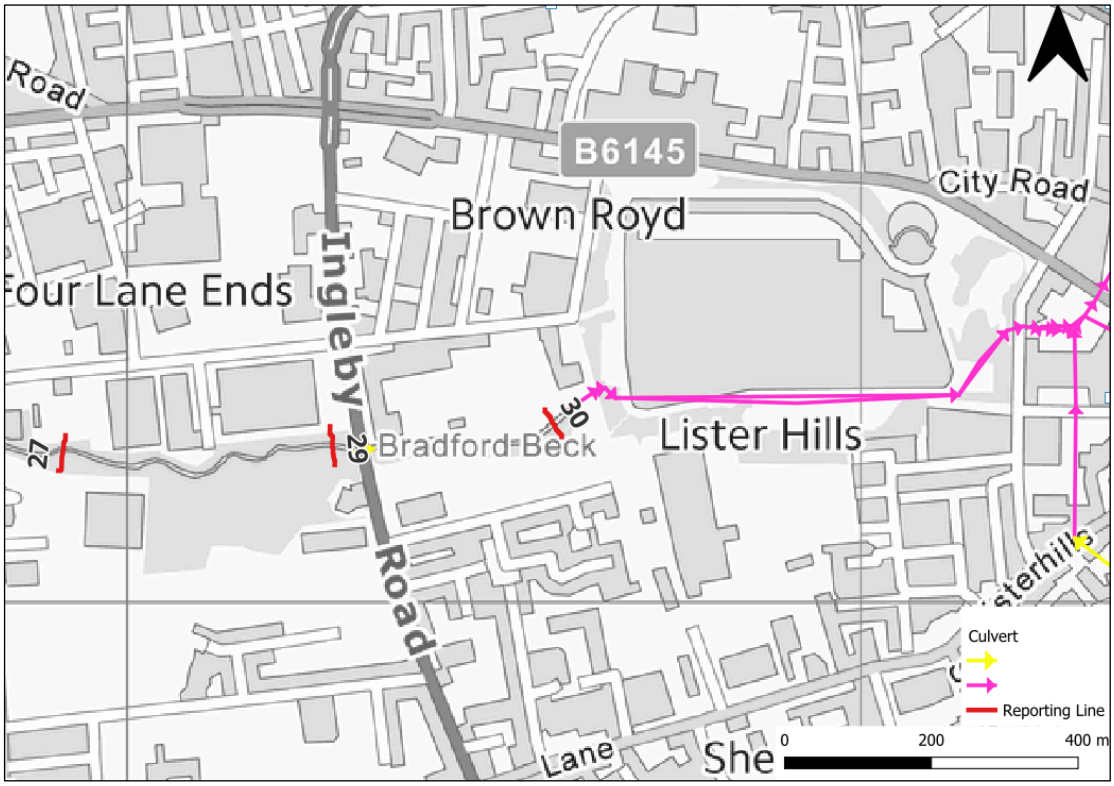


Figure 3-18 – Reporting Line 30 Location

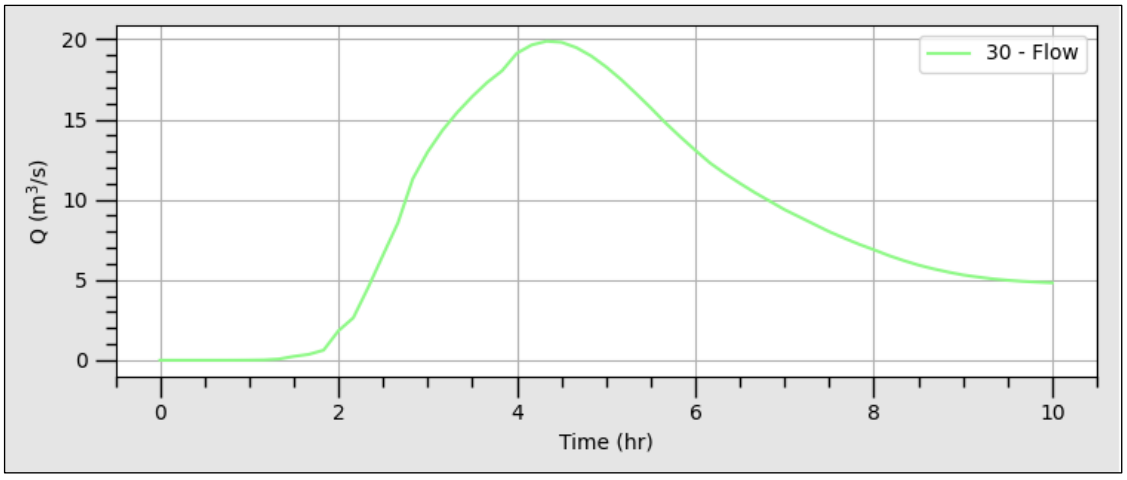


Figure 3-19 - Reporting Line 30 Flow

3.3 Model Health

3.3.1 Timestep

The timestep in the 1% AEP simulation is shown in Figure 3-20. At points during the simulation the timestep dops to 0.02 seconds which is outside of the generally acceptable limits. However, in a model such as this with relatively high flows and a large number of culverts it is understandable that the timestep drops to this level. The map displayed in Figure 3-21 shows the locations of the lowest timesteps over the 2d grid are within the Bradford Beck channel where there is deeper fast flowing water.

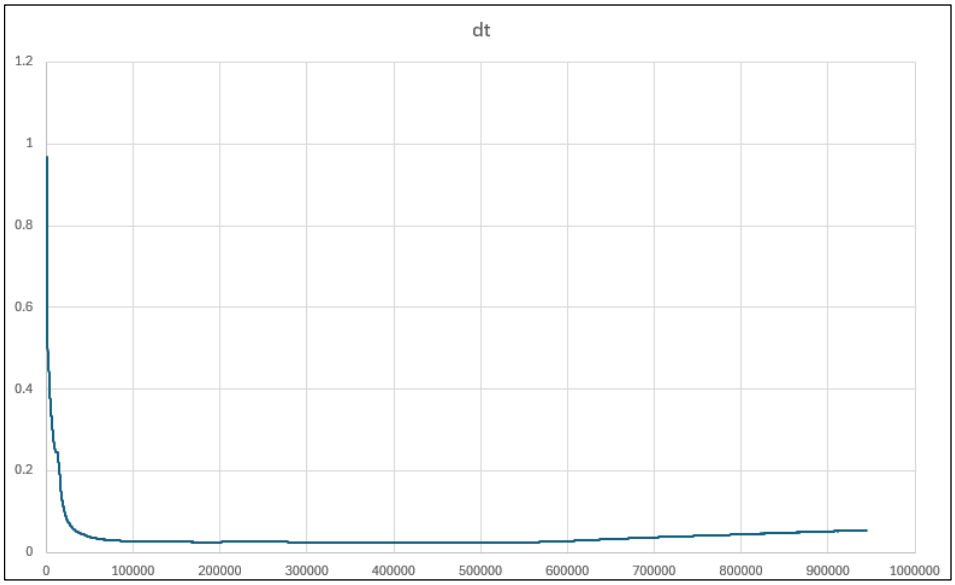


Figure 3-20 Timestep in 1% AEP simulation



Figure 3-21 – Timestep (dt) map

3.3.2 Model checks & warnings

The checks and warnings as well as justification for why they appear in the model are included in Table 3-1.

Table 3-1 – Model Checks

Check Number	Occurrence	Check Content	Justification
2118	97	Lower SX ZC Zpt to 1D node bed level.	This check relates to lowering of z points surrounding culvert inlets to match the DTM elevation. The SX boundary lines select multiple cells surrounding culvert inlets and outlets and applies a set elevation to match the culvert invert. Cells at the edge of the channel cross-section with the largest elevation difference to the centre of the bed are also lowered causing a noticeable reduction in cell elevation. This the recommended approach for modelling 1D culverts within a 2D channel.

Check Number	Occurrence	Check Content	Justification
1402	3	More than one culvert connected but could not create manhole at Node	Check relates to an incoming culvert entering above the obvert of the highest outlet, the culvert is not included in the manhole loss calculations. Where there are double culverts meeting in provided 1d network layer. Insignificant in comparison to the large number of culverts in the model.
2077	3	Beginning of 3d Z line is dangling	Located in area of large number of z points, the DEM_Z in the area has been reviewed and indicates that the model DTM at this location is comparable to the value of the dangling z point. No model changes required as it will incur no impact on results..
2370	3	Ignoring coincident point found in Create TIN layer.	Duplicated vertices within same layer, unlikely to have impact due to density of surrounding points. This will have no impact on results.
2934	35	At least one merge polygon vertex is located inside quadtree cell(s) from different nesting level.	Z shapes cross between different quadtree nesting levels. DEM_Z and zpt check have been reviewed and levels are comparable to z points. No model changes required. Changing will have no impact on results.
3548	1	Setting SGS Sample Distance Target to minimum grid zpt resolution of 1.	Sets Sub Grid Sampling to 1m to match the DTM cell size. Deemed acceptable.

Table 3-2 – Model Warnings

Warning Number	Occurrence	Content	Justification
2118	90	Lower SX ZC Zpt to 1D node bed level.	This warning relates to lowering of z points surrounding culvert inlets by above 0.3m to match the DTM elevation. The SX boundary lines select multiple cells surrounding culvert inlets and outlets and applies a set elevation to match the culvert invert. Cells at the edge of the channel cross-section with the largest elevation difference to the centre of the bed are also lowered causing a noticeable reduction in cell elevation. This the recommended approach for modelling 1D culverts within a 2D channel.
1099	2	Object ignored. Only Points and Regions used.	Blank feature no longer required, no impact on results.
1313	4	No inlet culvert connected to Manhole	This warning is expected when any inlet pipe has an invert above the highest soffit of all outlet pipes. Due to location there will be no impact on results.
2073	72	Object ignored. Only Points and Regions used.	Blank feature no longer required, no impact on results.
2587	23	Unused characters in "Map Output Data Type" are: H	H no longer an output of 2d_PO lines due to recent TUFLOW update. Water level results can be visualised in TUFLOW viewer or 2d head grid result file. No impact to results.
3526	3	SGS Sample Distance command is ignored in SGS Approach == Method C.	SGS is set at 1m, therefore, it samples the underlying DTM and the 1m SGS command is ignored.
2583	4	Material ID contains a manning's n value	Occurs in very few locations, value has been

Warning Number	Occurrence	Content	Justification
		(0.500) greater than Wu n limit (0.100) - n value will be limited in Wu formulation	limited to 0.1 therefore, minimal impact on results.
1991	107	Negative depth at Node culv	Occurrences of negative depths within the model simulation. Expected to have some negative depths in models with such large flows passing through large numbers of culverts. Has no overall impact on model results.

3.3.3 Time to Max Depth

The time to maximum TUFLOW output for the 1% AEP + Higher Climate Change scenario is shown in Figure 3-22. The map shows the peak water depth has been reached in areas surrounding the channel during the model simulation of 10 hours. There are small areas of ponding which are still to peak at 10 hours, analysis of the maximum depth time series results in these areas show they are rising at a very slow rate. Therefore, running the model for longer is unlikely to have noticeable impacts on depths and extents. This shows the model has been run for long enough to understand predicted flood depths across the catchment.

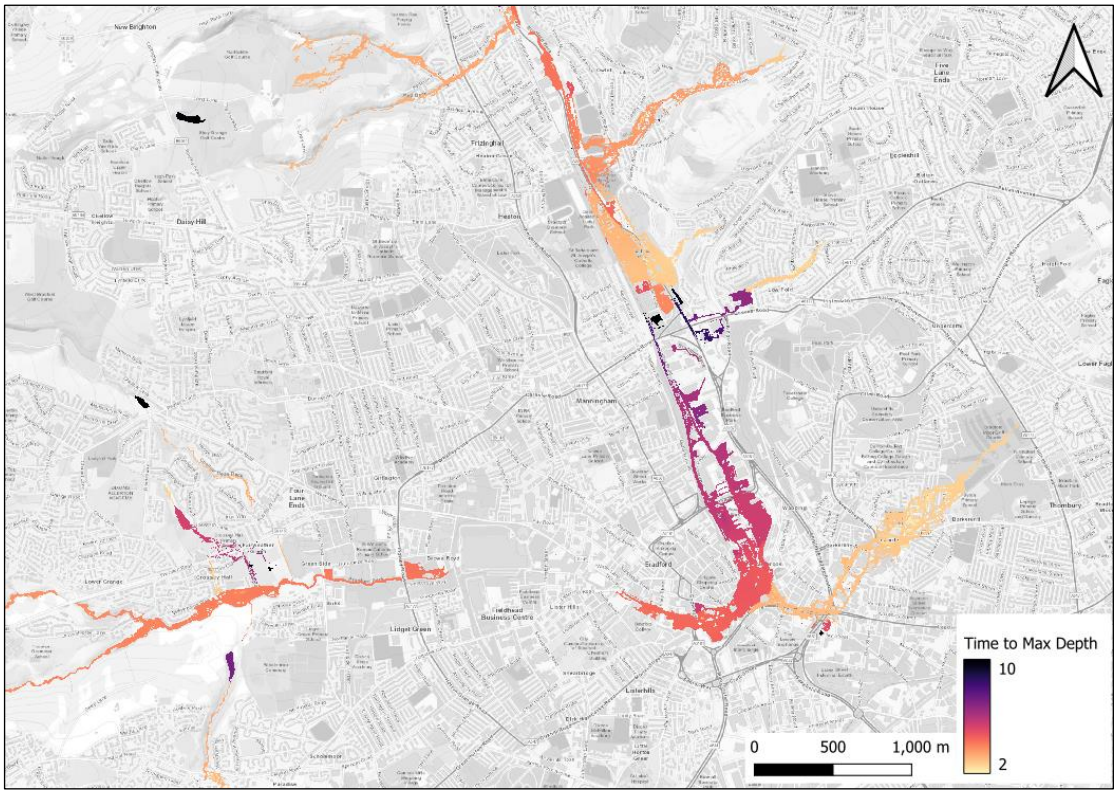


Figure 3-22 – Time to Maximum, 1% AEP + Climate Change Scenario

3.3.4 Mass Balance

The cumulative mass error is within allowable limits of +/- 1% (Figure 3-23). There are culverts in the northern area of the catchment which show signs of instabilities which may be causing the fluctuation in mass error and lowering of timestep. The dvol output for the 1% AEP event is shown in Figure 3-24, it has expected fluctuations as the inflows into the model are at their peak between 2 and 4 hours and water then begins to leave the model at 6 hours.

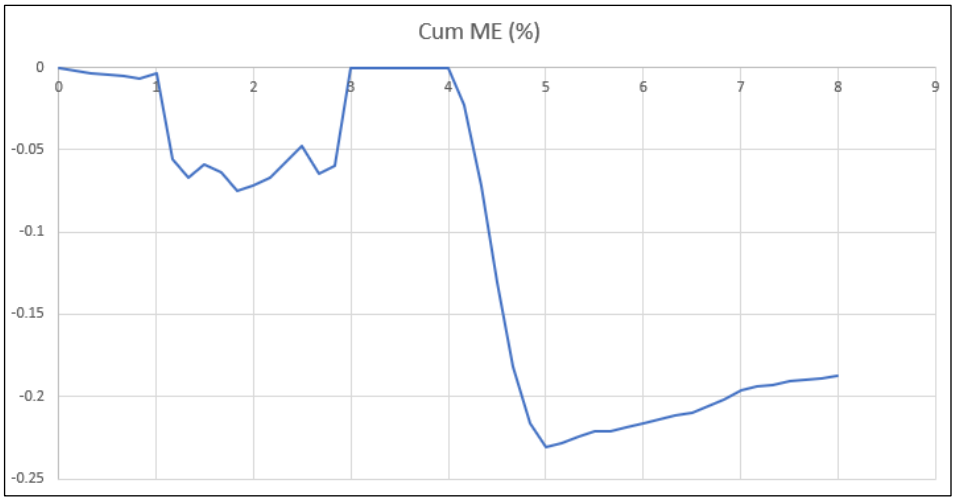


Figure 3-23 – Cumulative Mass Error , 1% AEP

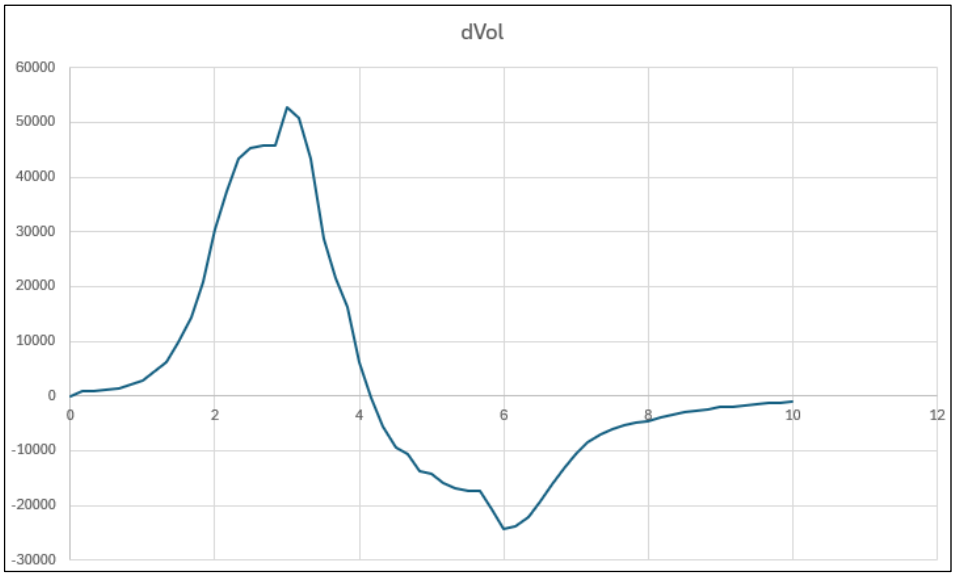


Figure 3-24, dvol Output, 1% AEP

3.3.5 Negative Depths

A large number of negative depths within a model can be an Indicator of minor instabilities. In the 1% AEP event there are 123 1d negative depths recorded. There are large flows entering the model from 1d and 2d inputs, this in tandem with high predicted depths and velocities mean this number of negative depths is not unusual for a model of this scale.

3.3.6 Nu Output

The TUFLOW Nu (courant) output (Figure 3-25) peaks at 0.75 at the start of the simulation. Nu values of 0.7 would suggest a larger cell size could better handle the initial higher velocities within the model. The courant number reduces to 0.2 before a further spike which coincides with the upward limb of the inflow hydrographs. This suggests an increase in velocity within the model at this simulation time, as expected. The Nu value stabilises before a final spell of oscillation at the time large volumes leave the model. Reasons for this are unknown; however, it could potentially be as a result of an increase in backwater level as water leaves the model which result in rapid changes in velocity.

The Nu value has a control value of less than or equal to 1 and generally behaves as expected. Increasing the cell size could help combat the spikes in Nu value, however this would result in an overall loss of model accuracy. Therefore, the cell size is deemed appropriate for the model.

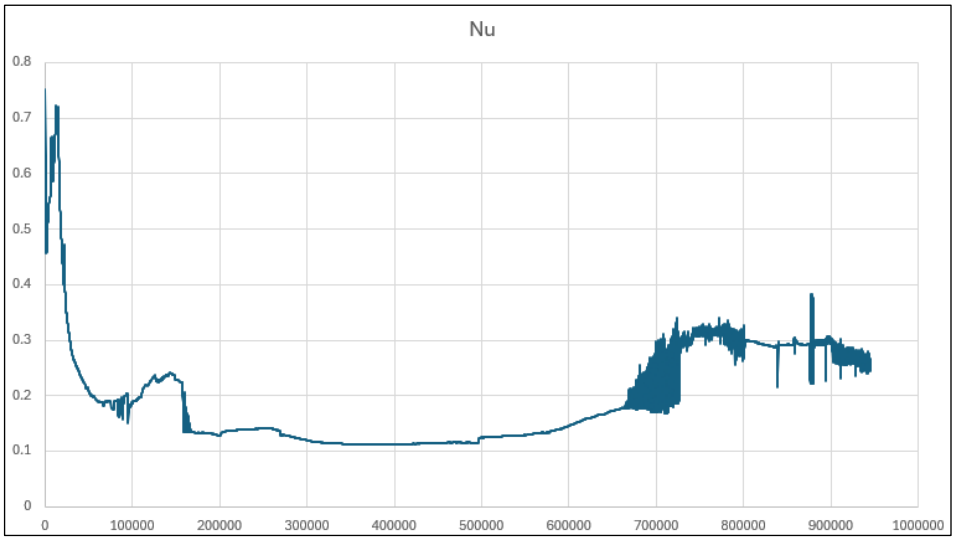


Figure 3-25 – Nu Output, 1% AEP

3.4 Sensitivity Analysis

Sensitivity analysis has been undertaken on the 1% AEP event for the following scenarios:

- Removal of downstream boundary
- Roughness increase by 20%
- Roughness decrease by 20%
- 50% blockage to all culverts.
- Inflows increased by 20%
- Inflows decreased by 20%

The results of the downstream boundary sensitivity test are shown in Figure 3-26 and Figure 3-28. They show that if water was not able to leave the model, there would be increases predominately within the channel for approximately 1.4km, to Firizinghall Road. The increase does not impact as far as Bradford City Centre.

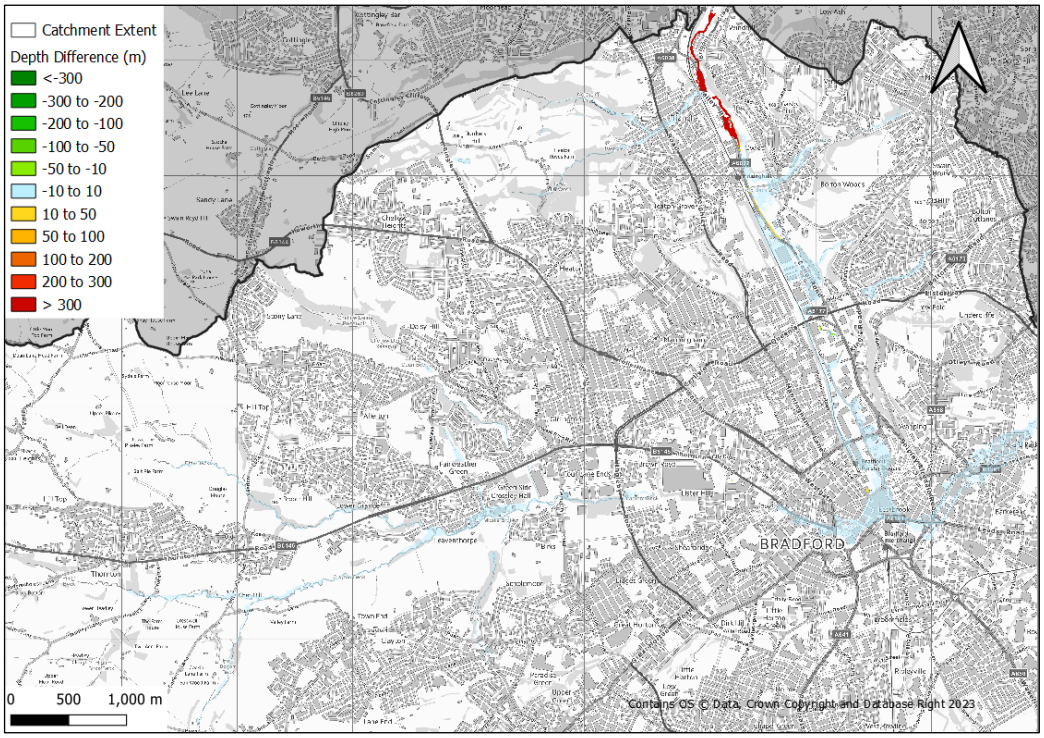


Figure 3-26 – Downstream Boundary Sensitivity Test, 1% AEP.

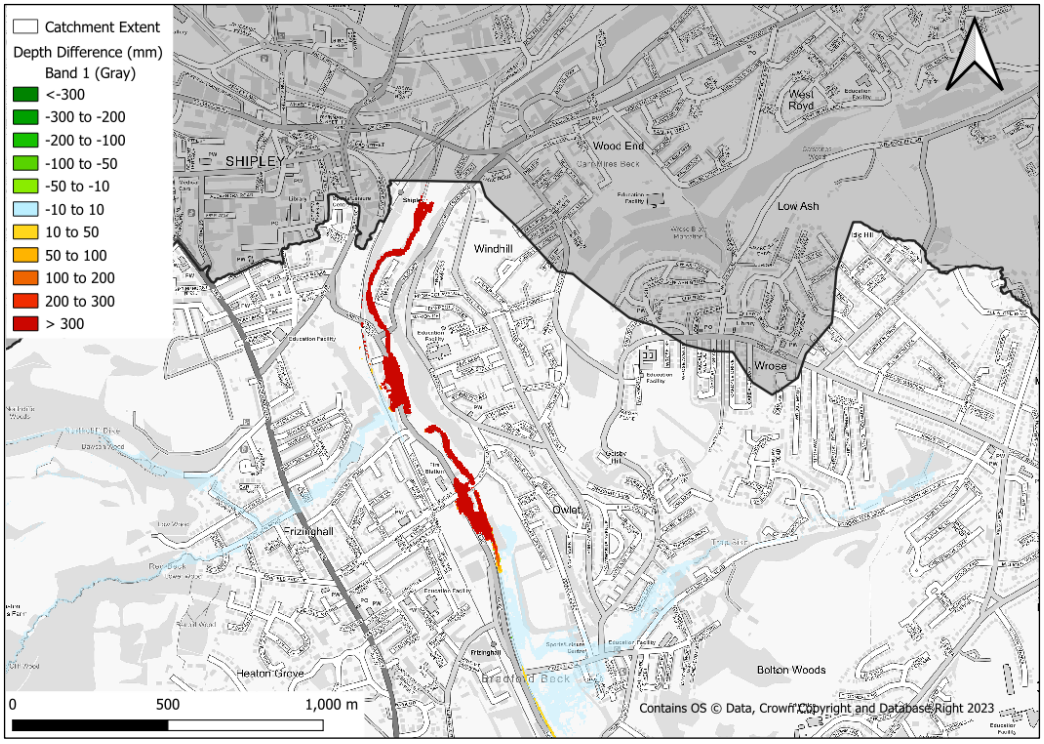


Figure 3-27 – Downstream boundary sensitivity test, downstream area results.

The results of the 20% increase in model roughness scenario are shown in Figure 3-28. It shows there is a predicted increase across the majority of the catchment, as expected. However, in general this is relatively minor. In the centre of Bradford, the increases are predicted to be up to 17mm.

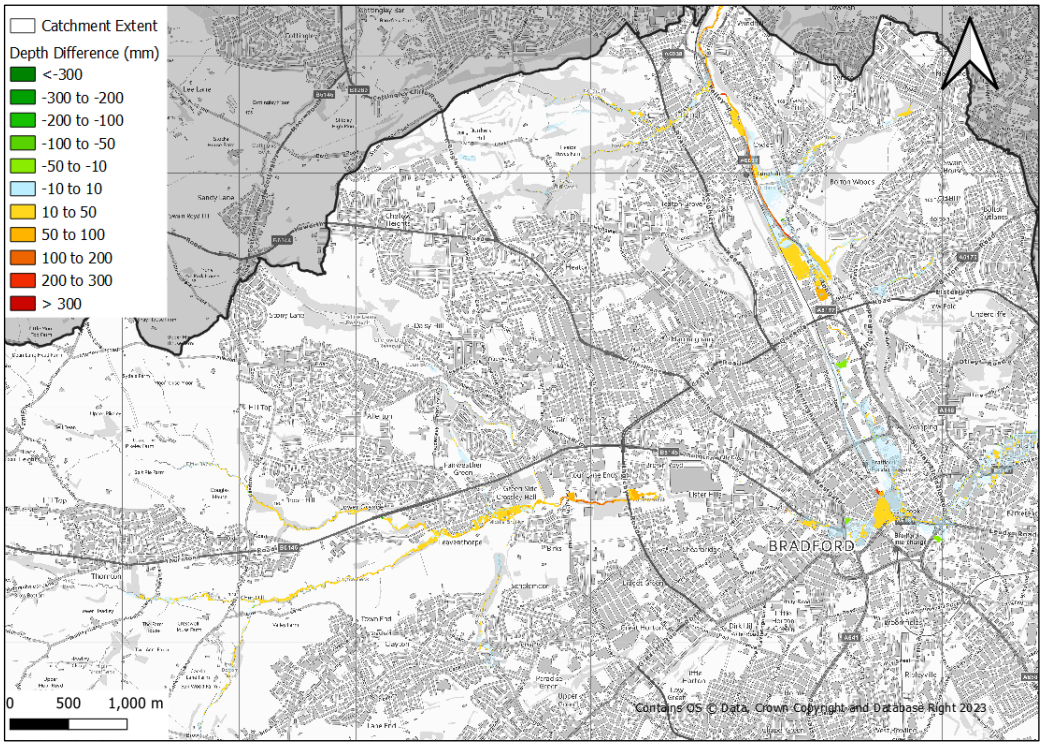


Figure 3-28 – 20% Roughness Increase Sensitivity Test, 1% AEP

The results of the 20% decrease in model roughness scenario are shown in Figure 3-29. It shows there is a predicted decrease across the majority of the catchment, as expected. The locations of decreased flood depths are generally comparable to those of the increased flood depths in the 20% increase scenario.

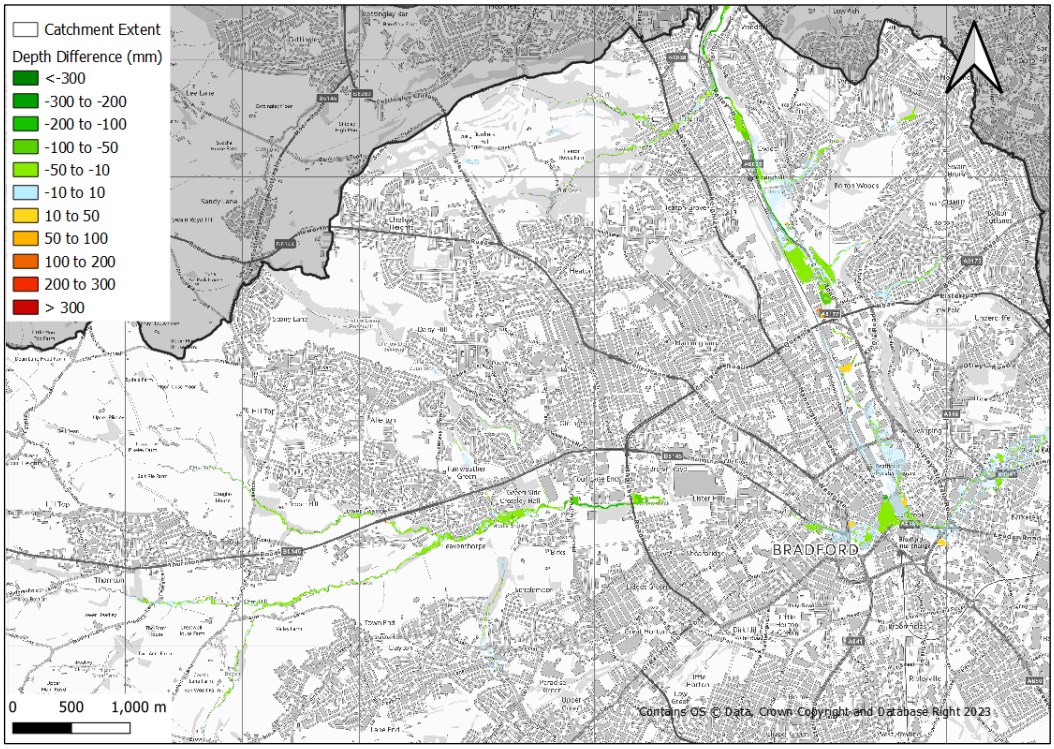


Figure 3-29 - 20% Roughness Increase Sensitivity Test, 1% AEP

The results of the hydraulic model for the culvert blockage sensitivity test are shown in Figure 3-30. There are only minor changes in depth or extent caused by the addition of blockage to culverts. There are minor areas of increase of up to 150mm upstream of culvert inlets. This is most prominent in culverts in the upper reaches of the catchment.

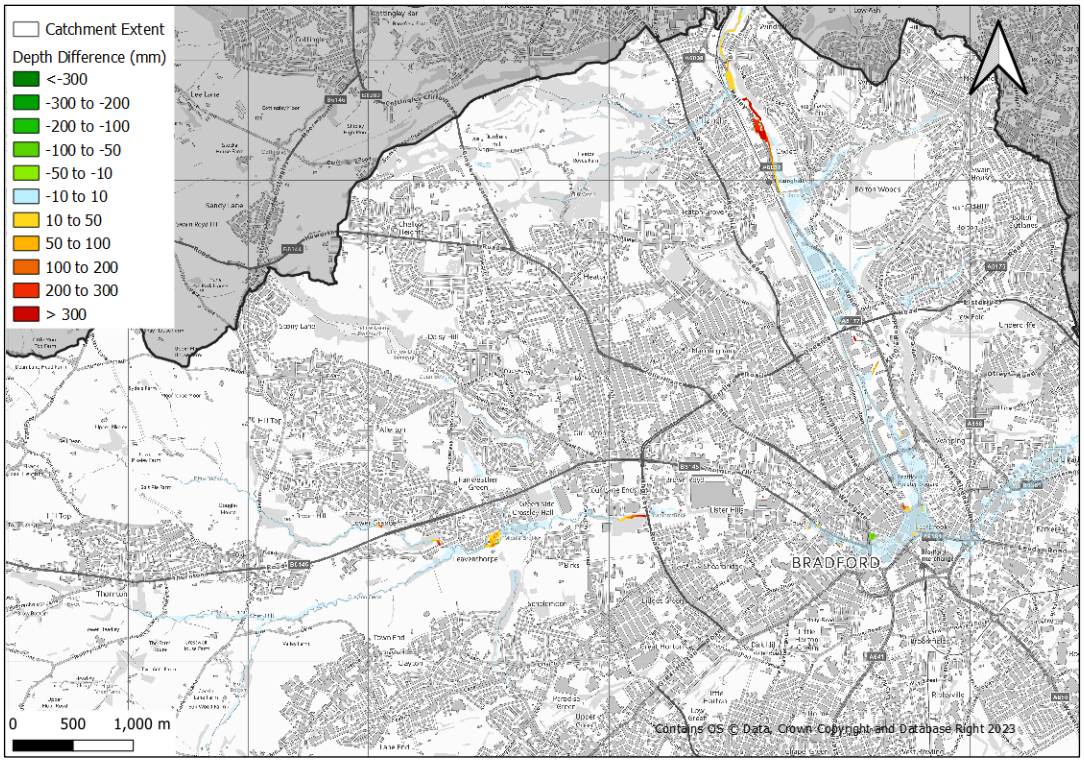


Figure 3-30 - 50% Culvert Blockage Sensitivity Test, 1% AEP

A sensitivity analysis has also been undertaken with a 20% increase of flows into the model and a 20% decrease in flow into the model, this is shown in Figure 3-31 and Figure 3-32. The decrease in maximum flows show a decrease in depths across the whole model extent, there is reduction in the flooded extent to the north of Bradford City Centre. When an increase in flow is applied broadly the opposite results are predicted with increases in extent primarily to the north of the city centre.

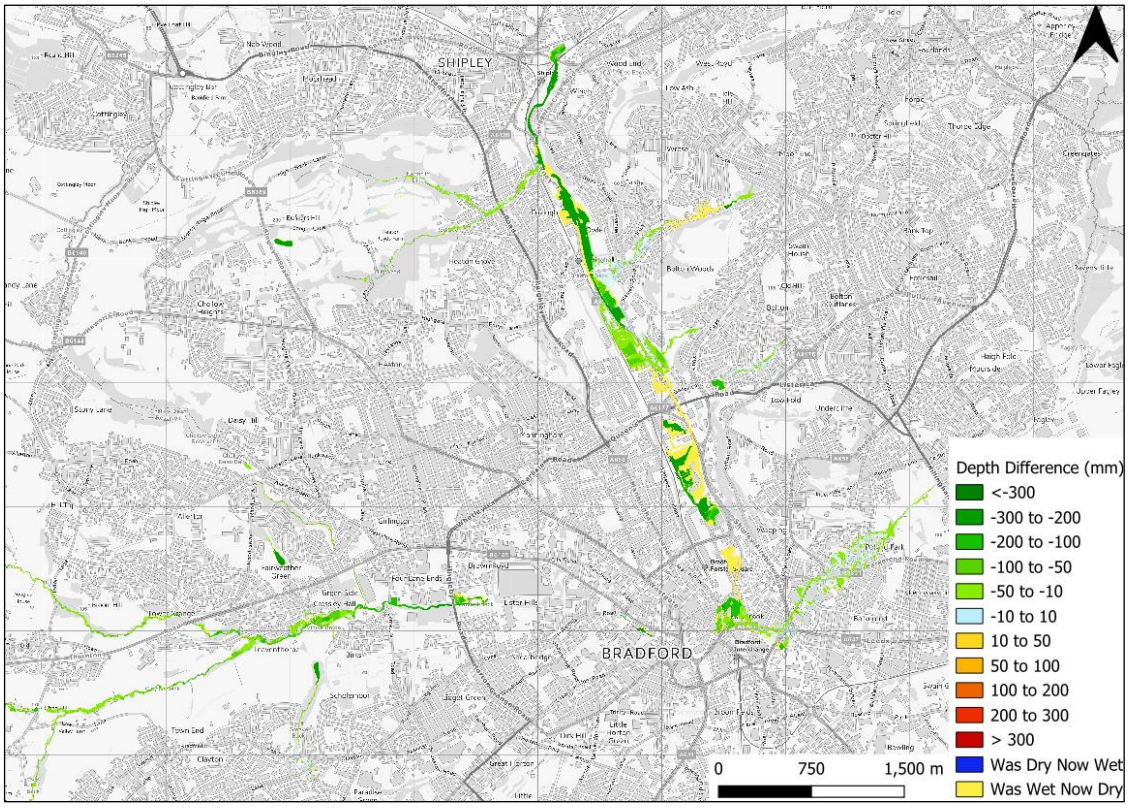


Figure 3-31 – 20% decrease in inflows

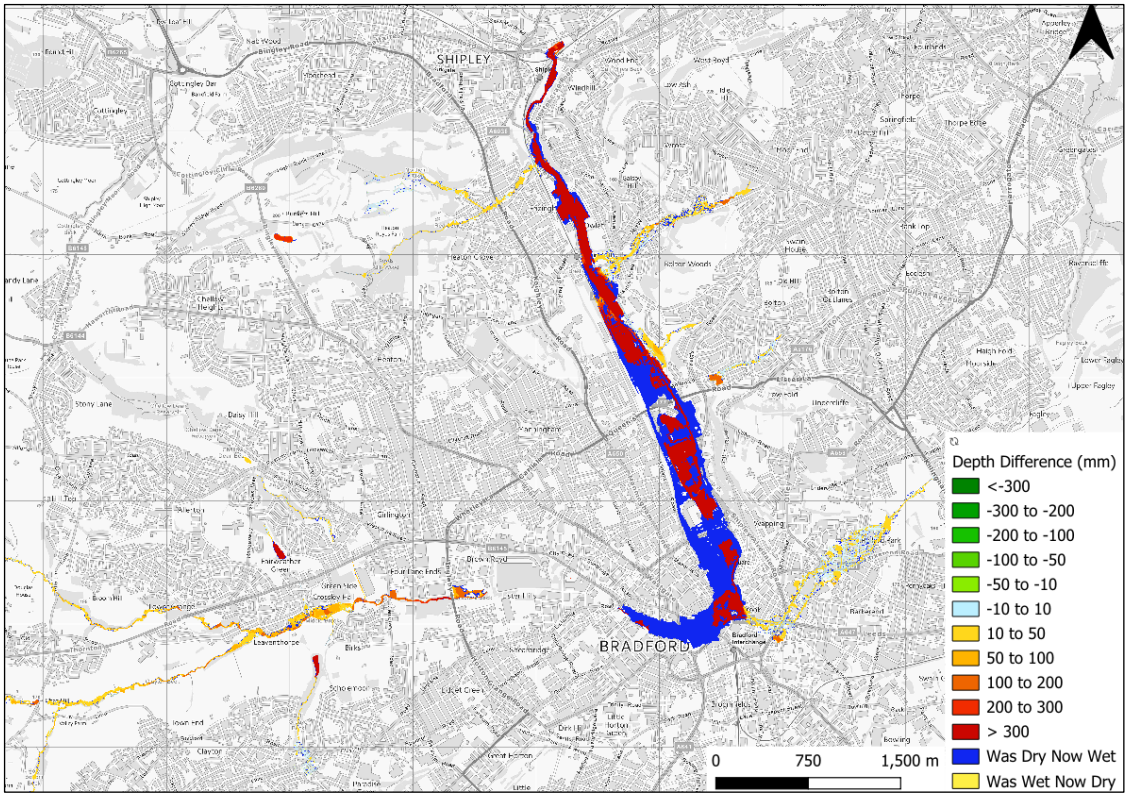


Figure 3-32 – 20% Increase in inflows

4 Assumptions & Limitations

All numerical models are required to make some form of approximation to solve the basic principles of hydraulics, and consequently all have their limitations. These may be related to geometric limitations, numerical simplification, or the use of empirical correlations. It is important to remember that the hydraulic model in this study has been built to assess flooding from fluvial flooding. Local features can greatly affect the chance and severity of flooding. The model may be adapted to model other, or multiple, sources of flooding, but they must be modified accordingly.

The following assumptions have been made within the model:

- Where culvert inverts collected by the survey were not similar to the LiDAR data. Inverts have been estimated from the LiDAR data to ensure there are no depressions or uplifts in the channel from applying the survey inverts. Using the surveyed inverts would have caused localised ponding upstream and downstream of structures.
- In cases where structures vary in diameter and shape between the inlets and outlets, the smallest dimension has been modelled. This ensures a conservative approach.
- Building roughness – Assumes 0.5 Mannings for above 0.03m

The list of modelling limitations is provided below:

- The hydraulic model results are suitable for identifying areas susceptible to fluvial flooding. Detailed modelling may be required for assessing individual properties at risk and options to mitigate that risk. The largely culverted sections to the south and east of Bradford have not been modelled, hence differences in comparison to national surface water flood mapping.
- Survey data collection was not possible in all required locations, therefore much of the channel is based on LiDAR. Anecdotal evidence from CBMDC indicated there have been limited changes to the culvert network in the centre of Bradford since the previous modelling study was completed, therefore locations of culverts and diameters were maintained from previous study.
- 1d inflows were preferred to 2D inflows into the model in locations it was not obvious where 2d flows should be applied.
- The 1d inflows have been applied in the larger culverts towards the centre of Bradford for greater model stability. It was found that when applying 1d inflows to the culverted reaches of the Bowling Beck and Scholemoor catchment that instabilities occurred in the culverts with smaller dimensions.
- Initial water level not implemented; initial flows so small in comparison to flood event that its inclusion is not deemed necessary.
- A site visit was undertaken to the open channel sections of the West Brook catchment, south west of Bradford City Centre. Measurements were able to be taken for the section of open channel within the University Grounds. Access was not possible to the other sections of open channel therefore estimations of the dimensions of the channel have had to be made.

5 Conclusion

This model update has utilised the latest TUFLOW software version to provide a better understanding of fluvial flood risk within the Bradford Beck catchment.

Detailed survey has been collected, primarily within the upper catchment which has been included within the hydraulic model. This has enabled an accurate representation of the tributaries of the Bradford Beck which have not been included in previous modelling studies.

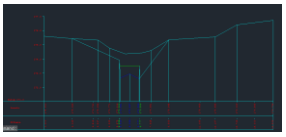
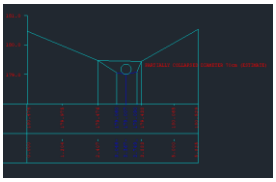
Sensitivity analysis has been carried out to provide a better understanding of the impact of minor changes to the model, ensuring a robust assessment of flood risk.

The development of the Bradford Beck model has provided a local, detailed and refined version of the existing mapping. This includes the subsurface elements of Bradford Beck and its headwaters including the flood relief tunnel, allowing for a more accurate representation of the catchment.

Furthermore, this hydraulic model could be built upon for future studies to identify potential mitigation options to reduce flood risk within the catchment.

Appendix A – Structure Log

The table below details the surveyed structures included within the hydraulic model.

Culvert ID	Source	Type	Width (m)	Height (m)	Assumptions
Struc_01	Survey	Rectangular	1.425	0.927	Inverts interpolated from LiDAR at upstream and downstream to ensure channel not depressed surrounding culvert inlet and maintain channel slope. This is the case for all structures in this table derived from survey.
Struc_03	Survey	Rectangular	1.5	1.43	
Struc_05	Survey	Irregular Arch	3.69	1.54	
Struc_08	Survey	Rectangular	1.4	0.566	Height halved due to uneven bed level for conservative approach. 
Struc_09	Survey	Irregular Arch	3.31	2.05	
Struc_11	Survey	Irregular Arch	2.55	0.96	Uses a combination of structure 11 and structure 12 from survey.
Struc_15	Survey	Circular	0.36		Modelled as 0.36m diameter - This is the width of surveyed upstream structure. Downstream diameter is 1.2m.
Struc_17	Survey	Irregular	1.25	0.54	
Struc_19	Survey	Circular	0.67		
Struc_25	Survey	Irregular arch			
Struc_31	Survey	Circular	0.75		Used width of structure 32 from survey.
Struc_35	Survey	Circular	0.35		Partially collapsed 750mm so modelled as 350mm. 
Struc_37	Survey	Circular	0.55		
Struc_41	Survey	Circular	0.9		

Struc_44	Survey	Rectangular	3.6	2.4	
Scul2	Survey	Circular	0.53		
Scul5	Estimated Location	Circular	0.4		No Survey information available, Assumed size and inverts from LiDAR data.
Scul6	Estimated Location	Circular	0.75		No Survey information available, Assumed size and inverts from LiDAR data.
Scul8	Estimated Location	Circular	0.6		Location estimated from Detailed River Network Provided by Environment Agency
Scul50	Survey	Rectangular	10.09	3.03	Survey shows 2 arches at upstream but rectangular at downstream. It was assumed the effective area was smaller for the rectangular as so this shape was preferred to represent the full culvert.
ASH1	Topo Drawings supplied by CBMDC on 01/07/2025	Circular	0.6		Width and approximate location taken from topographic drawings. Inverts estimated based on surrounding LiDAR levels.
ASH2	Topo Drawings supplied by CBMDC on 01/07/2025	Circular	0.6		Width and approximate location taken from topographic drawings. Inverts estimated based on surrounding LiDAR levels.
ASH3	Topo Drawings supplied by CBMDC on 01/07/2025	Circular	0.9		Width and approximate location taken from topographic drawings. Inverts estimated based on surrounding LiDAR levels.
DRN1	Environment Agency Detailed River Network	Circular	0.9		Location, width and inverts estimated from the Environment Agency Detailed River Network.
DRN2	Environment Agency Detailed River Network	Circular	1.45		Location, width and inverts estimated from the Environment Agency Detailed River Network.

The table below details the omitted structures from the survey with reasons for omission.

Culvert ID	Source	Type	Reason for omission
Struc_22	Survey	Circular	Unable to see location of inflow or outflow in LiDAR or aerial imagery. Already a defined channel in the DTM. The upstream and downstream dimensions and widths would have to be assumed introducing more uncertainty into the model. The culvert is located in the upper catchment on a small tributary so would have limited impact.
Struc_21	Survey	Circular	Unable to see location of inflow or outflow in LiDAR or aerial imagery. Already a defined channel in the DTM. Located in the upper

				catchment on small tributary so would have limited impact.

The table below details the structures provided by CBMDC from the previous modelling study.

Culvert ID	Type	Width (m)	Height (m)	Assumption
culv_998	R	10.014	5.01	
culv_99	C	0.5	1	
culv_985	R	6.348	3.379	
culv_982	R	6.637	2.735	
culv_977	R	4.64	3.82	Contains survey information of Structure 28
culv_972	R	17.1	3.67	Contains survey information of Structure 28
culv_969	R	4.15	3.7	
culv_965	R	4.15	3.7	Contains survey information of Structure 28
culv_961	R	4.3	5.59	Contains survey information of Structure 28
culv_96	C	1.2	1.2	
culv_953	R	3.63	3.19	
culv_945	R	3.8	3.08	
culv_940	R	3.64	2.25	
culv_937	R	3.89	2.02	
culv_930	R	8.38	1.9	
culv_93	R	1.2	1.2	
culv_925	R	5.22	2.8	
culv_920	R	5.67	2.8	

culv_914	R	4.5	2.2
culv_908	R	4.5	2.2
culv_905	R	4.57	2.14
culv_90	C	1.37	1.2
culv_898	R	4.57	2.14
culv_894	R	5.49	2.38
culv_891	R	6.25	2.15
culv_888	R	6.71	2.44
culv_885	R	6.86	2.62
culv_882	R	6.4	1.89
culv_879	R	6.7	1.98
culv_876	R	5.49	1.7
culv_873	R	5.79	1.98
culv_870	R	6.7	1.83
culv_87	R	1.53	1.53
culv_867	R	5.49	2.16
culv_864	R	5.49	2.16
culv_861	R	5.49	2.16
culv_858	R	5.49	2.16
culv_855	R	5.49	2.16
culv_851	R	5.49	2.16
culv_848	R	3.7	3.229

culv_845	R	4.5	2.1
culv_842	R	4.5	2.1
culv_841	R	4.5	2.1
culv_84	C	1.6	1.8
culv_836	R	3.7	3.3
culv_834	C	2.4	2.4
culv_831	C	2.44	2.44
culv_828	R	2.44	2.44
culv_825	R	3	1.9
culv_819	R	5.6	2.2
culv_817	R	5.9	5.305
culv_813	R	2.8	2.8
culv_81	C	1.53	1.53
culv_809	R	2.8	2.8
culv_804	R	5.78	2.8
culv_800	R	3.7	2.4
culv_795	R	3.3	2.325
culv_790	R	3.3	2.325
culv_786	R	5.61	2.35
culv_782	R	5.9	2.2
culv_78	C	1.5	1.5
culv_778	R	3.6	2.4
culv_777	R	4.5	1.775
culv_772	R	4.5	1.9
culv_75	C	1.48	1.48
culv_74	C	1.48	1.48
culv_68	C	1	1
culv_663	R	4.95	2.07
culv_659	C	1.88	1.88

culv_656	R	2.02	1.6
culv_655	R	2.02	1.6
culv_650	R	2.8	1.57
culv_65	C	1	1
culv_647	R	2.8	1.57
culv_645	R	1.55	2.5
culv_643	R	2.5	2.35
culv_640	C	2.1	1.25
culv_639	R	1.8	1.8
culv_634	R	1.78	2.3
culv_631	R	1.52	1.82
culv_628	R	1.52	1.82
culv_625	R	1.52	1.82
culv_622	R	1.9	1.82
culv_62	C	1	1
culv_619	R	5.9	3.3
culv_616	R	2.3	2.05
culv_612	R	2.3	2.05

culv_610	R	0.95	0.95
culv_607	R	1.21	1.435
culv_604	C	1.168	1.482
culv_601	C	0.65	0.65
culv_598	C	0.65	0.65
culv_595	C	0.65	0.65
culv_592	C	0.65	0.65
culv_59	C	1	1
culv_589	C	0.65	0.65
culv_586	C	0.65	0.65
culv_583	C	1.05	1.05
culv_580	C	1.05	1.05
culv_58	R	1	1
culv_577	C	1.35	1.35
culv_575	C	1.35	1.35
culv_571	C	1.35	1.35
culv_568	C	1.2	1.2
culv_565	C	1.2	1.2
culv_562	C	1.05	1.05
culv_559	C	1.5	1.5
culv_556	C	1.5	1.5
culv_553	C	1.5	1.5
culv_550	C	1.5	1.5
culv_547	C	1.5	1.5
culv_544	C	2	2
culv_541	C	2	2
culv_538	R	1.9	1.9
culv_535	R	2.2	1.9
culv_532	R	2.2	1.9

culv_530	R	2.2	1.9
culv_525	R	2.3	1.9
culv_520	R	1.5	1.7
culv_515	R	1.5	1.7
culv_511	R	1.5	1.35
culv_503	R	1.5	1.7
culv_50	R	3.3	2.325
culv_497	R	2.5	1.3
culv_491	R	1.5	1.7
culv_483	R	1.5	1.7
culv_475	R	1.5	1.7
culv_474	C	2.85	2.85
culv_468	R	2.9	2.9
culv_465	R	3.27	2.17
culv_461	R	3.2	1.7
culv_458	R	1.5	1.7
culv_451	R	1.5	1.7
culv_446	R	1.7	1.35

culv_442	R	1.7	1.35	
culv_44	R	3.3	2.325	
culv_434	R	3.45	2.1	
culv_431	R	4.46	1.74	
culv_427	R	4.42	1.94	
culv_424	R	4.63	1.82	
culv_421	R	7.04	1.71	
culv_418	R	6.06	2.79	
culv_415	R	6.06	2.79	
culv_412	R	6.19	2.5	
culv_410	R	6.18	2.5	
culv_406	R	6.17	2.61	
culv_403	R	6.17	2.61	
culv_399	R	7.2	1.6	Minor adjustment to inverts to ensure smooth gradient
culv_394	R	3.13	1.76	Minor adjustment to inverts to ensure smooth gradient
culv_389	R	2.24	2.03	Minor adjustment to inverts to ensure smooth gradient
culv_384	R	3.13	1.76	Minor adjustment to inverts to ensure smooth gradient
culv_38	R	3.3	2.325	
culv_379	R	2.24	2.03	Minor adjustment to inverts to ensure smooth gradient
culv_378	R	5.55	2.58	Minor adjustment to inverts to ensure smooth gradient
culv_371	R	5.14	2.41	Minor adjustment to inverts to ensure smooth gradient
culv_366	R	3.81	2.286	
culv_361	R	3.81	2.286	

culv_355	R	3.27	2.63
culv_349	R	3.9	2.17
culv_346	R	3.52	2.74
culv_337	R	3.89	2.38
culv_331	R	3.8	2.3
culv_330	R	3.8	2.3
culv_32	R	3.3	2.325
culv_319	R	3.8	2.3
culv_314	R	3.8	2.3
culv_307	R	3.8	2.3
culv_301	R	3.8	2.3
culv_295	R	3.94	1.93
culv_289	R	5.18	2.01
culv_283	R	4.79	1.99
culv_282	R	4.96	1.91
culv_271	R	3.6	1.82
culv_27	R	3.3	2.325
culv_266	R	3.42	1.85
culv_26	R	3.3	2.325
culv_258	R	3.6	1.82

culv_251	R	3.42	1.85
culv_250	R	3.6	2.431
culv_239	R	3.6	2.431
culv_235	R	7.66	1.99
culv_231	R	7.66	2.13
culv_224	R	3.74	2.82
culv_218	R	3.68	2.64
culv_215	R	0.7	0.65
culv_212	R	1.5	1.6
culv_209	R	1.5	1.6
culv_206	R	1.5	1.6
culv_203	R	0.85	0.68
culv_202	R	0.85	0.68
culv_197	C	1.02	1.02
culv_194	R	1.52	1.52
culv_191	C	3	1.1
culv_19	R	5.75	3.99
culv_187	C	2.1	2.1
culv_186	C	0.5	0.5
culv_182	C	1.1	1.1
culv_18	R	5.75	3.99
culv_179	C	1.1	1.1
culv_176	R	1.2	1.2

culv_173	R	1	1.1
culv_170	R	1	1.1
culv_17	C	4.17	4.17
culv_167	R	1	1.1
culv_164	R	1	1.1
culv_161	R	1	1.1
culv_158	C	1	1.1
culv_155	C	0.9	0.9
culv_154	C	0.9	0.9
culv_149	C	0.9	0.9
culv_146	C	0.9	0.9
culv_143	C	0.9	0.9
culv_140	R	0.9	0.9
culv_14	R	1.46	1.46
culv_137	R	3.2	2.2
culv_134	C	3.2	2.2
culv_131	C	2.85	2.85
culv_127	C	2.85	2.85
culv_124	R	0.72	0.44
culv_122	R	0.72	0.44
culv_118	R	0.72	0.44
culv_115	R	0.72	0.44
culv_112	R	0.72	0.44
culv_11	R	4.41	1.304
culv_109	R	0.72	0.44

culv_106	R	0.72	0.44
culv_103	R	0.72	0.44
culv_1016	C	2.3	2.3
culv_1013	R	2.43	1.201

Appendix B – Hydrological Methodology

Hydrology Estimation Calculation Record

Project code: 65205277

Project title: Bradford Beck Hydraulic Modelling

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

Page

1 METHOD STATEMENT ---------- 3

2 LOCATIONS WHERE FLOOD ESTIMATES REQUIRED ---------- 9

3 STATISTICAL METHOD ---------- 20

4 REVITALISED FLOOD HYDROGRAPH (REFH2) METHOD ---------- 26

5 DISCUSSION AND SUMMARY OF RESULTS ---------- 28

Approval

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:		Andrew Sims (Hydraulic Modeller)	1
Calculations checked by:		Jack Pickering	3
Calculations approved by:		Jack Pickering	3

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

Purpose of study

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	A hydraulic model for the Bradford Beck is being developed to understand the present day flood risk surrounding the Beck and it's tributaries. The hydrology estimates presented in this document were assessed to support the hydraulic modelling. Both peak flows and flood hydrographs were required. The area of the full Bradford Beck catchment is 57.94km^2. Flow estimates have been generated for the following return periods: 1 in 2, 5, 10, 20, 30, 50, 100, 200, and 1000 year return periods.

Overview of catchment

Item	Comments
Description of catchment	The Bradford Beck is an ordinary watercourse that passes through Bradford City Centre. Through the central and downstream areas of the catchment Bradford Beck flows through a heavily urbanised area and is largely culverted. The upper catchment is more rural in nature. The Bradford Beck catchment is heavily urbanised ($URBEXT_{2000=}$ 0.4214) and moderately permeable, BFIHOST 0.549. The entire Bradford Beck catchment has an area of 57.6km^2. For the purpose of this study the catchment has been split up to understand the different characteristics of each area. Three separate catchments with varying catchment descriptors have been analysed to obtain accurate flows for the respective watercourses in the catchment. As these catchments represent the varying nature of the whole Bradford Beck catchment, flows have been derived for them and scaled based on their area to the other subcatchments of the Bradford Beck Obtaining peak flows for subcatchments of the Bradford Beck allows for more accurate representation of the flows arising from each watercourse and the predicted flood risk. The catchment descriptors purchased and analysed are: • Catchment 1: Clayton and Pitty Beck (412750 432950) • Catchment 2: Red Beck (415050 436700) • Catchment 3: Bowling Beck (416400 432800) The Pitty and Clayton Beck are at the headwaters of the Bradford Beck catchment, it is 14.9km^2 and considered slightly to moderately urbanised ($URBEXT_{2000}$ = 0.1003). It includes residential areas of Thornton and Allerton The wider catchment is of mixed geology and of moderate permeability (BFIHOST = 0.592) This catchment has been used to derive flows for the more rural subcatchments of the Bradford Beck. The Red Beck is a tributary of the Bradford Beck in the north of the catchment. It joins the Bradford Beck approximately 1.5km to the south of the confluence with the River Aire. The catchment has an area of 4km^2 and is considered heavily urbanised ($URBEXT_{2000}$ = 0.2203). It is considered permeable with a BFIHOST of 0.672. This catchment has been used to derive flows for semi rural sub catchments of the Bradford Beck. The Bowling Beck is a tribuatary to the Bradford Beck to the south of the city centre with a catchment area of 5.8km^2. It is a very heavily urbanised with a $URBEXT_{2000}$ of 0.5597. The Bowling Beck catchment descriptors are largely representative of the other urbanised catchments that contribute to flow in the

	Bradford Beck. Its BFIHOST is 0.358. The Bowling Beck catchment has been used to create hydrographs for the majority of the smaller delineated catchments within the study area. This catchment has been used to derive flows for the more heavily urbanised sub catchments of the Bradford Beck. The flows from this catchment were scaled to the majority of the sub catchments due the generally built of area of the Bradord Beck catchment. Catchment descriptors have been purchased for the 3 catchments described above. The descriptors have been used and adjusted where necessary to create inflows for all sub catchments within the Bradford Beck catchment. The Bradford Beck catchment has been delineated into 22 separate sub catchments, inflows have been derived for each. Analysis has also been completed on the Chellow Dean Beck due to the reservoir located in the upper catchment impacting flows. For this catchment the descriptors from the Red Beck have been used and tests have been undertaken for an adjusted FARL.

Flood estimates required

Item	Comments
Description of catchment	The assessment required the return periods 1 in 2, 10, 30, 50, 75, 100, 200, and 1000 year return periods. Adjustments of 25% (higher) and 40% (upper) to peak river flows were applied to the 100 year event for the consideration of climate change.

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 11 of the NFA Peak Flow Dataset

Gauging stations (flow or level at the sites of flood estimates or nearby at potential donor sites) All Catchments

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catchment area (km²)	Type	Period of available data
Calder	Mytholmroyd	F1204	27088	SE011260	141.9	Velocity Area	1989 -
Eastburn Beck	Crosshills	F1525	27084	SE020452	43.4	Flat V Weir	1988 -
Crimple	Burn Bridge	F2120	27051	SE283518	8.1	Flat V weir	1972 -
Wharfe	Tadcaster	F2002	27089	SE477441	818	Multi Path Ultrasonic	1991 -

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catchment area (km²)	Type	Period of available data
Tame	Uppermill	692418	69048	SD994051	40.6	Non Standard Weir	1998 -
Wharfe	Wetherby Flint Mill	F2004	27002	SE422473	758.9	Masonry Mill Weir	1936 -
Aire	Kildwick Bridge	F1503	27035	SE011456	282.3	Velocity Area Station	1966 -

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
Calder @ Mytholmroyd	1989 -	No	Yes	Yes	No	Heavily reservoired. Estimated 21.4% of catchment area drains through around 8 impoundments.December 2015 event was much higher than previous maximum and led to significant by-pass
Eastburn Beck @ Crosshills	1988 -	No	Yes	Yes	No	All flows contained, no known bypassing. Backing-up from the River Aire (confluence <100m downstream) causes drowning at high flows. Natural regime. No known artificial influences.
Crimple @ Burn Bridge	21/01/1972 - N/A	No	Yes	Yes	No	Flashy flow regime in catchment headwaters. No known artificial influences. overtops in very high flows and structure thought to drown in large floods. No bypassing and theoretical rating thought to give a good representation of flow throughout the range.
Wharfe @ Tadcaster	1936 -	No	Yes	Yes	No	Regulation effect of headwater reservoirs evident at low flows. Only known bypass in Dec 2015 event.

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
Tame @ Uppermill	1998 -	No	Yes	No	No	Several abstractions and discharges, the main influence being from the reservoirs . Station opened in July 1968 on an existing non-standard weir with a low, sharp metalwork crest and gradual downstream stone slope
Wharfe @ Wetherby Flint Mill	1936 -	No	Yes	Yes	No	Regulation effect of headwater reservoirs evident at low flows. Weir control insensitive at low flows. Unlikely to drown at high flows, though small amount of bypassing on the right bank possible.
Aire@Kildwick Bridge	1966	No	27035	Yes	No	Abstraction for supply is made from reservoirs at Embsay and Elslack and for canal support at Winterburn. The Leeds-Liverpool Canal can influence the flow pattern but has a small overall impact.
Give link/reference to any further data quality checks carried out			N/A			

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Example Rating Equation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Eastburn Beck @ Crosshills	Extrapolation	Q = 26.405 * (h - 0.2510) ^ 1.747	No	Good corelation, Minor Scatter All flows contained, no known bypassing . Gauged to 30% of QMED but theoretical rating expected to be reasonable at QMED
Calder @ Mytholmroyd	Extrapolation	Q = 2.086 * (h + 0.8560) ^ 2.515	No	Minor Scatter, strong correlation. Ultasonic and hydraulic model have been used to review rating
Crimple @ Burn Bridge	Theoretical Equation	Q = 7.262 * (h - 0.05200) ^ 1.676		Minor Scatter, strong correlation
Wharfe @ Tadcaster		Q = 17.730 * (h + 0.05600) ^ 2.259		Satisfactory Correlation, Gauged above QMED. Full range ultrasonic flow gauge
Tame @ Uppermill		Q = 29.909 * (h - 0.04931) ^ 1.434		Very good correlation

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Example Rating Equation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Wharfe @ Wetherby Flint Mill		Q = 74.004 * (h - 0.2620) ^ 1.654		Very good correlation
Aire @ Kildwick Bridge		Q = 4.700 * (h + 0.5900) ^ 2.232		Moderater Scatter in the ratings curve.
Give link/reference to any rating reviews carried out		None		

Other data available and how it has been obtained

Type of data	Comments
Check flow gaugings (if planned to review ratings)	Ratings reviewed for each gauge used in pooling
Historic flood data – give link to historic review if carried out.	EA Recorded Flood Outlines online map, no further information.
Extra data for other sites in pooling groups	All pooling group data taken from HiFows v11 and NRFA – no additional data collated.
Flow data for events	Stage data provided by the EA for two locations
Rainfall data for events	Rainfall Data provided for the catchment.
Potential evaporation data	Not provided
Results from previous studies	Bradford Beck Modelling 2012
Other data or information (e.g. groundwater, tides)	No other data used.

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	A hybrid method was used, calibrating the ReFH2 hydrographs with the derived peak flows from the FEH Statistical method. Flows were derived for 3 sub catchments within the Bradford Beck catchment. These sub catchments were deemed representative of the other catchment types within the area. The flows from these catchments were scaled to all other sub catchments based on their area. This method was chosen due to the homogeneity of the site, the BFIHOST, FARL and SAAR for each site are all very similar for the other sub catchments. Further detail on which of the 3 catchments is used to scale the other sub catchments can be found later in the report. Sewer capacity has not been altered. An assessment of the locations of sewers has been undertaken and there are not areas which drain out of the Bradford Beck catchment area. Further detail of sewer analysis is shown in figure 2-7.
Outline the conceptual model, addressing questions such as:	The entirety of the Bradford Beck catchment is of interest, with the aim of the study to provide updated

• Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	flood maps to inform present day flood risk. Flood volumes assicated with peak flows are the likely causes of flooding. There is potentially a need to consider temporary debris. There is potentially a need to consider the attenuation from Chellow Dean reservoir.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.75 (or BFIHOST19 >0.65), consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing, extensive floodplain storage – consider choice of method carefully	The Bradford Beck catchment is moderately permeable, BFIHOST 0.549. It is Heavily urbanised (Urbext2000: 0.4214) The Clayton Beck The catchment is considered moderately permeable (BFIHOST19 = 0.576). The catchment is considered moderately urbanised (URBEXT2000 = 0.1003). The Red Beck Catchment has $URBEXT_{2000}$ = 0.2203 and it is considered permeable with a BFIHOST of 0.672. The Bowling Beck Catchment is heavily urbanised $URBEXT_{2000}$ = 0.5597 and BFIHOST of 0.358. The Chellow Dean drainage basin has a reservoir located in the upper catchment. The catchmentis located to the west of the Red Beck catchment. The impact of a reduced FARL will be tested on this catchment.
Initial choice of method(s) and reasons Will the catchment be split into sub-catchments? If so, how?	The catchment was split into sub-catchments based on a watershed analysis in QGIS using the latest EA 1m LiDAR. This gave 22 separate sub-catchments within the Bradford Beck catchment. A hybrid method will be used, calibrating the ReFH hydrographs with the derived peak flows from the FEH Statistical method
Software to be used (with version numbers)	FEH Web Service v3.0[1] WINFAP-FEH v5[2] ReFH2.3

[1] https://fehweb.ceh.ac.uk/GB/map

[2] WINFAP-FEH v5 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

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.

Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA (km^2)	Revised AREA if altered
01	Clayton and Pitty Beck	Site 01	457750	448500	9.20	N/A
02	Red Beck	Site 02	415050	436700	4.03	N/A
03	Bowling Beck	Site 03	416400	431114	5.79	N/A
Reasons for choosing above locations		Site 01: The Clayton and Pitty Beck catchment was chosen as it represents the catchments upstream of the Bradford urban area. This location has been chosen as they are tributaries to the Bradford Beck representing the more rural upstream catchment. Detailed analysis of this catchment will give a more accurate flow into the Bradford Beck. Flows from this catchment have been scaled to other subcatchments with similar characteristics. Site 02: The Red Beck was chosen as it is a clear separate catchment downstream of the main Bradford Beck catchment. It is less rural than the Clayton and Pitty Beck but does not have as much urban extent as the majority of the Bradford Beck catchment. Flows from this catchment have been scaled to other subcatchments with similar characteristics. Site 03: The Bowling Beck catchment was chosen as it is a heavily urbanised catchment representative of the majority of the central area of Bradford, offering catchment descriptors which are representative of the urban city centre therefore providing data to estimate wider flows proportionately. Flows from this catchment have been scaled to other subcatchments with similar characteristics. Information on what catchment flows have been scaled based on the above catchments are shown in the sections below.				

Important catchment descriptors at each catchment.

Site	FARL	PROPWET	BFIHOST	BFIHOST (19)	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
Clayton and Pitty Beck	1	0.57	0.576	0.592	3.47	108.8	1044	20.61%	0.1003	0.0105
Red Beck	0.988	0.57	0.636	0.672	2.45	85.3	905	17.64	0.2203	0.0205
Bowling Beck	1	0.57	0.339	0.358	2.14	54.2	877	37.68	0.5597	0.0324

Checking catchment descriptors

Record how the catchment boundary was checked and describe any changes (refer to maps if needed)	The catchment boundary is presented in Figure 2-1. The FEH catchments for Clayton and Pitty Beck, Bowling Beck and Red Beck are shown in figures 2-2, 2-3, 2-4 and 2-5. The assessed catchment was split into sub-catchments based on hydrological analysis, and the final catchment area kept as is. All of the subcatchments are shown in figure 2-6.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	FEH Web Service provides URBEXT values for the year 2000 ($URBEXT_{2000}$). $URBEXT_{2000}$ is not simply an update of $URBEXT_{1990}$ but it is based on new data produced using different mapping techniques. Table 3.1 shows the re-statement of the categories of urbanisation distinguished in the FEH according to their URBEXT 1990 values, together with 'equivalent' URBEXT 2000 values. To assess whether the URBEXT2000 value required adjustment, the urban extent from catchment descriptors was overlaid over current OS mapping to determine whether there were any discrepancies in the urban extent in relation to the present day. No discrepancies were found, therefore the URBEXT2000 value was assumed to be representative of the current catchment conditions and no adjustment was required. The Urban Expansion Factor method is no longer in the current guidance due as it uses nationally averaged factors and employs a 50x50km^2 grid. Urban adjustments have been assessed by comparing current satellite mapping and the urbext layer extents., it was found that negligible adjustments would be required so left as is.

Category	URBEXT1990	URBEXT2000
Essentially rural	0.000 <_ $URBEXT_{1990}$ < 0.025	0.000 <_ $URBEXT_{2000}$ < 0.030
Slightly urbanised	0.025 _ $URBEXT_{1990}$ < 0.050	0.030 _ $URBEXT_{2000}$ < 0.060
Moderately urbanised	0.050 _ $URBEXT_{1990}$ < 0.125	0.060 _ $URBEXT_{2000}$ < 0.150
Heavily urbanised	0.125 _ $URBEXT_{1990}$ < 0.250	0.150 _ $URBEXT_{2000}$ < 0.300
Very heavily urbanised	0.250 _ $URBEXT_{1990}$ < 0.500	0.300 _ $URBEXT_{2000}$ < 0.600
Extremely heavily urbanised	0.500 _ $URBEXT_{1990}$ _ 1.000	0.600 _ $URBEXT_{2000}$ _ 1.000

Source of URBEXT	URBEXT2000
Method for updating of URBEXT	N/A

Figure 2-1 shows the full Bradford Beck catchment. Catchment descritptors have also been purchased for the catchments shown in Figure 2-2. These catchment descriptors are assumed to be representative of the varying sub catchments of the Bradford Beck. They have then been used to estimate the flows for each part of the catchment. The Clayton and Pitty Beck descriptors have been used for sub catchments which are largely rural. Bowling Beck catchment descritptors have been used for sub catchments which are heavily urbanised. The Red Beck catchment descriptors have been used for catchments which are slightly urbanised.

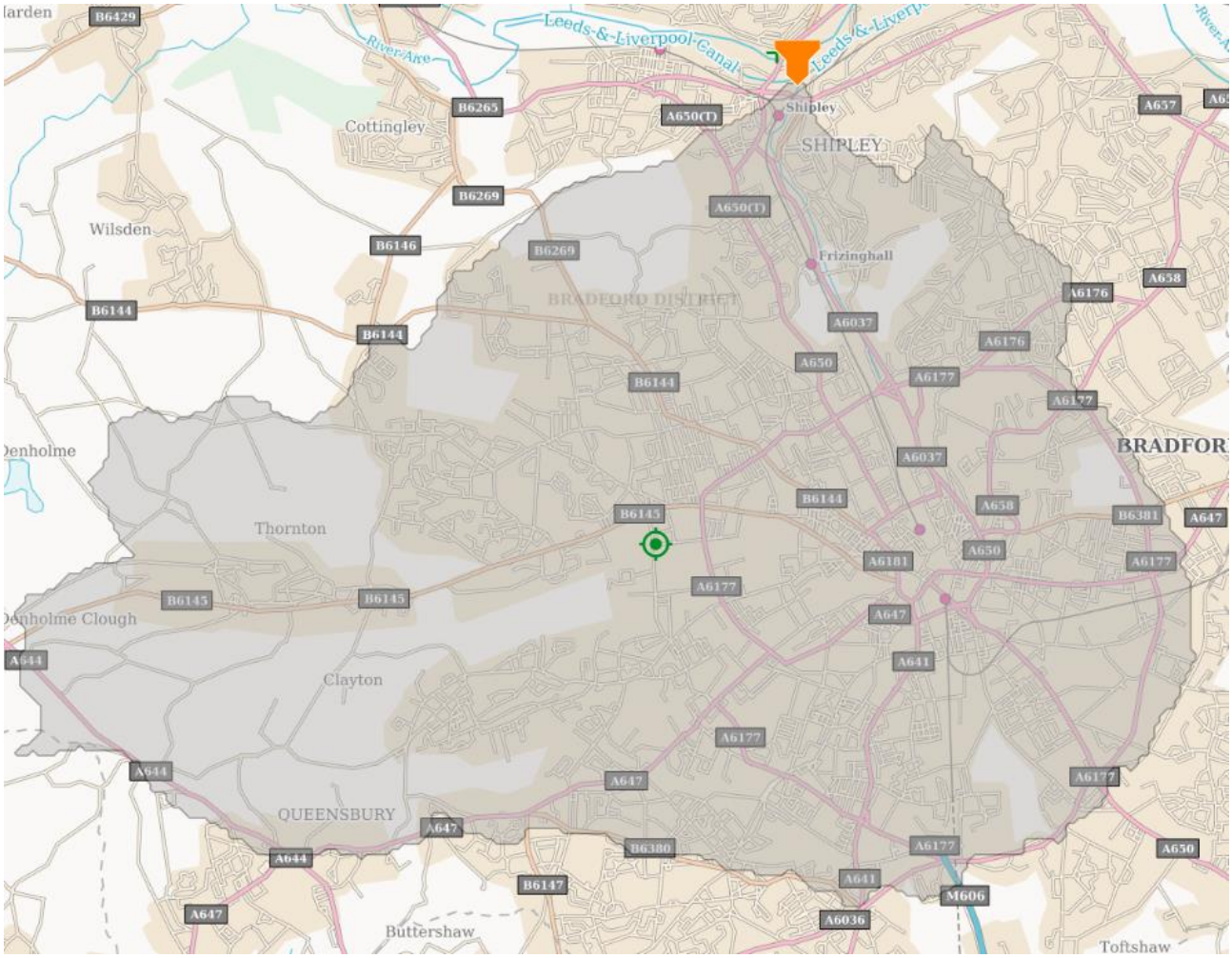


Figure 2-1 FEH Full Bradford Beck Catchment

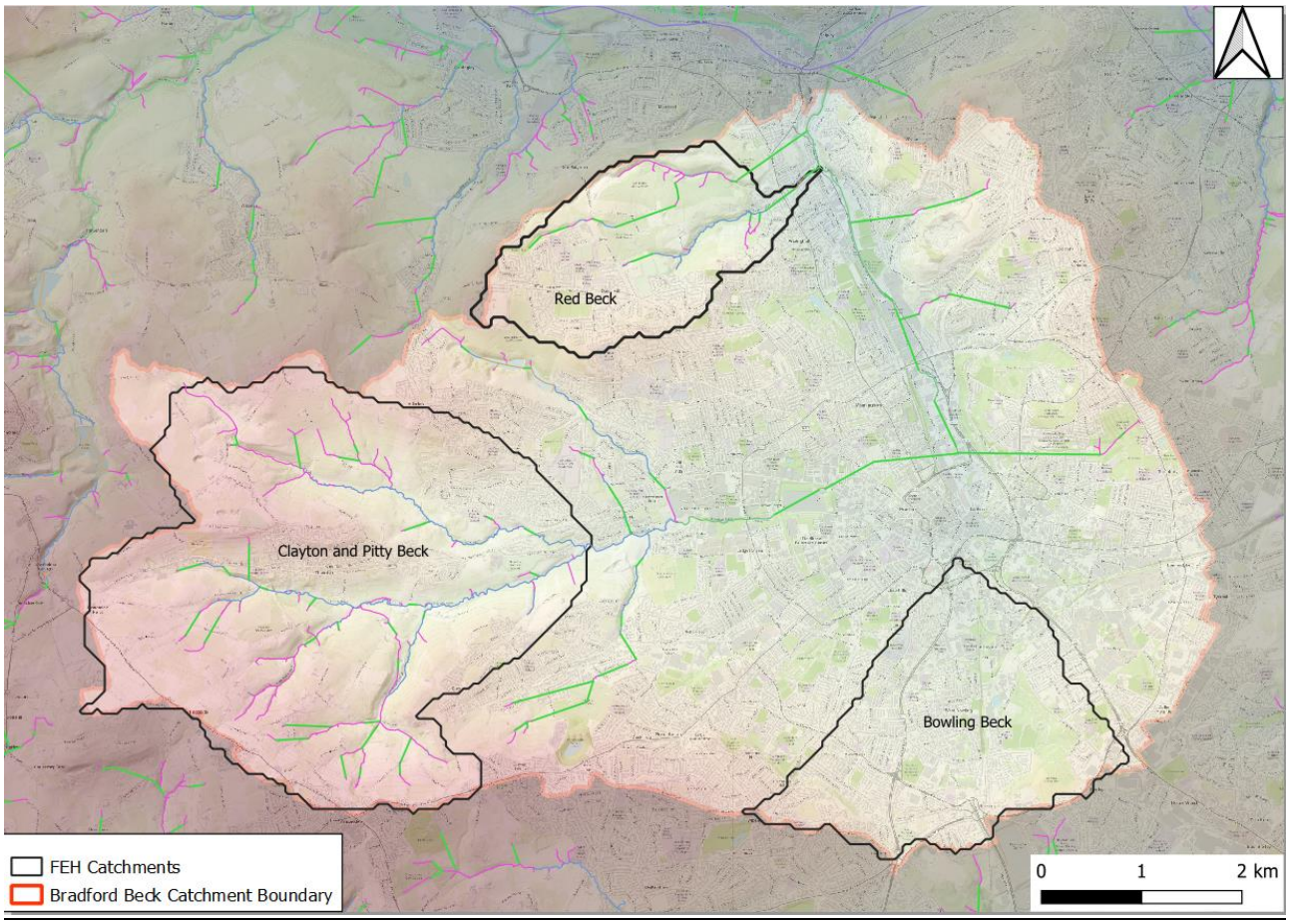


Figure 2-2 Red Beck, Clayton and Pitty Beck and Bowling Beck catchment boundaries

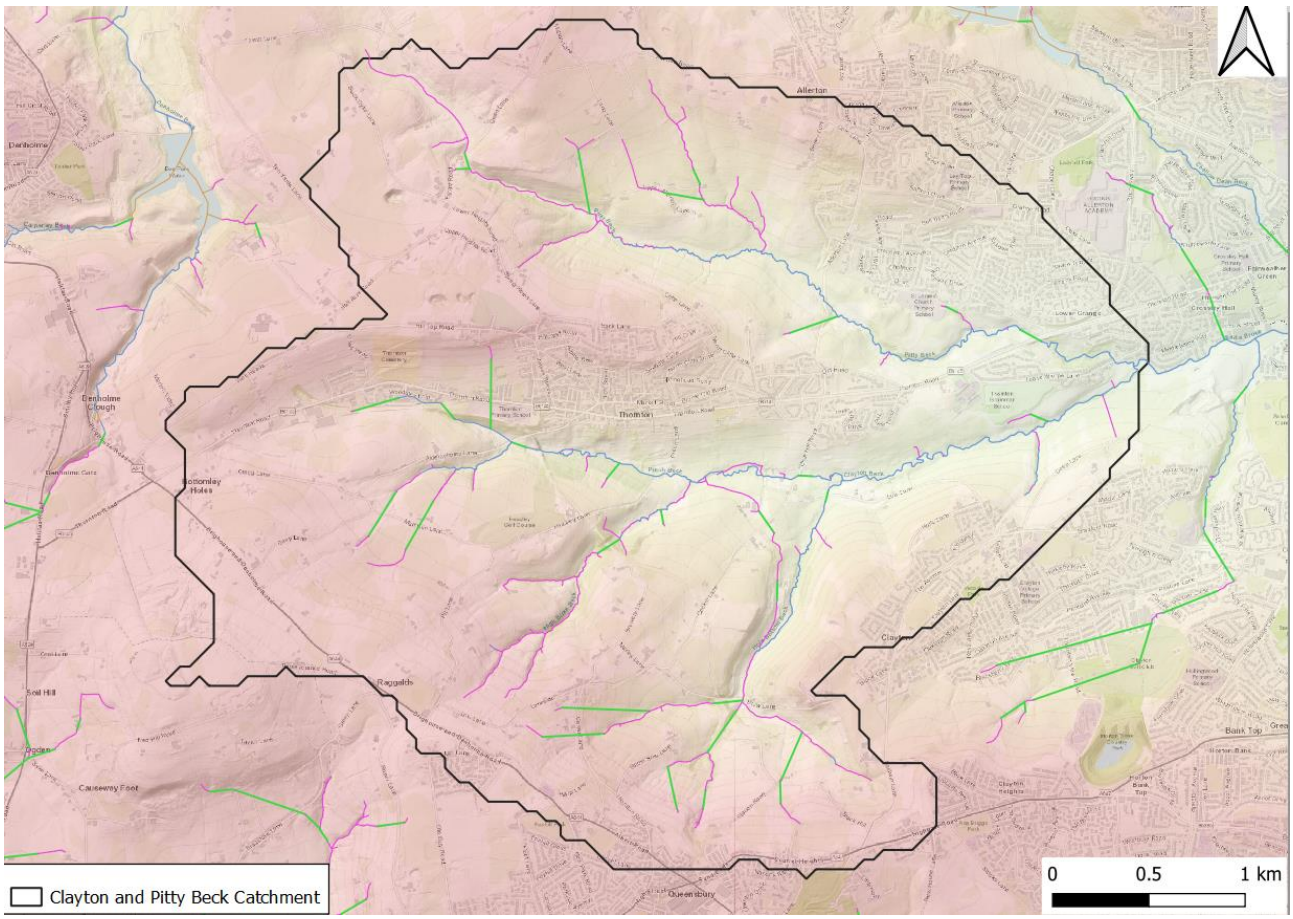


Figure 2-3 Clayton and Pitty Beck Catchment, Site 02

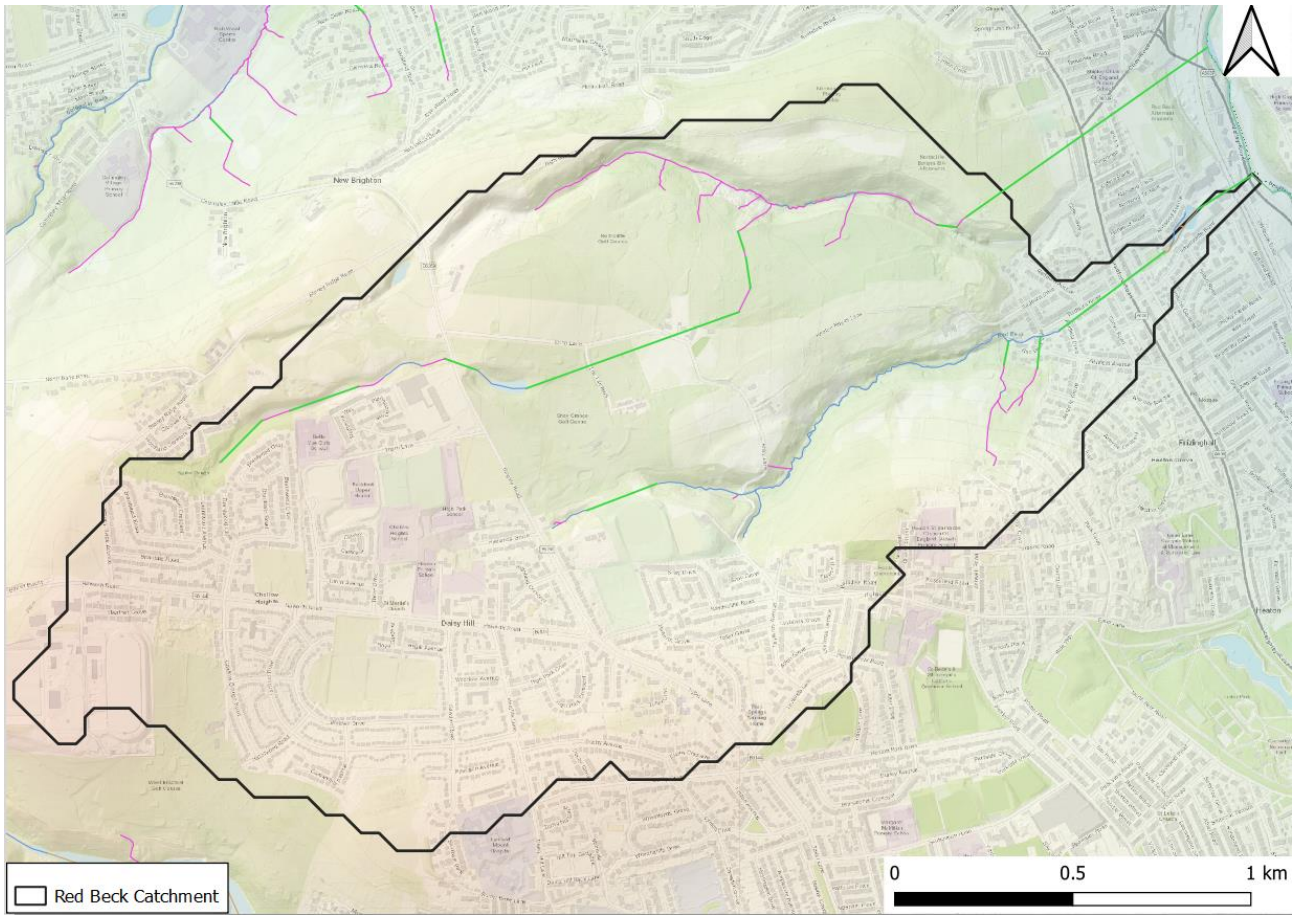


Figure 2-4 Red Beck FEH Catchment, Site

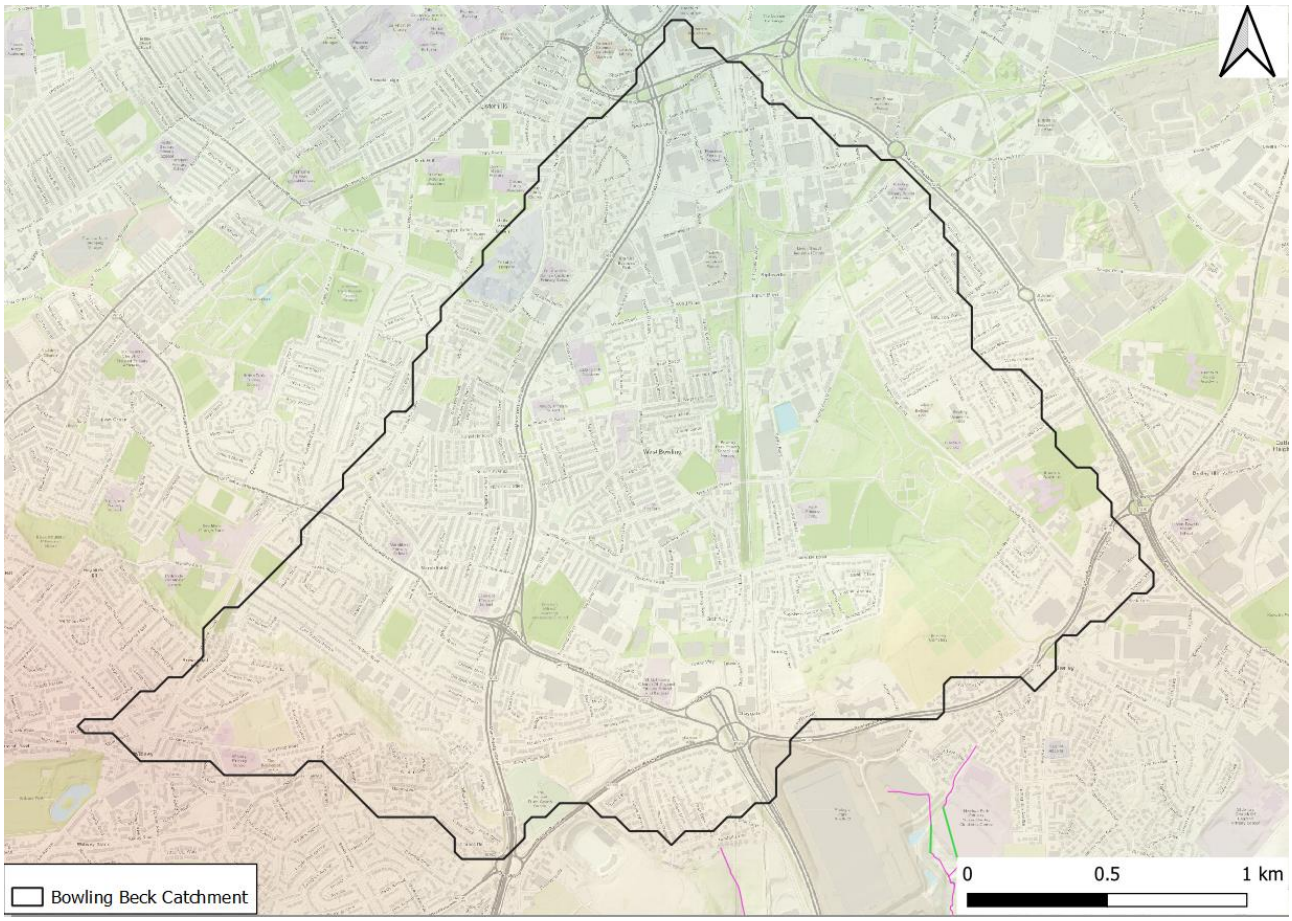


Figure 2-5: Bowling Beck Catchment, Site 03

The sub catchments used for the hydrology are shown in Figure 2-6. Hydrographs for all required return periods have been derived for each sub catchment. Catchment descriptors for each sub catchment have been based on the purchased catchment descriptor shown in Figure 2-2.

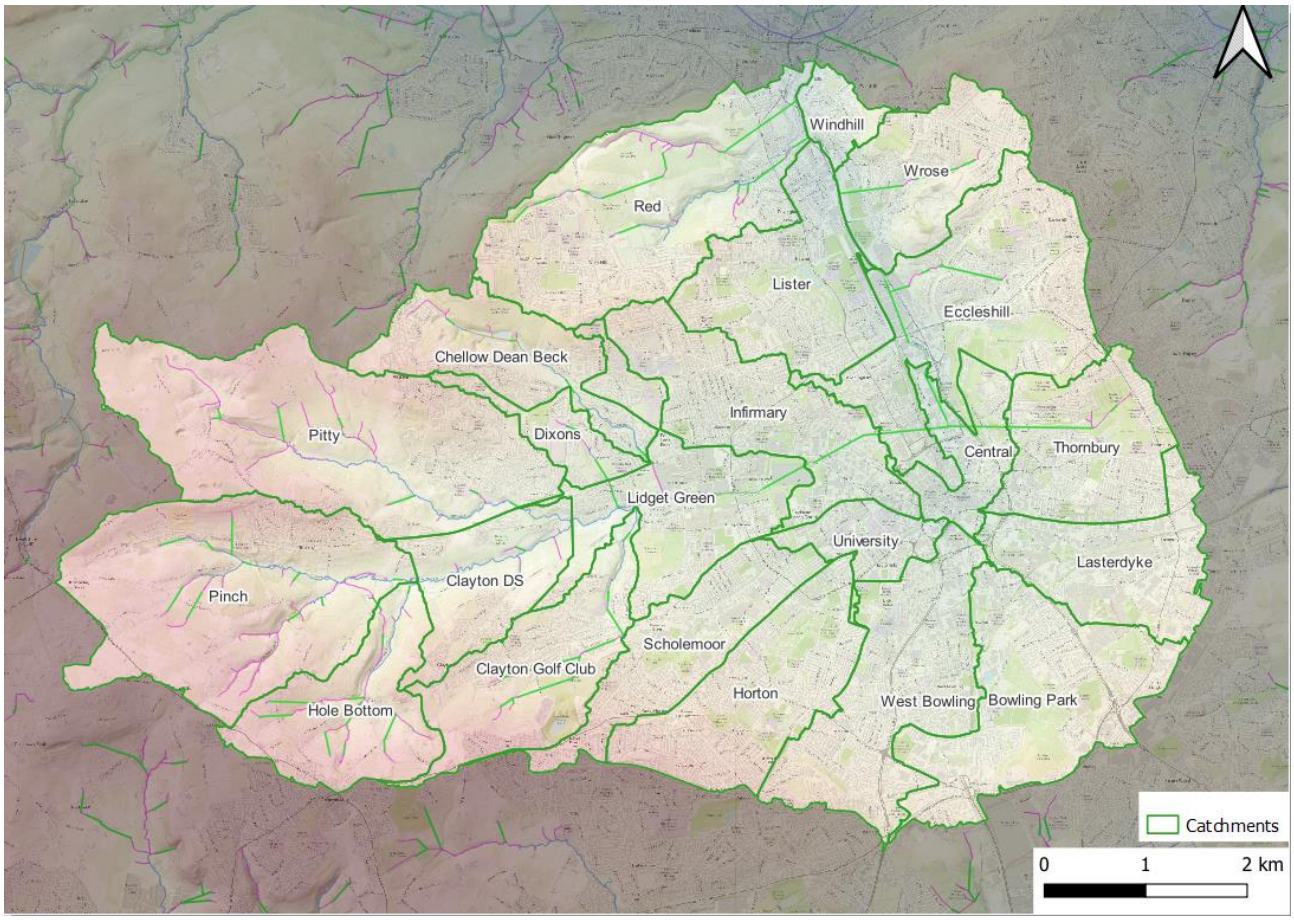


Figure 2-6: Hydrology Catchments.

Catchments with similar descriptors as Clayton and Pitty Beck are:

- Clayton DS
- Hole Bottom
- Pinch
- Pitty.

Catchments with similar descriptors as the Red Beck are:

- Clayton Golf Club
- Red Beck
- Chellow Dean

Catchments with similar descriptors as the Bowling Beck are:

- Bowling Park
- West Bowling
- Dixons
- Lidget Green
- Infirmary
- Lasterdyke
- Thornbury
- Eccleshill
- Wrose
- Scholemoor
- Windhill
- Horton
- Lister

- Central
- University

To create hydrographs for the sub catchments the catchment descriptors from the Clayton and Pitty Beck, Red Beck and Bowling Beck have been used. The descriptors have been adjusted where necessary to create a hydrograph for each sub catchment.

Sewer Flows Analysis

The potential impact of sewer systems having a different catchment area to the Bradford Beck sub catchments have been analysed. If the sewer system has differing sub catchmetns the overland sub catchments alterations may be required reflect this. The Bradford Beck sub catchments follow similar patterns to the overland flow routes defined from the EA LiDAR data. There are also no known sewers which transport water into another catchment boundary away from the Bradford Beck. This is shown in Figure 2-7

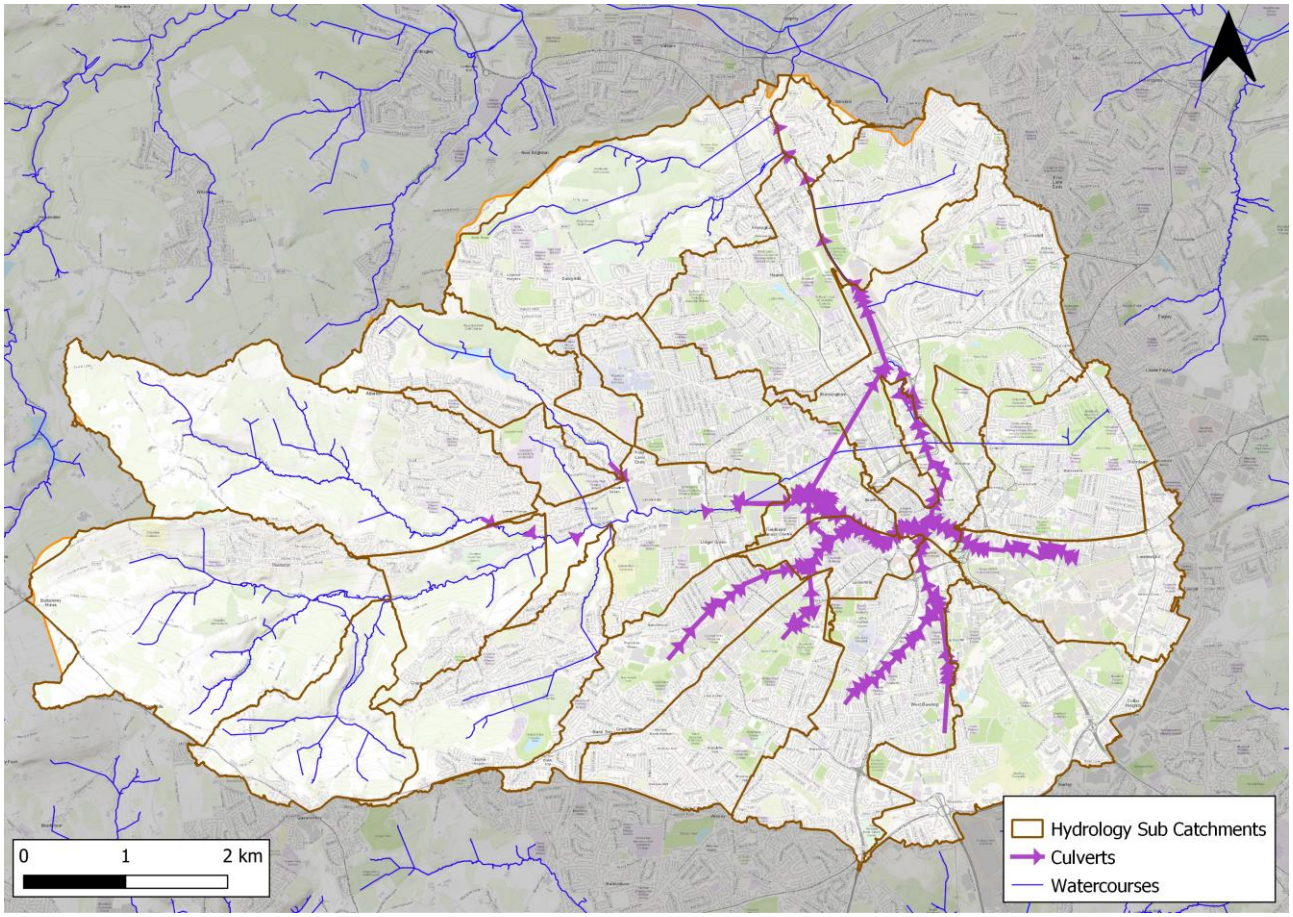


Figure 2-7 Known locations of Bradford Beck culverts

Summary of catchment descriptors: Site 01 Clayton and Pitty Beck

CD	01 - Clayton and Pitty Beck
Grid Ref	412750, 432950
AREA	14.9025
ALTBAR	255
ASPBAR	68
ASPVAR	0.35
BFIHOST	0.576
BFIHOST19	0.592
DPLBAR	3.47
DPSBAR	108.8
FARL	1
FPEXT	0.0105
FPDBAR	0.116
FPLOC	0.707
LDP	6.72
PROPWET	0.57
RMED-1H	10.5
RMED-1D	36.2
RMED-2D	49.3
SAAR	1044
SAAR4170	1022
SPRHOST	20.61
$URBCONC_{1990}$	0.628
$URBEXT_{1990}$	0.0508
$URBLOC_{1990}$	0.709
$URBCONC_{2000}$	0.844
$URBEXT_{2000}$	0.1003
$URBLOC_{2000}$	0.739
C	-0.02583
D1	0.37932
D2	0.41442
D3	0.34608
E	0.30282
F	2.39745
C(1km)	-0.025
D1(1km)	0.389
D2(1km)	0.4
D3(1km)	0.335
E(1km)	0.302
F(1km)	2.377
Adjusted AREA	
Notes on changes made:	No changes made

Summary of Catchment Descriptors: Site 02 Red Beck

CD	02 - Red Beck
Grid Ref	413225, 435890
AREA	4.0325
ALTBAR	187
ASPBAR	56
ASPVAR	0.59
BFIHOST	0.636
BFIHOST19	0.672
DPLBAR	2.45
DPSBAR	85.3
FARL	0.988
FPEXT	0.0205
FPDBAR	0.19
FPLOC	0.678
LDP	4.25
PROPWET	0.57
RMED-1H	10.5
RMED-1D	35.8
RMED-2D	47.5
SAAR	905
SAAR4170	894
SPRHOST	17.64
$URBCONC_{1990}$	0.686
$URBEXT_{1990}$	0.1386
$URBLOC_{1990}$	1.088
$URBCONC_{2000}$	0.865
$URBEXT_{2000}$	0.2203
$URBLOC_{2000}$	1.076
C	-0.025
D1	0.36827
D2	0.39367
D3	0.3309
E	0.30074
F	2.39794
C(1km)	-0.025
D1(1km)	0.385
D2(1km)	0.386
D3(1km)	0.339
E(1km)	0.303
F(1km)	2.367
Adjusted AREA	
Notes on changes made:	No changes made

Summary of Catchment Descriptors: Site 03 Bowling Beck

CD	03 - Bowling Beck
Grid Ref	416400, 432800
AREA	5.785
ALTBAR	172
ASPBAR	6
ASPVAR	0.6
BFIHOST	0.339
BFIHOST19	0.358
DPLBAR	2.14
DPSBAR	54.2
FARL	1
FPEXT	0.0324
FPDBAR	0.201
FPLOC	0.709
LDP	3.87
PROPWET	0.57
RMED-1H	10.9
RMED-1D	36.8
RMED-2D	49.4
SAAR	877
SAAR4170	900
SPRHOST	37.68
$URBCONC_{1990}$	0.893
$URBEXT_{1990}$	0.497
$URBLOC_{1990}$	0.902
$URBCONC_{2000}$	0.896
$URBEXT_{2000}$	0.5597
$URBLOC_{2000}$	0.931
C	-0.02542
D1	0.38397
D2	0.39966
D3	0.29265
E	0.30339
F	2.39786
C(1km)	-0.025
D1(1km)	0.382
D2(1km)	0.402
D3(1km)	0.311
E(1km)	0.303
F(1km)	2.391
Adjusted AREA	
Notes on changes made:	No changes made

3 Statistical method

The FEH statistical method constructs a flood frequency curve based on the estimation of QMED, which is then used to calculate peak flow estimates for each return period. FEH methods should not normally be applied on catchments smaller than 0.5km².

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.	In order to check the suitability of the closest donor sites, a set of criteria was applied to the catchment descriptors and compared with that of the subject site. The donor site was chosen based on the following criteria, with the greatest importance given to the centroid distance of the donor site to the subject site; • SAAR: Factor of less than 1.1 • AREA: Factor of less than 5 • BFIHOST: Difference of less than 0.18 • FARL: Difference of less than 0.05 Further donor selection information can be found in **Annex A.** Donor sites were assessed based on the above criteria. Donor site **27051 (Crimple @ Burn Bridge)** was a site where the majority of CDs were within the allowable limits for Clayton and Pitty Beck, and Bowling Beck. **27084 Eastburn Beck @ Crosshills** was used as the donor site for Red Beck.

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.

Donor sites chosen and QMED adjustment factors

NRFA no.	Station	Reasons for choosing or rejecting	Study Site	Method (AM or POT)	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)
27051	Crimple @ Burn Bridge	Most CDs within allowable limits and not groundwater influenced, Similar catchment size.	01 – Clayton and Pitty Beck	AM	4.56	3.976	1.14
27084	Eastburn Beck @ Crosshills	Most CDs within allowable limits and not groundwater influenced, Similar catchment size.	02 – Red Beck	AM	28.9	27.216	1.06
27051	Crimple @ Burn Bridge	Most CDs within allowable limits and not groundwater influenced, Similar catchment size.	03 – Bowling Beck	AM	4.56	3.976	1.14

The data transfer procedure is the revised one from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Tables 4.3 and 4.4. 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.

$$a = 0.4598*\exp(-0.020*d_{ij})+(1-0.4598)*\exp(-0.4785*d_{ij})$$

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.

Estimation of QMED at subject site

Site Site	Method	Initial estimate of QMED (m^3/s)	Data transfer						Estimate of QMED (m^3/s)	Final QMED (m^3/s) Urban Adjusted
			NRFA no. used	Distance between centroids d_{ij} (km)	Weight a	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor			
							Weight	Weighted average adjustment factor		
Clayton and Pitty Beck	Donor Adjustment	4.676	27088	15.87	0.335	1.009	N/A	N/A	4.851	4.851 – no urban adjustment required as rural is recommended approach for this catchment
Red Beck	Donor Adjustment	0.820	27084	17.93	0.321	0.986	N/A	N/A	0.831	0.831 no urban adjustment required as rural is recommended approach for this catchment
Bowling Beck	Donor Adjustment	2.945	27051	23.33	0.288	0.962	N/A	N/A	3.060	4.869, urbanised results
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?						YES				

Derivation of pooling groups

The composition of the pooling groups is given in **Annex A**. 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)

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)
	01	No	The initial pooling group had 528 years of data from 14 catchments. The initial pooling group was 'heterogenous' and a review of the pooling group was desirable. A number of stations were removed from the automatically created pooling group, for reasons such as to limited recording years and differing FARL values, The removed stations included: 49005 (Bolingey Stream @ Bolingey Cocks Bridge) due to limited recording years, 27010 (Hodge Beck @ Bransdale Weir) as the site closed in 1979 so does not capture recent increases in flows due to flows, 24006 (Rookhope Burn @ Eastgate) as it is now a level only site, 48007 (Kennal @ Ponsanooth) due to a large reservoir upstream affecting flows causing a low FARL value, 73015 (Keer @ High Keer Weir) due to a stepped flood frequency curve which indicates bypassing of the channel, 44013 (Piddle @ Little Puddle) due ot low flow data and large amounts of no flood years, 49004 (Gannel @ Gwills) as the gauge is being bypassed in high flow events. Catchments were added to ensure the pooling group had at least 500 years of data: 47021 (Kensey @ Launceston Newport) 47009 (Tiddy @ Tideford), 49002 Hayle @ St Erth, 44003 (Asker @ Bridport), 48004 (Warleggan @ Trengoffe), 54025, (Dulas @ Rhos-y-pentref) and (Dove @ Hollingsclough). All catchments have acceptable BFIHOST and SPRHOST values and the final years of data for the new pooling group is 525.	$L\text{-}CV_{final} = 0.235$ $L\text{-}Skew_{final} = 0.234$

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)
	02	No	The initial pooling group had 520 years of data from 15 catchments. The initial pooling group was 'heterogenous' and a review of the pooling group was desirable. The following stations were removed or rejected due to limited recording years and differing FARL values: 49005 (Bolingey Stream @ Bolingey Cocks Bridge) due to limited years of data 27010 (Hodge Beck @ Bransdale Weir), as the site closed in 1979 so does not capture recent increases in flows due to climate change, 76011 (Coal Burn @ Coalburn) due to low bfihost, 26017 (Ings Beck @ South Newbald), due to steps in the flood frequency curve indicating bypassing of the gauge. 44013 (Piddle @ Little Puddle), due ot low flow data and large amounts of no flood years, 41020 (Bevern Stream @ Clappers Bridge), due to steps in the flow record showing bypassing of the gauge, . 26016 (Gypsey Race @ Kirby Grindalythe), due to low flows and non flood years and 27073 Brompton Beck @ Snainton Ings) due to steps in the flood frequency curve indicating bypassing of the gauge. The catchments below were added to ensure the pooling group had at least 500 years of data: 36010 (Bumpstead Brook @ Broad Green), 44003 (Asker @ Bridport), 48004 (Warleggan @ Trengoffe), 53017 (Boyd @ Bitton), 47012 (Kensey @ Launceston Newport), 49002 Hayle @ St Erth, 27095 (Pickering Beck @ Pickering), 54025 (Dulas @ Rhos-y-pentref). All catchments have acceptable BFIHOST and SPRHOST values and the final years of data for the new pooling group is 551.	$L\text{-}CV_{final} = 0.255$ $L\text{-}Skew_{final} = 0.243$

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)
	03	No	The initial pooling group had 504 years of data from 16 catchments. The initial pooling group was 'heterogenous' and a review of the pooling group was desirable. The following stations were removed or rejected:: 49005 (Bolingey Stream @ Bolingey Cocks Bridge), due to a limited number of recording years, 27010 (Hodge Beck @ Bransdale Weir),, as the site closed in 1979 so does not capture recent increases in flows due to climate change, 76011 (Coal Burn @ Coalburn), due to a the low bfihost value, 44013 Piddle @ Little Puddle, due to low flow data and limited flood years, 44008 (South Winterboure @ Winterbourne Steepleton), due to a stepped flood frequency curve which shows bypassing of the gauge in high flow events, 25058 Henmore Brook @ Ashbourne, due to negative skew values which indicates that the gauge is bypassed during the highest flow event, 26014 (Water Forlornes @ Driffield), due to high BFIHOST value indicating that the catchment is too permeable, 41020 (Bevern Stream @ Clappers Bridge), as the highest gauged events were shown as before 2005 and the gauge was not useable in this period.7011 (Black Burn @ Pluscarden Abbey). Due to limited recording history. The catchments below were added to ensure the pooling group had at least 500 years of data: 72014 Conder @ Galgate, 24006 Rookhope Burn @ Eastgate, 51003, Washford @ Beggeam Huish, 53017 Boyd @ Bitton, 36010 Bumpstead Brook @ Broad Green, 49002 Hayle @ St Erth, 47021 Kensey @ Launceston Newport, Warleggan @ Trengoffe. All catchments have acceptable BFIHOST and SPRHOST values and the final years of data for the new pooling group is 529.	L-CV $_{final}$ = 0.249 L-Skew $_{final}$ = 0.214

Notes

Pooling groups were derived using the revised procedures from Science Report SC050050 (2008).

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

Derivation of flood growth curves at subject sites

Site code	Method	Distribution used and reason for choice	Any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments
01	Pooled	Kappa 3, lowest z value	N/A	N/A

Site code	Method	Distribution used and reason for choice	Any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments
02	Pooled	Kappa 3, lowest z value	N/A	N/A
03	Pooled	Kappa 3, lowest z value	yes urban adjustment required.	N/A

Growth curves

Site code	Growth curve factor for the following return periods (in years)								
	2	5	10	20	30	50	100	200	1000
01	1.00	1.57	1.95	2.33	2.56	2.84	3.22	3.62	4.56
02	1.00	1.44	1.77	2.13	2.36	2.67	3.13	3.66	5.17
03	1.00	1.30	1.54	1.82	2.01	2.28	2.70	3.37	4.83

Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	20	30	50	100	200	1000
01	4.85	6.79	8.24	9.80	10.78	12.11	14.09	16.32	22.62
02	0.83	1.20	1.47	1.77	1.96	2.22	2.61	3.04	4.30
03	4.87	6.31	7.50	8.88	9.80	11.10	13.16	15.64	23.53

4 Revitalised flood hydrograph (ReFH2) method

Parameters for ReFH2 model

The Revitalised Flood Hydrograph (ReFH) method was developed by CEH to provide a more realistic representation of flood hydrology. This method is generally believed to perform reasonably well on most catchments. However, this method is not currently appropriate for either 'heavily urbanised' or 'very heavily urbanised' based on the values of URBEXT2000 extracted from FEH Web Service because its summer design event was only calibrated on seven urban catchments, and further research to improve the ReFH method has been recommended.

Parameters used to derive the ReFH method hydrographs are provided in the tables below. For this study, the critical storm duration of each catchment has been calculated (based on the 1 in 100 event) in order to generate the maximum peak flow estimate produced by each catchment.

Site	**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
Clayton and Pitty Beck	**Catchment Descriptors**	1.674	465.203	38.328	2.799
Red Beck	**Catchment Descriptors**	1.482	572.654	38.364	3.201
Bowling Beck	**Catchment Descriptors**	1.584	253.315	25.427	1.527
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		N/A			

Design events for ReFH2 method

Site	**Urban or rural**	**Season of design event (summer or winter)**	**Storm duration / Timestep (hours)**	**Storm area for ARF** (if not catchment area)
01: Clayton and Pitty Beck	**Rural**	Winter	3 hours 15 Min / 15 min	0.935
02 Red Beck	**Rural**	Summer	2 Hours 45 Min / 15 min	0.956
03 Bowling Beck	**Urban**	Summer	2 Hours 45 Min / 15 min	0.95
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?		It is possible the storm durations and seasonality will be changed due to a analysis in the hydraulic model.		

Catchment descriptors have been input into ReFH2 to create hydrographs. The peak flows from ReFH2 are displayed in the table below. For site 01 and 02 rural estimates have been chosen as per the guidance for sites with their urbext values. Site 3 (Bowling Beck) has an urbext value of 0.5597, therefore the FEH guidance suggests that urbanised values are used.

Flood estimates from the ReFH2 method

Site code	2	5	10	30	50	100	200	1000
01	3.65	5.14	6.27	8.42	9.63	11.60	14.03	21.49
02	0.75	1.1	1.39	1.95	2.28	2.84	3.56	5.96
03	5.93	8.59	10.59	14.11	16.03	19.07	22.91	35.27

5 DISCUSSION AND SUMMARY OF RESULTS

Comparison of results from different methods

Site code	Summary of peak flow estimates			
	Return period 2 years		Return period 100 years	
	FEH Stat	ReFH2.3	FEH Stat	ReFH2.3
01	4.85	3.65	14.09	11.60
02	0.83	0.75	2.61	2.84
03	4.87	5.93	13.16	19.07

Final choice of method

Item	Comments
Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	A hybrid method was used, calibrating the ReFH hydrographs scaled to the derived peak flows from the FEH Statistical method. This was completed by adjusting the cini value so the peak flows are the same in ReFH2.3, hydrographs were then exported. The hydrographs which were exported from ReFH2 were scaled to each sub-catchment based on an area factor.The sub-catchments cover the total area of the Bradford Beck catchment.

Assumptions, limitations and uncertainty

Item	Comments
List the main assumptions made (specific to this study)	Assumed AMAX data is reliable for the catchments in the pooling groups.
Discuss any particular limitations e.g. applying methods outside the range of catchment types or return periods for which they were developed	The catchment is both urban and rural with high permability which results in summer profiles for areas of the catchment, and winter for others. Because of this both Summer and Winter design events will be run through the hydraulic model to test for sensitivity, and to identify which seasonality across the whole catchment produces the highest flood depths. One seasonal profile should be applied to the hydrology for the purposes of deriving inflow hydrographs. The use use of urbanised results for subcatchment 2 rather than 'as rural will also be tested in the hydraulic model.
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).	FEH methods are well known to have great uncertainty especially when assessing small catchments. ReFH2 has a slightly lower factorial standard error (1.47) vs the FEH Statistical when using one donor, which is recommended for small catchments (1.50). ReFH2 hydrographs have been scaled based on the statistical method peak This is due to the statistical methods better performance at predicting Qmed larger catchmetns, therefore, uncertainty has been minimised where possible.
Comment on the suitability of the results for future studies- e.g. at nearby locations or for different	The results have made use of the most up-to-date data and methods and could be applied to future studies within the area of study.

purposes.	
Give any other comments on the study, for example suggestions for additional work.	Previous hydrological estimates for the catchment do exist, however, catchment areas and urban extents are different between studies and therefore they should not be considered for comparison. The EA were consulted for historic flood information, however, were not able to provide. There have been historic flood events in Bradford such as 2nd July 1968, in this instance anecdotal evidence suggests flooding was caused as a result of heavy rainfall and blocked gully's. Similar flooding mechanisms are mentioned for other minor floods. Thunderstorm caused flooding in Bradford city centre | Bradford Telegraph and Argus (thetelegraphandargus.co.uk)

Checks

Item	Comments
Are the results consistent, for example at confluences?	Yes. The lumped catchment has been assessed in the FEH statistical method. For the 0.1% Annual Exceedance Probability event gave a predicted flow of 121.4m3/s as a rural model. The outflow of the combined catchmetns shown in the large table below gives a combined outflow of 168.8. A majority of the flows in out study are based on the Bowling Beck catchment which is heavily urbanised. This explains the increase in flow in our study.
What do the results imply regarding the return periods of floods during the period of record?	N/A – there is no gauged record of flooding for the catchment other than historical outlines which do not correspond to an RP Results from preliminary runs of the model show a similar extent to the previous .
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 for site 01, Clayton and Pitty Beck is: 2.90 Site 02, Red Beck: 3.14 Site 03, Bowling Beck: 2.71

Final results

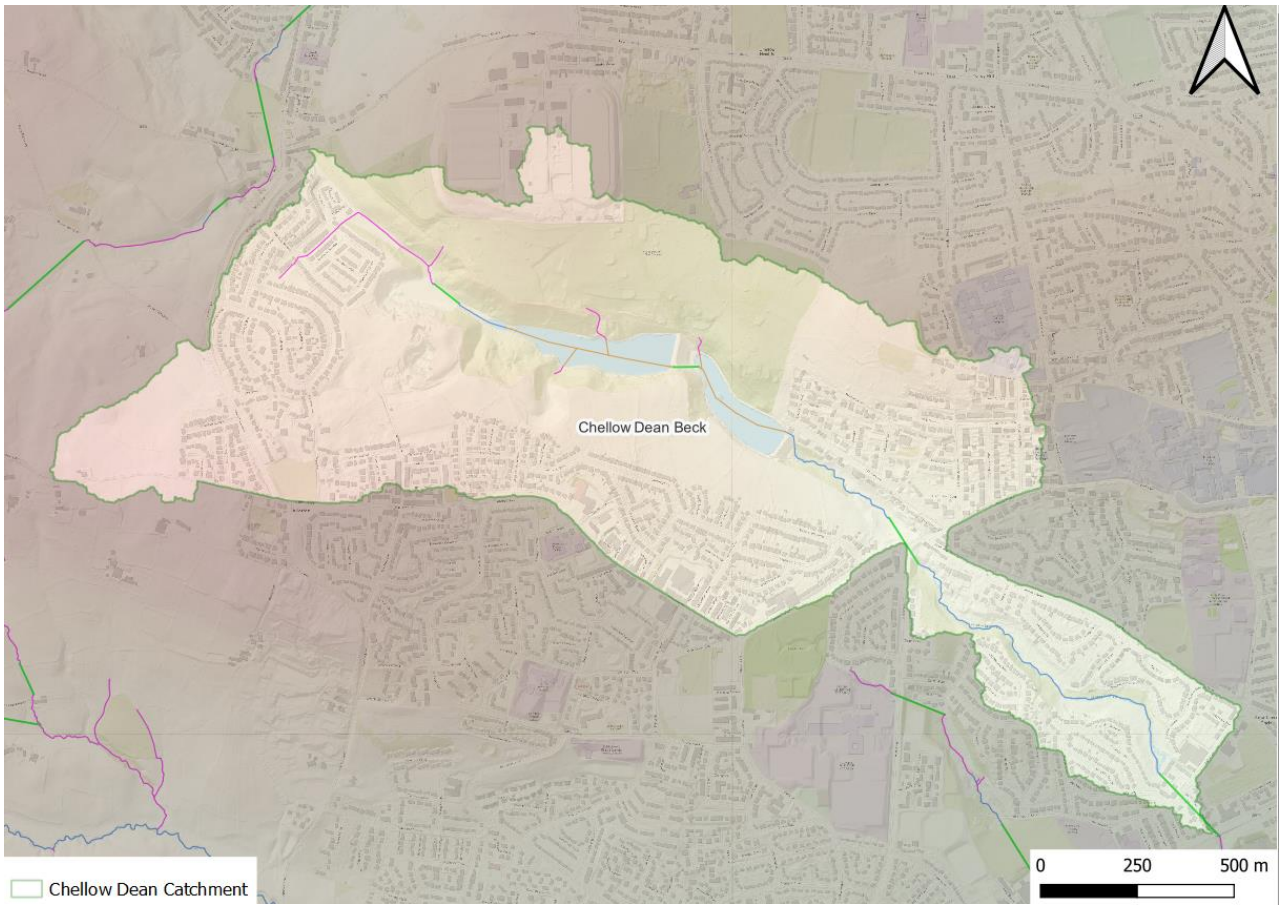
Peak hydrograph flows FEH Catchment

Site code	Peak flow (m^3/s) for the following return periods (in years)										
	2	5	10	20	30	50	100	100+ 25% CC	100 + 40% CC	200	1000
01	4.85	6.79	8.24	9.80	10.78	12.11	14.09	17.61	19.73	16.32	22.62
02	0.83	1.20	1.47	1.77	1.96	2.22	2.61	3.25	3.64	3.04	4.30
03	4.87	6.31	7.5	8.88	9.80	11.10	13.16	16.45	18.42	15.64	23.53

The below table shows the peak flows for each sub catchment of the Bradford Beck. These have been derived using the relevant catchment descriptors discussed above and adjusted based on area.

Peak scaled hydrograph flows m3/s for the delineated sub-catchments scaled from the final adjusted catchment.

Sub-Catchment	Return Period										
	2	5	10	30	50	75	100	100 + 25% CC	100 + 40% CC	200	1000
West Bowling	2.73	3.53	4.20	5.49	6.21	6.86	7.3	9.13	10.22	8.76	13.2
Pitty	1.91	2.67	2.93	4.24	4.77	5.21	5.59	6.98	7.83	6.42	8.91
Hole Bottom	0.75	1.05	1.28	1.67	1.87	2.05	2.2	2.75	3.08	2.53	3.50
Pinch	1.73	2.41	2.93	3.83	4.30	4.71	5.05	6.31	7.07	5.80	8.04
Clayton DS	0.57	0.80	0.97	1.27	1.43	1.56	1.68	2.1	2.35	1.93	2.67
Dixons	0.59	0.77	0.91	1.19	1.35	1.49	1.60	2.00	2.24	1.91	2.87
Chellow Dean Beck	0.42	0.61	0.78	0.99	1.12	1.23	1.31	1.64	1.83	1.53	2.17
Red Beck	0.83	1.20	1.54	1.96	2.22	2.44	2.60	3.25	3.64	3.04	4.3
Wrose	1.73	2.24	2.66	3.91	3.94	4.35	4.67	5.84	6.54	5.55	8.36
Eccleshill	3.51	4.55	5.41	7.06	7.99	8.83	9.48	11.85	13.27	11.27	16.98
Thornbury	1.94	2.51	2.98	3.90	4.41	4.87	5.23	6.54	7.35	6.22	9.37
Lasterdyke	1.82	2.36	2.81	3.66	4.15	4.58	4.92	6.14	6.89	5.85	8.81
Clayton Golf Club	0.51	0.75	0.96	1.22	1.38	1.52	1.61	2.01	2.25	1.89	2.67
Horton	2.27	2.94	3.49	4.56	5.17	5.71	6.13	7.66	8.58	7.28	10.97
Scholemoor	1.71	2.22	2.64	3.45	3.91	4.31	4.63	5.79	6.48	5.50	8.29
Bowling Park	3.002	3.89	4.62	6.04	6.84	7.56	5.50	6.86	7.7	9.64	14.53
Lidget Green	2.32	3.00	3.567	4.66	5.28	5.83	6.26	7.83	8.76	7.44	11.20
Windhill	0.42	0.55	0.65	0.85	0.96	1.07	1.14	1.43	1.60	1.36	2.05
University	0.68	0.89	1.05	1.38	1.56	1.72	1.85	2.31	2.59	2.20	3.31
Infirmary	2.32	3.01	3.58	4.67	5.29	5.84	6.27	2.3	2.59	7.45	11.22
Central	0.96	1.24	1.48	1.93	2.19	2.42	2.59	3.24	3.63	3.08	4.64
Lister	2.22	2.88	3.42	4.47	5.06	5.59	6.00	7.49	8.40	7.14	10.75



4.3.2 Indexing the effects of individual reservoirs and lakes

It was decided that only on-line water bodies would be used in index evaluation, to reflect the likelihood that they have a more important role in flood attenuation. This effect for individual reservoirs and lakes is indexed by:

$$\alpha = \left(1 - \sqrt{r}\right)^{w} \qquad (4.1)$$

where r is the relative size of the reservoir or lake to its subcatchment, i.e.

$$r = \frac{surface\ area}{subcatchment\ area} \qquad (4.2)$$

and w is a weight which reflects the importance of the reservoir or lake in terms of the flood behaviour at the catchment scale, defined by:

$$w = \frac{subcatchment\ area}{catchment\ area} \qquad (4.3)$$

QMED was estimated using the statistcal method for a FARL of 1 and the adjusted FARL of 0.86. The catchment descriptors from the Red Beck were used and the area adjusted to the Chellow Dean catchment. Results are shown in the below table.

QMED (m3/s) FARL 1	QMED (m3/s) FARL 0.86
0.42	0.284

Due to the nature of the catchment being very small in area, there are no suitable catchments for an appropriate pooling group. Typically, low FARL catchments have very large catchment areas and high SAAR values which are not comparible to the study catchment. Based on this, the decision was made to not

represent any storage within the hydrological assessment.This ensures that the flows from the catchment will not tbe understimated and can give a worst case scenario. The effects of storage from the reservoirs will be represented hydraulically witin the model.

Appendix C – Flood Maps

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- 20% AEP Extent
- 5% AEP Extent
- 1.33% AEP Extent
- 1% AEP Extent
- 1% AEP + Climate Change Extent
- 0.1% AEP Extent
- 0.1% AEP + Climate Change Extent

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-1 : Baseline Extents

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-2 : Baseline 2-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.



PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-3 : Baseline 5-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-4 : Baseline 10-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-5 : Baseline 20-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.



PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER
Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk
SWECO

CLIENT
City Hall
Centenary Square
Bradford
BD1 1HY
City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE
A-6 : Baseline 30-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropilitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-7 : Baseline 75-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-8 : Baseline 100-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-9 : Baseline 100-year + Climate Change Higher

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-10 : Baseline 1000-year Flood Depth

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

Maximum depth (m)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-11 : Baseline 1000-year Flood Depth + Climate Change Higher

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-12 : Baseline 2-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-13 : Baseline 5-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-14 : Baseline 10-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-15 : Baseline 20-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-16 : Baseline 30-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-17 : Baseline 100-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-18 : Baseline 100-year + Climate Change Higher

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-19 : Baseline 1000-year Hazard

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.

PROJECT

Bradford Beck Hydraulic Model

LEGEND

- Low Hazard
- Danger for Some
- Danger for Most
- Danger for All

NOTES

© Crown copyright and database rights 2025 Ordnance Survey 100030649.
Use of this data is subject to terms and conditions.

DESIGNER

Grove House
Mansion Gate Drive
Leeds
LS7 4DN
+44 (0)113 262 0000
www.sweco.co.uk

SWECO

CLIENT

City Hall
Centenary Square
Bradford
BD1 1HY

City of BRADFORD METROPOLITAN DISTRICT COUNCIL

DRAWING TITLE

A-20 : Baseline 1000-year Hazard + Climate Change Higher

INTERNAL PROJECT REF. NO	SHEET SIZE	SCALE	Rev.Ver
65216733	A3	1:20000 @A3	P01.01

0 500 1,000 m

This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Sweco UK Ltd was commissioned. Sweco UK Ltd accepts no responsibility for this drawing to any party other than the person by whom it was commissioned. This drawing has been prepared on behalf of City of Bradford Metropolitan District Council by Sweco UK Ltd for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of City of Bradford Metropolitan District Council being obtained. Sweco UK Ltd accepts no responsibility or liability for the consequences of this drawing being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on this drawing for such other purpose agrees, and will by such use or reliance be taken to confirm his/her agreement, to indemnify Sweco UK Ltd for all loss or damage resulting therefrom.