Essex Pluvial Model Update Braintree

Reference: ECC_BRT_Pluvial_Model_Update_Report_FINAL.docx
Date: September 2020
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Essex Pluvial Model Update Braintree

Braintree and Witham

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Document:	ECC BRT Pluvial Model Update Report FINAL.docx
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Synopsis:

This report is a technical summary of the hydrological and hydraulic modelling methodologies adopted to update the hydraulic model for Essex County Council in Braintree and Witham. The purpose of the model updates are to provide an accurate understanding of current flood risk and identification of Critical Drainage Areas to inform future mitigation works.

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
1	24/07/2020	SD	24/07/2020	RK	24/07/2020
2	18/08/2020	SD	18/08/2020	RK	18/08/2020
3	11/09/2020	RK	11/09/2020	RK	11/09/2020

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
ECC		X	X	X							
BMT File		X	X	X							

Executive Summary

The Braintree and Witham catchment has a long history of significant flooding, particularly from fluvial and surface water sources. The catchment encompasses the towns of Braintree, Boking, Great Notley, and Witham, all of which fall within the Braintree District of Essex.

The original study completed by AECOM in 2016 developed a dynamically linked 1d2d TUFLOW model for several select sub-catchments within the Braintree and Witham area. The SWMP models undertaken focused on three areas of concern to further investigate potential mitigation options. BMT were commissioned by Essex County Council to review the hydraulic model produced for the Braintree and Witham Surface Water Management Plan (2016). Based on the findings of that model review, a number of proposed updates were necessary in-line with changes in methodology and software. Namely, creating a whole catchment model, improving the representation of the drainage network, enforce schematisation of the watercourse, revising the rainfall, and catchment roughness. Essex County Council subsequently commissioned BMT to then undertake these updates to improve the estimation of surface water flood risk based on the review findings.

An integrated (hydrological and hydraulic) catchment wide model was subsequently constructed to predict the complex interaction between different sources of flood risk, including surface water, ordinary watercourses and sewer flooding. Rainfall from eight design rainfall events (3 hour critical duration) was calculated using the ReFH2 method that generates both rural and urban hyetographs. Each respective rainfall classification was applied directly onto the Braintree and Witham catchment, with runoff modelled dynamically. Maximum flood depth, velocity and hazard were calculated.

Critical Drainage Areas were identified in consultation with Essex County Council. Of the four original Local Flood Risk Zones identified of the original Surface Water Management Plan, Warwick Close, Braintree has been discounted. An additional three areas have been identified.

Property counts were undertaken for each Critical Drainage Area using the Environment Agency methodology for estimating properties at risk from surface water flooding. Flood damage estimations have been undertaken considering both tangible and intangible damages. The results are presented for each Critical Drainage Area in the table below:

Critical Drainage Area	Total Estimated Number of Flooded Properties (1% AEP Event)	Total Estimated Damages (Net Present Value)
WTH 001: Maltings Lane, Witham	29	5,437,895
WTH 002: Blunts Hall Road, Witham	17	4,293,317
BRT 001: Bradford Street, Braintree	67	19,134,909
WTH 003: Spa Road, Witham	17	5,366,124
WTH 004: Elderberry Gardens, Witham	33	24,796,306

The outcomes of this study have provided an improved understanding of surface water flood risk to the urban areas of Braintree, Boking, Great Notley, and Witham. The results can be used to inform a future update of the Surface Water Management Plan, and to prioritise CDAs for any future flood risk alleviation investigations.

Glossary

Term	Definition
AEP	Annual Exceedance Probability represented as a % (e.g. 1 in 100 year event = 1% AEP)
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.
DEM	Digital Elevation Model: 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).
Depth Discharge Curve	The relationship between depth over a gully pot to discharge into the sewer network.
DSM	Digital Surface Model: a topographic model of the bare earth/underlying terrain of the earth's surface including objects such as vegetation and buildings.
DTM	Digital Terrain Model: 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 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.
IUD	Integrated Urban Drainage, a concept which aims to integrate different methods and techniques, including sustainable drainage, to effectively manage surface water within the urban environment.
Lead Local Flood Authority	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).
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.
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.
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.
Surface water runoff	Rainwater (including snow and other precipitation) which is on the surface of the ground (whether or not it is moving), and has not entered a watercourse, drainage system or public sewer.
Anglian Water	The Water Authority for this area.

Acronyms

Term	Definition
AEP	Annual Exceedance Probability
AW	Anglian Water
BGS	British Geological Survey
DTM	Digital Terrain Model
EA	Environment Agency
ECC	Essex County Council
FEH	Flood Estimation Handbook
IUD	Integrated Urban Drainage
LiDAR	Light Detection and Ranging
LLFA	Lead Local Flood Authority
mAOD	Metres Above Ordnance Datum (UK)
USDA	United States Department of Agriculture

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1 Introduction

BMT have been commissioned by Essex County Council (ECC) as part of their role as Lead Local Flood Authority (LLFA) to update the hydraulic modelling used to inform the Braintree and Witham Surface Water Management Plan (SWMP)[1]. A total of seven SWMPs have been completed by ECC since 2012 and different methodologies adopted in their approach. These SWMPs outline the preferred surface water management strategy across the ECC administrative area hence there is a requirement for consistency in their delivery.

A peer review of the hydraulic modelling used to inform the Braintree and Witham SWMP was undertaken in 2018. The review findings highlighted a number of model limitations that should be addressed to provide a more accurate understanding of surface water flood risk. In addition, new datasets have been made available since the construction of the original models.

This report outlines the methodology taken in updating the hydraulic modelling based on the recommendations of the peer review. The results of the updated hydraulic modelling have been used to identify revised Local Flood Risk Zones (LFRZs) and LFRZ source areas, referred to as Critical Drainage Areas (CDAs) in this report.

1.1 Study Area

Braintree is situated approximately 16km north of Chelmsford. The town is split by two rivers, the River Brain in the south, and the River Blackwater in the north. Both main rivers are susceptible to flooding. The entire catchment of the River Brain has been modelled from Great Bardfield north west of Braintree Town Centre, then flowing in a south easterly direction towards Witham and its confluence with the River Blackwater. As part of this study, the town of Witham has also been assessed for surface water flooding. The contributing catchment exhibits a number of ordinary watercourses draining towards both the River Brain and Blackwater through the urban centres of Braintree and Witham.

Historically the Braintree and Witham areas have been affected by significant flooding particularly from fluvial and surface water sources (Figure 1-1 – Left: Mill Lane, Witham; Right: Church Lane, Braintree)[2].

[1] Braintree and Witham Surface Water Management Plan (AECOM 2016)
[2] Sourced from: http://www.bbc.co.uk/essex/content/image_galleries/flood_feb_2009_gallery.shtml?40 and https://www.braintreeandwithamtimes.co.uk/news/15336963.exasperated-residents-must-wade-or-drive-through-floodwater-in-church-lane-bocking-every-time-it-rains/

Figure 1-1 Flooding Examples

Figure 1-2 Study Area

2 Review of Existing Hydraulic Model

The Braintree and Witham hydraulic models were constructed by AECOM in 2016 as part of the Braintree and Witham SWMP. This comprised of three individual pluvial models representing critical drainage areas; one located in Braintree and two in Witham. A high-level review of the model was undertaken in 2018 by BMT. The aim of the review was to establish the quality of the models for the purpose of assessing potential surface water flood mitigation measures within the catchment. Recommendations for updating the underlying model datasets and the hydrological and hydraulic modelling methodologies were agreed with ECC, in-line with current best practice. The updates proposed were prioritised based on their potential to impact the predicted surface water flood risk.

A summary of the key recommendations for the Braintree and Witham models are provided below.

2.1 Key Recommendations

- The original SWMP model methodology used the Risk of Flooding from Surface Water Map to identify Local Flood Risk Zones (LFRZs) to take forward for more detailed modelling. Three hydraulic models of four prioritised LFRZs were constructed as part of the SWMP. One of the limitations of the national map is the hydraulic modelling was carried out on 6km x 6km tiles. Continuity of flow between tiles is not considered and therefore should a flow path span across more than one tile, flow from the upper parts of the catchment are not considered in the lower catchment. For this reason, the peer review recommended a whole of catchment model is constructed for the Braintree and Witham study area. The results of this model can be used to verify the selection of the LFRZs and identify any other priority areas not considered as part of the SWMP.
- Rainfall application
  - The original SWMP assumed that rain falling on tops of buildings was routed to gullies within the study area. A number of the gullies within the catchment were missing and connectivity cannot be verified. An alternative approach is to apply rainfall to all active areas and allow the hydraulic model to route the surface water runoff.
- Infiltration
  - The previous models utilised runoff coefficients to estimate the percentage of rainfall that is converted to surface water runoff and what which is infiltrated into the ground. This approach does not model the spatial infiltration process and no further loss is considered once the rainfall stops. It is recommended to model infiltration dynamically within the ‘urban’ areas.
- Drainage Network Representation
  - Flow through the modelled gullies was limited to 15% of the specified depth-discharge relationship. This will impact the amount of overland flow able to enter the drainage network. Justification for this approach was not found in the model report. It is recommended to investigate the gully inlet capacity further.
- Watercourses
  - Ensure a continuous flow path along main watercourses

    - Ensure road decks are represented where they may have an impact on overland flow routes
    - Update the main river sections with an initial water level as this will influence the drainage networks ability to draining to the watercourse
- CDA selection
    - Following completion of the model updates, it was recommended that the new results be used to verify the current SWMP CDAs and identify any others.

3 Data Review

Various sources of data were obtained for the update to the Braintree and Witham hydraulic models. A summary of the key data made available and used within the model is provided below. The key datasets were provided by the following partners:

- Essex County Council;
- Anglian Water (AW);
- Environment Agency (EA); and
- National Rail (NR).

3.1 Essex County Council

3.1.1 Gullies

As part of the ECC's endeavour to improve the gully dataset for the county, Map 16 were commissioned to conduct post-processing and filtering of the available gully datasets. Only a part-processed copy of this dataset was provided for use in this study. Review of this dataset found inconsistencies, such as duplicates of gully pits and areas of missing data within both Braintree and Witham. This study proceeded with using the as issued, incomplete dataset due to time constraints in agreement with ECC. Future modelling studies should seek to use the latest, complete dataset.

ECC commissioned the survey of gullies along key urban areas of interest. In total, 1465 gullies were surveyed over an area of approximately 1.7km^2 in Braintree, and 644 gullies over an approximate area of 0.3km^2 in Witham. Information on the coordinates and gully type were supplied along with on-site photos. This information along with the Map 16 data was used to create an integrated urban drainage model. An overview of the supplied gully datasets can be seen in Figure 3-1.

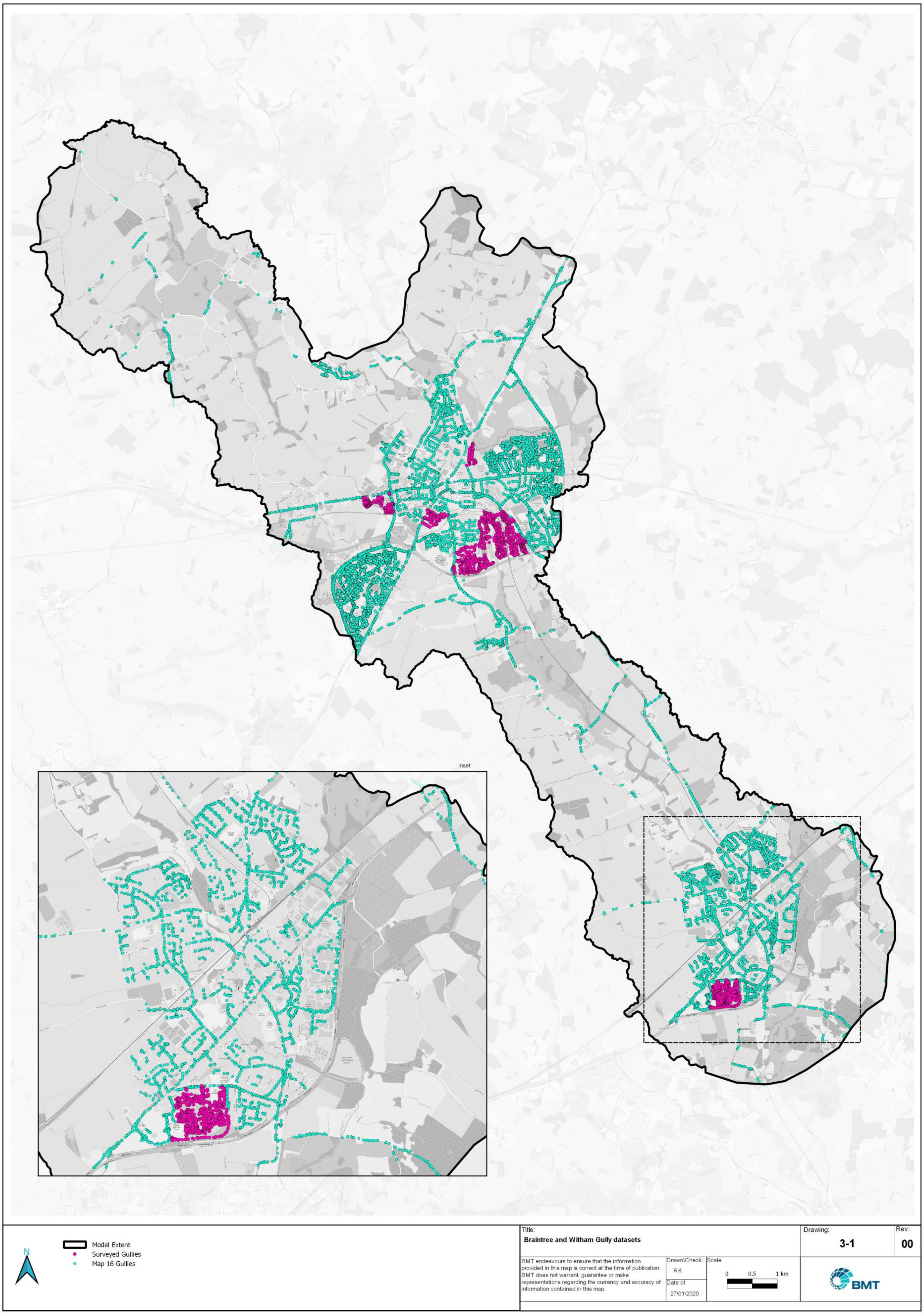

Figure 3-1 Gully Datasets

3.1.2 Building Threshold Levels

ECC provided building threshold levels surveyed by Jacobs in 2017 for a number of properties in Witham. The building elevations from this dataset were enforced in the hydraulic model. Figure 3-2 shows the locations of the surveyed building thresholds. Please note building thresholds outside of this survey dataset were uplifted using the methodology outlined in section 4.2.4.1.

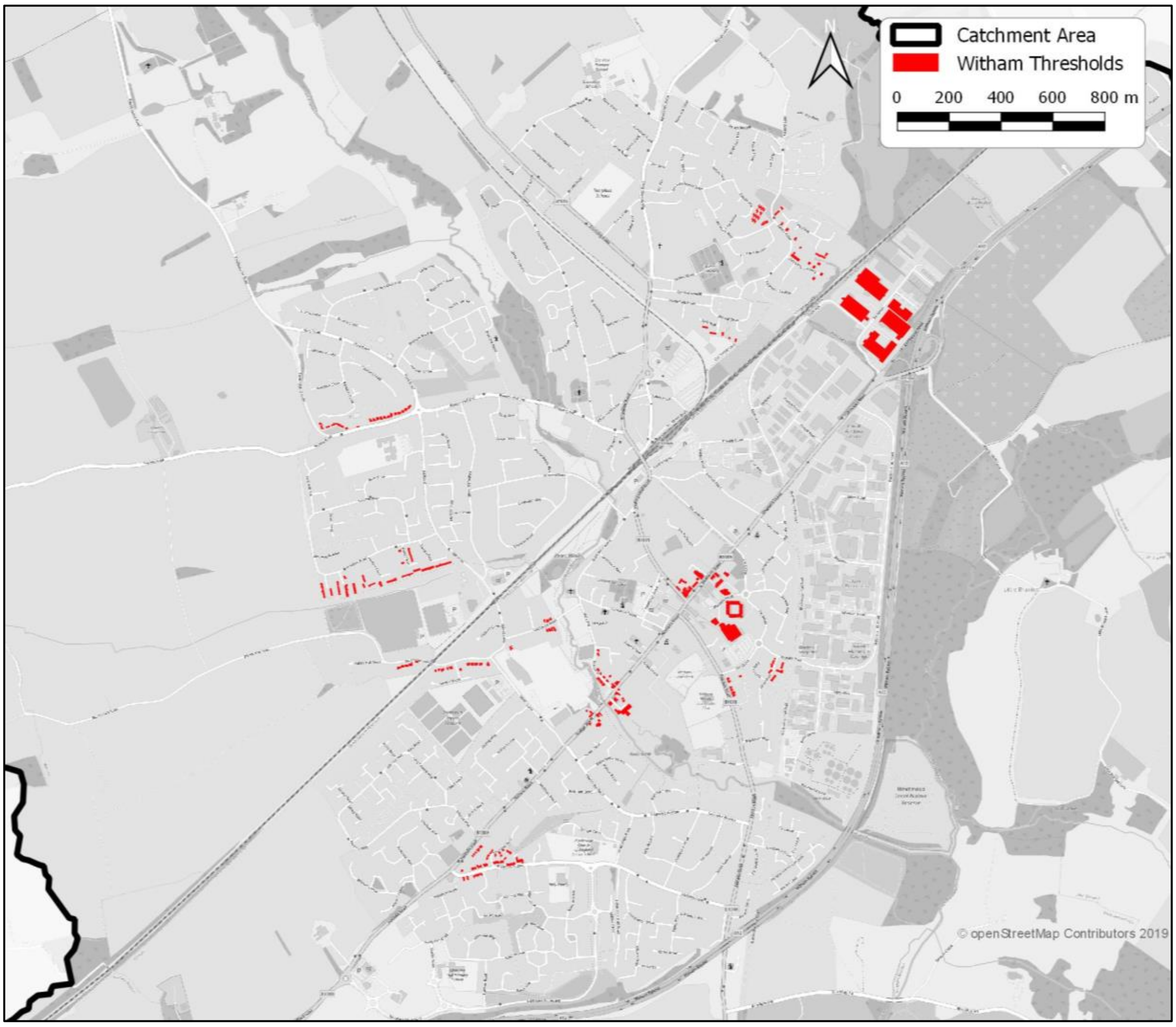

Figure 3-2 Witham Building Threshold Survey

3.2 Anglian Water

3.2.1 Anglian Water GIS dataset

The existing SWMP models provide a representation of the drainage network only in areas encompassed by the three individual model extents. This approach was taken in part due to the known issues with the quality of the AW data relating to pipe inverts and diameters.

GIS datasets of the underlying drainage system for Braintree and Witham were requested and provided by AW as part of this study. Areas that exhibited poor invert level data were highlighted and assessed. The spatial extent of the dataset was reviewed and a reasonable coverage was found in the predominantly urban areas of the study area. Approximately 50% of AW pipes are shown to have both invert levels present (Figure 3-3) although this does not always indicate a usable invert as some culverts have been shown to use duplicate values from adjacent pipes. Subsequent checks were undertaken to verify the validity of the invert data by undertaking a comparison with the LiDAR DTM. This found a number of locations within the drainage system with erroneous issues, such as inconsistent culvert inverts, and sewer network pipes with invert levels above ground.

A different approach to representing the drainage network was therefore adopted in areas identified to have a lack of data or where there is lower confidence in the data quality. These typically include areas where invert data was missing for large parts of the network. Figure 3-4 highlights the spatial distribution of drainage invert quality within the catchment, with pockets of poor and reasonable invert reliability. The drainage network representation in the hydraulic model is discussed in Section 4.2.6.

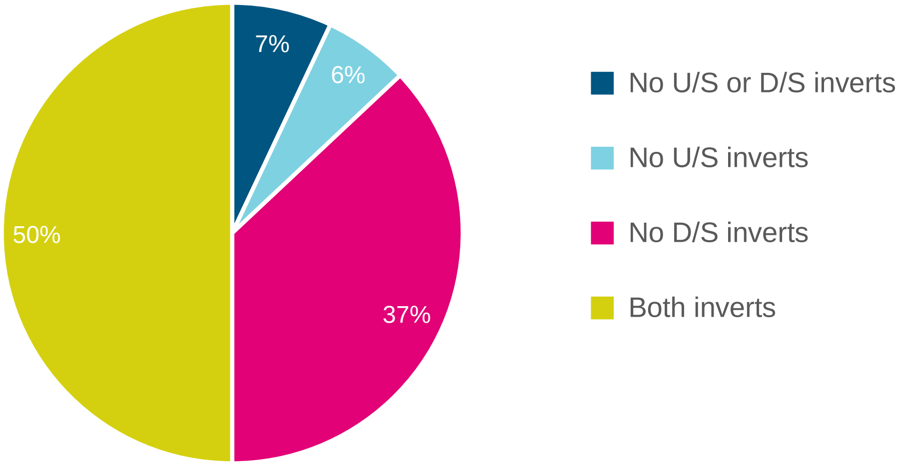

Figure 3-3 Pipe Invert Data Quality

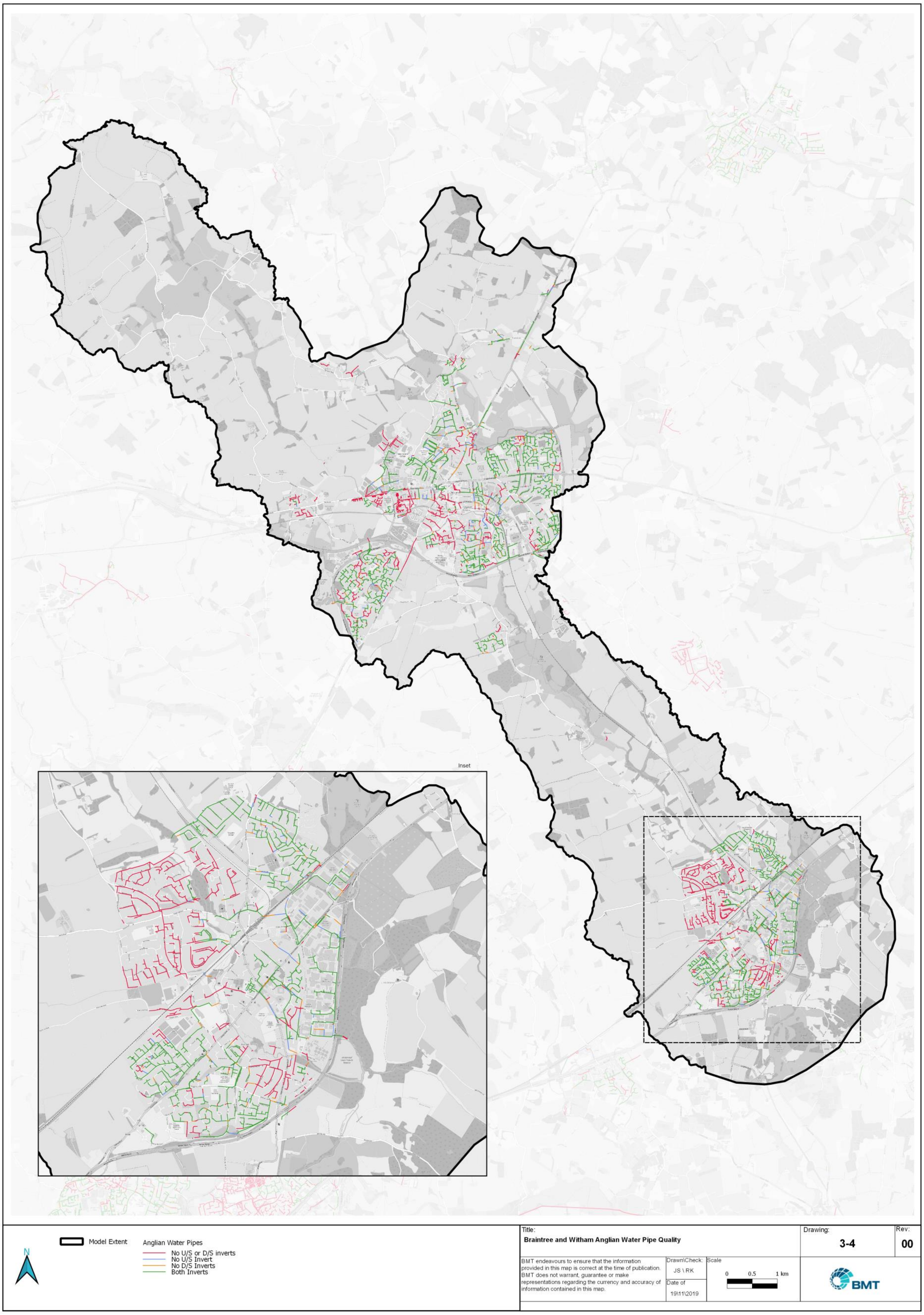

Figure 3-4 Anglian Water Pipe Quality

3.3 National Rail

National Rail (NR) has two railway lines extending through the model domain; one line transects through Witham, and the other extends from Braintree through to Witham in the south. NR provided a dataset that identified the location of hydraulic structures that cross beneath the rail corridor. These locations translated into 34 hydraulic structures for representation in the model. Several of these locations coincide with areas of identified ponding water. Some supplied structure locations were ignored as these were positioned at low points along the railway and a transecting structure from either side of the embankment would results in the structure sitting above the tracks. More information on the structures and their application within the model can be found within Section 4.2.11.

3.4 Environment Agency

The Environment Agency (EA) provided several existing models which fall within the study area. These include models of the River Brain and Blackwater constructed as part of the “River Blackwater Model Update Project” (JBA Consulting, July 2010).The ISIS-TUFLOW model used a 1D-2D representation within the urban areas and a 1D only approach (using extended cross-sections) elsewhere. Figure 3-5 shows the locations of the 1D ISIS nodes. in the urban areas and where structure information will be taken to inform main river channel edits.

These models were used to inform several main river structures along both watercourses. This is of particular importance as hydraulically significant structures may attenuate and influence surface water drainage that outfall into the main river. The cross-sectional information was also utilised to ensure continuous flow paths were enforced into the modelled ground elevations and conveyance is represented appropriately.

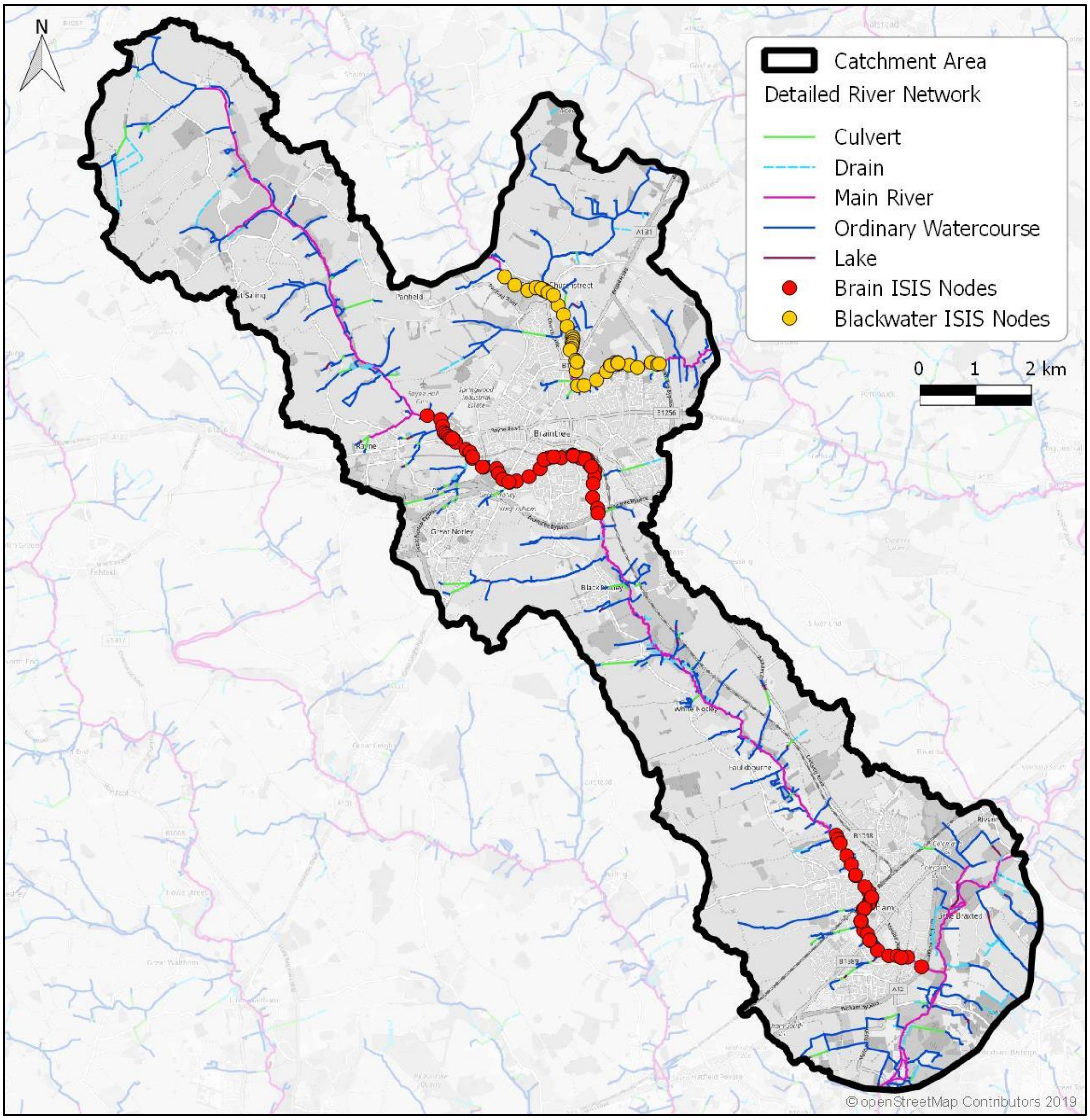

Figure 3**-**5 **EA Model Coverage**

4 Methodology

4.1 Hydrological Model

4.1.1 Design Rainfall Events

A direct rainfall approach was selected that simulates rain falling on the catchment, losses due to infiltration and any subsequent runoff that contributes to surface water flooding. This approach represents current best practice for predicting surface water flooding, and uses design rainfall hyetographs, which vary in duration and storm frequency. Revitalised Flood Hydrograph Model (ReFH2) software has been used generate design hyetographs appropriate to the catchment. FEH catchment descriptors were obtained from the Centre for Ecology and Hydrology FEH website[3].

These descriptors contain catchment specific details which enable derivation of runoff rates and volumes to support drainage design using the Flood Estimation Handbook rainfall runoff methods. The FEH2013 rainfall model has been selected to inform the design hyetographs, as the latest available datasets.

Net rainfall was taken from ReFH2 and applied to the rural modelled catchment area, which removes the losses using the ReFH2 model prior to applying rainfall in the hydraulic model. This approach is in line with EA guidance (May, 2019)[4], which advises against using direct rainfall approaches in rural catchments due to a number of limitations including representation of antecedent conditions, infiltration parameters, and the runoff generation process.

The revised hydrological approach has considered spatially varying rainfall due to the catchment size being greater than $10km^2$. The catchment was divided into an upper Braintree and lower Witham catchment. Rainfall depths were extracted at two locations (Table 4-1) across the catchment from the Flood Estimation Handbook (FEH) webservice.

Design events for the following annual exceedance probability (AEP) events were generated for the summer rainfall critical duration:

- 50% AEP (1 in 2 year)
- 20% AEP (1 in 5 year)
- 10% AEP (1 in 10 year)
- 5% AEP (1 in 20 year)
- 3.33% AEP (1 in 30 year)
- 1.33% AEP (1 in 75 year)
- 1% AEP (1 in 100 year)
- 0.5% AEP (1 in 200 year)

[3] https://fehweb.ceh.ac.uk/
[4] Submitting locally produced information for updates to the Risk of Flooding from Surface Water map (Environment Agency, Map 2019)

Table 4-1 Rainfall Depth Extraction Points

Model Catchment	Town	Eastings	Northings
Braintree & Witham	Braintree	575700	223900
	Witham	581050	214650

4.1.2 Baseflow

Baseflow is the proportion of flow within watercourses sustained between rainfall events. It is directly linked to the routed direct runoff and the recharge gained via infiltration. For the purpose of the hydraulic model, the calculated baseflow rates have been applied over the course of the model simulation as generated from ReFH2. Baseflows were applied as inflow points on the upper reaches of the River Brain and Blackwater and are only applied in 'rural' catchments. The 'urban' hydrology produced as part of the ReFH2 process has not considered infiltration within the hydrological model, therefore this needs to be simulated dynamically as part of the TUFLOW model .

BF_o (initial baseflow) values of 0.149m^3/s for the Braintree catchment and 1.001m^3/s for the lower Witham catchment were calculated. The application of the baseflow has not been proportioned by sub-catchment area in each respective hydrological domain. Rather the entire baseflow has been applied along the main flow path through the catchment.

4.1.3 Critical Rainfall Duration

The critical rainfall duration is defined as that duration which produces the greatest flood extent and flood depth. Even within a small area, the critical duration can vary due to several factors, including topography, land use, size of the upstream catchment and nature of the drainage systems.

The previous SWMP modelling generated three separate critical storm durations using the Revitalised Flood Studies Report (FSR)/Flood Estimation Handbook (FEH) methods. The critical duration for each model area is listed below:

- Bradford Street and Warwick Close, Braintree of 1.3 hours (80 minutes) (Summer Storm);
- Spa Road, Witham - 0.8 hours (rounded up to 60 minutes) (Summer Storm); and
- Rectory Lane, Witham– 5.5 hours (rounded up to 360 minutes) (Winter Storm).

For this updated study, five rainfall durations were simulated in the model for the 1% AEP event to determine the critical duration. The 1-hour, 2-hour, 3-hour, 6-hour and 9-hour (summer and winter) durations were tested. Following simulation of the hydraulic models, the predicted max depth results were processed for each rainfall duration. This was classified as such to highlight the source rainfall duration which has produced the maximum flood depth at locations across the study area. The grid was then 'trimmed' using a depth threshold of greater than 0.1m to distinguish the main flow paths within the catchment (Figure 4-1 Braintree Critical DurationFigure).

Peak depths within the fluvial extent are driven by the 9-hour and 3-hour durations, a similar pattern is shown downstream in Witham where the River Brain meets the River Blackwater. Where the 1-

hour duration produced the peak depths, these corresponded to areas of shallow, sheet flow (less than 0.1m).

The critical duration in the three CDAs identified in the original SWMP were assessed. The results showed a summer profile consistently resulted in higher peak depths when compared to the winter profile. The 2-hour and 3-hour durations tended to be the durations that produce the greatest peak flood depths in the urban areas. The magnitude difference between the two durations is small (less than 0.01m) in the Bradford Street and Warwick Close CDAs where the 2-hour duration is dominant. A 3-hour summer profile was therefore chosen as the critical duration for the catchment.

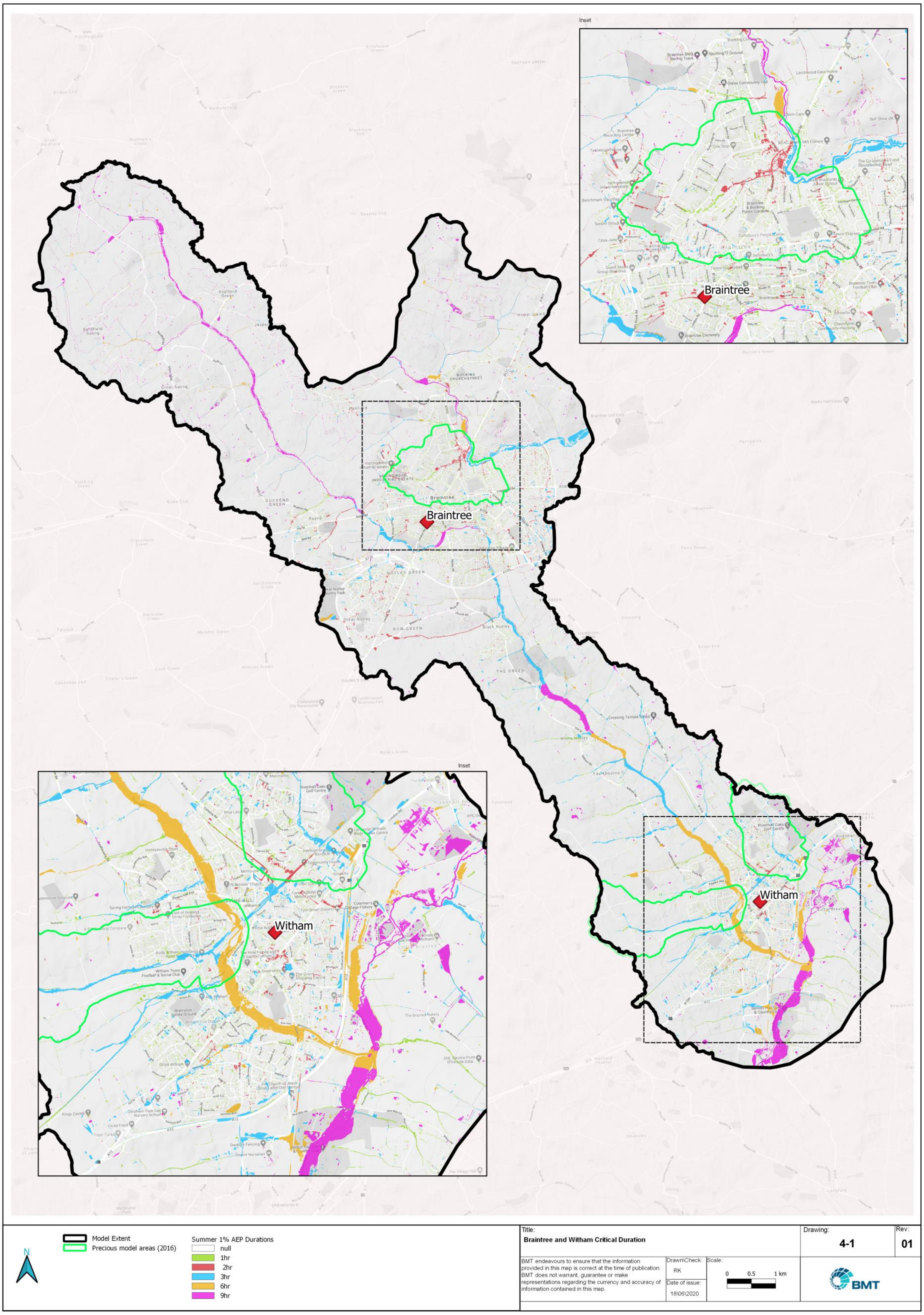

Figure 4-1 Braintree Critical Duration

4.1.4 Climate Change

In February 2016, the Environment Agency updated their guidance on climate change allowances to inform flood risk and strategic flood risk assessments. Table 4 of the guidance is relevant for this study, and provides peak rainfall intensity allowances in small and urban catchments. This information has been reproduced below within Table 4-3.

This guidance document was released after the finalisation of the Braintree and Witham SWMP hence the model developed assesses the impact of climate change based on dated guidance.

Table 4-2 Peak Rainfall Intensity Allowance (Small and Urban Catchments)[5]

Allowance Category	Total potential change anticipated for 2010 to 2039	Total potential change anticipated for 2040 to 2059	Total potential change anticipated for 2060 to 2115
Upper End	10%	20%	40%
Central	5%	10%	20%

The Environment Agency guidance recommends assessing both the central and upper end allowances to provide a range of the potential impacts of climate change. The 'central' (20%) and 'upper end' (40%) allowances for the 2060 to 2115 epoch have been applied to the 1% AEP event.

4.2 Hydraulic Model

4.2.1 Model Software Selection

The existing SWMP models were constructed in TUFLOW in 2015. To enable a catchment wide analysis, TUFLOW HPC (2018-03-AE-iSP-w64) was selected to undertake the model update due to its use of Graphical Processing Units (GPU) and ability to simulate large models at a high resolution. It is therefore suitable for assessing surface water flood risk in urbanised areas where micro-topographic features influence flooding mechanisms.

The TUFLOW suite of products were benchmarked by the EA[6] in 2010 and 2013. It represents industry standard software and is determined to be suitable for assessing surface water flood risk.

4.2.2 Model Extent

A 'rolling ball' analysis was carried out to determine the contributing surface water catchment for Braintree and Witham. The definition of the model extent also considers the contributing extent of the underlying drainage and pipe network (Section 4.2.7).

The Braintree and Witham model extent covers the entire River Brain catchment and also a portion of the River Blackwater which passes through Braintree. This was necessary to fully account for the interaction between both rivers at the confluence downstream of Witham but also to best represent the fluvial network which impacts surface water outfalls draining to the network. The updated model extent covers 100km^2 and can be seen in Figure 4-2 below.

[5] 'Adaption to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities' (Environment Agency, 2016)
[6] Benchmarking the Latest Generation of 2D Hydraulic Modelling Packages SC120002 (Environment Agency, August 2013)

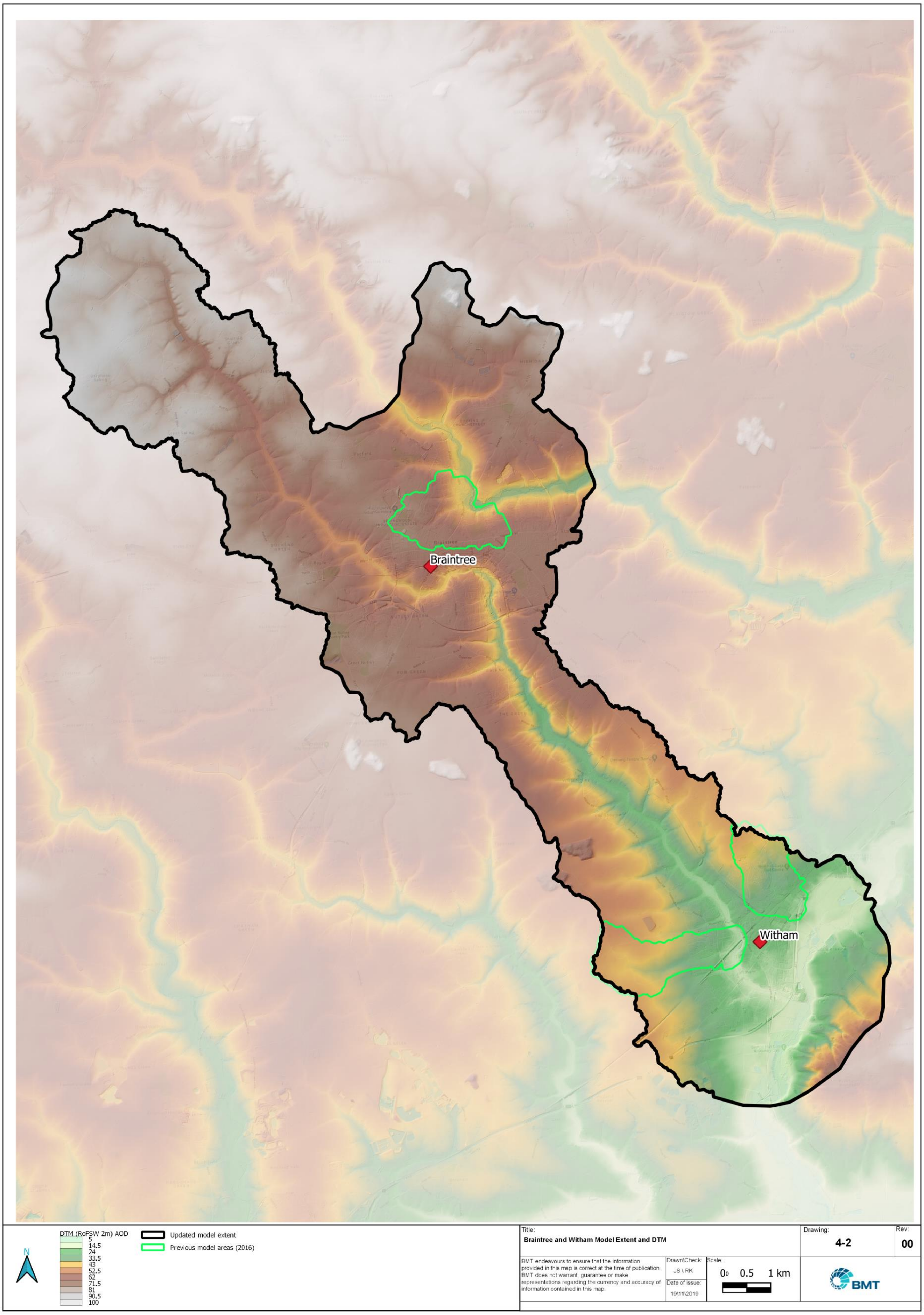

Figure 4-2 Model Extent and RoFSW DTM

4.2.3 Cell Size

The routing of water through a pluvial hydraulic model is primarily influenced by the underlying terrain. The cell size of the previous three CDA models were set at 2m and focussed on specific sub-catchments (Figure 4-2 above). A cell size of 3m was selected to facilitate development of a whole of catchment model, overcoming the limitations of the previous models which does not consider hydraulic connectivity between sub-catchments. Figure 4-3 shows a visual comparison of how the choice of cell size influences the representation of the underlying model area. It highlights the minimal difference in results between a choice of 2m and 3m cell size.

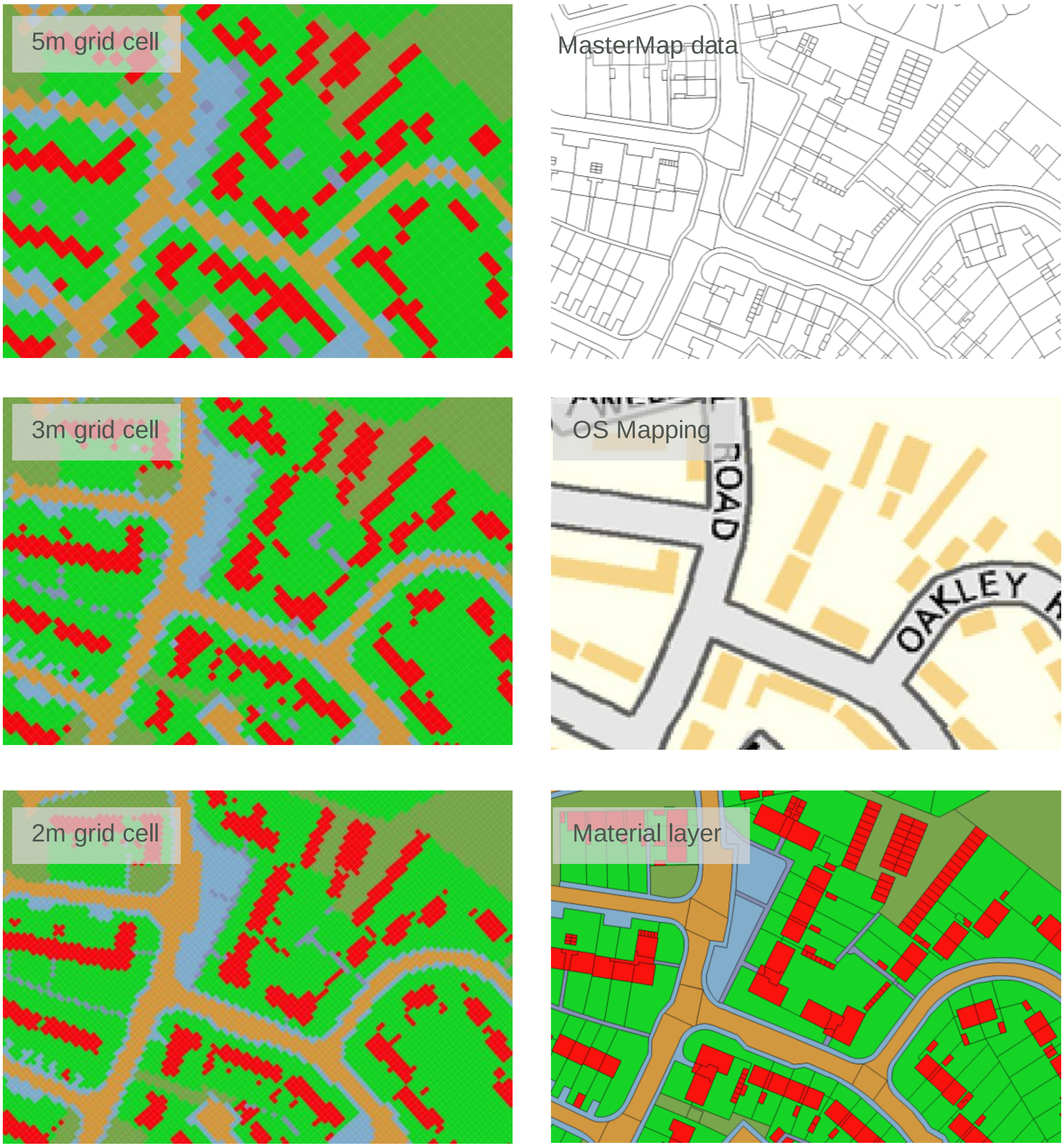

Figure 4-3 Cell size resolution difference

4.2.4 Topography

The ground elevation data has been retained from the original SWMP modelling study. The DTM used to produce the EA Risk of Flooding from Surface Water[7] (RoFfSW) Maps has been used as it includes several pre-processed topographic amendments, including:

- Incorporation of a building upstand of 0.3m to represent deflection of surface water at shallow depths;
- Definition of kerbs by lowering of road ground levels by 0.125m, the height of a British Standard kerb; and
- Definition of flow through structures, such as under bridges and through embankments, found to impede the flow of surface water.

In addition, the latest EA 2m LiDAR was stamped on top of the RoFSW to update observed discrepancies in channel and urban environments. The extent of the EA LiDAR was also trimmed in locations to interface with the RoFSW DTM more appropriately and prevent sharp edges between the two DTM datasets (Figure 4-4). The updated LiDAR covers a majority of the catchment area and entirety of the urban areas in both Braintree and Witham.

4.2.4.1 Urban Environment

The resolution of the underlying 2m DTM is sufficient such that post-processing of kerb levels was deemed as not required. However, as buildings have been filtered from the EA DTM, an approach of building upstand representation has been adopted to match the methodology used in the RoFfSW DTM which applies a 0.3m upstand. This is described within the Updated Flood Map for Surface Water 2013 report[1].

4.2.4.2 Watercourses

The Spa Road, Witham (W2) LFRZ features an ordinary watercourse which conveys runoff from the rural upper catchment. The watercourse flows in an easterly direction adjacent to an urbanised area located on the northern bank. The previous model results predict the capacity of the watercourse is exceeded resulting in flooding of adjacent properties on Teign Drive and Ness Walk. Upon reviewing preliminary updated results, it was found that the underlying RoFSW DTM was erroneous, due to poor resolution in the area, and was directing surface runoff into the adjacent urban area. This issue was further validated when comparing the surveyed building thresholds to the RoFSW DTM and finding differences in elevation of 1m+ in some locations. To improve channel representation and limit similar issues discovered at Spa Road, the topography was updated with the latest available EA LiDAR. Figure 4-4 shows the extent of LiDAR replaced within the model domain.

Where cross-sectional information was available through supplied EA ISIS models, the invert data was extracted and used to enforce the channel profile to better represent conveyance. In addition, 2D open channels have also utilised the 'gully' option as a recommended approach as it both lowers an entire cell and ensures a continuous flow path is enforced - therefore water is not artificially held back.

[7] *'Updated Flood Map for Surface Water: National Scale Surface Water Flood Mapping Methodology'* (Environment Agency, May 2013).

Additional topographic amendments were made to ensure flow paths within the areas of interest were defined and any other erroneous issues that were encountered.

4.2.5 Land Use

Flow velocity depends on the amount of friction 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 represents the roughness of the land surface, or river channel, in the hydraulic model.

OS MasterMap data provided by ECC was used to identify different land-uses within the Braintree and Witham modelled area (Figure 4-5). Manning's *n* roughness coefficients are unchanged from the SWMP models, with the key exception of applying a depth varying roughness to buildings to more accurately model the impact of rainfall on buildings. The Manning's *n* is reduced at shallow depth representing a rapid runoff response associated with rainfall on building roofs. The Manning's *n* is increased at greater depths to show the impact of slower flow through houses and walls.

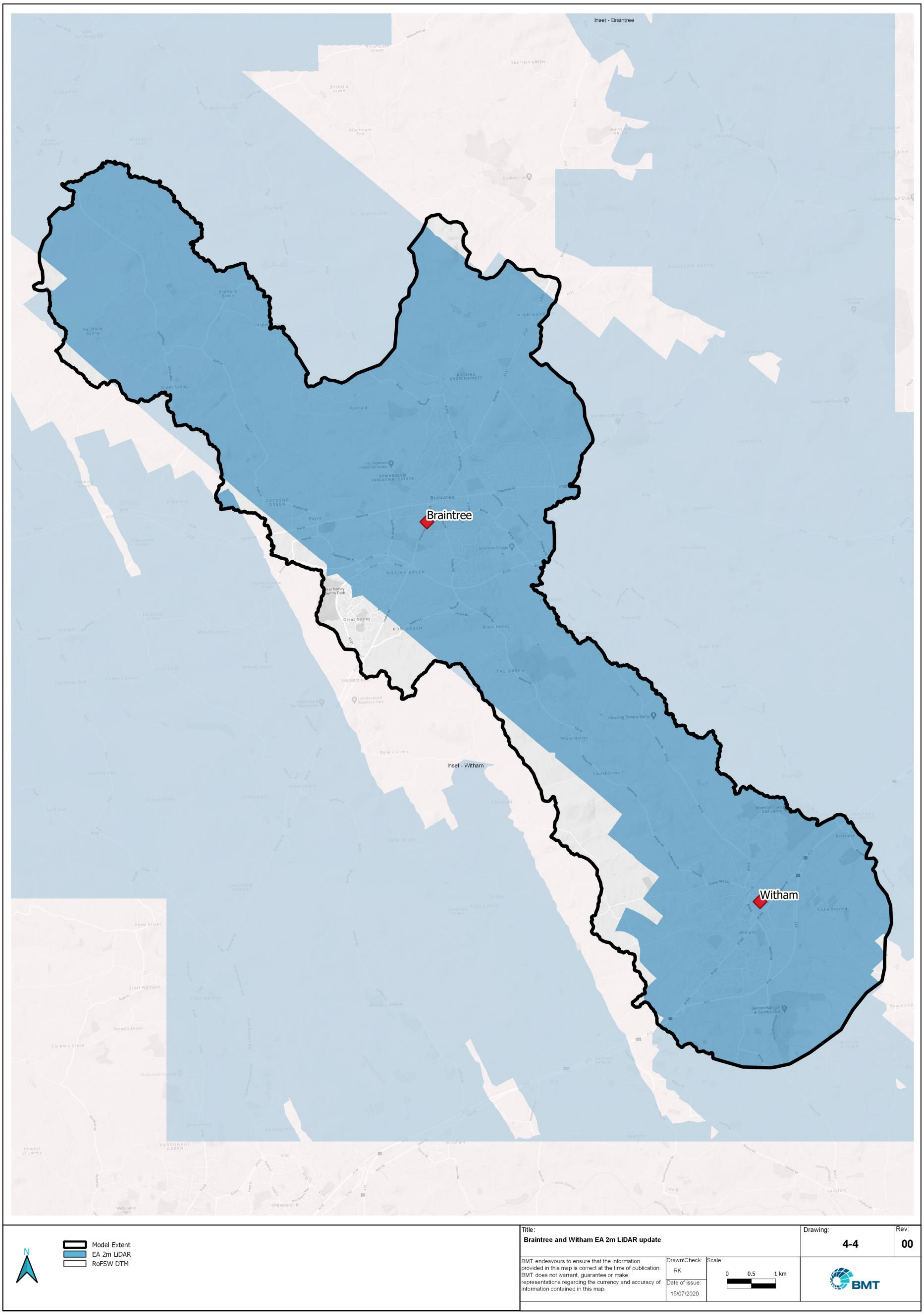

Figure 4-4 EA LiDAR update

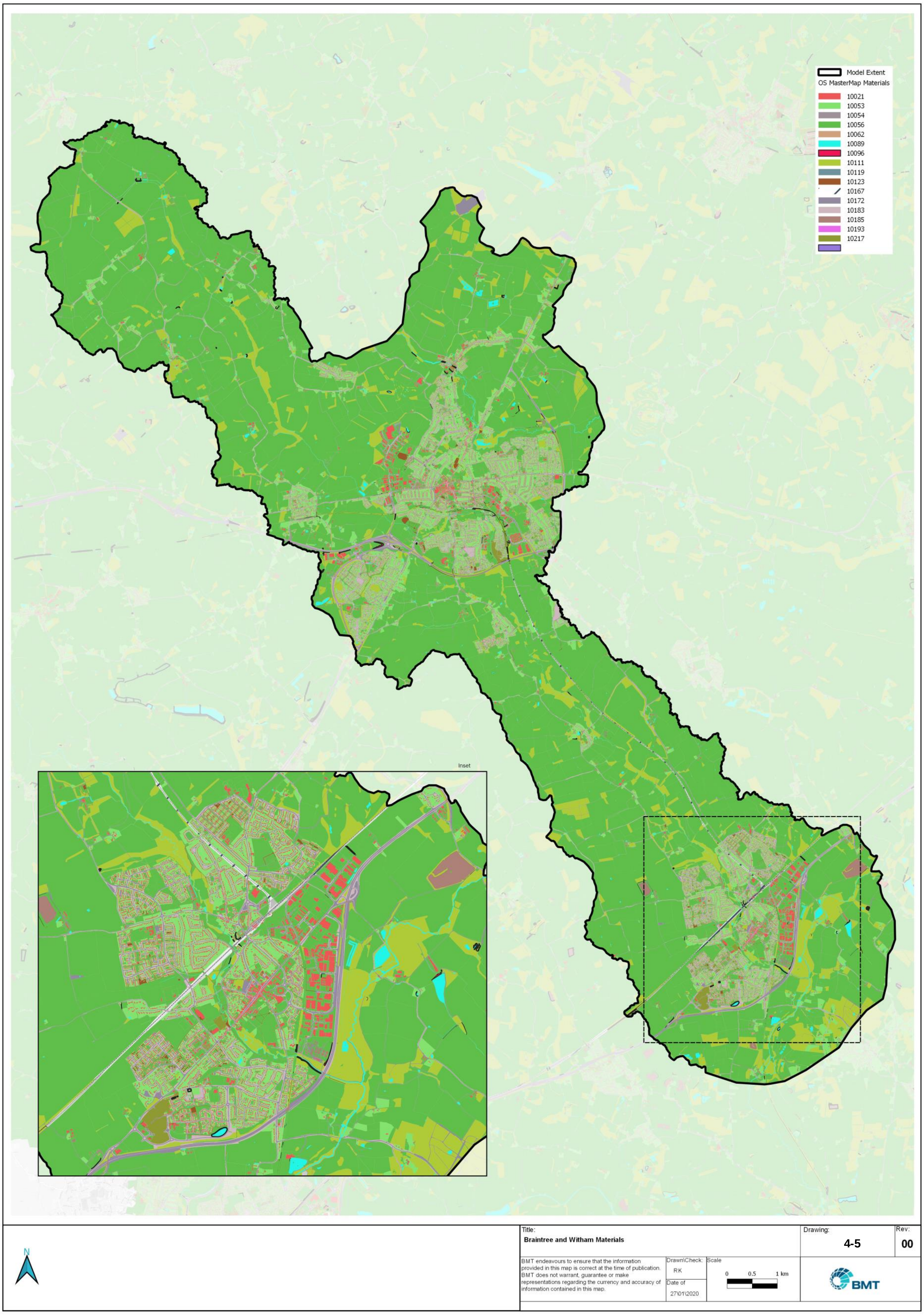

Figure 4-5 Land Use Classification

4.2.6 Drainage Network

This model update has focused on correcting anomalies, incorporating new datasets (Section 3), and providing greater coverage of the modelled network. This was of importance as this update covers the entire urban centres of both Braintree and Witham as opposed to the previous modelling.

The drainage network has been modelling in one of two ways – 'Virtual Pipes' or Integrated Urban Drainage (IUD). The choice of method is based on data quality and quality. A full IUD was represented in preference where sufficient information on the sewer network (pipe location, geometry, invert levels, manholes and gullies) was available. A full IUD was represented across most of the modelled extent.

A 'Virtual Pipes' approach was adopted where there was insufficient information in the sewer record to construct a full IUD. This approach requires gully locations and is most suitable in areas where the pipe transit times are small and the limiting factor is the gully inlet capacity.

The following section of this report provides further detail on the updates undertaken to the modelled drainage network.

4.2.7 Pipe Network

The representation of the drainage network in this catchment wide model utilises the latest Anglian Water pipe dataset. An overview of the spatial distribution and data quality can be seen in Figure 3-3 and Figure 3-4 respectively. The network was filtered by fluid type (surface water and combined only) and data quality (known invert levels and pipe diameters) before a detailed interrogation of connectivity was conducted. Isolated areas of disconnected pipe network that offered no reasonable connectivity and short lengths of pipe with no connecting gullies were removed from the dataset where observed. The only area to utilise 'combined' AW sewer pipes was in the region of The Grove Shopping Centre, Witham where upstream surface water networks drain into the combined system and the network also collects local gully discharge. All other location use the AW 'surface water' pipe dataset.

As was noted in the Braintree & Witham SWMP Technical Note (AECOM, 2015; Amended Modelling Methodology), there are observable deficiencies in the Anglian Water dataset. Stretches of the drainage network were inconsistent along certain alignments, and contained invert levels above the ground level in the LiDAR DTM. A data cleaning process was undertaken where sensible to infill data gaps and amend invert levels to improve the understanding of underground drainage interaction in the catchment.

As the quality and quantity varies around the catchment a second approach was needed to cater for areas with particularly poor pipe network data. Where insufficient information was available to infer missing diameters and inverts, the decision was made to utilise the virtual pipe approach that simulates the dynamic interaction of gully discharge during a storm event. The locations that predominantly utilise the virtual pipe approach are centres around areas of no upstream or downstream inverts (Figure 3-4; clusters of red pipes). More details concerning virtual pipes is described in Section 4.2.9.

4.2.8 Gullies

The 1D network was dynamically linked to the 2D domain through boundary cells. These boundary cells pass water from the surface into the stormwater sewer and vice versa. In urban drainage models, it is usual for the exchange of water between the 1D pipe network and the 2D domain to occur at road gullies or culverts inlets and outlets.

The datasets described in Section 3.1.1 were used to represent gullies across the modelled catchment. The gully inlet capacity in the SWMP models were limited to 15% of the total capacity and has the impact of reducing the amount of flow that is able to enter and leave the drainage system. This study has found no evidence to justify representing a reduced gully inlet capacity.

The gully inlet capacity in this model update was represented by calculating a depth-discharge relationship for each gully grate type based on the Design Manual for Roads and Bridges (DMRB). For example, a ‘Type R’ gully grate has a depth discharge curve limited to $0.01m^3/s$ (10L/s). Further consideration was also given to the overall longitudinal road gradient where gullies were positioned and applying a discharge curve based upon ‘steepness’. Figure 4-6 shows the difference in discharge curved for both steep and shallow gradients.

Based on survey photos (Figure 4-6) and Street View observations, additional gullies in this study have been assumed to be ‘Type R’ and ‘Type K’ (kerb) with assumed kerb inlet widths at 0.3m wide. Connection of the gully dataset to the stormwater network is based on a pit search radius that will automatically link gullies to the underground drainage. Through a review of the gully-pipe connectivity, where gullies were incorrectly connected using the automatic pit search radius, manual connections were made using the ‘x-connector’ feature in TUFLOW which will connect a gully to a nearby pipe manhole. The ‘x-connector’ feature is similar to the pit search radius and will allow for the transfer of flow from one point to another.

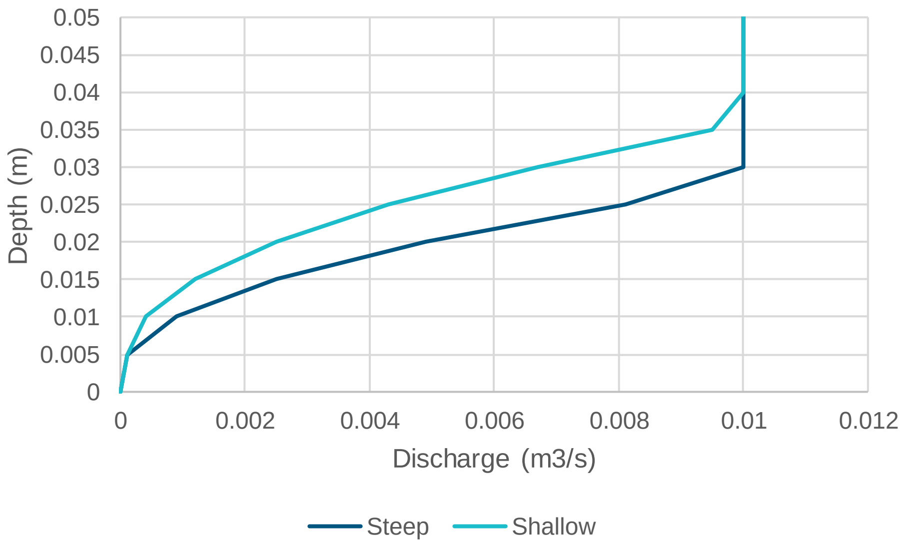

Figure 4-6 Gully pit types

4.2.9 Virtual Pipes

The Virtual Pipes method was used to represent the removal of surface water by the sewer network in designated areas of Braintree and Witham that were missing underground stormwater networks, and in areas where it could not be reasonably determined how they connected to the drainage network. This method only requires information on gully locations. Flow into a gully is represented using the same approach as described in Section 4.2.8. Areas where a pipe network existed but exhibited limited invert levels and pipe diameter data (thus was removed from the IUD approach) were used to infer outfall locations for where a 'virtual pipes' approach was adopted were inferred from the provided AW data. These outfall locations were typically into the ordinary and main watercourses such as the River Brain and Blackwater (Figure 4-7).

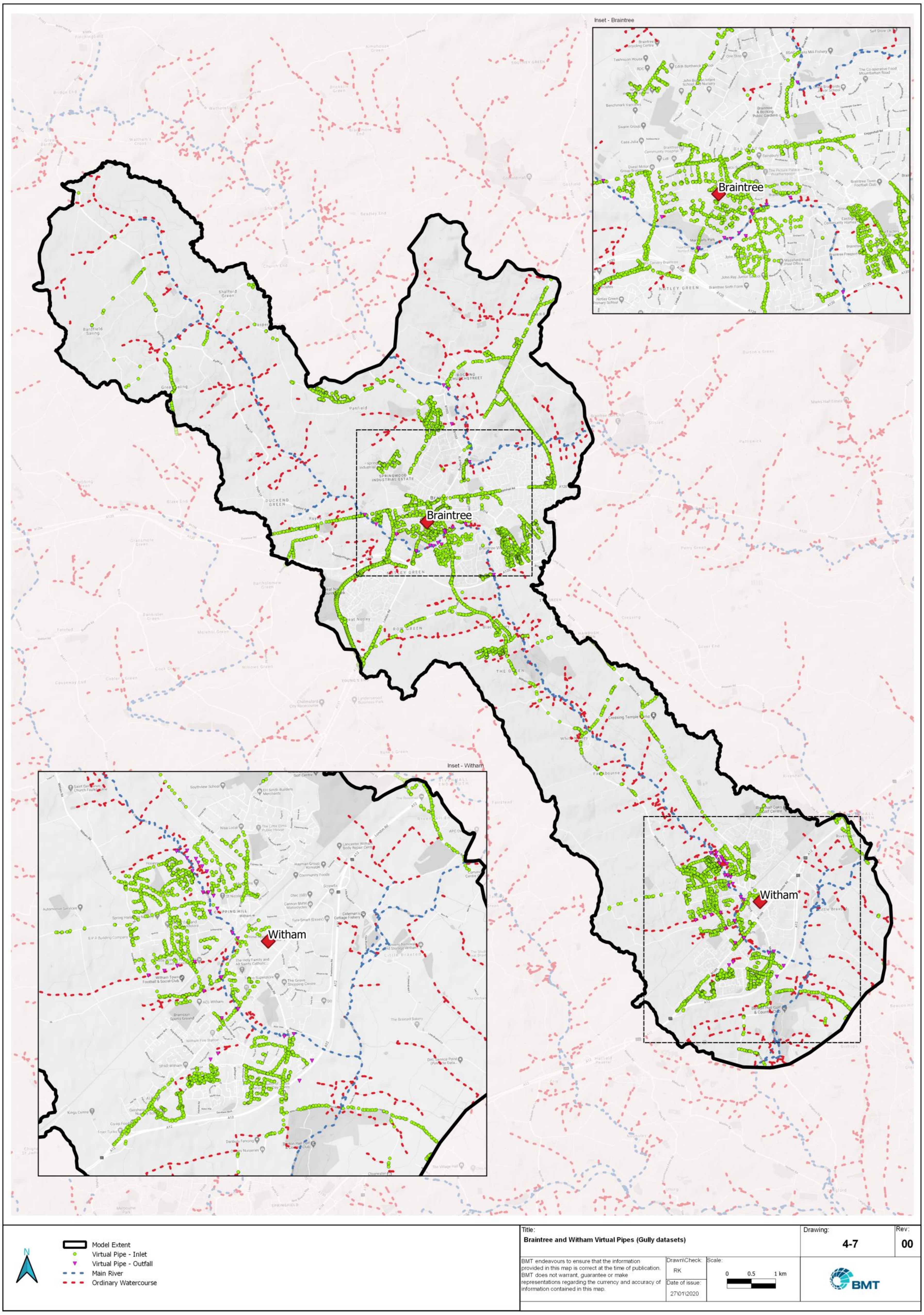

Figure 4-7 Modelled Gullies using a 'Virtual Pipes' Approach

4.2.10 Boundary Conditions

A hydraulic model requires the specification of inflow boundaries and outlet boundaries to allow water into and out of the model domain. Often, 2D hydraulic models will have external and internal inflow boundaries. The external inflow boundaries account for flow generated from outside of the model extents (external boundaries) whereas internal boundaries account for the runoff/rainfall generated from within the model extents. Flow is removed from the model through downstream boundaries, which are generally a fixed water level or a rating curve.

4.2.10.1 Internal Boundaries

4.2.10.2 Rainfall

The rainfall generation process is described in Section 4.1 and highlights the steps taken to produce the hyetographs for Braintree and Witham. Design rainfall was developed for inclusion in the hydraulic model as catchment wide boundaries. The hydraulic model utilised the direct rainfall approach within TUFLOW. This rain-on-grid method works on the principle of applying rainfall directly onto the catchment land surface. This is particularly beneficial when analysing lower magnitude, higher probability, rainfall events as the impact of dry and saturated ground conditions can be assessed. This differs from the existing SWMP models, where the rain that falls on buildings was applied directly to roads and equally distributed at the locations of gullies. This method aims to replicate rainfall being collected via roof gutters and routed to the drainage network via drain pipes. applied rainfall to all areas apart from buildings. The approach adopted for this study allows the hydraulic model to route the rainfall automatically, and provides a more accurate representation of the interaction between surface water runoff and the drainage network.

A separate rainfall profile for Witham and Braintree was produced to represent the spatially varying rainfall in catchments greater than 10km². The Witham rainfall profile was applied to the south portion of the model domain up to the A120 in Braintree. The Braintree rainfall profile covered the remainder of the model in the upper catchment.

4.2.10.3 Infiltration

The SWMP models represented infiltration by applying varying runoff coefficients to landuses within the catchment. For example, a 0.5 coefficient has been used for areas designated as gardens. This assumes that 50% of the rainfall is lost through infiltration. This approach does not model the infiltration process removing the rainfall prior to application in the model. Another limitation of this approach is that once the rainfall stops, so does the loss / infiltration. Consequently, at the end of the modelled storm duration, no water can infiltrate into the ground for the remainder of the simulation.

This model update has adopted different approaches for the rural and urban parts of the catchment which have been defined using the DEFRA Built up Areas (2011) dataset for England and Wales. Infiltration in the rural areas have been calculated using the ReFH2 hydrological model (section 4.1.1). Baseflows (Section 4.1.2) representing the recharge gained via infiltration are applied as inflow points on the upper reaches of the River Brain and Blackwater.

The rural catchment is then divided into sub-catchments using the rolling-ball method to allow for the baseflow to be proportioned based on the ratio of sub-catchment area to total rural area.

The Green-Ampt approach to model soils infiltration losses has been applied in urban areas to permeable land uses. The Green-Ampt approach varies the rate of infiltration over time based on the soil's hydraulic conductivity, suction, porosity and initial moisture content. Surfaces such as roads, buildings and paving are classed as impervious and do not allow infiltration. Residential yards are classed as only 40% pervious, to account for paving and sheds instead of grassed areas or garden beds. In these instances, the infiltration was modified based on the land use definition, see Appendix A:. A dry soil antecedent condition has been assumed given that there is no evidence of previous flooding whereby the soil saturation was a major factor.

The underlying soil types across the modelled extent were based on data identified by Cranfield University. The Cranfield University dataset provides a broad scale summary of the soil landscapes for England and Wales. The predominant soil type was '*loamy clayey soils with impeded drainage'.* The soil descriptions were then aligned with a representative United States Department of Agriculture (USDA) soil types that are hardwired into TUFLOW (Appendix B:). The hydraulic parameters for each soil type can be found within the TUFLOW Manual[8].

In line with the new hydrological method, net rainfall was applied to rural areas of the model and the underlying infiltration parameters were not represented. This is to account for losses that have already been factored into the hydrological method. Conversely in urban areas, the gross rainfall is applied and soil infiltration has been taken into account.

The depth to groundwater was originally considered to be included within the model, though a review of groundwater levels supplied in borehole logs revealed that this is unlikely to be a factor in the local flooding mechanisms within the study area. A depth to groundwater was therefore not accounted for in the model.

4.2.10.4 Initial Conditions

Initial water levels (IWLs) were applied within the model to define the initial condition within watercourses. A 2D IWL has been generated for the River Brain and River Blackwater. The inflows have been derived from the calculated baseflows from the ReFH2 method described in Section 4.1.2. The inflows have been applied via a 2d_sa region layer at the upstream model extent of each river system. Once a steady state was reached, the maximum 2D water level attained from the applied flow was applied to the hydraulic model as an IWL (Figure 4-8).

4.2.10.5 External Boundaries

Downstream boundaries in the Braintree and Witham model were included in locations where confined flow, as in a river or valley, exits the 2D domain. A 2D stage-time (HT) boundary has been implemented at downstream boundary locations at Witham and Boking (Figure 4-8). A stage-time (HT) boundary assigns a normal condition at the external boundary to the model domain. This allows water to flow out of the active area driven by the hydraulic head generated from within the model.

[8] TUFLOW Manual, 2018; Table 6-14

4.2.11 Structures

The hydraulic model has been updated to reflect conveyance through bridges and culverts where information is available on those that are hydraulically significant for this study. The supplied EA ISIS models were used to extract dimension and invert details on those structures located along the River Brain and River Blackwater. Larger fluvial structures were modelled using a 2D layered flow constriction shape that accounts for the contraction/expansion losses, as well as the interaction of the bridge deck.

Supplied point information from Network Rail was also used to inform floodplain structures along the north-south leg of the railway that runs from Braintree to Witham. The data gave approximate coordinates and dimensions for 34 locations, however the structure type ('circular') and inverts had to be assumed from the underlying DTM elevations.

As identified within the peer review[9], the structure at Bradford Street (Bradford Bridge) had not been explicitly modelled. This has presumably been excluded to allow for continuous flow along the River Blackwater. The absence of the road deck in the previous model prevents surface water flowing along Bradford Street from continuing north-east to Broad Road. The model instead allows for this water to enter the River Blackwater directly. The updated model completed as part of this study has reinstated the Bradford Street road deck over the River Blackwater. This includes the surrounding bridge parapets to improve the flooding mechanisms along this street. The bridge structure has been represented as twin rectangular box culverts based on dimensions supplied within the EA ISIS model.

[9] Braintree and Witham SWMP Model Review; BMT; September 2018 (BraintreeWitham_SWMP_Model_Review_03.pdf)

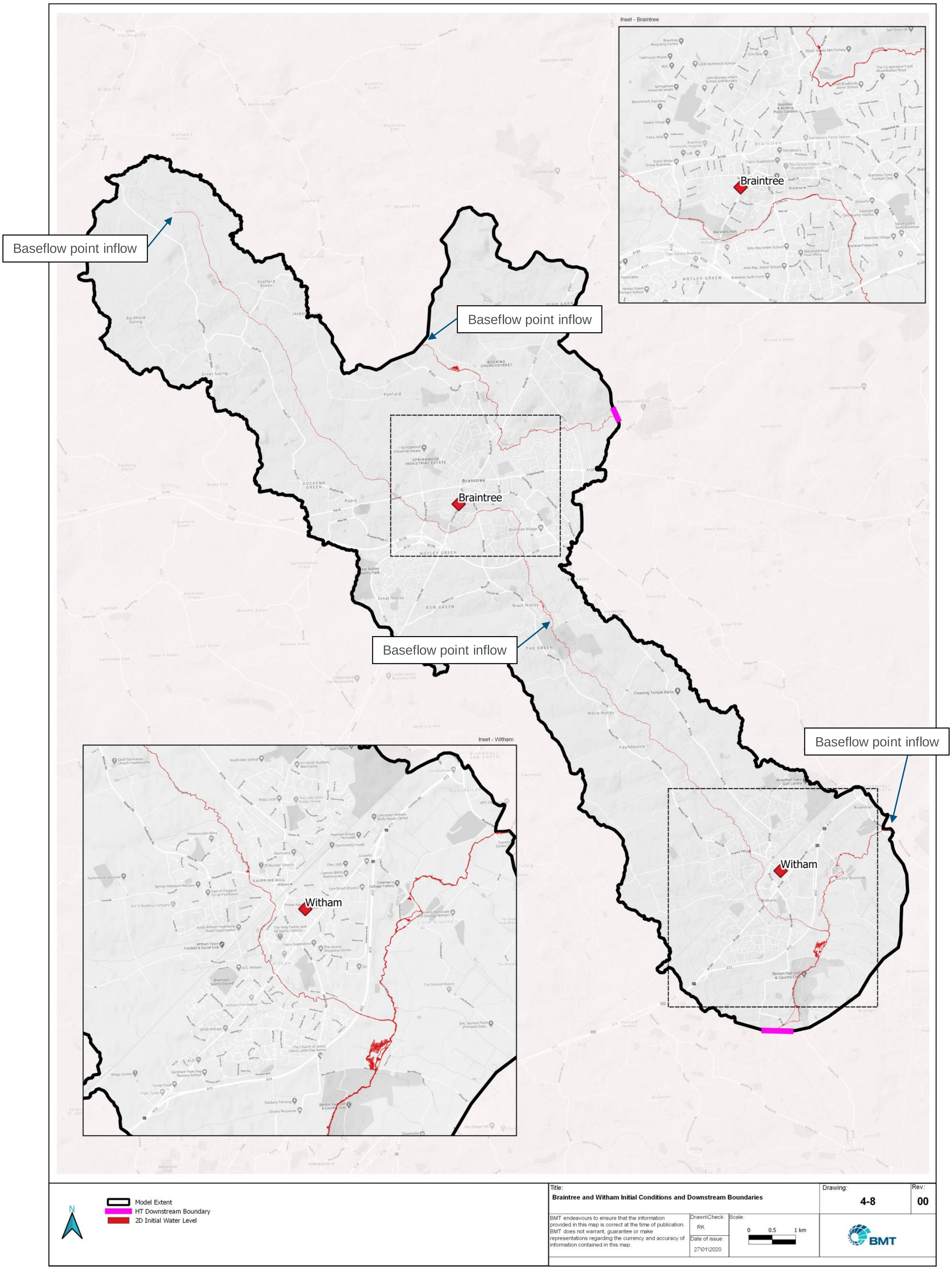

Figure 4-8 2D Initial Water Levels and Downstream Boundaries

4.3 Sensitivity Analysis

Sensitivity analysis is the study of how the variation in the output of a model (depth) can be apportioned, qualitatively or quantitatively, to different changes in the model inputs (model variables, boundary conditions and parameters).

Sensitivity analysis is used to identify:

- The factors that potentially have the most influence on model outputs;
- The factors that need further investigation to improve confidence in the model; and
- Regions in space of inputs where the variation in the model output is maximum.

For the purpose of the Braintree and Witham model update, gully blockage was sensitivity tested.

4.3.1 Gully Blockage

Gully blockage can influence peak flood depths in lower magnitude rainfall events. To simulate the impact of gullies blocking from debris, a sensitivity test was conducted that blocks all gullies by 100%. This would be a worst case scenario and provides a conservative assessment of gully function during pluvial flooding.

The hydraulic model was simulated for the 10% AEP, 3.33% AEP and 1% AEP rainfall events to assess the impact of gully blockage on surface water flood risk. The sensitivity test results were assessed by examining the change in peak depth for each rainfall event compared to the baseline scenario as described in Section 4.2. Depth difference figures can be seen in Appendix D:.

In Braintree and Witham, much of the observable difference in peak flood depths occur in areas where ponding is seen in the baseline results. This is because the blockage of gullies has resulted in an increase in surface water runoff which pools in low-lying areas. In the 10% AEP event, the removal of gully function produces expected increases in peak water levels within the urban environment. Areas that typically pond water saw increases ranging up to 50%, and in some locations higher, on the baseline results. Shallow flow routes through the urban roads where gully networks influence localised surface water runoff also predict large percentage increases in peak flood depths. However, the increased water levels are relatively shallow (10-50mm) and are confined primarily to the road network and overland flow paths. The sensitivity test indicates that the lower return events produce the greatest percent differences in peak flood depths within the pluvial domain.

The 3.33% and 1% AEP events show similar areas of peak water level increases within the urban areas. In Braintree, Pod's Brook Road attenuates the increased runoff from the rural areas resulting in an observable reduction downstream along the River Brain. Conversely, greater peak water levels in the fluvial corridor are seen in Witham where the runoff from the urban area flows towards the main river. The differences in results coincide with less water discharging from the urban environment via the drainage network and gully pits. The largest difference in the fluvial flood plain originates in the 3.33% AEP rainfall event, with the 10% AEP rainfall event dominating the road network in Braintree and Witham.

5 Model Results

This section provides a brief overview of the flood mapping process used in this flood study.

5.1.1 Datasets

Geo-referenced datasets defining peak water depths, velocity and hazard throughout each of the model domains were output from the models. Each of the rainfall events listed in Section 4.1.1 were simulated for one critical rainfall duration. Time varying results were produced based on an appropriate output interval, balancing the temporal resolution of displayed results and overall file size. Depth, Velocity and Hazard outputs were generated in time varying (.XMDF) and static maximum grids (.flt). The flood hazard results are based on the Flood Hazard Rating defined by the DEFRA/Environment Agency guidance document[10] using the following formulae:

$$Flood\ Hazard\ Rating\ (HR) = d \times (v + 0.5) + DF$$

Where:

d = depth of flooding (m)

v = velocity of flood waters (m/s)

DF = Debris Factor, according to depth

A Debris Factor of 0.5 was used for depths less than and equal to 0.25m, and a debris factor of 1.0 was used for depths greater than 0.25m. Following the flood hazard rating calculation, a flood hazard category is assigned based on the criteria outlined in Table 5-1.

Table 5-1 Hazard Rating Category

Flood Hazard		Description
Low	<0.75	**Caution** – Flood zone with shallow flowing or deep standing water
Moderate	0.75 – 1.25	**Dangerous for some (i.e. children)** – Flood zone with deep or fast flowing water
Significant	1.25 – 2.0	**Dangerous for most people** – Flood zone with fast flowing water
Extreme	>2.0	**Dangerous for all** – Flood zone with deep fast flowing water

5.1.2 Comparison to previous model

Three hydraulic models were produced for the Braintree and Witham Surface Water management Plan (prepared by AECOM, December 2016). These models encompass four LFRZs:

- Bradford Street, Braintree (‘B3’ model);
- Warwick Close, Braintree (‘B3’ model);
- Spa Road Witham (‘W2’ model); and
- Rectory Lane Witham (‘W6’ model).

[10] Flood Risk Assessment Guidance for New Development - FD2320/TR2 (DEFRA/Environment Agency, October 2005).

The SWMP model extents were derived based on the results of the EA RoFfSW map. Property counts were undertaken to identify clusters of properties identified as flooded within the RoFfSW maps. LFRZs were then identified and four areas selected to take forward to hydraulic modelling in consultation with the SWMP Project Steering Group. A key limitation of this approach as identified in the peer review is the potential for some areas at risk of surface water flooding to remain unidentified. This is a consequence of the tiled approach adopted in the modelling that informs the RoFfSW maps.

A whole-of-catchment hydraulic model has been produced for this study to validate this key assumption in the previous approach adopted. This will ensure continuity of predicted flow routes is modelled providing a more accurate representation of surface water flood risk. The results of the whole-of-catchment model highlight comparable flooding mechanisms with the RoFfSW. As part of this study BMT have therefore included additional CDAs as agreed with ECC. These are discussed in further detail in Section 6.3 of this report.

A comparison of the updated model results with the SWMP results for each of the modelled areas is presented below:

- The Braintree ‘B3’ model contains two LFRZs at Bradford Street and Warwick Close. The updated model results generally show a reduction in predicted flood depths along roads and an increase around buildings. This change in results correlates with the change in application of rainfall. Rainfall has been applied to all areas of the model extent in this updated model (Section 4.2.10.2), whereas the SWMP study applied rainfall falling on buildings directly to roads. The increase in gully inlet capacity (Section 4.2.8) represented in the updated model allows for a greater volume of surface water to enter the drainage network and discharge to The River Blackwater. These two key changes in the updated model provide a more accurate representation of the flooding mechanisms in the ‘B3’ sub-catchment and the predicted surface water flood risk in the Bradford Street and Warwick Close LFRZs.
- The Rectory Lane Witham ‘W6’ model generally shows a decrease in peak depths upstream of the Network Rail embankment and a decrease downstream. The changes in flood depths are driven by the change in rainfall application, hydrology and improvement in gully inlet capacity. The AW drainage network through the urban area also discharges to the downstream side of the railway, as a result greater peak water levels are observed in the Eastways and Rosewood Business Park commercial area (Figure 5-2).
- The Spa Road catchment ‘W2’ shows reasonable correlation when compared to the Braintree and Witham whole-catchment updated results. The changes are largely driven by the improved representation of the ground topography. An increase in gully inlet capacity (Section 4.2.8) represented in the updated model allows for a greater volume of surface water to enter the drainage network. However, the local gully network discharges directly into the watercourse and leads to an increase in peak water levels (Figure 5-3).

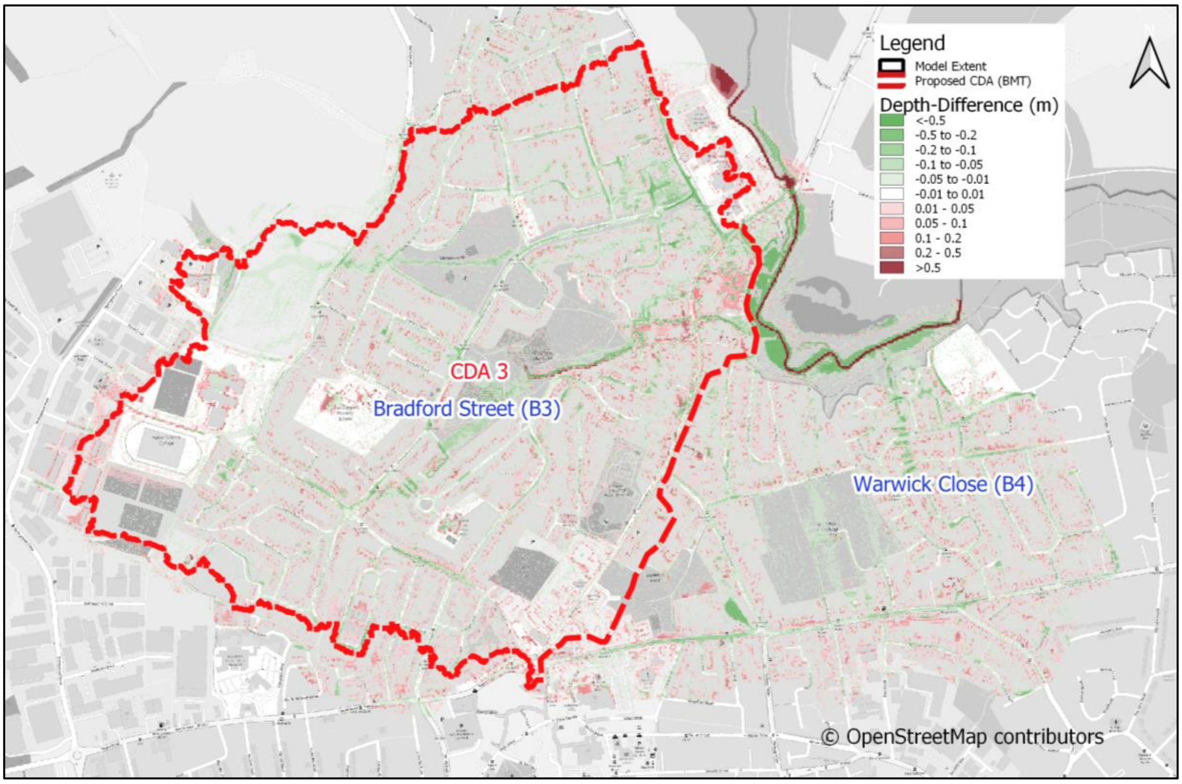

Figure 5-1 'B3' peak flood depth comparison (1% AEP 3hr v 1% AEP 80min)

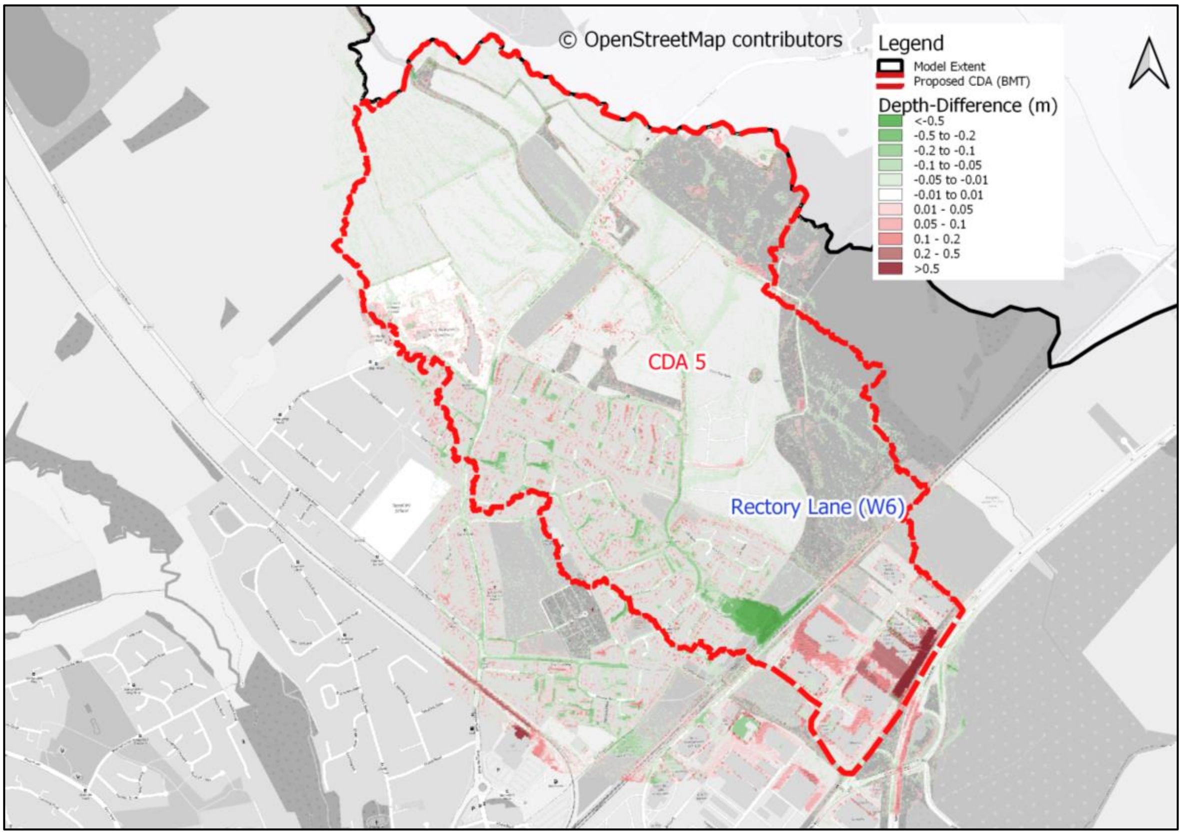

Figure 5-2 'W6' peak flood depth comparison (1% AEP 3hr v 1% AEP 60min)

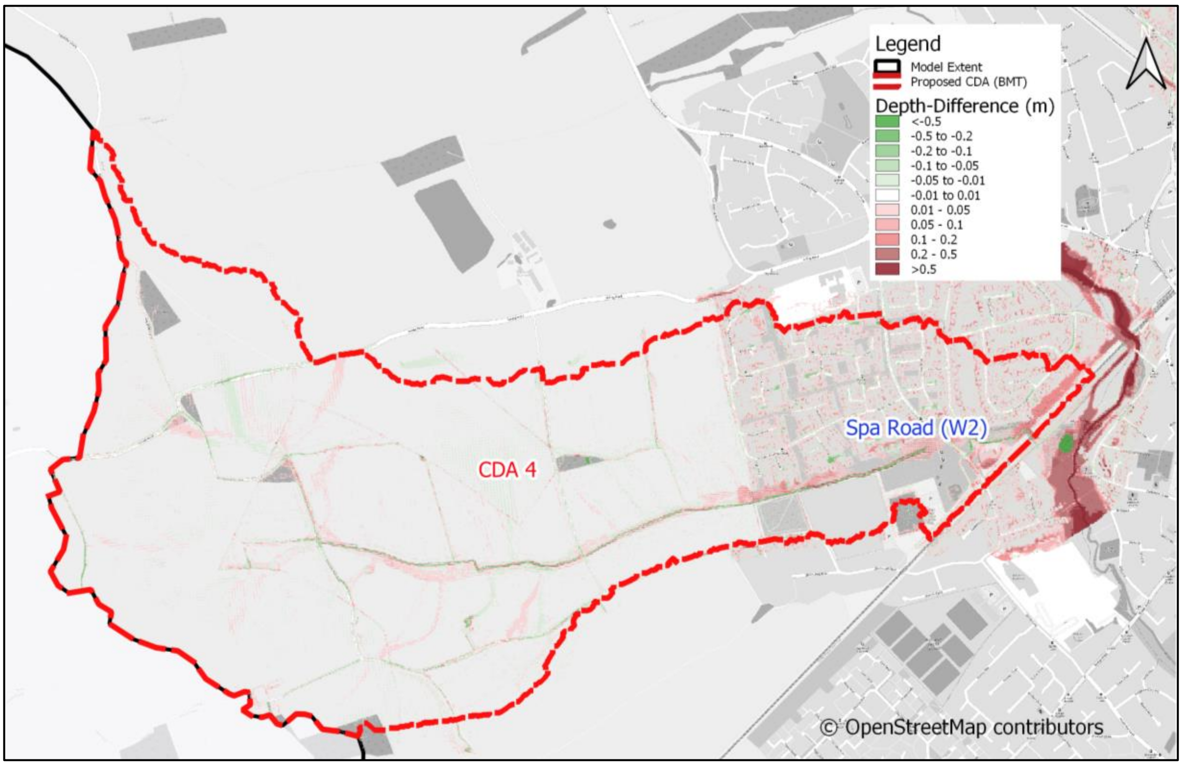

Figure 5-3 'W2' peak flood depth comparison (1% AEP 3hr v 1% AEP 6hr)

6 CDA Identification

This chapter presents the methodology and outcomes of the damages predicted to accrue over a 100 year appraisal period. The results of the property count and baseline economic assessment was used to identify CDAs within the catchment for further investigation and mitigation assessments.

6.1 Properties at Risk

An accurate estimation of the properties at risk is critical for evaluating the economic benefits of flood mitigation measures. However, counts of properties at risk of flooding from surface water can be sensitive to the method used, and the assumptions made.

6.1.1 Methodology

An estimation of properties at risk of flooding was completed using property counts using the following datasets:

- The National Receptor Dataset (NRD);
- The Ordnance Survey Master Map (OSMM) building polygons; and
- The predicted flood depth results for the baseline and options scenarios.

The EA methodology uses the NRD property points and building footprints from the OSMM Topographic Area layer. The OSMM and the NRD typically have a degree of mismatch as they are updated at different times (Figure 6-1). Where data is lacking, the building classification (residential, non-residential or critical services) has been manually filled. The manual assumption of classification has been based on satellite imagery, mapping and surrounding building class. Where no classification was clear, the building has been assumed to be residential.

Figure 6-1 OS MasterMap and NRD

OSMM polygons representing garages and sheds can skew property count and damage estimation results. These have been filtered out using an area threshold of 20m². A threshold of 20m² was selected due to the identification of several small residential properties that should be included in the final dataset. Remaining garages and sheds of area greater than 20m² have been manually removed where easily identifiable.

The latest method developed by the EA for estimating the properties at risk from surface water flooding has been used in this analysis. A summary of the method developed by the EA is provided below. Further details can be found in the report accompanying the uFMfSW Property Points dataset[11].

The building footprints in the OSMM are buffered to reduce the gridded effect of the raised building footprint and flood extent. The recommendation for the buffer size is the modelled grid size, therefore, a 3m buffer has been applied. The analysis is then carried out on the buffered building boundary and is adjusted for internal building perimeters, for example when properties are terraced or semi-detached. The proportion of the buffered boundary where the depth is greater than a specified threshold is calculated, as shown by the blue line in Figure 6-2.

[11] The updated Flood Map for Surface Water (uFMfSW) Property Points dataset, Report version – 1.0, July 2014

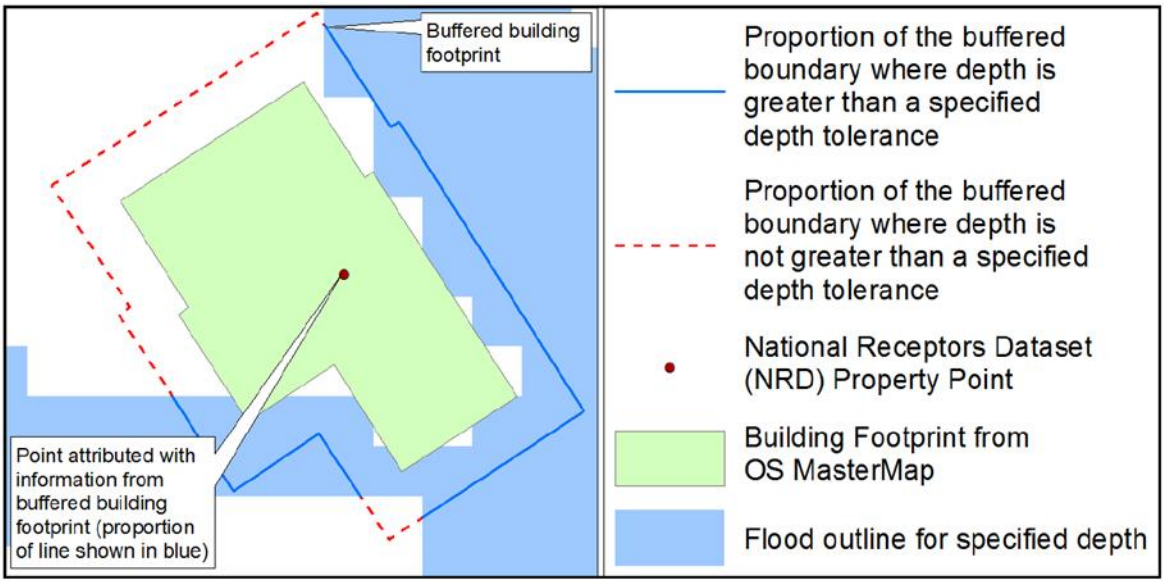

Figure 6-2 Property Count Methodology (EA, July 2014)

The final dataset is then filtered according to local judgement on the proportion of the buffered building boundary and depth threshold to produce locally applicable counts of properties that are at risk of surface water flooding.

A property is considered at risk of surface water flooding if the following criteria is satisfied:

- > 50% wetted perimeter AND ≥ 0.2m depth threshold; OR
- > 25% wetted perimeter AND ≥ 0.3m depth threshold.

The first parameter combination was used to derive the national Property Points dataset[12] for surface water flooding. However, this parameter combination does not select properties that experience deeper flooding over a smaller proportion of the perimeter. Therefore, the second parameter combination was applied as a local enhancement to the EA methodology. The depth threshold corresponds to the average height of building threshold or airbrick allowing floodwater to enter the property. This depth threshold corresponds to the national standard of 0.2m.

Each building polygon that met the criteria is marked as 'flooded'. For multiple properties within one building (e.g. units within a multi-storey building) only basement and ground floor properties are counted. Property counts have been calculated separately for residential, non-residential and critical infrastructure. It should be acknowledged that the previous economic analysis completed in December 2016 separated property counts for the Braintree-Witham catchment at 0.13m (0.03 internally) and 0.6m (0.5m internally) depth thresholds. Although the latest EA methodology for pluvial flooding has been used, the depth threshold criteria is different and therefore differences in property counts are expected.

[12] The updated Flood Map for Surface Water (uFMfSW) Property Points dataset, Report version – 1.0, July 2014

6.1.2 Property Counts

Property counts have been calculated based on the property type (Table 6-1) within the catchment area. The properties anticipated to be impacted are typically restricted to the main flood risk areas, defined in the CDAs in Section 6.3. The majority of predicted receptors are residential, reflecting the nature of the catchment, particularly near the main water courses and other flow routes. However, there are notable clusters of commercial receptors in areas such as West and South Braintree, and East Witham.

The number of properties expected to be inundated increases substantially from the 10% to 5% AEP rainfall events, suggesting that the catchment and receptors are most sensitive to events of this magnitude. Maps for Braintree and Witham showing the location of properties that are at risk, colour coded by the rainfall event that causes initial property inundation, are provide in Appendix E:.

Table 6-1 Properties at Risk of Flooding: Property Type

AEP	Property Count Estimation			
	Residential	Non-Residential	Critical Service	Total
50%	36	13	1	50
20%	57	34	1	92
10%	94	48	2	144
5%	235	78	2	315
3.33%	305	91	2	398
1.33%	387	111	2	500
1%	457	128	2	587
0.50%	616	169	2	787
1% CCL	628	172	2	802
1% CCU	831	223	5	1059

6.2 Flood Damage Estimation

Flood damages for the Braintree and Witham catchments have been estimated based on the modelled results across a range of rainfall events. The methodology used in this appraisal follows the principles of Flood and Coastal Erosion Risk Management Appraisal Guidance[13], the Multicoloured Manual[14], the Multicoloured Handbook (MCH)[15] and the Treasury Green Book[16]. Flood damages from the MCH have been updated to the appraisal base date using Consumer Price Index (CPI) and House Price Index (HPI) factors.

A full summary of the methodology is provided below.

6.2.1 Residential Property Damages

To calculate the residential losses, the following must be estimated:

[13] FCERM-AG; Environment Agency, 2010
[14] MCM; Flood Hazard Research Centre, 2017 including latest 2018 guidance
[15] MCH; Flood Hazard Research Centre, 2016
[16] HM Treasury, 2003

- The type of each affected property;
- Property valuation;
- The depth of water in relation to ground floor level; and
- The duration of the flooding.

The property type was taken from the National Receptor Database provided by ECC. Threshold data (finished flood levels) has been taken from LiDAR levels, calculated using the EA equation for uplift (refer to 4.2.4.1)4.2.5, and has been superseded with survey data where available in Witham.

The above data sources are the most reasonable sources of valuation data short of detailed individual property surveys.

Property value - The property value data was obtained from average current values available on property websites. This value was averaged across residential properties in Braintree and Witham.

Depth of water - Flooding has been assessed by comparing predicted flood depths from the hydraulic model to the threshold levels taken from both survey and LiDAR. Damages begin to accrue once depths are within 300mm of a property threshold level, this is to account for below floorboard damage within homes. The damage values are provided by the MCM guidance and accompanying economic damage tables, they are varied depending on the duration of flooding.

Duration of flooding - For Braintree and Witham, the duration of flooding was taken to be less than 8 hours based on the critical duration of flooding being 3 hours.

The extent and depth of flooding associated with the modelled return periods was established from hydraulic modelling. All buildings within the study area were assigned a property type (residential or commercial) as well as a unique ID and threshold floor level. To allow an accurate depth / damage relationship (curve) to be derived, water levels were assigned to each property for each return period using the closest water level.

The damages incurred are also dependant on the duration of inundation (i.e. less than 8 hours, longer than 8 hours, or much longer than 8 hours). For this study it was confirmed that all affected properties would be flooded for a total duration of less than 8 hours based on hydraulic modelling.

6.2.2 Non-Residential Property Damages

The MCM provides flood damage data for Non-Residential Properties (NRPs) in terms of floor-plan area of premises inundated, depth and duration of inundation, and type of business. The depth of the flood water was estimated in the same way as for the residential properties (i.e. flood level minus floor level). Property valuations were obtained from business rates data available at www.gov.uk for specific properties. These were uplifted by a factor of 10 as per the MCM guidance.

6.2.3 Emergency and Clean-Up Costs

The MCH recommends that emergency costs are calculated as 10.7% of the economic property damage for floods of all annual probabilities; the 10.7% represents the additional damages accrued due to the rural nature of the location. The data sources used by Flood Hazard Research Centre

(FHRC) for this estimation included District and County Councils, the fire, police and ambulance services, the military, water authorities and voluntary services.

Clean-up costs are applied to non-residential properties as 3% of total economic damage as defined in the MCH.

6.2.4 Indirect / Intangible Damages

Although there are clear economic benefits to be derived from protecting residential and non-residential properties from flooding, there are other benefits that are more difficult to quantify economically and typically account for a relatively small percentage of the overall losses. Typical indirect and intangible benefits can include benefits associated with the following:

- Vehicle damages
- Utility services
- Road Closures
- Transportation Network - Rail
- Agriculture
- Recreational gains and losses
- Environmental losses
- Evacuation
- Risk to life
- Loss of income
- Indirect damages for schools
- Indirect damages for hospitals
- Intangibles - stress and emotional effects of flooding

The more significant of these aspects have been included in this economic appraisal to derive more accurate damage costs. The following indirect / intangible elements have been assessed and included in the benefits appraisal:

Vehicle Damage

For floods 350mm above ground level, any cars trapped in floodwaters can be taken to be written off. Write off values are based on the average vehicle value in the UK, taken as £3,600 (MCM 2018). When flood levels are greater than 350mm, £3,600 is added to the flooding damage for that property, in that return period, assigning 1 vehicle per property.

Evacuation

Evacuation costs have been included based on property type and respective flood depths at each property. The Evacuation ‘Initial - Mid Tier” damages have been taken from the MCM 2018 residential tables. These damages have been included as part of the direct damages calculation and contribute to the PV damages for each property.

6.2.5 Total Damage

When flood damages over the appraisal period exceed the current market value of the property, the damages are "capped" at the current market value of the property. This prevents flood damage estimates from being over-inflated.

The Braintree and Witham catchment has a calculated Total NPV damage of £260,000,000.

6.3 CDA Identification

A CDA can be described as a discrete geographic area (usually a hydrological catchment) where multiple or interlinked sources of flood risk cause flooding during a severe rainfall event thereby impacting people, property or local infrastructure.

The upstream 'contributing' catchment, the drainage and surface water catchments and potentially downstream areas of influence, spatially describe a CDA. CDAs are usually located within Flood Zone 1, but extend to other flood zones where a clear surface water flood risk (dominant in cause) is observed historically or in the modelling. The following have been considered when defining a CDA:

- Pluvial flood depth and hazard extent: CDAs include areas that experience high flood depths and/or hazard to people;
- Predicted impact to properties and infrastructure: including residential and commercial properties, main roads, rail networks, hospitals and schools. Access to hospitals or evacuation routes is critical in higher magnitude events;
- Potential sewer capacity and areas of uncertainty;
- Historic flooding: locations that are known to be susceptible to surface water flooding;
- Source, pathway and receptor: holistic consideration of flooding within the CDA; and
- Cross boundary linkages and appropriate definition of area: CDA selections that are free of political or administrative boundaries, including the hydraulic catchment contributing to the CDA and the area available for flood mitigation options.

Four LFRZs were identified in the existing Braintree and Witham SWMP (Figure 6-3). The updates to the hydraulic model have resulted in a reduced estimate of surface water flood risk to the LFRZs Bradford Street and Warwick Close in Braintree. Following examination of the results and estimated properties at risk, Warwick Close was discounted as a CDA in agreement with ECC. All other LFRZs have been taken forward in this study.

Additional CDAs other than the three LFRZs from the SWMP have been identified and discussed in the next section of this report.

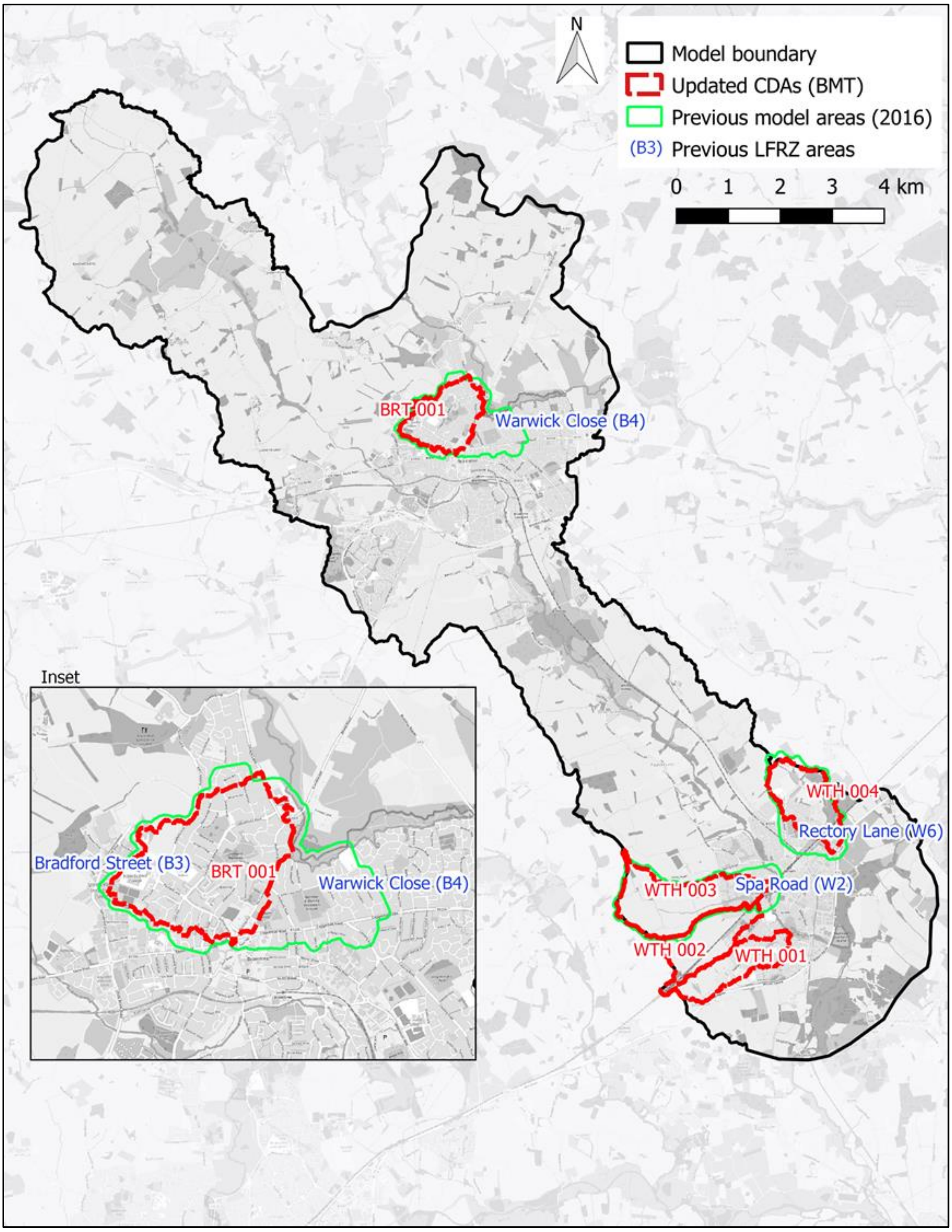

Figure 6-3 Proposed Critical Drainage Areas

6.4 Overview of Flood Risk within WTH 001: Maltings Lane, Witham

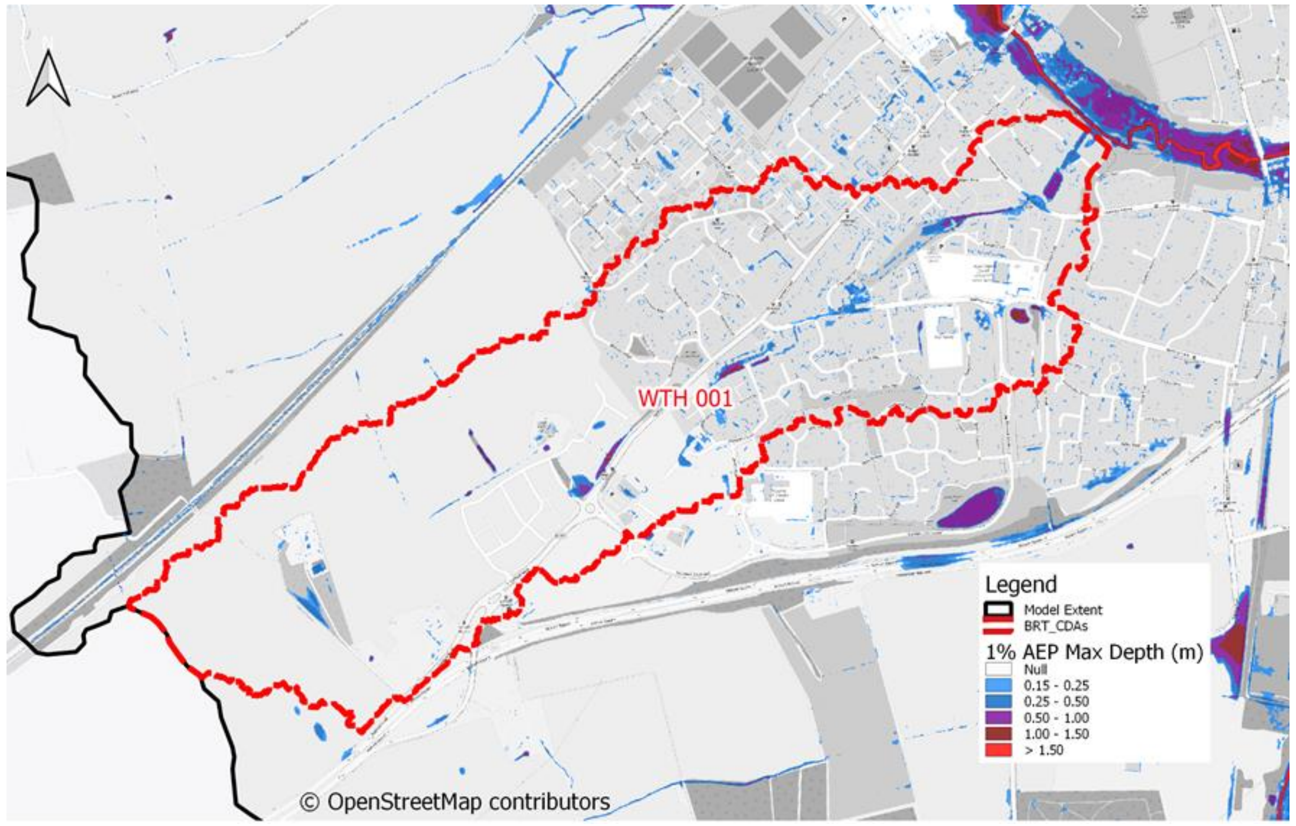

Figure 6-4 WTH 001 - 1% AEP Rainfall Event, Maximum Depth

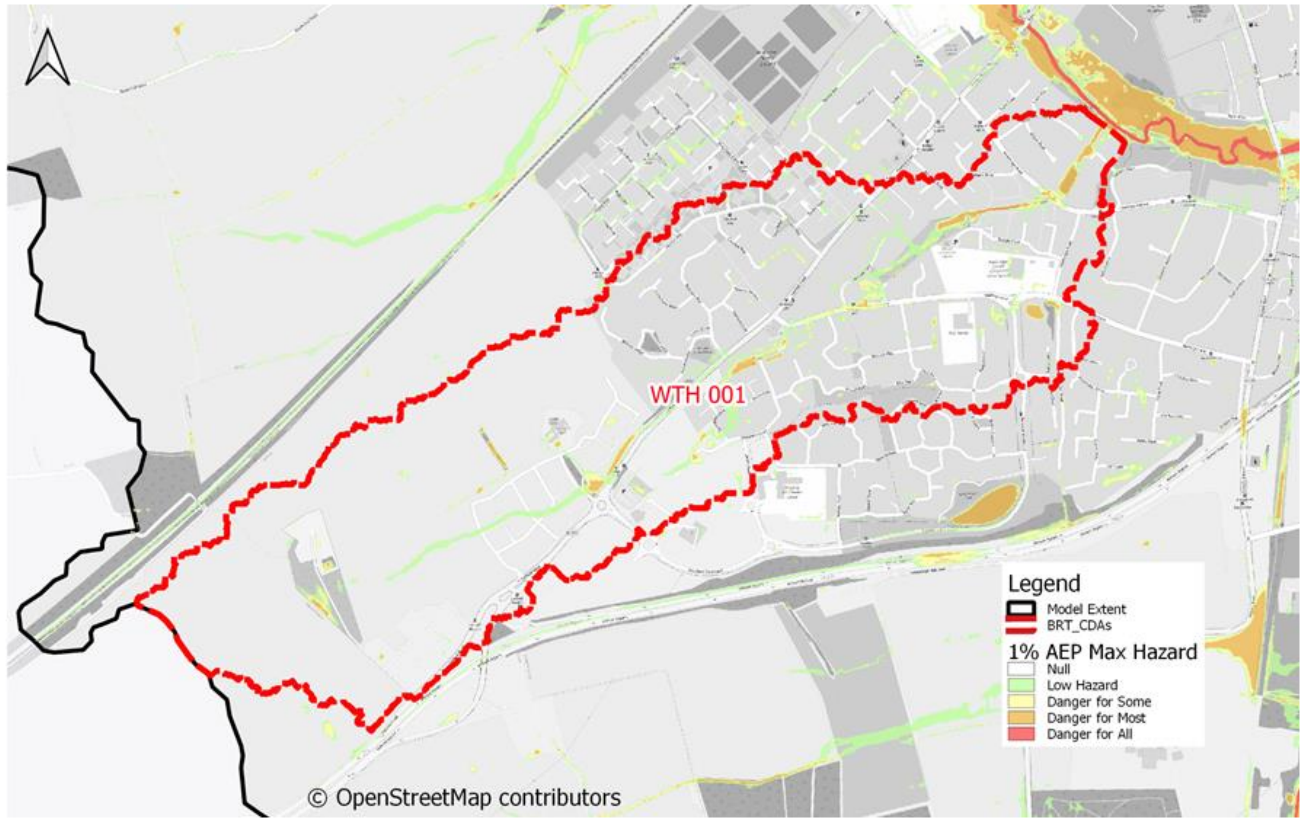

Figure 6-5 WTH 001 - 1% AEP Rainfall Event, Maximum Hazard

Source
The source for flooding in the Maltings Lane CDA is primarily from overland flow originating near the Kings Centre Church in the rural upper catchment to the west. Localised urban runoff also contributes to the main flow path through the catchment.
Pathway
Runoff ponds adjacent to Hatfield Road, near the roundabout with Gershwin Boulevard before over topping and flowing north-east down the road. Further localised catchments converge at Augustus Way to impact properties in this area and downstream along Maltings Lane. In the open space near Maltings Lane and adjacent to the Howbridge Junior School, culvert inlets which drain the open space further downstream exceed their capacity from the 5% AEP rainfall event. This contributes to the ponding in the topographic depressions near Holy Family Primary School and Howbridge Hall Road. The outlet of these pipes that collects runoff from the open space then discharge into an ordinary watercourse downstream. Water is conveyed through culverts under Howbridge Road with flow from the 20% AEP rainfall event exceeding capacity of these pipes causing flooding of the road.
Receptor
Properties impacted within WTH 001 are focussed along the main flow route through the sub-catchment. Haygreen Road is shown to have properties inundated from the 50% AEP rainfall event. Additionally, clustered properties downstream between Maltings Lane and Town End Field are impacted from the 20% AEP rainfall event. High hazard in these areas is characterised by the peak depth of predicted water. Worth noting is the current hydraulic model does not represent the recent commercial development across from Gershwin Boulevard and Hatfield Road. The supplied model files did not include new buildings areas therefore it is recommended that future studies assess the impact. The predominant rural flow path passes through this area and could potentially add to property counts and damages.

Table 6-2 WTH 001 – Maltings Lane, Property Count Estimation

AEP	Residential	Non-Residential	Critical	TOTAL
50%	1	0	0	1
20%	5	0	0	5
10%	6	0	0	6
5%	17	0	0	17
3.33%	21	0	0	21
1.33%	23	0	0	23
1%	29	0	0	29
0.50%	37	0	0	37
1% CCL	37	0	0	37
1% CCU	42	0	0	42

Table 6-3 WTH 001 – Maltings Lane, Damage Estimation

Economic Damage Summary	Tangible Damage NPV	Intangible Damage NPV	Total Damage NPV
WTH 001: Baseline	£4,618,695	£819,200	£5,437,895

6.5 Overview of Flood Risk within WTH 002: Blunts Hall Road, Witham

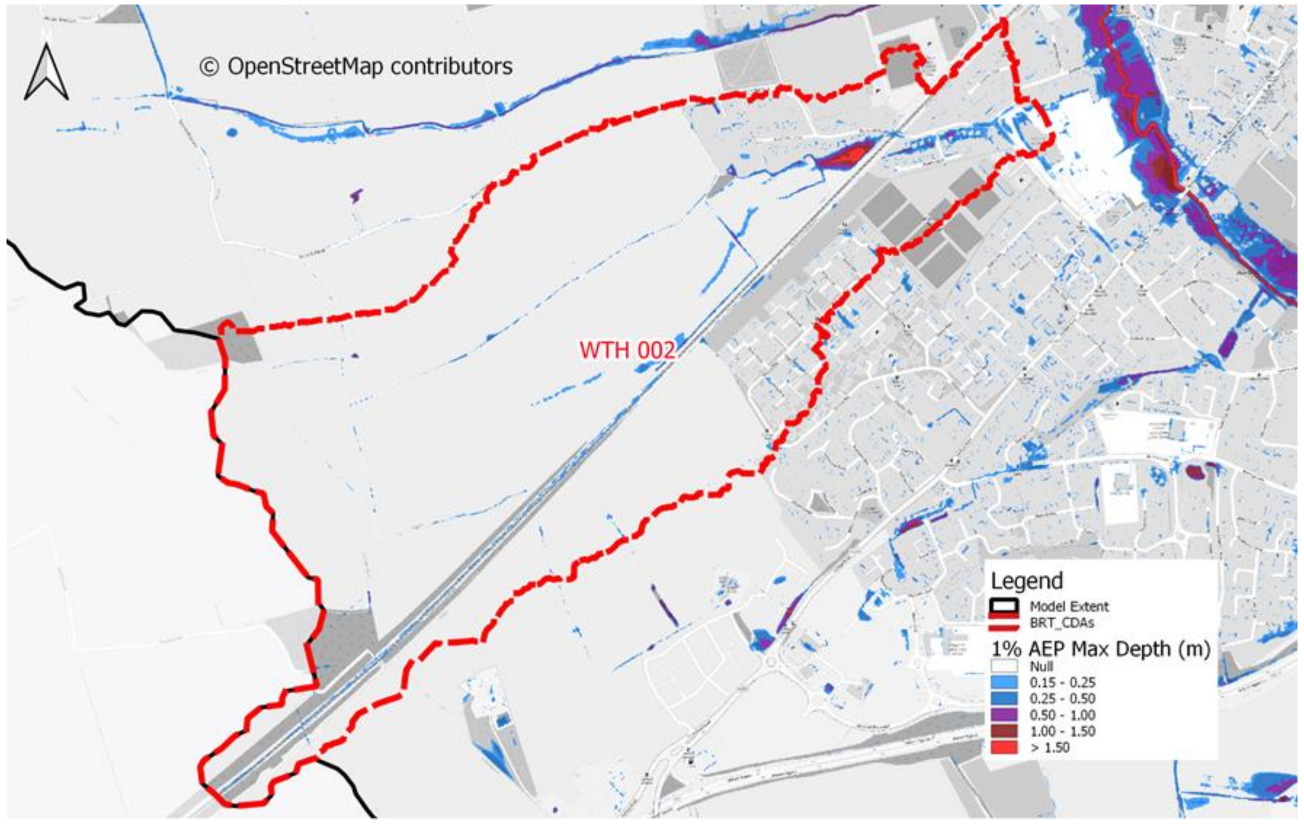

Figure 6-6 WTH 002 - 1% AEP Rainfall Event, Maximum Depth

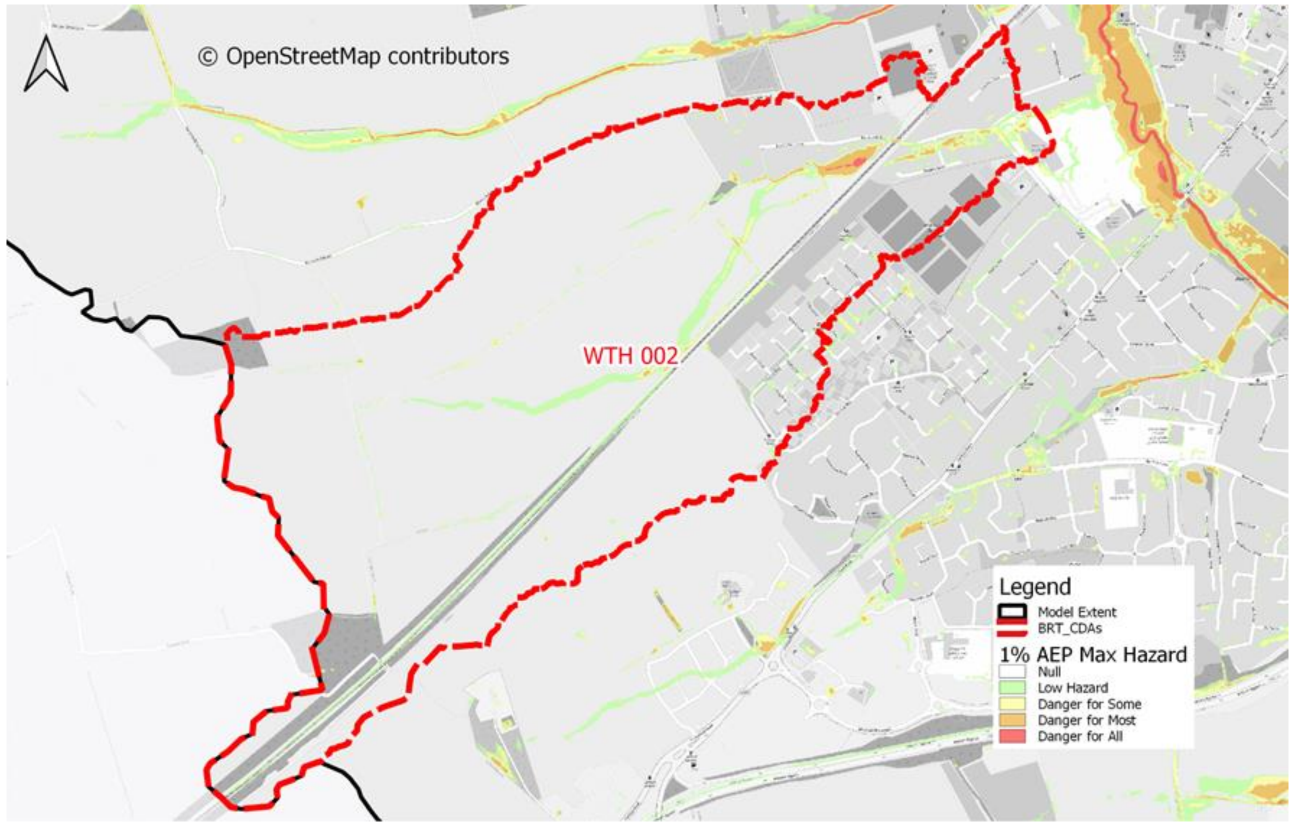

Figure 6-7 WTH 002 - 1% AEP Rainfall Event, Maximum Hazard

Source
The source for flooding in the Blunts Hall Road CDA is primarily from overland flow originating in the rural upper catchment to the west.
Pathway
Surface runoff from the rural catchment becomes channelised to the south of Blunts Hall Drive (east of the Greater Anglia rail line). Runoff from the rural area ponds behind the railway embankment at a topographic depression. As the water level rises, water then begins to flow through the arch underpass to the north on Blunts Hall Road. Properties adjacent to the small channel downstream of the Greater Anglia rail line are inundated as overland flow crosses Spinks Lane before discharging to the River Brain.
Receptor
Properties on Blunts Hall Road are shown to be impacted in events greater than the 50% AEP rainfall event. Most of the impacted properties within WTH 002 are located along the same stretch of Blunts Hall Road to the east of the Greater Anglia rail line.

Table 6-4 WTH 002 – Blunts Hall Road, Property Count Estimation

AEP	Residential	Non-Residential	Critical Services	TOTAL
50%	5	0	0	5
20%	6	0	0	6
10%	10	0	0	10
5%	13	0	0	13
3.33%	17	0	0	17
1.33%	17	0	0	17
1%	17	0	0	17
0.50%	18	0	0	18
1% CCL	18	0	0	18
1% CCU	19	0	0	19

Table 6-5 WTH 002 – Blunts Hall Road, Damage Estimation

Economic Damage Summary	Tangible Damage NPV	Intangible Damage NPV	Total Damage NPV
WTH 002: Baseline	£3,562,894	£730,423	£4,293,317

6.6 Overview of Flood Risk within BRT 001: Bradford Street, Braintree

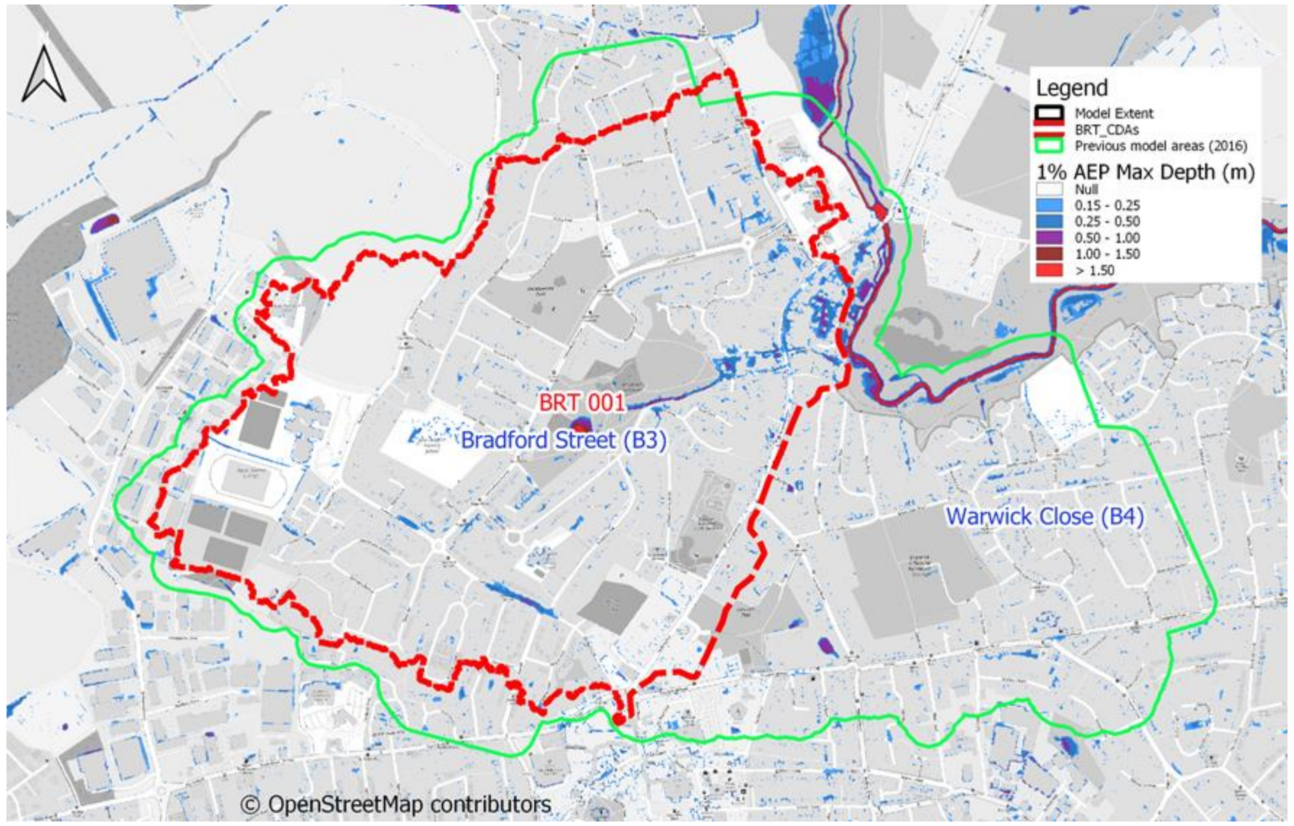

Figure 6-8 BRT 001 - 1% AEP Rainfall Event, Maximum Depth

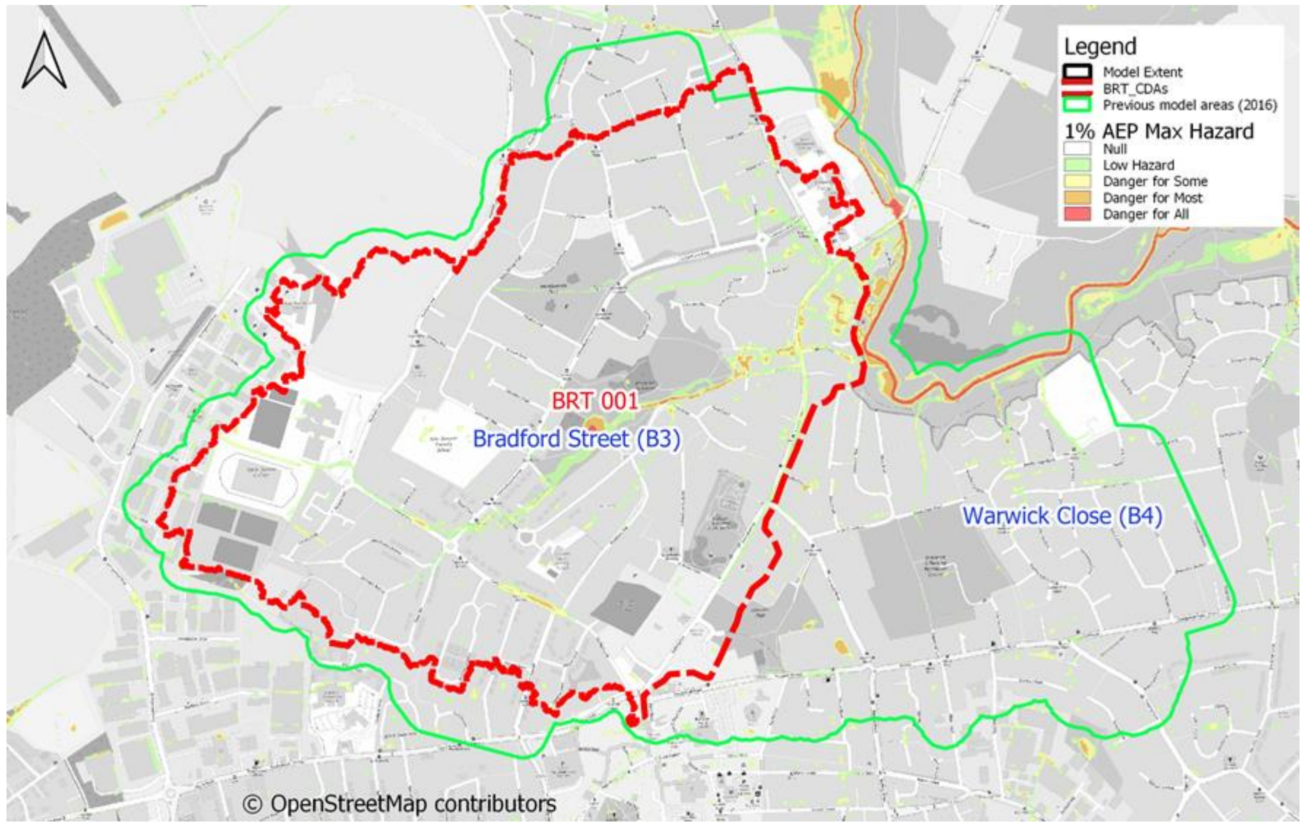

Figure 6-9 BRT 001 - 1% AEP Rainfall Event, Maximum Hazard

Source
The source for flooding within the Bradford Street CDA is primarily from overland flow originating in the urban catchment to the West and South. The CDA catchment is highly urbanised with some non-commercial areas.
Pathway
The CDA is dominated by a central flow route that originates from the round-about at Coldnailhurst Avenue and Panfield Lane. Overland flow collects within a drain located in Bradford Meadow open space, however overland runoff does not naturally attenuate within the wider green space as the channel is incised to sufficiently convey the flow. Surface water runoff is predicted to flow along Bradford Street to the South before ponding at the intersection with Woolpack Lane. Road gullies collect runoff and convey water to the River Blackwater via the drainage network. Flooding of the road and nearby properties occurs when the capacity of the gullies is exceeded. A topographic depression is located adjacent to Kingfisher Gate and River Mead. Surface water runoff ponds at this location resulting in inundation of neighbouring properties in higher probability events.
Receptor
Properties adjacent to River Mead are shown to be impacted in events with a lower probability than the 20% AEP rainfall event. Additional properties upstream on Woolpack Lane, Williams Drive and Phillips Chase are shown to be impacted in events with a lower probability than the 5% AEP rainfall event. In lower probability events, the flood extent impacts further properties in the same general area, as well as a small cluster near Coldnailhurst Avenue. The confined flow path that is conveyed in Bradford Meadows results in high velocity flows through Williams Drive to the River Blackwater. The localised ponding and confined surface water flow exacerbates the number of flooded properties in this area.

Table 6-6 BRT 001 – Bradford Street, Property Count Estimation

AEP	Residential	Non-Residential	Critical Services	TOTAL
50%	0	1	0	1
20%	4	2	0	6
10%	6	2	0	8
5%	26	3	0	29
3.33%	39	5	0	44
1.33%	54	5	0	59
1%	62	5	0	67
0.50%	100	7	0	107
1% CCL	102	7	0	109
1% CCU	142	8	0	150

Table 6-7 BRT 001 – Bradford Street, Damage Estimation

Economic Damage Summary	Tangible Damage NPV	Intangible Damage NPV	Total Damage NPV
BRT 001: Baseline	£16,389,854	£2,745,055	£19,134,909

6.7 Overview of Flood Risk within WTH 003: Spa Road, Witham

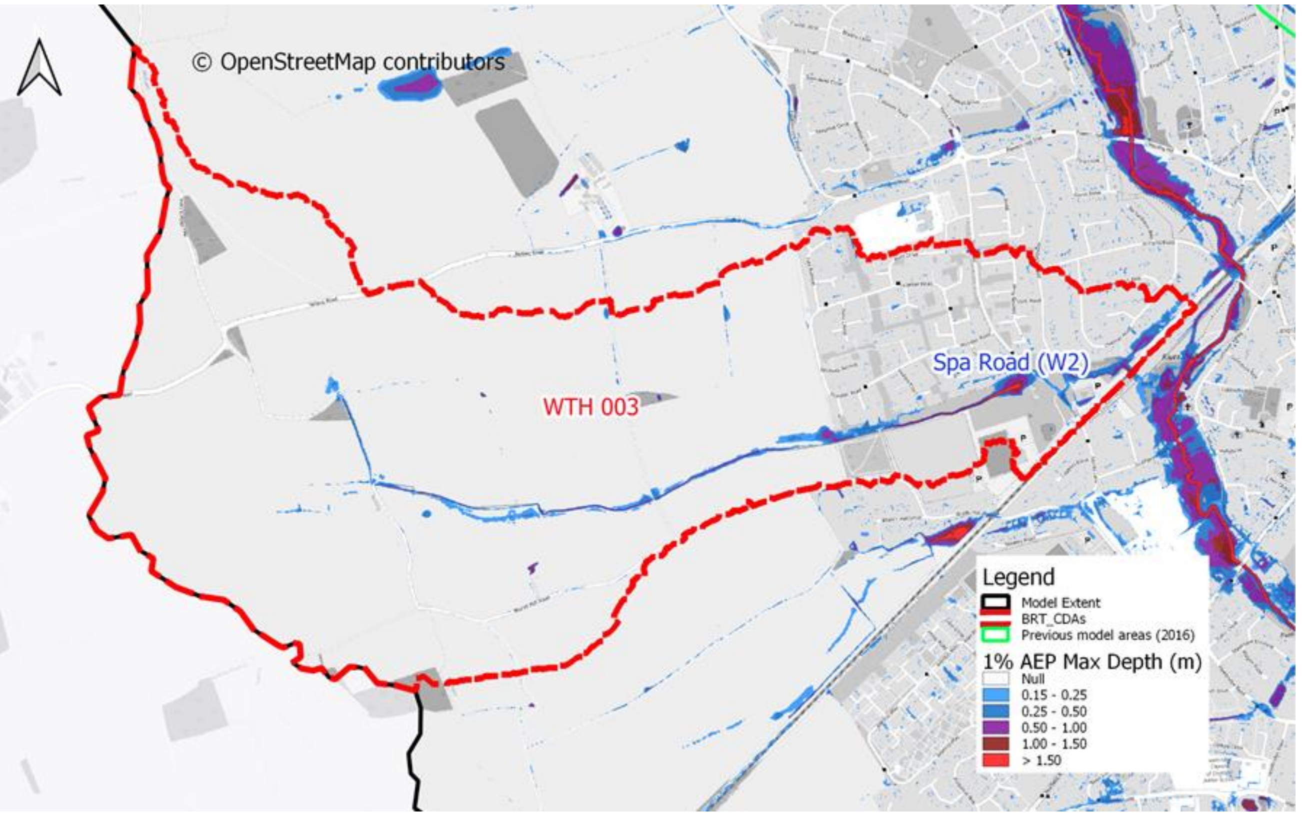

Figure 6-10 WTH 003 - 1% AEP Rainfall Event, Maximum Depth

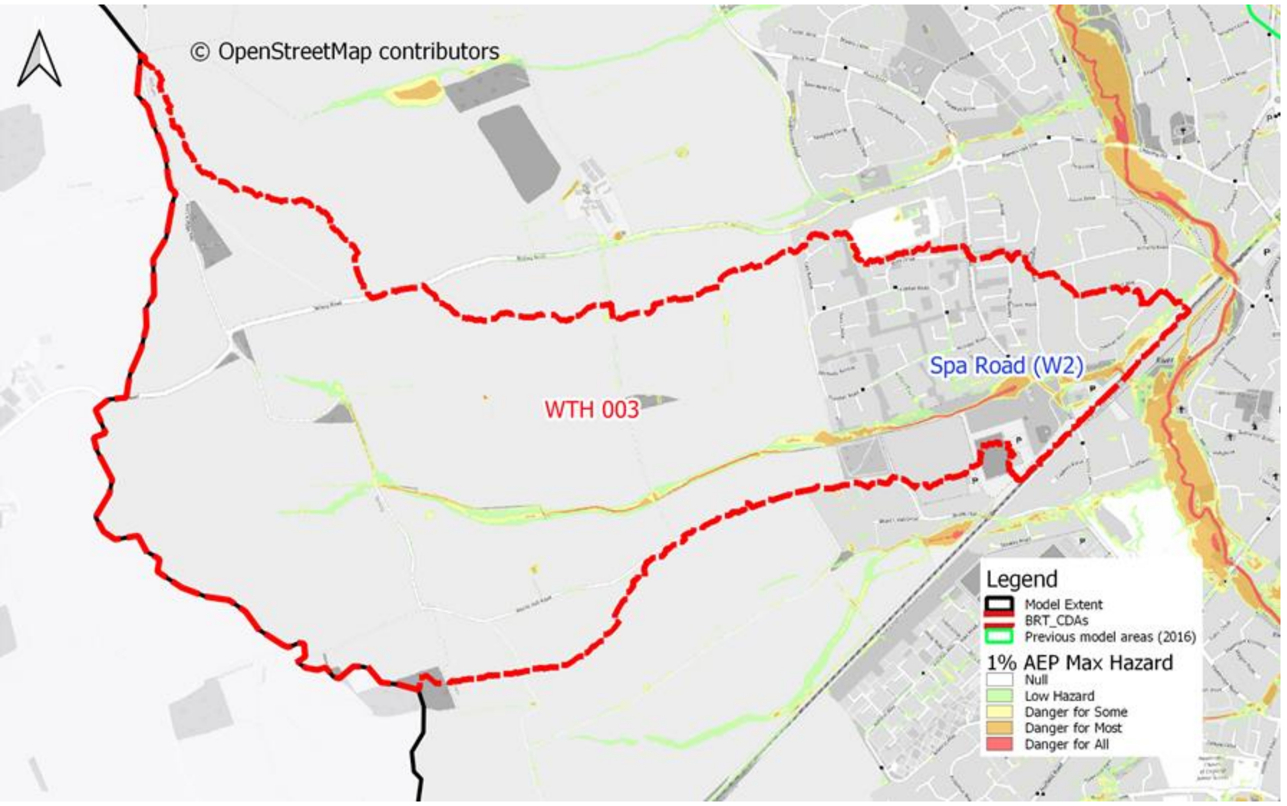

Figure 6-11 WTH 003 - 1% AEP Rainfall Event, Maximum Hazard

Source
The source for flooding within the Spa Road CDA is primarily from overland flow originating in the rural catchment to the west, combined with localised surface water runoff from the impervious urban areas. Localised urban runoff also contributes to the main flow path through the catchment, however the flow is dominated by the contribution from the rural areas.
Pathway
Overland flow from the upstream rural environment is primarily channelised in an ordinary watercourse flowing from west to east towards the urban area. The capacity of the watercourse is exceeded as it enters the urban area resulting in flooding along the northern bank impacting houses on Ness Walk. Adjacent fields immediately upstream of the urban area also convey flow in all AEP events which exacerbates the inundation close to the properties on Ness Walk and Teign Drive. The watercourse then passes through a culvert beneath Spa Road. Inundation of properties at the bottom of Colne Chase, and onto Spa Road is predicted in a similar extent compared to the previous modelling (as is discussed in Section 5.1.2). The water on Spa Road and Highfields Road floods the Asda Supermarket which is situated in a topographic depression. Overland flow from Highfields Road continues up to the railway and is culverted under the embankment before eventually discharging to the River Brain. AW data was not sufficient in this area to model an IUD, therefore the virtual pipe feature has been utilised which will assume an instantaneous transfer of water to the outfall locations.
Receptor
One Property on Ness Walk is predicted to be impacted in the 20% AEP rainfall event. Additional properties downstream on Colne Chase and Asda on Highfields Road are shown to be impacted in events with a lower probability than the 5% AEP rainfall event. In lower probability events, the flood extent impacts further properties in the same general area, including Brent Close. The flooded properties are mostly focused along the ordinary watercourse which flows through the CDA.

Table 6-8 WTH 003 – Spa Road, Property Count Estimation

AEP	Residential	Non-Residential	Critical Services	TOTAL
50%	0	0	0	0
20%	1	0	0	1
10%	6	0	0	6
5%	11	2	0	13
3.33%	11	2	0	13
1.33%	12	2	0	14
1%	15	2	0	17
0.50%	19	2	0	21
1% CCL	19	2	0	21
1% CCU	25	2	0	27

Table 6-9 WTH 003 – Spa Road, Damage Estimation

Economic Damage Summary	Tangible Damage NPV	Intangible Damage NPV	Total Damage NPV
WTH 003: Baseline	£2,389,799	£2,976,325	£5,366,124

6.8 Overview of Flood Risk within WTH 004: Elderberry Gardens, Witham

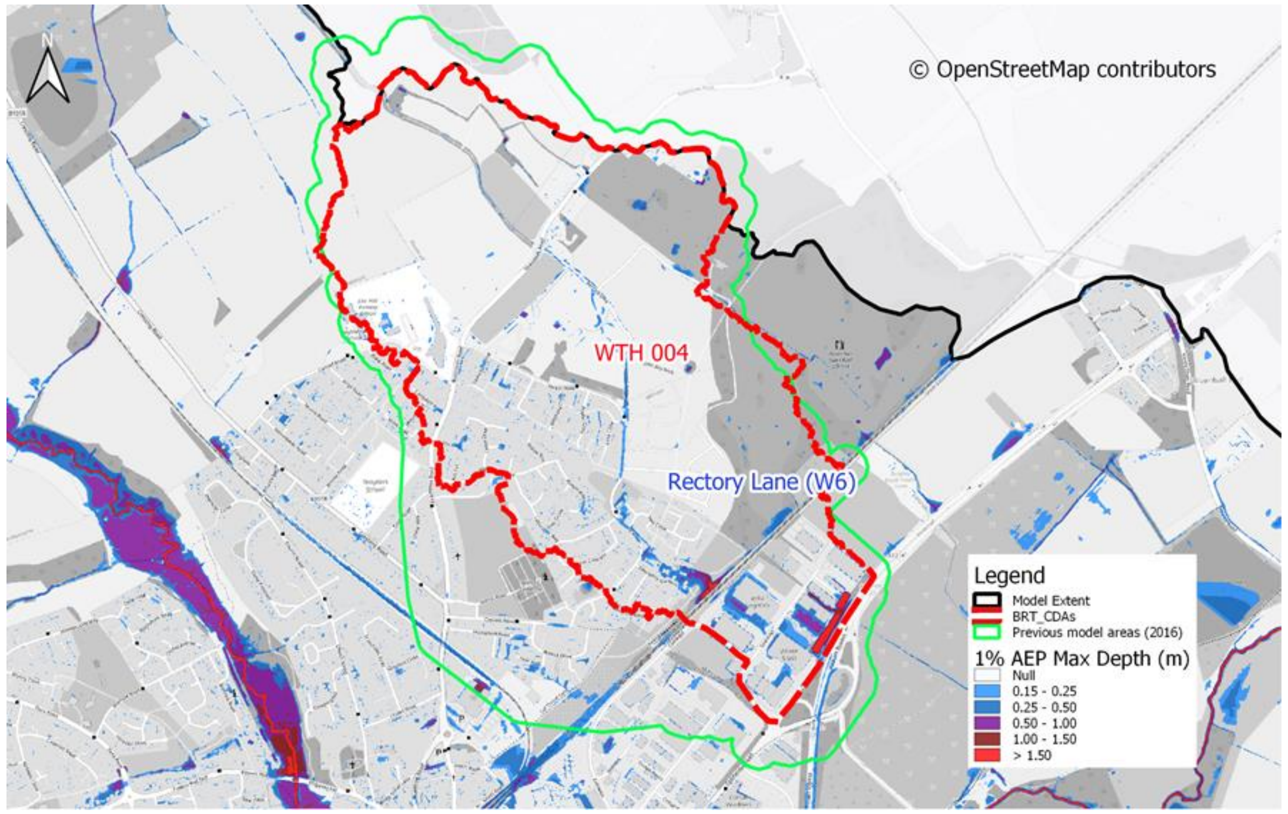

Figure 6-12 WTH 004 - 1% AEP Rainfall Event, Maximum Depth

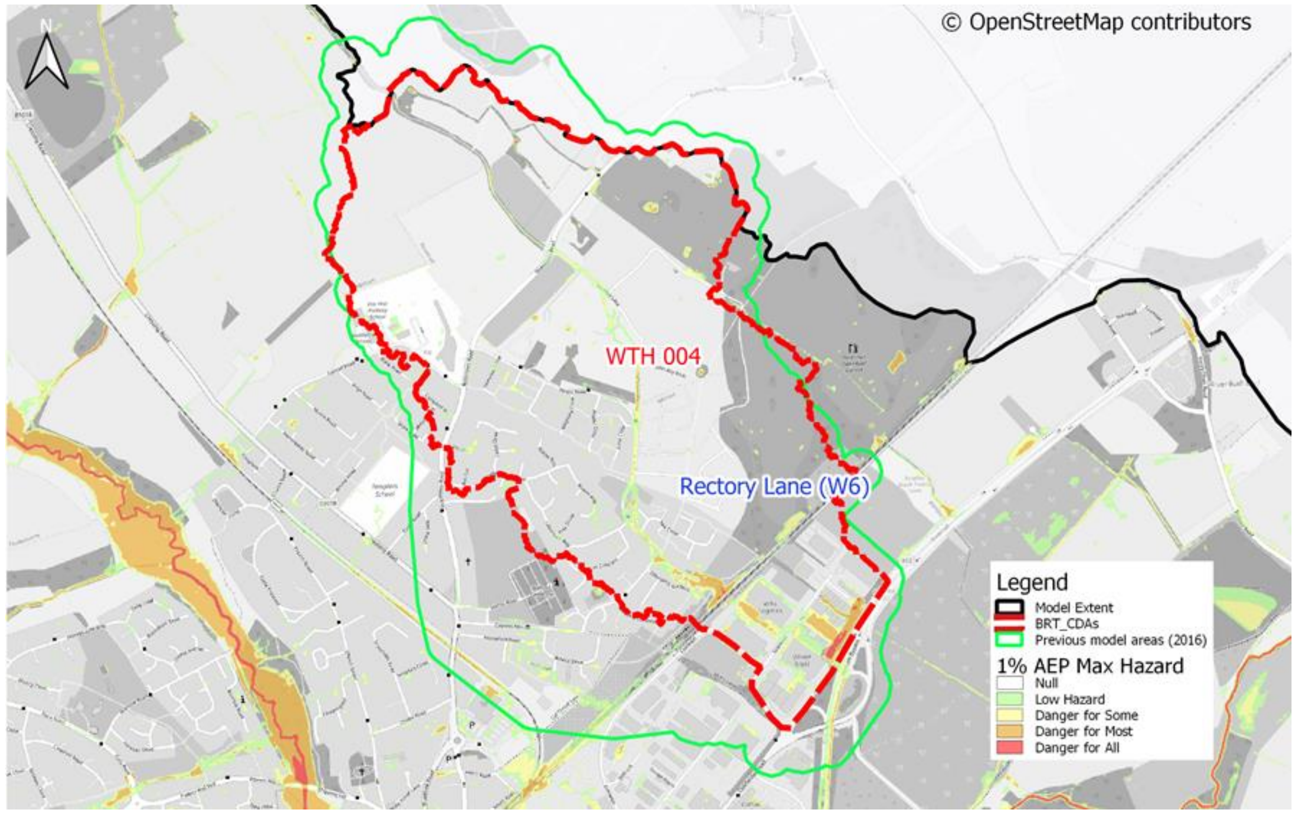

Figure 6-13 WTH 004 - 1% AEP Rainfall Event, Maximum Hazard

Source
The source for flooding within the Bradford Street CDA is partially from overland flow originating in the rural catchment to the north, combined with localised surface water runoff from the impervious urban areas.
Pathway
The CDA is dominated by a central flow route along Rectory Lane which collects runoff from the rural catchment to the north. The flow route then connects to Forest Road in the urban area. Contributions from localised surface water runoff causes flooding of properties along Forest Road on Yew Close. The main flow path continues and flows into a drain running parallel to Elderberry Gardens. The drain flows beneath the railway embankment via a 900mm diameter culvert. Inundation of properties on Elderberry Gardens occurs when the capacity of the drain and culvert are exceeded. The culvert then discharges into another drain downstream eventually outfalling to the River Blackwater located outside of this CDA. East of the railway multiple non-residential properties are inundated in Eastways Industrial Estate from localised runoff. AW data quality was sufficient to allow a full IUD through the whole CDA.
Receptor
One property on Yew Close and non-residential buildings in Eastways Industrial Estate are shown to be impacted by the 20% AEP rainfall event. The current hydraulic model does not represent the recent development adjacent to Forest Road that sits in the centre of the CDA. The supplied model files did not include new buildings or drainage areas therefore it is recommended that future studies assess the impact. Additional properties on Yew Close and Eastways Industrial Estate are shown to be impacted in events with a lower probability than the 5% AEP rainfall event, as well as properties on Elderberry Gardens. In lower probability events, the flood extent impacts further properties in the same general area. The flooded properties are mostly focused along the main flow path and ordinary watercourse which flows through the CDA.

Table 6-10 WTH 004 – Elderberry Gardens, Property Count Estimation

AEP	Residential	Non-Residential	Critical Services	TOTAL
50%	0	0	0	0
20%	1	5	0	6
10%	3	5	0	8
5%	14	11	0	25
3.33%	15	11	0	26
1.33%	18	11	0	29
1%	22	11	0	33
0.50%	32	12	0	44
1% CCL	32	12	0	44
1% CCU	39	15	1	55

Table 6-11 WTH 004 – Elderberry Gardens, Damage Estimation

Economic Damage Summary	Tangible Damage NPV	Intangible Damage NPV	Total Damage NPV
WTH 004: Baseline	£10,028,857	£14,767,449	£24,796,306

6.9 Comparison of CDA Flooded Properties

A review of the total number of flooded properties within each CDA can assist with prioritising any future flood risk alleviation investigations. Figure 6-14 presents the number of flooded properties within each CDA for all rainfall events. Figure 6-15 shows the properties flooded for each AEP rainfall event as a percentage per CDA.

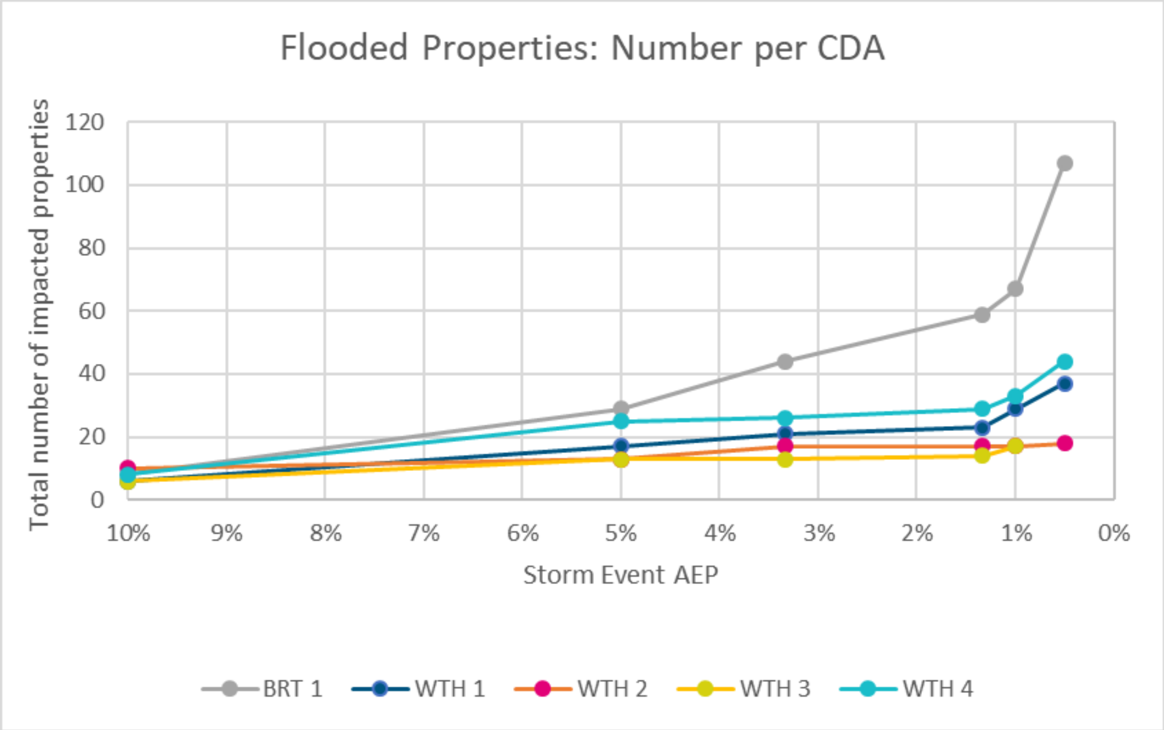

Figure 6-14 Total Number of Flooded Properties per CDA

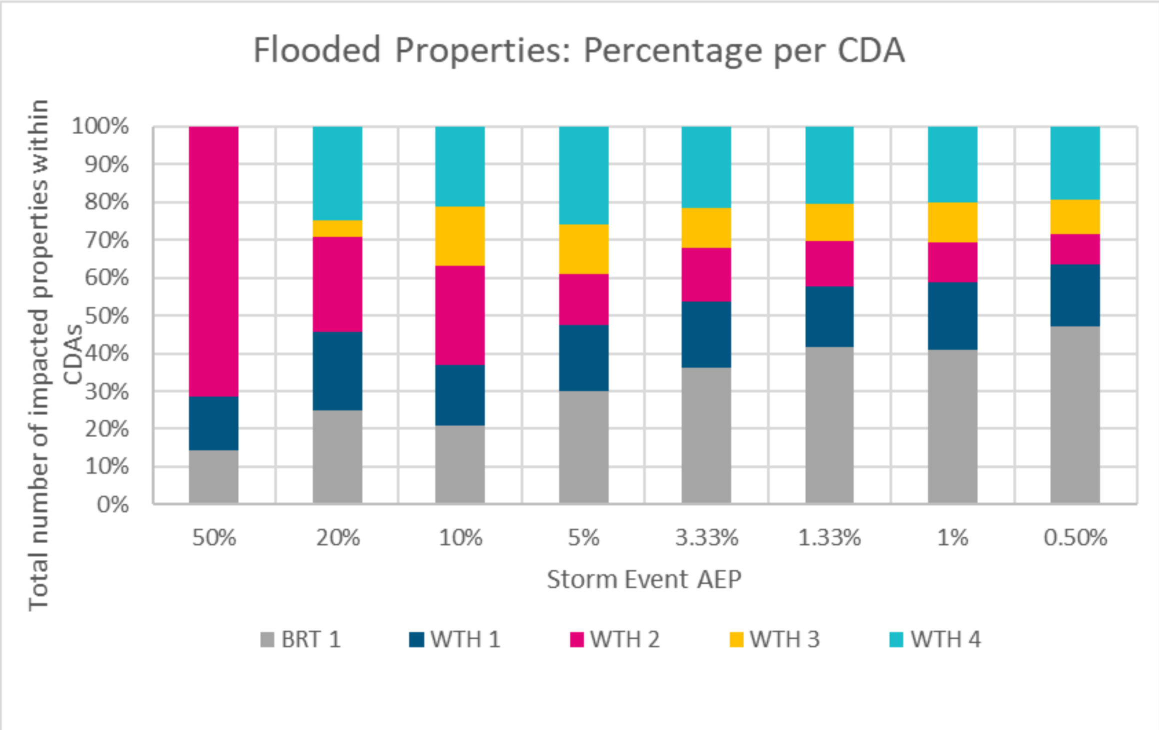

Figure 6-15 Percentage of Flooded Properties per Rainfall Event

7 Key Limitations and Recommendations

A list of the key limitations and recommendations for the study has been provided below. These were selected based on their potential impact on the predicted flooding and practical considerations such as efficacy, budget and time.

- Accurate highway gully information is important for modelling the impact of the sewer network on surface water flooding. The gully inlet determines the volume of water that enters and exits the drainage network. This study has made use of a part-processed survey dataset of gullies. Future studies Although some areas of the road gully network was surveyed, the supplied Map 16 data was still undergoing refinement and filtering at the time of use in the model.
- Urban topographic features (walls, fences, etc) have not been included in the hydraulic model. CDA specific assessments should ideally include these obstructions to overland and out of bank flow to influence the flooding mechanisms within the areas of interest.
- The stormwater sewer network has been represented using a ‘Virtual Pipes’ or full IUD approach throughout the Braintree and Witham areas.
    - In many locations, the IUD approach required amendments to inverts, diameters and gully connectivity as a result of missing or erroneous data. Where mitigation options look to utilise the AW network, it is recommended to survey the surrounding network to ensure those original or amended network details are fit for purpose. Notable areas where a full IUD has not been represented, is the Spa Road urban area within Witham where AW pipe data quality was poor. Pipe storage and travel time is not accounted for; however, the locations of outfalls has been maintained to ensure gully inflows are discharging to where they realistically should be within an IUD network.
    - The ‘Virtual Pipes’ approach assumes the limiting factor is the flow capacity of the grating/pot and not the associated pipework and downstream outfall constraints. Surcharging from road gullies is not represented. The construction of a fully integrated urban drainage model within the key areas of interest is recommended for future detailed studies. This requires accurate data on the pipe network, including pipe dimensions, invert levels, manholes and outfalls.
- National Rail hydraulic structures play an important role in conveying flow downstream in the model. The dimensions of the hydraulic structures underneath the railway have based on supplied point information, particularly at locations of ordinary watercourses. Railway overpasses on main rivers have utilised data supplied within the EA ISIS models. In locations where conveyance of overland water is deemed to influence predicted flood risk downstream, survey of these structures should be prioritised to confirm representation.
- Information supplied by ECC for this study show planning sites are located in many of the CDAs identified in Section 6. Development of these sites may present an opportunity to construct future mitigation schemes whilst minimising costs. In addition, several CDAs were highlighted to contain recent developments that are not represented in the model. Future

mitigation should consider including these developments in the model to assess the impact on predicted flood risk. .

- The risk of flooding from multiple sources has not been considered in this study. The influence of fluvial flooding sources should be investigated with a joint probability assessment.
- To improve the calculation of the NPV damages and any future mitigation option, the 0.1% AEP rainfall event should be simulated.
- New EA guidance was released in May 2019 that superseded older guidance from 2016. This guidance outlines the minimum and recommended standard for new hydraulic modelling for inclusion in a future update to the RoFfSW National Map. Should ECC wish to include this hydraulic model, amendments to the model may be required to ensure consistency of approach. Some key changes relevant to this study include a revision to the hydrological approach and simulation of the 0.1% AEP rainfall event.

8 Conclusions

A whole catchment hydraulic model of Braintree and Witham has been developed addressing limitations identified in modelling undertaken as part of the Braintree and Witham SWMP. The results provide an improved understanding of surface water flood risk to the urban areas of Braintree, Boking, Great Notley, and Witham.

Of the four LFRZs identified in the SWMP, one has been discounted and the remaining three taken forward in this study. An additional two CDAs were identified bringing the total CDAs in Braintree and Witham to five, in agreement with ECC. An estimate of number of flooded properties and flood damage estimation has been undertaken on each CDA. The results of this study can be used to update the SWMP and to prioritise CDAs for any future flood risk alleviation investigations.

Appendix A: Manning's *n* Coefficient

Table A-1 Land Use Roughness

OS Master Map Feature Code	Manning's n Coefficient	Fraction Impervious	Description
10021	Depth Varying	1	Buildings
10053	0.04	0.6	General Surface (Residential Yards)
10054	0.025	1	General Surface (Step)
10056	0.03		General Surface (Grass Parkland)
10062	Depth Varying	1	Building (Glasshouse)
10076	0.5		Land - Heritage and Antiques
10089	0.035	1	Water (Inland)
10099	0.1		Natural Environment
10111	0.1		Natural Environment
10119	0.02	1	Roads Tracks and Paths (Manmade)
10123	0.025		Roads Tracks and Paths (Dirt Tracks)
10167	0.05	1	Rail
10172	0.02	1	Roads Tracks and Paths (Tarmac)
10183	0.02	1	Roads Tracks and Paths (Pavement)
10096	0.03	1	Roadside structure
10185	0.03	1	Structures (Roadside Structure)
10193	0.03	1	Structure
10187	0.5	1	Structures (Generally on top of Buildings)
10203	0.04	1	Water (Foreshore)
10210	0.035	1	Water (Tidal)
10217	0.035		Land (Unclassified)
99	0.04		Default value
5	0.017	1	Concrete (unfinished)

Appendix B: Soil Types

Table B-1 Model Soil Types

BGS definitions	TUFLOW	
SoilScape Textures	**Soil ID**	**USDA Soil Type**
Lime-rich loamy and clayey soils with impeded drainage	4	Clay loam
Slightly acid loamy and clayey soils with impeded drainage	4	Clay loam
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	4	Clay loam
Freely draining slightly acid loamy soils	8	Loam
Loamy and clayey floodplain soils with naturally high groundwater	4	Clay loam

Appendix C: Baseline Flood Maps

Appendix D: Gully Sensitivity

Appendix E: Baseline Property Impacts

Appendix F: Model Operation

F.1 Model Control

F.1.1 TUFLOW Build

The TUFLOW build used to run the updated models are provided in Table F-1.

Table F-1 Model TUFLOW Builds

Model	Numerical Engine	TUFLOW Build
Braintree and Witham	TUFLOW HPC	2018-03-AE-iSP-w64

TUFLOW has both single precision (iSP) and double precision (iDP) build versions available to modellers, the choice between using one or the other depends on the situation being modelled. For models on higher ground or utilising the direct rainfall approach it is normally recommended to use the double precision build to take advantage of the additional significant figures in the calculations.

TUFLOW HPC uses depth in the calculations due to its explicit nature, unlike TUFLOW Classic that uses water level. Therefore, precision issues associated with applying a very small rainfall to a high water level are not applicable. Consequently, the Braintree and Witham model was simulated using a single precision (iSP) TUFLOW HPC build.

F.1.2 Scenario Logic

Initialisation of the hydraulic model utilised a standard Windows Batch file (*.bat), TUFLOW Control file (tcf) and the relevant event and scenario logic. Typical naming translations are outlined in Table F-2.

Table F-2 Typical Model Naming Convention

EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf			
	Variable Name	Filename Convention	Description
~e1~	Rainfall Return Period	002R	1 in 2 year return period (50% AEP) rainfall event
		005R	1 in 5 year return period (20% AEP) rainfall event
		010R	1 in 10 year return period (10% AEP) rainfall event
		020R	1 in 20 year return period (5% AEP) rainfall event
		030R	1 in 30 year return period (3.33% AEP) rainfall event
		075R	1 in 75 year return period (1.33% AEP) rainfall event
		100R	1 in 100 year return period (1% AEP) rainfall event
		200R	1 in 200 year return period (0.5% AEP) rainfall event
		100RCCU	1 in 100 year return period (1% AEP) rainfall event with 'upper end' climate change allowance [40%]
		100RCCL	1 in 100 year return period (1% AEP) rainfall event with 'central' climate change allowance [20%]
~e2~	Rainfall Duration	01hr	1 hour rainfall duration
		02hr	2 hours rainfall duration

EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf			
		03hr 06hr 09hr	3 hours rainfall duration (critical) 6 hours rainfall duration 9 hours rainfall duration
~e1~	Scenario	EXG SSA	Baseline model Soil Sensitivity Test – gullies blocked
--	Model Name	BRT	Braintree and Witham

F.1.3 Run Execution

All simulations for executed using a Windows batch file (.bat). Batch files are text files which contain a series of commands and allow for a large degree of flexibility in starting TUFLOW simulations. Due to the number of variables being modelled, event and scenario management wildcards were utilised within the batch file to easily run simulations in series or concurrently.

Example batch file configuration for Baseline runs is given below:

```
:: Existing
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 002R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 005R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 010R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 020R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 030R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 075R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 100R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 200R -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 100RCCL -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf
start "TUFLOW" /wait "F:\IT\Software\TUFLOW\Builds\2018-03\2018-03-AE\2018-03-AE\TUFLOW_iSP_w64.exe" -b -e1 100RCCU -e2 03hr -s1 EXG ECC_BRT_~e1~_~e2~_~s1~_036.tcf


pause
```

F.1.4 Baseline Stability

All models were run on a Nvidia GTX 1080. A summary of the negative depths (1D), repeated timesteps and clock time is given in Table F-3.

Table F-3 Baseline Run Statistics

Scenario	Negative Depths	Repeat Timesteps	Run Time (hr)
50% AEP	0	0	14.27
20% AEP	0	0	15
10% AEP	0	0	15.4
5% AEP	0	0	15.5
3.33% AEP	0	0	15.5
1.33% AEP	0	0	15.75
1% AEP	0	0	17
0.5 AEP	0	0	16

Scenario	Negative Depths	Repeat Timesteps	Run Time (hr)
1% AEP plus 20% climate change	0	0	16.75
1% AEP plus 40% climate change	0	0	17

F.1.5 GPU driver version

The following driver version was used in this study. To ensure backward compatibility of model compile and results between different Nvidia GPUs, it is recommended to have the same GPU driver version.

GTX 1080: 26.21.14.3200

F.2 Model Quality Assurance

Quality assurance (QA) is a methodology used in the development of hydraulic models that ensure a level of quality in their production. QA encompasses the processes and procedures that systematically monitor different aspects of a model build to detect and correct problems or variances that fall outside of established standards. This section outlines the Quality Assurance (QA) measures undertaken.

F.2.1 General Quality Assurance

Part of the general model QA involves reviewing the TUFLOW messages generated during the model compilation stage and resolving any issues. Warnings produced by TUFLOW during the run are also investigated. Locations causing recurring warnings were identified and a solution implemented to reduce or remove the source of the issue.

F.2.2 Mass Balance and Conservation

Review of the HPX parameters (Courant Number, Wave Speed and Momentum Diffusion) are important checks in the QA process for model health and a proxy for solution accuracy (Figure F-1). As part of the QA process, the following checks were performed:

- 1D/2D links were selecting the correct number of cells and allowing a 'free interchange' of water. This involved checking the 1d_to_2d_check file in comparison to surrounding DTM levels;
- Material roughness was checked by importing and thematically mapping the uvpt_check file to ensure surface resistance was applied correctly with respect to aerial images;
- Initial water levels in the model were checked by reviewing the grd_check file and first timesteps in the 2D time varying results;
- The extent of the 2D domain was reviewed to unsure it was not limiting flood extents in the larger flood events within the area of interest;
- Minimum dT values across the 2D domain were reviewed to highlight any troublesome areas that were slowing down overall run time;

- Flow rates through key structures were reviewed to check for 'wobbles' in the flux through a structure; and
- The IUD network across the catchment was plotted longitudinally and in 3D to ensure that erroneous inverts of sewer pipes were not impacting network connectivity and were below ground levels where achievable.

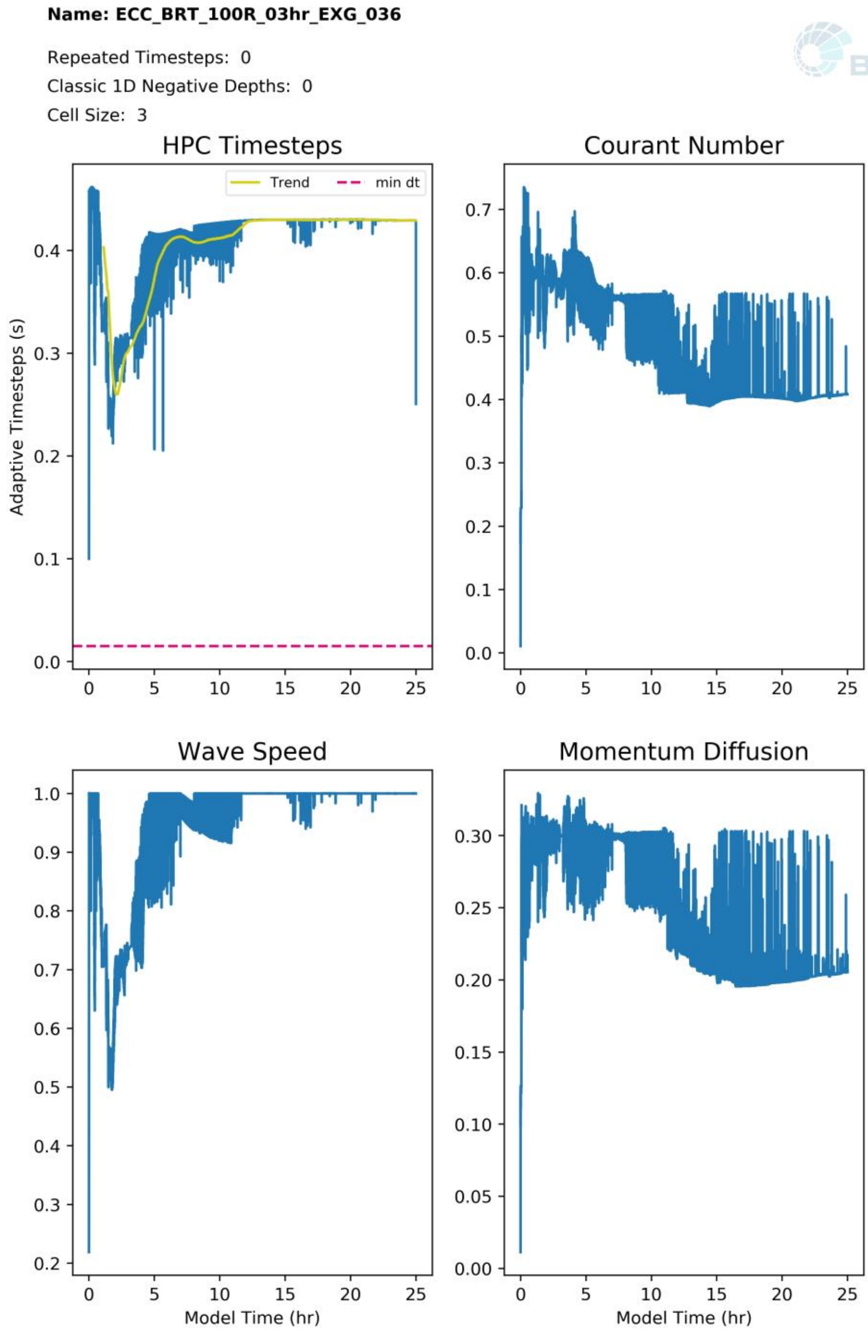

Figure F-1 1% AEP HPC stability

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