TECHNICAL NOTE

JBA Project Code	2020s0744
Contract	Faithful & Gould - Solihull Level 2 SFRA
Client	Solihull Metropolitan Borough Council
Day, Date and Time	July 2020
Author	Tom Singleton
Reviewer / Sign-off	Ed Hartwell
Subject	Solihull Site 4 - ESTRY-TUFLOW model build

1 Introduction

1.1 Overview

In May 2020 JBA Consulting were commissioned to produce a Level 2 Strategic Flood Risk Assessment (SFRA) for several proposed development sites within the Solihull Metropolitan Borough Council's (SMBC) administrative boundary. For several of the development sites, flood risk had not previously been assessed relating to Ordinary watercourses in their vicinity. This document summarises the approach of the strategic modelling undertaken to provide flood risk data for Whitlock's End Farm, South of Shirley (SMBC26).

1.2 Study extent

The study extent is focussed on a small Ordinary Watercourse, a tributary of the River Cole, through Shirely, Solihull. The modelled reach is approximately 2km in length and extends from 430m upstream of Tythe Barn Lane, at Old Yardleians Rugby Football Club (SP 410350 276686) to its confluence with the River Cole (SP 410250 278219). The stretch of watercourse is predominantly open channel with multiple culverts, including under Tythe Barn Lane, the Stratford upon Avon Canal, the railway line, and Haslucks Green Road. There are a series of interconnecting ponds towards the downstream reach, where the watercourse passes through Woods Farm Fishery.

Surface water and groundwater are not specifically assessed within this study but may also contribute to flood risk in the area.

The modelled watercourse is displayed in Figure 1-1.

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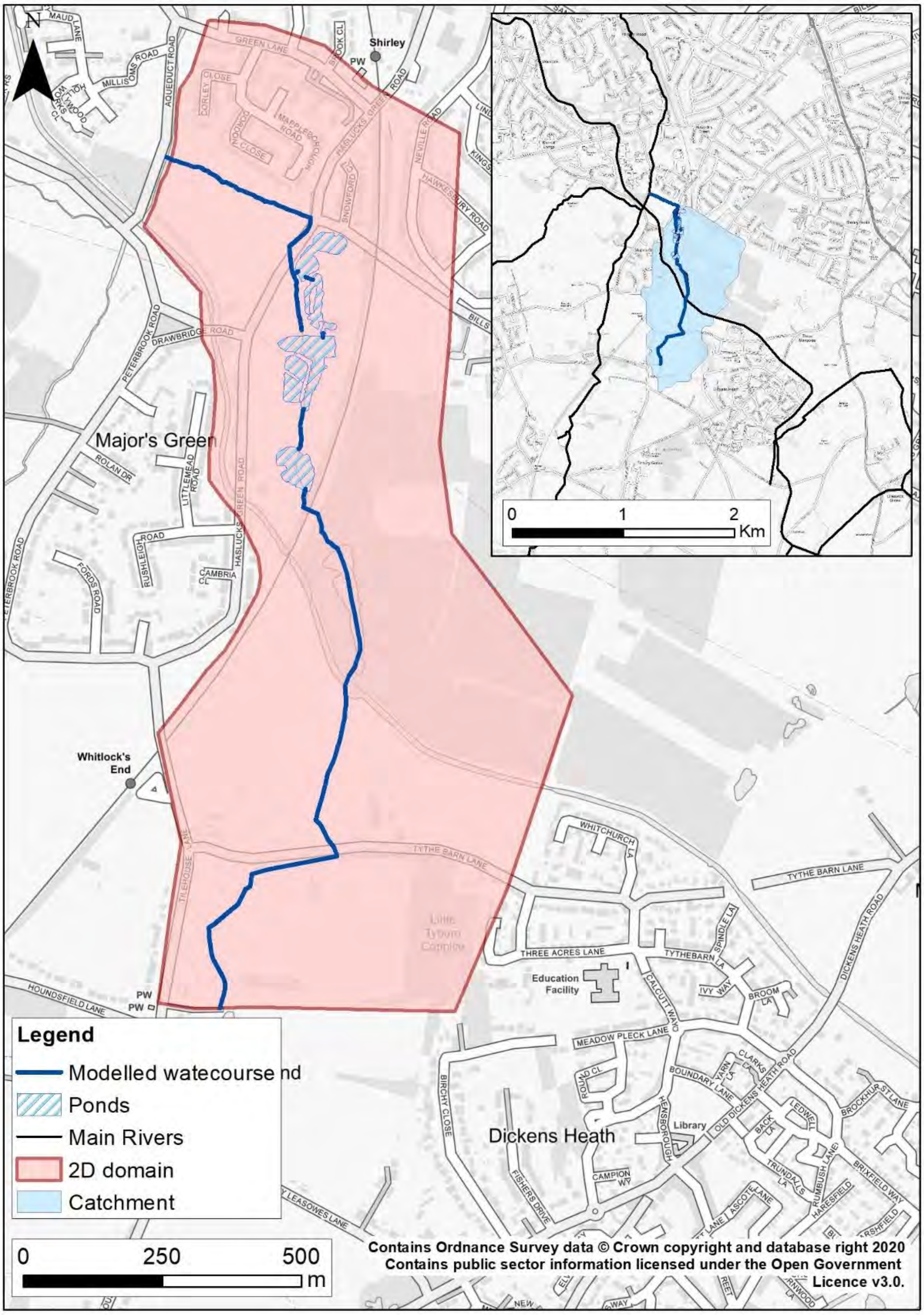

Figure 1-1: Location plan

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2 Input data

A range of existing datasets were available for use within this study. Table 2-1 lists and describes the data and information used within the study.

Table 2-1: List of available data for this study

Data type	Source of data	Comments
Channel survey data	Survey	Survey conducted by Grantham Coates Surveys (GCS) Ltd. Open channel and structure survey of the 2km Ordinary Watercourse through Shirely: SP 410350 276686 to SP 410250 278219.
Mapping	Ordnance Survey (OS)	1:25,000 and 1:50,000 scale mapping, as well as OS MasterMap data.
LIDAR	Digital Terrain Models (DTM)	Provided at a 1m (2019) and 2m (2017) resolution; downloaded from the Defra Data Services platform. The LIDAR datasets covered the same area, therefore only the 2019 1m resolution dataset was used to derive model geometry as it better represented floodplain features.
	Integrated Height Model (IHM) DTM	DTM provided by the Environment Agency for the entire Solihull Borough. This dataset is to provide topographic data where there is no LIDAR coverage (at the very southern part of the model).
Other	Photographic information	Photographs taken as part of the watercourse survey by GCS, as well as during a JBA site visit in July 2020.

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3 TUFLOW modelling

3.1 Modelling approach and choice of software

A new hydraulic model was built from existing survey data and LIDAR downloaded from the Environment Agency website. A 2D modelled approach has been adopted using TUFLOW. TUFLOW allows for a detailed representation of the floodplain, using efficient techniques to manipulate the model grid to define floodplain features which control flood mechanisms. Given the low flow regime through the watercourse, ESTRY (TUFLOWs primary 1D engine) has been used to define the channel and the multiple structures encountered along the watercourse.

The 2D model provides a more detailed approach to the floodplain modelling once water overtops the banks, representing the interactions between the open channel and out of bank flow. A 2D model domain cell size of 2m was selected for the hydraulic model, which covers an area of approximately 0.9km^2. This provides enough detail of floodplain flow routes within the catchment but will not capture smaller scale features influencing flow routes such as kerbs and minor passageways between buildings. TUFLOW modelling software is well understood by the Environment Agency.

Schematising the model using the 1D-2D approach provides several benefits including:

- Storage of flood water and attenuation that the floodplain provides should be more reliably modelled as flow paths, storage volumes and conveyance are more explicitly represented in the 2D grid (and the user does not need to schematise these features within a 1D model approach)
- Mapped outputs (depth, velocity, water level and hazard rating) are exported for the floodplain extent where flooding is predicted, meaning outputs are simpler to extract and differences in flood extents and depths, velocity etc. can be more easily derived for scenario tests.

Figure 3-1 displays the 1D and 2D extents of the model.

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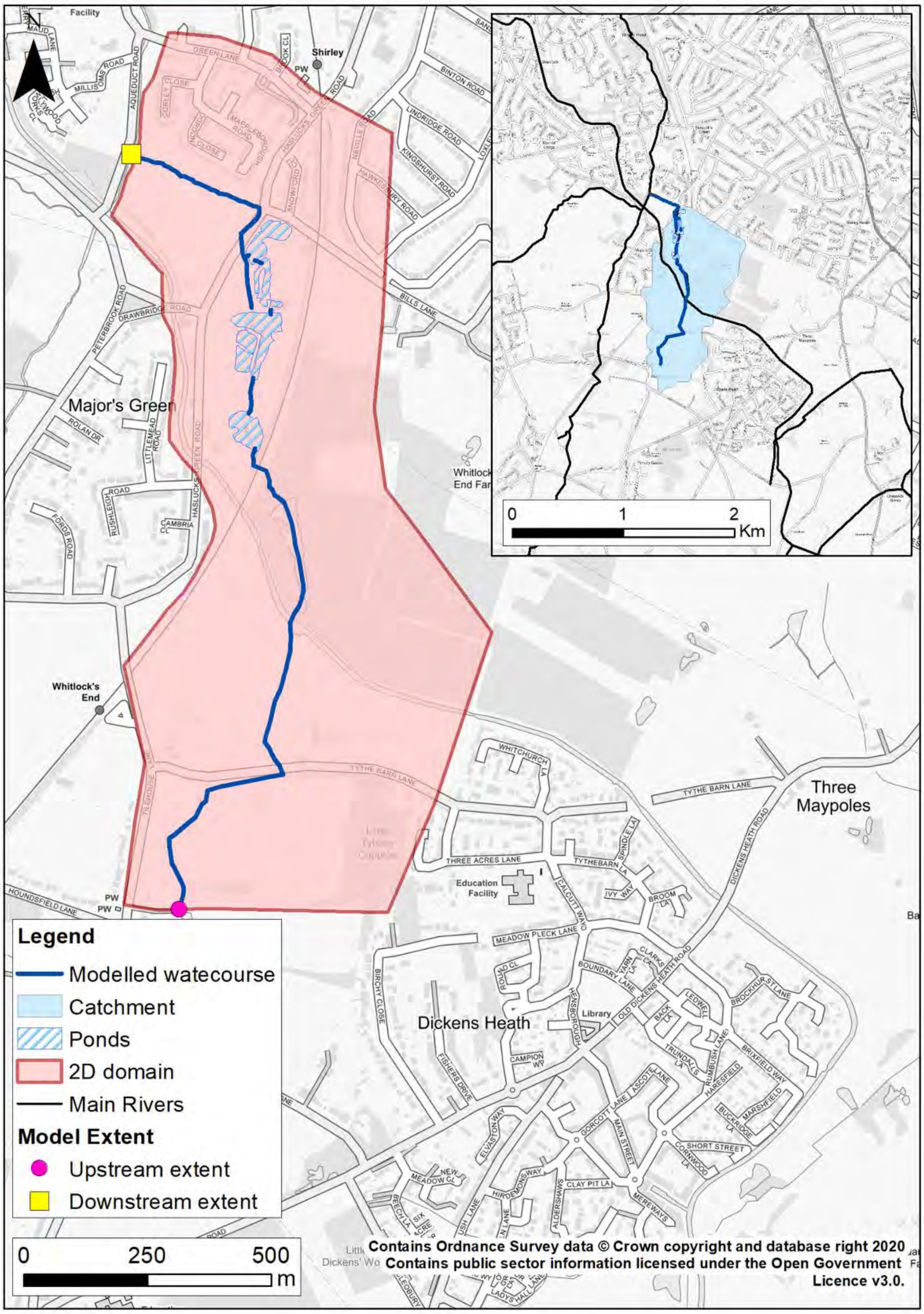

Figure 3-1: Model schematic

3.2 Topographic overview

shows that the majority of the model area is covered by the 2019 1m LIDAR data. However, the upstream extent of the model has no LIDAR coverage but has levels represented using the IHM dataset. This dataset is based off a coarser resolution subset of data and as such is a lesser detail of accuracy when portraying topographic features in the floodplain. Therefore, in this area, there may be instances where features are not represented to their full extent. This should be taken into account when interpreting the model results in this location.

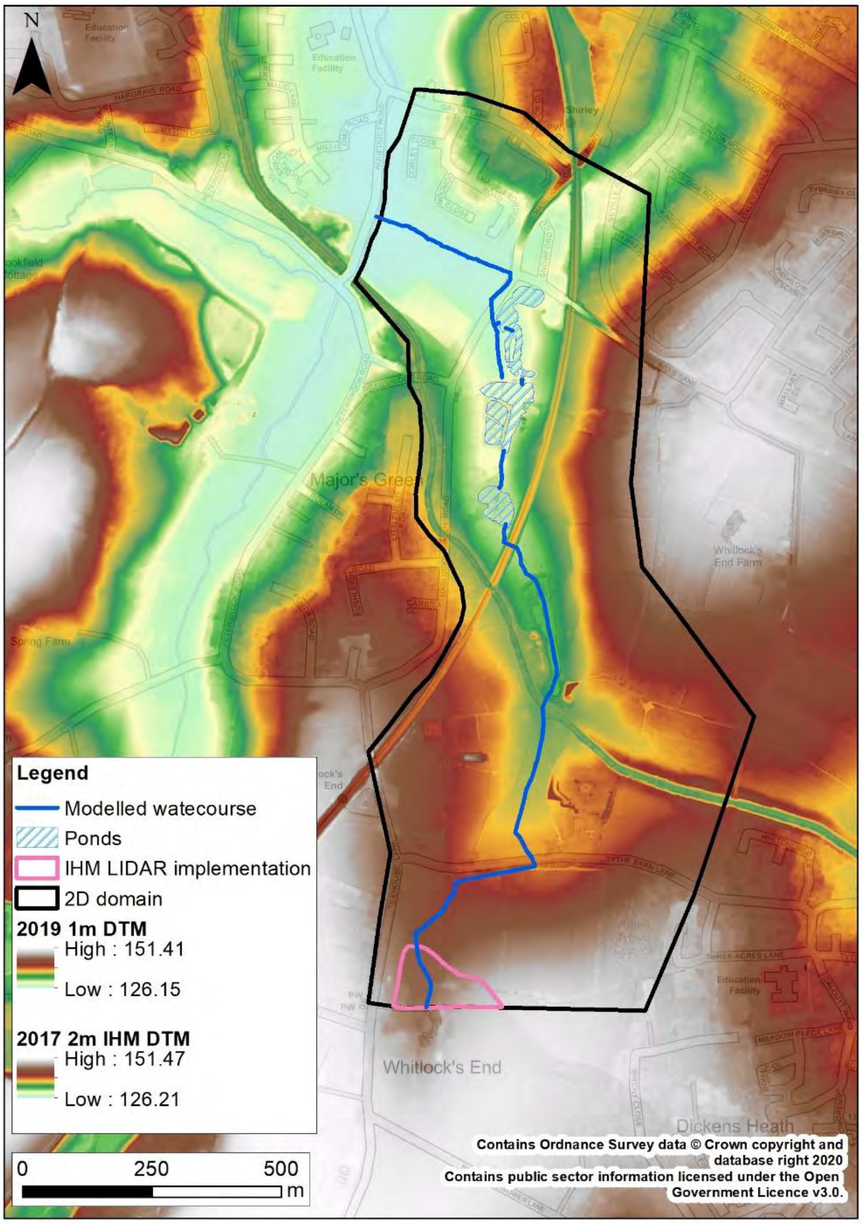

Figure 3-2: 1m LIDAR and 2m IHM DTM coverage

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3.3 General schematisation

3.3.1 Channel

The majority of the modelled watercourse is based upon survey data and as built drawings which have been provided for this study. Schematisation of the lower reaches, where the watercourse flows through Woods Farm Fishery has been complimented by site visit inspections. Additional channel cross-sections, using the 2019 1m LIDAR were extracted to enable a better conveyance of flow through the upstream lake (NGR: SP 410577 277460).

3.3.2 Channel structures

In total, 11 structures have been represented using 1D ESTRY units within the model domains. Details of these structures and any assumptions are shown in Table 3-1.

Table 3-1: Modelled structures

Structure no.	ID	Type	Width / diameter (m)	Height (m)	Upstream invert level	Down-stream invert level	Source
1	RIV_1849C	Circular culvert	0.375	-	143.34	143.330	GCS channel survey
2	RIV_1672C	Circular culvert	0.450	-	141.72	140.280	GCS channel survey
3	RIV_1300C	Circular culvert	0.460	-	138.14	138.130	GCS channel survey
4	RIV_1225C1	Rectangular culvert	0.460	-	136.96	136.400	GCS channel survey
5	RIV_1225C2	Circular culvert	0.920	-	136.40	135.840	GCS channel survey
6	RIV_0860C	Circular culvert	0.920	-	134.35	134.330	GCS channel survey
7	RIV_0382C	Circular culvert	0.430	-	130.36	130.350	GCS channel survey
8	Weir_001	Weir	1.500	-	133.30	132.160	JBA site visit
9	Pond_001a	Weir	0.72	-	134.54	134.44	GCS channel survey, and JBA site visit
10	Pond_001b	Weir	0.98	-	134.85	134.65	GCS channel survey, and JBA site visit
11	Pond_003	Circular culvert	0.250	-	132.16	131.750	JBA site visit
12	Pond_004	Circular culvert	0.250	-	131.75	131.000	JBA site visit
13	Poond_004b	Circular culvert	0.250	-	131.75	131	JBA site visit

14	RIV_0930C	Circular culvert	0.150	-	136.21	135.45	GCS channel survey
15	RIV_0930W	Weir	36.024	-	136.51	135.67	GCS channel survey
16	RIV_1300W	Weir	10.165	-	138.88	138.74	GCS channel survey

3.3.3 Waterbodies in the floodplain

Due to the watercourse flowing through Woods Farm Fishery and interconnecting the ponds, they have been included in the 2D domain. No bathymetric survey of the ponds is available; therefore, Environment Agency LIDAR and OS Mapping has been utilised to inform the overall shape and location of the lakes. Initial conditions in the 2D domain have been used to set initial water levels in the lakes, and the levels of the lakes has been lowered using Z-Shape layers to provide 500mm depth of water at the start of the simulations. Culverts and weirs have been included in the mode to connect the ponds, and the downstream extent of the watercourse together, this was identified following the site visit.

3.3.4 Buildings

Buildings within the floodplain are identified by Ordnance Survey MasterMap topographic Area layer data with the feature code '10021'. At buildings, a hydraulic roughness of n=0.3 has been applied. No adjustment to ground levels has been made at building footprints (for instance to account for the presence of building thresholds).

3.3.5 Bank levels and topographic features

Bank levels and significant features on the floodplain have been implemented in to the 2D domain via the use of Z-lines and Z-shapes, where these have not been picked up by the base model Z-points (informed by LIDAR). These will be modelled using levels from LIDAR data. Where there are structures, 1D spill units have been used to allow the flood water to drain from the floodplain into the channel. These have been connected to the 2D domain using and SX line with a CN connection.

3.3.6 **Manning's *n*** coefficient

Manning's *n* values have been used to represent hydraulic roughness in the 2D domain throughout the study extent. The roughness values recorded in Table 3 1 were used in the model and are based on land cover types recorded in the Ordnance Survey Master Map Topographic Area layer dataset.

Table 3-2: 2D hydraulic roughness

Landuse	TMF Code	Roughness coefficient (Manning's *n*)
General land use	1	0.060
Boulders	2	0.065
Coniferous trees	3	0.120
Coniferous trees – scattered	4	0.070
Coppice or osiers	5	0.090
Marshes	6	0.060
Non-coniferous trees	7	0.090
Non-coniferous trees – scattered	8	0.060
Rough grassland	9	0.060
Scrub	10	0.070
Rock	11	0.070
Heath	12	0.090
Buildings	10021	0.300
Inland water	10089	0.045
Path	10119	0.050
Rail	10167	0.045
Road	10172	0.035
Roadside	10183	0.050
Roadside	10123	0.050

The roughness values used for the floodplain not only account for the surface friction but also account for the increased resistance induced by the presence of features such as garden fences, walls and hedgerows.

While there is no formal guidance or single agreed approach for representing buildings in the floodplain the approach selected (representing buildings with a high roughness value) is an approach which has been tested in literature (e.g. Syme 2008). Not enforcing building footprints is considered to be a benefit if damage analysis is conducted at a later stage given there is not threshold data available.

3.4 Hydrology and model boundaries

3.4.1 Inflow boundaries

Inflows have been applied to the model using 2D Time-Flow (QT) boundaries, as point inflows and a lateral inflow. Three point-inflows, and a singular region-inflow. Each inflow has a series of Excel CSV inflow tables attributed to it via a unique name. Flows have been generated for the following AEP events (Table 3-3 and Figure 3-3 describe and outline the inflows to the model respectively).

3.4.2 Downstream boundary

A Downstream boundary has been applied to the model to ensure that the models do not have flood water "glass-walling" against the edge of the domain. A Stage-Flow (HQ) boundary representing the gradient of the land at the boundary location has been implemented to allow water to exit the model domain. Figure 3-3 outlines the location of the HQ downstream boundary.

Table 3-3: Model inflows

Inflow	Description
HEATH03	Inflow applied at upstream extent of the model representing the upstream catchment
HEATH02	Lateral inflow applied to HEATH02 catchment (hydrograph is equally distributed to all nodes falling within the region)
HEATH_IA_01	Point inflow for just after first pond along the watercourse
HEATH_IA_02	Point inflow for the downstream extent of the model

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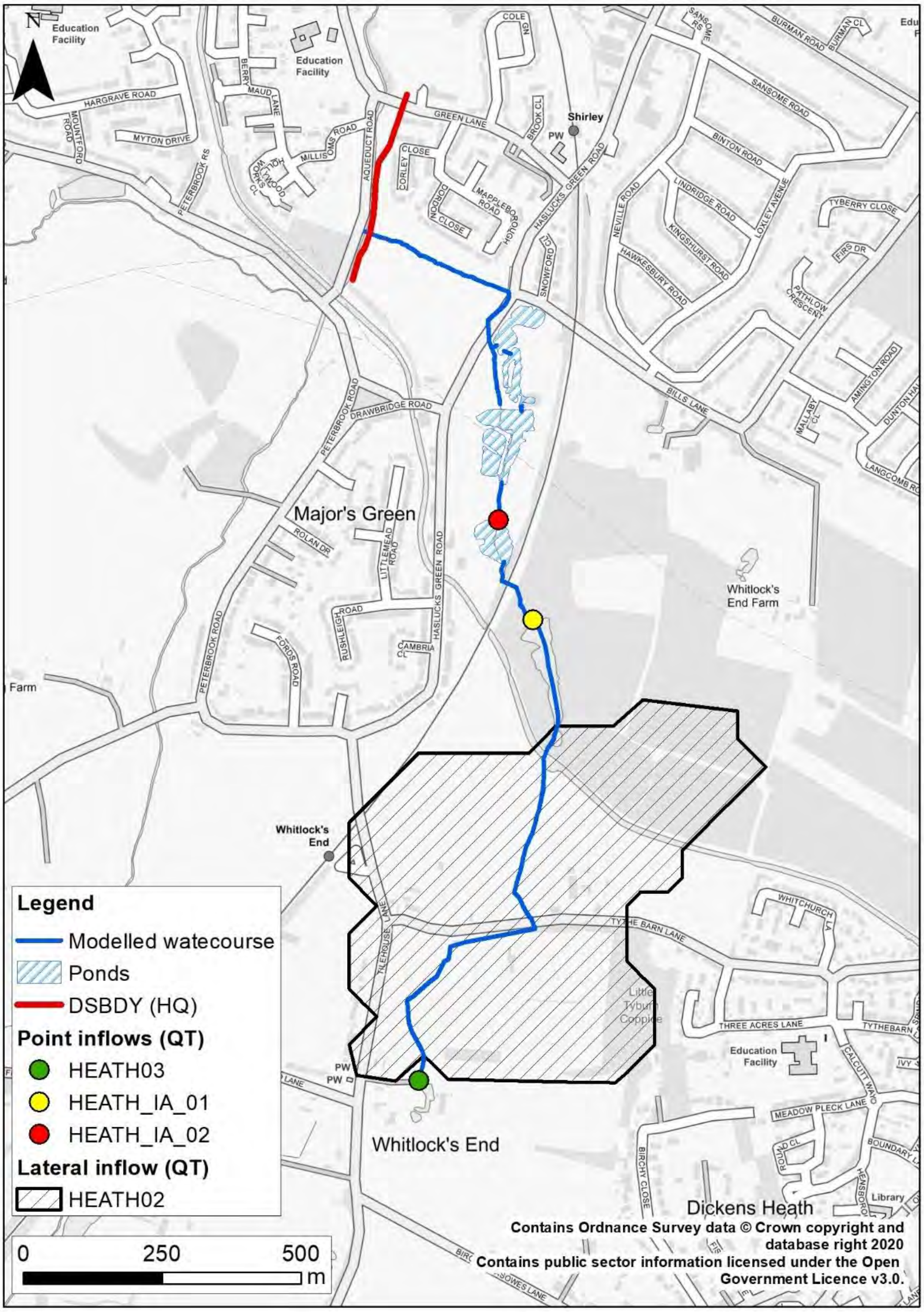

Figure 3-3: Model inflow locations

3.4.3 Other boundaries

The standard approach to linking 1D ESYTRY and 2D TUFLOW model domains has been adopted. Within the 2D domain a lateral spill (HX boundary) is defined for the left and right banks and the channel area in between classified as 'inactive' in the 2D grid. The HX boundaries are linked to the respective cross sections in ESTRY using CN connection lines and are discontinued at bridge, culvert and weir structures (amongst others). Along these boundaries, water levels in the channel and floodplain interact dynamically and thus control floodplain wetting and drying. Source boundaries (SX) have been applied to the 1D structure nodes to allow flow to pass onto the 2D domain.

3.4.4 Modelling limitations

The following limitations should be considered when interpreting the strategic modelling results:

- 2D modelling techniques do not explicitly represent the channel capacity or all the hydraulic structures which influence the conveyance of water downstream. The primary purpose is to give a broadscale understand of flood risk. If a more detailed site-specific assessment is required, then a more detailed hydraulic model with more topographic survey and detail of the channel would be required.
- Topographic survey of the ground levels within the site was not available for the strategic modelling. It is therefore unknown if the DTMs used for the study accurately represent existing ground levels. This should be investigated as part of future detailed site-specific assessments.
- In areas covered by the IHM dataset there are uncertainties in the elevation of floodplain features and the channel levels. Basic assumptions have been applied to stamp a channel into the DTM for this assessment but its recommended that this is improved if further data becomes available or if a detailed site-specific assessment is required.
- Although survey has been collected for the main channel within this model domain, no connections could be found which drain the site. It is recommended that this is reviewed as part of a future detailed site-specific assessment.

4 Model simulations

A series of design events were simulated, including the 5%, 1% and 0.1% AEP events. These simulations were completed for only the undefended case as there are no formal flood defences along the watercourse. The design events modelled in this study represent Flood Zone 3b (5% AEP), Flood Zone 3a (1% AEP), and Flood Zone 2 (0.1% AEP), which are required for a Level 2 SFRA.

The potential impact of climate change on predicted flows and flood extents was assessed for the undefended case using the 1% AEP events. The adjustments made used flood flow rates informed by the current Environment Agency guidance on climate change for the Humber Basin District. The guidance indicated anticipated potential uplift factors of +20%, +30%, and +50%.

4.1 Undefended design events

Undefended case design runs of the model were carried out for a range of flood magnitudes. Figure 4-1 displays the modelled flood extents for the 5%, 1% and 0.1% AEP events. The following observations have been made from analysis of the undefended model results.

- During the 5% AEP event, are there significant areas of widespread flooding. At the upstream extent of the watercourse, flood water comes out of bank at the Tythe Barn Lane culvert, flows over Tythe Barn Lane forming a flow route parallel to the watercourse, before re-entering the watercourse approximately 200m further downstream. Flooding also occurs upstream of the railway caused by water overtopping the embankment on the downstream side of the lake. Water overtops the first pond, immediately downstream of the railway line and floods the land on the western bank of the watercourse. Water also overtops the second pond at the north-western corner, forming an additional flow path before re-joining the watercourse approximately 50m downstream. Widespread flooding also occurs on the floodplain downstream after overtopping Haslucks Green Road.
- During the 1% AEP event, modelled flood extents are predicted to only increase marginally when compared to the 5% AEP event. The greatest area of increased flood extent can be seen where flows overtop the Tythe Barn Lane culvert towards the upstream extent of the watercourse. Increased flooding can also be seen immediately upstream of the lake, where flows overtop the banks to the culvert flowing under the canal. The flood extent is also predicted to increase immediately upstream of the railway embankment. Modelled flood predictions at the downstream extent of the watercourse also displays increased out of bank flows from the fishery ponds and on the floodplain downstream of Haslucks Green Road.
- There is a significant increase in modelled flood extents for the 0.1% AEP event compared to that during the 1% AEP event. Out of bank flow now occurs towards the very upstream extent of the watercourse, approximately 100m upstream from Tythe Barn Lane. Large increases in flooding along the canal is also predicted, with two additional flow routes forming from the canal back to the watercourse. Firstly, immediately upstream of the railway embankment and second just downstream of the railway embankment which subsequently flows into the first upstream fishery pond. Increased downstream flood extent is also observed.

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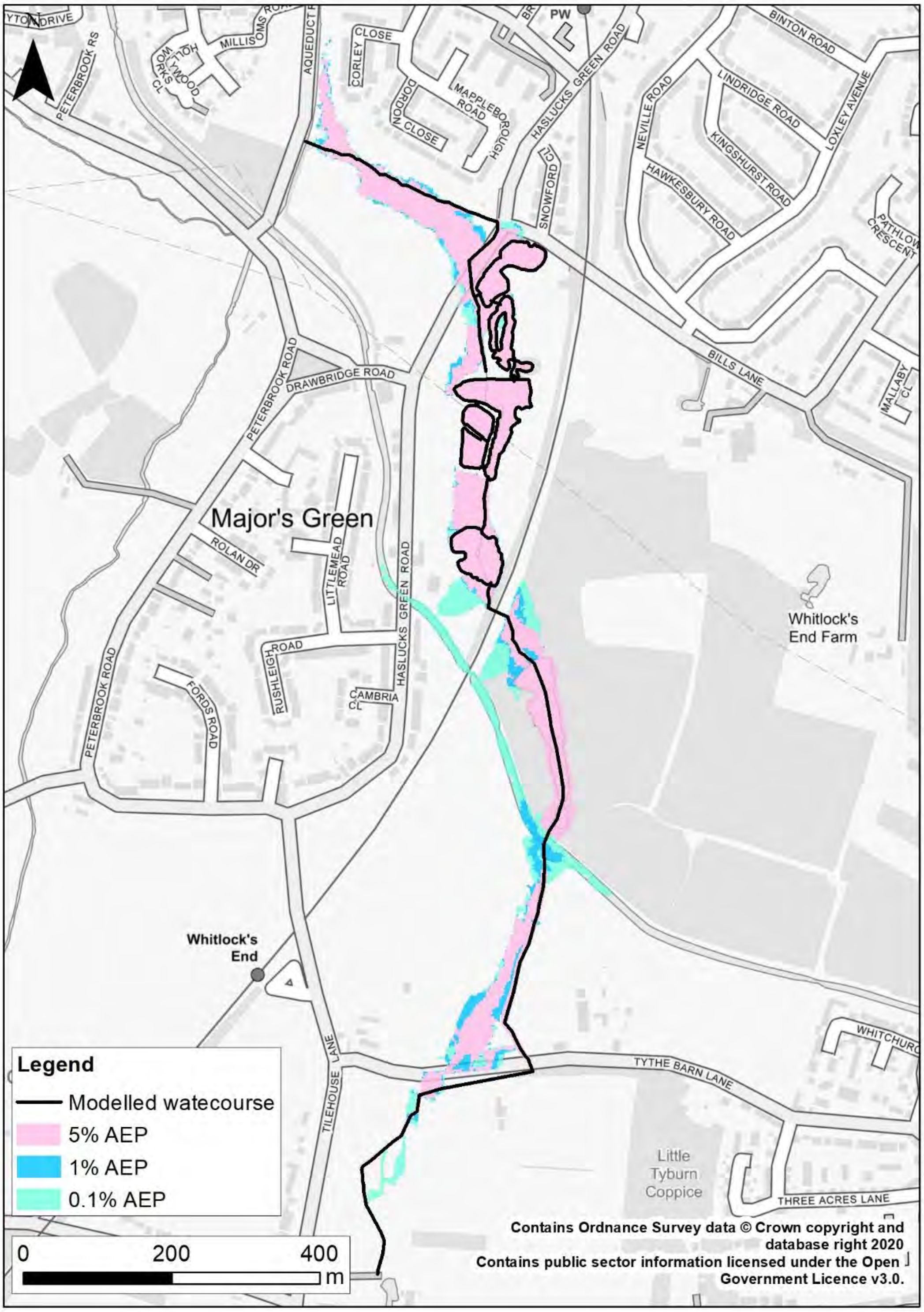

Figure 4-1: Undefended case (present day) flood extents for the 5%, 1%, and 0.1% AEP events

4.2 Climate change events

The impact of climate change was assessed for the 1% AEP event. The adjustments made used flood flows informed by the current Environment Agency guidance on climate change for the Humber Basin District. The guidance indicates anticipated potential change factors of +20%, +30%, and +50%, which were tested in model scenarios.

Mapping showing the undefended case flood extents for these climate change scenarios is displayed in Figure 4-2.

The following observations are made for the undefended case climate change extents compared to the 1% AEP baseline.

- For the 1% AEP plus 20% event, the flood extents are predicted to be marginally larger than the 1% AEP event where there is increased out of bank flow at the upstream culvert under Tythe Barn Lane, along the canal and also at the downstream culvert under Haslucks Green Road.
- For the 1% AEP plus 30% event, there is only a very slightly increase in flood extent compared to the 1% AEP plus 20% event. The area of most significant increase is where the flow comes out of bank from the culvert under the canal and cascades along the canal.
- For the 1% AEP plus 50% event, there is a significant increase in flood extent compared to the other climate changes simulations. The most notable increase in flooding is the formation of an additional flow route between the canal and the watercourse immediately downstream of the railway embankment, with water re-joining the watercourse at the most upstream of fishery ponds. Additional increases in flooding can be seen in areas immediately upstream of the railway embankment and also towards the downstream extent of the model where the watercourse flows under Haslucks Green Road.

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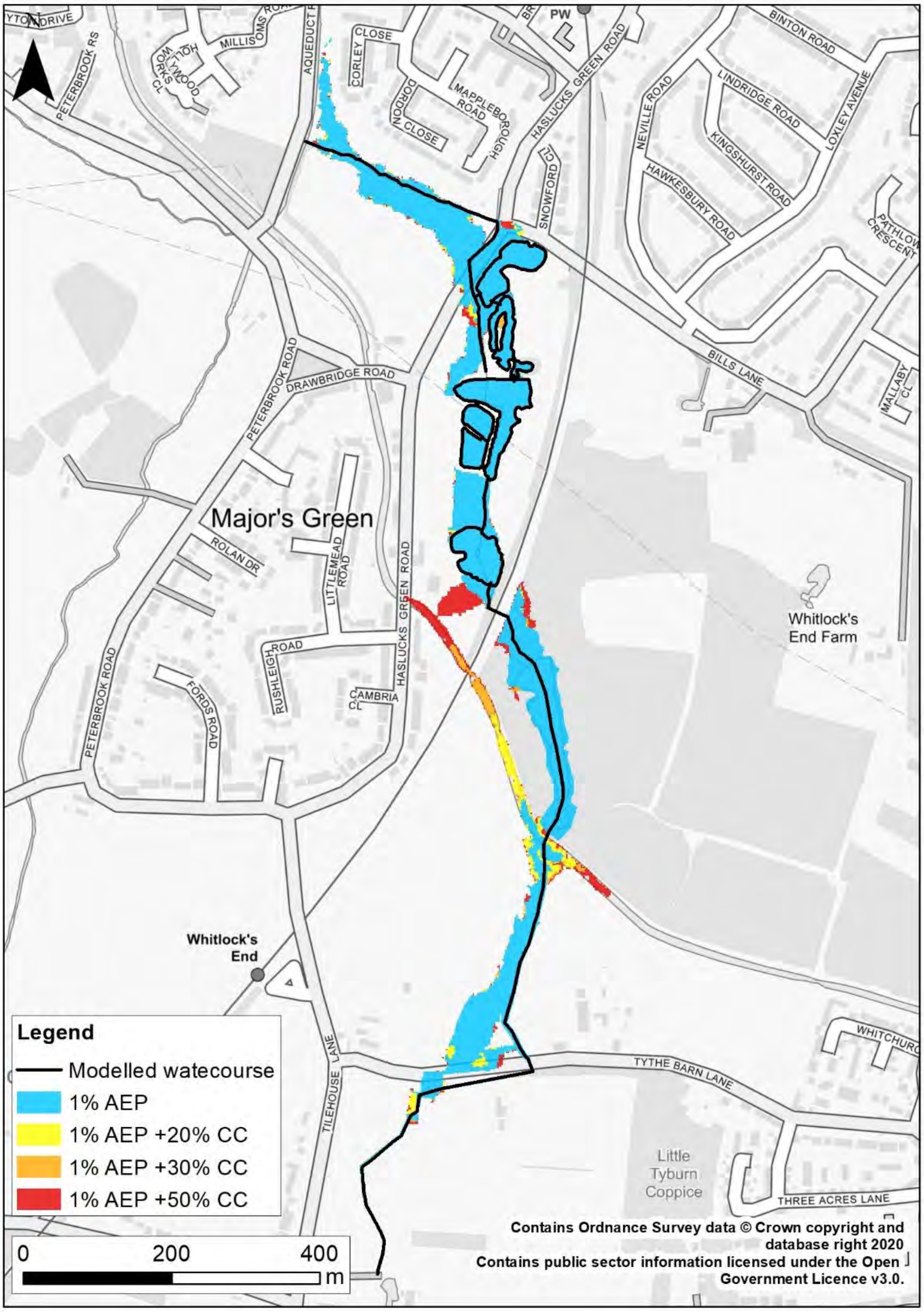

Figure 4-2: Undefended case (present day) flood extents for the 1% AEP event and the 1% AEP climate change events (+20%, +30%, and +50%).

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4.3 Model proving and sensitivity

Confidence in the predictions made by hydraulic models is increased through model proving and sensitivity activities, undertaken to understand the uncertainty associated with the choice of model parameters and inputs, and the significance of this on model results. Sensitivity testing allows for greater understanding of the impact caused by the various assumptions made during model developments.

Sensitivity analysis was prepared for the scenarios described in Table 4-1.

Table 4-1: Sensitivity analysis parameters and inputs

Sensitivity parameter	Variance	AEP events tested
Manning's *n* roughness coefficient	+20%	1% AEP
	-20%	
Downstream boundary condition (Originally 0.007m/m)	decreased by half (0.0035m/m)	1% AEP
	increased by double (0.014m/m)	

The sensitivity and significance of each parameter was considered in terms of the change in modelled water depth and flood extent. Mapping showing what the changes in flood extent was for varying the roughness and boundary conditions is presented in Figure 4-3 and Figure 4-4 respectively. It should be noted that the layering of flood extent applied in the mapping is as per the legend.

Table 4-2: Summary of sensitivity testing results

Model proving scenario	Outcomes of testing and influence on the final model configuration
Sensitivity to manning's *n* roughness coefficient	Varying manning's *n* roughness in the 1D and 2D domains resulted very little degree of change in flood extent across the entire watercourse. Very small pockets of increased flood extent can be noted towards the upstream extent of the watercourse, immediately south of Tythe Barn Lane, and also towards the downstream extent by the ponds at Woods Farm Fishery. A reduction in roughness by 20% has a minimal impact on flood extent along the watercourse. The greatest reduction in flooding can be seen immediately upstream of the downstream boundary but is considered negligible.

Sensitivity to downstream boundary condition	Adjusting the gradient of downstream boundary by half/double has little to no effect on predicted flood extent along majority of the watercourse. A very slight difference in extent can be seen at the downstream extent of the model, but this is deemed negligible. An increase in gradient decreases flood extent as water cannot easily pool due to less gravitational effect. Whereas a decrease in gradient allows the water to remain on the floodplain as it has less gravitational force acting upon it, increasing flood extent.

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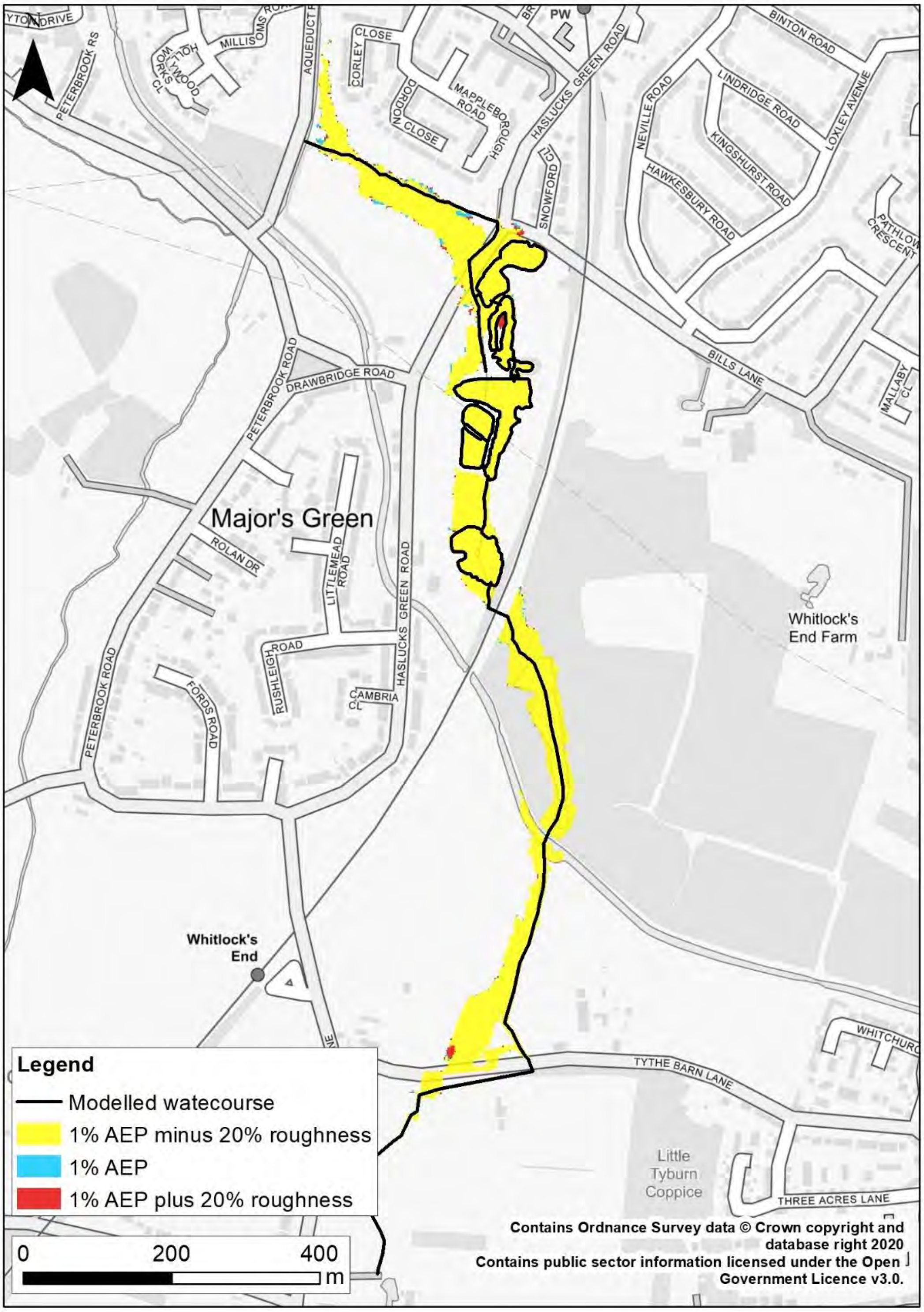

Figure 4-3: Sensitivity to roughness - comparison of flood extents for the 1% AEP event

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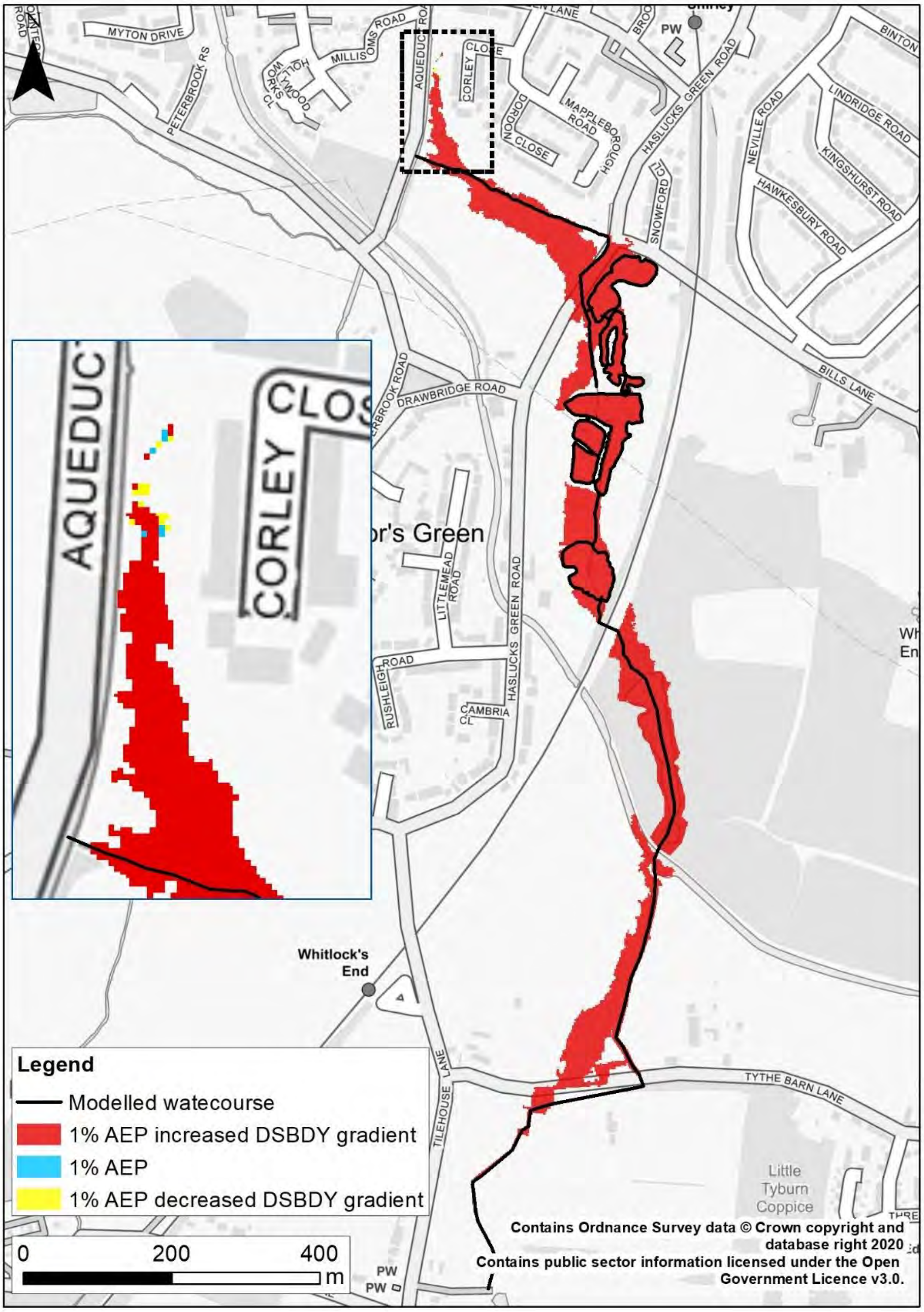

Figure 4-4: Sensitivity to the downstream boundary - comparison of flood extents for the 1% AEP event

5 Limitations and future improvements

During any hydraulic modelling study, there will always be associated limitations. For example, with uncertainty, data availability and so on. The representation of any complex system by a model requires a number of assumptions to be made. In the case of the hydraulic model it has been assumed that:

- Cross sections accurately represent the shape and variation of the river
- Model parameters have been determined appropriately
- Design flows are an accurate representation of flows of a given annual exceedance probability
- The surveyed cross-sections of the hydraulic structures and the units used to represent them in the model provide an adequate representation of the situation
- LIDAR accurately reflects the bank heights (used for all banks within the model) and particularly that the filtered LIDAR has appropriately removed the influence of vegetation and other features.

In terms of model construction, the initial model schematisation and the approach adopted can be a limitation. In this study, a 1D-2D ESTRY-TUFLOW model was developed. This schematisation allows for a detailed representation of the floodplain, using efficient techniques to manipulate the model grid to define floodplain features which control flood mechanisms. The 1D-2D (ESTRY-TUFLOW) approach was considered to be the most appropriate to represent the risk of fluvial flooding as the catchment is predominantly rural and a 1D-2D model provides a more detailed approach to the floodplain modelling once water overtops the banks. In addition, given the low flow regime and a low number of structures present along the watercourse, TUFLOWs 1D engine, ESTRY, was considered suitable to model the open channel flows of the watercourse.

The LIDAR used to set the base topography in the 2D model domain is a source of uncertainty. The bare earth DTM is filtered to remove the presence of the buildings and vegetation. The LIDAR data used within this study is predominantly at 1m resolution. This subsequently allows for a more accurate definition of the model domain, therefore limiting uncertainty. However, there was a small area at the very southern extent of the model domain that was not captured by either the EAs 1m or 2m LIDAR. Therefore, the Environment Agency Integrated Height Model (IHM) was used. This dataset provides elevation data at a 2m spatial resolution and is based off AirPhoto Great Britain Height photogrammetry (5m resolution resampled to 2m resolution). Due to the larger spatial resolution compared to the EAs 2019 1m LIDAR, the floodplain and channel banks are not as well defined in this area. However, due to the IHM dataset being used for only a small area of the model domain, the effect of larger resolution would be minimal. The model grid resolution of 2m is larger than the native LIDAR data and may introduce some simplification to the definition of flow routes and features of the floodplain. These grid sizes are considered to be a balance between providing enough detail of the floodplain and flow routes, while limiting the computational size of the model outputs.

The fishery ponds towards the downstream end had not been surveyed, therefore several assumptions had to be made. The depth of each of the ponds was unknown, only an initial water level was provided in the topographic survey by GCS Ltd.

Therefore, the representation of ponds in the model has been implemented in the 2D domain only, by using Z-Shape features to capture their shape and to enforce an elevation (determining their depth). The elevation of the ponds was set to 500mm below the initial water level. As the initial water level for each pond was set to the outlet level of the pond, the depth has no impact on the storage capacity of each of the ponds.

The structures between the fishery ponds were not captured in the topographic survey by GCS Ltd, but they were identified in the JBA site visit. The representation of these structures in the model were informed by site visit photographs and best practice guidance. Therefore, the true geometry of the structures may not have been captured and consequently the conveyance of flow through them is simplified.

The downstream extent of the watercourse has been modelled in the 2D domain only through the use of a Z-Line feature which carves a channel in the domain by enforcing the elevation of the LIDAR. This approach was adopted because the site visit undertaken by JBA identified that the fishery ponds were the controlling features of flow through the watercourse in this part of the model. However, compared to using TUFLOWs 1D Engine, ESTRY, to model the channel geometry, the true nature of flow conveyance is not captured as the geometry of the channel is not as accurately represented.

General modelling assumptions relate to the selection of various parameters within the model, more example, the roughness values used within the model, representation of certain structures and their coefficients. A programme of model proving has been undertaking to understand uncertainties associated with the choice of parameters and their impact upon model results

6 Conclusions and recommendations

6.1 Study objectives

The purpose of this study was to understand the flood risk for a range of flood events for the tributary of the River Cole. Model simulations have been undertaken for sensitivity testing as well as a selection of design events, and three alternative scenarios for climate change.

6.2 Key flood risk messages

This modelling study has indicated that:

- The main areas at risk of flooding are at the culverts under Tythe Barn Lane and under the canal. At these locations, there is significant flooding during all flood magnitudes simulated.
- Flood extents for the climate change allowances tested display a general expansion of the predicted present-day flooding, posing an increased risk to the land and any properties within close proximity to the watercourse.

6.3 Recommendations and further work

Recommendations following this study are:

- A detailed survey of the entire watercourse, focussing on the structures, the downstream fishery ponds and top of bank levels would provide more confidence in the onset of extent of flooding along the watercourse.
- For a site-specific flood risk assessment, an assessment of the quality of the channel and floodplain representation in close proximity to the site should be undertaken to better understand the onset of flooding and the flow patterns across the floodplain.
- Further hydrological work could be undertaken to better understand the risk of flooding posed by culvert and structure blockages. In particular the culvert under Tythe Barn Lane and the arch culvert under the railway as these areas have been highlighted to be sensitive to flows.