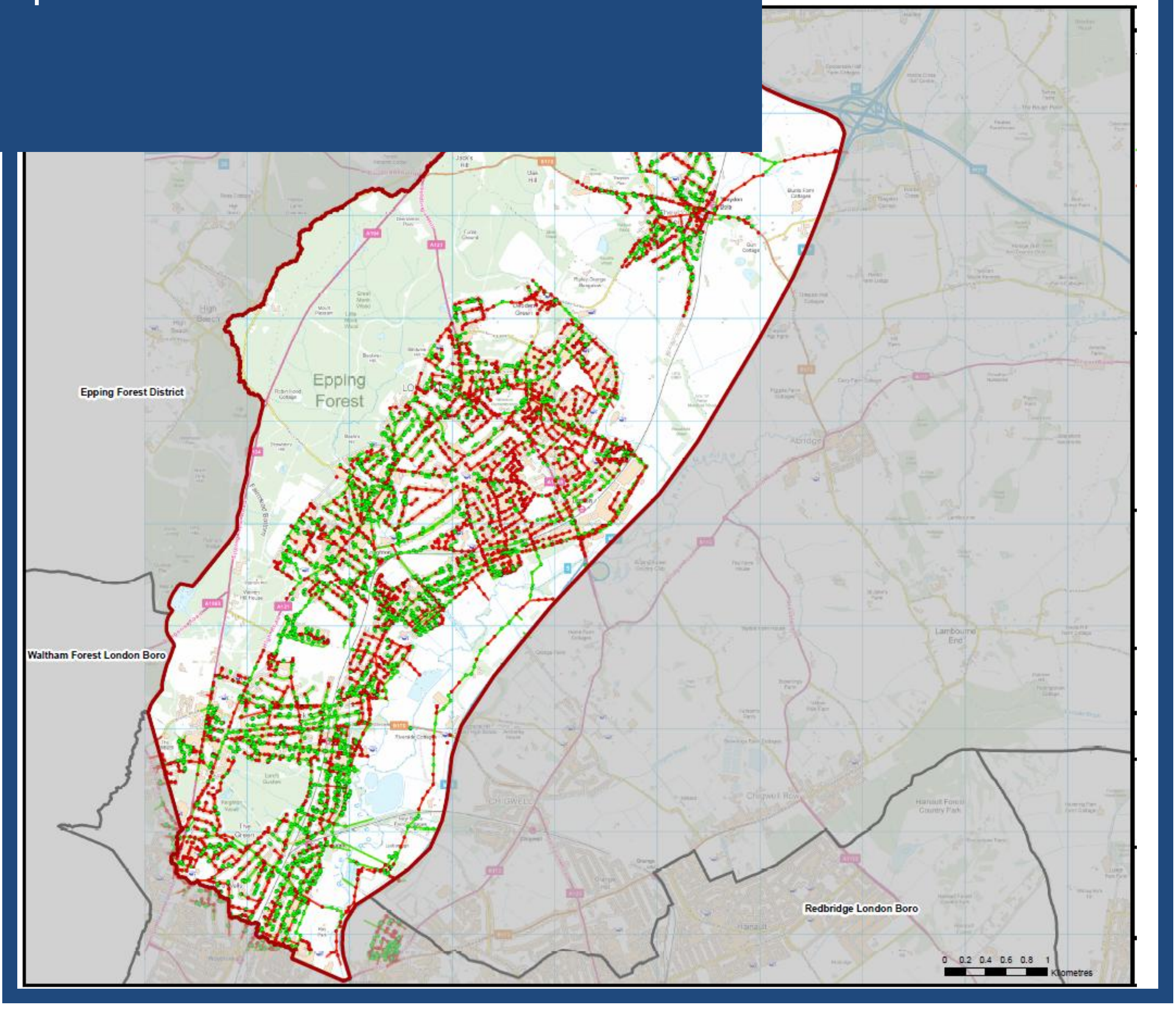
CAPITA

Loughton, Buckhurst Hill and Theydon Bois

Modelling Technical Report
April 2016



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1. Introduction

The purpose of this study is to develop a detailed understanding of the existing and future surface water flood risk within Loughton, Buckhurst Hill and Theydon Bois (LBT) based on the creation of an integrated urban drainage (IUD) model that represents the combined drainage system, roads, ground surface and other local water infrastructure that affects the drainage of the town.

Identifying the pluvial flood risk will assist Essex County Council (ECC) and partners in selecting practical, feasible and cost effective outline solution(s) to manage surface water flood risk. The creation of the IUD model will also assist with the development a robust action plan that identifies additional works and actions to manage the risk identified from the hydraulic modelling of the town. The IUD model has been constructed using TUFLOW (**T**wo-Dimensional **U**nsteady **Flow**) software.

The aim of this document is to outline the overall approach to the development of the IUD model. The data collected for the study has been assessed, any data gaps noted and recommendations made for additional data capture.

2. Data Collection

2.1 Topographic Data

Topographic data has been provided by the Environment Agency (EA) in the form of 1m resolution LiDAR data. The EA have confirmed that this was flown in March 2009. The EA has also provided 0.5m resolution LiDAR data for the study, which covers the entire study area. The 0.5m LiDAR is more recent (it was flown in 2014) and is considered a good representation of the local topography therefore this was the one used to built the model.

2.2 Sewer Network Data

Thames Water has provided GIS layers of the sewer network pipes and manholes within LBT (data were provided in July 2015). The GIS layers provide limited information on the sewer network. A review of the dataset highlighted missing invert levels for pipes and manholes as well as missing sizes / dimensions (refer to Figure 2-1 below).

An initial review of the pipe network should there was a total of 1376 pipes surface water pipes >= 300mm. Of which:

- 150 are missing pipe size (10.9%)
- 520 were missing upstream invert level (37.8%)
- 555 were missing downstream invert level (40.3%)
- 285 were missing both US and DS invert levels (20.7%)

A review of the manhole showed there were 2314 manholes that intersected the pipes detailed above, of which:

- 371 were missing cover level data (16%)
- 543 were missing invert level data (23.5%)
- 365 had neither cover levels nor invert levels (15.8%)
- 1462 were missing chamber width data (63.2%)
- 1066 were missing chamber diameter data (46.1%)

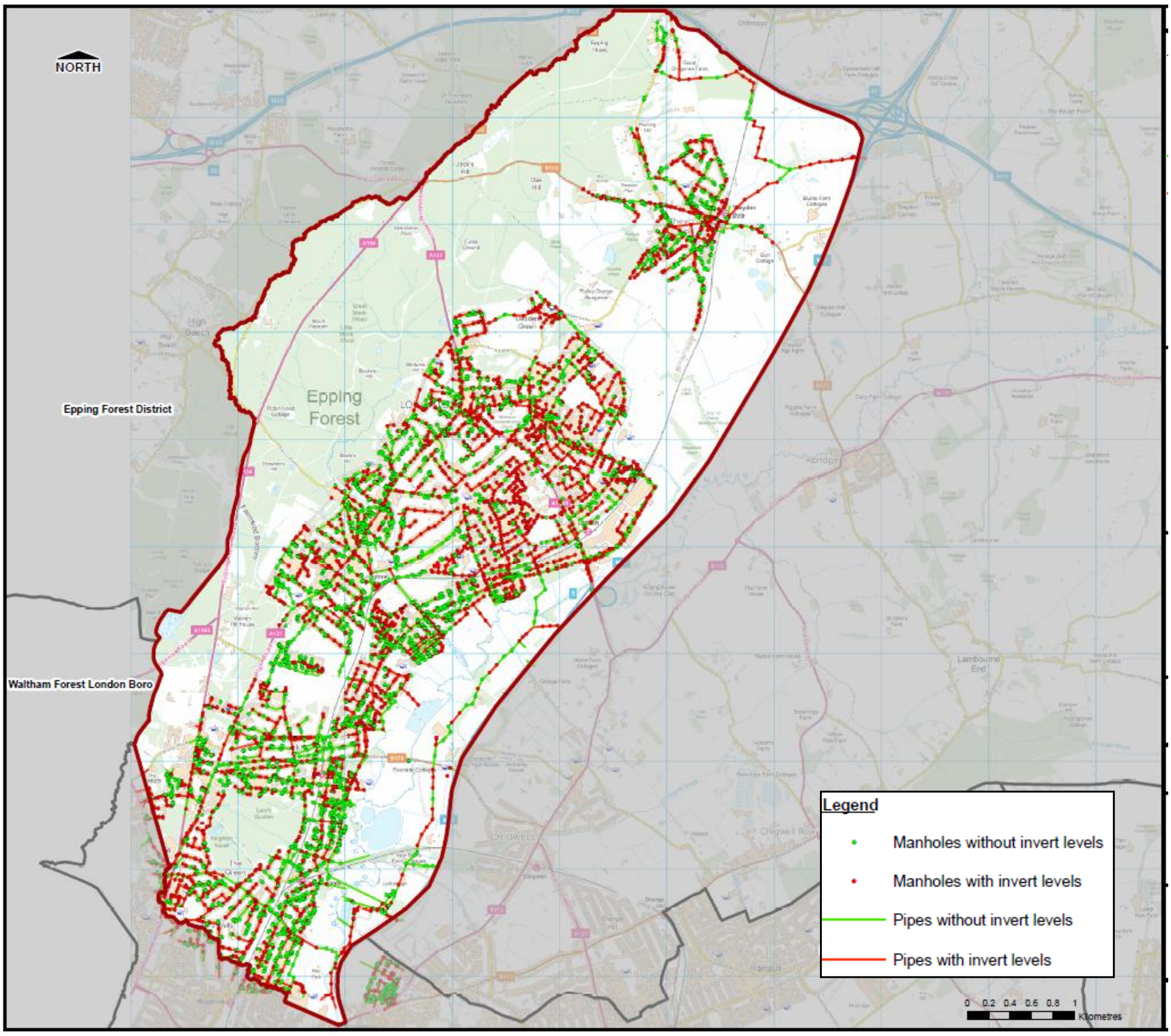

Figure 2-1: Missing Invert Levels

Essex Highways has provided a GIS layer of gullies within the study area. The layer provides gully locations only –no information has been provided on invert levels, dimensions or gully type.

2.3 Historical Flood Information

Historic flooding records were provided by Essex County council (ECC) the data we provided in CSV and converted into a point layer in order to make it useful for the purpose of this study. Historic Fluvial Flood Outlines for River Roding were also provided by the EA. Thames Water has provided DG5 register of sewer flooding incidents for the study area. This data was used for verification of model outputs.

2.4 Existing Model

The ISIS model previously developed by the EA as part of the EA Middle Roding Flood Risk Mapping Study' (2012) has been used as the basis of modelling the main rivers within this assessment.

2.5 Defence Data

Details of fluvial defence and structural assets have been provided however these were not explicitly modelled as no modelling of fluvial networks in 1D was planned as part of this study (see Section 3.6). It was assumed that Fluvial Defences have been adequately represented in the LiDAR data used in the model.

3. Model Methodology

A linked 1D-2D hydraulic model covering the Loughton, Buckhurst Hill and Theydon Bois area was constructed using TUFLOW software. In order to appropriately replicate the pluvial flooding mechanism, combined with the fluvial mechanism, an Integrated Urban Drainage model has been created in TUFLOW using ESTRY to represent the drainage network.

The ISIS model previously developed by the EA as part of the EA Middle Roding Flood Risk Mapping Study' (2012) has been used as the basis of modelling the main rivers within this assessment.

3.1 Model Extent

A ‘rolling ball analysis’ has been performed using QGIS software to determine contributing catchments from LiDAR data and to visualise likely flow paths. This analysis has been used in conjunction with the parish boundary data to ensure that all areas of interest are included in the model and that all possible contributing rainfall is being captured within the 2D model domain. The proposed model extent is indicated by the red line boundary below. This model extent was validated during the initial stages of the model development to ensure the correct extent was applied. The 2D domain was selected using the highest points surrounding the area of interest. The extent is bounded by the M25 to the north. To the west, the model extent follows a ridge through Epping Forest. The extent then continues along a ridge to the south down to Woodford Wells. The southern model boundary is located just north of Woodford Green, following the Epping Forest District Council boundary. The eastern model extent follows the M11 which is located at a higher ground level. The study area is largely urban with a few surrounding rural areas. The total area of the catchment to be modelled is approximately 31km^2. Figure 3-1 below shows the model extent.

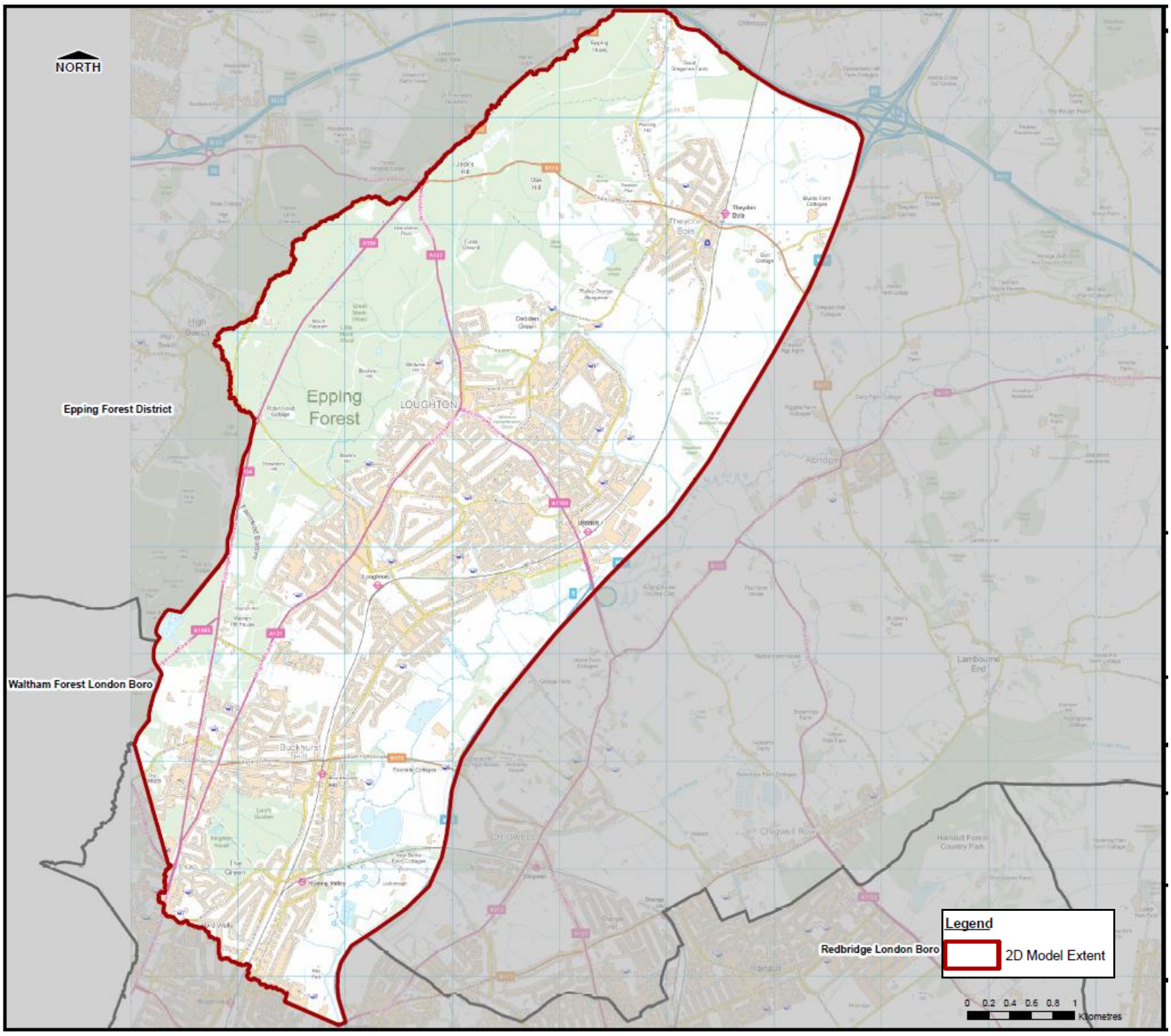

Figure 3-2: Model Coverage

3.2 Model Inflows

3.2.1 *2D Inflows*

Total rainfall depths for a range of return periods were extracted from the FEH CD-ROM (v3) Depth Duration Frequency (DDF) model at 1km grid points for several locations across the modelled area.

Rainfall hyetographs were generated for the following rainfall events:

- 1 in 10 year
- 1 in 30 year
- 1 in 75 year
- 1 in 100 year
- 1 in 100 year plus climate change (1 in 100year +30%)
- 1 in 200 year

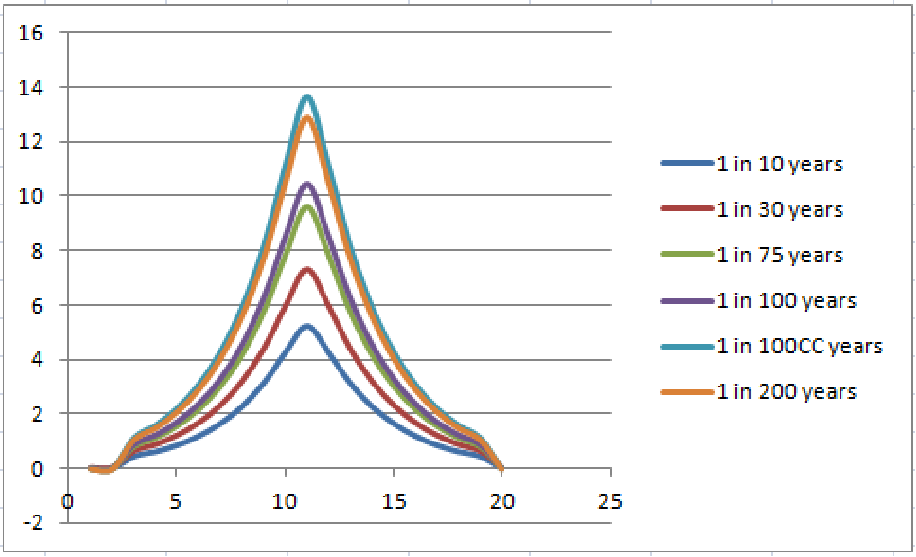

Figure 3-2: Rainfall Hyetographs

The hyetographs were applied as inflows into the models using two layers. The first layer consists of a polygon covering the model 2D domain with the areas corresponding to buildings (defined using OS MasterMap) removed. This boundary condition layer enables TUFLOW to apply the rainfall hyetograph corresponding to each event and duration as a distributed rainfall to the whole model except where buildings are located. No rainfall is applied directly onto buildings, to reflect the routing of rainfall from roofs into the subsurface drainage network.

The second layer accounts for the rainfall onto roofs. In this layer the rainfall was scaled to correspond only to the area of the buildings in the domain. This rainfall was equally distributed to all 2D grid cells in which pits are present, to better represent the routing of rainfall into the network through gutters and drainpipes.

3.3 Critical Duration

Critical duration is a complex issue when modelling large areas for surface water flood risk. The critical duration can vary greatly even within a small area, due to the topography, land use, size of the upstream catchment and nature of the drainage systems.

The hydraulic model was simulated for a range of storm durations to determine the critical duration for the site. The durations tested were 1 hour, 3 hours, 5.5 hours and 14 hours. The maximum flood depth and extent of surface water flooding for the three durations were compared and it was found that the 3 hour duration produced the largest flood extent and maximum flood depth for the area of interest, therefore providing the most conservative results. As such, storm duration of 3 hours was selected for this study.

3.4 Downstream Boundaries

Along the River Roding a downstream boundary has been applied, a relevant gradient was chosen from the LiDAR data. The purpose of this boundary is to allow the surface water to drain into the River Roding and flow further downstream. The water levels assigned along the River Roding are in bank levels.

Other downstream boundaries in the models were included where it was observed that water was able to flow outside of the model extent. The type of downstream boundary used was a flow vs. stage (level) relationship, or HQ boundary. The rating relationship is generated by TUFLOW automatically using a gradient provided by the modeller. Any outfalls to the main rivers or to the ordinary watercourses were modelled using SX connectors.

A head vs. time, or HT boundary was used in the north eastern part of the model to allow water under the M11 to flow outside of the model boundary. Water level was assumed at 2/3 of the pipe diameter on top of the downstream pipe invert.

3.5 Drainage Network Representation

The combined drainage network within the study area flows in an eastward direction toward the River Roding located in the eastern boundary of the model. The drainage network is considered to be dry at the start of the simulation and no blockage was applied to surface water pipes.

As mentioned above the sewer network data provided have missing attributes. Appropriate modelling assumptions were used to fill any identified gaps in the data sets.

These include:

- Only pipes >=300mm were included in the model.
- For the manholes missing invert levels the levels were determined based on the levels of the connecting pipes. In the case where invert levels are missing from connecting pipe data, the cover level was dropped by a specific level determined by looking at the height of the surrounding manholes.
- For the manholes with missing chamber dimensions it was assumed that they are similar to the surrounding manholes.
- For manholes with missing cover levels the values were extracted from the LiDAR.
- For the pipes with missing shape it was assumed that the pipes are circular.
- For the pipes with unknown dimensions (sizes), the dimensions were derived by integrating the dimensions of the connecting pipes upstream and downstream. It was also assumed that the pipes downstream are of the same or larger size.
- For the pipes with missing upstream invert levels the level was derived from the adjoining pipes, assuming that the upstream invert level of the outgoing pipe is the same as the downstream invert level of the incoming pipe. For the pipes with missing levels and where levels cannot be taken from the connecting pipes, the levels were extracted from the manhole information, either using the original data or using the assumptions discussed above.
- The pipes in the drainage network were defined in 1D using ESTRY feature 1d_nwk. The manholes in the drainage network were defined using the ESTRY feature 1d_mh.

The gully information provided by The Essex Highways were used to define the principal means of connecting the 2D (surface) model to the 1D drainage (sub-surface) model. A “pit search distance” command enabled the gullies to automatically connect to the nearest channel end within a radial distance of **600** m. Manual checks were done to ensure that gullies connected to the correct part of the network.

The gullies were defined in ESTRY as a 1d_nwk layer. A standard UK “Type R” gully and a profile of “Steep-shallow”, corresponding to a steep longitudinal road gradient and shallow cross fall was used.

3.6 Watercourses

Three primary rivers flow through the model area before feeding into the River Roding.

1. The unnamed watercourse that flows from Theydon Bois eastwards before flowing south towards the Roding.
2. The Loughton Hall Farm Ditch / Pyrles Brook which flows to the east of Loughton and comprises of two smaller tributaries that join adjacent to Debden Park High School and St John Fisher Primary School.
3. The Loughton Brook flows through the centre of Loughton.

An initial review of the hydrology and the 'time to peak' showed that short duration peak rainfall on Loughton Brook catchment would fall before River Roding begins to rise. Therefore the three rivers have been represented in the IUD model as bank full. For the Loughton Brook and the Loughton Hall Farm Ditch, the bed levels were extracted from the river section in the ISIS model (built as part of the EA Middle Roding Flood Risk Mapping Study) and applied to the 2D domain of the TUFLOW model using a 2d_shape.

Analysis of the 1D modelled cross sections for the two watercourses showed that in the upper reaches, the channel width is approximately 4m. The grid size chosen was therefore suitable to represent these channels within the 2D domain. A bank full water level was applied along the river.

The unnamed watercourse at Theydon Bois was also represented using a 2d_zshape line however since there was no survey data available the levels were extracted from LiDAR data. Analysis of LiDAR data and GoogleEarth showed that the width of this watercourse in its upper reaches is approximately 10m from bank to bank and was therefore well represented within the 2D domain.

There is a number of drains within the study area which interact with the 1D drainage network. Examination of LiDAR data indicated that the majority is 4m wide and they are well resolved within the 2D domain. However, where field drains are narrower than 4m they were represented in the TUFLOW model using a series of 2d_zshapes with flow constrictions and storage reduction factors feature. The elevation of the drains was extracted from the drainage network and the LiDAR.

3.7 Model Grid Size

The model was constructed with a 4m grid size. This grid size was chosen as it represented a good balance between the degree of accuracy (i.e. ability to model overland flow paths along roads or around buildings) whilst maintaining reasonable model run ("simulation") times. For example, refining the grid size from a 4m grid to a 2m grid will significantly increase the model simulation time.

3.8 Structures

Hydraulically significant structures have been modelled in 1D in the study area. These structures were indentified during the site visits, analysis of the existing Surface Water Maps and from initial model runs.

Initially, a base hydraulic model was simulated without the structures to identify where structures should be included or not represented at all. Based on the output, the hydraulic model was then amended to better represent the key structures (large culverts, road underpasses etc). The key structures that are explicitly modelled in 1D are listed in Table 3-1 below. Details of the structures were taken from the ISIS model developed as part of the EA Middle Roding Flood Risk Mapping Study.

Table 3-1: List of Structures

Structure Name	Location & Brief Description
Loughton Brook - Railway Bridge	Conduit for Loughton Brook under railway
Debden Park High	Access bridge to school.

Structure Name	Location & Brief Description
School Bridge	
Debden Park High School Footbridge	Footbridge to school just downstream of road bridge
LD_1.031Cu	The Boundary Culvert. Culvert at upstream end of model adjacent to property.
LD_2.007	Davenant Foundation School Culvert. Culvert at upstream end of model.
PY_1.022	Pyrles Lane Culvert.
1.013Cu	Colebrook Lane Culvert. Concrete culvert and footbridge.
PY_1.008Ca	Westall Road Culvert. Concrete pipe and asphalt footbridge.
PY_1.003Cu	Willingdale Road Culvert. Concrete culvert, concrete parapet and footbridge.
LB_2760C	Long culvert under shaftesbury
LB_2280C	Long culvert underneath High Road
LB_1215	Railway Bridge. Culvert underneath railway embankment.
2.002 (XS and culvert)	Flood Relief Culvert & Labyrinth Weir. Flood relief culvert designed to accommodate overflow in channel for large events.
BR00.015	Roding Lane, B170 Bridges.
BR00.001U	Railway Bridge.

3.9 Building and Road Representation

In order to determine the influence raised building pads will have within the model, the following approach has been used for the representation of buildings in the models through the coding of the TUFLOW Materials File (*.tmf) file.

- A GIS layer containing the locations of all 'buildings' was created based on the buildings polygons in the OS Mastermap dataset;
- The LiDAR DTM was then interrogated to obtain an average 'bare earth' ground level for each building polygon.
- This average ground level was applied to the building polygons to give them their base elevation in the Tuflow model; and
- The building polygons were then raised 150mm above their average 'bare earth' ground level to create stubby building pads (reflecting an average building threshold level). This ensures that the buildings form an obstruction to flood water and that shallow flows must pass round the buildings (and not flow through them).

A high Manning's n value (n = 0.5) was applied to the buildings to represent the high resistance that buildings have to flow.

The rainfall falling on the buildings has been redirected to the nearest manholes to represent the transfer of water by the building's external drainage system into the drainage network.

All roads (identified using OS MasterMap) were dropped by 125mm such that flow is preferentially routed down the roads.

3.10 Manning's Roughness Values

Roughness values in the floodplain have been defined based on landuse demarcated within the OS MasterMap data provided by the Environment Agency. These were inserted to the model as roughness zones. Each roughness zone has been used to identify land use and assigned a roughness value. Generally, the MasterMap data represented accurately the current landuses.

Table 3-2 below shows the Manning's n roughness values applied to each land use within the floodplain.

Table 3-2: Manning's Roughness

Feature Code	Descriptive Group	Comment	Manning's Roughness
10021	Building		0.5
10053	General Surface	Residential yards	0.04
10054	General Surface	Steps	0.02
10056	General Surface	Grass, parkland	0.05
10057	General Surface	Manmade	0.02
10058	General Surface		0.03
10062	Building	Glasshouse	0.5
10076	Land; Heritage And Antiquities		0.5
10089	Water	Inland	0.045
10093	Landform		0.1
10096	Landform	Dense vegetation, Cliff, Cultivation areas	0.1
10111	Natural Environment (Coniferous/Non-coniferous Trees)	Heavy woodland and forest	0.12
10112	Natural Environment (Coniferous/Non-coniferous Trees)	Scattered	0.075
10113	Natural Environment (Coppice or Oseirs)		0.11
10114	Marsh Reed or Saltmarsh		0.055
10115	Scrub		0.07
10119	Roads Tracks And Paths	Steps, manmade	0.015
10123	Roads Tracks And Paths	Tarmac or dirt tracks, manmade	0.035
10167	Rail	Manmade	0.025
10168	Rail	Natural	0.05
10172	Roads Tracks And Paths	Tarmac	0.017
10183	Roads Tracks And Paths (Roadside)	Pavement	0.03

10185	Structure	Roadside structure	0.04
10187	Structure	Generally on top of buildings	0.5
10193	Structure	Pylon	0.04
10203	Water	Foreshore	0.04
10210	Water	Tidal water	0.035
10217	Land (unclassified)	Industrial Yards, Car parks	0.035

3.11 Infiltration Losses

Infiltration of rainfall into the ground has been applied in the model using the Green-Ampt method so that infiltration losses are applied to permeable surfaces based on the underlying soil textural class. TUFLOW uses the hydraulic properties (hydraulic conductivity, suction and porosity) corresponding to each textural class, as well as the initial moisture content, to vary the rate of infiltration over time. The entirety of the model extent is assumed to be unsaturated at the start of the simulation.

A 2d_soil layer was created to represent the soils present in the study area based on the Soilscapes Viewer from Cranfield University's National Soil Resources Institute (NSRI), supported by Defra. Polygons have been digitised to represent the different soil types in the study area. These polygons were then allocated a unique code according to textural class. The soil textural classes and corresponding TUFLOW codes, as defined in the TUFLOW manual.

An impermeable layer has been defined in the model, which included roads and buildings. A Soil Type number of ‘99’ has been applied to this layer and a value of NONE has been applied. This mean no water is infiltrated on the road and buildings.

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4. Key Assumptions - Overview

- The model extent is assumed to be appropriately sized to capture all relevant flow paths through the key areas of interest.
- The grid size that has been used is assumed to sufficiently to represent the flow paths along the river and between the buildings.
- The catchment is assumed to be unsaturated at the start of the model run.
- Rainfall falling onto buildings has been assumed to convey directly into the drainage system.
- The road is assumed to be the main flow path and therefore the level of the roads has been reduced by 125mm.
- Buildings are assumed to have a floor level of 0.15m above the average DTM height and have been raised in the modelling.
- It has been assumed that flood waters can flow through the buildings above the finished floor level threshold.
- Infiltration has been represented using Green-Ampts method which is hardwired in TUFLOW. It has been assumed that the parameters used in TUFLOW provide a fair representation of U.K. soils.
- It has been assumed that buildings, roads and watercourses are impermeable and therefore no infiltration losses have been applied."

The key assumptions within the model which relate to the drainage network include:

- Foul drainage has not been included in the network. Only storm/surface water drain types are included.
- Only drains that flow away or towards the main areas of interest have been included in the model.
- Where there is missing information in the drainage network appropriate assumption has been made to fill in gaps. These are discussed in detail in the Sewer Network section 3.5 above (i.e. only pipes >=300mm, cover levels from ground model etc).

5. Model Simulation

The hydraulic model was run using TUFLOW build 2013-12-AE-iDP. This represents the latest version of the software at the time of model construction. The model was run on the 64bit version of this build to take advantage of the faster simulation times and more advanced handling of larger models.

The model naming convention adopted is detailed below:

LOU_~s~_~e~_xxx

LOU: Loughton
~s~: Scenario
~e~: Event
xxx: Version number

e.g. LOU_OPT_0100R_3HR_015 denotes the model run for the Option Scenario for a 100 year return period storm event of 3 hour duration, for version 15.

5.1 Simulation Time

All design events for the Loughton model were simulated for 8 hours. The simulation time was established by trial and error method as follows:

The model results for the final few time steps were checked to determine if water depths in the floodplain were still increasing significantly, and whether new flow paths were forming or existing flow paths still propagating. If either of these conditions were found to exist, the simulation time was extended for a further hour after which the checks were repeated until none of the conditions were satisfied. The 8 hour duration was found to be suitable for the model using this assessment method.

5.2 Time step

The model was simulated with a 1 second time step in the 2D domain and 0.5 seconds time step for the 1D domain. The chosen time steps were deemed suitable for the model grid size and were shown to produce stable model results.

6. Model Stability

Assessing the stability of a model is a critical step in understanding the robustness of a model and its ability to simulate a flood event accurately. Stability in a TUFLOW model is assessed by examining the cumulative error (or mass balance) of the model as well as the warnings outputted by the model during the simulation. Figures 6-1 shows the cumulative error of the models is within the recommended range of throughout the simulation for all return periods.

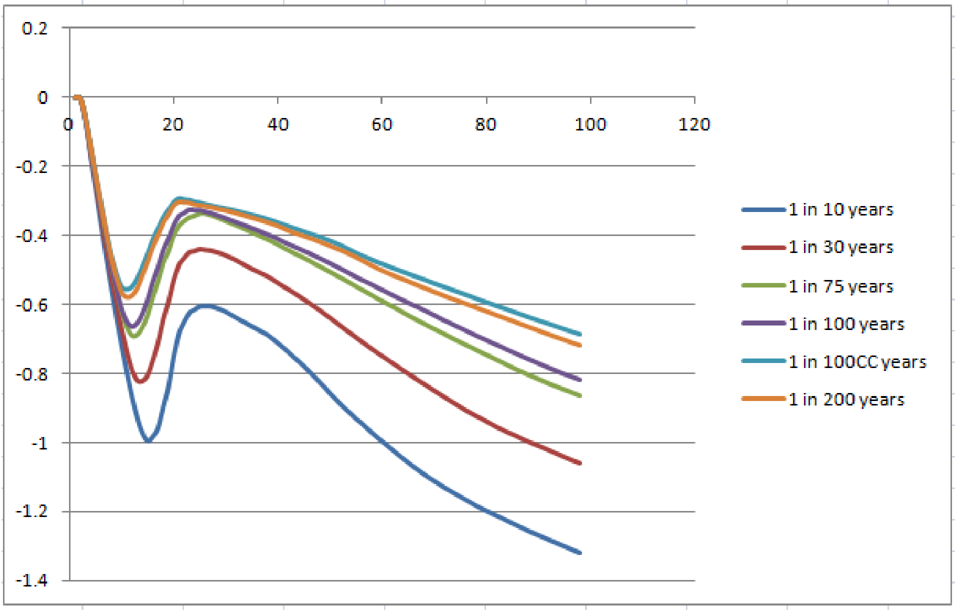

Figure 6-1: Mass Balance

7. Conclusions and Recommendations

Recommendations for future improvements to the model include (but are not limited to) the following:

- Improved data for the 1D network: include smaller pipes that have currently been removed.
- More detailed study into soil textural classes and the associated infiltration rates for UK soils. There is uncertainty in the soil classification and associated infiltration rates due to the broadscale nature of the data source;
- Inclusion of survey data for more structures;
- Reduction in model grid size in key areas of risk; and
- The use of better quality or more up to date topographic information particularly in areas of recent development.

Although the recommendations above would be beneficial to the model’s representation of 1D-2D flows within the study area they are unlikely to provide the significant changes in the model results.

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