



South Essex Surface Water Management Plan **Pluvial Modelling Report**

Final
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Prepared for



Revision Schedule

Surface Water Management Plan - Phase II August 2011

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1 Introduction

1.1 Background

URS Scott Wilson has been commissioned to prepare a Surface Water Management Plan (SWMP) for South Essex, which covers the administrative areas of Basildon Borough Council (BC), Castle Point Borough Council and Rochford District Council (DC). URS Scott Wilson completed Phase 1 of the SWMP in January 2011. Phase 2 – Risk Assessment was commenced in February 2011, and includes pluvial hydraulic modelling to identify areas at risk of surface water flooding and provide preliminary information for Phase 3 - Options.

This report presents the technical methodology for the Phase 2 pluvial modelling. The results from the modelling exercise are presented and discussed within the SWMP final report.

1.2 Aim

The overall aim of the pluvial modelling is to inform the risk assessment from surface water flooding as part of the Phase 2 SWMP.

This report is divided into the following sections:

- Section 2 – Methodology;
- Section 3 – Model Outputs and Results;
- Section 4 – Model Sensitivity; and
- Section 5 – Conclusions.

2 Methodology

The following section describes the methodology applied as part of the direct rainfall pluvial modelling, which has been undertaken to understand the risk from surface water flooding across South Essex.

2.1 Data

Table 1 presents the data used as part of the pluvial modelling.

Table 1: Data collected for South Essex pluvial modelling

Data	Source	Utilisation
LiDAR	Environment Agency	Base topography of model
SAR		Further topographical data for model
OS mapping	Basildon BC, Castle Point BC and Rochford DC	Delineating roughness and rainfall surfaces
Flood Estimation Handbook	URS Scott Wilson	Rainfall Profiles
Authority boundaries	Basildon BC, Castle Point BC and Rochford DC	Delineating model boundaries
Basildon Washlands	Basildon BC	Delineating bank full level
Watercourse GIS data	Environment Agency, Basildon BC, Castle Point BC and Rochford DC	Delineating bank full level
Sewer networks	Anglian Water	Delineating CDAs
Fluvial / tidal flood zones	Environment Agency	Delineating CDAs
Critical Infrastructure		Delineating CDAs

2.2 General Assumptions

The pluvial modelling for South Essex has been based upon the following assumptions:

- All watercourses and washlands were assumed to be at bank full capacity for each entire pluvial model simulation. This was undertaken to represent a conservative approach which was intended to allow for wet antecedent conditions.
- Flooding from fluvial sources does not occur at the same time as surface water flooding.
- Minor obstructions upon flood flow pathways, such as walls or fences, have not been considered.
- Variation of roughness associated with land use i.e. roads, grass, railways, has been considered, but the variation of roughness with water depth has not.
- As agreed with Anglian Water, an infiltration rate of 11 mm/hr is applied across the study area to represent a simplified yet pragmatic approach to account for general losses associated with the sewer network. The impact of sewers was not included in the hydraulic model in any other way.
- Drainage of surface water into the sea or estuarine areas has not been considered. This assumes a tide locking scenario. The impact of pumps, designed to drain Canvey Island have also not been considered. This was undertaken for simplicity, but represents a conservative approach, for example if the pumps were to fail.

2.3 Rainfall Profiles

Rainfall profiles (hyetographs) were created for the 3.3% (1 in 30 year), 1.3% (1 in 75 year), 1% (1 in 100 year) and 0.5% (1 in 200 year) annual exceedance probability (AEP) events. These were created by importing catchment descriptors and storm durations into the Flood Estimation Handbook (FEH) boundary unit within ISIS software. The rainfall profile provides the rainfall intensity (in mm/hr) throughout the storm duration. The 1% AEP event (1 in 100 year) profile was increased by 30% to account for the predicted impact of climate change over the next 100 years, as required by current policy (Planning Policy Statement 25 (PPS25): Development and Flood Risk). The summer profile (rather than a winter profile) was deemed to be the worst-case scenario for these largely urbanised catchments, because it produces a shorter, more intense storm event which typically results in more significant surface water flooding.

An important aspect of estimating a rainfall profile is the critical storm duration. In order to ensure that the worst case scenario is assessed and that the entire catchment is contributing to surface water runoff, the critical storm duration should be estimated. In this case, three storm durations were analysed in order to determine the optimal duration to adopt for the pluvial modelling; 1 hour, 3 hour and 6 hour.

The results of this assessment are illustrated below in two examples.

Figure 1 illustrates flood depths identified at Noak Bridge. Figure 2 illustrates the corresponding flood depths across the floodplain in section (shown by the pink arrow on Figure 1), for the 1 hour, 3 hour and 6 hour storm duration events.

Figure 3 and Figure 4 provide the same information but for a site in Billericay.

Figure 1: Flood depth map at Noak Bridge (Basildon BC)

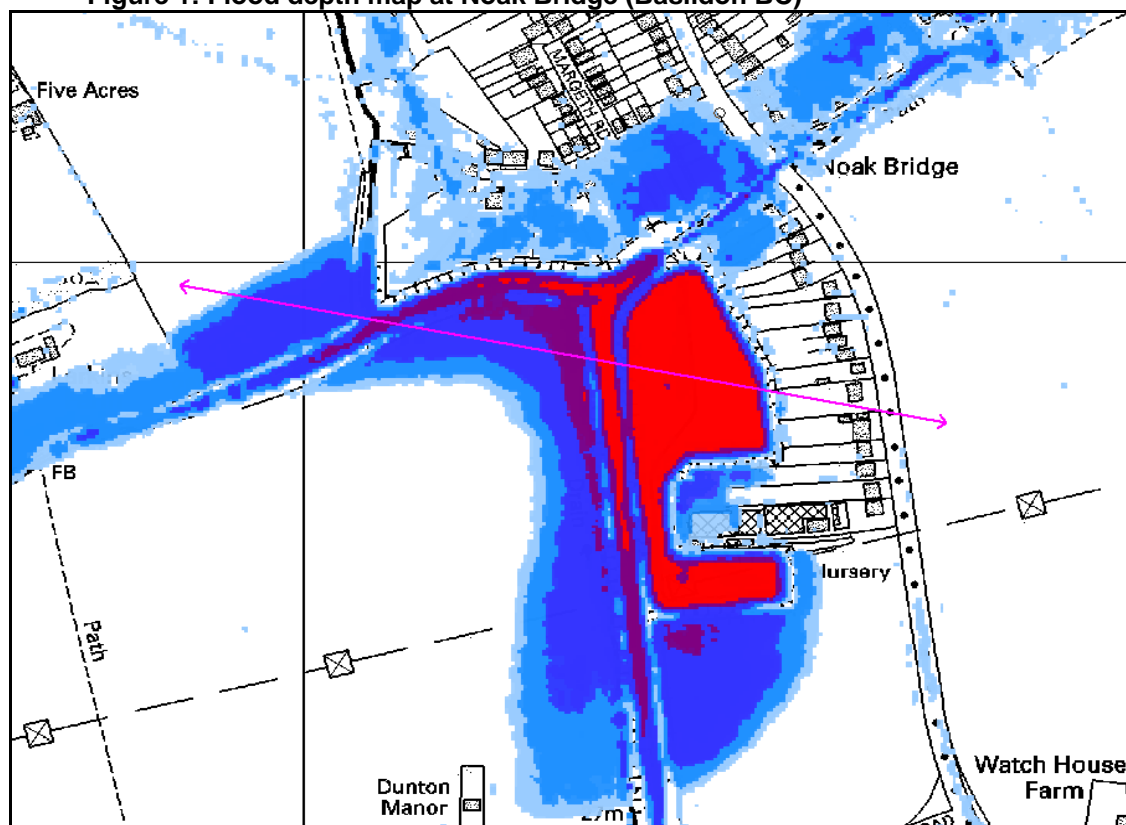


Figure 2: Profile of flood depth across the floodplain at Noak Bridge (Basildon BC)

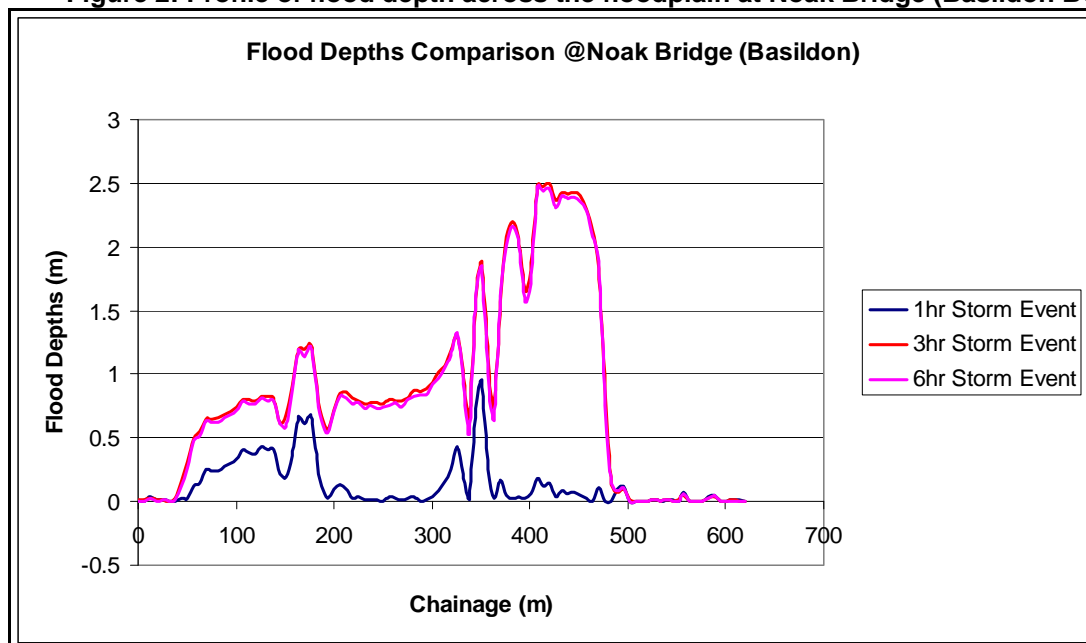


Figure 3: Flood depth map at Great Cowbridge Grange Farm (Billericay)

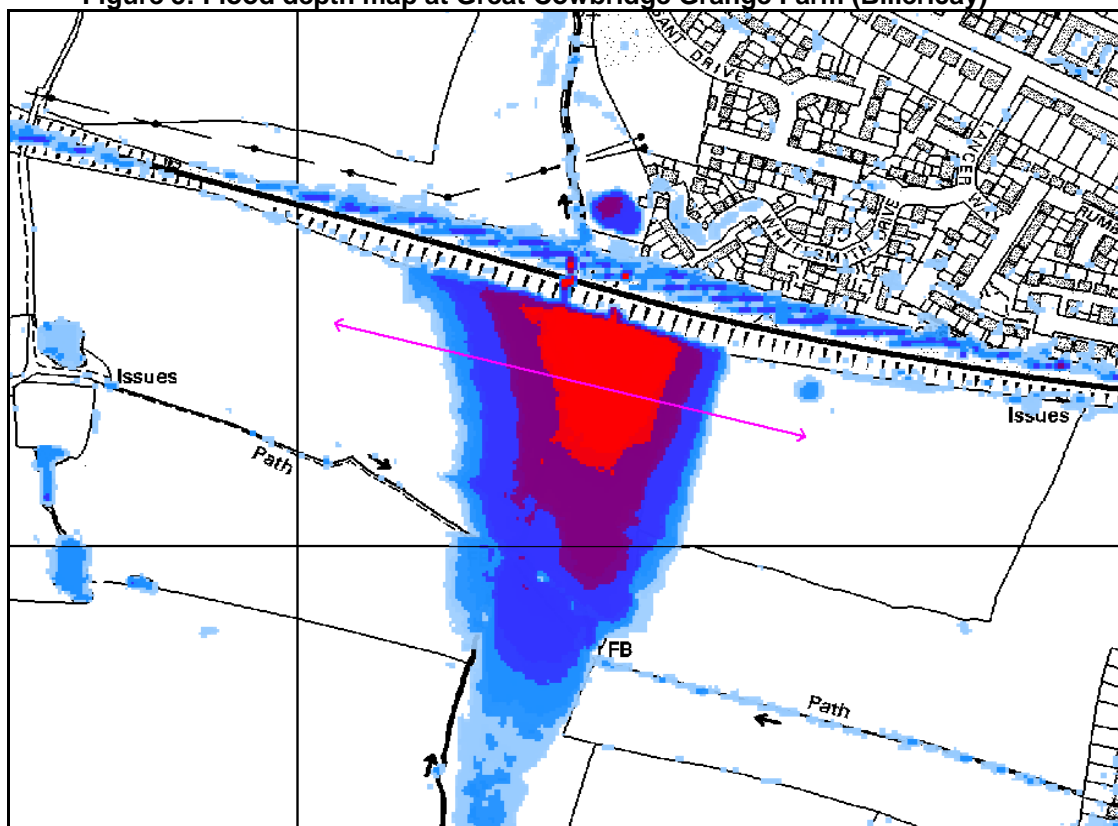
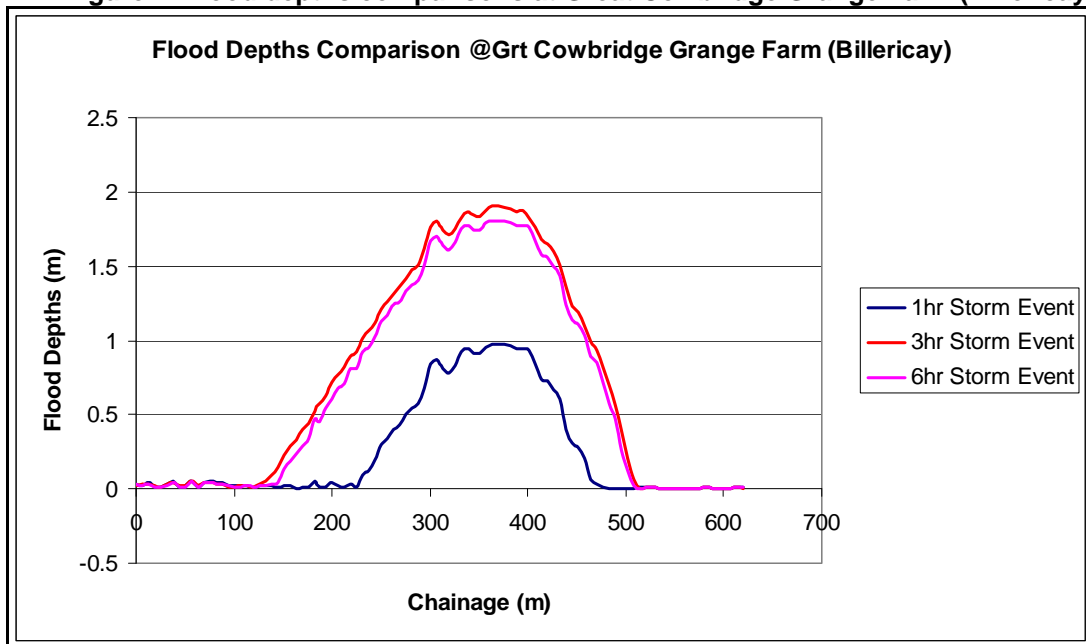
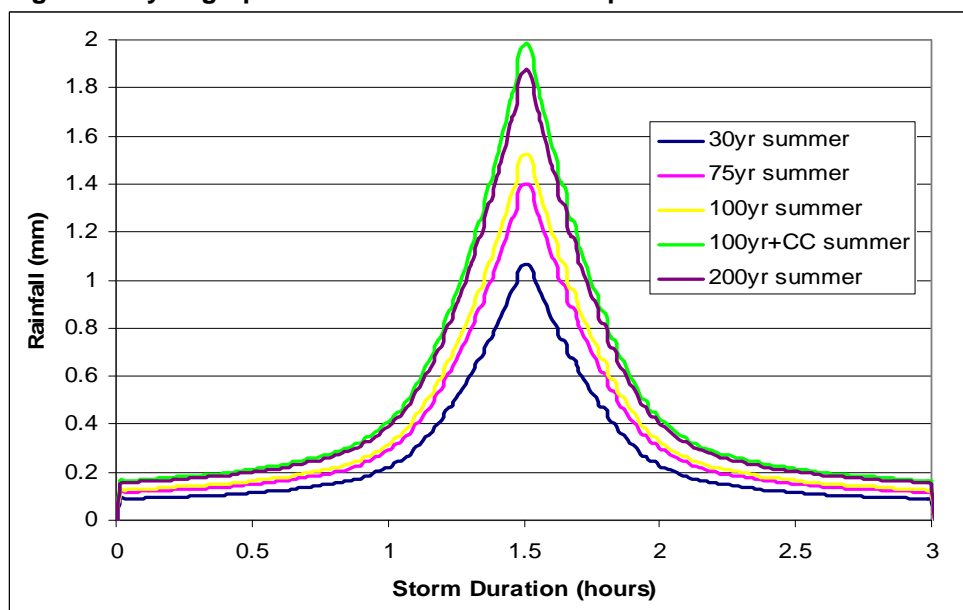


Figure 4: Flood depths comparisons at Great Cowbridge Grange Farm (Billericay)



The 1 hour storm event recorded the lowest flood depths, as a result of a comparatively small total rainfall volume associated with the short duration. The 3 hour storm event generally recorded similar or higher flood depths to the 6 hour storm event. In order to select an appropriate storm duration, a balance is required between a storm duration that will result in maximum flooding but does not require excessive model run times. Therefore the 3 hour storm event, run for 6 hours, was adopted for the pluvial modelling. An example of the 3 hour hyetographs used in the pluvial modelling is presented in Figure 5.

Figure 5: Hyetographs used in the Castle Point pluvial models



2.4 Model Build

2.4.1 Model Software Selection

In order to understand and analyse the complex nature of the floodplain flow paths and dynamics that influence surface water flooding, sophisticated hydraulic modelling techniques are required. TUFLOW is a 2D hydrodynamic modelling tool that simulates water level variations and flows for depth-averaged unsteady 2D free-surface flows. The resultant model can be used to provide flood depths, velocities and hazard across the entire study area.

The latest version of TUFLOW available at the time of model construction (version 2010-10-AA-w64-iDP) was used in the assessment. It should be noted that running the model with a different TUFLOW model build may generate minor differences in results.

2.4.2 Set Up and Control

To facilitate the review and retrieval of data a number of actions were carried out, these included:

- The use of a standard folder structure;

TUFLOW

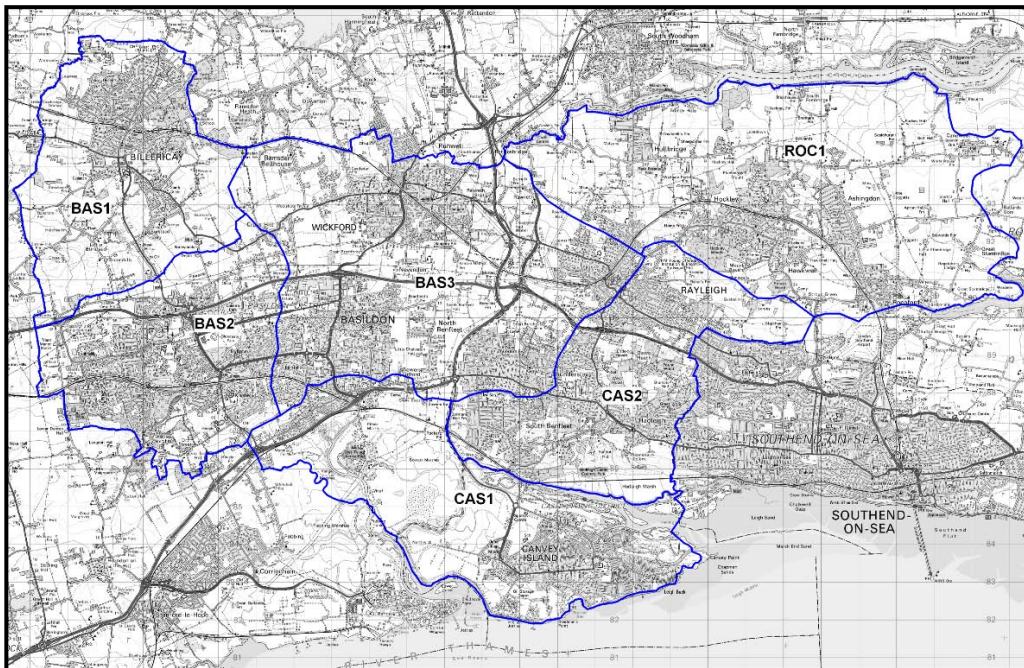
- **bc_dbase** (*Boundary control files .csv*)
 - **Checks** (*Check files produced during model runs*)
 - **Model** (*.tgc, .tbc & .tmf files found here*)
 - **mi** (*all GIS Input Layers in .MIF / .MID / .TAB format*)
 - **QA** (*Model review forms*)
 - **Results** (*Final stored results*)
 - **Runs** (*Tuflow control file .tcf*)
 - **Batch** (*Batch files to start runs .bat*)
 - **Log** (*Tuflow log files .log and message files*)
 - **Model log** (*Excel file with 'run' log, 'built' log, etc*)
- A standardised naming convention that included the model name (e.g. BAS1), initial (I) or design (D) run, scenario or return period (e.g. 100 year), grid size (i.e. 5m), timestep (i.e. 1.25 seconds) and version number e.g. BAS1_I_100yr_5m_1p25s_001.
 - Model logs provide a clear and concise record of model development and decision making.
 - Each model was reviewed by a senior modeller following URS Scott Wilson's standard Quality Assurance protocol, which incorporated all model files used in the model set-up.

2.4.3 Model Coverage

To achieve more efficient run times, the study area was split into six sub-models (BAS1, BAS2, BAS3 covering the administrative area of Basildon BC; CAS1, CAS2 covering the administrative area of Castle Point BC; and ROC1, which covered the western half (i.e. the urban area) of the administrative area of Rochford DC). Model boundaries were based upon the administrative boundaries with an additional 250m buffer zone (or more where necessary). This was undertaken to prevent the impact of boundary effects on model results and to include

the entire contributing catchment. Figure 6 below shows the entire study area applied to the pluvial modelling.

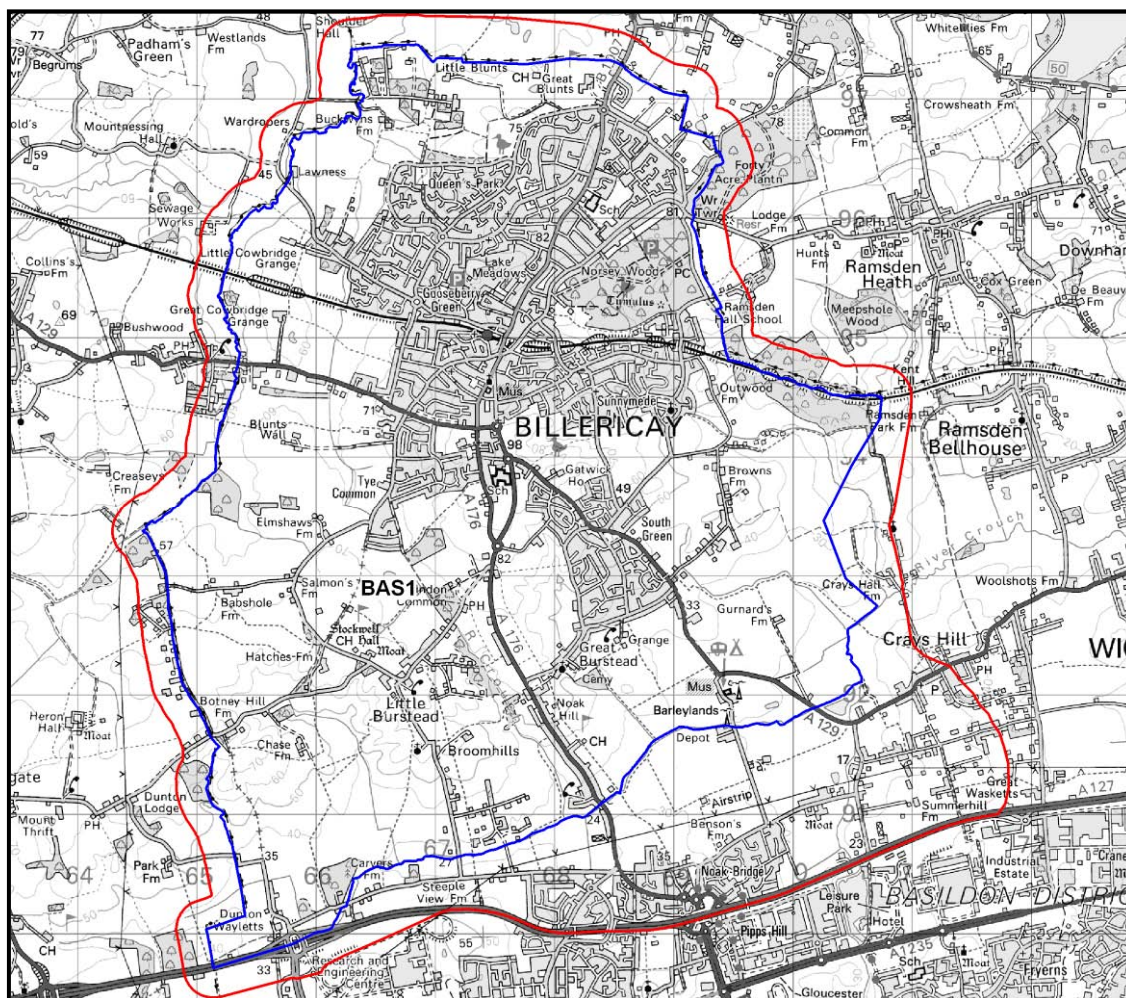
Figure 6: South Essex Study Area



BAS1 Model – Basildon BC

The BAS1 model covers the entire town of Billericay, extending south to include the upper River Crouch catchment. Figure 7 below shows the true model boundary (in blue, which is used for processing results) and the buffered model boundary (in red, which is used for modelling purposes and includes the buffer zone etc, as described above).

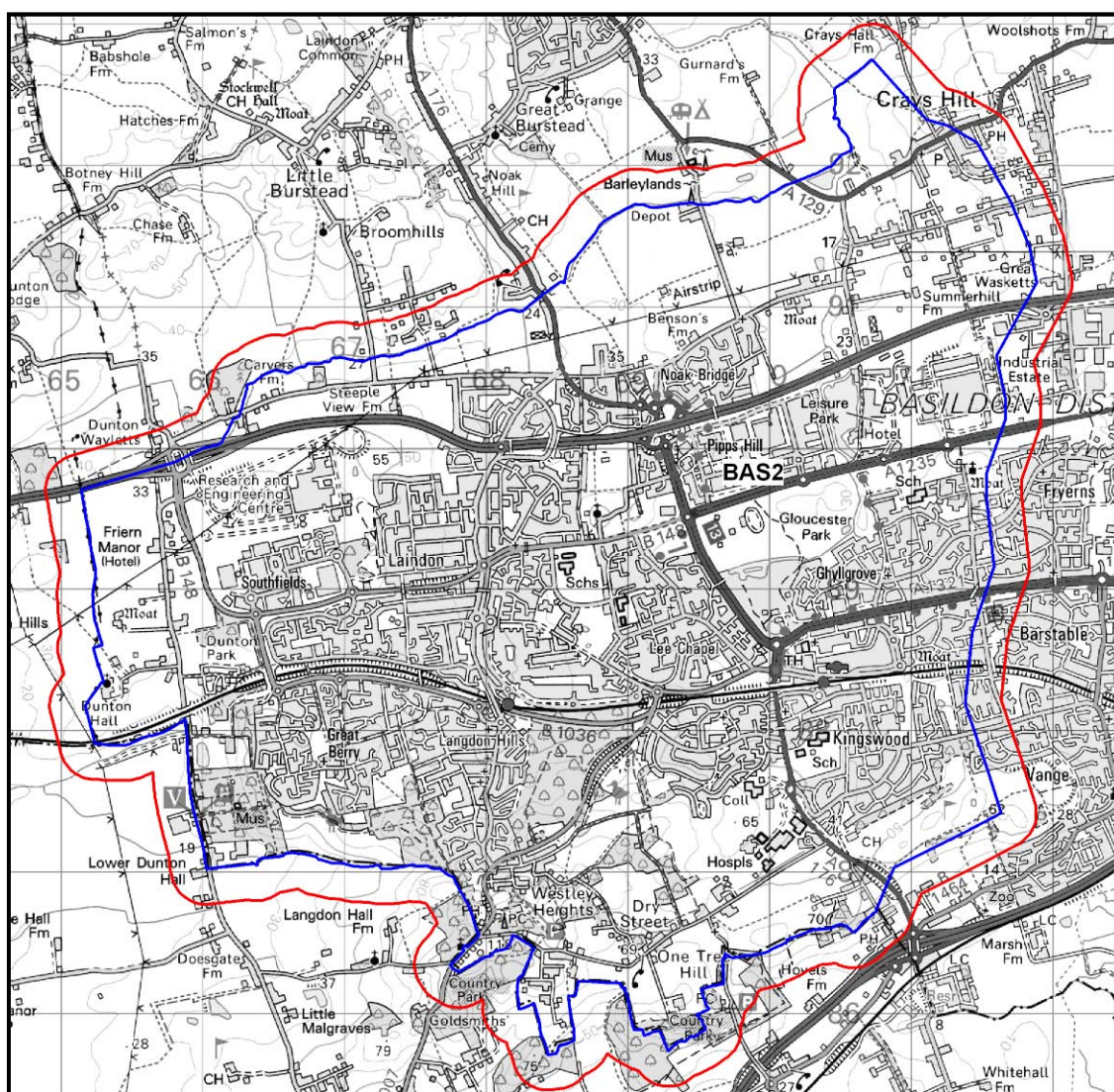
Figure 7: BAS1 model boundary (mainly Billericay)



BAS2 Model – Basildon BC

BAS2 model extends from the River Crouch to the north and covers Basildon, Southfields, Laindon, Noak Bridge, Lee Chapel and Kingswood. Figure 8 shows the true model boundary (in blue, which is used for processing results) and the buffered model boundary (in red, which is used for modelling purposes).

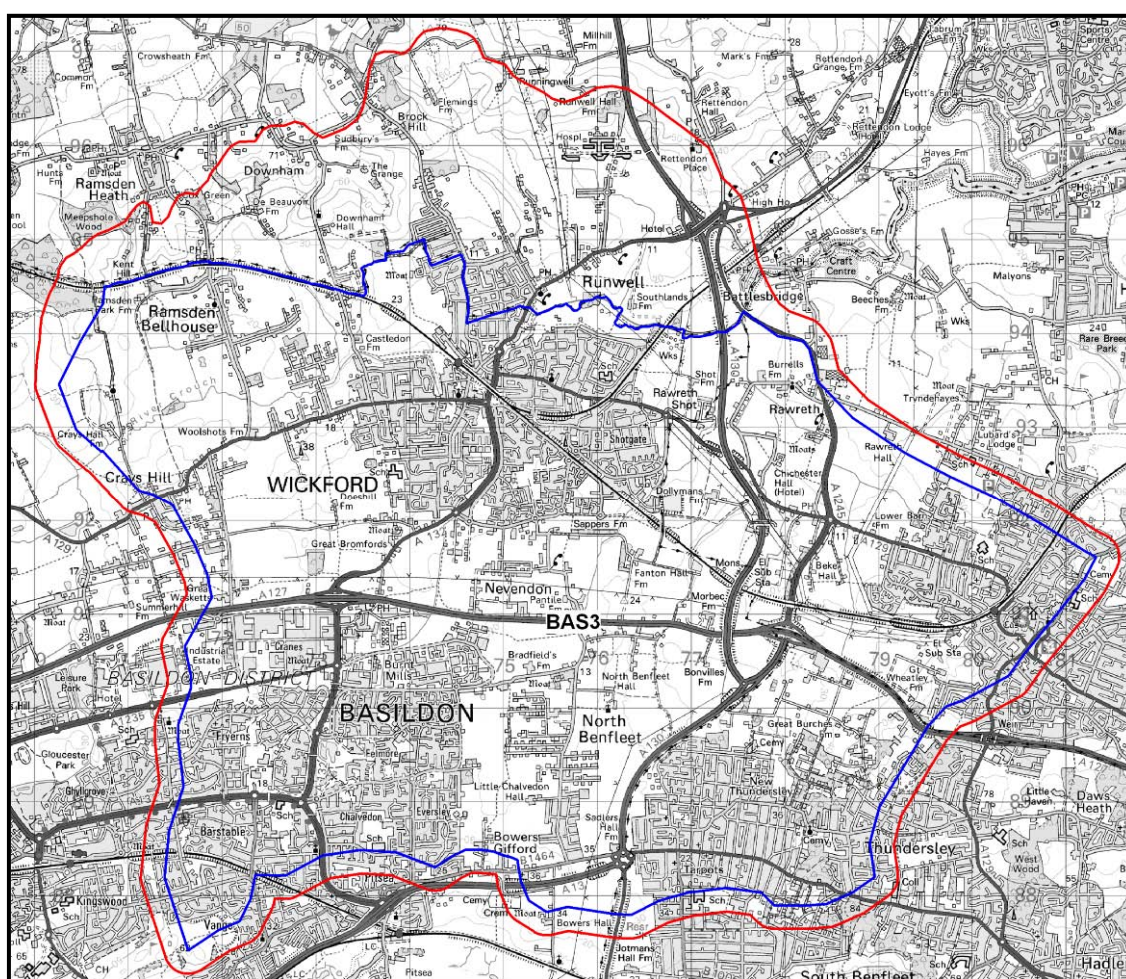
Figure 8: BAS2 model boundary (mainly Basildon)



BAS3 Model – Basildon BC, Rochford DC and Castle Point BC

BAS3 model covers the remainder of Basildon BC (i.e. Barstable, Chalvedon, Eversley, Burnt Mills, Ramsden Bellhouse, North Benfleet and Wickford), extending into Castle Point BC (New Thundersley) and Rochford DC (Rawreth and parts of Rayleigh). Figure 9 shows the true model boundary (in blue, which is used for processing results) and the buffered model boundary (in red, which is used for modelling purposes – extended all the way to South Hunningfield and Runwell in the north to include the whole basin contributing flows towards Basildon BC).

Figure 9: BAS3 model boundary (Basildon BC and parts of Castle Point BC & Rochford DC)

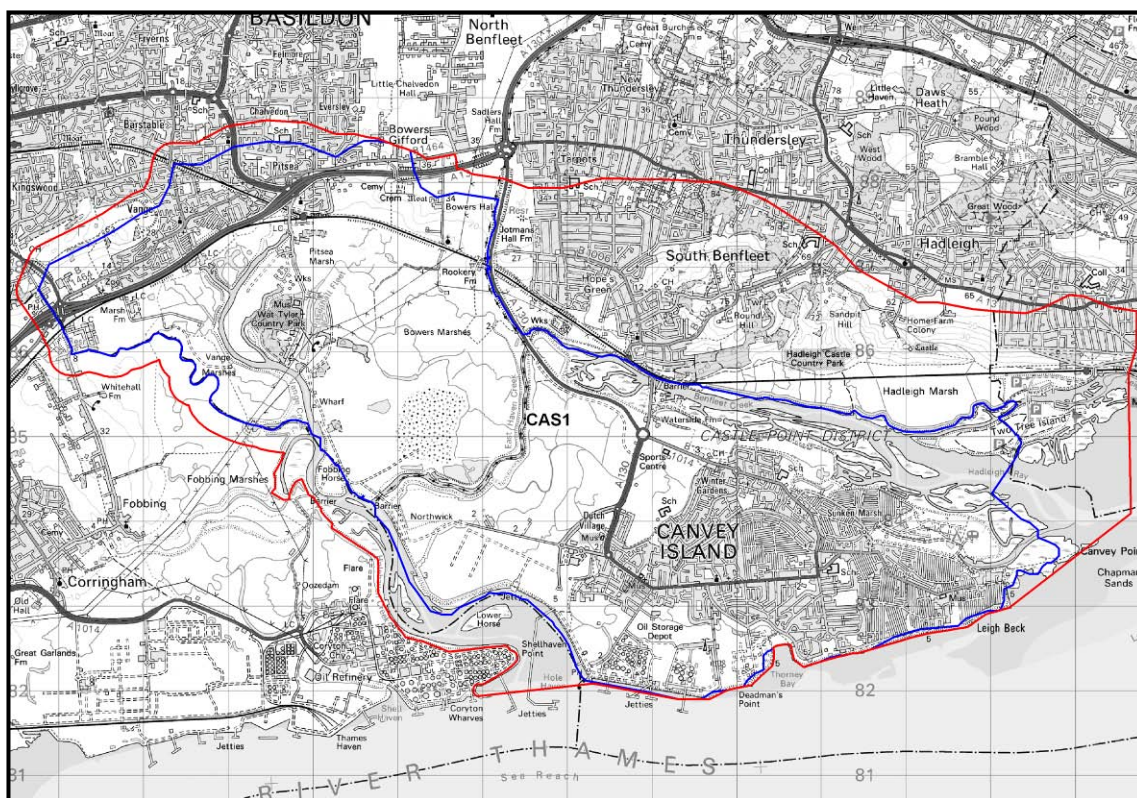


CAS1 Model – Castle Point BC

CAS1 model covers the entire Canvey Island and extends north-west into Basildon BC (Vange and Pitsea).

Figure 10 shows the true model boundary (in blue, which is used for processing results) and the buffered model boundary (in red, which is used for modelling purposes).

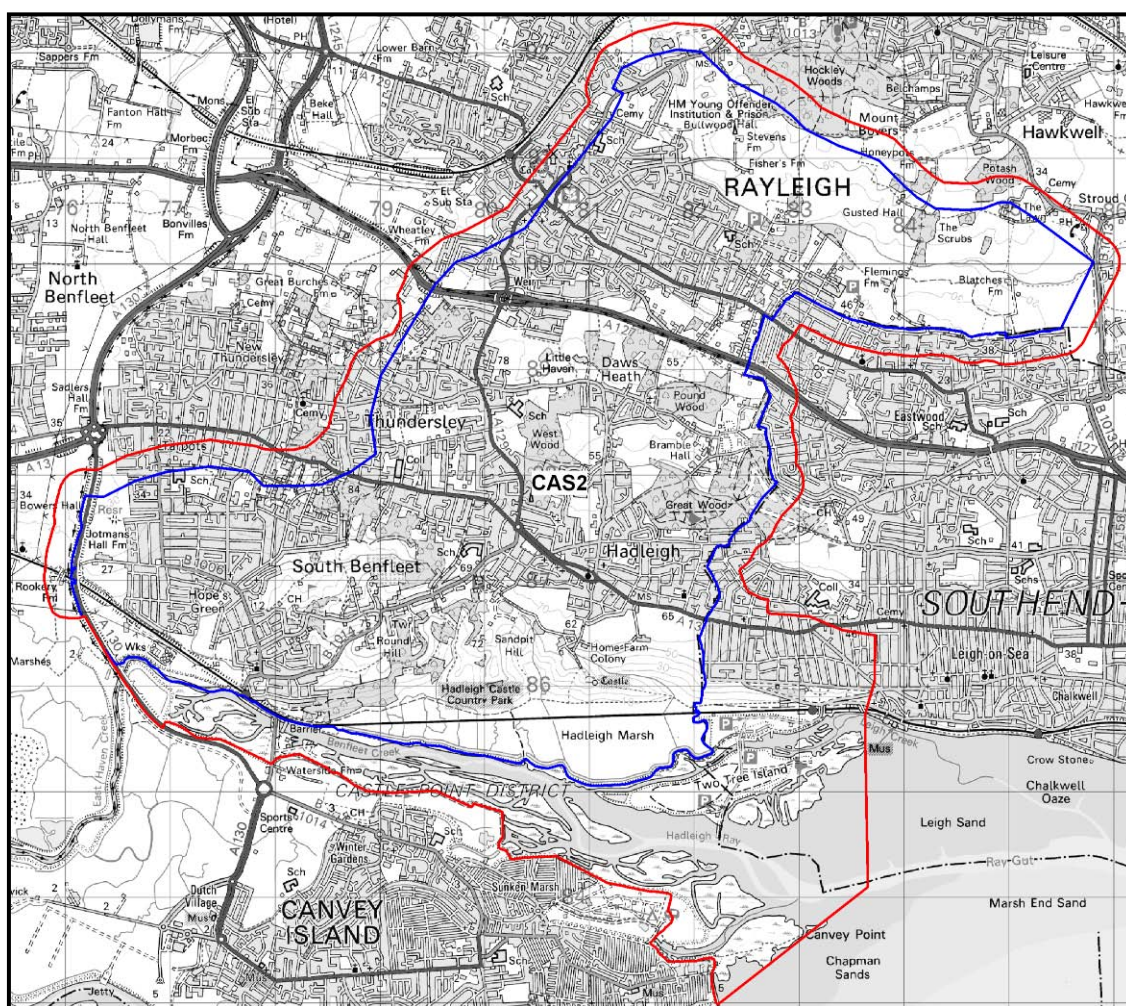
Figure 10: CAS1 model boundary (Canvey Island and parts of Basildon BC)



CAS2 Model – Castle Point BC

CAS2 model covers the mainland part of the administrative area of Castle Point BC (South Benfleet, Hadleigh Marsh and Daws Heath) to the north of Benfleet Creek, and Rayleigh in Rochford DC. Figure 11 shows the true model boundary (in blue, which is used for processing results) and the buffered model boundary (in red, which is used for modelling purposes).

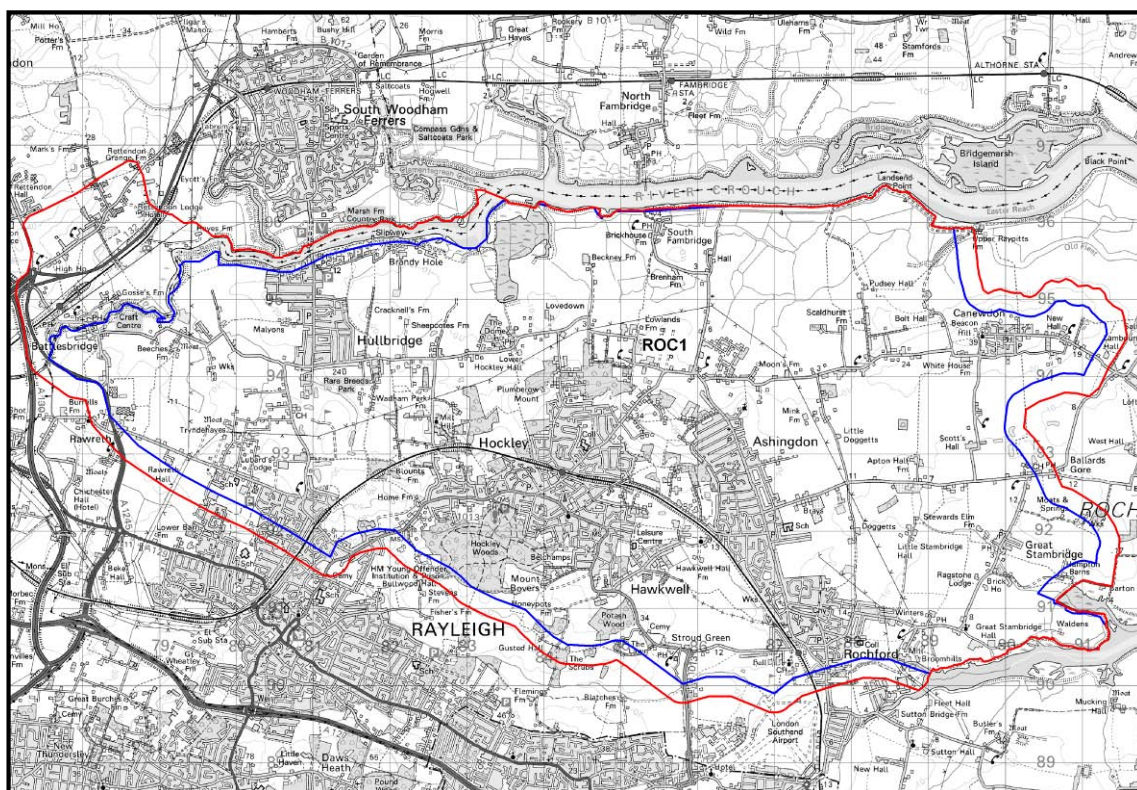
Figure 11: CAS2 model boundary (Castle Point BC & Rayleigh in Rochford DC)



ROC1 Model – Rochford DC

ROC1 model covers the urbanised parts of Rochford DC (i.e. Hockley, Hawkwell, Hullbridge, Rayleigh, Ashingdon, Canewdon and Great Stambridge). Figure 12 shows the true model boundary (in blue, which is used for processing results) and the buffered model boundary (in red, which is used for modelling purposes).

Figure 12: ROC1 model boundary (Rochford except rural western parts)



2.4.4 Model Topography

A Digital Terrain Model (DTM) was created for the entire study area of South Essex, which formed the basis for the pluvial modelling of surface water flow. LiDAR (Light Detection and Ranging) was the most accurate topographical data available and almost covered the entire study area. It was available in two forms, the first was an unfiltered Digital Surface Map (DSM) and the other was a filtered DTM. The DSM is the raw elevation data that has been captured and the DTM has been filtered to exclude vegetation and buildings from this raw data.

Generally filtered LiDAR data is used as the base topography (or DTM) for modelling purposes, in preference to unfiltered data. This applies a bare earth surface, which excludes vegetation and buildings, providing a smoother topographical surface to reduce potential model instabilities. The impact of vegetation and buildings are considered in the modelling methodology, which is discussed below.

Filtered LiDAR data used for this study was provided by the Environment Agency – Geomatics Group. This was available at a 2 m resolution for the majority of the Borough and at 25 cm resolution along the coastal defences. The 25 cm LiDAR grid was re-sized to 2 m resolution

and combined with the 2m grid to form one DTM. There were some areas of missing data; therefore Synthetic Aperture Radar (SAR) data was used to fill up these gaps. MapInfo stamping procedure was used to combine the grids together, with preference given to 25 cm LiDAR DTM, followed by 2m and finally SAR data. Figure 13, Figure 14 and Figure 15 show the topographical data coverage by resolution.

Figure 13: LiDAR coverage - 25cm resolution

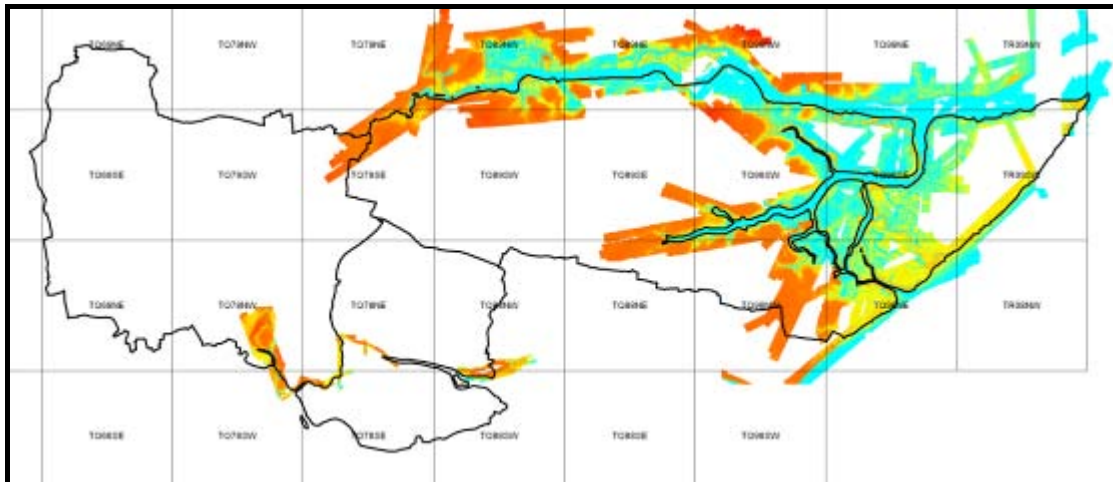


Figure 14: LiDAR coverage – 2m resolution

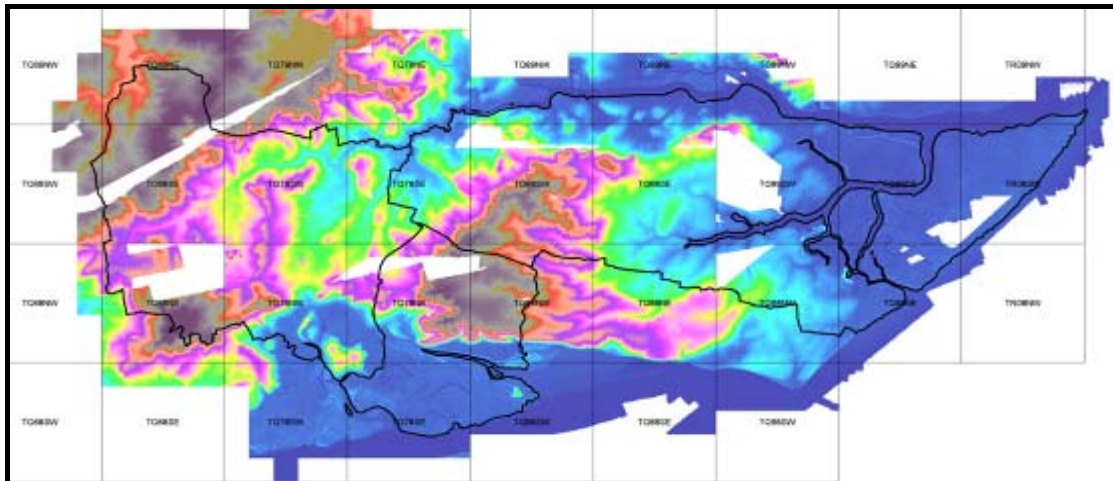
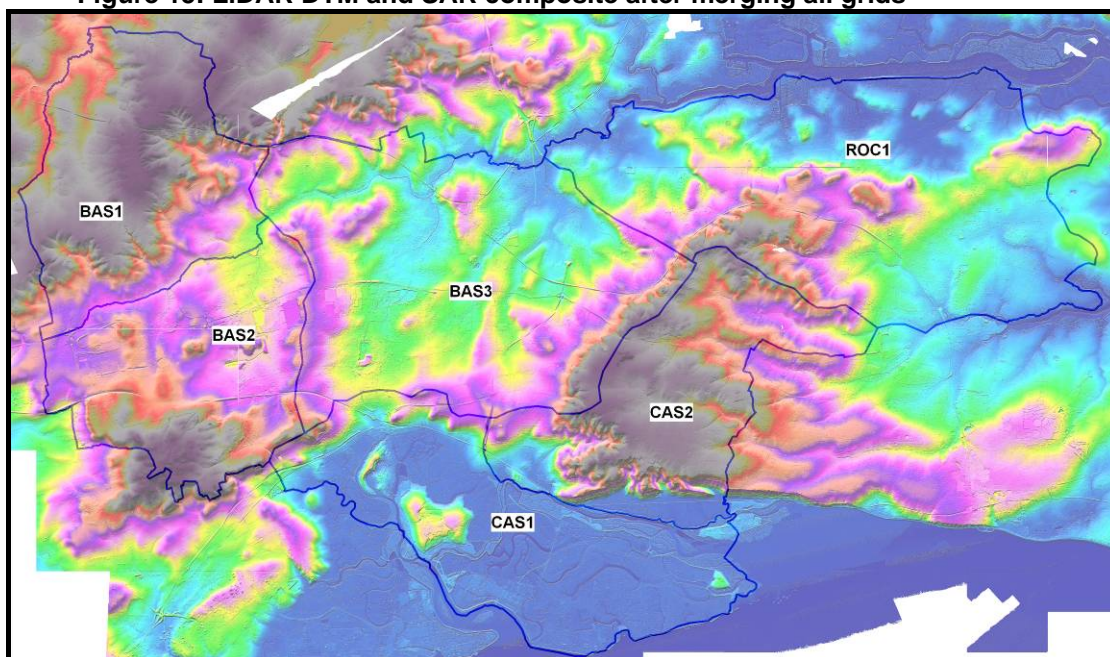


Figure 15: LiDAR DTM and SAR composite after merging all grids



2.4.5 Model Resolution

A 5m cell size was used to represent the study area. This is considered to be of sufficient resolution to capture major flow paths, such as roads and between buildings, in the largely urbanised study area and accurately represent surface water flooding mechanisms.

2.4.6 Model Roughness

Roughness values were specified using Manning's n parameters, by using GIS polygons to define Manning's n values for different land uses (buildings, grass, paved areas, etc). The location of each land use was determined through use of Ordnance Survey (OS) MasterMap. Previous studies¹ and experience were used to select appropriate roughness coefficients for the different land uses within the study area, as shown below in Table 2.

Table 2: Manning's 'n' parameters used in South Essex pluvial modelling

	OS Mastermap	
Buildings	10021	0.030
General Surface (Residential Yards)	10053	0.040
General Surface (Step)	10054	0.025
General Surface (Grass Parkland)	10056	0.030
Buildings (Glasshouse)	10062	0.030
Land – Heritage and Antiques	10076	0.500
Water (Inland)	10089	0.035
Natural Environment (Coniferous/Non Coniferous Trees)	10111	0.100
Roads, Tracks and Paths (Manmade)	10119	0.020
Roads, Tracks and Paths (Dirt Tracks)	10123	0.025
Rail	10167	0.050
Roads, Tracks and Paths (Tarmac)	10172	0.020
Roads, Tracks and Paths (Pavement)	10183	0.020
Structures (Roadside Structure)	10185	0.030
Structures (Generally on top of Buildings)	10187	0.500
Water (Foreshore)	10203	0.040
Water (Tidal)	10210	0.035

¹ Such as, Chow, V.T. (1984) 'Open Channel Hydraulics' McGraw Hill, Singapore

Land (Unclassified)	10217	0.035
Dummy value to everywhere undefined		0.040

2.4.7 Building Footprints

Buildings are likely to have a local impact upon surface water flow paths. An ‘up-stand’ was applied in the DTM to represent the footprint of individual buildings, derived based from the OS MasterMap dataset and set to be 0.1 m above the average ground level within building footprint (as defined by filtered LiDAR data).

2.4.8 Hydraulic Structures

Following an initial run of base hydraulic models (i.e. without structures such as culverts, bridges and flood control devices), a screening exercise of the preliminary outputs was undertaken to identify where structures have either been misrepresented or not represented at all. The effect on surface water flooding formed the primary aspect of the decision process for inclusion of a particular structure.

To remove structures, such as bridges or culverts from the DTM, ‘z lines’ were used in TUFLOW which interpolate river bed levels based upon the elevation upstream and downstream of each structure (i.e. as defined in the DTM). Generally, this was undertaken for short structures, such a culverts or bridges beneath roads or railway embankments. This allowed bridges and culverts to be represented as a gap or gully in a railway or road embankments etc. Without this, surface water generated upstream would accumulate behind the particular feature rather than flow downstream.

The method described above effectively forms a gully in the DTM. This is acceptable to represent short culverts in raised embankments etc, but where long culverts exist through industrial areas or housing estates etc, the representation of the culvert flow path as an elongated open gully is considered to be poor. Generally, the flow path associated with these features has been ignored. However, all known culverts were investigated in terms of the likely impact upon the surface water flood risk identified through pluvial modelling and the impact was not considered to be significant. As part of more detailed modelling the use of 1D structures should be considered, where necessary.

2.4.9 Boundary Conditions

Rainfall boundaries were applied based upon a rainfall analysis undertaken as described in Section 2.3. TUFLOW allows direct rainfall to be applied to an area covered by a GIS polygon (2d_rf), which can then be linked via a command in TUFLOW to a look-up spreadsheet which contains the relevant rainfall hyetograph.

A normal depth downstream boundary was applied to all models. This prevents surface water from ponding at the model edge through glass-walling, which may in turn cause artificial accumulation of floodwater. In addition to the downstream boundary, all models were buffered at least 250 m away from the true model boundary to provide further mitigation.

2.4.10 Cross-Boundary Contributions

In the case of model BAS3 and ROC1, the area contributing to surface water flooding is potentially extended by the wider river catchment area located upstream of the model boundary.

The headwaters of the River Crouch are located to the south and east of Billericay, which is located in model BAS1. The River Crouch subsequently flows through model BAS3 before

discharging into the tidal reach located within model ROC1. Surface water generated upstream, in model BAS1, will potentially contribute to flooding in model BAS3. Flow within the River Crouch was recorded from model BAS1 (using a 'po line') and peaked at approximately 2.4 hours in each model run (see Section 2.4.12). The hydrographs were subsequently applied to model BAS3 using a (QT) boundary condition.

As described above, model ROC1 also receives flow via the River Crouch. However, in model ROC1 the River Crouch is tidal and forms a wide estuarine channel. The catchment upstream is relatively large and the hydrograph recorded (using a 'po line') had not reached its peak after the 6 hour model simulation. The purpose of the surface water modelling was to investigate short duration high intensity rainfall events, which lead to surface water, rather than fluvial flooding. Therefore, this inflow was excluded from the ROC1 model because it was not considered to impact surface water flooding. Furthermore, the recipient river reach is a large tidal feature with large raised coastal defences on either bank, which are very unlikely to become overtopped by the flows recorded.

The River Roach also flows into model ROC1 from model CAS2, upstream of Rochford. The hydrographs from model CAS2 were recorded (using a 'po line') from each model run, and peak flows occurred between 3 and 3.5 hours. Flow within the River Roach at the boundary of model ROC1 was applied as a (QT) boundary condition.

2.4.11 Run Parameters

Hydraulic modelling was undertaken using 2-D hydraulic modelling software TUFLOW (version 2010-10-AA-w64-iDP). The models simulated a 3 hour storm event for six hours with the peak rainfall occurring at around 1.5 hours into the storm (Section 2.3). A time step of 1.25 seconds was used in line with the TUFLOW recommendation².

2.4.12 Model Runs

The six models were run for the following scenarios:

- 3.3% (1 in 30 year) annual probability scenario;
- 1.3% (1 in 75 year) annual probability scenario;
- 1% (1 in 100 year) annual probability scenario;
- 1% (1 in 100 year) annual probability scenario including the effects of climate change; and
- 0.5% (1 in 200 year) annual probability scenario.

2.4.13 Post Processing

TUFLOW outputs data in a format which can be exported into GIS. As part of the South Essex pluvial modelling a series of ASCII grids and MapInfo TAB files were created for all model runs, which include:

- Depth Grids;
- Velocity Grids; and,
- Hazard Grids.

² TUFLOW User Manual – GIS Based 2D/1D Hydrodynamic Modelling – 2010 (Build 2010-10-AA)

2.4.14 Flood Hazard Mapping

The hydraulic model was also used to assess flood hazard, based on the Flood Hazard Rating defined in DEFRA Flood Risks to People FD2321/Tr1, 2005³. The flood hazard formula was developed to quantify hazard to people, vehicles and property. Flood hazard is classified as low, moderate, significant and extreme based upon a function of velocity and depth:

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

Where:

- d = depth of flooding (m)
- v = velocity of floodwaters (m/s)
- DF = Debris Factor, according to depth

A precautionary approach was adopted in line with FD2321; 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.

The maximum hazard rating value for each point in the model was then converted to a flood hazard rating category (Table 3). The outputs produced represent the maximum hazard rating at any given time throughout the simulation.

Table 3: Derivation of Hazard Rating Category

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 – 2.5	Dangerous for most people – Flood zone with fast flowing water
Extreme	>2.5	Dangerous for all – Flood zone with deep fast flowing water

2.4.15 Flood Risk to Properties – Property Count

To ascertain the flood risk to properties it was necessary to count the number of buildings within the flood extent. This was carried out in MapInfo using an SQL query of the number of building in the OS MasterMap layer that are within the flood extent from different flood events.

³ Defra/EA (2005) 'Flood Risk to People, FD2321/TR1', HR Wallingford: Wallingford

3 Model Sensitivity

3.1 Introduction

The process of sensitivity testing helps to determine how sensitive a result is to the choice of parameters or assumptions. The process involves calculating an estimate of sensitivity using a range of different scales to determine the resultant variation, if any.

Sensitivity testing undertaken with regards to the affect of critical storm duration was undertaken and discussed in Section 2.3.

The only other sensitivity testing undertaken was with respect to the washlands located through the administrative area of Basildon BC.

3.2 Washlands

As discussed in Section 2.2, all washlands were modelled at bank full level. A sensitivity test was undertaken to determine what impact would be observed if the same event were to occur with all washlands at normal (low) level. The washlands were located within models BAS1, BAS2 and BAS3. Therefore, this sensitivity test was only applied to these models.

The results of the sensitivity test illustrated a relatively varied response and with washlands set at bank full:

- Greater depths of floodwater were observed.
- Largest depths were generally within close proximity to the washland, but dependant upon topography.
- An increase in flood depth was generally observed both up and downstream of the washland. However, a negligible impact was observed with approximately one half of the washlands.
- The impact observed was very specific to the particular washland, with the depth to bank directly influencing the volume of floodwater displacement.
- A cumulative affect was observed where interlinked washlands (i.e. in the same river valley) resulted in greater flood depths. This was evident in model BAS2, where a total of eight washlands were set at bank full on the River Crouch through Basildon.
- The increase in flood depth for a single washland varies from zero to approximately less than 0.1 m. However, the cumulative impact associated in Basildon increased flood depths by up to 0.6 m. This was exacerbated by topography and more general increases in flood depth were approximately 0.2 m.

The modelling assumptions incorporated all washlands to be set at bank full level⁴. It can be concluded from this sensitivity test that this is a conservative approach, which is considered to be appropriate for the strategic nature of the assessment.

⁴ A GIS file was provided by Basildon BC that identified the location of all washlands within their administrative boundary. However, through a desk study, a number of these washlands were not considered to offer a flood storage function and where therefore not set at bank full level and not directly considered as part of the sensitivity test.