Phase 2 - Model Methodology

Final Report

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Revision history

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29/06/2018	Draft Report v1	Charlotte Kemp and Ryan Thomas
11/07/2018	Draft Report v2	Charlotte Kemp and Ryan Thomas
28/08/2018	Final Draft Report v3	Charlotte Kemp and Ryan Thomas
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Contract

This report describes work commissioned by Hertfordshire County Council, by a letter dated 2nd August 2017. Hertfordshire County Council's representatives for the contract was Charlotte Kemp and Ryan Thomas. Cheryl Briars and Alistair Clark of JBA Consulting carried out this work.

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Purpose

This document has been prepared as a Final Report for Hertfordshire County Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

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Carbon footprint

JBA is aiming to reduce its per capita carbon emissions.

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Abbreviations

HCC	Hertfordshire County Council
SWMP	Surface water management plan
TRDC	Three Rivers District Council
WHBC	Welwyn-Hatfield Borough Council
SBC	Stevenage Borough Council
HBC	Hertsmere Borough Council
TW	Thames Water
PLR	Property level resilience
ReFH	Revitalised flood hydrograph
FEH	Flood estimation handbook
RoFSW	Risk of flooding from surface water

1 Introduction

1.1 Modelling methodology

This report outlines the baseline methodology that will be followed for the model builds of the hotspots that are being taken forward from Phase 1 of the Hertfordshire SWMPs. The report follows a structure which firstly summarises the findings from Phase 1 with detail of the survey specifications and scoping, followed by a general schematisation of the models that will be built over Phase 2 and Phase 3 of the project.

1.2 Outcomes from Phase 1

Phase 1 of the SWMP process identified the hotspot areas in each of the four boroughs/districts that would be carried forward as either a modelled hotspot, non-modelled hotspot, or as a hotspot that was not to be taken any further forward.

Modelling is an important part of developing the evidence-base for the risk assessment and options. For the HCC SWMPs, it is an objective that the detailed model developed at hotspot locations will be suitable to update and improve the RoFSW maps. Several aspects were considered when defining the catchment area of the hotspots, including whether it was a small upstream catchment, or whether it contains limited drainage networks which could be used to define the extent of detail in the model. In other instances, a detailed localised model was agreed for some hotspots, nested within a wider model of the natural/urban drainage catchment, such that upstream inflows and downstream boundary conditions could be appropriately represented.

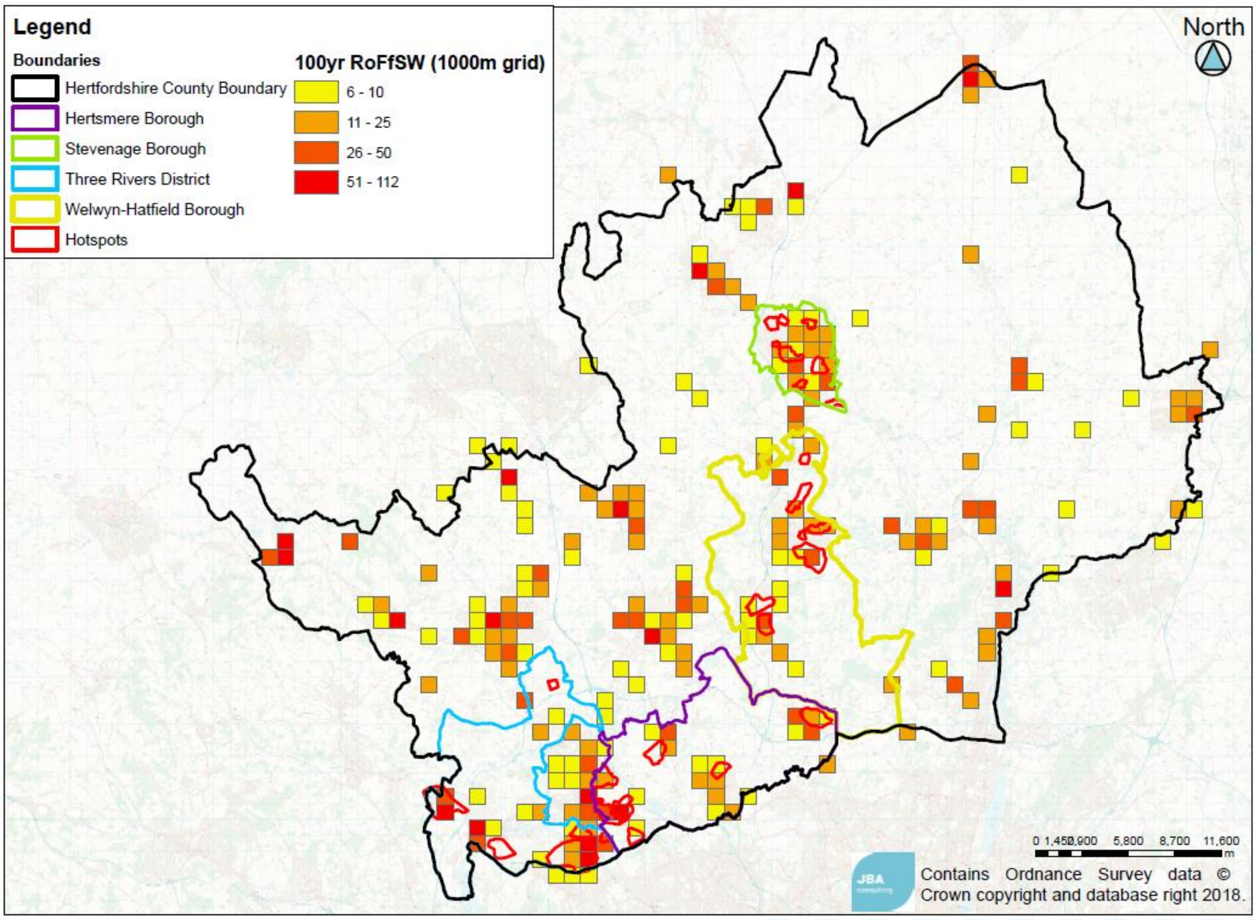
Non-modelled hotspots were chosen not to be modelled as they were deemed to not to benefit from being modelled. Simple calculations will be required for these hotspots, to support the cost-benefit case for various interventions that will be identified. This could involve for example, an assessment of peak flows for a range of return periods to calculate the impact of an opportunistic flood storage intervention.

Appendix A details a table of the hotspots that have either been carried on in Phase 2 as either a modelled, non-modelled or a hotspot that requires no further action for each borough/ district. There are a total of 14 hotspots that have been chosen to be carried forward to the modelling phase across the four districts and 8 non modelled hotspots which will require further investigation into the flood evidence database, such as by additional site investigation or small scale hydrological studies, or resilience measures can be resolved using property level protection measures (PLR). The modelled hotspots have been scaled into large, medium or small. The scaling has been based on a combination of the detail that is required to go into the model as per the complexity of the surface water sewer network and flood mechanisms that exist in the hotspot, such as the presence of watercourses and weirs, as well as the general area that the hotspot covers, based on ensuring the catchment draining to the area is covered based on the topographic boundary.

1.3 Flood risk metric analysis

Flood risk metric analysis of the National Receptor Database (NRD) and the risk of flooding from surface water map (RoFfSW) confirmed the location of the hotspots were sensible against the mapped surface water risk exposed to them under the 1 in 30, 100 and 1000-year return periods. Figure 1-1 shows the hotspots against the risk under the 100-year return period. A 1000m square grid was used to display the results of RoFfSW against a ranking system based on the number of properties that would be at risk per 1000m. The hotspot locations coincide with the hotspots that were identified under the 1 in 30, 1 in 100 and 1 in 1000-year return periods.

Figure 1-1: RoFfSW mapping property count flood risk results



2 Survey

2.1 Survey specification

Survey of manholes, culverts and open channel cross sections was commissioned for the modelled hotspots in February 2018.

Manhole surveys targeted areas where there was missing sewer data or the sewer network required validation checking. In addition, manholes were identified on culverted watercourses, which may interact with the public surface water sewer network or combined sewer network via Combined Sewer Overflows (CSOs).

Cross-section surveys were commissioned for open channel watercourses in the hotspot areas and also included major structures such as bridges, weirs and culvert inlets.

The survey work was undertaken by Precision Point Surveys and Dene-Tech Services Ltd and provided to JBA Consulting in May 2018.

2.2 Site visit

HCC, JBA and Precision Point surveyors attended a site visit walk over of survey points in three areas where cross sections in HBC3, TRDC1 and TRDC2 needed additional clarification and scoping out, particularly where there was uncertainty over access to the channel due to densely wooded areas, and whether additional survey needed to be picked up that existed outside the hotspot boundary in order to gain a better representation of the hydraulics. The site visit was conducted on 29/03/2018 and scoped out a few additional cross section requirements that were agreed with the survey contractors and HCC.

After visiting TRDC1 and assessing the interactions between the various channels within the hotspot, it was evident that this hotspot needed to be treated as two smaller hotspots to better assess the complex interactions in the area between the surface water sewer network, connection with the watercourses, culverts and trash screens that were identified, along with the culvert and trash screen by the railway in Eastbury owned by TFL. As a result, the west of the hotspot covering the area of Eastbury was renamed as TRDC2a, whilst the area to the east of Sandy Lane was renamed as TRDC2b.

2.3 Additional data requirements

Additional threshold surveys of properties may be required at a later stage of the modelling process, to calibrate the modelling results.

3 General schematisation

This section outlines the general schematisation that will be followed for the model builds for the 14 modelled hotspots.

Item	Comments
Software:	InfoWorks ICM v8.0.5 (latest version) InfoWorks ICM was chosen due to its suitability to simulate direct rainfall, sewer networks and river channels simultaneously. The software also uses an irregular mesh to represent the 2d ground surface, which provides greater precision and flexibility than a 2D grid, in particular enabling greater detailing in areas of interest without creating excessive simulation times.

General Schematisation:	The Hertfordshire SWMP models will represent the surface water sewer network, highways drainage, watercourses and topographic catchment. The Thames Water Surface Water sewer network GIS data will be imported into the model networks in Infoworks ICM. No foul network or flows will be represented in the models. Combined sewer overflows will not be represented in the model. In areas where there is no sewer network the flood risk will be represented using 2d flow routing only. The river network will be imported from cross section survey information in the form of ISIS hard bed files. This entails information on the stretch of the watercourse modelled, cross sections including bank information and roughness values of the channel. Structures will be reproduced in InfoWorks ICM. The hydrology of the study area uses sub-catchments in each of the modelled hotspots that will be represented by the buildings that had been identified by the OS Mastermap data. A direct rainfall approach will be applied to the models, this will allow rainfall to be applied directly to the model surface and runoff routed based on topography and surface features such as roads and buildings Rainfall will be derived using FEH13 catchment descriptors. This approach considered an appropriate method to use to represent rainfall within the sub-catchments for each of the four boroughs. A 2D zone representing the surface of the catchment for each hotspot will be generated. The extent of this is based on topographic catchment delineation. A finer mesh size will be used for built up area in each of the modelled hotspots and a coarser mesh will be used elsewhere in the 2D zone. The topographic levels of the 2D domain will be based on a DTM composite of 1m LIDAR data that has been provided by Hertfordshire County Council. This was the best available topographic data at the time of model build. The 2D zone mesh will represent a bare earth scenario. In addition, buildings will be represented by porous polygons. These polygons will limit the through flow and present an obstacle to overland flow routes. Studies have shown that roads can be a significant conveyance route for surface water in an urban environment. To maintain detail in the 2d mesh, roads will be represented as break lines. No amendment will be made to the level of the road as this is generally well represented within the LIDAR. The different surface roughnesses identified will be represented as roughness zones based on OS MasterMap data. The roughness values will be defined using standard values of the different polygons in the mapping data initially and this will then be refined based on aerial imagery as well as photographs that were taken during site visits.

Design Events	The following pluvial design events will be run: 1 in 2 year, 5 year, 20 year, 30 year, 75 year, 100 year, 100 year plus climate change, and 1000 year events. Critical duration analysis will be completed using the 1 in 10, 1 in 30 and 1 in 100 year summer and winter storm events. The following durations will be tested: 30, 60, 120, 180, 240, 360 and 480 minutes.

Rainfall	The ReFH2 Rainfall Generator will be used with both a summer and winter rainfall profile, created directly in ICM, as this method was used in the previous model (Northwood) provided by Thames Water, and this method allows direct use of the catchment descriptors that have been generated with the FEH web service Different catchment descriptors for each borough were extracted for use in each of the hotspots, as described in Table 3-1 and Table 3-2.

Table 3-1: DDF catchment descriptors, C - F

Borough	C	D1	D2	E	F
TRDC	-0.029	0.302	0.35	0.321	2.483
WHBC	-0.029	0.285	0.315	0.321	2.486
HBC	-0.3	0.301	0.334	0.324	2.465
SBC	-0.027	0.287	0.335	0.32	2.468

Table 3-2: DDF catchment descriptors for Area - PROPWET

Borough	Area (km2)	SAAR	BFIHOST	PROPWET
TRDC	382.69	685	0.55	0.29
WHBC	4.94	656	0.513	0.3
HBC	13.9	678	0.348	0.29
SBC	28.9	632	0.669	0.3

Table 3-3: Rainfall Initial Conditions

	Summer	Winter
Antecedent depth (mm)	10	10
Evaporation (mm/day)	3	1
UCWI	50	120
New PR API30 (mm)	2.01	2.88

Climate Change	Environment Agency (February 2017) Climate change allowances for planners 1 provides change factors to account for climate change to rainfall levels. The allowance for climate change used for the epochs are summarised in Table 3-4 based on the recommended national precautionary sensitive range for 2085 to 2115. Table 3-4: Climate change uplift parameters Epoch | Rainfall | River flow Higher | - | 70% Central | 20% | 35% Upper End | 40% | 25%
Rainfall Runoff	A different rainfall runoff value has been used for each of the four district modelled hotspots, based on the SPR Host value that was calculated from the FEH catchment descriptors. For Three Rivers District, 36% will be applied across the modelled domains. In the Hertsmere modelled hotspots, 43% will be used, whilst 31% will be used for Stevenage modelled hotspots and 43% will be used for the Welwyn-Hatfield hotspots. This rainfall runoff value has been used for any area that is not covered by sub-catchments. This assumes that the remainder of the percentage runoff is intercepted by the catchment, based on the permeability of the land.
Coefficients	Standard Manning's n and Colebrook-White roughness coefficients are used to represent hydraulic roughness in the open watercourse and surface and waste water drainage network. The Manning's n roughness values and structure coefficients within the watercourses have been applied. The bank discharge coefficients will be set to 1.1 and the bank modular ratio of watercourses will be set to 0.9. A standard Colebrook-White value of 0.6 for the bottom roughness and 0.6 for the top roughness will be used throughout the storm water network model. Head loss coefficients for conduits added to each of the modelled hotspots will be inferred using the InfoWorks ICM inference tool. Roughness zones will be used across the 2D Zone based on OS Mastermap data. The Manning's n value used for each land cover type is displayed in Table 6-1. Where there are no roughness zones a standard 2D roughness value of 0.060 will be used.

1 Environment Agency (February 2017) Climate change allowances for planners (accessible via https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances)

Model Proving	The Thames Water Model for St Mary's Avenue will be integrated into the model build of TRDC2a. This model has previously been verified and stabilised. Model calibration will be undertaken using existing hydrometric and data, rain gauges and radar rainfall data where available. Historical verification of the models will draw upon records of flooding including Section 19 reports, as well as photographs and videos where available.

Modelling assumptions and limitations	The representation of any complex system by a model requires a number of assumptions to be made. In the case of the one dimensional element of the model it must be assumed that: - GIS data and the network model provided by Thames Water is accurate. Manhole surveys were conducted to provide additional data where details were missing from the existing data and sensibility checks have been undertaken on the sewer data where appropriate. - Geometry of the cross sections and schematisation of the structures remains as per the Precision Point surveys of the various watercourses that were received in May 2018 on which the ISIS hard bed files were incorporated into the model builds. - The units used to represent the hydraulic structures within the model represent the situation accurately - A stable numerical solution can be achieved In terms of the two dimensional element of the model, the assumptions include: - LIDAR is representative of the land surface and no errors have been introduced through the filtering algorithms - ReFH2 design rainfall inflows accurately represent rainfall for a given return period storm event - Where roughness zones have not been implemented, a Manning's n value of 0.06 is representative of overland flows Whilst the accuracy of a hydraulic model depends largely on the accuracy of the hydrological, topographical and structural data, some assumptions and uncertainty can be introduced as part of the modelling process. These could include: - Estimates of model parameters such as roughness, structure coefficients and percentage runoffs are representative - The variant percentage runoff is representative of the natural land surfaces in each of the modelled hotspots that aren't covered by sub-catchments - Gully information was received from Hertfordshire County Council. To model these cover levels were queried from LIDAR level and they were all assumed to be continuous grate type of gully, represented as 2D elements in the model - Decisions made during model proving for example where some data has been inferred or assumed, for

	example, based on neighbouring parts of the network. It should be noted that the models will be built to understand the interaction between rainfall, watercourses and the sewer networks to assess the surface water flood risk to each of the hotspot areas. The models would require additional sensitivity testing before they could be considered suitable for uses other than investigating Hertfordshire's flood risk from surface water in the districts/boroughs of Three Rivers, Welwyn-Hatfield, Hertsmere and Stevenage.
Sensitivity testing	Sensitivity testing will be undertaken as part of this study. The scenarios will include testing the following: Percentage runoff Sediment and roughness in pipes and channels

4 Model operation

Operation	Description
Run purpose	To assess the surface water flood mechanisms in each of the modelled hotspots
Operation and model running instructions	It is important that the correct version of InfoWorks ICM is installed (version 8.0). If running an updated version of ICM the software will prompt the user to allow it to update the models compatibility with the latest version. Note once this is done you cannot revert to running the model with earlier versions. Import the transportable database into InfoWorks ICM. All necessary files to complete reruns of the model and results are contained within these files. Ideally the InfoWorks root directory should be set to"C:\Infoworks_local_root" to maintain continuity of the original project. Open a new run group; select the network; set the run parameters; set the time-varying inputs and hit 'Run Simulations'
Infoworks ICM	
Master database	2017s6531 – Hertfordshire County Council – Hertfordshire SWMPs – Hertfordshire SWMP v1.icmm All model files will be contained within the model database or its equivalent transportable database.
Network	Three Rivers modelled hotspot networks will be labelled as TRDC1, TRDC2a, TRDC2b, TRDC4, TRDC8, TRDC9 Welwyn-Hatfield modelled hotspot networks will be labelled as WHBC3 and WHBC6 Hertsmere modelled hotspot networks will be labelled as HBC3, HBC6 and HBC6 Stevenage modelled hotspot networks will be labelled as SBC1, SBC2, SBC4a, and SBC4b
Network version	TBC
Scenario	Base

Rainfall Events	Various rainfall events will be run for the present day plus the climate change scenarios based on the FEH13 Design Rainfall. These will include the 1 in 2 year, 5 year, 20 year, 30 year, 75 year, 100 year, 100 year plus climate change, and 1000 year events, with simulations for critical durations tested for the 30 minutes, 60 minutes, 120 minutes, 240 minutes and 480 minutes storms as set out above.

5 Modelling approach

5.1 Available data

Item	Comments
Models	For the SWMP hotspot model builds there will be some available data other than the Thames Water surface water sewer network that will be incorporated into the model builds. Exiting Infoworks ICM models: • 2D model of Northwood, "Transfer of Batchworth Lane" completed as part of St Mary's Avenue Phase 2. This will be used for the model build of TRDC2a, that has been provided by Thames Water for use • Rickmansworth hydraulic model developed by Thames Water – provided by Hertfordshire County Council, and will be incorporated into the model builds for TRDC hotspots • Information from S19 reports will also incorporated into the model builds including survey of the Moor Park Stream watercourse and railway culvert that was surveyed as part of the flood investigation

Survey data	Survey of manholes, culverts and open channel cross sections were commissioned for the modelled hotspots in February 2018. Additional threshold survey of properties in areas with records of surface water flooding or low thresholds identified during the week of site visits may also be undertaken in the future to validate the modelling results. Manhole survey was targeted in areas where there was missing sewer network information within the GIS data provided by Thames Water. In addition, manholes were identified on culverted watercourses, which may interact with the public sewer network. Cross-section surveys were commissioned for open channel watercourses in the hotspot areas and also included major structures such as bridges, weirs and culvert inlets. The survey work was undertaken by Precision Point Surveys and Dene-Tech Services Ltd and was delivered in May 2018. A site visit was undertaken whilst the survey work was being carried out in March 2018, to areas where cross sections in hotspot HBC3, TRDC1 and TRDC2 needed additional clarification and scoping out. After visiting TRDC2 and assessing the interactions between the various channels within the hotspot, it was evident that this hotspot needed to be treated as two smaller hotspots to better assess the complex interactions in the area between the surface water sewer network, connection with the watercourses, culverts and trash screens that were identified, along with the culvert and trash screen by the railway in Eastbury owned by TFL. As a result, the west of the hotspot covering the area of Eastbury was renamed as TRDC2a, whilst the area to the east of Sandy Lane was renamed as TRDC2b.
Other Network Data	Hertfordshire County Council provided data to support the project. • Gully locations • Culvert detailed examination reports where available The Environment Agency provided information on additional structures
LIDAR & other Topographic Data	1m filtered LIDAR data (EA Geostore) will be used as it covers the modelled hotspot areas. This data will be used inform the elevation of the land.
Map Data	OS MasterMap and OS Open Data
Gauging station flows / levels	None available.

Gauging station rating curves	None available.

5.2 Data flags

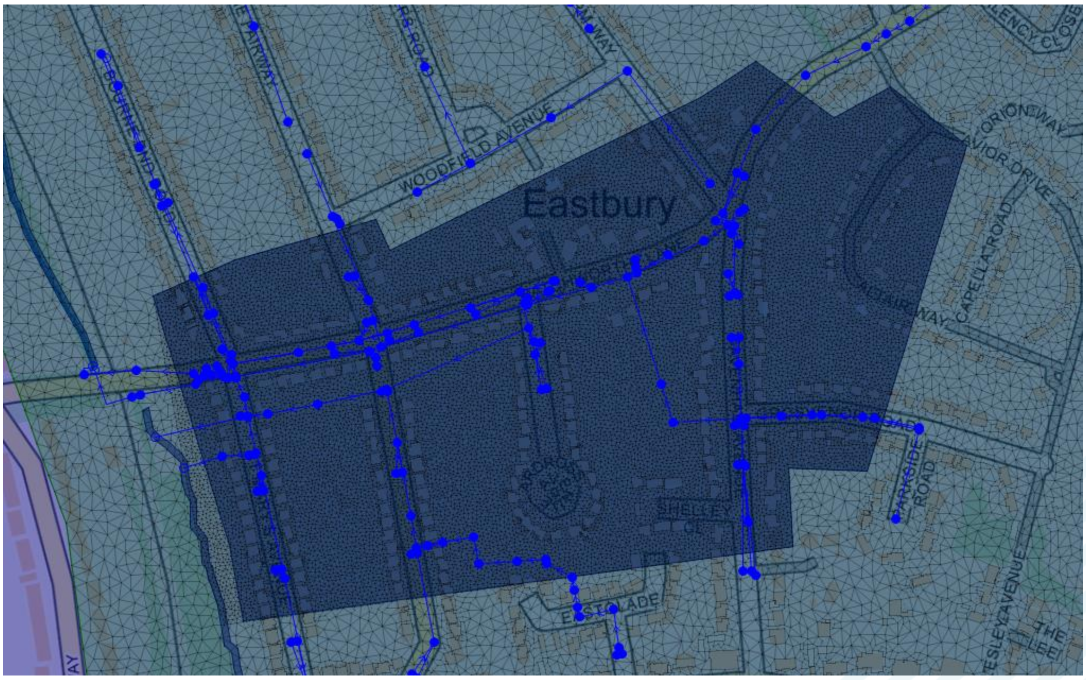
Flag	Description
#A	"Asset Data"
#D	"System Default"
#G	"Data From GeoPlan"
#I	"Model Import"
#S	"System Calculated"
#V	"CSV Import"
AS	"Engineered Assumption
AT	"Attention!!"
DD	"District data"
HCC	"Hertfordshire Data"
IN	"Interpolated value"
SD	"Survey data"
TFL	"TFL"
TW	"Thames Water Model"
TWS	"Thames Water Survey"

6 Model overview

River reaches in the modelled hotspots will use a 1D sim engine to calculate in channel flows. The surface water sewer system will be represented in the model as nodes or outfalls and conduits (pipes). The flood type for manholes will be set to 2D within the 2D zone and any manholes outside of the 2D zone will be set to sealed. Gullies will also be modelled where appropriate and will be represented with a flood type of Inlet 2D.

Figure 6-1 shows an image of the model developed for TRDC which visualises the model build and the elements.

Figure 6-1: Example visualisation of a hotspot model build



Description	Buildings	Roads	Roughness
Land cover	Porous polygons modelled as defined by the OS Mastermap Porosity = 0.05 Height = 100mm above LIDAR ground level	Outline/kerbs as break line	Roughness zones will be based on land use from OS MasterMap

6.1 Overview of fluvial model

Description	Buildings
General Schematisation:	The watercourses in the Hertfordshire SWMP models will either be represented as 1D with embankments if the river reach is a small dry ditch or in a woodland area for example. Alternatively, they will be represented as a river reach that will have a separate mesh zone. The channel cross sections will be truncated at the join with the bank lines within the river reach where they have been linked to the 2D domain. Bank lines will link the channel system to the overland flow environment (2D domain). A modular limit of 0.90 and a coefficient of discharge of 1.10 will be used. These were selected to broadly represent the ability of flow to leave the channels and are based on the recommendations provided within InfoWorks ICM help, as well as through the use of the basic weir equation. The 1D cross-sections have been trimmed to the top of bank which allows more accurate flow, hazard and velocity measurements. Note that not all hotspots have a watercourse in them to be represented in the models.
Upstream Boundaries	Upstream boundaries of the fluvial aspects of the model will be defined when the building of the model has taken place.
Lateral Catchments	Lateral inflow will occur throughout the length of the river models as direct rainfall can flow under gravity into the river network. Point inflows occur at surface water outfalls where rain water channelled by the sewer network is discharged.
Downstream Boundaries	Downstream boundaries will be at outfalls that have been modelled. A normal depth boundary will be used at the edge of the 2d zone to allow surface flows to run off the 2d surface where appropriate. This has been chosen to limit the effect of glass walling along the boundary of the 2D zone
Length of Model (km):	The lengths of the watercourses that will be modelled are yet to be defined.
Other structures:	Several structures will be modelled including bridges, culverts, weirs, pumps, flap valves and orifices.

Labelling/ Numbering System Used:	Labelling of the cross sections have been based on the hotspot name with a number. E.g. TRDC_01_LB for the left bank of a TRDC embankment. Interpolated sections have been labelled as InfoWorks ICM labels them when automatically creating interpolated sections at regular intervals.
Hydraulic roughness values used	Channel roughness in the models will vary along with the culvert roughness. It is expected that this will range between 0.03 and 0.05 for the types of watercourses included in the models.
Amendments to the model	Cross sections that have been surveyed and brought into the model will be cut to bank top and additional changes have been made to the representation of some structures to improve stability.

6.2 Overview of sewer model

Other structures:	Several structures will be modelled including bridges, culverts, weirs, pumps, flap valves and orifices.
Sewer Network:	The available surface water sewer network has been imported from Thames Water using the DAP Live tool. Outfalls from the surface water network drain into the watercourses and will be connected to the fluvial parts of the model where appropriate. Gully data was provided by Hertfordshire County Council and will be incorporated into the models where appropriate. InfoWorks ICM calculates in-sewer flows by solving the Saint-Venant equations using a 4-point Preissmann scheme.
Inflows:	Inflows to the surface water network model are generated using sub-catchments, which will be represented by roofs in each of the models. These designated runoff areas for different runoff surface type (roads, roofs, permeable) and will be set up in the model. The default infiltration surface of the 2D Zone for each of the models will be set to permeable (fixed runoff value of 0.4). To improve the representation of the rainfall response, infiltration zones will be used for roads with a higher fixed runoff value (0.9), and a fixed runoff value of 0.3 will be used for general surfaces. Manholes in the 2D zone will be coupled to the surfaces in each of the modelled hotspots. Therefore, additional inflow could be made if surface water was to run over a node. Highway gullies within each modelled hotspot will be modelled as 2D inlet nodes so they will be coupled with the surface. Therefore additional inflow could be made if surface water runs over a highway gully. Equally, where gullies might surcharge, sewer flow could route onto the surface.
Pipe Inverts:	Pipe inverts have been taken from the Thames Water network data. Where data is missing or outfall connections inferred to the fluvial model pipe inverts will be assumed by interpolating between known data points or estimating based on the ground level at that point. Gully pots will be assumed to be 0.3m deep and upstream inverts equivalent to these chamber floor levels. Downstream inverts will be assumed to be 0.5m below downstream node ground level.

Pipe Dimensions:	Pipe dimensions have been taken from available Thames Water sewer network data. Where data was missing, dimensions will be inferred from the upstream or downstream connection. No minimum pipe dimension will be excluded from the model builds No pipe dimension data was available for gullies. Gullies have been assumed to connect with 100mm dimension pipes to their nearest manhole.
Length of Models (km):	TBC
Total Number of nodes and structures :	TRDC hotspots include: Manholes: 715 Gullies: Up to 2347 Outfalls: TBC WHBC hotspots include: Manholes: 710 Gullies: Up to 3582 Outfalls: TBC SBC hotspots include: Manholes: 880 Gullies: Up to 2296 Outfalls: TBC HBC hotspots include: Manholes: 827 Gullies: Up to 3145 Outfalls: TBC Note that the total number could change based on interpolation and addition of outfalls during each of the model builds.

Labelling/ Numbering System Used:	As per Thames Water’s network data. The node ID is the National Grid Reference Any additional nodes added to the models will be given an individual ID which either relates to where the information came from e.g. from TFL survey, or where the node is near e.g. Moor Park Stream (MPS) or by adding a letter to the end of the grid reference of the neighbouring node.
Hydraulic roughness values used	In most cases: Bottom roughness Colebrook-White value = 0.6mm Top roughness Colebrook-White value = 0.6mm

6.3 Overview of 2D model

2D element	Description
Triangular mesh:	The 2D domain for each of the modelled hotspots will be constructed internally within InfoWorks ICM using the Delaunay Triangulation Algorithm. This creates a triangular mesh of ground elevation based on the DTM that is used in the model.
Overland flow:	The 2D domain solves the Shallow Water Equations (SWEs) across the triangular mesh.
Area of 2D domain:	The 2D domain for each of the modelled hotspots vary in size, based on whether it has been classified as a large, medium or small hotspot (based on the modelled detail and the size of the area covered). The sizes of the hotspots are between 3.4km2 and 2.6km2.
Boundary condition:	The boundary condition of the 2D Zone will be set to be 'normal condition'. Depth and velocity are kept constant when water reaches the boundary, so water can flow out without losses.
DTM	Filtered LiDAR 1m from the EA LiDAR will be used.
Roads	Roads have been represented using the kerb line as a break in the mesh. The roads will therefore be well defined in the mesh, it would be double counting to also lower the roads by an additional 0.15 m – which is the UK standard curb height. The use of break lines on the boundary of the road ensures that triangles are snapped to the road outline - best representing the shape of them.
Buildings	Buildings have been represented as porous polygons. A porosity of 0.05 has been assigned representing a restriction to flow but allowing a small amount of water to infiltrate. A value of 0.05 is assumed to be the likely percentage of the building where water could enter, for example doors or airbricks. Representing the buildings as porous polygons also means the ground model tin is meshed to the outlines. The building threshold level has been set to 0.1m throughout. A threshold survey of the whole area was not identified as feasible for this study; however some threshold survey may be carried out to assist in validating the models.

<table>
<tr><td>Infiltration Zones</td><td> The 2D Zone will be set to an infiltration surface with fixed runoff of 90% to represent the areas of hardstanding. General surfaces will also be input into the models as infiltration zones and the surface will be set to match the SPRHOST value of the catchment. These infiltration zones will be set to 'excluded' when creating a 2D mesh. </td></tr>
<tr><td>Roughness Zones</td><td> The default roughness of the 2D Zone will be set to 0.06 which is typical of a rural area. However roughness zones have been used across the majority of the study area with surface types informed from OS MasterMap. Table 6-1 lists the hydraulic roughness values used for the 2D domains in the models. Table 6-1: Hydraulic roughness values used <table><tr><th>Land Cover</th><th>Manning's n</th></tr><tr><td>General surface</td><td>0.040</td></tr><tr><td>Multi-surface</td><td>0.030</td></tr><tr><td>Roads, paths and tracks</td><td>0.030</td></tr><tr><td>Inland Water</td><td>0.035</td></tr></table></td></tr>
<tr><td>Terrain Sensitive Meshing</td><td>Terrain sensitive meshing will be used to better represent changes in gradient in the DTM. It allows smaller triangles to be generated where there is greater difference in height between triangle vertices. The cost is that more triangles are created – which increases run time, but it is a valuable addition to identify surface water flow routes, particularly in coarser meshes.</td></tr>
<tr><td>Maximum triangle size (m2):</td><td>100</td></tr>
<tr><td>Minimum element area (m2):</td><td>25</td></tr>
<tr><td>Terrain sensitive meshing:</td><td>Yes</td></tr>
<tr><td>Maximum height variation (m):</td><td>1</td></tr>
<tr><td>Minimum angle (degrees):</td><td>25</td></tr>
<tr><td>Roughness (Manning's n)</td><td>0.060</td></tr>
</table>

Appendices

A Outcome of hotspot assessment from Phase 1 selection process

Modelled hotspots			
Hotspot	**Location**	**Potential benefit from modelling**	**Scale of model**
Welwyn-Hatfield Borough			
WHBC3	- Hyde Valley, Cole Green Lane and Beehive Green (in Woodhall) in the east and Great Ganet, Little Gannet, Thistle Grove, Desborough Close, and Autumn Grove in the west	Hotspot has potential for flood water storage.	Medium scale model
WHBC6	Rosedale, Digswell Water, Harwood Close, Sewells, Hertford Road	To assess potential opportunity to keep surface water on the road. To undertake questionnaire with HCC at Sewells Road to improve reporting and to better understand the flood risk.	Small scale model
Three Rivers District			
TRDC1	Oxhey Drive, Eastbury, Nanscot and Oxhey Wood, South Oxley, Gosforth Lane and Little Furze Field	Potential to hold surface water flow upstream or to the west	Medium scale model

TRDC2 – now TRDC2a and TRDC2b	Oxhey Drive, Eastbury, Nanscot and Oxhey Wood, South Oxley, Gosforth Lane and Little Furze Field	Potential for flood risk interventions and better understanding of flood mechanisms	One large and one medium scale model
TRDC4	Chorleywood	Potential interventions in upstream areas	Small scale model
TRDC8	Oxhey Brook	Assessment of detention and attenuation capacity (there is a need to consider groundwater flood risk too)	Small scale model
TRDC9	Prestwick Road, Brookdene Avenue and Raglan Gardens	Potential for SuDS e.g. Tree pits around Oaklands Avenue	Small scale model
Stevenage Borough			
SBC1	Matthews Close, Rectory Lane and Chancellors Road	Assessment of potential water storage upstream	Medium scale model
SBC2	Bragbury Lane	Assess potential of upstream storage and the feasibility of connecting the ditch	Small scale model
SBC4a	Blair Close and London Road	Assessment of potential mitigation alongside completion of the EA Stevenage Brook model	Small scale model

SBC4b	Roebuck Gate	Potential to hold water back	Small scale model
Hertsmere Borough			
HBC3	Moatfield Road	Water storage potential and PLR	Large scale model. This hotspot area is the focus of flood risk in the borough of Hertsmere
HBC5	Crown Road	PLR potential	Small scale model
HBC6	Bushey (Roads including Moatfield Road, Spring cross, Vale Road, Hayden Road and Homefield Road)	Water storage potential and control over flood mechanisms in the hotspot area	Medium scale model

Non-modelled hotspots		
Hotspot	**Location**	**Reason**
Welwyn-Hatfield Borough		
WHBC1	Travellers Lane	Recommendations from the reactive study being undertaken by HCC will be taken forward for this hotspot.
WHBC5	Swallowfields, Swiftfields, Knella Road	PLR work to be carried out at this hotspot.
WHBC7	Heayfields, Wren Wood, Westly Wood	PLR work in this hotspot area.
Three Rivers District		
TRDC10	Moor Wood	Small scale hydrology and site investigation to identify potential measures.
Stevenage Borough		
SBC6	Mildmay Road and Durham Road	It is recommended that this site is carried forward as a non-modelled hotspot as it has been identified as one that is of lower priority. The committed development in the hotspot poses potential for SuDS opportunities.
Hertsmere Borough		
HBC1	Radlett	After site visit investigations and the hotspot workshop, it was decided that this hotspot would be taken forward as a non-modelled hotspot due to the sporadic flood incident record and only 2 internal property flooding incidents recorded. It was a agreed that there would be little benefit of modelling to confirm the RoFfSW, however future modelling may assist option design.

HBC4	Prowse Avenue	Undertake PLR work at this location, with potential for maintenance work on the drainage curb.
HBC8	Highview and Darkes Lane	The risk to this hotspot has been recognised at this hotspot and further investigation of the recorded flood incidents will be undertaken.

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