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Revision History

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Purpose

This report provides a record of information required to operate the hydraulic model constructed for the Staplehurst SWMP modelling project.

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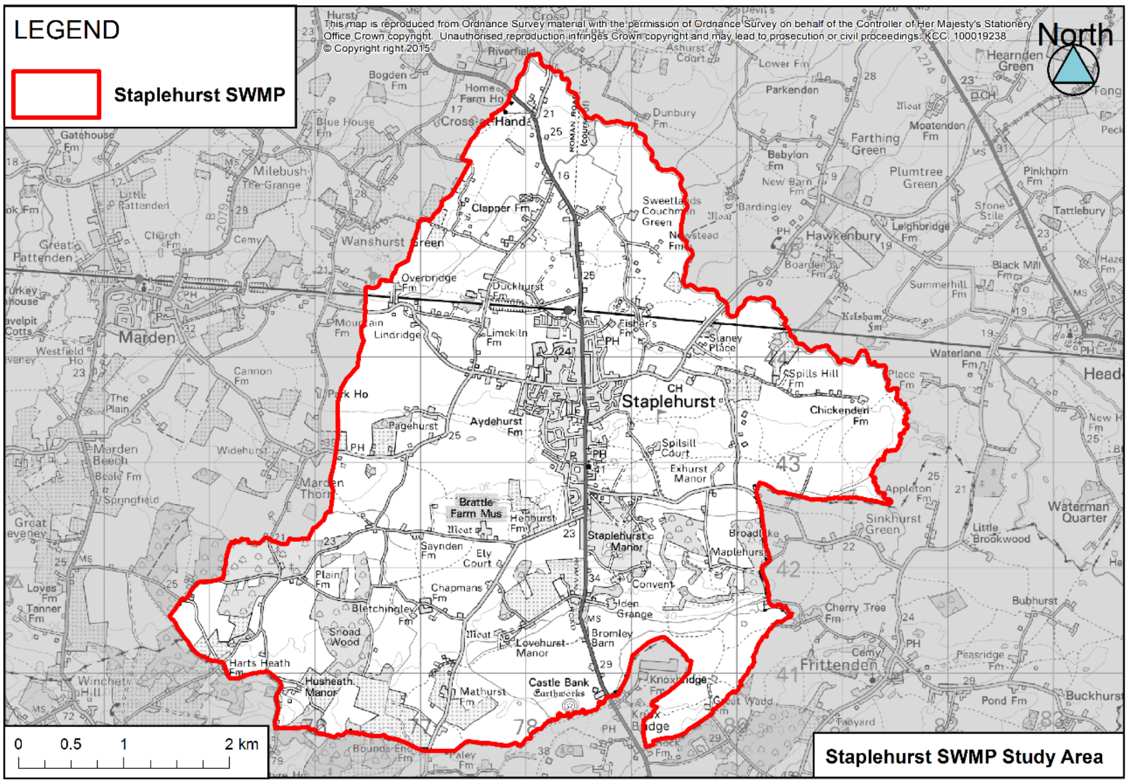
1 Model Log

As Lead Local Flood Authority, Kent County Council (KCC) has undertaken a number of Stage 1 Surface Water Management Plans (SWMPs) across Kent to identify areas where more detailed investigations are required. The 2012 Stage 1 SWMP for the Maidstone area identified that the villages of Marden, Staplehurst and Headcorn have a significant local flood risk, with a flood history from surface water to highways and properties. To address this risk, a detailed Surface Water Management Plan in is required for each of the villages with the purpose of producing a 2D hydrodynamic model of the sewers, roads, ground surface and other local water infrastructure that affects the drainage of the parishes.

1.1 Study area

The SWMP focuses on the village of Staplehurst within the Maidstone Borough. This area includes the entire parish and is shown in **Error! Reference source not found.**. This includes Cross-at-Hand to the north and Bowling Alley Wood to the south.

Figure 1-1: Modelled extent of Staplehurst



2 Model build

Staplehurst SWMP required a modelling approach that would simulate the response to rainfall and the interactions with the full drainage arrangement. While historically the different aspects of the urban drainage system have been treated in isolation, the technical tools used to represent and understand drainage systems have begun to allow greater interaction of the river, coastal, above ground, and below ground urban drainage environments. These are relatively new techniques, which are commonly referred to as Integrated Urban Drainage (IUD) modelling approaches. The development of IUD techniques has been partly in response to the floods of 2007 and a number of consultations, including Making Space for Water, Foresight Future Flooding, and the Pitt Review.

For the Staplehurst SWMP modelling InfoWorks ICM was selected. InfoWorks ICM is the most suitable software in this case as it is able to represent the interactions between direct rainfall, overland flows, sewer networks and fluvial systems simultaneously within one modelling platform. It is also the software used by Southern Water and so compatible with their existing models. The software version was InfoWorks ICM 6 which was the latest available version.

2.1 Available data

This section outlines the data used to inform the Staplehurst SWMP modelling project.

2.1.1 Surveys

To support this and previous studies of Staplehurst, a number of surveys have been undertaken which are relevant to the SWMP. These are listed in Table 2-1.

Table 2-1: Surveys in the Staplehurst relevant to the SWMP

Survey	Date	Description
Watercourse survey - KCC	January 2014	Topographic survey of river cross sections and structures
Highway drainage survey - KCC	February 2015	Asset documentation of highway gullies and connected pipework
Sewer survey - Southern Water	October 2015	CCTV of foul sewers on Marden Road
Lidar topographic survey - Environment Agency	Various	1m resolution elevation data covering 75% of Staplehurst
Lidar topographic survey - Environment Agency	Various	2m resolution elevation data covering an additional 2% of Staplehurst
Photogrammetric topographic survey - KCC	2013	5m resolution elevation data covering the additional 23% of Staplehurst

These surveys have been used as a basis for the existing models (outlined in Section 2.1.2) and referenced though out the model development (explained in Section 2.2).

2.1.2 Existing models

Southern Water held an existing sewer model for Staplehurst which included the foul and combined drainage. This model was built and verified in InfoWorks-CS. The model was migrated to InfoWorks ICM and included in the Staplehurst SWMP model.

2.1.3 Asset data

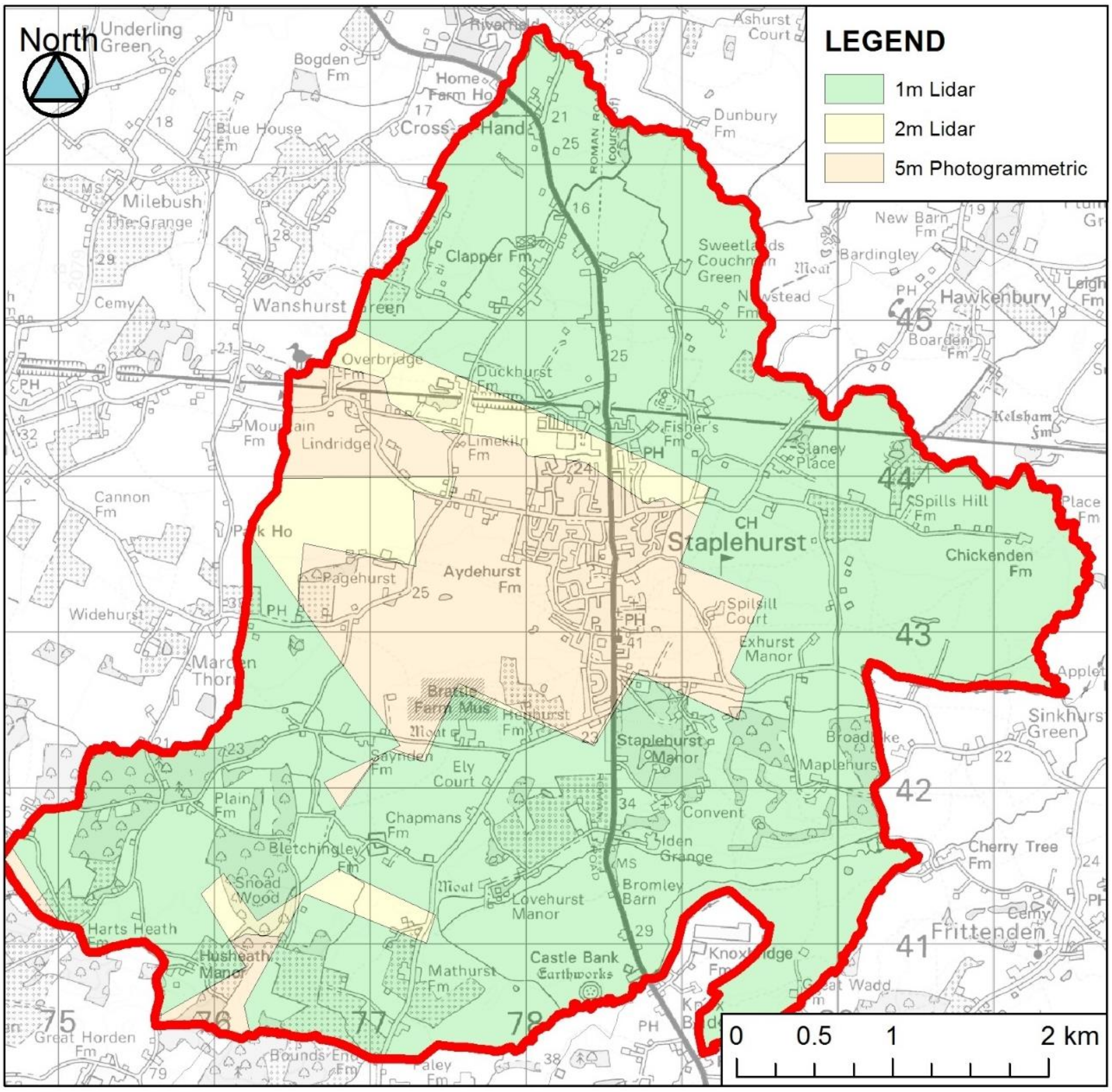
In addition to the DAP model, Southern Water also provided an Impermeable Area Survey which had been used in the development of the DAP model to understand what areas are positively drained to the sewerage system.

Kent County Council keep a GIS record of their gully pots which documents the type of gully and its condition during the last inspection. This database does not include details on the piped network, which is why KCC commissioned further surveys to provide this information.

2.1.4 Topographic data

Lidar data was no available across the study area and was supplemented by photogrammetric elevation data collected by KCC. The 75% of the study area is covered with one metre resolution data as shown in Figure 2-1. Where one metre Lidar data was not available, two metre resolution Lidar data or five metre photogrammetric data has been used to fill the gaps. The DTM data were mosaicked into one DTM surface at a one metre resolution to preserve the detail of the better quality data.

Figure 2-1: DTM resolution coverage across the Staplehurst study area



2.1.5 Land use data

Kent County Council have provided Ordnance Survey Master Map data to support the project. This has been used in the model to define where surfaces are manmade, natural or multiple (such as gardens). The Master Map has also been used to inform building foot prints and surface roughness's.

2.2 Model development

The Staplehurst model has been based on the Southern Water DAP model, which is 1D only. However, as the purpose of these models is different, model development was required to meet the objectives of the Staplehurst SWMP study. Most significantly, this included;

- adding a 2D domain to understand surface routing of sewer exceedance and pluvial runoff and developing the 1D model so it is compatible with 2D modelling;
- adding the ordinary watercourse and IDB drains to the model;
- adding highway gullies to the sewerage model; and
- representing the Main Rivers using downstream conditions.

2.2.1 2D model

The development of a 2D model is outlined in Table 2-2.

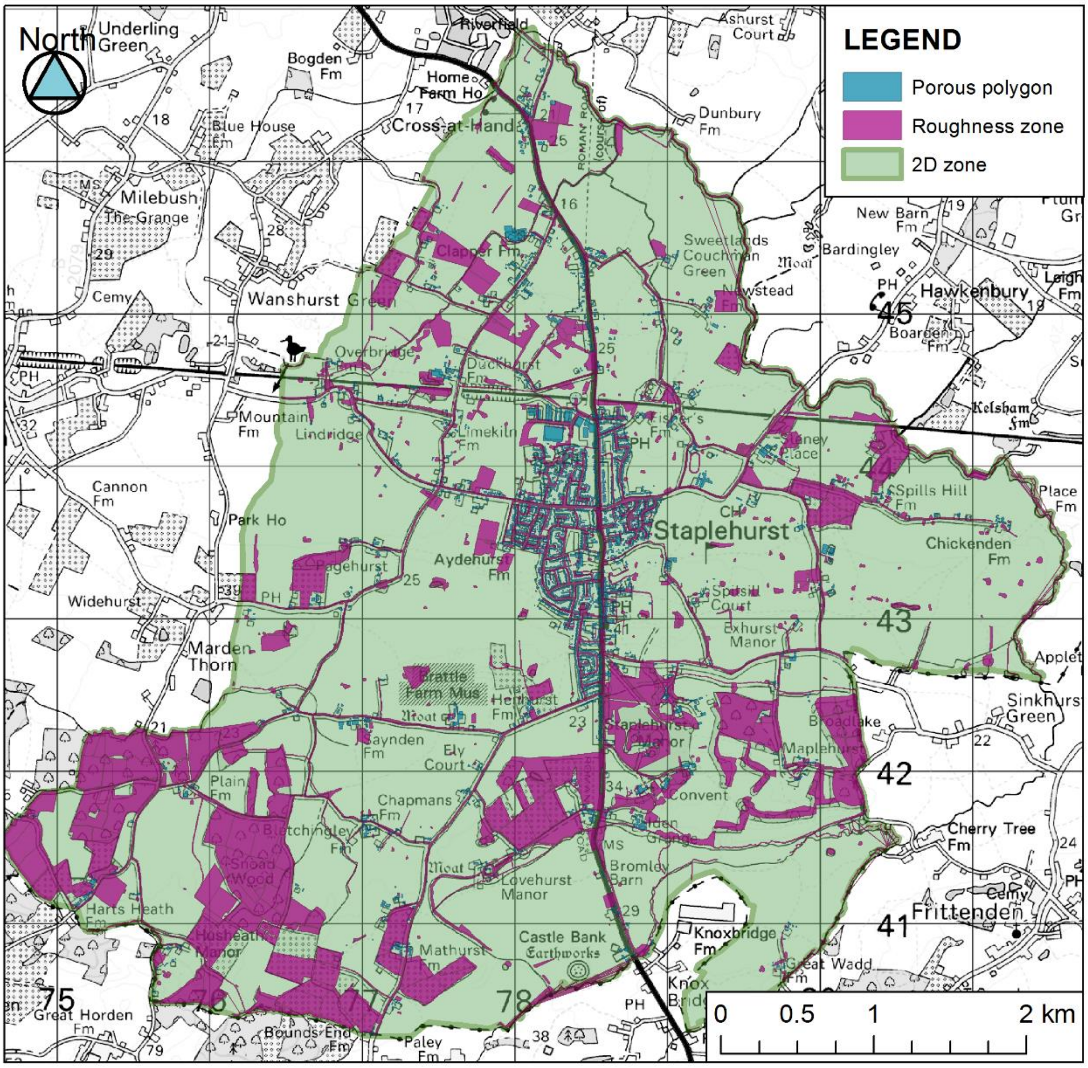
Table 2-2: 2D model development

Physical Feature	Model Feature	Count	Description
Topography	2D zone	1	The 2D zone was the whole parish and surrounding areas which would drain in. The 2D zone was divided into a mesh of elements. Each element took its elevation from the DTM The elements varied in size between 25 and 1 m^2 The roughness, infiltration and porosity of each element was set by overlying zones Rainfall was applied outside of subcatchments
	Mesh Zone	1	The village centre is covered by a mesh zone to create a more detailed mesh in this location. This is to better represent local changes in topography. The elements varied in size between 10 and 1 m^2
Land cover	Roughness zones	2107	The roughness zones were imported from Master Map Each land surface has its own roughness Structure/ building = 0.3 Parkland/ garden = 0.03 - 0.04 Roads/ pavements = 0.02 Water = 0.035
Buildings	Porous polygons	2832	The porous polygons were imported from Master Map The polygons were merged and their geometry simplified as the boundary of polygons are used as break lines in the mesh. The porosity of each building was set to 0.05 - allowing 5% of flows through the building. There was no crest level set (as water depth would not exceed roof height) so the buildings were infinitely tall
Roads	Break lines	80	Breaklines force the mesh to generate triangles along its edge, which ensures that the areas near to the breakline have well defined linear features. Breaklines have been used within the models to define the edges of roads where road kerbs help to direct and contain shallow surface water flows. The breaklines used to model the roads were generated using OS MasterMap data.
Rainfall losses	Infiltration zones	9853	The infiltration zones were imported from Master Map Two runoff surfaces have been used according to land use and soil type

Physical Feature	Model Feature	Count	Description
			Impermeable land uses have a fixed runoff rate (using the Fixed model). • Low density residential = 80% Permeable land uses have a time varying runoff rate (using the Horton model) • Rural areas inside soil WRAP class 4 = 44 mm/hr initial and 1 mm/hr limiting

Figure 2-2 shows the 2D model schematic although it should be noted that some pf the infiltration zones overly roughness zones, so not all the roughness zones are shown in this diagram.

Figure 2-2: Staplehurst 2D model schematic



2.2.2 1D model

The developments to Southern Waters DAP model have been summarised in Table 2-3.

Table 2-3: 1D model development

Feature	Description	Development	Justification
River reach	Create ordinary watercourse and IDB drains model	Import survey data to the model and convert to river reaches linked to the 2D domain. Apply inflow and DS condition.	Understand flooding from watercourses, backing up and discharge limitations of SW systems

Feature	Description	Development	Justification
Watercourse structures	Create bridges, culverts and sluices	Use survey data to construct structures, including inlets/ outlets and spills	Represent contraction caused by structures.
Surface Water sewers	Create sewers from asset data	Use Southern Water data to build surface water sewer model	Represent rainfall lost to sewers and sewer flooding.
Subcatchments	Define areas contributing to surface water	Create subcatchments geometry to areas of manmade / multiple land use which would drain to sewers	Applies flows to the 1D sewer model
Subcatchments	Define areas contributing to foul sewers	Shrunk foul subcatchments to circles with 1m diameter. No change to population.	Prevent foul subcatchments limiting overland runoff generation.
Inlet 2D	Represent highway drainage gullies	Inlet 2D nodes added to the model to represent KCC gullies.	Represent overland flow accessing sewerage. Allow 1D 2D connectivity.
Highway drainage sewers	Piped connections between gullies to SW sewer or drainage ditch.	Build pipe connection from KCC survey were available. Some assumptions required where data was missing.	Allow discharge of highway gullies.
Manholes	Represent sewer manholes	Set flooding manholes from 'lost' flood type to '2D' flood type	Allow flooding out on to the mesh

Subcatchments

The surface water catchments for each drainage area was delineated into a number of sub catchments in order facilitate flows into the surface water network. These predominately represented the roofs of the buildings within the drainage areas. Each of the sub-catchments has a defined unit hydrograph, which is representative of an urban catchment with user defined Time to peak values. Open areas such as parks, gardens and areas within the topographic catchment but outside of the drainage network were modelled using direct rainfall as this was considered a more suitable approach for these areas.

Runoff surfaces

All sub-catchments in Staplehurst were less than 2.5 Ha therefore there was no requirement to use large sub-catchment routing models.

Table 2-4: Runoff zone parameters

Runoff Surface ID	Runoff Routing Value	Runoff Volume Type	Surface Type	Initial Loss Type	Routing Model	Runoff Coefficient	New UK Depth
10	1	Fixed	Impervious	Slope	Wallingford	0.75	-
20	1	Fixed	Impervious	Slope	Wallingford	0.75	-
21	4	New UK	Pervious	Abs	Wallingford	-	0.1

Each land use class was assigned a runoff zone for one of three runoff surfaces, which were defined as follows:

- Runoff surface 1 - Roads and Pavements (ID - 10)
- Runoff surface 2 - Building roofs (ID - 20)
- Runoff surface 3 - Permeable areas (ID - 21)

The runoff surfaces within each of the sub-catchments were defined using the MasterMap land use types which were used to calculate the absolute areas of runoff within each sub-catchment.

2.2.3 1D 2D connectivity

The 1D and 2D models were connected at selected manholes and along the banks of the modelled river reach. The manholes where connected to the 2D zone using a 2D flood type. Only a selection of manholes where connected to prevent and unrealistic amount of surface water draining to the sewers. Instead the manholes predicted to flood where set to 2D. As a result, the exceedance flows were able to route across the 2D zone.

2.2.4 Boundary conditions

There are several outfalls from the surface water network into the watercourses that surround Staplehurst. The surface water network to the South East of Staplehurst outfalls into Sweetlands Drain which then flows to the East out falling into the River Beult (579635, 144613).

The surface water network to the West and North of Staplehurst flows into Fishers Road Drain which joins Overbridge Farm stream and outfalls into the River Beult (578663, 146234).

2.3 Model overview

A summary of the modelled features is listed in Table 2-5.

Table 2-5: Features included in the Staplehurst model

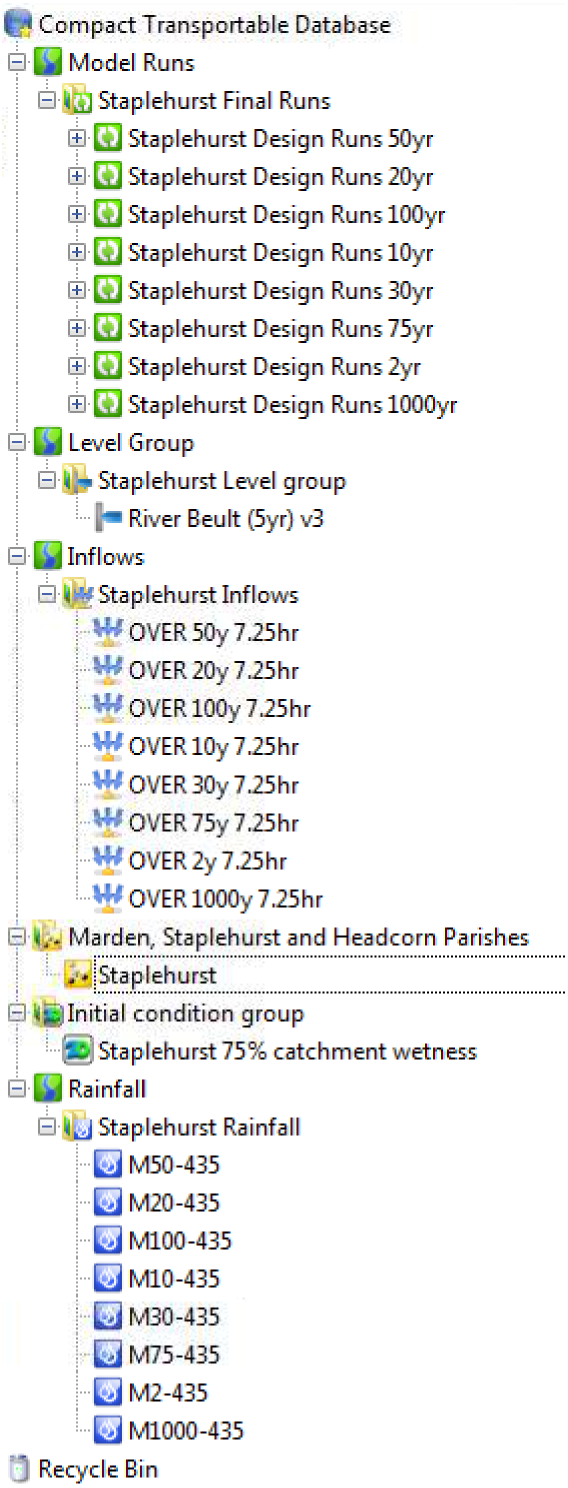
River	Channel (km)
Overbridge Farm Stream	3
Fishers Road Drain	1
Sweetlands Drain	2.1
Royston Farm Drain	1.3

Sewers	Nodes	Pipes (km)
Surface Water System	1088	18
Foul System	352	17

Roughness Zone	Porous Polygon	Infiltration Zones
2,107	2,832	9,853

3 File structure

Table 3-1: Staplehurst model file structure



Model Folder	Content	Description
Network Group	Staplehurst	Network used for design runs (scenarios include flood alleviation options)
Ground model grid group	LIDAR_Kent_v4	ASCII composite of 1 & 2m Lidar data and 5m photogrammetric data
Rainfall	M50-435 M20-435 M100-435 M10-435 M75-435 M2-435 M1000-435 M100+cc-435	ReFH rainfall hyetographs. 435-minute storm - judged the critical duration No losses applied except seasonal correction factor and aerial reduction factor. Losses to infiltration applied in the model.
Inflows	OVER 50y 7.25hr OVER 20y 7.25hr OVER 100y 7.25hr OVER 10y 7.25hr OVER 75y 7.25hr OVER 2y 7.25hr OVER 1000y 7.25hr	ReFH hydrograph fitted to a FEH Stats peak for the Overbridge Drain. Inflow to other watercourse calculated using direct rainfall.
Level group	River Beult (5yr) v3	Hydro-static water level representing peak of 5yr storm (lowest return period modelled by EA Medway study).
Initial conditions group	Initial conditions 2D - 75%	75 % catchment wetness
Run groups	Staplehurst Final Runs	Final design runs and option tests

4 Model Verification

The performance of the Staplehurst model has been tested against two data sets. The first is flood records collected from the project partners, including a mapping workshop and the second is ReFH check flows calculated by the hydrology.

4.1 Historic verification

Information on flood incidents in Staplehurst was collected from Kent County Council, Southern Water and Staplehurst Parish Council. These recorded incidents have been used to check the model performance.

Each of the pluvial flooding incidents reported are predicted by the IUD model however, some of the flood incidents reported due to operation issues such as blocked gullies or collapsed culvert are not recreated in the model as it is assumed that all assets are free of obstruction. For example, no surface water flooding is predicted on the High Street but two incidents have been reported due to blocked drainage. The model does however predict flooding at Corner Farm Road where flooding has been reported five times due to blocked drainage. This suggests the drainage could be hydraulically inadequate, but flooding may be exacerbated by blockages.

4.2 Model workshop

The baseline model results were presented to the project steering group for their comment based on local knowledge of flood mechanisms. This meeting found the model to under predict the frequency of flooding seen in Staplehurst, particularly at Clapper Lane.

This led to applying a downstream boundary to the model which represented peak water level on the River Beult during a 20% AEP event. The event was selected as it was the smallest event modelled as part of the Medway modelling and mapping study (Environment Agency 2015). This restricted discharge of ordinary watercourses and surface water drainage systems increased the frequency of flooding in line with observed events.

A further model amendment was made following the workshop to alter the runoff rate from rural areas from fixed runoff (using SPRHOST to dictate the runoff rate) to variable runoff using the Horton model. This was because the longer storm duration of seven hours was found to be critical and increasing soil saturation and therefore increased runoff can be expected in a storm of this length. The variable runoff rate increased the surface water generated in the rural parish.

4.3 FEH Statistical method check flows

At hydraulic model testing stage, the use of the direct rainfall to calculate fluvial flows on Sweetlands Drain and Fishers Road Drain was tested against FEH Statistical flow estimates. The results of this comparison after the model changes listed above including application of a downstream boundary and using a variable runoff rate from rural areas are shown in Table 4-1 and Table 4-2.

Table 4-1: Comparison of FEH Stats and modelled flows on Sweetlands Drain

Method	Flood peak (m^3/s) for the following AEP (%) events							
	50	10	5	3.33	2	1.33	1	0.1
FEH Stats	0.4	0.7	0.8	0.8	0.9	1.0	1.1	1.9
Modelled	0.4	0.8	0.9	0.9	0.9	0.9	1.0	1.1

Table 4-2: Comparison of FEH Stats and modelled flows on Fishers Road Drain

Method	Flood peak (m^3/s) for the following AEP (%) events							
	50	10	5	3.33	2	1.33	1	0.1
FEH Stats	0.5	0.8	1.0	1.1	1.2	1.3	1.4	2.3
Modelled	0.2	0.6	0.9	1.0	1.0	1.2	1.2	1.5

The testing concluded that the modelled flows derived from direct rainfall were a good match for the FEH flows. There are always inherent uncertainties in hydrology but two methods agreeing peak flows increased overall confidence. It should be noted that the 0.1% AEP modelled flows are lower than the hydrology estimated for the same event. This could be caused to hydraulic constrictions such as culverts and out of bank flows and does not necessarily mean the model is under predicting.

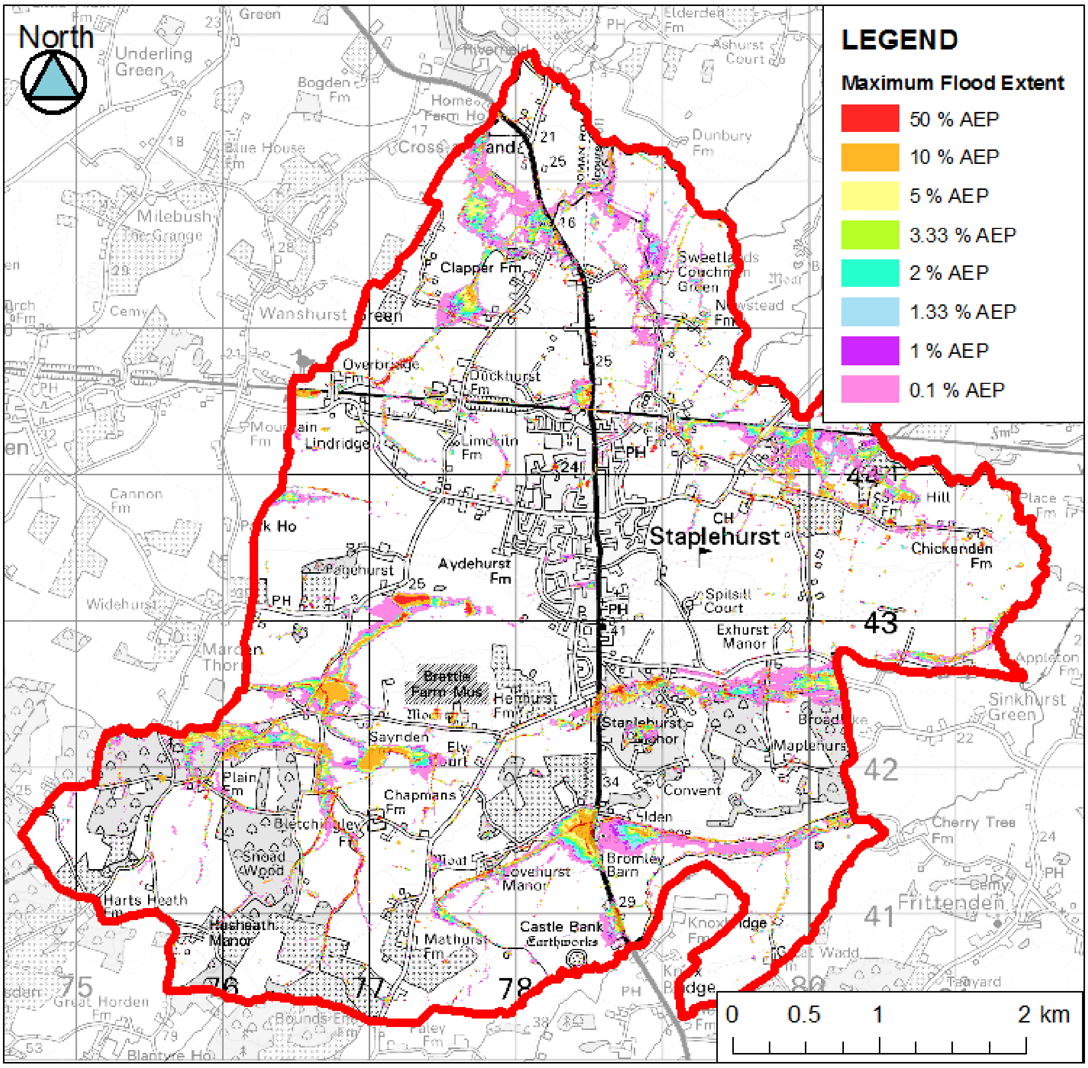
This test was not completed for the Overbridge Farm Stream because the whole catchment wasn't modelling 2D and therefore direct rainfall was not an appropriate method to estimate flows. Instead a point inflow was added at the upstream extent of the Overbridge Farm Stream model based on ReFH hydrographs fitted to an FEH Statistical method peak.

5 Model results

5.1 Baseline model

The maximum flood extent predicted for design storms is shown in Figure 5-1.

Figure 5-1: Maximum extent of design storms



The outlines show the village of Staplehurst is generally at low risk of flooding. The greatest flood risk follows the fluvial corridors, particularly Overbridge Farm Stream, the drain at the southern extent of Staplehurst and Fishers Road Drain. Within Staplehurst, the greatest flood risk is to Corner Farm Road and Offens Drive. The incorporation of highway drainage and Fishers Lane Drain into the model reduced the predicted flood risk to Fishers Road compared to the uFMfSW.

5.1.1 Property count

Property counts were based on the results from the Integrated Urban Drainage Model as this was considered the best representation of flood risk in the catchment. The analysis was undertaken using Frism, a JBA GIS-based tool for analysing flood impact and damages. A detailed count was undertaken which utilises the Master Map building footprints in conjunction with the NRD property points. A property point is counted as flooded if its corresponding building footprint is within the flood outline, even if the property itself may not fall within the flood outline.

The total number of properties counted at each return period is shown in Table 5-1.

Table 5-1: Baseline property count at each Annual Exceedance Probability (AEP) event

Flood Event Return Interval	Residential Properties Flooded	Commercial Properties Flooded	Total
50% AEP event	24	7	31
10% AEP event	43	13	56
5% AEP event	52	21	73
3.33% AEP event	58	22	80
2% AEP event	75	24	99
1.33% AEP event	83	26	109
1% AEP event	93	27	120
0.1% AEP event	157	35	192

The model results show that an increasing number of properties are flooded at each return period, as would be expected. There are considerably more residential properties at risk of flooding than commercial properties, which again is expected as the properties in Staplehurst are predominately residential.

The number of properties at risk does not increase significantly between 2% between the 1% AEP events but then increased by 50% during the 0.1% AEP event illustrating a significant increase in flood extent for the 0.1% event.

5.1.2 Damage calculation

Internal flooding of properties has an economic impact. The majority of financial cost is due to the damage incurred to the property (direct damages) but there are also secondary costs such as the emergency response (indirect damages) and the impact to health (intangible damages).

The damage calculation includes all of these costs. The Multi-Coloured Manual (MCM) 2013 provides a methodology for calculating damages, as well as cost versus flood depth curve which has informed this assessment.

A property threshold level of 0.15 metres has been assumed. This means that if a property is intersected by a flood depth less than 0.15m, it has been assumed that no direct damage will be incurred as the flood water could not access the property.

The damages curve for each of the properties was adjusted to account for inflation. This was done by using the monthly variation of the Customer Price Index (CPI) which was inputted at 132.6. The CPI uses the prices of a representative sample to statistically estimate the variation in the real property value whilst accounting for the changes in the rate of inflation.

The economic damages estimated for the baseline scenario for each Annual Exceedance Probability (AEP) is shown in Table 5-2.

Table 5-2: Baseline damage calculation at each Annual Exceedance Probability (AEP) event to the nearest £k

Flood Event Return Interval	Residential (£)	Commercial (£)	Total Damage (£)
50% AEP event	322,000	608,000	930,000
10% AEP event	810,000	1,125,000	1,935,000
5% AEP event	932,000	1,480,000	2,412,000
3.33% AEP event	984,000	1,575,000	2,559,000
2% AEP event	1,094,000	1,605,000	2,699,000
1.33% AEP event	1,199,00	1,712,000	2,911,000
1% AEP event	1,269,000	1,778,000	3,047,000
0.1% AEP event	2,301,000	2,037,000	4,338,000

At the lower return periods tested the commercial damages are calculated to be higher than the residential damages, despite the smaller number of properties to be at risk. This is because the commercial properties predicted to be a risk have a large floor plan and locally the flooding can be quite deep, despite not inundating the entire building. During the higher return period events, the residential damages become costlier than the commercial damages. This is due to the increasing number of properties predicted to be at risk.