JBA Office

8a Castle Street

Wallingford

OX10 8DL

JBA Project Manager

Jenny Hill

Revision History

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Prepared by Chris Matthias BSc MSc

Reviewed by Jennifer Hill BSc MSc

Purpose

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

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Contents

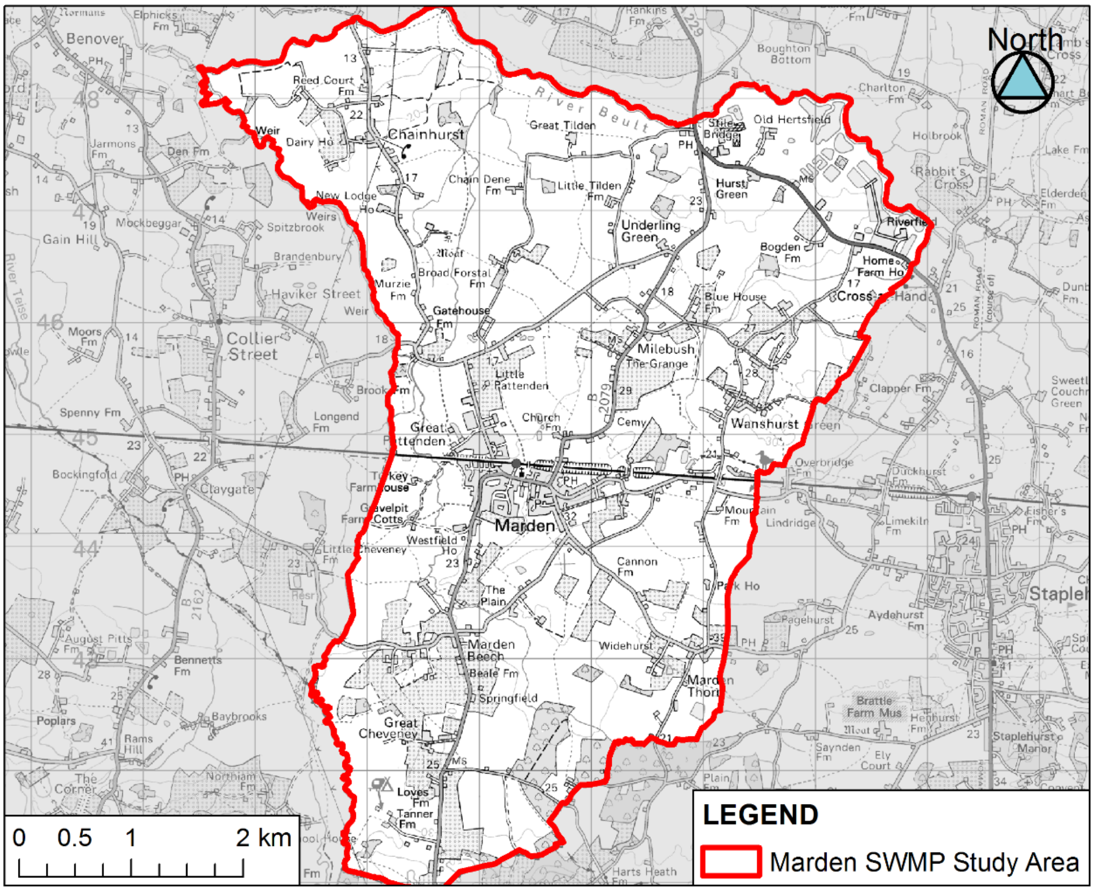
1 Model Log

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 Marden within the Maidstone Borough. This area includes the entire parish and is shown in Figure 1-1. This spans north to Chainhurst and south to Winchet Hill.

Figure 1-1: Modelled extent of Marden



2 Model build

Marden 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 Marden 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 Marden SWMP modelling project.

2.1.1 Surveys

To support this and previous studies of Marden, 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 Marden 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
Lidar topographic survey - Environment Agency	2009	1m resolution elevation data covering 100% of Marden
Lidar topographic survey - Environment Agency	2002	2m resolution elevation data covering an additional 100% of Marden

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 Horsmonden which includes Marden. This model 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 Marden SWMP model.

2.1.3 Asset data

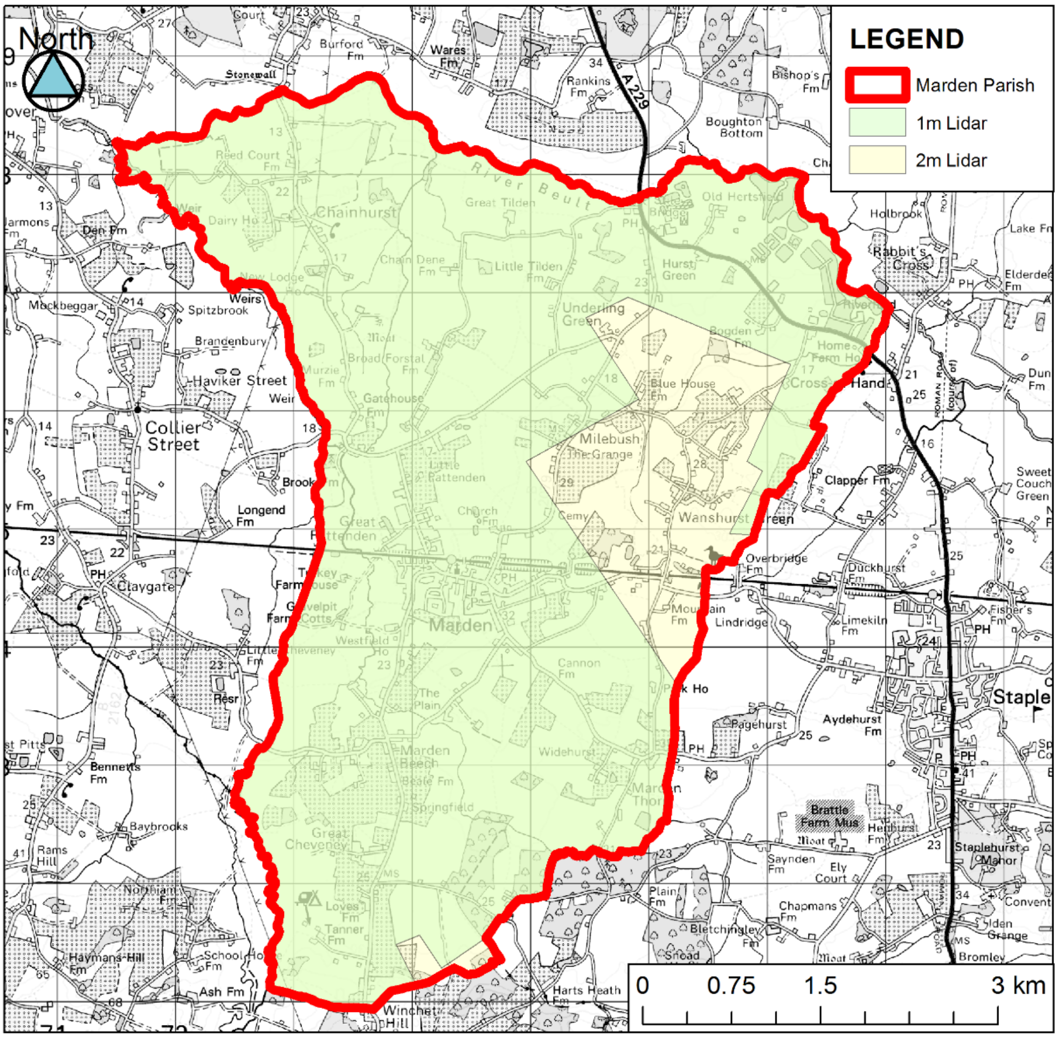
In addition to the DAP model, Southern Water also provided an Impermeable Area Survey which had been used in the development of the DAP model to understand what areas are positively drained to the sewerage system.

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 85% 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 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 Marden 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 Marden 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 Marden 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.

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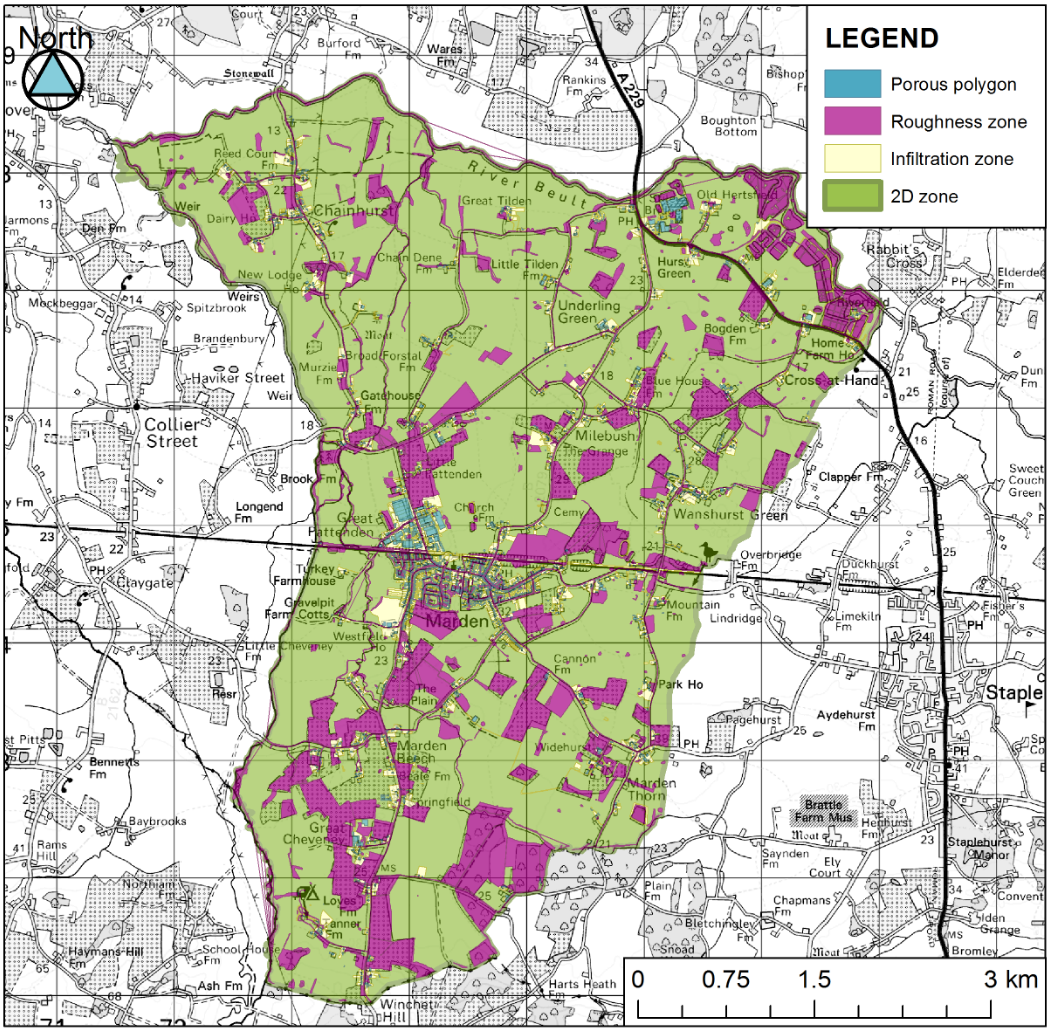
Table 2-2: 2D model development

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 Impermeable land uses have a fixed runoff rate (using the Fixed model).

Physical Feature	Model Feature	Count	Description
			• 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: Marden 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
Watercourse structures	Create bridges, culverts and sluices	Use survey data to construct structures, including inlets/ outlets and spills	Represent contraction caused by structures.

Feature	Description	Development	Justification
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 Marden 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 Cockpit Drain at Marden. Outfall locations include The Cockpit, Goudhurst Lane, Sovereigns Way and the Wheelbarrow Estate. At these locations, the sewer network model has been dynamically connected to the Cockpit Drain to allow fluvial backing up (where flap valves allow).

2.3 Model overview

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

Table 2-5: Features included in the Marden model

River	Channel (km)
Cockpit Drain	3

Sewers	Nodes	Pipes (km)
Surface Water System	309	5.5
Foul System	663	35.8

Roughness Zone	Porous Polygon	Infiltration Zones
1,262	2,076	6,455

3 File structure

Table 3-1: Marden model file structure

Item
Compact Transportable Database
Model Runs
Marden Direct Rainfall Runs
Marden Design Runs v6 100yr 9.5 hr!
Marden Design Runs v6 1000yr 9.5 hr
Marden Design Runs v6 20yr 9.5 hr!
Marden Design Runs v6 50yr 9.5 hr
Marden Design Runs v6 75yr 9.5 hr
Marden Design Runs v6 30yr 9.5 hr
Marden Design Runs v6 10yr 9.5 hr
Level Group
Marden Level Group
Marden DS 20% AEP
Inflows
Marden IDB watercourse
100yr 9.25 hr
1000yr 9.25 hr
20yr 9.25 hr
50yr 9.25 hr
75yr 9.25 hr
30yr 9.25 hr
10yr 9.25 hr
Marden, Staplehurst and Headcorn Parishes
Marden!
Initial condition group
Marden 75% catchment wetness
Rainfall
Marden Rainfall
100 Year 9.25 mm/hr
1000 Year 9.25 hr v2
20 Year 9.25 mm/hr
50 Year 9.25 hr v2
75 Year 9.25 hr v2
30 Year 9.25 hr v2
10 Year 9.25 hr v2
Recycle Bin

Model Folder	Content	Description
Network Group	Marden!	Network used for design runs (scenarios include flood alleviation options)
Ground model grid group	LIDAR_Kent_v4	ASCII composite of 1 & 2m Lidar data
Rainfall	100 Year 9.25 mm/hr 1000 Year 9.25 mm/hr 20 Year 9.25 mm/hr 50 Year 9.25 mm/hr 75 Year 9.25 mm/hr 30 Year 9.25 mm/hr 10 Year 9.25 mm/hr	ReFH rainfall hyetographs. 555-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\ Marden IDB watercourse	100yr 9.25 hr 1000yr 9.25 hr 20yr 9.25 hr 50yr 9.25 hr 75yr 9.25 hr 30yr 9.25 hr 10yr 9.25 hr	ReFH hydrograph fitted to a FEH Stats peak for the Patternden Farm Drain through Marden.
Level group	Marden DS 20% AEP	Hydro-static water level representing peak of 5yr storm (lowest return period modelled by EA Medway study).
Initial conditions group	Marden 75% catchment wetness	75 % catchment wetness
Run groups	Marden Direct Rainfall Runs	Final design runs and option tests

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4 Model Verification

The performance of the Marden 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 Marden was collected from Kent County Council, Southern Water and Marden Parish Council. These recorded incidents have been used to check the model performance.

Locations where pluvial runoff have been reported have been well represented by the IUD model, with Howland Road, Goudhurst Road, Pattenden Lane and the Cockpit all predicting flooding where pluvial runoff has been reported. However, surface water runoff is also predicted on Park Road and Thorn Road which has not been reported. Flooding from surface water when drainage was blocked has been reported on Stanley Road and Maidstone Road which is not predicted by the IUD model. In the model as it is assumed that all assets are free of obstruction, therefore it is possible the surface water flooding at these locations could be avoided if the drainage network was running clear.

4.2 Model workshop

The baseline model results were presented to the project steering group for their approval based on local knowledge of flood mechanisms. This meeting found that the flood extents predicted at Howland Road and Goudhurst Road matched well with flood extents observed in the winter of 2013/2014. However, the flooding at the Wheelbarrow Estate under predicted what was observed.

This led to testing of downstream boundaries on the model and the understand that flooding at the Wheelbarrow Estate is driven by the Lesser Teise rather than the Cockpit Drain or Patternden Farm Drain. The final model uses a downstream boundary which represented peak water level on the Lesser Teise 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 the Cockpit 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.

Table 4-1: Comparison of FEH Stats and modelled flows on Cockpit 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	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5
Modelled	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.6

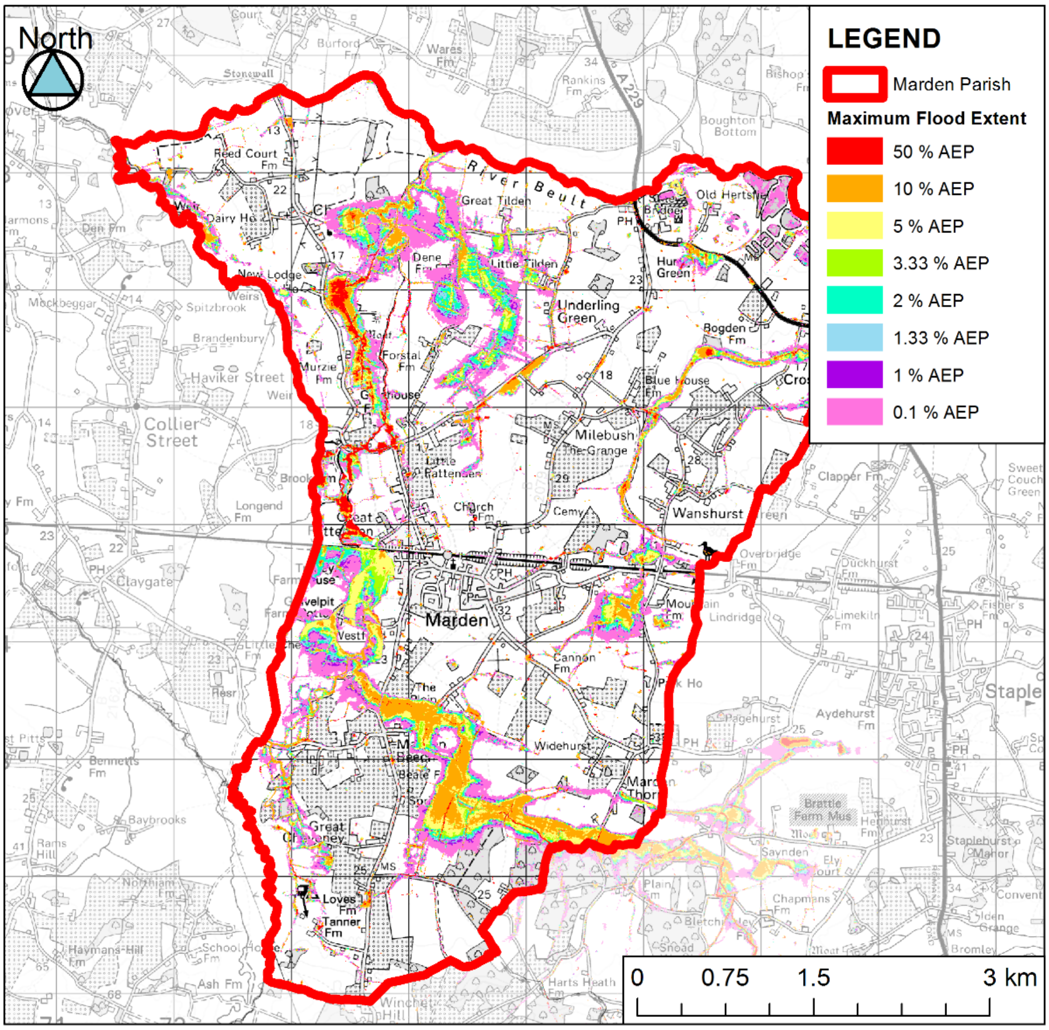
The testing concluded that the modelled flows derived from direct rainfall were a good match for the FEH flows. There are always inherent uncertainties in hydrology but two methods agreeing peak flows increased overall confidence. It should be noted that the modelled peak flow across the length of the Cockpit Drain was shown to increase by 25% through the modelled reach. This indicates that a direct rainfall, which distributes inflow throughout the length, is more appropriate than a single lumped FEH inflow.

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 Marden is generally at low risk of flooding. The greatest flood risk follows the fluvial corridors, particularly Patternden Farm Drain. Within Marden, the greatest flood risk is to the Wheelbarrow Estate and Howland Road.

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	Non Residential Properties Flooded	Total
50% AEP event	31	27	58
10% AEP event	60	79	139
5% AEP event	70	94	164

Flood Event Return Interval	Residential Properties Flooded	Non Residential Properties Flooded	Total
3.33% AEP event	83	100	183
2% AEP event	89	116	205
1.33% AEP event	94	132	226
1% AEP event	98	138	236
0.1% AEP event	137	206	343

The model results show that an increasing number of properties are flooded at each return period, as would be expected. The results suggest relatively few properties are at risk in a 50 % AEP event and the number of residential properties at risk is does not increase significantly between a 3.33 and 1 % AEP event. There are more non-residential properties at risk than residential properties. This shows how the less vulnerable land uses have been permitted in areas with greater probability of flooding. Non-residential properties predicted to flood are generally outside of the village, within the wider parish with exception of commercial buildings at Wheel Barrow Estate.

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	332,000	2,694,000	£3,026,000
10% AEP event	689,000	3,628,000	£4,317,000
5% AEP event	886,000	3,846,000	£4,732,000
3.33% AEP event	985,000	4,133,000	£5,118,000
2% AEP event	1,132,000	4,352,000	£5,484,000
1.33% AEP event	1,286,000	4,799,000	£6,085,000
1% AEP event	1,363,000	4,985,000	£6,348,000
0.1% AEP event	2,153,000	4,982,000	£7,135,000

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.