Appendix A

Model Build and Validation Report

Kent County Council – Flood Alleviation Study

Paddock Wood

Hydraulic Model Build & Validation Report

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Kent County Council – Flood Alleviation Study

Paddock Wood

Hydraulic Model Build & Validation Report

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Glossary

1D	Linear hydrodynamic equations of fluid motion
2D	2-dimentional hydrodynamic shallow water equations
CoP	Code of Practice
GIS	Geographical Information Systems
Infiltration zones	Polygons to apply infiltration parameters to the 2D extent
IUD	Integrated Urban Drainage
LIDAR	Light Detection and Ranging DTM
Mesh zones	Polygons to apply adjustments to 2D elements (detail / topographic)
Roughness zones	Polygons to apply roughness parameters to the 2D extent
SPS	Sewer Pumping Station
STW	Sewage Treatment Works
Subcatchments	Polygons to apply runoff parameters to 1D network
SWMP	Surface Water Management Plan
TWL	Top Water Level

1 Introduction

JacksonHyder was commissioned by Kent County Council (KCC) in January 2014 to undertake a study aimed at providing KCC and its partners with a comprehensive understanding of the flood risk mechanisms in Paddock Wood. The study was also to investigate potential solutions to flooding and provide an evidence base for planning policy.

In order to do this the existing hydraulic model was enhanced with the new channel survey (2013) of Paddock Wood Stream, Rhoden Stream, Alder Stream, Tudeley Brook and Graveley Way watercourse. Additional sewer network has been added in places to increase the model detail and network coverage, including the representation of the highway drainage system.

1.1 Catchment Description

The catchment comprises Paddock Wood and the river basins of a number of watercourses which pass through and adjacent to the town, located in mid-Kent. All the watercourses within the study area eventually flow into the River Medway about 2km to the north (*OS NGR TQ67434867*). The catchment location is illustrated in Figure 1-1 below.

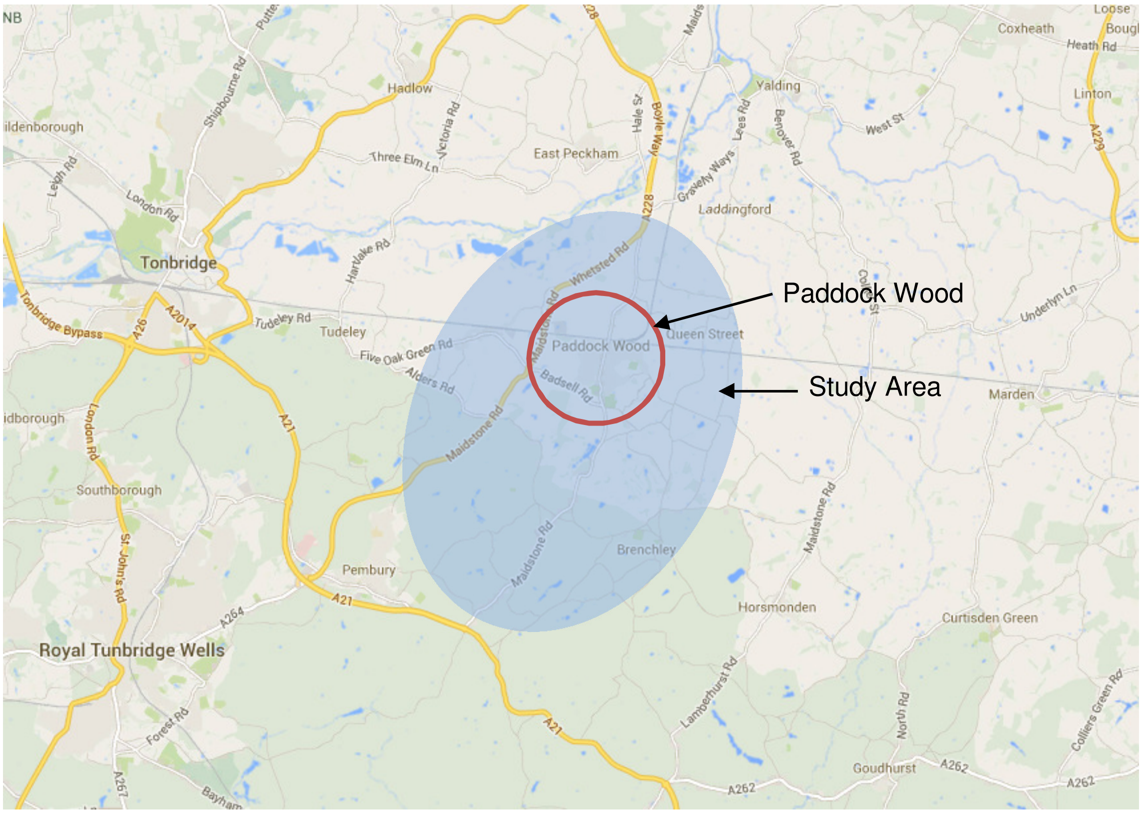


Figure 1-1 Location Plan of Paddock Wood (courtesy of www.google.co.uk)

1.1.2 Nature of Urban Drainage System

The total catchment area is approximately 3,600ha, with an elevation range of approximately 140m (from 7mAOD to 149mAOD). The sewerage system is primarily separate and is served by Paddock Wood Sewage Treatment Works (STW) (*OS NGR TQ67844529*)

The Paddock Wood foul drainage system is split into two distinct areas by the Tudeley Brook. The western area comprises the village of Five Oak Green and a number of hamlets and farms to the south, connected to the Paddock Wood network by a terminal SPS. In Paddock Wood piped flows drain north east to two terminal SPS discharging to Paddock Wood STW.

The surface water drainage network follows the highway layout and discharges at a number of locations to the Rhoden Stream, Gravelly Ways Stream and Paddock Wood Brook. There are also surface water attenuation ponds predominantly located in the south of the town, for which Paddock Wood Town Council are responsible for.

Paddock Wood Brook passes through the urban area of Paddock Wood and is culverted for the majority of its length. There are two main unculverted sections, one off Rowan Close and a section alongside The Cedars. The Gravely Ways Stream is a narrow water course which borders the western extent of the town into which some of the urban runoff discharges.

1.1.3 Nature of River System

The total river basin area upstream of Paddock Wood is approximately 1,900ha, with an elevation range of approximately 123m (from 26mAOD to 149mAOD). There are four main watercourses which influence drainage and flooding in and adjacent to Paddock Wood, two of which pass through the urban area.

- Rhoden (East & West)
- Paddock Wood
- Gravelly Ways
- Tudeley Brook

A catchment plan can be found in Appendix D.

All these rivers eventually flow into the River Medway and Teise approximately 2km north of Paddock Wood.

2 Type of Model and Intended Purpose

The previously existing InfoWorks ICM model has been enhanced to a Type III detailed design hydraulic model aimed at enhancing the detail in the following elements:

- Sewer & highway drainage network
- River reaches, channels and structures
- Topographic surface model

The model enhancement works was undertaken in accordance with the WaPUG CoP and the WaPUG IUD Modelling Guide. The model was built using InfoWorks ICM v4.5 / 5.0 and used to evaluate sewer, fluvial and surface water flooding, and the performance of a range of flood alleviation schemes.

The modelling results will be used to re-assess the flood risk to properties and important infrastructure assets identified. The assessment will consider both the physical flood depth as well as the likelihood of internal property flooding.

3 Model Description

3.1 Model History

An InfoWorks ICM model of the catchment was built for the Paddock Wood SWMP study and provided for this project. This model was based on an existing InfoWorks CS model provided by Thames Water.

An integrated modelling approach was employed for the Paddock Wood SWMP, which has included all the main drainage systems, except for private sewerage and pipe networks <150mm dia. The model network included watercourses *(ordinary watercourses and main rivers)* which were incorporated using channel surveys that were provided. This includes structures *(bridges, culverts etc)* on these watercourses.

Outside of the urban areas of Paddock Wood the watercourses were represented on the 2D surface as defined by the topography and mapping data.

The foul and surface water sewerage systems were also included using an existing 1D sewer network model provided by Southern Water. The surface water sewer network was connected directly to the river reaches where applicable to represent discharges from the outfalls of the surface water sewer into the watercourses.

4 Network / Survey Data

All data received was reviewed and confirmed acceptable for use, prior to use in the model.

4.1 River Surveys

The following survey datasets were obtained for the modelling:

- River survey sections in ISIS model format, cross section drawings *(dwg / pdf / mapinfo files)*
- Hard bed and soft bed ISIS survey models

4.2 Sewer Network Data

Southern Water provided an extract from their corporate GIS system of the sewerage system, including all recorded pipes, manholes and sewer ancillaries.

The existing SWMP ICM model was used as the basis for the new ICM model. Gully location data was obtained to enhance the highway drainage model.

4.3 Railway Culverts

Visual survey reports, and detailed examination reports where available, were provided by Network Rail for some railway culverts.

4.4 Highway Gullies

Highway gully locations for Paddock Wood and surrounding area were provided by Kent Highways Services.

5 Model Build

Data interpolation has been undertaken where necessary, based on sound modelling judgment and the quality of known data.

The SWMP ICM model provided was reviewed and determined to be suitable for use as the basis of the enhanced model.

5.1 River Network Build & Enhancements

The primary aim of the model build was to enhance the existing model with new survey and topographic information, and to add more detail where necessary to improve confidence in model predictions.

5.1.1 River Reaches

The existing InfoWorks ICM model river reaches were updated with the new survey data where appropriate. Cross section data was trimmed to match the existing banks where there were overlaps.

New surveyed sections of river were added to the new model. Cross sections were trimmed to the banks, as identified using the profiles. Bank lines were created with reference to the trimmed cross sections and the LIDAR data. Cross sections within the previous SWMP model which did not overlap the locations of the newly surveyed sections were retained where possible.

5.1.2 River Structures

Existing river structures were updated based on the survey cross sections, railway culvert inspection reports and site walkover photos. Bridge structures were modelling using bridge records in InfoWorks ICM. Culverts were modelled using conduits and culvert inlet / outlet records, the parameters for which were identified from photos and survey information.

5.2 Highway Gullies

All known highway gullies were explicitly represented in the model. Gully pot dimensions were assumed from standard construction details and were connected to the nearest node on the main sewer network. The appropriate system to connect the highway gullies to was determined by the runoff characteristics within the existing model subcatchments.

The location the highway gullies provided were reviewed against the OS MasterMap to ensure they are within the highway carriageway.

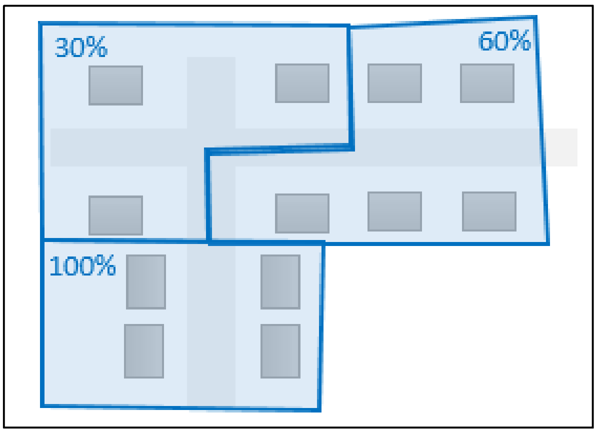
5.3 Rainfall Runoff

To increase the understanding of overland flow paths and surface water flooding the direct rainfall method was used.

To enable this the runoff areas in the existing 1D subcatchments covering the urban area were reverted to zero. Individual property roof 1D subcatchments were then created and connected into the appropriate nodes, based on the existing 1D subcatchments destination. To match the existing verified runoff areas the number of individual 1D subcatchments were revised to ensure the total roof area in the new model *(sum of individual roof 1D subcatchments overlapping the* *existing 1D subcatchments)* equals the existing roof area as close as possible, as demonstrated in Figure 5-2 overleaf.

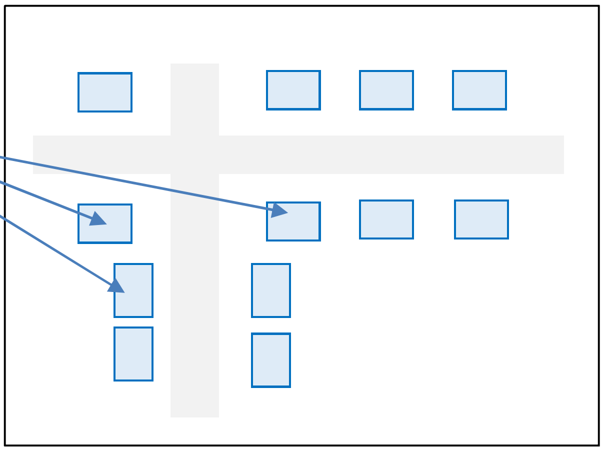
Existing 1D Subcatchments

(percentages represent the modelled roof runoff area vs. the OS roof area).



New Property 1D Subcatchments

Existing 1D subcatchments removed and new property 1D subcatchments created.



Revised & Finalised Property 1D Subcatchments

New property 1D subcatchments removed to ensure total roof area within existing subcatchments matches existing 1D subcatchments, based on the proportional difference from the OS roof area.

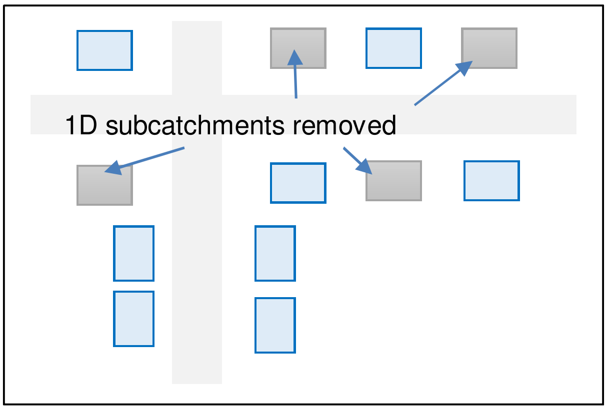


Figure 5-2 1D Subcatchment generation for direct rainfall runoff method

The direct rainfall method applies the rainfall to everywhere in the model outside of the new 1D subcatchments.

The existing 1D subcatchments were retained to maintain the verified foul flows and baseflows. To allow the direct rainfall runoff method to be applied the existing 1D subcatchments were shifted geographically outside of the 2D zone.

5.4 2D Model

OS MasterMap topographic data provided the underlying topographic and land use information to ensure the resolution of surface features were explicitly defined, including properties, road kerbs, traffic calming islands and property boundaries.

5.4.1 Mesh / Model Detail

Mesh zones were used to create topographical adjustments to the 2D model.

Road Curbs

Highway carriageway polygons were extracted from the OS MasterMap and used to lower the mesh by 150mm to replicate the impact of road kerbs which can influence overland flow routes.

Building Footprints

The footprints of buildings and structures were extracted from the OS MasterMap and used to provide a 100mm threshold by raising the mesh. This is aimed at representing a typical step height into a property and to prevent flooding being report from small flow depths flowing into properties, such as from rear gardens.

Walls

A number of walls and un-mapped structures were identified from Google Street View and added to the model, where they were considered to potentially affect overland flows.

Mesh simplification

Mesh zones were also used on the outlying areas of the 2D extent, largely in field and agricultural areas, to simplify the 2D mesh. Within these areas the maximum triangle areas were increased to reduce the resolution of flooding, reducing simulation times and exported data memory requirements.

5.4.2 Roughness

Roughness zones were created from the OS MasterMap data based on the land type classifications. A set of standard Manning's roughness figures were applied based on the OS MasterMap land classification, and are as follows:

- Roads and Paved Surfaces = 0.013
- Buildings and Structures = 0.1
- Urban Green Spaces = 0.03
- Rural Green Spaces = 0.035

5.4.3 Infiltration

Infiltration zones with a fixed runoff coefficient of 1 were created from the OS MasterMap for all impermeable surfaces. A fixed runoff coefficient of 0.4 was applied to the 2D zone to replicate infiltration.

5.5 Flood Types, Flood Cones and Floodable Areas

Highway gully nodes were modelled with a flood type of “Inlet 2D” which enables an accurate representation of typical gully grates and a 30% ‘clogging’ factor to be applied, which can be increased to 100% for the ‘Do Nothing’ model scenario.

Non-gully nodes located within the highway have 2D Gully flood type with a headloss curve derived to simulate the hydraulic impact of manhole covers popping. With a head of <0.5m above the cover level the nodes act like sealed nodes. A head >0.5m will allow flooding to occur based on the hydraulic capacity of the manhole shaft area.

5.6 Trade Flows

There are no known trade effluent discharges within the Paddock Wood catchment.

6 Model Validation

There was no recorded flow or level data available to undertake a verification / calibration exercise. As a result a range of sensitivity tests and historical flood record validation was undertaken to confirm the models performance.

6.1 Sensitivity Testing

A range of sensitivity tests were undertaken to test the model's performance and confirm assumptions made during the model build were appropriate. A range of plans for the various sensitivity tests can be found in Appendix A.

6.1.1 Down Stream River Boundary Conditions

Local reports of flooding indicated that fluvial flooding from the River Medway to the north was extensive and inundates the northern fringes of Paddock Wood. This would affect the selection and performance of any flood alleviation schemes.

River TWL for a range of design events was obtained from the EAs main river models. Using plans provided which identified the node locations associated with the TWLs 2D boundary lines were created which abutted along the northern edge of the 2D zone, matching with the River Medway.

Without re-running the existing main river models it was not possible to apply the TWLs using a time varying curve, as would be experienced during a flooding event. In addition, the responses of the main river basins and those in the Paddock Wood study area are likely to be significantly different. As a result the probability of coincidental peak river levels would be difficult to calculate in this study. Instead a continuous level was used at each 2D boundary line to simulate a worst case flood event where peak fluvial flows in the Paddock Wood catchment correspond to the peak of fluvial flooding from the main rivers.

Six events were tested, listed below:

- 1 in 30 year (3.33% AEP) 60min event
- 1 in 30 year (3.33% AEP) 600min event
- 1 in 100 year (1% AEP) 60min event
- 1 in 100 year (1% AEP) 600min event
- 1 in 1000 year (0.1% AEP) 60min event
- 1 in 1000 year (0.1% AEP) 600min event

The results of the sensitivity analysis indicates that fluvial flooding from the main rivers won't significantly affect flooding in and around the urban area of Paddock Wood. The extent of downstream influence extends to approximately 700m north of the railway, around Lucks Ln.

The majority of options will look to attenuate or manage fluvial and surface water flows north of Paddock Wood. Therefore, downstream impacts are not considered significant so the downstream boundary conditions can be omitted from the assessment of options.

6.1.2 2D Surface Roughness

The standard roughness parameters applied to the 1D river reaches and 2D surface were doubled to test the sensitivity of runoff to roughness. Two events were tested, listed below:

- 1 in 30 year (3.33% AEP) 60min event
- 1 in 100 year (1% AEP) 60min event

The results show that the area around Addington Road and Dimmock Close are slightly sensitive to roughness during the 1 in 100 year (1% AEP) event, with flood depths predicted to be up to 0.3m lower with an increased roughness. However, there are no major differences within the urban area during the 1 in 30 year (3.33% AEP) event.

6.1.3 Infiltration Methodology

The extent of permeable agricultural land and use of direct rainfall to derive fluvial inflows indicates that the 2D infiltration parameters are a significant factor in the simulated hydrology. To test the infiltration assumptions two different infiltration approaches were tested against 4 events, listed below:

- Fixed @ 0.7 - 1 in 30 year (3.33% ARP) 60min event
- Fixed @ 0.7 - 1 in 100 year (1% ARP) 60min event
- Fixed @ 0.7 - 1 in 30 year (3.33% ARP) 600min event
- Fixed @ 0.7 - 1 in 100 year (1% ARP) 600min event
- Horton (medium soil type) - 1 in 30 year (3.33% ARP) 60min event
- Horton (medium soil type) - 1 in 100 year (1% ARP) 60min event
- Horton (medium soil type) - 1 in 30 year (3.33% ARP) 600min event
- Horton (medium soil type) - 1 in 100 year (1% ARP) 600min event

The Fixed rate of 0.7 relates to the SWMP modelling assumptions for ‘Urban’ permeable spaces. The Horton method assumes initial saturation of 0% and a medium soil type, as defined by Innovyze guidance notes.

The results of the sensitivity analysis show that flood depths along the major overland pathways and at key receptors within the urban area would be greater with a Fixed infiltration of 0.7, as would be expected. The average increase in depth is no greater than 0.5m for the majority of the catchment during a 1 in 100 year (1% AEP) event. However, increases in depth differences of greater than 0.5m did occur around the train station, Dimmock Close and the industrial estate on Transfesa Road during a 1 in 30 year (3.33% AEP) event.

The Horton method resulted in very little difference in peak depths across the catchment. This indicates that the use of the Fixed rate of 0.4 is appropriate and matches flood predictions using the Horton method, which is considered a more robust and representative method.

6.2 Historical Flooding

Flooding locations from the SWMP report and flood photos provided for this study were digitised and used to correlate predicted flood extents. A map showing the main flood record locations and predicted flood frequency can be seen in Appendix B.

The historical flooding identified on the map are only indicative of the locations *(i.e. roads or named properties)* and do represent the actual extent of any real flooding events.

A good correlation has been achieved for most of the key flood risk areas along the southern edge of the railway. Since these are the most significant areas of flood depth and extent this provides good confidence in the model predictions.

A few minor roads identified in the SWMP do not correlate too well with modelled flooding. Since the mapped predictions represent flood depths >=0.15m it is expected that flood records relate to less severe flood depths and / or major conveyance routes *(such as Old Kent Road and Rowan Close)*.

A lack of correlation where the East Rhoden is culverted under the railway indicates there may be unidentified condition issues restricting pass through flows. Alternatively minor topographic features not resolved in the LIDAR data may prevent overland flow travelling east as it does in the model.

7 Model Audit checks

An internal model build and validation checklist was used to QA the model, the details of which can be found in Appendix C.

8 Model Performance Statement

The model predictions are considered to replicate historical flooding well in the key flood risk locations and is suitable for the development of flood alleviation optioneering. The sensitivity tests indicate the model to be robust and representative of the hydrological conditions of the catchment.

The approach to generating the 2D surface has increased the level of detail of structures and topographic features within the flood plains. This increases the confidence in predicted surface runoff, fluvial flows and overland pathways within the urban areas of Paddock Wood.

Due to the complexity of the watercourses and interconnected nature of the public drainage system the model does experience stability issues during some events. This can be compensated for by maintaining a simulation time step of 1 second.