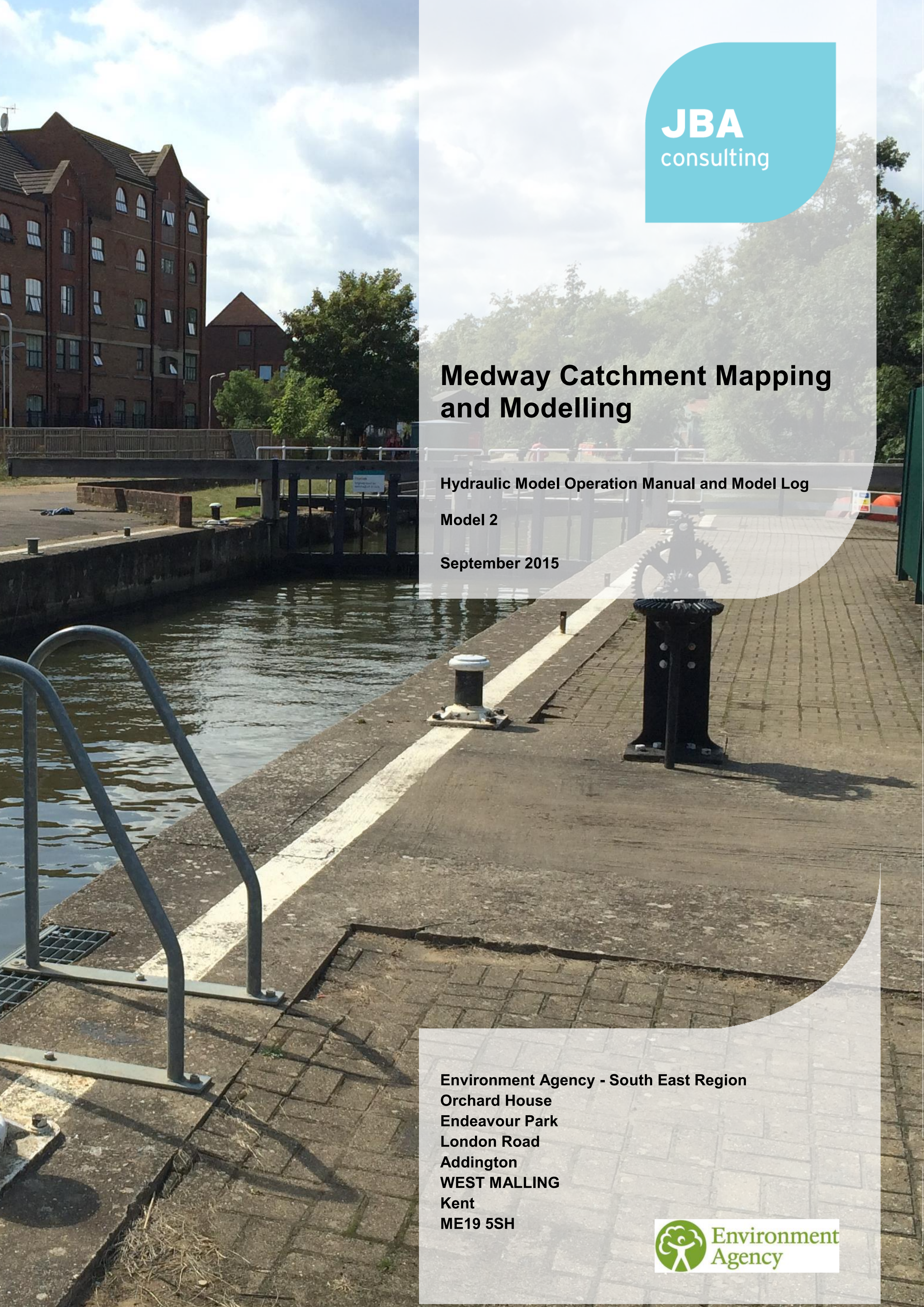

JBA consulting

Medway Catchment Mapping and Modelling

Hydraulic Model Operation Manual and Model Log

Model 2

September 2015

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Revision History

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Draft v0.5 November 2014 (Issued to assist with model review)	-	Emma Dauben and Neil Gunn (Environment Agency)
Draft Final v1.0 September 2015	Amendments following draft review of Model 1.	Emma Dauben and Neil Gunn (Environment Agency)

Contract

This report describes work commissioned by Emma Dauben, on behalf of Environment Agency South East Region, for the Medway Catchment Mapping and Modelling commission under the Environment Agency's Water and Environment (WEM) Framework. Environment Agency's representative for the contract was Emma Dauben.

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Purpose

This report provides a detailed record of information required to operate the hydraulic model of the River Medway through Tonbridge (Model 2) updated and developed under the Medway Catchment Modelling and Mapping project. The appendices contain the hydraulic model check files; these should complement the information in the main report which provides more general information on the model.

Acknowledgements

Thanks to Emma Dauben and Neil Gunn for the provision of information and assistance during the project.

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Abbreviations

1D .... One-dimensional

2D .... Two-dimensional

AEP................................. Annual Exceedance Probability

DSM .... Digital Surface Model

DTM .... Digital Terrain Model

ESTRY .... Proprietary 1D modelling software developed by WBM BMT

FEH................................. Flood Estimation Handbook

FSA .... Flood Storage Area

ISIS .... Proprietary modelling software developed by Halcrow/CH2M Hill (all instances of ISIS in this report refer specifically to ISIS 1D)

LIDAR .... Light Detection and Ranging

m AOD .... Metres Above Ordnance Datum Newlyn

OS.................................... Ordnance Survey

TCF .... TUFLOW Control File

TUFLOW......................... Proprietary modelling software developed by WBM BMT (all instances of TUFLOW in this report refer to TUFLOW 'Classic' - a 2D modelling approach)

1 Introduction

The River Medway hydraulic Model 2 extends from downstream of Leigh Flood Storage Area (FSA) and terminates at Hartlake Road. Modelling involves a linked 1D-2D ISIS-TUFLOW approach throughout. The study area has been split into three domains, one domain with a 5m grid resolution within Tonbridge between the railway line and Cannon Lane Bridge (Domain 2). Upstream (Domain 1) and downstream (Domain 3) of Tonbridge the domains have a 20m grid cell size. The total length of the watercourse modelled is 20km.

The model has been developed principally from the existing River Medway Modelling and Flood Mapping Updates (2008) ISIS model and supplemented with information for the Gas Works Stream, Botany Stream and Mill Streams from the Tonbridge Hazard Mapping study (2010). Representation of the Hilden Brook and Hawden Stream watercourses has been taken from the Hilden Brook and Hawden Stream Flood Risk Mapping (2006). Data implemented from previous models has undergone a detailed review as part of this Medway Catchment Mapping and Modelling study. New survey data of structures and bank levels within Tonbridge, collected in 2014 for this commission, was also implemented.

Noted within this model operation manual are the more major changes made during the model update process as well as new files and model setup.

This Model Operation Manual has been put together to enable future users of the model to use the model with ease. Section 2 provides a brief technical overview of the model; further details about the model build and results can be found in the Main Report and in the Modelling Approach and Overview section (Appendix A of this document). Section 3 describes the files and folder structure in which the model has been supplied, with Section 4 providing the information required to run the model. The document also contains information as to how the model has been developed throughout the course of the study.

2 Technical Summary

What software & reason for choice	ISIS-TUFLOW: ISIS v 3.7.1 (64-bit), double precision TUFLOW build 2013-12-AC-iSP-w64 ISIS was used for the 1D component of the model due to the existing model from the 2010 study being developed in this. ISIS version 3.7.1 was used as this was the latest release of the ISIS software at project commencement. TUFLOW Build 2013-12-AC-iSP-w64 was selected as this was the latest release on undertaking design runs. Double precision versions of both software were used as it was found that double precision TUFLOW improved the mass balance across the 2D-2D link between domains.
General Schematisation	The model is 1D-2D linked throughout. The channel is represented by the ISIS 1D model and the floodplain represented by the TUFLOW 2D domain. Connections between the 1D and 2D domains are implemented as HX lines. There are three 2D domains. A 5m grid cell size is used within Tonbridge between the railway line and Cannon Lane Bridge. Upstream and downstream of this region a 20m grid cell size is used. The River Medway has many tributaries (Hilden Brook, Hawden Stream) and branches (e.g. at Tinker's Island, Gas Works Stream and Mill Stream) within Tonbridge, all of which have been included within this hydraulic modelled.
Design Events	The model was built to simulate defended design events for the following events: 20%, 10% (+20% flows to represent climate change), 5%, 3.33%, 2%, 1.33%, 1%, 1% (+20% flows to represent climate change), 0.4% and 0.1% Annual Exceedance Probability (AEP). The model was also simulated for the following undefended events: 5%, 1%, 1% (+20% flows to represent climate change) and 0.1% AEP.
Structures	Structures can be found listed sections B.1 to B.5 of the Appendix.
Calibration Coefficients	Structure coefficients and spill weir coefficients are detailed in sections B.1 to B.5.
Model Proving	**Calibration and verification** Please see the main project report, Appendix C. **Sensitivity testing** Sensitivity testing of the following parameters were tested as part of the study. The outputs of this testing are summarised within the main study report. - A global change of +20% and -20% in the channel roughness (Manning's 'n') - A global change of +20% and -20% in the total inflows - An adjustment both up and down (+20% and -20%) on downstream boundary condition - Culvert blockage of 20%
Strengths, Weaknesses and Future development	**Strengths** The model is considered the best representation of the River Medway, its multiple channels and tributaries given the available survey and LIDAR data. A coarser grid size was implemented upstream and downstream on Tonbridge (domains 1 and 3) where there are fewer flood risk receptors. Modelling of these areas was required to meet the objectives of the study and a compromise between model detail (e.g. ground level representation and 1D-2D linking) was reached in these areas. The most up to date information available for the study has been implemented within the model. This includes new channel section information collected at structures and bank top surveys within Tonbridge. **Weaknesses** *Low flows*

The model has been built for the purpose of flood risk mapping; therefore it will be optimised for high flows and would need adapting before it was suitable to be used for more low flows.
Minimum flows are applied to model inflows as the model becomes unstable at low flows, typically at structure sections. Further work would be required to schematise the model for low flow modelling. This is likely to include representing bed levels in more detail, including reducing the distance between sections and incorporating channel features not currently represented e.g. minor/informal weirs and bed level variations.

Hilden Brook and Hawden Stream
Representation of the Hilden Brook and Hawden Stream watercourses has been taken from the Hilden Brook and Hawden Stream Flood Risk Mapping study (2006). This model was not originally tested with such large events on the Medway and as a result high water levels on the River Medway resulted in model instability for some larger events tested. Measures were taken to stabilise the model which are recorded below.

Model stability
Due to model stability three different approaches were taken for the design model simulations. These were:

1. Model version _049: Baseline model
2. Model version _049d: Hawden Stream and Hilden Brook removed. 'A' value applied to HX lines (ranging from 1 to 20 depending on magnitude of oscillations when not applied).
3. Model version _050: Baseline model, with 'A' value of 20 applied to HX lines on Hilden Brook and Hawden Stream (between HW1.002-BJD and HW1.010-BJU) to prevent inversion of water levels.

Model _050 was completed to stabilise a section of Hawden Stream where an inversion in water surface profile occurred when Medway water levels were high. This inversion was supressing water levels upstream in a manner that was not representative. Other than removing this inversion and stabilising the model differences in model predictions were negligible.

Removal of Hilden Brook and Hawden Stream within version _049d was required as very high water levels along the Medway in extreme events led to model failure along these watercourses. Removal of these channels and their 1D-2D linkages was considered acceptable as the risk from the River Medway is related to rising floodplain water levels which causes the the lower part of these watercourse join with the Medway. Applying a form loss ('A' value) to HX lines along the wider modelled reach was required to dampen oscillations in flow and level that arose from deep flood water and large flows passing into and out of channels.
Differences in model predictions within Tonbridge was limited to typically 2-3cm as a result of the changes. Along the upper parts of Hilden Brook changes were slightly greater at 3-4cm. The changes were agreed as acceptable with the Environment Agency.

Throughout the model operation manual the three types of simulation have been referred to as 049, 049d and 050. Which type of simulation has been used for each of the design model simulations is summarised in the table below.

Return Period	Type	Model version
5	Defended	_049
10CC	Defended	_049
20	Defended	_049
30	Defended	_049
50	Defended	_049
75	Defended	_050
100	Defended	_050
100CC	Defended	_050
250	Defended	_050
1000	Defended	_049d

Return Period	Type	Model version
20	Undefended	_050
100	Undefended	_050
100CC	Undefended	_049d
1000	Undefended	_049d
100	Sensitivity	All runs _50

Future development

Model scale

A grid size of 5m has been implemented within Tonbridge and 20m upstream and downstream of Tonbridge which is suitable given more detail is required in the built-up region of Tonbridge and less in the more rural regions of the model. If flood risk needs to be investigated at a specific area of the model it may be desirable to reduce the grid size. To achieve manageable run times this may necessitate truncating the model to the area of interest.

Lock/radial gate operation rules

The EA were consulted when checking and applying operation rules to locks and sluices. The rules governing gate operation within the radial gates are thought to be the best representation of how these structures operate in a flood event. Should the operation rules change in the future it is recommended the operation rules within the model are updated accordingly and the model re-run where necessary.

Observed flood events

Should a flood event occur in the future it is recommend that the hydrological and hydraulic model is re-visited and verification of observed vs. model predictions be made to assess the performance of the model.

Further comments

HX/CN schematisation

In general, HX lines have been digitised to match the widths of ISIS cross sections at cross section locations.

Between surveyed sections HX lines have been digitised to follow the bank top as evidenced by LIDAR or bank level survey, rather than digitising rigidly to a fixed width. This means that HX widths vary between sections resulting in some differences in section area. However the overall impact on floodplain volume is expected to be small. HX lines following the bank top provides consistent bank heights between sections improving stability by not picking up unrealistic low spots where a channel widens.

In some locations there is some variation between HX line widths and the ISIS cross section widths.

This occurs for a number of reasons:

1. The ISIS cross section has been trimmed to bank tops, however the LIDAR data suggests the channel is wider than the ISIS section (e.g. CS71D, CS19JU).
2. Bank top/defence data was available within Tonbridge. The surveyed data points picks up the irregular shape of the banks within the urbanised area more accurately than LIDAR. The HX lines have been digitised to follow the bank top survey points (e.g. CS31BJU/BJD, MEDW01_0.365).
3. At junctions CN lines have been digitised so that the cells linking the 1D and 2D domains are continuous (e.g. CS68, CS69, CS68A HW1.013 and HL1.010).

Lucifer Bridge

Bank top survey was collected at Lucifer gauging station by Maltby Land Surveys Ltd in 2014. The HX lines here were digitised to follow the bank top survey points. Slightly higher ground is present beyond the bank tops; therefore a separate Z-line layer was implemented along this reach to pick up the higher elevations. These elevations were extracted from 1m filtered LIDAR data.

Stability patch (high roughness)

Some mass balance error was noted in the 2D domain between cross sections CS53DIn1 and CS56. This is an area of low ground levels between two channels. The cells in this region are wet even at low flows and it is likely the mass balance error is due to water being transferred between the north and south channels. Adding an area of increased roughness (a stability patch) here reduced the mass balance errors. Impacts on model predictions are thought to be minor.

Floodplain culverts
The SX lines which connect to the Network Rail culverts have the Z flag applied which lowers the ZC elevation of the cell to 1cm below the culvert inverts. This is necessary to stop the model failing during initialisation. It is acceptable to lower the ZC elevation since it does not pick up the culvert invert levels due to the grid resolution (e.g. 20m/5m grid cell does not centre on the channel at structure 237) or the presence of water/vegetation in the channel (e.g. structure 237) when the LIDAR was collected.

As a result of using the Z flags a number of check and warning messages occur.

"CHECK 2118 – Lowered SX ZC Zpt by X.XXm to 1D node bed level"
"WARNING 2118 - Lowered SX ZC Zpt by X.XXm to 1D node bed level"

The adjustments have been checked and are considered suitable. The flow through the culverts are smooth implying the connectivity between the upstream and downstream cells is reasonable.

A Z-line has also been applied at the downstream invert of floodplain culvert 237. This is to cut a path into the DEM where there is a clear path present in the LIDAR, but the model grid definition was not representing this. Implementing this Z-Line reduced oscillations in flow through the culvert that were identified when this was not enforced.

Mill Stream
Mill Stream through Tonbridge is modelled within ISIS but downstream of Cannon Lane (A26) the channel is modelled within the 2D domain. Z-points have been derived from 1m LIDAR and are used to cut a channel into the 2D domain where the grid resolution has not picked up the bed levels. At the transition from modelling the channel within the 1D to the 2D a SX line has been used with the Z flag which lowers the ZC of the cell for the same reasons as explained above for the floodplain culverts.

An initial water level, 3cm below the HTBDY within ISIS, has also been applied to prevent initial instabilities caused by a large amount of water flowing either in or out of the 1D/2D boundary.

2D-2D links
A warning message occurs along both 2D-2D links at regular intervals.

"WARNING 2400 - Hidden node not allocated as a primary node to a 2D2D link cell in 2D Domain Model2_Domai. Review 2D2D link line shape and check vertex spacing is not too close."

The 2D-2D link has been checked and it is considered that 2D-2D link is working correctly and this warning message does not identify any errors in the computation of the model.

Sweetening flow
Sweetening flows were added at the top of Hawden Stream and Mill Stream to prevent the model running dry and destabilising the model before and after the flood flows enter the model. The flows applied are minor (Hawden Stream: 0.1m3/s for the first 50 hours; Mill Stream: 0.05m3/s for the whole event) and considered to have limited impact on model predictions.

3 Data Structure and File Names

The final design model files and results supplied contain a series of folders as displayed in Figure 3-1.

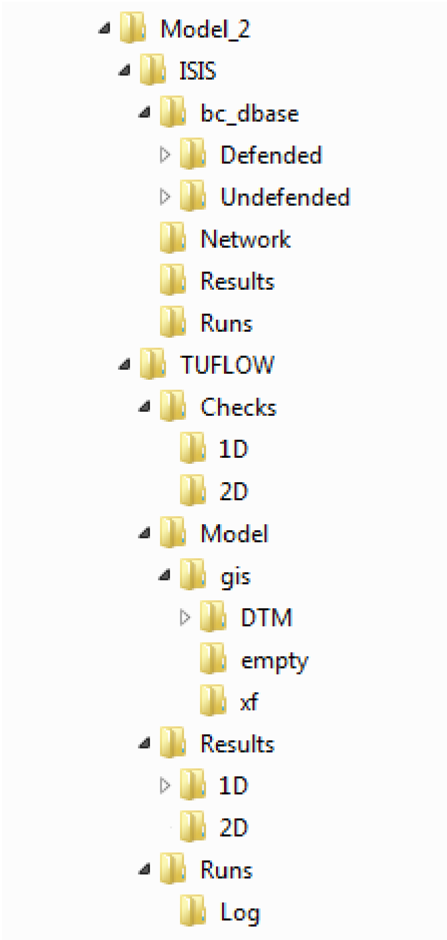
Table 3-1 shows the folder structure and notes the files stored within these.

Table 3-1: Folder Structure and contents of Final Design Model

Folder	SF1	SF2	SF3	SF4	SF5	Contents
ISIS	bc_bdase					Folder containing model boundary conditions in IED files (inflows)
	Network					ISIS Data File (DAT) and GIS Visualiser File (GXY)
	Results					ISIS Results Files
	Runs					ISIS Event Files (IEF)
TUFLOW	Checks	1D				1D ESTRY check files Medway_Model2_**###**_###_####_DDMMM########
		2D				2D TUFLOW check files Medway_Model2_**###**_###_####_DDMMM########
	Model					TUFLOW files: TUFLOW Materials File (.tmf) TUFLOW Boundary Conditions (.tbc) TUFLOW Geometry Control (.tgc)
		gis				Standard TUFLOW Model Files
			DTM			Ascii DTM used to define Zpts within the model
				xf		Binary dumps of selected input files, created by TUFLOW to speed up the start-up process next time a simulation is carried out
			empty			Empty geometry file templates
			xf			Binary dumps of selected input files, created by TUFLOW to speed up the start-up process next time a simulation is carried out
	Results	1D				1D ESTRY results files Medway_Model2_**###**_###_####_DDMMM########
		2D				2D TUFLOW results files Medway_Model2_**###**_###_####_DDMMM########
	Runs					TUFLOW Control Files (.tcf) and ESTRY Control Files (.ecf) Medway_Model2_002.ecf Medway_Model2_**###**_###_~e~.tcf
		Log				Standard TUFLOW Log files (.csv and .shp) Medway_Model2_**###**_###_####_DDMMM########

Note: **###** denotes model version (see explanation in "Strengths, Weaknesses and Future development**"** within Section 2). ### denotes **Defended** or **Undefended** case. #### denotes return period. DDMMM######## denotes event.

Figure 3-1: File Directory of Model



4 Model Operation

Run reference	Design runs
Run purpose	Flood Risk Mapping
Operation and model running instructions	Prior to running the hydraulic model, the most straight forward approach is to save all the folders supplied (as listed in Section 3) onto the user's C drive. All the supplied files will then need to be uncompressed with care taken to preserve the supplied folder structure. The 'Default File Path' within each ISIS event file (.ief) should be amended to reflect the revised 'Runs' folder location. To run the model, open the ISIS .ief file in ISIS v3.7.1 (64-bit) and then click run simulation. It is important that both ISIS and TUFLOW are installed on the machine as the ISIS component will not provide accurate results if run independently. Three domains are used within the model, meaning that a multi-domain TUFLOW license and three TUFLOW network threads will be required. An ISIS run file (.ief) has been supplied with each of the models so the model should run without any alteration (provided the 'Default File Path' has been updated).
Explanation of file types	**ISIS** .dat = ISIS Data File .ied = ISIS Event Data File .zzn = ISIS Unsteady Results File .iic = ISIS Initial Conditions Files (used as initial conditions for model runs) .zzl = ISIS labels for unsteady results .ief = ISIS Run Settings (Event File) **TUFLOW** .tcf = TUFLOW Control File .tgc = TUFLOW Geometry Control File .tbc = TUFLOW Boundary Condition Control File .ecf = ESTRY Control File

4.1 ISIS

DAT	Medway_Model2_049.DAT - for all events but the 1% + CC and 0.1% AEP undefended events and the 0.1% AEP defended event. Medway_Model2_049c.DAT (with Hilden Brook and Hawden Stream removed) - 1% + CC and 0.1% AEP undefended events and the 0.1% AEP defended event.
IED	The IED for each return period and defended / undefended events are displayed in the table below.

Return period	Defended	Undefended
5	30Aug65522100	-
10CC	09Feb67040300	-
20	26Feb34932000	11Dec20420400
30	16Dec44232000	-
50	12Dec57910900	-
75	09Jan28672100	-
100	27Nov43551900	18Feb54602100
100CC	27Nov43551900	18Feb54602100
250	07Dec68062100	-
1000	01Jan31620200	02Jan32620000

IEF	Medway_Model2_**###**_###_####_DDMMM########.ief Note: **###** denotes model version. (see explanation in "Strengths, Weaknesses and Future development" within Section 2) Note: ### denotes **Defended** or **Undefended** case. #### denotes return period. DDMMM######## denotes event.

Model run parameters (as specified in .ief event files)	ISIS 1D timestep (except for 0.4% AEP defended and 1% AEP undefended events) = 1.25s ISIS 1D timestep for 0.4% AEP defended and 1% AEP undefended events = 1.00s Save interval = 300s The parameters listed below were adjusted from defaults. An explanation for each is provided. **Automated Preissmann Slot for River Sections** A triangular slot added to the base of a river section. This aids model stability during periods of low flow. This is required for smaller sections of channel/ secondary channels which receive low flow prior to increase of flows during the flood event. **Maximum iterations = 13 (default is 6).** Increases the number of iterations at each timestep. This is considered acceptable to allow greater iterations for the model to converge where otherwise non-convergence would be recorded. For the 0.1% AEP defended event, 1% +CC and 0.1% undefended events the maximum iterations were increased to 23. This approach was completed to provide additional iterations for the model to converge. The additional iterations are used only at a small number of periods of non-convergence and are not expected to influence model reuslts.

4.2 TUFLOW

2D Control files (.tcf) **ESTRY Control file (.ecf)**	ECF: Medway_Model2_002 TCF: Medway_Model2_**###**_###_~e~.tcf Note: **###** denotes model version. (see explanation in "**Strengths, Weaknesses and Future development"** within Section 2) Note: ### denotes **Defended** or **Undefended** case.
2D Boundary condition control file (.tbc)	**Domain 1 (Upstream of railway line)** Medway_Model2_Domain1_006 - 049 and 050 Defended and 050 Undefended events Medway_Model2_Domain1_006d - 049d Defended and Undefended events **Domain 2 (Between railway line and Cannon Lane bridge)** Medway_Model2_Domain2_012 - 049 Defended events Medway_Model2_Domain2_012d - 049d Defended and Undefended events Medway_Model2_Domain2_013 - 050 Defended and Undefended events **Domain 3 (Downstream of Cannon Lane Bridge)** Medway_Model2_Domain3_006 - 049 and 050 Defended and 050 Undefended events Medway_Model2_Domain3_006d - 049d Defended and Undefended events
2D Geometry Control file (.tgc)	**Domain 1 (Upstream of railway line)** Medway_Model2_Domain1_006 - 049 and 050 Defended and 050 Undefended events Medway_Model2_Domain1_006c - 049d Defended and Undefended events **Domain 2 (Between railway line and Cannon Lane bridge)** Medway_Model2_Domain2_011 - 049 and 050 Defended events Medway_Model2_Domain2_011_undefended_v2 - 050 Undefended events Medway_Model2_Domain2_011c - 049d Defended events Medway_Model2_Domain2_011c_undefended_v2 - 049d Undefended events **Domain 3 (Downstream of Cannon Lane Bridge)** Medway_Model2_Domain3_004 - All events
1D/2D link files	1d_nd_ISIS_Model2_P_006.shp - All events except 049d Defended and Undefended events 1d_nd_ISIS_Model2_P_006c.shp - 049d Defended and Undefended events **Domain 1** 2d_bc_hxi_Model2_domain1_L_004.shp - 049 and 050 Defended and 050 Undefended events 2d_bc_hxi_Model2_domain1_L_004d.shp - 049d Defended and Undefended events

	Domain 2 2d_bc_hxi_Model2_domain2_L_012.shp - 049 Defended events 2d_bc_hxi_Model2_domain2_L_012d.shp - 049d Defended and Undefended events 2d_bc_hxi_Model2_domain2_L_013.shp - 050 Defended and Undefended events **Domain 3** 2d_bc_hxi_Model2_domain3_L_004.shp - 049 and 050 Defended and 050 Undefended events 2d_bc_hxi_Model2_domain3_L_004d.shp - 049d Defended and Undefended events 2d_bc_hxi_Model2_domain3_P_001.shp - All events
2D/2D link files	2d_2d_bc_Model2_domain1&2_L_002.shp - Between domains 1 and 2 2d_2d_bc_Model2_domain2&3_L_002.shp - Between domains 2 and 3
ESTRY culvert link files	1d_nwke_railway_floodplain_structures_L_002.shp **Domain 1** 2d_bc_floodplain_structures_domain1_L_001.shp - All events **Domain 2** 2d_bc_floodplain_structures_domain2_L_002.shp - 049 and 050 Defended events and 050 Undefended events 2d_bc_floodplain_structures_domain2_L_002c.shp - 049d Defended and Undefended events
Downstream boundary condition(s)	2d_bc_DSBDY_Model2_L_002.shp QH boundary with the slope equal to the slope of the 1D channel.
2D grid files	**Grid location** 2d_loc_Model2_domain1_L_001.shp (domain 1) 2d_loc_Model2_domain2_L_001.shp (domain 2) 2d_loc_Model2_domain3_L_001.shp (domain 3) **Grid dimensions in metres (X,Y)** 2600, 2700 (domain 1) 3600, 2800 (domain 2) 4200, 3100 (domain 3) **Cell size in metres** 20m (domain 1 and domain 3) 5m (domain 2) **Ascii grids** LIDAR_filtered_Medway_Model2_1m.asc (all domains) 1m resolution filtered LIDAR data used to update ground levels within all domains **Active area file** Domain 1 2d_code_activate_Model2_domain1_R_002.shp - 049 and 050 Defended and 050 Undefended events 2d_code_activate_Model2_domain1_R_002c.shp - 049d Defended and Undefended events Domain 2 2d_code_activate_Model2_domain2_R_002.shp - 049 and 050 Defended events and 050 Undefended events 2d_code_activate_Model2_domain2_R_002c.shp - 049d Defended and Undefended events Domain 3 2d_code_activate_Model2_domain3_R_002.shp - All events **Inactive area file** Domain 1 2d_code_deactivate_Model2_domain1_R_002.shp - All events

	Domain 2 2d_code_deactivate_Model2_domain2_R_007.shp - 049 and 050 Defended events and 050 Undefended events 2d_code_deactivate_Model2_domain2_R_007c.shp - 049d Defended and Undefended events Domain 3 2d_code_deactivate_Model2_domain3_R_001.shp - All events
2D Model Geometry files	**Domain1 (Upstream of railway line)** 2d_zln_banks_Model2_L_004.shp 2d_zln_banks_DTM_Model2_P_003.shp 2d_zln_banks_DSM_Model2_P_002.shp 2d_zln_banks_MLSltd_Model2_L_002.shp 2d_zln_banks_MLSltd_Model2_P_002.shp 2d_zln_banks_Lucifer_Model2_L_001.shp 2d_zln_banks_Lucifer_Model2_P_001.shp 2d_zsh_Model2_domain1_railway_R_002.shp 2d_zln_railway_embankment_Model2_L_002.shp 2d_zln_railway_embankment_Model2_P_002.shp **Domain2 (Between railway line and Cannon Lane bridge)** 2d_zsh_Model2_roads_L_001.shp 2d_zsh_Model2_roads_P_001.shp 2d_zsh_cannon_lane_topo_R_001.shp 2d_zsh_cannon_lane_topo_P_001.shp 2d_ztin_cannon_lane_topo_embankment_R_002.shp 2d_ztin_cannon_lane_topo_embankment_L_002.shp 2d_ztin_cannon_lane_topo_embankment_P_002.shp 2d_zln_banks_Model2_domain2_L_006.shp - 049 and 050 Defended events and 050 Undefended events 2d_zln_banks_Model2_domain2_L_006c.shp - 049d Defended and Undefended events 2d_zln_banks_DTM_Model2_domain2_P_005.shp - 049 and 050 Defended events and 050 Undefended events 2d_zln_banks_DTM_Model2_domain2_P_005c.shp - 049d Defended and Undefended events 2d_zln_banks_DSM_Model2_domain2_P_004.shp - 049 and 050 Defended events and 050 Undefended events 2d_zln_banks_DSM_Model2_domain2_P_004c.shp - 049d Defended and Undefended events 2d_zln_banks_Cannon_Lane_Survey_Model2_L_001.shp 2d_zln_banks_Cannon_Lane_Survey_Model2_P_001.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_L_001a.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_P_001a.shp 2d_zln_railway_embankment_Model2_L_002.shp 2d_zln_railway_embankment_Model2_P_002.shp 2d_zln_culvert_inverts_L_001.shp 2d_zln_culvert_inverts_P_001.shp 2d_zsh_TON_footpaths_A001_L_001.shp 2d_zsh_TON_footpaths_A001_P_001.shp 2d_zpt_Supermarket_voids_R_001.shp *Defended only* 2d_zln_Defences_Model2_domain2_L_003.shp 2d_zln_Defences_Model2_domain2_P_003.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_L_001b.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_P_001b.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_L_001c.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_P_001c.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_L_001d.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_P_001d.shp 2d_zln_banks_MLSltd_Model2_domain2_L_004.shp 2d_zln_banks_MLSltd_Model2_domain2_P_004.shp 2d_zln_banks_MLSltd_LIDAR_fill_Model2_domain2_P_002.shp 2d_zln_banks_JCWhite_Model2_domain2_Big_Bridge_P_001.shp 2d_zln_banks_River_Walk_RB_Model2_domain2_L_001.shp 2d_zln_banks_River_Walk_RB_Model2_domain2_P_001.shp

	Undefended only 2d_zln_Defences_Model2_domain2_undefended_L_003.shp 2d_zln_Defences_Model2_domain2_undefended_P_003.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_undefended_L_001c.shp 2d_zln_banks_JCWhite_Model2_domain2_GasWorks_undefended_P_001c.shp 2d_zln_banks_MLSltd_Model2_domain2_undefended_L_004.shp 2d_zln_banks_MLSltd_Model2_domain2_undefended_P_004.shp 2d_zln_banks_MLSltd_LIDAR_fill_Model2_domain2_P_002.shp 2d_zln_Tonbridge_undefended_L_001.shp 2d_zln_Tonbridge_undefended_P_001.shp **Domain3 (Downstream of Cannon Lane Bridge)** 2d_zln_banks_Model2_L_004.shp 2d_zln_banks_DTM_Model2_P_003.shp 2d_zln_banks_DSM_Model2_P_002.shp 2d_zsh_Mill_Stream_Model2_L_001.shp 2d_zsh_Mill_Stream_Model2_P_001.shp 2d_zln_Defences_Model2_L_001.shp 2d_zln_Defences_Model2_P_001.shp
Materials file (.tmf)	Medway_Model2_005

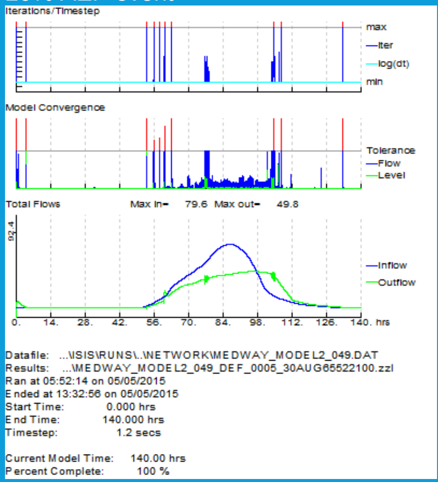
4.2.1 Run settings

Model start time (hrs)	0	**Model end time (hrs)**	140
Map save interval (s)	1800	**Time series save interval (s)**	300
Map outputs (TUFLOW Flag) DAT data format	d h q v MB1 MB2 ZUK0 Z0	**Time Step (s)**	2.5 (except for 0.4% AEP defended and 1 % AEP undefended events - 1.0s)

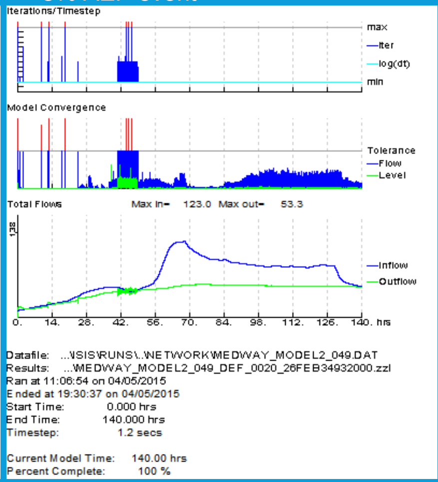
4.2.2 Model stability

Comments on results	See plots of Cum ME (%), dVol and ISIS convergence below. The ISIS convergence plots show the model is generally stable, although a period of non-convergence is evident at the start of the simulation. This is associated with gate hunting at Eldridge's Lock and Radial gate. The change in volume (dVol) plot shows smooth transitions between timesteps, which generally follows the same pattern and model inflows. This indicates the 1D-2D links are stable. CUM ME (%) is initially large (negative mass error) when the 2D domain first becomes wet but the mass error returns to closer to 0 during the peak flow and is never outside of the recommended range of ±1%.
ISIS convergence plots	See next page.

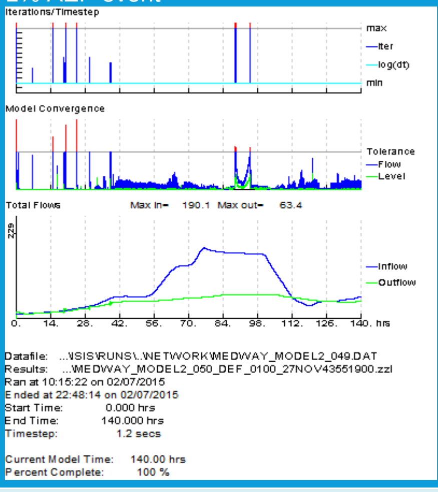
20% AEP event



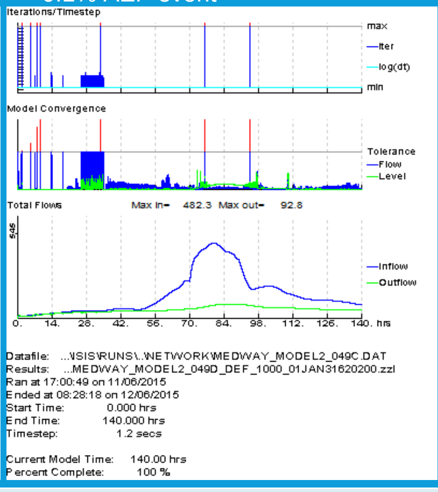
5% AEP event



1% AEP event

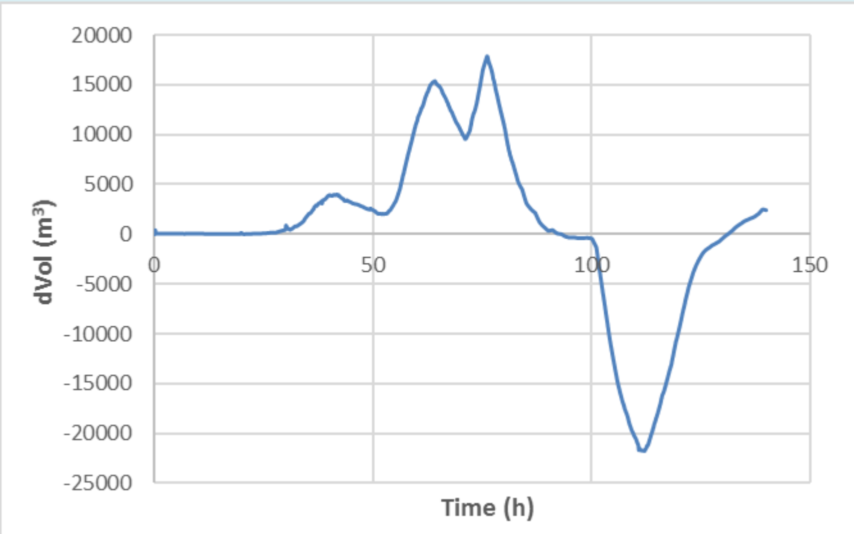


0.1% AEP event

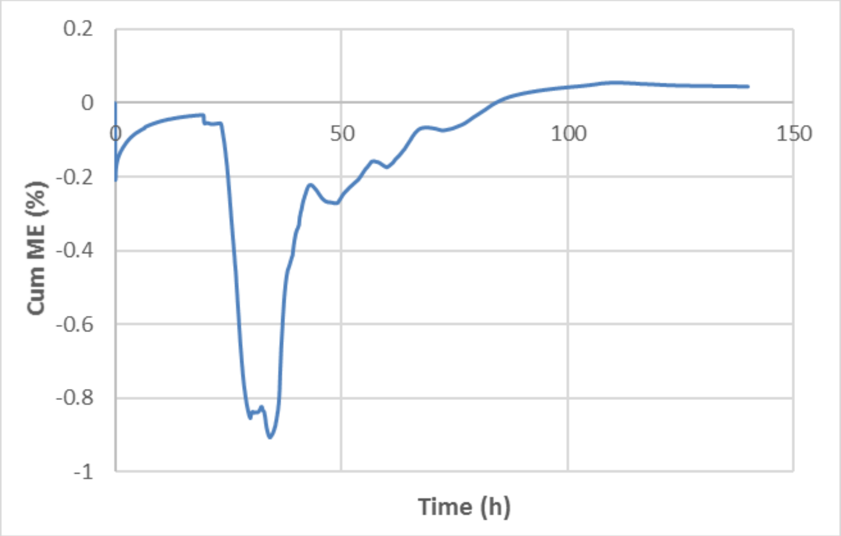


dVol (m^3)

1% AEP



Cum ME (%)	1% AEP



Appendices

A Modelling approach and overview

A.1 Modelling Approach

A.1.1 Available Data

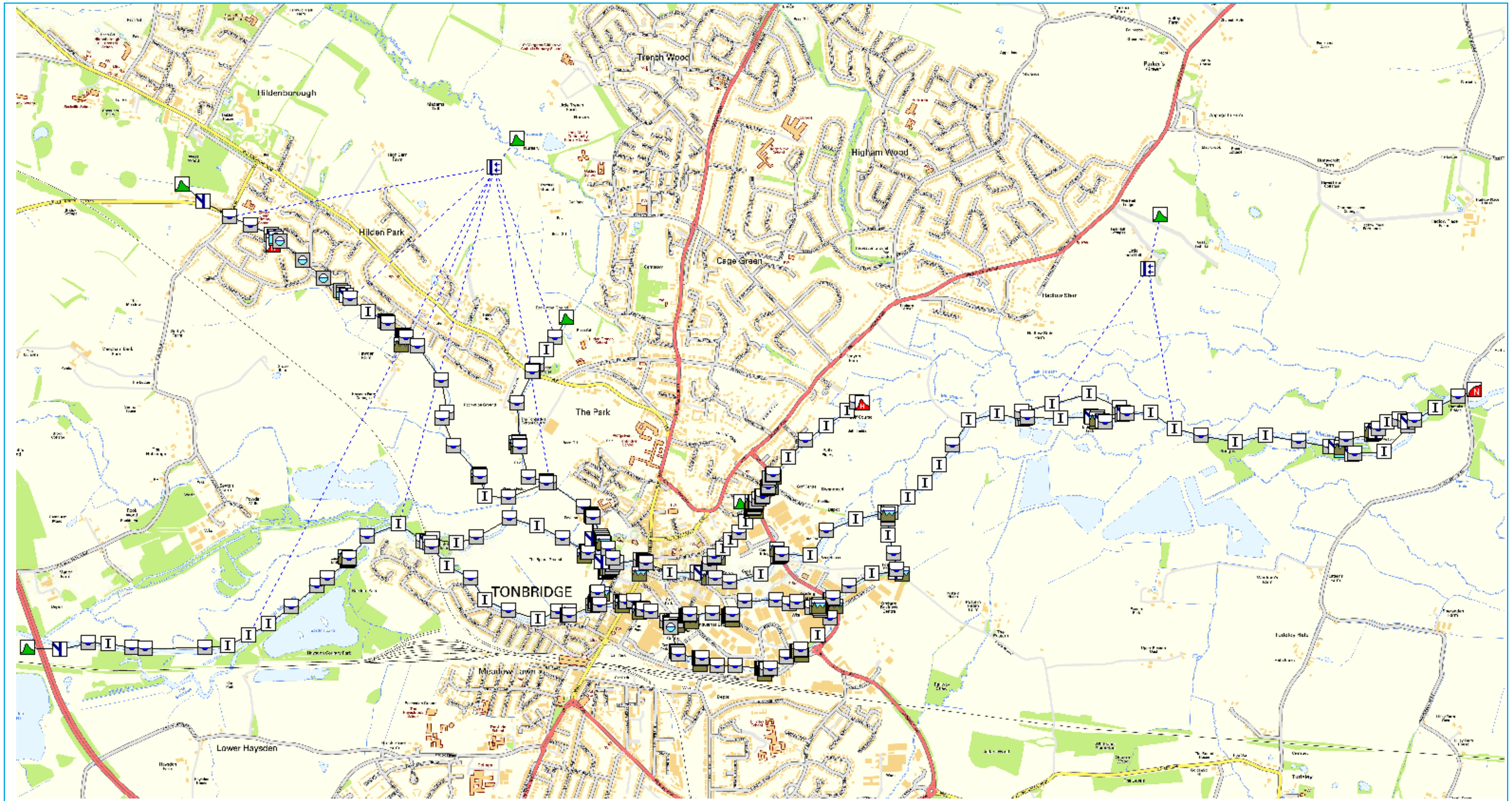
Cross-section survey	A number of survey datasets were used within the model. The 2008 River Medway model, which makes up a large majority of the ISIS model, is constructed from the 1995 Flynn & Rothwell data. Hilden Brook and Hawden stream were modelled within both the Hilden Brook & Hawden Stream Flood Risk Mapping (2006) study and the Tonbridge Hazard Mapping Study (2010) represented by a 1D ISIS and ESTRY model respectively. The survey data used to construct Hilden Brook & Hawden Stream within these models is from the Medway Tributaries Survey, Capital Surveys Ltd, 2005. The Tonbridge Hazard Mapping model was also developed from a combination of the of the Cannon Lane 1D-2D model of Tonbridge (developed in 2008, which was developed from the original Section 105 Environment Agency study of the River Medway, which was updated in 2006 as part of Tonbridge and Malling's SFRA) and the Updated Flood Forecasting Model of the Upper Medway for Routing. The original survey data used to construct the Tonbridge Hazard Mapping Study (2010) was not available. A selection of other datasets of note are listed below with the date of the survey indicated by (date) and the survey company is indicated by [company]: Survey data commissioned for this study: Gauging Stations (2014) [Maltby Land Surveys Ltd] Tonbridge (River Medway, Gas Works Stream, Botany Stream , Mill Stream) (2014) [Maltby Land Surveys Ltd] Floodplain structures and other channel cross sections (2014) [Maltby Land Surveys Ltd] Previous survey data available: Medway Tributaries Survey (2005) [Capital Surveys Ltd] River Medway (1995) [Medway Regime Study - Flynn & Rothwell] Tonbridge Eastern Relief Hadlow Road - Cannon Lane: Garden Road Culvert General Arrangement (1986) [Kent County Council Highways & Transportation Department]
Bank Top Survey	Primary bank level and defence survey data was available for part of Tonbridge: Survey data commissioned for this study: Gauging Stations (2014) [Maltby Land Surveys Ltd] Tonbridge (River Medway, Gas Works Stream, Botany Stream , Mill Stream) (2014) [Maltby Land Surveys Ltd] Previous survey data available: Lambert's Yard survey (2015) [J C White] Upstream of Big Bridge (2014) [J C White] Topographic survey of Cannon Lane (2007) [Walker Ladd Ltd] Defence/bank levels represented within the 2D domain of the Tonbridge Hazard Mapping study are derived from the survey data collected for the Tonbridge and Malling

	Borough Council SFRA (2006), Cannon Lane Site Flood Risk Assessment (Mott MacDonald, January 2008) and spot levels surveys (conducted for the Hazard Mapping study, 2010). The original survey data used to construct the Tonbridge Hazard Mapping Study (2010) was not available.
LIDAR & other Topographic Data:	1m filtered and unfiltered LIDAR data (flown December 2011 / April 2009)
Map Data:	OS Open Data, OS 1:10,000, OS 1:25,000, OS 1:50,000 and OS MasterMap.

A.2 Model Overview

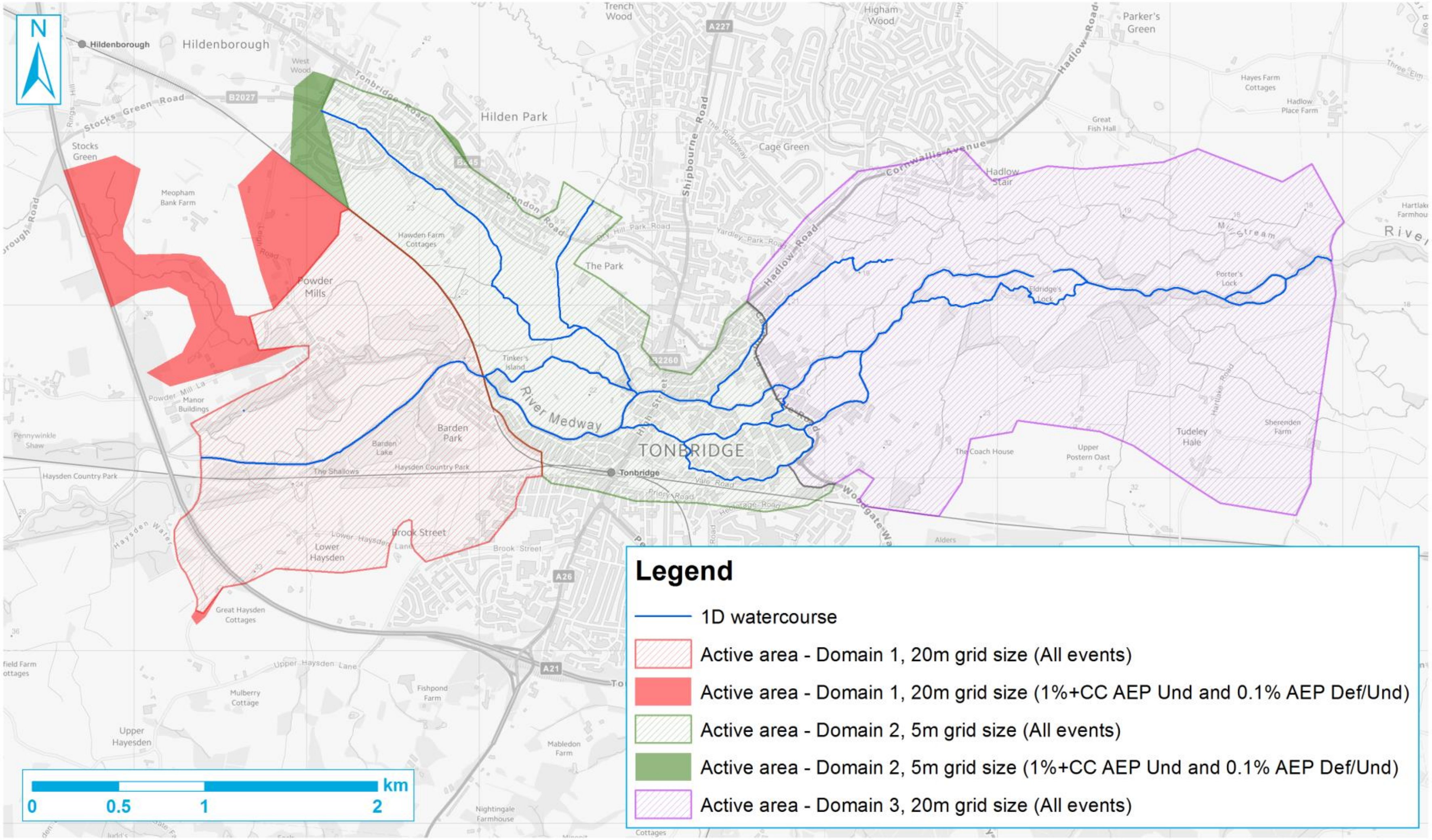
The ISIS Model Schematic (.GXY) is displayed in Figure A-1, whilst a schematic of the ISIS-TUFLOW model setup is displayed in Figure A-2.

Figure A-1: ISIS Model Schematic (supplied with the model files as a .GXY file)



Medway_Model2_049.DAT. Contains Ordnance Survey data © Crown copyright and database right 2014.

Figure A-2: ISIS-TUFLOW model schematic



A.2.2 Overview of 1D Model

Upstream Boundaries	River Medway: Downstream of Leigh Flood Storage Area Hilden Brook: : 250m upstream of London Road (B245) Hawden stream: : Leigh Road (B2027)
Lateral Catchment Weighting	Inflows were assigned to the model based on the schematisation within the flood forecasting model which is used for continuous simulation hydrological modelling. These inflows were then weighted to various parts of the hydraulic model according to catchment areas derived using the FEH CD-ROM. Three hydrological inflows are implemented, with two split between two or more lateral inflows. Additionally, there are two sweetening inflows implementing a small amount of flow to prevent model failure at very low flows. One is located on Hawden Stream and the other on Mill Stream. See Appendix C for further details.
Downstream Boundary	**Hartlake Bridge** A normal depth boundary (NCDBDY boundary unit) is implemented at the downstream boundary with the slope specified equal to the slope of the 1D channel bed.
Total Number of nodes and structures	The Medway_Model2_049.DAT ISIS model consists of 411 nodes including: 172 River Sections 44 Spill units (some represent inline weirs) 41 Interpolate units 19 USBPR Bridges 8 Circular conduits 6 Arch Bridges 6 Flow-Time (QTBDYs) 5 Round nosed broad crested weir units 5 Vertical Sluice units 4 Culvert outlet units 3 Culvert inlet unit 3 Orifice units 2 Rectangular conduits 2 HTBDY 2 Lateral units 1 Bernouilli Loss unit 1 Radial Sluice unit 1 Normal Depth (NCDBDYs) (downstream boundary)
Labelling/ Numbering System Used	Labelling conventions of the model generally remains as per the existing River Medway Modelling and Flood Mapping Updates (2008) model, the Tonbridge Hazard Mapping Study (2010) and the Hilden Brook & Hawden Stream Flood Risk Mapping study (2006). Where new survey has been implemented the labelling follows from the survey cross section labels. An overview of sections nomenclature is provided below, in addition to a description of whether this was retained from the previous modelling (indicated by a 'R'), or adjusted or implemented as part of the model updates ('indicated by a 'U'). CS## (R) River Medway downstream of Leigh Barrier CSD## (R) River Medway northern channel, Tinker's Island CSJ# (R) River Medway bifurcation channel GW_## (R) Gas Works Stream BS_## (R) Botany Stream MS_## (R) Mill Stream HL1.0## (R) Hilden Brook HW1.0## (R) Hawden Stream LUCI01_#### (U) Lucifer Bridge MEDW01_#### (U) River Medway MEDW02_#### (U) River Medway northern channel, Tinker's Island TONB01_#### (U) Gas Works Stream MILL01_#### (U) Mill Stream

	UNKN01_#### (U) Culvert Hawden Stream
Hydraulic roughness values used	Channel roughness values have been represented in the model by Manning's n. In order to determine the channel roughness, descriptions in Chow (1959)[1] were examined against photographic evidence, survey data and satellite imagery. Roughness values for sections retained from previous models were reviewed and it was not proposed to adjust the roughness coefficients. However, where sections from previous models are between sections from the 2014 survey data and the roughness coefficients are reasonably different, the roughness coefficients of the sections from the previous models have been updated. Appendix E has more information relating to the roughness coefficients chosen for the new survey and for sections from the previous models updated. Sensitivity tests were undertaken to test the effect of increases and decreases in roughness. Please refer to the main study report for a summary of these tests.

1 Chow V.T. (1959) Open Channel Hydraulics McGraw Hill

A.2.3 Overview of 2D Model

Area of 2D domain	**Domain 1** 2.7km^2 - 049 and 050 defended and 050 undefended events 3.5 km^2 - 049d defended and undefended events **Domain 2** 2.8km^2 - 049 and 050 defended events and 050 undefended events 3.0km^2 - 049d defended and undefended events **Domain 3** 5.6km^2	**DTM data source**	LIDAR. Supplied by Geomatics Group Ltd
Resolution of grid	Domain 1 and 3: 20m Domain 2: 5m	**DTM resolution**	1m
Orientation of grid	Domain 1: SW to NE ↗ Domain 2: W to E → Domain 3 : WSW to ENE ↗		

Modifications to model topography (Domain 1)

File	Description
2d_zln_banks_DTM_ Model2_P_003.shp	Bank levels derived from 1m filtered LIDAR data at 5m intervals.
2d_zln_banks_DSM_ Model2_P_002.shp	Bank levels derived from 1m unfiltered LIDAR data in areas of poor filtering.
2d_zln_banks_MLSltd_ Model2_P_002.shp	Bank survey data from Maltby Land Survey, 2014.
2d_zln_banks_Lucifer_ Model2_P_001.shp	Bank levels derived from 1m filtered LIDAR data at Lucifer bridge where the Maltby Land Survey data is inside of the highest topography at the bank tops.
2d_zsh_Model2_domain1 _railway_R_002.shp	Z-shape around areas of poor filtering in the LIDAR. Creates a flow route under railway line south of CS7 and at Lower Haysden Lane.
2d_zln_railway_ embankment_Model2_ P_002.shp	Railway line upstream of Tonbridge enforced by z-line. Elevations derived from LIDAR 1m DTM at maximum spacing of 10m.

Modifications to model topography (Domain 2)

File	Description
2d_zsh_Model2_roads_P_ 001.shp	Elevations for roads within Tonbridge which can act as a flow route once water is out of bank. Levels extracted from 1m filtered LIDAR data. Z-Shape used in preference to a Z-Line to provide a continuous flow route between ZC points.
2d_zsh_cannon_lane_ topo_P_001.shp	Topographic survey of Cannon Lane. Survey was carried out in 2007 by Walker Ladd Ltd, drawing no 8022/2 and files 1159-0.dwg and TOPO.dwg.
2d_ztin_cannon_lane_ topo_embankment_P_002 .shp	Topographic survey of Cannon Lane. Survey was carried out in 2007 by Walker Ladd Ltd, drawing no 8022/2 and files 1159-0.dwg and TOPO.dwg.
2d_zln_banks_DTM_ Model2_P_005.shp / 2d_zln_banks_DTM_ Model2_P_005c.shp	Bank levels derived from 1m filtered LIDAR data at 5m intervals.
2d_zln_banks_DSM_ Model2_P_004.shp /	Bank levels derived from 1m unfiltered LIDAR data in areas of poor filtering.

2d_zln_banks_DSM_ Model2_P_004c.shp	
2d_zln_banks_Cannon_ Lane_Survey_Model2_ P_001.shp	Bank levels from Cannon Lane Survey - taken from Tonbridge Hazard Mapping Study (2010). Original survey data collected for the Cannon Lane Site Flood Risk Assessment (Mott MacDonald, January 2008).
2d_zln_banks_JCWhite_ Model2_domain2_ GasWorks_P_001a.shp	Bank levels on north bank of Gas Works Stream collected by J C White in February 2015 (Lambert's Yard survey).
2d_zln_railway_ embankment_Model2_ P_002.shp	Railway line upstream of Tonbridge enforced by z-line. Elevations derived from LIDAR 1m DTM at maximum spacing of 10m.
2d_zln_culvert_inverts_P_ 001.shp	Z-line creates clear path of cells at downstream of railway floodplain structure 237 that is present in LIDAR but grid definition does not pick it up.
2d_zsh_TON_footpaths_ A001_P_001.shp	Level for footpaths through buildings (shopping centre). Data taken from Tonbridge Hazard Mapping Study (2010).
2d_zpt_Supermarket_ voids_R_001.shp	Estimated level of voids at supermarket where LIDAR filtering does not represent this.

Defended only

File	Description
2d_zln_Defences_Model2 _P_003.shp	Survey data taken from Tonbridge Hazard Mapping Study (2010). Note: defence line between Big Bridge and Town Lock updated as per EA email dated 1 April 2015 with digitised line.
2d_zln_banks_JCWhite_ Model2_domain2_ GasWorks_P_001b.shp	Bank levels on north bank of Gas Works Stream collected by J C White in February 2015 (Lambert's Yard survey).
2d_zln_banks_JCWhite_ Model2_domain2_ GasWorks_P_001c.shp	Bank levels on north bank of Gas Works Stream collected by J C White in February 2015 (Lambert's Yard survey).
2d_zln_banks_JCWhite_ Model2_domain2_ GasWorks_P_001d.shp	Bank levels on north bank of Gas Works Stream collected by J C White in February 2015 (Lambert's Yard survey).
2d_zln_banks_MLSltd_ Model2_domain2_P_004.s hp	Bank survey data from Maltby Land Survey, 2014.
2d_zln_banks_MLSltd_ LIDAR_fill_Model2_ domain2_P_002.shp	Supplements 2d_zln_banks_MLSltd_ Model2_domain2_P_004.shp with a couple of LIDAR points where high ground was not identified by survey.
2d_zln_banks_JCWhite_ Model2_domain2_Big_ Bridge_P_001.shp	J C White Survey data (September 2014) upstream of Big Bridge.
2d_zln_banks_River_Walk _RB_Model2_domain2_P _001.shp	Wall levels on right bank of River Medway just north of Wharf Road bridge where wall has been re-built following tree falling into river during December 2013 flood event. Data from file: PB2636-KSL0484-102.pdf . Revision C2, August 2014.

Undefended only

File	Description
2d_zln_Defences_Model2 _undefended_P_003.shp	Undefended case of 2d_zln_Defences_Model2_P_003.shp with some defences removed.
2d_zln_banks_JCWhite_ Model2_domain2_ GasWorks_undefended_P _001c.shp	Undefended case of 2d_zln_banks_JCWhite_ Model2_domain2_ GasWorks_P_001c.shp with some defences removed.
2d_zln_banks_MLSltd_ Model2_domain2_ undefended_P_004.shp	Undefended case of 2d_zln_banks_MLSltd_ Model2_domain2_P_004.shp with some defences removed.
2d_zln_banks_MLSltd_ LIDAR_fill_Model2_ domain2_P_002.shp	Supplements 2d_zln_banks_MLSltd_ Model2_domain2_undefended_P_004.shp with a couple of LIDAR points where high ground was not identified by survey.
2d_zln_Tonbridge_ undefended_P_001.shp	Replaced defence level Z-Lines with elevations from LIDAR for undefended case.

Modifications to model topography (Domain 3)

File	Description
2d_zln_banks_DTM_ Model2_P_003.shp	Bank levels derived from 1m filtered LIDAR data at 5m intervals.
2d_zln_banks_DSM_ Model2_P_002.shp	Bank levels derived from 1m unfiltered LIDAR data in areas of poor filtering.
2d_zln_Defences_ Model2_P_001.shp	Survey data taken from Tonbridge Hazard Mapping Study (2010).
2d_zsh_Mill_Stream_ Model2_P_001.shp	Bed levels of Mill Stream downstream of Cannon Lane (A26) derived from 1m LIDAR to cut a channel into the 2D domain.

Hydraulic roughness used within the 2D domain

Ordnance Survey MasterMap Topographic Area data was used to define the 2D floodplain roughness values for individual MasterMap feature classes. The Manning's *n* values used are tabulated below.

Table 4-1: Manning's n roughness values for the 2D domains, based on OS MasterMap land cover classes

Land cover	Manning's n
Building	0.300
General surface - multi surface	0.090
General surface - step	0.090
General surface	0.100
Glasshouse	0.200
Inland water	0.095
Landform	0.100
Boulders	0.105
Coniferous trees	0.160
Coniferous trees - scattered / Orchard	0.110
Coppice or osiers	0.130
Marsh reeds or saltmarsh	0.100
Non-coniferous trees	0.130
Non-coniferous trees - scattered	0.100
Rough grassland	0.100
Scrub	0.110
Path	0.090
Rail	0.080
Road	0.080
Roadside	0.090
Structure	0.300
Structure - upper level of communication	0.300
Structure - pylon	0.100
Tidal water	0.095
Unclassified	0.100
Rock	0.110
Heath	0.130
Stability	0.100
Stability	0.300

A.2.4 1D-2D Linking

JBA have retained the standard approach to linking 1D ISIS and 2D TUFLOW models in each domain. Within the TUFLOW model HX boundaries are defined for the left and right banks and the channel area in between classified as 'inactive' in the 2D grid. The HX boundaries are linked to the respective ISIS nodes using CN connection lines and are discontinued at structures and confluences. Along these boundaries, water levels in the channel and floodplain interact dynamically and thus control floodplain wetting and drying.

B List of structures

The tables within the following sections outline the structures included within the hydraulic model. Listed are those on the main Medway channel, other channels along the River Medway, Hilden Brook, Hawden Stream, Mill Stream, Gas Works Stream and Botany Stream. Floodplain structures modelled within ESTRY have also been listed.

Where the representation of the modelled structures differs from default (e.g. non-default parameters or coefficients) these are recorded. Links are also provided to structure photos where available.

B.1 River Medway

Structure name	Structure type	Structure updated	Upstream node	Downstream node	Survey reference	Model representation	Spill unit attached	Spill Weir coefficient	Spill Modular limit	Structure photo
Lucifer Bridge	Footbridge	Implemented	LUCI01_0018BU	LUCI01_0018BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.10	0.90	Section **D.1**
-	Footbridge	Implemented	MEDW_0154BU	MEDW_0154BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.30	0.90	Section **D.1**
-	Footbridge	Implemented	MEDW_0853BU	MEDW_0853BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.00	0.90	Section **D.1**
-	Footbridge	Implemented	MEDW_0666BU	MEDW_0666BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.00	0.90	Section **D.1**
New Wharf Road bridge	Road bridge	No change	CS30BU	CS30BD	Flynn & Rothwell 1995	Bernoulli Loss unit	Yes	1.00	0.90	Section **D.1**
The Big Bridge	Road bridge	Implemented	MEDW_0356BU	MEDW_0356BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.10	0.90	Section **D.1**
Town Lock gate	Lock	Updated	CS36LU	CS36LD	108825-0900-0008-PB-Town.pdf and T4163_Town.dwg	Vertical Sluice unit	Yes*	1.20	0.90	Section **D.1**
Radial gate at Town Lock	Sluice gate	No change	CS36RU	CS36RD	108825-0900-0008-PB-Town.pdf and T4163_Town.dwg	Vertical Sluice unit	Yes*	1.20	0.90	Section **D.1**
Long and higher weir at Town Lock	Weir	No change	CS36WU3	CS36WD3	Town Lock Canoe and Fish Pass As Builts.pdf	Broad crested round-nosed weir	Yes*	1.20	0.90	Section **D.1**
Short and lower weir at Town Lock	Weir	No change	CS36WU4	CS36WD4	Town Lock Canoe and Fish Pass As Builts.pdf	Broad crested round-nosed weir	Yes*	1.20	0.90	Section **D.1**
Fish and canoe pass at Town Lock	Fish pass	Implemented	CS36FPU	CS36FPD	WNNMFP-310 Rev Z.dwg and WNNMFP-303 Rev Z.dwg	ISIS Spill unit	N/a	0.57	0.90	Section **D.1**
Cannon Bridge	Road bridge	Implemented	CS39BU	CS39BD	Tonbridge Hazard Mapping (2010) Estry data	Bridge (USBPR 1978)	Yes	1.70	0.90	No photo available
-	Weir	No change	CSJ1U	CSJ1	Flynn & Rothwell 1995	Broad crested round-nosed weir	N/a	-	-	No photo available
Eldridges Lock	Lock	Updated	CS56LU	CS56LD	108825-0900-0005-PB-Eldridges Lock.pdf and T4180_Eldridges Topo Survey (Halcrow)with updated points.dwg	Vertical Sluice unit	Yes*	1.00	0.50	No photo available
Radial gate at Eldridges Lock	Radial gate	Updated	CS56RU	CS56RD	WN-NELR-310 RA.pdf and 6359.01 Construction Drawings 24.01.2011.pdf	Radial Sluice unit	Yes*	1.00	0.50	No photo available
Fish and canoe pass at Eldridges Lock	Fish pass	Implemented	CS56FPU	CS56FPD	WN-NAVS-05C-053 Rev0.pdf	ISIS Spill unit	N/a	0.57	0.90	No photo available
Radial Gate at Porter's Lock	Radial gate	No change	CS68RU	CS68RD	Flynn & Rothwell 1995	Vertical Sluice unit	Yes*	1.50	0.90	No photo available
Fish and canoe pass at Porter's Lock	Fish pass	Implemented	CS68FPU	CS68FPD	PORTERS LOCK CFP AS BUILT DRAWINGS.pdf	ISIS Spill unit	N/a	0.57	0.90	No photo available
Porter's Lock	Lock	Updated	CS70LU	CS70LD	X- T4163_Porters.dwg and 108825-0900-0001-PA-Porters.pdf	Vertical Sluice unit	Yes*	1.10	0.90	Section **D.1**

*Spill used to represent bypassing flow

B.2 Hilden Brook and Hawden Stream

Structure name	Structure type	Structure updated	Upstream node	Downstream node	Survey reference	Model representation	Spill unit attached	Spill Weir coefficient	Spill Modular limit	Structure photo
London Road bridge (Hilden Bridge)	Road bridge	Implemented	HL1.003-BU	HL1.003-BD	Capital Surveys Ltd 2005	Bridge (Arch)	No	-	-	No photo available
-	Footbridge	Implemented	HL1.006-BU	HL1.006-BD	Capital Surveys Ltd 2005	Bridge (USBPR 1978)	Yes	1.70	0.90	No photo available
-	Access bridge	Implemented	HL1.007-BU	HL1.007-BD	Capital Surveys Ltd 2005	Bridge (USBPR 1978)	Yes	1.20	0.90	No photo available
The Slade road bridge	Road bridge	Implemented	HL1.012-BU	HL1.012-BD	Capital Surveys Ltd 2005	Bridge (USBPR 1978)	Yes	1.00	0.90	No photo available
-	Footbridge	Implemented	HL1.013-BU	HL1.013-BD	Capital Surveys Ltd 2005	Bridge (USBPR 1978)	Yes	1.70	0.90	No photo available
-	Drop in bed level/informal weir	Implemented	HL1.014D	HL1.015D	Capital Surveys Ltd 2005	ISIS Spill unit	N/a	1.70	0.90	No photo available
-	Culvert	Implemented	HW1.001C1	HW1.001C4	Maltby Land Surveys 2014	Circular culvert	Yes	0.50	0.90	Section **D.2**
-	Footbridge	Implemented	HW1.002-BU	HW1.002-BD	Capital Surveys Ltd 2005	Bridge (USBPR 1978)	Yes	1.00	0.90	No photo available
Hawden Lane road bridge	Culvert	Implemented	HW1.003CU	HW1.003CD	Capital Surveys Ltd 2005	Circular culvert	Yes	1.70	0.90	No photo available
-	Access bridge	Implemented	HW1.010-OU	HW1.010-OD	Capital Surveys Ltd 2005	Orifice unit	Yes	1.20	0.90	No photo available

B.3 Mill Stream

Structure name	Structure type	Structure updated	Upstream node	Downstream node	Survey reference	Model representation	Spill unit attached	Spill Weir coefficient	Spill Modular limit	Structure photo
-		Implemented	MS_02OU	MS_02OD	Tonbridge Hazard Mapping (2010) Estry data	Orifice unit	Yes	1.00	0.90	No photo available
-	Access bridge	Implemented	MILL_0145BU	MILL_0145BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	0.90	0.90	Section **D.3**
-	Access bridge	Implemented	MILL_0110BU	MILL_0110WU	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.00	0.90	Section **D.3**
-	Drop in bed level/informal weir	Implemented	MILL_0110WU	MILL_0110WD	Maltby Land Surveys Ltd 2014	ISIS Spill unit	N/a	1.70	0.90	Section **D.3**
-	Drop in bed level/informal weir	Implemented	MS_06	MS_06D	Tonbridge Hazard Mapping (2010) Estry data	ISIS Spill unit	N/a	1.70	0.90	No photo available
Garden Road bridge	Road bridge	Implemented	MILL_004BU	MILL_004BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.3**
Cannon Lane road bridge		Implemented	MS_07cu	MS_07cd	Kent County Council Highways & Transportation Department (1986). Drawing: (130306) 39810 General Arrangement 1986.pdf	Rectangular culvert	Yes	1.20	0.90	No photo available

B.4 Gas Works and Botany Stream

Structure name	Structure type	Structure updated	Upstream node	Downstream node	Survey reference	Model representation	Spill unit attached	Spill Weir coefficient	Spill Modular limit	Structure photo
Buleys weir	Weir	No change	GW_02WU	GW_02WD	Medway Catchment & Modelling (2008) model and drawing PB2636/KSL0328/112 (Sept 2014)	Broad crested round-nosed weir	N/a	-	-	Section **D.4**
High Street Road bridge	Road bridge	Implemented	TONB_1109BU	TONB_1092BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.00	0.90	Section **D.4**
-	Footbridge	Implemented	TONB_1007BU	TONB_1007BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.20	0.90	Section **D.4**
-	Weir	No change	GW_10WU	GW_10WD	Medway Catchment & Modelling (2008) model	Broad crested round-nosed weir	Yes*	1.00	0.90	Section **D.4**
-	Footbridge	Implemented	TONB_0833BU	TONB_0833BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.20	0.90	Section **D.4**
Sovereign Way road bridge	Road bridge	Implemented	TONB_0772BU	TONB_0772BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.4**
Walter's Farm Road bridge	Road bridge	Implemented	TONB_0554BU	TONB_0554BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.4**
Vale Road bridge	Road bridge	Implemented	TONB_0017BU	TONB_0017BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.4**
Postern Lane bridge	Road bridge	Implemented	GW_24BU	GW_24BD	Tonbridge Hazard Mapping (2010) Estry data	Bridge (USBPR 1978)	Yes	1.20	0.90	No photo available
-	Culvert	Implemented	BS_01CU	BS_01CD	Tonbridge Hazard Mapping (2010) Estry data	Circular culvert	No	-	-	Section **D.4**
-	Footbridge	Implemented	BS_02BU	BS_02BD	Tonbridge Hazard Mapping (2010) Estry data	Bridge (USBPR 1978)	Yes	1.20	0.90	No photo available
Sovereign Way road bridge	Road bridge	Implemented	BS_05BU	BS_05BD	Tonbridge Hazard Mapping (2010) Estry data	Bridge (USBPR 1978)	Yes	1.20	0.90	No photo available
Morley Road bridge	Road bridge	Implemented	BS_09BU	BS_09BD	Tonbridge Hazard Mapping (2010) Estry data	Bridge (USBPR 1978)	Yes	1.20	0.90	No photo available

*Spill used to represent bypassing flow

B.5 Floodplain structures (ESTRY networks)

Structure name	Structure reference	Structure updated	Model name	Model domain	Source of data	Model representation	JBA Comment	Structure photo
Railway culvert (North of Tinker's Island)	231	Implemented	231	Domain 1 and 2	Network Rail examination report (2013): Length, height, width 1m filtered LIDAR: Invert level	Rectangular culvert (ESTRY)	Invert level estimated from 1m filtered LIDAR	Section **D.5**
Railway culvert (North of Tinker's Island)	233	Implemented	233	Domain 1 and 2	Network Rail examination report (2013): Length, height, width 1m filtered LIDAR: Invert level	Rectangular culvert (ESTRY)	Invert level estimated from 1m filtered LIDAR	Section **D.5**
Railway culvert (North of Tinker's Island)	234	Implemented	234	Domain 1 and 2	Network Rail examination report (2013): Length, diameter 1m filtered LIDAR: Invert level	Circular culvert (ESTRY)	Invert level estimated from 1m filtered LIDAR	No photo available
Railway culvert (North of Tinker's Island)	235	Implemented	235	Domain 1 and 2	Network Rail examination report (2013): Length, diameter 1m filtered LIDAR: Invert level	Circular culvert (ESTRY)	Invert level estimated from 1m filtered LIDAR	Section **D.5**
Railway culvert (North of Tinker's Island)	237	Implemented	237	Domain 1 and 2	Network Rail examination report (2013): Length, height, width 1m filtered LIDAR: Invert level	Rectangular culvert (ESTRY)	Invert level estimated from 1m filtered LIDAR and photos in Network Rail report showing approximately 0.5m of water in channel.	Section **D.5**
Railway culvert (North of Tinker's Island)	238	Implemented	238	Domain 1 and 2	Network Rail examination report (2013): Length, height, width 1m filtered LIDAR: Invert level	Rectangular culvert (ESTRY)	Invert level estimated from 1m filtered LIDAR	Section **D.5**

C Model inflows and weightings

C.1 Introduction

This section outlines the inflows into the Model 2 hydraulic model and explains how the weightings were derived.

Inflow areas from the Routing model (Flood Forecasting model adapted or extended for use in the Medway Catchment Mapping and Modelling Study) were retained for inflows to the hydraulic model. The catchment area assigned to each inflow (TOTAL area listed in the table below) were compared with those from the FEH CD-ROM v3.

In some instances the Routing/FF model inflows require weighting, to:

- Enable flows to be input upstream of this point location (e.g. where the flood mapping model extends further upstream than the flood forecasting model)
- Distribute flows from the Routing/FF model to a number of locations when the inflow is considered either
    - representing an 'intervening area' (where there is not a defined tributary, but rather a general increase in catchment area with distance downstream)
    - representing more than one tributary

The table below documents the model inflow (QTBDY), labels which connect the inflow to the corresponding model node, the location of the inflow/model node points, the area of the inflow assigned in the Routing/FF model and the corresponding area derived from the FEH CD-ROM v3. This is then used to apply a weighting for flows to each model node, based upon the ratio of the sub-area catchment derived from the FEH CD-ROM v3 and the total area derived from the FEH CD-ROM v3. Comments are made where applicable.

C.2 Model 1 inflows

Model inflows are listed in Table C-1, with the connecting model node indicated.

Table C-1: Inflows applied to relevant nodes

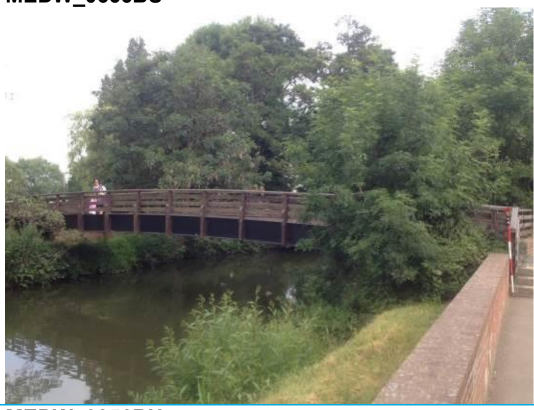
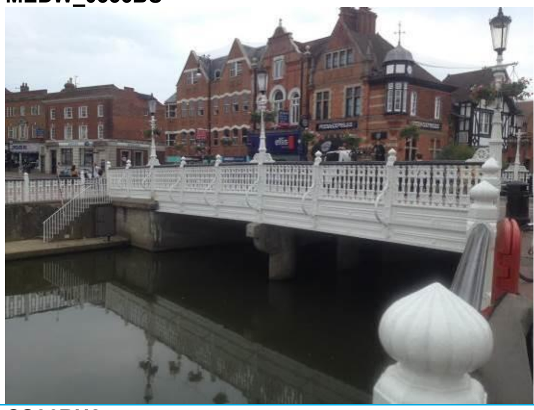
Inflow QTBDY	Lateral node label	Connected ISIS Node	Easting (m)	Northing (m)	Area in Routing/FF model (km^2) TOTAL Area	Area in FEH CD-ROM v3 (km^2) TOTAL Area	Area in FEH CD-ROM v3 (km^2) SUB-AREA Area	Weighting	Comment
HI01 (Hilden Brook and Hawden Stream)	HI01_1	Hilden	558685	147652	53.0	49.39	18.13	0.37	37% weighting to Hilden Brook inflow (Hilden), 1% to Hawden Stream inflow (UNKN01_0219), 49% weighting assigned to Bid Stream catchment area north west of the railway line (unnamed watercourse/drain on OS mapping) (CS16In1), and 10% weighting to area between the downstream of Leigh FSA and Lucifer Bridge (input at CS8 as this is the location that runoff from the south would enter the Medway). The lateral inflows HI01_3, HI01_4 and HI01_5 represent inflows from small drains joining along Hawden Stream and area has been calculated from difference in area along Hawden Stream. The lateral inflow weightings are based on FEH catchment area weightings.
	HI01_2	UNKN01_0219	557087	148126			0.50	0.01	
	HI01_3	HW1.001	557660	147740			1.07	0.02	
	HI01_4	HW1.005	557979	147512			0.35	0.01	
	HI01_5	HL1.010	558603	146868			0.44	0.01	
	HI01_6	CS16In1	557887	146673			23.96	0.49	
	HI01_7	CS8	557129	146120			4.94	0.10	
MI01 (Mill Stream)	MI01_1	CSJ1In1	560983	147242	27.0	25.26*	7.30	0.30	30% weighting to Pen Stream inflow and 70% to the drain joining on the right bank (unamed). Inflow weightings based on FEH catchment area weightings.
	MI01_2	CS57JDIn2	561561	147122			17.43	0.70	
OutflowLB (Outflow from Leigh FSA)	n/a	CS1	556418	146111	n/a	n/a	n/a	1.00	Inflow for the River Medway (outflow from the Leigh FSA).

*FEH CD-ROM does not show Pen Stream catchment clearly. Total area equals catchment area downstream of small tributary (561650 147550) minus Mill Stream contributing area (560700 147450), plus catchment area of drain on right bank (MI01_2).

D Structure photos

D.1 River Medway

Return to section **B.1**.

LUCI01_0018BU 	**MEDW_0154BU** 
MEDW_0853BU 	**MEDW_0666BU** 
CS30BU 	**MEDW_0356BU** 
CS36SU1 (looking downstream)  **(upstream lock gates)**	**CS36RU2** 

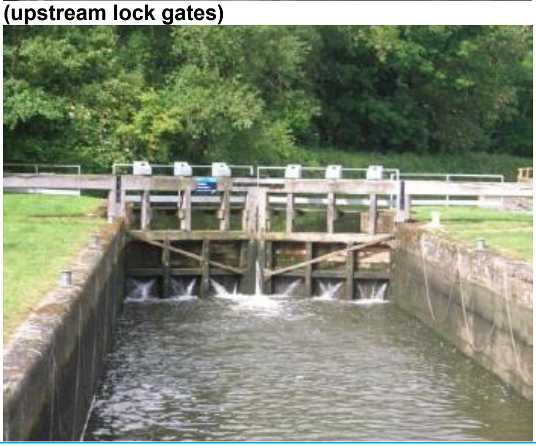
CS36WU3 (left hand side)

CS36WU4 (right hand side)

CS36FPU

CS70LU (looking downstream)

(upstream lock gates)



D.2 Hilden Brook and Hawden Stream

Return to section **B.2.**

HW1.001C1 	

D.3 Mill Stream

Return to section **B.3.**

MILL_0145BU 	**MILL_0110BU** 
MILL_0110WU 	**MILL_004BU** 

D.4 Gas Works and Botany Stream

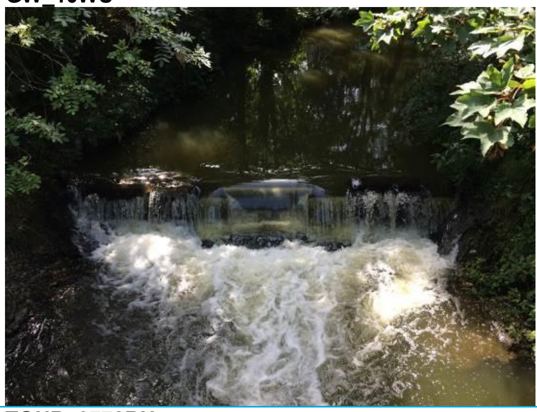
Return to section **B.4.**

GW_02WU

TONB_1109BU

TONB_1007BU

GW_10WU



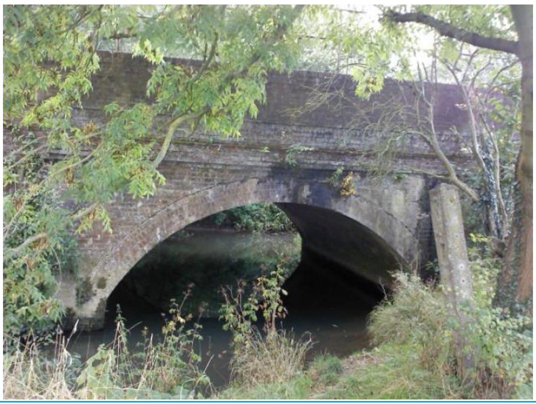
TONB_0833BU

TONB_0772BU

TONB_0554BU	TONB_0017BU
	
BS_01CU (pipe on right hand side is upstream face)  (downstream face) 	

D.5 Floodplain structures (ESTRY networks)

Return to section **B.5.**

231 	233 
235 	237 
238 	

E Roughness values used within the 1D hydraulic model

E.1 Introduction

Model 2 consists of cross sections from a number of models and new survey. Roughness coefficients from the sections within the River Medway Catchment Modelling and Flood Mapping Updates (2008) project, Tonbridge Hazard Mapping project (2010) and Hilden Brook and Hawden Stream Flood Risk Mapping (2006) study have previously been reviewed and these roughness coefficients were not originally intended to be adjusted. New channel survey data has also been included in the model. The survey was undertaken by Maltby Land Surveys Ltd in June 2014.

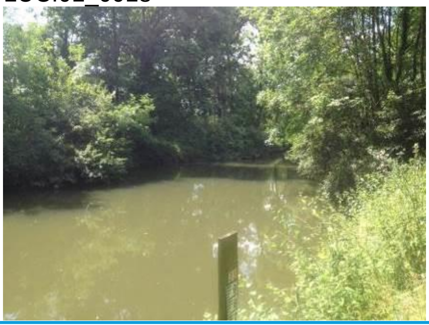
The purpose of this section is to outline the roughness values chosen for the new survey data on the River Medway, Botany Stream, Gas Works Stream and Mill Stream. Where sections from the previous models are between sections from the 2014 survey data and the roughness coefficients chosen are reasonably different, the roughness coefficients of sections from the previous models were updated. There are a number of sources of reference for channel roughness values. Here, the main point of reference was Chow's (1959)[2] description of natural streams – minor streams.

In order to determine the roughness of the channel cross sections, photographic, survey data and satellite imagery was used in conjunction with Chow's (1959) Manning's *n* values.

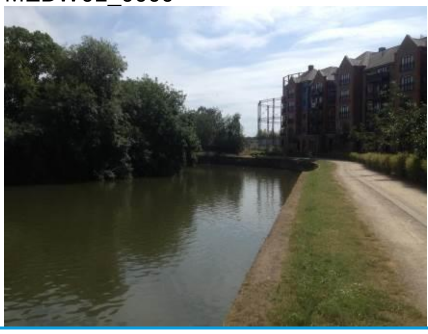
Unless otherwise stated the photographic evidence for the new channel survey is taken from the 2014 Maltby Land Survey Ltd survey undertaken in June. Given the photographs were taken in summer, it was kept in mind that assessing Manning's *n* values from these may result in conservative estimates of channel roughness (e.g. higher values compared with times of the year when vegetation growth may be less).

E.2 New survey of River Medway, Botany Stream, Gas Works Stream and Mill Stream

E.2.1 River Medway

Node label(s)	Manning's n	Photograph(s)	Surrounding sections updated
LUCI01_0365 – LUCI01_00018D	Bed: 0.055 LB/RB: 0.075	LUCI01_0018 	CS1 to CS19
MEDW02_0154 – MEDW02_0154D	Bed: 0.055 LB/RB: 0.075	MEDW02_0154D 	CSD1 to CS24

2 Chow V.T. (1959) Open Channel Hydraulics McGraw Hill

MEDW01_0853 – MEDW01_0666D	Bed: 0.055 LB/RB: 0.075	MEDW01_0727 	CS30BJU to CS31
MEDW01_0372 – MEDW01_0000	Bed: 0.055 LB/RB: 0.075	MEDW01_0000 	CS38 to CS76U

E.2.2 Botany Stream

Node label(s)	Manning's n	Photograph(s)	Surrounding sections updated
TONB01_1109 – TONB01_1092	Bed: 0.065 LB/RB: 0.075	TONB01_1109 	GW_02 and GW_04
TONB01_1007 - TONB01_1007D	Bed: 0.065 LB/RB: 0.075	TONB01_1007 	GW_06
TONB01_0017 – TONB01_0017D	Bed: 0.065 LB/RB: 0.075	TONB01_0017	GW_08, GW_21, GW_23 to GW_26 and BS_01 to BS_12JU

E.2.3 Gas Works Stream

Node label(s)	Manning's n	Photograph(s)	Surrounding sections updated
TONB01_0833 – TONB01_0554	Bed: 0.065 LB/RB: 0.075	TONB01_0772 	GW_09, GW_10, GW_11, GW_13, GW_14
TONB01_0190	Bed: 0.065 LB/RB: 0.075	TONB01_0190 	GW_15, GW_16, GW_17, GW_18, GW_19

4.2.3 Mill Stream

Node label(s)	Manning's n	Photograph(s)	Surrounding sections updated
MILL01_0145 – MILL01_0110	Bed: 0.050 LB/RB: 0.070	MILL01_0145  MILL01_0110 (structure)	MS_01 to MS_03

			
MILL_01 – MILL_03	Bed: 0.050 LB/RB: 0.070	MILL_01 (pond)  MILL_02  © 2014 Microsoft Corporation © Getmapping plc © 2014 Nokia	MS_06, MS_06D,
MILL01_0004 – MILL01_0004D	Bed: 0.050 LB/RB: 0.070	MILL01_0004  MILL01_0004 	MS_07 to MS_10

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