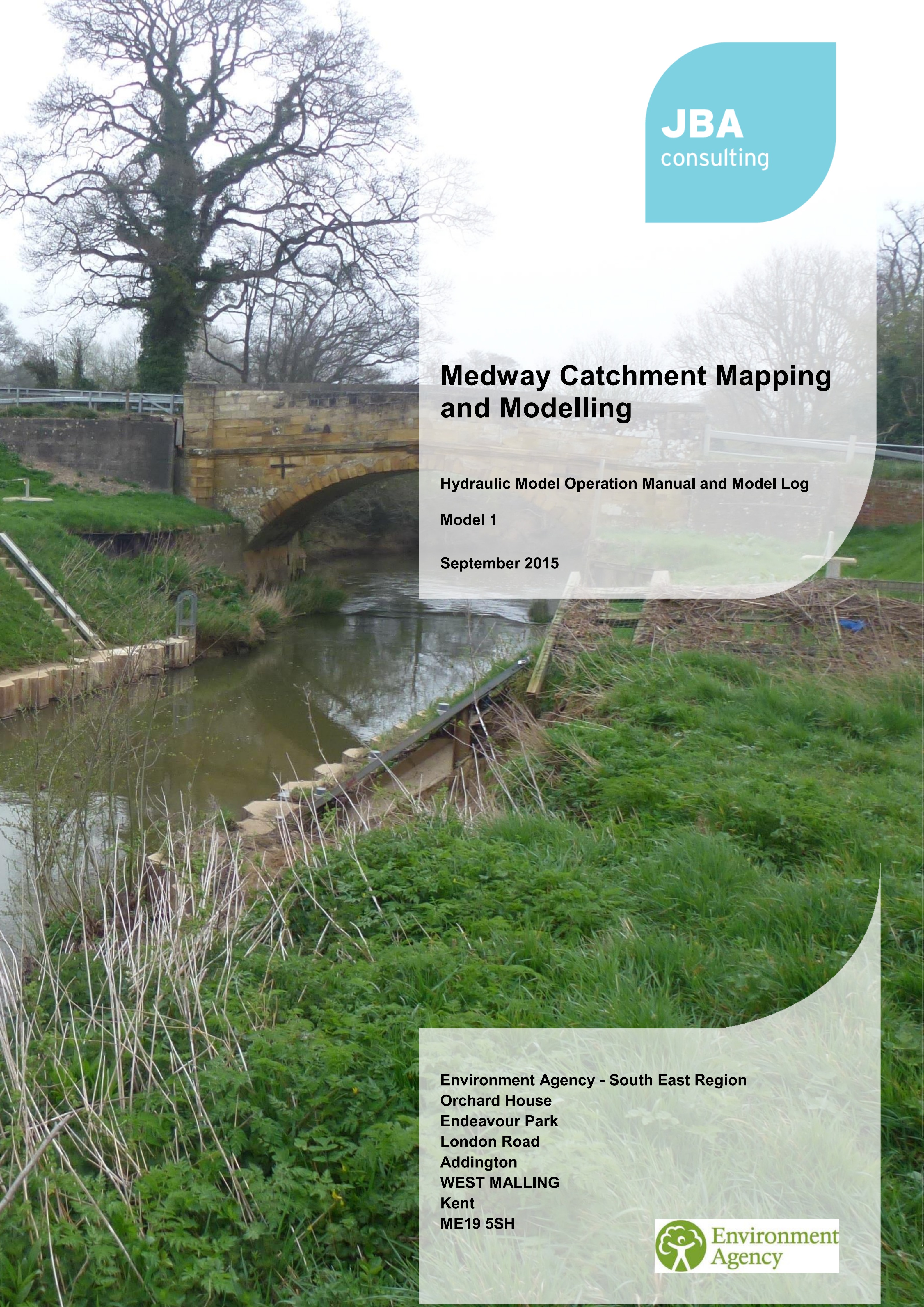

JBA consulting

Medway Catchment Mapping and Modelling

Hydraulic Model Operation Manual and Model Log

Model 1

September 2015

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
Draft v0.3 September 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, River Eden and Eden Brook (Model 1) 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

EA .... Environment Agency

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 1 extends from Blindley Heath on the Eden Brook, the railway crossing at Crowhurst on the River Eden, and from downstream of Weir Wood Reservoir, Forest Row on the River Medway. The model terminates at Leigh Flood Storage Area.

Modelling of the study area downstream of the railway line at Edenbridge (including the River Medway watercourse) is 1D ISIS with extended river sections to represent the floodplain. Upstream of the railway line is modelled as a linked 1D-2D ISIS-TUFLOW model which is divided into two domains split at the confluence of Eden Brook and the River Eden. A 20m grid was implemented within domain 1 (located upstream of the River Eden and Eden Brook), whilst a finer 5m grid size is used within Edenbridge (domain 2). The total length of the watercourse modelled is 68km.

The model has been developed from the existing River Medway Modelling and Flood Mapping Updates (2008) ISIS model based on a detailed model review conducted as part this Medway Catchment Mapping and Modelling study. The 2008 model was supplemented with information from the Edenbridge ABD and Hazard Mapping Study (2010), more recent LIDAR data and new survey data for the River Eden, Eden Brook and certain structures along existing surveyed reaches.

Noted within this Model Operation Manual are the more major changes made during the model update process.

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 Project Report and in the Modelling Approach and Overview section (Appendix A of this document). Sections 4 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-iDP-w64 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-iDP-w64 was selected as this was the latest release on undertaking design runs. Double precision versions of both software were used as these can be advantageous when models contain reservoir units (as is the case for part of Leigh FSA). It was also found that double precision TUFLOW improved the mass balance across the 2D-2D link between domains 1 and 2.
General Schematisation	Modelling of the study area is composed of a 1D-2D section and a 1D section. The River Medway and downstream of the railway line in Edenbridge on the River Eden are modelled by 1D ISIS with extended river sections to represent the floodplain. Upstream of the railway line the floodplain is represented by TUFLOW. There are two 2D domains. Upstream of the confluence between the River Eden and Eden Brook a single HX line approach linking the 1D and 2D domain is implemented on both rivers. Downstream of the confluence connections between the 1D and 2D domains are implemented using a HX line on both the left and right banks. A finer 5m grid cell size is used within Edenbridge, and a coarser 20m grid cell size upstream.
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. Within the undefended case, the FSA embankment and radial gate structures at Leigh FSA are removed. This approach replicates open floodplain upstream and downstream in the absence of the FSA. Extended channel sections are simulated at the 'former' embankment location as per the model upstream and downstream (note: the ISIS RESERVOIR unit representing Haysden Water remains in the undefended case). The downstream boundary in this model is a flow-stage relationship applied 400m downstream of the 'former' Leigh FSA embankment, informed by results extracted from the Model 2 ISIS-TUFLOW linked hydraulic model. The railway line intersecting Leigh FSA remains within the undefended model as it forms a defacto defence. Under the defended case the rules of the radial gates are altered to hold water back in the storage reservoir and protect the regions downstream. The operations of the rules vary for each design event.
Structures	Structures can be found listed in sections B.1 to B.3 of the Appendix.
Calibration Coefficients	Structure coefficients and spill weir coefficients are detailed in sections B.1 to B.3 of the Appendix. The coefficients have largely been updated from the 2008 model as they were previously very low. The values chosen were all deemed appropriate for the situation being modelled.

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
Strengths, Weaknesses and Future development	**Strengths** The model is considered the best representation of the River Medway, River Eden and Eden Brook following the approach that was agreed with the Environment Agency. The most up to date model information available for the study has been implemented within the model. This includes new channel section information along the River Eden and Eden Brook, defence level information in Edenbridge and updated channel section information at gauging stations. **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. **Future development** *Model scale* A grid cell size of 5m has been implemented in Edenbridge (domain 2) where greater detail is required and a 20m grid cell size upstream of Edenbridge (domain 1), which was agreed with the EA given the rural nature of the catchment. Should investigating flood risk at a specific location in the model be required it may be advantageous to reduce the grid cell size in this area. To maintain manageable run times this may require truncating the model to the area of interest. *River Eden/Eden Brook* The River Eden and Eden Brook channels are narrow, typically 6-8m, compared to the model cell size of 20m. Therefore a single HX line was implemented along these channels meaning a single 2D cell represents the left and right banks. If investigating flood risk at a specific site along these channels is required, it is recommended that the model grid cell size is reduced and the model is truncated to include either the River Eden or Eden Brook. This will enable both left and right banks to be represented as separate HX lines with different bank elevations. *Forest Row* Forest Row is modelled as 1D extended sections. Flood extent and depth information produced following 1D mapping routines in rural floodplains is suitable due to the absence of complex features such as floodplain storage cells and notably divergent flow routes. However, given Forest Row is a built-up region and the 1D extended sections only model the flood risk from the Medway consideration should be given to the accuracy of the model at site level. Should detailed investigation of flood risk in Forest Row be required then a linked 1D-2D modelling approach (such as the Forest Row pre-feasibility study (2010)) may provide more accurate extent, depth and velocity outputs on the floodplain. *Leigh Flood Storage Area (FSA)* The representation of the Leigh FSA has been implemented as a combination of extended river sections and a reservoir unit representing the

	right bank of a number of sections including the area of Haysden Water. This level information has been based on the most up to date 1m LIDAR data available. If amendments are made to the area in future, it is recommended that this information is reviewed. *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.

3 Data Structure and File Names

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

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

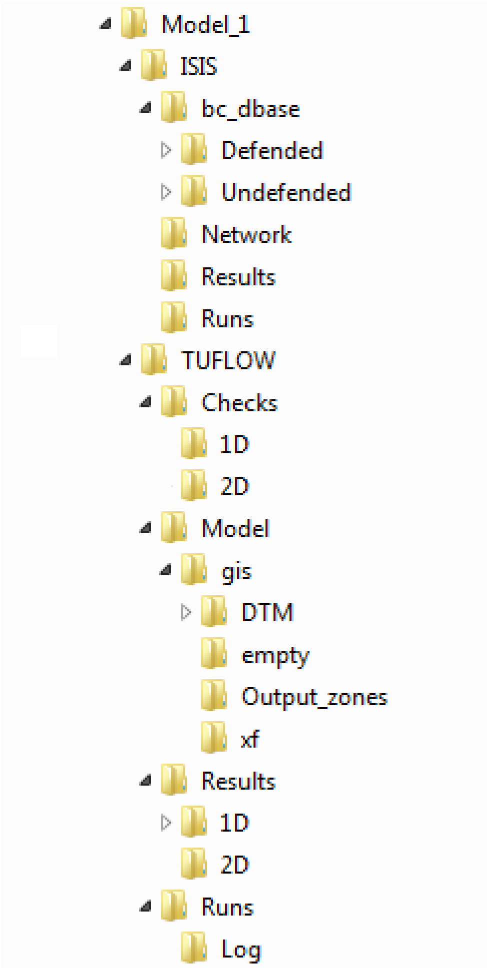
Table 3-1: Folder Structure and contents of Final Design Model

Folder	SF1	SF2	SF3	SF4	SF5	Contents
ISIS	bc_bdase					Folder containing model boundary conditions in IED files (inflows and tidal boundary)
	Network					ISIS Data File (DAT) and GIS Visualiser File (GXY)
	Results					ISIS Results Files
	Runs					ISIS Event Files (IEF)
TUFLOW	bc_dbase					Boundary conditions for the TUFLOW component of the hydraulic model
	Checks	1D				1D ESTRY check files Medway_Model1_017_**###**_###_####_DDMMM########
		2D				2D TUFLOW check files Medway_Model1_017_**###**_###_####_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
			Output_zones			Output zone GIS files
			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_Model1_017_**###**_###_####_DDMMM########
		2D				2D TUFLOW results files Medway_Model1_017_**###**_###_####_DDMMM########
	Runs					TUFLOW Control Files (.tcf) and ESTRY Control File (.ecf) Medway_Model1_017_**###**_###_~e~.tcf Medway_Model1_001.ecf
		log				Standard TUFLOW Log files (.csv and .shp) Medway_Model1_017_**###**_###_####_DDMMM########

Note: **###** denotes output zone. ### denotes **Defended** or **Undefended** case. #### denotes return period. DDMMM######## denotes event.

Note: 1000-year events begin **Medway_Model1_017_###b**

Figure 3-1: File Directory of Final Design 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. Two domains are used within the model, meaning that a multi-domain TUFLOW license and two 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 .ecf = ESTRY Control File - controls ESTRY 1D model parameters .tgc = TUFLOW Geometry Control File .tbc = TUFLOW Boundary Condition Control File

4.1 ISIS

DAT	Medway_Model1_017_HTBDY - for all defended events but the 0.1% AEP event Medway_Model1_017b_HTBDY - 0.1% AEP defended event Medway_Model1_017_undefended - for all undefended events but the 0.1% AEP event Medway_Model1_017b_undefended - 0.1% AEP undefended event

IED

The IED for each output zone and return period are displayed in the tables below.

Defended
There are two IED files for each event (both with the same name), an inflow IED and a downstream boundary IED.

	Return period		
Output zone	**5**	**10CC**	**20**
1	26Dec68221600	11Jan47492100	13Jan67461400
2	05Dec34880500	22Aug21531500	15Feb59091200
3	01Jan42121200	17Dec46141700	08Feb46921500
4	11Mar52290800	24Jan63240300	21Dec38751300
5	07Feb45110300	23Nov24840900	08Mar25460000
6	12Jan48590000	24Feb44751600	06Jan58061900
7	28Dec36031300	15Feb59861000	07Nov21131900
8	24Dec43262000	14Jan34492200	11Jan68071700

	Return period		
Output zone	**30**	**50**	**75**
1	03Dec46622100	18Feb61962000	10Jan19241100
2	27Mar59270600	15Dec44422100	17Nov65300200
3	17Feb62700600	16Dec21431600	11Jan28050600
4	17Jan57850700	13Dec50891700	10Nov61440700
5	04Jan39851300	09Dec49682200	27Mar59270600
6	11Feb65461900	05Jan66770500	02Jan30082300
7	25Feb25480600	06Jan40350800	09Apr49050300
8	09Mar22430800	07Feb59102000	07Feb36270800

	Return period		
Output zone	**100 and 100CC**	**250**	**1000**
1	14Dec27631200	15Feb29831200	31Jan40160100
2	01Jan19291000	24Dec19102300	01Jan31620200
3	21Jan37410300	06Dec55712300	23Jan37940800
4	30Jan23480300	19Nov19470600	22Dec49590000
5	26Dec39672100	22Dec49590000	30Nov42960300
6	27Nov31180100	26Oct46130200	01Jan31620200
7	29Dec37922000	30Nov42960300	08Jan31582100
8	25Nov35581900	19Nov19470600	01Jan31620200

Undefended
Single inflow IED file for each event.

	Return period		
Output zone	**20**	**100 and 100CC**	**1000**
4	21Dec38751300	30Jan23480300	22Dec49590000
7	07Nov21131900	29Dec37922000	08Jan31582100
8	11Jan68071700	25Nov35581900	01Jan31620200

IEF

Medway_Model1_017_**###**_###_####_DDMMM########.ief

Note: **###** denotes output zone. ### denotes **Defended** or **Undefended** case. #### denotes return period. DDMMM######## denotes event.
Note: 1000-year events begin **Medway_Model1_017_###b**

Model run parameters (as specified in .ief event files)

ISIS 1D timestep = 1.25s
Save interval = 300s

The parameters listed below were adjusted from defaults. An explanation for each is provided.

Automated Preissmann Slot for River Sections
This aids model stability during periods of low flow.

	dflood (m) = 5 (default is 3) Height (m) of vertical walls added to the highest point on each river cross section to allow for flooding. Minor increase considered acceptable. **Minimum iterations = 5 (default is 2)** It is often recommended that hydraulic models containing reservoir units are run with double precision since at each timestep the change in stage or flows entering a reservoir unit can be small compared with the area and volume of such areas (running ISIS as double precision is recommended for this reason also). If inflows and stage are not recorded correctly by ISIS, volume errors can occur. Following testing, it was found that using double precision with minimum iteration of 5 compared to single precision with minimum iteration of 2 reduced the volume error in the ISIS model from 1% to 0.4%. Consequently, increasing minitr to 5 (and also running double precision was taken forward). **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. Given that minimum iterations has been increased it is advantageous to increase

4.2 TUFLOW

1D Control files (.ecf) **2D Control files (.tcf)**	ECF: Medway_Model1_001.ecf TCF: Medway_Model1_017_**###**_###_~e~.tcf Note: **###** denotes output zone. ### denotes **Defended** or **Undefended** case. ~e~ is replaced by the return period and event as specified in the 'Run Option' within the .ief. Note: 1000-year events begin **Medway_Model1_017_###b**
2D Boundary condition control file (.tbc)	**Domain 1 (upstream of Edenbridge)** Medway_Model1_Domain1_005 **Domain 2 (Edenbridge)** Medway_Model1_Domain2_006 - for all events but the 0.1% AEP event Medway_Model1_Domain2_006b - 0.1% AEP events
2D Geometry Control file (.tgc)	**Domain 1 (upstream of Edenbridge)** Medway_Model1_Domain1_006 - for all events but the 0.1% AEP event Medway_Model1_Domain1_006b - 0.1% AEP events **Domain 2 (Edenbridge)** Medway_Model1_Domain2_007 - for all defended events but the 0.1% AEP event Medway_Model1_Domain2_007b - 0.1% AEP defended event Medway_Model1_Domain2_007_undefended - for all undefended events but the 0.1% AEP event Medway_Model1_Domain2_007b_undefended - 0.1% AEP undefended event
1D/2D link files	1d_nd_ISIS_Model1_P_002.shp - for all events but the 0.1% AEP event 1d_nd_ISIS_Model1_P_002b.shp - 0.1% AEP events **Domain 1** 2d_bc_hxi_Model1_domain1_L_004.shp 2d_bc_hxi_Model1_domain1_P_002.shp **Domain 2** 2d_bc_hxi_Model1_domain2_L_006.shp
2D/2D link files	2d_2d_bc_Model1_L_003.shp
ESTRY culvert link files	**Domain 1** 2d_bc_SX_floodplain_structures_Model1_domain1_L_001.shp

	Domain 2 2d_bc_sx_Model1_domain2_railway_L_001.shp
Downstream boundary condition(s)	Railway line downstream of Edenbridge acts as boundary between 1D-2D section of model and 1D section of model. Peak water levels not ever expected to overtop embankment so no requirement for a downstream boundary condition.
2D grid files	**Grid location** 2d_loc_Model1_domain1_L_001.shp (upstream of Edenbridge) 2d_loc_Model1_domain2_L_001.shp (Edenbridge) **Grid dimensions in metres (X,Y)** 7100, 4700 (domain 1) 2500, 4000 (domain 2) **Cell size in metres** 20m (domain 1) 5m (domain 2) **Ascii grids** LIDAR_filtered_Medway_Model1_1m.asc (both domains) 1m resolution filtered LIDAR data used to update ground levels within both domains **Active area file** 2d_code_activate_Model1_domain1_R_002.shp (upstream of Edenbridge) 2d_code_activate_Model1_domain1_R_002b.shp - 0.1% AEP event extension 2d_code_activate_Model1_domain2_R_002.shp (Edenbridge) 2d_code_activate_Model1_domain2_R_002b.shp - 0.1% AEP event extension **Inactive area file** 2d_code_deactivate_Model1_domain1_railway_R_001.shp (upstream of Edenbridge) Deactivate railway cutting represented in 1D model 2d_code_deactivate_Model1_domain2_R_004.shp (Edenbridge)
2D Model Geometry files	**Domain 1 (upstream of Edenbridge)** 2d_zln_banks_Model1_domain1_L_002.shp 2d_zln_banks_DTM_Model1_domain1_P_003.shp 2d_zln_banks_DSM_Model1_domain1_P_001.shp 2d_zln_orifice_Model1_L_001.shp 2d_zsh_banks_Model1_domain1_R_001.shp 2d_zsh_banks_DTM_Model1_domain1_P_002.shp 2d_zsh_banks_DSM_Model1_domain1_P_001.shp **Domain2 (Edenbridge)** 2d_zln_banks_Model1_domain2_L_004.shp 2d_zln_banks_DTM_Model1_domain2_P_004.shp 2d_zln_banks_DSM_Model1_domain2_P_001.shp *Defended only* 2d_zln_defence_Church_Wall_Model1_domain2_L_001.shp 2d_zln_defence_Edenbridge_EA_12303_model1_domain2_P_001.shp 2d_zln_defence_Edenbridge_MLS_12303_Model1_domain2_P_002.shp 2d_zln_defence_Edenbridge_Model1_domain2_L_002.shp 2d_zln_defence_Mill_Stream_embankment_Model1_domain2_L_001.shp *Undefended only* 2d_zsh_defence_removal_Model1_domain2_P_001.shp 2d_zsh_defence_removal_Model1_domain2_R_001.shp
Materials file (.tmf)	Medway_Model1_005

4.2.1 Run settings

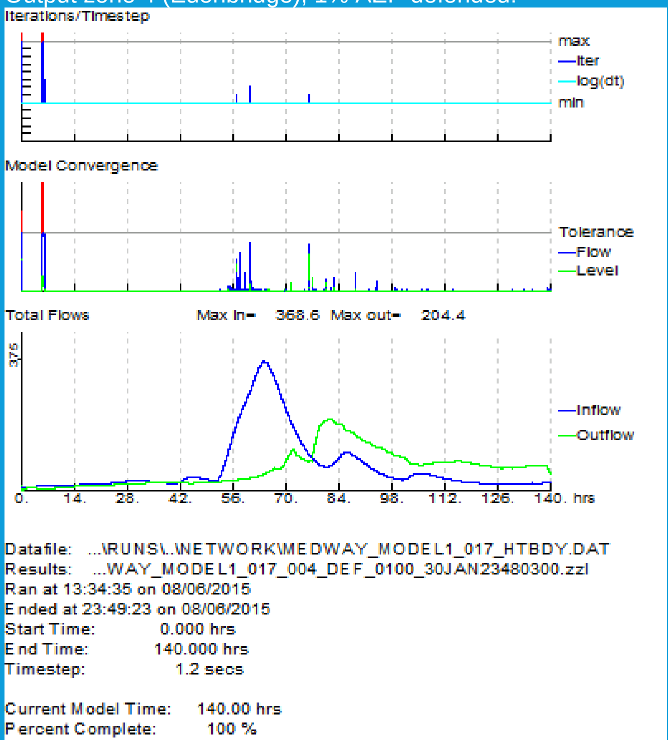
Model start time (hrs)	0	**Model end time (hrs)**	140 hours
Map save interval (s)	1800	**Time series save interval (s)**	300
Map outputs (TUFLOW Flag) XMDF data format	d h q v MB1 MB2 ZUK0 Z0	**Time Step (s)**	2.5

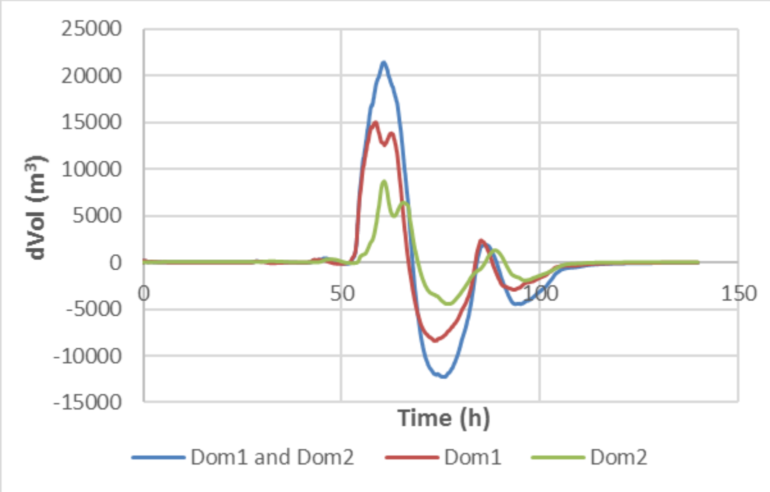
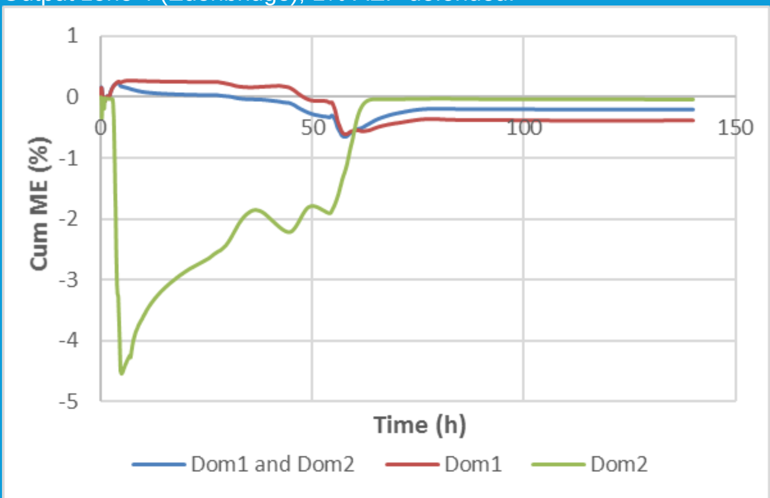
4.2.2 Model stability

<table>
<tr><td>Comments on results</td><td>Refer to plots of Cumulative Mass Error (Cum ME %), dVol and ISIS convergence plot below for output zone 4 (Edenbridge) for the 1% AEP defended event.

The ISIS convergence plot shows that the ISIS model is stable, with only one period of non-convergence identified early within the simulation.

The difference in volume at each save interval (dVol) within both TUFLOW domains displays a smooth transition in volume which is consistent with the inflows to the model, indicative of a stable model.

TUFLOW model mass balances show that the Cumulative Mass Error (Cum ME %) is initially large (negative mass error) when domain 2 first becomes wet. This is associated with a comparatively low number of the total number of cells that eventually become wet. As widespread flooding occurs this returns to within reasonable bounds ±1%, which is the case for domain 1 and both domains combined.
On inspection of the mass balance gridded outputs (MB1 and MB2), no areas of notably high mass error are apparent indicating that the model is stable.</td></tr>
<tr><td>ISIS convergence plots</td><td>Output zone 4 (Edenbridge), 1% AEP defended:

</td></tr>
</table>

dVol (m^3)	Output zone 4 (Edenbridge), 1% AEP defended: 
Cum ME (%)	Output zone 4 (Edenbridge), 1% AEP defended: 

Appendices

A Modelling approach and overview

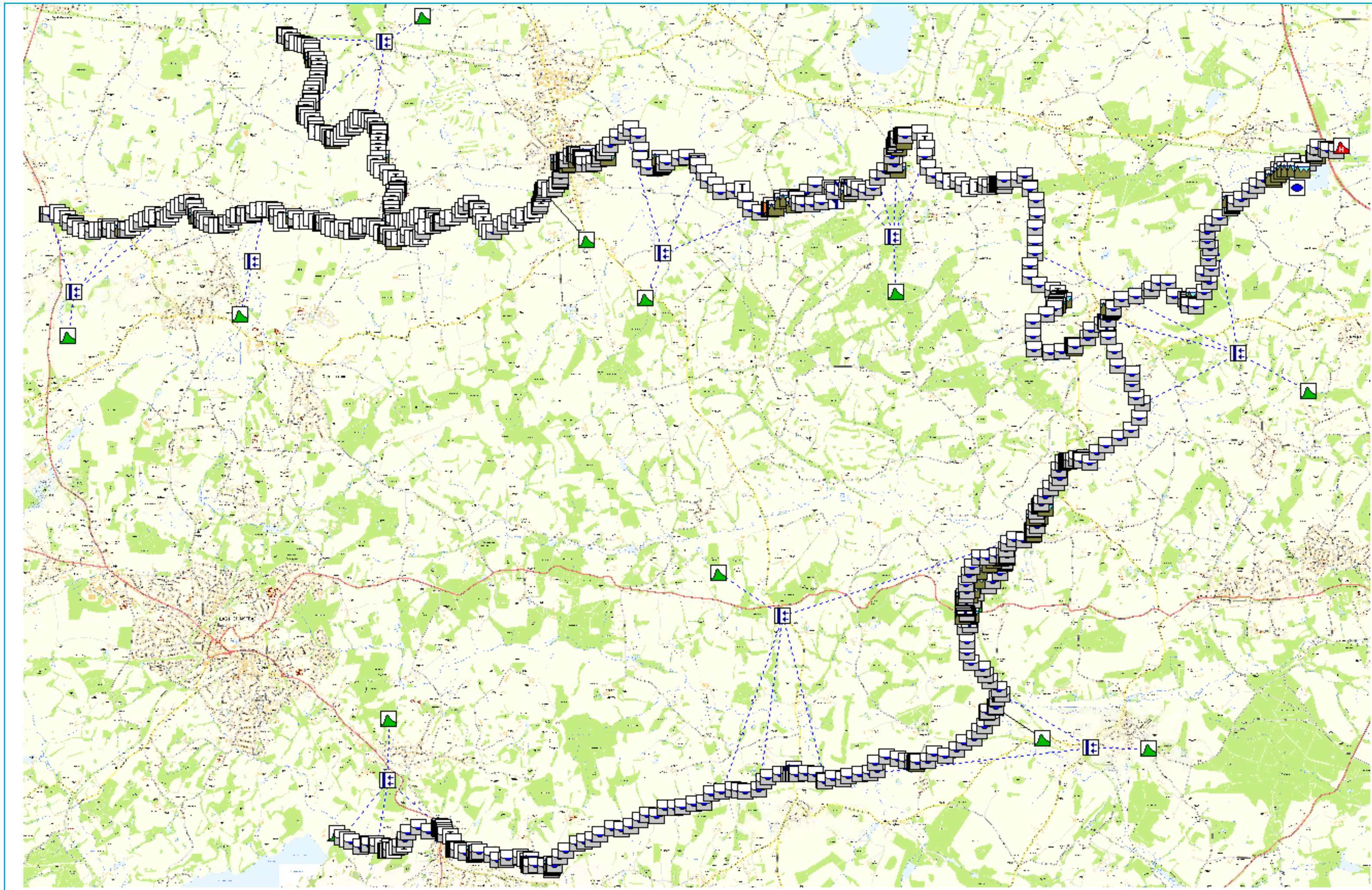
A.1 Modelling Approach

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 2002 Longdin & Browning data as well as the 1995 Flynn & Rothwell data. The 1D-2D part of the model upstream of Edenbridge is predominately constructed from 2014 Maltby Land Survey data collected for this study. 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: River Eden & Eden Brook (2014) [Maltby Land Surveys Ltd] Gauging Stations (2014) [Maltby Land Surveys Ltd] Floodplain structures and other channel cross sections (2014) [Maltby Land Surveys Ltd] Previous survey data available: Chafford Gauging Station (2013) [EDI Surveys Ltd] Collier Land Bridge Gauging Station (2013) [EDI Surveys Ltd] Penshurst Gauging Station (2013) [EDI Surveys Ltd] Vexour Bridge Gauging Station (2013) [EDI Surveys Ltd] Medway silt assessment, Edenbridge (2012) [Maltby Land Surveys Ltd] River Medway (2002) [Longdin & Browning Surveys] River Eden (2002) [Longdin & Browning Surveys] River Medway (1995) [Medway Regime Study - Flynn & Rothwell]
Bank Top Survey	Primary bank level and defence survey data was available for part of Edenbridge from the Edenbridge ABD and Hazard Mapping study (2010) Medway Crest Levels, Edenbridge and Leigh FSA (2009/2010)
LIDAR & other Topographic Data:	1m filtered and unfiltered LIDAR data (flown April 2009) 2m filtered and unfiltered LIDAR data
Map Data:	OS Open Data, OS 1:10,000, OS 1:25,000, OS 1:50,000 and OS MasterMap.

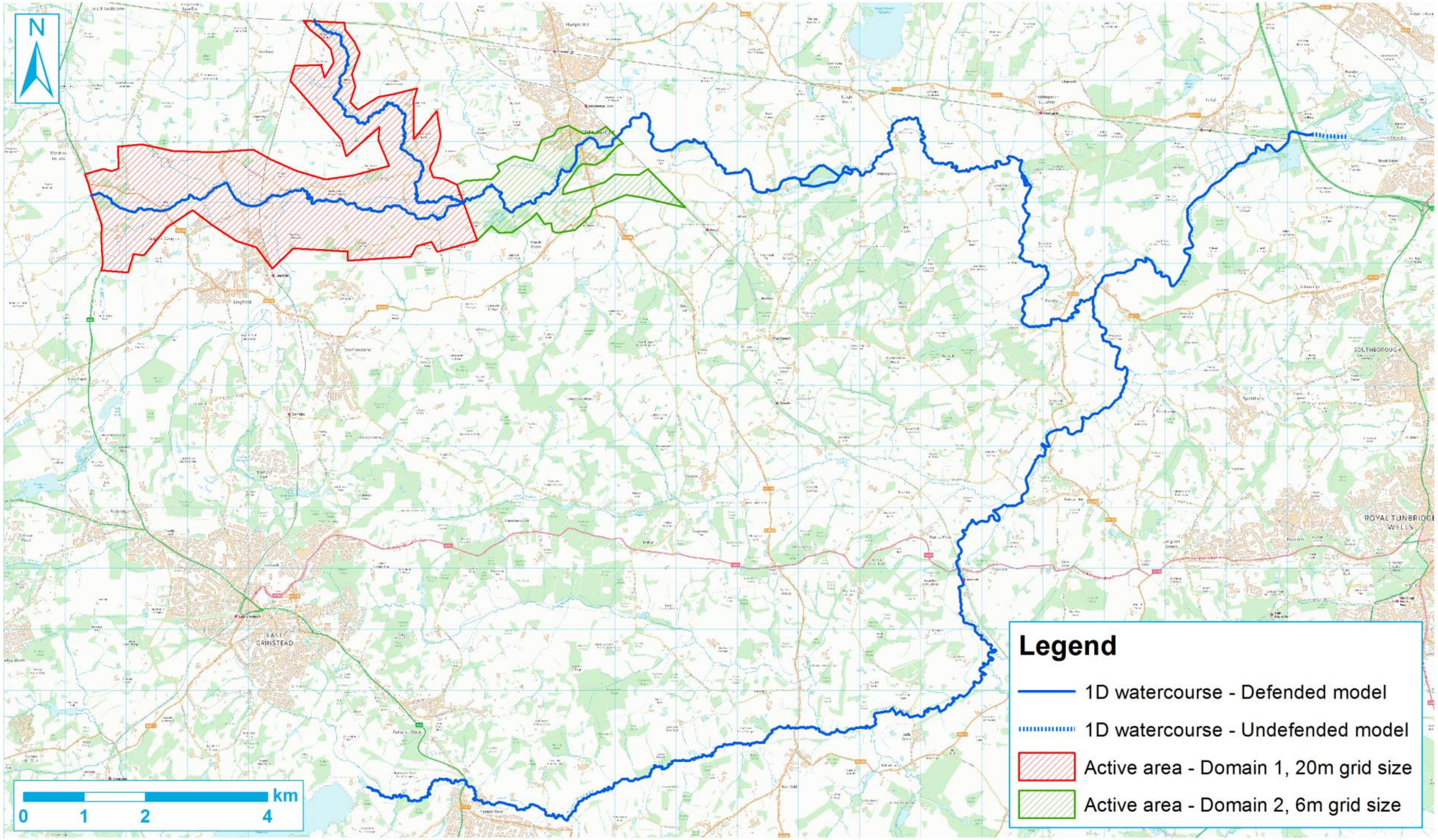
A.2 Model Overview

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



Defended model (Medway_Model1_017_HTBDY.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 Weir Wood reservoir, Forest Row River Eden: Railway crossing, Crowhurst Eden Brook: A22, Blindley Heath
Lateral Catchment Weighting	Inflows were assigned to the model based on the routing models and weighted according to the topographic drainage of the catchment informed from the DTM. In total 11 hydrological inflows were established, with 9 of them split into two or more regions. Additionally, there is one minor sweetening inflow into the bypass channel at Ashurst. See Appendix C for details.
Downstream Boundary	**Leigh Flood Storage Area** *Defended* A head time boundary has been implemented upstream of the Leigh barriers in ISIS. Water level time series data is from the corresponding routing model event which has produced the optimum gate outflow regulation. *Undefended* A flow head boundary has been implemented downstream of where the Leigh barriers would be. The rating curve has been derived from the water level at node CS7 and flow from OutflowLB nodes in the 1000-year undefended flood event on Medway Model 2.
Total Number of nodes and structures	The Medway_Model1_017_HTBDY.DAT (defended) ISIS model consist of 1054 nodes including: 502 River Sections 152 Interpolate units 106 Spill units (some represent inline weirs) 23 USBPR Bridges 15 QTBDYs 14 Bernoulli Loss units 11 Round nosed broad crested weir units 10 Arch Bridges 8 Vertical Sluice units 8 Sharp-crested weir units 8 Lateral inflow units 4 Orifice units 3 General purpose weir unit 2 Reservoir units (representing Haysden lake and Hever Castle) 2 HTBDYs (1 SX connection) 1 Flat-V weir
Labelling/ Numbering System Used	Labelling conventions of the model generally remains as per the existing River Medway Modelling and Flood Mapping Updates (2008) model. 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'). M-### (R) River Medway upstream of Colliers land Bridge CSM## (R) River Medway between Colliers land Bridge and Leigh Barrier CS## (R) River Medway downstream of Leigh Barrier E-### (R) River Eden between confluence with Eden Brook and Vexour bridge E-HV## (R) Channel at Hever Castle (River Eden) CSE## (R) River Eden downstream of Vexour Bridge EDE01_#### (U) River Eden upstream of confluence with Eden Brook EBR01_#### (U) Eden Brook CLB_0010 (U) Culvert under Crowhurst Road

	M-AB## (U) CH_XS-## (U) CLB_XS-## (U) P_XS-## (U) 1.002 (U)	Bypass channel at Ashurst (River Medway) Chafford House Colliers land Bridge Penshurst Penshurst weir
Hydraulic roughness values used	Channel roughness values have been represented in the model by Manning's n. Roughness values for sections retained from previous models were updated along with channel sections implemented as part of the model updates. In order to determine the channel roughness, descriptions in Chow (1959)[1] were examined against photographic evidence, survey data and satellite imagery. Appendix E has more information relating to the roughness coefficients chosen. 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 (upstream of Edenbridge): $10.8km^2$ Domain 2 (Edenbridge): $3.1km^2$	**DTM data source**	LIDAR. Supplied by Geomatics Group Ltd
Resolution of grid	Domain 1: 20m Domain 2: 5m	**DTM resolution**	1m
Orientation of grid	Domain 1: W to E → Domain 2: NNW to SSE ↓		

Modifications to model topography (Domain 1)

File	Description
2d_zln_banks_DTM_Model1_domain1_P_003.shp	Bank levels derived from 1m filtered LIDAR data at 10m intervals.
2d_zln_banks_DSM_Model1_domain1_P_001.shp	Bank levels derived from 1m unfiltered LIDAR data at 10m intervals in areas of poor filtering.
2d_zln_orifice_Model1_L_001.shp	Sets the cell level of three cells, where an ISIS orifice unit connects, to be 1cm below the invert level of the orifice to form a flow path.
2d_zsh_banks_DTM_Model1_domain1_P_002.shp	Z-shape around channel. Bank levels derived from 1m filtered LIDAR data at 10m intervals.
2d_zsh_banks_DSM_Model1_domain1_P_001.shp	Z-shape around channel. Bank levels derived from 1m unfiltered LIDAR data at 10m intervals in areas of poor filtering.

Modifications to model topography (Domain 2)

File	Description
2d_zln_banks_DTM_Model1_domain2_P_004.shp	Bank levels derived from 1m filtered LIDAR data at 10m intervals.
2d_zln_banks_DSM_Model1_domain2_P_001.shp	Bank levels derived from 1m unfiltered LIDAR data at 10m intervals in areas of poor filtering.
2d_zln_defence_Church_Wall_Model1_domain2_L_001.shp	Church wall defence on left bank of River Eden downstream of High Street. Level of 40.60m AOD ties to high ground at High Street and Mill Stream embankment.
2d_zln_defence_Edenbridge_EA_12303_model1_domain2_P_001.shp	Survey of defence/embankment levels at Edenbridge collected by Environment Agency in 2014.
2d_zln_defence_Edenbridge_MLS_12303_Model1_domain2_P_002.shp	Survey of defence/embankment levels at Edenbridge collected by Maltby Land Surveys in 2014.
2d_zln_defence_Mill_Stream_embankment_Model1_domain2_L_001.shp	Mill Stream embankment on left bank of River Eden downstream of Church Wall defence. Level of 40.65m AOD ties to high ground to the north.
2d_zsh_defence_removal_Model1_domain2_P_001.shp	Z_shape used in the undefended runs which removes defence components which are recorded in the LIDAR data. Z-Shapes fills across defences with ground levels either side of the defence.

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. The Manning's *n* values chosen were largely the result of the rating review models.

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

Land cover	Manning's n
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

In each domain 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.

For the Edenbridge domain (domain 2), JBA have retained the standard approach to linking 1D ISIS and 2D TUFLOW models. 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.

Within domain 1, upstream of the confluence between the River Eden and Eden Brook, the nature of the channel necessitated a slight divergence from this approach, whereby a single HX line is implemented for the watercourse, representing both banks. This approach was adopted as the channels are narrow (generally 6-9m wide), which in light of the 20m cell size means that assigning left and right banks would mean that either the ISIS sections, HX lines, or both would need to be widened. In the first case inspection of survey information showed defined banks for most of the channel, meaning extending sections would act to represent floodplain conveyance before the true bank top had been reached. In the second case, widening the HX lines in isolation would cause a discrepancy between 1D and 2D width, which would act to lessen the available storage on the floodplain, potentially impact flood level and flow predictions.

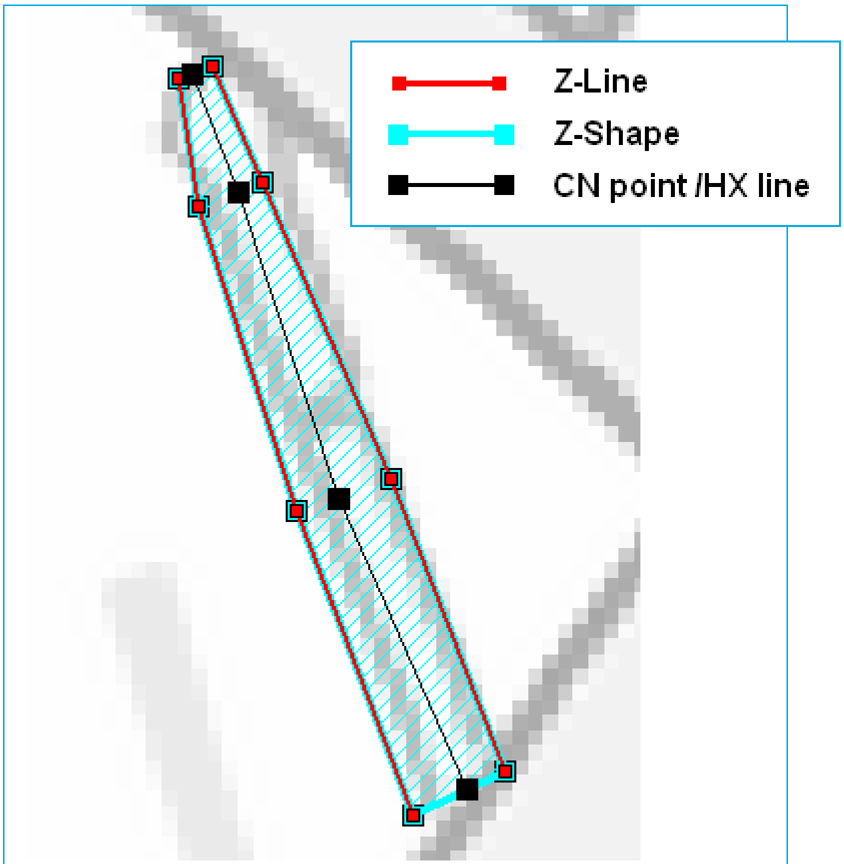
Single HX line approach

The single HX line approach was favoured as it reduces the flux across the ISIS-TUFLOW HX links in a given timestep (which is based on water levels either side of the HX link - i.e. in channel and on the floodplain). When channels are small, the effect of taking large volumes out of the 1D channel can be that the water level drops notably, meaning in the next timestep the flux is dramatically reduced (or even reversed) and water level rises again. Between timesteps this manifests itself as oscillations in water levels and flows (instability).

Under the single HX line approach the inactive area typically assigned to the channel in the 2D domain was removed, with Z-Lines and Z-Shapes implemented to enforce the bank elevation at 1D-2D linked cells. This approach is displayed in Figure A-3.

The single HX line approach means that conveyance and storage above bank levels is represented both in the channel and in the 2D boundary cells, effectively doubling it. However, given that the depth of water above the level of the bank will be relatively small and that the single HX line approach was found to be more stable, the additional storage represented by this approach is not considered significant.

Figure A-3: Single HX line and Z-Line/Z-Shapes enforcing bank levels



B List of structures

The tables within the following sections outline the structures included within the hydraulic model. Listed are those on the main River Medway, River Eden and Eden Brook channels, as well as other structures on bypass channels.

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
-	Track bridge	No change	M-147BU	M-147BD	Longdin & Browing 2002	Bernoulli Loss unit	Yes	1.20	0.90	Section **D.1**
-	Track bridge	No change	M-146ABU2	M-146BBD2	Longdin & Browing 2002	Bernoulli Loss unit	Yes	1.20	0.90	Section **D.1**
Brambletyne Manor Farm	Track bridge	No change	M-144BU	M-144BD	Longdin & Browing 2002	Bernoulli Loss unit	Yes	0.60	0.90	No photo available
-	Weir	No change	M-138WU_L	M-138WD_L	Longdin & Browing 2002	Round nosed broad crested weir	Yes*	1.20	0.90	Section **D.1**
-	Weir	No change	M-138WU_M	M-138WD_M	Longdin & Browing 2002	Round nosed broad crested weir	Yes*	1.20	0.90	Section **D.1**
London Road (A22) bridge	Road bridge	Updated	M-137BU	M-136WU	Longdin & Browing 2002	Bridge (USBPR 1978)	Yes	0.60	0.90	Section **D.1**
-	Drop in bed level/informal weir	Updated	M-136WU	M-136WD	Longdin & Browing 2002	Round nosed broad crested weir	Yes*	0.60	0.90	Section **D.1**
A22 road bridge	Road bridge	Implemented	M-137OU	M-137OD	Royal Haskoning 2009	Orifice unit	Yes	0.60	0.90	No photo available
-	Road bridge	Updated	M-131BU	M-131WU	Longdin & Browing 2002	Bridge (USBPR 1978)	Yes	0.60	0.90	Section **D.1**
-	Drop in bed level/informal weir	Implemented	M-131WU	M-131WD	Longdin & Browing 2002	ISIS Spill unit	N/a	1.50	0.90	Section **D.1**
Forest Way track	Track	No change	M-127BU	M-127BD	Longdin & Browing 2002	Bernoulli Loss unit	Yes	0.60	0.90	Section **D.1**
Pixton Hill Farm	Road bridge	No change	M-119BU	M-119BD	Longdin & Browing 2002	Bernoulli Loss unit	Yes	0.60	0.90	Section **D.1**
Ashdown Farm	Road bridge	No change	M-115ABU	M-114BD	Longdin & Browing 2002	Bernoulli Loss unit	Yes	0.60	0.90	No photo available
Hartfield High Street	Road bridge	No change	M-86BU	M-86BD	Longdin & Browing 2002	Bernoulli Loss unit	Yes	0.60	0.90	Section **D.1**
Beech Green Lane	Road bridge	Updated	M-69BU	M-68BD	Longdin & Browing 2002	Bridge (Arch)	Yes	0.60	0.90	Section **D.1**
-	Railway bridge	Implemented	M-AB11OU	M-AB11OD	Longdin & Browing 2002	Orifice unit	Yes	1.20	0.90	Section **D.1**
-	Railway bridge	Implemented	M-RBU	M-RBD	-	ISIS Spill unit	N/a	0.60	0.90	No photo available

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
-	Weir	No change	M-44WU	M-44WD	Longdin & Browing 2002	Round nosed broad crested weir	Yes*	1.20	0.90	Section **D.1**
Ashurst Bridge	Road bridge	Implemented	M-40BU	M-40BD	Longdin & Browing 2002	Bridge (USBPR 1978)	Yes	0.60	0.90	Section **D.1**
-	Railway bridge	Implemented	M-37BU	M-37Bd	Longdin & Browing 2002	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.1**
Chafford Bridge	Road bridge	Updated	M-23BU	M-23WU	Longdin & Browing 2002	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.1**
-	Drop in bed level/informal weir	Implemented	M-23WU	M-23WD	Longdin & Browing 2002	ISIS Spill unit	N/a	1.50	0.90	Section **D.1**
-	Radial gate	Updated	M-21RSU	M-21RSD	Longdin & Browing 2002	Vertical Sluice unit	Yes*	0.60	0.90	Section **D.1**
Chafford House	Weir	Updated	CH_XS-02	CH_XS-02WD	Longdin & Browing Gauging Station Survey 2001	Round nosed broad crested weir	Yes*	0.60	0.90	Section **D.1**
Colliersland Bridge	Road bridge	Updated	COLL_0170bu	COLL_0170bd	Maltby Land Surveys Ltd 2014	Bernoulli Loss unit	Yes	1.10	0.90	Section **D.1**
-	Weir	No change	CSM9WU	CS98WD	Flynn & Rothwell 1995	Round nosed broad crested weir	Yes*	0.60	0.90	Section **D.1**
Penshurst Bridge	Road Bridge	No change	CSM25BU	CSM25BD	Flynn & Rothwell 1995	Bernoulli Loss unit	Yes	0.60	0.90	No photo available
-	Weir	No change	CSM33AU	CSM34AD	Flynn & Rothwell 1995	Round nosed broad crested weir	Yes*	0.60	0.90	No photo available
-	Weir	No change	CSM33BU	CSM34BD	Flynn & Rothwell 1995	Round nosed broad crested weir	Yes*	0.60	0.90	No photo available
Ensfield Bridge	Road bridge	No change	CSM46BU	CSM46BD	Flynn & Rothwell 1995	Bernoulli Loss unit	Yes	0.60	0.90	No photo available
Leigh Flood Storage Area	Storage region	Updated	Haysden	CSM50L, CSM52L, CSM52L, CSM55BUL, CSM56L, CSM51L, CSM54L	-	Reservoir	N/a	-	-	No photo available
-	Railway bridge	No change	CSM57BU	CSM57BD	Flynn & Rothwell 1995	Bernoulli Loss unit	Yes	0.60	0.90	No photo available

*Spill used to represent bypassing flow

B.2 River Eden

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
Caterfield Bridge	Road bridge	Implemented	EDN_6617BU	EDN_6617BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.2**
-	Weir	Implemented	EDN_6012WU	EDN_6012WD	Maltby Land Surveys Ltd 2014	Sharp Crested weir	Yes*	1.00	0.90	Section **D.2**
Sluice House	Sluice gate	Implemented	EDN_5160VSU	EDN_5160VSD	Maltby Land Surveys Ltd 2014	Vertical Sluice unit	Yes*	0.50	0.90	Section **D.2**
-	Track bridge	Implemented	EDN_4907BU	EDN_4907BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.40	0.90	Section **D.2**
-	Sluice gate	Implemented	EDN_4186VSU	EDN_4186VSD	Maltby Land Surveys Ltd 2014	Vertical Sluice unit	Yes*	1.00	0.90	Section **D.2**
-	Weir	Implemented	EDN_4186WU	EDN_4186WD	Maltby Land Surveys Ltd 2014	Sharp Crested weir	Yes*	1.00	0.90	Section **D.2**
-	Weir	Implemented	EDN_2904WU	EDN_2904WD	Maltby Land Surveys Ltd 2014	Sharp Crested weir	Yes*	1.00	0.90	Section **D.2**
-	Track bridge	Implemented	EDN_2418BU	EDN_2418BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **D.2**
Haxsted Mill - main sluice	Sluice gate	Implemented	EDN_1692VSU1	EDN_1692VSD1	Maltby Land Surveys Ltd 2014	Vertical Sluice unit	Yes*	1.00	0.90	Section **D.2**
Haxsted Mill - side sluice	Sluice gate	Implemented	EDN_1692VSU2	EDN_1692VSD2	Maltby Land Surveys Ltd 2014	Vertical Sluice unit	Yes*	1.00	0.90	Section **D.2**
Haxsted Road bridge	Road bridge	Implemented	EDN_1631BU	EDN_1631BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **D.2**
-	Footbridge	Implemented	EDN_1014BUL	EDN_1014BDL	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.00	0.90	Section **D.2**

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
-	Footbridge	Implemented	EDN_1014BUR	EDN_1014BDR	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.00	0.90	Section **D.2**
-	Sluice gate	Implemented	EDN_0170VSU	EDN_0170VSD	Maltby Land Surveys Ltd 2014	Vertical Sluice unit	Yes*	1.00	0.90	Section **D.2**
-	Drop in bed level/informal weir	Implemented	EDN_0087WU	EDN_087WD	Maltby Land Surveys Ltd 2014	ISIS Spill unit	N/a	1.30	0.90	Section **D.2**
-	Sluice gate	Updated	E-106WU	E-106WD	Longdin & Browning 2002	Sharp Crested weir	Yes*	0.60	0.90	Section **D.2**
-	Drop in bed level/informal weir	Updated	E-91WU	E-91WD	Longdin & Browning 2002	ISIS Spill unit	N/a	0.60	0.90	Section **D.2**
-	Sluice gate	Updated	E-93RCWU	E-93RCWD	Longdin & Browning 2002	Sharp Crested weir	Yes*	0.60	0.90	Section **D.2**
-	Weir	Updated	EDE01_1199WU	EDE01_1199WD	11798 Maltby Land Surveys Ltd 2012	General purpose weir unit	Yes*	1.20	0.90	Section **D.2**
B2026	Road bridge	Updated	EDE01_0926BU	EDE01_0926BD	11798 Maltby Land Surveys Ltd 2012	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.2**
High Street bridge	Road bridge	Updated	EDE01_0845BU	EDE01_0845BD	11798 Maltby Land Surveys Ltd 2012	Bridge (Arch)	Yes	1.20	0.90	Section **D.2**
-	Footbridge	Implemented	EDE01_0834BU	EDE01_0834BD	11798 Maltby Land Surveys Ltd 2012	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.2**
-	Footbridge	Implemented	EDE01_0660BU	EDE01_0660BD	11798 Maltby Land Surveys Ltd 2012	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.2**
-	Footbridge	Implemented	EDE01_0533BU	EDE01_0533BD	11798 Maltby Land Surveys Ltd 2012	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.2**
-	Railway bridge	Updated	EDE01_0009BU	EDE01_0009BD	11798 Maltby Land Surveys Ltd 2012	Bridge (USBPR 1978)	Yes	1.20	0.90	Section **D.2**
-	Weir	No change	E-67WU1	E-67WD1	Longdin &	General purpose	Yes*	0.50	0.90	Section **D.2**

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
					Browning 2002	weir unit				
Hever Bridge	Road bridge	Updated	E-48BU	E-48BD	Longdin & Browning 2002	Bridge (Arch)	Yes	0.60	0.90	Section **D.2**
-	Road bridge	Updated	S9.001BU	S9.001BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	0.60	0.90	Section **D.2**
Hever Castle	Storage region	Implemented	Hever	E-46L, E-45AL, E-HV12UL, E-HV12L	-	Reservoir	N/a	-	-	No photo available
Hever Castle sluice gate (Southern)	Sluice gate	Updated	E-39VSU-S	E-39VSD-S	Longdin & Browning 2002	Vertical Sluice unit	Yes*	0.60	0.90	Section **D.2**
Hever Castle sluice gate (Northern)	Sluice gate	Updated	E-39VSU-N	E-39VSD-N	Longdin & Browning 2002	Vertical Sluice unit	Yes*	0.60	0.90	Section **D.2**
-	Drop in bed level/informal weir	Updated	E-HV5SPU1	E-HV5SPD1	Longdin & Browning 2002	ISIS Spill unit	N/a	1.30	0.90	Section **D.2**
Mill Farm bridge	Road bridge	No change	E-28BU	E-28BD	Longdin & Browning 2002	Bernoulli Loss unit	Yes	0.60	0.90	Section **D.2**
-	Flume	No change	E-26AWU1	E-26AWD1	Longdin & Browning 2002	General purpose weir unit	Yes*	0.60	0.90	Section **D.2**
-	Flume	No change	E-26AWU2	E-26AWD2	Longdin & Browning 2002	Round nosed broad crested weir	Yes*	0.60	0.90	Section **D.2**
Vexour Bridge	Road bridge	Updated	VEXO_0277bu	VEXO_0277bd	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.10	0.90	Section **D.2**
-	Drop in bed level/informal weir	Implemented	CSE11	CSE11d	Flynn & Rothwell 1995	ISIS Spill unit	N/a	1.30	0.70	No photo available
Salmans Farm bridge	Road bridge	No change	CSE21BU	CSE21BD	Flynn & Rothwell 1995	Bernoulli Loss unit	Yes	0.60	0.90	No photo available
Penshurst weir	Weir	Updated	1.002WU	1.002WD	11658 EDI Surveys Ltd 2013	Flat-V weir	Yes*	0.60	0.90	Section **D.2**

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
-	Weir	No change	CSE29WU	CSE29WD	Flynn & Rothwell 1995	Round nosed broad crested weir	N/a	-	-	No photo available
B2188 Long Bridge	Road bridge	No change	CSE29BU2	CSE29BD2	Flynn & Rothwell 1995	Bernoulli Loss unit	Yes	0.60	0.90	No photo available

*Spill used to represent bypassing flow

B.3 Eden Brook

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
-	Footbridge	Implemented	EBR_7455BU	EBR_7455BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Access bridge	Implemented	EBR_6903BU	EBR_6903BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Access bridge	Implemented	EBR_6843BU	EBR_6843BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.30	0.90	Section **0**
Ray Bridge	Road bridge	Implemented	EBR_6602BU	EBR_ 6602BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Access bridge	Implemented	EBR_5853BU	EBR_5853BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.00	0.90	Section **0**
-	Culvert	Implemented	CLB_0010OU	CLB_0010OD	Maltby Land Surveys Ltd 2014	Orifice unit	No	-	-	Section **0**
-	Access bridge	Implemented	EBR_5063BU	EBR_5063BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Weir	Implemented	EBR_4984WU	EBR_4984WD	Maltby Land Surveys Ltd 2014	Round nosed broad crested weir	Yes*	1.00	0.90	Section **0**
-	Road bridge	Implemented	EBR_4976BU	EBR_4976BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Access bridge	Implemented	EBR_4925BU	EBR_4925BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Railway bridge	Implemented	EBR_4558BU	EBR_4558BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.40	0.90	Section **0**
-	Railway bridge	Implemented	EBR_4558OU	EBR_4558OD	Maltby Land Surveys Ltd 2014	Orifice unit	Yes	1.40	0.90	No photo available
-	Road bridge	Implemented	EBR_4219BU	EBR_4219BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.40	0.90	Section **0**
-	Weir	Implemented	EBR_4040WU	EBR_4040WD	Maltby Land Surveys Ltd 2014	Sharp Crested weir	Yes*	1.00	0.90	Section **0**

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
-	Access bridge	Implemented	EBR_2945BU	EBR_2945BD	Maltby Land Surveys Ltd 2014	Bridge (USBPR 1978)	Yes	1.40	0.90	Section **0**
-	Weir	Implemented	EBR_2462WU	EBR_2462WD	Maltby Land Surveys Ltd 2014	Sharp Crested weir	Yes*	1.20	0.90	Section **0**
-	Weir	Implemented	EBR_1169WU	EBR_1169WD	Maltby Land Surveys Ltd 2014	Sharp Crested weir	Yes*	1.00	0.90	Section **0**
-	Road bridge	Implemented	EBR_1015BU	EBR_1015BD	Maltby Land Surveys Ltd 2014	Bridge (Arch)	Yes	1.40	0.90	Section **0**

*Spill used to represent bypassing flow

C Model inflows and weightings

C.1 Introduction

This section outlines the inflows into the Model 1 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
ForestRow	ForestRow_1	M-150_SUB_1	540899	135452	50.0	42.74	35.01	0.85	85% weighting to River Medway inflow, 6% and 9% to the tributaries joining on right bank. One upstream of Forest Row (M-146BBD) and the other joining at the A22 road bridge (M-138WJD). Inflow weightings based on FEH catchment area weightings.
	ForestRow_2	M-146BBD	541519	135269			2.66	0.06	
	ForestRow_3	M-138WJD	542507	135530			3.33	0.09	
MedwayL1	MEDWAYL1_1	M-95	546848	136109	75.0	62.00*	1.83	0.03	53% to Kent Water (M-26), 42% to the river joining on left bank after B2026 (M-81JD) and 3% and 2% to the nodes M-95 and M-91 which account for the area between M-95 and M-81JU (548421, 136287). The weightings are based on FEH catchment area weightings.
	MEDWAYL1_2	M-91	547425	136141			1.31	0.02	
	MEDWAYL1_3	M-81JD	548449	136276			22.91	0.42	
	MEDWAYL1_4	M-26	551375	140042			28.75	0.53	
MedwayL2	MEDWAYL2_1	M-76	549139	136392	75.0	76.16**	50.43	0.69	69% to southern tributary joining on right bank at Withyham (M-76) and 31% to southern tributary (River Grom, M-53JD) based on FEH catchment area weightings.
	MEDWAYL2_2	M-53JD	551188	137625			23.08	0.31	
MedwayL3	MEDWAYL3_1	CSE16	556192	144511		51.93	13.25	0.26	Representing additional 10% increase in catchment area between Colliers Land Bridge and Vexour Bridge gauges. Distributed along Eden and Medway upstream of confluence and also downstream of confluence. 26% weighting at right bank inflow on Eden (CSE16), 42% weighting at right bank inflow on River Medway (CSM16), 14% weighting for additional area to confluence of River Medway and River Eden, and 18% weighting representing additional area between confluence and Leigh FSA embankment.
	MEDWAYL3_2	CSM16	553358	142172			21.57	0.42	
	MEDWAYL3_3	CSM24	552821	143457			7.22	0.14	
	MEDWAYL3_4	CSM44	554434	144984			9.89	0.18	
Hendal	-	M-55JD	551093	137437	52.0	54.86	54.86	1.00	Inflow from River Hendal.
EDEN06Lat	EDEN06Lat_1	E-37JD	548904	145548	36.5	18.88	5.60	0.33	Variable weighting to each inflow based on

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
	EDEN06Lat_2	E-33	549263	145697			2.66	0.15	FEH catchment area weightings. In order of most upstream to downstream: northern tributary joining immediately after Hever Castle pond (E-37JD); southern tributary joining on right bank (E-33); Bough Beech Brook joining on left bank (E-27JD) and tributary joining on right bank (E-21).
	EDEN06Lat_3	E-27JD	549573	146311			8.07	0.47	
	EDEN06Lat_4	E-21	549993	146027			0.90	0.05	
EDEN05Lat	EDEN05Lat_1	E-73	545372	146394	36.5	37.43	3.90	0.11	Variable weighting to each inflow based on FEH catchment area weightings. In order of most upstream to downstream: northern tributary joining on left bank (E-73); second northern tributary joining on left bank (E-60JD); and third inflow represents the sum of the southern tributary joining on right bank (at E-58) and the southern tributary joining on right bank before Hever Bridge (E-50).
	EDEN05Lat_2	E-60JD	546488	145897			21.29	0.60	
	EDEN05Lat_3	E-50	547432	145163			10.19	0.27	
KentBrook	-	E-91	544084	145491	16.1	14.37	14.37	1.00	Inflow from Kent Brook
Haxstead	Haxstead_1	EDN_6783	540108	147922	64.5	51.64	43.13	0.85	85% weighting to River Eden (EDN_6783), 9% weighting to Crowhurst Stream (EDN_4923) and 6% weighting to northern tributary on left bank (EDN_3163) and area between EDN_4923 and EDB_3163. Inflow weightings based on FEH catchment area weightings.
	Haxstead_2	EDN_4923	540395	146698			4.75	0.09	
	Haxstead_3	EDN_3163	541445	146577			3.27	0.06	
LingfieldWWT	LfieldWWT_1	EBR_7989D	536437	145121	39.7	31.84	12.30	0.42	42% weighting to Eden Brook inflow (EBR_7989D), 42% to northern tributary joining on left bank (EBR_5620) and 18% to southern tributary joining at B2029 road bridge (EBR_6602D). Inflow weightings based on FEH catchment area weightings.
	LfieldWWT_2	EBR_6602D	537628	144878			5.17	0.18	
	LfieldWWT_3	EBR_5620	538383	145181			12.03	0.42	
LingfieldUS	LfieldUS_1	EBR_4025In2	539766	145204	29.5	31.88	31.88	1.00	Inflow from southern tributary joining Eden Brook on right bank downstream of Lingfield.
M-AB9	n/a	M-AB9	539766	145204	29.5	31.88	31.88	n/a	Sweetening inflow of 0.001m3/s input for a floodplain channel represented with individual ISIS River Section.

*area equals catchment area between M-95 and M-26 minus MedwayL2 total area and Hendal catchment area

**area excludes Hendal catchment area

D Structure photos

D.1 River Medway

Return to section **B.1**.

M-147BU 	M-146ABU2 
M-138WU_L and M-138WU_M 	M-137BU 
M-136WU 	M-131BU 
M-131WU	M-127BU

	
M- 119BU	M- 86BU
	
M- 69BU	M-AB11OU
	
M- 44WU	M- 40BU
	
M- 37BU	M-23BU and M-23WU

M-
21RSU

CH_XS-
02

COLL_0170bu

D.2 River Eden

Return to section **B.2**.

EDN_6617BU	EDN_6012WU
	
EDN_5160VSU	EDN_4907BU
	
EDN_4186VSU	EDN_4186WU
	
EDN_2904WU	EDN_2418BU
	
EDN_1692VSU1 (upstream face)	EDN_1692VSU2

(downstream face)

(transitions to a culvert)

EDN_1631BU

EDN_1014BUL

EDN_1014BUR

EDN_0170VSU

EDN_0087WU

E-106WU

E-91WU

E-
93RCWU

EDE01_1199WU

EDE01_0926BU

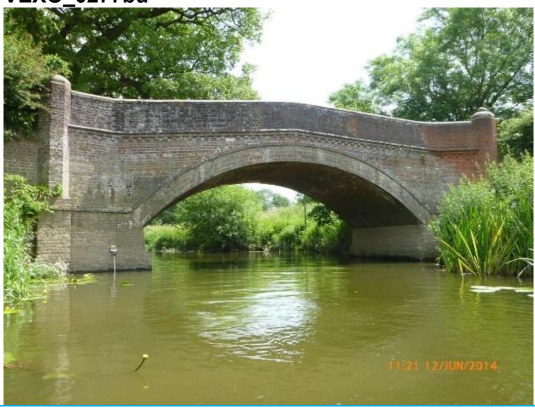
EDE01_0845BU

EDE01_0834BU

EDE01_0660BU

EDE01_0533BU

	
EDE01_0009BU	E-67WU1
	
E-48BU	S9.001BU
	
E-39VSU-S and E-39VSU-	E-HV5SPU1
N 	
E-28BU	E-26AWU1 and E-26AWU2

	
VEXO_0277bu 	**1.002WU** 

D.3 Eden Brook

Return to section **B.3**.

EBR_7455BU

EBR_6903BU

EBR_6843BU

EBR_6602BU

EBR_5853BU

CLB_0010OU

EBR_5063BU

EBR_4984WU

EBR_4976BU

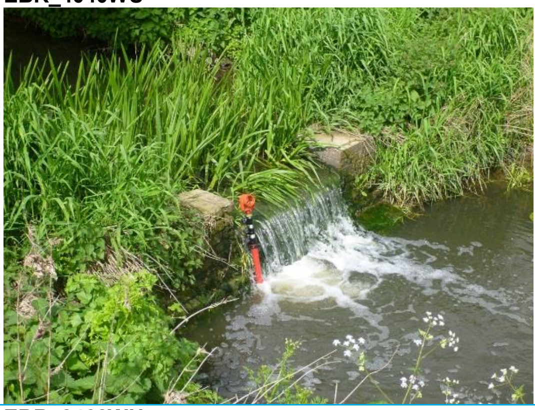
EBR_4925BU

EBR_4558BU

EBR_4219BU

EBR_4040WU

EBR_2945BU



EBR_2462WU

EBR_1169WU

EBR_1015BU

E Roughness values used within the hydraulic model

E.1 Introduction

Model 1 consists of an updated part of the River Medway Catchment Modelling and Flood Mapping Updates (2008) project and new survey at the upstream extent of the model. The new survey covers part of the River Eden upstream of the River Medway Catchment Modelling and Flood Mapping Updates (2008) and part of the Eden Brook.

The purpose of this section is to outline changes made to roughness values within the Medway Catchment Mapping and Modelling study and to outline the roughness values chosen for the new survey data of the River Eden and Eden Brook. 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 channel cross sections, photographic evidence, survey data and satellite imagery was used in conjunction with Chow's (1959) Manning's *n* values.

The Colliers Land Bridge and Vexour rating review models were also used to select appropriate in-channel Manning's *n* values.

Unless otherwise stated the photographic evidence from the River Medway Catchment Mapping and Modelling study is from the 2001 Longdin & Browning survey undertaken in June. Given the photographs were taken in summer, using them to determine a Manning's *n* value results in a conservative estimate of channel roughness.

The photographic evidence for the new channel survey is from the 2014 Maltby Land Surveys Ltd survey undertaken in May. Due to the photographs being taken in spring/summer, using them to determine a Manning's *n* value results in a conservative estimate of channel roughness.

E.2 River Medway Catchment Modelling and Flood Mapping Updates (2008)

Roughness coefficients for river sections within the 2008 hydraulic model are detailed below. Those in red were considered too high. More detail can be found in the Medway Detailed Model Review document.

Model sections	Reach	Channel roughness	Floodplain roughness	Comment
M-150_SUB_1 to M-75	River Medway (upstream of River Eden confluence)	0.050	0.083	Reasonably high floodplain roughness, akin to medium to dense brush (Chow, 1959)
M-74 to M-61		0.050	0.078	Reasonably high floodplain roughness
M-60 to CSM8U		0.045	0.073	Reasonably high floodplain roughness
CSM8D		0.035	0.060	-
CSM9WJU		**0.062**	**0.088**	Higher channel roughness than elsewhere in close proximity Reasonably high floodplain roughness
CSM9WJD to CSM14		0.035	0.060	-
CSM15 to CSM23		0.045	0.068	-
E-110-SUB-5 to E-90	River Eden	0.045	0.068	-
E-89AWJU to E-71		0.026 / 0.031	0.068	-
E-70		0.045	0.068	-
E-69 to CSE7D		0.045	0.078	Reasonably high floodplain roughness
CSE8		**0.078**	**0.082**	High channel roughness,

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

Model sections	Reach	Channel roughness	Floodplain roughness	Comment
to CSE15				suggesting either ineffective/sluggish channel and/or dense vegetation Reasonably high floodplain roughness
CSE16 to CSE21D		0.052	0.080	Reasonably high floodplain roughness
CSE22WU to CSE22WD		0.042	0.080	Reasonably high floodplain roughness
CSE23 to CSE33		0.052	0.080	Reasonably high floodplain roughness
CSM24 to CSM30	River Medway (River Eden confluence to Leigh FSA)	0.045	0.060	-
CSM31 to CSM43		0.040	0.060	-
CSM44 to CSM60		0.036	0.045	-
CSM61		0.032	0.041	-
CS1 to CS19	River Medway (Downstream of Leigh FSA)	0.025	0.052	-
CSD1 to CS30BJU		0.028 / 0.032	0.052	-
CS31BJD to CS36		0.028	0.041 / 0.045	-
CS37 to CS87		0.032	0.052	-
CS88BJU		0.027	0.052	-
CS90BJD to CST8JU		0.032	0.052	-
CST9JD to CS215		0.027 / 0.030	0.050	-

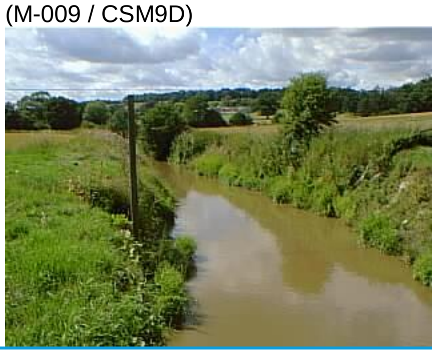
E.3 Updates to River Medway Catchment Mapping and Modelling study

E.3.1 In channel roughness

River Medway

Node label(s)	Manning's n	Photograph(s)
M-150_SUB_1 – M-137	Bed: 0.060 LB/RB: 0.080	(M-147) 
M-136 – M-119	Bed: 0.057 LB/RB: 0.070	(M-124) 

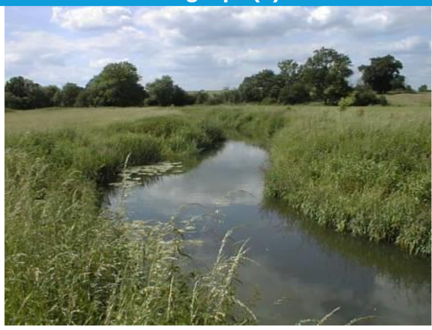
Node label(s)	Manning's n	Photograph(s)
M-118 – M75	Bed: 0.060 LB/RB: 0.075	(M-113) 
M-74 – M-63	Bed: 0.057 LB/RB: 0.070	(M-071) 
M-62 – M-58	Bed: 0.060 LB/RB: 0.080	(M-061) 
M-57 – M-039	Bed: 0.055 LB/RB: 0.065	(M-045) 
M-038 – M-025	Bed: 0.055 LB/RB: 0.060	(M-034) 

Node label(s)	Manning's n	Photograph(s)
M-024 – M-020	Bed: 0.055 LB/RB: 0.065	(M-023) 
M-019 – CH_XS-01	Bed: 0.057 LB/RB: 0.078	(M-015) 
M-016	Bed: 0.057 LB: 0.055 RB: 0.070 Note that the roughness values for this section was retained from the Colliersland Bridge rating model.	(M-016) 
M-015 – M-013	Bed: 0.057 LB: 0.078 / 0.055 RB: 0.078 / 0.070 Note that the roughness values for these sections were retained from the Colliersland Bridge rating model.	(M-015) 
CSM9WJU – CSM11	Bed: 0.070 LB/RB: 0.085 / 0.070 Note that the roughness values for these sections were retained from the Colliersland Bridge rating model.	(M-009 / CSM9D) 
CSM012 – CSM15	Bed: 0.055 LB/RB: 0.070 / 0.055 Note that the roughness values for these sections were retained from the Colliersland Bridge rating model.	(M-001 near CSM013)

Node label(s)	Manning's n	Photograph(s)
		
CSM16	Bed: 0.055 LB/RB: 0.070	Satellite imagery shows vegetated banks with some trees, and a winding open channel with few weeds.
CSM17 – CSM23	Bed: 0.055 LB/RB: 0.075	Satellite imagery shows more vegetated banks with some trees.
CSM24 – CSM34	Bed: 0.057 LB/RB: 0.075	 © 2014 Google Rogues Hill near CSM24, view downstream.
CSM35 – CSM39	Bed: 0.055 LB: 0.055 RB: 0.080	Satellite shows clean winding open channel, few weeds. Left bank open pasture land. Right bank is wooded, light-medium brush.
CSM40 – CSM44	Bed: 0.055LB/RB: 0.070	Satellite shows clean winding open channel, few weeds. Left and right bank open pasture land but with light brush, long grass and trees on banks.
CSM45 – CSM50	Bed: 0.055 LB: 0.055 RB: 0.080	Satellite shows clean winding open channel, few weeds. Right bank open pasture land. Left bank is wooded, light-medium brush.  © 2014 Google. Ensfield Bridge, CSM46, view upstream.
CSM51 - CSM61	Bed: 0.055 LB/RB: 0.065	Satellite shows clean winding open channel, few weeds. Left and right bank open pasture land but with light brush, long grass and trees on banks.  © 2014 Google.

Node label(s)	Manning's n	Photograph(s)
		Tonbridge Bypass, view upstream. CSM59.
CS1 – CS7	Bed: 0.055 LB/RB: 0.078	Satellite image shows relatively straight open clean channel. Banks are largely vegetated with trees and brush.
M-AB9 – M-AB3JU	Bed: 0.055 LB/RB: 0.070	(M-AB7) 

River Eden

Node label(s)	Manning's n	Photograph(s)
E-110-SUB-5 – E-102	Bed: 0.040 LB/RB: 0.048	(E-106) 
E-101 – E-098	Bed: 0.045 LB/RB: 0.055	(E-100) 
E-097 – EDE01_0926	Bed: 0.040 LB/RB: 0.060	(E-090) 

Node label(s)	Manning's n	Photograph(s)
EDE01_0926D – EDE01_0845D	Bed: 0.040 LB/RB: 0.040	(E-085) 
EDE01_0834 –EDE01_0426	Bed: 0.040 LB/RB: 0.053	(E-081) 
E-079 – EDE01_0009D	Bed: 0.048 LB/RB: 0.050	(E-078) 
E-075 – E-072	Bed: 0.040 LB: 0.055 RB: 0.040	(E-075) 
E-071 – E-068	Bed: 0.040 LB/RB: 0.060	(E-071) 

Node label(s)	Manning's n	Photograph(s)
E-067AWJU – E-059	Bed: 0.055 LB/RB: 0.075	(E-065) 
E-58 – E-50	Bed: 0.055 LB/RB: 0.070	(E-054) 
E-049 – E-038 and HV-12 – HV-1	Bed: 0.045 LB/RB: 0.063	(E-043) 
E-037 – E-019	Bed: 0.055 LB/RB: 0.080	(E-030) 
E-018 – E-012	Bed: 0.050 LB/RB: 0.075 Note that the roughness values for these sections were retained from the Vexour rating model.	(E-012) 
VEXO01_0385 – VEXO01_0277u	Bed: 0.050 LB/RB: 0.070 Note that the roughness values for these sections were retained from the Vexour rating model.	(VEXO01_0303)

Node label(s)	Manning's n	Photograph(s)
		 Maltby Land Surveys Ltd (2014)
VEXO01_0277d – VEXO01_0230	Bed: 0.050 LB/RB: 0.060 Note that the roughness values for these sections were retained from the Vexour rating model.	(VEXO01_0230)  Maltby Land Surveys Ltd (2014)
VEXO01_0226	Bed: 0.065 LB/RB: 0.075 Note that the roughness values for this section was retained from the Vexour rating model.	(VEXO01_0226)  Maltby Land Surveys Ltd (2014)
VEXO01_0199 – VEXO01_0062	Bed: 0.065 LB/RB: 0.105 Note that the roughness values for these sections were retained from the Vexour rating model.	(VEXO01_0160)  Maltby Land Surveys Ltd (2014)
CSE8 – CSE10	Bed: 0.067 LB/RB: 0.085 Note that the roughness values for these sections were retained from the Vexour rating model.	(E-006 near CSE8) 
CSE11 –	Bed: 0.052	(E-001 near CSE11)

Node label(s)	Manning's n	Photograph(s)
CSE19	LB/RB: 0.070 Note that the roughness values for these sections were retained from the Vexour rating model.	
CSE20 – CSE-24	Bed: 0.057 LB/RB: 0.075	Satellite shows clean winding open channel, few weeds. Banks contain light brush / long grass, occasional trees.  (P_XS-03) Gauging station topographic survey, Longdin & Browning Surveys (2001)
CSE25 – CSE31	Bed: 0.058 LB/RB: 0.078	Satellite shows clean winding open channel, few weeds. Banks contain higher proportion of brush to long grass and a larger amount of trees.  © 2014 Google. Long Bridge, Falcombe Road, view downstream. CSE29.
CSE32 – CSE33	Bed: 0.055 LB/RB: 0.075	Satellite shows clean winding open channel, few weeds. Banks contain light brush / long grass, occasional trees.

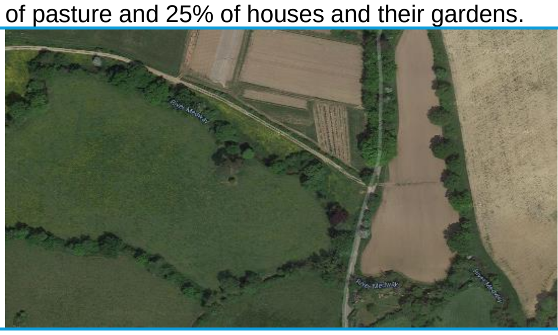
E.3.2 Floodplain roughness

As part of the model updates for Model 1, floodplain information within River Sections was re-defined. This involved re-extending the cross-sections and extracting ground levels from filtered LIDAR data at 1m resolution. During this process, roughness values for floodplain sections were updated. Ordnance Survey MasterMap and satellite imagery information was used to determine the land cover for a given section, whilst reference was made to Chow (1959) when assessing suitable Manning's *n* roughness values.

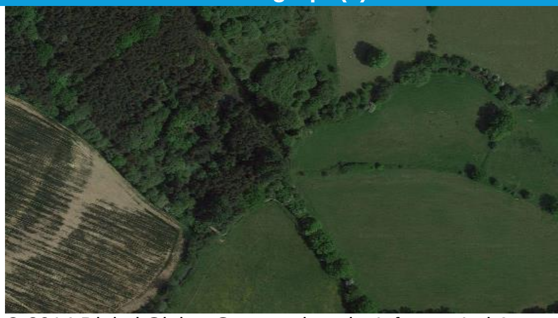
Across a given cross-section/transect there may be several land cover types (e.g. grassland, crops, woodland, waterbody). Rather than specifying individual roughness values for these land cover types, which may not be representative when cross-sections are typically 100-200m apart, a generalised value was specified for the banks, accounting for the range of land cover types. The information within the tables below provides justification for these values.

River Medway

Node label(s)	Manning's n	Photograph(s)
M-150-SUB-1 – M-147ABD	LB/RB: 0.050	 © 2014 Google Satellite imagery and MasterMap data shows pasture with short to medium length grass. Small amount of rough grassland.
M-146ABU – M-143	LB: 0.050 RB: 0.075	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain:** satellite imagery and MasterMap data shows pasture with short to medium length grass. **Right floodplain:** predominately coniferous trees, with regions of pasture and non-coniferous trees. Satellite imagery shows the trees to be dense.
M-142 – M-139	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd &

Node label(s)	Manning's n	Photograph(s)
		Bluesky © 2014 Google Satellite imagery and MasterMap data shows pasture with short to medium length grass.
M-138WJD – M-129	LB/RB: 0.110	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap themes and satellite imagery shows the floodplain to be composed of a mixture of pasture, buildings and other manmade surfaces. Some small regions of shrubs.
M-128BU – M-121	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery and MasterMap data shows pasture with short to medium length grass as well as cultivated regions. Small regions of woodland.
M-120BU – M-115A	LB: 0.050 RB: 0.075	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain** is composed of short pasture. **Right floodplain** is composed approximately 75% of pasture and 25% of houses and their gardens.
M-114 – M-106	LB/RB: 0.050	

Node label(s)	Manning's n	Photograph(s)
		© 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery and MasterMap data shows pasture and cultivated regions over both banks. Small regions of woodland.
M-105 – M-102	LB: 0.065 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain** contains 75% sparsely populated non-coniferous trees and 25% cultivated land. **Right floodplain** contains pasture and cultivated regions.
M-101 – M-99	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery and MasterMap data shows pasture and cultivated regions over both banks.
M-98 – M-91	LB: 0.050 RB: 0.070	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain:** satellite imagery and MasterMap data shows pasture and cultivated regions. **Right floodplain:** contains roughly 50:50 ratio of woodland and shrubs and pasture.

Node label(s)	Manning's n	Photograph(s)
M-90 – M-89	LB: 0.110 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain** contains densely populated coniferous trees. **Right floodplain** is pasture with short grass.
M-88 – M-71	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows a mixture of pasture fields with short grass and cultivated fields.
M-70 – M-68	LB/RB: 0.070	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap themes and satellite imagery shows the floodplain on both the left and right bank to be composed of a mixture of pasture (approximately 50%), buildings and other man-made surfaces (approximately 50%).
M-67 – M-42WJD	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows a mixture of pasture and fields with short grass and cultivated

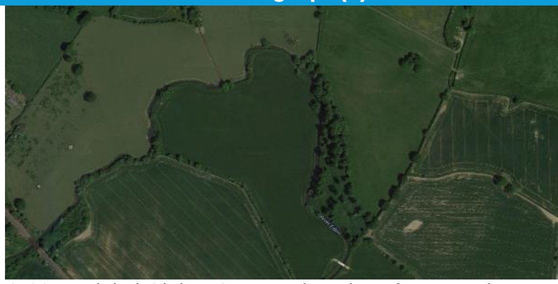
Node label(s)	Manning's n	Photograph(s)
		fields.
M-41 – M-37D	LB/RB: 0.080	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Both sides of the floodplain contain dense trees and shrubs, with small areas of open pasture.
M-36 – M-25	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery shows fields of pasture as well as cultivated fields over both banks.
M-AB9 – M-AB7	LB: 0.050 RB: 0.080	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Left floodplain: satellite imagery shows fields of pasture as well as cultivated fields on the left bank. Right floodplain: roughly even mix of pasture and woodland.
M-AB6 – M-AB3JU	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery shows fields of pasture as well as cultivated fields over both banks.

Node label(s)	Manning's n	Photograph(s)
M-24 – M-13	LB: 0.050 RB: 0.065	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain:** MasterMap themes and satellite data show that the left floodplain is composed of pasture and some cultivated land. **Right floodplain** is composed of a mixture of land types, including woodland, pasture, buildings and hard surfaces.
COLL01_0409 – CSM25BJU	LB/RB: 0.060	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery and MasterMap themes show both sides of the floodplain to contain a mixture of fields of short grass pasture and cultivated fields.
CSM25BJD – CSM27	LB: 0.060 RB: 0.055	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google **Left floodplain:** MasterMap themes and satellite data show that the left floodplain is composed of pasture (75%) with some woodland and orchards (25%). **Right floodplain** is composed mainly of pasture (80%) with a few buildings and manmade surfaces.
CSM28 – CSM30	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky

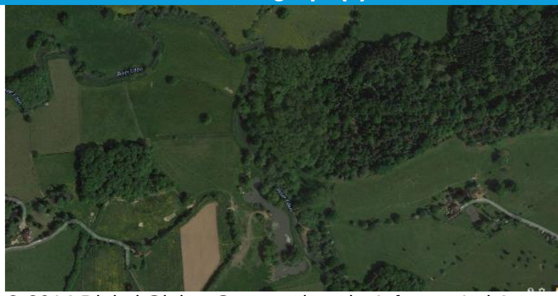
Node label(s)	Manning's n	Photograph(s)
		© 2014 Google Floodplain on both left and right floodplain is composed of pasture and cultivated fields.
CSM31 – CSM32	LB: 0.065 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google Satellite imagery shows the **right floodplain** to be composed of short pasture and cultivated fields. The **left floodplain** is a composed of 60% pasture and 40% scrub and woodland.
CSM33 – CSM39	LB: 0.050 RB: 0.110	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the **left floodplain** to be composed of short grass. The **right floodplain** is composed of dense woodland and shrubs, with few regions of open pasture.
CSM40 – CSM44	LB: 0.070 RB: 0.090	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed of a mixture of pasture and dense woodland and shrubs. Roughly a 1:3 ratio on the **right floodplain**, and 1:1 ratio on the **left floodplain**.
CSM45 – CSM50	LB\RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd &

Node label(s)	Manning's n	Photograph(s)
		Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed predominately of pasture and cultivated land, with some small regions of shrubs and trees.
CSM51 – CSM56	LB: 0.050 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the **left floodplain** to be pasture land with sparse trees. The **right floodplain** contains inland water (approx. 20%) and pasture land (approx. 80%).
CSM57U – CSM61	LB: 0.090 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the **right floodplain** is composed predominately of pasture. The **left floodplain** is composed mainly of woodland with a mixture of rough grassland and pasture.
CS1 – CS7	LB: 0.050 RB: 0.065	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the **right floodplain** is composed of a mixture of pasture and scrub. The **left floodplain** is composed of mostly of cultivated land regions of trees (25%).

River Eden

Node label(s)	Manning's n	Photograph(s)
EDE01_0009D – E-68	LB/RB: 0.040	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed predominately of pasture and cultivated land.
E-67AWJU – E-65	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed predominately of pasture and cultivated land with some small regions of low vegetation.
E-62 – E-61	LB: 0.050 RB: 0.070	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap themes and satellite imagery shows the **left floodplain** to be composed of pasture, whilst the **right floodplain** has an area of non-coniferous trees as well as pasture.
E-60 – E-51	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed predominately of

Node label(s)	Manning's n	Photograph(s)
		pasture and cultivated land.
E-50 – E-39AVSU	LB/RB: 0.055	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery show the area around Hever Castle is composed of a mixture of land uses including pasture, shrub and trees.
E-37JD – E-27JD	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed predominately of pasture and cultivated land.
E-26AWJU – E-25AWJD	LB: 0.050 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right floodplains are composed predominately of pasture and cultivated land. The left floodplain has a large region of rough grassland.
E-24 – CSE10	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right side of the floodplain are composed predominately of pasture and cultivated land.

Node label(s)	Manning's n	Photograph(s)
CSE11 – CSE12	LB: 0.110 RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the **right floodplain** is composed of pasture and cultivated land. The **left floodplain** is composed of woodland and shrub.
CSE13 – CSE24	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right areas of floodplain are composed predominately of pasture and cultivated land.
CSE25 – CSE29BU	LB: 0.050 RB: 0.075	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the **left floodplain** is composed of pasture and cultivated land. The **right floodplain** is composed 50:50 of woodland and shrub and pasture.
CSE29BD – CSE33	LB/RB: 0.050	 © 2014 Digital Globe, Getmapping plc, Infoterra Ltd & Bluesky © 2014 Google MasterMap and satellite imagery shows the left and right sides of the floodplain are composed predominately of pasture and cultivated land.

E.4 New survey of River Eden and Eden Brook

E.4.3 In channel roughness

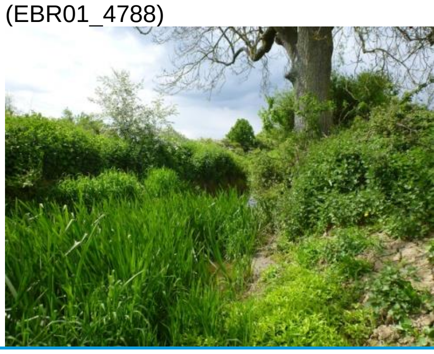
River Eden

Node label(s)	Manning's n	Photograph(s)
EDN01_6783 – EDN01_6617	Bed: 0.040 LB/RB: 0.040	(EDN01_6617) 
EDN01_6205 – EDN01_6003	Bed: 0.045 LB/RB: 0.045	(EDN01_6021) 
EDN01_5708 – EDN01_4184	Bed: 0.045 LB/RB: 0.060	(EDN01_5708)  (EDN01_4652) 
EDN01_4160 – EDN01_2894	Bed: 0.045 LB/RB: 0.050	(EDN01_3557)

Node label(s)	Manning's n	Photograph(s)
		 (EDN01_3677) 
EDN01_2418 – EDN01_1703	Bed: 0.040 LB/RB: 0.045	(EDN01_2048) 
EDN01_1693 – EDN01_1014	Bed: 0.035 LB/RB: 0.035	(EDN01_1297) 
EDN01_0978 – EDN01_0153	Bed: 0.040 LB/RB: 0.050	(EDN01_0173) 
EDN01_0093 – EDN01_0013	Bed: 0.045 LB/RB: 0.055	(EDN01_0013)

Node label(s)	Manning's n	Photograph(s)
		

Eden Brook

Node label(s)	Manning's n	Photograph(s)
EBR01_7995 – EBR01_6843	Bed: 0.045 LB/RB: 0.060	(EBR01_7989) 
EBR01_6697 – EBR01_6602	Bed: 0.050 LB/RB: 0.055	(EBR01_6697) 
EBR01_6540 – EBR01_4976	Bed: 0.040 LB/RB: 0.050	(EBR01_5620) 
EBR01_4925 – EBR01_4382	Bed: 0.045 LB/RB: 0.060	(EBR01_4788) 

Node label(s)	Manning's n	Photograph(s)
		(EBR01_4382) 
EBR01_4223 – EBR01_1015D	Bed: 0.040 LB/RB: 0.045	(EBR01_4040)  (EBR01_2474) 
EBR01_0757 – EBR01_0018	Bed: 0.040 LB/RB: 0.050	(EBR01_0018) 

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