Lower Thames Crossing

6.3 Environmental Statement Appendices
Appendix 14.6 - Flood Risk Assessment - Part 4

APFP Regulation 5(2)(a) and (5)(2)(e)

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

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Lower Thames Crossing

Appendix 14.6 - Flood Risk Assessment - Part 4

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1 Introduction

1.1 Context

1.1.1 This document forms Part 4 of the Flood Risk Assessment (the FRA) for the A122 Lower Thames Crossing (the Project).

1.1.2 The FRA forms Appendix 14.6 of the Environmental Statement (ES) (Application Document 6.3).

1.2 Form of assessment

1.2.1 The FRA is presented in nine principal parts and one affiliated part. These parts and a brief description of their contents are detailed in Plate 1.1.

1.2.2 All drawings referenced within this document can be found within Part 9 of the FRA.

1.3 Basis of assessment

1.3.1 The FRA for the Project is based on the design as presented in the Development Consent Order application.

1.3.2 The FRA includes an assessment of flood risk for both the construction phase and the operational phases of the Project.

1.4 Project design and mitigation

1.4.1 The Project includes a range of environmental commitments. Commitments are identified in the Project under the following categories:

a. Embedded mitigation: measures that form part of the engineering design, developed through the iterative design process summarised above.

b. Good practice: standard approaches and actions commonly used on infrastructure development projects to avoid or reduce environmental impacts, and typically applicable across the whole Project.

c. Essential mitigation: any additional Project-specific measures needed to avoid, reduce or offset potential impacts that could otherwise result in effects considered to be significant in the context of the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017. Essential mitigation has been identified by environmental topic specialists, taking into account the embedded and good practice mitigation.

1.4.2 Embedded mitigation is included within the Design Principles (Application Document 7.5) or as features presented on ES Figure 2.4: Environmental Masterplan (Application Document 6.2). Design Principles relevant to mitigation of effects on flood risk are described in this document, each with an alpha-numerical reference code (e.g. LSP. XX). Good practice and essential mitigation are included in the Register of Environmental Actions and Commitments (REAC). The REAC forms part of ES Appendix 2.2, the Code of

Construction Practice (CoCP) (Application Document 6.3). Each entry in the REAC has an alpha-numerical reference code [e.g. RDWE0XX] to provide cross reference to the secured commitment. Where appropriate, the REAC and Design Principle reference codes for secured commitments and actions have been cross referenced in this document and are shown in square brackets.

1.4.3 The Design Principles, Environmental Masterplan, CoCP and REAC, all form part of the Project control plan. The control plan is the framework for mitigating, monitoring and controlling the effects of the Project. It is made up of a series of ‘control documents’ which present the mitigation measures identified in the application that must be implemented during design, construction and operation to reduce the adverse effects of the Project. Further explanation of the control plan and the documents which it comprises is provided in the Introduction to the Application (Application Document 1.3).

1.5 Overview of hydraulic modelling for the Mardyke

1.5.1 This document summarises the modelling approach followed to assess fluvial and tidal flood risk where the Project crosses the fluvial flood plains of the Mardyke and its tributaries.

1.5.2 The aim of the modelling is to inform the FRA and the design of the Project. To achieve this aim, a 1D/2D coupled Flood Modeller/TUFLOW model has been developed to assess flood risk to the Project and its impact on flooding elsewhere.

1.5.3 The sections that form Part 4 of the FRA are presented in Plate 1.2.

Plate 1.1 Form of the FRA

Principal parts

Part 1: Introduction	This part sets out the objectives of the FRA and describes the methodology used in its development. It also includes a list of stakeholders and the glossary for the FRA.
Part 2: Planning Policy	This part summarises the national, regional and local legislation that is directly or indirectly related to flood risk.
Part 3: Environmental setting	This part provides descriptive information about the existing environmental condition within the Order Limits.
Part 4: Hydraulic assessment – Mardyke	This part describes the hydraulic modelling undertaken to analyse flooding scenarios in the River Mardyke catchment.
Part 5: Hydraulic assessment – West Tilbury Main	This part describes the hydraulic modelling undertaken to analyse flooding scenarios in Tilbury Marshes. It also describes the hydraulic breach modelling undertaken to analyse tidal flood risk.
Part 6: Flood risk	The probability and the potential consequences of flooding from all sources are considered in this part, along with a matrix of mitigation measures.
Part 7: Surface water drainage	This part reviews the existing surface water drainage provisions and sets out the drainage strategy for the Project.
Part 8: Technical summary	This part includes a technical summary of the FRA and sets out conclusions that would be used to inform the design.
Part 9: Drawings	All drawings that support the FRA are included in this part.

Affiliated part

Part 10: Watercourse crossings and diversions	This part details the watercourse crossings and diversions that would be required to construct and operate the Project.

Plate 1.2 Form of Part 4 of the FRA

Section 1: Introduction	This section sets out the context of the assessment and describes its objectives. This section also includes a high-level overview of the hydraulic modelling for the Mardyke and sets out the form of the assessment.
Section 2: Study area	This section includes the background and the history of the study area.
Section 3: Data input plan	This section describes the data that was available and used for the hydrological assessment and the development of the hydraulic model.
Section 4: Hydrological assessment	This section describes the methodology that was applied for the hydrological assessment.
Section 5: Model development	This section covers the development of the hydraulic model, describing the procedure that was followed to create the 1D and 2D parts of the model.
Section 6: Calibration and validation	This section details calibration and validation of the modelling against historic flood datasets.
Section 7: Design simulations and results	This section provides the model run parameters and the results of the design simulations.
Section 8: Conclusions	This section includes a summary of conclusions of the modelling undertaken.

2 Study area

2.1 Study area

2.1.1 The Mardyke catchment covers an area of 102m^2 and is located in Thurrock. The catchment extends from the sluice gate at Purfleet, where the Mardyke discharges to the River Thames (hereinafter referred to as the Mardyke Sluice), to its headwaters at West Horndon. The river alignment flows north to south for the upper part and north-east to south-west for the downstream part. The catchment is characterised as rural for its majority, except the part downstream of Stifford gauging station which is characterised as urban. The catchment is low-lying, with an average elevation lower than 12m above ordnance datum (AOD) (Mott MacDonald, 2019). This low-lying topography leads to substantial areas of floodplain. Most of the catchment is underlain by London Clay, whilst along the River Thames near Purfleet the catchment is underlain by Chalk. Adjacent to this Chalk there is a section of Oldhaven, Blackheath, Woolwich, Reading and Thanet beds (Mott MacDonald, 2019). Generally, it can be concluded that the geology of the catchment is characterised by mixed permeability and superficial deposits, with high permeability bedrock downstream of Stifford gauging station.

2.2 Flood history

2.2.1 Flood history within the Mardyke catchment is detailed in previous study hydrology reports (JBA, 2011; Mott MacDonald, 2019). Historically, the most affected areas in the catchment lie between Stifford gauging station and Purfleet and the areas of Bulphan and West Horndon in the northern part of the catchment (JBA, 2011; Mott MacDonald, 2019).

2.2.2 JBA (2011) reports that there are records of flooding in South Essex dating from 1227. However, based on the previous studies, there is more confidence in event descriptions after 1880 (JBA, 2011; Mott MacDonald, 2019).

2.2.3 Previous studies (JBA, 2011; Mott MacDonald, 2019) reported that in 1888, 1947, 1958 and 1968 there were severe floods that affected the Mardyke catchment. However, there is no information regarding affected areas and sources of flooding for the 1888 and 1947 events. For the 1958 event, the information indicates the source of flooding was heavy rainfall and the affected area was Stanford-le-Hope. The 1968 event, which was created by heavy rainfall, resulted in the Mardyke overtopping its river banks, affecting the West Horndon area.

2.2.4 The Mott MacDonald hydrology report (2019) included a table provided by the Environment Agency listing the most significant flood events in the Mardyke catchment. This table is reproduced in Table 2.1. The February 2010 event was caused by heavy rainfall and resulted in flooding in the Bulphan area (Mott MacDonald, 2019).

Table 2.1 Summary of significant flood events recorded in the Mardyke catchment

Year	Date	Type	Description	Parameters	Areas affected
1958	September 5	Rainfall	Rivers Blackwater and Brain (limited flooding), Can, Wid, Crouch, Mardyke	3.27 inches (81mm) in 24 hours	Stanford-le-Hope, Puddle Dock
1965	8–10 December	Fluvial	Rainfall	Rainfall on 8 and 9 December on the Stour, Colne, Chelmer, Blackwater, Crouch, Thameside	Grays
1968	12–15 January	Fluvial	Colne – Rainfall 9am Friday 12 to 9am Monday 15: 31 inches (787mm)	Mardyke – out in low flood plain – levels up to 12 inches (300mm) over bank	West Horndon
1968	September 15	Rainfall	Rivers Mardyke, Roach, Crouch and Stour	3,500cusecs Nayland	Purfleet
2002	December 31	No information – assumed fluvial	Mardyke TQ 63846 85579	N/A	Bulphan
2003	January 23	Road drainage	563855 185488	N/A	Bulphan
2010	28 February/1 March	Heavy rainfall	N/A	N/A	Bulphan
2012	July	No information – assumed fluvial	Photographs showing extended flooding that reaches bridge levels	N/A	Not identified

Source: Mott MacDonald, 2019

2.3 Previous studies

2.3.1 A model of the Mardyke catchment was developed by the Environment Agency (JBA, 2011). The study required the construction of a 1D-2D hydraulic model, using Flood Modeller–TUFLOW software, to cover the Mardyke catchment from the A127 road just north of West Horndon, down to its confluence with the River Thames. The objective was to develop flood outlines, levels and areas benefiting from defences for a range of return period events including 20 year, 20 year + climate change, 75 year, 100 year, 100 year + climate change, and 1,000 year. Outputs also included velocity, flow and depth grids from the 2D part of the model.

2.3.2 The Environment Agency's 2011 model was further updated in 2019 (Mott MacDonald, 2019), with the latest available data to ensure that the outputs were reliable and up to date for use in Environment Agency applications. The study provided an update of the existing Mardyke 1D-2D hydrodynamic model, and updated flood flow estimation.

2.3.3 Peak flood estimates derived by previous studies are discussed further in Section 4.

3 Data input plan

3.1 Data

3.1.1 A range of data has been provided by the Environment Agency and used to develop an updated 1D-2D model of the Mardyke. The data is summarised in Table 3.1. The extent of the new model and 2m resolution LiDAR is displayed in Plate 3.1.

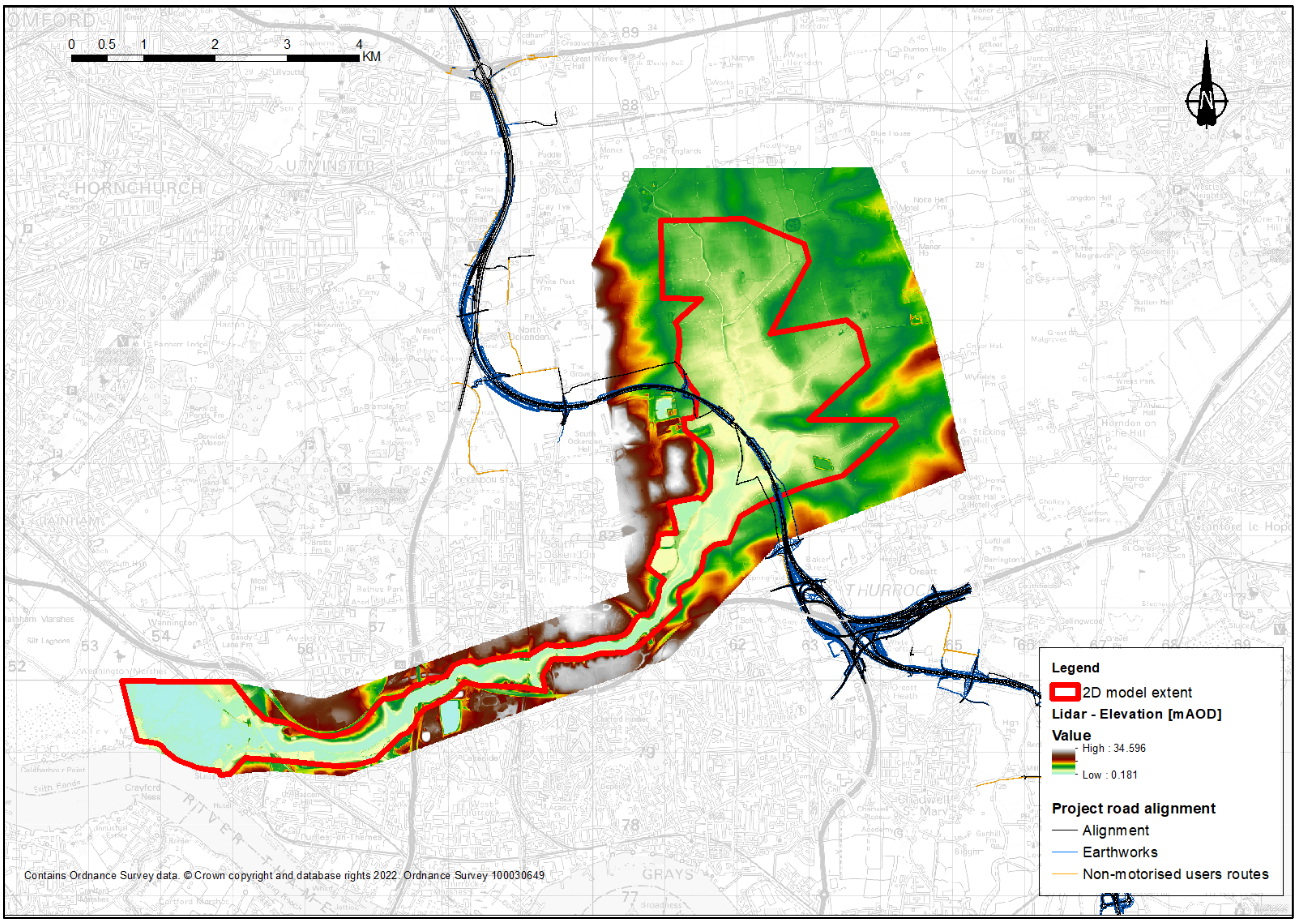
Table 3.1 Environment Agency data summary

Data type	Data format	Comment	Available for the study
Existing modelling studies (model reports, topographic surveys, 1D-2D models)	PDF, 1D-2D models, topographic surveys (DWG, DAT, JPG)	JBA Consulting, March 2011, Mardyke Flood Risk Study Mott MacDonald, May 2019, PDU4 Mardyke Hydraulic Modelling Report	Yes
LiDAR	ASC	ltc_lidar_2m_v3.asc (dated 2017)	Yes
Flow/level gauges	CSV, XLS	Stifford gauging station 15-minute level data (01/10/1992–29/12/2017) Stifford gauging station rating curve Stifford daily max flow (11/10/1974-29/12/2017) Stifford daily mean flow (11/10/1974-29/12/2017) Stifford gauging station annual maximum flow data (01/10/1974–01/10/2016) Stifford gauging station annual maximum level data (01/10/1992–01/10/2017) Mardyke Sluice gate 15-minute upstream level data (08/05/2006–14/03/2018) Mardyke Sluice gate 15-minute downstream level data (08/05/2006–14/03/2018) Mardyke Sluice gate 15-minute gate opening in percentage (08/05/2006–14/03/2018)	Yes
Rain gauges	CSV	BASILDON Sewage Treatment Works (STW) (TELEM) (TQ7362990679) Sub-daily (mostly 15-minute)/daily rainfall data (1996-2017) BENFLEET BARRIER RG (TELEM) (TQ7807085590) Sub-daily (mostly 15-minute)/daily rainfall data (2000-2017) BRENTWOOD RG (TELEM) (TQ5958891411) Sub-daily (mostly 15-minute)/daily rainfall data (1989-2017)	Yes

Data type	Data format	Comment	Available for the study
		CROPPENBURG (TELEM) (TQ8169483417) Sub-daily (mostly 15-minute)/daily rainfall data (2014–2017) SCARHOUSE (TELEM) (TQ7936482301) Sub-daily (mostly 15-minute)/daily rainfall data (2014–2017) Central Park (TQ4992286440) 15-minute/daily rainfall data (1990–2018) DARTFORD STW RG (TQ5522176541) 15-minute/daily rainfall data (1990–2018) EAST HAVEN BARRIER RG (TQ7473084312) Sub-daily (mostly 15-minute)/daily rainfall data (1999–2017) HUTTON SHENFIELD STW RG (TELEM) (TQ6504595964) Sub-daily (mostly 15-minute)/daily rainfall data (1996–2017) Nags Head Lane (TQ5666491532) 15-minute/hourly rainfall data (1989–2018) STIFFORD (TELEM) (TQ5926980051) 15-minute/daily	
Soil moisture deficit values	Values included in an email	Soil moisture deficit values for Met Office Rainfall and Evaporation Calculation System (MORECS) square 162 for dates preceding the calibration/ validation events (11/01/2011, 11/07/2012, 17/12/2013, 18/11/2014, 21/06/2016)	Yes
Lower Thames Crossing Channel Survey, undertaken for this study Storm Geomatics (November/ December 2018)	DWG, PDF, DAT, JPG, DOCX, XLSX, TXT	No.1 Mardyke No.2 Orsett Fen Sewer No.3 Golden Bridge Sewer No 4. Stringcock Sewer No.5 East Mardyke No.6 West Mardyke No.10 Extent No.11 Control No.12 Report	Yes
Historic flood data	XLS, DOCX, JPG, SHP, PDF	• July 2012, February 2014, 1953, 1968, 1978, 2009 events • Spreadsheet including information from members of the public and newspapers regarding Purfleet, North Stifford and South Ockendon for the 1953, 1968, 1978, 2009 events (Mardyke Flood History.xls) • Word document with the locations of the photographs from the July 2012 event and a link for a video from the February 2014 event (Mardyke historical fluvial	Yes

Data type	Data format	Comment	Available for the study
		flooding downstream of Stifford Gauge.docx) • Photographs from the July 2012 event from different locations (P7160007.JPG, P7160008.JPG, P7160009.JPG, P7160010.JPG, P7160011.JPG) • 1953, 1968, 1974, 1978, 1992, 2007, 2011, 2012, 2016 recorded flood outlines • EA_HistoricFloodMap.shp • EA_RecordedFloodOutlines.shp • 1968 Event flood outline • 76391 P4 Combined (002).pdf	
Tidal data	PDF, XLSX	Thames Estuary 2100 – design flood levels for the tidal River Thames (5, 10, 20, 50, 100, 200 and 1,000-year return periods)	Yes

Plate 3.1 Model extent and 2m resolution LiDAR



4 Hydrological assessment

4.1 Catchment delineation

Flood Estimation Handbook sub-catchments

4.1.1 Flood Estimation Handbook (FEH) catchment boundaries, downloaded from the FEH web server (UK Centre for Ecology and Hydrology, 2020a), are listed in Table 4.1 and shown in Plate 4.1 to 4.3.

Table 4.1 Downloaded FEH catchment boundaries

Catchment boundary	Date downloaded	Catchment name
FEH_Catchment_554850_178750.shp	18/03/2019	Sluice Gate*
FEH_Catchment_559650_1850400.shp	18/03/2019	Stifford GS*
FEH_Catchment_562050_183700.shp	18/03/2019	Project Road*
FEH_Catchment_561800_184950.shp	18/03/2019	Northern Confluence
FEH_Catchment_562050_183500.shp	18/03/2019	Golden Bridge Confluence
FEH_Catchment_563950_183450.shp	18/03/2019	Orsett Fen Top*
FEH_Catchment_562150_183950.shp	18/03/2019	Stringcock Sewer Confluence
FEH_Catchment_562700_185800.shp	18/03/2019	East Mardyke*
FEH_Catchment_561300_186350.shp	18/03/2019	West Mardyke*
FEH_Catchment_561900_182450.shp	25/03/2019	Southern Confluence
FEH_Catchment_561750_185000.shp	25/03/2019	C5.1
FEH_Catchment_561900_182400.shp	22/06/2017	Orsett Fen Confluence
FEH_Catchment_562050_183900.shp	13/06/2017	C4.1
FEH_Catchment_561800_184400.shp	04/08/2017	C4.2

**These are the catchments upstream of the Flood Estimation Points (FEPs) with the same name (shown in Plate 4.4)*

Plate 4.1 FEH catchment extents 1

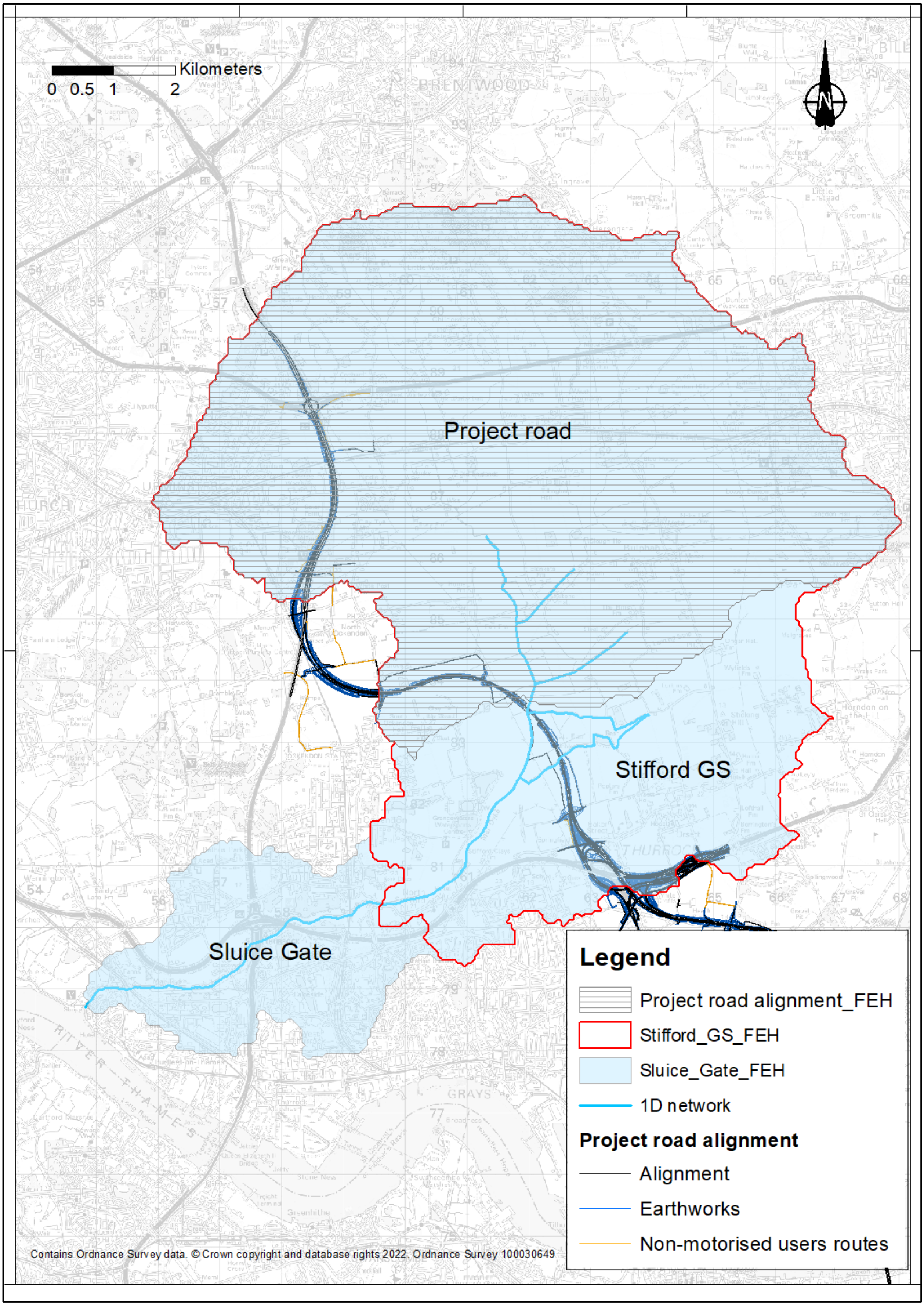


Plate 4.2 FEH catchment extents 2

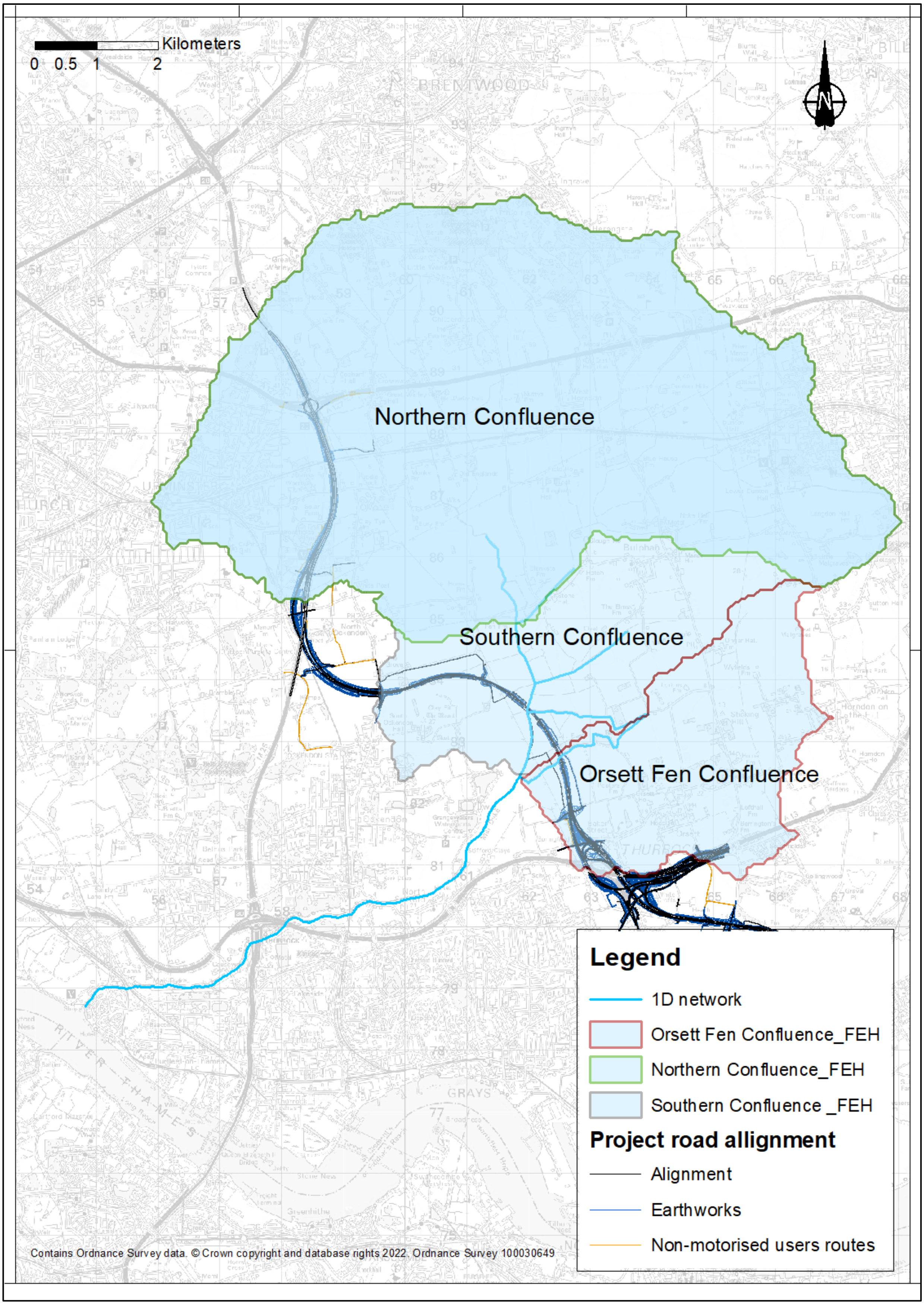
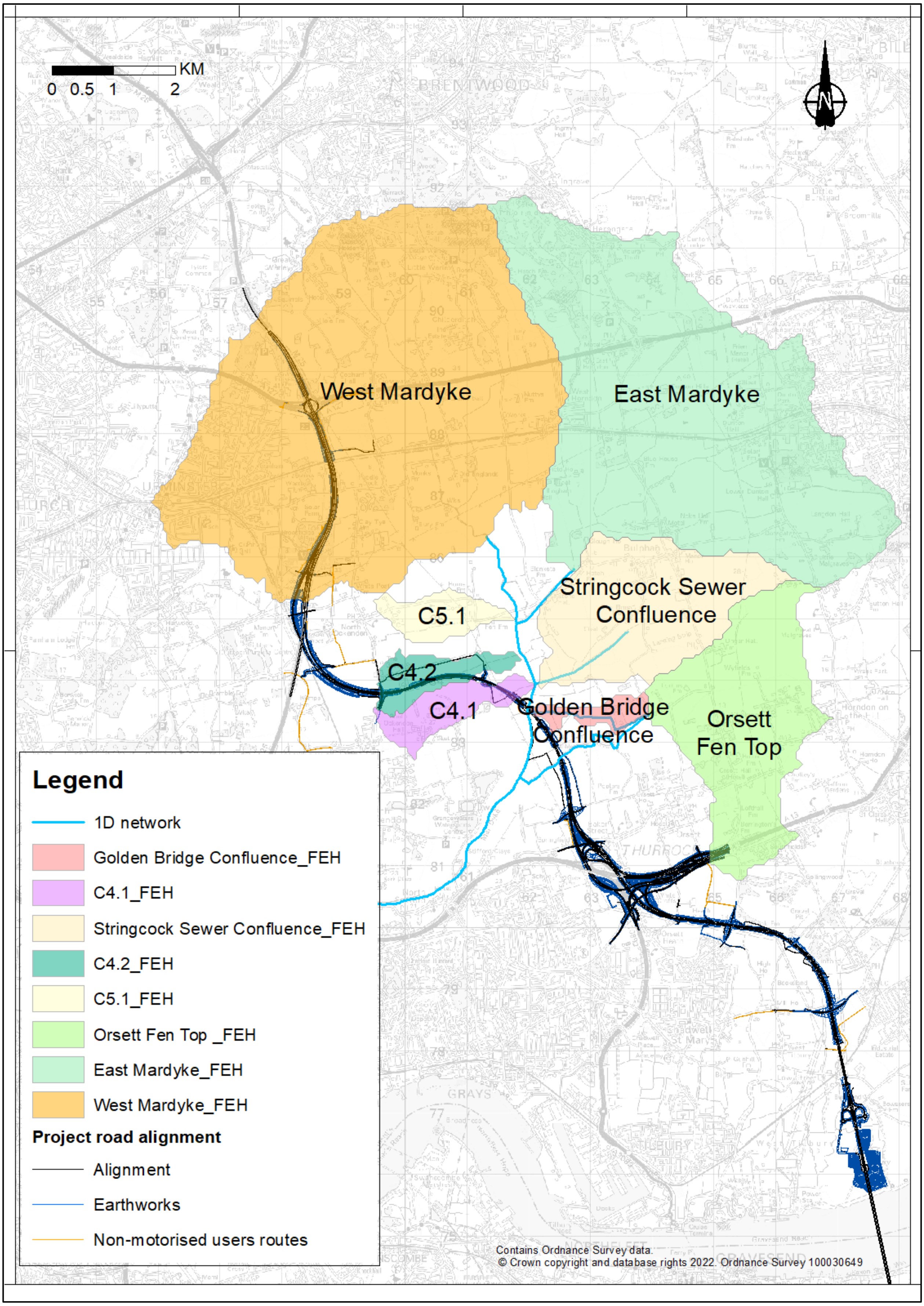


Plate 4.3 FEH catchment extents 3



Review of FEH catchment boundaries

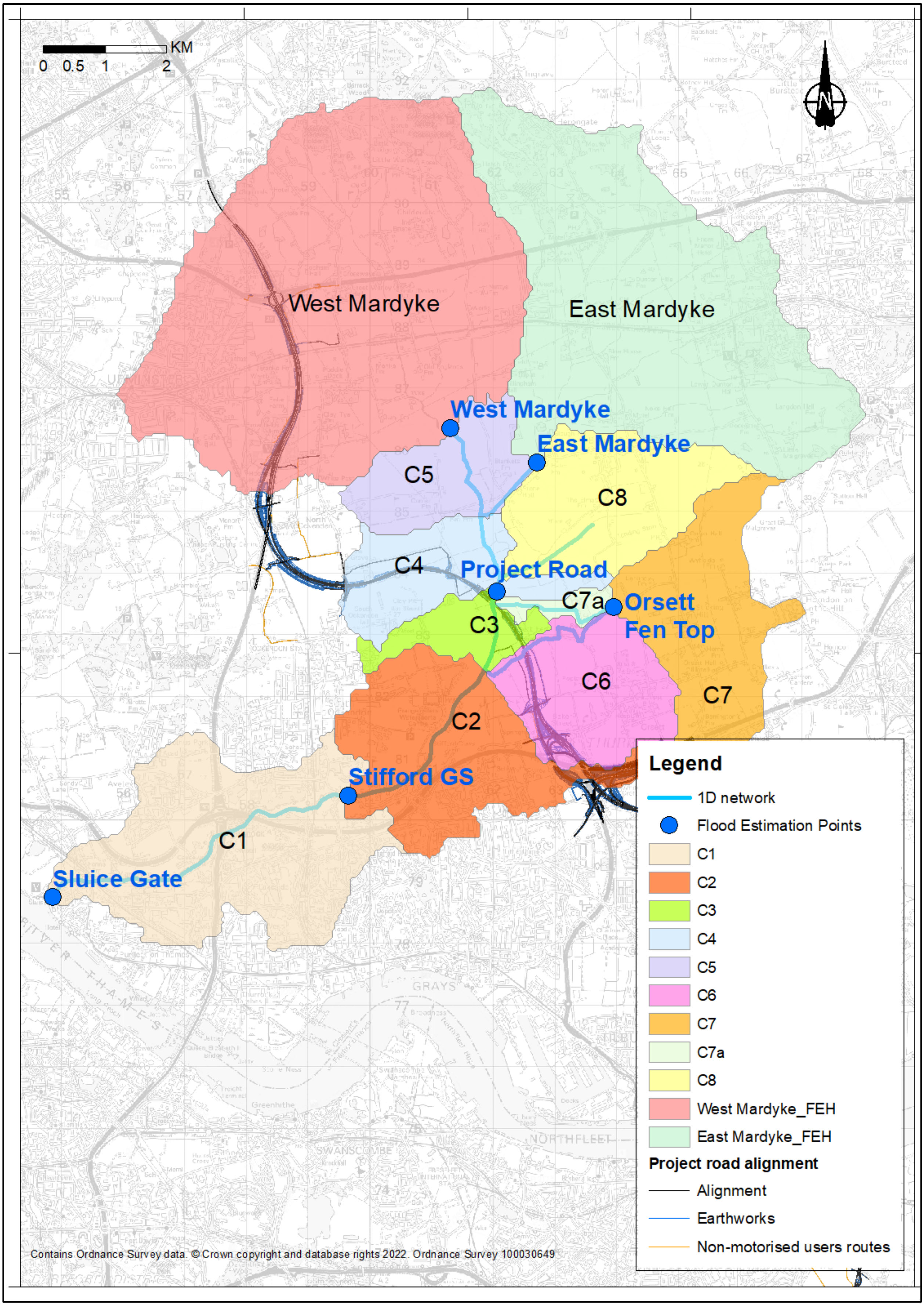
4.1.2 The FEH catchment boundaries were reviewed against Ordnance Survey (OS) mapping and LiDAR topographic data with 2, 1 and 0.5 metre resolution. The purpose of the review was to identify any required changes to the FEH catchment extents in light of the more detailed available topographic datasets.

4.1.3 The resulting FEH catchment adjustments are presented in Annex C.

Final catchment delineation

4.1.4 Following the amendments of FEH catchment extents, the final delineation of the sub-catchments was undertaken, based on significant features within the model extent (Stifford gauging station, Project alignment crossing of modelled watercourses, confluences of watercourses). Plate 4.4 shows the final catchment delineation as well as Flood Estimation Points (FEPs), at which FEH statistical method flood estimates have been derived.

Plate 4.4 Final catchment delineation



4.2 Catchment descriptors

4.2.1 The derivation of catchment descriptors for the delineated sub-catchments, and the catchments upstream of the FEPs, based on the downloaded FEH catchment descriptors, is described in Table 4.2.

4.2.2 Further details for sub-catchments C3, C4 and C5 are in Annex C.

4.2.3 The derived catchment descriptors are listed in Table 4.3.

Table 4.2 Catchment descriptors estimation methodology

Catchment	Methodology	Downstream catchment	Upstream catchment
Model inflow sub-catchments			
C1	Inter spreadsheet*	Sluice Gate	Stifford GS
C2	Inter spreadsheet	Stifford GS	Orsett Fen Confluence
C3	Representative catchment (see Annex C)	N/A	N/A
C4	Addition of 2 catchments (see Annex C)	N/A	N/A
C5	Representative catchment (see Annex C)	N/A	N/A
C6	Inter spreadsheet	Orsett Fen Confluence	Orsett Fen Top
C7a	FEH (area adjusted, see Annex C, Section C.1)	N/A	N/A
C8	FEH (area adjusted, see Annex C, Section C.1)	N/A	N/A
Model inflow sub-catchments and Flood Estimation Points			
C7 (Orsett Fen Top)	FEH (area adjusted, see Annex C, Section C.1)	N/A	N/A
East Mardyke	FEH (with no adjustment)	N/A	N/A
West Mardyke	FEH (with no adjustment)	N/A	N/A
Flood Estimation Points			
Sluice Gate	FEH (area adjusted, see Annex C, Section C.1)	N/A	N/A
Stifford GS	FEH (area adjusted, see Annex C, Section C.1)	N/A	N/A
Project Road	FEH (with no adjustment)	N/A	N/A

** The inter spreadsheet was developed by the Centre for Ecology and Hydrology. It can be used to calculate catchment descriptors for intervening catchment areas, based on upstream and downstream catchment descriptors.*

Table 4.3 Final catchment descriptors*

Catchment	AREA (km^2)	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	FPEXT	SAAR (mm)	SPRHOST	URBEXT1990 (not updated to 2027)	URBEXT2000 (not updated to 2027)
Model inflow sub-catchments											
C1	12.156	0.97	0.27	0.789	4.34	19.5	0.199	561.0	21.65	0.1467	0.2796
C2	8.375	0.98	0.27	0.583	2.69	18.0	0.237	551.3	31.73	0.0943	0.1313
C3	2.059	1.00	0.27	0.423	1.86	10.7	0.425	544.0	40.00	0.0017	0.0000
C4	4.331	1.00	0.27	0.425	1.86	14.3	0.360	544.5	40.18	0.0010	0.0000
C5	3.949	1.00	0.27	0.305	1.34	20.4	0.297	545.0	44.90	0.0439	0.0184
C6	5.451	1.00	0.27	0.456	2.87	12.1	0.267	547.0	37.63	0.0659	0.0797
C7a	0.637	1.00	0.27	0.324	1.27	7.3	0.694	544.0	43.54	0.0000	0.0000
C8	6.390	1.00	0.27	0.352	3.50	7.6	0.624	547.0	43.08	0.0213	0.0215
Model inflow sub-catchments and Flood Estimation Points											
C7 (Orsett Fen Top)	7.322	1.00	0.27	0.318	2.42	15.4	0.195	554.0	44.05	0.0069	0.0265
East Mardyke	22.305	0.99	0.27	0.188	5.23	29.6	0.234	566.0	50.02	0.0143	0.0420
West Mardyke	28.963	0.99	0.27	0.251	4.53	31.2	0.233	575.0	47.28	0.0536	0.0785
Flood Estimation Points											
Sluice Gate	101.935	0.97	0.27	0.368	14.46	22.5	0.288	561.0	41.74	0.0492	0.0839
Stifford GS	89.780	0.98	0.27	0.311	9.98	22.9	0.300	561.0	44.46	0.0360	0.0574
Project Road	65.938	0.99	0.27	0.259	6.67	26.0	0.310	565.0	46.92	0.0308	0.0510

** Catchment descriptors are defined in Bayliss (1999) and Bayliss et al. (2006)*

4.3 FEH statistical method

4.3.1 This section details the derivation of flood estimates by the FEH statistical method.

Index flood estimation

4.3.2 The index flood (QMED) has been estimated based on gauged annual maximum (AMAX) flow values at Stifford gauging station and for all study sub-catchments and FEPs, and by applying the FEH catchment descriptor equation. The application of these methods and selection of preferred QMED estimates is detailed below.

QMED estimate at Stifford based on gauged AMAX record

Rating of high flows at Stifford

4.3.3 The National River Flow Archive (NRFA) (UK Centre for Ecology and Hydrology, 2020b) considers Stifford gauging station to be unsuitable for QMED estimation or inclusion in Pooling Group analysis. The gauging station weir is reported to experience non-modular flow conditions and drowning of the weir arising due to backing up of flows upstream of Mardyke Sluice and weed growth. The Environment Agency has provided the text below (in the document 'Stifford additional information.docx', attached to email from the Environment Agency dated 30 November 2018), which also notes that non-modular flow conditions are frequent, and a non-modular adjustment is applied to rated flows:

'*The structure has a theoretical modular limit of 0.79m above crest level (mAC) however, non-modular flow can occur from as little as 0.2mAC. The structure is an Essex Standard Weir (Modified flat vee crump) and so its modular limit occurs when the crest level is within 70% of the stage. This structure drowns completely on a frequent basis. There is an operational gate downstream of the structure which does have an effect on the modularity of the site. Additionally, in previous years we have had issues with maintenance and weed growth (2000-2012). Finally, there is a river restoration scheme downstream of the weir which is also believed to have an effect on modularity. This has been in place since ~2015. Flood plain storage begins at 1.1mAC.*

Our current method of calculating non-modular flows is through a reduction curve within our database. The drowning percent is determined by dividing the crest by the flow. When this is above 0.3, the raw flow data is reduced via a reduction curve within our database. When 100% drowned, the drowned flow is taken as 30% of modular flow. This is calculated automatically and is provided in our FQ.CorrectedFinal.15.O time series in the WISKI[1] *database.*'

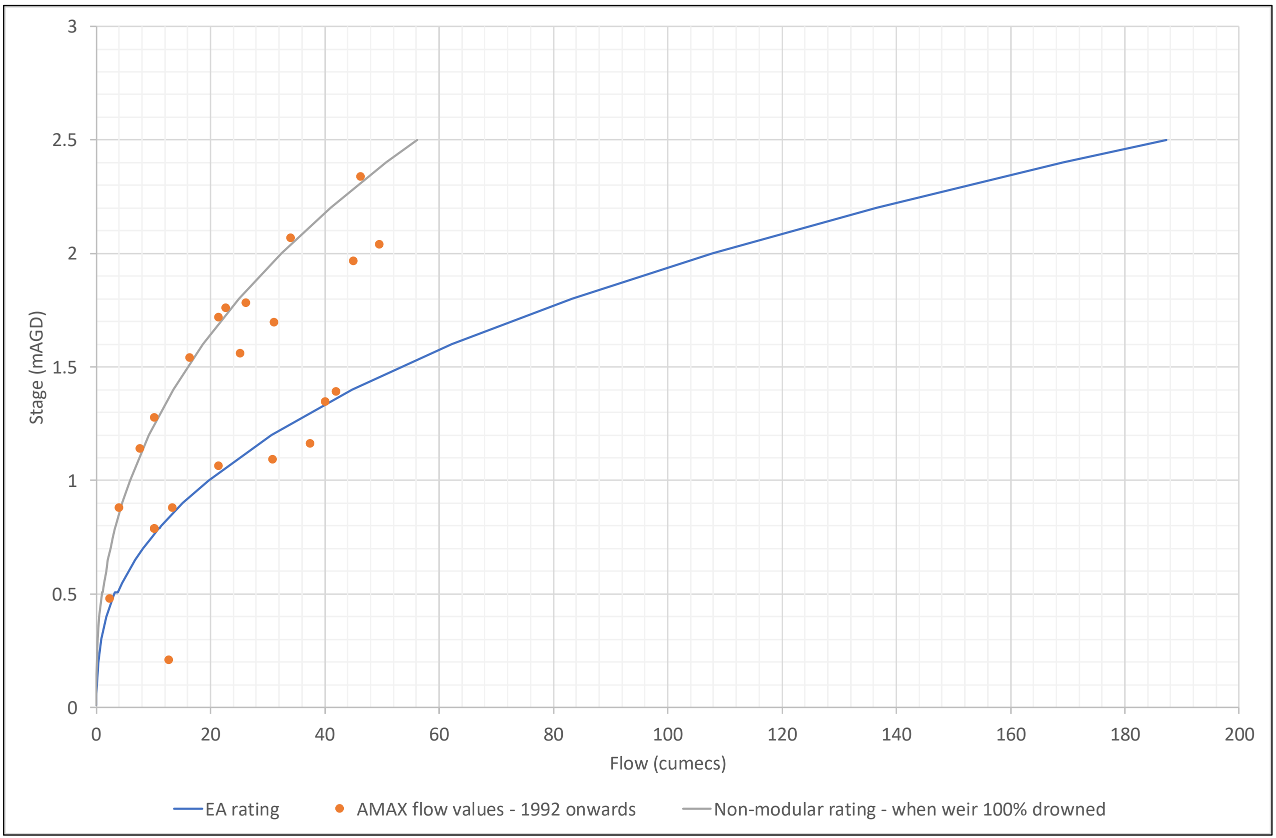
4.3.4 Plate 4.5 shows the Stifford stage-discharge rating, both with and without the 100% drowned non-modular adjustment (flow taken as 30% of modular flow). The plate also shows AMAX flows plotted against corresponding level values for the post-1992 AMAX series (i.e. the AMAX flow values for which

[1] WISKI is the Environment Agency's hydrological database

corresponding level values are available). Plate 4.5 shows that the AMAX values plotted generally lie within the bounds of the two rating curves plotted. There are three outliers with flow values higher than implied by the modular rating.

4.3.5 It is not clear how reliable the non-modular adjustment applied is, as no flow gauging measurements were provided to verify the rating. The rating of high flows at Stifford is therefore considered uncertain and QMED estimated from gauged AMAX records at Stifford will therefore be uncertain. The impact of this uncertainty on the FRA is considered further in Section 4.5.

Plate 4.5 Stifford ratings and AMAX events



Gauged QMED values

4.3.6 AMAX flow data recorded at Stifford gauging station was provided by the Environment Agency for the water years 1 October 1974 to 1 October 2016. The data quality codes of the AMAX values provided are all flagged as either ‘suspect’ or ‘estimated’, except for two AMAX values for which the quality code is ‘good’. These AMAX values are plotted in Plate 4.6.

4.3.7 Plate 4.6 shows an apparent qualitative difference in Stifford AMAX flow values before and after approximately 1992. Additionally, corresponding river levels are available for the post-1992 AMAX flow values provided but not for the pre-1992 values. This suggests a change in how data was recorded in approximately 1992. Table 4.4 lists QMED values calculated from the AMAX values provided for the whole record, pre-1992 only and post-1992 only, as well as the gauged QMED estimate reported in the Environment Agency 2010 Mardyke modelling study (JBA, 2011).

Plate 4.6 Stifford AMAX values

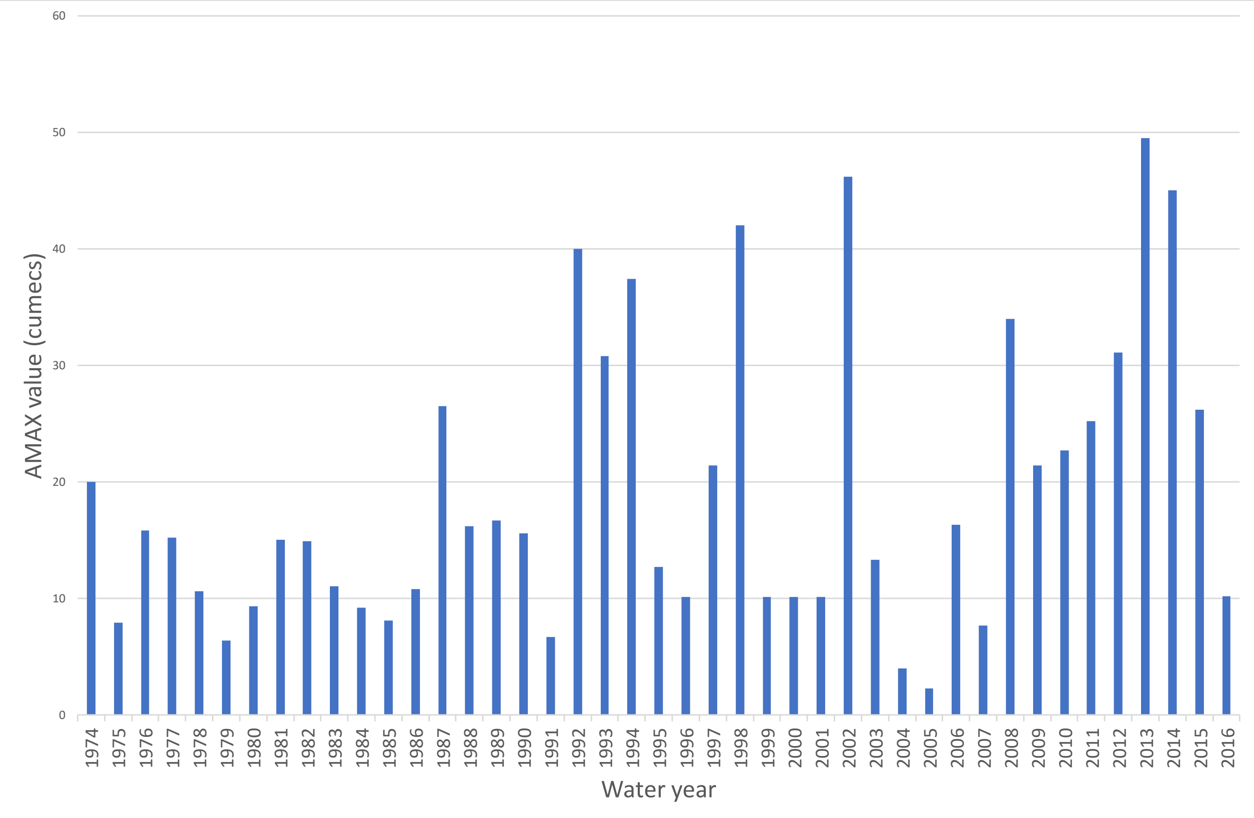


Table 4.4 QMED values derived by gauged AMAX values

Dataset	Water years used to calculate QMED	Calculated AMAX value (cumecs)	Comment
Provided for the Project by the Environment Agency	1974 to 2016	15.2	
	1974 to 1991	13.0	
	1992 to 2016	21.4	Considered best gauged QMED estimate
Previous Environment Agency Mardyke modelling study (JBA, 2011) (AMAX values for water years 2002 to 2009 are all higher than in the current AMAX dataset provided for use in the Project)	1974 to 2009	15.1	Based on data from two qualitatively different periods of record (pre-1992 and post-1992)
Previous Environment Agency Mardyke modelling study (Mott Macdonald, 2019)	AMAX values not used (and QMED at Stifford not estimated)	Not calculated	QMED at Stifford not estimated

4.3.8 The gauged QMED values in Table 4.4 provide further indication of a qualitative difference between AMAX values recorded pre- and post-1992 (with estimated QMED values for these periods of record of 13.0 and 21.4cumecs respectively). Given this change in data quality, QMED estimated by the later period (1992 onwards) is preferred, as data quality control is likely to be better for the later period of record. However, information is not available to verify this assumption.

4.3.9 The estimated QMED value reported in the previous Environment Agency Mardyke modelling study (JBA, 2011) is included in Table 4.5 for comparison. However, this makes use of data from both periods (pre- and post-1992), and the later AMAX values (2002 to 2009) have since been amended by the Environment Agency.

4.3.10 The most reliable gauged QMED estimate at Stifford is therefore considered to be the value based on current AMAX records for the period 1992 onwards, i.e. 21.4cumecs. However, confidence in this value is relatively low, due to the uncertainty in the rating of high flows at Stifford, as discussed above.

QMED values estimated by the FEH catchment descriptor equation

4.3.11 The updated FEH QMED catchment descriptor equation published in Environment Agency Science Report SC050050 (Kjeldsen *et al.*, 2008) was applied to derive QMED values for each sub-catchment and FEP. An urban adjustment was applied (Kjeldsen, 2010), with URBEXT2000 values updated to 2027 using the urban expansion formula (Kjeldsen *et al.*, 2010). Updating URBEXT2000 values to 2027 is consistent with the study base year[2] (2027), however the difference between updating URBEXT2000 to, e.g. 2019 or 2027 would have an insignificant impact on the resulting QMED estimates.

4.3.12 A donor adjustment was applied using Ingrebourne at Gaynes Park as a donor station. This was found to be the only relatively nearby (catchment centroid 7.7km from the centroid of the catchment upstream of the Project Road FEP), hydrologically similar station, recording data of suitable quality. Applying this donor adjustment results in scaling of QMED values (estimated by the FEH catchment descriptor equation) by 0.92.

4.3.13 Stifford gauging station was rejected for use as a donor station due to the uncertainty in the rating of high flows at Stifford (discussed above).

4.3.14 QMED values estimated by the FEH catchment descriptor equation are listed in Table 4.5. These results show that the urban adjustment has most influence for the downstream sub-catchments C1 and C2, which have higher urbanisation than the other sub-catchments. C1 is also permeable and so the relative impact of urbanisation on its calculated QMED value is higher. The donor adjustment has only a modest impact on calculated QMED values (adjustment ratios are 0.96 to 0.97).

[2] The hydrology study was undertaken before the Project opening year was extended from 2027 to 2030, and hence the Project climate change horizon was extended from 2127 to 2130

Table 4.5 QMED estimates by FEH catchment descriptor equation

	QMED estimates (cumecs)			
Sub-catchment/ Flood Estimation Point	**No urban adjustment and no donor adjustment**	**Applying urban adjustment only**	**Applying urban adjustment and donor adjustment**	**95% confidence limits (cumecs) lower / upper**
Model inflow sub-catchments				
C1	0.33	0.89	0.86	0.42 / 1.77
C2	0.56	0.71	0.69	0.34 / 1.41
C3	0.28	0.28	0.27	0.13 / 0.56
C4	0.53	0.53	0.51	0.25 / 1.05
C5	0.65	0.66	0.63	0.31 / 1.3
C6	0.60	0.67	0.65	0.32 / 1.32
C7a	0.13	0.13	0.13	0.06 / 0.26
C8	0.89	0.91	0.89	0.43 / 1.81
Model inflow sub-catchments and Flood Estimation Points				
C7 (Orsett Fen Top)	1.13	1.15	1.12	0.55 / 2.29
East Mardyke	3.63	3.72	3.60	1.76 / 7.38
West Mardyke	4.38	4.64	4.46	2.18 / 9.14
Flood Estimation Points				
Sluice Gate	9.01	9.78	9.46	4.62 / 19.38
Stifford GS	9.47	9.94	9.62	4.70 / 19.69
Project Road	8.31	8.64	8.34	4.07 / 17.08

Preferred QMED estimates

4.3.15 QMED has been estimated at Stifford from gauged AMAX records and by the FEH catchment descriptor equation, applying a donor adjustment.

4.3.16 Usually a gauged QMED estimate within the study catchment would be preferred to an estimate by the catchment descriptor equation, and the gauge within the study catchment would be used to apply a QMED donor adjustment at other sites in the study catchment. However, for this study, QMED estimates derived by the FEH catchment descriptor equation (listed in Table 4.5) are preferred as:

a. The rating of high flows at Stifford is uncertain (paragraphs 4.3.3 to 4.3.7).

b. QMED estimated by gauged AMAX values is higher than the statistical estimate 95% upper confidence limit (i.e. consistent with overestimation by the gauged AMAX record).

4.3.17 QMED values derived by the catchment descriptor equation are uncertain (95% confidence limits are listed in Table 4.5). To reduce uncertainty in model outputs, modelled design event flood extents have been reviewed against Environment Agency knowledge of flooding in the catchment. The Environment Agency review was based on limited evidence of flooding in the catchment but did not indicate the results were unrealistic. The significance of modelling uncertainty on the Project design and proposed mitigation measures is considered in paragraphs 7.6.16 to 7.6.20.

Growth curve development

4.3.18 Growth curves were developed for the study FEPs using the FEH pooling group methodology. WinFAP software version 3.0.003, with the NRFA Peak Flow Dataset – Version 7 (downloaded in April 2019) were used to create the pooling groups and pooled growth curves. Growth curves were developed at four locations (West Mardyke, Orsett Fen Top, Project Road and Stifford gauging station) to apply to the FEPs, as listed in Table 4.6.

Table 4.6 Growth curves applied at Flood Estimation Points

Flood Estimation Point	Upstream catchment area (km2)	Growth curve applied
West Mardyke	29.0	West Mardyke
East Mardyke	22.3	West Mardyke
Orsett Fen Top	7.3	Orsett Fen Top
Project Road	65.9	Project Road
Stifford gauging station	89.8	Stifford gauging station
Sluice Gate	101.9	Stifford gauging station

4.3.19 The default pooling groups were reviewed for hydrological similarity with the subject sites considering the FEH catchment descriptors AREA, SAAR, BFIHOST, SPRHOST, PROPWET, FPEXT and FARL. This review resulted in removal of stations from the default pooling groups. Additional stations were then added to the pooling groups to achieve the target pooling group size of 500 years, except for Orsett Fen Top, for which a pooling group size of 410 years was accepted, as the Orsett Fen catchment is not well represented in the pooling sites dataset (small catchment). The choice of whether or not to add additional sites to the pooling group to increase the total number of station-years in the pooling group dataset involves a trade-off between increasing the pooling group sample size and adding sites that may not be representative of the study site.

4.3.20 Generalised Logistic, Generalised Extreme Value and Pearson Type III distributions were considered to identify the most appropriate distribution at each site.

Stifford gauging station

4.3.21 A pooled growth curve was derived for Stifford gauging station. As the rating of high flows at Stifford gauge is considered unreliable, Stifford was rejected from its own pooling group and therefore an ungauged growth curve was derived. The default pooling group includes 11 stations with a total of 542 station-years of data. The default pooling group was edited based on the following criteria:

a. Subject site has BFIHOST value of 0.311. Stations with values outside the range 0.131 to 0.491 (i.e. 0.311 +/- 0.18) were removed.

b. Subject site has SPRHOST value of 44.46. Stations with values outside the range 29.46 to 59.46 (i.e. 44.46 +/- 15) were removed.

c. Stations with SAAR values greater than 1,000 were rejected.

d. The pooling group review resulted in removal of three stations and addition of two stations to achieve the target pooling group size of approximately 500 station years. The reviewed pooling group includes 10 stations with a total of 501 station-years of data. Goodness of fit measures for the Stifford gauging station pooling groups are listed in Table 4.7. Growth factors are listed in Table 4.8 for urbanised and Table 4.9 for rural growth curves.

4.3.22 Urban growth curve adjustments applied the Kjeldsen (2009) method, with URBEXT2000 values updated to 2027[3] applying the national average growth model. The preferred growth curve is the reviewed pooling group, Generalised Logistic, urbanised growth curve (Table 4.8), as this growth curve is derived for the edited pooling group with an acceptable goodness of fit measure.

Table 4.7 Goodness of fit for Stifford gauging station pooling groups

Pooling group	Z* value/acceptable distribution fit					
	Generalised Logistic		GEV		Pearson Type III	
Default	2.3268	x	-1.1780	v	-0.6976	v
Reviewed	1.3638	v	-1.7261	x	-1.3989	x

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Table 4.8 Stifford gauging station urban growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.352	1.391	1.388	1.348	1.387	1.387
10	1.579	1.621	1.615	1.577	1.620	1.617
25	1.877	1.882	1.875	1.883	1.892	1.884
50	2.111	2.056	2.053	2.126	2.077	2.069
100	2.357	2.214	2.221	2.385	2.248	2.244
200	2.618	2.358	2.380	2.662	2.408	2.411
500	2.987	2.530	2.581	3.060	2.602	2.623
1,000	3.286	2.647	2.727	3.388	2.738	2.778

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

[3] The hydrology study was undertaken before the Project opening year was extended from 2027 to 2030, and hence the Project climate change horizon was extended from 2127 to 2130.

Table 4.9 Stifford gauging station rural growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.361	1.403	1.398	1.358	1.398	1.397
10	1.593	1.636	1.628	1.592	1.635	1.630
25	1.894	1.897	1.890	1.900	1.907	1.900
50	2.128	2.069	2.069	2.144	2.091	2.086
100	2.374	2.224	2.236	2.402	2.259	2.261
200	2.631	2.363	2.395	2.676	2.413	2.427
500	2.994	2.528	2.594	3.067	2.600	2.638
1,000	3.286	2.638	2.739	3.387	2.728	2.791

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Project Road

4.3.23 An ungauged pooled growth curve was derived for the Project Road. The default pooling group includes 10 stations with a total of 501 station-years of data. The default pooling group was edited based on the following criteria:

a. Subject site has BFIHOST value of 0.259. Stations with values outside the range 0.079 and 0.439 (i.e. 0.259 +/- 0.18) were removed.

b. Subject site has SPRHOST value of 46.92. Stations with values outside the range 31.92 to 61.92 (i.e. 46.92 +/- 15) were removed.

c. Stations with SAAR values greater than 1,000 were rejected.

4.3.24 The pooling group review resulted in removal of three stations and addition of five stations to achieve the target pooling group size of approximately 500 station years. The reviewed pooling group includes 11 stations with a total of 517 station-years of data.

4.3.25 Goodness of fit measures for the Project Road pooling groups are listed in Table 4.10 and pooling group growth factors are listed in Table 4.11 for urbanised and Table 4.12 for rural growth curves. Urban growth curve adjustments applied the Kjeldsen (2009) method, with URBEXT2000 values updated to 2027[4] applying the national average growth model. The preferred growth curve is the reviewed pooling group, Generalised Logistic, urbanised growth curve (highlighted in Table 4.11), as this growth curve is derived for the edited pooling group with an acceptable goodness of fit measure.

[4] The hydrology study was undertaken before the Project opening year was extended from 2027 to 2030, and hence the Project climate change horizon was extended from 2127 to 2130.

Table 4.10 Goodness of fit for Project Road pooling groups

Pooling group	Z* value/acceptable distribution fit					
	Generalised Logistic		GEV		Pearson Type III	
Default	2.3505	x	-0.9984	v	-0.6096	v
Reviewed	0.8163	v	-2.0644	x	-1.8287	x

Table 4.11 Project Road urban growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.365	1.407	1.405	1.383	1.426	1.429
10	1.604	1.649	1.644	1.640	1.689	1.689
25	1.919	1.927	1.920	1.987	2.002	1.994
50	2.169	2.115	2.110	2.267	2.220	2.207
100	2.434	2.288	2.289	2.569	2.426	2.409
200	2.715	2.447	2.460	2.895	2.620	2.603
500	3.117	2.639	2.676	3.371	2.863	2.850
1,000	3.446	2.772	2.833	3.767	3.035	3.031

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Table 4.12 Project Road rural growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.375	1.417	1.414	1.393	1.437	1.439
10	1.617	1.662	1.656	1.654	1.704	1.702
25	1.935	1.941	1.934	2.005	2.017	2.009
50	2.186	2.128	2.125	2.286	2.234	2.223
100	2.449	2.297	2.304	2.586	2.436	2.425
200	2.728	2.452	2.474	2.909	2.626	2.619
500	3.124	2.637	2.689	3.377	2.859	2.865
1,000	3.445	2.763	2.845	3.765	3.023	3.045

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Orsett Fen Top

4.3.26 An ungauged pooled growth curve was derived for Orsett Fen Top. The default pooling group includes 14 stations with a total of 509 station-years of data. The default pooling group was edited based on the following criteria:

a. Stations with less than 13 years of data were removed.

b. Subject site has BFIHOST value of 0.318. Stations with values outside the range 0.138 to 0.498 (i.e. 0.318 +/- 0.18) were removed.

c. Subject site has SPRHOST value of 44.05. Stations with values outside the range 29.05 to 59.05 (i.e. 44.05 +/- 15) were removed.

4.3.27 The pooling group review resulted in removal of four stations yielding a pooling group containing 10 stations with a total of 410 station-years of data. Additional sites were not added to achieve the target pooling group size of 500 station years. A pooling group size of 410 station years was considered appropriate for Orsett Fen Top as:

a. The pooled uncertainty measure does not increase significantly until below approximately 200 to 250 station years (Kjeldsen *et al.*, 2008).

b. The study site is not well represented in the pooling sites dataset, due to its small size. The choice of whether or not to add additional sites to the pooling group to increase the total number of station years in the pooling group dataset involves a trade-off between increasing the pooling group sample size and adding sites that may not be representative of the study site.

4.3.28 Goodness of fit measures for the Orsett Fen Top pooling groups are listed in Table 4.13 and pooling group growth factors are listed in Table 4.14 for urbanised and Table 4.15 for rural growth curves. Urban growth curve adjustments applied the Kjeldsen (2009) method, with URBEXT2000 values updated to 2027[5] applying the national average growth model. The preferred growth curve is the reviewed pooling group, Generalised Logistic, urbanised growth curve (highlighted in Table 4.14), as this growth curve is derived for the edited pooling group with an acceptable goodness of fit measure, and the Generalised Logistic distribution gives the best overall fit to UK flood data (Institute of Hydrology, 1999).

[5] The hydrology study was undertaken before the Project opening year was extended from 2027 to 2030, and hence the Project climate change horizon was extended from 2127 to 2130.

Table 4.13 Goodness of fit for Orsett Fen Top pooling groups

Pooling group	Z* value/acceptable distribution fit					
	Generalised Logistic		GEV		Pearson Type III	
Default	1.4995	v	-0.4591	v	-0.9826	x
Reviewed	0.3752	v	-1.1417	v	-1.5558	x

Table 4.14 Orsett Fen Top urban growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.432	1.475	1.510	1.415	1.456	1.491
10	1.753	1.813	1.852	1.724	1.781	1.821
25	2.226	2.268	2.277	2.182	2.222	2.233
50	2.640	2.627	2.586	2.584	2.573	2.533
100	3.116	3.003	2.888	3.048	2.941	2.826
200	3.668	3.397	3.184	3.587	3.329	3.113
500	4.535	3.950	3.569	4.438	3.876	3.488
1,000	5.316	4.394	3.856	5.207	4.318	3.767

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Table 4.15 Orsett Fen Top rural growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.439	1.483	1.517	1.421	1.463	1.497
10	1.763	1.824	1.861	1.734	1.792	1.830
25	2.239	2.280	2.288	2.194	2.235	2.244
50	2.654	2.639	2.598	2.597	2.584	2.544
100	3.129	3.012	2.901	3.061	2.950	2.838
200	3.678	3.402	3.197	3.598	3.333	3.126
500	4.539	3.945	3.582	4.442	3.871	3.500
1,000	5.310	4.379	3.869	5.202	4.303	3.780

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

West Mardyke

4.3.29 An ungauged pooled growth curve was derived for West Mardyke. The default pooling group includes 12 stations with a total of 546 station-years of data. The default pooling group was edited based on the following criteria:

a. Stations with less than 13 years of data were removed.

b. Subject site has BFIHOST value of 0.251. Stations with values outside the range 0.071 to 0.431 (i.e. 0.251 +/- 0.18) were removed.

c. Subject site has SPRHOST value of 47.28. Stations with values outside the range 32.28 to 62.28 (i.e. 47.28 +/- 15) were removed.

4.3.30 The pooling group review resulted in removal of six stations and addition of four stations to achieve the target pooling group size of approximately 500 station years. The reviewed pooling group contained 10 stations with a total of 512 station-years of data.

4.3.31 Goodness of fit measures for the West Mardyke pooling groups are listed in Table 4.16 and pooling group growth factors are listed in Table 4.17 for urbanised and Table 4.18 for rural growth curves. Urban growth curve adjustments applied the Kjeldsen (2009) method, with URBEXT2000 values updated to 2027 applying the national average growth model. The preferred growth curve is the reviewed pooling group, Generalised Logistic, urbanised growth curve (highlighted in Table 4.17), as this growth curve is derived for the edited pooling group with an acceptable goodness of fit measure.

Table 4.16 Goodness of fit for West Mardyke pooling groups

Pooling group	Z* value/acceptable distribution fit					
	Generalised Logistic		GEV		Pearson Type III	
Default	3.5190	x	-0.1245	v	0.3654	v
Reviewed	0.4473	v	-2.3208	x	-2.0348	x

Table 4.17 West Mardyke urban growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.392	1.437	1.433	1.431	1.479	1.478
10	1.646	1.694	1.687	1.713	1.767	1.762
25	1.980	1.987	1.979	2.087	2.099	2.090
50	2.243	2.183	2.179	2.385	2.325	2.316
100	2.519	2.361	2.367	2.701	2.533	2.530
200	2.813	2.525	2.546	3.038	2.725	2.735

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
500	3.229	2.720	2.772	3.521	2.959	2.993
1,000	3.568	2.853	2.936	3.917	3.121	3.181

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Table 4.18 West Mardyke rural growth factors

Return period (years)	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1.000	1.000	1.000	1.000	1.000	1.000
5	1.407	1.454	1.448	1.447	1.498	1.407
10	1.667	1.716	1.707	1.736	1.791	1.667
25	2.005	2.009	2.001	2.116	2.124	2.005
50	2.269	2.202	2.202	2.414	2.346	2.269
100	2.544	2.376	2.390	2.728	2.549	2.544
200	2.833	2.532	2.568	3.060	2.733	2.833
500	3.239	2.716	2.792	3.531	2.953	3.239
1,000	3.567	2.839	2.954	3.914	3.103	3.567

D: Default pooling group
R: Reviewed pooling group
GL: Generalised logistic distribution
GEV: General extreme value distribution
P3: Pearson Type III distribution

Flood frequency curves

4.3.32 Flood frequency curves were constructed for the FEPs by applying the QMED values derived in Table 4.5 and the preferred growth curves reported in the above sections. The resulting flood frequency curves are tabulated in Table 4.19.

Table 4.19 Flood frequency curves

Return period (years)	West Mardyke	East Mardyke	Orsett Fen Top	Project Road	Stifford gauging station	Sluice Gate
2	4.46	3.60	1.12	8.34	9.62	9.46
5	6.39	5.16	1.58	11.54	12.96	12.76
10	7.65	6.17	1.93	13.68	15.17	14.93
25	9.32	7.52	2.44	16.57	18.11	17.82
50	10.65	8.59	2.89	18.91	20.45	20.12
100	12.06	9.73	3.41	21.43	22.94	22.57

Return period (years)	West Mardyke	East Mardyke	Orsett Fen Top	Project Road	Stifford gauging station	Sluice Gate
200	13.56	10.95	4.01	24.15	25.60	25.19
500	15.72	12.69	4.96	28.12	29.43	28.96
1,000	17.48	14.11	5.82	31.42	32.58	32.06

4.4 FEH rainfall-runoff model

4.4.1 Hydraulic model inflow hydrographs were derived using the FEH rainfall-runoff model. The Revitalised Flood Hydrograph (ReFH) model was rejected as there is potential for tide locking of flood flows to result in critical design event durations significantly longer than the characteristic ReFH model event durations. The ReFH rainfall-runoff model can overestimate flood volumes when simulating events with durations significantly longer than recommended, due to overestimation of baseflow (Environment Agency, 2017a). The ReFH method is therefore not recommended for use in the Project's assessment of flood risk in the Mardyke catchment. Instead, the FEH rainfall-runoff model is recommended, as this gives more realistic event volumes when simulating long-duration events.

4.4.2 FEH rainfall-runoff models were specified for each study sub-catchment and FEP, applying the FEH catchment descriptor estimates of model parameter values. FEH rainfall-runoff hydrographs were generated using the Flood Modeller 4.4 FEH hydrology unit.

4.4.3 Initially, to derive flood peaks for comparison with the FEH statistical method estimates, design event hydrographs were derived for each sub-catchment and FEP rainfall-runoff model with the following:

a. Design storm area equal to the rainfall-runoff model catchment area

b. Winter storm profile

c. Time interval 0.25hr

d. FEH rainfall-runoff model design storm duration, rounded to nearest odd integer multiple of 0.25hr time interval

e. FEH rainfall-runoff model design Catchment Wetness Index

f. FEH depth-duration-frequency rainfall model parameter values of the sub-catchment or FEP upstream catchment applied

4.4.4 For the later simulation of design events with the Project Mardyke hydraulic model, appropriate design storm areas and durations were specified according to locations of interest in the hydraulic model.

4.4.5 Hydrographs were derived for the 2, 5, 10, 20, 25, 50, 100, 200, 500 and 1,000-year return period floods for winter rainstorm profiles[6]. FEH rainfall-runoff model flood return periods and corresponding rainfall return periods are specified in Flood Modeller according to FEH. Those applied in the study are listed in Table 4.20.

Table 4.20 FEH rainfall-runoff model rainfall return periods

Flood return period (years)	Rainfall return period (years)
2.33	2
5	8
10	17
20	35
25	42.5
50	81
100	140
200	246.7
500	520
1,000	1,000

4.4.6 FEH rainfall-runoff method parameter/event values are listed in Table 4.21. Resulting peak flows, derived for each sub-catchment and FEP, are listed in Table 4.22.

[6] The two-year simulations are actually 2.33-year design events, as the FEH rainfall-runoff method applies non-equal rainfall and flood return periods, and the two-year rainfall event gives a 2.33-year design flood (the model does not allow rainfall return periods lower than two years).

Table 4.21 FEH rainfall-runoff method parameter/event values

Parameter/ event value	West Mardyke	East Mardyke	C8	C7a	C7	C6	C5	C4	C3	C2	C1	Sluice Gate	Stifford GS	Project Road
Catchment area (km^2)	28.96	22.31	6.39	0.64	7.32	5.45	3.95	4.33	2.06	8.38	12.16	101.9	89.8	65.9
Tp(0) (hr)	5.93	8.29	10.32	6.91	7.19	6.02	3.79	6.67	7.34	4.29	4.04	12.79	11.30	8.94
BF (cumecs)	0.069	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.081	0.072	0.082
Design storm duration (hr)	9.75	13.25	16.25	10.75	11.25	9.75	6.25	10.25	11.75	6.75	6.25	20.25	17.75	14.25

Table 4.22 Peak floods derived by the FEH rainfall-runoff method

Return period (years)	West Mardyke	East Mardyke	C8	C7a	C7	C6	C5	C4	C3	C2	C1	Sluice Gate	Stifford GS	Project Road
2	8.45	5.36	1.06	0.14	1.55	1.08	1.39	0.82	0.36	1.72	1.87	14.06	14.57	13.67
5	13.14	8.43	1.71	0.21	2.44	1.67	2.19	1.28	0.57	2.70	2.40	22.38	23.08	21.59
10	16.93	10.72	2.19	0.28	3.17	2.22	2.84	1.68	0.75	3.54	2.94	28.38	29.31	27.55
20	21.29	13.39	2.74	0.35	4.00	2.84	3.64	2.15	0.95	4.62	3.83	35.40	36.57	34.51
25	22.63	14.20	2.92	0.38	4.26	3.03	3.88	2.29	1.02	4.95	4.20	37.55	38.80	36.64
50	27.68	17.29	3.57	0.47	5.24	3.75	4.81	2.84	1.26	6.22	5.49	45.65	47.20	44.71
100	32.86	20.43	4.24	0.56	6.25	4.50	5.77	3.40	1.51	7.55	7.12	53.91	55.76	52.95
200	39.27	24.31	5.06	0.67	7.50	5.44	6.97	4.10	1.82	9.22	9.21	64.09	66.31	63.13
500	49.75	30.61	6.42	0.85	9.55	6.99	8.95	5.27	2.34	12.02	12.97	80.64	83.48	79.74
1,000	61.35	37.55	7.92	1.06	11.83	8.72	11.17	6.58	2.91	15.19	16.83	98.84	102.37	98.09

4.5 Preferred flood estimates and comparison with previous estimates

Preferred flood estimates

4.5.1 Flood estimates at the FEPs derived by the FEH rainfall-runoff and FEH statistical methods are listed in Table 4.23.

4.5.2 Table 4.23 shows that flood estimates from the FEH rainfall-runoff method are consistently higher than those estimated by the FEH statistical method, by a factor 1.4 to 1.9 for QMED, and 1.8 to 2.7 for the 100 year return period.

4.5.3 The FEH statistical estimates (highlighted in Table 4.23) are preferred as:

a. Whilst there is a gauging station at Stifford, the rating of high flows at Stifford is unreliable and the catchment is treated as essentially ungauged. For ungauged catchments, statistical estimates are often preferred over rainfall-runoff methods (Environment Agency, 2017a).

b. Ungauged FEH rainfall-runoff method flood estimates are known to overestimate flood peaks on average, and for most applications the method has been superseded by ReFH.

c. Lower flood estimates than the FEH rainfall-runoff (RR) estimates listed in Table 4.23 are supported by the outcome of joint calibration of the hydrological and hydraulic models (see Calibration and validation), which resulted in scaling the ‘time to peak’ (Tp) parameter value of the FEH rainfall-runoff models by a factor of two for winter events, and three for summer events, which acts to reduce flood peaks estimated by the rainfall-runoff models.

Table 4.23 Peak floods derived by the FEH rainfall-runoff and statistical methods

Return period (years)	West Mardyke		East Mardyke		Orsett Fen Top		Project Road		Stifford gauging station		Sluice Gate	
	RR	Stat.	RR	Stat.	RR	Stat.	RR	Stat.	RR	Stat.	RR	Stat.
2	8.45	4.46	5.36	3.60	1.55	1.12	14.06	8.34	14.57	9.62	14.06	9.46
5	13.14	6.39	8.43	5.16	2.44	1.58	22.38	11.54	23.08	12.96	22.38	12.76
10	16.93	7.65	10.72	6.17	3.17	1.93	28.38	13.68	29.31	15.17	28.38	14.93
25	22.63	9.32	14.20	7.52	4.26	2.44	37.55	16.57	38.80	18.11	37.55	17.82
50	27.68	10.65	17.29	8.59	5.24	2.89	45.65	18.91	47.20	20.45	45.65	20.12
100	32.86	12.06	20.43	9.73	6.25	3.41	53.91	21.43	55.76	22.94	53.91	22.57
200	39.27	13.56	24.31	10.95	7.50	4.01	64.09	24.15	66.31	25.60	64.09	25.19
500	49.75	15.72	30.61	12.69	9.55	4.96	80.64	28.12	83.48	29.43	80.64	28.96
1,000	61.35	17.48	37.55	14.11	11.83	5.82	98.84	31.42	102.37	32.58	98.84	32.06

RR denotes FEH rainfall-runoff
Stat. denotes FEH statistical method

4.5.4 However, as the FEH statistical estimates are ungauged, they are uncertain. To reduce uncertainty in model outputs, modelled design event flood extents have been reviewed against Environment Agency knowledge of flooding in the catchment. The Environment Agency review was based on limited evidence of flooding in the catchment but did not indicate the results were unrealistic. The significance of modelling uncertainty on the Project design and proposed mitigation measures is considered in paragraphs 7.6.16 to 7.6.20.

Comparison with previous flood estimates

Previous study results

4.5.5 Table 4.24 lists the preferred estimates derived for this study with those derived by JBA (2011) and Mott MacDonald (2019).

Table 4.24 Comparison of flood estimates at Stifford gauging station

Return period (years)	Peak flood estimates at Stifford (cumecs)		
	This study: FEH statistical method	JBA (2011): Uncalibrated ReFH	Mott MacDonald (2019): Uncalibrated ReFH
2	9.62	–	16.1
5	12.96	–	21.4
10	15.17	–	25.6
20	–	24.39	29.9
25	18.11	–	–
50	20.45	–	36.8
75	-	–	40.4
100	22.94	32.15	43.1
200	*25.60	–	51.2
500	*29.43	–	–
1,000	*32.58	58.67	80.0

** For return periods greater than 100 years, the same factors applied to reconcile the 100-year FEH rainfall-runoff model inflows with the statistical estimate have been applied.*

JBA (2011) estimates

4.5.6 The JBA (2011) study derives preferred flood estimates by ReFH sub-catchment model inflows, populated with catchment descriptors, routed through the hydraulic model.

4.5.7 The JBA (2011) flood estimates are consistently higher than the preferred estimates for this study. However, the ReFH model inflows were not calibrated. During joint hydrological/hydraulic model calibration for the current study, it was found that FEH model Tp parameter scaling factors of approximately 2.5 to 3 were required to improve model calibration of the timing of fluvial peak flows. It is likely a similar Tp adjustment would apply if the JBA (2011) ReFH model were calibrated, and so the JBA (2011) ReFH derived estimates would reduce.

Mott MacDonald (2019) estimates

4.5.8 Mott MacDonald (2019) derived 'target peak flows' at Stifford by the ReFH rainfall-runoff method. It is assumed these were derived with a lumped ReFH model representing the catchment upstream of Stifford gauging station, however this is not stated explicitly in the Mott MacDonald (2019) hydrology reporting.

4.5.9 To verify these values, a lumped catchment ReFH model was populated with FEH catchment descriptors for the Mott MacDonald (2019) reported Stifford gauging station catchment extent (the 90.01km^2 FEH catchment upstream of Stifford gauging station) and simulated storm duration (16.5 hours). A comparison of these ReFH lumped catchment flows and the Mott MacDonald (2019) 'target peak flows' is presented in Table 4.25. Whilst the results differ slightly, they are close enough to suggest the Mott MacDonald (2019) derived 'target peak flows' at Stifford were derived by a lumped catchment ReFH model. Differences may be due to, for example, urban adjustment applied, or simulated storm duration.

Table 4.25 Comparison of ReFH lumped catchment flows and the Mott MacDonald (2019) 'target peak flows' at Stifford

Return period (years)	Mott MacDonald (2019) 'target flows' at Stifford	Stifford lumped catchment ReFH model	Difference (%)
2	16.1	16.3	1.4
5	21.4	21.7	1.3
10	25.6	25.9	1.3
20	29.9	30.5	1.9
30	32.7	33.3	1.8
40	35.0	35.6	1.8
50	36.8	37.6	2.1
75	40.4	41.2	2.1
100	43.1	44.2	2.4
200	51.2	52.7	3.0
1,000	80.0	82.7	3.4

4.5.10 As is the case for the JBA (2011) flood estimates, the Mott MacDonald (2019) flood estimates are consistently higher than the preferred estimates for this study. Again, the ReFH model inflows were not calibrated. During joint hydrological/hydraulic model calibration for the current study, it was found that FEH model Tp scaling factors of approximately 2.5 to 3 were required to improve model calibration of the timing of fluvial peak flows. It is likely a similar Tp adjustment would apply if the Mott MacDonald (2019) ReFH model were calibrated, and so the Mott MacDonald (2019) ReFH derived estimates would reduce.

Summary

4.5.11 Whilst the flood estimates of the previous JBA (2011) and Mott MacDonald (2019) studies are higher than those derived by the FEH statistical method for the current study, for both studies these were derived from uncalibrated ReFH models.

4.5.12 During joint hydrological/hydraulic model calibration for the current study, it was found that FEH model Tp scaling factors of approximately 2.5 to 3 were required to improve model calibration of the timing of fluvial peak flows. It is likely a similar Tp adjustment would apply if the ReFH models of the previous studies were calibrated, and so ReFH derived flood estimates of the previous studies would reduce.

4.5.13 Although the Mardyke catchment is gauged at Stifford, the rating of high flows at Stifford is unreliable (FEH statistical method) and the catchment is considered essentially ungauged for the purpose of flood estimation. For ungauged catchments, the FEH statistical method estimate of QMED is usually preferred (Environment Agency, 2017a).

4.5.14 It is recognised that the preferred FEH statistical method flood estimates of this study are uncertain, as they are derived from ungauged QMED estimates from the FEH catchment descriptor regression equation (QMED factorial standard error 1.43). Whilst there is uncertainty in the flood estimates and associated model outputs, the modelling is considered appropriate for use in this Flood Risk Assessment as:

a. To reduce uncertainty in model outputs, modelled design event flood extents have been reviewed against Environment Agency knowledge of flooding in the catchment. The Environment Agency review was based on limited evidence of flooding in the catchment but did not indicate the results were unrealistic.

b. Sensitivity testing undertaken (Model sensitivity tests) shows that increasing inflows by +20% results in an increase in flood levels at the Project of approximately 0.1m (i.e. modelled flood levels at the Project are only moderately sensitive to inflows).

4.6 Calibration inflows

4.6.1 The sub-catchment FEH rainfall-runoff models, specified by FEH catchment descriptors (FEH rainfall-runoff model) were used to simulate calibration/validation event inflows for five historical events as listed in Table 4.26.

4.6.2 The events were selected from the Stifford AMAX flow series, with those chosen having an event peak greater than QMED. Candidate events were then checked for satisfactory data availability (full records of data from rainfall and water level gauges), event types (high flow, high tide and a combination of them) and rainfall data quality (considering recorded data quality score and consistency of cumulative event rainfall with that at other rain gauges).

4.6.3 For each calibration/validation event, catchment average 15-minute event rainfall time series were constructed for each sub-catchment by applying the Thiessen weights method, using rain gauges with available data for each event.

4.6.4 Sub-catchment Catchment Wetness Index (CWI) values were calculated for each event following the method described in FEH (vol 4) for simulation of historic events. Soil Moisture Deficit (SMD) values required for calculating CWI values were provided by the Environment Agency for the nearest available date before the start of each event.

Table 4.26 Calibration and validation events

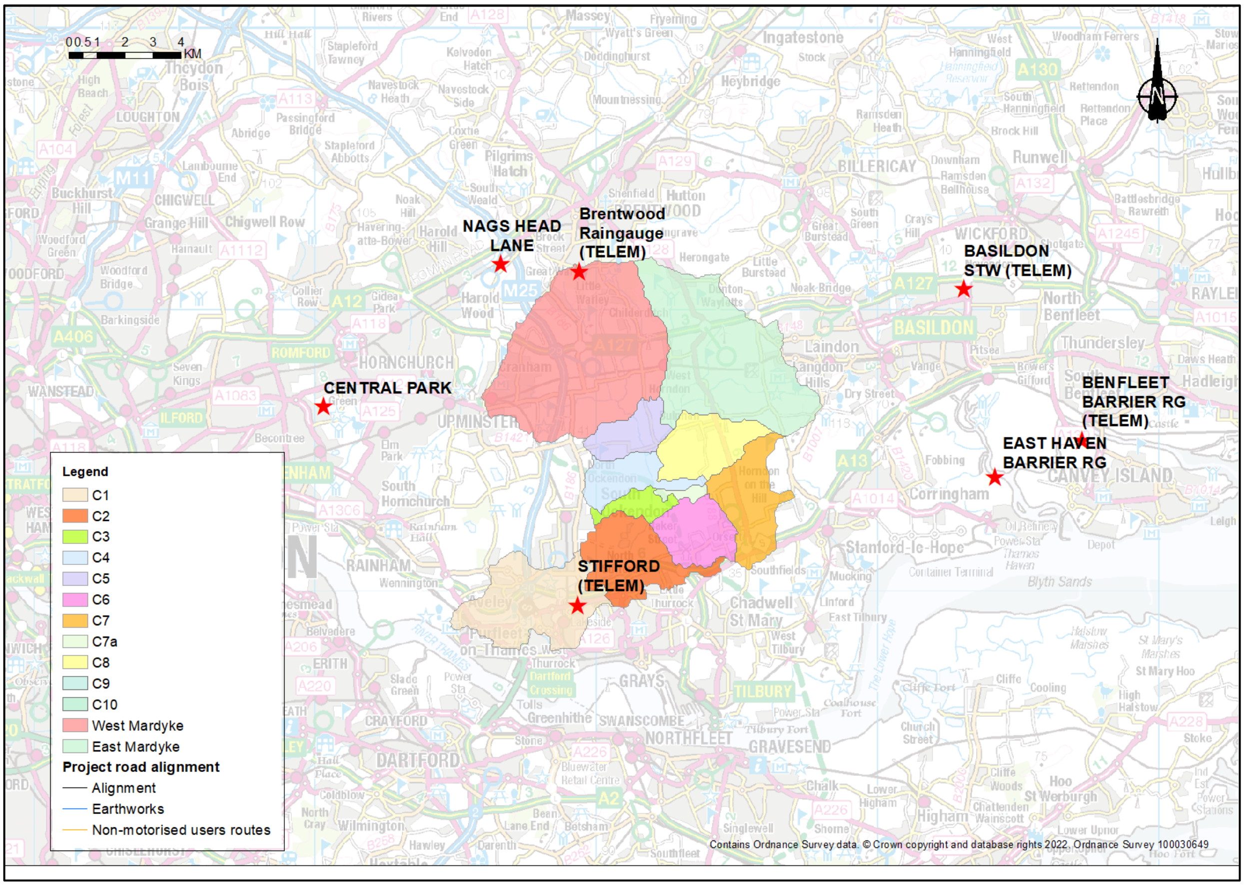
Event	Calibration or validation	Tide conditions	AMAX rank at Stifford	Recorded AMAX value at Stifford	SMD value	Available calibration check data
January 2011	Calibration	Low tide	13	22.7	17.9 (11/01/2011)	Stifford level data Mardyke Sluice level data
July 2012	Calibration	Low tide	–	–	38.9 (10/07/2012)	Stifford level data Mardyke Sluice level data Photographs from the area downstream of Stifford
December 2013	Validation	High tide	1	49.5	13.9 (17/12/2013)	Stifford level data Mardyke Sluice level data
November 2014	Calibration	High tide	3	45	14.3 (18/11/2014)	Stifford level data Mardyke Sluice level data
June 2016	Calibration	High tide	11	26.2	29.6 (21/06/2016)	Stifford level data Mardyke Sluice level data

4.6.5 Joint calibration of the hydrological and hydraulic model and resulting adjustment to the FEH rainfall-runoff parameter values, is reported in Calibration and validation.

Thiessen polygons and weights

4.6.6 Thiessen polygons were constructed to derive Thiessen weights for each sub-catchment, used to calculate catchment average rainfall data time series from 15-minute rain gauge data, for each simulated calibration and validation event. The locations of rain gauges used to derive Thiessen polygons are shown in Plate 4.7. The same rain gauges and Thiessen weights were used to derive catchment average daily rainfall required to specify the event CWI values.

Plate 4.7 Catchment schematisation and rainfall gauges



4.6.7 Calculated Thiessen weights are listed for each event in Table 4.27 to Table 4.31. Thiessen polygons constructed according to available rainfall data for each event are shown in Plate C.9 to Plate C.13 in Annex C.3.

Table 4.27 Thiessen weights for January 2011 calibration event

Sub-catchment	Rain gauges	
	Benfleet Barrier RG (Telem)	Nags Head Lane
C1	0%	100%
C2	0%	100%
C3	0%	100%
C4	0%	100%
C5	0%	100%
C6	0%	100%
C7	28.67%	71.33%
C7a	0%	100%
C8	0%	100%
East Mardyke	7.20%	92.8%
West Mardyke	0%	100%

Table 4.28 Thiessen weights for July 2012 calibration event

Sub-catchment	Rain gauges		
	Basildon STW (TELEM)	Brentwood rain gauge (TELEM)	Stifford (TELEM)
C1	0%	0%	100%
C2	0%	0%	100%
C3	0%	0%	100%
C4	0%	0%	100%
C5	0%	42.08%	57.92%
C6	0%	0%	100%
C7	0.67%	0.27%	99.06%
C7a	0%	0%	100%
C8	0%	30.07%	69.93%
East Mardyke	13.10%	86.90%	0%
West Mardyke	0%	97.39%	2.61%

Table 4.29 Thiessen weights for December 2013 calibration event

Sub-catchment	Rain gauges			
	Basildon STW (Telem)	Brentwood rain gauge (Telem)	Central Park	Nags Head Lane
C1	0%	11.49%	88.51%	0%
C2	0%	100%	0%	0%
C3	0%	100%	0%	0%
C4	0%	100%	0%	0%
C5	0%	100%	0%	0%
C6	0%	100%	0%	0%
C7	10.11%	89.89%	0%	0%
C7a	0%	100%	0%	0%
C8	0%	100%	0%	0%
East Mardyke	13.10%	86.90%	0%	0%
West Mardyke	0%	80.41%	0%	19.59%

Table 4.30 Thiessen weights for November 2014 calibration event

Sub-catchment	Rain gauges			
	Basildon STW (Telem)	Brentwood rain gauge (Telem)	Nags Head Lane	Stifford (Telem)
C1	0%	0%	0%	100%
C2	0%	0%	0%	100%

Sub-catchment	Rain gauges			
	Basildon STW (Telem)	Brentwood rain gauge (Telem)	Nags Head Lane	Stifford (Telem)
C3	0%	0%	0%	100%
C4	0%	0%	0%	100%
C5	0%	42.08%	0%	57.92%
C6	0%	0%	0%	100%
C7	0.67%	0.27%	0%	99.06%
C7a	0%	0%	0%	100%
C8	0%	30.07%	0%	69.93%
East Mardyke	13.10%	86.90%	0%	0%
West Mardyke	0%	78.20%	19.33%	2.47%

Table 4.31 Thiessen weights for June 2016 calibration event

Sub-catchment	Rain gauges		
	East Haven Barrier RG	Nags Head Lane	Stifford (TELEM)
C1	0%	0%	100%
C2	0%	0%	100%
C3	0%	0%	100%
C4	0%	0%	100%
C5	0%	3.03%	96.97%
C6	0%	0%	100%
C7	3.97%	0%	96.03%
C7a	0%	0%	100%
C8	0.63%	0%	99.37%
East Mardyke	22.72%	61.68%	15.60%
West Mardyke	0%	93.85%	6.15%

4.7 Hydraulic model inflow locations

4.7.1 The sub-catchment FEH rainfall-runoff model inflows are applied in the Project Mardyke hydraulic model as point inflows at some locations and lateral inflows at others, as appropriate. Model inflow locations are listed and described in Table 4.32.

Table 4.32 Hydraulic model inflow locations

Sub-catchment	Type	Node(s) applied (node label)	Description
C6	Point	OF2-026	C6 represents inflow from the catchment area between the Orsett Fen Top FEP and Orsett Fen confluence with the Mardyke.
C7	Point	GB3-020	Upstream sub-catchment of Orsett Fen and Golden Bridge
C8	Point	S4-016	C8 represents inflow from the catchment area between the Stringcock Sewer top point and Stringcock Sewer confluence to Mardyke.
East_Mardyke	Point	EM5-006	Upstream sub-catchment of East Mardyke
West_Mardyke	Point	WM6-008	Upstream sub-catchment of West Mardyke
C1	*Lateral	M1-017, M1-022, M1-026, M1-034	C1 represents inflow from the catchment area between Stifford GS and Mardyke Sluice.
C2	*Lateral	M1-050, M1-058, M1-059	C2 represents inflow from the catchment area between the Orsett Fen confluence with the Mardyke and Stifford GS.
C3	*Lateral	M1-063, M1-071	C3 represents inflow from the catchment area between Project Road FEP and Orsett Fen confluence with the Mardyke.
C4	*Lateral	M1-074, M1-077, M1-081	C4 represents inflow from the catchment area between the confluence of East Mardyke and West Mardyke and Project Road FEP.
C5	*Lateral	WM6-006, EM5-005	C5 represents inflow from the catchment area between the East and West Mardyke upstream inflows and the confluence between East and West Mardyke.
C7a	Lateral	GB3-015d	C7a represents inflow from the catchment area between the upstream inflow to Golden Bridge Sewer and its confluence with the Mardyke.

** Proportion of flow allocated to each node specified by areal weighting relative to contributing catchment areas*

4.8 Model downstream boundary

Calibration and validation simulations

4.8.1 The downstream extent of the Project Mardyke hydraulic model used to simulate calibration and validation events is the downstream side of Mardyke Sluice. For model calibration and validation runs, level-time series recorded at Mardyke Sluice (downstream side of Mardyke Sluice) is therefore applied at the model downstream boundary. The Mardyke Sluice level-time series has been verified by the Environment Agency to be recorded as mAOD (i.e. no further datum shift is required). A comparison of water levels observed during the Project Mardyke model topographic survey with Mardyke Sluice level-time series data available on the GaugeMap website is consistent with this datum.

Design event simulation

Design extreme water level time series

4.8.2 Design tidal time series boundaries were derived from the Thurrock Strategic Flood Risk Assessment (SFRA) (AECOM, 2018) breach model time series boundaries, as follows.

Adjusting TE2100 Extreme Water Levels in line with latest CFB2018 and UKCP18 datasets

4.8.3 The Environment Agency TE2100 Extreme Water Levels (EWLs) specified at Southend for different future years were compared with EWLs at Southend derived by applying the current coastal flood boundary dataset (CFB2018) and the current UK Climate Projections (UKCP18) sea level rise allowances (as specified in Environment Agency, 2022). Revised future years were assigned to the TE2100 EWLs at Southend (the years for which the TE2100 EWLs would apply if current datasets are used), and hence different years were assigned to the corresponding TE2100 EWLs in the Thames Estuary (i.e. at the location required for the Project Mardyke modelling, the TE2100 Dartford model node). Table 4.33 shows the results of assigning revised years for the five-year return period TE2100 EWLs at the TE2100 Dartford model node.

Table 4.33 Adjusted five-year return period TE2100 EWLs at TE2100 Dartford node

Year of TE2100 EWL	TE2100 EWL at Southend (mAOD)	Difference (m): TE2100 EWL - CFB2018 EWL (base year 2017)	Revised year in which CFB2018 value matches TE2100 EWL value (applying UKCP18 SLR to CFB2018 EWLs)	EWL at Dartford for revised year (mAOD)*
2005	3.94	- 0.02	2014	4.88
2040	4.15	0.19	2041	5.09
2070	4.46	0.50	2067	5.24
2100	4.86	0.90	2092	5.56
2120	5.16	1.20	2109	5.76

** The EWL values in this column are the EA's TE2100 values for the year of the TE2100 EWLs (first column). The revised years specified in the fourth column are assigned to these EWL values, which are then interpolated/extrapolated to provide the required EWL values in 2030 and 2130.*

4.8.4 The Project requires EWLs for 2030 and 2130. These values are interpolated (2030) and extrapolated (2130) from the values in Table 4.33 as 4.998mAOD and 5.995mAOD respectively for the five-year return period at the TE2100 Dartford model node.

Adjusting Thurrock SFRA breach modelling tidal time series boundaries to match required EWLs

4.8.5 For a given boundary location (i.e. TE2100 Dartford model node for the Project Mardyke modelling) and return period, the process is as follows:

a. Adjust TE2100 EWLs in line with latest CFB2018 and UKCP18 datasets as described above.

b. Start with the Thurrock SFRA breach model time series boundary for 2016, at the required location. If there is no boundary specified at the required location, select the nearest Thurrock SFRA breach model boundary.

c. Adjust to the required 2016 EWL (as derived above) by adding (or subtracting) a scaled surge component at this location. The surge component is constructed as the difference between the Thurrock Strategic Flood Risk Assessment breach model 1,000-year and 200-year return period time series.

d. To derive the 2030 tidal time series boundary, calculate the difference between 2030 and 2016 target levels (i.e. values derived above). Apply this difference as a uniform level shift to the 2016 time series.

e. To derive the 2130 tidal time series boundary, calculate the difference between 2130 and 2016 target levels (i.e. values derived above). Apply this difference as a uniform level shift to the 2016 time series.

Mean high water spring tide condition

4.8.6 A mean high water spring (MHWS) tide condition has been specified for the Project Mardyke model downstream extent, as follows:

a. A MHWS time series has been extracted from Tilbury tide level-time series data (based on records from 3 April 2003 to 12 September 2005).

b. The resulting MHWS time series has been adjusted for location, assuming the same relative level differences as for the TE2100 EWL values provided at locations in the River Thames. Differences for 2005 (-0.12m) were applied for 2030, and 2120 differences (-0.14) were applied for 2130.

c. MHWS time series were constructed for simulation years 2030 and 2130, by assuming the same uplift in levels relative to a 2005 base year as in the TE2100 EWLs.

Downstream boundary location

4.8.7 The Mardyke Sluice is approximately 500m upstream of the Mardyke outflow to the River Thames. As model results at the point where the Project route would cross the Mardyke are relatively insensitive to the model downstream boundary condition (paragraph 7.2.17), the River Thames design boundaries were applied around 30m downstream of the Mardyke Sluice.

5 Model development

5.1 Software

5.1.1 The Project's Flood Risk Assessment Mardyke hydraulic model was developed by applying Flood Modeller-TUFLOW hybrid 1D-2D software. The Project used the following versions of Flood Modeller and TUFLOW:

a. Flood Modeller Version 4.5 (double precision)

b. TUFLOW Version 2018-03-AD-iDP-w64

5.2 Check survey data

5.2.1 The channel survey data acquired for the Project in November/December 2018 (cross-sections of the channel and structures) and LiDAR data Plate 3.1) were checked for consistency. The methodology followed was to compare every surveyed cross-section against cross-sections derived from LiDAR data.

5.2.2 All of the surveyed cross-sections showed reasonable agreement with the LiDAR data (out of bank levels within approximately 0m to 0.3m) as illustrated in Plate 5.1 and Plate 5.2. In these figures, LiDAR derived cross-sections are shown with the blue dash line. It should be noted that the LiDAR does not penetrate the in-channel water and so does not capture the in-bank channel bed details.

Plate 5.1 Cross-section 1-058

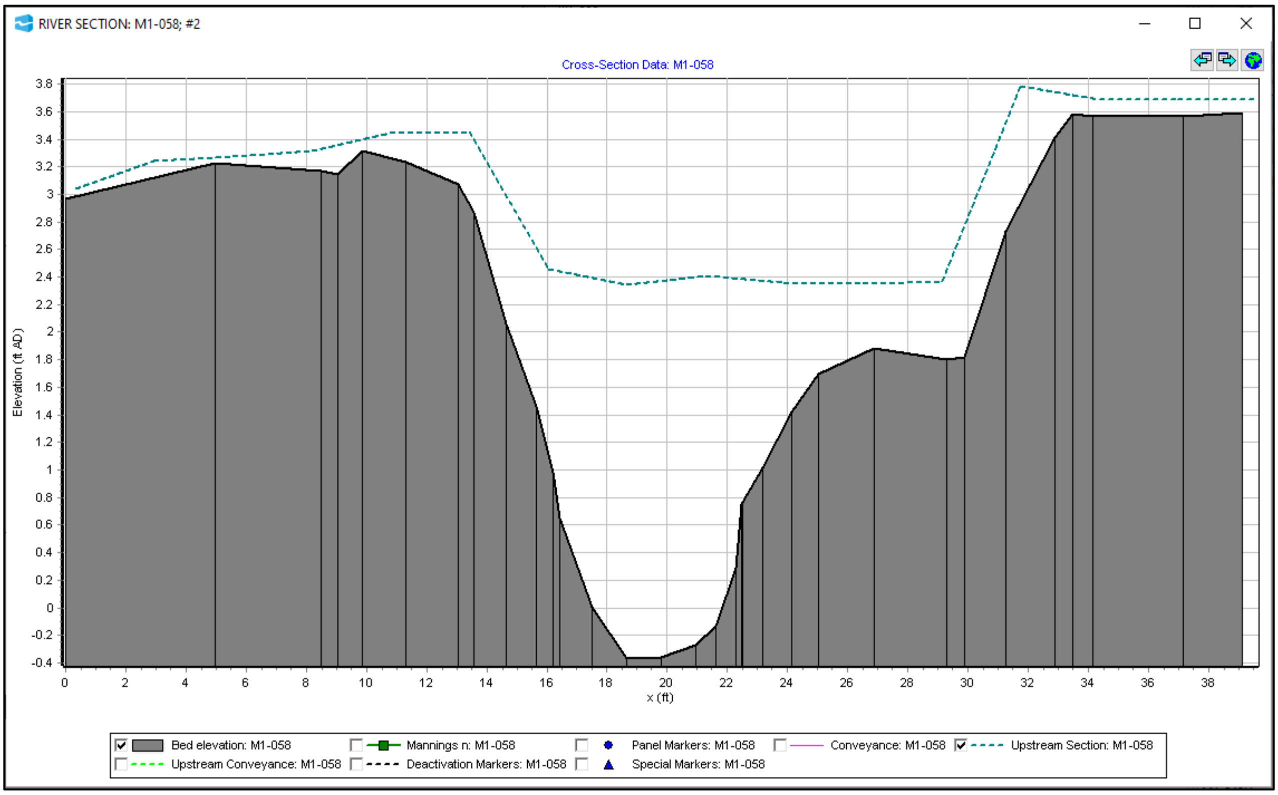
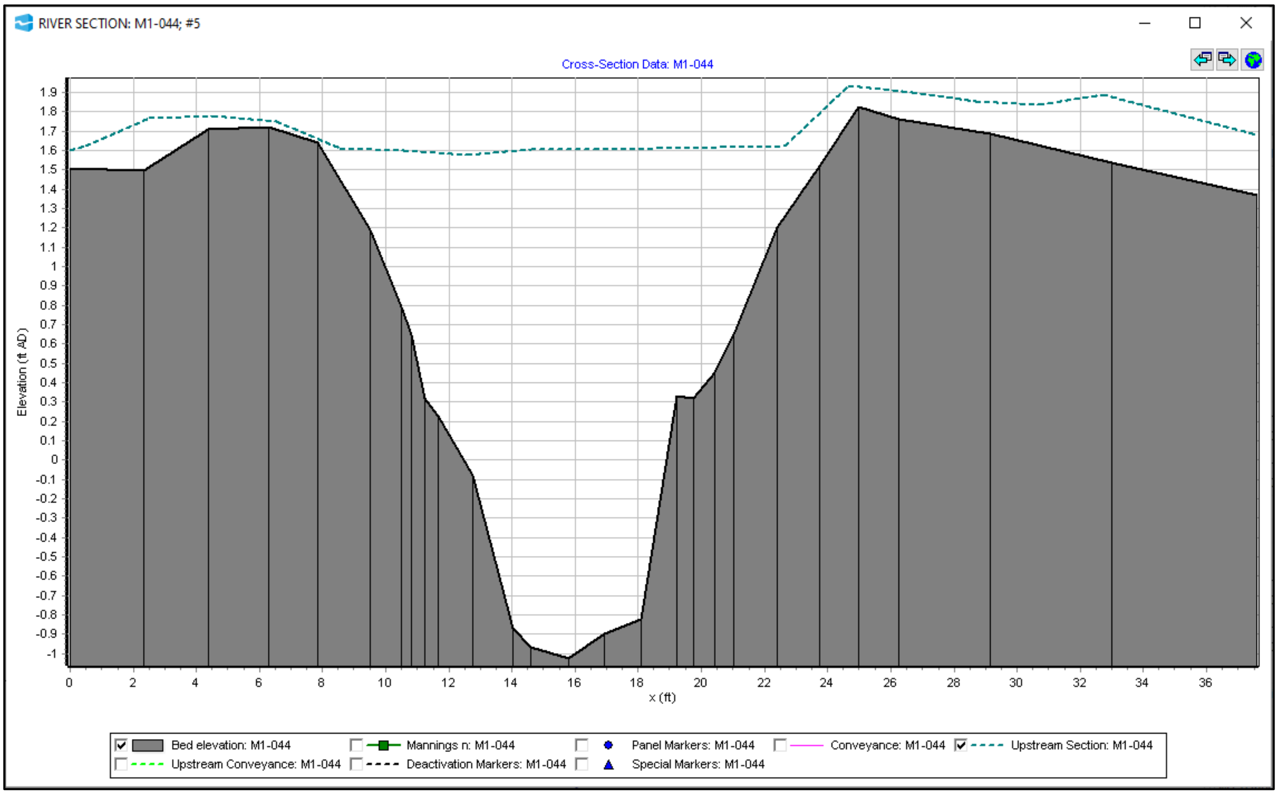


Plate 5.2 Cross-section 1-044



5.3 Model history

5.3.1 The topographic survey data used in the model of the Mardyke catchment developed by the Environment Agency in 2011 (Previous studies) was acquired by Maltby Land Surveys Ltd (2008), with additional survey data acquired by Maltby Land Surveys Ltd (2010) to infill survey gaps and to check the 2008 survey.

5.3.2 The Environment Agency's updated model (Mott MacDonald, 2019) incorporated the majority of data sources from the previous model (i.e. 2008 and 2010 survey data), adding data for specific locations (structures and check survey to assess siltation since 2008) based on the survey undertaken in 2018 for the Mott MacDonald (2019) model.

5.4 Model schematisation

5.4.1 A new 1D-2D model was developed using the datasets listed below.

a. LiDAR with 2m resolution (dated 2017).

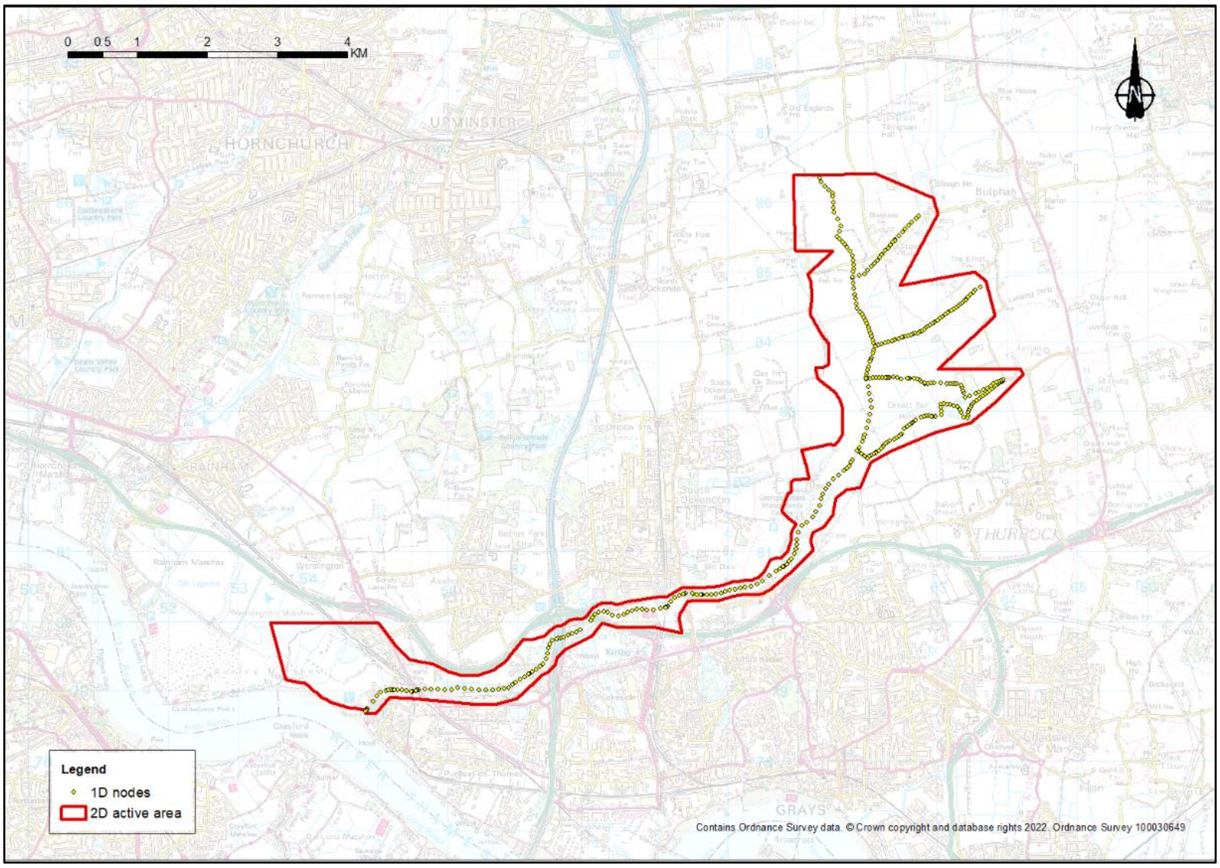
b. The channel survey was undertaken for this study by Storm Geomatics in November/December 2018.

c. Mardyke channel survey undertaken for the 2011 study by Maltby Land Surveys Ltd in 2010 (only used for node M1-003OU – Orifice unit representing the bypass at Sluice Gate).

5.4.2 The model was schematised as a linked Flood modeller-TUFLOW 1D-2D model for the whole model area as detailed in Plate 5.3.

5.4.3 A detailed list of modelled structures and their representation is in Annex B, Table B.1.

Plate 5.3 Model schematisation



1D schematisation

5.4.4 The model was schematised using the georeferenced 1D cross-sections from the channel survey. The cross-sections were trimmed to bank tops and connected to the 2D domain by using HX boundaries[7]. The HX polylines were connected to the appropriate Flood Modeller nodes using CN connection polylines[8]. The road, rail or path crossings have been represented using culvert or bridge units based on data extracted from the channel survey. These structures, and all other structures (sluice, orifices) are listed in Annex B, Table B.1.

[7] Where there is an exchange of flow between the 1D and 2D components of the model, a water level boundary is applied to the 2D cells along the 1D/2D interface. In TUFLOW terminology, the water level boundary applied to the 2D cells is referred to as an HX boundary, with the H indicating that a head (water level) boundary is used and the X indicating the value is coming from an external model (in this case the 1D model).

[8] The HX boundaries applied to 2D cells are linked to 1D nodes using CN connections (TUFLOW terminology).

5.4.5 During the construction and schematisation of the model, it was important to ensure the model is robust enough to stably simulate all the required simulations. Therefore, considering the schematisation of the 2D domain, the 1D time-step was set to one second.

2D schematisation

5.4.6 The cell size of the 2D model domain has been set at 10m, which is considered appropriate for the size of the whole model. Elevations for the 2D model were taken from the 2m composite LiDAR. Bank levels from the 1D cross-sections, where cross-sections were trimmed, were used to provide elevations along the boundary between the 1D and 2D models.

5.4.7 During the construction and schematisation of the model, it was important to ensure the model is robust enough to stably simulate all the required simulations. Therefore, the roughness coefficient was corrected at locations where there are discrepancies between 1D and 2D velocities, e.g. areas with steep river bank slopes.

5.5 Model boundaries

Inflows

5.5.1 The catchment inflows were applied to the model as point inflows for some catchments and distributed as lateral inflows for other catchments. Details are in Section 4.7.

Downstream boundary

5.5.2 The downstream boundary has been specified as a tidal level-time boundary reflecting the downstream tidal conditions. The boundary is applied at the downstream node of the model, approximately 30m downstream of Mardyke Sluice. For calibration of the model this is appropriate since levels recorded downstream of Mardyke Sluice are applied as the downstream boundary tidal level-time series.

5.5.3 For the design events, design tidal boundary conditions (design River Thames events and MHWS conditions) were derived as detailed in 4.8.

5.6 Roughness parameters

5.6.1 Roughness parameter values for the 1D cross-sections were specified as Manning’s n friction coefficients. Roughness values were derived from survey photos and a combination of modelling experience and information from Open Channel Hydraulics (Chow, 1959). The roughness coefficients adopted are reasonable compared to published ranges and are reported in Table 5.1, with site photographs of typical channel conditions detailed in Plate 5.4.

Table 5.1 1D Manning's n value

Land use	Description	Manning's n value
Natural channel	Typical channel sections	0.040
Culverts	Concrete type culverts	0.020 (with bed roughness set as channel type)
Banks/floodplain	Vegetation	0.060

Plate 5.4 Mardyke channel type

Source: Lower Thames Crossing Channel Survey, Storm Geomatics, November/December 2018

5.6.2 The roughness parameter values for the 2D model were specified using Ordnance Survey MasterMap data to define the coverage of different land types. The roughness coefficients adopted are listed in Table 5.2.

Table 5.2 2D Manning's n value

Land use	Material number	Manning's n value
Building	10021	0.500
Building or structure	10025	0.500
Built environment	10031	0.050
General feature	10044	0.050
General surface – multi surface – gardens	10053	0.080
General surface – step	10054	0.020
General surface	10056	0.050
Glasshouse	10062	0.500
Height control	10065	0.500
Historic interest	10076	0.500
Inland water	10089	0.035
Landform	10093	0.050
Landform – slope	10096	0.050
Landform – cliff	10099	0.050
Natural environment	10111	0.100
Network or polygon closing geometry	10116	0.040
Path – step	10119	0.020
Path	10123	0.020
Political or administrative	10126	0.500
Rail	10167	0.050
Road or track	10172	0.020
Roadside	10183	0.020
Structure	10185	0.500
Structure – upper level of communication	10187	0.500
Structure – archway	10190	0.500
Structure – pylon	10193	0.050
Terrain and height – foreshore	10199	0.050
Tidal water*	10203	0.035
Tidal water*	10210	0.035
Unclassified	10217	0.050
Stability	10500	0.060
Stability2	10600	0.100

** The Ordnance Survey MasterMap dataset applies two different code numbers for 'Tidal water' features*

6 Calibration and validation

6.1 Overview

6.1.1 Joint hydrological/hydraulic model calibration and validation was undertaken making use of available data.

6.1.2 The modelling scope (CASCADE, 2018), developed for the FRA in consultation with the Environment Agency, details that data available for calibrating and validating the Project Mardyke hydraulic model is limited. Available data consists of gauged level data at Stifford (15-minute records), gauged level data upstream and downstream of Mardyke Sluice (15-minute records), recorded gate openings for Mardyke Sluice, historic flood outlines for the 1968 flood event and photos taken during the flood event on 16 July 2012. Calibration and validation events are listed in Table 6.1 and additional details are in Table 4.26 in Section 4.6.

Table 6.1 Calibration and validation events (starting and ending dates)

Event	Calibration or validation	Start date	End date	Duration (hours)
January 2011	Validation	17/01/2011 05:45	25/01/2011 05:45	192
July 2012	Calibration	11/07/2012 17:30	19/07/2012 17:30	192
December 2013	Calibration	23/12/2013 11:45	30/12/2013 13:45	170
November 2014	Calibration	23/11/2014 03:00	30/11/2014 06:15	171.25
June 2016	Calibration	22/06/2016 22:15	30/06/2016 22:15	192

6.1.3 Model calibration boundaries consist of FEH rainfall-runoff derived inflows and levels recorded at Mardyke Sluice tidal gauge, applied at the downstream model boundary, as detailed in 4.8. The Environment Agency has verified that the Mardyke Sluice upstream and downstream level data is provided in mAOD. However, the Mott MacDonald (2019) report considers there is a difference in datum of -0.33m for Mardyke Sluice tidal gauge, based on an interpretation of the Mardyke 2018 survey.

6.1.4 The simulated operation of Mardyke Sluice during the calibration/validation events was based on recorded sluice gate setting data. This data specifies the gate percentage opening, recorded every 15 minutes, based on a gate fully open dimension of 3.55m (specified in an Environment Agency email).

6.1.5 Model calibration was reviewed primarily at Stifford gauging station, with results also checked at Mardyke Sluice. The July 2012 event model results were also compared with available photos taken after the flood event. Recorded level data at Stifford was converted to mAOD (datum 0.129mAOD).

6.1.6 Simulated levels at node M1-042, which represents the Stifford gauging station, and node M1-003, which represents the Mardyke Sluice upstream level gauge, were plotted and compared with observed levels for each event. Results are presented in Section 6.2.

6.1.7 Peak simulated levels were compared to peak observed levels at Stifford gauging station. Calibration adjustments were made to achieve unbiased results (average difference in peak levels for calibration events was approximately zero).

6.1.8 The parameters that were investigated during the calibration procedure included: FEH rainfall-runoff model unit hydrograph time to peak (Tp), 1D Manning's n values and inflow scaling factors. Table 6.2 summarises the modifications applied.

6.1.9 It was identified during calibration that the winter and summer events required different calibration adjustments to the model inflows, with summer events requiring a higher Tp scaling adjustment and greater reduction of inflows.

6.1.10 Simulated design events apply winter storm profiles and hence the winter Tp calibration adjustment has been applied. (Design event inflows have been further scaled to reconcile peak flows with the FEH statistical estimates.)

Table 6.2 Modifications applied

Parameter	Winter event	Summer event
Time to peak scaling factor	2	3
Manning's n	+50% (0.06 for bed and 0.09 for banks)	+50% (0.06 for bed and 0.09 for banks)
Inflow scaling factor	-10% (*except C1)	-40% (*except C1)
Gate operation	Recorded	Fully closed for the entire simulation

** The inflows at sub-catchment C1 were not adjusted during calibration as this inflow is downstream of Stifford gauging station, and the sub-catchment is qualitatively different (urban, permeable) to those upstream of Stifford, and so the uniform adjustments applied upstream of Stifford may not apply.*

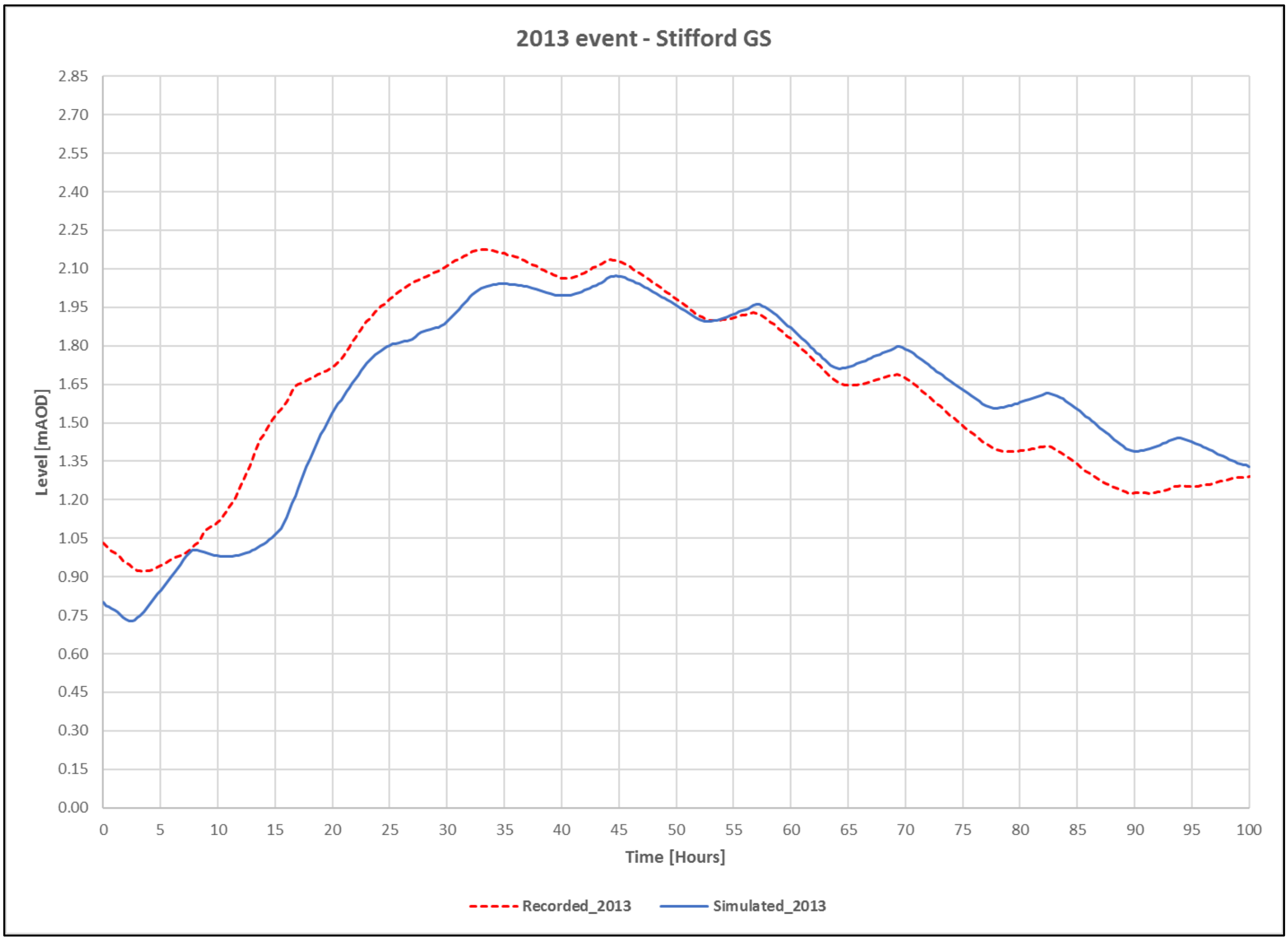
6.2 Calibration results

December 2013 event

6.2.1 The event was modelled for 100 hours covering the peak level observed at Stifford gauging station.

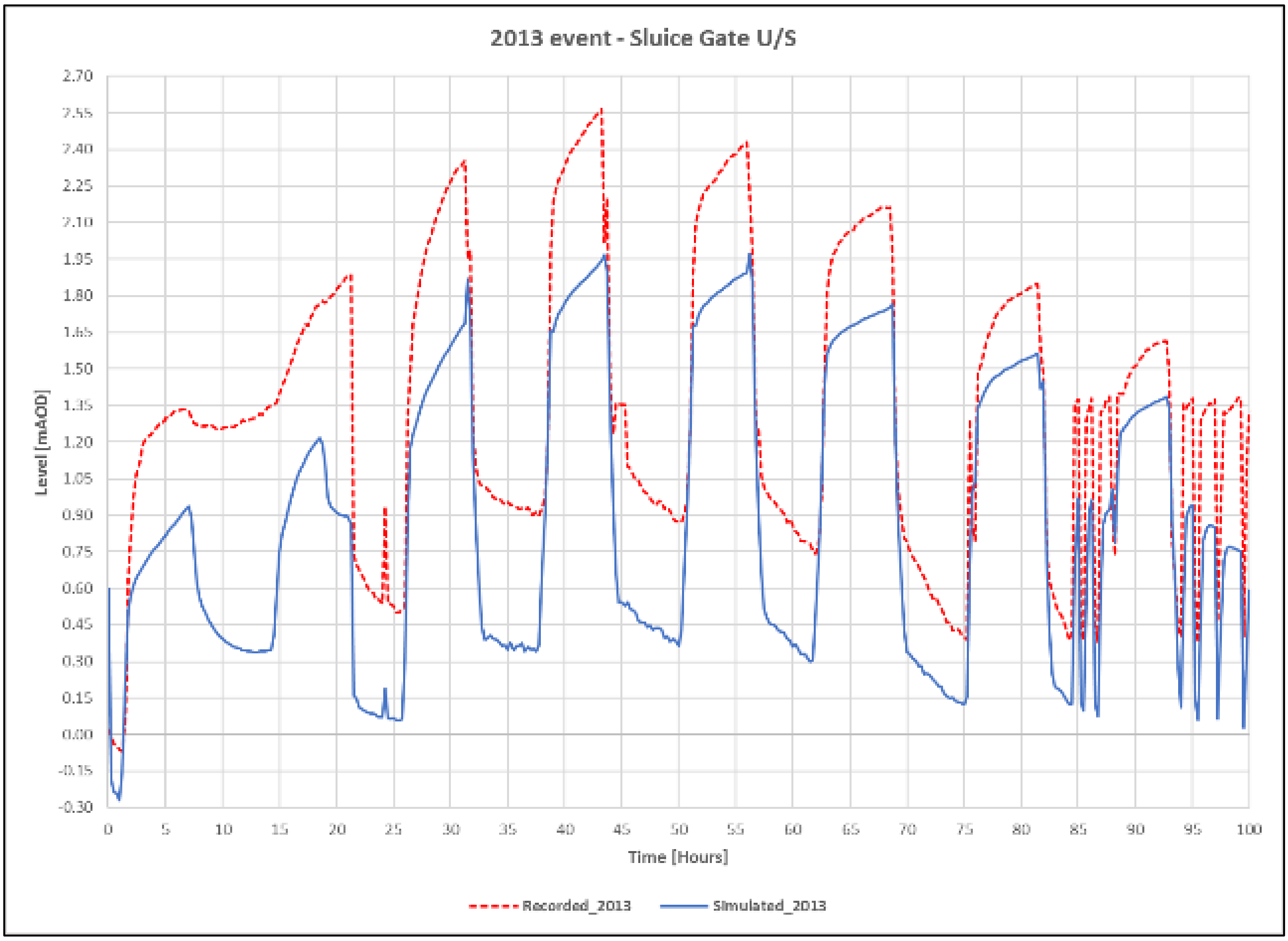
6.2.2 Plate 6.1 displays the comparison between the recorded and simulated levels at Stifford gauging station. It can be observed from the graph that the simulated level is generally similar to the recorded level, with a difference in peak levels of 0.103m. More specifically, simulated levels underestimate the stage for the first part of the simulation with a difference that varies from 0 to 0.15m and overestimate for the second part of the simulation with a difference that varies between 0 and 0.15m.

Plate 6.1 December 2013 event – Stifford gauging station



6.2.3 Plate 6.2 displays the comparison between the recorded and simulated levels upstream of the Mardyke Sluice. It can be observed from the graph that the timing is similar (as expected as the oscillations are a response to the tidal condition applied) and simulated levels underestimate the stage during the entire simulation, with a difference that ranges between approximately 0.3m and 0.6m. The difference is consistent for the entire simulation. This offset could be influenced by a possible downstream boundary datum shift (as noted in paragraph 6.1.3).

Plate 6.2 December 2013 event – upstream of Mardyke Sluice

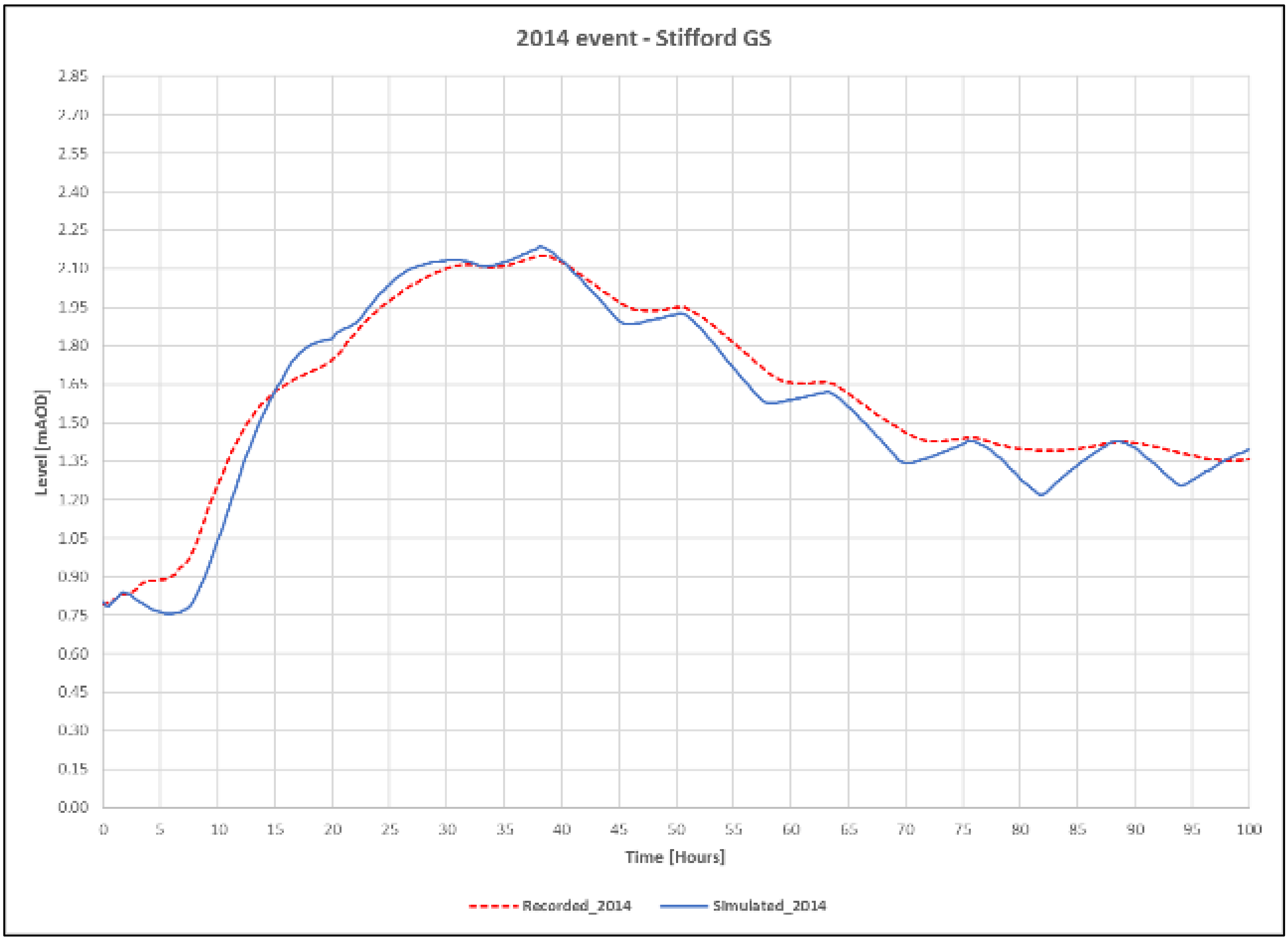


November 2014 event

6.2.4 The event was modelled for 100 hours covering the peak level observed at Stifford gauging station.

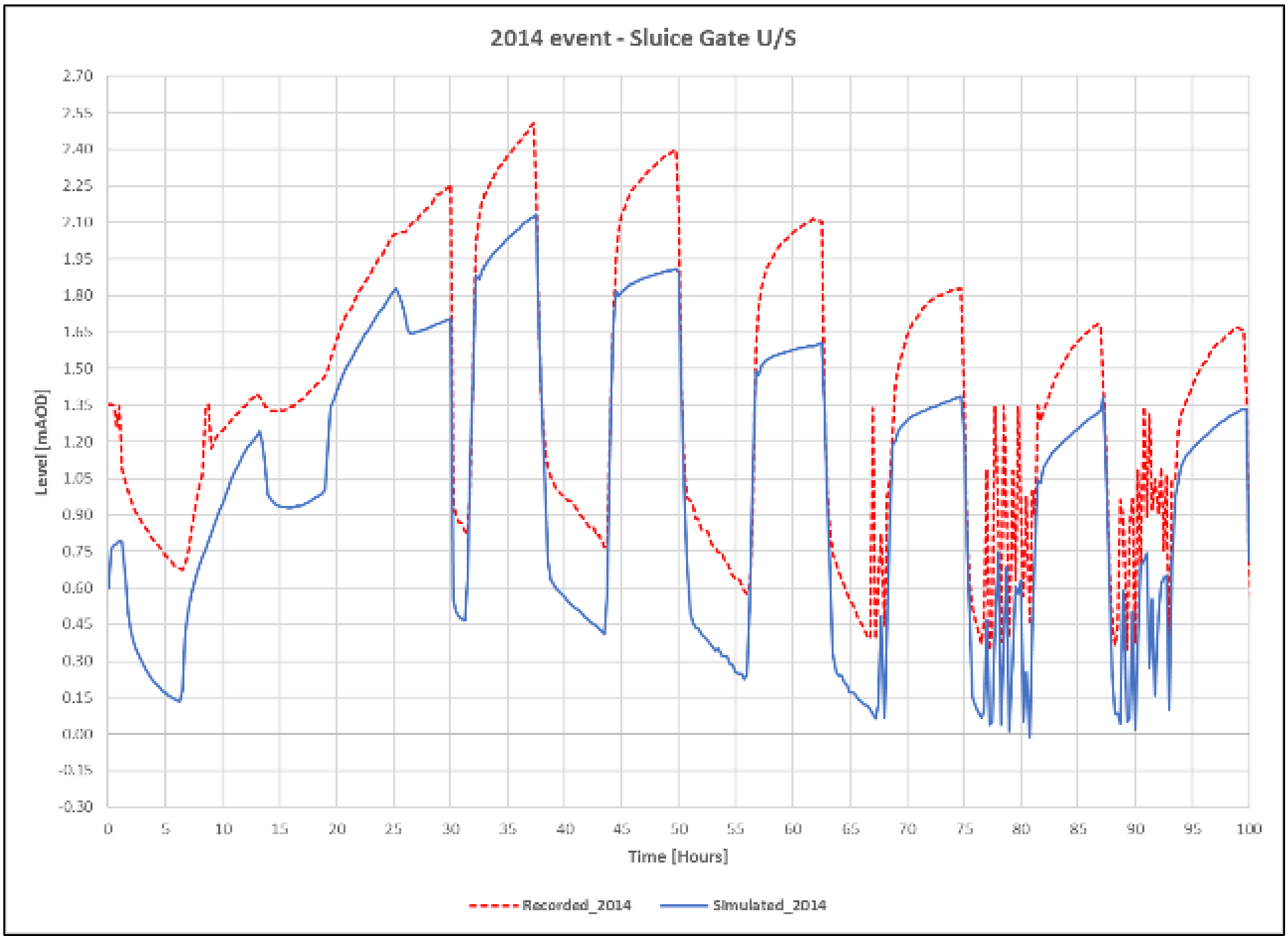
6.2.5 Plate 6.3 shows recorded and simulated levels at Stifford gauging station. Simulated and recorded levels are similar in profile with differences ranging between 0 and 0.15m. The difference in peak levels is 0.035m.

Plate 6.3 November 2014 event – upstream of Stifford gauging station



6.2.6 Plate 6.4 compares recorded and simulated levels upstream of Mardyke Sluice. The timing is similar (as expected, as the oscillations are a response to the tidal condition applied) and simulated levels underestimate the stage during the entire simulation with a difference that ranges between approximately 0.3 and 0.6m. The difference is consistent for the entire simulation. This offset could be influenced by a possible downstream boundary datum shift (as noted in paragraph 6.1.3).

Plate 6.4 November 2014 event – upstream of Mardyke Sluice



6.2.7 Table 6.3 tabulates the differences in recorded and simulated peak levels at Stifford gauging station for the winter calibration events.

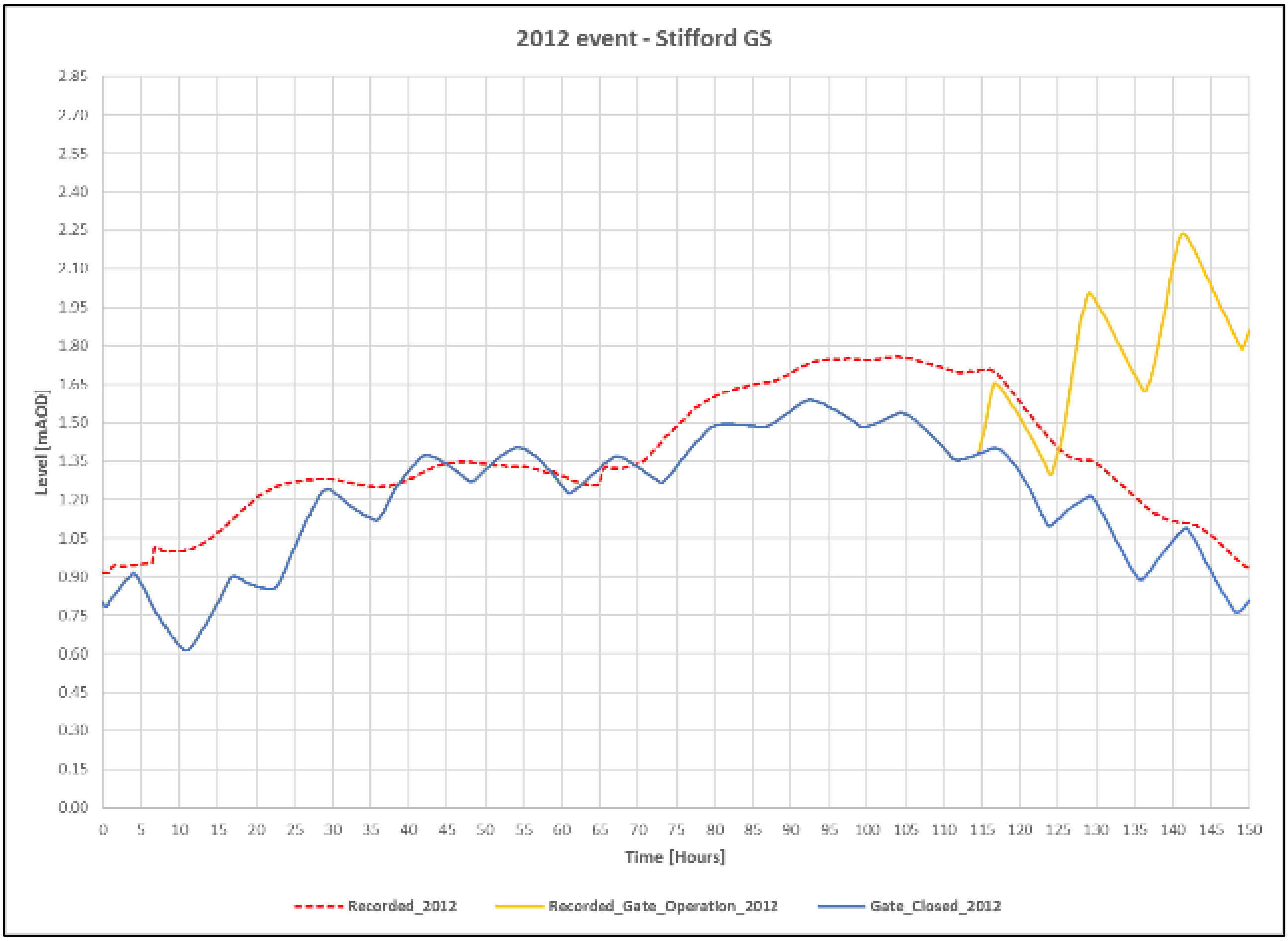
Table 6.3 Peak level differences (winter events)

Event	Stifford gauging station	Simulated	Difference
2013	2.175	2.072	-0.103
2014	2.151	2.186	0.035
Average			-0.034

July 2012 event

6.2.8 The event was modelled for 150 hours covering the peak level observed at Stifford gauging station. The 2012 event was simulated with gate operation (i) as specified by the Environment Agency gate operation data, and (ii) with the gate fully closed during the simulation. Plate 6.5 shows that towards the end of the simulation the fully closed gate setting results in simulated levels at Stifford closer to observed levels. Simulated levels underestimate observed levels for the majority of the simulation, with a difference which ranges between 0 and 0.3m. The difference in peak levels is 0.17m.

Plate 6.5 July 2012 event – Stifford gauging station

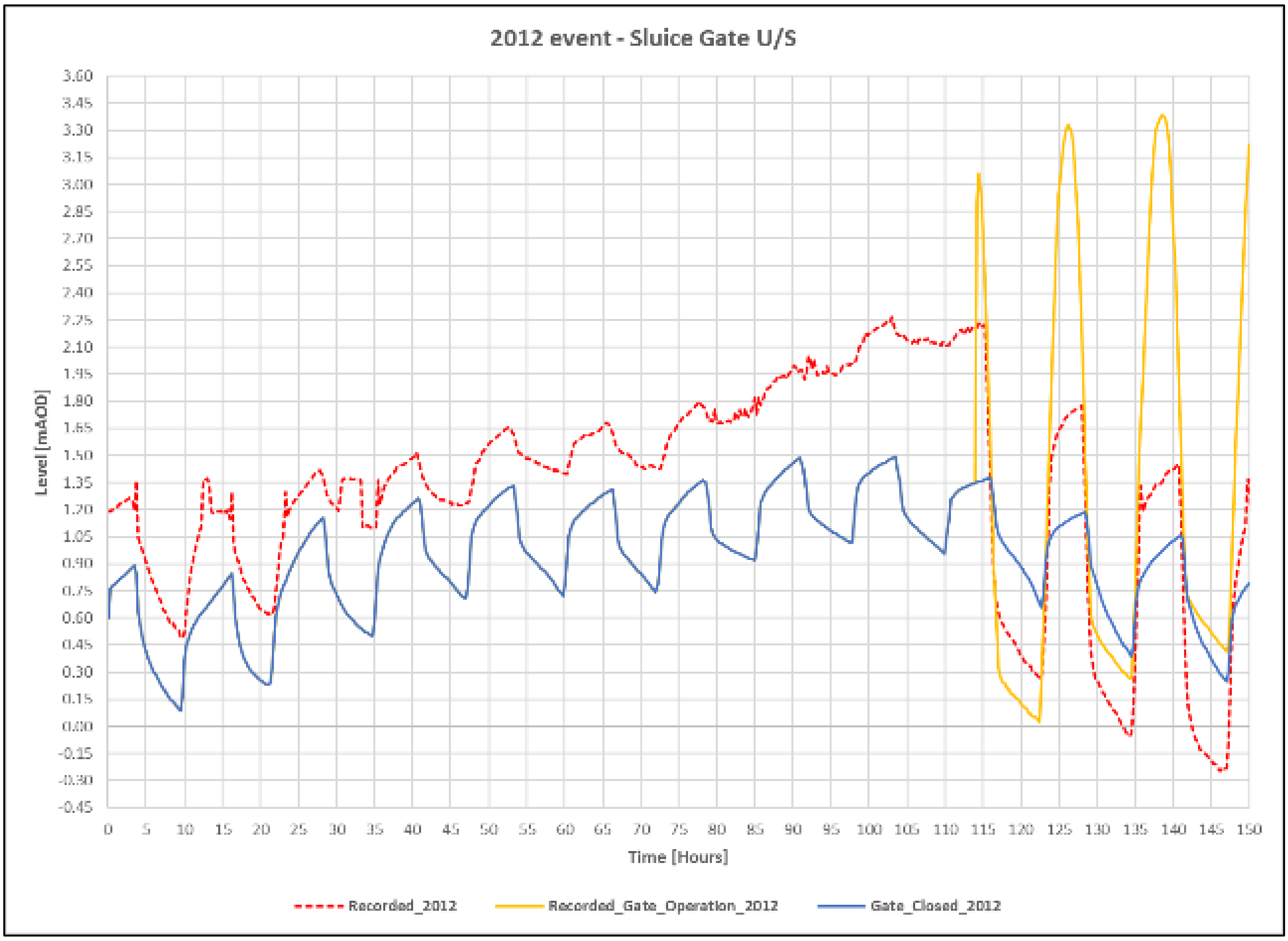


6.2.9 Plate 6.6 compares recorded and simulated levels upstream of the Mardyke Sluice (with both gate operations – applying recorded gate positions and with gate fully closed).

6.2.10 Simulated levels underestimate the observed stage for most of the simulation, with a difference that ranges between approximately 0.25m and 0.9m. Levels are overestimated when the tide is low towards the end of the simulation, with a difference between approximately 0.35m and 0.45m.

6.2.11 With the gate closed for the entire simulation, the results are closer to observed than in the simulation applying recorded gate settings, whilst the latter simulation results in a greater response to tidal levels than observed.

Plate 6.6 July 2012 event – upstream of Mardyke Sluice



6.2.12 For the July 2012 event, the Environment Agency provided photographs taken after the event. The photographs and their locations are displayed in Table 6.4. The Environment Agency has indicated all photographs were taken between 11:00 and 12:00 on Monday 16 July 2012. The locations at which the photographs were taken (based on their accompanying descriptions) are presented in Plate 6.7.

Table 6.4 July 2012 event – photographs

P71600/Stifford Bridge (B186 Road Bridge) looking towards Stifford gauging station (Source: Environment Agency)	
P716008/A13 towards M25 (Source: Environment Agency)	

P716009/on A13 slip road M25 lower level looking west (Source: Environment Agency)	
P716010/looking west from Ship Lane Bridge (Source: Environment Agency)	

P716011/Tank Hill Bridge (Source: Environment Agency)	

6.2.13 Plate 6.7 shows the simulated flood extent of the July 2012 event.

6.2.14 The simulated flood extent is consistent with that indicated by photographs P716008, P716009 and P716010.

6.2.15 Photographs P716007 and P716011 show water levels within bank and so remaining within the 1D model domain. This is consistent with Plate 6.8 and Plate 6.9, which show simulated peak water levels at corresponding model cross-sections (model node M1-041 at the location of P716007 and M1-007BU at the location of P716011).

Plate 6.7 July 2012 event – simulated flood extent

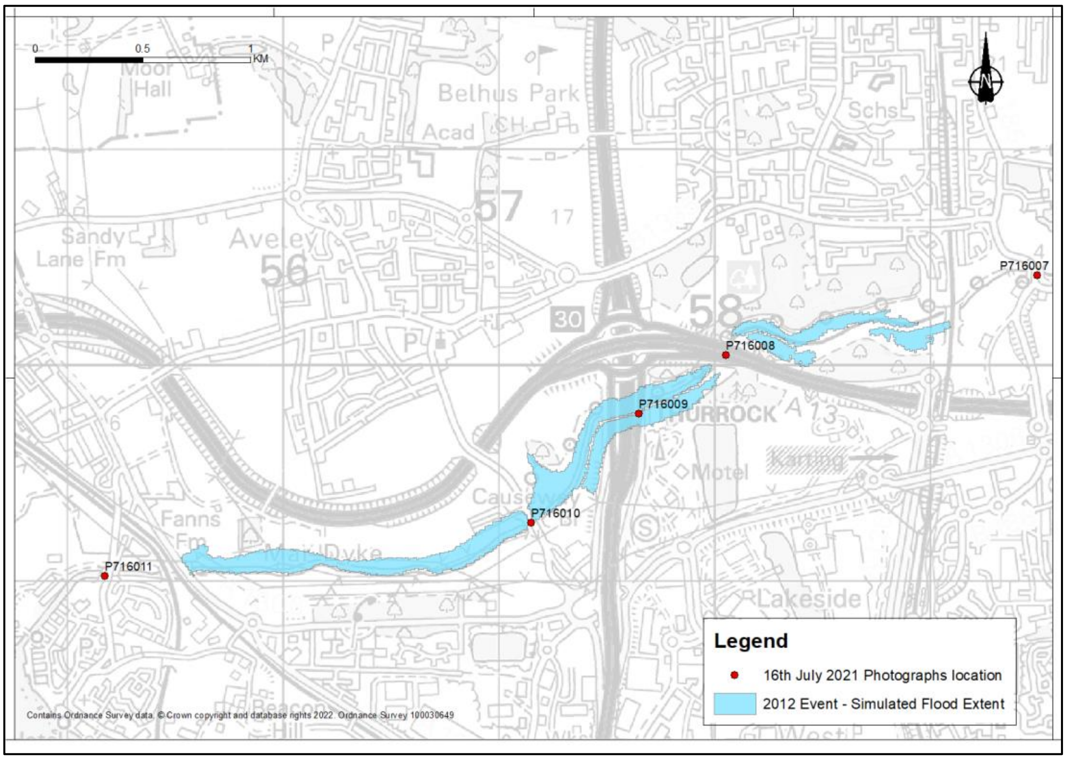


Plate 6.8 July 2012 event – simulated peak level at node M1-041 (just upstream of Stifford Bridge B186)

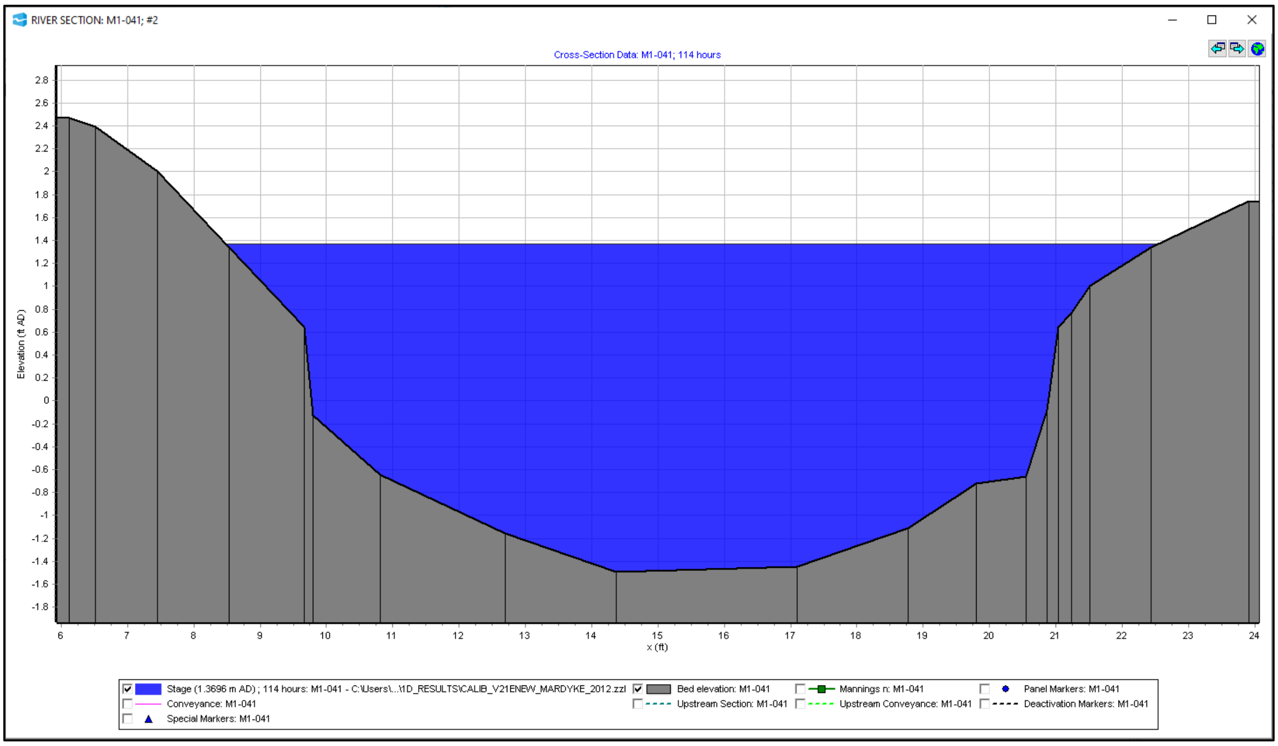
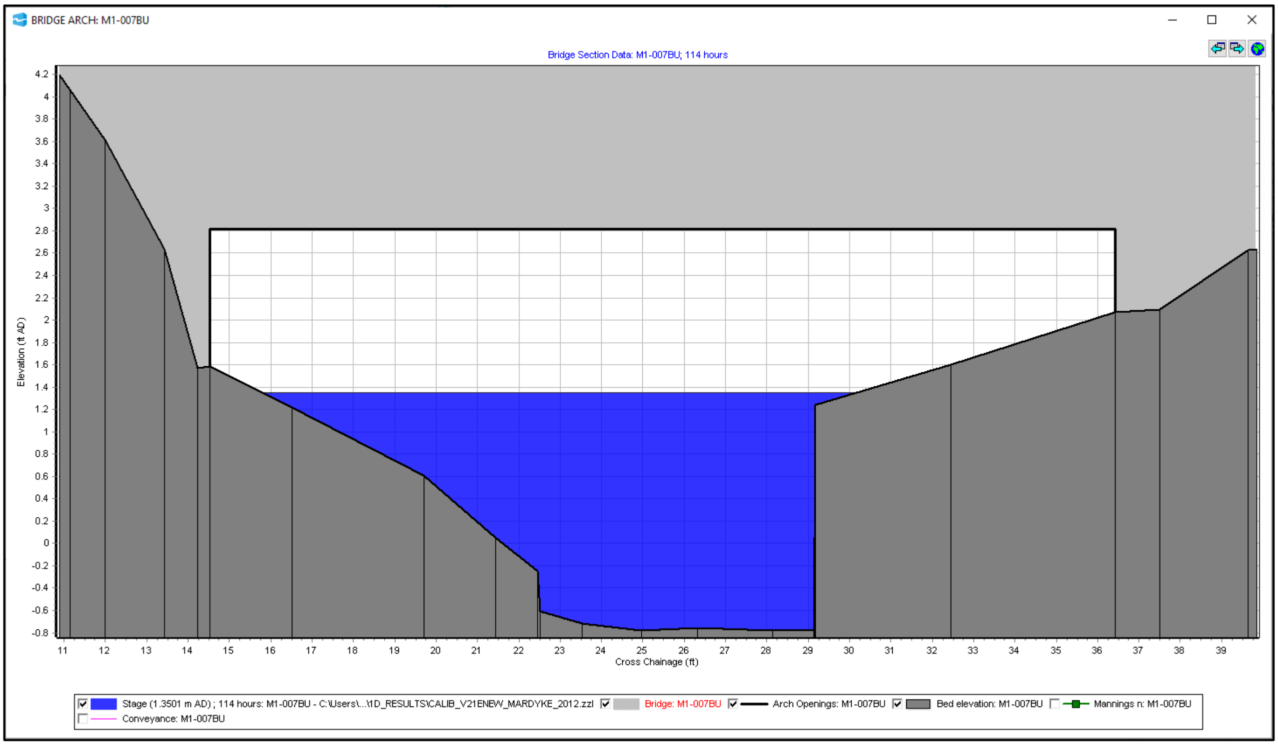


Plate 6.9 July 2012 event – simulated peak level at node M1-007BU (representing Tank Hill Bridge)



June 2016 event

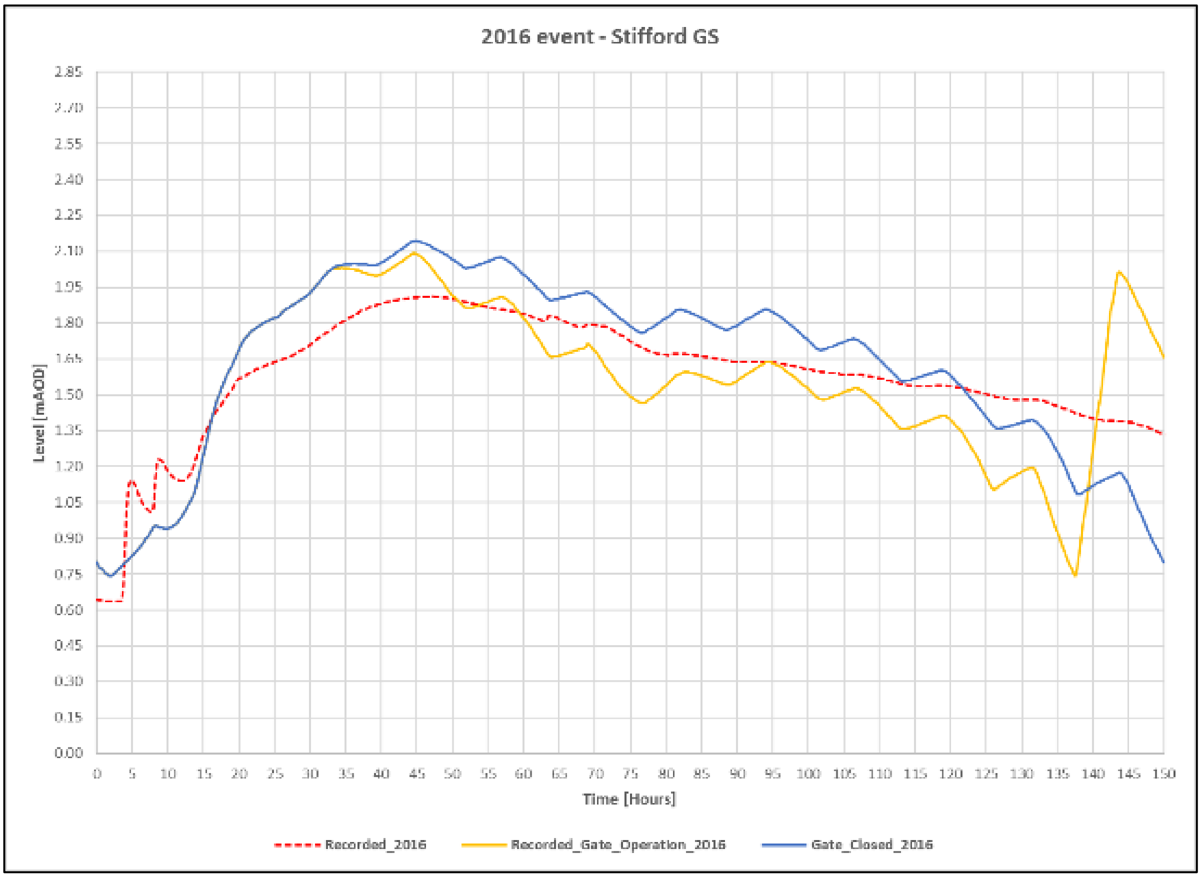
6.2.16 The event was simulated for 150 hours covering the peak level observed at Stifford gauging station.

6.2.17 The 2016 event was simulated with gate operation (i) as specified by the Environment Agency gate operation data, and (ii) with the gate fully closed during the simulation.

6.2.18 Plate 6.10 shows that towards the end of the simulation the fully closed gate setting results in simulated levels at Stifford closer to observed levels.

6.2.19 For the gate-closed case, simulated levels overestimate observed levels for the majority of the simulation with a difference of 0 to 0.3m, except the last part of the simulation where they underestimate with a difference of 0.15m to 0.45m. The difference in peak levels is 0.18m with the recorded gate operation and 0.23m with the gate closed.

Plate 6.10 June 2016 event – Stifford gauging station

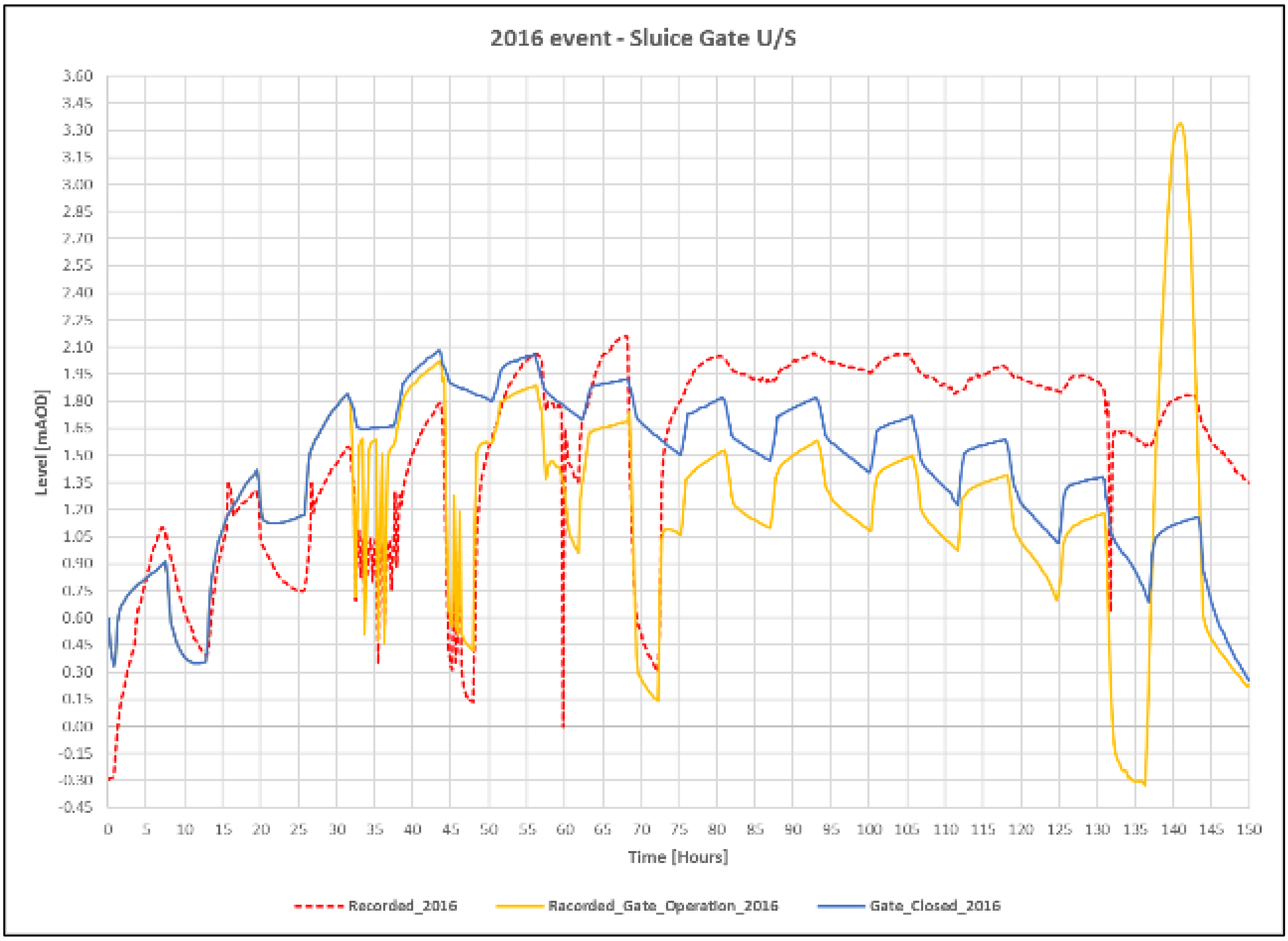


6.2.20 Plate 6.11 compares recorded and simulated levels upstream of the Mardyke Sluice (with both gate operations – applying recorded gate positions and with gate fully closed).

6.2.21 Simulated levels overestimate the observed stage for the earlier part of the simulation with a difference that ranges between approximately 0m and 0.3m when the tide is high, and 0 to 1.5m when the tide is low. Simulated levels underestimate the observed stage for the later part of the simulation with a difference that ranges between approximately 0.2m and 1.05m.

6.2.22 With the gate closed for the entire simulation, the results are closer to observed than in the simulation applying recorded gate settings, whilst the latter simulation results in a greater response to tidal levels than observed.

Plate 6.11 June 2016 event – upstream of Mardyke Sluice



6.2.23 Table 6.5 tabulates the differences in recorded and simulated peak levels at Stifford gauging station for the summer calibration events, for the gate-closed case.

Table 6.5 Peak level differences (summer events)

Event	Stifford gauging station	Simulated (gate-closed case)	Difference
2012	1.758	1.587	-0.171
2016	1.911	2.142	0.231
Average			**0.030**

6.3 Validation

6.3.1 The January 2011 event was modelled for 100 hours covering the peak level observed at Stifford gauging station. The event was simulated with the calibration adjustments derived for winter events, as follows:

a. Time to peak scaling factor = 2

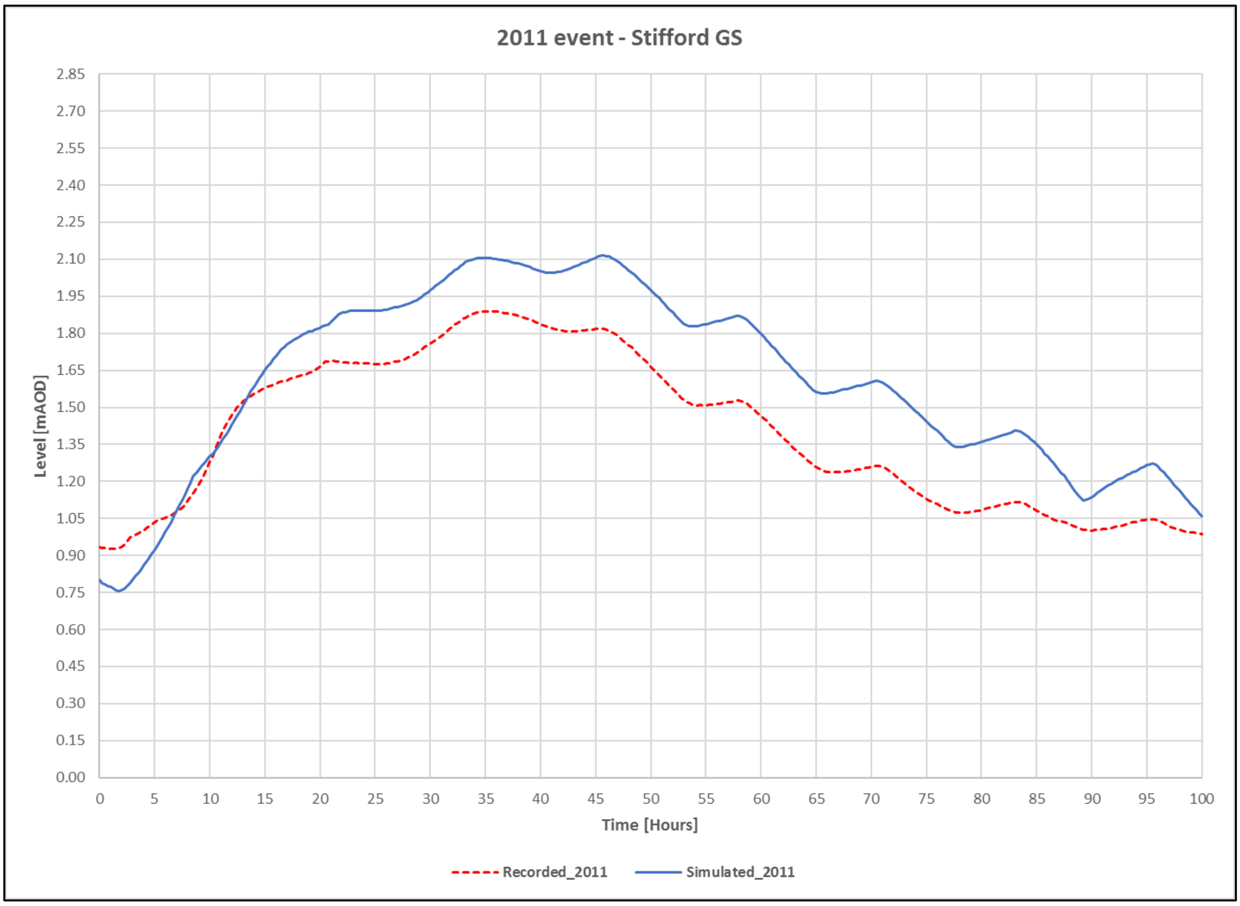
b. Increase Manning's n values by 50% for the 1D part of the model

c. Decrease inflow hydrographs by 10% except for sub-catchment C1

d. Apply recorded gate positions at Mardyke Sluice

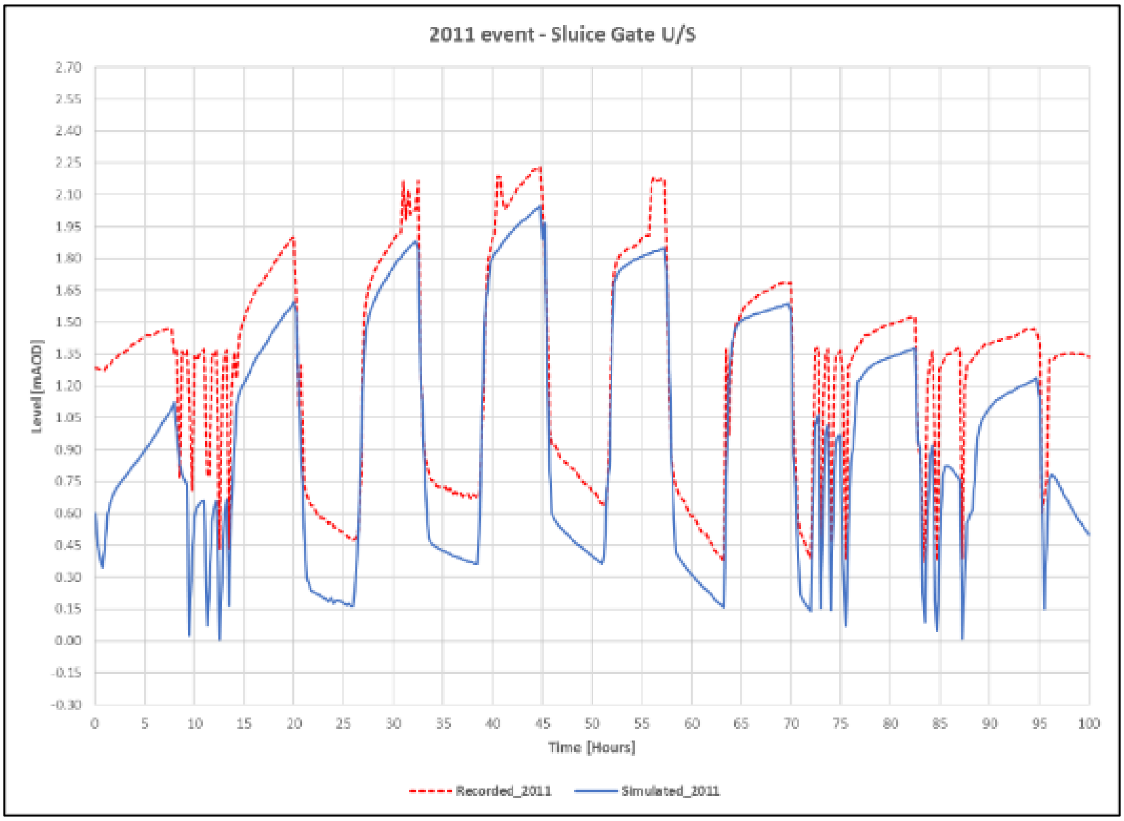
6.3.2 Plate 6.12 compares recorded and simulated levels at Stifford gauging station, showing that simulated levels overestimate observed levels during most of the simulation with a difference of approximately 0 to 0.3m. The difference between simulated and observed peak level is 0.22m.

Plate 6.12 January 2011 event – Stifford gauging station



6.3.3 Plate 6.13 compares recorded and simulated levels upstream of the Mardyke Sluice. Simulated levels underestimate the observed levels for most of the simulation, with a difference that ranges between approximately 0.1m and 0.6m. The modelled levels are consistently approximately 0.3m lower than observed during low tides. This offset could be influenced by a possible downstream boundary datum shift (as noted in 6.1).

Plate 6.13 January 2011 event – upstream of Mardyke Sluice



6.4 Summary of calibration and validation

6.4.1 Calibration results at Stifford show good agreement between simulated and recorded peak flows at Stifford for the winter events, and results at Stifford are influenced by assumed gate openings towards the end of the summer event simulations.

6.4.2 For the summer events, calibrated inflows are reduced more than for the winter events (reduced by 40% rather than 10%). Design events have simulated winter events, and inflows have been further scaled (either up or down) to match FEH statistical estimates of peak flows at Stifford gauging station, and at other locations within the hydraulic model extent.

6.4.3 The winter calibration and validation results at Mardyke Sluice show a good overall reproduction of the observed tidal variation, but with an offset of approximately 0.3m. This offset could be influenced by a possible downstream boundary datum shift (as noted in paragraph 6.1.3).

6.4.4 The summer calibration results do not perform as well as the winter events at Mardyke Sluice. In both summer events there is an increase in amplitude of tidal oscillation towards the end of the simulated event when recorded gate openings are applied in the simulations. The amplitude is reduced if the gate is simulated to be closed for the entire simulation. Peak levels at Stifford resulting from fluvial inflows are only slightly sensitive to the simulated gate operation conditions.

6.4.5 The simulated 2012 flood extents are broadly consistent with photographs of this event. However, the photographs do not enable precise identification of flood extents.

7 Design simulations and results

7.1 Further model development

Pre-development model build

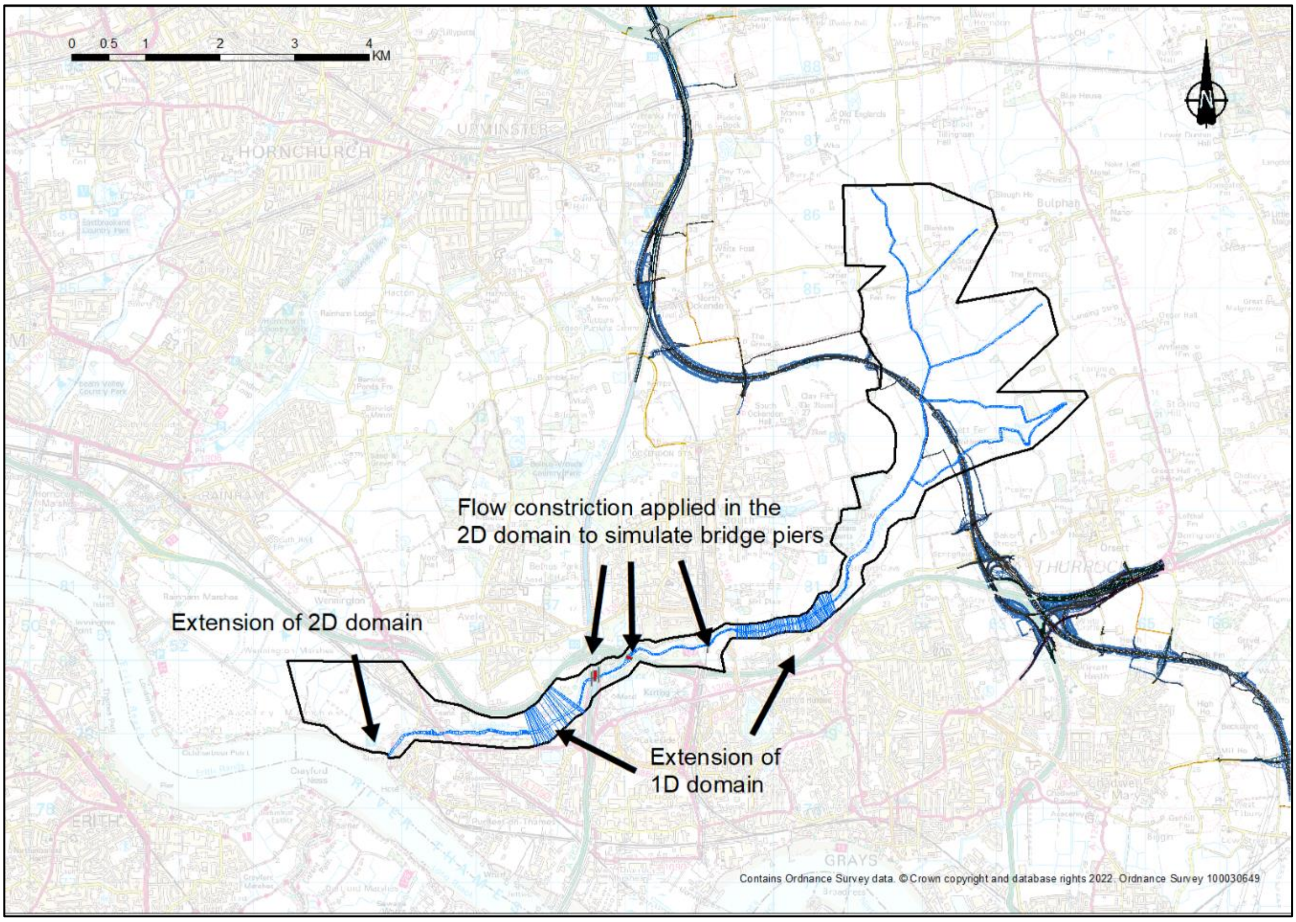
7.1.1 In response to the model review comments received from the Environment Agency and to stabilise the model results, the model developed for calibration has been adjusted further to provide a pre-development design model. The modifications made to the model are detailed in Table 7.1 and are presented in Plate 7.1.

Table 7.1 Pre-development model build

Location and nodes	Model modification
M1-034 – M1-034D M1-030 – M1-029 M1-027 M1-026 – M1-025 M1-024	Based on EA comment (on 11 February 2020) about using flow constrictions in the 2D domain, flow constrictions layers were included in the model's 2D domain to represent the piles of the bridges that exist in the 2D domain.
M1-049D – M1-040 M1-022D – M1-019U	Extend the 1D domain, at these areas, to the model domain boundary.
Downstream boundary near Mardyke Sluice	Extend the 2D domain near the downstream boundary.
Downstream boundary near Mardyke Sluice	Only for 1 in 1,000 year fluvial event in 2130, the flood defence near Mardyke Sluice was schematised by using a Z-shape feature to raise the topography.

7.1.2 The model files for the simulations are detailed in Annex A.

Plate 7.1 Pre-development model build



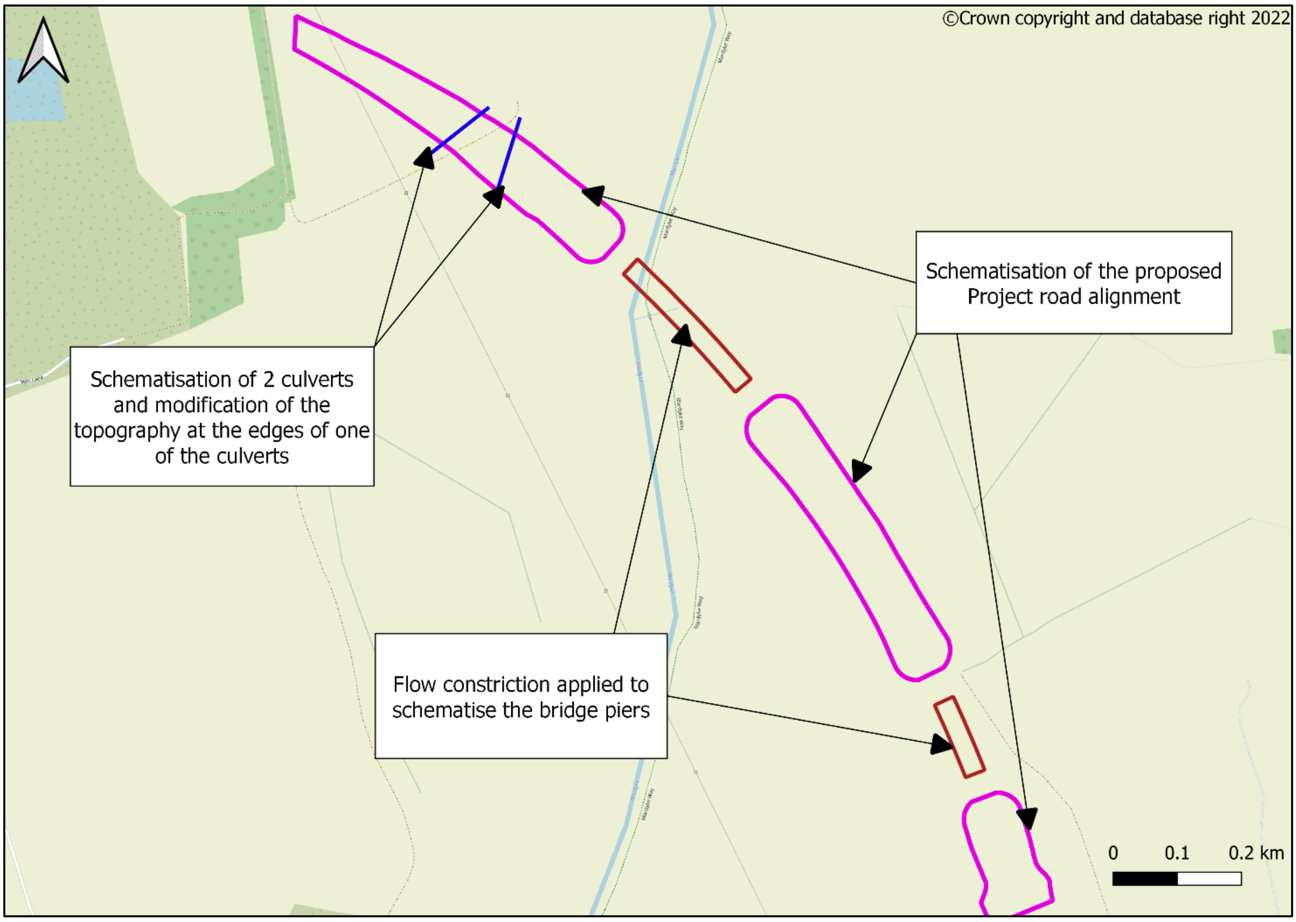
Post-development model build (without mitigation measures)

7.1.3 The pre-development model was used as the basis for the construction of a post-development model. The model was updated to incorporate the Project including proposed road embankments, culverts and bridge piers as per the design. The modifications made to the model are detailed in Table 7.2 and are presented in Plate 7.2.

Table 7.2 Post-development model build

File	Model modification
2d_zsh_Mardyke_LTC_DR3_R.shp 2d_zsh_Mardyke_LTC_DR3_L.shp 2d_zsh_Mardyke_LTC_DR3_P.shp	Schematisation of the proposed Project road embankments by using Z-shape features to raise the ground levels.
1d_nwk_LTC_L.shp 2d_bc_LTC_P.shp 2d_zsh_TopoMod_LTC_L.shp	Schematisation of two culverts (1.65m x 1.0m and 1.96m x 1.0m) with the accompanied TUFLOW model “SX” connections. Added Z-shape polyline to lower the ground levels at the culvert inlets/outlets.
2d_lfcsh_LTC_R.shp 2d_lfcsh_LTC_pts_P.shp	Representation of the bridge piers with flow constriction polygon and point features.

Plate 7.2 Post-development model build



Post-development model build with mitigation measures

7.1.4 A comparison of pre- and post-development model results (Section 7.2) indicates the proposed road as represented in the design impacts flood risk locally, as follows:

a. The road embankments and bridge piers displace Mardyke floodplain storage.

b. The road embankment to the north-west of the Mardyke obstructs conveyance in the Mardyke floodplain, and this results in increased flood levels upstream (see Section 7.3).

7.1.5 As described in Section 1.4, environmental considerations have influenced the Project throughout the design development process, from early route options assessment through to refinement of the Project design. An iterative process has facilitated design updates and improvements, informed by environmental assessment and input from the Project engineering teams, stakeholders and public consultation.

7.1.6 The mitigation measures identified in relation to potential effects of flooding in the Mardyke are shown in Plate 7.3, Plate 7.4 and Drawing 00181. A description is provided below, along with their securing mechanism:

a. Inclusion of floodplain compensation areas at locations hydraulically connected to the displaced floodplain storage, such that displaced floodplain volumes are replaced on a level-for-level basis (by locally lowering ground levels by approximately 0.2m within the identified compensation areas). The required floodplain compensation is also partly provided by the water vole habitat creation included in the Project design, with the habitat areas including lowered ponds and channels on both sides of the highway viaduct. The proposed water vole habitat creation design is shown on Plate 7.3 and is also presented on the Environmental Masterplan (ES Figure 2.4, Application Document 6.2). The proposed shape was simplified in the model representation due to the model 10m grid size (Plate 7.4). The representation of the habitat in the model provides the same amount of storage at corresponding levels as the design shown on Plate 7.3. This is secured through the Design Principles S12.15 and the REAC [RDWE037].

b. Raised bund along the eastern water vole habitat pond to prevent increased conveyance of flood water in the floodplain at this location [REAC Ref. RDWE039].

c. Implementing floodplain flow path around road viaduct abutment to retain floodplain connectivity [REAC Ref. RDWE040].

Plate 7.3 Proposed water vole habitat creation area

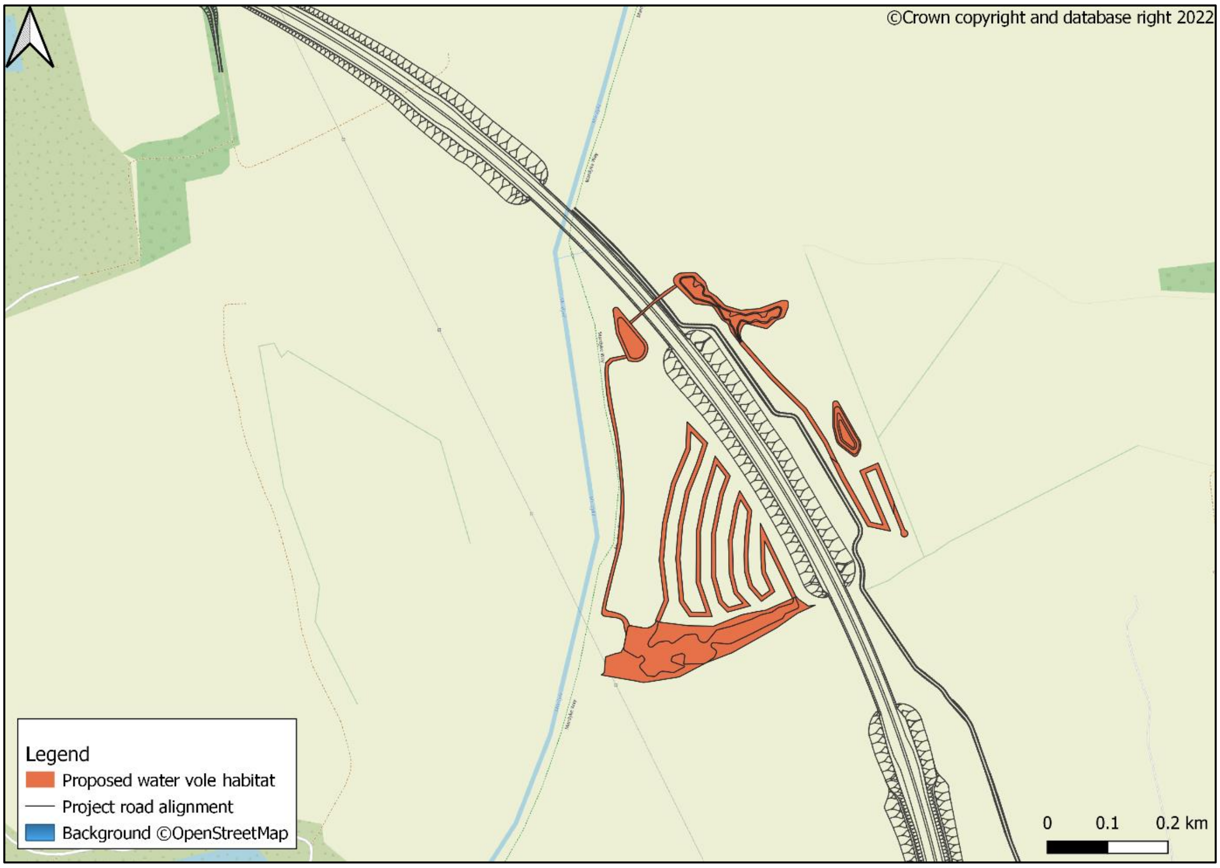
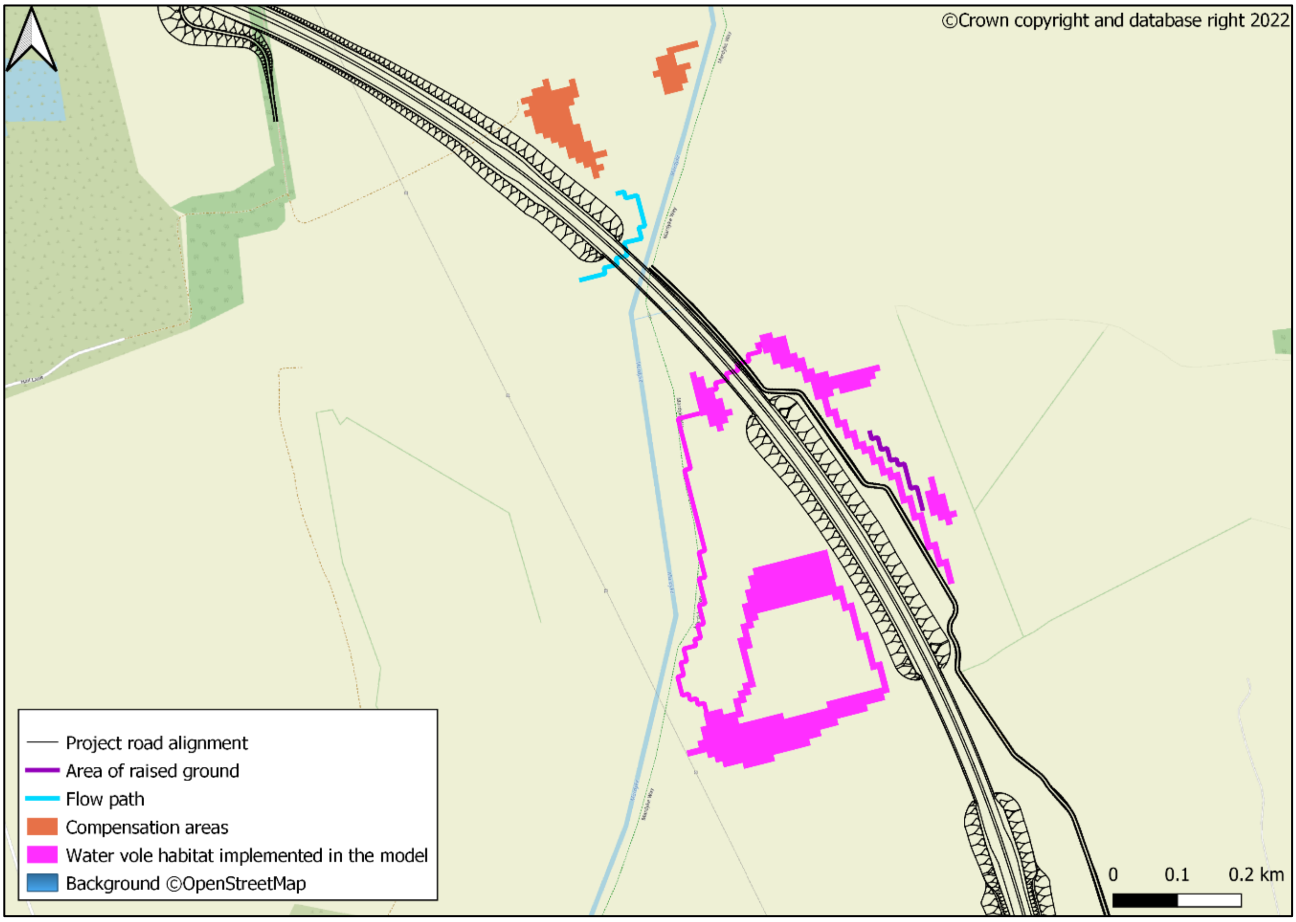


Plate 7.4 Model representation of mitigation measures in the Mardyke floodplain



7.1.7 In line with the Design Principle S12.15, the developed design of the mitigation area will be required to comply with the requirements of the FRA. The preliminary assessment of the mitigation measures presented in this report demonstrates that:

a. The offsite impacts are fully mitigated by the mitigation measures (Section 7.3).

b. The mitigation measures can be provided solely within land for which National Highways will be seeking permanent acquisition.

7.1.8 Table 7.3 to Table 7.5 list, for each element of the design resulting in displaced floodplain storage, the floodplain displaced by the design and the additional floodplain storage provided by the identified floodplain compensation areas (including the proposed water vole habitat creation area). Table 7.3 to Table 7.5 also show the correspondence between areas of displaced floodplain storage and floodplain compensation areas (quantified on a level-for-level basis). Table 7.3 to Table 7.5 demonstrate that the required floodplain storage volumes can be comfortably provided on a hydraulically linked level-for-level basis within land for which National Highways will be seeking permanent acquisition.

Table 7.3 Compensation for displaced floodplain areas 1 and FC1.1

Upper limit of level range (mAOD)	Lower limit of level range (mAOD)	Floodplain within level range displaced by the design (without mitigation) (m^3)	Floodplain compensation volume provided within level range (m^3)
3.6	3.5	0.00	32.08
3.7	3.6	8.20	180.36
3.8	3.7	169.06	486.80
3.9	3.8	512.62	839.15
4.0	3.9	933.27	1,147.31
4.1	4.0	1,026.12	1,379.00

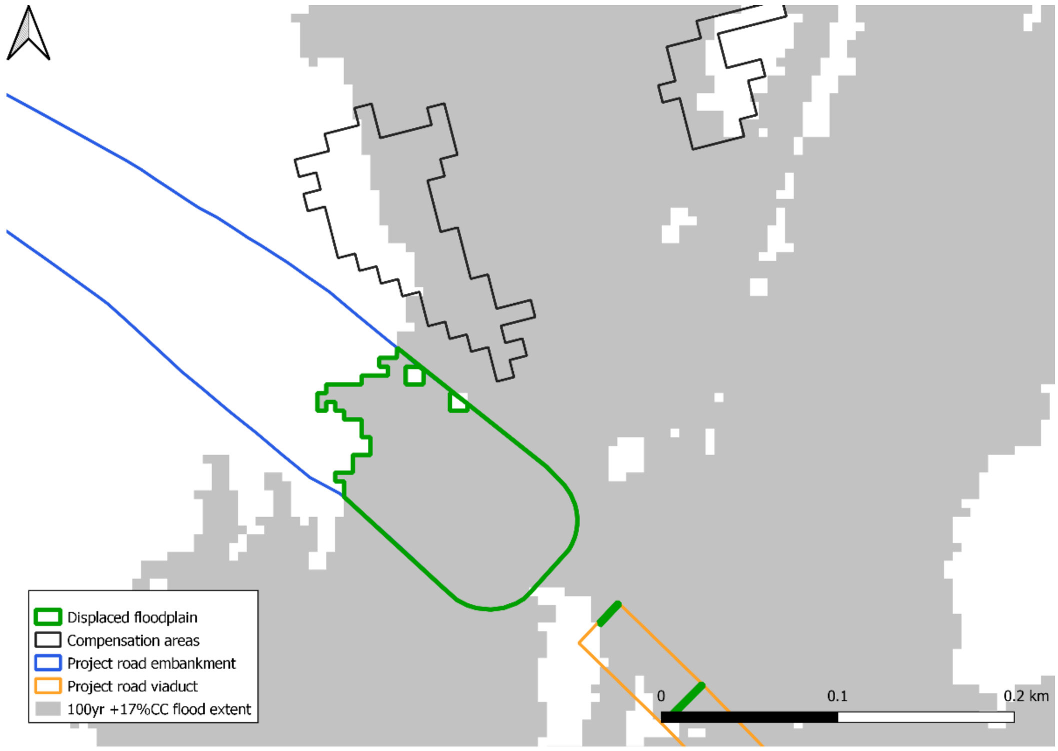


Table 7.4 Compensation for displaced floodplain areas 2, FC1.2, FC1.3, FC1.4, FC1.5 and FC1.6

Upper limit of level range (mAOD)	Lower limit of level range (mAOD)	Floodplain within level range displaced by the design (without mitigation) (m^3)	Floodplain compensation volume provided within level range (m^3)
3.0	2.9	0.00	1,382.10
3.1	3.0	0.00	1,269.07
3.2	3.1	1.37	1,124.44
3.3	3.2	135.42	996.55
3.4	3.3	345.29	932.60
3.5	3.4	401.11	853.78
3.6	3.5	447.40	876.64
3.7	3.6	496.26	1,249.50
3.8	3.7	551.67	1,070.03
3.9	3.8	582.43	1,002.86

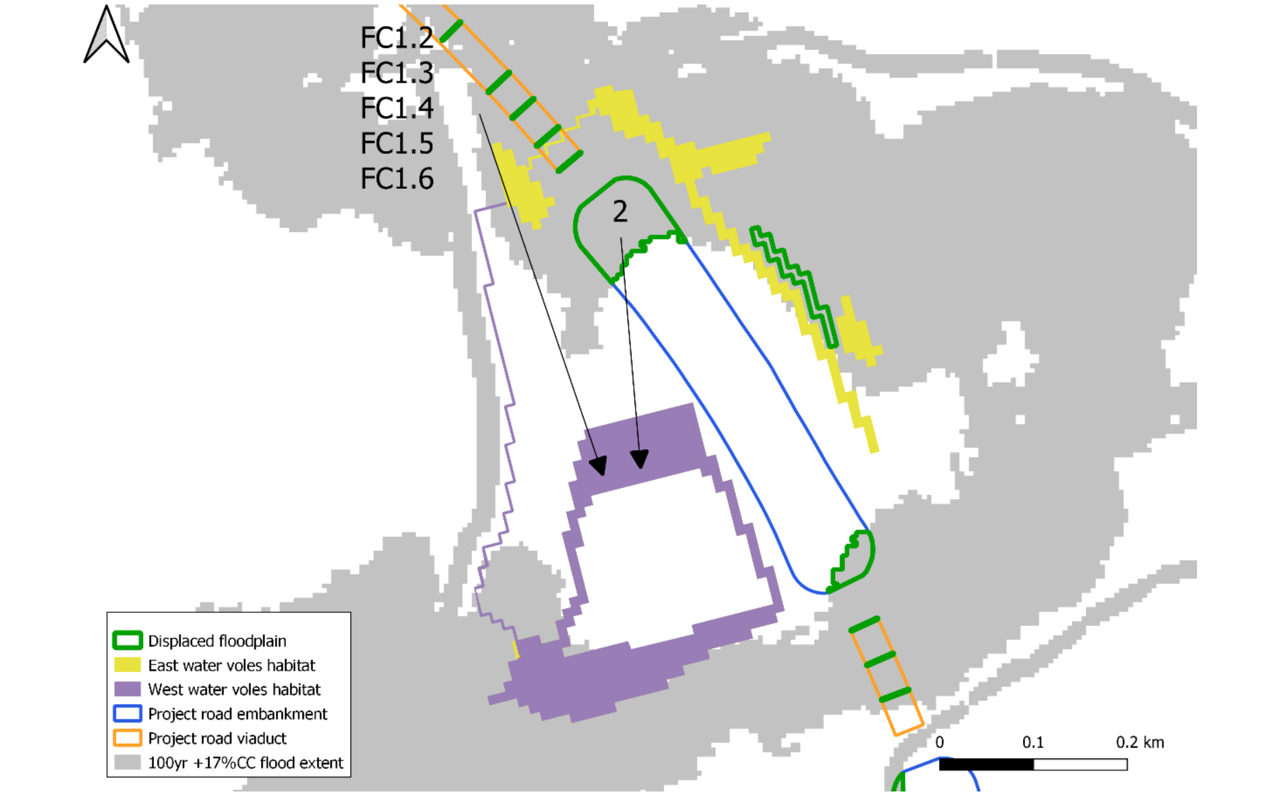
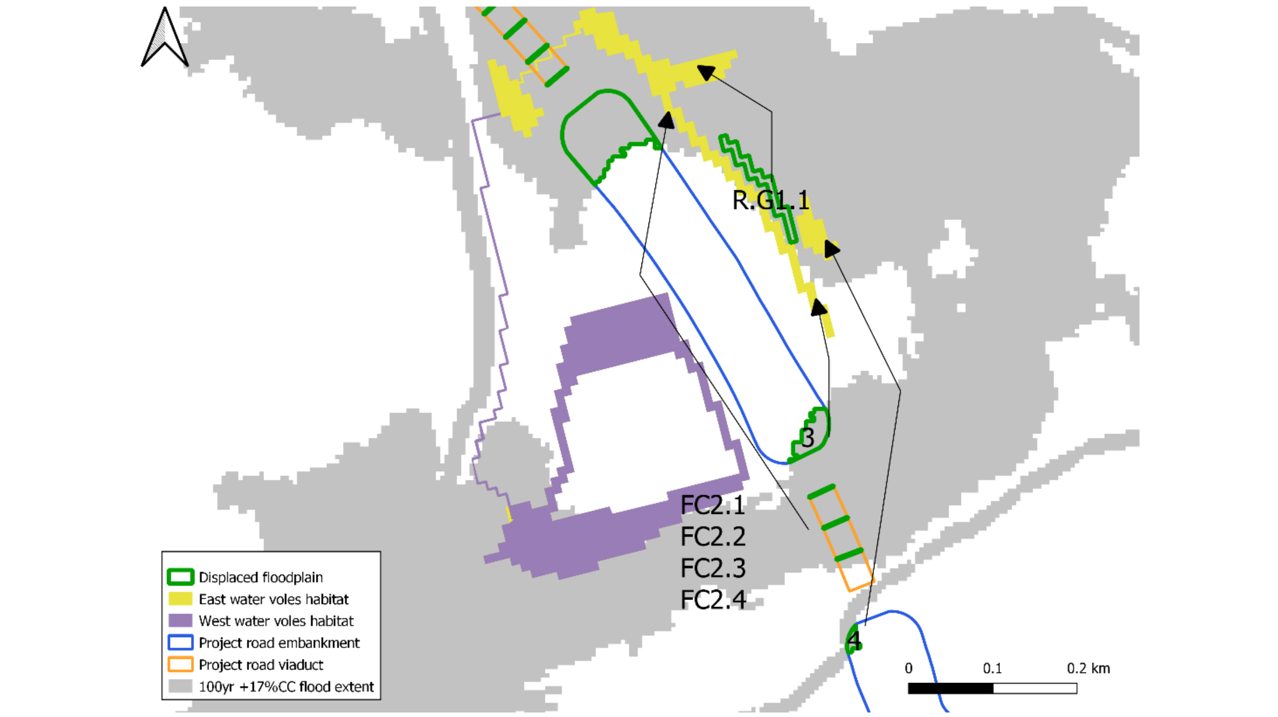


Table 7.5 Compensation for displaced floodplain area 3,4, FC2.1, FC2.2, FC2.3, FC2.4 and RG1.1

Upper limit of level range (mAOD)	Lower limit of level range (mAOD)	Floodplain within level range displaced by the design (without mitigation) (m3)	Floodplain compensation volume provided within level range (m3)
2.9	2.8	0.00	856.68
3.0	2.9	0.00	978.89
3.1	3.0	5.61	1,030.24
3.2	3.1	26.01	852.96
3.3	3.2	42.23	586.57
3.4	3.3	57.82	499.22
3.5	3.4	78.82	481.45
3.6	3.5	109.96	498.90
3.7	3.6	131.43	457.14



Mardyke Sluice operation during design simulations

7.1.9 The operation of the Mardyke Sluice during design simulations is specified by rules that were developed based on information provided by the Environment Agency (Reference: EAn/2018/76391). The rules are based on water levels upstream (node M1_003) and downstream (node M1_002) of the sluice. The rules are presented in Table 7.6.

Table 7.6 Mardyke Sluice rules

Rule name	Rule description text specified in hydraulic model
Closed1	IF (LEVEL(M1_003) .LT. 0.845) THEN POSITION =0.0 END
Opened1	IF (LEVEL (M1_003).GE.0.845.AND.LEVEL (M1_003).LT.1.665.AND.LEVEL (M1_003).GE.(LEVEL (M1_002)+0.2)) THEN POSITION =3.55 END
Moved0	IF (LEVEL (M1_003).GE.0.845.AND.LEVEL (M1_003).LT.1.665.AND.LEVEL (M1_003).LT.(LEVEL(M1_002)+0.2)) THEN MOVE =0.0 END
Opened2	IF (LEVEL (M1_003).GE.1.665.AND.LEVEL (M1_003).GE.(LEVEL (M1_002)+0.2)) THEN POSITION =3.55 END
Closed3	IF (LEVEL (M1_003).GE.1.665.AND.LEVEL (M1_003).LT.(LEVEL (M1_002)+0.2)) THEN POSITION =0.0 END

7.1.10 For the residual risk simulations, representing the Mardyke Sluice failure (gate stuck open and gate stuck closed), time-based control data was used as presented in Table 7.7. Note the second specified time of 1,000,000 hours is arbitrarily long (approximately 114 years) and ensures there is no gate movement during the simulation duration.

Table 7.7 Mardyke Sluice operation for residual risk simulations

Gate opened		Gate closed	
Time (h)	Opening (m)	Time (h)	Opening (m)
0.0	3.55	0.0	0.0
1,000,000.0	3.55	1,000,000.0	0.0

7.2 Design simulations

Critical storm durations

7.2.1 Critical storm durations were derived, in terms of peak flow, for each FEP as follows:

a. For each FEP, the 100-year return period storm was simulated for a range of storm durations, with storm area equal to the upstream catchment area, and a winter storm profile. Design flood hydrographs were applied only for the sub-catchment inflows upstream of the FEP. Sub-catchment inflows downstream of the FEP were set to contribute baseflow only.

b. For the FEPs with potential to be influenced by assumed downstream tide conditions (Stifford gauging station and Mardyke Sluice), a normal flow downstream model boundary was specified.

c. Critical duration selected as that with the highest peak flow (summing both 1D and 2D flows past the FEP).

7.2.2 The resulting critical durations are listed in Table 7.8.

Table 7.8 Critical storm durations

Flood Estimation Point	Critical storm duration (hours)
West Mardyke	18
East Mardyke	30
Orsett Fen Top	30
Project Road	30
Stifford gauging station	36
Sluice Gate	48

Reconciliation of FEH rainfall-runoff simulated design flows with FEH statistical estimates

7.2.3 Design flows were simulated with the Project Mardyke hydraulic model and results adjusted to give peak flows matching the preferred flood estimates (i.e. the FEH statistical estimates in Table 4.23) at the study FEPs. This reconciliation was undertaken for design events between two- and 200-year return periods. For more extreme events, the 200-year return period scaling factors were applied, recognising that the FEH statistical method is considered less reliable for such extreme events than the design rainfall growth factors (applied in the rainfall-runoff models), as rainfall statistics are typically based on longer datasets than flow statistics.

7.2.4 The initial approach to reconciliation of FEH rainfall-runoff simulated design flows with FEH statistical estimates at the study FEPs, was as follows:

a. Simulate design storms (with appropriate critical storm duration and storm area) at the most upstream FEPs (West Mardyke, East Mardyke and Orsett Fen Top). Adjust scaling factors for sub-catchment inflows upstream of each FEP to match target flows at the FEPs (FEH statistical estimates). These adjusted scaling factors are then fixed.

b. For the next FEP downstream (Project Road), simulate design storms (with appropriate critical storm duration and storm area). Adjust scaling factors for the upstream sub-catchment inflows that have not already been fixed to match the target flows. These adjusted scaling factors are then fixed.

c. Repeat step (b) for the Stifford gauging station and Sluice Gate FEPs.

7.2.5 However, it was not possible to specify realistic scaling factors for all sub-catchment inflows following steps (a) to (c), as described below.

7.2.6 Initially, the adjustment of scaling factors was undertaken for the upstream West Mardyke, East Mardyke and Orsett Fen Top FEPs, before undertaking reconciliation at Project Road. However, this resulted in the requirement for unrealistic scaling factors (as low as approximately 0.2) for the sub-catchments contributing between the upstream FEPs and Project Road FEP to match target flows at Project Road. It was therefore decided to adjust all contributing inflows upstream of Project Road uniformly, to achieve a match between modelled flow and target flows at the Project Road FEP as:

a. The Project crosses the Mardyke at Project Road FEP and Orsett Fen at Orsett Fen Top FEP. These are therefore considered the most important FEPs at which to match target flows.

b. The resulting differences between modelled and target flows at Project Road FEP and Orsett Fen Top FEP are within 1% (for events up to the 200-year return period).

c. The resulting differences between modelled and target flows at West Mardyke and East Mardyke are within approximately 23% (for events up to the 200-year return period). The target flows are ungauged FEH statistical estimates and are therefore uncertain (e.g. the factorial error for QMED is approximately 1.43). The differences between modelled and target flows at West Mardyke and East Mardyke are therefore within the uncertainty in the target flow estimates.

7.2.7 After fixing the scaling factors upstream of the Project Road FEP, an attempt was made to match target flows at Stifford gauging station by adjusting scaling factors of the sub-catchment inflows contributing between Project Road and Stifford gauging station. However, this resulted in unrealistic scaling factors (as low as approximately 0.2). It was therefore decided not to adjust the scaling factors for these inflows, which results in slightly higher modelled flows at Stifford than the target flows, by approximately +2% to +14% for events up to the 200-year return period. This is conservative and the resulting modelled flows are within the uncertainty of the ungauged FEH statistical estimated target flows at Stifford gauging station.

7.2.8 Similarly, scaling factors for sub-catchment inflows downstream of Stifford gauging station were not adjusted further to match target flows at the downstream Sluice Gate FEP. This resulted in differences between modelled flows and target flows of between -6% and +8% for events up to the 200-year return period.

7.2.9 In summary, the approach to reconciliation has resulted in modelled flows matching target flows (FEH statistical estimates) at the FEPs representing the Project location (Project Road and Orsett Fen Top) whilst providing modelled flows at the other FEPs within the understood uncertainty of the target flows.

7.2.10 Modelled design flows at the FEPs after reconciliation are compared with target flows (FEH statistical estimates) in Table 7.9. The final derived reconciliation scaling factors for each sub-catchment are listed in Table 7.10.

Table 7.9 Peak design flows at Flood Estimation Points

Flood Estimation Point		Peak flow (m3/s) for return periods (years)***								
		2	5	10	25	50	100	200	500	1,000
West Mardyke	Model flow*	4.46	6.13	7.41	9.47	11.14	13.89	15.47	19.44	23.75
	Target flow**	4.46	6.39	7.65	9.32	10.65	12.06	13.56	15.72	17.48
	Difference(%)	0.0	-4.1	-3.1	1.6	4.6	15.2	14.1	23.6	35.9
East Mardyke	Model flow*	2.89	4.01	4.80	5.99	7.04	8.84	9.70	12.65	15.60
	Target flow**	3.60	5.16	6.17	7.52	8.59	9.73	10.95	12.69	14.11
	Difference (%)	-19.7	-22.3	-22.2	-20.3	-18.1	-9.1	-11.4	-0.3	10.6
Orsett Fen Top	Model flow*	1.12	1.58	1.92	2.44	2.88	3.42	4	4.94	5.83
	Target flow**	1.12	1.58	1.93	2.44	2.89	3.41	4.01	4.96	5.82
	Difference (%)	0.0	0.0	-0.5	0.0	-0.3	0.3	-0.2	-0.4	0.2
Project Road	Model flow*	8.33	11.59	13.67	16.62	18.89	21.56	23.96	28.53	37.95
	Target flow**	8.34	11.54	13.68	16.57	18.91	21.43	24.15	28.12	31.42
	Difference (%)	-0.1	0.4	-0.1	0.3	-0.1	0.6	-0.8	1.5	20.8
Stifford gauging station	Model flow*	9.82	13.22	16.04	19.77	22.66	25.85	29.15	35.16	42.95
	Target flow**	9.62	12.96	15.17	18.11	20.45	22.94	25.60	29.43	32.58
	Difference (%)	2.1	2.0	5.7	9.2	10.8	12.7	13.9	19.5	31.8
Sluice Gate	Model flow*	9.22	12.03	14.12	17	20.84	24.38	26.45	34.99	43.66
	Target flow**	9.46	12.76	14.93	17.82	20.12	22.57	25.19	28.96	32.06
	Difference (%)	-2.5	-5.7	-5.4	-4.6	3.6	8.0	5.0	20.8	36.2

**After reconciliation*
***FEH statistical method estimate*
****For more extreme events than the 200-year return period, the 200-year return period scaling factors were applied, rather than reconciling the model flows with the FEH statistical estimates. This recognises that the FEH statistical method is considered less reliable for such extreme events than the design rainfall growth factors (applied in the rainfall-runoff models), as rainfall statistics are typically based on longer datasets than flow statistics. Hence the 500 and 1,000 year columns are 'greyed out'.*

Table 7.10 Inflow boundary scaling factors

Inflow node	Scaling factors for Project Road Flood Estimation Point for return periods (years)								
	2	5	10	25	50	100	200	500	1,000
West Mardyke	0.85	0.74	0.71	0.69	0.67	0.71	0.67	0.67	0.67
East Mardyke	0.85	0.74	0.71	0.69	0.67	0.71	0.67	0.67	0.67
C8	0.85	0.74	0.71	0.69	0.67	0.71	0.67	0.67	0.67
C7a	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C5	0.85	0.74	0.71	0.69	0.67	0.71	0.67	0.67	0.67
C4	0.85	0.74	0.71	0.69	0.67	0.71	0.67	0.67	0.67
C3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

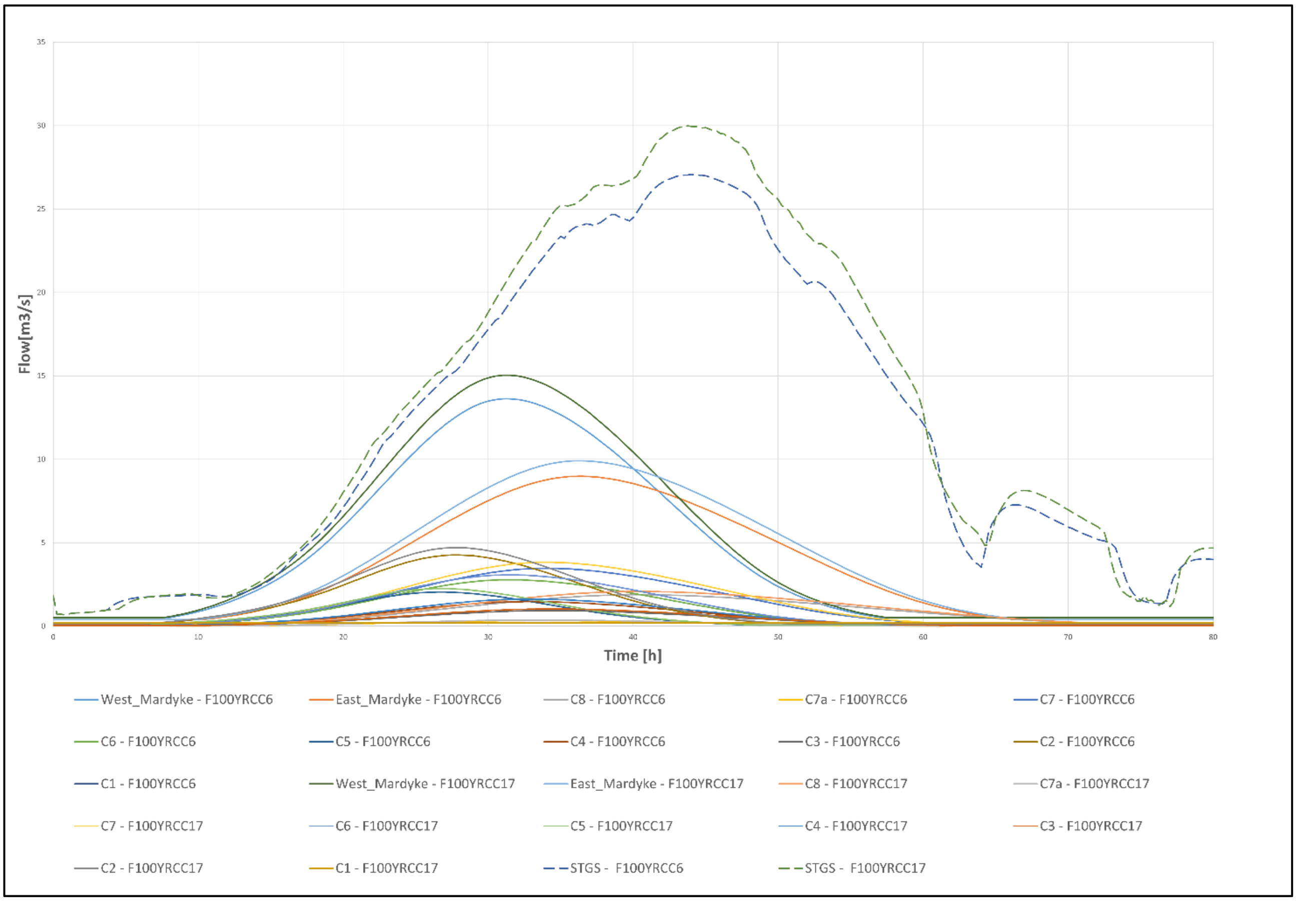
Design inflows

7.2.11 FEH rainfall-runoff model design inflows were specified at model inflow locations, specifying the winter event calibration adjustments, i.e. scaling the default Tp values by two.

7.2.12 When simulating design events for a given FEP, design flood hydrographs were applied only for the sub-catchment inflows upstream of the FEP. Sub-catchment inflows downstream of the FEP were set to contribute baseflow only.

7.2.13 Plate 7.5 presents modelled flows for the 100-year return period design event (in 2030 with +6% and in 2130 with +17% climate change allowance) for the design storm upstream of Project Road FEP. Simulated total flows (i.e. the sum of 1D and 2D flows) at Stifford gauging station are shown with a dashed line. Model inflow hydrographs are shown as solid lines.

Plate 7.5 Modelled inflows example



Climate change allowances applied to river flows

7.2.14 Following current Environment Agency guidance (Environment Agency, 2022), peak river flow allowances of +6% and +11% were applied for the 2030 ‘Central’ and ‘Higher central’ climate scenarios respectively, and +17% and +26% were applied for the 2130 ‘Central’ and ‘Higher central’ climate scenarios respectively. The upper end peak river flow allowance (+48% in 2130) was applied to represent the ‘credible maximum’ climate change scenario.

Downstream design tidal boundary

7.2.15 The derivation of design tidal boundaries is reported in 4.8.

Consideration of joint fluvial and tidal events

7.2.16 The modelling scoping note (CASCADE, 2018) developed for the FRA in consultation with the Environment Agency applied the FD2308 spreadsheet method (Defra/Environment Agency, 2005) to derive joint fluvial tidal combinations for a range of design event return periods. The design combinations specified to assess fluvial flood risk are listed in Table 7.11.

Table 7.11 Mardyke joint fluvial/tidal event combinations derived by the FD2308 simplified spreadsheet method

Design event	Combined fluvial/tidal event return period (years)	
	Fluvial	Tidal
20 year	20	MHWS
	Baseflow only	20
100 year	100	MHWS
	25	1
	5	5
1,000 year	1,000	2.5
	100	25
	50	50
	25	100
	2.5	1,000

7.2.17 Model simulations were undertaken to assess the sensitivity of fluvial results to downstream tide conditions, at the point where the Project Road would cross the Mardyke. Simulation results indicated peak flood levels at this location are relatively insensitive to downstream tidal conditions, and so for a given return period, the event combination with fluvial return period equal to the design event return period gives the highest flood levels at the point where the Project Road crosses the Mardyke. For example, the difference between peak flood levels simulated for the 100-year return period fluvial inflow (in 2127[9], +70% river flow allowance) with either a MHWS or 25-year return period tidal boundary condition, is only approximately 0.02m at the point where the Project Road crosses the Mardyke. Therefore, only the fluvial design event combinations with fluvial return period equal to the design return period were simulated, i.e. applying a MHWS for events up to 100-year return period, and a 2.5-year tidal condition for the 1,000-year event (although a five-year return period tidal boundary was applied instead, as the derivation of tidal boundaries required TE2100 EWLs, which were not available for a 2.5-year return period).

Design simulations

7.2.18 Fluvial design flood events have been simulated for the 2, 10, 25, 100 and 1,000-year return period events, with storm area and critical duration for the FEPs at Stifford gauging station and Orsett Fen Top. Initially simulations were going to be undertaken for critical events at the Project Road FEP, located where the Project road crosses the Mardyke. However design flood levels at the Project location are higher for the critical events at Stifford gauging station, due to floodplain flow from the Orsett Fen catchment joining the Mardyke floodplain. Stifford gauging station critical events were therefore applied instead.

[9] This sensitivity test was undertaken before the Project climate change horizon was extended from 2127 to 2130, and before the Environment Agency peak river flow climate change allowances were updated in July 2021 (the allowances were reduced for the study area in July 2021, as detailed in Environment Agency 2022).

7.2.19 Simulations were undertaken for the pre- and post-development cases. The post-development case was simulated both without and with mitigation measures (as described in paragraphs 7.1.3 to 7.1.8).

7.2.20 The simulations undertaken and associated flood mapping outputs are listed in Table 7.12. The flood mapping outputs include flood depth, velocity and hazard score maps, and maps comparing the maximum flood depths pre- and post-development. The simulations and flood mapping outputs listed in Table 7.12 were selected as follows:

a. Pre-development flood maps in 2030 with +6% Central and +11% Higher central peak river flow allowances applied and in 2130 with +17% Central and +26% Higher central allowances applied.

b. Post-development flood maps for the design (i.e. without mitigation measures) in 2030 with +6% Central and +11% Higher central peak river flow allowances applied and in 2130 with +17% Central and +26% Higher central allowances applied.

c. Post-development flood maps for the design also including mitigation measures in 2030 with +6% Central and +11% Higher central peak river flow allowances applied and in 2130 with +17% Central and +26% Higher central allowances applied.

d. Depth difference plots for the 100-year return period event in 2130 with the +26% Higher central peak river flow allowance applied, to demonstrate that receptors of offsite impacts of the design (without mitigation) do not include Essential Infrastructure, and so the Central peak river flow allowances (+6%in 2030 and +17% in 2130) should be applied to assess offsite impacts and fluvial floodplain compensation requirements, in accord with current guidance (Environment Agency, 2022).

e. Depth difference plots for the 10, 25 and 100 year return period events in 2030 with +6% Central peak river flow allowance applied in 2030, and +17% Central allowances in 2130, to demonstrate that the mitigation measures and floodplain compensation specified do provide the required mitigation and floodplain compensation.

f. 1,000-year return period flood maps with Higher central peak river flow allowances applied (+11% in 2030 and +26% in 2130), to demonstrate that the Project road would not be impacted during these events. This is in accord with current guidance (Environment Agency, 2022) which states that Higher central allowances should be applied to assess flood risk to Essential Infrastructure.

g. 1,000-year return period flood map with the Upper end peak river flow allowance applied (+48%) in 2130, to represent the ‘credible maximum’ climate change scenario.

Table 7.12 Simulations undertaken and associated flood mapping outputs

Design event return period (years) and peak river flow climate change allowance	Flood mapping outputs				
	Depth, velocity and hazard score maps			Depth difference plots	
	Pre-development	Post-development without mitigation	Post-development with mitigation	Post-development without mitigation minus pre-development	Post-development with mitigation minus pre-development
2 year in 2030 (+6%)	X	X	X		
2 year in 2030 (+11%)	X	X	X		
2 year in 2130 (+17%)	X	X	X		
2 year in 2130 (+26%)	X	X	X		
10 year in 2030 (+6%)	X	X	X	X	X
10 year in 2030 (+11%)	X	X	X		
10 year in 2130 (+17%)	X	X	X	X	X
10 year in 2130 (+26%)	X	X	X		
25 year in 2030 (+6%)	X	X	X	X	X
25 year in 2030 (+11%)	X	X	X		
25 year in 2130 (+17%)	X	X	X	X	X
25 year in 2130 (+26%)	X	X	X		
100 year in 2030 (+6%)	X	X	X	X	X

Design event return period (years) and peak river flow climate change allowance	Flood mapping outputs				
	Depth, velocity and hazard score maps			Depth difference plots	
	Pre-development	Post-development without mitigation	Post-development with mitigation	Post-development without mitigation minus pre-development	Post-development with mitigation minus pre-development
100 year in 2030 (+11%)	X	X	X		
100 year in 2130 (+17%)	X	X	X	X	X
100 year in 2130 (+26%)	X	X	X	X	X
1,000 year in 2030 (+11%)	X	X	X		
1,000 year in 2130 (+ 26%) Flood risk standard for North Portal (and higher than the 200-year flood risk standard for the highway)	X	X	X		
Credible maximum scenario: 1,000 year in 2130 (+ 48%) with 1,000 year credible maximum tidal EWL in 2130 (7.45mAOD)	X	X	X		

7.3 Design simulation results and interpretation

Flood maps

7.3.1 The flood mapping output drawings for the events listed in Table 7.12 are included in Annex D and summarised in Table D.1.

Impact of the Project on fluvial flood risk elsewhere

7.3.2 The drawings listed in Annex D (as summarised in Table D.1) are included in Part 9. These show simulated flood depth, velocity and hazard score at the Project route alignment, for the pre-development, post-development with mitigation and post-development without mitigation cases.

7.3.3 The difference plots in Part 9 (Drawings 00642 to 00655) show simulated peak depth differences (post-development minus pre-development depths) for the design (without mitigation measures) in 2030 and 2130 according to Table 7.12. These difference plots show that areas with a change in flood depth as a result of the design (without mitigation measures) do not include Essential Infrastructure, and so the Central rainfall allowances (+17%) should be applied to assess the mitigation of offsite impacts and fluvial floodplain compensation requirements, following Environment Agency (2022).

7.3.4 Drawings 00656 to 00669 in Part 9 include depth difference plots comparing results of the post-development scenario including the mitigation measures identified in Section 7.1 with the pre-development scenario, for the 10, 25, 100-year return period events in 2030 with +6% peak river flow allowances, and in 2130 with central peak river flow allowances with +17% peak river flow allowances, as well as for the 100-year return period event in 2130 with Upper end peak river flow allowances (+26%). These drawings show that including the identified mitigation measures fully mitigate the impacts of the Project, such that changes in flood depth outside of land for which National Highways will be seeking permanent acquisition, are mostly within +/-10mm and also include some larger reductions in flood depths as a result of the mitigation measures. Drawings 00660, 00661 and 00662 show a few isolated model grid cells (10m x 10m) with increases above +10mm. However, these grid cells are located in areas where the increase is generally less than +10mm, and so these isolated cases are considered modelling artefacts (e.g. caused by comparing flood depths at localised depressions that are dry for the pre-development case and wet for the post-development case).

Impact of fluvial flooding on Project

7.3.5 At the Mardyke and its floodplain, the Project road is above the 1,000-year return period Mardyke flood in 2130 with the Upper end peak river flow climate change allowance applied (+48%). The proposed road surface is more than 5m above the simulated 1,000-year return period flood level in 2130 with the Upper end peak river flow climate change allowance applied (+48%). The Project road would therefore remain operational during a 1,000-year return period flood in 2130 (with +48% peak river flow allowance). This exceeds the Project requirement for the proposed highway to remain operational during the 1,000-year return period flood in 2130, applying the Higher central peak river flow climate change allowance (+26%).

Peak water levels

7.3.6 Table 7.13 and Table 7.14 list peak 1D water levels simulated by the model at selected locations for the Stifford gauging station and Orsett Fen Top critical events respectively. Results are included for the pre-development case and post-development case with mitigation measures, for the following events:

a. 100-year return period event in 2030 and 2130 with central and higher central peak river flow climate change allowances (6% and 11% respectively in 2030, 17% and 26% respectively in 2130)

b. 1,000-year return period event in 2030 and 2130 with higher central peak river flow climate changes allowances (11% in 2030 and 26% in 2130)

c. 1,000-year return period event in 2130 with upper end peak river flow climate change allowance (48% in 2130)

7.3.7 For all events in Table 7.13 and Table 7.14, including the 100-year return period events in 2030 and in 2130 with central climate change allowances (i.e. the required mitigation standard), the differences between equivalent pre- and post-development flood levels are within +/-0.01m, i.e. negligible and within model tolerance.

7.3.8 The locations of model nodes referred to in Table 7.13 and Table 7.14 are shown in Plate 7.6.

Plate 7.6 Locations of the nodes

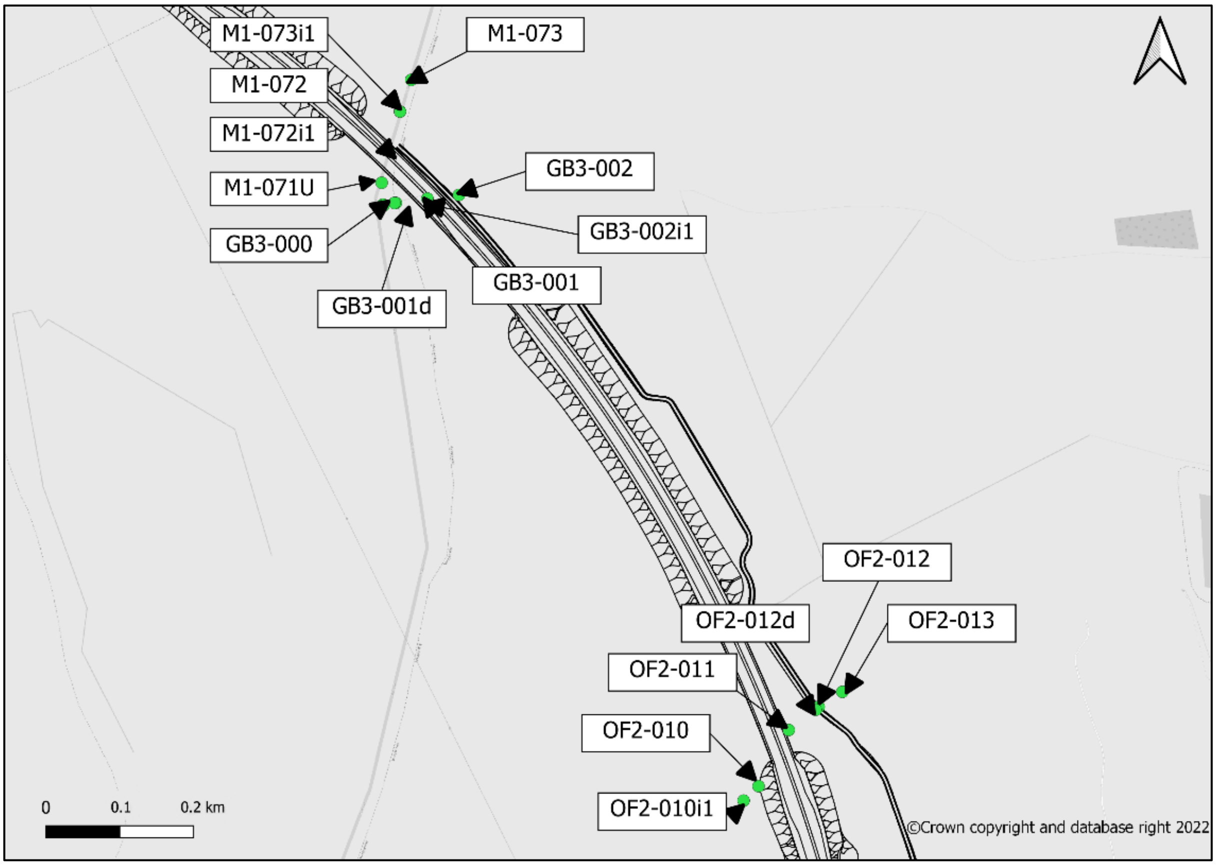


Table 7.13 Peak flood levels for Stifford gauging station critical event

Node	100-year return period in 2030 +6% peak river flow allowance		100-year return period in 2030 +11% peak river flow allowance		100-year return period in 2130 +17% peak river flow allowance		100-year return period in 2130 +26% peak river flow allowance		1,000-year return period in 2030 +11% peak river flow allowance		1,000-year return period in 2130 +26% peak river flow allowance		1,000-year return period in 2130 +48% peak river flow allowance	
	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)
M1-073	3.87	3.87	3.88	3.88	3.90	3.90	3.93	3.93	4.19	4.20	4.28	4.29	4.43	4.44
M1-073i1	3.84	3.84	3.86	3.86	3.88	3.88	3.91	3.91	4.19	4.19	4.28	4.28	4.43	4.43
M1-072	3.82	3.82	3.84	3.84	3.87	3.86	3.90	3.90	4.18	4.19	4.27	4.28	4.42	4.43
M1-072i1	3.80	3.80	3.82	3.82	3.85	3.84	3.88	3.88	4.18	4.17	4.27	4.27	4.42	4.42
M1-071U	3.78	3.78	3.81	3.80	3.83	3.83	3.87	3.87	4.17	4.17	4.27	4.27	4.42	4.42
GB3-002	3.79	3.80	3.82	3.82	3.85	3.85	3.89	3.89	4.17	4.18	4.26	4.27	4.42	4.42
GB3-002i1	3.79	3.79	3.81	3.82	3.84	3.84	3.88	3.88	4.17	4.18	4.27	4.27	4.42	4.42
GB3-001	3.79	3.79	3.81	3.81	3.84	3.83	3.88	3.88	4.17	4.18	4.27	4.27	4.42	4.42
GB3-001d	3.78	3.78	3.81	3.80	3.83	3.83	3.87	3.87	4.17	4.17	4.27	4.27	4.42	4.42
GB3-000	3.78	3.78	3.81	3.80	3.83	3.83	3.87	3.87	4.17	4.17	4.27	4.27	4.42	4.42
OF2-013	4.11	4.11	4.11	4.11	4.12	4.12	4.12	4.12	4.23	4.23	4.26	4.26	4.37	4.37
OF2-012	4.09	4.09	4.10	4.10	4.10	4.10	4.11	4.11	4.22	4.22	4.25	4.25	4.37	4.37
OF2-012d	4.06	4.06	4.06	4.06	4.07	4.07	4.07	4.07	4.20	4.20	4.24	4.24	4.37	4.37
OF2-011	4.04	4.04	4.04	4.04	4.05	4.05	4.06	4.06	4.19	4.19	4.23	4.23	4.37	4.37
OF2-010	3.98	3.98	3.98	3.99	3.99	3.99	4.00	4.00	4.17	4.17	4.22	4.22	4.36	4.36
OF2-010i1	3.95	3.95	3.96	3.96	3.97	3.97	3.98	3.98	4.16	4.16	4.21	4.21	4.36	4.36
M1-042(Stifford gauging station)	2.97	2.98	3.00	3.01	3.07	3.07	3.12	3.12	3.54	3.54	3.65	3.65	3.86	3.86

Table 7.14 Peak flood levels for Orsett Fen Top critical event

Node	100-year return period in 2030 +6% peak river flow allowance		100-year return period in 2030 +11% peak river flow allowance		100-year return period in 2130 +17% peak river flow allowance		100-year return period in 2130 +26% peak river flow allowance		1,000-year return period in 2030 +11% peak river flow allowance		1,000-year return period in 2130 +26% peak river flow allowance		1,000-year return period in 2130 +48% peak river flow allowance	
	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)	Pre-dev	Post-dev (with mitigation measures)
M1-073	2.51	2.51	2.55	2.55	2.59	2.60	2.65	2.65	2.96	2.96	3.06	3.06	3.26	3.26
M1-073i1	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.96	2.96	3.06	3.06	3.26	3.26
M1-072	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.96	2.96	3.06	3.06	3.26	3.26
M1-072i1	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.96	2.96	3.06	3.06	3.26	3.26
M1-071U	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.96	2.96	3.06	3.06	3.25	3.26
GB3-002	2.60	2.60	2.64	2.64	2.69	2.69	2.74	2.74	3.08	3.08	3.19	3.18	3.37	3.37
GB3-002i1	2.55	2.55	2.58	2.58	2.63	2.63	2.69	2.69	3.01	3.01	3.12	3.11	3.31	3.31
GB3-001	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.97	2.97	3.07	3.07	3.26	3.26
GB3-001d	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.97	2.97	3.06	3.06	3.26	3.26
GB3-000	2.51	2.51	2.55	2.55	2.59	2.59	2.65	2.65	2.96	2.96	3.06	3.06	3.25	3.26
OF2-013	4.11	4.11	4.11	4.11	4.11	4.11	4.12	4.12	4.14	4.14	4.15	4.15	4.17	4.17
OF2-012	4.09	4.09	4.09	4.09	4.10	4.10	4.10	4.10	4.13	4.13	4.13	4.13	4.15	4.15
OF2-012d	4.05	4.05	4.06	4.06	4.06	4.06	4.06	4.06	4.09	4.09	4.09	4.09	4.11	4.11
OF2-011	4.03	4.03	4.04	4.04	4.04	4.04	4.04	4.04	4.07	4.07	4.07	4.07	4.09	4.09
OF2-010	3.97	3.97	3.97	3.97	3.98	3.98	3.98	3.98	4.00	4.00	4.01	4.01	4.03	4.03
OF2-010i1	3.94	3.94	3.95	3.95	3.95	3.95	3.95	3.95	3.98	3.98	3.98	3.98	4.00	4.00
M1-042(Stifford gauging station)	1.89	1.89	1.91	1.92	1.98	1.98	2.01	2.01	2.28	2.28	2.44	2.44	2.89	2.90

7.4 Residual risk simulation results and interpretation

Residual risk and simulations

7.4.1 The following simulations were undertaken to assess residual flood risks to the Project:

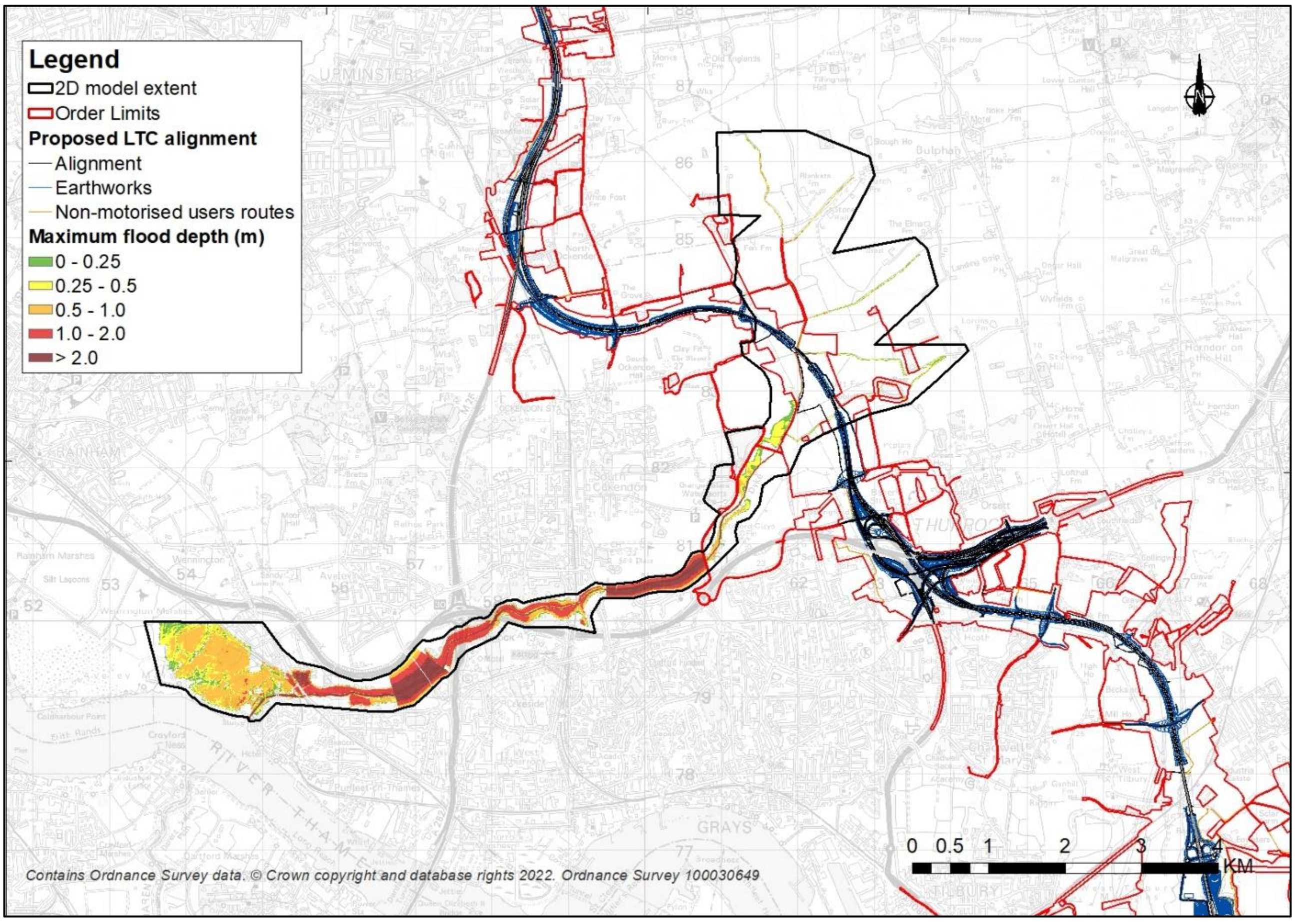
a. Failure of Mardyke Sluice, with the gate assumed to be stuck fully open and fully closed. Assessed for the 200-year return period tidal event in 2030 and 2130 (with gate stuck open only), and for the 100-year return period fluvial event in 2030 and 2130 (with gate stuck open and gate stuck closed).

b. Breach of River Thames tidal flood defences at Mardyke Sluice.

Mardyke Sluice failure scenarios

7.4.2 Plate 7.7 presents the maximum simulated flood depths for the 200-year tidal event in 2130 with the Mardyke Sluice stuck fully open. Plate 7.7 shows that flooding remains in channel at the point where the Project road would cross the Mardyke, and so there is no impact on the Project. The 200-year tidal event in 2030 would therefore also remain in-channel at the point where the Project road would cross the Mardyke.

Plate 7.7 Residual risk – 1 in 200 year Mardyke tidal event in 2130 – Mardyke Sluice opened



7.4.3 Plate 7.8 to Plate 7.11 show differences in peak flood depths (residual risk scenario minus post development) for the 100-year return period fluvial event in 2030 with +11% peak river flow allowance and in 2130 with +26% peak river flow allowance applied, for the Stifford gauging station FEP storm duration, for the gate stuck fully open and fully closed scenarios.

7.4.4 Plate 7.8 and Plate 7.9 show that the impact of the Mardyke Sluice stuck closed on flood risk at the point where the Project road would cross the Mardyke is minor (differences in peak flood depths are approximately between 0m and 0.014m).

7.4.5 Plate 7.10 and Plate 7.11 show that the impact of the Mardyke Sluice stuck open on flood risk at the point where the Project road would cross the Mardyke is more significant than the gate stuck closed, but still minor (differences in peak flood depths are approximately 0.01m to 0.05m).

Plate 7.8 Residual risk – 1 in 100 year Mardyke fluvial event with 11% climate change allowance in 2030 – Mardyke Sluice closed

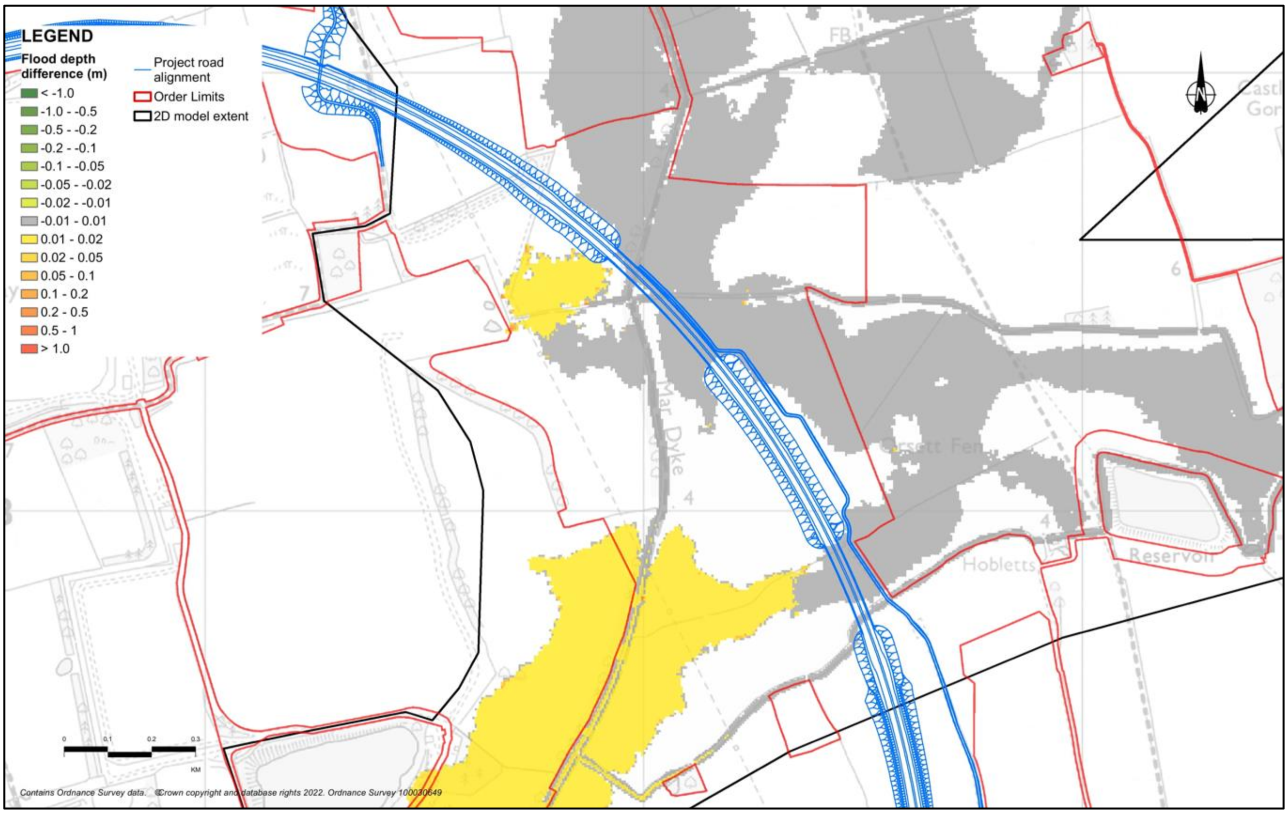


Plate 7.9 Residual risk – 1 in 100 year Mardyke fluvial event with 26% climate change allowance in 2130 – Mardyke Sluice closed

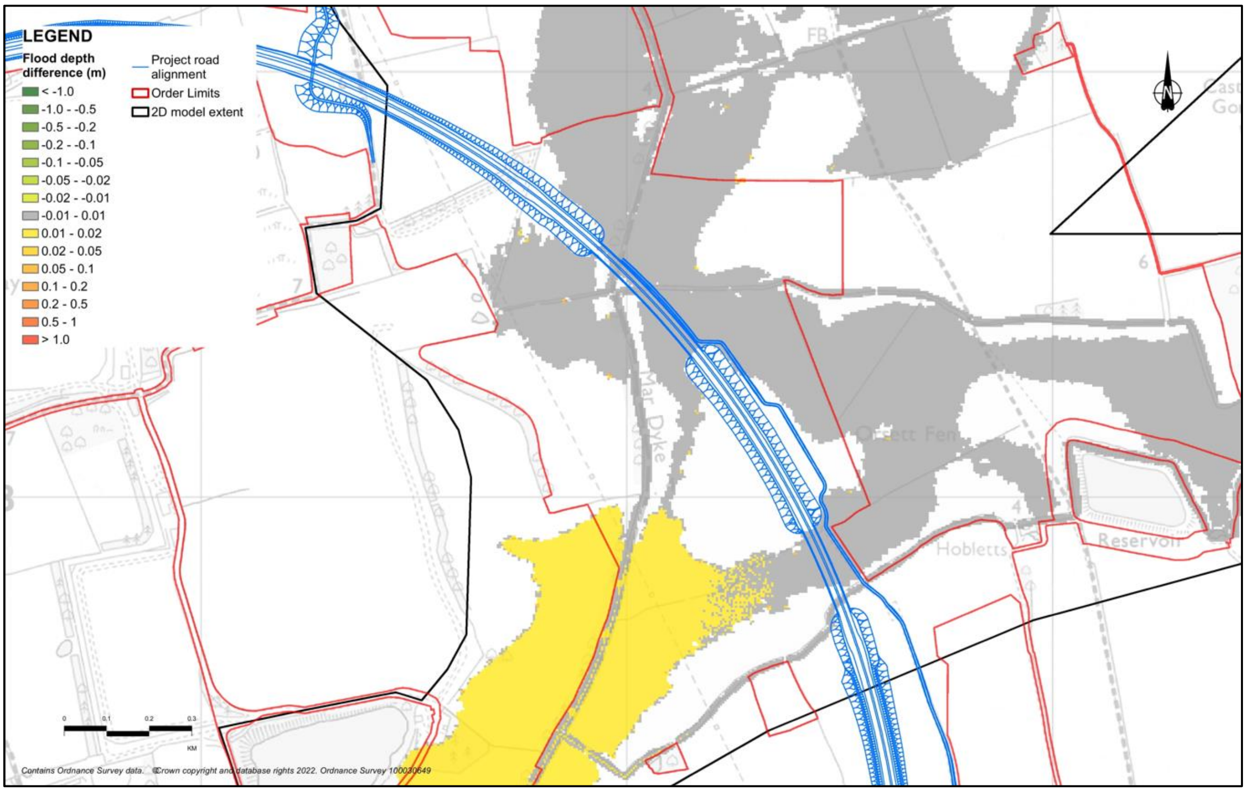


Plate 7.10 Residual risk – 1 in 100 year Mardyke fluvial event with 11% climate change allowance in 2030 – Mardyke Sluice opened

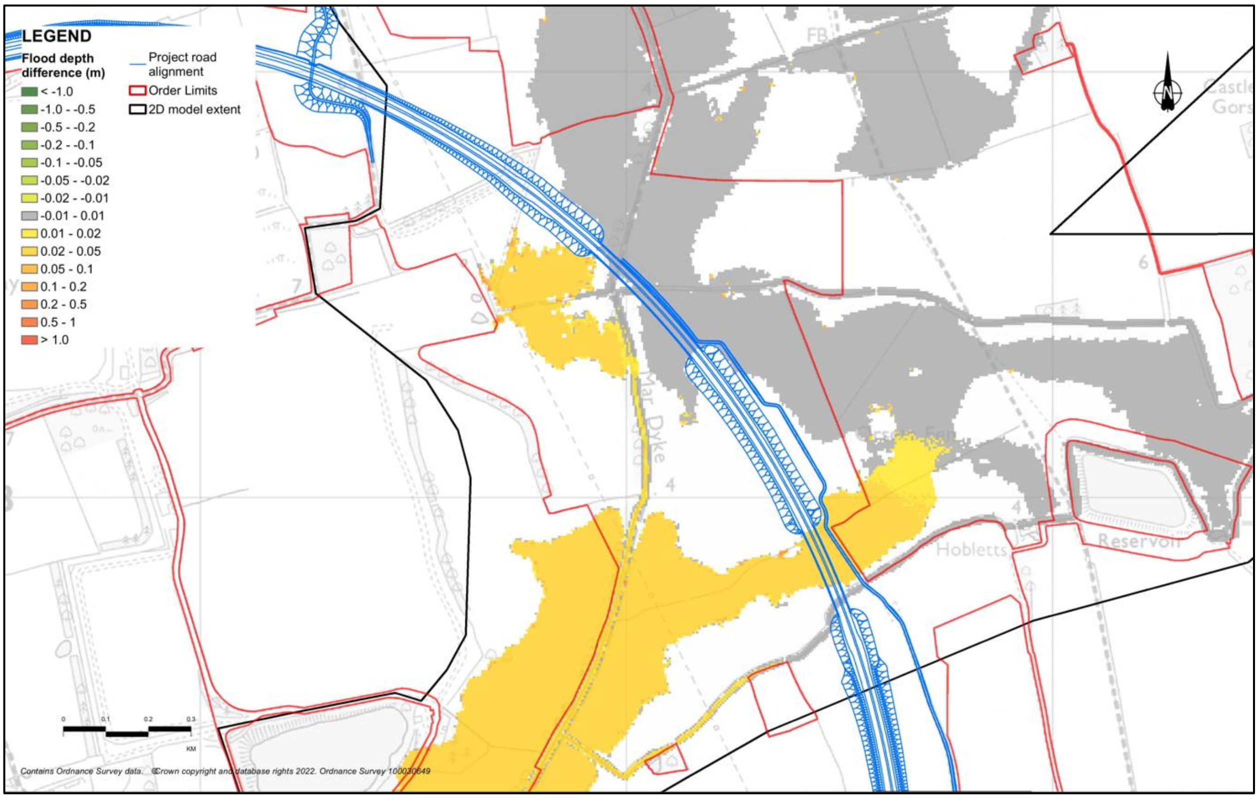
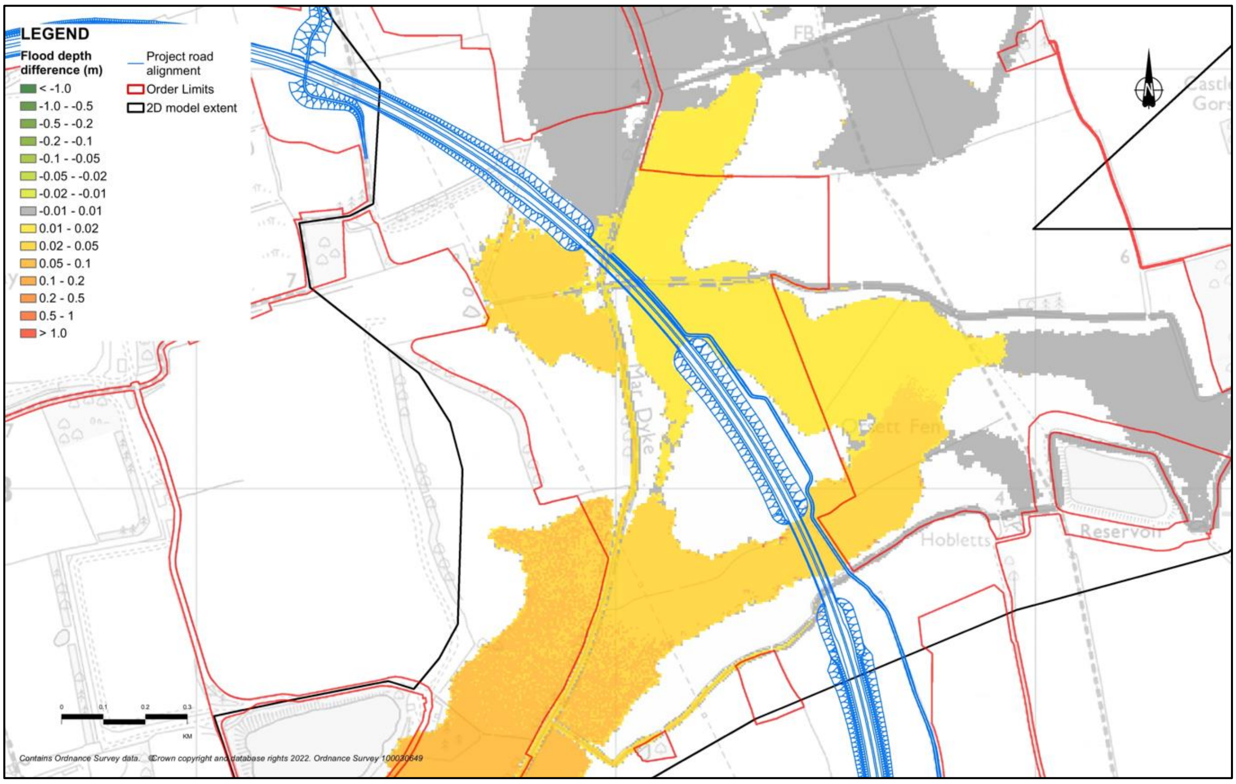


Plate 7.11 Residual risk – 1 in 100 year Mardyke fluvial event with 26% climate change allowance in 2130 – Mardyke Sluice opened



Breach of River Thames tidal defences

7.4.6 A breach of River Thames tidal flood defences at Mardyke Sluice was simulated using the Project Mardyke hydraulic model, as developed in this report.

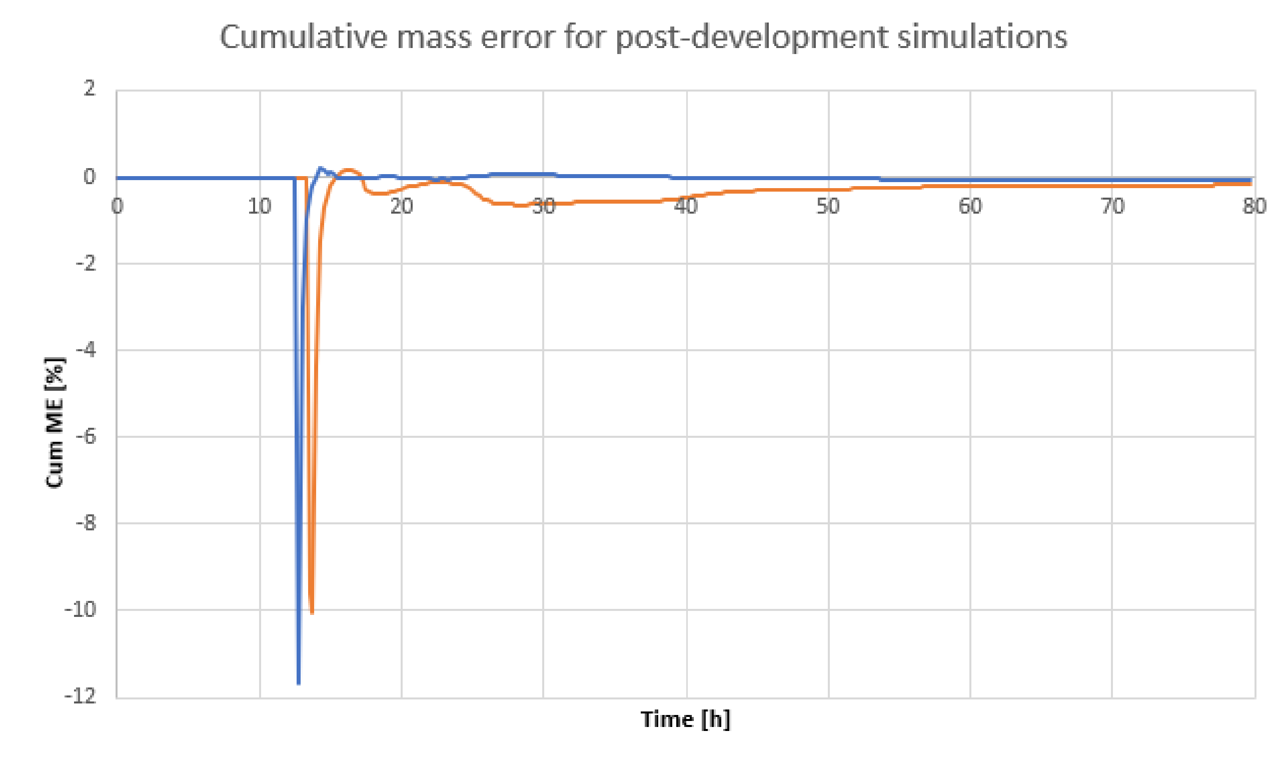
7.4.7 Simulation results indicate that following a breach at Mardyke Sluice during the 1,000-year return period River Thames tidal event in 2130, flooding remains in-channel at the point where the Project road crosses the Mardyke, and so there is no impact on the Project. Flooding following a breach at Mardyke Sluice during the 200-year return period River Thames tidal event in 2030 would therefore also remain in-channel at the point where the Project road would cross the Mardyke.

7.4.8 The breach modelling and resulting flood maps are reported in Annex E of Part 5 of the FRA.

7.5 Model performance

7.5.1 Model simulations were completed satisfactorily. The model was run to simulate for 80 hours which allowed enough time for the hydrograph to pass through the catchment. A fixed time-step of one second was applied to the 1D part of the model and a time-step of two seconds was applied to the 2D part of the model. These time-steps were chosen as they provided model stability and are appropriate given the cell size of the 2D grid (10m). Plate 7.12 shows the cumulative mass error for the post-development simulation 100-year return period event in 2130 with 17% peak river flow climate change allowance. Overall, the mass balance is within the acceptable limits of +/- 1% except for a peak value appearing around 13 hours.

Plate 7.12 Cumulative mass error output



7.5.2 Overall, the model can be characterised as stable given the absence of negative depth values in the domain and due to the satisfactory 1D-2D linking.

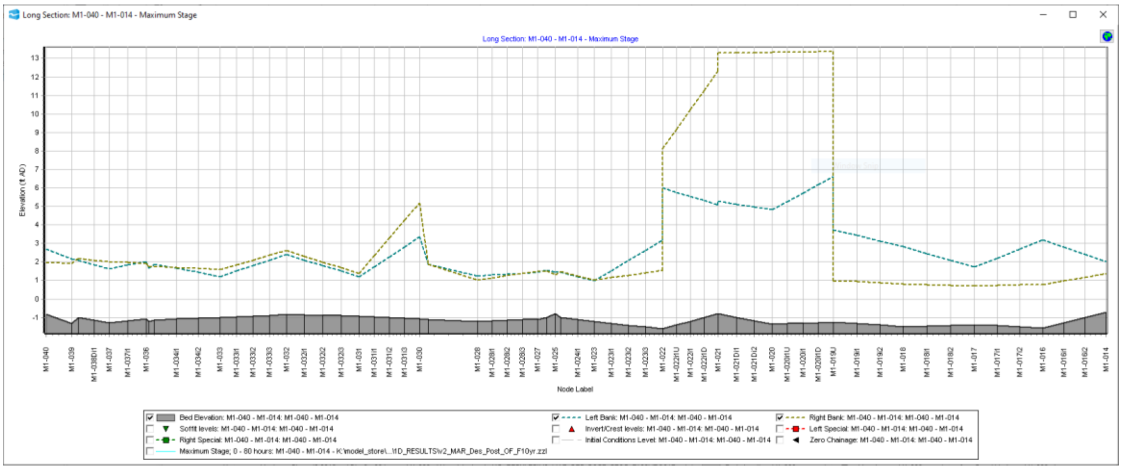
7.5.3 The bitmap outputs from the design runs of pre- and post-development (without measures) scenarios are included in Annex E.

7.5.4 There are instances of non-convergence in the model. These can be explained from the change in the opening and closing of the Mardyke Sluice which results in changes in stage and flows between time-steps.

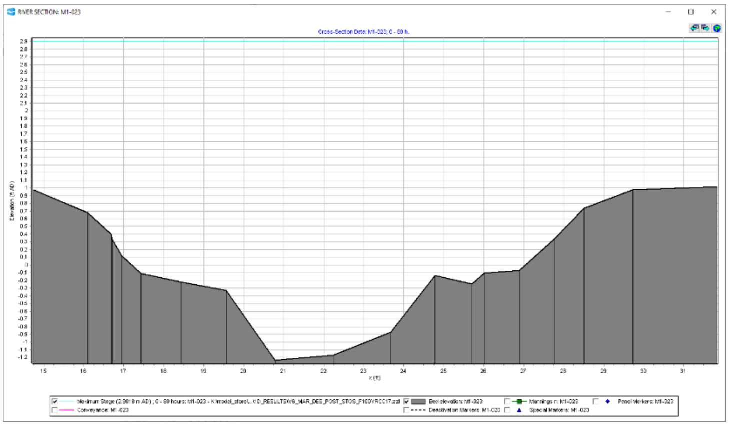
7.5.5 Conversely, the area downstream of node M1-040 and especially downstream of node M1-034 is relatively flat, as shown in Plate 7.13. This creates fluctuations in stage and flow during the simulation in different nodes (fluctuations at node M1-023 are shown in Plate 7.13). These fluctuations are the result of water ponding in the area, which can flow in multiple directions and between the 1D and 2D model domains, resulting in differences in stage and flow between sequential time-steps. These cross-sections are far from the area of interest and these fluctuations have no effect on the model results around the area of interest.

Plate 7.13 Model performance

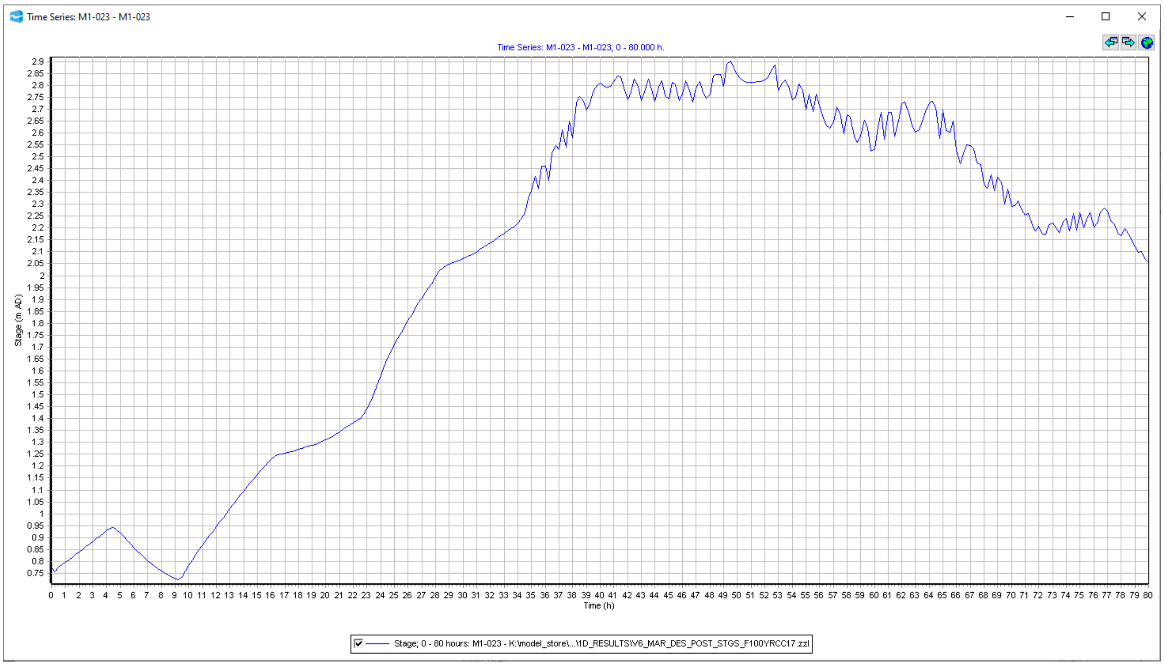
Long section between M1-040 to M1-014



M1-023 node



M1-023 stage results



7.6 Model sensitivity tests

7.6.1 Sensitivity tests were undertaken to explore a wider and credible range of alternative parameter values. Sensitivity tests are presented in Table 7.15.

7.6.2 In addition to the sensitivity tests listed in Table 7.15, this section includes a consideration of the Project adaptability to the credible maximum climate change scenario.

Table 7.15 Sensitivity tests

Test	Description
Sensitivity test 1	+20% in inflows
Sensitivity test 2	-20% in inflows
Sensitivity test 3	Downstream boundary uplift by 0.2m
Sensitivity test 4	Downstream boundary drop by 0.2m
Sensitivity test 5	+10% in Manning's n
Sensitivity test 6	-20% in Manning's n

7.6.3 Sensitivity runs were based on the 100-year return period fluvial flood in 2127 with 35% peak river flow climate change allowance, for the post-development scenario without mitigation measures. The sensitivity tests were undertaken before the Project climate change horizon was changed from 2127 to 2130, and before the Environment Agency peak river flow climate change allowances were updated in July 2021 (the allowances were reduced for the study area in July 2021, as detailed in Environment Agency, 2022). However, the sensitivity runs undertaken are considered to be valid tests as the change in climate change horizon by three years, and updated climate change allowances, are considered to have an insignificant influence on the model sensitivities.

7.6.4 The comparison of flood depths between each scenario and the post-development scenario without mitigation measures are shown in Plate 7.14 to Plate 7.20.

7.6.5 Plate 7.14 shows the comparison for increased inflows. A 20% increase in inflows results in an increase of approximately 0.1m in flood level around the area of interest. Plate 7.15 shows the flood extent comparison for decreased inflows. A 20% decrease in inflows results in a decrease of approximately 0.1m in flood level around the area of interest.

7.6.6 Plate 7.16 shows the comparison of maximum flood levels.

Plate 7.14 Sensitivity comparison: model inflows increased by 20%

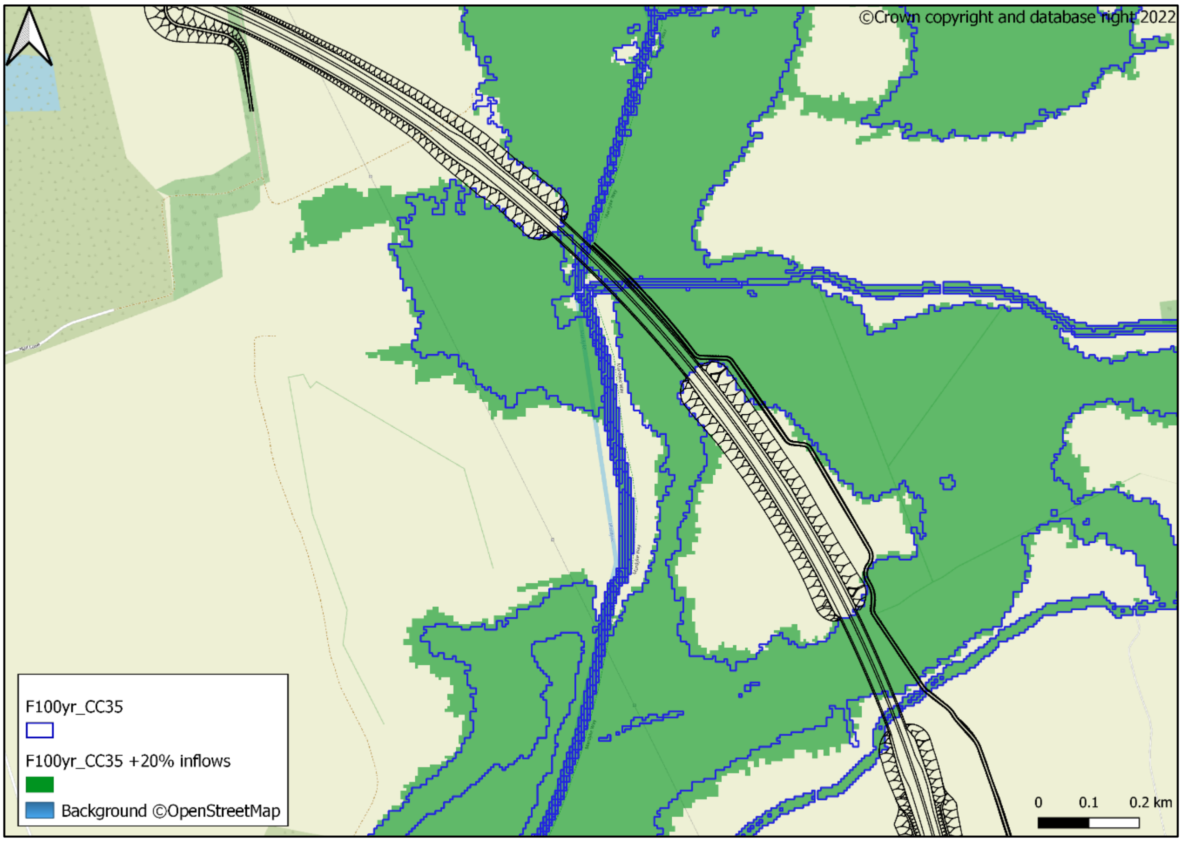


Plate 7.15 Sensitivity comparison: model inflows decreased by 20%

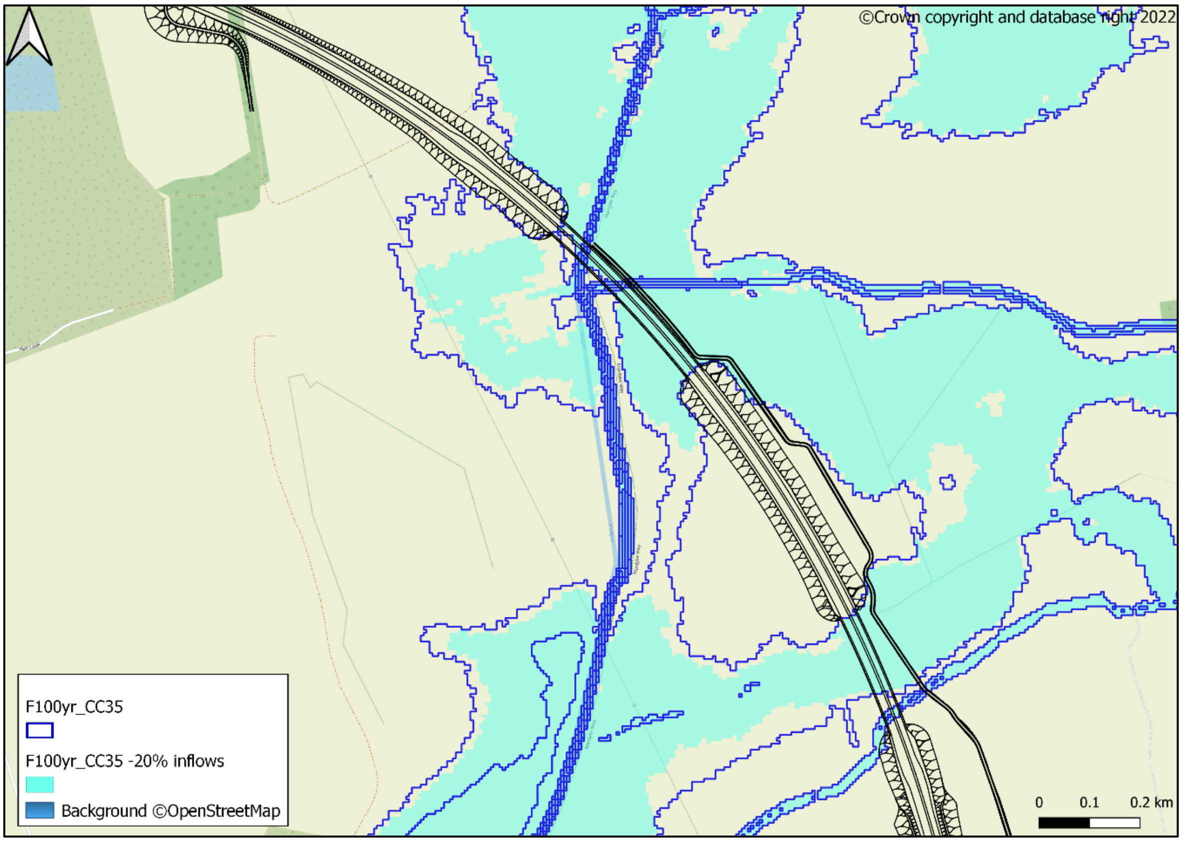


Plate 7.16 Location of 1D nodes used in sensitivity tables

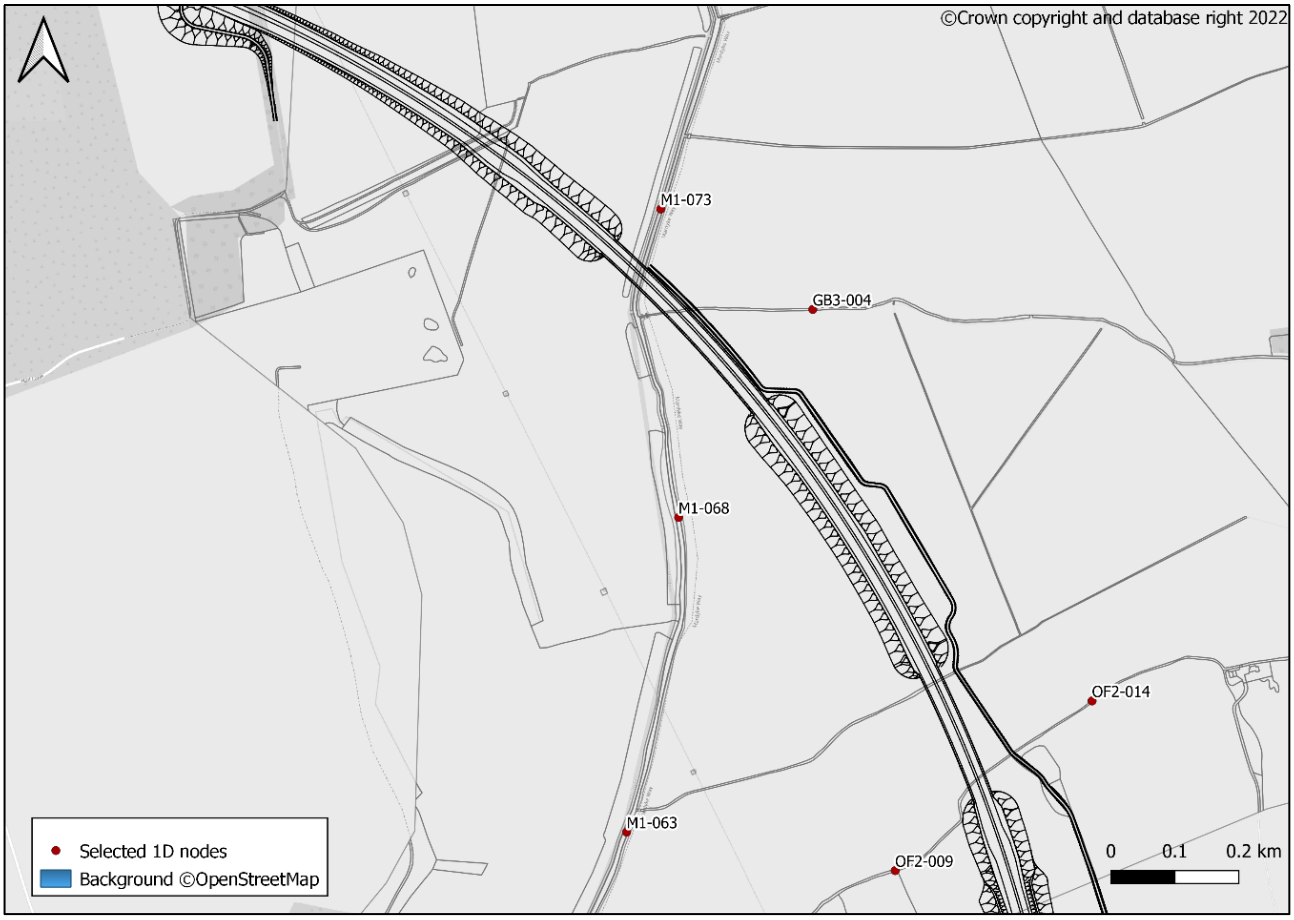


Table 7.16 Sensitivity to flow

Node	Flood level (baseline) (mAOD)	Flood level (-20% flow) (mAOD)	Difference (m)	Flood level (+20% flow) (mAOD)	Difference (m)
M1-073	3.954	3.873	-0.081	4.073	0.119
M1-068	3.784	3.656	-0.128	3.936	0.152
M1-063	3.629	3.462	-0.167	3.817	0.188
OF2-014	4.187	4.171	-0.016	4.216	0.029
OF2-009	3.890	3.831	-0.059	3.988	0.098
GB3-004	3.916	3.811	-0.105	4.033	0.117

7.6.7 Raising and lowering the downstream tidal boundary by 0.2m results in no difference in flood extents. The changes in maximum water levels are negligible (within +/-0.002m). Plate 7.17 and Plate 7.18 show the comparison of flood extent and Table 7.17 shows the comparison of maximum flood levels.

Plate 7.17 Sensitivity comparison: tidal boundary raised by 0.2m

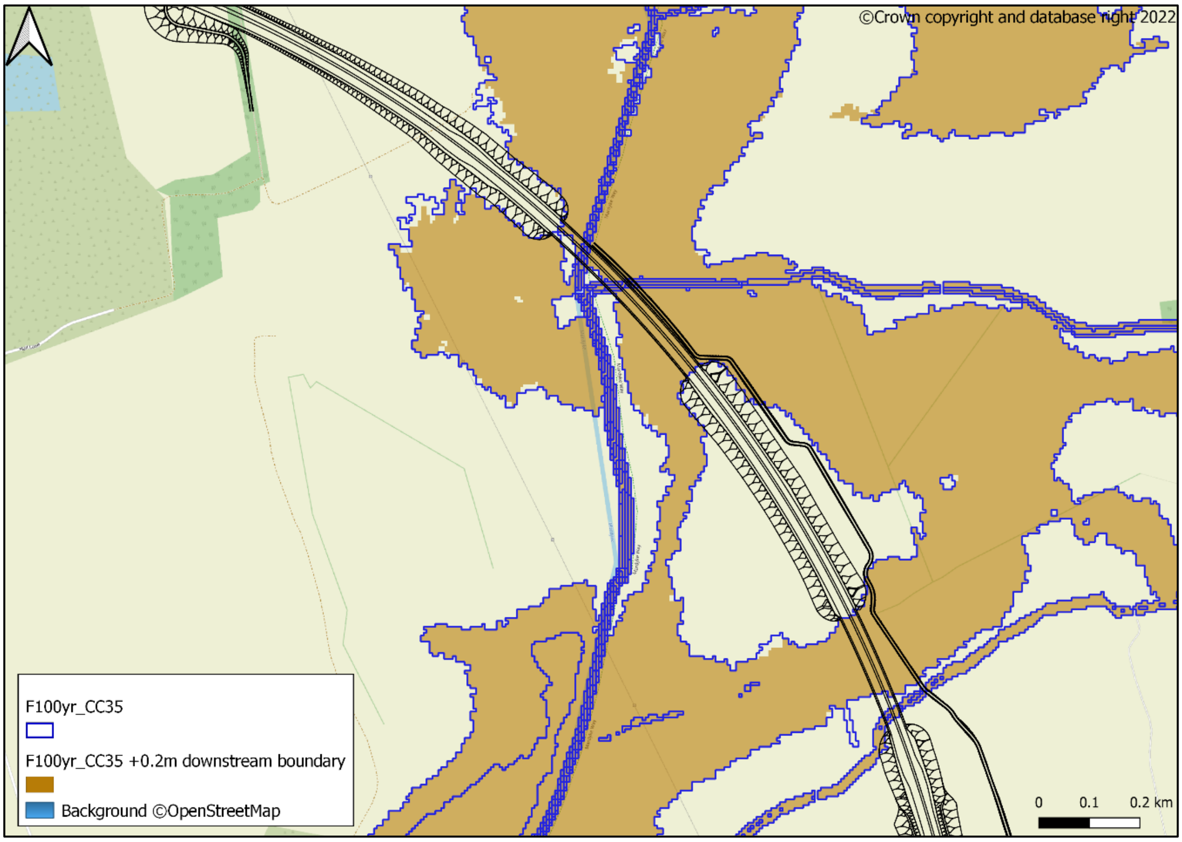


Plate 7.18 Sensitivity comparison: tidal boundary lowered by 0.2m

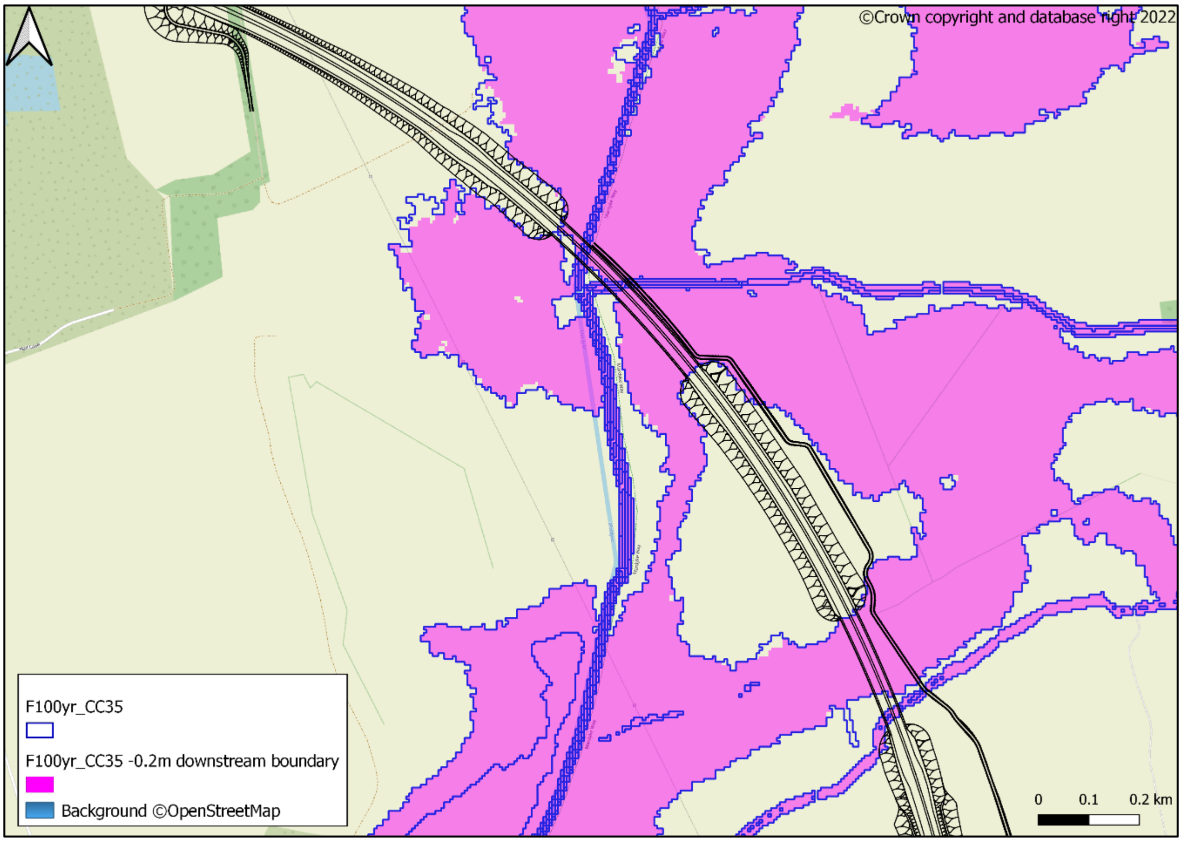


Table 7.17 Sensitivity to downstream boundary

Node	Flood level (baseline) (mAOD)	Flood level (rraised) (mAOD)	Difference (m)	Flood level (lowered) (mAOD)	Difference (m)
M1-073	3.954	3.955	0.001	3.954	0.000
M1-068	3.784	3.784	0.000	3.783	-0.001
M1-063	3.629	3.631	0.002	3.628	-0.001
OF2-014	4.187	4.187	0.000	4.187	0.000
OF2-009	3.890	3.891	0.001	3.889	-0.001
GB3-004	3.916	3.916	0.000	3.915	-0.001

7.6.8 A 10% increase in Manning’s n results in a minimal increase in flood extent and an increase of approximately 0.04m in water level. A 20% decrease in Manning’s n results in a moderate decrease in flood extent and a decrease of approximately 0.07m in water level. Plate 7.19 and Plate 7.20 show the comparison of flood extents and Table 7.18 shows the comparison of maximum water levels.

Plate 7.19 Sensitivity comparison: Manning’s n increased by 10%

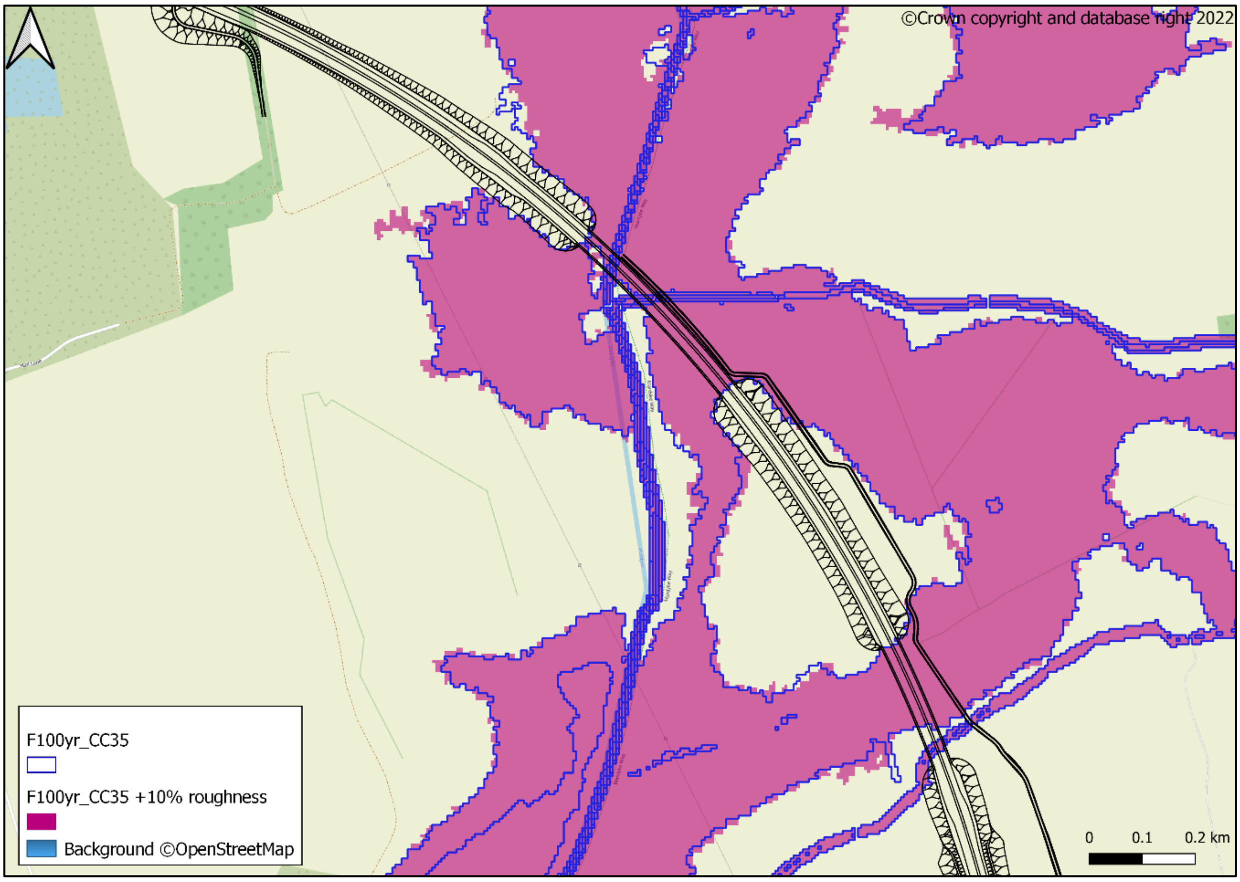


Plate 7.20 Sensitivity comparison: Manning's n decreased by 20%

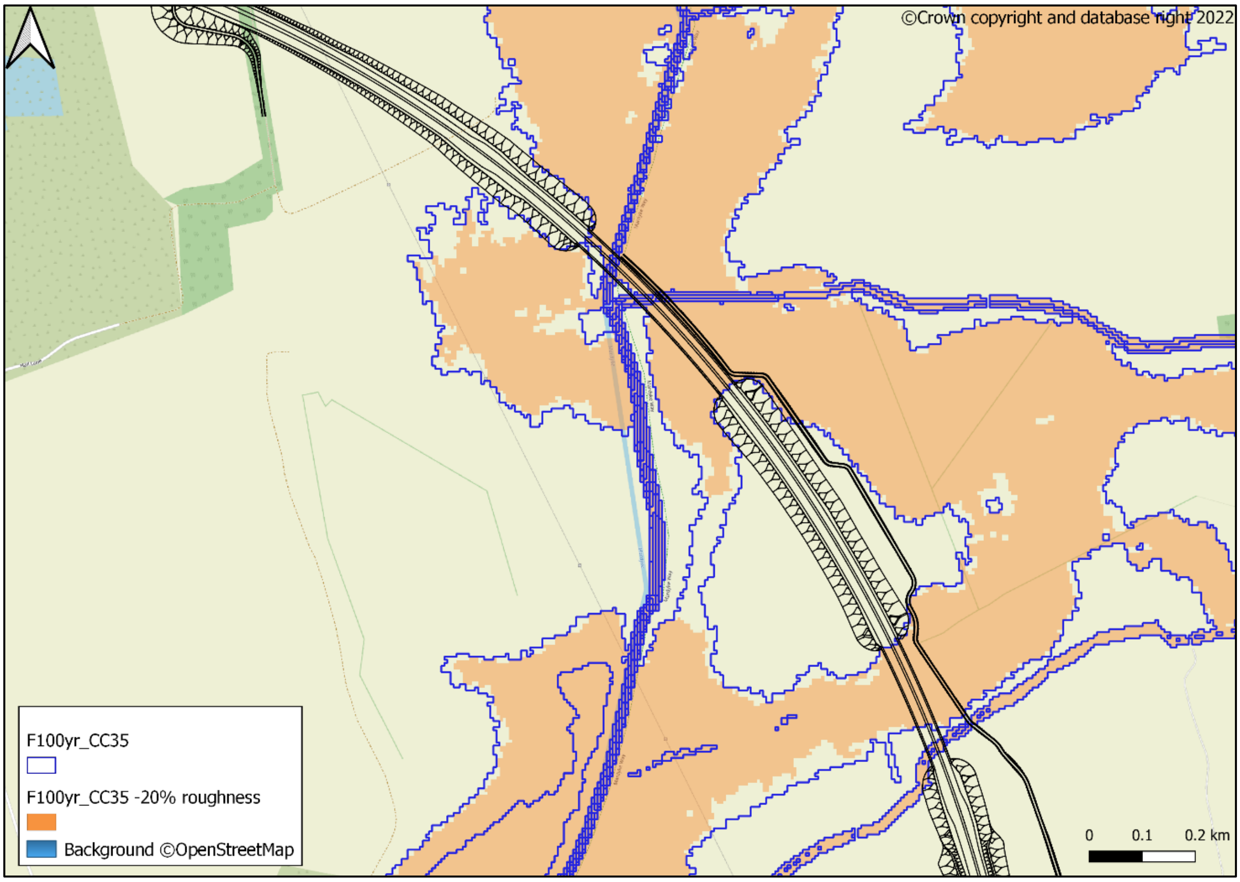


Table 7.18 Sensitivity to Manning's n

Node	Flood level (baseline) (mAOD)	Flood level (+10%) (mAOD)	Difference (m)	Flood level (-20%) (mAOD)	Difference (m)
M1-073	3.954	3.997	0.043	3.885	-0.069
M1-068	3.784	3.831	0.047	3.696	-0.088
M1-063	3.629	3.678	0.049	3.54	-0.089
OF2-014	4.187	4.198	0.011	4.156	-0.031
OF2-009	3.890	3.914	0.024	3.842	-0.048
GB3-004	3.916	3.956	0.040	3.835	-0.081

Consideration of a credible maximum climate change scenario

Peak river flow allowances

7.6.9 The current climate change guidance (Environment Agency, 2022) specifies Upper end peak river flow allowances should be applied to represent a credible maximum climate change scenario.

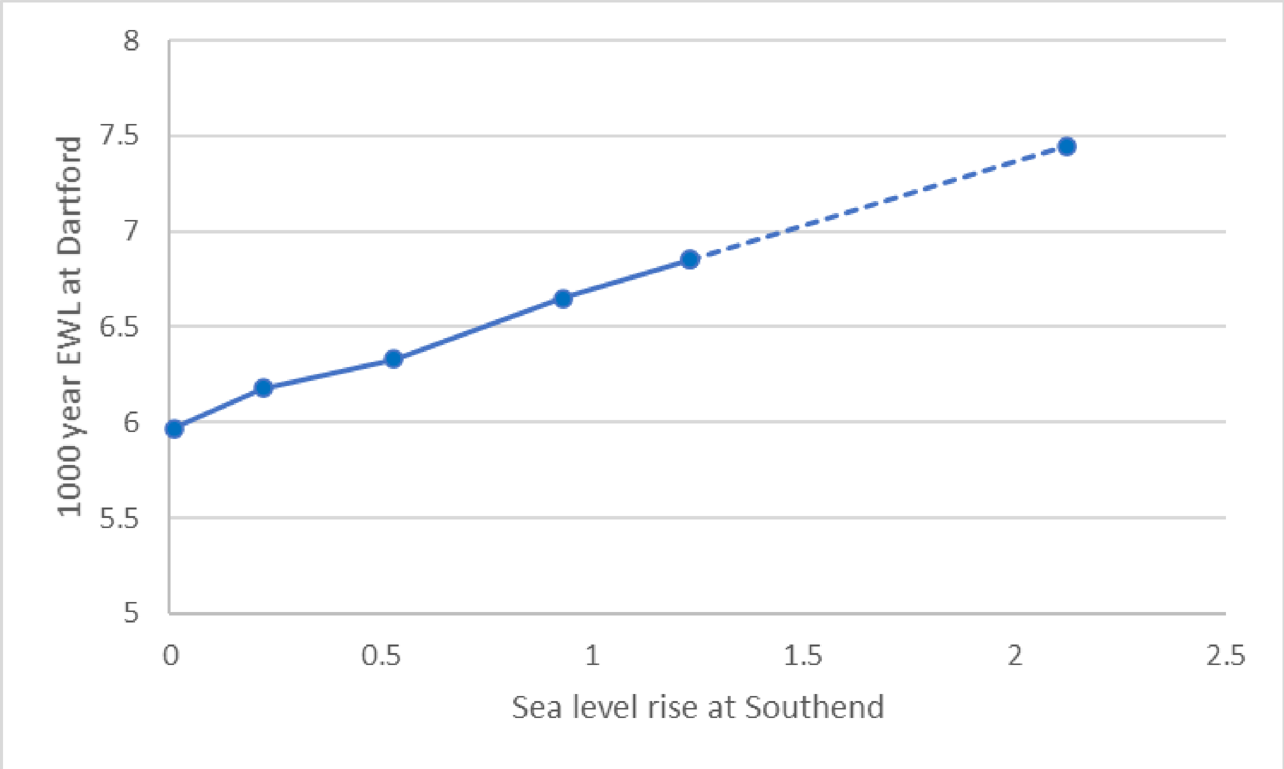
7.6.10 The Upper end peak river flow allowance for the Project in 2130 is +48% (this is the 2080s Upper end allowance for the South Essex Management Catchment of the current guidance).

Sea level rise

7.6.11 The current climate change guidance (Environment Agency, 2022) specifies H++ sea level rise allowances should be applied to represent a credible maximum climate change scenario, and 2mm/year storm surge from 2017 onwards. H++ sea level rise allowances are specified in the current guidance (Environment Agency, 2022) as +1.9m in 2100, with no specified value beyond 2100. Applying +1.9m sea level rise and 2mm/year storm surge from 2017 to 2130 gives a credible maximum sea level rise and storm surge allowance of +2.13m at Southend relative to 2017. This represents an increase in peak level rather than the whole level-time series, as whilst the sea level rise increase is applied as an upward shift to the whole level-time series, the increase in storm surge would be applied by scaling the storm surge component to match the required peak.

7.6.12 Plate 7.21 plots increase in EWL at Southend (UKCP18 sea level rise is applied in this Project relative to 2017, as specified in Environment Agency, 2022) against the 1,000-year return period EWL at the TE2100 Dartford model node derived as described in 4.8. The credible maximum sea level rise and storm surge allowance at Southend relative to 2017 is +2.13m. In Plate 7.21 the relationship between sea level rise at Southend and increase in EWL at Dartford is extrapolated to estimate a credible maximum EWL at Dartford of 7.45mAOD. This extrapolation at Dartford is considered more realistic than simply applying the credible maximum sea level rise and storm surge allowance at Dartford as it acknowledges that changes in EWL at Southend are attenuated within the estuary. The extrapolation is considered conservative as it does not account for the likely additional overtopping of flood defences in the Thames Estuary for the 1,000-year return period event under the credible maximum climate change scenario and hence additional attenuation of EWLs within the Thames Estuary.

Plate 7.21 Sea level rise (m) at Southend plotted against the 1,000-year return period extreme water level (m) at the TE2100 Dartford model node



Simulated credible maximum climate change scenario

7.6.13 The credible maximum climate change scenario was simulated as follows:

a. The 1,000-year return period fluvial flood event in 2130 was simulated applying Upper end peak river flow climate change allowances (+48%).

b. A 1,000-year return period credible maximum tidal boundary in 2130 was applied (7.45mAOD EWL).

7.6.14 This simulated credible maximum climate change simulation is conservative as it applies the 1,000-year return period fluvial and tidal conditions simultaneously. The simulated combined fluvial and tidal event would be significantly rarer than the 1,000-year return period fluvial or tidal events.

7.6.15 These simulation results indicate the proposed highway will be more than 5m above credible maximum climate change scenario peak flood levels in 2130. Therefore, if the credible maximum climate change scenario were realised, this would have negligible impact on the Project.

Significance of modelling uncertainty on Project design constraints

7.6.16 The Environment Agency published updated methods to allow for uncertainty in flood risk management decisions in 2017, including a simplified approach for development planning: Accounting for residual uncertainty: Updating the freeboard guide (Environment Agency, 2017b).

7.6.17 The simplified approach for development planning is described below:

a. Based on a consideration of the reliability of flood level estimates, a confidence rating for the estimates is derived (from ‘1 star’ to ‘5 star’ with ‘1 star’ indicating the lowest confidence rating).

b. Uncertainty allowances are then specified for a given confidence rating, as either a proportion of design flood depth or a specified minimum depth allowance.

c. The highest uncertainty allowance specified by the guidance (i.e. for a worst case ‘1 star’ confidence rating) is the greater of 40% of the design flood depth or 0.9m.

7.6.18 The maximum simulated fluvial flood level adjacent to the Project road is approximately 3.77mAOD with mitigation, for the 1,000-year return period fluvial event in 2130 with +48% peak river flow allowance applied (Upper end credible maximum climate change scenario); and the maximum simulated flood depths adjacent to the proposed Project road are mostly less than 1m, and less than 2m at locations with lowest ground levels. A worst-case uncertainty allowance applying the guidance (i.e. if a ‘1 star’ confidence rating were assigned) would therefore be 0.9m. Applying this uncertainty allowance to design fluvial flood levels would not influence the Project design, as the Project road is more than 5m above the simulated 1,000-year return period flood level in 2130 with the Upper end peak river flow climate change allowance applied (+48%). Constraints based on design fluvial flood levels therefore do not drive the design of the Project road levels. Instead, other considerations such as maintenance access requirements under the Project road crossing of the River Mardyke drive the design.

7.6.19 Additionally, for the sensitivity tests undertaken (paragraphs 7.6.1 to 7.6.8), simulated peak flood levels are found to be only modestly sensitive to the key uncertainties tested (model inflows and Manning’s n), with flood levels varying by approximately 0.1m with a +20% increase in flows, and by less than 0.1m for the Manning’s n tests.

7.6.20 The adequacy of the proposed floodplain compensation mitigation is considered robust with respect to model uncertainty, as:

a. Simulated flood levels are relatively insensitive to the modelling uncertainties tested.

b. The required flood compensation volumes are comfortably exceeded by the proposed mitigation (paragraph 7.1.8).

8 Conclusion

8.1 Conclusions

8.1.1 A hydraulic flood model of the Mardyke has been developed to inform the FRA for the Project and assess flood risk to the Project road and offsite impacts for a lifetime of 100 years (2130).

8.1.2 The modelling undertaken has developed fluvial flood hydrology, applying FEH statistical and rainfall-runoff methods, for the Mardyke catchment as well as downstream tidal conditions.

8.1.3 The Project Mardyke hydraulic model has been constructed based on the channel and structures topographic survey data acquired for the Project, and LiDAR topographic data.

8.1.4 The hydraulic model has been calibrated against the Environment Agency's available catchment flood data. Calibration results for Stifford show good agreement between simulated and recorded peak flows at Stifford (downstream of the Project) for the winter calibration and validation events. Results at Stifford are influenced by assumed gate openings towards the end of the summer calibration and validation event simulations. A consideration of modelling uncertainty concludes the Project design and proposed mitigation measures are considered robust.

8.1.5 Design simulations have been undertaken for the pre-development case, and for the post-development case without and with mitigation measures.

8.1.6 Mitigation secured through the REAC (Application Document 6.3) and the Design Principles (Application Document 7.5) include measures to convey a new floodplain flow path to maintain the Mardyke fluvial floodplain conveyance, and floodplain compensation areas (in part provided by the proposed water vole habitat creation area) to replace floodplain displaced by the proposed road embankment and bridge piers. There are no tidal event offsite impacts (and hence no mitigation for tidal flood events is required).

8.1.7 Without mitigation, offsite impacts would be limited to farmland and so, following Environment Agency guidance on climate change allowances for flood risk assessments, mitigation measures are assessed for the Central peak river flow climate change allowances (i.e. +17% in 2130).

8.1.8 The design simulations show that the secured mitigation measures would fully mitigate offsite impacts for all events up to the 100-year return period fluvial flood in 2130, such that any increased flood risk would not occur on third party land or property. The identified floodplain compensation areas would fully compensate for displaced floodplain storage on a hydraulically linked level-for-level basis.

8.1.9 The secured mitigation measures would be delivered entirely within land for which National Highways will be seeking permanent acquisition, and their design will be finalised during the detailed design of the Project.

8.1.10 The Project will meet operational requirements as follows:

a. At the point where the Project Road would cross the Mardyke, it would be above the 1,000-year return period Mardyke flood in 2130 with the Upper end peak river flow climate change allowance applied (+48%). The Project road level would be more than 5m above the simulated 1,000-year return period flood level in 2130 with the Upper end peak river flow climate change allowance applied (+48%), as the Project road level is dictated by factors other than flood risk at this location. The Project road would therefore remain operational during a 1,000-year return period flood in 2130 with +48% peak river flow allowance. This exceeds the Project requirement for the proposed highway to remain operational during the 1,000-year return period flood in 2130 applying the Higher central peak river flow climate change allowance (+26%).

b. The Project road would not be impacted by the 200-year return period River Thames tidal flood in 2130, even if Mardyke Sluice failed and was stuck open, as flooding at the Project location would remain in channel.

c. The Project road would not be impacted by a breach of the River Thames tidal defences at Mardyke Sluice during the 1,000-year return period River Thames tidal flood in 2130 as flooding at the Project Road location would remain in channel.

9 References

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Annex A Model files

A.1 Model files

A.1.1 The model files for the simulations are detailed in Table A.1.

Table A.1 Model files

Scenario	1D DAT	IEF	TCF	TGC/TBC/TMF	IED
	(1D model file name)	(Model simulation file name)	(2D model control file name)	(2D model filenames of model geometry control file, boundary control file and material file)	(1D model boundary file name)
Calibration (winter)	Mardyke_v16b_Calib_v6	Calib_v21anew_Mardyke_2013	Calib_v21anew_Mardyke_2013	Mardyke_v10_Baseline Mardyke_v6_Baseline_v1 Mardyke_2D	21anew_2013
		Calib_v21anew_Mardyke_2014	Calib_v21anew_Mardyke_2014		21anew_2014
Calibration (summer)	Mardyke_v16b_Calib_v6	Calib_v21enew_Mardyke_2012	Calib_v21enew_Mardyke_2012		21enew_2012
		Calib_v21e1new_Mardyke_2012	Calib_v21e1new_Mardyke_2012		21enew_2012
		Calib_v21enew_Mardyke_2016	Calib_v21enew_Mardyke_2016		21enew_2016
		Calib_v21e1new_Mardyke_2016	Calib_v21e1new_Mardyke_2016		21enew_2016
Validation (winter)	Mardyke_v16b_Calib_v6	Calib_v21anew_Mardyke_2011	Calib_v21anew_Mardyke_2011		21anew_2011
Pre-development	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F1000yrCC48.ief	v6_MAR_Des_Pre_OF_F1000yrCC48.tcf	Mardyke_v13_1000CC.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC48_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F1000yrCC26.ief	v6_MAR_Des_Pre_OF_F1000yrCC26.tcf	Mardyke_v13_1000CC.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC26_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F1000yrCC11.ief	v6_MAR_Des_Pre_OF_F1000yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC11_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F100yrCC26.ief	v6_MAR_Des_Pre_OF_F100yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F100yrCC17.ief	v6_MAR_Des_Pre_OF_F100yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F100yrCC11.ief	v6_MAR_Des_Pre_OF_F100yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F100yrCC6.ief	v6_MAR_Des_Pre_OF_F100yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F10yrCC26.ief	v6_MAR_Des_Pre_OF_F10yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F10yrCC17.ief	v6_MAR_Des_Pre_OF_F10yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F10yrCC11.ief	v6_MAR_Des_Pre_OF_F10yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F10yrCC6.ief	v6_MAR_Des_Pre_OF_F10yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F25yrCC26.ief	v6_MAR_Des_Pre_OF_F25yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F25yrCC17.ief	v6_MAR_Des_Pre_OF_F25yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F25yrCC11.ief	v6_MAR_Des_Pre_OF_F25yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F25yrCC6.ief	v6_MAR_Des_Pre_OF_F25yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F2yrCC26.ief	v6_MAR_Des_Pre_OF_F2yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F2yrCC17.ief	v6_MAR_Des_Pre_OF_F2yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F2yrCC11.ief	v6_MAR_Des_Pre_OF_F2yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_OF_F2yrCC6.ief	v6_MAR_Des_Pre_OF_F2yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F1000yrCC48.ief	v6_MAR_Des_Pre_STGS_F1000yrCC48.tcf	Mardyke_v13_1000CC.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC48_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F1000yrCC26.ief	v6_MAR_Des_Pre_STGS_F1000yrCC26.tcf	Mardyke_v13_1000CC.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC26_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F1000yrCC11.ief	v6_MAR_Des_Pre_STGS_F1000yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC11_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F100yrCC26.ief	v6_MAR_Des_Pre_STGS_F100yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F100yrCC17.ief	v6_MAR_Des_Pre_STGS_F100yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F100yrCC11.ief	v6_MAR_Des_Pre_STGS_F100yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F100yrCC6.ief	v6_MAR_Des_Pre_STGS_F100yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F10yrCC26.ief	v6_MAR_Des_Pre_STGS_F10yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F10yrCC17.ief	v6_MAR_Des_Pre_STGS_F10yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC17_MHWS.ied

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model filenames of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F10yrCC11.ief	v6_MAR_Des_Pre_STGS_F10yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F10yrCC6.ief	v6_MAR_Des_Pre_STGS_F10yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F25yrCC26.ief	v6_MAR_Des_Pre_STGS_F25yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F25yrCC17.ief	v6_MAR_Des_Pre_STGS_F25yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F25yrCC11.ief	v6_MAR_Des_Pre_STGS_F25yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F25yrCC6.ief	v6_MAR_Des_Pre_STGS_F25yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F2yrCC26.ief	v6_MAR_Des_Pre_STGS_F2yrCC26.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F2yrCC17.ief	v6_MAR_Des_Pre_STGS_F2yrCC17.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F2yrCC11.ief	v6_MAR_Des_Pre_STGS_F2yrCC11.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Pre_STGS_F2yrCC6.ief	v6_MAR_Des_Pre_STGS_F2yrCC6.tcf	Mardyke_v13.tgc, Mardyke_v14.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC6_MHWS.ied
Post-development without mitigation measures	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F1000yrCC48.ief	v6_MAR_Des_Post_OF_F1000yrCC48.tcf	Mardyke_v14_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC48_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F1000yrCC26.ief	v6_MAR_Des_Post_OF_F1000yrCC26.tcf	Mardyke_v14_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC26_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F1000yrCC11.ief	v6_MAR_Des_Post_OF_F1000yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC11_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F100yrCC26.ief	v6_MAR_Des_Post_OF_F100yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F100yrCC17.ief	v6_MAR_Des_Post_OF_F100yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F100yrCC11.ief	v6_MAR_Des_Post_OF_F100yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F100yrCC6.ief	v6_MAR_Des_Post_OF_F100yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F10yrCC26.ief	v6_MAR_Des_Post_OF_F10yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F10yrCC17.ief	v6_MAR_Des_Post_OF_F10yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F10yrCC11.ief	v6_MAR_Des_Post_OF_F10yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F10yrCC6.ief	v6_MAR_Des_Post_OF_F10yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F25yrCC26.ief	v6_MAR_Des_Post_OF_F25yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F25yrCC17.ief	v6_MAR_Des_Post_OF_F25yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F25yrCC11.ief	v6_MAR_Des_Post_OF_F25yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F25yrCC6.ief	v6_MAR_Des_Post_OF_F25yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F2yrCC26.ief	v6_MAR_Des_Post_OF_F2yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F2yrCC17.ief	v6_MAR_Des_Post_OF_F2yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F2yrCC11.ief	v6_MAR_Des_Post_OF_F2yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_OF_F2yrCC6.ief	v6_MAR_Des_Post_OF_F2yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F1000yrCC48.ief	v6_MAR_Des_Post_STGS_F1000yrCC48.tcf	Mardyke_v14_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC48_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F1000yrCC26.ief	v6_MAR_Des_Post_STGS_F1000yrCC26.tcf	Mardyke_v14_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC26_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F1000yrCC11.ief	v6_MAR_Des_Post_STGS_F1000yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC11_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F100yrCC26.ief	v6_MAR_Des_Post_STGS_F100yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F100yrCC17.ief	v6_MAR_Des_Post_STGS_F100yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F100yrCC11.ief	v6_MAR_Des_Post_STGS_F100yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F100yrCC6.ief	v6_MAR_Des_Post_STGS_F100yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F10yrCC26.ief	v6_MAR_Des_Post_STGS_F10yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC26_MHWS.ied

Scenario	1D DAT	IEF	TCF	TGC/TBC/TMF	IED
	(1D model file name)	(Model simulation file name)	(2D model control file name)	(2D model filenames of model geometry control file, boundary control file and material file)	(1D model boundary file name)
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F10yrCC17.ief	v6_MAR_Des_Post_STGS_F10yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F10yrCC11.ief	v6_MAR_Des_Post_STGS_F10yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F10yrCC6.ief	v6_MAR_Des_Post_STGS_F10yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F25yrCC26.ief	v6_MAR_Des_Post_STGS_F25yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F25yrCC17.ief	v6_MAR_Des_Post_STGS_F25yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F25yrCC11.ief	v6_MAR_Des_Post_STGS_F25yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F25yrCC6.ief	v6_MAR_Des_Post_STGS_F25yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F2yrCC26.ief	v6_MAR_Des_Post_STGS_F2yrCC26.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F2yrCC17.ief	v6_MAR_Des_Post_STGS_F2yrCC17.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F2yrCC11.ief	v6_MAR_Des_Post_STGS_F2yrCC11.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_STGS_F2yrCC6.ief	v6_MAR_Des_Post_STGS_F2yrCC6.tcf	Mardyke_v14.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC6_MHWS.ied
Post-development with mitigation measures	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F1000yrCC11.ief	v6_MAR_Des_Post_CS_OF_F1000yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC11_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F1000yrCC26.ief	v6_MAR_Des_Post_CS_OF_F1000yrCC26.tcf	Mardyke_v19b_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC26_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F1000yrCC48.ief	v6_MAR_Des_Post_CS_OF_F1000yrCC48.tcf	Mardyke_v19b_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F1000yrCC48_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F100yrCC11.ief	v6_MAR_Des_Post_CS_OF_F100yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F100yrCC17.ief	v6_MAR_Des_Post_CS_OF_F100yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F100yrCC26.ief	v6_MAR_Des_Post_CS_OF_F100yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F100yrCC6.ief	v6_MAR_Des_Post_CS_OF_F100yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F100yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F10yrCC11.ief	v6_MAR_Des_Post_CS_OF_F10yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F10yrCC17.ief	v6_MAR_Des_Post_CS_OF_F10yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F10yrCC26.ief	v6_MAR_Des_Post_CS_OF_F10yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F10yrCC6.ief	v6_MAR_Des_Post_CS_OF_F10yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F10yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F25yrCC11.ief	v6_MAR_Des_Post_CS_OF_F25yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F25yrCC17.ief	v6_MAR_Des_Post_CS_OF_F25yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F25yrCC26.ief	v6_MAR_Des_Post_CS_OF_F25yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F25yrCC6.ief	v6_MAR_Des_Post_CS_OF_F25yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F25yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F2yrCC11.ief	v6_MAR_Des_Post_CS_OF_F2yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F2yrCC17.ief	v6_MAR_Des_Post_CS_OF_F2yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F2yrCC26.ief	v6_MAR_Des_Post_CS_OF_F2yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_OF_F2yrCC6.ief	v6_MAR_Des_Post_CS_OF_F2yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_OF_F2yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F1000yrCC11.ief	v6_MAR_Des_Post_CS_STGS_F1000yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC11_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F1000yrCC26.ief	v6_MAR_Des_Post_CS_STGS_F1000yrCC26.tcf	Mardyke_v19b_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC26_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F1000yrCC48.ief	v6_MAR_Des_Post_CS_STGS_F1000yrCC48.tcf	Mardyke_v19b_1000CC.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F1000yrCC48_T5yr.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F100yrCC11.ief	v6_MAR_Des_Post_CS_STGS_F100yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F100yrCC17.ief	v6_MAR_Des_Post_CS_STGS_F100yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F100yrCC26.ief	v6_MAR_Des_Post_CS_STGS_F100yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F100yrCC6.ief	v6_MAR_Des_Post_CS_STGS_F100yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F100yrCC6_MHWS.ied

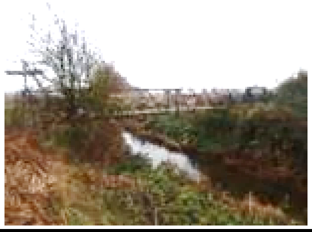
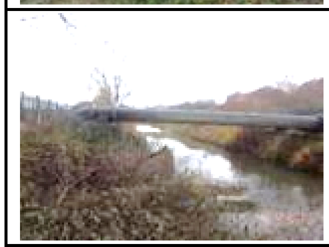
Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model filenames of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F10yrCC11.ief	v6_MAR_Des_Post_CS_STGS_F10yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F10yrCC17.ief	v6_MAR_Des_Post_CS_STGS_F10yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F10yrCC26.ief	v6_MAR_Des_Post_CS_STGS_F10yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F10yrCC6.ief	v6_MAR_Des_Post_CS_STGS_F10yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F10yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F25yrCC11.ief	v6_MAR_Des_Post_CS_STGS_F25yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F25yrCC17.ief	v6_MAR_Des_Post_CS_STGS_F25yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F25yrCC26.ief	v6_MAR_Des_Post_CS_STGS_F25yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F25yrCC6.ief	v6_MAR_Des_Post_CS_STGS_F25yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F25yrCC6_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F2yrCC11.ief	v6_MAR_Des_Post_CS_STGS_F2yrCC11.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC11_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F2yrCC17.ief	v6_MAR_Des_Post_CS_STGS_F2yrCC17.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC17_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F2yrCC26.ief	v6_MAR_Des_Post_CS_STGS_F2yrCC26.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC26_MHWS.ied
	Mardyke_v18.dat	v6_MAR_Des_Post_CS_STGS_F2yrCC6.ief	v6_MAR_Des_Post_CS_STGS_F2yrCC6.tcf	Mardyke_v19b.tgc, Mardyke_v15.tbc, Mardyke_2D.tmf	v2_Des_STGS_F2yrCC6_MHWS.ied
Breach	Mardyke_v18_BR1.dat	v6_BR_MAR001_Pre_T1000yrCC26.ief	v6_BR_MAR001_Pre_T1000yrCC26.tcf	Mardyke_v13_BR.tgc, Mardyke_v14_BR.tbc, Mardyke_2D.tmf	v2_BR_T1000yrCC26.ied, BR_MAR001_T1000CC.ied

Annex B Model Structures

B.1 Model structures

B.1.1 The structures that have been schematised in the model are detailed in Table B.1.

Table B.1 Model structures

Photos	Structure type	Location	Cross-section reference	Model node	Model unit & key features	Coefficients
	Footbridge	–	1-082	M1-082BU	Bridge & spill	Soffit level: 3.721mAOD Springing level: 3.721mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Pipe	–	1-077	Not included	–	–
	Road bridge	Medebridge Road	1-049	Not included	–	–
	Pipe	–	1-048	Not included	–	–
	Footbridge	–	1-046	M1-046BU	Bridge & spill	Soffit level: 2.139mAOD Springing level: 2.138mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Weir crest	Gauging station	1-042	M1-042	Spill	Modular limit: 0.9 Weir coefficient: 1.2
	Road bridge	B186	1-040	M1-040BU	Bridge & spill	Soffit level: 3.903mAOD Springing level: 3.902mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Pipe crossing	–	1-038	M1-038BU	Bridge & spill	Soffit level: 2.468mAOD Springing level: 2.467mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	1-036	M1-036BU	Bridge & spill	Soffit level: 2.049mAOD Springing level: 1.745mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Pipe crossing	–	1-035	M1-035BU	Bridge & spill	Soffit level: 2.191mAOD Springing level: 2.190mAOD Modular limit: 0.9 Weir coefficient: 1.2

Photos	Structure type	Location	Cross-section reference	Model node	Model unit & key features	Coefficients
	Rail bridge	–	1-034	Not included	–	–
	Road bridge	A13	1-030 1-029	Not included	–	–
	Road bridge	M25 slip road	1-027	Not included	–	–
	Road bridge	M25	1-026 1-025	Not included	–	–
	Road bridge	M25 slip road	1-024	Not included	–	–
	Road bridge	Ship Lane	1-021	M1-021BU	Bridge & spill	Soffit level: 2.057mAOD Springing level: 2.056mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Pipe (supported on bridge)	–	1-015	Not included	–	–
	Road bridge	A1306	1-014	M1-014BU	Bridge	Soffit level: 2.835mAOD Springing level: 2.834mAOD
	Rail bridge	–	1-013	M1-013BU	Bridge	Soffit level: 2.843, 2.838, 2.831mAOD Springing level: 2.842, 2.837, 2.830mAOD
	Pipe	–	1-012	Not included	–	–
	Rail bridge	–	1-011	M1-011BU	Bridge	Soffit level: 3.122mAOD Springing level: 3.121mAOD

Photos	Structure type	Location	Cross-section reference	Model node	Model unit & key features	Coefficients
	Footbridge	–	1-009	M1-009BU	Bridge	Soffit level: 2.726mAOD Springing level: 2.725mAOD
	Footbridge	–	1-008	M1-008BU	Bridge & spill	Soffit level: 1.713mAOD Springing level: 1.713mAOD Modular limit: 0.5 Weir coefficient: 1.0
	Road bridge	Tank Hill Road	1-007	M1-007BU	Bridge	Soffit level: 2.814mAOD Springing level: 2.814mAOD
	Footbridge	–	1-006	M1-006BU	Bridge & spill	Soffit level: 1.993mAOD Springing level: 1.992mAOD Modular limit: 0.5 Weir coefficient: 1.0
	Sluice gate	–	1-003	M1-003GU	1 sluice vertical and 1 orifice unit	Elevation of crest: -0.930mAOD Length of weir: 3.744 m Breadth of weir: 5.450 m Throat soffit level: 0.540mAOD (orifice) Throat invert level: -0.950mAOD (orifice)
	Footbridge	–	1-001	M1-001BU	Bridge	Soffit level: 6.001mAOD Springing level: 6.001mAOD
	Footbridge	–	5-004	EM5-004BU	Bridge & spill	Soffit level: 4.935mAOD Springing level: 4.934mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Road bridge	Fen Lane	5-003	EM5-003BU	Bridge & spill	Soffit level: 4.274mAOD Springing level: 4.024mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	6-004	WM6-004BU	Bridge & spill	Soffit level: 4.129mAOD Springing level: 4.128mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Road bridge	Fen Lane	6-002	WM6-002BU	Bridge & spill	Soffit level: 4.520mAOD Springing level: 4.519mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	2-024	OF2-024ou	Orifice & spill	Throat soffit level: 4.650mAOD Throat invert level: 3.660mAOD Modular limit: 0.9 Weir coefficient: 1.2

Photos	Structure type	Location	Cross-section reference	Model node	Model unit & key features	Coefficients
	Access bridge	–	2-022	OF2-022ou	Orifice & spill	Throat soffit level: 3.940mAOD Throat invert level: 3.180mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	2-019	OF2-019BU	Bridge & spill	Soffit level: 4.259mAOD Springing level: 4.259mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	2-017	OF2-017BU	Bridge & spill	Soffit level: 4.230mAOD Springing level: 3.733mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Culvert entrance	–	2-012	OF2-012cu	C. Conduit & spill	Diameter: 1.250m Conduit type code: type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	2-009	OF2-009bu	Bridge & spill	Soffit level: 4.505mAOD Springing level: 3.935mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Culvert entrance	–	2-005	OF2-005cu	C. Conduit & spill	Diameter: 1.200m Conduit type code: Type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.2
	Culvert	–	2-001	OF2-001cu	C. Conduit & spill & orifice	OF2-001cd orifice Throat Invert Level: 0.5mAOD Throat Soffit Level: 1.7mAOD Modular limit: 0.7 Diameter: 1.2m OF2-001cd conduit Elevation of invert: 0.5mAOD Diameter: 1.2m OF2-001cu conduit Elevation of invert: 1.014mAOD Diameter: 1.2m OF2-001ci inlet Type A OF2-001su spill unit Weir coefficient: 1.2 Modular limit: 0.9
	Footbridge	–	3-018	GB3-018bu	Bridge & spill	Soffit level: 4.524mAOD Springing level: 4.524mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	3-016	GB3-016bu	Bridge & spill	Soffit level: 4.192mAOD Springing level: 4.183mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	3-015	GB3-015bu	Bridge & spill	Soffit level: 4.319mAOD Springing level: 3.754mAOD Modular limit: 0.9 Weir coefficient: 1.2

Photos	Structure type	Location	Cross-section reference	Model node	Model unit & key features	Coefficients
	Access bridge	–	3-011	GB3-011bu	Bridge & spill	Soffit level: 4.008mAOD Springing level: 3.437mAOD Modular limit: 0.9 Weir coefficient: 1.0
	Access bridge	–	3-008	GB3-008bu	Bridge & spill	Soffit level: 3.899mAOD Springing level: 3.060mAOD Modular Limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	3-004	GB3-004bu	Bridge & spill	Soffit level: 3.670mAOD Springing level: 3.126mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	3-001	GB3-001bu	Bridge & spill	Soffit level: 3.663, 3.619, 3.637mAOD Springing level: 3.663, 3.619, 3.637mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Disused access bridge	–	4-014	S4-014cu	C. Conduit & spill	Diameter: 0.980 m Conduit type code: type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	4-013	S4-013bu	Bridge & spill	Soffit level: 3.790mAOD Springing level: 3.789mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	4-012	S4-012ou1	Orifice & spill	Throat soffit level: 4.010mAOD Throat invert level: 3.020mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Access bridge	–	4-011	S4-011bu	Bridge & spill	Soffit level: 4.188mAOD Springing level: 4.187mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Footbridge	–	4-005	S4-005bu	Bridge & spill	Soffit level: 3.976mAOD Springing level: 3.970mAOD Modular limit: 0.9 Weir coefficient: 1.2
	Culvert entrance	–	4-004	S4-004ci	Orifice	Throat soffit level: 2.907mAOD Throat invert level: 1.707mAOD
	Culvert entrance	–	4-001	S4-001ou	Orifice & spill	Throat soffit level: 3.091mAOD Throat invert level: 1.476mAOD Modular limit: 0.7 Weir coefficient: 1.0

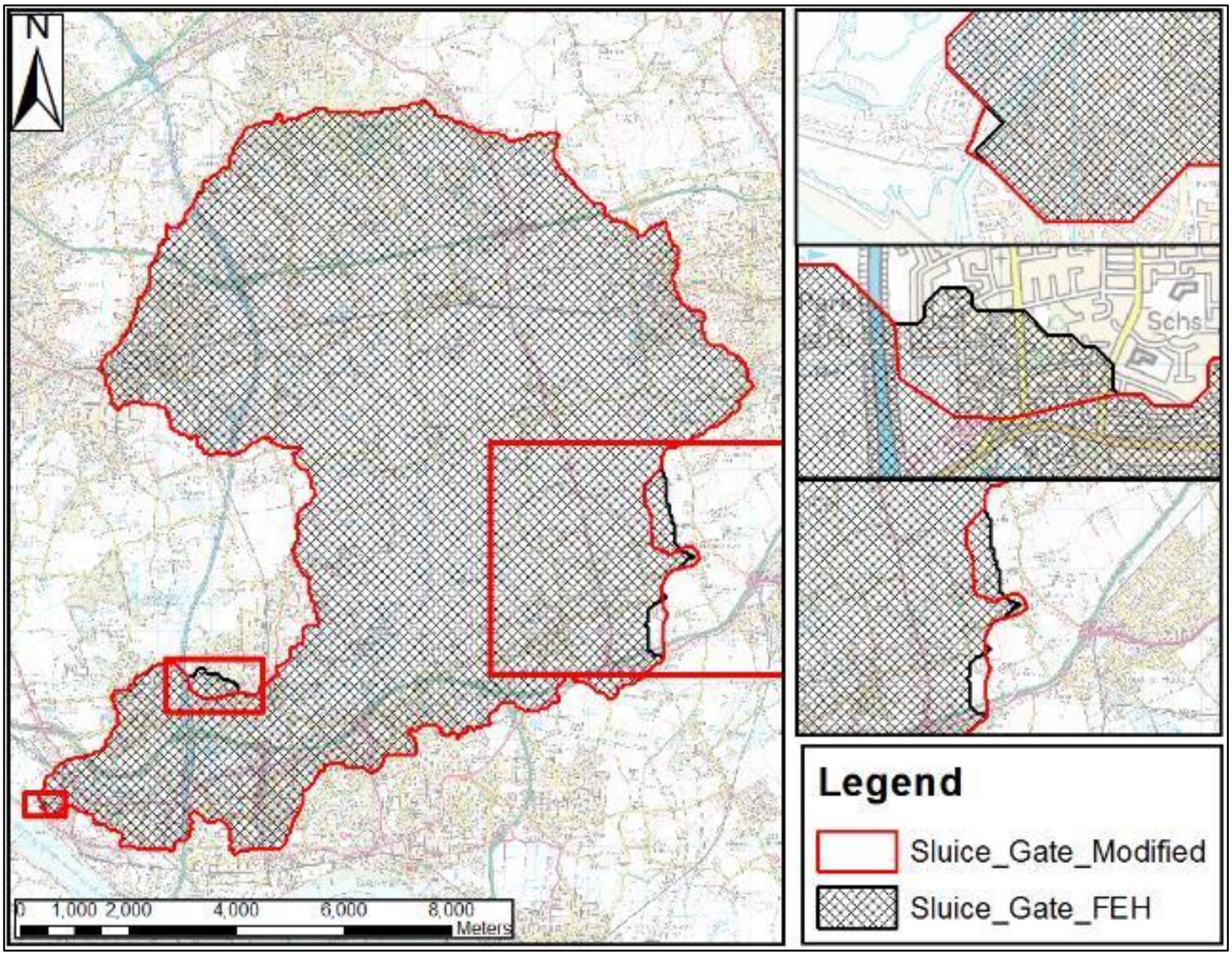
Source: Lower Thames Crossing Channel Survey, Storm Geomatics, November/December 2018

Annex C Hydrology

C.1 Review of FEH catchment boundaries

C.1.1 The boundary of the catchment Sluice Gate was amended at three locations as shown in Plate C.1. The reasons for the amendments were that the FEH boundary at one location intersected the river-based OS maps, and in the other two locations the FEH boundary was amended based on LiDAR data derived catchment extents (i.e. a more accurate topographic dataset than the FEH).

Plate C.1 Sluice Gate catchment amendments



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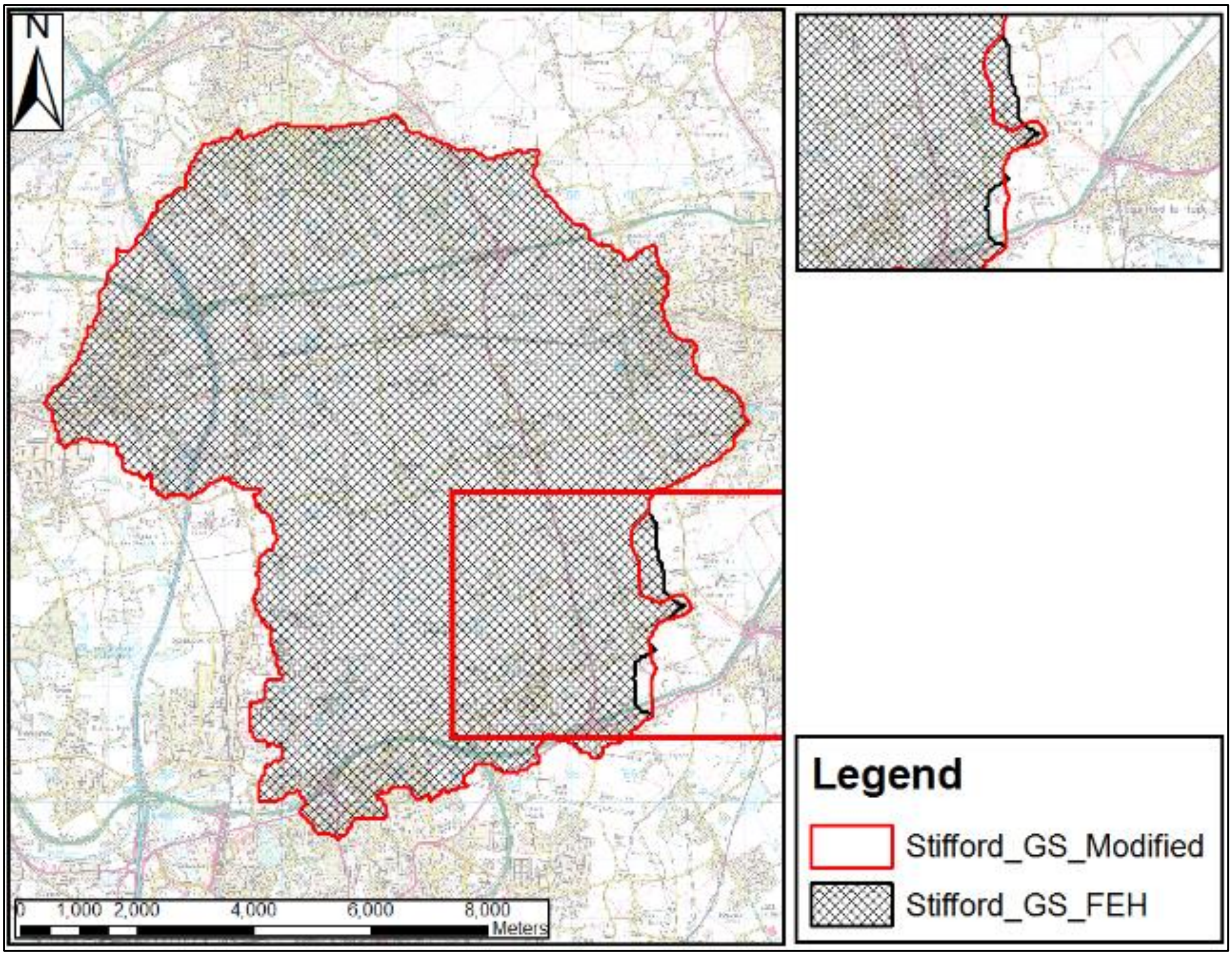
C.1.2 The boundary of Stifford GS was amended at one location as presented in Plate C.2 The FEH boundary was amended based on LiDAR data derived catchment extents (i.e. a more accurate topographic dataset than the FEH).

Plate C.2 Stifford GS catchment amendments



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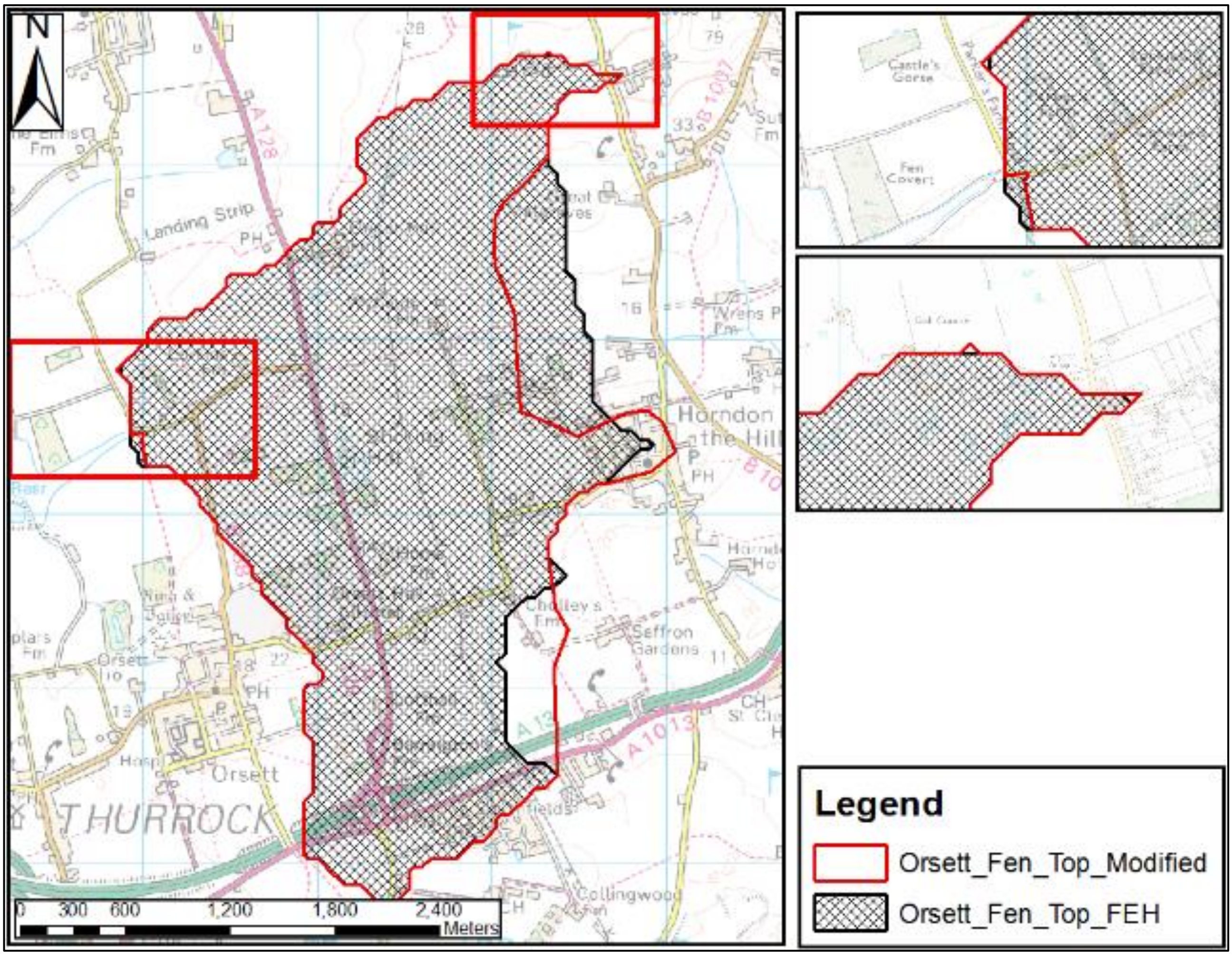
C.1.3 The boundary of Orsett Fen Top was amended as displayed in Plate C.3.

C.1.4 At the eastern location the FEH boundary was amended based on LiDAR data derived catchment extents (i.e. a more accurate topographic dataset than the FEH).

C.1.5 For the northern location, the boundary was amended to infill small gaps between adjacent FEH boundaries.

C.1.6 For the western location, the boundary was updated to exclude the Orsett Fen Sewer watercourse from this catchment.

Plate C.3 Orsett Fen Top catchment amendments



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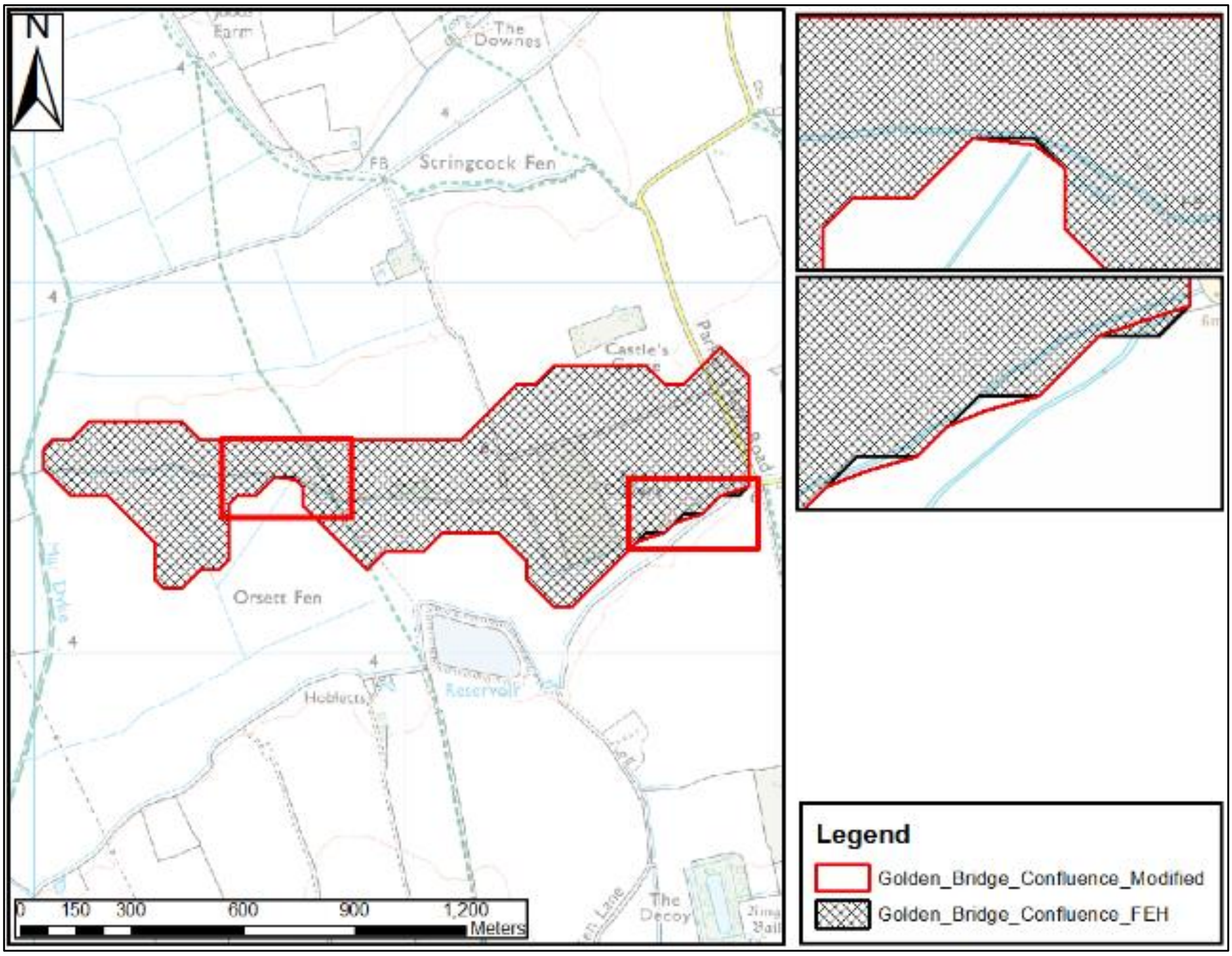
C.1.7 The boundary of Golden Bridge Confluence was amended at two locations as shown in Plate C.4. The reason for both amendments was that the FEH boundary intersected with the river reach.

Plate C.4 Golden Bridge Confluence catchment amendments



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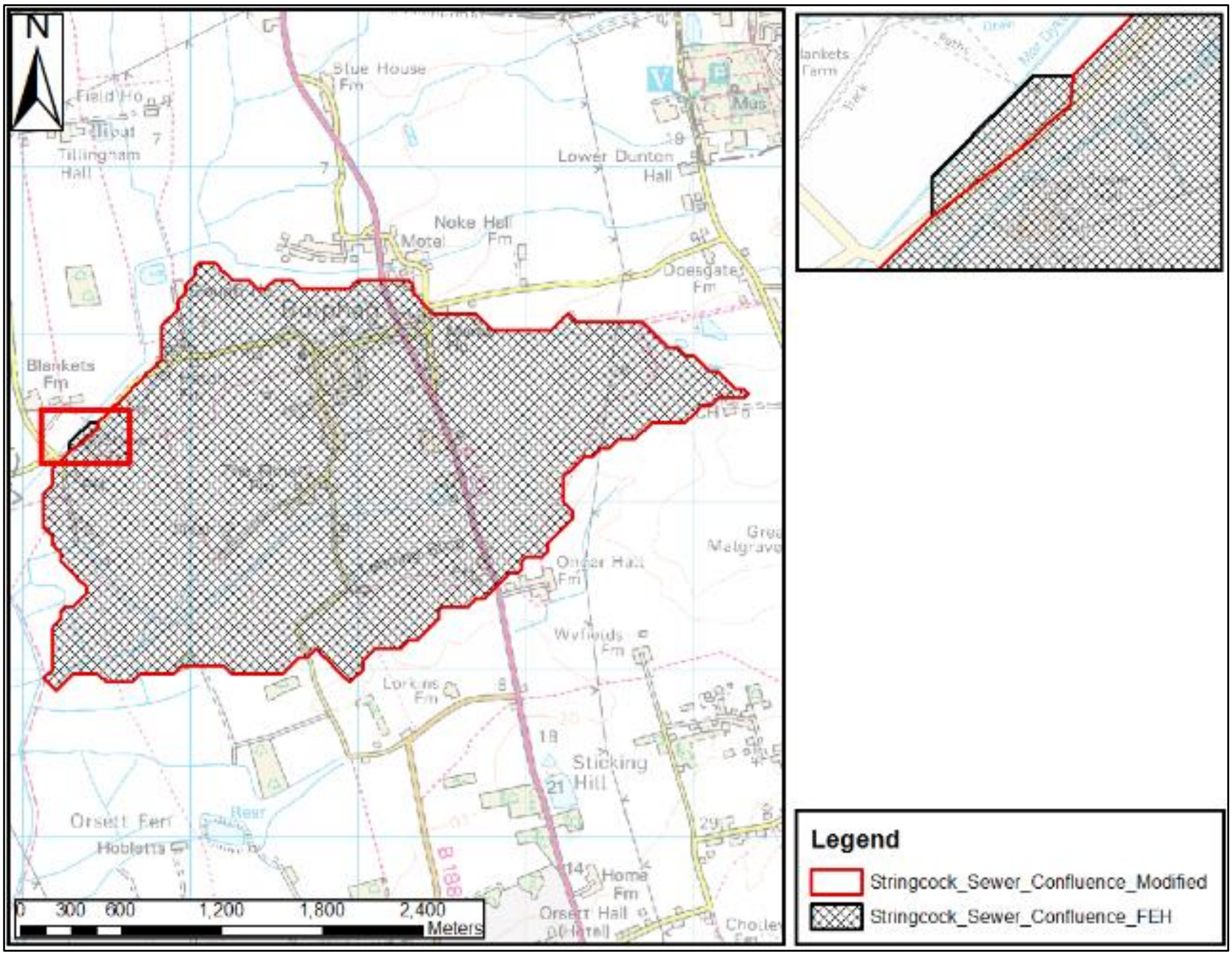
C.1.8 The boundary of Stringcock Sewer Confluence was amended at one location as shown in Plate C.5. The reason for the amendment was that the FEH boundary intersected the river reach.

Plate C.5 Stringcock Sewer Confluence catchment amendment



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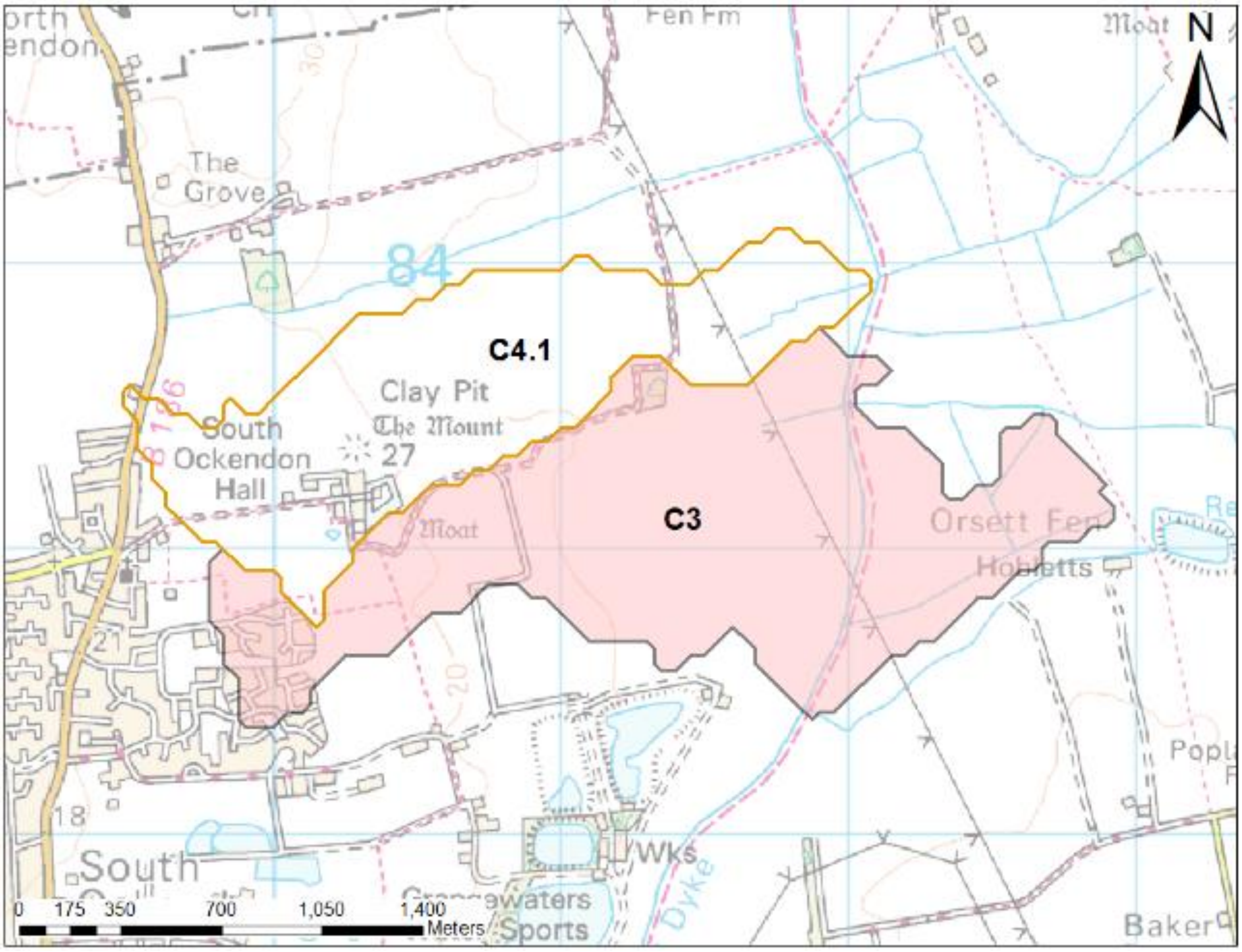
C.2 Catchment descriptors

C3 catchment descriptors estimation

C.2.1 Catchment descriptors were derived for C3 based on those of the representative catchment C4.1, shown in Plate C.6.

Plate C.6 Catchment C3 and representative catchment C4.1



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C.2.2 C4.1 is considered appropriate as a representative catchment as:

a. The catchments are adjacent, and their shape, size and aspect are similar.

b. Elevation varies from 5 to 25mAOD for both catchments.

c. Geology and land use of both catchments are similar.

C.2.3 Values of BFIHOST, DPLBAR, DPSBAR, FPEXT, PROPWET, SAAR, SAAR4170, SPRHOST, C, D1, D2, D3, E and F are therefore assumed to be the same for C3 as the representative catchment C4.1. The adopted FARL value is 1 as there are no reservoirs in the catchment.

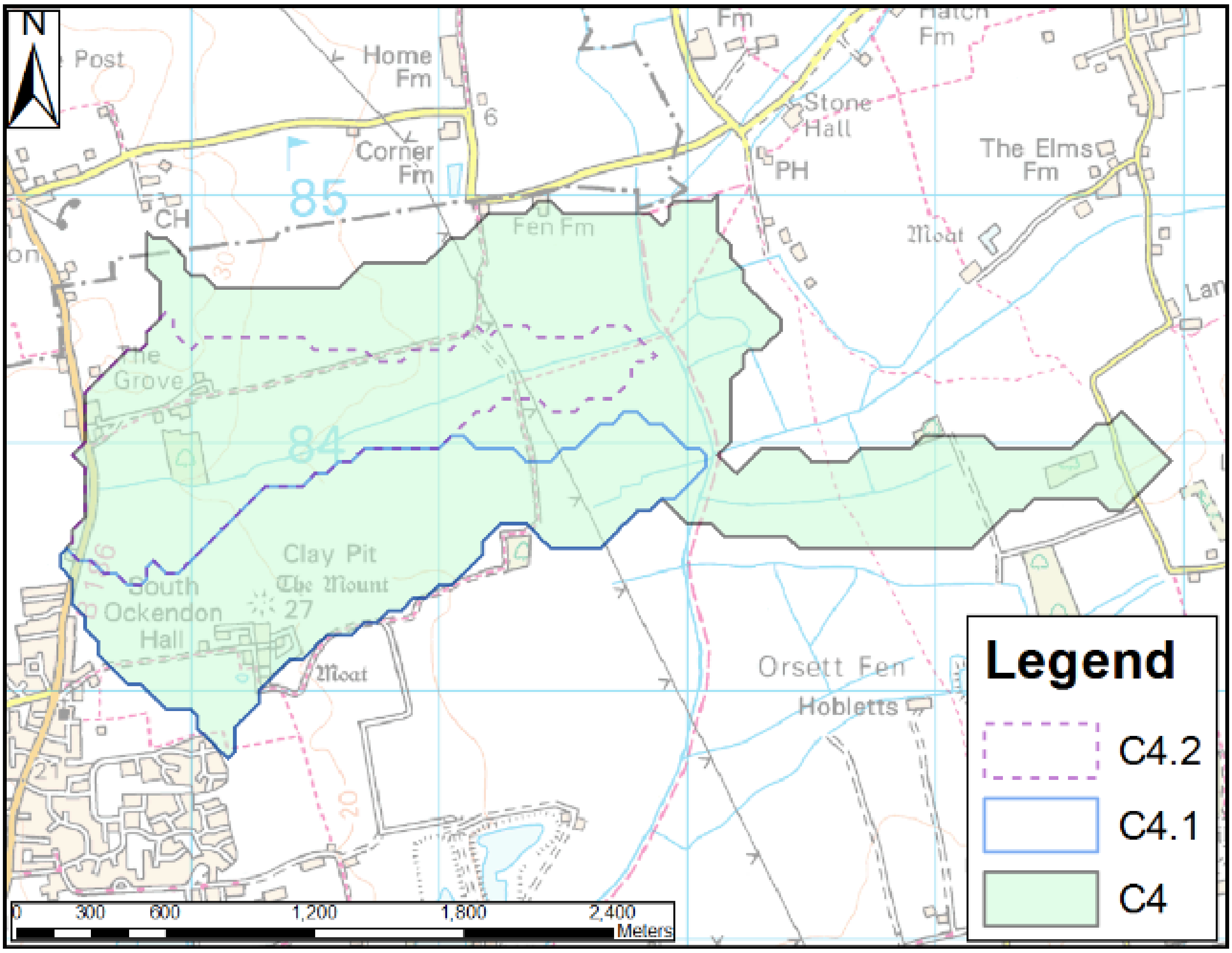
C.2.4 The values of URBEXT1990 and URBEXT2000 values for C3 were calculated by measuring the percentage of urban coverage (from maps) of both catchments in ArcMap and scaling the value of C4.1. according to the relative percentages to derive a value for C3.

C.2.5 The AREA catchment descriptor value for C3 was calculated with ArcMap.

C4 catchment descriptors estimation

C.2.6 For C4 the methodology of adding the catchment descriptors of two separate catchments and weighting them accordingly, as detailed in Volume 5 of the FEH, was applied. Catchments C4.1 and C4.2 were used as representative catchments. Catchments C4, C4.1 and C4.2 are displayed in Plate C.7.

Plate C.7 Catchment C4 and representative catchments C4.1 and C4.2



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C.2.7 C4.1 and C4.2 are considered appropriate as representative catchments for C4 as:

a. C4.1 and C4.2 both lie within C4

b. Elevations vary within C4.1 from 5 to 25mAOD and within C4.2 from 5m to 30mAOD

c. Geology and land use in C4, C4.1 and C4.2 are similar

C.2.8 Values of BFIHOST, DPSBAR, FPEXT, PROPWET, SAAR, SAAR4170, SPRHOST, URBEXT1990, URBEXT2000, C, D1, D2, D3, E and F were calculated applying the 'addition method'. The adopted FARL value is 1 as there are no reservoirs in the catchment.

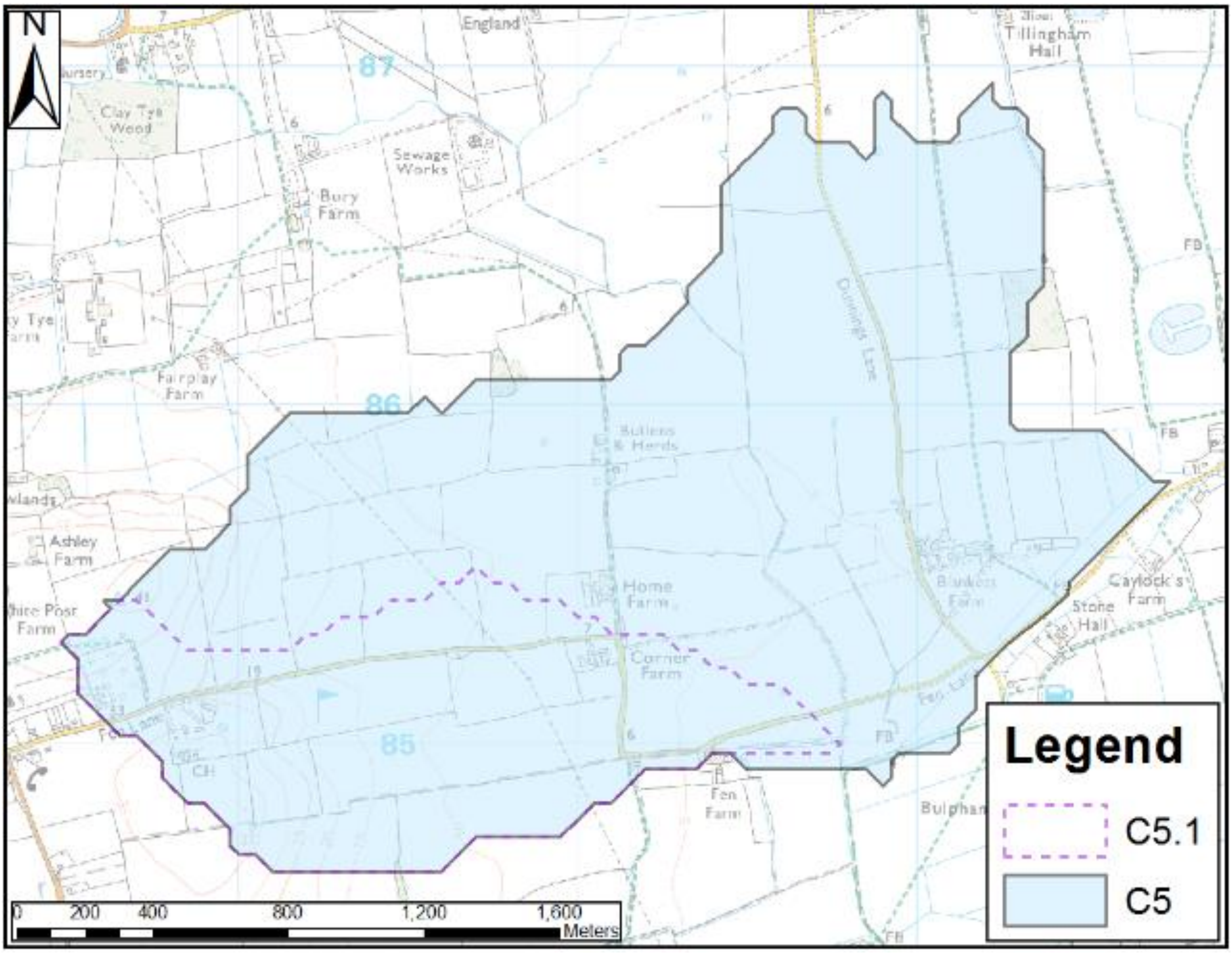
C.2.9 DPLBAR is assumed to be the same as for C4.1.

C.2.10 AREA value was calculated by the ArcMap (Calculate Geometry).

C5 catchment descriptors estimation

C.2.11 Catchment descriptors were derived for C5 based on those of the representative catchment C5.1. Both catchments are displayed in Plate C.8.

Plate C.8 Catchment C5 and representative catchment C5.1



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C.2.12 C5.1 is considered appropriate as a representative catchment as:

a. C5.1 lies within C5 and their shape, size and aspect are similar

b. Elevation varies from 5 to 40mAOD for both catchments

c. Geology and land use of both catchments are similar

C.2.13 Values of BFIHOST, DPLBAR, DPSBAR, FPEXT, PROPWET, SAAR, SAAR4170, SPRHOST, C, D1, D2, D3, E and F are therefore assumed to be the same for C5 as the representative catchment C5.1. The adopted FARL value is 1 as there are no reservoirs in the catchment.

C.2.14 The values of URBEXT1990 and URBEXT2000 values for C5 were calculated by applying an area-weighted method for both.

C.2.15 The AREA catchment descriptor value for C5 was calculated with ArcMap.

C.3 Thiessen polygons

C.3.1 Thiessen polygons constructed according to available rainfall data for each event are shown in Plate C.9 to Plate C.13.

Plate C.9 Thiessen polygons for January 2011 calibration event

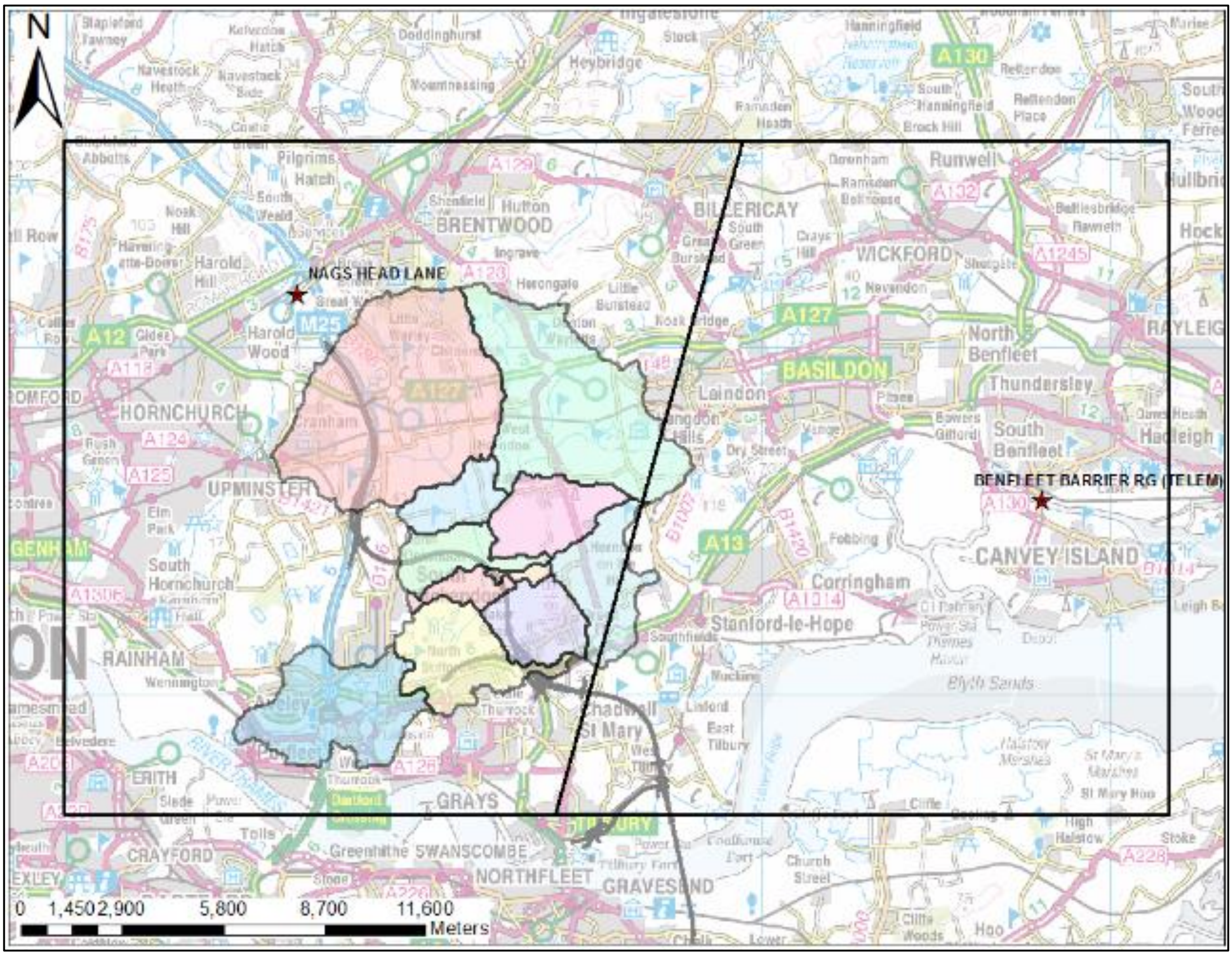

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Plate C.10 Thiessen polygons for July 2012 calibration event

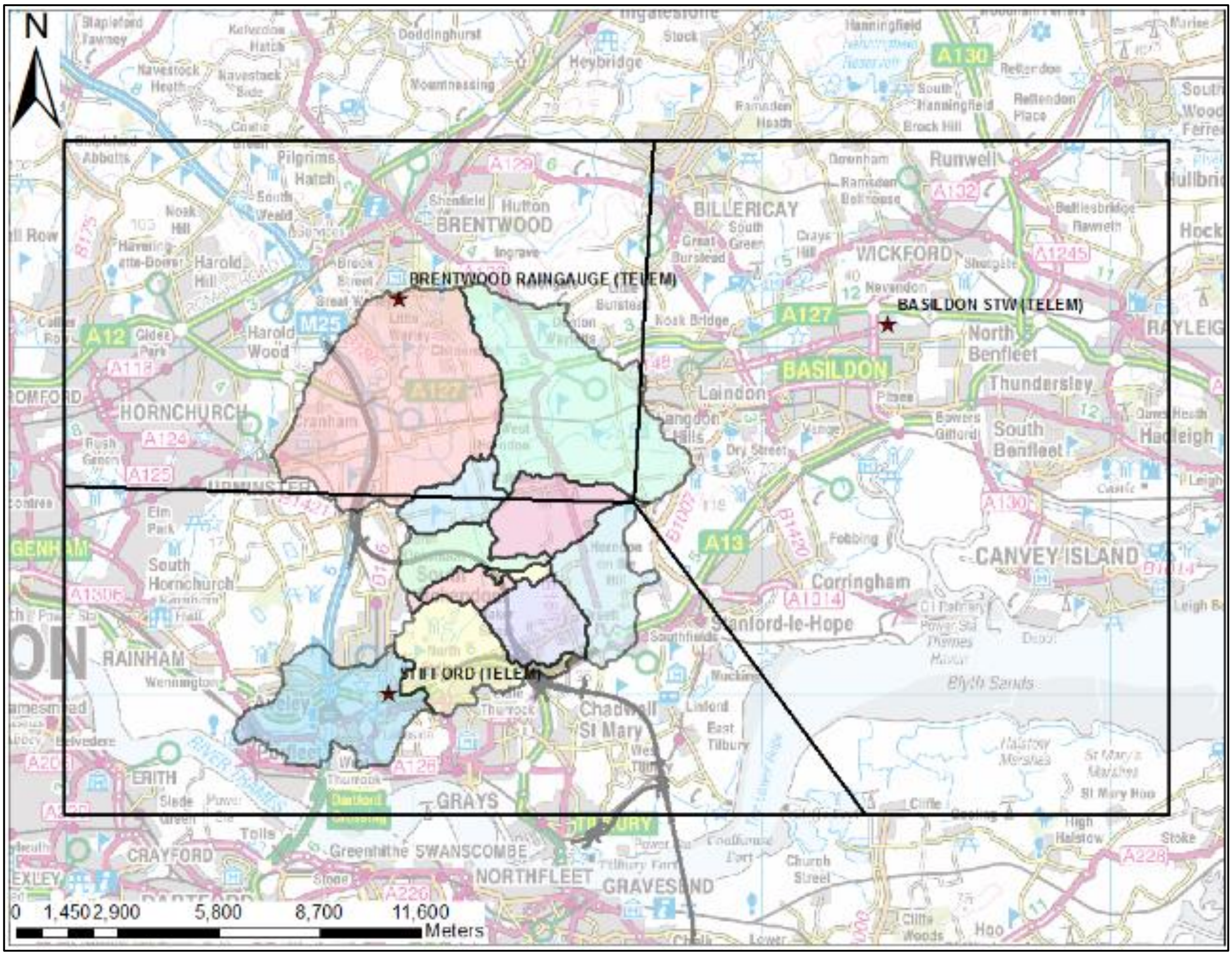

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Plate C.11 Thiessen polygons for December 2013 calibration event

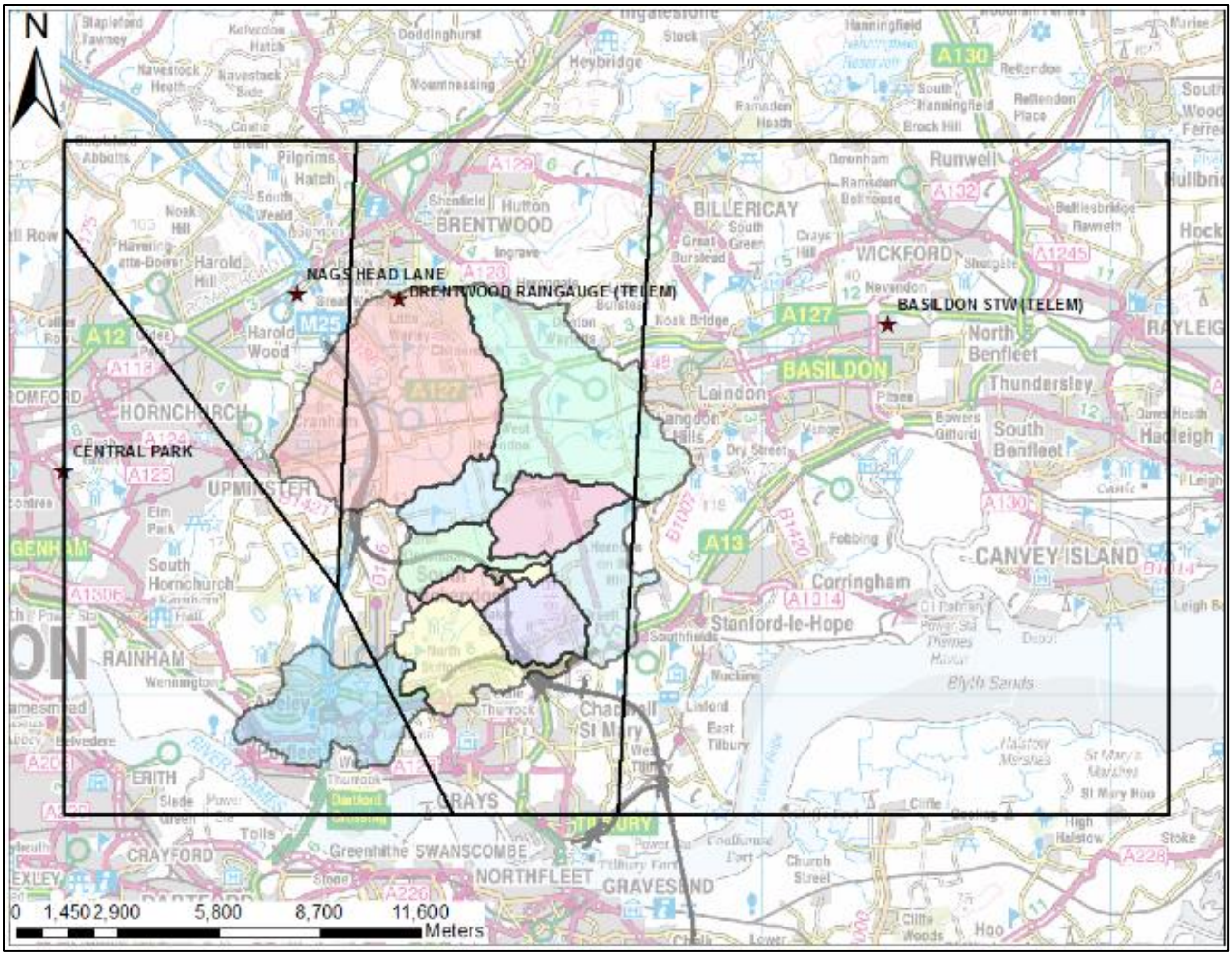

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Plate C.12 Thiessen polygons for November 2014 calibration event

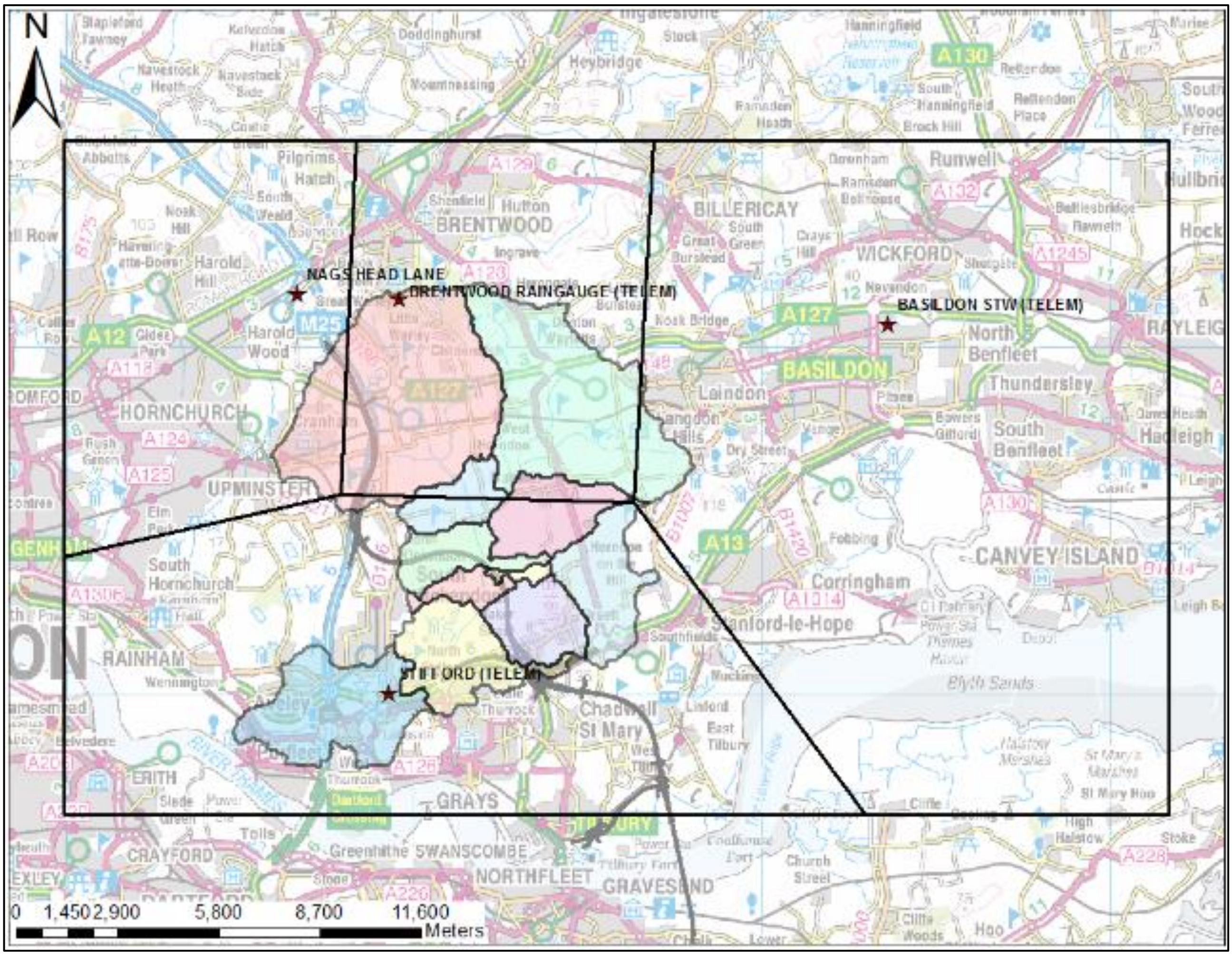

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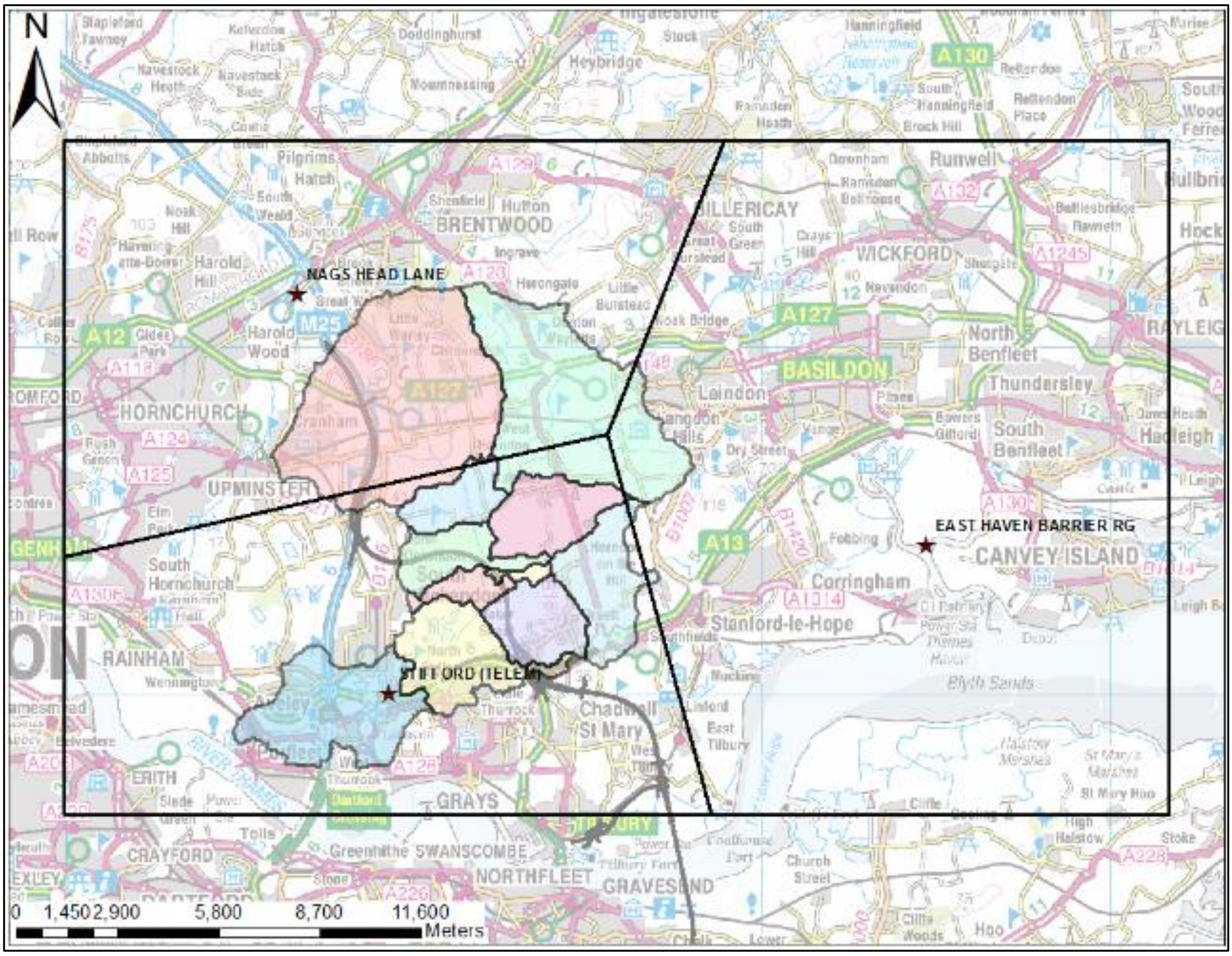
Plate C.13 Thiessen polygons for June 2016 calibration event



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Annex D Model results flood maps

D.1 Flood mapping

Table D.1 Flood mapping outputs figures

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
300	Maximum flood depth	Pre-development	OF_2	2030	6%
301	Maximum flood depth	Pre-development	OF_2	2030	11%
302	Maximum flood depth	Pre-development	OF_2	2130	17%
303	Maximum flood depth	Pre-development	OF_2	2130	26%
304	Maximum flood depth	Pre-development	OF_10	2030	6%
305	Maximum flood depth	Pre-development	OF_10	2030	11%
306	Maximum flood depth	Pre-development	OF_10	2130	17%
307	Maximum flood depth	Pre-development	OF_10	2130	26%
308	Maximum flood depth	Pre-development	OF_25	2030	6%
309	Maximum flood depth	Pre-development	OF_25	2030	11%
310	Maximum flood depth	Pre-development	OF_25	2130	17%
311	Maximum flood depth	Pre-development	OF_25	2130	26%
312	Maximum flood depth	Pre-development	OF_100	2030	6%
313	Maximum flood depth	Pre-development	OF_100	2030	11%
314	Maximum flood depth	Pre-development	OF_100	2130	17%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
315	Maximum flood depth	Pre-development	OF_100	2130	26%
316	Maximum flood depth	Pre-development	OF_1000	2030	11%
317	Maximum flood depth	Pre-development	OF_1000	2130	26%
318	Maximum flood depth	Pre-development	OF_1000	2130	48%
319	Maximum flood depth	Pre-development	STGS_2	2030	6%
320	Maximum flood depth	Pre-development	STGS_2	2030	11%
321	Maximum flood depth	Pre-development	STGS_2	2130	17%
322	Maximum flood depth	Pre-development	STGS_2	2130	26%
323	Maximum flood depth	Pre-development	STGS_10	2030	6%
324	Maximum flood depth	Pre-development	STGS_10	2030	11%
325	Maximum flood depth	Pre-development	STGS_10	2130	17%
326	Maximum flood depth	Pre-development	STGS_10	2130	26%
327	Maximum flood depth	Pre-development	STGS_25	2030	6%
328	Maximum flood depth	Pre-development	STGS_25	2030	11%
329	Maximum flood depth	Pre-development	STGS_25	2130	17%
330	Maximum flood depth	Pre-development	STGS_25	2130	26%
331	Maximum flood depth	Pre-development	STGS_100	2030	6%
332	Maximum flood depth	Pre-development	STGS_100	2030	11%
333	Maximum flood depth	Pre-development	STGS_100	2130	17%
334	Maximum flood depth	Pre-development	STGS_100	2130	26%
335	Maximum flood depth	Pre-development	STGS_1000	2030	11%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
336	Maximum flood depth	Pre-development	STGS_1000	2130	26%
337	Maximum flood depth	Pre-development	STGS_1000	2130	48%
338	Maximum flood depth	Post-development (without mitigation)	OF_2	2030	6%
339	Maximum flood depth	Post-development (without mitigation)	OF_2	2030	11%
340	Maximum flood depth	Post-development (without mitigation)	OF_2	2130	17%
341	Maximum flood depth	Post-development (without mitigation)	OF_2	2130	26%
342	Maximum flood depth	Post-development (without mitigation)	OF_10	2030	6%
343	Maximum flood depth	Post-development (without mitigation)	OF_10	2030	11%
344	Maximum flood depth	Post-development (without mitigation)	OF_10	2130	17%
345	Maximum flood depth	Post-development (without mitigation)	OF_10	2130	26%
346	Maximum flood depth	Post-development (without mitigation)	OF_25	2030	6%
347	Maximum flood depth	Post-development (without mitigation)	OF_25	2030	11%
348	Maximum flood depth	Post-development (without mitigation)	OF_25	2130	17%
349	Maximum flood depth	Post-development (without mitigation)	OF_25	2130	26%
350	Maximum flood depth	Post-development (without mitigation)	OF_100	2030	6%
351	Maximum flood depth	Post-development (without mitigation)	OF_100	2030	11%
352	Maximum flood depth	Post-development (without mitigation)	OF_100	2130	17%
353	Maximum flood depth	Post-development (without mitigation)	OF_100	2130	26%
354	Maximum flood depth	Post-development (without mitigation)	OF_1000	2030	11%
355	Maximum flood depth	Post-development (without mitigation)	OF_1000	2130	26%
356	Maximum flood depth	Post-development (without mitigation)	OF_1000	2130	48%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
357	Maximum flood depth	Post-development (without mitigation)	STGS_2	2030	6%
358	Maximum flood depth	Post-development (without mitigation)	STGS_2	2030	11%
359	Maximum flood depth	Post-development (without mitigation)	STGS_2	2130	17%
360	Maximum flood depth	Post-development (without mitigation)	STGS_2	2130	26%
361	Maximum flood depth	Post-development (without mitigation)	STGS_10	2030	6%
362	Maximum flood depth	Post-development (without mitigation)	STGS_10	2030	11%
363	Maximum flood depth	Post-development (without mitigation)	STGS_10	2130	17%
364	Maximum flood depth	Post-development (without mitigation)	STGS_10	2130	26%
365	Maximum flood depth	Post-development (without mitigation)	STGS_25	2030	6%
366	Maximum flood depth	Post-development (without mitigation)	STGS_25	2030	11%
367	Maximum flood depth	Post-development (without mitigation)	STGS_25	2130	17%
368	Maximum flood depth	Post-development (without mitigation)	STGS_25	2130	26%
369	Maximum flood depth	Post-development (without mitigation)	STGS_100	2030	6%
370	Maximum flood depth	Post-development (without mitigation)	STGS_100	2030	11%
371	Maximum flood depth	Post-development (without mitigation)	STGS_100	2130	17%
372	Maximum flood depth	Post-development (without mitigation)	STGS_100	2130	26%
373	Maximum flood depth	Post-development (without mitigation)	STGS_1000	2030	11%
374	Maximum flood depth	Post-development (without mitigation)	STGS_1000	2130	26%
375	Maximum flood depth	Post-development (without mitigation)	STGS_1000	2130	48%
376	Maximum flood depth	Post-development (with mitigation)	OF_2	2030	6%
377	Maximum flood depth	Post-development (with mitigation)	OF_2	2030	11%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
378	Maximum flood depth	Post-development (with mitigation)	OF_2	2130	17%
379	Maximum flood depth	Post-development (with mitigation)	OF_2	2130	26%
380	Maximum flood depth	Post-development (with mitigation)	OF_10	2030	6%
381	Maximum flood depth	Post-development (with mitigation)	OF_10	2030	11%
382	Maximum flood depth	Post-development (with mitigation)	OF_10	2130	17%
383	Maximum flood depth	Post-development (with mitigation)	OF_10	2130	26%
384	Maximum flood depth	Post-development (with mitigation)	OF_25	2030	6%
385	Maximum flood depth	Post-development (with mitigation)	OF_25	2030	11%
386	Maximum flood depth	Post-development (with mitigation)	OF_25	2130	17%
387	Maximum flood depth	Post-development (with mitigation)	OF_25	2130	26%
388	Maximum flood depth	Post-development (with mitigation)	OF_100	2030	6%
389	Maximum flood depth	Post-development (with mitigation)	OF_100	2030	11%
390	Maximum flood depth	Post-development (with mitigation)	OF_100	2130	17%
391	Maximum flood depth	Post-development (with mitigation)	OF_100	2130	26%
392	Maximum flood depth	Post-development (with mitigation)	OF_1000	2030	11%
393	Maximum flood depth	Post-development (with mitigation)	OF_1000	2130	26%
394	Maximum flood depth	Post-development (with mitigation)	OF_1000	2130	48%
395	Maximum flood depth	Post-development (with mitigation)	STGS_2	2030	6%
396	Maximum flood depth	Post-development (with mitigation)	STGS_2	2030	11%
397	Maximum flood depth	Post-development (with mitigation)	STGS_2	2130	17%
398	Maximum flood depth	Post-development (with mitigation)	STGS_2	2130	26%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
399	Maximum flood depth	Post-development (with mitigation)	STGS_10	2030	6%
400	Maximum flood depth	Post-development (with mitigation)	STGS_10	2030	11%
401	Maximum flood depth	Post-development (with mitigation)	STGS_10	2130	17%
402	Maximum flood depth	Post-development (with mitigation)	STGS_10	2130	26%
403	Maximum flood depth	Post-development (with mitigation)	STGS_25	2030	6%
404	Maximum flood depth	Post-development (with mitigation)	STGS_25	2030	11%
405	Maximum flood depth	Post-development (with mitigation)	STGS_25	2130	17%
406	Maximum flood depth	Post-development (with mitigation)	STGS_25	2130	26%
407	Maximum flood depth	Post-development (with mitigation)	STGS_100	2030	6%
408	Maximum flood depth	Post-development (with mitigation)	STGS_100	2030	11%
409	Maximum flood depth	Post-development (with mitigation)	STGS_100	2130	17%
410	Maximum flood depth	Post-development (with mitigation)	STGS_100	2130	26%
411	Maximum flood depth	Post-development (with mitigation)	STGS_1000	2030	11%
412	Maximum flood depth	Post-development (with mitigation)	STGS_1000	2130	26%
413	Maximum flood depth	Post-development (with mitigation)	STGS_1000	2130	48%
414	Maximum flood hazard category	Pre-development	OF_2	2030	6%
415	Maximum flood hazard category	Pre-development	OF_2	2030	11%
416	Maximum flood hazard category	Pre-development	OF_2	2130	17%
417	Maximum flood hazard category	Pre-development	OF_2	2130	26%
418	Maximum flood hazard category	Pre-development	OF_10	2030	6%
419	Maximum flood hazard category	Pre-development	OF_10	2030	11%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
420	Maximum flood hazard category	Pre-development	OF_10	2130	17%
421	Maximum flood hazard category	Pre-development	OF_10	2130	26%
422	Maximum flood hazard category	Pre-development	OF_25	2030	6%
423	Maximum flood hazard category	Pre-development	OF_25	2030	11%
424	Maximum flood hazard category	Pre-development	OF_25	2130	17%
425	Maximum flood hazard category	Pre-development	OF_25	2130	26%
426	Maximum flood hazard category	Pre-development	OF_100	2030	6%
427	Maximum flood hazard category	Pre-development	OF_100	2030	11%
428	Maximum flood hazard category	Pre-development	OF_100	2130	17%
429	Maximum flood hazard category	Pre-development	OF_100	2130	26%
430	Maximum flood hazard category	Pre-development	OF_1000	2030	11%
431	Maximum flood hazard category	Pre-development	OF_1000	2130	26%
432	Maximum flood hazard category	Pre-development	OF_1000	2130	48%
433	Maximum flood hazard category	Pre-development	STGS_2	2030	6%
434	Maximum flood hazard category	Pre-development	STGS_2	2030	11%
435	Maximum flood hazard category	Pre-development	STGS_2	2130	17%
436	Maximum flood hazard category	Pre-development	STGS_2	2130	26%
437	Maximum flood hazard category	Pre-development	STGS_10	2030	6%
438	Maximum flood hazard category	Pre-development	STGS_10	2030	11%
439	Maximum flood hazard category	Pre-development	STGS_10	2130	17%
440	Maximum flood hazard category	Pre-development	STGS_10	2130	26%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
* OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP					
441	Maximum flood hazard category	Pre-development	STGS_25	2030	6%
442	Maximum flood hazard category	Pre-development	STGS_25	2030	11%
443	Maximum flood hazard category	Pre-development	STGS_25	2130	17%
444	Maximum flood hazard category	Pre-development	STGS_25	2130	26%
445	Maximum flood hazard category	Pre-development	STGS_100	2030	6%
446	Maximum flood hazard category	Pre-development	STGS_100	2030	11%
447	Maximum flood hazard category	Pre-development	STGS_100	2130	17%
448	Maximum flood hazard category	Pre-development	STGS_100	2130	26%
449	Maximum flood hazard category	Pre-development	STGS_1000	2030	11%
450	Maximum flood hazard category	Pre-development	STGS_1000	2130	26%
451	Maximum flood hazard category	Pre-development	STGS_1000	2130	48%
452	Maximum flood hazard category	Post-development (without mitigation)	OF_2	2030	6%
453	Maximum flood hazard category	Post-development (without mitigation)	OF_2	2030	11%
454	Maximum flood hazard category	Post-development (without mitigation)	OF_2	2130	17%
455	Maximum flood hazard category	Post-development (without mitigation)	OF_2	2130	26%
456	Maximum flood hazard category	Post-development (without mitigation)	OF_10	2030	6%
457	Maximum flood hazard category	Post-development (without mitigation)	OF_10	2030	11%
458	Maximum flood hazard category	Post-development (without mitigation)	OF_10	2130	17%
459	Maximum flood hazard category	Post-development (without mitigation)	OF_10	2130	26%
460	Maximum flood hazard category	Post-development (without mitigation)	OF_25	2030	6%
461	Maximum flood hazard category	Post-development (without mitigation)	OF_25	2030	11%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
462	Maximum flood hazard category	Post-development (without mitigation)	OF_25	2130	17%
463	Maximum flood hazard category	Post-development (without mitigation)	OF_25	2130	26%
464	Maximum flood hazard category	Post-development (without mitigation)	OF_100	2030	6%
465	Maximum flood hazard category	Post-development (without mitigation)	OF_100	2030	11%
466	Maximum flood hazard category	Post-development (without mitigation)	OF_100	2130	17%
467	Maximum flood hazard category	Post-development (without mitigation)	OF_100	2130	26%
468	Maximum flood hazard category	Post-development (without mitigation)	OF_1000	2030	11%
469	Maximum flood hazard category	Post-development (without mitigation)	OF_1000	2130	26%
470	Maximum flood hazard category	Post-development (without mitigation)	OF_1000	2130	48%
471	Maximum flood hazard category	Post-development (without mitigation)	STGS_2	2030	6%
472	Maximum flood hazard category	Post-development (without mitigation)	STGS_2	2030	11%
473	Maximum flood hazard category	Post-development (without mitigation)	STGS_2	2130	17%
474	Maximum flood hazard category	Post-development (without mitigation)	STGS_2	2130	26%
475	Maximum flood hazard category	Post-development (without mitigation)	STGS_10	2030	6%
476	Maximum flood hazard category	Post-development (without mitigation)	STGS_10	2030	11%
477	Maximum flood hazard category	Post-development (without mitigation)	STGS_10	2130	17%
478	Maximum flood hazard category	Post-development (without mitigation)	STGS_10	2130	26%
479	Maximum flood hazard category	Post-development (without mitigation)	STGS_25	2030	6%
480	Maximum flood hazard category	Post-development (without mitigation)	STGS_25	2030	11%
481	Maximum flood hazard category	Post-development (without mitigation)	STGS_25	2130	17%
482	Maximum flood hazard category	Post-development (without mitigation)	STGS_25	2130	26%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
* OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP					
483	Maximum flood hazard category	Post-development (without mitigation)	STGS_100	2030	6%
484	Maximum flood hazard category	Post-development (without mitigation)	STGS_100	2030	11%
485	Maximum flood hazard category	Post-development (without mitigation)	STGS_100	2130	17%
486	Maximum flood hazard category	Post-development (without mitigation)	STGS_100	2130	26%
487	Maximum flood hazard category	Post-development (without mitigation)	STGS_1000	2030	11%
488	Maximum flood hazard category	Post-development (without mitigation)	STGS_1000	2130	26%
489	Maximum flood hazard category	Post-development (without mitigation)	STGS_1000	2130	48%
490	Maximum flood hazard category	Post-development (with mitigation)	OF_2	2030	6%
491	Maximum flood hazard category	Post-development (with mitigation)	OF_2	2030	11%
492	Maximum flood hazard category	Post-development (with mitigation)	OF_2	2130	17%
493	Maximum flood hazard category	Post-development (with mitigation)	OF_2	2130	26%
494	Maximum flood hazard category	Post-development (with mitigation)	OF_10	2030	6%
495	Maximum flood hazard category	Post-development (with mitigation)	OF_10	2030	11%
496	Maximum flood hazard category	Post-development (with mitigation)	OF_10	2130	17%
497	Maximum flood hazard category	Post-development (with mitigation)	OF_10	2130	26%
498	Maximum flood hazard category	Post-development (with mitigation)	OF_25	2030	6%
499	Maximum flood hazard category	Post-development (with mitigation)	OF_25	2030	11%
500	Maximum flood hazard category	Post-development (with mitigation)	OF_25	2130	17%
501	Maximum flood hazard category	Post-development (with mitigation)	OF_25	2130	26%
502	Maximum flood hazard category	Post-development (with mitigation)	OF_100	2030	6%
503	Maximum flood hazard category	Post-development (with mitigation)	OF_100	2030	11%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
504	Maximum flood hazard category	Post-development (with mitigation)	OF_100	2130	17%
505	Maximum flood hazard category	Post-development (with mitigation)	OF_100	2130	26%
506	Maximum flood hazard category	Post-development (with mitigation)	OF_1000	2030	11%
507	Maximum flood hazard category	Post-development (with mitigation)	OF_1000	2130	26%
508	Maximum flood hazard category	Post-development (with mitigation)	OF_1000	2130	48%
509	Maximum flood hazard category	Post-development (with mitigation)	STGS_2	2030	6%
510	Maximum flood hazard category	Post-development (with mitigation)	STGS_2	2030	11%
511	Maximum flood hazard category	Post-development (with mitigation)	STGS_2	2130	17%
512	Maximum flood hazard category	Post-development (with mitigation)	STGS_2	2130	26%
513	Maximum flood hazard category	Post-development (with mitigation)	STGS_10	2030	6%
514	Maximum flood hazard category	Post-development (with mitigation)	STGS_10	2030	11%
515	Maximum flood hazard category	Post-development (with mitigation)	STGS_10	2130	17%
516	Maximum flood hazard category	Post-development (with mitigation)	STGS_10	2130	26%
517	Maximum flood hazard category	Post-development (with mitigation)	STGS_25	2030	6%
518	Maximum flood hazard category	Post-development (with mitigation)	STGS_25	2030	11%
519	Maximum flood hazard category	Post-development (with mitigation)	STGS_25	2130	17%
520	Maximum flood hazard category	Post-development (with mitigation)	STGS_25	2130	26%
521	Maximum flood hazard category	Post-development (with mitigation)	STGS_100	2030	6%
522	Maximum flood hazard category	Post-development (with mitigation)	STGS_100	2030	11%
523	Maximum flood hazard category	Post-development (with mitigation)	STGS_100	2130	17%
524	Maximum flood hazard category	Post-development (with mitigation)	STGS_100	2130	26%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
525	Maximum flood hazard category	Post-development (with mitigation)	STGS_1000	2030	11%
526	Maximum flood hazard category	Post-development (with mitigation)	STGS_1000	2130	26%
527	Maximum flood hazard category	Post-development (with mitigation)	STGS_1000	2130	48%
528	Maximum flood velocity	Pre-development	OF_2	2030	6%
529	Maximum flood velocity	Pre-development	OF_2	2030	11%
530	Maximum flood velocity	Pre-development	OF_2	2130	17%
531	Maximum flood velocity	Pre-development	OF_2	2130	26%
532	Maximum flood velocity	Pre-development	OF_10	2030	6%
533	Maximum flood velocity	Pre-development	OF_10	2030	11%
534	Maximum flood velocity	Pre-development	OF_10	2130	17%
535	Maximum flood velocity	Pre-development	OF_10	2130	26%
536	Maximum flood velocity	Pre-development	OF_25	2030	6%
537	Maximum flood velocity	Pre-development	OF_25	2030	11%
538	Maximum flood velocity	Pre-development	OF_25	2130	17%
539	Maximum flood velocity	Pre-development	OF_25	2130	26%
540	Maximum flood velocity	Pre-development	OF_100	2030	6%
541	Maximum flood velocity	Pre-development	OF_100	2030	11%
542	Maximum flood velocity	Pre-development	OF_100	2130	17%
543	Maximum flood velocity	Pre-development	OF_100	2130	26%
544	Maximum flood velocity	Pre-development	OF_1000	2030	11%
545	Maximum flood velocity	Pre-development	OF_1000	2130	26%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
546	Maximum flood velocity	Pre-development	OF_1000	2130	48%
547	Maximum flood velocity	Pre-development	STGS_2	2030	6%
548	Maximum flood velocity	Pre-development	STGS_2	2030	11%
549	Maximum flood velocity	Pre-development	STGS_2	2130	17%
550	Maximum flood velocity	Pre-development	STGS_2	2130	26%
551	Maximum flood velocity	Pre-development	STGS_10	2030	6%
552	Maximum flood velocity	Pre-development	STGS_10	2030	11%
553	Maximum flood velocity	Pre-development	STGS_10	2130	17%
554	Maximum flood velocity	Pre-development	STGS_10	2130	26%
555	Maximum flood velocity	Pre-development	STGS_25	2030	6%
556	Maximum flood velocity	Pre-development	STGS_25	2030	11%
557	Maximum flood velocity	Pre-development	STGS_25	2130	17%
558	Maximum flood velocity	Pre-development	STGS_25	2130	26%
559	Maximum flood velocity	Pre-development	STGS_100	2030	6%
560	Maximum flood velocity	Pre-development	STGS_100	2030	11%
561	Maximum flood velocity	Pre-development	STGS_100	2130	17%
562	Maximum flood velocity	Pre-development	STGS_100	2130	26%
563	Maximum flood velocity	Pre-development	STGS_1000	2030	11%
564	Maximum flood velocity	Pre-development	STGS_1000	2130	26%
565	Maximum flood velocity	Pre-development	STGS_1000	2130	48%
566	Maximum flood velocity	Post-development (without mitigation)	OF_2	2030	6%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
567	Maximum flood velocity	Post-development (without mitigation)	OF_2	2030	11%
568	Maximum flood velocity	Post-development (without mitigation)	OF_2	2130	17%
569	Maximum flood velocity	Post-development (without mitigation)	OF_2	2130	26%
570	Maximum flood velocity	Post-development (without mitigation)	OF_10	2030	6%
571	Maximum flood velocity	Post-development (without mitigation)	OF_10	2030	11%
572	Maximum flood velocity	Post-development (without mitigation)	OF_10	2130	17%
573	Maximum flood velocity	Post-development (without mitigation)	OF_10	2130	26%
574	Maximum flood velocity	Post-development (without mitigation)	OF_25	2030	6%
575	Maximum flood velocity	Post-development (without mitigation)	OF_25	2030	11%
576	Maximum flood velocity	Post-development (without mitigation)	OF_25	2130	17%
577	Maximum flood velocity	Post-development (without mitigation)	OF_25	2130	26%
578	Maximum flood velocity	Post-development (without mitigation)	OF_100	2030	6%
579	Maximum flood velocity	Post-development (without mitigation)	OF_100	2030	11%
580	Maximum flood velocity	Post-development (without mitigation)	OF_100	2130	17%
581	Maximum flood velocity	Post-development (without mitigation)	OF_100	2130	26%
582	Maximum flood velocity	Post-development (without mitigation)	OF_1000	2030	11%
583	Maximum flood velocity	Post-development (without mitigation)	OF_1000	2130	26%
584	Maximum flood velocity	Post-development (without mitigation)	OF_1000	2130	48%
585	Maximum flood velocity	Post-development (without mitigation)	STGS_2	2030	6%
586	Maximum flood velocity	Post-development (without mitigation)	STGS_2	2030	11%
587	Maximum flood velocity	Post-development (without mitigation)	STGS_2	2130	17%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
* OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP					
588	Maximum flood velocity	Post-development (without mitigation)	STGS_2	2130	26%
589	Maximum flood velocity	Post-development (without mitigation)	STGS_10	2030	6%
590	Maximum flood velocity	Post-development (without mitigation)	STGS_10	2030	11%
591	Maximum flood velocity	Post-development (without mitigation)	STGS_10	2130	17%
592	Maximum flood velocity	Post-development (without mitigation)	STGS_10	2130	26%
593	Maximum flood velocity	Post-development (without mitigation)	STGS_25	2030	6%
594	Maximum flood velocity	Post-development (without mitigation)	STGS_25	2030	11%
595	Maximum flood velocity	Post-development (without mitigation)	STGS_25	2130	17%
596	Maximum flood velocity	Post-development (without mitigation)	STGS_25	2130	26%
597	Maximum flood velocity	Post-development (without mitigation)	STGS_100	2030	6%
598	Maximum flood velocity	Post-development (without mitigation)	STGS_100	2030	11%
599	Maximum flood velocity	Post-development (without mitigation)	STGS_100	2130	17%
600	Maximum flood velocity	Post-development (without mitigation)	STGS_100	2130	26%
601	Maximum flood velocity	Post-development (without mitigation)	STGS_1000	2030	11%
602	Maximum flood velocity	Post-development (without mitigation)	STGS_1000	2130	26%
603	Maximum flood velocity	Post-development (without mitigation)	STGS_1000	2130	48%
604	Maximum flood velocity	Post-development (with mitigation)	OF_2	2030	6%
605	Maximum flood velocity	Post-development (with mitigation)	OF_2	2030	11%
606	Maximum flood velocity	Post-development (with mitigation)	OF_2	2130	17%
607	Maximum flood velocity	Post-development (with mitigation)	OF_2	2130	26%
608	Maximum flood velocity	Post-development (with mitigation)	OF_10	2030	6%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
* OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP					
609	Maximum flood velocity	Post-development (with mitigation)	OF_10	2030	11%
610	Maximum flood velocity	Post-development (with mitigation)	OF_10	2130	17%
611	Maximum flood velocity	Post-development (with mitigation)	OF_10	2130	26%
612	Maximum flood velocity	Post-development (with mitigation)	OF_25	2030	6%
613	Maximum flood velocity	Post-development (with mitigation)	OF_25	2030	11%
614	Maximum flood velocity	Post-development (with mitigation)	OF_25	2130	17%
615	Maximum flood velocity	Post-development (with mitigation)	OF_25	2130	26%
616	Maximum flood velocity	Post-development (with mitigation)	OF_100	2030	6%
617	Maximum flood velocity	Post-development (with mitigation)	OF_100	2030	11%
618	Maximum flood velocity	Post-development (with mitigation)	OF_100	2130	17%
619	Maximum flood velocity	Post-development (with mitigation)	OF_100	2130	26%
620	Maximum flood velocity	Post-development (with mitigation)	OF_1000	2030	11%
621	Maximum flood velocity	Post-development (with mitigation)	OF_1000	2130	26%
622	Maximum flood velocity	Post-development (with mitigation)	OF_1000	2130	48%
623	Maximum flood velocity	Post-development (with mitigation)	STGS_2	2030	6%
624	Maximum flood velocity	Post-development (with mitigation)	STGS_2	2030	11%
625	Maximum flood velocity	Post-development (with mitigation)	STGS_2	2130	17%
626	Maximum flood velocity	Post-development (with mitigation)	STGS_2	2130	26%
627	Maximum flood velocity	Post-development (with mitigation)	STGS_10	2030	6%
628	Maximum flood velocity	Post-development (with mitigation)	STGS_10	2030	11%
629	Maximum flood velocity	Post-development (with mitigation)	STGS_10	2130	17%

Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
* OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP					
630	Maximum flood velocity	Post-development (with mitigation)	STGS_10	2130	26%
631	Maximum flood velocity	Post-development (with mitigation)	STGS_25	2030	6%
632	Maximum flood velocity	Post-development (with mitigation)	STGS_25	2030	11%
633	Maximum flood velocity	Post-development (with mitigation)	STGS_25	2130	17%
634	Maximum flood velocity	Post-development (with mitigation)	STGS_25	2130	26%
635	Maximum flood velocity	Post-development (with mitigation)	STGS_100	2030	6%
636	Maximum flood velocity	Post-development (with mitigation)	STGS_100	2030	11%
637	Maximum flood velocity	Post-development (with mitigation)	STGS_100	2130	17%
638	Maximum flood velocity	Post-development (with mitigation)	STGS_100	2130	26%
639	Maximum flood velocity	Post-development (with mitigation)	STGS_1000	2030	11%
640	Maximum flood velocity	Post-development (with mitigation)	STGS_1000	2130	26%
641	Maximum flood velocity	Post-development (with mitigation)	STGS_1000	2130	48%
642	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_10	2030	6%
643	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_10	2130	17%
644	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_25	2030	6%
645	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_25	2130	17%
646	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_100	2030	6%
647	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_100	2130	17%
648	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	STGS_100	2130	26%
649	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_10	2030	6%
650	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_10	2130	17%

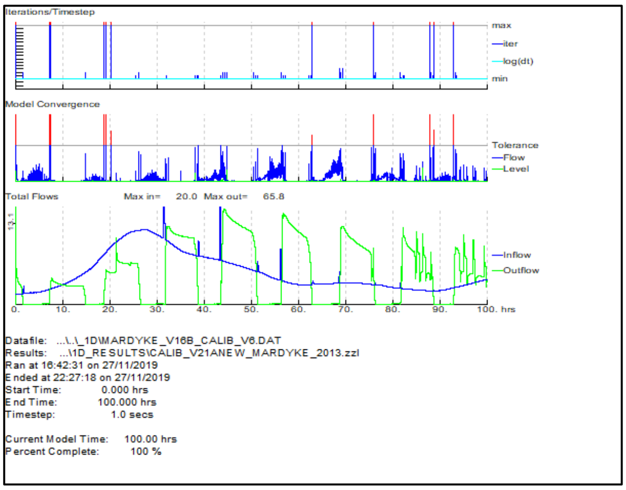
Drawing number	Type	Scenario	Design event (Flood Estimation Point and return period)*	Year	Peak river flow uplift applied
*** OF = Orsett Fen Top FEP; STGS = Stifford gauging station FEP**					
651	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_25	2030	6%
652	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_25	2130	17%
653	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_100	2030	6%
654	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_100	2130	17%
655	Difference in maximum flood depth	Post- (without mitigation) minus Pre-development	OF_100	2130	26%
656	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_10	2030	6%
657	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_10	2130	17%
658	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_25	2030	6%
659	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_25	2130	17%
660	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_100	2030	6%
661	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_100	2130	17%
662	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	STGS_100	2130	26%
663	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_10	2030	6%
664	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_10	2130	17%
665	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_25	2030	6%
666	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_25	2130	17%
667	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_100	2030	6%
668	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_100	2130	17%
669	Difference in maximum flood depth	Post- (with mitigation) minus Pre-development	OF_100	2130	26%

Annex E Model performance

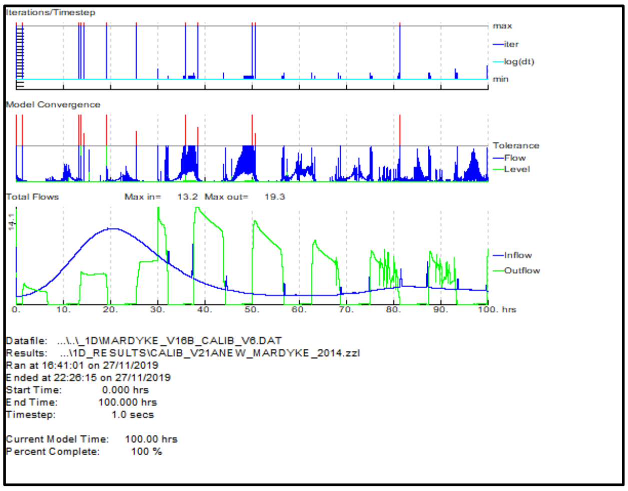
A.1 Simulations bitmaps for calibration runs

Table E.1 Simulation bitmaps outputs

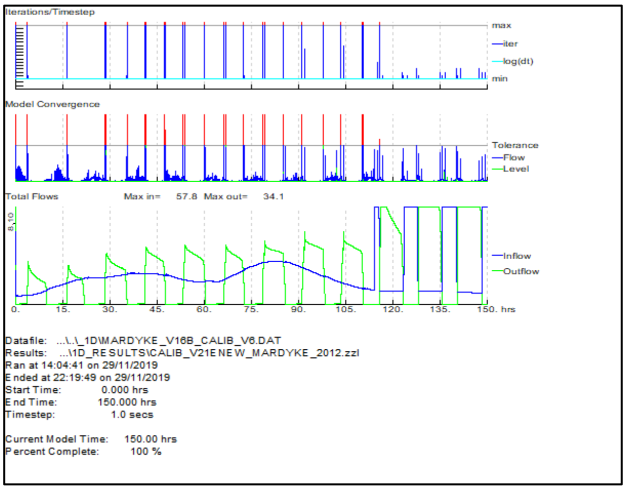
A.1.1



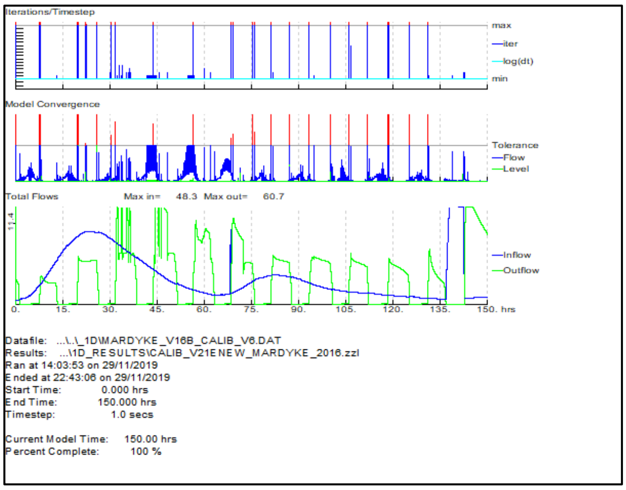
A.1.2



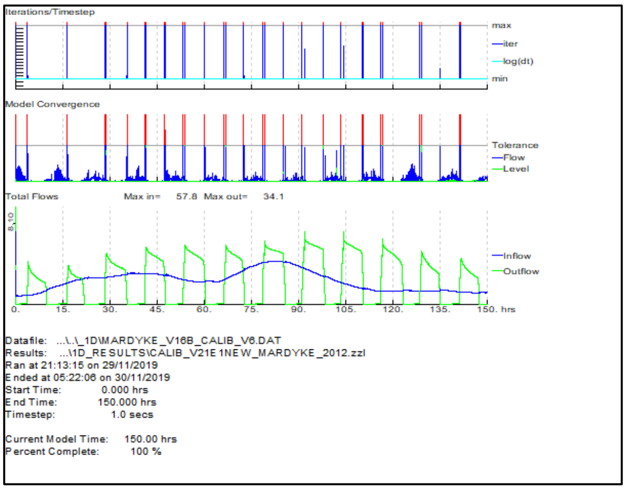
A.1.3



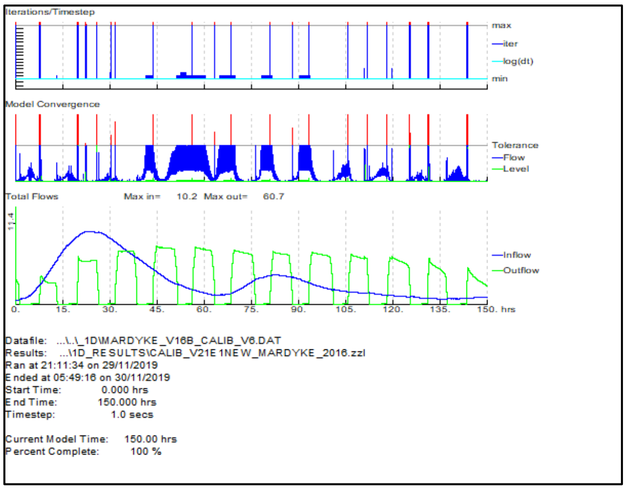
A.1.4



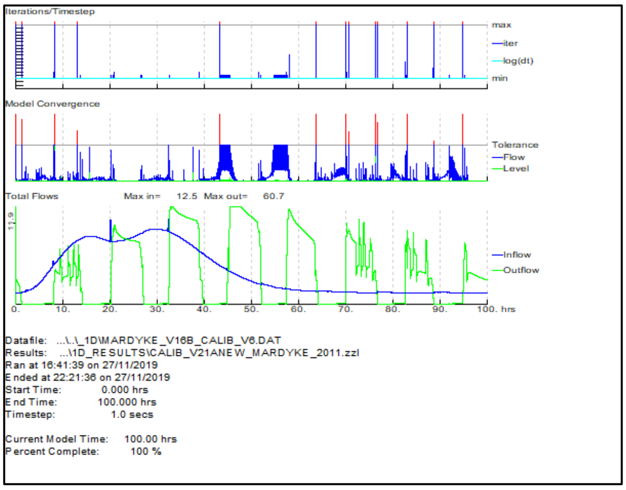
A.1.5



A.1.6

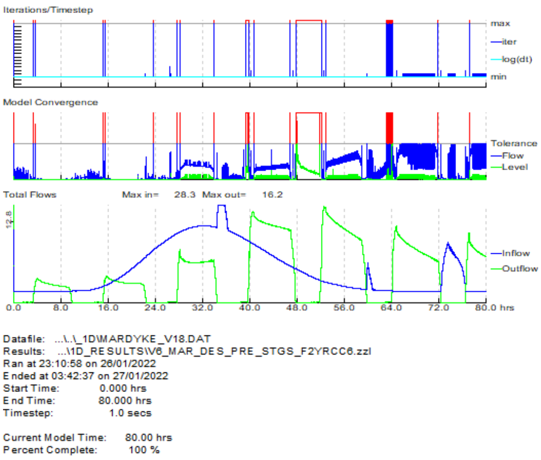
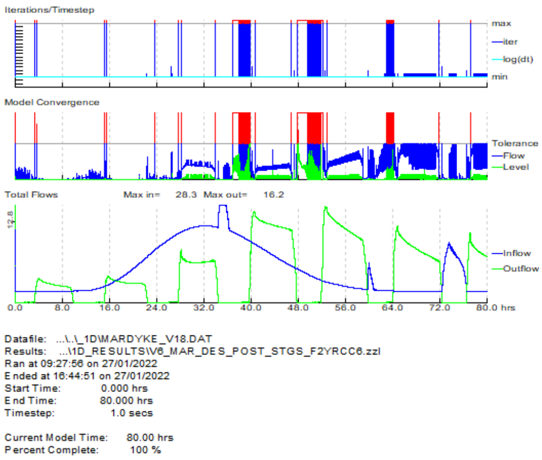
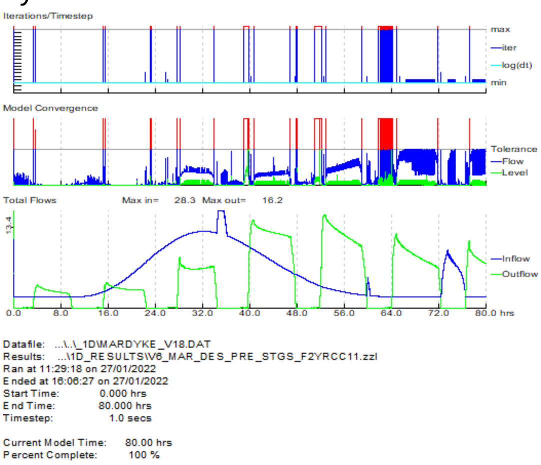
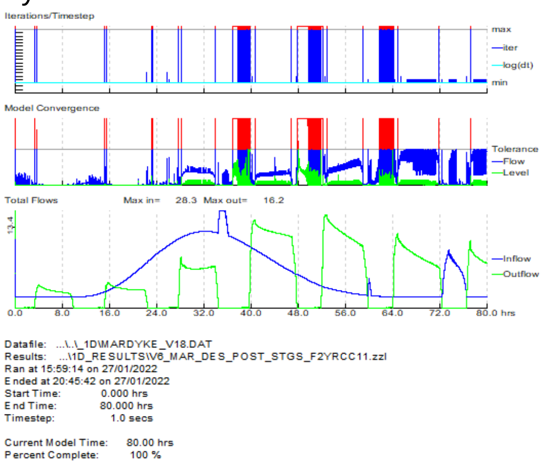


A.1.7



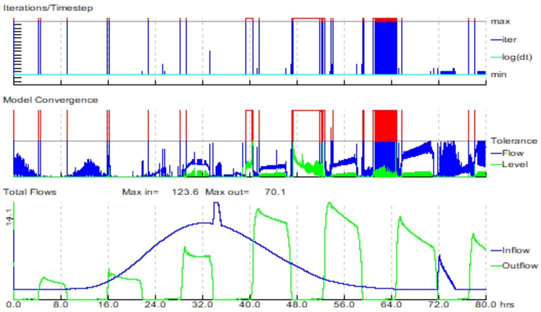
E.2 Simulation bitmaps for design runs

Table E.2 Design simulations bitmap outputs

<table>
<tr><th>Pre-development</th><th>Post-development</th></tr>
<tr><td>2yr 6%CC

</td><td>2yr 6%CC

</td></tr>
<tr><td>2yr 11%CC

</td><td>2yr 11%CC

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

<table>
<tr><th>Pre-development</th><th>Post-development</th></tr>
<tr><td>

2yr 17%CC

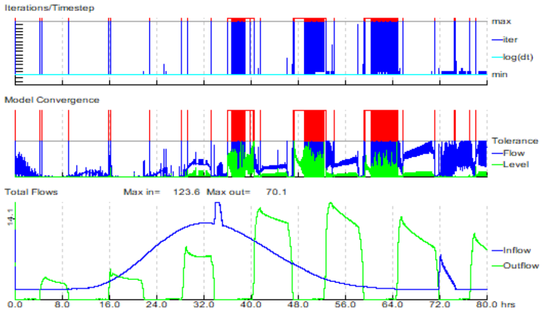


Datafile: ...\.._1D\MARDYKE_V18.DAT
Results: ...\1D_RESULTS\V6_MAR_DES_PRE_STGS_F2YRCC17.zzl
Ran at 10:26:21 on 27/01/2022
Ended at 15:06:54 on 27/01/2022
Start Time: 0.000 hrs
End Time: 80.000 hrs
Timestep: 1.0 secs

Current Model Time: 80.00 hrs
Percent Complete: 100 %

</td><td>

2yr 17%CC

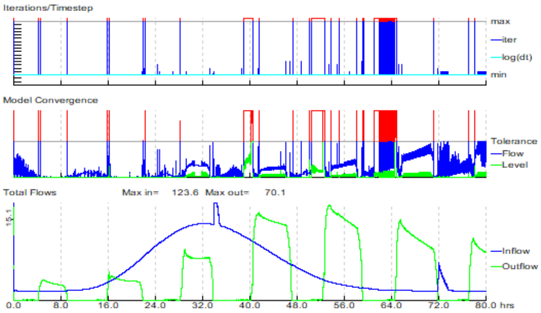


Datafile: ...\.._1D\MARDYKE_V18.DAT
Results: ...\1D_RESULTS\V6_MAR_DES_POST_STGS_F2YRCC17.zzl
Ran at 14:07:21 on 27/01/2022
Ended at 19:02:28 on 27/01/2022
Start Time: 0.000 hrs
End Time: 80.000 hrs
Timestep: 1.0 secs

Current Model Time: 80.00 hrs
Percent Complete: 100 %

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

2yr 26%CC

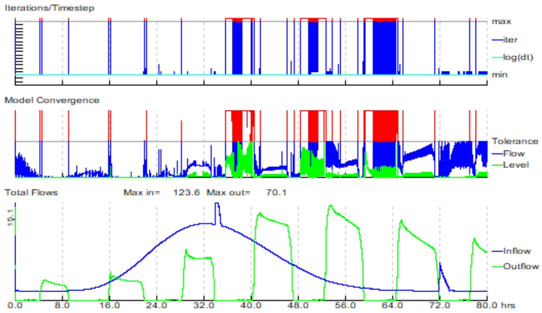


Datafile: ...\.._1D\MARDYKE_V18.DAT
Results: ...\1D_RESULTS\V6_MAR_DES_PRE_STGS_F2YRCC26.zzl
Ran at 04:29:52 on 27/01/2022
Ended at 09:10:56 on 27/01/2022
Start Time: 0.000 hrs
End Time: 80.000 hrs
Timestep: 1.0 secs

Current Model Time: 80.00 hrs
Percent Complete: 100 %

</td><td>

2yr 26%CC



Datafile: ...\.._1D\MARDYKE_V18.DAT
Results: ...\1D_RESULTS\V6_MAR_DES_POST_STGS_F2YRCC26.zzl
Ran at 04:11:26 on 27/01/2022
Ended at 09:08:34 on 27/01/2022
Start Time: 0.000 hrs
End Time: 80.000 hrs
Timestep: 1.0 secs

Current Model Time: 80.00 hrs
Percent Complete: 100 %

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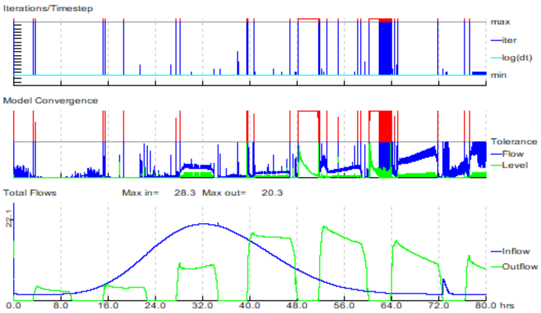
10yr 6%CC

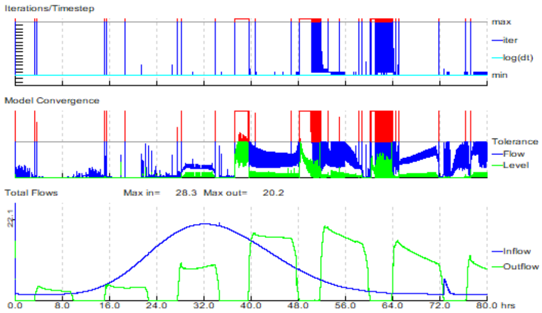


Datafile: ...\.._1D\MARDYKE_V18.DAT
Results: ...\1D_RESULTS\V6_MAR_DES_PRE_STGS_F10YRCC6.zzl
Ran at 02:45:09 on 27/01/2022
Ended at 07:36:27 on 27/01/2022
Start Time: 0.000 hrs
End Time: 80.000 hrs
Timestep: 1.0 secs

Current Model Time: 80.00 hrs
Percent Complete: 100 %

</td><td>

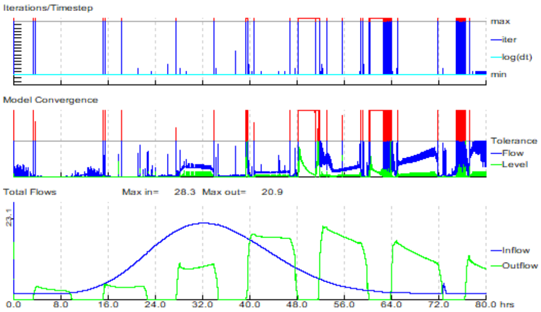
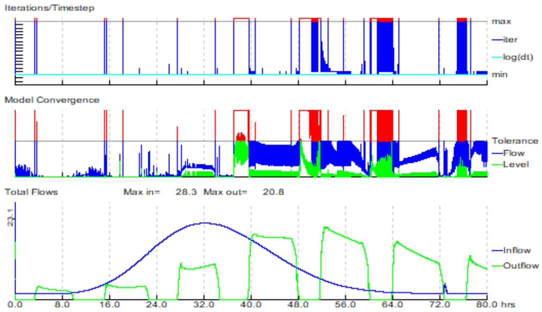
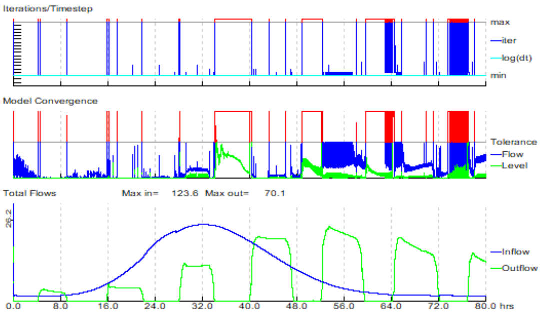
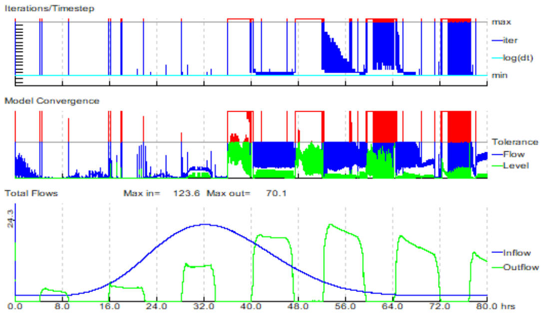
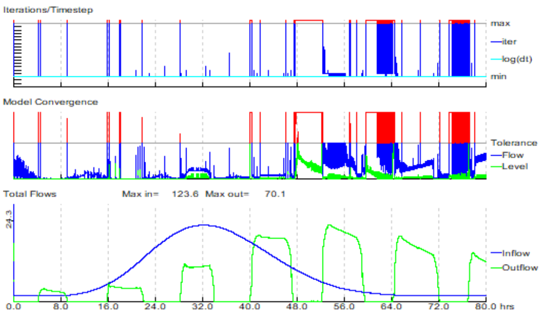
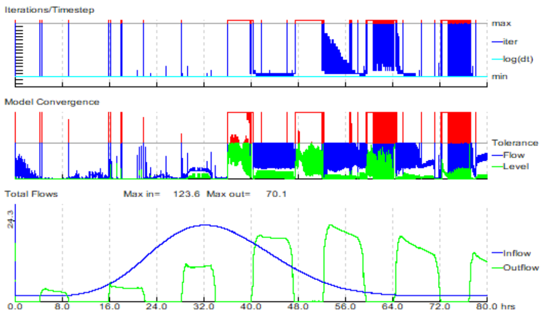
10yr 6%CC



Datafile: ...\.._1D\MARDYKE_V18.DAT
Results: ...\1D_RESULTS\V6_MAR_DES_POST_STGS_F10YRCC6.zzl
Ran at 14:17:12 on 27/01/2022
Ended at 19:12:28 on 27/01/2022
Start Time: 0.000 hrs
End Time: 80.000 hrs
Timestep: 1.0 secs

Current Model Time: 80.00 hrs
Percent Complete: 100 %

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

Pre-development	**Post-development**
10yr 11%CC  Datafile: ...\.._1D\MARDYKE_V18.DAT Results: ...\1D_RESULTS\V6_MAR_DES_PRE_STGS_F10YRCC11.zzl Ran at 03:33:29 on 27/01/2022 Ended at 08:30:01 on 27/01/2022 Start Time: 0.000 hrs End Time: 80.000 hrs Timestep: 1.0 secs Current Model Time: 80.00 hrs Percent Complete: 100 %	10yr 11%CC  Datafile: ...\.._1D\MARDYKE_V18.DAT Results: ...\V6_MAR_DES_POST_STGS_F10YRCC11.zzl Ran at 09:48:40 on 27/01/2022 Ended at 15:00:49 on 27/01/2022 Start Time: 0.000 hrs End Time: 80.000 hrs Timestep: 1.0 secs Current Model Time: 80.00 hrs Percent Complete: 100 %
10yr 26%CC  Datafile: ...\.._1D\MARDYKE_V18.DAT Results: ...\1D_RESULTS\V6_MAR_DES_PRE_STGS_F10YRCC26.zzl Ran at 05:56:29 on 27/01/2022 Ended at 11:21:33 on 27/01/2022 Start Time: 0.000 hrs End Time: 80.000 hrs Timestep: 1.0 secs Current Model Time: 80.00 hrs Percent Complete: 100 %	10yr 26%CC  Datafile: ...\.._1D\MARDYKE_V18.DAT Results: ...\V6_MAR_DES_POST_STGS_F10YRCC17.zzl Ran at 13:40:58 on 27/01/2022 Ended at 18:51:43 on 27/01/2022 Start Time: 0.000 hrs End Time: 80.000 hrs Timestep: 1.0 secs Current Model Time: 80.00 hrs Percent Complete: 100 %
10yr 17%CC  Datafile: ...\.._1D\MARDYKE_V18.DAT Results: ...\1D_RESULTS\V6_MAR_DES_PRE_STGS_F10YRCC17.zzl Ran at 13:34:03 on 27/01/2022 Ended at 18:34:59 on 27/01/2022 Start Time: 0.000 hrs End Time: 80.000 hrs Timestep: 1.0 secs Current Model Time: 80.00 hrs Percent Complete: 100 %	10yr 17%CC  Datafile: ...\.._1D\MARDYKE_V18.DAT Results: ...\V6_MAR_DES_POST_STGS_F10YRCC17.zzl Ran at 13:40:58 on 27/01/2022 Ended at 18:51:43 on 27/01/2022 Start Time: 0.000 hrs End Time: 80.000 hrs Timestep: 1.0 secs Current Model Time: 80.00 hrs Percent Complete: 100 %

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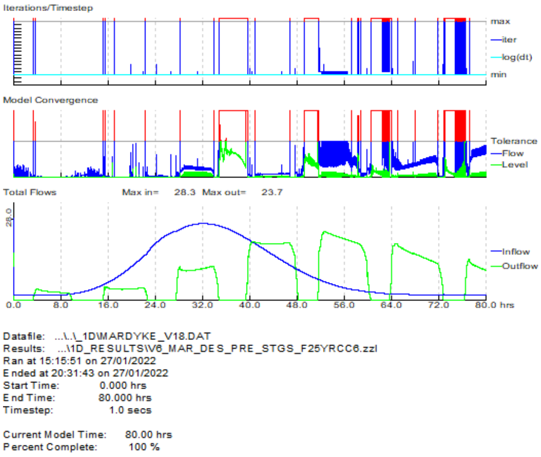
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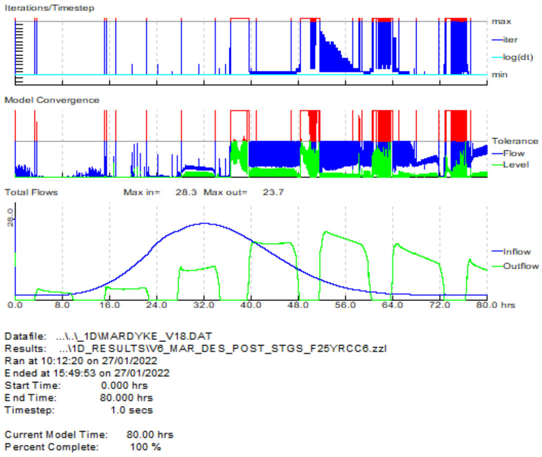
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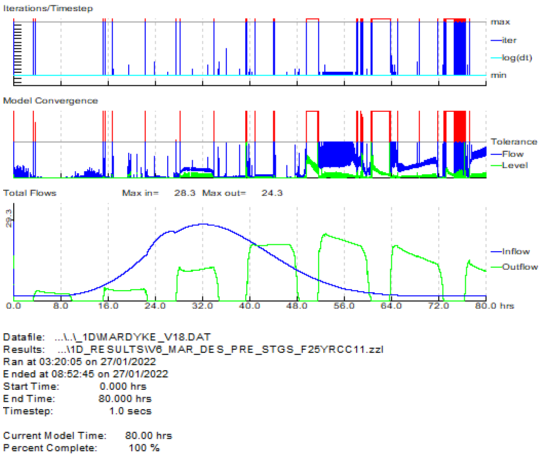
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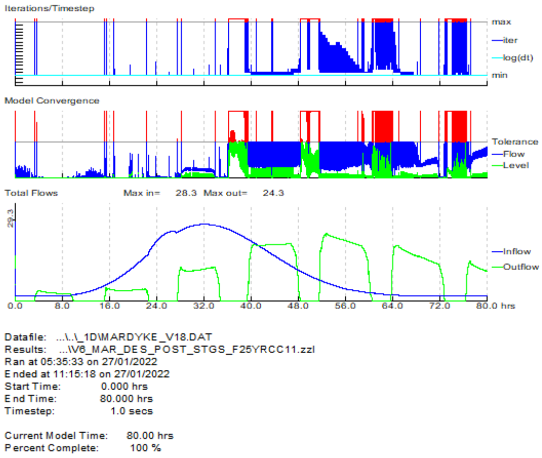
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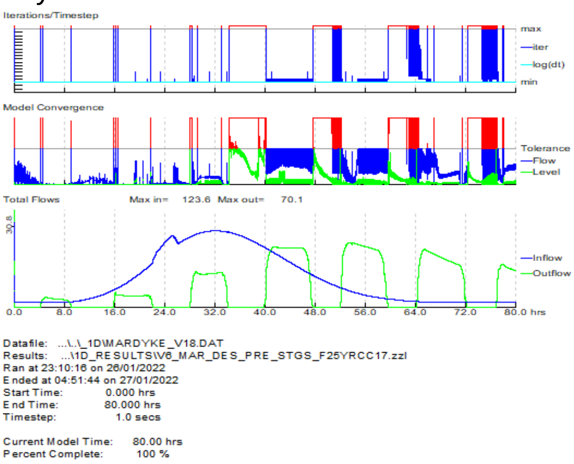
<tr><td>25yr 17%CC

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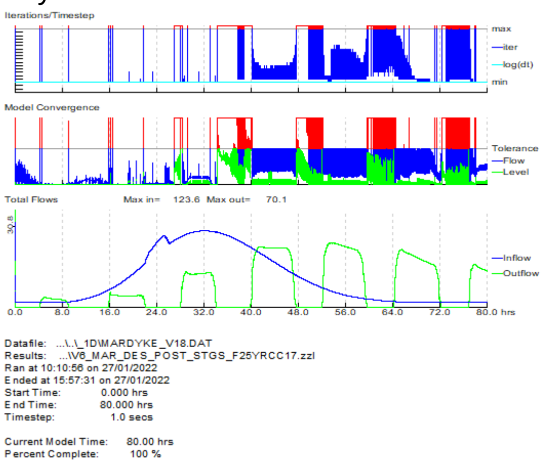
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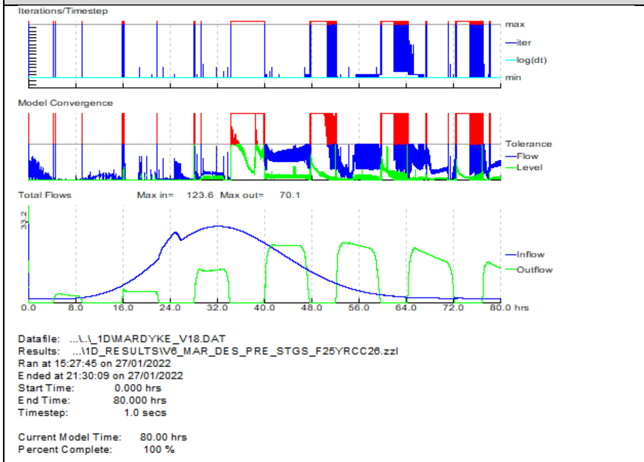
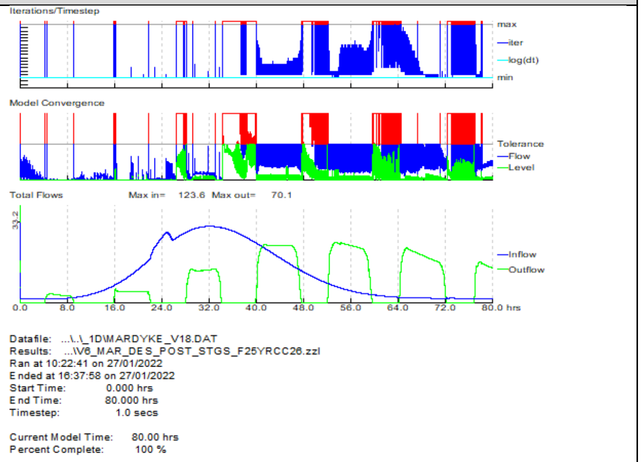
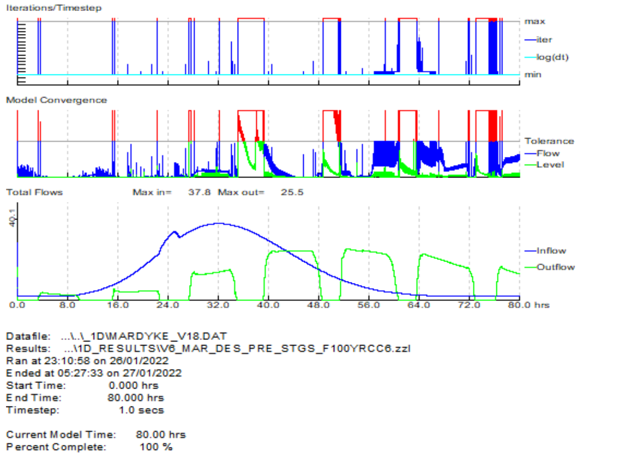
Pre-development



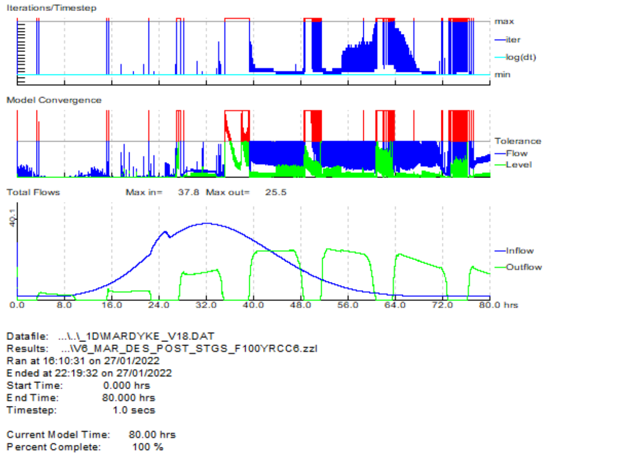
Post-development



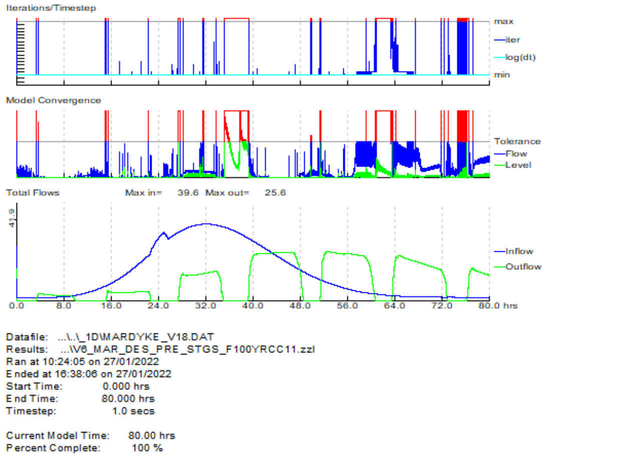
100yr 6%CC



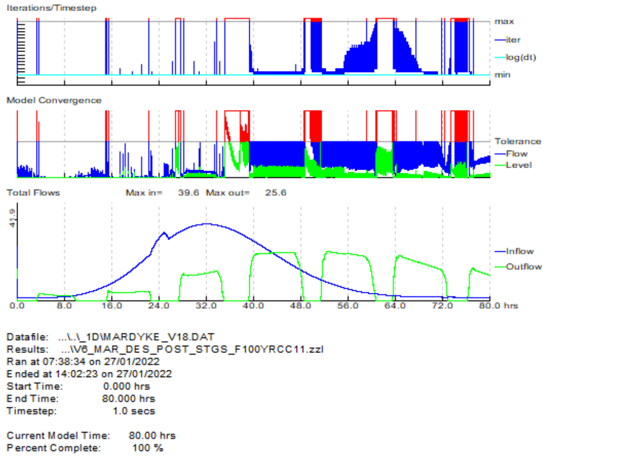
100yr 6%CC



100yr 11%CC

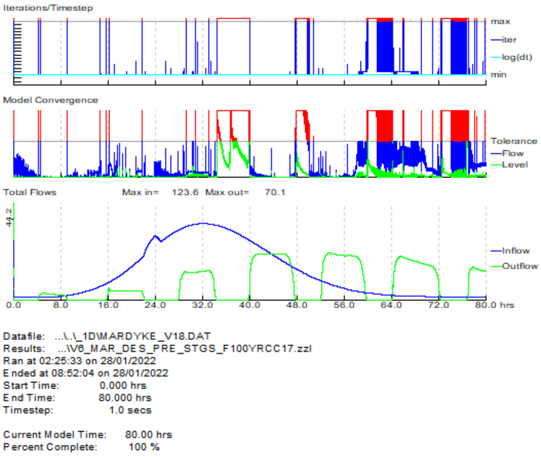


100yr 11%CC



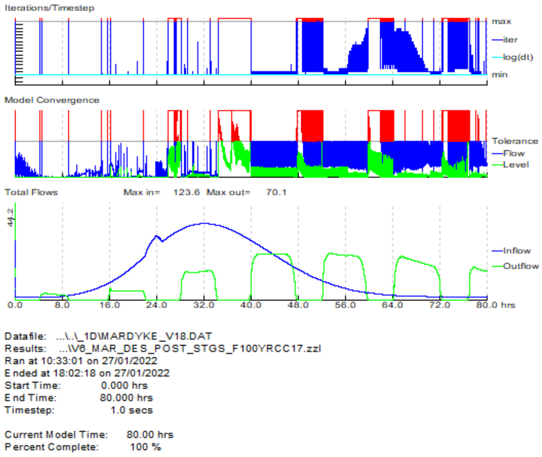
Pre-development

100yr 17%CC



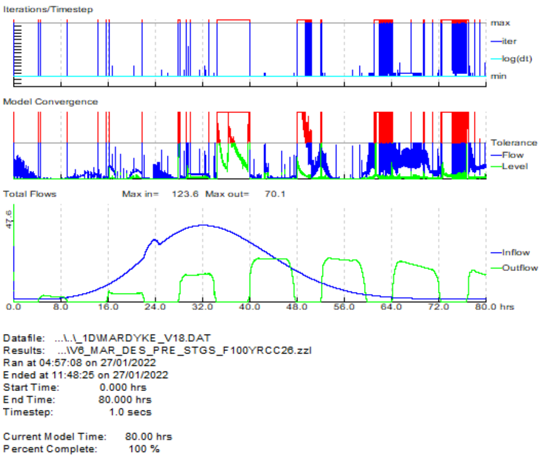
Post-development

100yr 17%CC



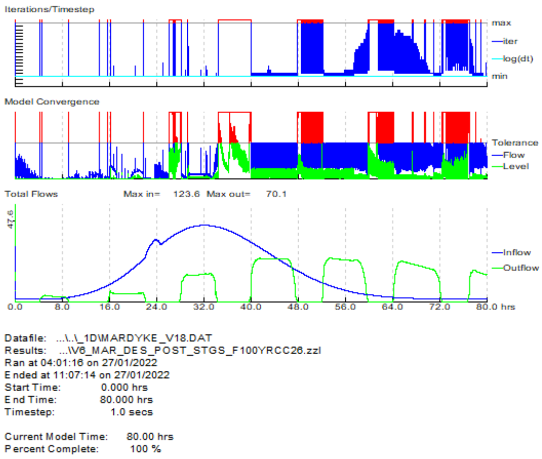
Pre-development

100yr 26%CC



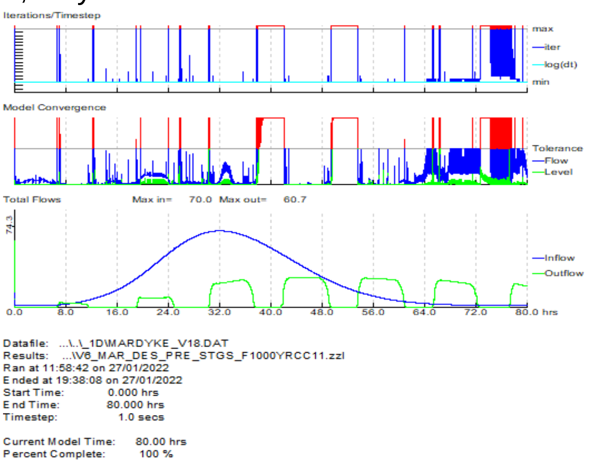
Post-development

100yr 26%CC



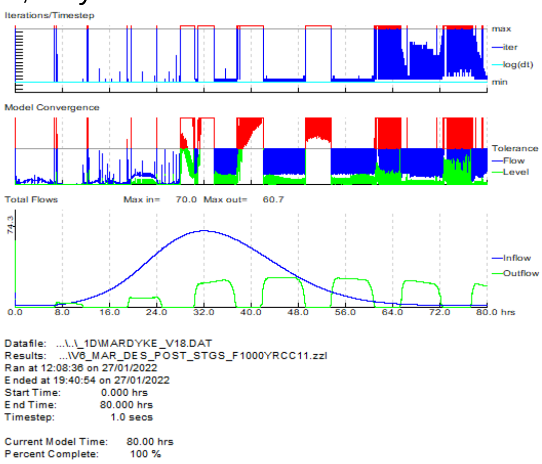
Pre-development

1,000yr 11%CC



Post-development

1,000yr 11%CC



<table>
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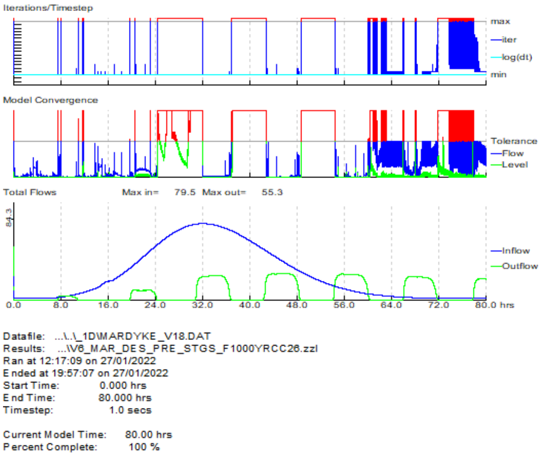
1,000yr 26%CC



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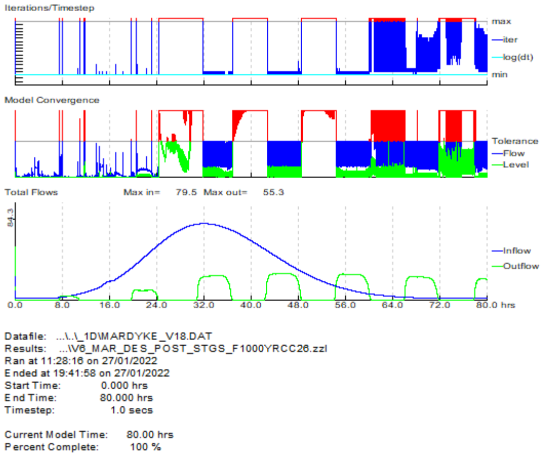
1,000yr 26%CC



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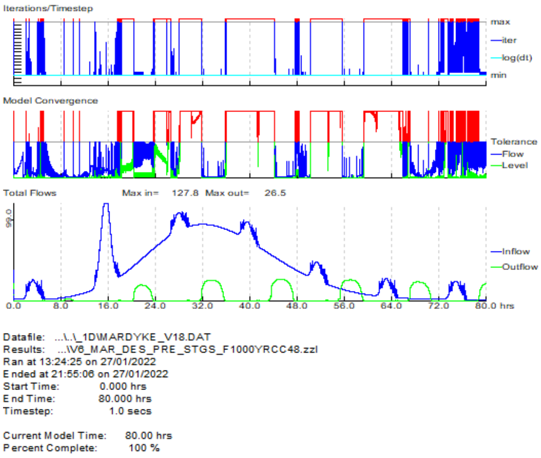
1,000yr 48%CC



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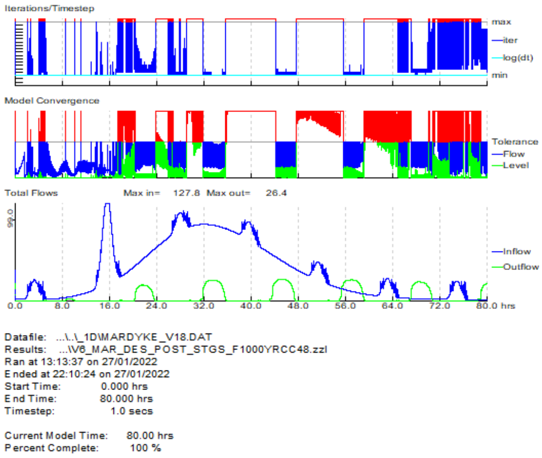
1,000yr 48%CC



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