national highways

Lower Thames Crossing

6.3 Environmental Statement Appendices
Appendix 14.6 – Flood Risk Assessment - Part 5

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

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

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Lower Thames Crosing

6.3 Environmental Statement Appendices Appendix 14.6 – Flood Risk Assessment - Part 5

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1 Introduction

1.1 Context

1.1.1 This document forms Part 5 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).

1.2 Form of assessment

1.2.1 The FRA is presented in nine separate parts. 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 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 West Tilbury Main

1.5.1 The brief for this Project reflected the need for a holistic appraisal of flood risk on a catchment-wide level from the fluvial sources of flood risk, as well as tidal flood risk associated with a breach of River Thames tidal defences.

1.5.2 The aim of the fluvial assessment is to build a 1D/2D coupled Flood Modeller/TUFLOW model representing relevant features of the catchment and to produce flood mapping for a range of design events.

1.5.3 This document summarises the modelling approach followed to assess fluvial flood risk where the Project would cross the West Tilbury Main fluvial floodplains. The form of this part is presented in Plate 1.2.

1.5.4 This document also details breach modelling undertaken to assess the impacts of a breach of River Thames tidal defences on the Project, and the impact of the Project on flood risk elsewhere during a breach (Annex E).

Plate 1.1 Form of the FRA

Part	Description
Core 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 parts	
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 5 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 description of the Project 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

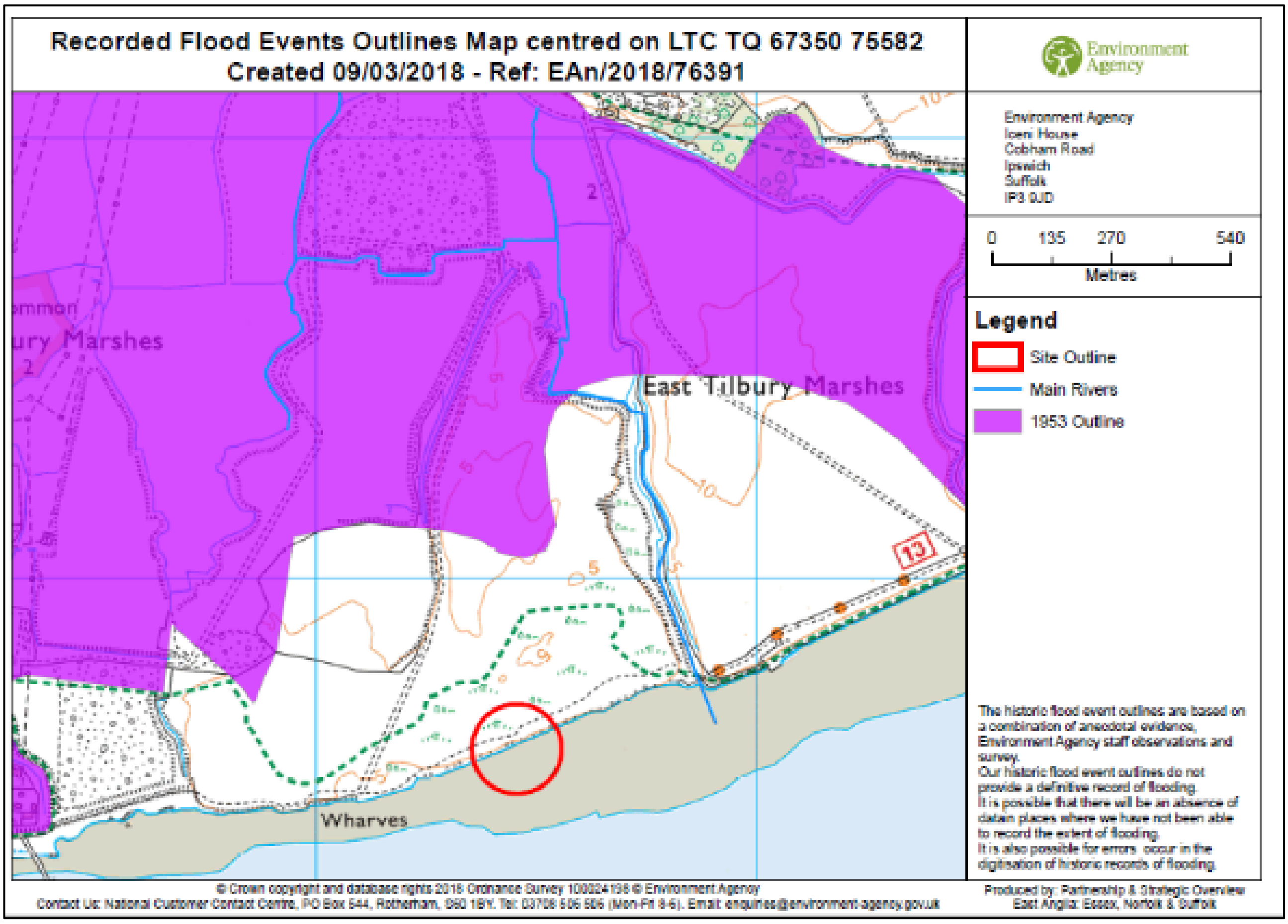
2.1.1 Tilbury is located on the north bank of the Thames Estuary on low-lying marshland. The topography is essentially flat, with ground levels at around 0m above ordnance datum (AOD). The study area is located to the north of Tilbury and incorporates West Tilbury Main (main river) which discharges into the tidal River Thames via the Bowaters Sluice. Bowaters Sluice consists of a pre-cast concrete culvert connecting the landward watercourse to the tidal River Thames, a penstock with manhole access, and an outfall flap valve. Siteinspection details indicate that the sluice system was not functioning as intended (in February 2019), with sitting water at the inlet possibly due to a blockage within the culvert.

2.1.2 Flood Estimation Handbook (FEH) catchment descriptors for the study area indicate that the catchment is permeable (BFIHOST values from 0.765 to 0.865 – see Section 4). However, soils maps (Cranfield University, 2020) indicate that the soils in the southern part of the study area have naturally high groundwater levels, and so may be more responsive to rainfall than typical permeable catchments (further details are in Section 4). The Environment Agency's Easimap dataset suggests the predominant soil type is a seasonally wet deep clay (WALLASEA 1) which is a marine alluvium, and this overlays a chalk bedrock. The study area is almost entirely rural.

2.2 Flood history

2.2.1 A historic flood map outline for the 1953 flood event was provided by the Environment Agency (Plate 2.1). The historic flood map covers the southern part of the study area. The 1953 flood is understood to have been a tidal flooding event and so these flood extents are not considered to be representative of West Tilbury Main fluvial flood extents. Note that the 'Site Outline' shown in Plate 2.1 is not associated with the Project but is a spatial locator used by the Environment Agency when preparing the map for use here.

Plate 2.1 Historic 1953 flood outline (source: Environment Agency)



2.3 Previous studies

2.3.1 No previous studies are available.

3 Data input plan

3.1 Data

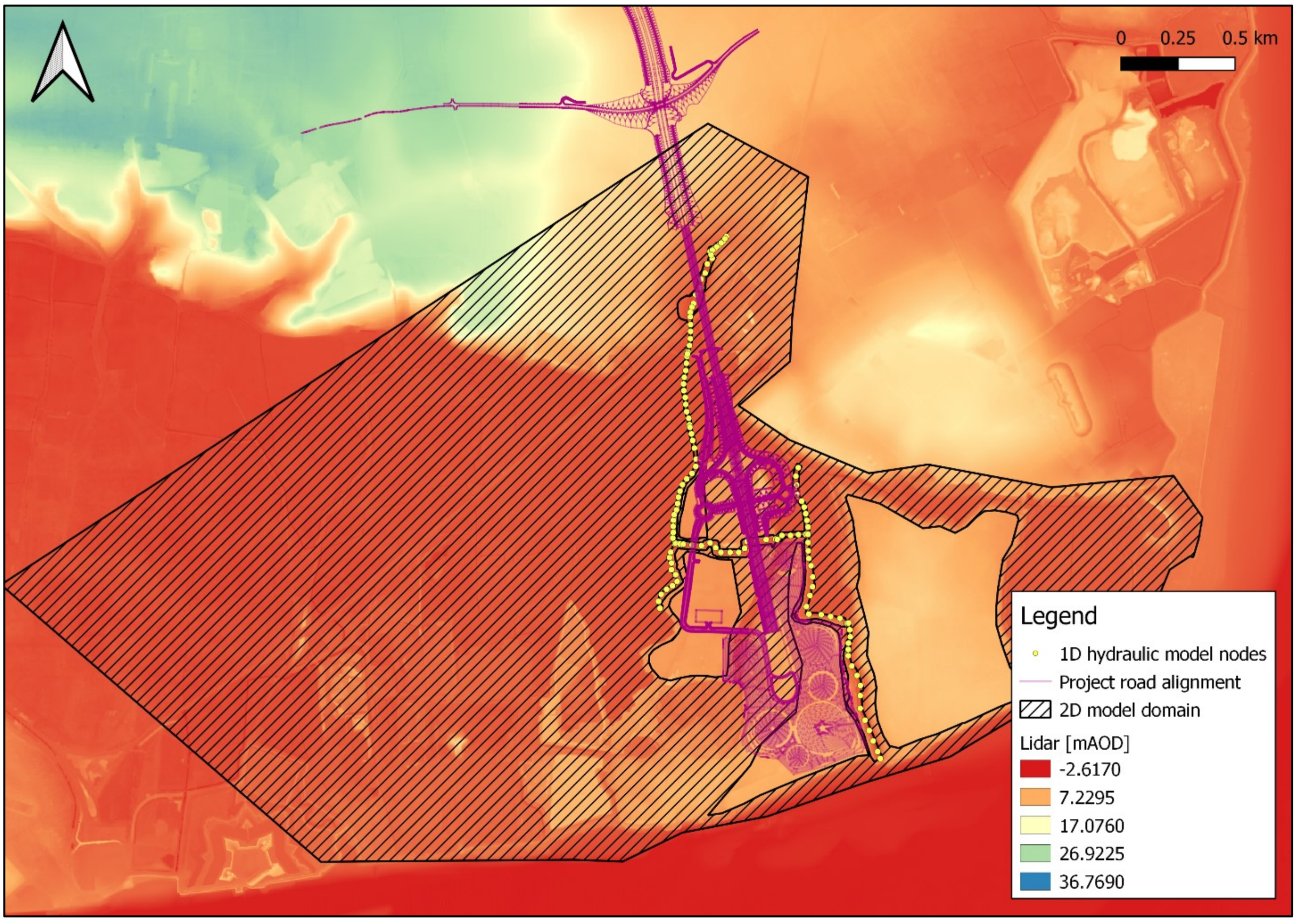
3.1.1 A range of data has been provided by the Environment Agency and Thurrock Council to develop the 1D-2D model. The data is summarised in Table 3.1. The extent of the new model and the 2m-resolution Light Detection and Ranging (LiDAR) is displayed in Plate 3.1.

Table 3.1 Provided data

Data type	Data format	Comment	Source
Existing modelling study	XLSX	Design tide level time series from Thurrock Strategic Flood Risk Assessment (SFRA) Breach Modelling Study	Thurrock Council (2018) – model data received April 2019
	PDF	Thames Estuary 2100 (TE2100) design Extreme Water Levels (EWLs)	Environment Agency (provided as part of EA FRA Product 4 dataset, and noted to be from TE2100 project) received in June 2019
LiDAR	ASC	2m resolution and 25cm horizontal resolution (dated 2017)	Environment Agency – downloaded from the Defra data services platform (https://environment.data.gov.uk/) – downloaded in August 2018.
Tide level gauges	XLSX	Station name: Tilbury t.s Station number: t475601 Period of records: 1996–2005	Environment Agency hydrometry team (data received in July 2019)
	XLSX	Station name: Tilbury Reference: E23873 Period of records: 1994–2019	Environment Agency hydrometry team (data received in July 2019)
	XLSX	Station name: TILBURY TL Station number: 5620TH Period of records: 1994–2019	Environment Agency hydrometry team (data received in July 2019)
Channel topographic survey	DWG, PDF, DAT, JPG, DOCX, XLSX, TXT	Flood Modeller Network (.dat) files, survey data, photographs, survey report	Project survey (dated January 2019)
Asset data	PDF	Flood defence data	Environment Agency (provided as part of EA FRA Product 4 dataset) – received in November 2018

Data type	Data format	Comment	Source
FEH catchment extents and catchment descriptors	SHP, CD files	Downloaded from FEH web service	UK Centre for Ecology and Hydrology (2020a) – catchment data downloaded in February 2019
Project route	DWG, SHP, XLSX	Post-development Project route including elevations	Project design (2022)
Project watercourse crossings	XLSX	Dimensions of the proposed Watercourse Crossings (HE540039-CJV-EFR-GEN-CALC-ENV-0005.xlsx)	Project design (2022)
Proposed land raising at Goshems Farm	PDF	Goshems Farm Reclamation Scheme, Planning Application 1998 (https://regs.thurrock.gov.uk/online-applications/applicationDetails.do?activeTab=documents&keyVal=NNKBVHQG0LR00)	Thurrock Council online planning applications – accessed May 2020

Plate 3.1 Model extent and 2m resolution LiDAR (pre-development)



4 Hydrological assessment

4.1 Catchment delineation

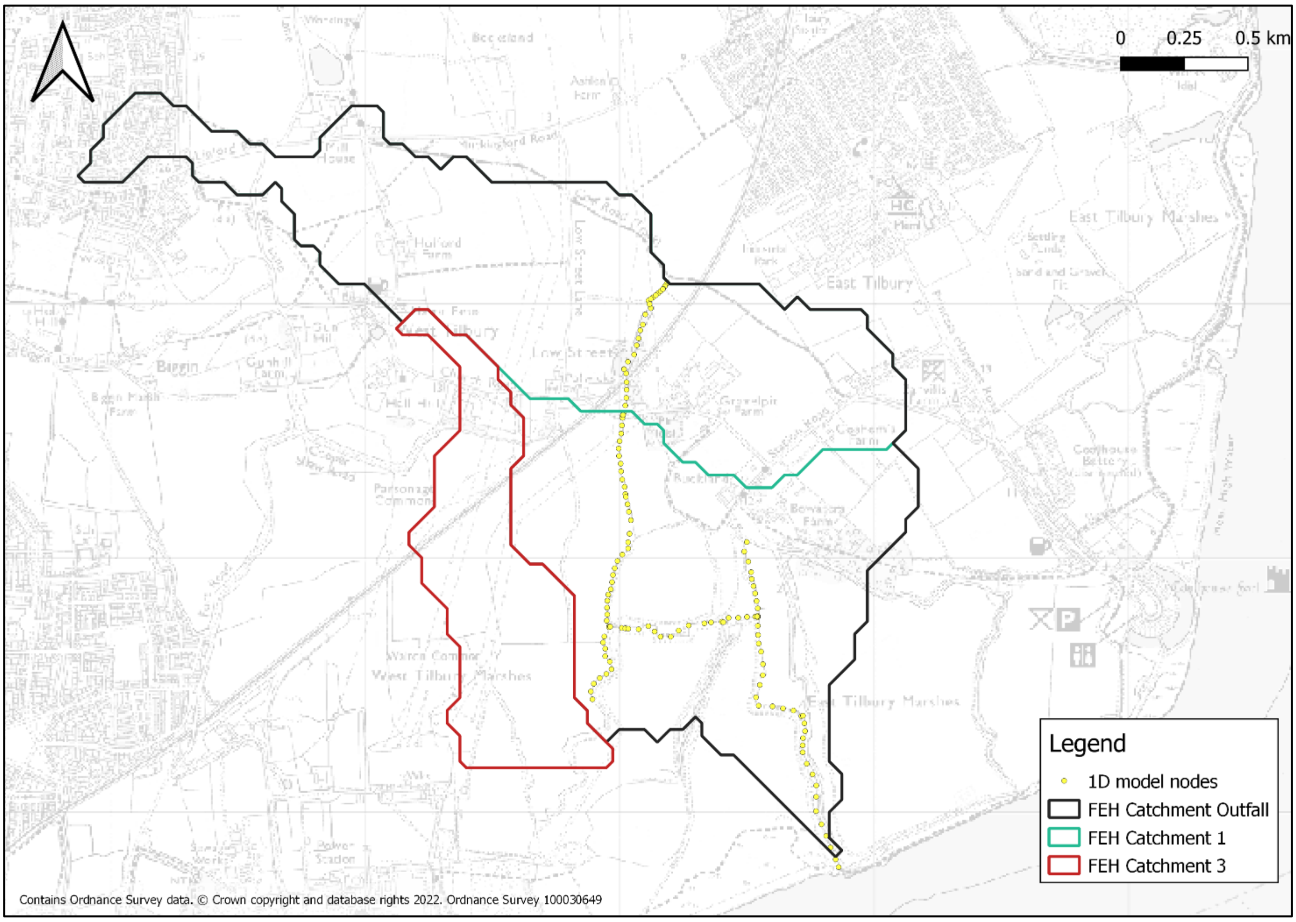
FEH sub-catchments

4.1.1 FEH catchment boundaries, downloaded from the FEH web service (UK Centre for Ecology and Hydrology, 2020a), are listed in Table 4.1 and shown in Plate 4.1.

Table 4.1 Downloaded FEH catchment boundaries

Catchment boundary	Date downloaded	Name
FEH_Catchment_567000_177600.shp	25/03/2019	FEH_Catchment 1
FEH_Catchment_566400_176250.shp	25/03/2019	FEH_Catchment 3
FEH_Catchment_567850_175850.shp	13/06/2017	FEH_Catchment Outfall

Plate 4.1 FEH catchment extents



LiDAR derived catchment extents

4.1.2 Ground levels in the mid-southern part of the study area are generally level, and ground levels in the northern and eastern areas are generally undulating.

4.1.3 FEH delineated catchment boundaries are not reliable for small flat catchments, due to the resolution of the FEH national Digital Terrain Model. Hence LiDAR topographic data was used in the current study to improve estimation of the catchment boundaries, also informed by consideration of Ordnance Survey (OS) mapping data.

4.1.4 This delineation approach involved a combination of automatically producing catchment extents using the hydrology toolbox from the Spatial Analyst tools of the ArcMap software and drawing the catchments manually, based on OS mapping and LiDAR derived topographic datasets of 2m and 0.25m resolution.

4.1.5 The final delineation of the LiDAR derived catchment extents is shown in Plate 4.2. A detailed description of the methodology followed for the delineation of catchment boundaries for each of the six individual catchments is provided in Annex C.

Uncertainty in catchment delineation

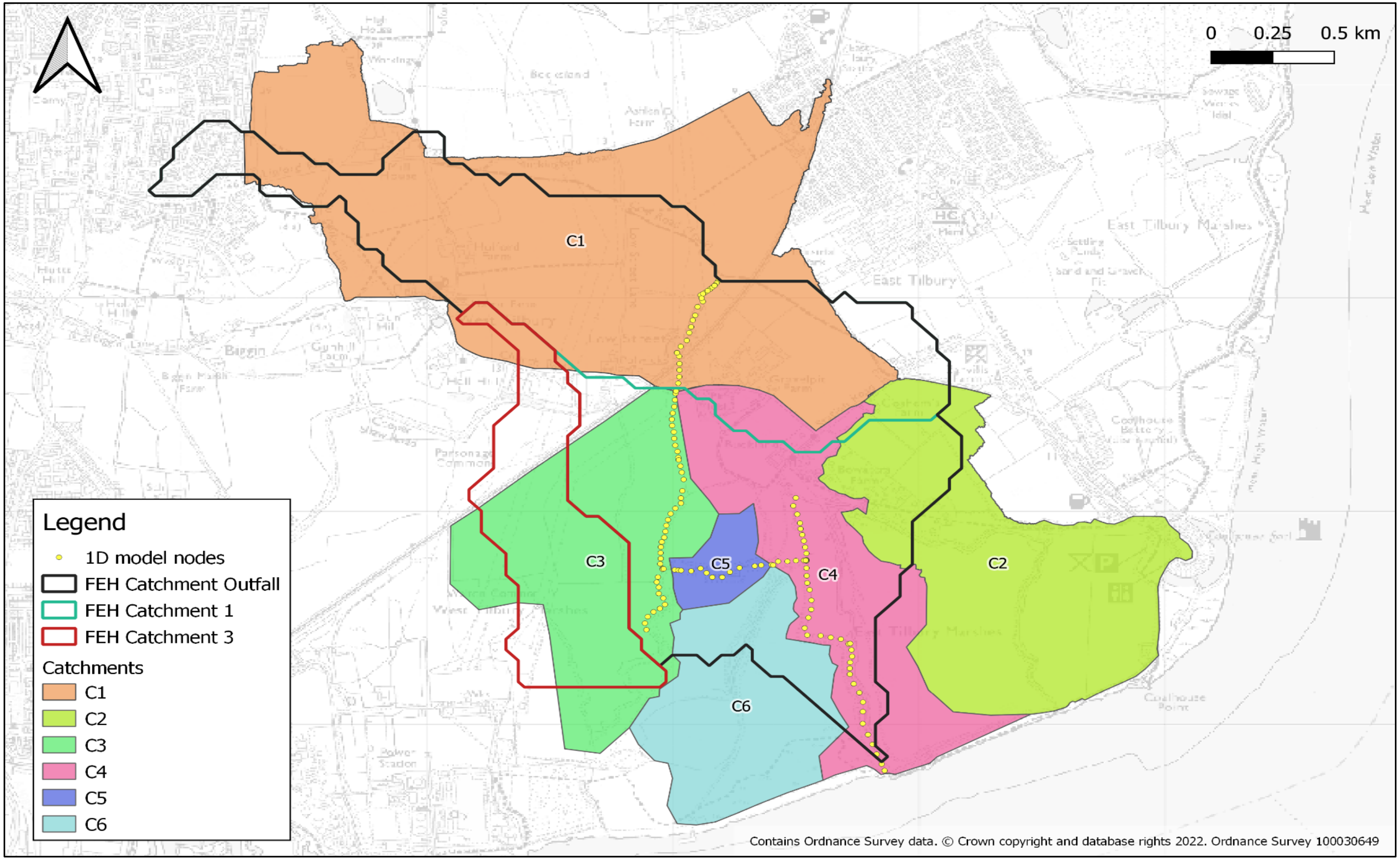
4.1.6 As most of the study site lies in a very flat topographic area, and delineation of catchment extents is more uncertain in flat areas, the catchment delineation is correspondingly uncertain in some areas. This uncertainty in catchment area contributed to overall uncertainty in the design flow estimates. Table 4.2 lists the relative uncertainty in estimating the extents of Catchments 1 to 6. Whilst the design flow estimates are uncertain, the selection of preferred design flood estimates is precautionary (Section 4.5) and simulated flood extents have been 'sense checked' against the local flood risk knowledge of Thurrock Council and the Environment Agency (Section 4.5).

Table 4.2 Uncertainty in catchment delineation

Name	Uncertainty (justification)	Area (km^2)
Catchment 1	**Low** – 2m LiDAR and ArcMap tool used and manually modified to specify the road network as boundaries, as appropriate.	2.39
Catchment 2	**Medium** – 25cm LiDAR and ArcMap tool used and manually modified to set the high ground levels as boundaries, as appropriate; catchment extent on the eastern side of the catchment has higher uncertainty due to the flat gradient.	1.23
Catchment 3	**High** – The topography is very flat without clear flow direction. Railway line has been chosen as the catchment boundary.	1.00
Catchment 4	**Medium** – The catchment delineation has been manually derived from the 25cm LiDAR data.	0.90

Name	Uncertainty (justification)	Area (km^2)
Catchment 5	**High** – The catchment delineation has been manually derived from the 25cm LiDAR data. Unclear gradient in the eastern part of the catchment.	0.12
Catchment 6	**Medium** – The catchment delineation has been manually derived from the 25cm LiDAR data.	0.65

Plate 4.2 Final catchment delineation



4.2 Catchment descriptors

Overview

4.2.1 FEH catchment descriptors for the study sub-catchments, Catchments 1 to 6, were derived from representative FEH catchment descriptors downloaded from the FEH web service (UK Centre for Ecology and Hydrology, 2020a). The methodology applied to estimate the catchment descriptors for each study sub-catchment is presented in Table 4.3.

Table 4.3 Catchment descriptors derivation methodology

Catchment	Representative FEH catchment / adjustment methodology	* Inter spreadsheet downstream catchment	* Inter spreadsheet upstream catchment	Justification
C1	FEH Catchment 1 / area-weighting	N/A	N/A	The catchments are largely overlapping
C2	FEH Intervening catchment / area-weighting	FEH Catchment Outfall	FEH Catchment 1	Similar to the resulting intervening catchments
C3	FEH Catchment 3 / area-weighting	N/A	N/A	FEH Catchment 3 was used instead of FEH_Intervening catchment, as catchments FEH Catchment 3 and C3 are predominantly flat, in contrast to the 'Intervening' catchment which also contains hilly areas. (For derivation of DPLBAR value, see paragraph 4.2.12.)
C4	FEH Intervening catchment / area-weighting	FEH Catchment Outfall	FEH Catchment 1	Similar to the resulting intervening catchments
C5	FEH Intervening catchment / area-weighting	FEH Catchment Outfall	FEH Catchment 1	Similar to the resulting intervening catchments
C6	FEH Intervening catchment / area-weighting	FEH Catchment Outfall	FEH Catchment 1	Similar characteristics

** 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.*

4.2.2 Table 4.4 and Table 4.5 provide an overview of the approach followed to derive catchment descriptors required for use in design flood flow estimation by the FEH rainfall-runoff model and FEH statistical method respectively. Further details of the derivation of catchment descriptor values is detailed in paragraphs 4.2.5 to 4.2.18.

Table 4.4 Catchment descriptors required for FEH rainfall-runoff model

Catchments	Catchment descriptors*	Methodology
C1 to C6	AREA (catchment area)	Measured in GIS
	SAAR (standard-period annual average rainfall)	Same as FEH 'Outfall' catchment
	URBEXT1990 (measure of catchment urbanisation)	Set to zero
	SPRHOST (standard percentage runoff estimated from soil types)	Based on FEH revised representative catchments and information about soil land classification and landfill coverage
	FEH rainfall model depth, duration and frequency (DDF) parameters	Same as FEH 'Outfall' catchment
	DPLBAR (catchment mean drainage path length)	Scaled according to $Area^{0.548}$ in accordance with FEH regression equation for DPLBAR (see paragraph 4.2.12)
	DPSBAR (catchment mean drainage path slope)	Same as for representative catchment

** Catchment Descriptors are as defined in FEH volume 5, UK Centre for Ecology and Hydrology (1999)*

Table 4.5 Catchment descriptors required for FEH statistical method

Catchments	Catchment descriptors*	Methodology
C1 and C_Outfall***	AREA (catchment area)	Measured in GIS
	SAAR (standard annual average rainfall)	Same as FEH 'Outfall' catchment
	URBEXT2000 (measure of catchment urbanisation)	Set to zero
	FARL (measure of flood attenuation due to reservoirs and lakes)	Set to 1
	BFIHOST (fraction of runoff from base flow estimated from soil types)	Based on FEH revised representative catchments and information about soil land classification except for C3, C5, C6 which are set to 0.6
	FPEXT (measure of floodplain extent within a catchment)	Same as for representative catchments, except for C_Outfall which applies alternative area-weighting

** Catchment Descriptors are as defined in FEH volume 5, UK Centre for Ecology and Hydrology (1999), Defra/Environment Agency (2006) and Kjeldsen et al. (2008)*
*** C_Outfall is the catchment comprising the sum of the individual catchment areas (C1 to C6)*

Intervening catchment descriptors

4.2.3 The intervening catchment between FEH_Catchment Outfall and FEH_Catchment 1 (Plate 4.2) was considered representative of Catchments C2, C4, C5 and C6 due to the similarity of their underlying topography. The Inter.xlsx spreadsheet has therefore been used to calculate the catchment descriptors for this intervening area based on the downloaded FEH catchment descriptors for the upstream FEH Catchment 1 and the downstream FEH Catchment Outfall. This intervening catchment is named ‘FEH Intervening catchment’.

BFIHOST adjustment

4.2.4 The FEH BFIHOST values have been adjusted to better represent the soil responsiveness to rainfall, based on soils maps (Cranfield University, 2020). FEH derived BFIHOST values are relatively high, indicating that the catchments are permeable. However, the soils map (Plate 4.3) indicates that the soils in the southern part of the catchment (blue areas) have naturally high groundwater levels, and so are likely to be more responsive to rainfall than typical permeable catchments.

4.2.5 The soil class shown in blue in Plate 4.3 constitutes marshland (i.e. 'naturally wet' area) and hence BFIHOST values were reduced to 0.6. SPRHOST values were increased to 40 for this area, to represent an increased response to rainfall. For the brown coloured area (freely draining), FEH BFIHOST and SPRHOST values were retained.

4.2.6 As shown in Plate 4.3, the FEH catchments include both soil classes. The adjustment of the BFIHOST for the FEH representative catchments (i.e., FEH Catchment Outfall, FEH Catchment 1 and FEH Catchment 3) applied an area-weighting of assumed values for the blue area and FEH catchment descriptor values, based on the area fractions listed in Table 4.6.

Plate 4.3 Soil classification for FEH catchments

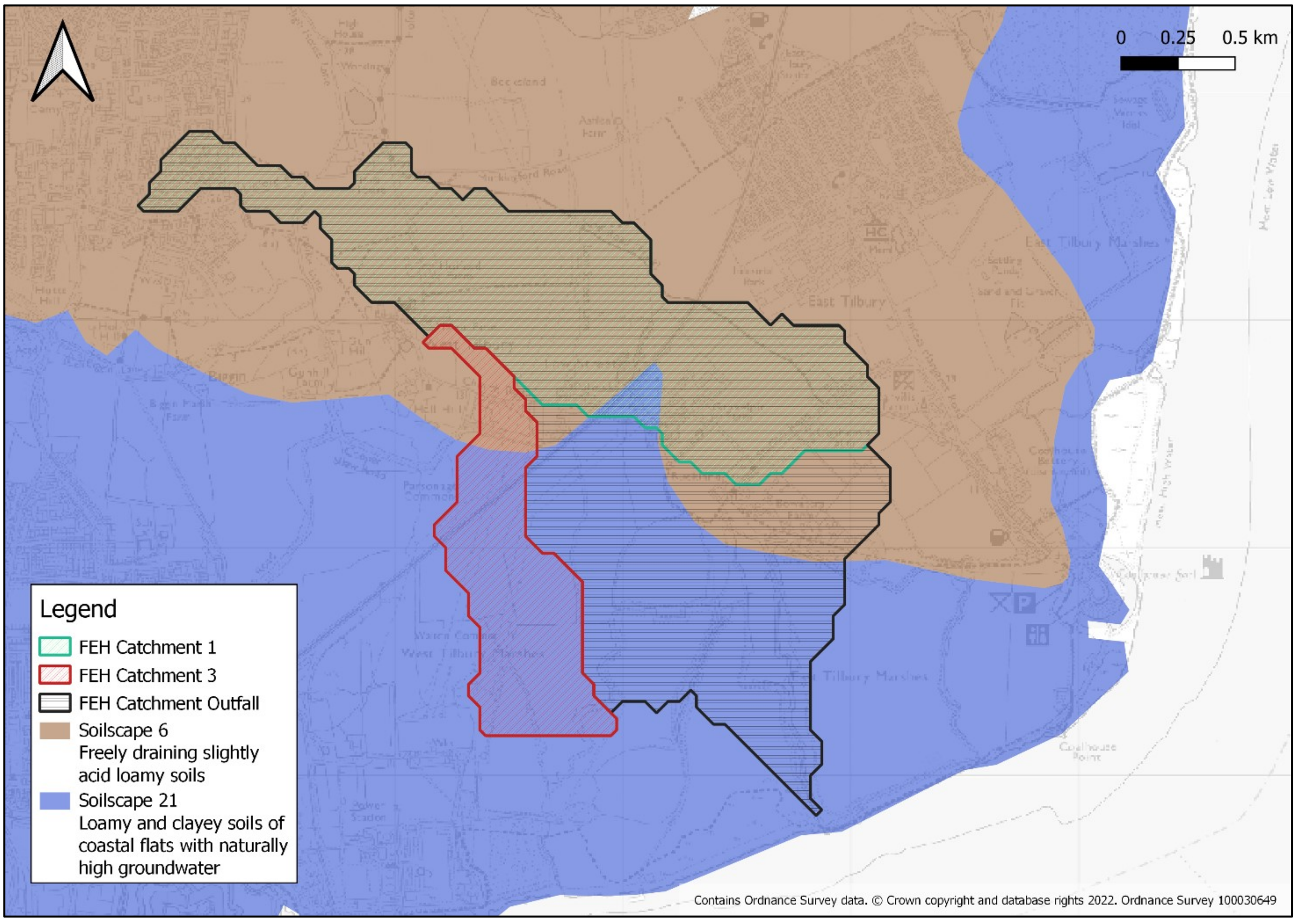


Table 4.6 Soil classification area-weighting for BFIHOST adjustment

Catchments	FEH catchment outfall	FEH Catchment 1	FEH Catchment 3	FEH intervening catchment
Drainage area (km^2) (ArcMAP)	3.388	1.815	0.670	1.57
'Blue' area (km^2)	1.244	0.045	0.567	1.197
'Brown' area (km^2)	2.143	1.770	0.103	0.373
Fraction 'Blue'	0.367	0.025	0.846	0.762
Fraction 'Brown'	0.633	0.975	0.154	0.238
$BFIHOST_{FEH}$	0.833	0.865	0.765	0.796
$BFIHOST_{Adjusted}$	0.747	0.858	0.625	0.619

4.2.7 Plate 4.4 shows that catchments C3, C5 and C6 lie completely in the blue area, and so BFIHOST and SPRHOST values for these catchments are set to 0.6 and 40 respectively. For catchments C1, C2 and C4, BFIHOST and SPRHOST values of the overlapping (representative) FEH catchment (FEH Catchment 1 for C1, FEH intervening catchment for C2 and C4) are assumed, as the soil classification fractions are similar. BFIHOST and SPRHOST values applied for catchment C1 to C6 are listed in Table 4.7.

Plate 4.4 Soil classification for final catchments

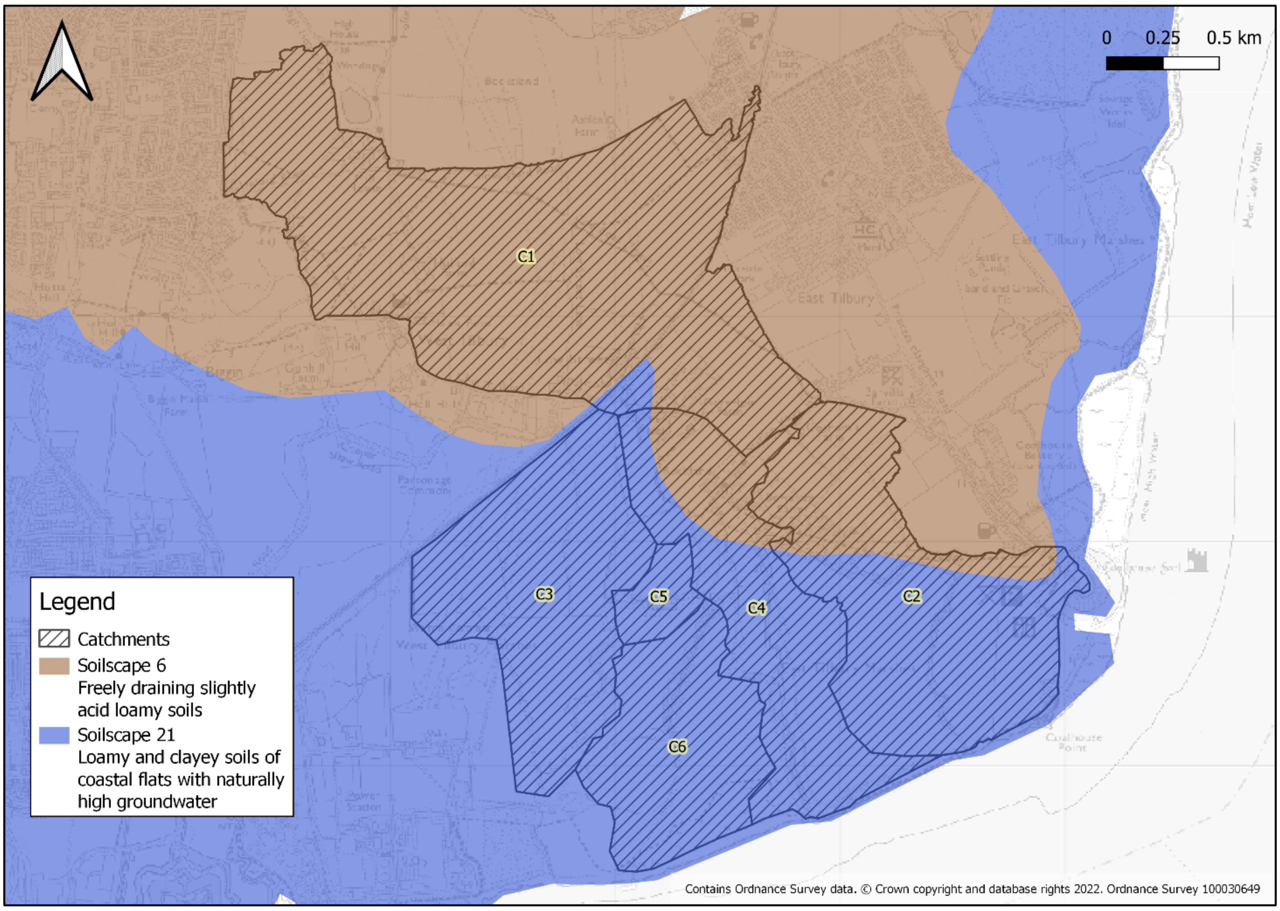


Table 4.7 BFIHOST values adopted for catchments C1 to C6

Catchments	C1	C2	C3	C4	C5	C6
Drainage area (km2) (ArcMAP)	2.390	1.230	1.000	0.900	0.120	0.650
Blue area (km2)	0.039	0.808	N/A	0.673	N/A	N/A
Brown area (km2)	2.351	0.422	N/A	0.227	N/A	N/A
Fraction blue	0.016	0.657	N/A	0.748	N/A	N/A
Fraction brown	0.984	0.343	N/A	0.252	N/A	N/A
BFIHOST	0.858	0.619	0.60	0.619	0.60	0.60

SPRHOST adjustment

4.2.8 SPRHOST values have been adjusted to better represent the soil responsiveness based on enhanced knowledge derived from the Soilscapes Viewer (Cranfield University, 2020) for soil classification and also from a consideration of areas occupied by landfill sites (i.e. likely to be clay capped). Similar to the BFIHOST adjustment presented previously, SPRHOST modifications were based on the following assumptions:

a. The soil class indicated with 'blue' constitutes marshland (i.e. 'naturally wet' area) and hence it has been decided to increase its SPRHOST value to 40 (unless occupied by landfill – see below).

b. For the 'brown' area, for which FEH catchment descriptor values are considered representative, the SPRHOST value of catchment C1 (19.18) is assumed, (unless occupied by landfill – see below).

c. The ‘pink’ area indicates areas occupied by landfill sites. For these areas, the SPRHOST value is increased to 60, representative of a clay capping (and this overrides the values assigned above). This is conservative in terms of assumed catchment response to rainfall as some of the ‘pink’ areas may not have clay capping (information detailing which sites are clay capped was not available).

4.2.9 Plate 4.5 overlays the soil classification boundaries, the landfill sites coverage boundaries and the final catchment boundaries. SPRHOST values applied for catchments C1 to C6 are listed in Table 4.8.

Plate 4.5 Landfill coverage and soil classification for final catchments

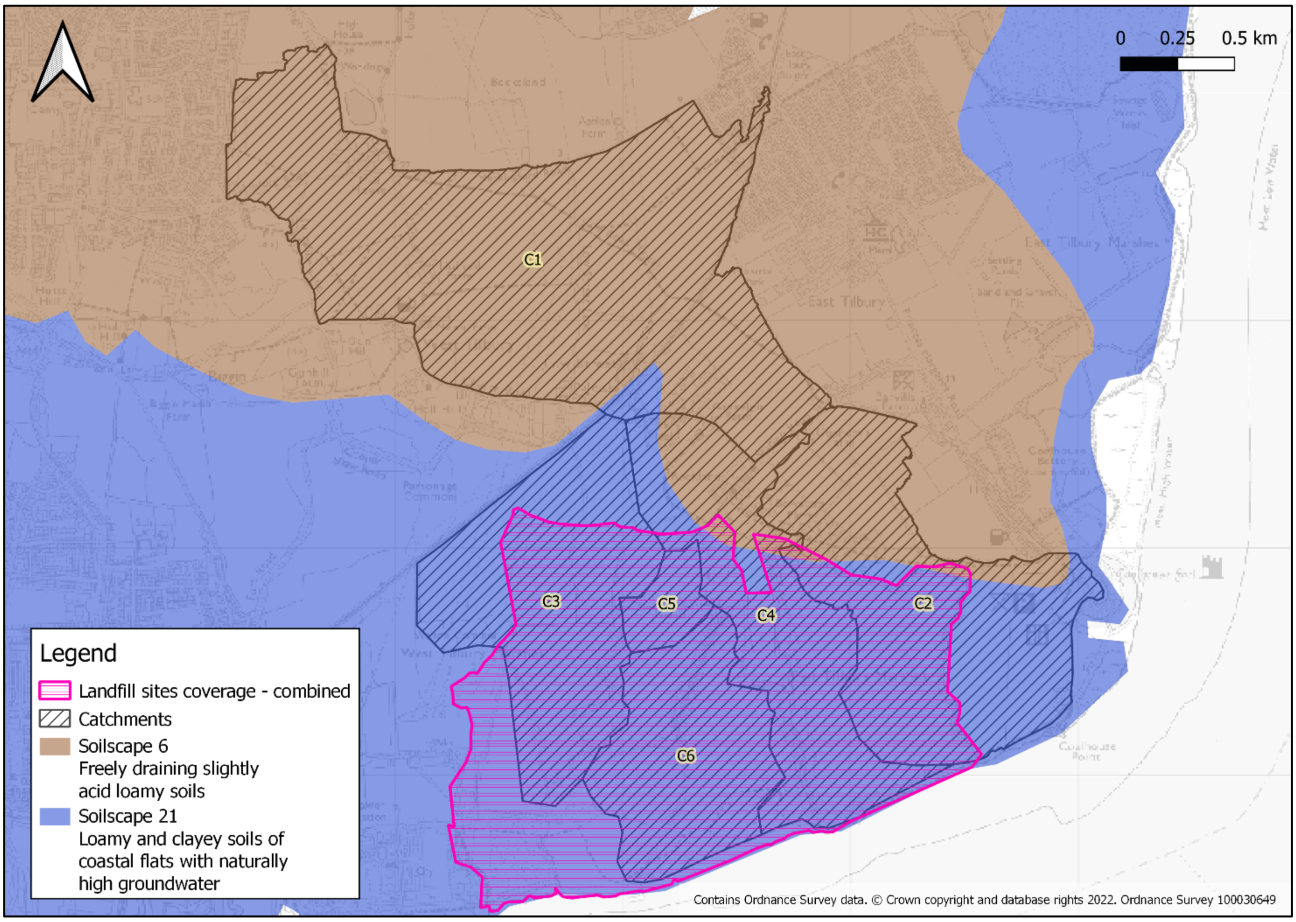


Table 4.8 SPRHOST values adopted for catchments C1 to C6

Catchment	C1	C2	C3	C4	C5	C6
Adjusted SPRHOST values	19.18	40.12	52.16	48.34	60	60

FPEXT

4.2.10 FPEXT and DPSBAR values are the same as for the representative catchments listed in Table 4.3 for Catchments C1 and C3. For Catchments C2, C4, C5 and C6, FPEXT values are the same as for the FEH Intervening catchment. The calculation of FPEXT for the FEH Intervening catchment is not present in the original 'Inter.xlsx' spreadsheet. An area-weighting method was applied (justified as FPEXT is an aerial measure).

FARL

4.2.11 FARL values are equal to 1 for FEH Catchment 1 and FEH Catchment 3. A value of 1 has therefore also been applied for all study catchments (C1 to C6).

DPLBAR

4.2.12 DPLBAR values for catchments C2 to C6 have been adjusted by scaling the FEH Intervening catchment values by an area adjustment factor, based on the FEH DPLBAR regression equation, as follows:

$$DPLBAR_{catchment} = DPLBAR_{FEH\_Inter} \times \left(\frac{Area_{catchment}}{Area_{FEH\_Inter}} \right)^{0.548}$$

4.2.13 For catchments C1 and C_Outfall the FEH Catchment 1 and FEH Catchment Outfall values have been adjusted by applying the equation above.

URBEXT1990 and URBEXT2000

4.2.14 The catchment schematisation map (Plate 4.2) indicates that URBEXT1990 is approximately zero for all catchments, as there are no urbanised areas within the study catchments. URBEXT1990 and URBEXT2000 values have therefore been set to 0.

SAAR and FEH rainfall depth-duration-frequency (DDF) model parameter values

4.2.15 SAAR values and FEH rainfall DDF model parameter values for the FEH ‘Catchment_Outfall’ catchment (Plate 4.2) have been adopted for all sub-catchments. This is appropriate because the study catchment is small, and these values do not vary significantly within the scale of the study catchment.

Estimation of catchment descriptors for C Outfall (lumped study catchment)

4.2.16 Area is equal to the sum of the individual catchment areas.

4.2.17 The required catchment descriptor values of the FEH 'Outfall' catchment are adopted except for BFIHOST, DPSBAR, FPEXT and SPRHOST, which are calculated as the area-weighted sum of values of the component catchments C1 to C6.

Summary of catchment descriptors

4.2.18 The final catchment descriptors used in the hydrological analysis are listed in Table 4.9.

Table 4.9 Final catchment descriptors

Catchment descriptor	C1	C2	C3	C4	C5	C6	C_Outfall
AREA (km^2)	2.39	1.23	1.00	0.90	0.12	0.65	6.29
BFIHOST	0.86	0.62	0.60	0.62	0.60	0.60	0.70
DPLBAR	1.42	1.63	1.45	1.37	0.45	1.15	4.28
DPSBAR	14.70	8.67	6.20	8.67	8.67	8.67	10.57
FARL	1	1	1	1	1	1	1
FPEXT	0.1515	0.3753	0.4925	0.3753	0.3753	0.3753	0.31
PROPWET	0.27	0.27	0.27	0.27	0.27	0.27	0.27
SAAR	545	545	545	545	545	545	545
SPRHOST	19.18	40.12	52.16	48.34	60	60	19.18
URBEXT2000	0	0	0	0	0	0	0
URBEXT1990	0	0	0	0	0	0	0
C	-0.02514	-0.02514	-0.02514	-0.02514	-0.02514	-0.02514	-0.02514
D1	0.26446	0.26446	0.26446	0.26446	0.26446	0.26446	0.26446
D2	0.40754	0.40754	0.40754	0.40754	0.40754	0.40754	0.40754
D3	0.23163	0.23163	0.23163	0.23163	0.23163	0.23163	0.23163
E	0.31883	0.31883	0.31883	0.31883	0.31883	0.31883	0.31883
F	2.57537	2.57537	2.57537	2.57537	2.57537	2.57537	2.57537

4.3 FEH statistical method

4.3.1 The FEH statistical method was used to produce flood frequency curves at the downstream extents of catchments C1 and C_Outfall.

QMED estimation

4.3.2 Q_{MED} values have been estimated based on catchment descriptors (Table 4.9) applying the Q_{MED} regression equation (Kjeldsen *et al.*, 2008). URBEXT2000 values are zero for the study catchments and therefore no urban adjustment was applied. There are no suitable (small, rural, nearby) donor catchments for Q_{MED} donor adjustment. Therefore, no donor adjustment was applied. The summary of QMED estimations is presented in Table 4.10.

Table 4.10 Summary of Q_{MED} estimations

Catchment	C1	C2	C3	C4	C5	C6	C_Outfall
Q_{MED}	0.058	0.098	0.088	0.075	0.015	0.061	0.277

Growth curve development

4.3.3 Growth curves were developed for the downstream extents of C1 and C_Outfall catchments, using the FEH statistical method pooling group methodology. The pooling groups were developed using WinFAP software version 3.0.003, with the National River Flow Archive (NRFA) Peak Flow dataset version 7 (downloaded in April 2019) (UK Centre for Ecology and Hydrology, 2019).

4.3.4 The default pooling groups were reviewed for hydrological similarity in catchment descriptors including AREA, SAAR, BFIHOST, SPRHOST, PROPWET, FPEXT and FARL. This review resulted in removal of stations from the default pooling groups. Generalised Logistic, Generalised Extreme Value and Pearson Type III statistical distributions were considered to identify the most suitable distribution at each site.

C_Outfall

4.3.5 The default pooling group included 15 stations with a total of 548 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. Stations with SAAR value <1,000 or AREA value >10 were removed.

c. Data quality for the remaining stations was reviewed based on the station description, AMAX and rating curve graphs for each site reported on the NRFA (UK Centre for Ecology and Hydrology, 2020b). Based on this review, sites considered to be unreliable for pooling analysis were removed.

4.3.6 The reviewed pooling group included seven stations with a total of 275 station years of data. A pooling group size of 275 station years is considered appropriate 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 (small, flat catchment with wet and permeable components). 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. Sites were not rejected based on consideration of BFIHOST, SPRHOST, PROPWET, FPEXT and FARL values as, after rejecting sites, this would require sites to be added with a higher similarity distance measure that may be less representative of the study site.

4.3.7 Goodness of fit measures for the C_Outfall pooling groups are listed in Table 4.11 and pooling group growth factors are listed in Table 4.12.

Table 4.11 Goodness of fit for C_Outfall pooling group

Pooling group	Z* value/acceptable distribution fit					
	Generalised Logistic		GEV		Pearson Type III	
Default	1.6695	x	-0.6544	v	-0.9139	x
Reviewed	0.8917	v	-0.7923	v	-0.9633	v

Table 4.12 C_Outfall growth factors

Return period	Pooling group (D = default, R = reviewed, GL = Generalised Logistic, GEV = Generalised Extreme Value, P3 = Pearson Type 3)					
	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1	1	1	1	1	1
5	1.398	1.439	1.456	1.434	1.48	1.497
10	1.679	1.732	1.748	1.739	1.798	1.813
25	2.077	2.105	2.102	2.169	2.199	2.195
50	2.413	2.384	2.355	2.53	2.497	2.467
100	2.788	2.662	2.599	2.931	2.792	2.729
200	3.209	2.94	2.836	3.38	3.086	2.984
500	3.848	3.31	3.142	4.059	3.475	3.312
1,000	4.403	3.592	3.369	4.646	3.768	3.555

C1

4.3.8 The default pooling group included 16 stations with a total of 508 station years of data. Adopting the same approach as for C_Outfall catchment (removing stations with a SAAR value <1,000 or AREA value >10 would) leave only two stations in the pooling group (i.e. before adding additional sites). This indicates the study site is not well represented in the pooling site dataset. The default pooling group was therefore edited based on the following criteria to provide an indicative pooling group analysis:

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

b. A pooling group from the remaining data was created with 316 station years of pooling data, by accepting sites with lowest similarity distance measures.

c. Data quality for the remaining 316 station years was reviewed based on the station description, AMAX and rating curve graphs for each site reported on the NRFA (UK Centre for Ecology and Hydrology, 2020b). Based on this review, two AMAX values from station 26802 were rejected.

4.3.9 The reviewed pooling group includes 10 stations with a total of 314 station years of data. A pooling group size of 314 station years is considered appropriate as the Pooled Uncertainty Measure does not increase significantly until below approximately 200 to 250 station years (Kjeldsen et al., 2008) and adding additional sites to increase the pooling group size may add sites that are not representative of the study site.

4.3.10 Goodness of fit measures for the C1 pooling groups are listed in Table 4.13 and pooling group growth factors are listed in Table 4.14.

Table 4.13 Goodness of fit for C1 pooling group

Pooling group	Z* value/acceptable distribution fit					
	Generalised Logistic		GEV		Pearson Type III	
Default	0.9474	v	-0.7095	v	-1.3377	x
Reviewed	0.8038	v	-0.5275	v	-0.903	x

Table 4.14 C1 growth factors

Return period	Pooling group (D = default, R = reviewed, GL = Generalised Logistic, GEV = Generalised Extreme Value, P3 = Pearson Type 3)					
	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	1	1	1	1	1	1
5	1.379	1.416	1.449	1.395	1.435	1.462
10	1.663	1.715	1.752	1.684	1.738	1.767
25	2.084	2.12	2.13	2.105	2.14	2.144
50	2.454	2.443	2.406	2.469	2.451	2.416
100	2.882	2.784	2.675	2.885	2.773	2.681
200	3.38	3.144	2.94	3.361	3.106	2.94
500	4.168	3.653	3.285	4.102	3.565	3.276
1,000	4.882	4.065	3.542	4.762	3.927	3.527

Flood frequency curves

4.3.11 Growth curves in Table 4.12 and Table 4.14, are tabulated in Table 4.15 and Table 4.16. The preferred FEH statistical method estimates (highlighted in Table 4.15 and Table 4.16) are those from the reviewed pooling groups, applying the Generalised Logistic distribution, which has an acceptable goodness of fit and is considered to be appropriate for UK flood data.

Table 4.15 C_Outfall flood frequency curves

Return period	Pooling group (D = default, R = reviewed, GL = Generalised Logistic, GEV = Generalised Extreme Value, P3 = Pearson Type 3)					
	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	0.28	0.28	0.28	0.28	0.28	0.28
5	0.39	0.40	0.40	0.40	0.41	0.41
10	0.46	0.48	0.48	0.48	0.50	0.50
25	0.57	0.58	0.58	0.60	0.61	0.61
50	0.67	0.66	0.65	0.70	0.69	0.68
100	0.77	0.74	0.72	0.81	0.77	0.76
200	0.89	0.81	0.78	0.94	0.85	0.83
500	1.06	0.92	0.87	1.12	0.96	0.92
1,000	1.22	0.99	0.93	1.29	1.04	0.98

Table 4.16 C1 flood frequency curves

Return period	Pooling group (D = default, R = reviewed, GL = Generalised Logistic, GEV = Generalised Extreme Value, P3 = Pearson Type 3)					
	D - GL	D - GEV	D - P3	R - GL	R - GEV	R - P3
2	0.06	0.06	0.06	0.06	0.06	0.06
5	0.08	0.08	0.08	0.08	0.08	0.08
10	0.10	0.10	0.10	0.10	0.10	0.10
25	0.12	0.12	0.12	0.12	0.12	0.12
50	0.14	0.14	0.14	0.14	0.14	0.14
100	0.17	0.16	0.16	0.17	0.16	0.16
200	0.20	0.18	0.17	0.19	0.18	0.17
500	0.24	0.21	0.19	0.24	0.21	0.19
1,000	0.28	0.24	0.21	0.28	0.23	0.20

4.4 FEH rainfall-runoff model

Model specification

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 peaks when simulating events with durations significantly longer than the recommended duration, 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 West Tilbury Main catchment. Instead, the FEH rainfall-runoff model is recommended, as this gives more realistic event peaks when simulating long duration events.

4.4.2 FEH rainfall-runoff hydrographs were generated using the Flood Modeller 4.5 FEH hydrology unit. Hydrographs were derived for the two-year[1], 20-year, 100-year and 1,000-year return period floods for both summer and winter rainstorm profiles. Design event rainfall return periods are specified automatically in Flood Modeller if flood return periods are specified (and rainfall return periods are not specified). FEH rainfall-runoff flood return periods and corresponding rainfall return periods applied in the study are listed in Table 4.17.

Table 4.17 FEH rainfall-runoff model return period relationship

Flood return period (years)	Rainfall return period (years)
2.33	2
20	35
100	140
1,000	1,000

4.4.3 FEH rainfall-runoff model parameter values were specified based on the catchment descriptors for each sub-catchment (Table 4.9). Required inputs to the FEH rainfall-runoff model are detailed in Table 4.18. Model parameter values for the study catchments are listed in Table 4.19.

[1] 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 4.18 FEH rainfall-runoff model parameters

Model parameter	Value/method
Catchment area	Catchment descriptors
Urban extent	Catchment descriptors
SAAR	Catchment descriptors
SPR	Catchment descriptors
Storm area	0 (set to upstream catchment area of site of interest)
Snow melt rate	0
Data interval	0.5
Storm duration	Adjusted to give critical duration at site of interest
Areal reduction factor (ARF)	0 (derived by model based on storm area and duration)
Rainfall return period	Not specified explicitly – assigned based on flood return period
Flood return period	As per each event
DDF parameters	Catchment descriptors
Storm profile	Winter or summer as per each event (untick option to apply equal rainfall and flood return periods)
DPLBAR	Catchment descriptors
DPSBAR	Catchment descriptors
PROPWET	Catchment descriptors
Tp coefficient	1
TB scale factor	1
Minimum flow	0
Time delay	0

Table 4.19 Model parameter values for the study catchments

Model parameter	C1	C2	C3	C4	C5	C6	C_Outfall
AREA (km^2)	2.39	1.23	1.00	0.90	0.12	0.65	6.29
SPRHOST	19.18	40.12	52.16	48.34	60	60	37.69
Tp(0)	5.74	7.44	7.86	6.77	3.71	6.16	11.692
Baseflow	0	0	0	0	0	0	0
Design event storm duration	9.5	11.5	12.5	10.5	6.5	9.5	18.5

FEH rainfall-runoff model design flows

4.4.4 Design flows generated by the FEH rainfall-runoff models are listed in Table 4.20.

Table 4.20 Summary of FEH rainfall-runoff model design flows

Catchment	Flood peaks (m^3/s) for return periods (years) for 30hrs storm duration			
	2.33	20	100	1,000
C1	0.108	0.464	0.800	1.700
C2	0.221	0.574	0.867	1.571
C3	0.254	0.619	0.915	1.607
C4	0.222	0.549	0.816	1.446
C5	0.051	0.121	0.177	0.306
C6	0.223	0.531	0.778	1.347

4.5 Preferred flood estimates

4.5.1 For the design simulations, the flood estimates from the FEH rainfall-runoff method are preferred for the following reasons:

a. The study catchment is ungauged and is not well represented in the pooling dataset (small, flat) and so FEH statistical estimates are particularly uncertain.

b. The rainfall-runoff method peak flows are higher than those of the FEH statistical method (i.e. more precautionary). However, simulated flood extents have been ‘sense-checked’ against the local flood risk knowledge of the Environment Agency, and based on this review no further adjustments were applied. The significance of modelling uncertainty on the Project design and proposed mitigation measures is discussed in Section 7.3.

c. Design event volumes are directly linked to design rainfall volumes.

4.5.2 The design flows listed in Table 4.20 apply design storm durations and areas to simulate design peak flows for the individual catchment models. However, model inflows have been used to simulate design storms appropriate for locations within the hydraulic model, e.g. road crossing of watercourse, with storm durations and areas adjusted as appropriate.

4.6 Calibration inflows

4.6.1 There is no available data for use in model calibration. Calibration therefore was not undertaken. Sensitivity to modelling assumptions was assessed, and design event model outputs were ‘sense checked’.

4.7 Model inflow locations

Deriving weights for distribution of catchment C1 inflows

4.7.1 The upstream catchment C1 was delineated further using LiDAR topographic data to assess the locations of model inflows from catchment C1, and the proportion of total C1 catchment inflows applied at each inflow location. For each inflow location, sub-catchment area weighting was applied to distribute total C1 catchment inflows to the model inflow locations.

4.7.2 This further level of detail was required for catchment C1 to provide a more realistic assessment of proposed flood compensation storage north of the railway (Section 5.3). Whilst the pre-development model applies inflows from C1_west_1, C1_west_2 and C1_west_3 at the same model location, the post-development model with proposed flood compensation storage north of the railway applies these inflows at different locations (mitigation measures are detailed later in Section 5.3).

4.7.3 The resulting delineation of catchment C1 and inflow weights is shown in Table 4.21. The pre-development model schematisation of catchment C1 inflows is shown in Plate 4.6 and Plate 4.7.

4.7.4 Further details of catchment C1 delineation are in Annex C.

Plate 4.6 Catchment C1 delineation

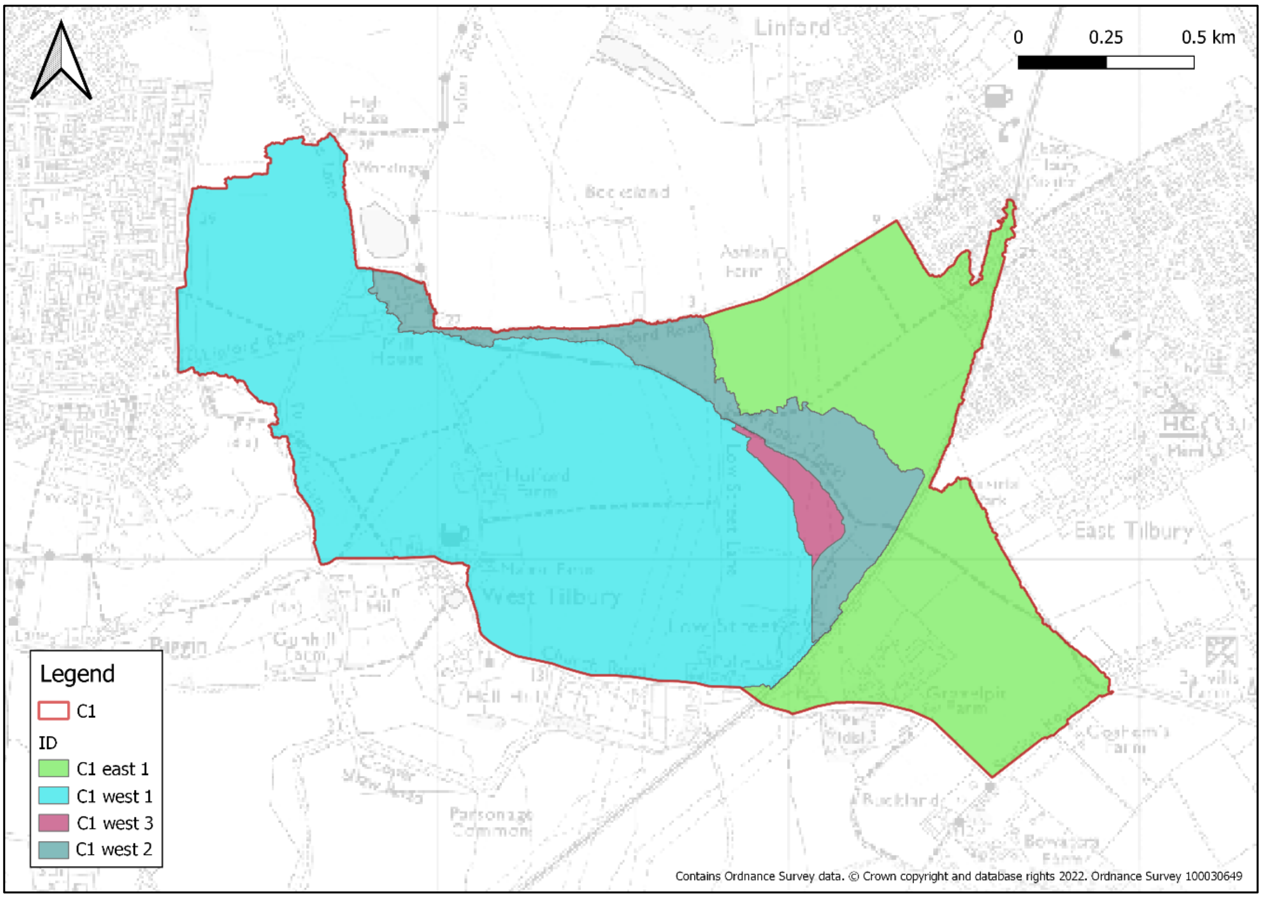
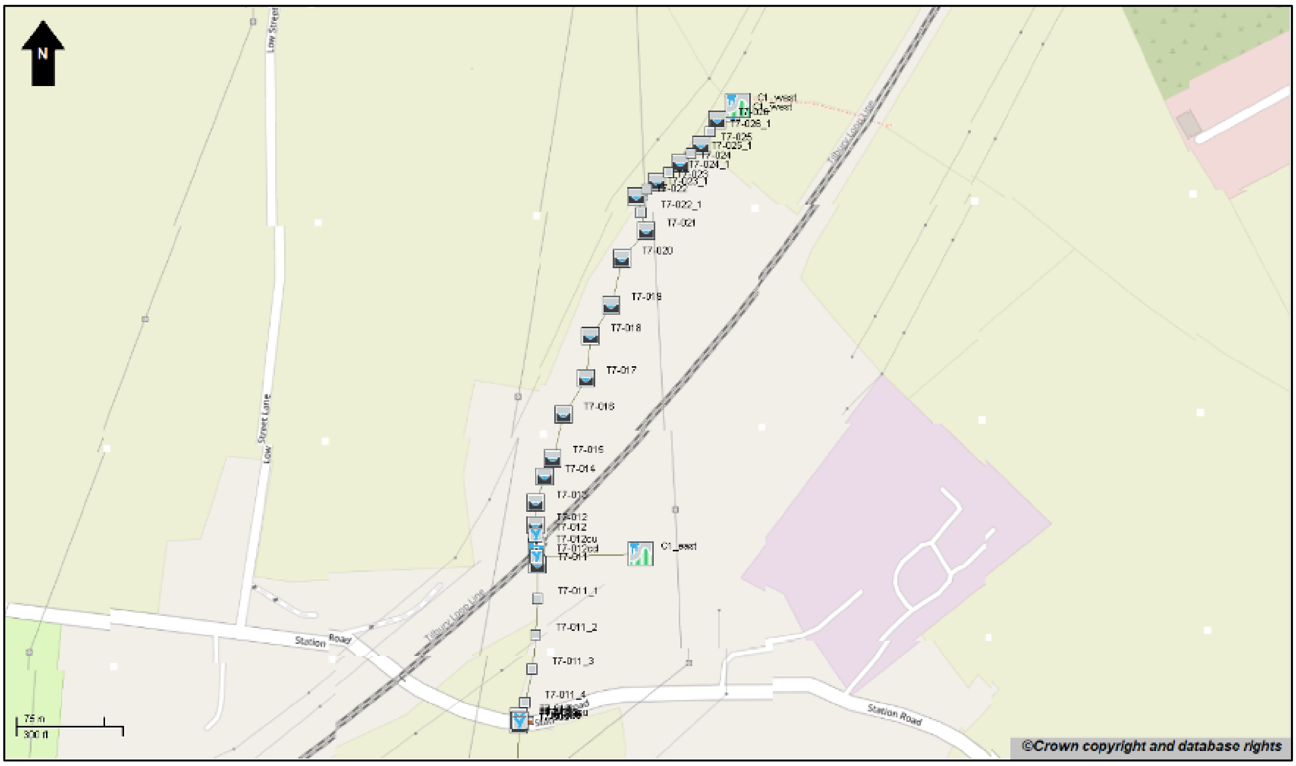


Table 4.21 Delineation of catchment C1

C1 sub-catchment	Area (km2)	Percentage of total C1 catchment area
C1_west_1	1.4	58.5
C1_west_2	0.22	9.2
C1_west_3	0.04	1.7
C1_east_1	0.74	30.6
Sum	2.39	100

Plate 4.7 Pre-development model: Catchment C1 inflow schematisation



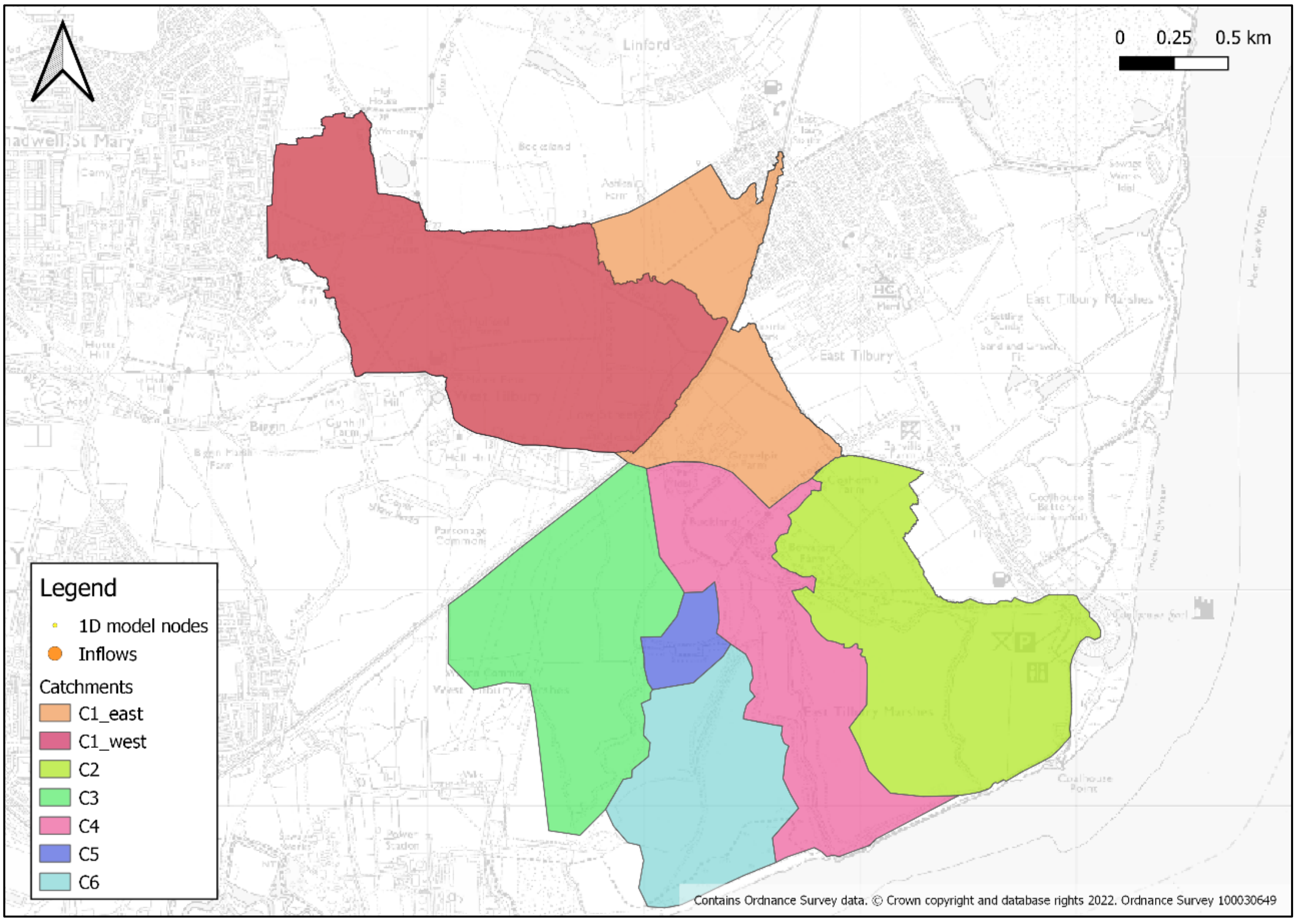
Inflow locations and weights

4.7.5 The catchment inflows were applied to the model as either point inflows or distributed as lateral inflows, as detailed in Table 4.22 and shown on Plate 4.8.

Table 4.22 Pre-development model inflow locations

Catchment	Type	Node applied (label)	Percentage of flow assigned to node
C1	Point (Sub-catchment C1_east)	T7-012cd	30.6
	Point (Sub-catchment C1_west)	T7-026	69.4
C2	Point	T9-011	100
C3	Point	T7-001	100
C4	Lateral	T9-002	30
	Lateral	T9-008	34
	Lateral	T9-011	36
C5	Point	T8-004	100
C6	Point	T8-004	100

Plate 4.8 Pre-development model inflow locations



4.7.6 Catchment C1 delineation and inflow locations are discussed above in paragraphs 4.7.1 to 4.7.5.

4.7.7 C2 represents the water drained from the eastern C2 catchment to an upstream extent of the hydraulic model.

4.7.8 The C3 hydraulic model inflow location was chosen to be at the upstream model extent of a modelled tributary.

4.7.9 The C4 hydraulic model inflow locations were chosen to have approximately equal contributing catchment areas.

4.7.10 Model inflow points for catchments C5 and C6 were chosen as the outfall locations for each catchment.

4.8 Model downstream boundary

4.8.1 Bowaters Sluice constitutes the downstream boundary of the model, as the location where West Tilbury Main discharges into the River Thames. Due to the insensitivity of model results to the Bowaters Sluice gate blockage condition (see Annex D), design event simulations are undertaken applying the 100% blockage condition.

4.8.2 Hence, simulations are not influenced by downstream boundary conditions. For the sensitivity simulations (see Table D.1), model downstream tidal boundaries have been specified as Mean High Water Springs (MHWS) time series based on gauged data at Tilbury tide level gauge (see Section 5).

5 Model development

5.1 Software

5.1.1 The West Tilbury Main hydraulic model was developed using hybrid Flood Modeller – TUFLOW software. This combines two software packages for managing overland flow and rapid inundation modelling. The Project used the following versions of Flood Modeller and TUFLOW:

a. Flood Modeller Version 4.6 (double precision)

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

5.2 Model history

5.2.1 There is no existing modelling to assess flood risk in the West Tilbury Main catchment.

5.3 Model schematisation

5.3.1 A new 1D-2D model was developed using the datasets listed in Table 3.1, namely:

a. LiDAR: 2m resolution and 25cm horizontal resolution (source: Environment Agency)

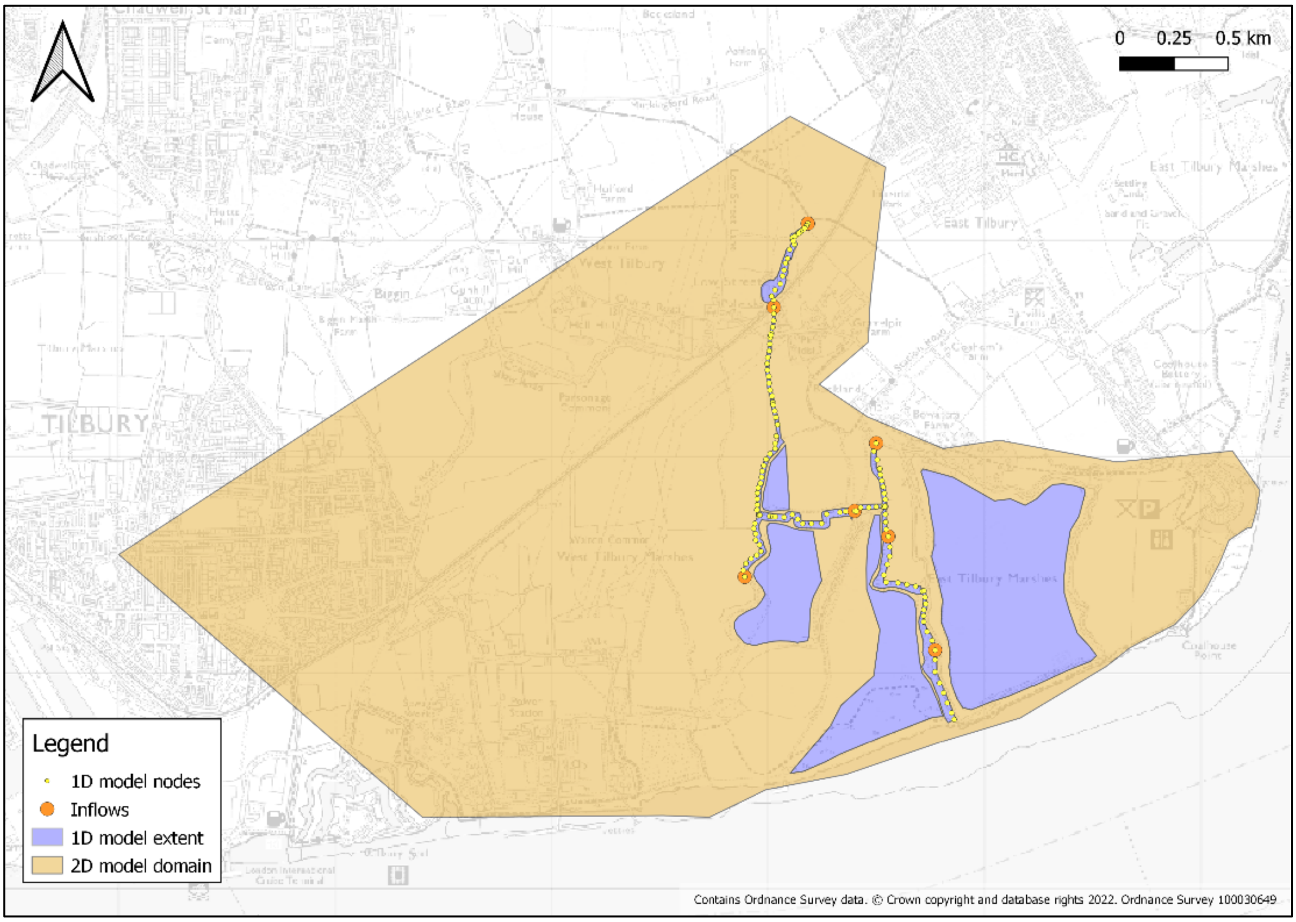
b. Channel topographic survey (source: Project)

c. Flood defence data: Bowaters Sluice and Star Dam as-built drawings (source: Environment Agency)

5.3.2 The Project channel topographic survey was used to build the 1D model network, while a LiDAR topographic dataset was used in the 2D model domain. In the absence of recent topographic survey data for the Bowaters Sluice outfall, the Environment Agency's as-built drawings (1976) were used to represent this structure in the 1D model node.

5.3.3 The model was schematised as a linked 1D-2D model as shown in Plate 5.1. The area covered by the 2D model domain is shown in orange in Plate 5.1 and the 1D domain is shown in light blue. As shown in Plate 3.1, the study area includes very flat topography as well as some hilly topography. Due to the significantly high bank elevation values compared to the channel bed level within the hilly areas (i.e. at the central and the lower modelled reaches), out-of-bank flow is not expected in those areas and hence it was decided to model those areas as 1D only to reduce model run times, whilst also providing robust model outputs.

Plate 5.1 Model schematisation



Note: The area covered by the 2D model domain is shown in orange, and the 1D domain along with the inactive 2D areas are shown in light blue.

1D schematisation

5.3.4 The model was schematised using the georeferenced 1D cross-sections from the channel survey undertaken for the Project. The cross-sections were trimmed to bank tops and connected to the 2D domain by using HX boundaries[2]. The HX polylines are connected to the appropriate Flood Modeller nodes using CN connection polylines[3]. 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 Table B.1 of Annex B.

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

5.3.5 In some areas, 1D domains of the model have been extended outside the channel to reduce model instability related to deep ponding on the HX lines. This is because in areas where there are large volumes of standing water over HX links, relatively large flows oscillate between the 1D and 2D models. This is problematic when the volume of flow oscillating is large compared to the conveyance capacity of the 1D channel. To resolve this, the conveyance capacity of the 1D channel is increased by extending the 1D sections beyond the bank locations. The above modifications were carried out upstream of the T7 and T9 reaches and at the confluence of the T8 and T9 reaches.

5.3.6 The West Tilbury Main discharges into the River Thames via the Bowaters Sluice. The Bowaters Sluice consists of a pre-cast concrete culvert connecting the landward watercourse to the River Thames, a penstock with manhole access, and an outfall flap valve. Site inspection in February 2019 showed that the sluice system was not functioning as intended, with sitting water at the inlet possibly due to a blockage within the culvert.

2D schematisation

5.3.7 The cell size of the 2D model domain has been set at 6m, 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.

5.3.8 The topographic survey and LiDAR datasets have been checked for consistency at all the channel section bank locations (zln_bank points) at the interface between 1D and 2D model domains. Overall, the topographic datasets appear to compare well with minor differences in the range of approximately +/- 300mm.

Post-development – without mitigation measures

5.3.9 The pre-development model was used as the basis for the construction of the post-development model. The post-development model build followed a staged approach. Initially, a post-development model was built to simulate the post-development scenario without any measures to mitigate the potential increase in flood risk due (i.e. representing the design). Subsequently, the results from the ‘Post-development – without mitigation’ model simulations were used to assess the impact of the design on flood risk elsewhere, and identify measures to mitigate the potential impact on flood risk. These mitigation measures will be incorporated into the Project’s developed design.

5.3.10 The pre-development model was modified to represent the ‘Post-development – without mitigation’ case by incorporating the proposed embankment and highway, the bridge piers at the location of the proposed viaduct and the watercourse crossing (in culvert) of the West Tilbury Main. The post-development model also includes the proposed realignment of an agricultural reservoir north of the railway, to allow for proposed highway bridge piers, as secured through REAC [RDWE015].

5.3.11 The modifications applied are detailed in Plate 5.2 and Table 5.1.

Plate 5.2 Post-development (without mitigation) model updates

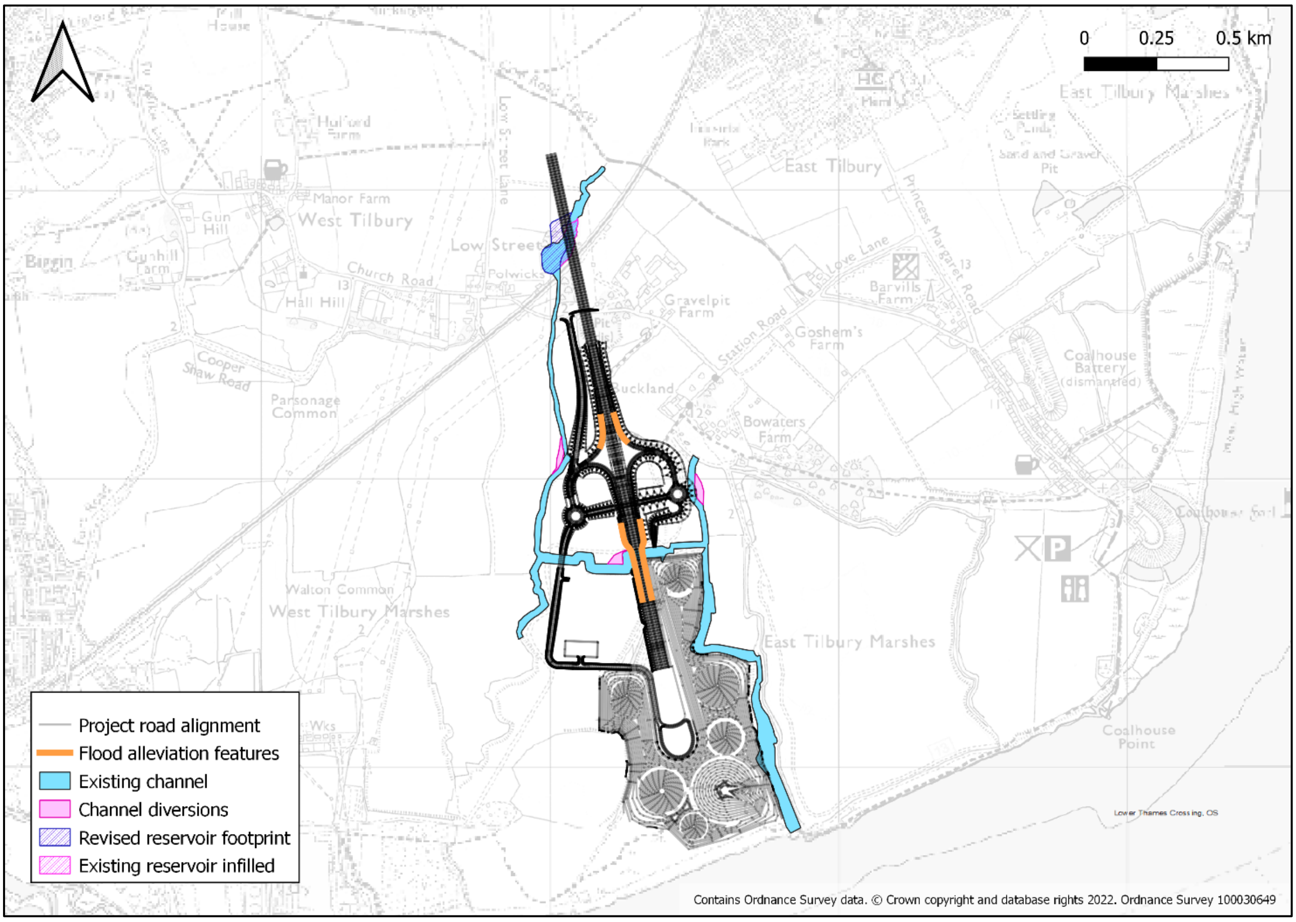


Table 5.1 Post-development (without mitigation) model updates

File description	Comment
Proposed highway embankment 2d_zsh polygon, point and polyline features	Schematisation of the proposed highway by using Z-shape features to raise the ground levels.
Proposed flood alleviation features	Schematisation of the proposed flood alleviation features using Z-shape to raise ground levels
Proposed culvert T8-003cd	Adding the proposed culvert unit in Flood Modeller (and removal of T8-004cd culvert unit due to the removal of the existing road); length=61m; width=4.5m; height=2.8m
Proposed channel diversion 2d_zsh point and polyline features	Use of a Z-shape polyline to adjust the topography of the channel diversion adjacent to the proposed culvert.
Proposed viaduct 2d_lfcsh polygon and point features	Schematisation of the proposed bridge piers under the proposed viaduct by using flow constriction polygon and point features.
Proposed viaduct piers 2d_zsh polygon and point features	Schematisation of the proposed bridge piers under the proposed viaduct using 2d_zsh polygon and point features.

File description	Comment
Proposed channel diversion next to the compensation area	Realignment of the existing reservoir using 2d_zsh polygon and point feature, amending 2d_bc layer and 1d network to fit new shape of the pond. Infilling existing channel with 2d_zsh polygon and point feature with elevation of area adjacent to infilled channel.
Proposed channel diversions in places where channel overlapped proposed highway embankment	Realignment of the existing 1d_nwk and 2d_zln layers in the area of the overlap with proposed highway embankment

Post-development – with mitigation

5.3.12 Further to the simulations undertaken with the 'Post-development – without mitigation' model, a number of mitigation measures were identified to mitigate the impacts of the Project on flood risk. These mitigation measures will be incorporated into the Project developed design. Without mitigation measures, the design affects flood risk by displacing floodplain storage and by intercepting the floodplain flow conveyance from the western side of the highway to the eastern side (and vice versa).

5.3.13 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.

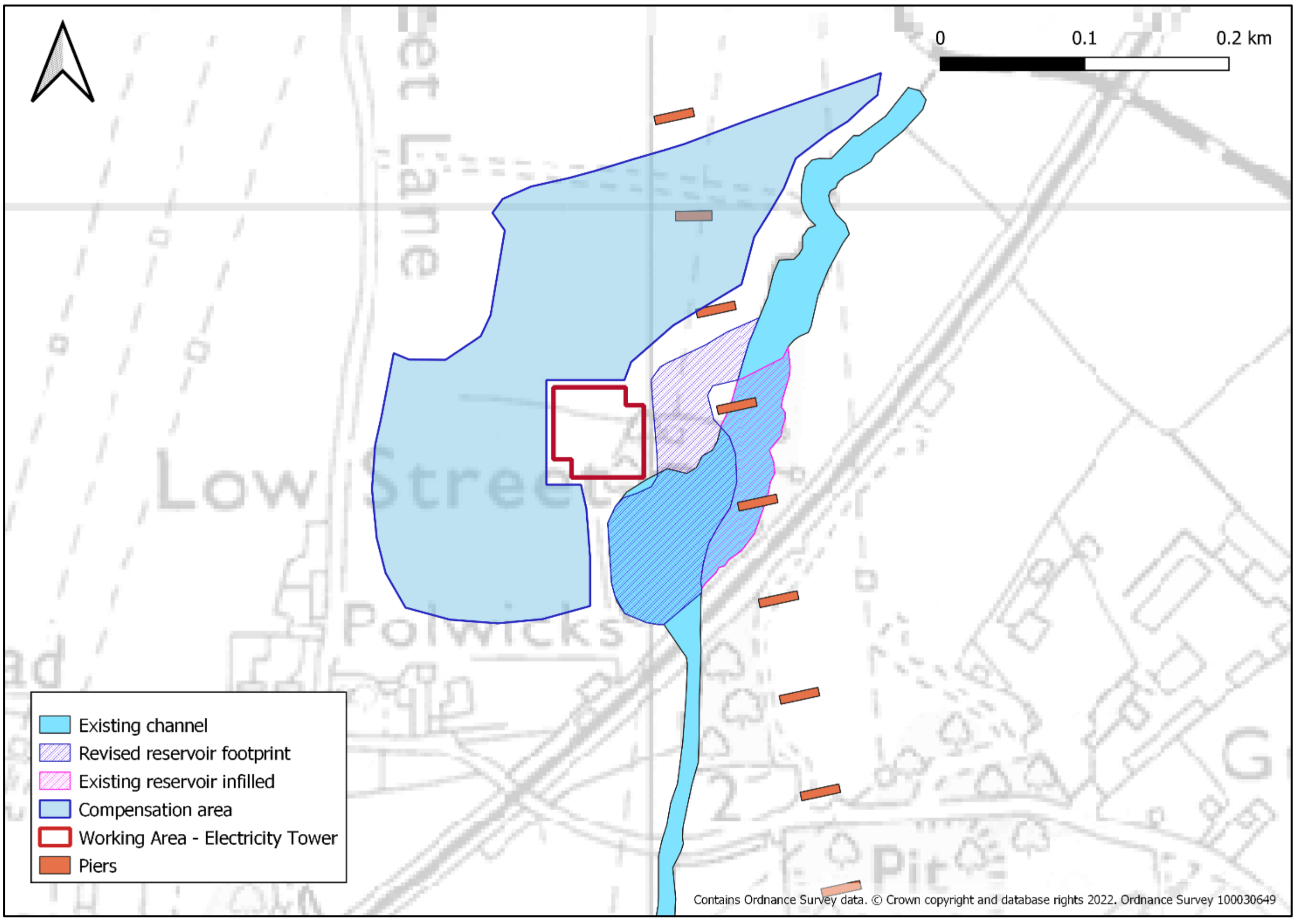
5.3.14 The mitigation measures identified in relation to potential effects of flooding in the West Tilbury Main catchment are described below along with their securing mechanisms; they include:

a. Incorporating a compensatory flood storage area to the north of the Tilbury Loop railway line, secured through the REAC [RDWE037].

b. To maintain the West Tilbury Main flood flow path, replacement of an existing culvert, at model node T8-001, with a 2.8m by 4m box culvert (structure ref X-EFR-2-02) and the removal of two existing culverts to the east of the Project road as illustrated on Drawing 10180 of the FRA. The mitigation measures also include a bespoke structure to reproduce the hydraulic behaviour of the existing culvert for lower return period flood events (paragraph 5.3.19). This is secured through the REAC [RDWE046].

5.3.15 The proposed compensation storage area size and shape has been specified to avoid electricity pylons. The existing reservoir has been realigned to fit between the proposed highway piers, and part of the existing reservoir will be infilled (Plate 5.3).

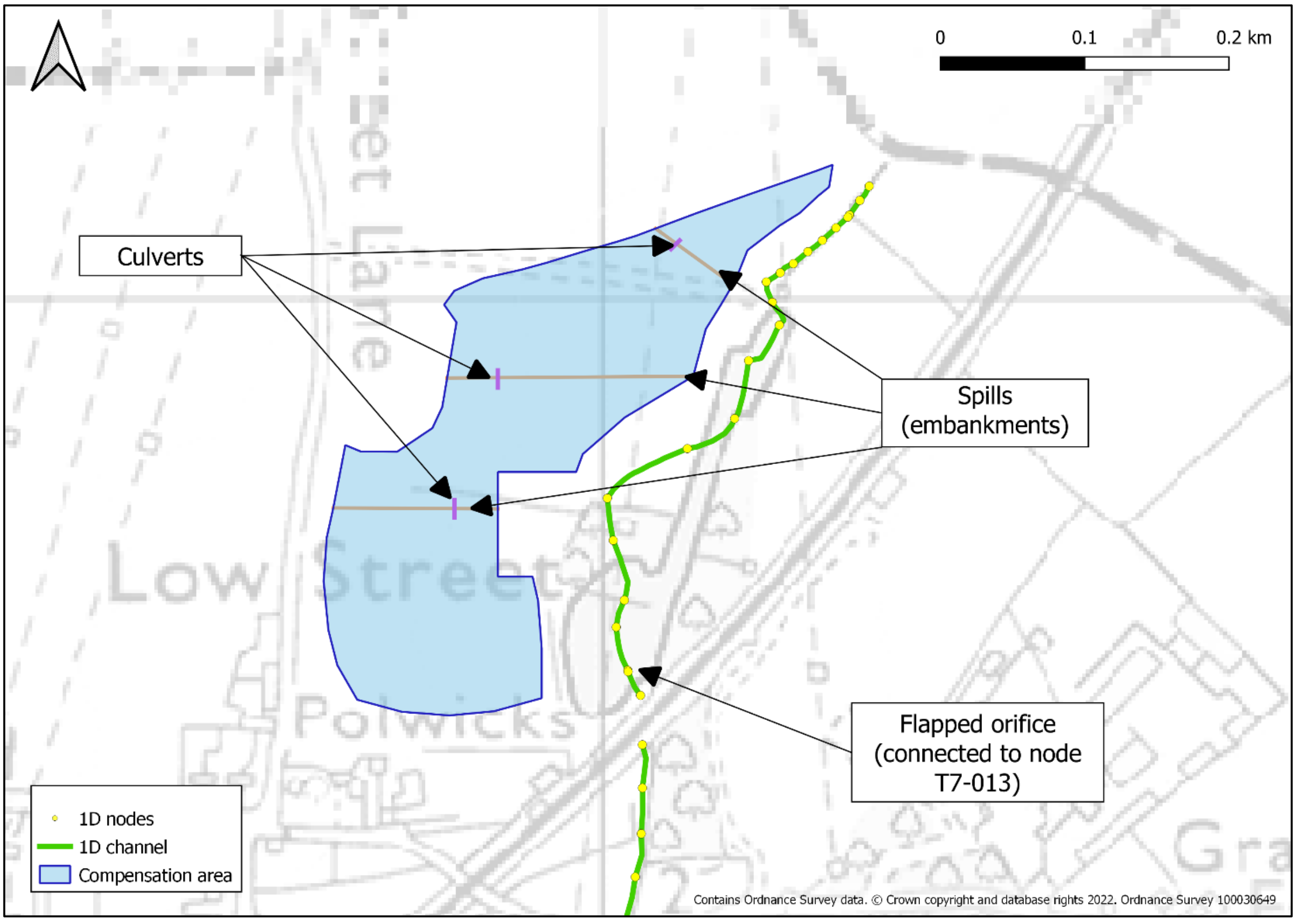
Plate 5.3 Post development with mitigation schematisation



5.3.16 The proposed compensation storage area is designed to intercept approximately 60% of flows from the upstream catchment C1 and so reduce flows and volumes passing downstream compared to the pre-development case.

5.3.17 The proposed compensation storage area is represented in the post-development with mitigation model by modifying the underlying topography using Z-shape features. The storage area is linked to the 1D network via a flapped orifice unit linked to the T7-013 model node. The flow entering the compensation area is then cascaded downstream through four lowered floodplain compartments, which are connected by culverts and higher-level spills (embankments) to convey overflow during higher flows. At the downstream end of the compensation area a flapped orifice controls the water flowing back to the main 1D channel. This arrangement results in a stepped water surface through the storage area. The proposed storage area spills and outfall are shown schematically in Plate 5.4.

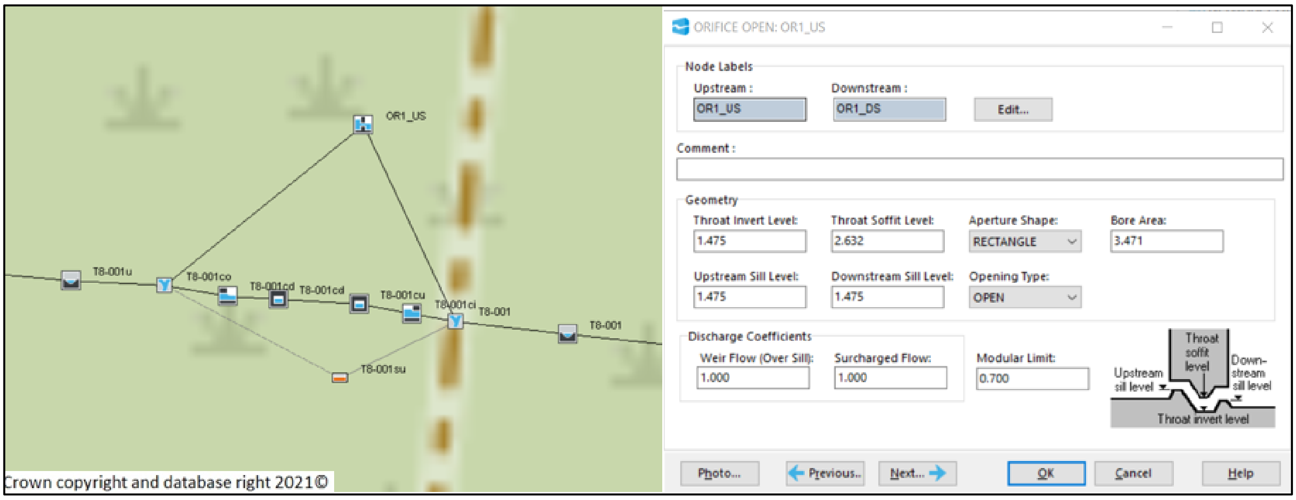
Plate 5.4 Schematic representation of proposed storage area spills and outfall



5.3.18 The available flood storage in the compensation area is such that the volume stored during design event simulations significantly exceeds the volume of floodplain displaced by the Project (see Section 7.2).

5.3.19 For the post-development case without mitigation, the existing Tilbury Main culvert (at model node T8-001) limits conveyance of flood flows between the floodplain east and west of the proposed highway. This culvert will therefore be enlarged as part of the mitigation measures, such that for in-channel flood levels up to the peak two-year return period pre-development scenario, there will be no change in conveyance, but for larger events there will be an increase in conveyance via a larger culvert cross-section area. It was found that a two-stage structure is required to mitigate the impacts of larger events, whilst not changing the hydraulic behaviour during smaller events. This will be achieved by installing a larger culvert, with an inset thin plate notch to control flows at lower levels. This is represented in the model by adding an orifice unit in parallel with the culvert at node T8-001. The orifice invert level is specified to be 0.001m higher than the maximum water level for the two-year event for the pre-development case (Plate 5.5).

Plate 5.5 T8-001 culvert schematisation



5.3.20 Due to the proposed compensation area intercepting the drainage of part of catchment C1, there is need to amend the distribution of catchment C1 model inflows. Catchment C1 has therefore been subdivided into catchments C1_east_1, C1_west_1, C1_west_2 and C1_west_3 (Table 5.2, Plate 5.6 and

5.3.21 Plate 5.7).

5.3.22 The hydraulic model modifications applied to the ‘Post-development – with mitigation’ model are detailed in Plate 5.8 and Table 5.3.

Table 5.2 Inflow locations for post-development model

Catchment	Type	Node applied (label)	Percentage of flow assigned to node
C1	Point (Sub-catchment C1_east_1)	T7-012cd	30.6
	Point (Sub-catchments C1_west_1 and C1_west_3)	Compensation area	60.2
	Point (Sub-catchment C1_west_2)	T7-026	9.2
C2	Point	T9-011	100
C3	Point	T7-001	100
C4	Lateral	T9-002	30
	Lateral	T9-008	34
	Lateral	T9-011	36
C5	Point	T8-004	100
C6	Point	T8-004	100

Plate 5.6 Post-development model inflow locations

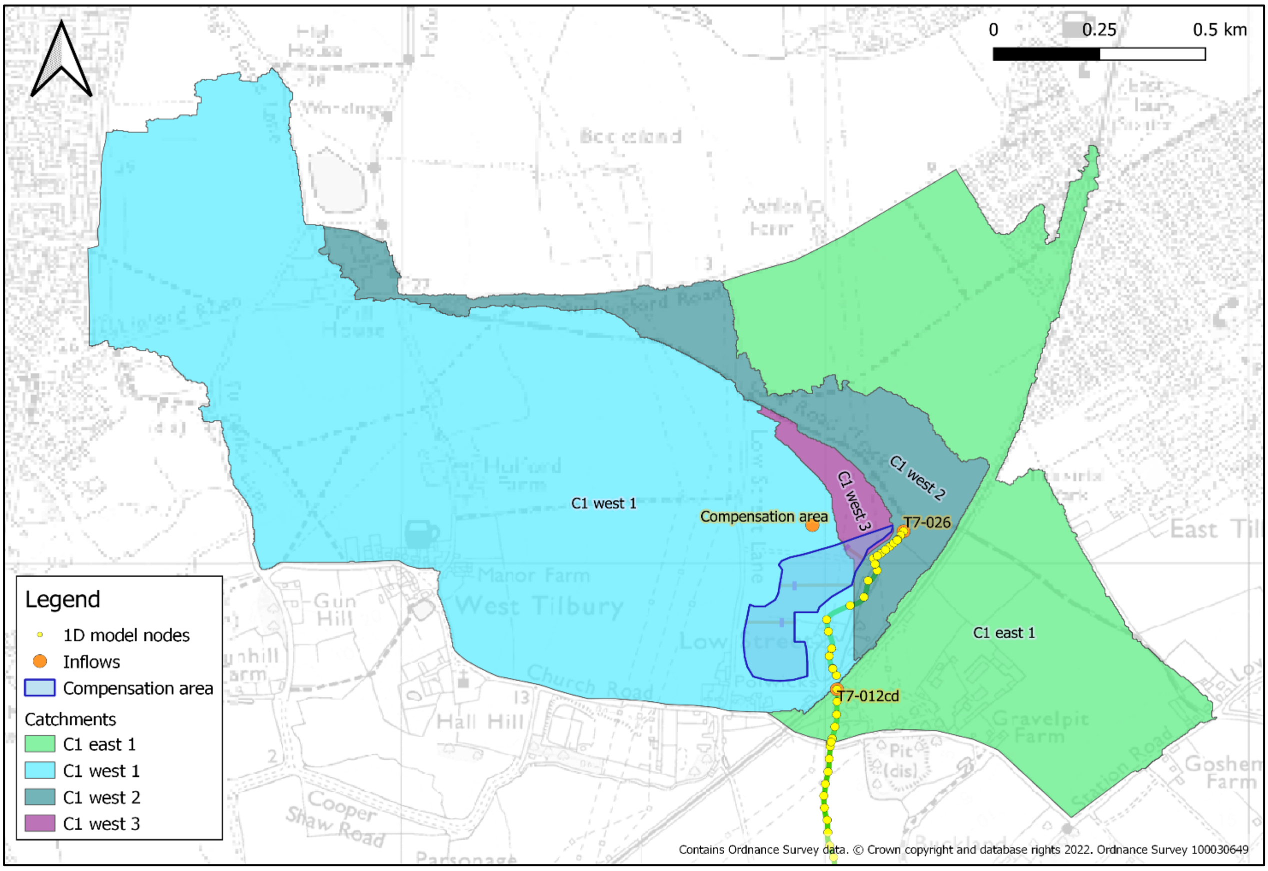


Plate 5.7 Detail of post-development inflow locations for C1 catchment

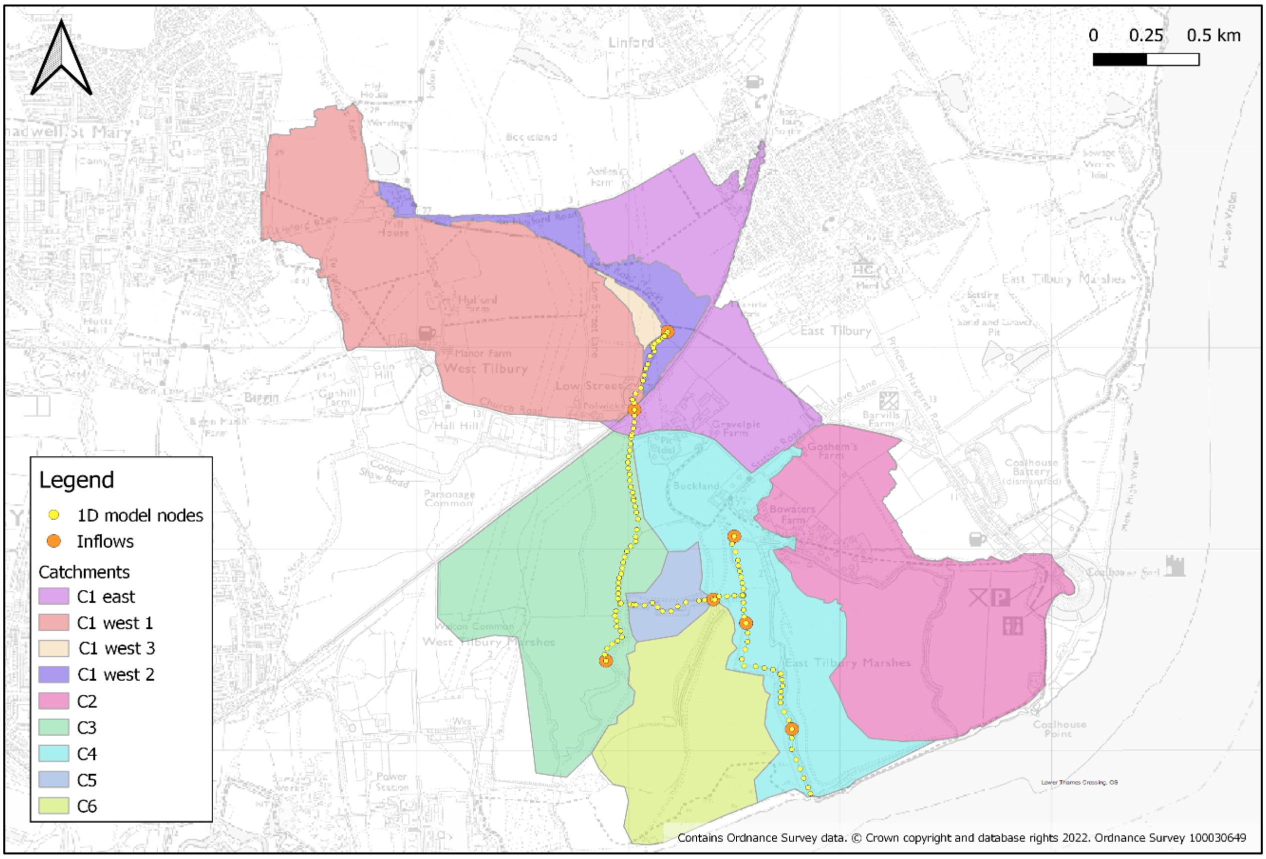


Plate 5.8 Post-development (with mitigation) model updates

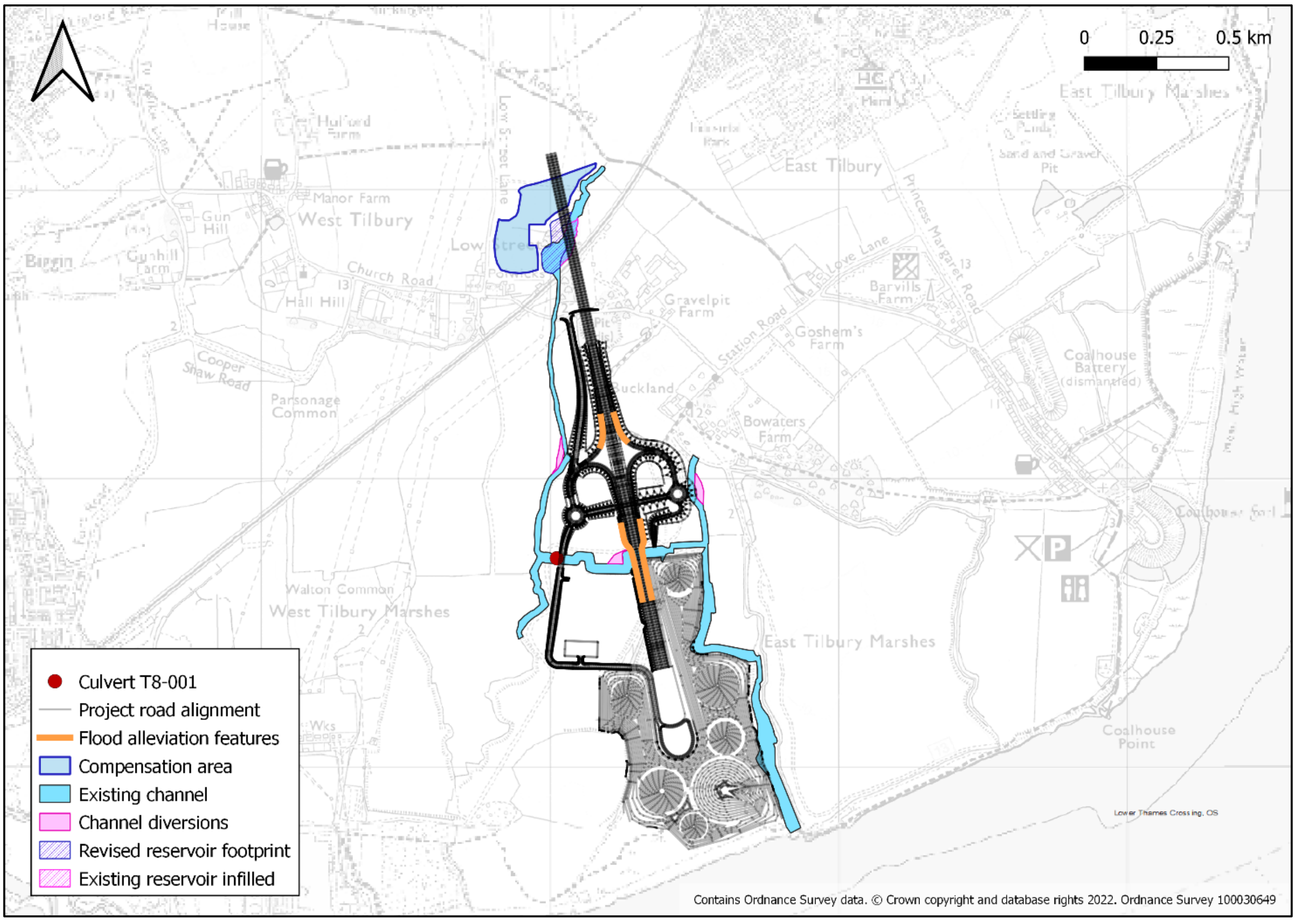


Table 5.3 Post-development (with-mitigation) model updates

File description	Comment
Proposed compensation area 2d_zsh polygon, point and polyline features	Compensation area north of the railway by using Z-shape features to lower the ground levels and spill/orifice units to allow the flow to be diverted from/into the channel. Shape of the compensation area was adjusted to fit utilities in the adjacent area [REAC Ref. RDWE037].
Amendment of culvert at node T8-001	Above the existing culvert, a new orifice unit has been added to allow more flow to be conveyed for higher events than the two-year return period event for the pre-development case. The invert level is set up to be 0.001m higher than maximum water level for two-year return period event for the pre-development case [REAC Ref. RDWE046].

5.4 Model boundaries

Inflows

5.4.1 The catchment inflows were applied in the model as point inflows for some catchments and distributed as lateral inflows for other catchments (see Section 4.7).

Downstream boundary

5.4.2 For design event simulations, Bowaters Sluice is modelled as 100% blocked, so simulations are not influenced by downstream boundary conditions.

5.4.3 For the sensitivity testing simulations with Bowaters Sluice represented as 75% blocked, a MHWS tide condition was specified for the West Tilbury Main model downstream extent, as follows:

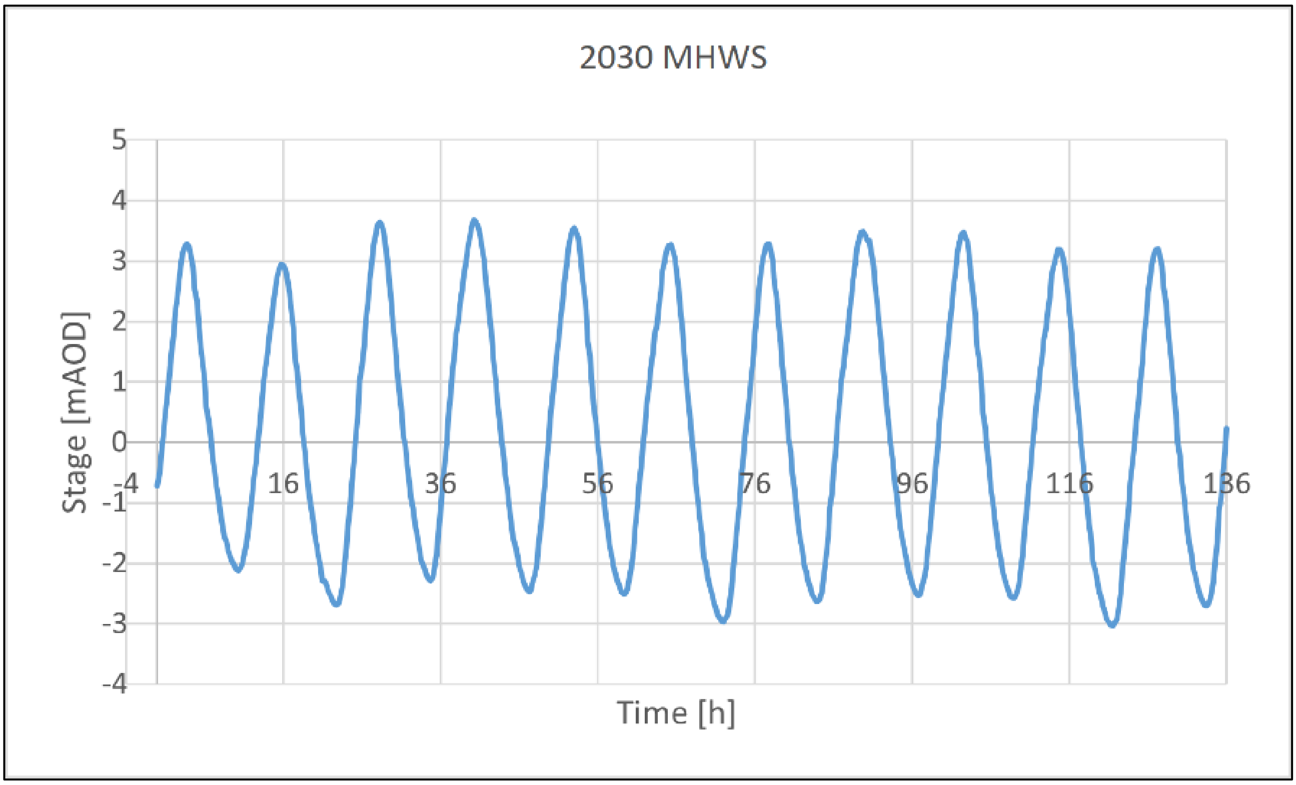
a. A MHWS time series was extracted from Tilbury tide level time-series data (based on records from 3 April 2003 to 12 September 2005).

b. The resulting MHWS time series was adjusted for location, assuming the same relative level differences as for the TE2100 EWL values provided at locations in the River Thames. The 2005 differences were applied to adjust for location for the 2030 time series, and 2100 differences (-0.16m) were applied to adjust for location for the 2130 time series.

c. MHWS time series were constructed for simulation years 2030 and 2130, by assuming the same rate of uplift in levels relative to a 2005 base year as in the TE2100 EWLs (i.e. interpolating for 2030, and extrapolating beyond 2120 for 2130).

d. The 2030 MHWS tide level series applied for the Tilbury model downstream extent is shown in Plate 5.9. As these boundaries were only used in sensitivity testing, the TE2100 design EWLs were not adjusted further to account for the latest UKCP18 sea level rise projections (Met Office, 2018) and CFB2018 coastal EWLs dataset.

Plate 5.9 2030 MHWS tide level series



5.4.4 For the sensitivity to Bowaters Sluice blockage simulations, the relative timing of the fluvial and tidal peaks was adjusted so that the fluvial peak at the downstream model extent approximately coincided with the earlier of the two highest tide peaks (at approximately 28 hours in Plate 5.9).

Climate change allowances

Peak river flow allowances

5.4.5 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 specification of peak river flow allowances is discussed further in Part 6 of the FRA.

Sea level rise allowances

5.4.6 For the design simulations, Bowaters Sluice is assumed to be 100% blocked, and so simulations are not influenced by the downstream boundary conditions. For the sensitivity testing with 75% blockage applied for Bowaters Sluice, sea level rise allowances were assumed to have the same rate of uplift in levels relative to a 2005 base year as in the TE2100 EWLs (paragraph 5.4.3).

5.5 Roughness parameters

5.5.1 Roughness parameter values for the 1D cross-sections were specified using Manning's n friction values. The roughness values are a means of representing the channel and floodplain conveyance based on the vegetation, composition and sinuosity. The study derived the roughness values from survey photos and a combination of modelling experience and information from Open-Channel Hydraulics (Chow, 1959). The roughness coefficients adopted are listed in Table 5.4. Plate 5.10 shows a site photograph of a typical West Tilbury Main channel reach (T9 reach).

Table 5.4 1D Manning's n value

Land use	Description	Manning's n value
Natural channel	Typical channel sections	0.040
Culverts	Concrete type culverts	0.015
Banks/floodplain	Vegetation	0.060
Pond	Pond modelled as 1D channel section	0.036

Plate 5.10 Tilbury channel type (T9 reach)

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

5.5.2 The roughness parameters for the 2D model domain were specified using OS MasterMap data to define the coverage of the different land types. The roughness coefficients adopted are listed in Table 5.5.

Table 5.5 2D Manning's n value

Land use	Material number	Manning's n value
Building	10021	0.500
General surface – multi-surface – gardens	10053	0.080
General surface – step	10054	0.020
General surface	10056	0.050
Inland water	10089	0.035
Landform	10093	0.050
Landform – slope	10096	0.050
Natural environment	10111	0.100
Path	10123	0.020
Rail	10167	0.050
Road or track	10172	0.020
Roadside	10183	0.020
Structure	10185	0.500
Structure – pylon	10193	0.050
Tidal water	10203	0.035

6 Calibration and validation

6.1 Calibration

6.1.1 No calibration data was available, so calibration was not undertaken. This is not uncommon for small ungauged catchments.

6.2 Validation

6.2.1 No validation data was available, so validation was not undertaken. This is not uncommon for small ungauged catchments.

7 Design simulations and results

7.1 General

Design simulations

7.1.1 Fluvial design flood events have been simulated for the 2, 20, 100 and 1,000-year return period events.

7.1.2 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 Section 5.3).

7.1.3 The simulations undertaken and associated flood mapping outputs are listed in Table 7.1. 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 7.1 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 peak river flow 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 peak river flow 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 peak river flow 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 2, 20 and 100-year return period events in 2030 with +6% Central peak river flow allowance applied and in 2130 with a +17% Central peak river flow allowance applied, 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.

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

Table 7.1 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	X	X
2 year in 2030 (+ 11%)	X	X	X		
2 year in 2130 (+ 17%)	X	X	X	X	X
2 year in 2130 (+ 26%)	X	X	X		
20 year in 2030 (+ 6%)	X	X	X	X	X
20 year in 2030 (+ 11%)	X	X	X		
20 year in 2130 (+ 17%)	X	X	X	X	X
20 year in 2130 (+ 26%)	X	X	X		
100 year in 2030 (+ 6%)	X	X	X	X	X
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 tunnel 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 H++ EWL (7.28mAOD)	X	X	X		

Bowaters Sluice blockage condition

7.1.5 The Environment Agency advised that the Bowaters Sluice outfall is 75% blocked, to reflect its current condition. Sensitivity runs were undertaken to compare pre-development model results with a 75% and 100% blockage of Bowaters Sluice outfall.

7.1.6 Results for both 75% and 100% blockage scenarios show similar maximum depths and maximum flood extents, which indicates the impact of simulating a 100% blockage condition compared to 75% is minor (see Annex D). For the 20-year return period event in 2030 with 11% peak river flow climate change allowance, the effect of 75% compared to 100% blockage is between +0.01m and +0.04m for the entire domain (i.e. levels are higher for the 100% blockage scenario). Higher values of approximately +0.04m occur at the eastern side compared to the western part of the domain with approximately +0.015m difference, with the exception of some small areas at the lower western part of the domain showing differences of approximately +0.25 to +0.40m. Similarly, for the 100-year return period event in 2130 with +17% peak river flow climate change allowance, the differences on the west side of the Project road are negligible (within +/-0.01m), except for areas to the south where differences are between +0.02m and +0.04m. For the Higher event (100-year return period in 2130 with +26% river flow allowance), the impact of Bowaters Sluice blockage is smaller compared to the lower events presented above. The depth differences are smaller than 0.01m for most of the western part of the domain, with areas of depth difference ranging between +0.01m and +0.03m for the rest of the domain (i.e. levels are higher for 100% blockage scenario).

7.1.7 Given this insensitivity of model results to the blockage condition, design model simulations apply a 100% blockage condition for the Bowaters Sluice tidal outfall. This provides slightly conservative (precautionary) outputs and discounts the requirement to simulate a matrix of joint probability combinations of tidal and fluvial events, as with the 100% blockage condition, downstream tide conditions would not influence simulation results.

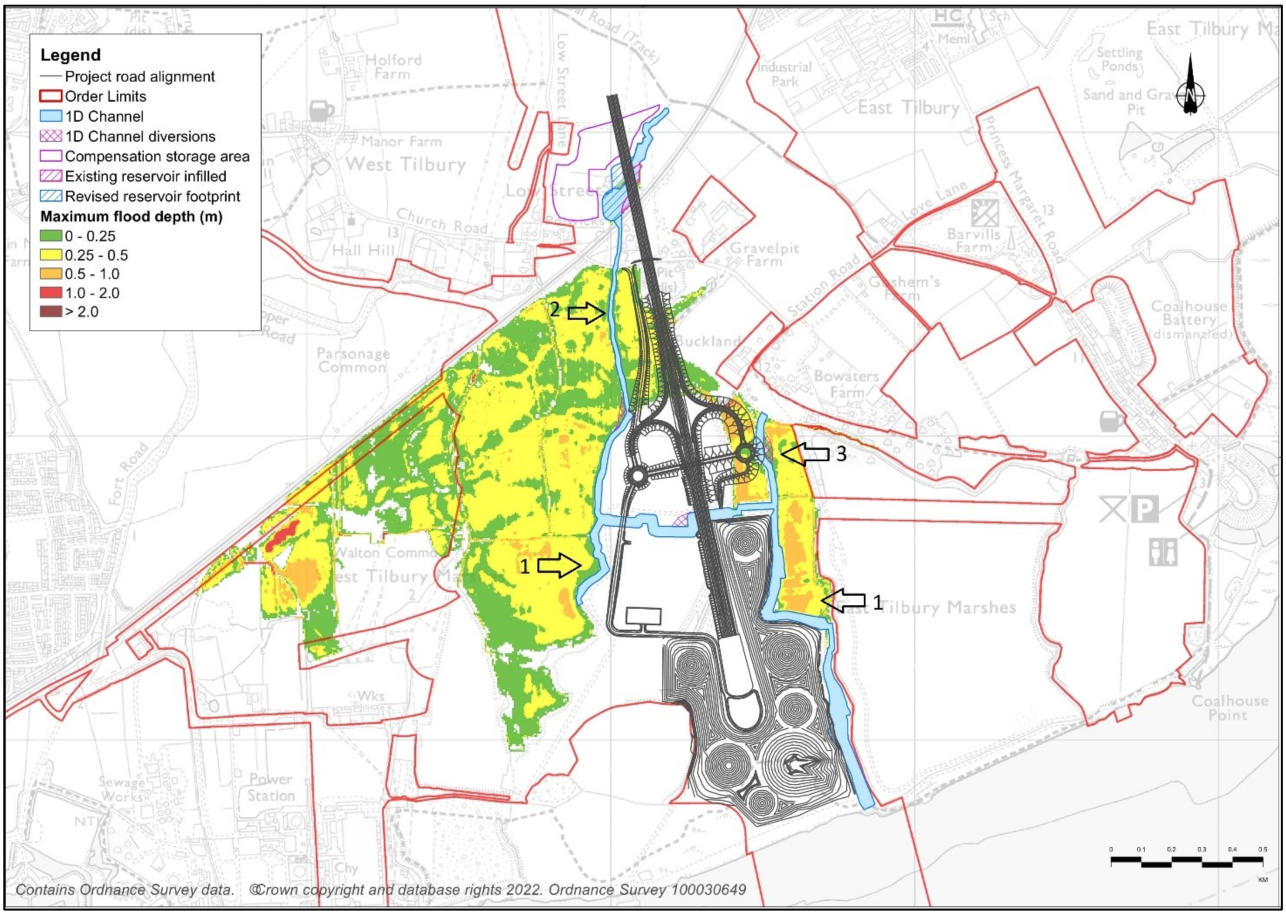
7.2 Design model results interpretation

7.2.1 The flood mapping outputs are listed in Table D.1 in Annex D.

Pre-development flood mechanisms

7.2.2 Plate 7.1 (pre-development, 100-year return period event in 2130 with +17% Central peak river flow allowance) is annotated to illustrate the flood mechanism in the study area for the pre-development scenario. Out of bank flow occurs initially at the lower T7 and T9 modelled reaches (arrow 1 in Plate 7.1). Subsequently, out of bank flow occurs at the middle modelled T7 reach as well as at the upstream modelled T9 reach (arrows 2 and 3). Due to the tide locking conditions and the magnitude of the simulated fluvial model inflows, flow directions can vary within the model, which in turn affects the simulated flood extents.

Plate 7.1 Maximum flood depth for pre-development design simulation – 1 in 100 year fluvial event with 17% climate change allowance in 2130



Impact of design (post-development without mitigation) on flood risk

7.2.3 Plate 7.2 (100-year return period event in 2130 with +26% Higher central peak river flow allowance year event) is annotated to illustrate the maximum flood depth difference between the post-development (without mitigation) and the pre-development scenarios.

7.2.4 This plate shows that the Project road embankment would block the floodplain connectivity from the eastern to the western side of the road, which in turn results in increased flood depths on the eastern side of the road of approximately 0.1m to 0.6m (arrow 2 in Plate 7.2).

7.2.5 The area shown in green under the Project road embankment (arrow 1 in Plate 7.2) indicates the floodplain volume that would be displaced by the Project road.

7.2.6 To the west of the Project road, the results indicate that the impact on flood depths would be minor (approximately -0.01m to 0.01m). There are also localised increases of around 0.01m to 0.15m (arrow 3 in Plate 7.2).

7.2.7 1D in-channel depth differences are not visualised in Plate 7.2 (represented by the light blue area), but the differences are similar to the values shown in the adjacent out-of-the-bank 2D domain.

7.2.8 The areas with an increase in flood depth do not include Essential infrastructure (as defined in the National Planning Policy Framework (Department for Levelling Up, Housing and Communities, 2022)), and so following current Environment Agency (2022) guidance, the Central peak river flow allowances (+6% in 2030 and +17% in 2130) were applied to assess offsite impacts and mitigation measures.

Plate 7.2 Maximum flood depth difference (post-development without mitigation minus pre-development design simulation – 1 in 100 year fluvial event with 26% climate change allowance in 2130)

7.2.9 Plate 7.3 (100-year return period event in 2130 with +17% Central peak river flow allowance) is annotated to illustrate the maximum depth difference between the post-development (without mitigation) and the pre-development scenarios.

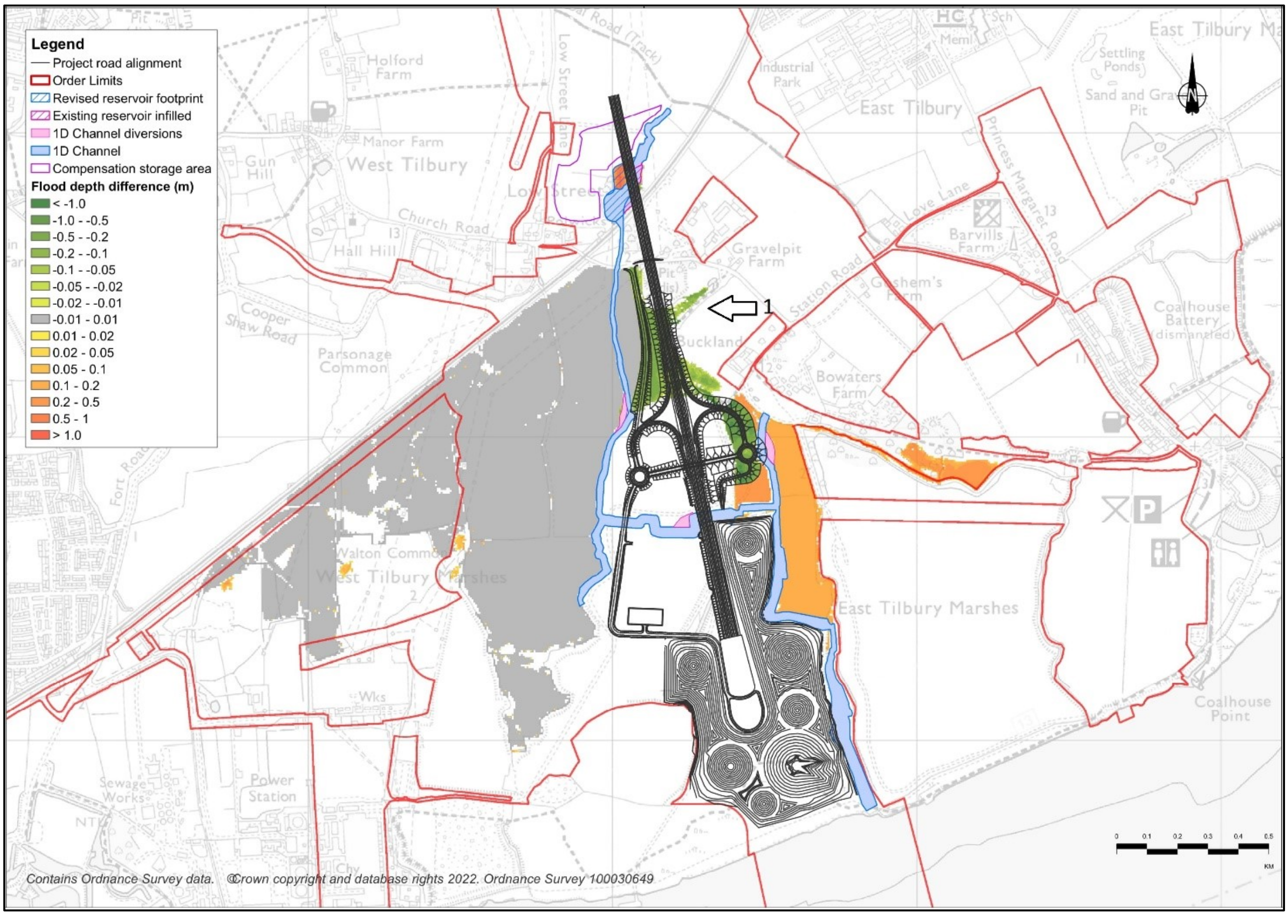
7.2.10 This plate shows that the Project road embankment would block the floodplain connectivity from the eastern to the western side of the road, and displaces floodplain storage, which in turn results in increased flood depths on the eastern side of the road of approximately 0.05m to 0.5m (areas shown in orange).

7.2.11 The area shown in green (arrow 1 in Plate 7.3) under the Project road embankment indicates the floodplain volume that would be displaced by the road.

7.2.12 To the west of the Project road, the results indicate that the impact on flood depths would be generally minor (approximately -0.01m to 0.01m). There are some localised higher increases with increases above +0.01m. However, these grid cells are located in areas where the increase is generally less than +0.01m, 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).

7.2.13 1D in-channel depth differences are not visualised in Plate 7.3 (represented by the light blue area), but the differences are similar to the values shown in the adjacent out-of-the-bank 2D domain.

Plate 7.3 Maximum flood depth difference (post-development without mitigation minus pre-development design simulation – 1 in 100 year fluvial event with 17% climate change allowance in 2130)



Influence of identified mitigation measures

7.2.14 Plate 7.4 (100-year return period event in 2130 with +17% Central peak river flow allowance) shows the maximum depth difference between the post-development (with mitigation measures) and the pre-development scenarios. The identified mitigation measures, described in Section 5.3, result in mitigation of the offsite impacts due to development of the Project for all events simulated (see Annex D). Increases in floodplain depths are limited to the floodplain compensation area (arrow 1 in Plate 7.4) and the area adjacent to and east of the road (arrow 2 in Plate 7.4) where the increase in flood depth is

0.01m to 0.2m, on land which National Highways will be seeking permanent acquisition. The 1D in-channel depth differences are not visualised in Plate 7.4 (represented by the light blue area), but the differences are similar to the values shown in the adjacent out-of-the-bank 2D domain.

7.2.15 Usually floodplain compensation would be provided to replace the floodplain volume displaced by the Project on a hydraulically linked 'level-for-level' basis, with volumes displaced within level ranges, replaced within the same level ranges. However, this is not possible in the West Tilbury Main catchment due to the low level, flat floodplain. However, the mitigation measures proposed would fully mitigate the impacts of the Project (as shown in the flood depth difference drawings in Annex D).

7.2.16 Table 7.2 lists the maximum volumes displaced by the road and peak additional floodplain storage provided in compensation area for the simulated events. Table 7.2 shows that, for all events simulated, the additional peak floodplain storage provided by the compensation area exceeds the peak flood storage displaced by the Project.

Plate 7.4 Maximum flood depth difference (post-development with mitigation minus pre-development design simulation – 1 in 100 year fluvial event with 17% climate change allowance in 2130)

Table 7.2 Maximum volumes displaced by the road and peak additional floodplain storage in compensation area for the simulated events

Event	'Total' volume stored (m^3)	'Total' volume displaced by Project (m^3)	'Total' difference (stored minus displaced) (m^3)
1,000yr +48%	63,857.59	49,980.44	13,877.15
1,000yr+26%	62,560.38	49,339.17	13,221.20
1,000yr+11%	61,518.89	46,559.03	14,959.87
100yr+26%	49,113.40	42,195.84	6,917.56
100yr+17%	46,489.65	40,749.82	5,739.84
100yr+11%	44,460.71	40,163.31	4,297.39
100yr+6%	43,035.76	39,426.35	3,609.41
20yr+26%	33,963.58	30,345.52	3,618.07
20yr+17%	30,995.04	22,136.41	8,858.63
20yr+11%	32,150.86	19,794.22	12,356.64
20yr+6%	29,899.08	15,363.32	14,535.76
2yr+26%	14,247.15	6,916.53	7,330.62
2yr+17%	13,369.04	6,833.41	6,535.63
2yr+11%	13,242.41	6,726.63	6,515.78
2yr+6%	12,927.85	6,639.28	6,288.56

Project highway and tunnel North Portal operation during extreme flooding

7.2.17 Plate 7.5 and Plate 7.6 show the maximum simulated flood depths for the post-development scenario with mitigation and without mitigation respectively, during the 1,000-year return period flood event in 2130 with +48% Upper end peak river flow climate change allowance, i.e., the credible maximum climate change allowance specified in Environment Agency (2022). This event exceeds the operational design standard for the proposed highway (operational design standard of 1,000-year return period flood event in 2130 with +26% Higher central peak river flow climate change allowance) and tunnel portal (operational design standard of 1,000-year return period flood event in 2130 with +26% Higher central peak river flow climate change allowance).

7.2.18 During this event, the Project would not be impacted (i.e. no overtopping of the Project highway or tunnel North Portal). The proposed defence embankment protecting the tunnel North Portal and road is designed with a crest level of 7.83mAOD, whereas the maximum simulated flood level adjacent to the proposed highway is 2.82mAOD for the case without mitigation and 2.32mAOD for the case with mitigation.

7.2.19 The Project would therefore continue to operate during the flood events defined by its operational design standard.

Plate 7.5 Maximum flood depth for post-development (with mitigation) design simulation – 1 in 1000 year fluvial event with 48% climate change allowance in 2130

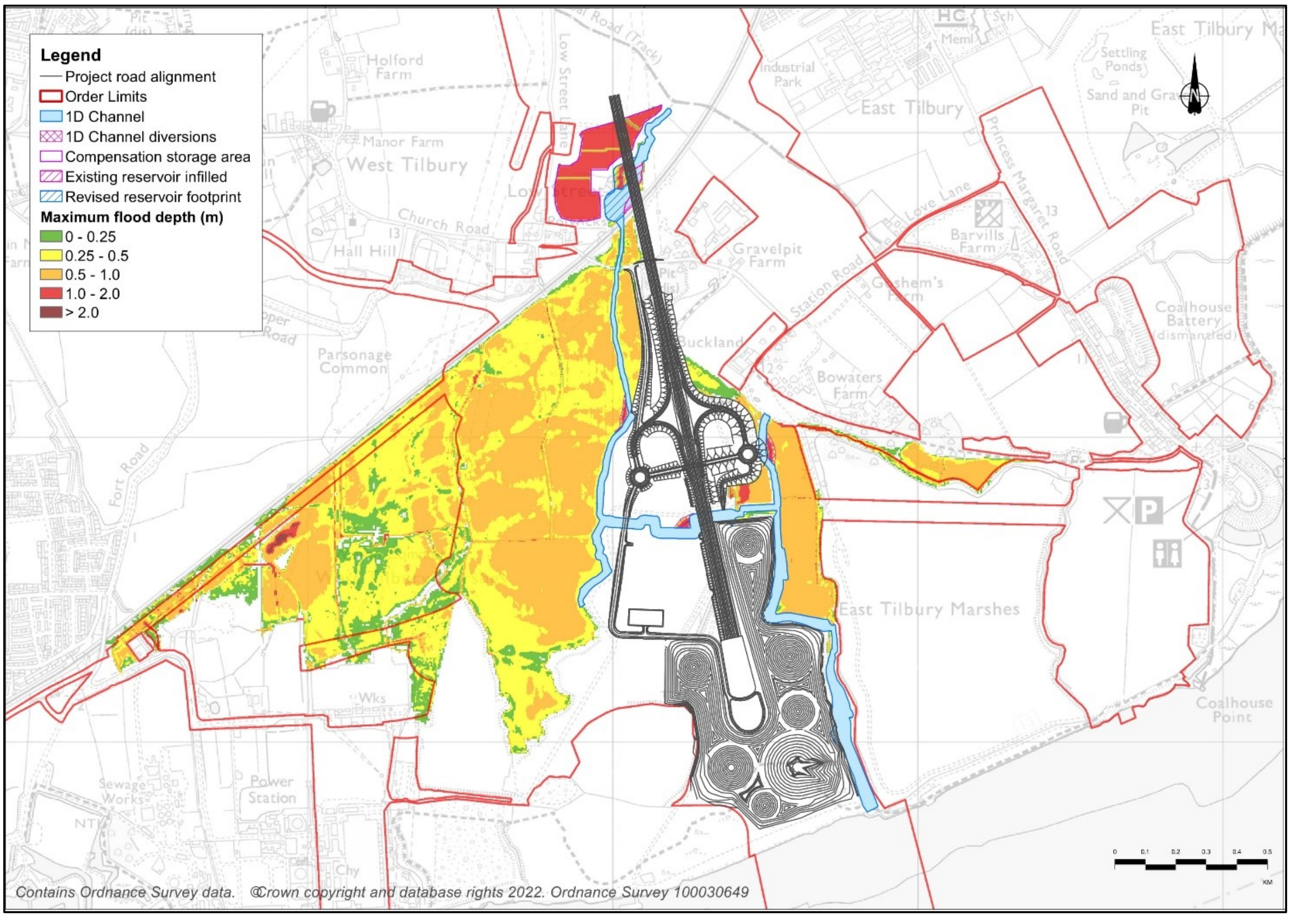
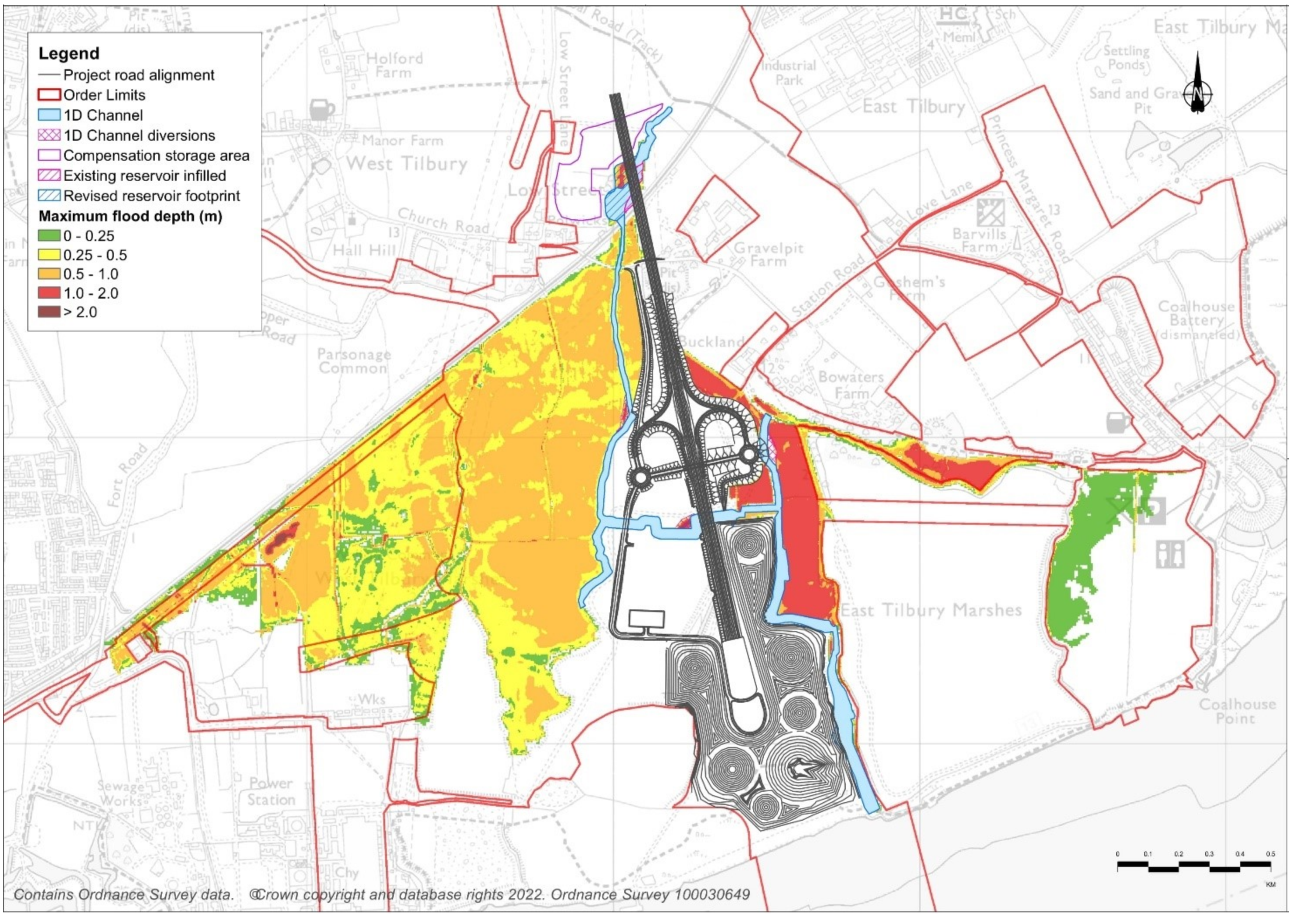


Plate 7.6 Maximum flood depth for post-development (without mitigation) design simulation – 1 in 1000 year fluvial event with 48% climate change allowance in 2130



7.3 Sensitivity testing interpretation

7.3.1 Further to the sensitivity simulations undertaken to compare pre-development model results with a 75% and 100% blockage of Bowaters Sluice outfall described in Section 7.1, a number of additional simulations were undertaken to assess the model sensitivity to key elements:

a. ±20% uplift/decrease of Manning's n roughness in both the 1D and 2D model domains

b. ±20% uplift/decrease in model inflows

c. 50% blockage of the proposed West Tilbury Main culvert

7.3.2 Sensitivity testing has been undertaken for the 100-year return period event in 2130 with +26% Higher central peak river flow allowance, and results have been compared with those of the post-development with mitigation model. The flood mapping outputs of all sensitivity test simulations undertaken are included in Annex D.

7.3.3 In addition to the sensitivity tests detailed above, this section includes a consideration of:

a. The Project's adaptability to the credible maximum climate change scenario

b. The significance of the omission of railway culverts in the model (floodplain area towards the north-west of simulated flooding) on assessment of offsite impacts beyond the railway

±20% Manning's n roughness

7.3.4 Plate 7.7 and Plate 7.8 show the maximum differences in flood depths, compared to the design simulations, for the sensitivity tests with 20% uplift and 20% decrease in Manning's n roughness values applied in both the 1D and 2D model domains (100-year return period event in 2130 with +26% Higher central peak river flow allowance).

7.3.5 The results indicate that the impact of Manning's n roughness values on flood depths is minor (approximately -0.01m to 0.01m) for both sensitivity scenarios, with exceptions as follows. For the 20% increase in roughness simulation there is a decrease of approximately -0.12m and two small areas with increases of approximately 0.04m and 0.11m on the west side of the road. On the east side there is a small area with an increase of approximately 0.06m to 0.15m, east of the Project road culvert. For the 20% decrease in roughness simulation there is an increase of approximately 0.02m and two areas of decrease (-0.10m and -0.20m) on the west side of the road. There is also a decrease of approximately -0.15m east of the Project road culvert.

7.3.6 1D in-channel depth differences are not visualised in Plate 7.7 and Plate 7.8 (represented by the light blue area), but the modelled differences are consistent with the values shown in the adjacent out-of-bank 2D domain.

Plate 7.7 Maximum flood depth difference (+20% Manning's n minus post-development design simulation – 1 in 100 year fluvial event with 26% climate change allowance in 2130)

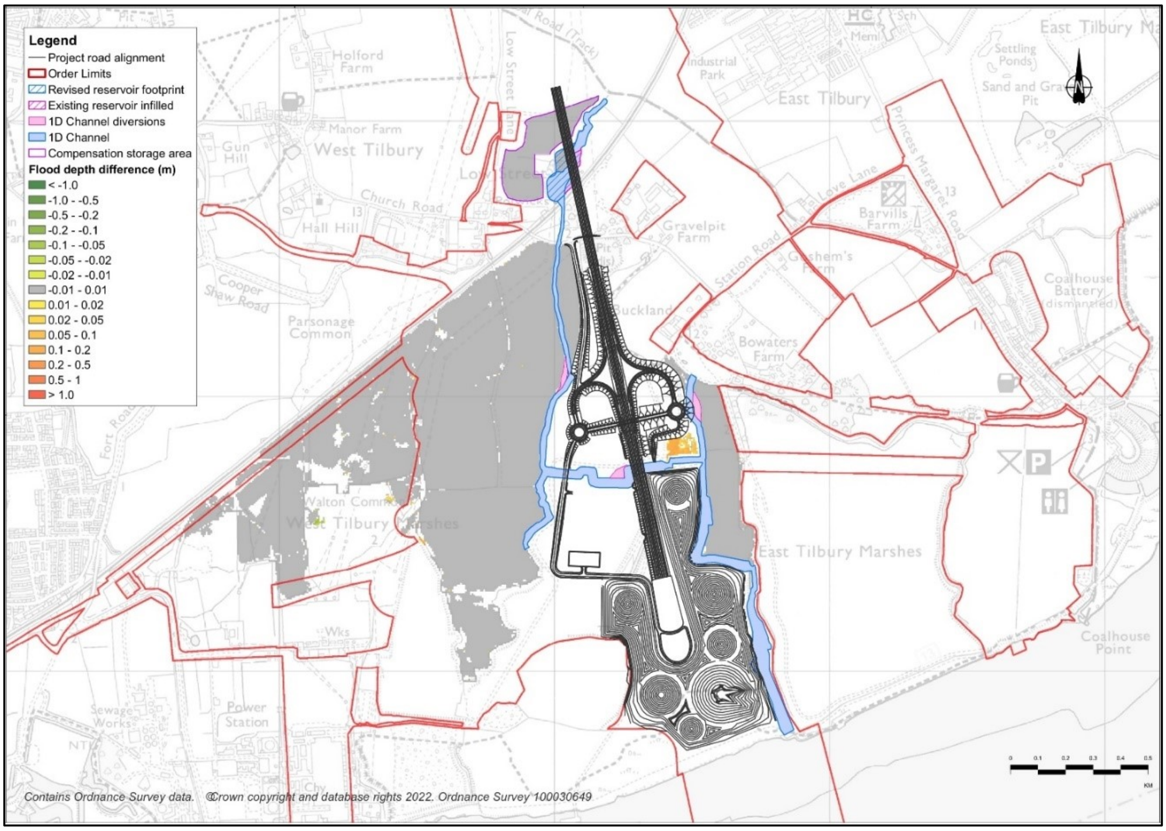


Plate 7.8 Maximum flood depth difference (-20% Manning's n minus post-development design simulation – 1 in 100 year fluvial event with 26% climate change allowance in 2130)

±20% inflows

7.3.7

7.3.8 Plate 7.9 and Plate 7.10 show the maximum differences in flood depths, compared to the design simulations, for the sensitivity tests with 20% uplift and 20% decrease in model inflows (100-year return period event in 2130 with +26% Higher central peak river flow allowance). The impact of increased/decreased model inflows is as expected, with differences of approximately +0.03m to +0.5m for the 20% uplift scenario and -0.03m to -0.2m for the 20% decrease scenario.

7.3.9 Plate 7.9 and Plate 7.10 (represented with light blue area), but the modelled differences are consistent with the values shown in the adjacent out-of-bank 2D domain.

Plate 7.9 Maximum flood depth difference (+20% inflows minus post-development design simulation – 1 in 100 year fluvial event with 26% climate change allowance in 2130)

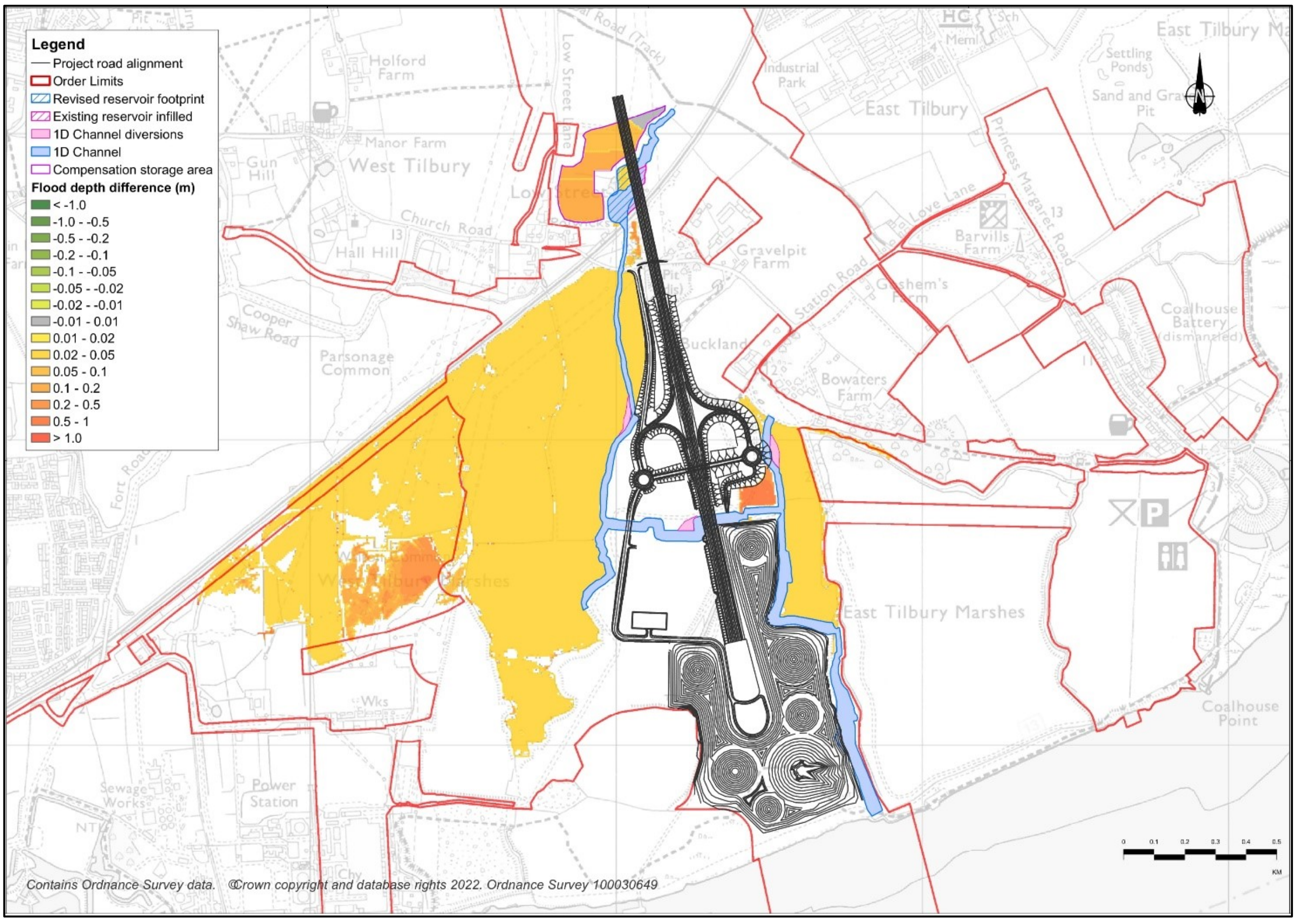


Plate 7.10 Maximum flood depth difference (-20% inflows minus post-development design simulation – 1 in 100 year fluvial event with 26% climate change allowance in 2130)

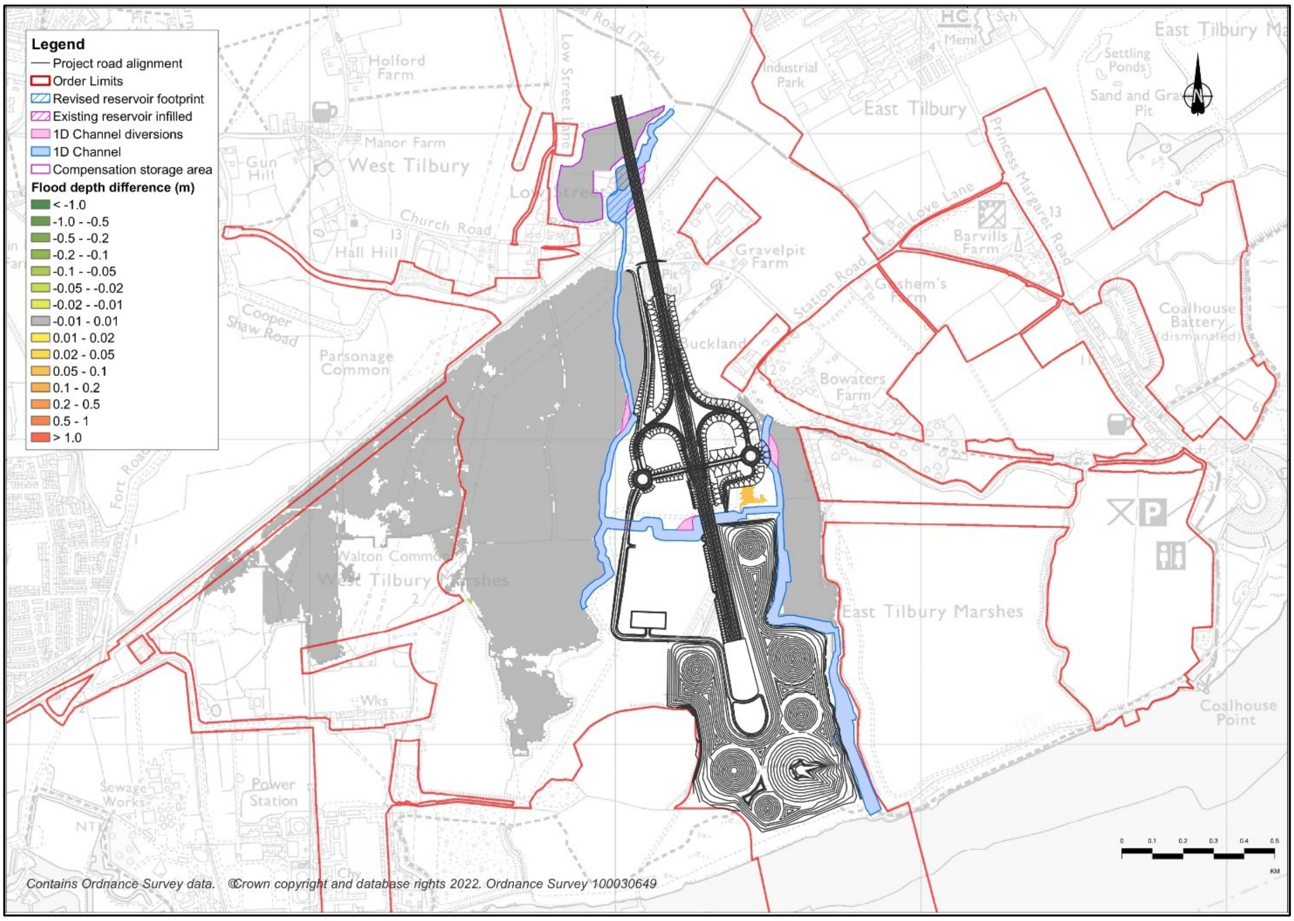
50% blockage of the proposed West Tilbury Main culvert

7.3.10 Plate 7.11 shows the maximum differences in flood depths, compared to the design simulation, for the sensitivity test with a 50% blockage of the proposed West Tilbury Main culvert (100-year return period event in 2130 with +26% Higher central peak river flow allowance).

7.3.11 The results indicate that the impact of a 50% blockage of the proposed West Tilbury Main culvert on flood depths would be minor, with differences between approximately -0.01m to 0.01m for most of the model domain. Plate 7.11 shows a small area with an increase of approximately 0.08m adjacent to the Project road.

7.3.12 1D in-channel depth differences are not visualised in Plate 7.11 (represented with light blue area), but the modelled differences are consistent with the values shown in the adjacent out-of-bank 2D domain.

Plate 7.11 Maximum flood depth difference (50% blockage of the proposed West Tilbury Main culvert minus post-development design simulation – 1 in 100 year fluvial event with 26% climate change allowance in 2130)



Consideration of a credible maximum climate change scenario

Peak river flow allowances

7.3.13 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.

7.3.14 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).

7.3.15 The proposed defence embankment protecting the tunnel and Project road will be designed with a crest level of 7.83mAOD whereas the maximum simulated flood level adjacent to the Project road is 2.82mAOD without mitigation and 2.33mAOD with mitigation, for the 1,000-year return period fluvial event in 2130 with +48% peak river flow allowance applied (and simulating Bowaters Sluice to be 100% blocked). The Project road would therefore not be impacted by fluvial flooding under the credible maximum climate change scenario.

Sea level rise and storm surge

7.3.16 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 climate change 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.

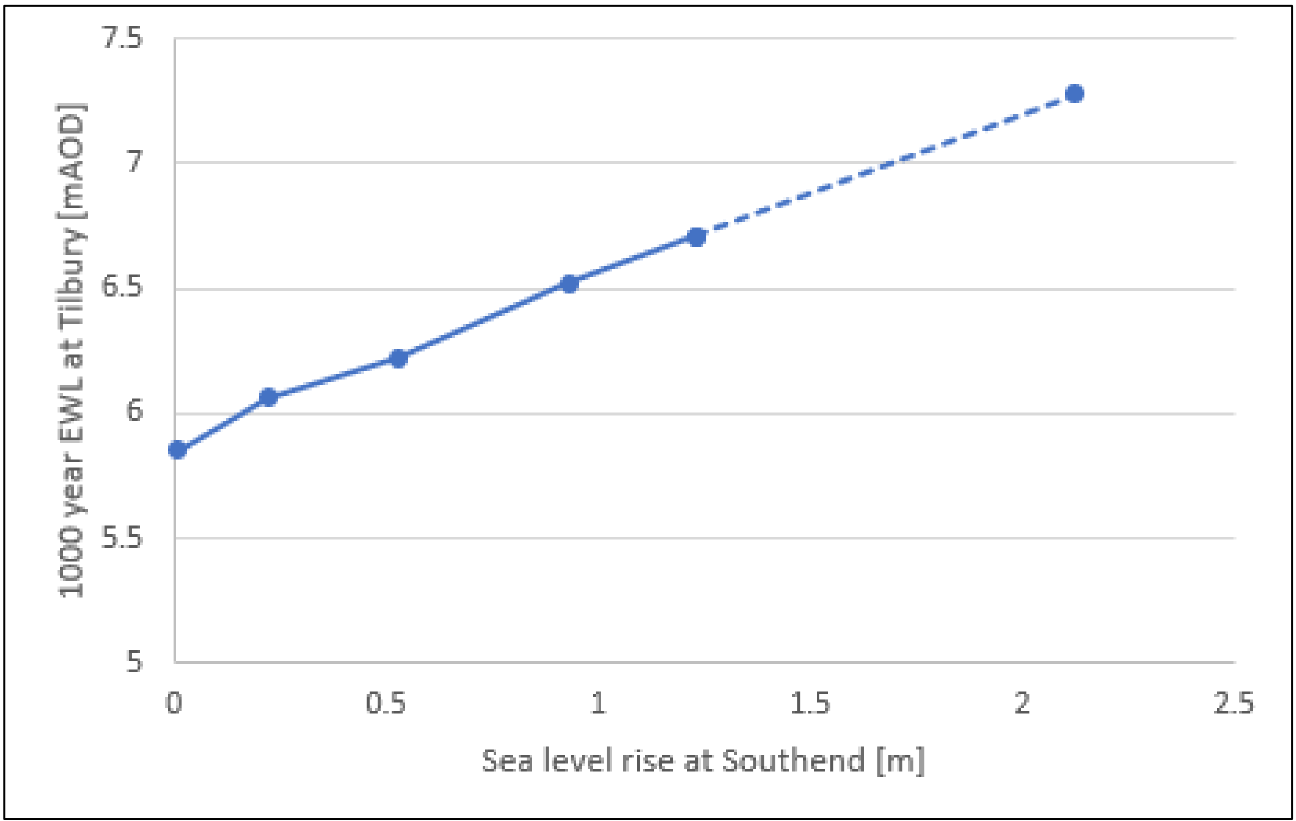
7.3.17 Plate 7.12 plots increase in EWL at Southend (UKCP18 sea level rise is applied in this Project relative to 2017) against the 1,000-year return period EWL at the TE2100 East Tilbury Marshes model node derived as described in Section 4.8. The credible maximum sea level rise and storm surge allowance at Southend relative to 2017 is +2.13m. In Plate 7.12 the relationship between sea level rise at Southend and increase in EWL at East Tilbury Marshes is extrapolated to estimate a credible maximum EWL at East Tilbury Marshes of 7.28mAOD. This extrapolation at East Tilbury Marshes is considered more realistic than simply applying the sea level rise and storm surge allowance at East Tilbury Marshes 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.

7.3.18 This estimated credible maximum 1,000-year return period EWL at East Tilbury Marshes is approximately 0.45m higher than the 1,000-year EWL at East Tilbury Marshes of 6.83mAOD, applied in this study.

7.3.19 The proposed defence embankment protecting the proposed tunnel and Project road will be designed with a crest level of 7.83mAOD (i.e. design EWL of 6.83mAOD plus 1m freeboard allowance), and the level of this structure determines the standard of flood protection of the Project road in the West Tilbury Main catchment.

7.3.20 If the credible maximum climate change scenario were realised, the Project could be adapted at this location by raising the embankment protecting the tunnel and Project road to the credible maximum level (7.28mAOD) plus a freeboard allowance (the design applies a 1m freeboard allowance which would give a bund height of 8.28mAOD), with the bund tying into higher ground as in the Project design. In the West Tilbury Main catchment, the Project is therefore considered readily adaptable to the credible maximum climate change scenario.

Plate 7.12 Sea level rise (m) at Southend plotted against the 1,000-year return period EWL (m) at the TE2100 East Tilbury Marshes model node

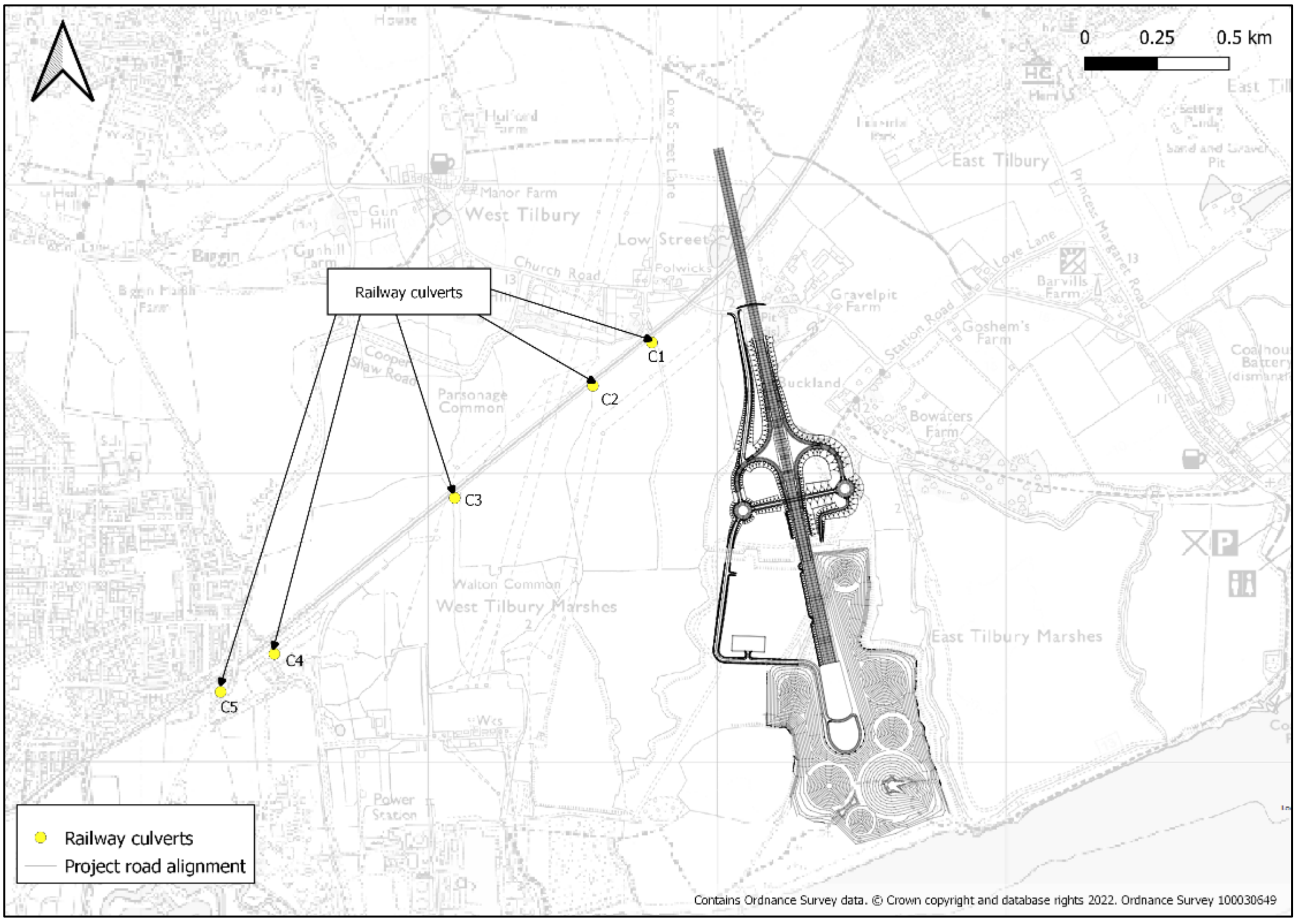


Significance of omitting railway culverts from model on assessing offsite impacts

7.3.21 The Tilbury Main model excludes the railway culverts labelled C1 to C5 in Plate 7.13, as topographic survey data was not available for these culverts and their omission is conservative in terms of simulated flood impacts at the Project road alignment.

7.3.22 This section considers the impact of omitting these culverts on the assessment of offsite impacts north-west of the railway (i.e. towards Tilbury).

Plate 7.13 Location of railway culverts



7.3.23 The proposed floodplain compensation area intercepts and retains flood water from its upstream catchment, such that for simulations with the compensation area (i.e. the post-development with mitigation simulations), flood levels in the floodplain adjacent to the omitted railway culverts have a lower peak level and rise more slowly than for the pre-development case. This is illustrated in Plate 7.14 to Plate 7.16 which show simulated level-time series, for the 100-year return period flood in 2130 with +17% Central peak river flow climate change allowances, at culvert locations C1, C2 and C3 (flood extents do not reach locations C4 and C5 for this simulated event) for the pre-development and post-development with mitigation cases.

7.3.24 These results show that if the railway culverts were included in the model, simulated flood risk north-west of the railway would be reduced for the post development case with mitigation compared to the pre-development case, due to the proposed compensation area. Omitting the railway culverts from the model therefore does not overlook potential offsite impacts north-west of the railway.

Plate 7.14 Simulated level-time series for the pre-development and post-development with mitigation cases at culvert location C1

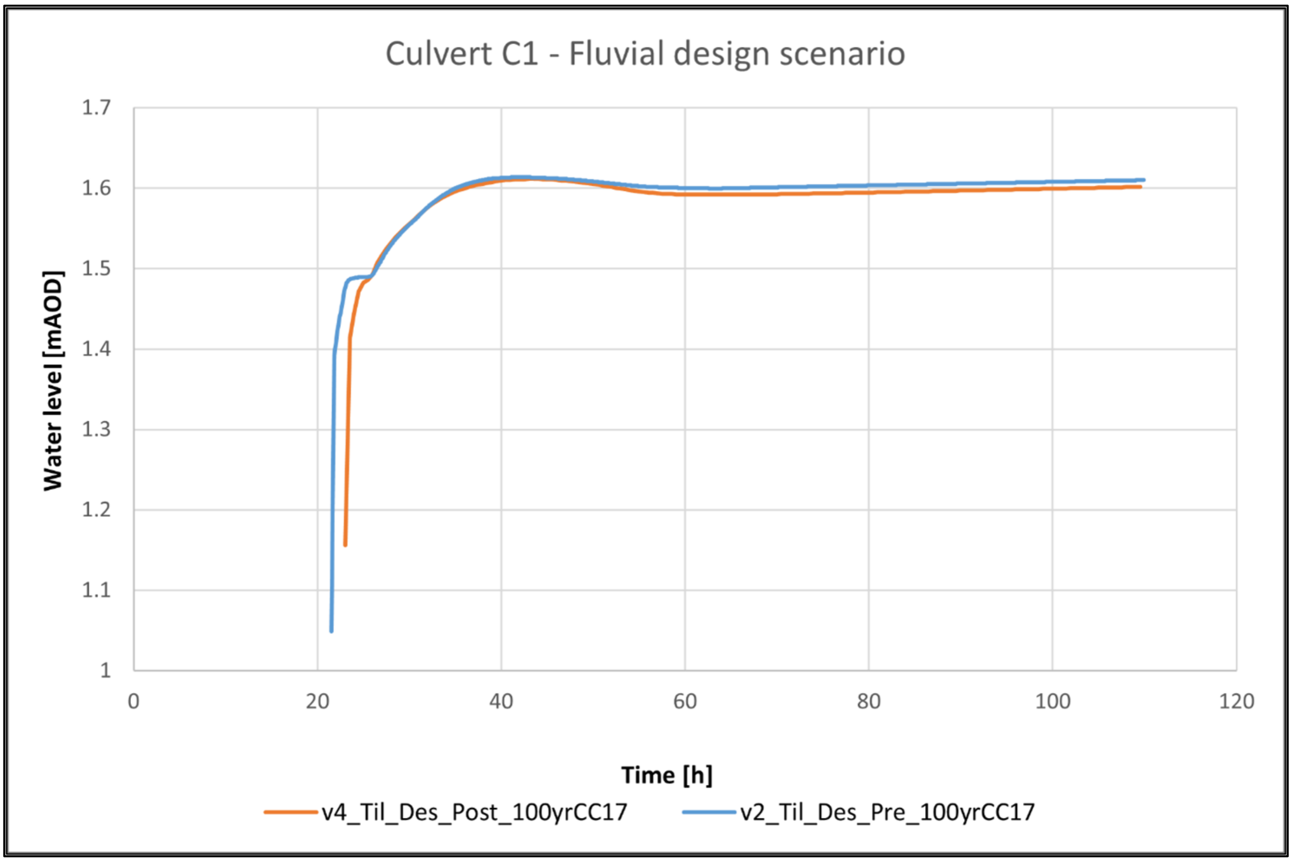


Plate 7.15 Simulated level-time series for the pre-development and post-development with mitigation cases at culvert location C2

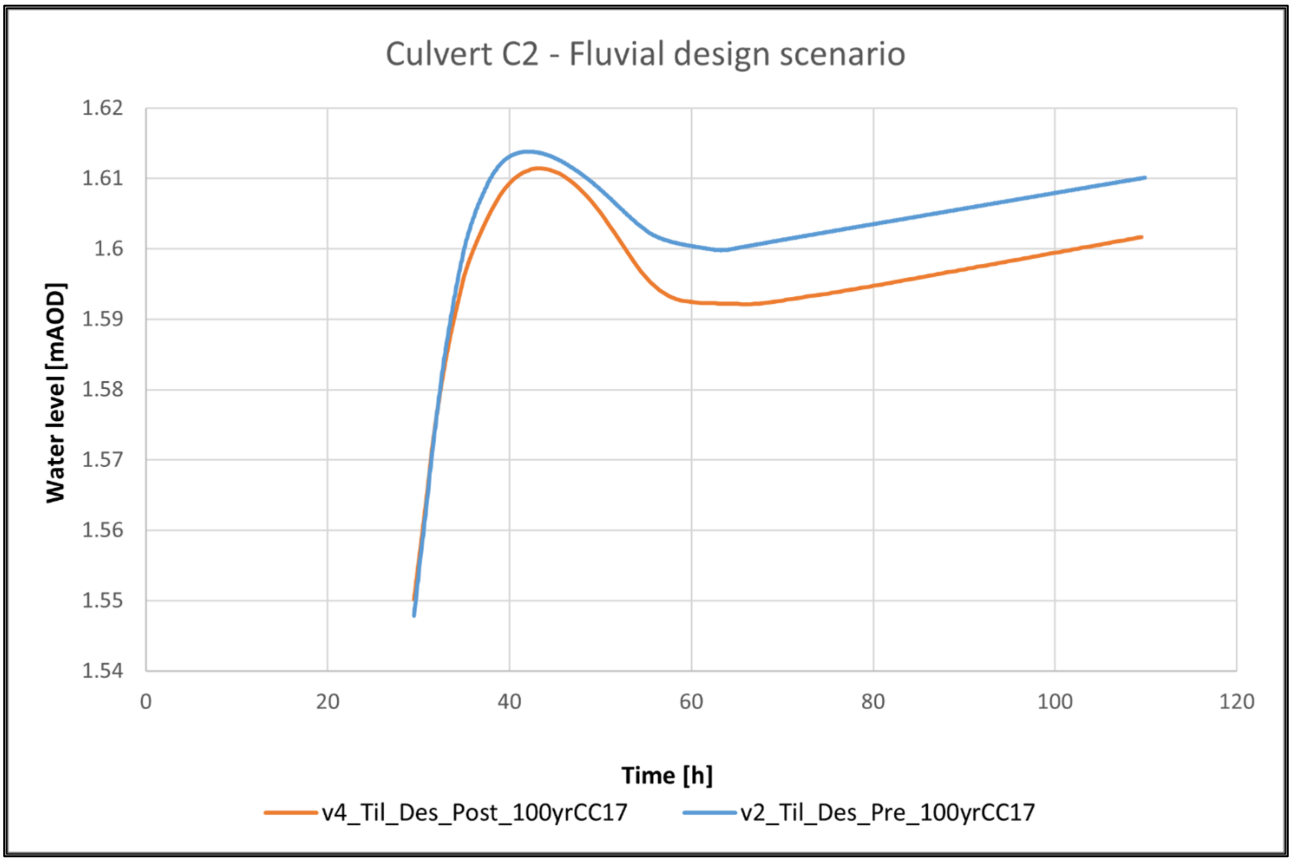
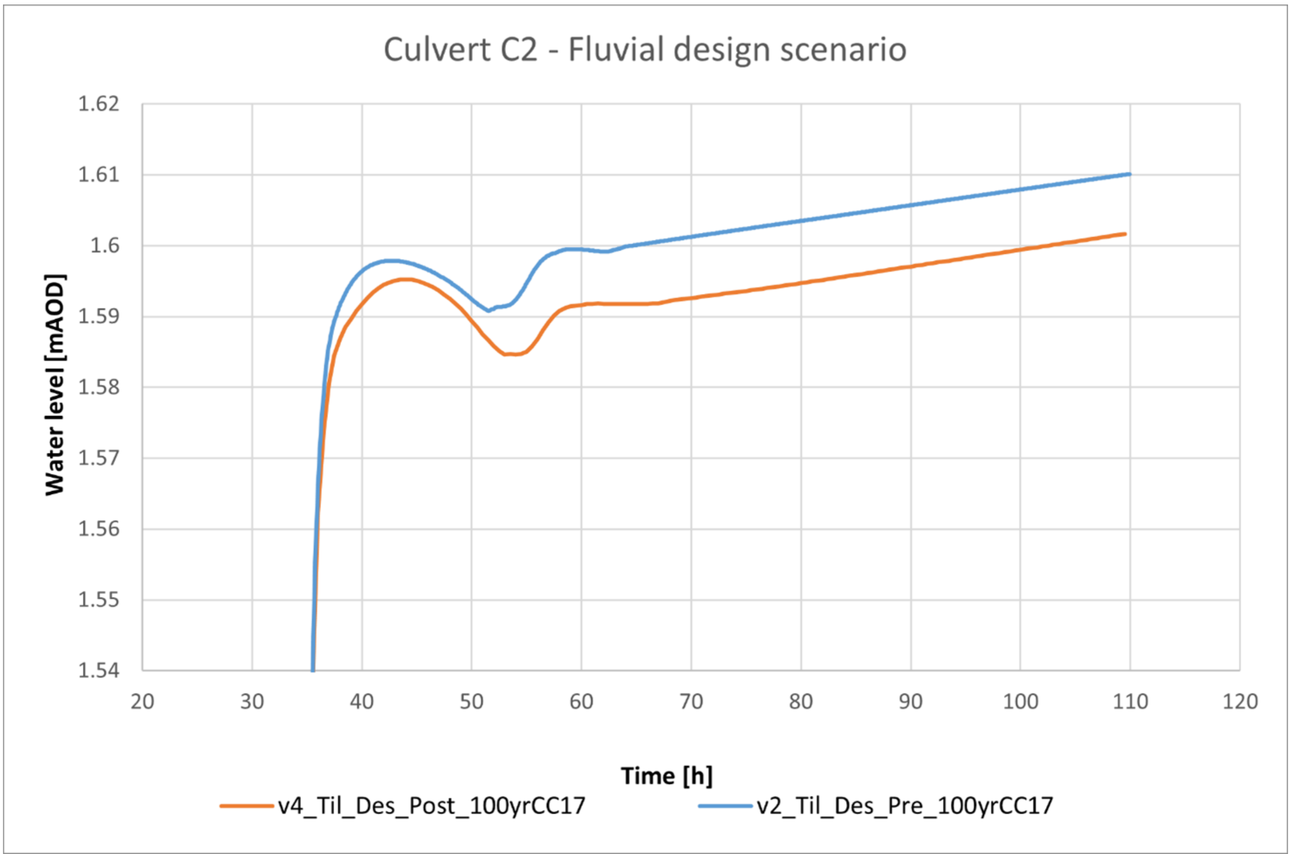


Plate 7.16 Simulated level-time series for the pre-development and post-development with mitigation cases at culvert location C3



Significance of modelling uncertainty on Project design constraints

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

7.3.26 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.

7.3.27 The proposed defence embankment protecting the proposed tunnel and Project road would be designed with a crest level of 7.83mAOD (i.e. design River Thames tidal EWL of 6.83mAOD plus 1m freeboard allowance), and the level of this structure determines the standard of flood protection of the Project road in the West Tilbury Main catchment.

7.3.28 The maximum simulated fluvial flood level adjacent to the Project road is 2.33mAOD with mitigation, for the 1,000-year return period fluvial event in 2130 with +48% peak river flow allowance applied (credible maximum climate change scenario), and the maximum simulated flood depth adjacent to the proposed defence embankment is less than 1m (Plate 7.5). 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 proposed defence embankment crest level (7.83mAOD) is 5.5m above the highest simulated design fluvial flood level. Constraints based on design fluvial flood levels therefore do not drive the design of the proposed defence embankment.

7.3.29 Additionally, for the sensitivity tests undertaken, 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 up to 0.5m locally (and by approximately 0.03m more generally) with a +20% increase in flows, and by less than 0.25m for the Manning’s n tests.

7.3.30 The adequacy of the proposed floodplain compensation mitigation is considered robust with respect to model uncertainty as the required flood compensation volumes are comfortably exceeded by the proposed flood compensation storage area (paragraph 7.2.16).

Model performance

7.3.31 The model simulations completed satisfactorily without non-convergence issues (Plate 7.17 and Plate 7.19). The model was run to simulate 110 hours which allowed sufficient time for the hydrograph to pass through the catchment. A fixed time-step of two seconds was applied to the 1D element of the model and a time-step of four seconds was applied to the 2D element of the model. These time-steps were chosen as they provided model stability and are appropriate given the cell size of the 2D grid (6m). Plate 7.18 and Plate 7.20 detail the 2D output of cumulative mass error and dVol (change in model volume) for pre-development simulations for the 1 in 100-year event with +6% climate change and with 17% climate change uplift respectively. As shown in Plate 7.18 and Plate 7.20, the mass balance is within acceptable limits and the dVol plot shows a smooth output.

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

Plate 7.17 1D model convergence (pre-development, 1 in 100-year event in 2030, +6% CC)

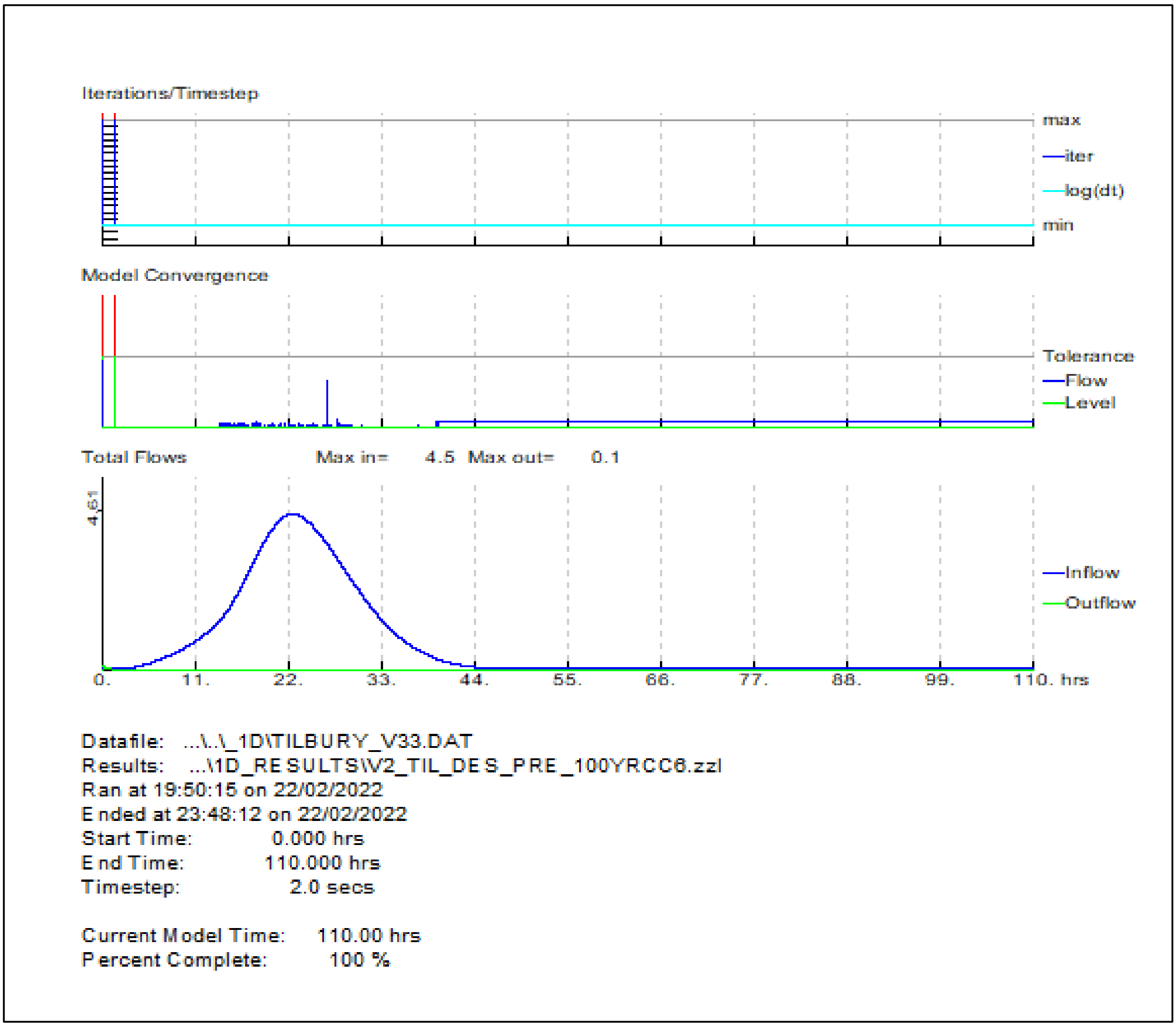


Plate 7.18 2D mass error and dVol (pre-development, 1 in 100-year event in 2030, +6% CC)

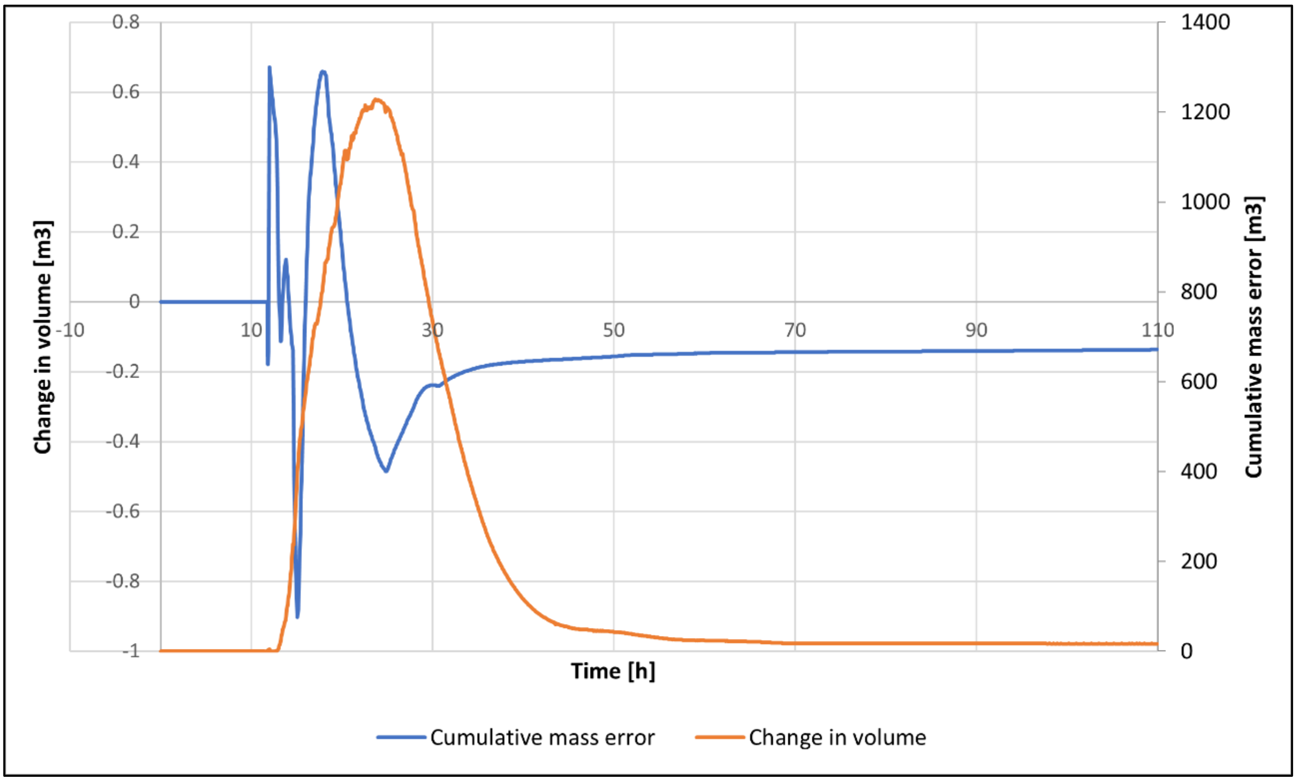


Plate 7.19 1D model convergence (pre-development, 1 in 100-year event in 2130, +17% CC)

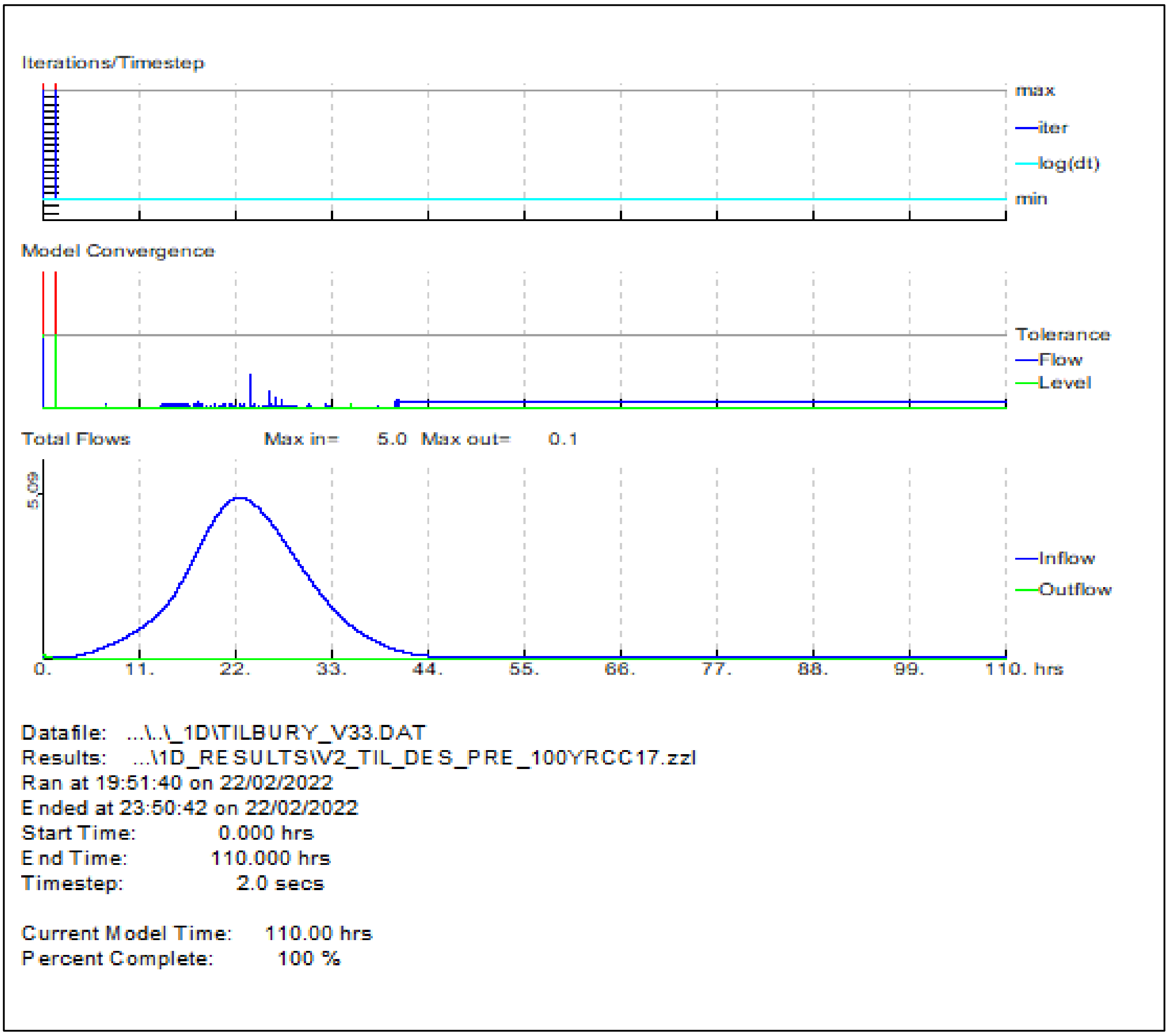
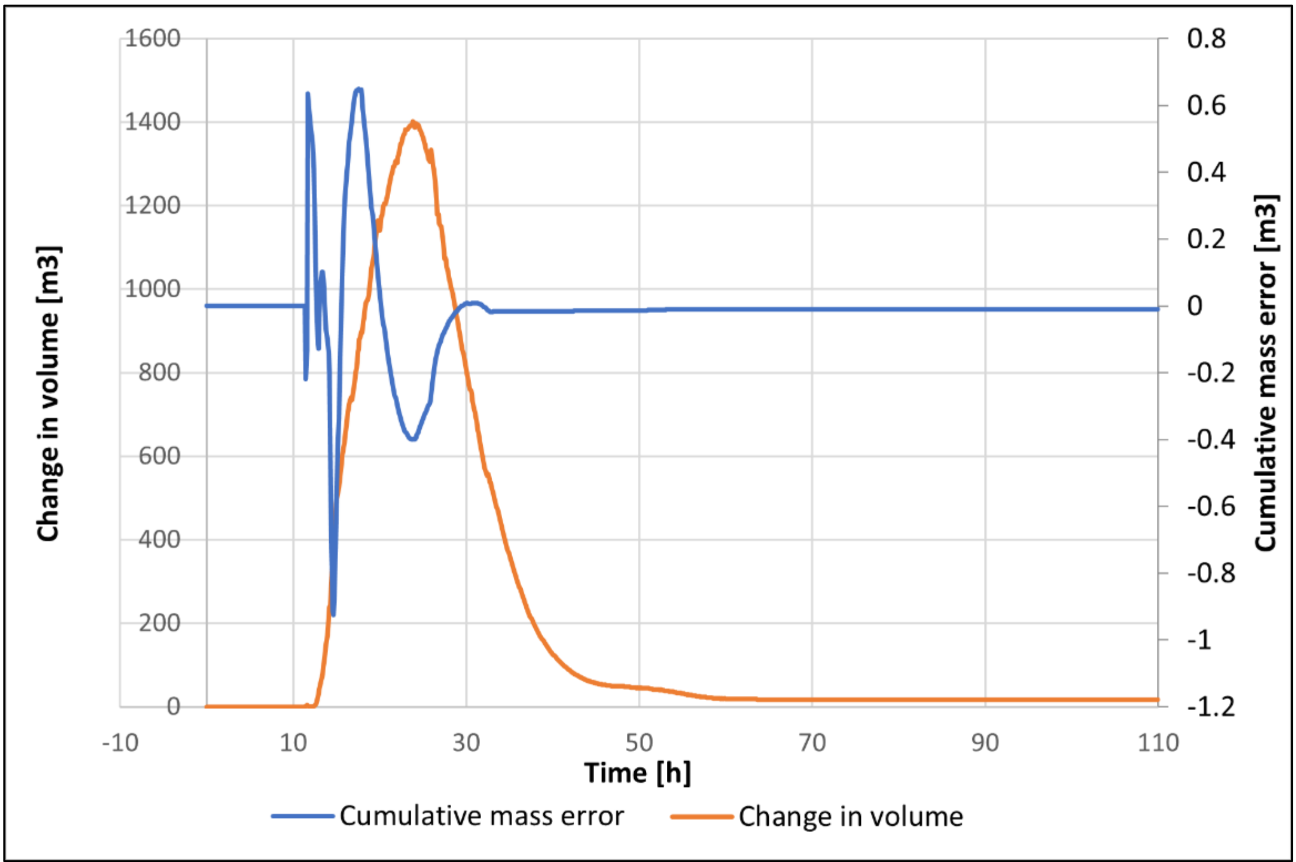


Plate 7.20 2D mass error and dVol (pre-development, 1 in 100-year event in 2130, +17% CC)



8 Conclusions

8.1.1 A hydraulic flood model of the West Tilbury Main has been developed to inform the FRA for the Project. The hydraulic model has been used to assess flood risk to the Project road and tunnel and offsite impacts for lifetime of 100 years (2130).

8.1.2 The modelling undertaken has developed fluvial flood hydrology for the West Tilbury Main catchment as well as downstream tidal conditions.

8.1.3 The hydraulic model has been constructed based on channel and structures topographic survey data acquired for the Project and LiDAR topographic data. Whilst data was not available to calibrate the model, a consideration of modelling uncertainty (Section 7.3) concludes the Project design and proposed mitigation measures are considered robust.

8.1.4 Design simulations have been undertaken for the pre-development case, and for the post-development case without and with mitigation measures, designed to mitigate offsite impacts.

8.1.5 Mitigation measures will include changes to the Tilbury Main culvert (model node T8-001) to maintain connection between the West Tilbury Main fluvial floodplain east and west of the road during flood events [REAC Ref. RDWE046], and floodplain compensation to replace floodplain displaced by the Project road embankments [REAC Ref. RDWE037].

8.1.6 Without mitigation, offsite impacts would be limited to undeveloped land 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).

8.1.7 The design simulations show that the proposed 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.

8.1.8 Usually floodplain compensation would be provided to replace the floodplain volume displaced by the Project on a hydraulically linked ‘level-for-level’ basis, with volumes displaced within level ranges replaced within the same level ranges. However, this is not possible in the West Tilbury Main catchment due to the low level, flat floodplain. Instead, floodplain compensation storage will be provided north of the Tilbury Loop railway. However, for all events simulated, the additional peak floodplain storage provided by the compensation area exceeds the peak flood storage displaced by the Project.

8.1.9 The identified mitigation measures could be delivered entirely on land within the Order Limits, on land which National Highways will be seeking permanent acquisition of rights, and their design will be finalised during the Project design development.

8.1.10 The Project would meet operational requirements as follows:

a. At West Tilbury Main and its floodplain, the proposed tunnel North Portal flood protection embankment would be above the 1,000-year return period West Tilbury Main fluvial flood level in 2130 with +48% Upper end peak river flow climate change allowance (i.e. with a higher climate change allowance than the +26% Higher central operational requirement), and any part of the Project road not protected by this embankment would be at a higher level. The Project would therefore remain operational during a 1,000-year return period flood in 2130 (with +48% peak river flow allowance).

b. The proposed tunnel flood protection embankment would be above the 1,000-year return period tidal River Thames flood level in 2130 with sea level rise allowance applied, and any part of the Project road not protected by this embankment would be at a higher level. The Project would therefore remain operational during a 1,000-year return period River Thames flood in 2130, including with a breach of the tidal River Thames flood defences (Annex E).

8.1.11 Annex E reports modelling undertaken to assess the impact of the Project on flood risk elsewhere following a breach of the tidal River Thames flood defences. Breach locations considered are at Bowaters Sluice and near the former Tilbury power station site. Annex E concludes that overall, model results indicate the Project would result in a reduction in flood risk hazard score category following a breach for Tilbury urban area, and there would be no increase in flood hazard score category for properties. There would be no significant change to flood risk along Fort Road and Tilbury Loop railway. Annex E notes that a breach is very unlikely to occur within the Project’s lifetime as it requires an extreme River Thames flood condition to occur as well as failure of the River Thames flood defences.

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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 to Table A.3.

Table A.1 Pre-development design model files

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v2_Til_Des_Pre_1000yrCC11	Tilbury_v33.dat	v2_Til_Des_Pre_1000yrCC11 .ief	v2_Til_Des_Pre_1000yrCC11 .tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	1000yr_CC11_Sum_30h_Til_ v7.ied
v2_Til_Des_Pre_1000yrCC26	Tilbury_v32.dat	v2_Til_Des_Pre_1000yrCC26 .ief	v2_Til_Des_Pre_1000yrCC26 .tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	1000yr_CC26_Sum_30h_Til_ v7.ied
v2_Til_Des_Pre_1000yrCC48	Tilbury_v33.dat	v2_Til_Des_Pre_1000yrCC48 .ief	v2_Til_Des_Pre_1000yrCC48 .tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	1000yr_CC48_Sum_30h_Til_ v7.ied
v2_Til_Des_Pre_100yrCC11	Tilbury_v33.dat	v2_Til_Des_Pre_100yrCC11. ief	v2_Til_Des_Pre_100yrCC11. tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	100yr_CC11_Sum_30h_Til_v7. ied

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v2_Til_Des_Pre_100yrCC17	Tilbury_v33.dat	v2_Til_Des_Pre_100yrCC17.ief	v2_Til_Des_Pre_100yrCC17.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	100yr_CC17_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_100yrCC26	Tilbury_v33.dat	v2_Til_Des_Pre_100yrCC26.ief	v2_Til_Des_Pre_100yrCC26.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	100yr_CC26_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_100yrCC6	Tilbury_v33.dat	v2_Til_Des_Pre_100yrCC6.ief	v2_Til_Des_Pre_100yrCC6.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	100yr_CC6_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_20yrCC11	Tilbury_v33.dat	v2_Til_Des_Pre_20yrCC11.ief	v2_Til_Des_Pre_20yrCC11.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	20yr_CC11_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_20yrCC17	Tilbury_v33.dat	v2_Til_Des_Pre_20yrCC17.ief	v2_Til_Des_Pre_20yrCC17.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	20yr_CC17_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_20yrCC26	Tilbury_v33.dat	v2_Til_Des_Pre_20yrCC26.ief	v2_Til_Des_Pre_20yrCC26.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	20yr_CC26_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_20yrCC6	Tilbury_v33.dat	v2_Til_Des_Pre_20yrCC6.ief	v2_Til_Des_Pre_20yrCC6.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	20yr_CC6_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_2yrCC11	Tilbury_v33.dat	v2_Til_Des_Pre_2yrCC11.ief	v2_Til_Des_Pre_2yrCC11.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	2yr_CC11_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_2yrCC17	Tilbury_v33.dat	v2_Til_Des_Pre_2yrCC17.ief	v2_Til_Des_Pre_2yrCC17.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	2yr_CC17_Sum_30h_Til_v7.ied

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v2_Til_Des_Pre_2yrCC26	Tilbury_v33.dat	v2_Til_Des_Pre_2yrCC26.ief	v2_Til_Des_Pre_2yrCC26.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	2yr_CC26_Sum_30h_Til_v7.ied
v2_Til_Des_Pre_2yrCC6	Tilbury_v33.dat	v2_Til_Des_Pre_2yrCC6.ief	v2_Til_Des_Pre_2yrCC6.tcf	Bas_Til_v18.tgc, Bas_Til_v10.tbc, Tilbury.tmf	2yr_CC6_Sum_30h_Til_v7.ied

Table A.2 Post-development (with-mitigation) design model files

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v4_Til_Des_Post_1000yrCC11	TILPOST_v17.dat	v4_Til_Des_Post_1000yr CC11.ief	v4_Til_Des_Post_1000yr CC11.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	1000yr_CC11_Sum_30h_ Til_v7_Post.ied
v4_Til_Des_Post_1000yrCC26	TILPOST_v17.dat	v4_Til_Des_Post_1000yr CC26.ief	v4_Til_Des_Post_1000yr CC26.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	1000yr_CC26_Sum_30h_ Til_v7_Post.ied
v4_Til_Des_Post_1000yrCC48	TILPOST_v17.dat	v4_Til_Des_Post_1000yr CC48.ief	v4_Til_Des_Post_1000yr CC48.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	1000yr_CC48_Sum_30h_ Til_v7_Post.ied
v4_Til_Des_Post_100yrCC11	TILPOST_v17.dat	v4_Til_Des_Post_100yr CC11.ief	v4_Til_Des_Post_100yr CC11.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	100yr_CC11_Sum_30h_ Til_ v7_Post.ied
v4_Til_Des_Post_100yrCC17	TILPOST_v17.dat	v4_Til_Des_Post_100yr CC17.ief	v4_Til_Des_Post_100yr CC17.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	100yr_CC17_Sum_30h_Til_ v7_Post.ied

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v4_Til_Des_Post_100yrCC26	TILPOST_v17.dat	v4_Til_Des_Post_100yrCC26.ief	v4_Til_Des_Post_100yrCC26.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	100yr_CC26_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_100yrCC6	TILPOST_v17.dat	v4_Til_Des_Post_100yrCC6.ief	v4_Til_Des_Post_100yrCC6.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	100yr_CC6_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_20yrCC11	TILPOST_v17.dat	v4_Til_Des_Post_20yrCC11.ief	v4_Til_Des_Post_20yrCC11.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	20yr_CC11_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_20yrCC17	TILPOST_v17.dat	v4_Til_Des_Post_20yrCC17.ief	v4_Til_Des_Post_20yrCC17.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	20yr_CC17_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_20yrCC26	TILPOST_v17.dat	v4_Til_Des_Post_20yrCC26.ief	v4_Til_Des_Post_20yrCC26.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	20yr_CC26_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_20yrCC6	TILPOST_v17.dat	v4_Til_Des_Post_20yrCC6.ief	v4_Til_Des_Post_20yrCC6.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	20yr_CC6_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_2yrCC11	TILPOST_v17.dat	v4_Til_Des_Post_2yrCC11.ief	v4_Til_Des_Post_2yrCC11.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	2yr_CC11_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_2yrCC17	TILPOST_v17.dat	v4_Til_Des_Post_2yrCC17.ief	v4_Til_Des_Post_2yrCC17.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	2yr_CC17_Sum_30h_Til_v7_Post.ied
v4_Til_Des_Post_2yrCC26	TILPOST_v17.dat	v4_Til_Des_Post_2yrCC26.ief	v4_Til_Des_Post_2yrCC26.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	2yr_CC26_Sum_30h_Til_v7_Post.ied

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v4_Til_Des_Post_2yrCC6	TILPOST_v17.dat	v4_Til_Des_Post_2yrCC6.ief	v4_Til_Des_Post_2yrCC6.tcf	TILPOST_v35.tgc, TILPOST_v34.tbc, Tilbury.tmf	2yr_CC6_Sum_30h_Til_v7_Post.ied

Table A.3 Post-development (without-mitigation) design model files

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v3_Til_Des_Post_NM_1000yr CC11	TILPOST_v17_NM.dat	v3_Til_Des_Post_NM_1000yr CC11.ief	v3_Til_Des_Post_NM_1000yr CC11.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	1000yr_CC11_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_1000yr CC17	TILPOST_v17_NM.dat	v3_Til_Des_Post_NM_1000yr CC17.ief	v3_Til_Des_Post_NM_1000yr CC17.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	1000yr_CC26_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_1000yr CC48	TILPOST_v17_NM.dat	v3_Til_Des_Post_NM_1000yr CC48.ief	v3_Til_Des_Post_NM_1000yr CC48.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	1000yr_CC48_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_100yr CC11	TILPOST_v17_NM.dat	v3_Til_Des_Post_NM_100yr CC11.ief	v3_Til_Des_Post_NM_100yr CC11.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	100yr_CC11_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_100yr CC17	TILPOST_v17_NM.dat	v3_Til_Des_Post_NM_100yr CC17.ief	v3_Til_Des_Post_NM_100yr CC17.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	100yr_CC17_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_100yr CC26	TILPOST_v17_NM.dat	v3_Til_Des_Post_NM_100yr CC26.ief	v3_Til_Des_Post_NM_100yr CC26.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	100yr_CC26_Sum_30h_Til_v7.ied

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)	IED (1D model boundary file name)
v3_Til_Des_Post_NM_100yr CC6	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_100yr CC6.ief	v3_Til_Des_Post_NM_100yr CC6.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	100yr_CC6_Sum_30h_Til_v7. ied
v3_Til_Des_Post_NM_20yr CC11	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_20yr CC11.ief	v3_Til_Des_Post_NM_20yr CC11.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	20yr_CC11_Sum_30h_Til_v7. ied
v3_Til_Des_Post_NM_20yr CC17	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_20yr CC17.ief	v3_Til_Des_Post_NM_20yr CC17.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	20yr_CC17_Sum_30h_Til_v7. ied
v3_Til_Des_Post_NM_20yr CC26	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_20yr CC26.ief	v3_Til_Des_Post_NM_20yr CC26.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	20yr_CC26_Sum_30h_Til_v7. ied
v3_Til_Des_Post_NM_20yr CC6	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_20yr CC6.ief	v3_Til_Des_Post_NM_20yr CC6.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	20yr_CC6_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_2yr CC11	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_2yr CC11.ief	v3_Til_Des_Post_NM_2yr CC11.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	2yr_CC11_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_2yr CC17	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_2yr CC17.ief	v3_Til_Des_Post_NM_2yr CC17.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	2yr_CC17_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_2yr CC26	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_2yr CC26.ief	v3_Til_Des_Post_NM_2yr CC26.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	2yr_CC26_Sum_30h_Til_v7.ied
v3_Til_Des_Post_NM_2yr CC6	TILPOST_v17_ NM.dat	v3_Til_Des_Post_NM_2yr CC6.ief	v3_Til_Des_Post_NM_2yr CC6.tcf	TILPOST_v29_NM.tgc, TILPOST_v16_NM.tbc, Tilbury.tmf	2yr_CC6_Sum_30h_Til_v7.ied

Annex B Model structures

B.1 Model structures

B.1.1 The structures that have been schematised in the model.

Table B.1 1D model structures

Photo/survey ref	Structure type	Cross-section reference	Model node	Model unit & key features	Coefficients
N/A	Culvert	T7-012	T7-012cu	Orifice & spill	Throat soffit level: 0.8mAOD Throat invert level: 2.3mAOD Bore area: 4.500 Modular limit: 0.7 Weir coefficient: 1.2 Estimated based on Digital Elevation Model (DEM) and Google Earth
	Culvert	T7-010	T7-010bu	Orifice & spill	Throat soffit level: 1.5mAOD Throat invert level: 0.45mAOD Bore area: 2.250 Modular limit: 0.7 Weir coefficient: 1.2

Photo/survey ref	Structure type	Cross-section reference	Model node	Model unit & key features	Coefficients
	Culvert	T7-007	T7-007cu	C.conduit & spill	Diameter: 0.300m Conduit type code: Type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.3
N/A	Culvert	T8-006d1	T8-006du	C.conduit & spill	Width: 0.690m Height: 0.640m Conduit type code: Type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.7
	Culvert	T8-001	T8-001cu	C.conduit & spill & orifice	Width: 0.668m Height: 0.858m Conduit type code: Type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.2 Orifice: Throat invert level: 1.475m AOD Throat soffit level: 2.632m AOD Bore area: 3.471m^2

Photo/survey ref	Structure type	Cross-section reference	Model node	Model unit & key features	Coefficients
N/A	Culvert	T9-005	T9-005cu	C.conduit & spill	Diameter: 0.900m Conduit type code: Type A Loss coefficient: 1.0 Modular limit: 0.9 Weir coefficient: 1.2
N/A	Culvert	T9-000	T9-000cu	C.conduit	Diameter: 0.350m Conduit type code: Type A
N/A	Sluice gate	T9000	T9000cd	Orifice	Throat soffit level: -0.393mAOD Throat invert level: -0.743mAOD Bore area: 0.096
N/A (proposed)	Culvert	T8-003	T8-003cu	R.conduit & spill	Width: 4.500m Height: 2.800m Modular limit: 0.9 Weir coefficient: 1.7
N/A	Culvert	Star Dam culvert	nwk ESTRY	R.conduit	Diameter: 0.300m
N/A	Culvert	Clv_N	nwk ESTRY	R.conduit	Width: 0.89m Height: 0.89m Estimated based on DEM, Google Earth and adjacent surveyed culverts.
N/A	Culvert	Clv_E	nwk ESTRY	R.conduit	Width: 0.89m Height: 0.89m Estimated based on DEM, Google Earth and adjacent surveyed culverts.

Annex C Catchment delineation

C.1 Catchment delineation methodology

C.1.1 The delineation of catchment boundaries for each of the six individual catchments is described below.

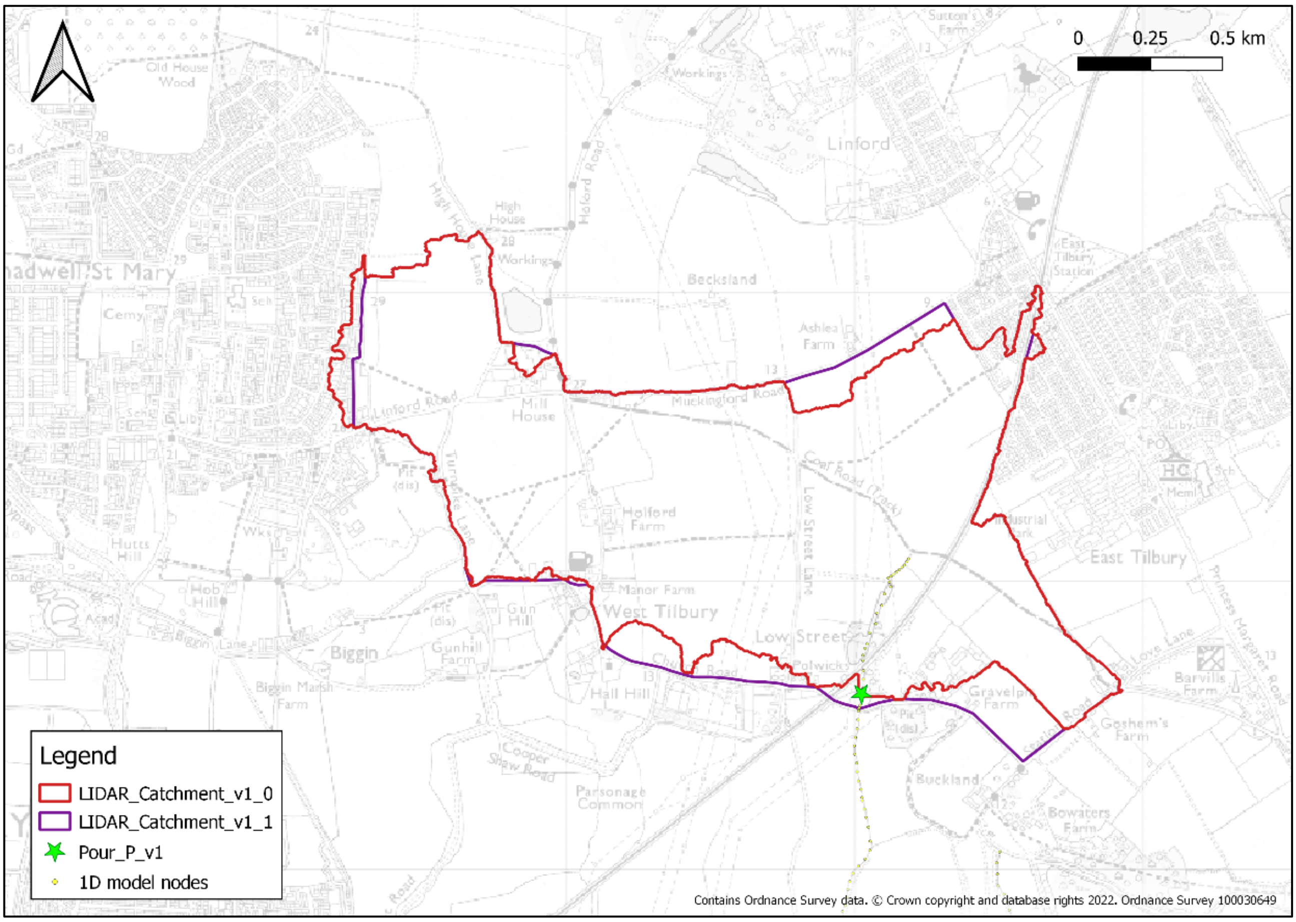
C.1.2 The initial version of each catchment is named applying the format (for catchment number N) 'LiDAR_Catchment vN_0', and the amended version is 'LiDAR_Catchment vN_1'.

C.1.3 The 25cm resolution Digital Terrain Model was not available for the northern part of the study area and therefore the 2m resolution Digital Terrain Model was used instead for that area.

Catchment C1

C.1.4 For the delineation of catchment 1, ArcMap Hydrology tools were used to derive a catchment extent based on the 2m LiDAR dataset. The catchment outline derived automatically with the ArcMap hydrology tool was then amended manually based on OS Maps/Google Earth (Plate C.1) to match with the road.

Plate C.1 Catchment C1 delineation



Catchment C1 further delineation

C.1.5 Catchment C1 was further delineated using LiDAR topographic data to specify sub-catchments north and south of the railway, and to better define inflow allocations for the post development with mitigation model (i.e. with the proposed flood compensation area north of the railway – see main report Section 5.3). The LiDAR analysis showed that the railway does not completely split Catchment C1. Because of the lower elevation of the northern section of the railway there is a flow path across the railway. Based on this analysis Catchment C1 was split into four sub-catchments as detailed in Plate C.2 and Table C.1.

Plate C.2 Updated delineation of C1 catchment

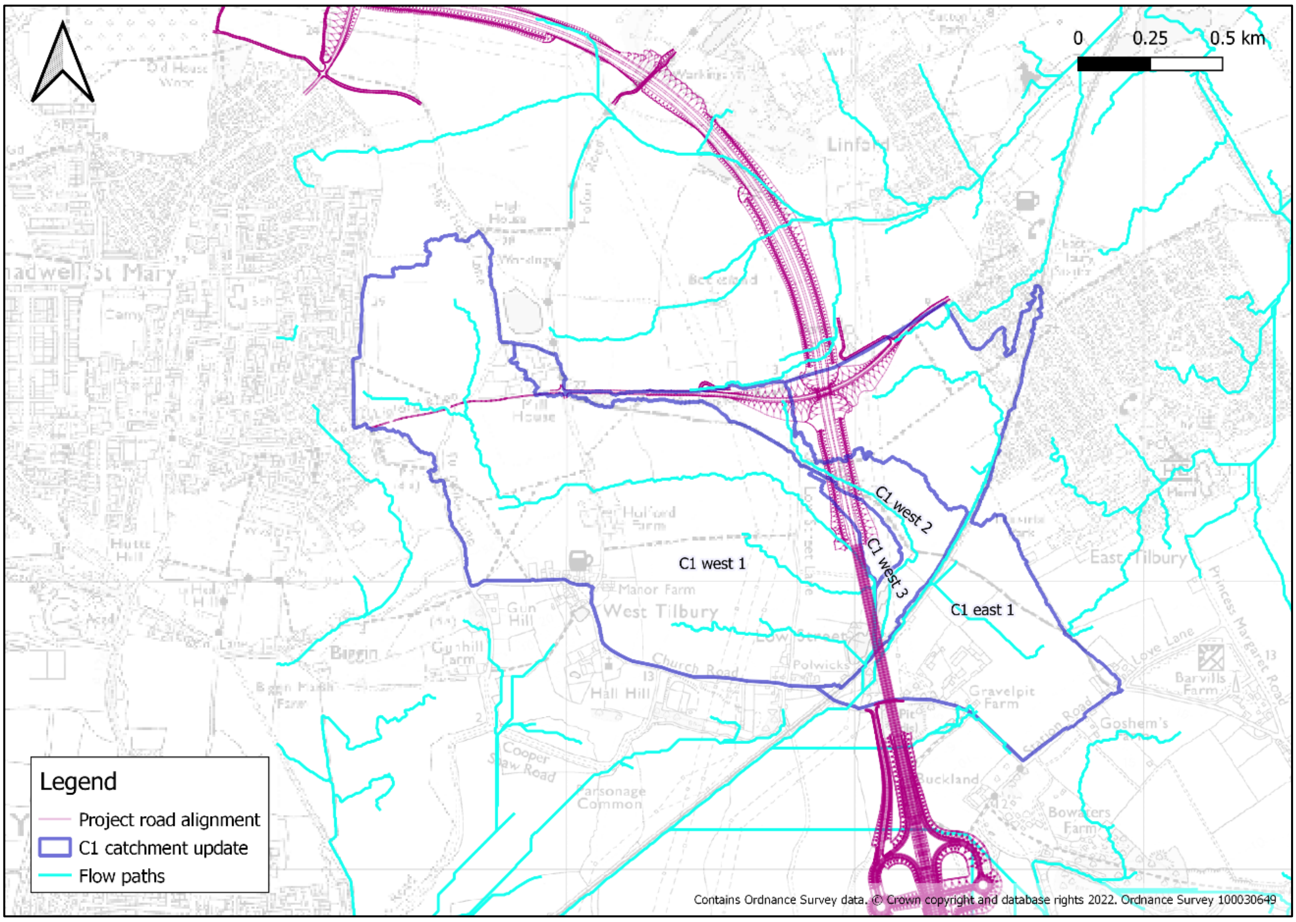


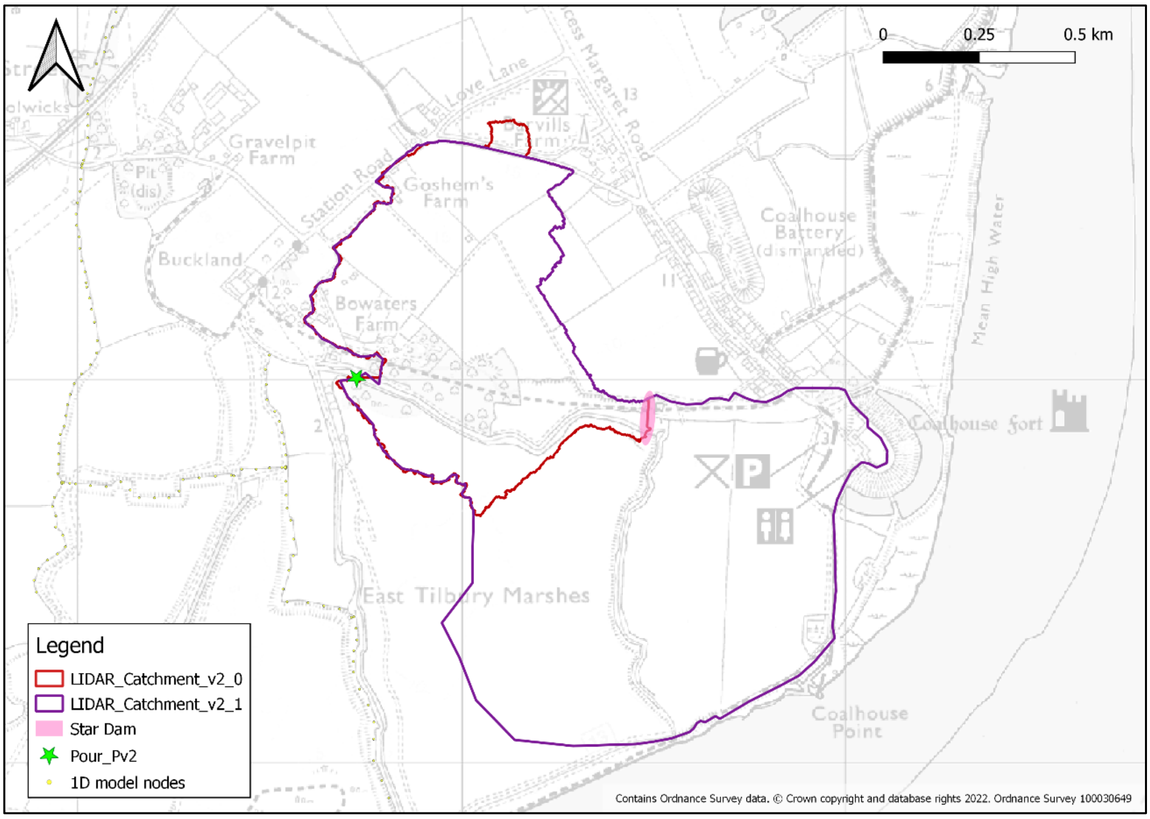
Table C.1 Delineation of catchment C1

C1 sub-catchment	Area (km2)	Percentage of total C1 catchment area
C1_west_1	1.4	58.5
C1_west_2	0.22	9.2
C1_west_3	0.04	1.7
C1_east_1	0.74	30.6
Sum	2.39	100

Catchment C2

C.1.6 For the delineation of Catchment C2, ArcMap Hydrology tools were used to derive a catchment extent based on the 25cm LiDAR dataset. The catchment outline derived automatically with the ArcMap hydrology tool was then amended manually based on OS Maps/Google Earth as well as the 25cm LiDAR data. The catchment was extended to include the drainage area east of Star Dam (Plate C.3), as the culvert through Star Dam is not represented in the LiDAR dataset and hence the catchment area east of Star Dam is not included in the automatically derived catchment extent. No ArcMAP generated boundaries are available for the eastern area (beyond the Star Dam) as the area is very flat and the ArcMap Hydrology tools do not perform well in flat areas. The catchment boundary here has therefore been specified manually based on the 25cm LiDAR dataset.

Plate C.3 Catchment C2 delineation



Catchment C3

C.1.7 The delineation of Catchment C3 was undertaken manually based on the 25cm LiDAR dataset. As shown in Plate C.4, the topography of the eastern part of the site is relatively hilly and hence the delineation of the catchment extents here is relatively accurate (Plate C.4). For the remaining area, which is very flat, the catchment extent was delineated based on flow directions implied by the gradient of the drainage network, based on LiDAR-derived channel cross-sections. Due to the very flat topography, it was not always possible to identify channel gradients and hence the delineation was based on assumed flow direction (Plate C.5).

Plate C.4 Delineation of Catchment C3 eastern boundary based on 25cm LiDAR dataset

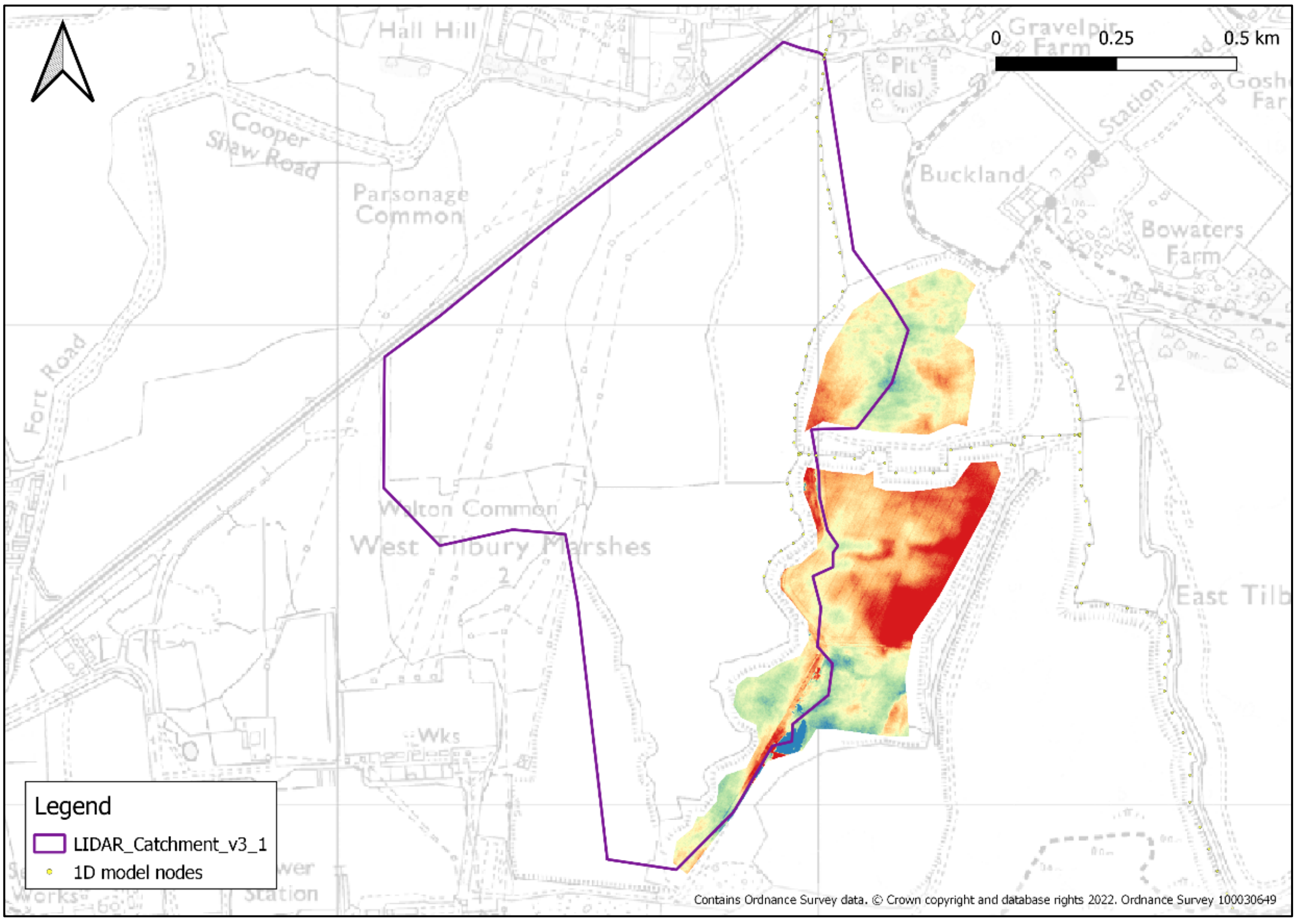
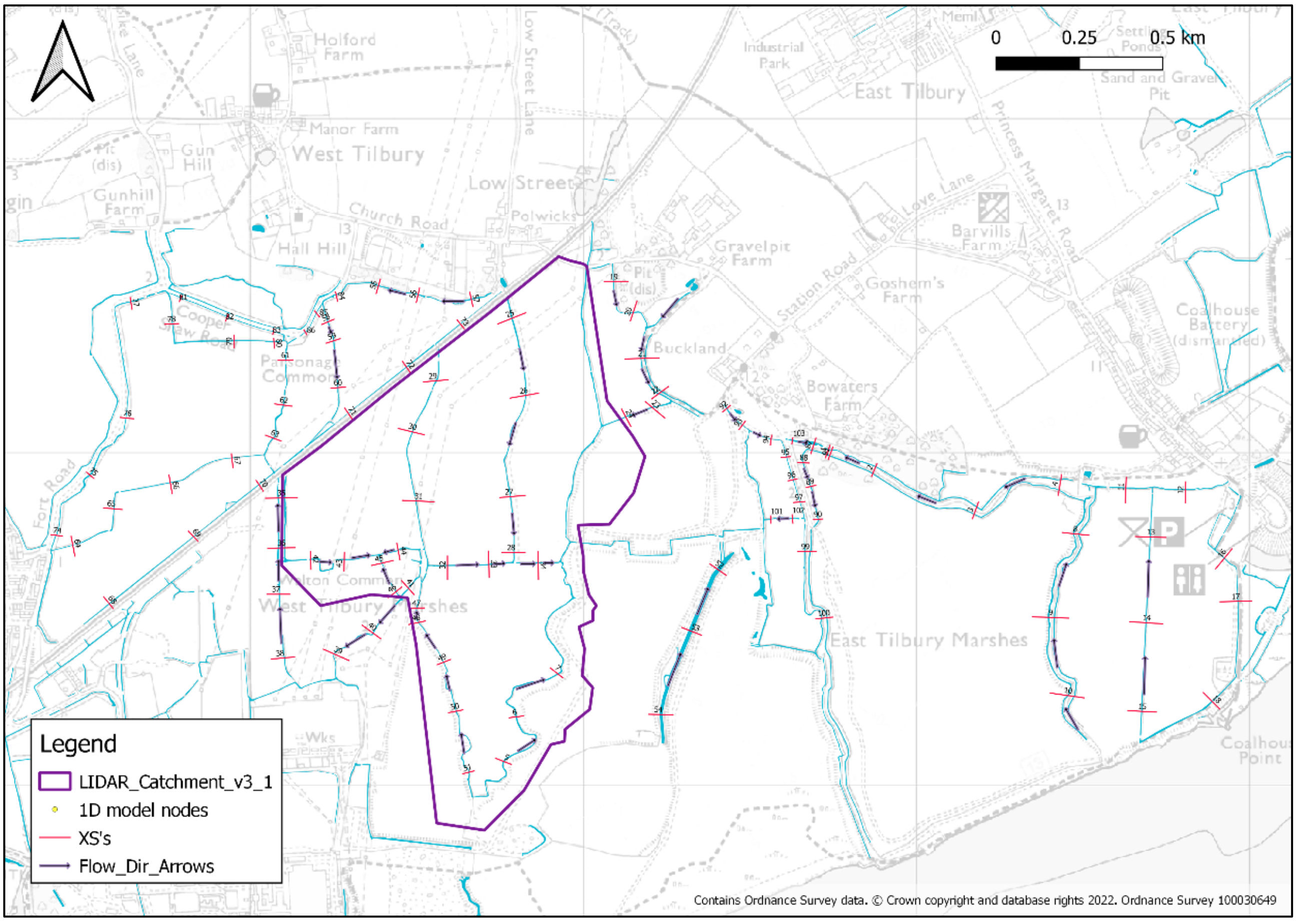


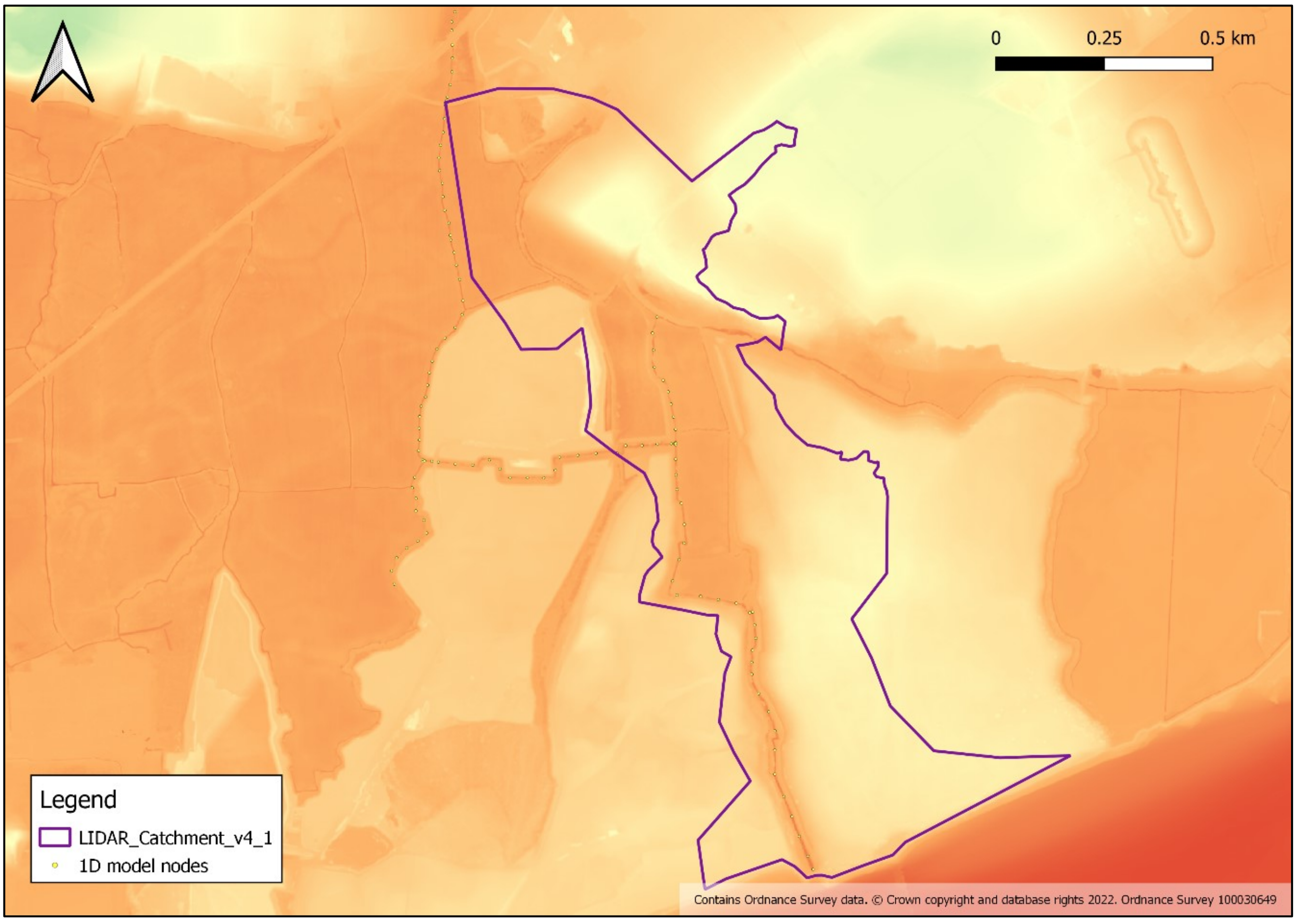
Plate C.5 Catchment C3 cross-sections and flow direction arrows



Catchment C4

C.1.8 The delineation of Catchment C4 (Plate C.6) has been completed as the last step of this delineation analysis and hence the boundaries of this catchment were chosen as the remaining drainage area up to the outfall of the hydraulic model.

Plate C.6 Catchment C4 delineation

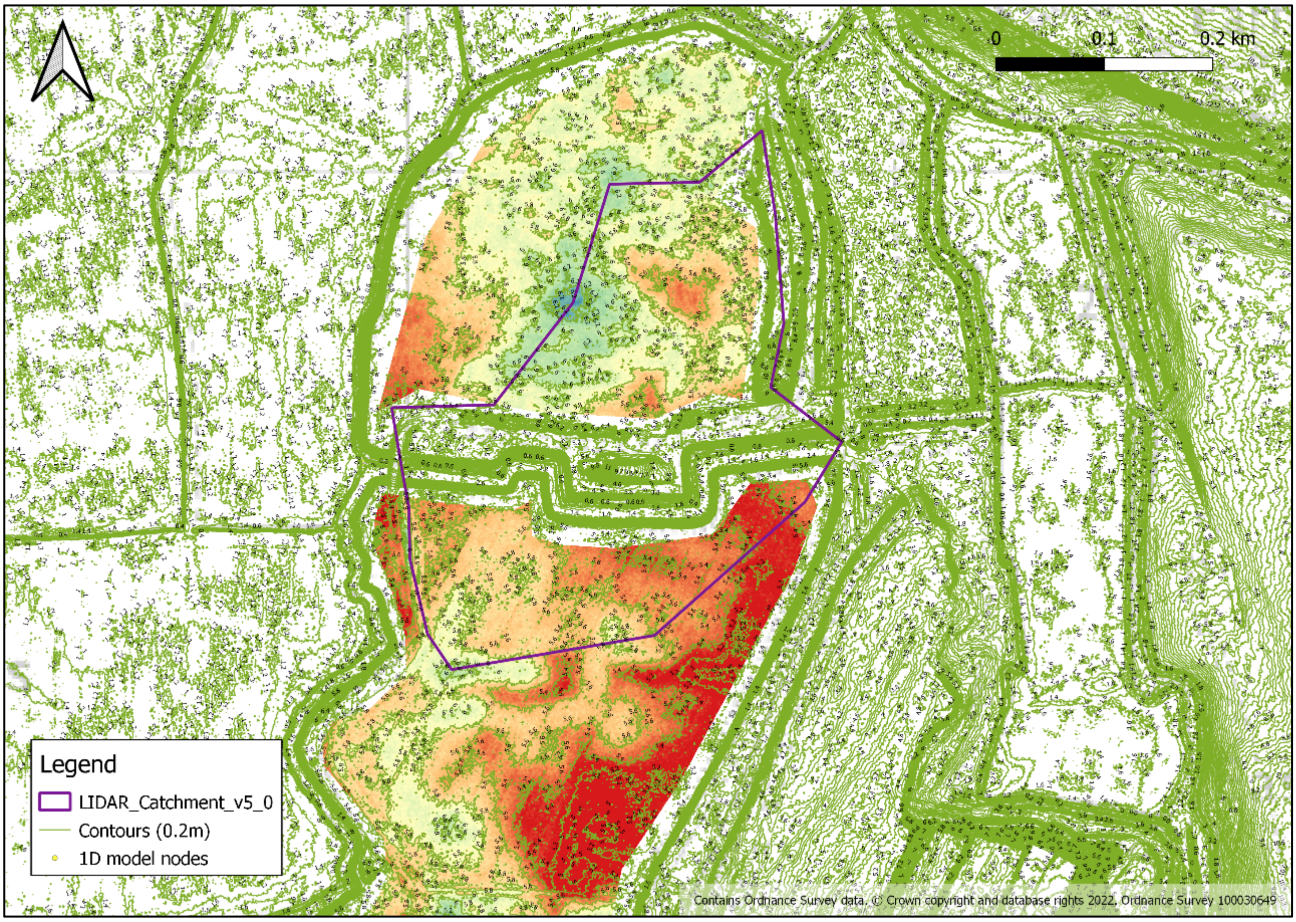


Catchment C5

C.1.9 The delineation of Catchment C5 was specified manually based on the 25cm LiDAR dataset. Plate C.7 shows the catchment outline along with contours derived from the LiDAR data (20cm intervals) and the 25cm LiDAR topographic dataset. On the eastern edge of the catchment (i.e. the boundary between Catchment C4 and Catchment C5) the gradient is uncertain as the area is very flat.

C.1.10 Here the catchment was delineated to match with the hydraulic model (i.e. to tie in with the T8-004 hydraulic model node). The impact of this uncertainty in catchment boundary specification is small compared to the overall uncertainty in specification of the study catchments.

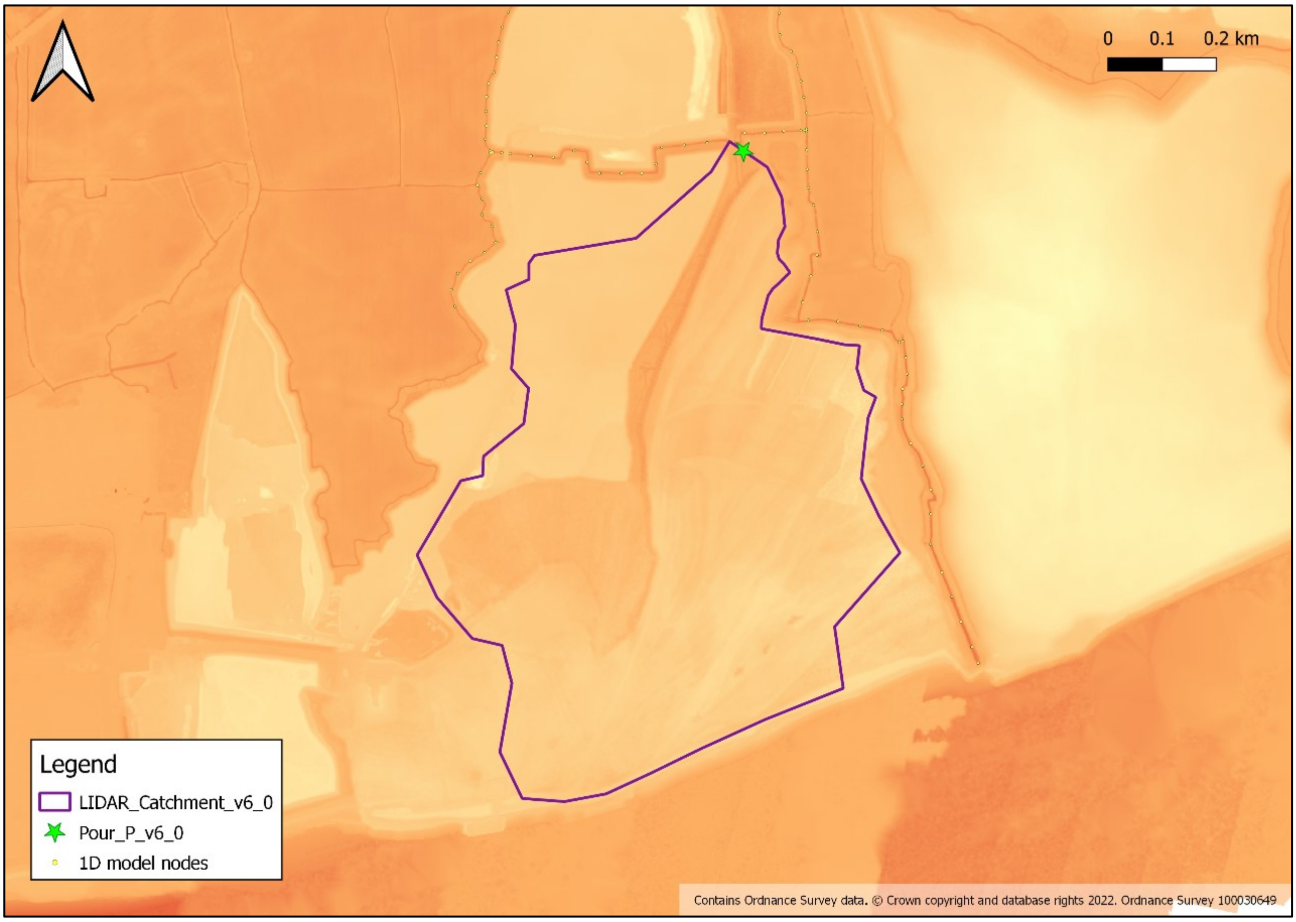
Plate C.7 Catchment C5 delineation



Catchment C6

C.1.11 The delineation of Catchment C6, shown in Plate C.8, was undertaken manually based on the 25cm LiDAR dataset. The northern and western catchment boundaries were based on the delineation of Catchment C5 and Catchment C3 respectively. The southern catchment boundary was trimmed to the flood wall which acts as a flow obstacle.

Plate C.8 Catchment C6 delineation



Annex D Design results

Table D.1 Flood mapping outputs figures

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
900	Maximum flood depth	Pre-development	2yr	6	2030	Not applicable
901	Maximum flood depth	Pre-development	2yr	11	2030	Not applicable
902	Maximum flood depth	Pre-development	2yr	17	2130	Not applicable
903	Maximum flood depth	Pre-development	2yr	26	2130	Not applicable
904	Maximum flood depth	Pre-development	20yr	6	2030	Not applicable
905	Maximum flood depth	Pre-development	20yr	11	2030	Not applicable
906	Maximum flood depth	Pre-development	20yr	17	2130	Not applicable
907	Maximum flood depth	Pre-development	20yr	26	2130	Not applicable
908	Maximum flood depth	Pre-development	100yr	6	2030	Not applicable
909	Maximum flood depth	Pre-development	100yr	11	2030	Not applicable
910	Maximum flood depth	Pre-development	100yr	17	2130	Not applicable
911	Maximum flood depth	Pre-development	100yr	26	2130	Not applicable
912	Maximum flood depth	Pre-development	1,000yr	11	2030	Not applicable
913	Maximum flood depth	Pre-development	1,000yr	26	2130	Not applicable
914	Maximum flood depth	Pre-development	1,000yr	48	2130	Not applicable
915	Maximum flood depth	Post-development (without mitigation)	2yr	6	2030	Not applicable
916	Maximum flood depth	Post-development (without mitigation)	2yr	11	2030	Not applicable
917	Maximum flood depth	Post-development (without mitigation)	2yr	17	2130	Not applicable
918	Maximum flood depth	Post-development (without mitigation)	2yr	26	2130	Not applicable
919	Maximum flood depth	Post-development (without mitigation)	20yr	6	2030	Not applicable
920	Maximum flood depth	Post-development (without mitigation)	20yr	11	2030	Not applicable
921	Maximum flood depth	Post-development (without mitigation)	20yr	17	2130	Not applicable
922	Maximum flood depth	Post-development (without mitigation)	20yr	26	2130	Not applicable

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
923	Maximum flood depth	Post-development (without mitigation)	100yr	6	2030	Not applicable
924	Maximum flood depth	Post-development (without mitigation)	100yr	11	2030	Not applicable
925	Maximum flood depth	Post-development (without mitigation)	100yr	17	2130	Not applicable
926	Maximum flood depth	Post-development (without mitigation)	100yr	26	2130	Not applicable
927	Maximum flood depth	Post-development (without mitigation)	1,000yr	11	2030	Not applicable
928	Maximum flood depth	Post-development (without mitigation)	1,000yr	26	2130	Not applicable
929	Maximum flood depth	Post-development (without mitigation)	1,000yr	48	2130	Not applicable
930	Maximum flood depth	Post-development (with mitigation)	2yr	6	2030	Not applicable
931	Maximum flood depth	Post-development (with mitigation)	2yr	11	2030	Not applicable
932	Maximum flood depth	Post-development (with mitigation)	2yr	17	2130	Not applicable
933	Maximum flood depth	Post-development (with mitigation)	2yr	26	2130	Not applicable
934	Maximum flood depth	Post-development (with mitigation)	20yr	6	2030	Not applicable
935	Maximum flood depth	Post-development (with mitigation)	20yr	11	2030	Not applicable
936	Maximum flood depth	Post-development (with mitigation)	20yr	17	2130	Not applicable
937	Maximum flood depth	Post-development (with mitigation)	20yr	26	2130	Not applicable
938	Maximum flood depth	Post-development (with mitigation)	100yr	6	2030	Not applicable
939	Maximum flood depth	Post-development (with mitigation)	100yr	11	2030	Not applicable
940	Maximum flood depth	Post-development (with mitigation)	100yr	17	2130	Not applicable
941	Maximum flood depth	Post-development (with mitigation)	100yr	26	2130	Not applicable
942	Maximum flood depth	Post-development (with mitigation)	1,000yr	11	2030	Not applicable
943	Maximum flood depth	Post-development (with mitigation)	1,000yr	26	2130	Not applicable
944	Maximum flood depth	Post-development (with mitigation)	1,000yr	48	2130	Not applicable
945	Maximum flood depth	Pre-development	2yr	6	2030	With steady-state initial conditions
946	Maximum flood depth	Pre-development	2yr	11	2030	With steady-state initial conditions
947	Maximum flood depth	Pre-development	2yr	17	2130	With steady-state initial conditions
948	Maximum flood depth	Pre-development	2yr	26	2130	With steady-state initial conditions

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
949	Maximum flood depth	Pre-development	20yr	6	2030	With steady-state initial conditions
950	Maximum flood depth	Pre-development	20yr	11	2030	With steady-state initial conditions
951	Maximum flood depth	Pre-development	20yr	17	2130	With steady-state initial conditions
952	Maximum flood depth	Pre-development	20yr	26	2130	With steady-state initial conditions
953	Maximum flood depth	Pre-development	100yr	6	2030	With steady-state initial conditions
954	Maximum flood depth	Pre-development	100yr	11	2030	With steady-state initial conditions
955	Maximum flood depth	Pre-development	100yr	17	2130	With steady-state initial conditions
956	Maximum flood depth	Pre-development	100yr	26	2130	With steady-state initial conditions
957	Maximum flood depth	Pre-development	1,000yr	11	2030	With steady-state initial conditions
958	Maximum flood depth	Pre-development	1,000yr	26	2130	With steady-state initial conditions
959	Maximum flood depth	Pre-development	1,000yr	48	2130	With steady-state initial conditions
960	Maximum flood depth	Post-development (with mitigation)	2yr	6	2030	With steady-state initial conditions
961	Maximum flood depth	Post-development (with mitigation)	2yr	11	2030	With steady-state initial conditions
962	Maximum flood depth	Post-development (with mitigation)	2yr	17	2130	With steady-state initial conditions
963	Maximum flood depth	Post-development (with mitigation)	2yr	26	2130	With steady-state initial conditions
964	Maximum flood depth	Post-development (with mitigation)	20yr	6	2030	With steady-state initial conditions
965	Maximum flood depth	Post-development (with mitigation)	20yr	11	2030	With steady-state initial conditions
966	Maximum flood depth	Post-development (with mitigation)	20yr	17	2130	With steady-state initial conditions
967	Maximum flood depth	Post-development (with mitigation)	20yr	26	2130	With steady-state initial conditions
968	Maximum flood depth	Post-development (with mitigation)	100yr	6	2030	With steady-state initial conditions
969	Maximum flood depth	Post-development (with mitigation)	100yr	11	2030	With steady-state initial conditions
970	Maximum flood depth	Post-development (with mitigation)	100yr	17	2130	With steady-state initial conditions
971	Maximum flood depth	Post-development (with mitigation)	100yr	26	2130	With steady-state initial conditions
972	Maximum flood depth	Post-development (with mitigation)	1,000yr	11	2030	With steady-state initial conditions
973	Maximum flood depth	Post-development (with mitigation)	1,000yr	26	2130	With steady-state initial conditions
974	Maximum flood depth	Post-development (with mitigation)	1,000yr	48	2130	With steady-state initial conditions

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
975	Maximum flood velocity	Pre-development	2yr	6	2030	Not applicable
976	Maximum flood velocity	Pre-development	2yr	11	2030	Not applicable
977	Maximum flood velocity	Pre-development	2yr	17	2130	Not applicable
978	Maximum flood velocity	Pre-development	2yr	26	2130	Not applicable
979	Maximum flood velocity	Pre-development	20yr	6	2030	Not applicable
980	Maximum flood velocity	Pre-development	20yr	11	2030	Not applicable
981	Maximum flood velocity	Pre-development	20yr	17	2130	Not applicable
982	Maximum flood velocity	Pre-development	20yr	26	2130	Not applicable
983	Maximum flood velocity	Pre-development	100yr	6	2030	Not applicable
984	Maximum flood velocity	Pre-development	100yr	11	2030	Not applicable
985	Maximum flood velocity	Pre-development	100yr	17	2130	Not applicable
986	Maximum flood velocity	Pre-development	100yr	26	2130	Not applicable
987	Maximum flood velocity	Pre-development	1,000yr	11	2030	Not applicable
988	Maximum flood velocity	Pre-development	1,000yr	26	2130	Not applicable
989	Maximum flood velocity	Pre-development	1,000yr	48	2130	Not applicable
990	Maximum flood velocity	Post-development (without mitigation)	2yr	6	2030	Not applicable
991	Maximum flood velocity	Post-development (without mitigation)	2yr	11	2030	Not applicable
992	Maximum flood velocity	Post-development (without mitigation)	2yr	17	2130	Not applicable
993	Maximum flood velocity	Post-development (without mitigation)	2yr	26	2130	Not applicable
994	Maximum flood velocity	Post-development (without mitigation)	20yr	6	2030	Not applicable
995	Maximum flood velocity	Post-development (without mitigation)	20yr	11	2030	Not applicable
996	Maximum flood velocity	Post-development (without mitigation)	20yr	17	2130	Not applicable
997	Maximum flood velocity	Post-development (without mitigation)	20yr	26	2130	Not applicable
998	Maximum flood velocity	Post-development (without mitigation)	100yr	6	2030	Not applicable
999	Maximum flood velocity	Post-development (without mitigation)	100yr	11	2030	Not applicable
1000	Maximum flood velocity	Post-development (without mitigation)	100yr	17	2130	Not applicable

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1001	Maximum flood velocity	Post-development (without mitigation)	100yr	26	2130	Not applicable
1002	Maximum flood velocity	Post-development (without mitigation)	1,000yr	11	2030	Not applicable
1003	Maximum flood velocity	Post-development (without mitigation)	1,000yr	26	2130	Not applicable
1004	Maximum flood velocity	Post-development (without mitigation)	1,000yr	48	2130	Not applicable
1005	Maximum flood velocity	Post-development (with mitigation)	2yr	6	2030	Not applicable
1006	Maximum flood velocity	Post-development (with mitigation)	2yr	11	2030	Not applicable
1007	Maximum flood velocity	Post-development (with mitigation)	2yr	17	2130	Not applicable
1008	Maximum flood velocity	Post-development (with mitigation)	2yr	26	2130	Not applicable
1009	Maximum flood velocity	Post-development (with mitigation)	20yr	6	2030	Not applicable
1010	Maximum flood velocity	Post-development (with mitigation)	20yr	11	2030	Not applicable
1011	Maximum flood velocity	Post-development (with mitigation)	20yr	17	2130	Not applicable
1012	Maximum flood velocity	Post-development (with mitigation)	20yr	26	2130	Not applicable
1013	Maximum flood velocity	Post-development (with mitigation)	100yr	6	2030	Not applicable
1014	Maximum flood velocity	Post-development (with mitigation)	100yr	11	2030	Not applicable
1015	Maximum flood velocity	Post-development (with mitigation)	100yr	17	2130	Not applicable
1016	Maximum flood velocity	Post-development (with mitigation)	100yr	26	2130	Not applicable
1017	Maximum flood velocity	Post-development (with mitigation)	1,000yr	11	2030	Not applicable
1018	Maximum flood velocity	Post-development (with mitigation)	1,000yr	26	2130	Not applicable
1019	Maximum flood velocity	Post-development (with mitigation)	1,000yr	48	2130	Not applicable
1020	Maximum flood velocity	Pre-development	2yr	6	2030	With steady-state initial conditions
1021	Maximum flood velocity	Pre-development	2yr	11	2030	With steady-state initial conditions
1022	Maximum flood velocity	Pre-development	2yr	17	2130	With steady-state initial conditions
1023	Maximum flood velocity	Pre-development	2yr	26	2130	With steady-state initial conditions
1024	Maximum flood velocity	Pre-development	20yr	6	2030	With steady-state initial conditions
1025	Maximum flood velocity	Pre-development	20yr	11	2030	With steady-state initial conditions
1026	Maximum flood velocity	Pre-development	20yr	17	2130	With steady-state initial conditions

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1027	Maximum flood velocity	Pre-development	20yr	26	2130	With steady-state initial conditions
1028	Maximum flood velocity	Pre-development	100yr	6	2030	With steady-state initial conditions
1029	Maximum flood velocity	Pre-development	100yr	11	2030	With steady-state initial conditions
1030	Maximum flood velocity	Pre-development	100yr	17	2130	With steady-state initial conditions
1031	Maximum flood velocity	Pre-development	100yr	26	2130	With steady-state initial conditions
1032	Maximum flood velocity	Pre-development	1,000yr	11	2030	With steady-state initial conditions
1033	Maximum flood velocity	Pre-development	1,000yr	26	2130	With steady-state initial conditions
1034	Maximum flood velocity	Pre-development	1,000yr	48	2130	With steady-state initial conditions
1035	Maximum flood velocity	Post-development (with mitigation)	2yr	6	2030	With steady-state initial conditions
1036	Maximum flood velocity	Post-development (with mitigation)	2yr	11	2030	With steady-state initial conditions
1037	Maximum flood velocity	Post-development (with mitigation)	2yr	17	2130	With steady-state initial conditions
1038	Maximum flood velocity	Post-development (with mitigation)	2yr	26	2130	With steady-state initial conditions
1039	Maximum flood velocity	Post-development (with mitigation)	20yr	6	2030	With steady-state initial conditions
1040	Maximum flood velocity	Post-development (with mitigation)	20yr	11	2030	With steady-state initial conditions
1041	Maximum flood velocity	Post-development (with mitigation)	20yr	17	2130	With steady-state initial conditions
1042	Maximum flood velocity	Post-development (with mitigation)	20yr	26	2130	With steady-state initial conditions
1043	Maximum flood velocity	Post-development (with mitigation)	100yr	6	2030	With steady-state initial conditions
1044	Maximum flood velocity	Post-development (with mitigation)	100yr	11	2030	With steady-state initial conditions
1045	Maximum flood velocity	Post-development (with mitigation)	100yr	17	2130	With steady-state initial conditions
1046	Maximum flood velocity	Post-development (with mitigation)	100yr	26	2130	With steady-state initial conditions
1047	Maximum flood velocity	Post-development (with mitigation)	1,000yr	11	2030	With steady-state initial conditions
1048	Maximum flood velocity	Post-development (with mitigation)	1,000yr	26	2130	With steady-state initial conditions
1049	Maximum flood velocity	Post-development (with mitigation)	1,000yr	48	2130	With steady-state initial conditions
1050	Maximum flood hazard category	Pre-development	2yr	6	2030	Not applicable
1051	Maximum flood hazard category	Pre-development	2yr	11	2030	Not applicable
1052	Maximum flood hazard category	Pre-development	2yr	17	2130	Not applicable

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1053	Maximum flood hazard category	Pre-development	2yr	26	2130	Not applicable
1054	Maximum flood hazard category	Pre-development	20yr	6	2030	Not applicable
1055	Maximum flood hazard category	Pre-development	20yr	11	2030	Not applicable
1056	Maximum flood hazard category	Pre-development	20yr	17	2130	Not applicable
1057	Maximum flood hazard category	Pre-development	20yr	26	2130	Not applicable
1058	Maximum flood hazard category	Pre-development	100yr	6	2030	Not applicable
1059	Maximum flood hazard category	Pre-development	100yr	11	2030	Not applicable
1060	Maximum flood hazard category	Pre-development	100yr	17	2130	Not applicable
1061	Maximum flood hazard category	Pre-development	100yr	26	2130	Not applicable
1062	Maximum flood hazard category	Pre-development	1,000yr	11	2030	Not applicable
1063	Maximum flood hazard category	Pre-development	1,000yr	26	2130	Not applicable
1064	Maximum flood hazard category	Pre-development	1,000yr	48	2130	Not applicable
1065	Maximum flood hazard category	Post-development (without mitigation)	2yr	6	2030	Not applicable
1066	Maximum flood hazard category	Post-development (without mitigation)	2yr	11	2030	Not applicable
1067	Maximum flood hazard category	Post-development (without mitigation)	2yr	17	2130	Not applicable
1068	Maximum flood hazard category	Post-development (without mitigation)	2yr	26	2130	Not applicable
1069	Maximum flood hazard category	Post-development (without mitigation)	20yr	6	2030	Not applicable
1070	Maximum flood hazard category	Post-development (without mitigation)	20yr	11	2030	Not applicable
1071	Maximum flood hazard category	Post-development (without mitigation)	20yr	17	2130	Not applicable
1072	Maximum flood hazard category	Post-development (without mitigation)	20yr	26	2130	Not applicable
1073	Maximum flood hazard category	Post-development (without mitigation)	100yr	6	2030	Not applicable
1074	Maximum flood hazard category	Post-development (without mitigation)	100yr	11	2030	Not applicable
1075	Maximum flood hazard category	Post-development (without mitigation)	100yr	17	2130	Not applicable
1076	Maximum flood hazard category	Post-development (without mitigation)	100yr	26	2130	Not applicable
1077	Maximum flood hazard category	Post-development (without mitigation)	1,000yr	11	2030	Not applicable
1078	Maximum flood hazard category	Post-development (without mitigation)	1,000yr	26	2130	Not applicable

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1079	Maximum flood hazard category	Post-development (without mitigation)	1,000yr	48	2130	Not applicable
1080	Maximum flood hazard category	Post-development (with mitigation)	2yr	6	2030	Not applicable
1081	Maximum flood hazard category	Post-development (with mitigation)	2yr	11	2030	Not applicable
1082	Maximum flood hazard category	Post-development (with mitigation)	2yr	17	2130	Not applicable
1083	Maximum flood hazard category	Post-development (with mitigation)	2yr	26	2130	Not applicable
1084	Maximum flood hazard category	Post-development (with mitigation)	20yr	6	2030	Not applicable
1085	Maximum flood hazard category	Post-development (with mitigation)	20yr	11	2030	Not applicable
1086	Maximum flood hazard category	Post-development (with mitigation)	20yr	17	2130	Not applicable
1087	Maximum flood hazard category	Post-development (with mitigation)	20yr	26	2130	Not applicable
1088	Maximum flood hazard category	Post-development (with mitigation)	100yr	6	2030	Not applicable
1089	Maximum flood hazard category	Post-development (with mitigation)	100yr	11	2030	Not applicable
1090	Maximum flood hazard category	Post-development (with mitigation)	100yr	17	2130	Not applicable
1091	Maximum flood hazard category	Post-development (with mitigation)	100yr	26	2130	Not applicable
1092	Maximum flood hazard category	Post-development (with mitigation)	1,000yr	11	2030	Not applicable
1093	Maximum flood hazard category	Post-development (with mitigation)	1,000yr	26	2130	Not applicable
1094	Maximum flood hazard category	Post-development (with mitigation)	1,000yr	48	2130	Not applicable
1095	Maximum flood hazard category	Pre-development	2yr	6	2030	With steady-state initial conditions
1096	Maximum flood hazard category	Pre-development	2yr	11	2030	With steady-state initial conditions
1097	Maximum flood hazard category	Pre-development	2yr	17	2130	With steady-state initial conditions
1098	Maximum flood hazard category	Pre-development	2yr	26	2130	With steady-state initial conditions
1099	Maximum flood hazard category	Pre-development	20yr	6	2030	With steady-state initial conditions
1100	Maximum flood hazard category	Pre-development	20yr	11	2030	With steady-state initial conditions
1101	Maximum flood hazard category	Pre-development	20yr	17	2130	With steady-state initial conditions
1102	Maximum flood hazard category	Pre-development	20yr	26	2130	With steady-state initial conditions
1103	Maximum flood hazard category	Pre-development	100yr	6	2030	With steady-state initial conditions
1104	Maximum flood hazard category	Pre-development	100yr	11	2030	With steady-state initial conditions

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1105	Maximum flood hazard category	Pre-development	100yr	17	2130	With steady-state initial conditions
1106	Maximum flood hazard category	Pre-development	100yr	26	2130	With steady-state initial conditions
1107	Maximum flood hazard category	Pre-development	1,000yr	11	2030	With steady-state initial conditions
1108	Maximum flood hazard category	Pre-development	1,000yr	26	2130	With steady-state initial conditions
1109	Maximum flood hazard category	Pre-development	1,000yr	48	2130	With steady-state initial conditions
1110	Maximum flood hazard category	Post-development (with mitigation)	2yr	6	2030	With steady-state initial conditions
1111	Maximum flood hazard category	Post-development (with mitigation)	2yr	11	2030	With steady-state initial conditions
1112	Maximum flood hazard category	Post-development (with mitigation)	2yr	17	2130	With steady-state initial conditions
1113	Maximum flood hazard category	Post-development (with mitigation)	2yr	26	2130	With steady-state initial conditions
1114	Maximum flood hazard category	Post-development (with mitigation)	20yr	6	2030	With steady-state initial conditions
1115	Maximum flood hazard category	Post-development (with mitigation)	20yr	11	2030	With steady-state initial conditions
1116	Maximum flood hazard category	Post-development (with mitigation)	20yr	17	2130	With steady-state initial conditions
1117	Maximum flood hazard category	Post-development (with mitigation)	20yr	26	2130	With steady-state initial conditions
1118	Maximum flood hazard category	Post-development (with mitigation)	100yr	6	2030	With steady-state initial conditions
1119	Maximum flood hazard category	Post-development (with mitigation)	100yr	11	2030	With steady-state initial conditions
1120	Maximum flood hazard category	Post-development (with mitigation)	100yr	17	2130	With steady-state initial conditions
1121	Maximum flood hazard category	Post-development (with mitigation)	100yr	26	2130	With steady-state initial conditions
1122	Maximum flood hazard category	Post-development (with mitigation)	1,000yr	11	2030	With steady-state initial conditions
1123	Maximum flood hazard category	Post-development (with mitigation)	1,000yr	26	2130	With steady-state initial conditions
1124	Maximum flood hazard category	Post-development (with mitigation)	1,000yr	48	2130	With steady-state initial conditions
1125	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	2	6	2030	Not applicable
1127	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	2	17	2130	Not applicable
1129	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	20	6	2030	Not applicable
1131	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	20	17	2130	Not applicable

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1133	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	100	6	2030	Not applicable
1135	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	100	17	2130	Not applicable
1136	Difference in maximum flood depth	Post-(without mitigation) minus pre-development	100	26	2130	Not applicable
1137	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	2	6	2030	Not applicable
1139	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	2	17	2130	Not applicable
1141	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	20	6	2030	Not applicable
1143	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	20	17	2130	Not applicable
1145	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	6	2030	Not applicable
1147	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	17	2130	Not applicable
1148	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	26	2130	Not applicable
1149	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	2	6	2030	With steady-state initial conditions
1151	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	2	17	2130	With steady-state initial conditions
1153	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	20	6	2030	With steady-state initial conditions
1155	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	20	17	2130	With steady-state initial conditions
1157	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	6	2030	With steady-state initial conditions
1159	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	17	2130	With steady-state initial conditions
1160	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	26	2130	With steady-state initial conditions

Drawing number	Type of map	Scenario	Return period	Climate change allowance (%)	Epoch	Storm duration
1161	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	2	6	2030	Downstream sluice 75% blocked
1163	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	2	17	2130	Downstream sluice 75% blocked
1165	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	20	6	2030	Downstream sluice 75% blocked
1167	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	20	17	2130	Downstream sluice 75% blocked
1169	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	6	2030	Downstream sluice 75% blocked
1171	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	17	2130	Downstream sluice 75% blocked
1172	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	100	26	2130	Downstream sluice 75% blocked
1173	Difference in maximum flood depth	Sensitivity minus post-development	100	26	2130	50% blockage of the Project Main culvert
1174	Difference in maximum flood depth	Sensitivity minus post-development	100	26	2130	-20% Manning's n roughness
1175	Difference in maximum flood depth	Sensitivity minus post-development	100	26	2130	+20% Manning's n roughness
1176	Difference in maximum flood depth	Sensitivity minus post-development	100	26	2130	-20% Model inflows
1177	Difference in maximum flood depth	Sensitivity minus post-development	100	26	2130	+20% Model inflows

Annex E Breach modelling

E.1 Introduction

E.1.1 As part of the Flood Risk Assessment, hydraulic breach modelling has been undertaken to assess:

a. The impacts of a breach of River Thames tidal flood defences on the Project

b. The impacts of the Project on flood risk elsewhere following a breach of River Thames tidal defences

E.2 Model development

Data

E.2.1 Data to support the breach modelling provided by the Environment Agency and Thurrock Council is summarised in Table E.1.

Table E.1 Data provided to support the breach modelling

Data type	Data format	Comment	Source
Existing Breach Modelling Study	XLSX	Design tide level time series from Thurrock SFRA Breach Modelling Study, 2017	Thurrock Council
	PDF	Environment Agency Thames Estuary 2100 (TE2100) design EWLs	TE2100 project and Environment Agency Product 4 dataset
LiDAR	ASC	2m resolution and 25cm horizontal resolution	Environment Agency
Channel topographic survey	DWG, PDF, DAT, JPG, DOCX, XLSX, TXT	Flood Modeller Network (.dat) files, survey data, photographs, survey report	Project
Asset data	PDF	Flood defence data Bowaters Sluice as-built drawings East Tilbury and Star Dam Engineering Investigation Report and Drawings	Environment Agency
Mardyke Fluvial Modelling study for assessing the Project road (2022)	Flood Modeller, TUFLOW	As described in Part 4 of the FRA	Project

Software

E.2.2 The Project breach models were developed using hybrid Flood Modeller – TUFLOW software. This combines two software packages for managing overland flow and rapid inundation modelling. The Project used the following versions of Flood Modeller and TUFLOW:

a. Flood Modeller Version 4.6 (double precision)

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

Modelling approach

E.2.3 The breach scenarios were simulated with 1D/2D hydraulic modelling to provide flood depth, velocity and hazard score outputs. Simulations were undertaken for the pre-development case and post-development case (with fluvial flood risk mitigation measures included).

E.2.4 For the Tilbury breach simulations, two new 1D-2D models were developed (refer to paragraphs E.2.12 to E.2.14 for details). The 1D Flood Modeller suite was used to apply the tidal boundaries to the 2D domain which is modelled using the TUFLOW software. Developing new Tilbury breach models incorporated the most up-to-date LiDAR topographic data, allowed simulation of dynamic breaches (rather than static 'always open' breaches simulated in the Thurrock SFRA breach modelling) and allowed simulation of a breach at Bowaters Sluice (this breach location was not included in the SFRA breach modelling).

E.2.5 For the Mardyke breach simulations, the 1D-2D Mardyke hydraulic model, developed to assess fluvial flood risk in the Project FRA, was used to propagate breach flooding inland through the Mardyke catchment. This approach is considered more accurate than the SFRA breach model (which is 2D only).

Breach locations

E.2.6 A review of the 21 SFRA breach locations (refer to Plate E.1) and associated SFRA flood extents was used as the basis to identify the breach locations relevant to the Project. The SFRA breach locations TIL005 (near the former Tilbury power station site) and MAR001 (at Mardyke Sluice) in addition to a new location at the Bowaters Sluice (named as TIL006 to follow the notations used in the SFRA study) were chosen as the breach locations to be simulated in this study, as shown in Plate E.2 and listed in Table E.2 also includes the breach simulation parameters, discussed in paragraphs E.2.7 to E.2.11.

Plate E.1 Breach locations in Thurrock SFRA breach modelling

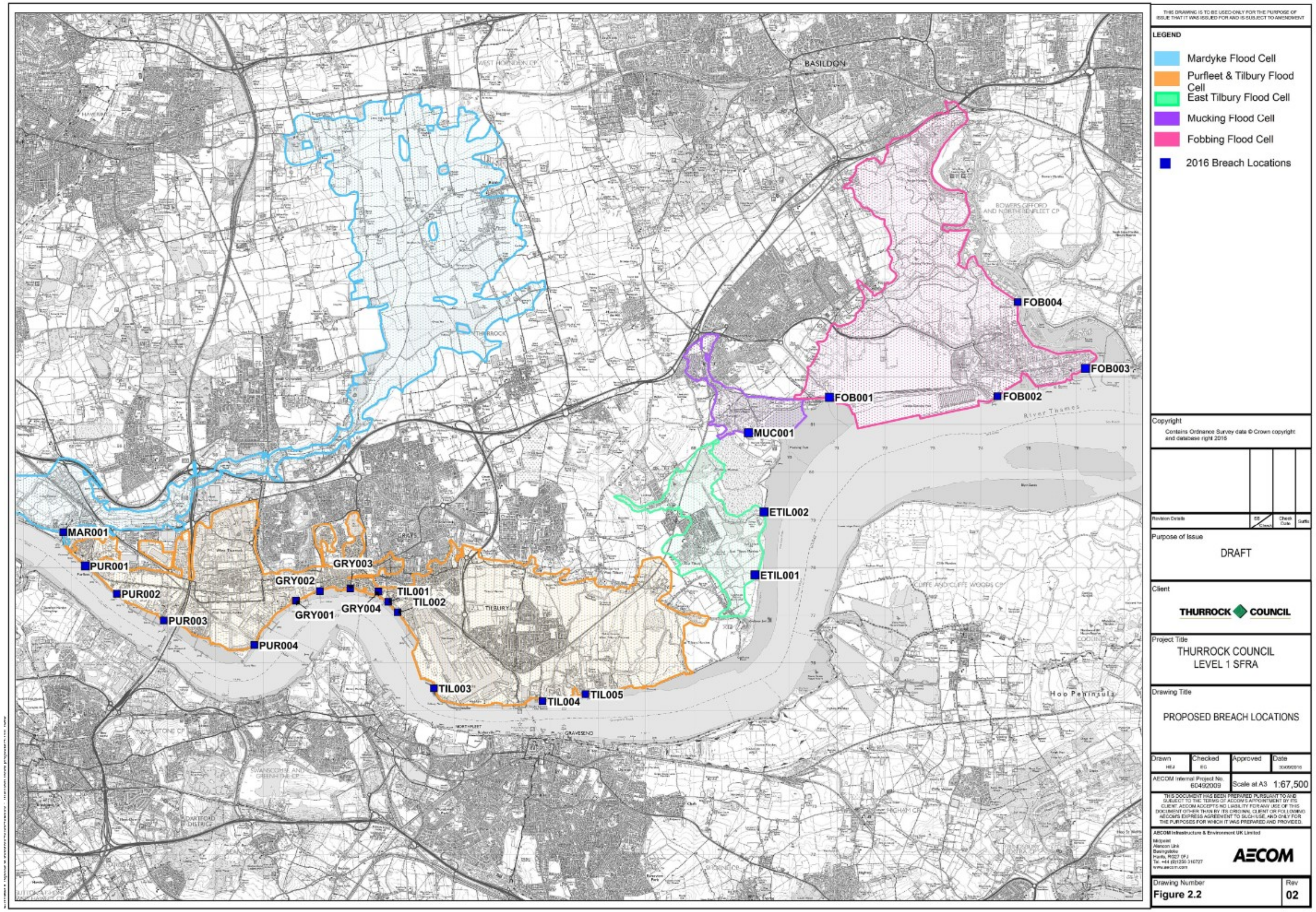


Plate E.2 Breach locations simulated in this study

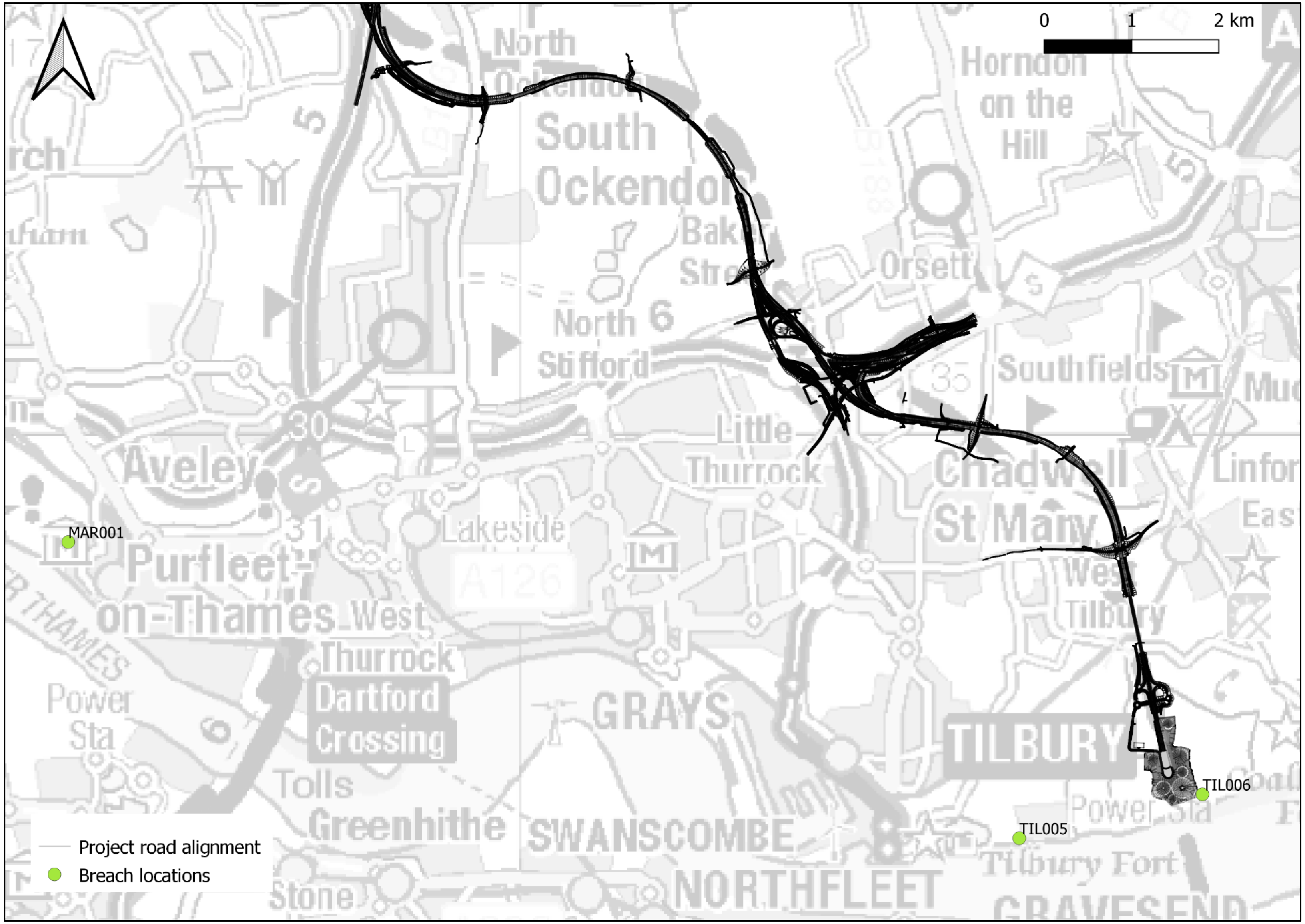


Table E.2 Breach locations for 2022 Project breach modelling study

Breach ID	TIL005	TIL006	MAR001
Location	Near the former Tilbury power station site	Bowaters Sluice	Mardyke Sluice
Easting	565741	567865	554826
Northing	175349	175773	178741
Defence type	Hard defence	Sluice/hard defence/ embankment	Sluice
Width (m)	20	50	5.45
Breach duration (hours)	18	30	12.75 (Gates fail on low tide preceding the peak level with emergency closure effected during the following low tide)

Breach width and time of open/closure

E.2.7 Environment Agency (2018) guidance on breach simulation states that the start time of a breach of a defence asset should be when there is at least some loading on the defence. The guidance suggests the following:

a. In a river or 'non wave' tidal situation, the breach starting time can be considered to be when the water level is at ¾ of the defence height (relative to the defence toe level).

b. An instantaneous breach is considered as a necessary simplification in most modelling studies.

c. Breach duration (until breach closure) for different types of defences are listed in Table E.3 (which reproduces Table 2 of Breach of Defences Guidance (Environment Agency, 2018)).

E.2.8 As shown in Table E.3, the Environment Agency guidance recommends the width of a simulated breach with tidal-driven flows to be 50m for an earth bank defence type, 20m for reinforced concrete defence type and equal to the gate width for sluice/tidal gate defence type.

Table E.3 Environment Agency breach parameter recommendation

Source	Defence type	Breach width (m)	Time to close – urban (hours)	Time to close – rural (hours)
Estuary/tidal river	Earth bank	50	30	30
	Reinforced concrete	20	18	18
Open coast	Earth bank	200	44	56
	Earth bank with facing	100	44	56
	Dunes	100	44	56
	Shingle bank	100	30	30
	Reinforced concrete	50	18	30
River	Earth bank	40	30	56
	Reinforced concrete	20	18	18
Tidal/coastal	Tidal gates	Gate width	Gates fail on low tide preceding the peak level with emergency closure effected during the following low tide	

Source: Table 2, Breach of Defences Guidance (Environment Agency, 2018)

Breach invert (toe) level

E.2.9 The invert level of the breach was determined through an interrogation of the LiDAR on the landward side of the breach location. Following the Environment Agency guidance, the lowest ground level within a radius the same width as the breach was used as the breach invert level.

E.2.10 The invert level at the locations taken from the Thurrock SFRA (Thurrock Council, 2018) model (MAR001 and TIL0005) have been reviewed and updated based on the current LiDAR topographic datasets used for the current modelling.

E.2.11 The invert levels used for each of the three breach locations are listed in Table E.4. Section 0 provides more information regarding the identification of these invert levels.

Table E.4 Breach invert levels

	MAR01	TIL005	TIL006
Invert level (mAOD)	-0.93	3.177	-0.608

Model schematisation

Pre-development

E.2.12 The pre-development model topography was based on the LiDAR data. Surface features such as significant land drains and rivers, were included in the model using additional TUFLOW geometry files (Z-line and Z-shape features) based on the Project's Hydraulic Modelling Study.

E.2.13 For Mardyke breach (MAR001), the pre-development model (reported in Part 4 of the Project FRA) was used with some modifications on the downstream part of the model. More specifically, a breach unit was implemented at the downstream model end (instead of a sluice gate applied in the fluvial simulations) and this was connected directly to the downstream boundary.

Post-development

E.2.14 The Project's Tilbury hydraulic model was used as the basis for construction of the post-development model.

E.2.15 The modifications for the post-development model incorporate the proposed Project embankment and road, the bridge piers at the location of the proposed Project viaduct and the water course crossing (culvert) of the West Tilbury Main under the Project embankment. They also incorporate the proposed mitigation measures detailed in the Project's Tilbury hydraulic modelling study, namely a compensation area at the northern edge of the model domain upstream from the railway culvert, and a culvert under the Project road embankment west of the top of T9 modelled reach (see Section 5.3).

E.2.16 For Mardyke breach (MAR001), the post-development model of Mardyke was used with some modifications on the downstream part of the model, as presented in the Mardyke hydraulic modelling report (Part 4 of the FRA).

Model boundaries

Tidal boundaries

E.2.17 Design tidal time-series boundaries were derived from the Thurrock SFRA (Thurrock Council, 2018) breach model time-series boundaries, as follows.

Adjusting TE2100 EWLs in line with latest CFB2018 and UKCP18 datasets

E.2.18 The Environment Agency's Thames Estuary 2100 (TE2100) 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 UKCP18 sea level rise allowances. 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 locations required for the Project modelling). Table E.5 shows an example of assigning revised years for the 1,000-year return period TE2100 EWLs at the TE2100 Gravesend model node.

Table E.5 Adjusted TE2100 EWLs at TE2100 Tilbury 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 Gravesend for revised year (mAOD)*
2005	5.03	0.01	2018	5.78
2040	5.24	0.22	2044	5.99
2070	5.55	0.53	2069	6.14
2100	5.95	0.93	2094	6.44
2120	6.25	1.23	2110	6.65

** The EWL values in this column are the Environment Agency'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.*

E.2.19 The Project requires EWLs for 2030 and 2130. These values are interpolated (2030) and extrapolated (2130) from the values in Table E.5 as 5.877mAOD and 6.890 mAOD respectively for the TE2100 Gravesend model node (for use at breach TIL005).

E.2.20 The same method was applied to adjust EWLs at TE2100 model node East Tilbury Marsh (for use at breach TIL006), and to derive 200-year return period EWLs in 2030 and 2130.

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

E.2.21 For a given boundary location and return period, the following approach was followed:

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 SFRA 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.

E.2.22 Tabulated EWLs and level versus time plots of the tidal boundaries applied in the breach simulations are included in Section E.5.

Fluvial boundaries

E.2.23 The Tilbury breach models do not include fluvial inflows.

E.2.24 For the MAR001 breaches, which were simulated using the Project Mardyke fluvial model, fluvial inflows were set to generate baseflow only.

Model simulations

E.2.25 The Mardyke breach modelling simulated only one event (as this was sufficient to inform this assessment): 1 in 1,000 years in 2130. Tilbury breach models were used to simulate two scenarios, namely pre-development and post-development, for the following events:

a. Tidal flood event with a return period of 1 in 200 years in 2030 (present day)

b. Tidal flood event with a return period of 1 in 200 years in 2130 (Project lifetime)

c. Tidal flood event with a return period of 1 in 1,000 years (present day 2030)

d. Tidal flood event with a return period of 1 in 1,000 years in 2130 (Project lifetime)

E.2.26 TIL005 and TIL006 breach models were run for 100 hours with a time of closure of 30 hours for earth embankments (Bowaters Sluice) and 18 hours for concrete wall defences (near the former Tilbury power station site). The MAR001 breach model was run for 80 hours.

Application of boundaries

E.2.27 For TIL005 and TIL006 simulated breaches, the design tidal boundary conditions were applied to the 2D model through a linked 1D Flood Modeller network via a SX 2D Flow Boundary. The 1D network applies the tidal level time-series boundary condition across the 2D cells defining the breach, and the breach opening is simulated dynamically as specified in the Environment Agency (2018) guidance.

E.2.28 For the MAR001 simulated breach, the design tidal boundary conditions were applied to the downstream 1D Flood Modeller unit of the Project Mardyke Fluvial model (Part 4 of the FRA). Breach flows are propagated upstream within the linked 1D (Flood Modeller)/2D (TUFLOW) model. The 1D Flood Modeller network accounts for a ‘dynamic’ breach mechanism by applying the Flood

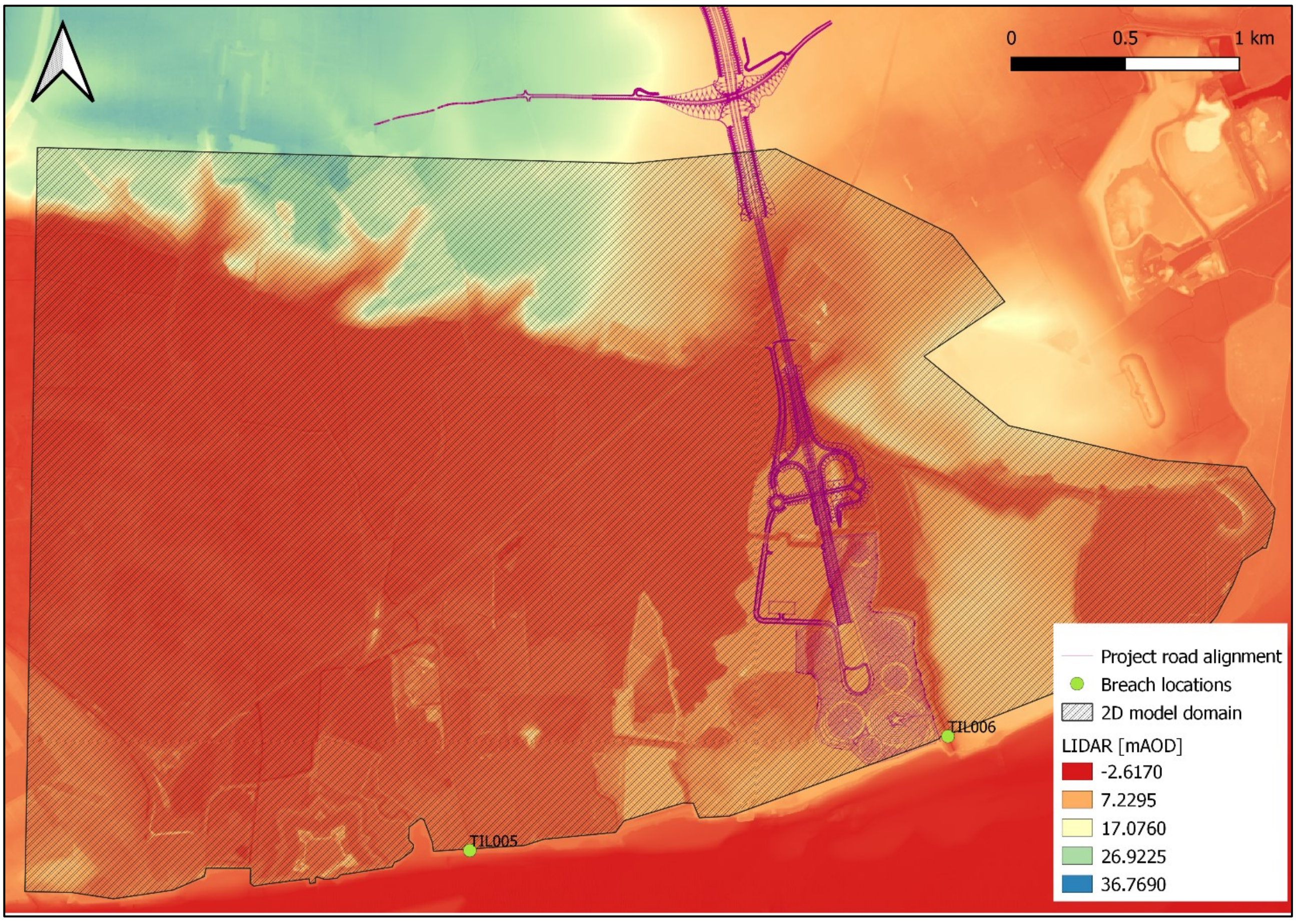
Modeller Breach unit to simulate opening/closing of the breach at the required times, as specified by the Environment Agency's (2018) methodology.

Model topography

E.2.29 For each breach model, the TUFLOW 2D model domain was constructed to cover the breach flood cell using filtered LiDAR data provided by the Environment Agency. The model grids were orientated, as close as practically possible, to be perpendicular to the breaches. The choice of grid cell size influences how accurately the model represents the sampled LiDAR data: the finer the resolution the more accurate the representation is. However, a finer grid resolution results in longer model run times, and so a balance needs to be achieved. A 6m grid resolution was adopted for the TIL005 and TIL006 breach simulations, and a 10m grid resolution was adopted for the MAR001 breach simulation.

E.2.30 The extent of the TIL005 and TIL006 models and the 2m resolution LiDAR is shown in Plate E.3.

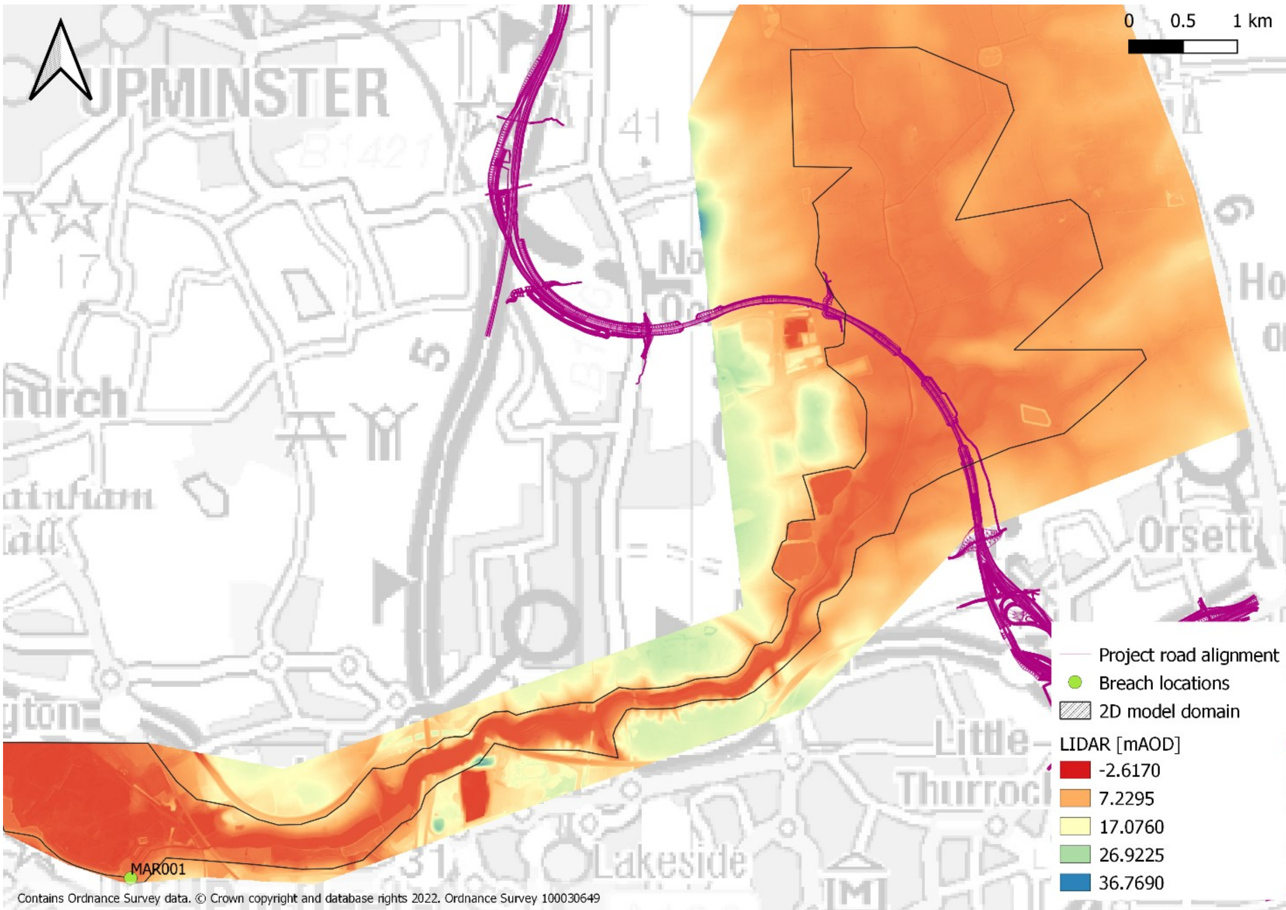
Plate E.3 TIL005 and TIL006 model extent and 2m resolution LiDAR



E.2.31 For the Project Mardyke fluvial model used to simulate the MAR001 breach, the 1D model topography was developed using the channel topographic survey acquired for the Project. The 2D model topography is based on LiDAR.

E.2.32 The extent of the Mardyke breach model and the LiDAR are shown in Plate E.4.

Plate E.4 MAR001 model extent and 2m resolution LiDAR



Roughness parameter values

E.2.33 The roughness parameters for the 2D model domains were specified for OS MasterMap data land types as listed in Table E.6.

Table E.6 2D Manning's n value

OS MasterMap land use	Material number	Manning's n value
Building	10021	0.500
General surface – multi-surface – gardens	10053	0.080
General surface – step	10054	0.020
General surface	10056	0.050
Inland water	10089	0.035
Landform	10093	0.050
Landform – slope	10096	0.050
Natural environment	10111	0.100
Path	10123	0.020
Rail	10167	0.050

OS MasterMap land use	Material number	Manning's n value
Road or track	10172	0.020
Roadside	10183	0.020
Structure	10185	0.500
Structure – pylon	10193	0.050

Overtopping

E.2.34 Overtopping of the defences would occur if River Thames EWLs exceed the defence crest levels. The Thames Estuary 2100 Plan (Environment Agency, 2012) developed by the Environment Agency, sets out how tidal flood risk is expected to be managed in the short, medium and long-term future[4]. This includes recommendations for defence heights.

E.2.35 The Project study area falls within the Thames Estuary 2100 Plan Policy Unit 4, for which the Thames Estuary 2100 Plan states: *'Policy unit – Purfleet, Grays & Tilbury (P4) – Our recommended flood risk management policy is policy P4 to take further action to keep up with climate and land use change so that flood risk does not increase*'.

E.2.36 Star Dam is on the boundary between Policy Units 4 and 3 and, for the purpose of the FRA, is classified as part of the Purfleet, Grays and Tilbury Policy Unit 4, as its purpose is to defend Tilbury.

E.2.37 For Policy Unit 3, the TE2100 Plan states: '*Policy unit – East Tilbury & Mucking Marshes (P3) – Our recommended policy for East Tilbury & Mucking Marshes is policy P3, to continue with existing or alternative actions to manage flood risk. We will continue to maintain flood defences at their current level, accepting that the likelihood and/or consequences of a flood will increase because of climate change*'.

E.2.38 Hence, overtopping over the defence crest levels was not considered in the Project breach modelling as the TE2100 Plan policy details that the crest levels will be increased in the future to maintain a 1 in 1,000-year standard of protection.

E.2.39 If the River Thames tidal defences were not upgraded in the future, and overtopped during River Thames EWLs, flooding on the landward side of the defences would be more gradual than after a breach. Therefore, a conservative estimate of peak water levels in the tidal River Thames floodplain would be an assumption that floodplain levels are equal to River Thames flood levels (conservative upper limit – and likely to be an overestimate as EWLs would not persist for long enough for landward flood levels to rise to the same level).

[4] Short and medium-term cover the period up to the end of 2049; long-term covers from 2050 into the 22nd century

The 1,000-year return period EWLs in 2130 applied in the breach modelling are 6.890mAOD for location TIL005 and 6.834mAOD for location TIL006.

The proposed tunnel North Portal flood defence bund is designed with a top level of 7.83mAOD, and the adjacent undefended highway (i.e. north of the tunnel defence bund) is designed to be above 7.83mAOD. If the River Thames tidal defences were not upgraded in the future, the Project road and tunnel would remain operational during the 1,000-year return period EWLs in 2130.

E.3 Design breach model results

TIL005 model results

General

E.3.1 TIL005 breach event flood maps showing modelled maximum depth, velocity and hazard score category for the pre- and post-development cases and differences between maximum depths and hazard score categories for the 200-year and 1,000-year return period tidal events in 2030 and 2130 are shown on the drawings in Part 9 and are listed in Table E.7.

Table E.7 TIL005 breach event flood maps – 200-year and 1,000-year return period events

Drawing number	Type of map	Scenario	Return Period (years)	Epoch
1186	Maximum flood depth	Pre-development	200	2030
1187	Maximum flood depth	Pre-development	200	2130
1188	Maximum flood depth	Pre-development	1,000	2030
1189	Maximum flood depth	Pre-development	1,000	2130
1190	Maximum flood depth	Post-development (with mitigation)	200	2030
1191	Maximum flood depth	Post-development (with mitigation)	200	2130
1192	Maximum flood depth	Post-development (with mitigation)	1,000	2030
1193	Maximum flood depth	Post-development (with mitigation)	1,000	2130
1202	Maximum flood velocity	Pre-development	200	2030
1203	Maximum flood velocity	Pre-development	200	2130
1204	Maximum flood velocity	Pre-development	1,000	2030
1205	Maximum flood velocity	Pre-development	1,000	2130
1206	Maximum flood velocity	Post-development (with mitigation)	200	2030

Drawing number	Type of map	Scenario	Return Period (years)	Epoch
1207	Maximum flood velocity	Post-development (with mitigation)	200	2130
1208	Maximum flood velocity	Post-development (with mitigation)	1,000	2030
1209	Maximum flood velocity	Post-development (with mitigation)	1,000	2130
1218	Maximum flood hazard category	Pre-development	200	2030
1219	Maximum flood hazard category	Pre-development	200	2130
1220	Maximum flood hazard category	Pre-development	1,000	2030
1221	Maximum flood hazard category	Pre-development	1,000	2130
1222	Maximum flood hazard category	Post-development (with mitigation)	200	2030
1223	Maximum flood hazard category	Post-development (with mitigation)	200	2130
1224	Maximum flood hazard category	Post-development (with mitigation)	1,000	2030
1225	Maximum flood hazard category	Post-development (with mitigation)	1,000	2130
1228	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	200	2030
1229	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	200	2130
1232	Difference in maximum flood hazard category	Post-(with mitigation) minus pre-development	200	2030
1233	Difference in maximum flood hazard category	Post-(with mitigation) minus pre-development	200	2130

Impact of the Project on flood risk elsewhere

E.3.2 Plate E.5 and Plate E.6 (breach event during the 200-year return period tidal event in 2030 and 2130 respectively) show the maximum depth difference between the post-development and the pre-development scenarios. Plate E.5 shows that the Project would have no impact on breach impacts elsewhere in 2030 as the simulated breach flood extent does not reach the Project. Plate E.6 shows that the Project would result in floodplain volume displacement with an increase in flood depths of approximately 0.01m to 0.03m on the western side adjacent to the Project road. The areas shown with an increase in flood depth in Plate E.6 are all low vulnerability (undeveloped land), located between the Project road and Tilbury to the west. Plate E.6 shows localised increases in flood depth at low points along Fort Road, which is above the simulated breach flood level for most of its length. Plate E.6 also shows an increase in flood depths along Tilbury Loop railway (0.09m to 0.22m), however for the pre-development case the railway would be impassable during a breach (with flood depths up to approximately 1m to 2m at some locations).

E.3.3 The difference (post-development minus pre-development) in hazard score category for the 200-year (2030 and 2130) events are shown in Plate E.7 and Plate E.8 respectively. As illustrated in Plate E.7 (200-year 2030 event), the proposed Project road embankment would not result in an increase in hazard category (the breach flood extent does not reach the Project road). Plate E.8 (200-year 2130 event) shows an increase by 1–2 hazard categories in some areas on the western side of the Project road. The areas showing an increase in flood hazard score category are all low vulnerability (undeveloped land), located between the Project road and Tilbury to the west.

E.3.4 Plate E.8 shows localised increases in flood hazard category at low points along, and adjacent to, Fort Road, which is above the simulated breach flood level for most of its length. Plate E.8 also shows isolated pixels with an increase in flood hazard category along Tilbury Loop railway, however for the pre-development case the railway would be impassable during a breach (with flood hazard category ‘Danger for most’ along most of its length within the breach flood extent).

E.3.5 Overall, the impact of the Project on flood risk elsewhere following a breach at TIL005 is not considered to be significant (i.e. no increase in hazard score category for properties, and no significant change to flood risk along Fort Road and Tilbury Loop railway). It is also noted that this risk is very unlikely to be realised within the Project’s lifetime as it requires an extreme River Thames flood condition to occur as well as failure of the River Thames flood defences at the TIL005 modelled breach location.

Plate E.5 Maximum flood depth difference (post-development minus pre-development design simulation – 200-year 2030 tidal event) – TIL005

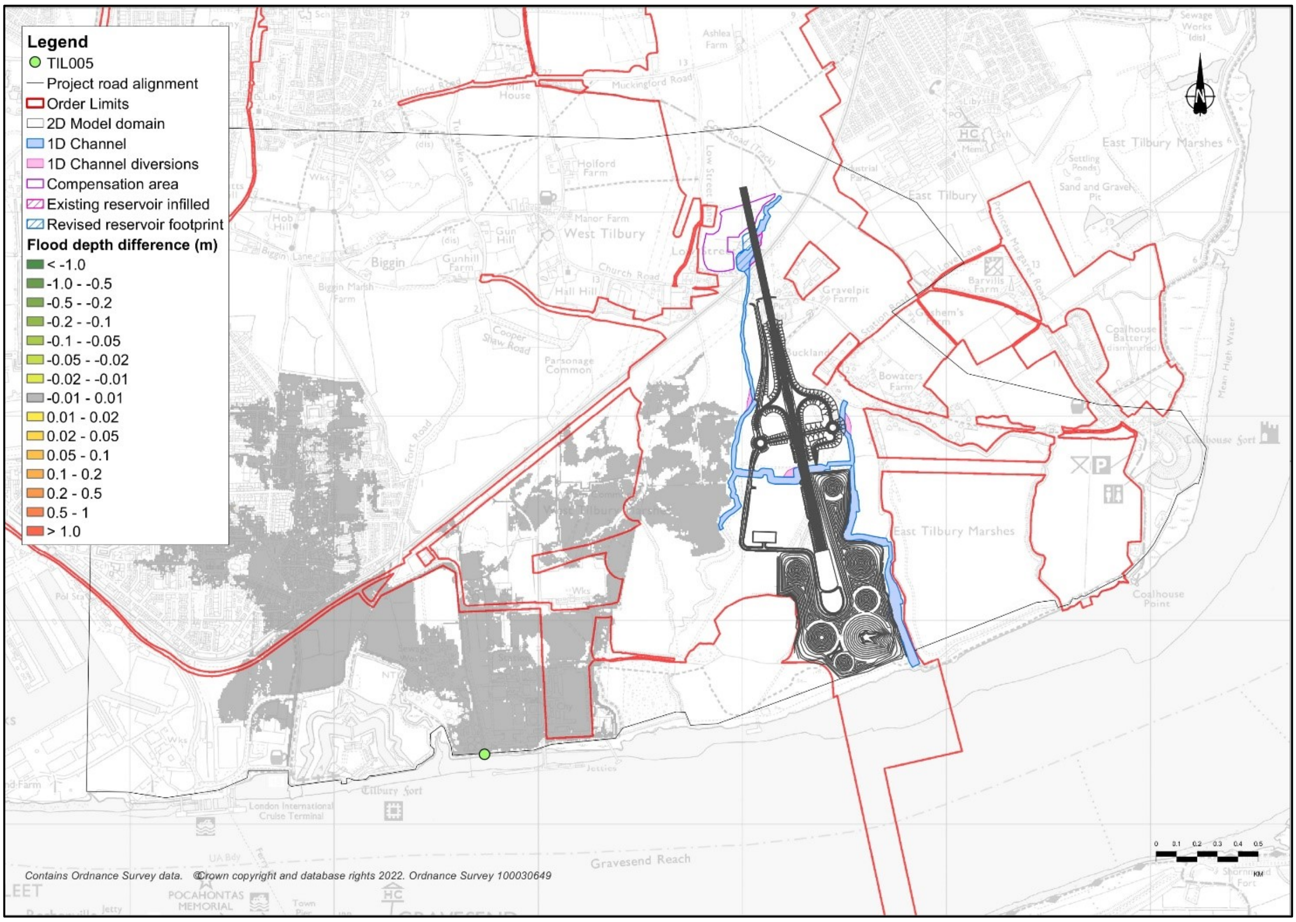


Plate E.6 Maximum flood depth difference (post-development minus pre-development design simulation – 200-year 2130 tidal event) – TIL005

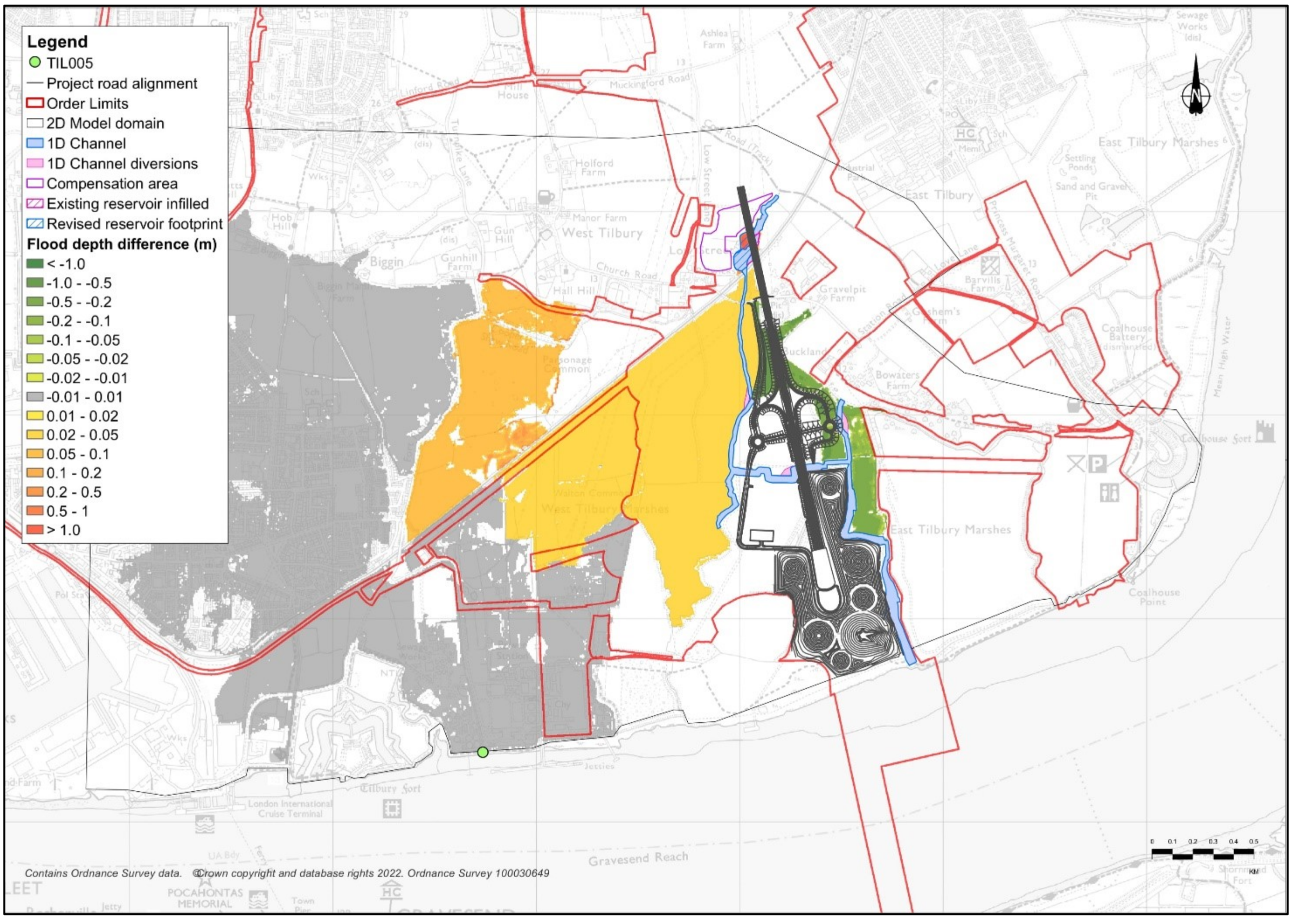


Plate E.7 Hazard category difference (post-development minus pre-development design simulation – 200-year 2030 tidal event) – TIL005

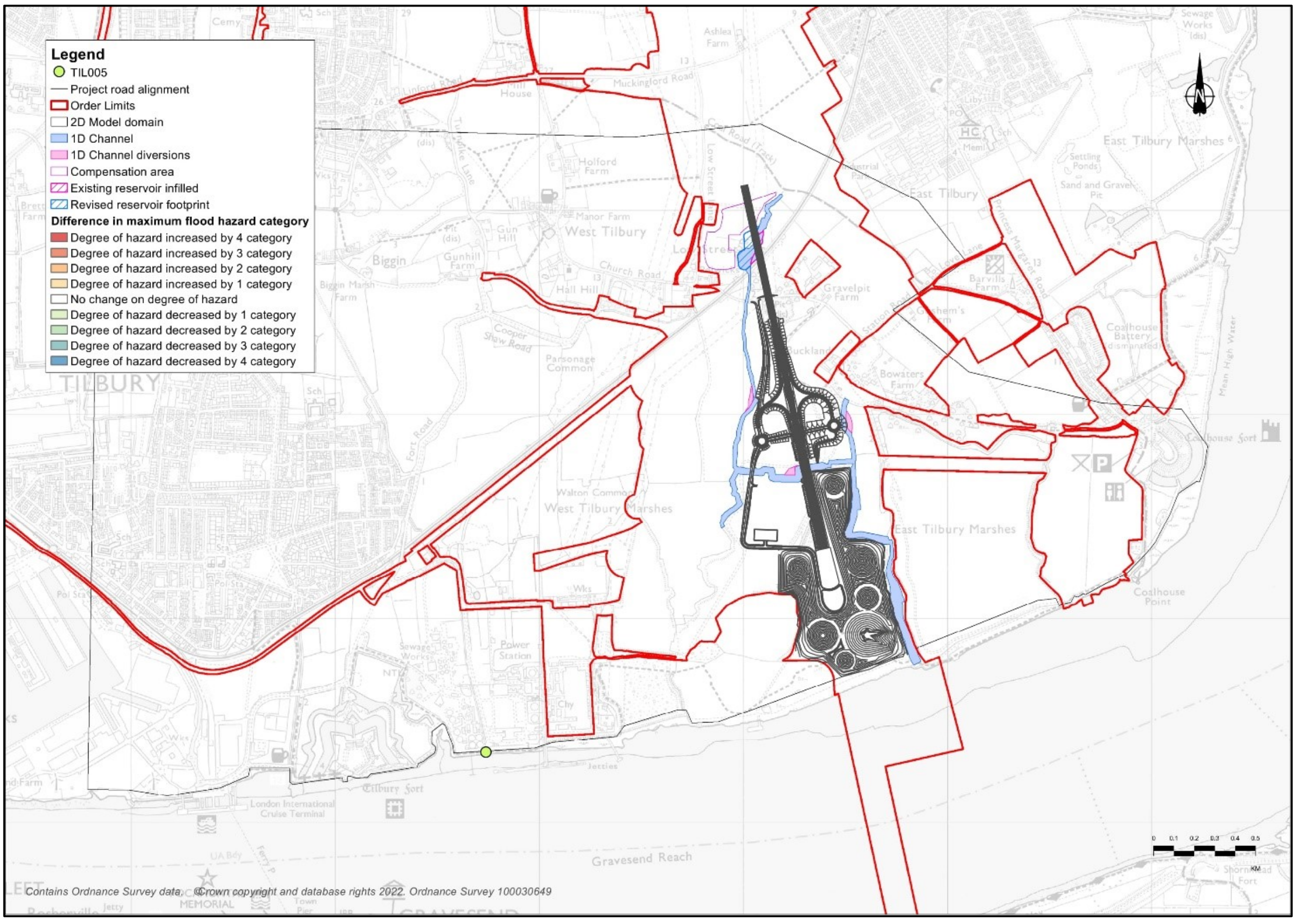
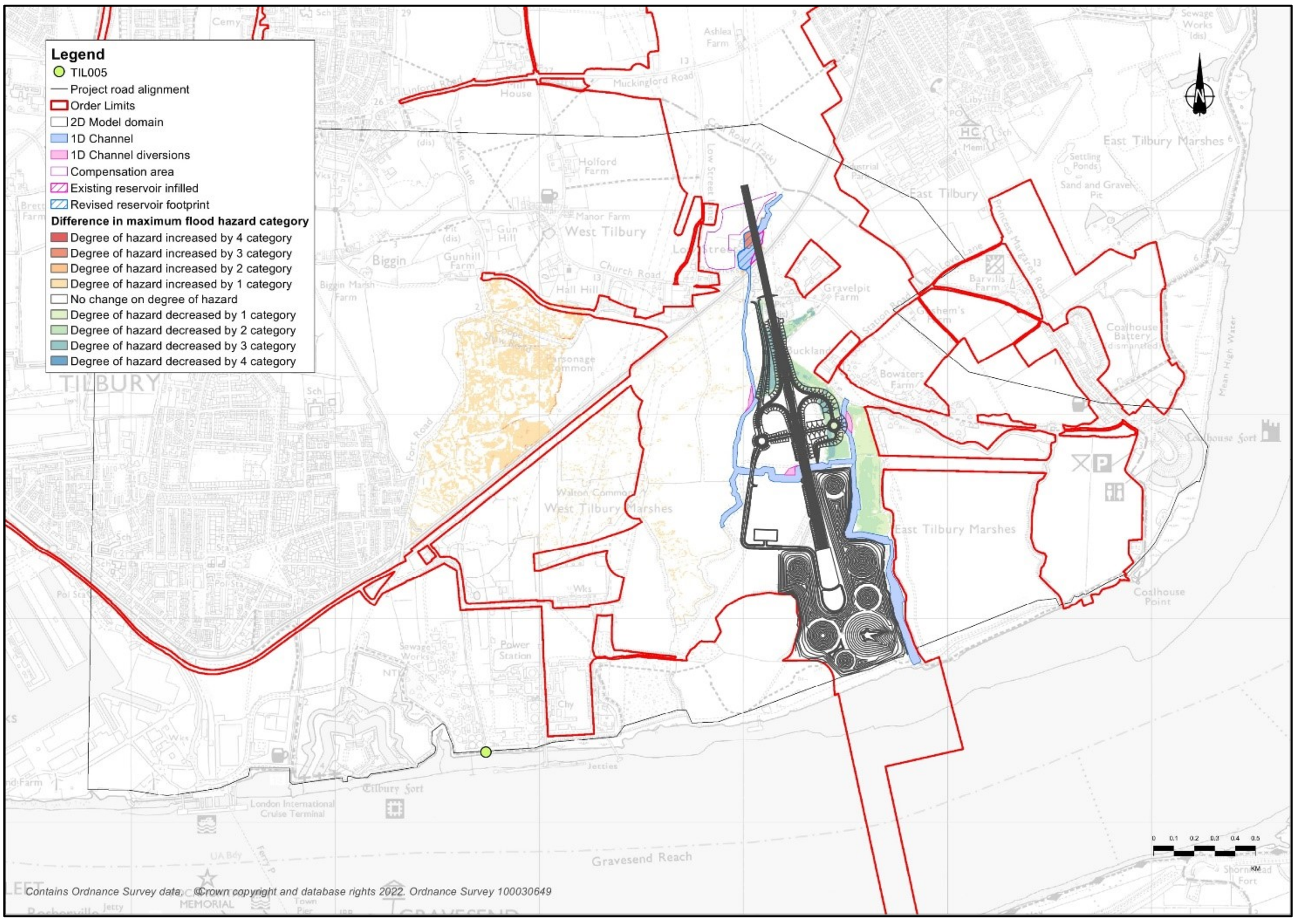


Plate E.8 Hazard category difference (post-development minus pre-development design simulation – 200-year 2130 tidal event) – TIL005



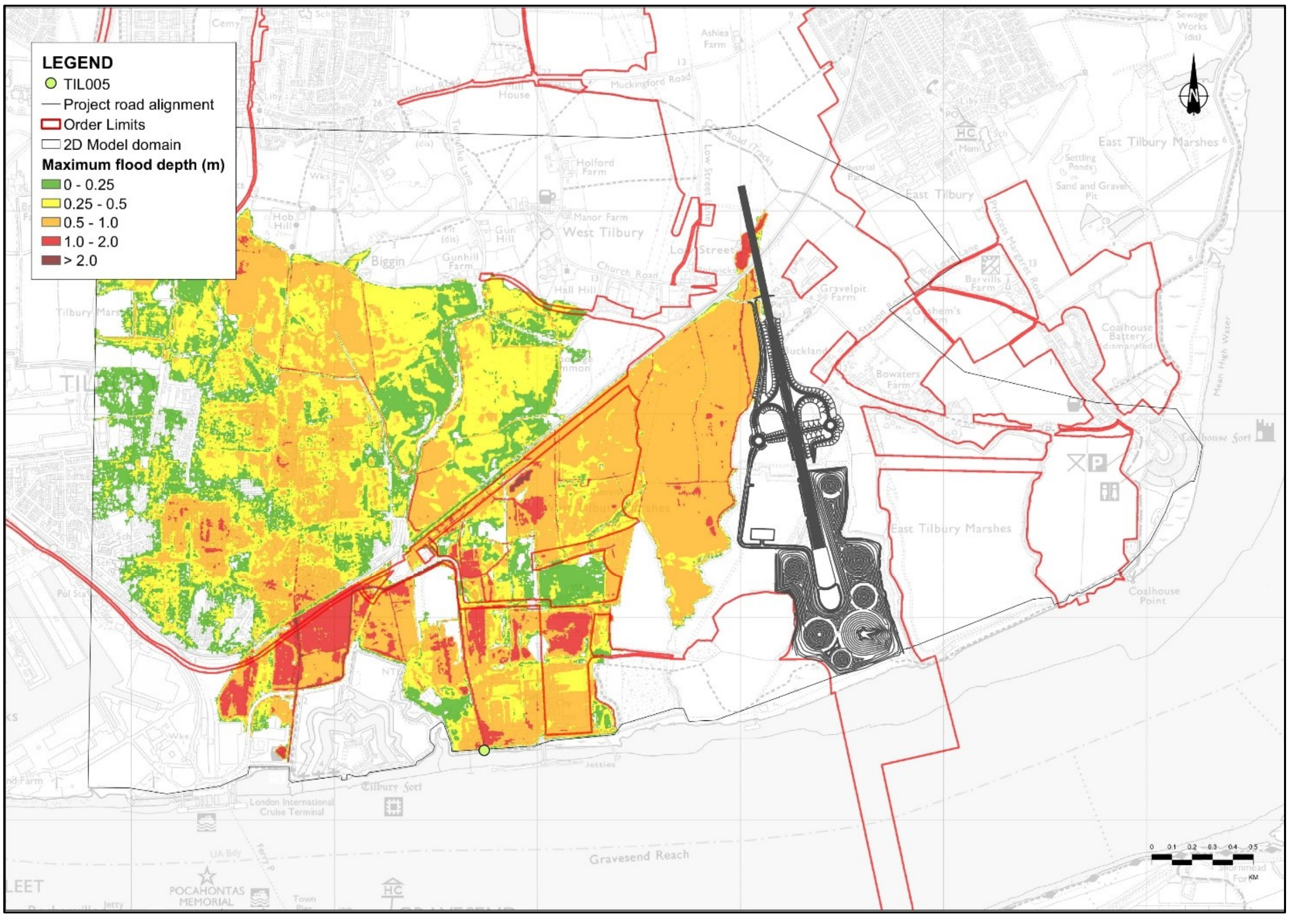
Impact of a breach on the Project

E.3.6 Plate E.9 shows simulated maximum flood depths following a breach event during the 1,000-year return period tidal event in 2130, for the post-development with mitigation scenario. Plate E.9 shows the Project road would not be impacted (i.e. no overtopping).

E.3.7 Breach flooding does not reach the area adjacent to the tunnel North Portal embankment. Maximum flood levels adjacent to the road are 2.10mAOD. The proposed tunnel North Portal flood defence bund is designed with a top level of 7.83mAOD, and the adjacent undefended highway (i.e. north of the tunnel defence bund) is designed to be above 7.83mAOD.

E.3.8 The Project road (including the section in tunnel) would therefore remain operational during a breach at location TIL005 during the 1,000-year return period tidal River Thames flood in 2130.

Plate E.9 Maximum flood depth for post-development design simulation – 1,000-year 2130 tidal event (TIL005)



TIL006 model results

General

E.3.9 TIL006 breach event flood maps showing modelled maximum depth, velocity and hazard score category for the pre- and post-development cases and differences between maximum depths and hazard score categories, for the 200-year and 1,000-year return period tidal events in 2030 and 2130 are shown on the drawings in Part 9, which are listed in Table E.8.

Table E.8 TIL006 breach event flood maps – 200-year and 1,000-year return period events

Drawing number	Type of map	Scenario	Return Period (years)	Epoch
1178	Maximum flood depth	Pre-development	200	2030
1179	Maximum flood depth	Pre-development	200	2130
1180	Maximum flood depth	Pre-development	1,000	2030
1181	Maximum flood depth	Pre-development	1,000	2130

Drawing number	Type of map	Scenario	Return Period (years)	Epoch
1182	Maximum flood depth	Post-development (with mitigation)	200	2030
1183	Maximum flood depth	Post-development (with mitigation)	200	2130
1184	Maximum flood depth	Post-development (with mitigation)	1,000	2030
1185	Maximum flood depth	Post-development (with mitigation)	1,000	2130
1194	Maximum flood velocity	Pre-development	200	2030
1195	Maximum flood velocity	Pre-development	200	2130
1196	Maximum flood velocity	Pre-development	1,000	2030
1197	Maximum flood velocity	Pre-development	1,000	2130
1198	Maximum flood velocity	Post-development (with mitigation)	200	2030
1199	Maximum flood velocity	Post-development (with mitigation)	200	2130
1200	Maximum flood velocity	Post-development (with mitigation)	1,000	2030
1201	Maximum flood velocity	Post-development (with mitigation)	1,000	2130
1210	Maximum flood hazard category	Pre-development	200	2030
1211	Maximum flood hazard category	Pre-development	200	2130
1212	Maximum flood hazard category	Pre-development	1,000	2030
1213	Maximum flood hazard category	Pre-development	1,000	2130
1214	Maximum flood hazard category	Post-development (with mitigation)	200	2030
1215	Maximum flood hazard category	Post-development (with mitigation)	200	2130
1216	Maximum flood hazard category	Post-development (with mitigation)	1,000	2030
1217	Maximum flood hazard category	Post-development (with mitigation)	1,000	2130
1226	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	200	2030
1227	Difference in maximum flood depth	Post-(with mitigation) minus pre-development	200	2130

Drawing number	Type of map	Scenario	Return Period (years)	Epoch
1230	Difference in maximum flood hazard category	Post-(with mitigation) minus pre-development	200	2030
1231	Difference in maximum flood hazard category	Post-(with mitigation) minus pre-development	200	2130

Impact of the Project on flood risk elsewhere

E.3.10 Plate E.10 and Plate E.11 (breach event during the 200-year return period tidal event in 2030 and 2130 respectively) show the maximum depth difference between the post-development and the pre-development scenarios. Both plates show that the Project would result in reduced conveyance of breach flows from east to west across the Project road, and floodplain volume displacement, with an increase in flood depths on the eastern side of the road of higher than 1m for the floodplain constrained by the proposed embankment on the west (the highest increase on the eastern side of the road is approximately 3.3m, typical values are approximately 2.0m to 2.5m), Star Dam defence on the east and the surrounded hilly areas, and an increase of approximately 0.15m to 0.21m in the area east of Star Dam. Plate E.10 and Plate E.11 also show a significant reduction in flood depths on the western side of the Project road including in the Tilbury urban area by approximately 0.20m to 1m. The areas with an increase in flood depth are all low vulnerability (undeveloped land).

E.3.11 The difference (post-development minus pre-development) in hazard score category for the 200-year return period events in 2030 and 2130 are shown in Plate E.12 and Plate E.13 respectively. Both plates show that the Project would result in an increase in hazard category in some areas on the eastern side of the Project road by 1 to 4 categories. The highest increases are where the post-development flood extents increase beyond the pre-development flood extents. Plate E.12 and Plate E.13 also show a significant reduction on the western side of the road, with a reduction in Tilbury urban area by 1 to 4 categories, with the largest reductions generally at locations that are outside of the post-development breach flood extent, but inside the pre-development extent. The areas with an increase in hazard category are all low vulnerability (undeveloped land). Overall, the impact of the Project on flood risk elsewhere following a breach at TIL006 is an increase in hazard score category for areas of undeveloped land, while showing a clear benefit (reduction in flood hazard category) in Tilbury urban area, where vulnerable receptors are located (i.e. properties). Some of the impacted areas of undeveloped land will be on land for which National Highways will be seeking permanent acquisition, and some will be on third-party land.

E.3.12 It is noted that this risk is very unlikely to be realised within the Project's lifetime as it requires an extreme River Thames flood condition to occur as well as failure of the River Thames flood defences at the TIL006 modelled breach location (Bowaters Sluice).

Plate E.10 Maximum flood depth difference (post-development minus pre-development design simulation – 200-year 2030 tidal event) – TIL006

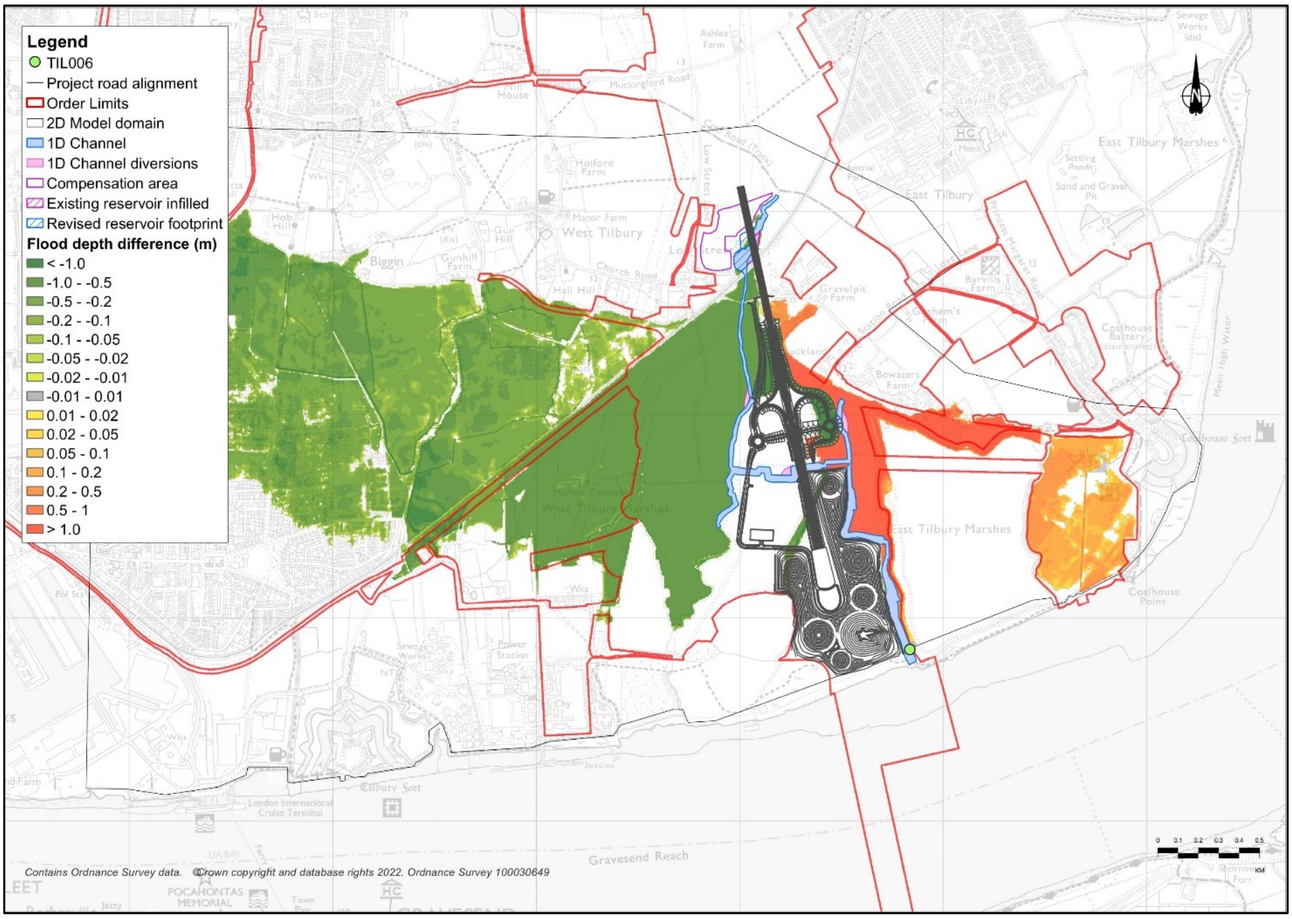


Plate E.11 Maximum flood depth difference (post-development minus pre-development design simulation – 200-year 2130 tidal event) – TIL006

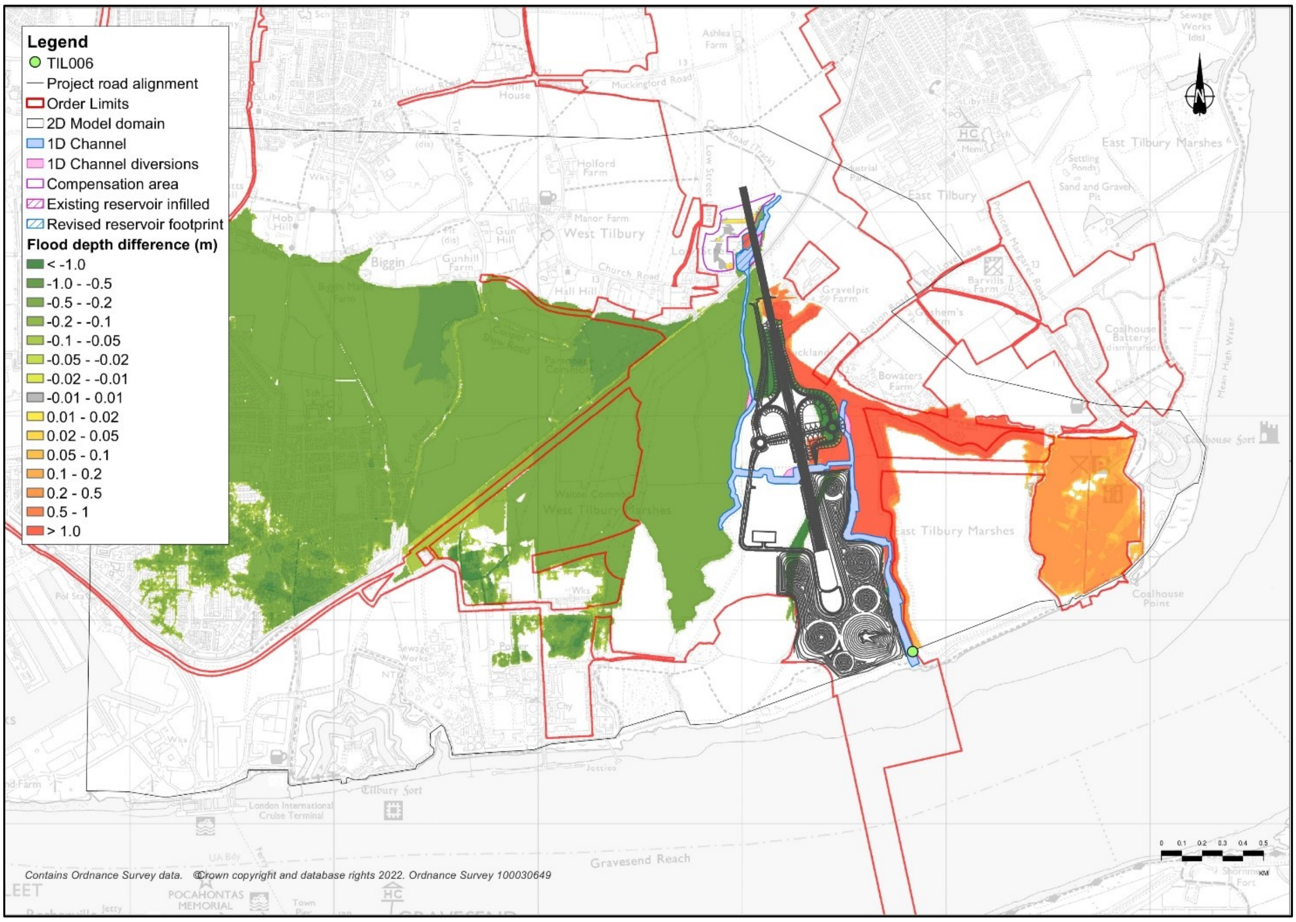


Plate E.12 Hazard category difference (post-development minus pre-development design simulation – 200-year 2030 tidal event) – TIL006

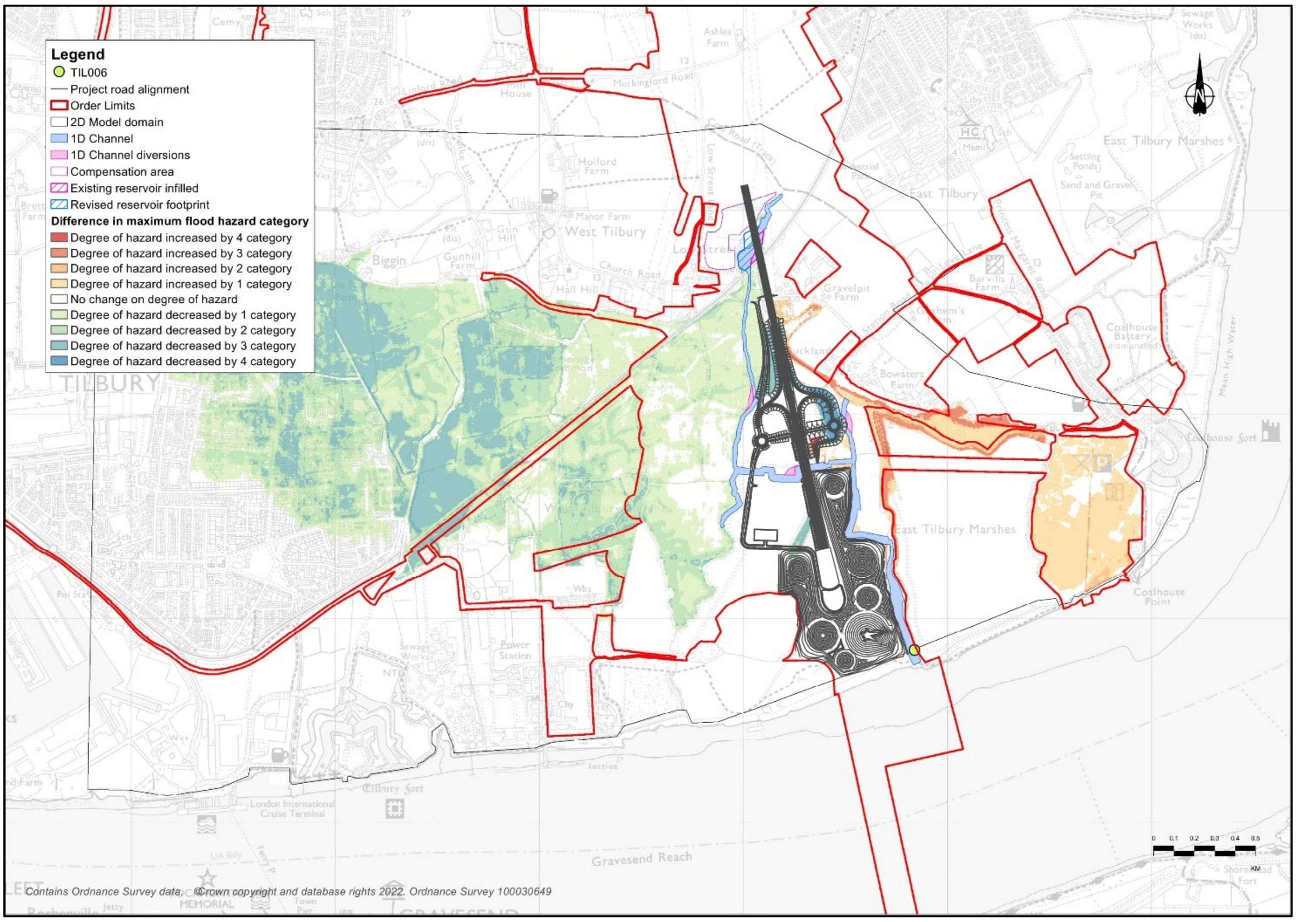
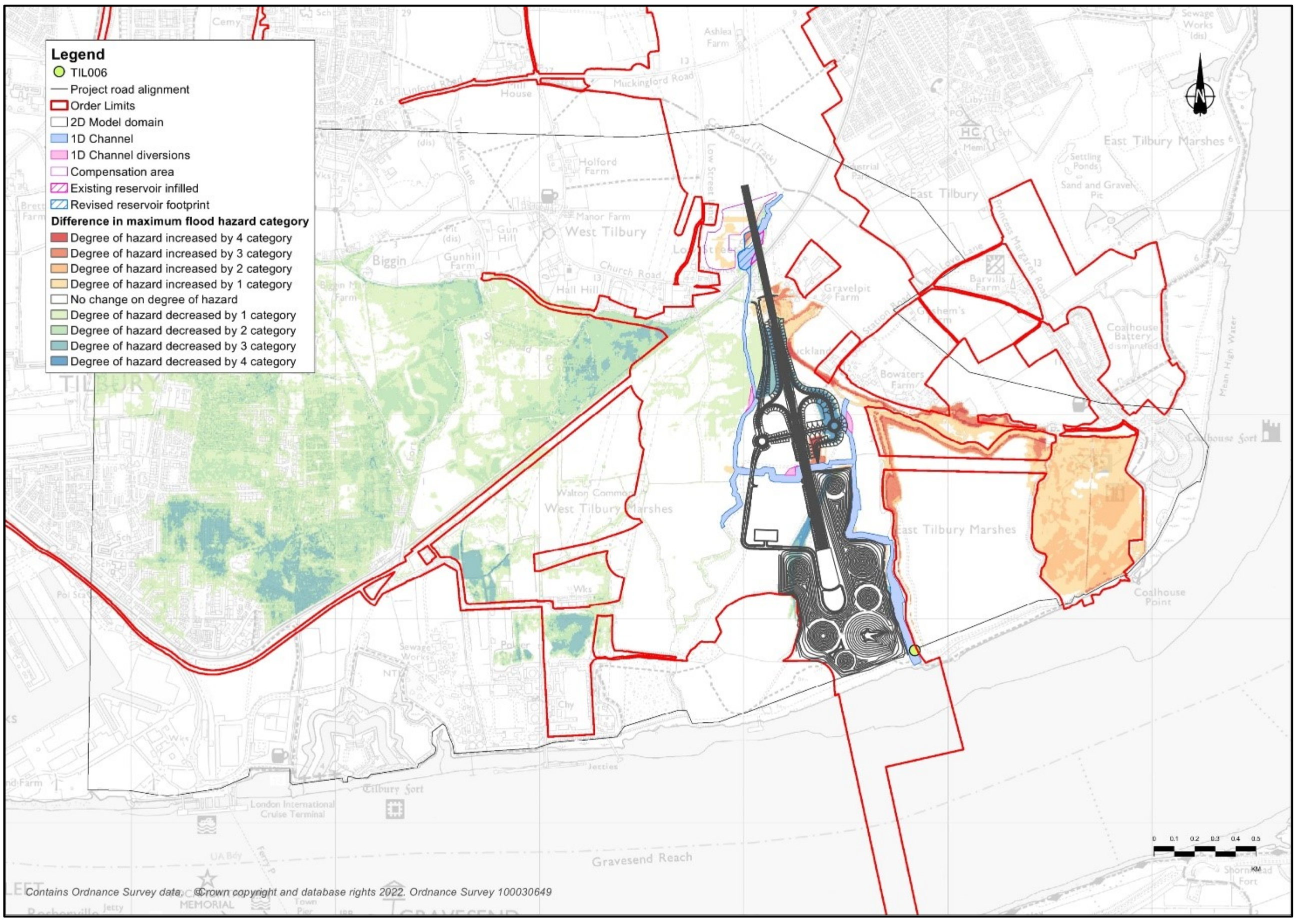


Plate E.13 Hazard category difference (post-development minus pre-development design simulation – 200-year 2130 tidal event) – TIL006



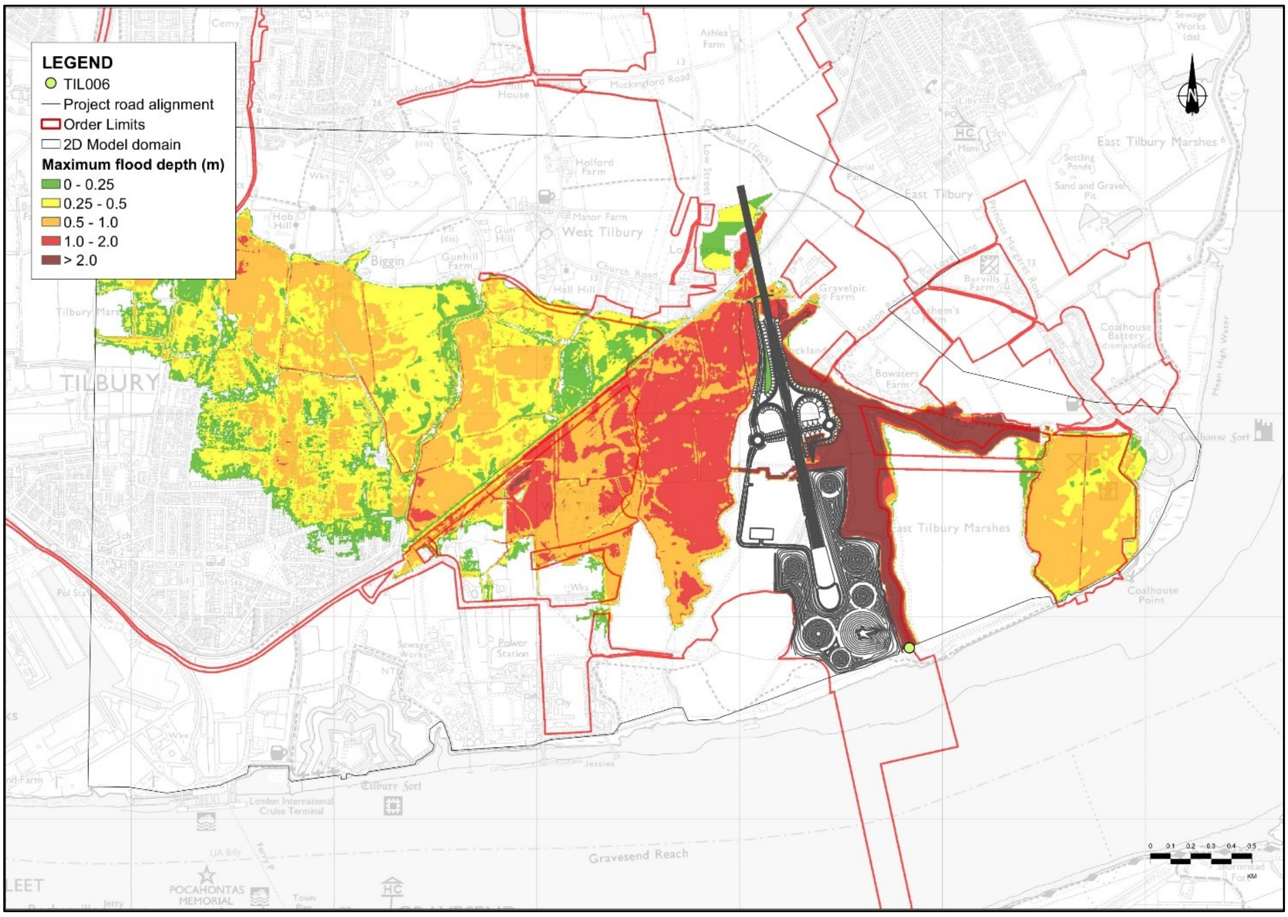
Impact of a breach on the Project

E.3.13 Plate E.14 shows simulated maximum flood depths following a breach event during the 1,000-year return period tidal event in 2130, for the post-development with mitigation scenario. Plate E.14 shows the Project road would not be impacted (i.e., no overtopping).

E.3.14 Maximum flood levels adjacent to the road are 6.35mAOD to 6.7mAOD on the eastern side of the road and 2.42mAOD on the western side. The proposed tunnel North Portal flood defence bund is designed with a top level of 7.83mAOD, and the adjacent undefended highway (i.e. north of the tunnel defence bund) is designed to be above 7.83mAOD.

E.3.15 The Project road (including the section in tunnel) would therefore remain operational during a breach at location TIL006 during the 1,000-year return period tidal River Thames flood in 2130.

Plate E.14 Maximum flood depth for post-development design simulation – 1,000-year 2130 tidal event (TIL006)

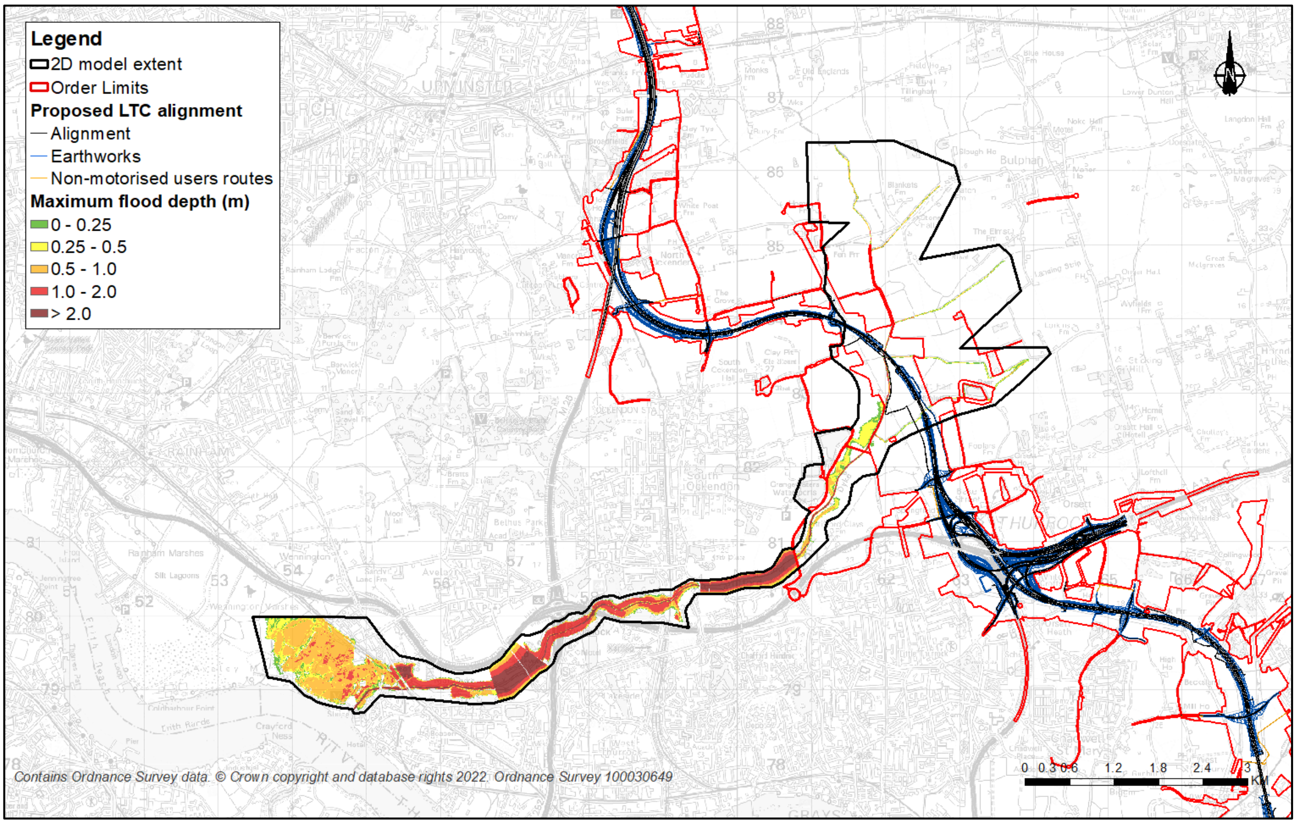


MAR001 model results

E.3.16 Plate E.15 shows the simulated maximum flood depths for a breach at MAR001 during the 1,000-year return period tidal River Thames flood event in 2130 (the pre-development case was simulated).

E.3.17 Since most of the breach flood water flows to the low-lying marshes located near to the Mardyke sluice gate, at the Project road location breach flows would be contained in the river channel. Therefore, for a breach at location MAR001, the Project would not be impacted by flooding and it would have no impact on flooding elsewhere.

Plate E.15 Flood depth for 1 in 1,000-year tidal event in 2130



E.4 Breach invert level and flood defence crest level

E.4.1 The invert level of the breach was determined through an interrogation of the LiDAR on the landward side of the breach location. Following the Environment Agency (2018) guidance, the lowest ground level within a radius the same width as the breach was used as the breach invert level.

TIL005

E.4.2 The breach invert level for the TIL005 breach location was specified based on the updated LiDAR topographic dataset and set to 3.177mAOD (the lowest LiDAR elevation on the landward side of the breach location) instead of the 3m applied in the Thurrock SFRA breach model (Thurrock Council, 2018). A breach width of 20m was applied following Environment Agency guidance.

E.4.3 The flood defence level was set to 6.48mAOD based on the information received from the Environment Agency for Asset Number 152988 (EAN/2018/76391, 2018). This level agrees with the information detailed in the Tilbury Fixed Defences, Essex Engineering Investigations Report, TEAM (TEA-3F-00.00-RP-AI-DE-000002,2016) and also with the LiDAR topographic dataset. An illustration of the typical cross-section is presented in Plate E.18. The foreshore level (i.e. at the toe of the structure) was set to 3.75mAOD, as detailed in the TEAM asset report (TEA-3F-00.00-RP-AI-DE-000002,2016) and consistent with LiDAR data (see Plate E.16, Plate E.17 and Plate E.18).

Plate E.16 2m LiDAR (clipped at TIL005 breach location)

Plate E.17 EAN/2018/76391, 2018

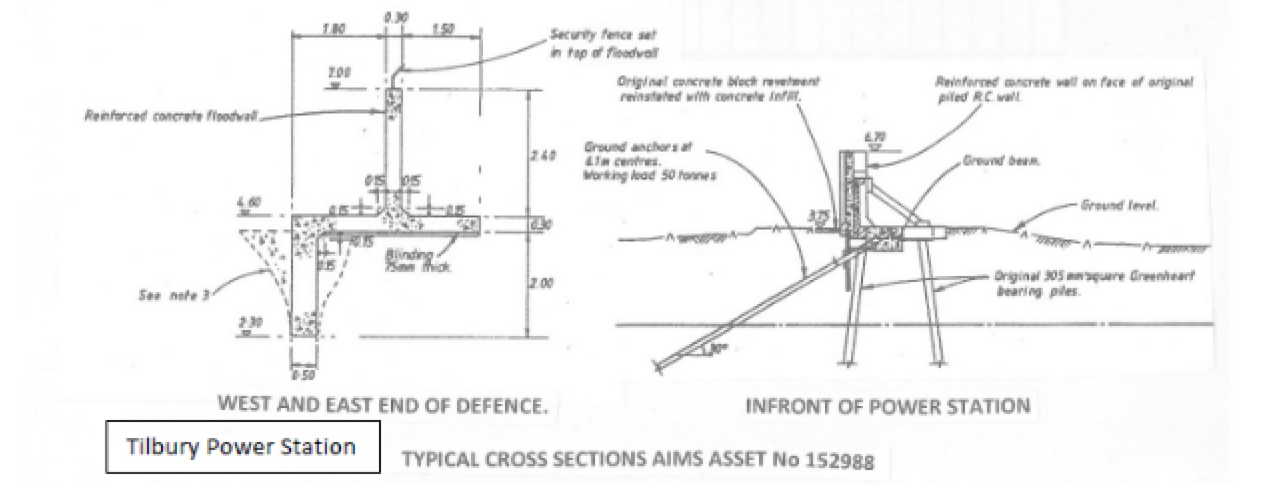
Date: 08/03/2018
Datasheet Reference: EAN/2018/76391

Environment Agency

Defence Information

Asset Reference	Maintainer	Bank	Asset Type	Asset Description	Overall Condition Grade	Crest Level
109492	Environment Agency	left	wall	Sheet Piling Wall	3	6.700
109493	Environment Agency	left	wall	Piling with embankment	4	6.670
109494	Environment Agency	left	wall	Wall with embankment	2	6.720
130132	Environment Agency	left	wall	Wall with embankment	2	6.710
130315	Environment Agency	left	wall	Steel Wall	2	6.480
130316	Environment Agency	left	wall	Cruise Liner terminal	3	6.630
130317	Environment Agency	left	wall	Wall	3	6.450
151470	Environment Agency	coastal	embankment	Embankment	3	3.070
151471	Environment Agency	left	embankment	Embankment	3	4.500
152778	Environment Agency	left	wall	Wall with embankment	2	6.700
152779	Environment Agency	left	embankment	Embankment	2	7.200
152780	Environment Agency	left	embankment	Embankment	3	4.930
152781	Environment Agency	left	embankment	Embankment	3	4.590
152988	Environment Agency	left	wall	Wall	5	6.480
178893	Environment Agency	coastal	wall	Star Dam	2	6.550
475722	Environment Agency		wall	Concrete Wall	3	

Plate E.18 TEA-3F-00.00-RP-AI-DE-000002,2016



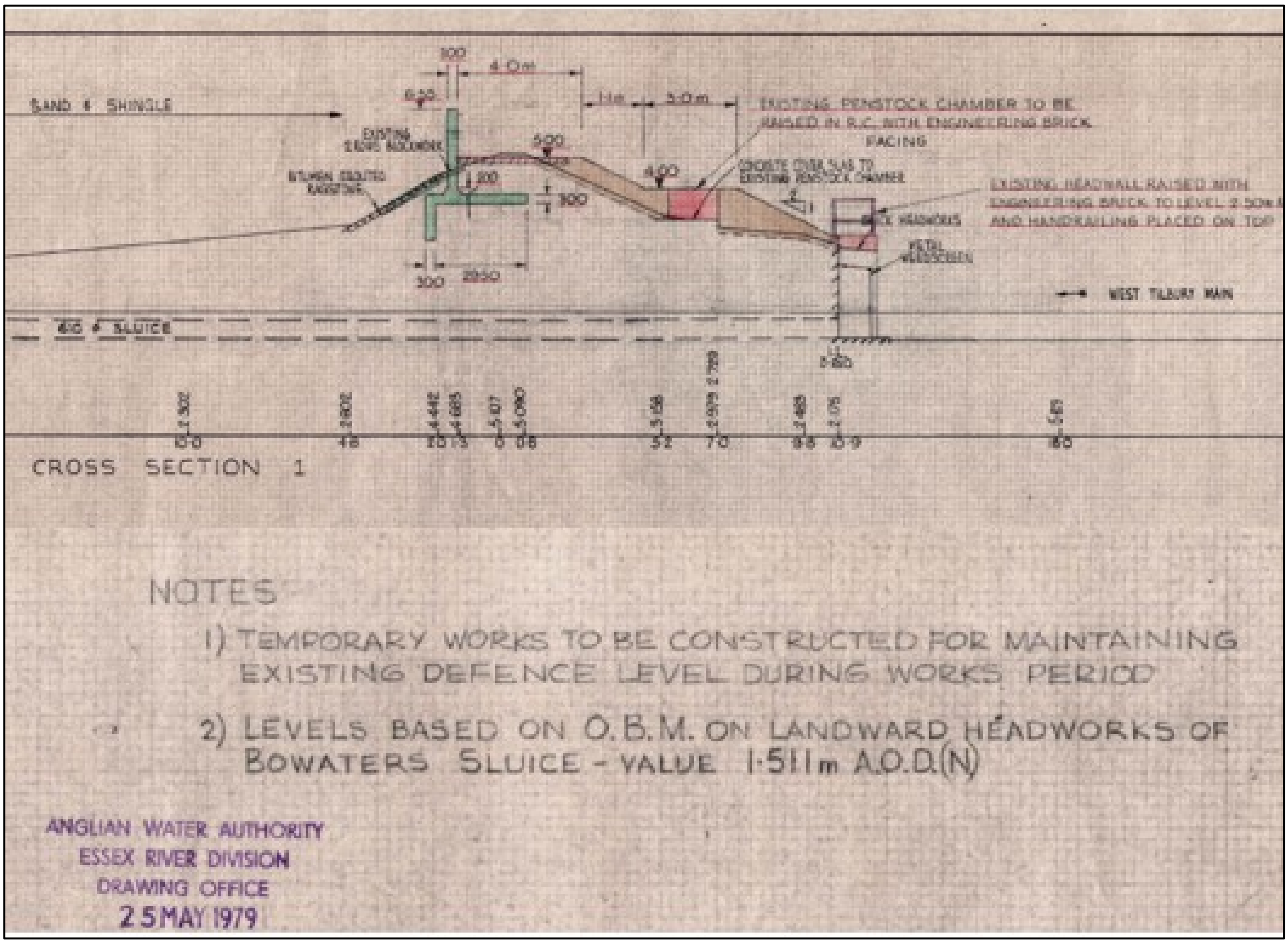
TIL006

E.4.4 The TIL006 breach location at Bowaters Sluice has been shifted upstream (at the landward side) for modelling purposes. This model adjustment would have no effect on the model results.

E.4.5 The breach invert level for TIL006 breach location was set to -0.615mAOD (cross-section T9-001_2) based on the Project Tilbury Hydraulic Modelling Study (Part 5 of the FRA). A breach width of 50m was applied following the

Environment Agency (2018) guidance. The flood defence level was set to 4.99mAOD (6.5mAOD - 1.511m) as shown on the as-built drawing (Plate E.19). The foreshore level (i.e. the toe of the structure) was set to the surveyed channel bed level at the culvert invert (i.e. 0.701mAOD).

Plate E.19 Environment Agency's as-built drawing



MAR001

E.4.6 The breach location for MAR001 is near the sluice gate at Purfleet. The breach is represented in the model by a breach unit (Plate E.20). The cross-section just before the sluice and spill unit connecting breach was amended to have 20m width. The simulated breach is 20m wide.

E.4.7 The configuration of the breach unit is displayed in Plate E.20. The rules applied to specify functioning of the breach are presented in Table E.9.

Plate E.20 Flood Modeller unit representing Mardyke Sluice

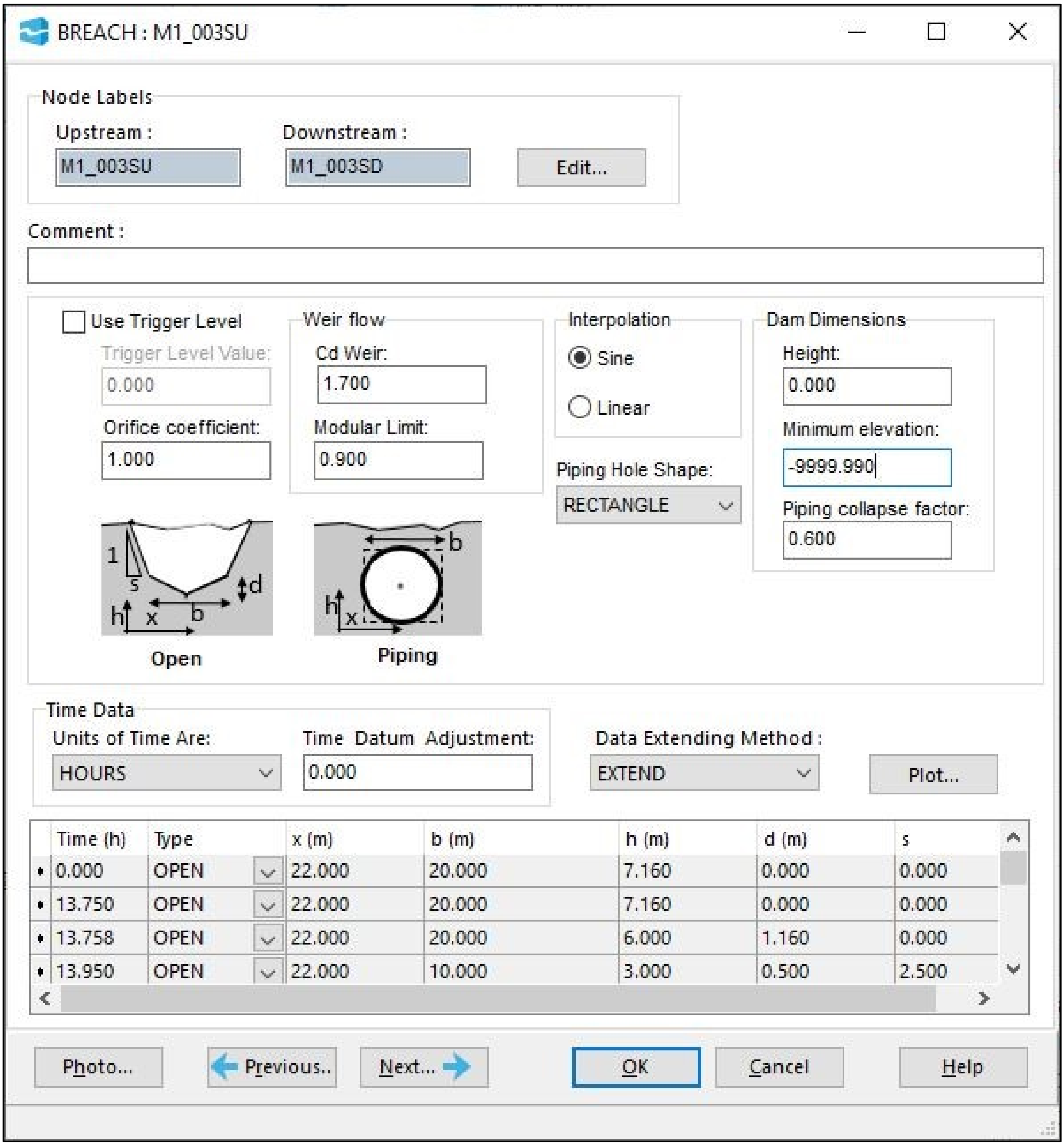


Table E.9 Mardyke breach time control data

Time (h)	x (m)	b (m)	h (m)	d (m)	s
0	22	20	7.16	0	0
1.992	22	20	7.16	0	0
2	22	20	7	0.16	0
2.25	22	20	5.4	1.76	0
2.5	22	10	3.2	0.8	1.582
2.75	22	20	-0.93	0.5	0
20.75	22	20	-0.93	0.5	0
21.75	22	20	7.16	0	0
36	22	20	7.16	0	0
100	22	20	7.16	0	0

E.5 Tidal boundary conditions

Table E.10 TIL005 breach: Extreme Water Levels

EWLs applied in Project modelling (mAOD)			EWLs Applied in Thurrock SFRA Breach modelling (mAOD)			TE2100 EWLs (mAOD)		
Year	200yr	1,000yr	Year	200yr	1,000yr	Year	200yr	1,000yr
2016	5.38	5.76	**2016**	5.56	6.09			
2030	5.50	5.89						
2130	6.53	6.89	**2116**	6.57	7.05	**2120**	6.32	6.65

Table E.11 TIL006 breach: Extreme Water Levels

EWLs applied in Project modelling (mAOD)			EWLs Applied in Thurrock SFRA Breach modelling (mAOD)			TE2100 EWLs (mAOD)		
Year	200yr	1,000yr	Year	200yr	1,000yr	Year	200yr	1,000yr
2016	5.24	5.62	**2016**	5.56	6.09			
2030	5.36	5.74						
2130	6.47	6.83	**2116**	6.57	7.05	**2120**	6.23	6.56

Table E.12 MAR001 breach: Extreme Water Levels

EWLs applied in Project modelling (mAOD)			EWLs Applied in Thurrock SFRA Breach modelling (mAOD)			TE2100 EWLs (mAOD)		
Year	**200yr**	**1,000yr**	**Year**	**200yr**	**1,000yr**	**Year**	**200yr**	**1,000yr**
2016		5.95	**2016**	5.94	6.43			
2130		7.08	**2116**	6.84	7.31	**2120**	6.52	6.85

Plate E.21 Tidal boundary time series – TIL005 200 year events

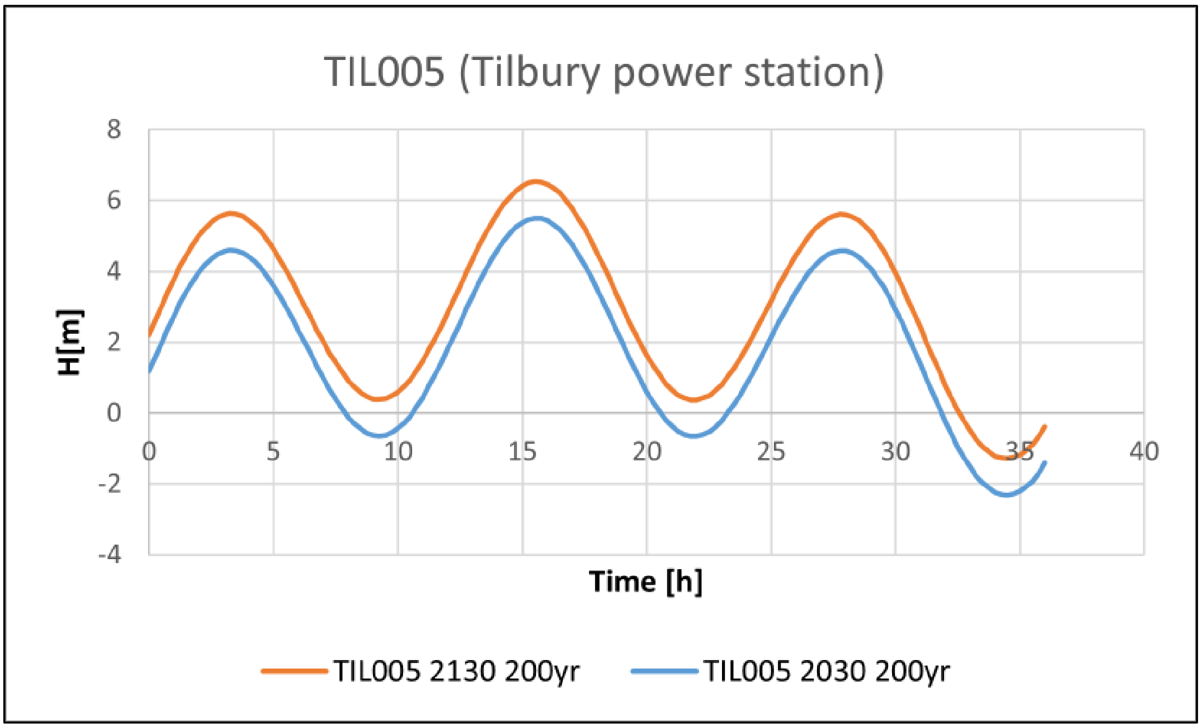


Plate E.22 Tidal boundary time series – TIL005 1,000 year events

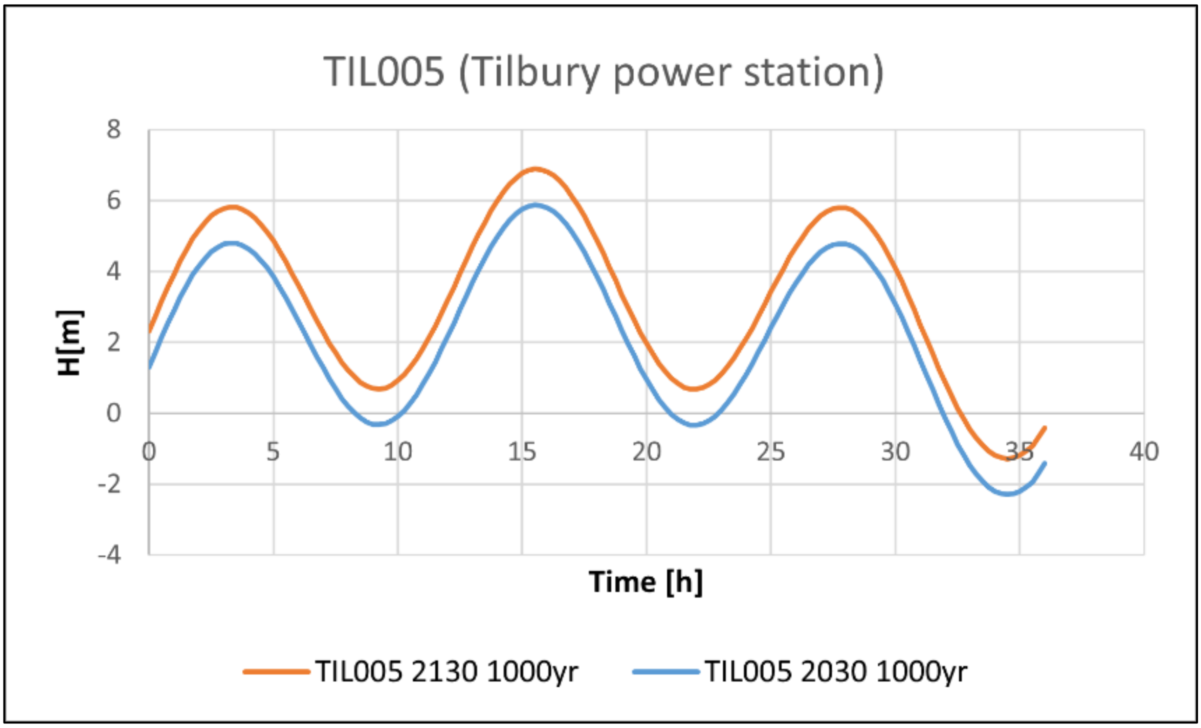


Plate E.23 Tidal boundary time series – TIL006 200 year events

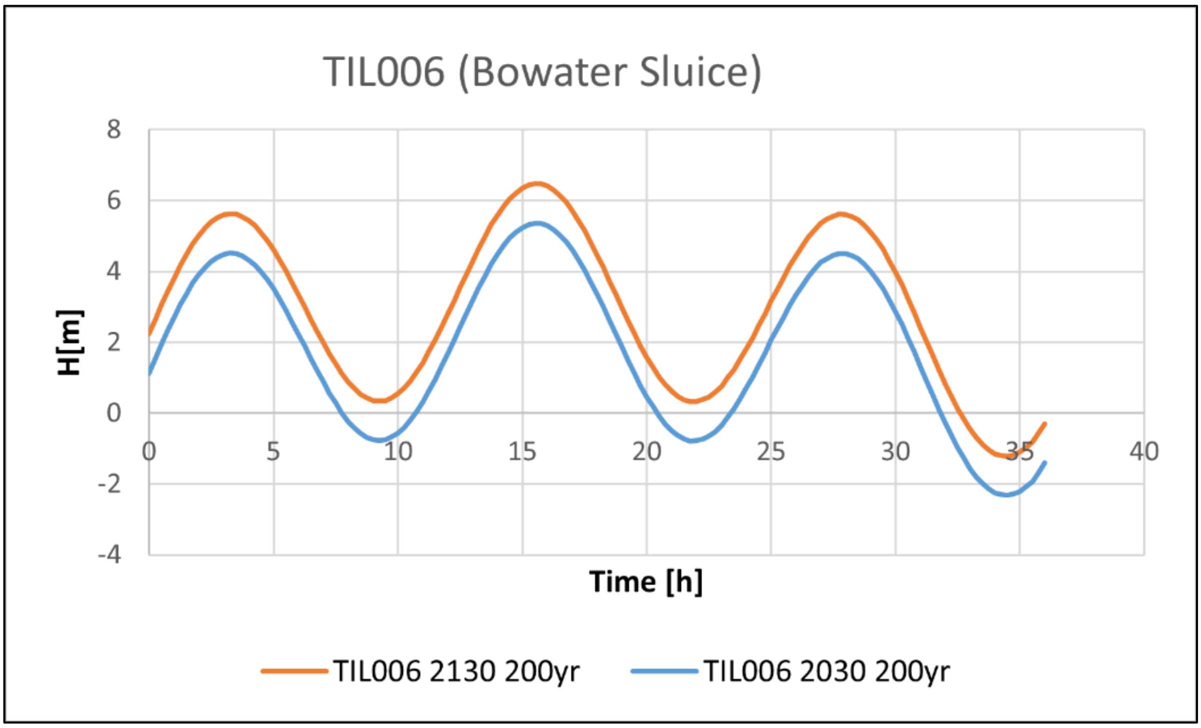


Plate E.24 Tidal boundary time series – TIL006 1,000 year events

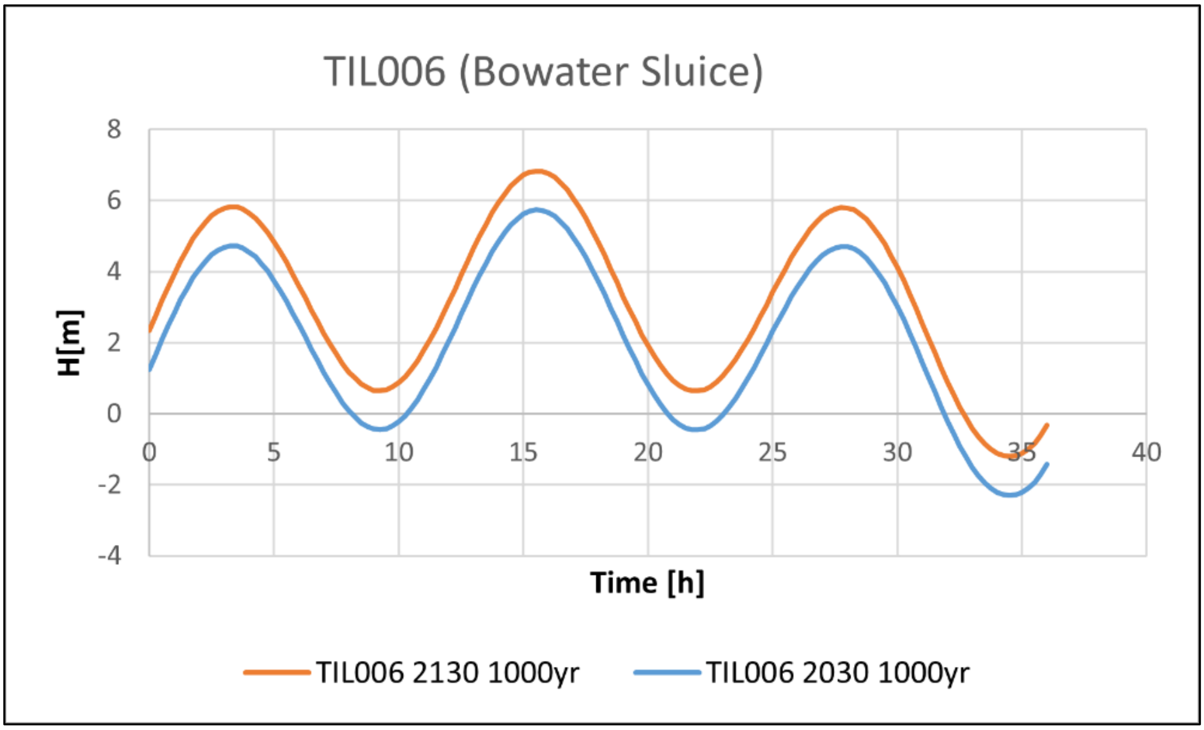
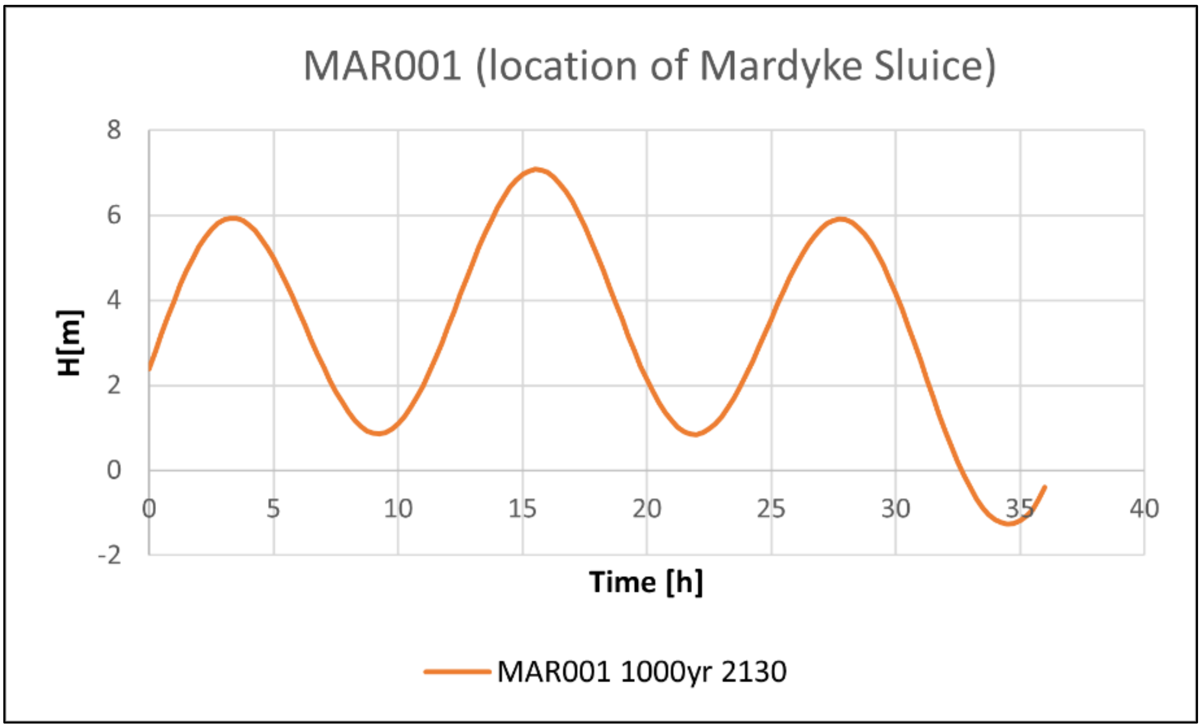


Plate E.25 Tidal boundary time series – MAR001 1,000 year event in 2130



E.6 Model files

Table E.13 MAR001 Breach model files (1,000yrs)

Model Input Files	Files
1D run file (ief)	v6_BR_MAR001_Pre_T1000yrCC26
1D model file (DAT)	Mardyke_v18_BR1.dat
1D boundary files (IED)	Storm duration: v2_BR_T1000yrCC26.ied Gate operation: BR_MAR001_T1000CC.ied
2D run file (tcf)	v6_BR_MAR001_Pre_T1000yrCC26.tcf
2D geometry file (tgc)	Mardyke_v13_BR.tgc
2D boundary file (tbc)	Mardyke_v14_BR.tbc
2D materials file (tmf)	Mardyke_2D.tmf

Table E.14 TIL005 Breach Model Files (200yrs, 1,000yrs)

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)
V3_BR_TIL005_Post_1000YR_2030	TIL005_1000YR2030.dat	V3_BR_TIL005_Post_1000YR_2030.ief	V3_BR_TIL005_Post_1000YR_2030.tcf	V3_BR_TIL005_Post_v05.tgc, V3_BR_TIL005_Post_v04.tbc, Tilbury.tmf
V3_BR_TIL005_Post_1000YR_2130	TIL005_1000YR2130.dat	V3_BR_TIL005_Post_1000YR_2130.ief	V3_BR_TIL005_Post_1000YR_2130.tcf	V3_BR_TIL005_Post_v05.tgc, V3_BR_TIL005_Post_v04.tbc, Tilbury.tmf
V3_BR_TIL005_Post_200YR_2030	TIL005_200YR2030.dat	V3_BR_TIL005_Post_200YR_2030.ief	V3_BR_TIL005_Post_200YR_2030.tcf	V3_BR_TIL005_Post_v05.tgc, V3_BR_TIL005_Post_v04.tbc, Tilbury.tmf
V3_BR_TIL005_Post_200YR_2130	TIL005_200YR2130.dat	V3_BR_TIL005_Post_200YR_2130.ief	V3_BR_TIL005_Post_200YR_2130.tcf	V3_BR_TIL005_Post_v05.tgc, V3_BR_TIL005_Post_v04.tbc, Tilbury.tmf
BR_TIL005_Pre_1000YR_2030	TIL005_1000YR2030.dat	BR_TIL005_Pre_1000YR_2030.ief	BR_TIL005_Pre_1000YR_2030.tcf	BR_TIL005_Post_v05.tgc, BR_TIL005_Post_v04.tbc, Tilbury.tmf
BR_TIL005_Pre_1000YR_2130	TIL005_1000YR2130.dat	BR_TIL005_Pre_1000YR_2130.ief	BR_TIL005_Pre_1000YR_2130.tcf	BR_TIL005_Post_v05.tgc, BR_TIL005_Post_v04.tbc, Tilbury.tmf
BR_TIL005_Pre_200YR_2030	TIL005_200YR2030.dat	BR_TIL005_Pre_200YR_2030.ief	BR_TIL005_Pre_200YR_2030.tcf	BR_TIL005_Post_v05.tgc, BR_TIL005_Post_v04.tbc, Tilbury.tmf
BR_TIL005_Pre_200YR_2130	TIL005_200YR2130.dat	BR_TIL005_Pre_200YR_2130.ief	BR_TIL005_Pre_200YR_2130.tcf	BR_TIL005_Post_v05.tgc, BR_TIL005_Post_v04.tbc, Tilbury.tmf

Table E.15 TIL006 Breach Model Files (200yrs, 1,000yrs)

Scenario	1D DAT (1D model file name)	IEF (Model simulation file name)	TCF (2D model control file name)	TGC/TBC/TMF (2D model file names of model geometry control file, boundary control file and material file)
V3_BR_TIL006_Post_1000YR_2030	TIL006_1000YR2030.dat	V3_BR_TIL006_Post_1000YR_2030.ief	V3_BR_TIL006_Post_1000YR_2030.tcf	V3_BR_TIL006_Post_v05.tgc, V3_BR_TIL006_Post_v04.tbc, Tilbury.tmf
V3_BR_TIL006_Post_1000YR_2130	TIL006_1000YR2130.dat	V3_BR_TIL006_Post_1000YR_2130.ief	V3_BR_TIL006_Post_1000YR_2130.tcf	V3_BR_TIL006_Post_v05.tgc, V3_BR_TIL006_Post_v04.tbc, Tilbury.tmf
V3_BR_TIL006_Post_200YR_2030	TIL006_200YR2030.dat	V3_BR_TIL006_Post_200YR_2030.ief	V3_BR_TIL006_Post_200YR_2030.tcf	V3_BR_TIL006_Post_v05.tgc, V3_BR_TIL006_Post_v04.tbc, Tilbury.tmf
V3_BR_TIL006_Post_200YR_2130	TIL006_200YR2130.dat	V3_BR_TIL006_Post_200YR_2130.ief	V3_BR_TIL006_Post_200YR_2130.tcf	V3_BR_TIL006_Post_v05.tgc, V3_BR_TIL006_Post_v04.tbc, Tilbury.tmf
BR_TIL006_Pre_1000YR_2030	TIL006_1000YR2030.dat	BR_TIL006_Pre_1000YR_2030.ief	BR_TIL006_Pre_1000YR_2030.tcf	BR_TIL006_Post_v05.tgc, BR_TIL006_Post_v04.tbc, Tilbury.tmf
BR_TIL006_Pre_1000YR_2130	TIL006_1000YR2130.dat	BR_TIL006_Pre_1000YR_2130.ief	BR_TIL006_Pre_1000YR_2130.tcf	BR_TIL006_Post_v05.tgc, BR_TIL006_Post_v04.tbc, Tilbury.tmf
BR_TIL006_Pre_200YR_2030	TIL006_200YR2030.dat	BR_TIL006_Pre_200YR_2030.ief	BR_TIL006_Pre_200YR_2030.tcf	BR_TIL006_Post_v05.tgc, BR_TIL006_Post_v04.tbc, Tilbury.tmf
BR_TIL006_Pre_200YR_2130	TIL006_200YR2130.dat	BR_TIL006_Pre_200YR_2130.ief	BR_TIL006_Pre_200YR_2130.tcf	BR_TIL006_Post_v05.tgc, BR_TIL006_Post_v04.tbc, Tilbury.tmf

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