

TECHNICAL NOTE

JBA Project Code	2022s1459
Contract	Northfleet Flood Modelling
Client	RMA Environmental Ltd
Date	05/09/2023
Author	Paul Redbourne BSc, PGCert, MCIWEM, C.WEM
Reviewer / Sign-off	Jenni Essex BSc MSc PhD CEnv MCIWEM C.WEM
Subject	Northfleet Flood Modelling Technical Note

1 Introduction

1.1 Terms of reference

JBA Consulting (JBA) was commissioned by RMA Environmental Ltd to undertake a hydraulic modelling study of the River Ebbsfleet in Northfleet, Gravesham. A mixed-use development is being proposed consisting of residential units, businesses, and replacement of the Ebbsfleet football stadium. During pre-application consultation, the Environment Agency raised concerns with the current understanding of fluvial flood risk in the study area. It was recommended that a new flood modelling exercise was undertaken to provide an improved understanding of flood risk for the proposed development.

This technical note has been produced to provide a summary of the flood modelling works that have been completed as well as providing an analysis of the model results. The document also includes discussion on the assumptions and uncertainties that are present within the model.

1.2 Study area

The modelled study area covers the reach of the River Ebbsfleet from Springhead, located immediately to the north of Watling Street, to the confluence with the River Thames at Robins Creek. The location of the proposed site boundary, the model domain and the river network are shown in Figure 1-1.



Figure 1-1: Modelled study area

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2 Model review

The existing hydraulic model of the River Ebbsfleet is a 1D-2D linked ISIS-TUFLOW model developed by Capita URS in 2015. The purpose of that study was to provide updated flood risk mapping for the River Ebbsfleet. This followed on from the original River Ebbsfleet flood model, developed in 2005, which consisted of a 1D-only approach using extended cross-sections to represent the floodplain.

As part of the study for the Northfleet mixed use development, a review of the 2015 hydraulic model was completed. A summary of the findings and recommendations are provided below:

- A 1D-2D linked approach is considered appropriate but the hydraulic modelling software versions are now outdated and any new modelling should be updated to utilise latest available software.
- The downstream boundary used a tide series to represent the potential tide locking mechanism present on the River Thames. Although appropriate, this has used the Highest Astronomical Tide (HAT), rather than the Mean High-Water Spring (MHWS) tide curve which is considered standard practice.
- The model included a simulation for climate change with a 20% uplift applied to the 1% annual exceedance probability (AEP) event. This was appropriate at the time of the previous study, but climate change guidance has since been updated and new uplifts should be applied.
- The HAT tidal boundary was not updated to include an uplift for climate change in the fluvial 1% AEP event plus climate change scenario. When simulating a climate change scenario, climate change should be applied to both the fluvial and tidal boundary conditions.
- New LIDAR data covering the modelled study area was flown in 2018/2019 and therefore it is recommended that this is incorporated into the new River Ebbsfleet model.
- Analysis of the 1D model schematisation identified that improvements could be made to the 1D conveyance plots through the addition of panel markers at river channel sections and embankment markers at structures.
- The representation of structures could be improved, particularly the long culvert that runs through the proposed development site. It is recommended that all structures are updated to more closely align with the river channel survey data that was collected by Maltby Land Surveys Ltd in 2013.
- The 2015 model includes sections originally derived from LIDAR as part of the 2005 study. Analysis of the 2013 river channel survey data showed that these sections are not required and should be removed.
- The 2015 study included a new hydrological assessment. This is now outdated, and a new hydrological assessment is recommended that makes use of best available data, methods, guidance, and software.
- The 2015 modelling study and the Environment Agency pre-application consultation comments highlighted the potential influence of groundwater within the catchment, and that this should be investigated further during this study.

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3 Baseline modelling

3.1 General schematisation

The new hydraulic model of the River Ebbsfleet is a 1D-2D linked Flood Modeller - TUFLOW model. Flood Modeller version 5.0 and TUFLOW version 2023-03-AB have been used for the final design event simulations. A more recent version of the Flood Modeller software has been released since the commission of this study, but the use of v5.0 is considered acceptable and importantly represent a significant improvement to the previous modelling completed in 2015.

The model has adopted a 4m grid resolution for the 2D domain. This is the same resolution as the existing model and is considered to provide an acceptable balance between the representation of floodplain features and managing acceptable run times. Given the 4m resolution, a 2D timestep of 2s has been adopted, along with a 1D timestep of 1s, which aligns with industry best practice.

3.2 1D domain

The 1D open channel and structure geometry has been reviewed and updated to improve the 1D model performance, the representation of channel and structure geometry, and in-channel conveyance. The 2015 model schematisation was reviewed against the 2013 river channel survey data collected specifically for that study. Where required the 1D open channel and structure geometry has been updated to be more representative of the surveyed cross-sections. The 2013 river channel survey is provided in Appendix B.

The existing 2015 model contained sections derived from LiDAR data and site measurements based on the 2005 model, which were applied alongside cross-sections based on the 2013 survey. Upstream of the outfall to Robins Creek any sections based on the 2005 model have been removed and the channel geometry has been defined based on the 2013 river channel survey data only.

The representation of the wetland area upstream of the A226 Thames Way Road (between model nodes 1.024 and 1.019) has been improved as the 2015 model was inconsistent in its approach. This wetland reach is now represented with more consistent channel widths within the 1D domain. Within this wetland area some of the surveyed cross-sections were extended based on more recent LiDAR data from the 1m EA 2022 composite DTM. In addition, two cross-sections (1.020_u2, 1.020_u1) based on the 1m EA 2022 composite DTM, with modifications to represent extrapolated channel bed levels, were included to account for a notable change in width that would otherwise not have been accounted for in the surveyed sections.

Other updates to the model 1D domain have included:

- the addition or alteration of panel/embankment markers to improve 1D conveyance,
- updates to the top of bank deactivation locations to improve the 1D-2D linkage interaction,
- corrections to chainages and skew angles to better match the 2013 survey data, and
- the addition of interpolate sections to provide a more stable and reliable set of model outputs.

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Table 3-1 outlines the structures included within the model. It should be noted that the Springhead Park Bridge which would be located at approximately 1.022 and the railway bridge located just downstream of model node 1.016 were not included within the 2013 survey and therefore could not be represented. These omissions are discussed further within the model assumptions and limitations in Section 6.

Pipe crossings which were considered unlikely to have a significant impact on flow within the channel and have also not been represented within the 1D model.

Table 3-1 Model structures

Structure ID / Comments	Photograph
1.029_Bu Modelled as a USBPR bridge unit. US Invert level = 3.17mAOD Soffit level = 5.11mAOD Overtopping modelled in the 1D domain with a separate spill unit.	
1.024_Bu Modelled as a USBPR bridge unit. US Invert level = 1.321mAOD Soffit level = 4.725mAOD Overtopping modelled in the 2D domain with a separate bridge 2D zshape to represent the bridge deck elevation.	

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1.019C1_1 & 1.019C2_1

Modelled as twin rectangular conduit units.

Left opening

US Invert level = 1.34mAOD

Soffit level = 2.57mAOD

Right opening

US Invert level = 1.34mAOD

Soffit level = 2.57mAOD

A roughness of 0.015 has been used.

Overtopping modelled in the 2D domain with the base LIDAR used to set to the bridge deck elevation.

An orifice unit has been used to represent the circular flood relief culvert present at this structure.



1.018C1_1 & 1.018C2_1

Modelled as twin rectangular conduit units.

Left opening

US Invert level = 1.27mAOD

Soffit level = 2.54mAOD

Right opening

US Invert level = 1.23mAOD

Soffit level = 2.54mAOD

A roughness of 0.015 has been used.

Overtopping modelled in the 2D domain with the base LIDAR used to set to the bridge deck elevation and separate 2D Z-Shape lines used to set overtopping levels based on 2013 survey.



1.015C2_1 & 1.015C3_1

Modelled as twin rectangular conduit units.

Left opening

US Invert level = 1.27mAOD

Soffit level = 2.54mAOD

Right opening

US Invert level = 1.23mAOD

Soffit level = 2.54mAOD

A roughness of 0.015 has been used.

Overtopping modelled in the 2D domain with the base LIDAR used to set to the bridge deck elevation and separate 2D Z-Shape lines used to set overtopping levels based on 2013 survey.



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1.012Bu & 1.012Su

Modelled as a USBPR bridge unit.
US Invert level = 1.439mAOD
Soffit level = 2.830mAOD
Overtopping modelled in the 1D domain with a spill unit used to represent the bridge deck elevations. A weir coefficient of 1.2 was applied.



1.009Bu, 1.009_Su, 1.009C1_u, 1.009C3_u,

Modelled as a USBPR bridge unit with two high level flood relief culverts modelled as orifice units. Weir located close to (within) the downstream portion of the culvert represented by a spill unit.

Left opening (orifice unit)

US Invert level = 2.280mAOD
Soffit level = 3.180mAOD

Central opening (USBPR unit)

US Invert level = 1.151mAOD
Soffit level = 2.830mAOD

Right opening (orifice unit)

US Invert level = 2.180mAOD
Soffit level = 3.080mAOD

Overtopping modelled in the 2D domain with the base LIDAR used to set to the bridge deck elevation and separate 2D Z-Shape lines used to set overtopping levels based on 2013 survey.

Upstream face



Downstream face



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LngClv2, to LngClv3

Modelled as consecutive circular conduit units with invert levels and diameters based on the 2013 survey long section which appears to be based on cover lifting undertaken as part of that survey. This is considered an improvement over the representation in the 2015 model which assumed a constant gradient within the culvert.

Replicates were included throughout the conduit sections, at approximately 50m intervals, to aid model stability.

LngClv2

US Invert level = 0.750mAOD

Soffit level = 2.460mAOD

LngClv2b

US Invert level = 0.980mAOD

Soffit level = 2.430mAOD

LngClv2d

US Invert level = 0.630mAOD

Soffit level = 2.400mAOD

LngClv2f

US Invert level = 0.660mAOD

Soffit level = 2.236mAOD

LngClv3

US Invert level = 0.710mAOD

Soffit level = 2.210mAOD

Overtopping modelled in the 2D domain with the base LIDAR used to set to the bridge deck elevation and separate 2D Z-Shape lines used to set overtopping levels based on 2013 survey.



1.005C_1, 1.005C_2 (and associated spill unit)

The main barrel of the culvert has been approximately represented with two irregular conduit units based on measurements from the 2013 survey. The complex outflow arrangement to Robins Creek could not be represented based on the available survey data and a spill unit has been used to drop water levels into Robins Creek. The main barrel of the culvert

Upstream face

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represents the smallest opening area in the outflow structure and has been represented within the conduit units.

Overtopping modelled in the 2D domain with the base LIDAR used to set to the bridge deck elevation and separate 2D Z-Shape lines used to set overtopping levels based on 2013 survey.



Downstream face



Upstream face

OUT1 to CHAMB2

Tidal outfall structure unchanged, tidal flood wall across Robins Creek represented as per the 2015 model.

Consideration was given to re-schematising the representation of Robins Creek and the tidal outfall structure. However, a review of

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the hydraulic model found that the approach taken was broadly acceptable and there was little benefit to altering this reach of the model.



Intermediate chamber



Downstream face



3.3 Boundary conditions

3.3.1 Model inflows

The review of the 2015 River Ebbsfleet flood modelling identified that a new hydrological assessment should be completed to make best use of the latest available software, guidance, and methods, and to utilise any available hydrometric data.

The previous modelling adopted a joint fluvial / groundwater approach due to the chalk geology of the upper catchment. The Environment Agency highlighted as part of the pre-application consultation that there is an uncertainty with the application of groundwater inputs, and these should be considered further as part of any new assessment.

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The previous study included a detailed groundwater analysis which was undertaken to derive a suitable baseflow boundary for application to the hydraulic model. A groundwater level of 4.3mAOD was found to have an annual probability of 0.025 and represents the upper 95% confidence interval. The 4.3mAOD groundwater level was applied to the model as a time invariant level using a head-time boundary (HTBDY) and a Bernoulli loss unit. Consideration was given to applying a groundwater level and Bernoulli loss unit as per the previous study, updating the analysis to use the latest data. However, findings from the current study concluded that this is not recommended, and instead a fluvial only approach has been adopted. The FEH Calculation Record provided in Appendix A provides a detailed breakdown of the limitations; a summary is provided below.

- There is no clear justification within the 2015 report for the approach used to generate the groundwater input and how this benefits the study.
- There is uncertainty regarding the location of the borehole used in the previous study. Regardless of this the location of the borehole is not at the location where the groundwater level is applied to the model and converted to flow (upstream model extent). This means that there cannot be confidence that the level being applied to the model is representative of the actual groundwater level at the upstream model extent.
- There are large variations in peak levels at the boreholes, both between the two assessed for this study, and the values for the borehole used in the previous study. This is likely to be dependent on hydraulic connectivity, which may also be influenced by Sawyer's Lake.
- There will be uncertainty in the way in which the Bernoulli loss unit converts level to flow. This will not account for the spatial variation in groundwater level, so flow is very dependent on which borehole is used for the analysis.
- An arbitrary choice of design event to use for groundwater input appears to have been made. The input flow does not change with design event / return period.
- It is believed that there is no information on groundwater flow for this area and there is no river flow data against which to compare the groundwater response. This means that the flow generated from groundwater level is highly uncertain as there is no data to verify it against.
- This type of analysis is not something that is generally undertaken for fluvial modelling studies and there are many other catchments like this in terms of groundwater dominance for which this type of analysis has not been carried out. If groundwater analysis had not been applied in the past it is highly unlikely that it would be requested for this catchment now.

It was concluded that adoption of standard FEH methods (FEH Statistical and ReFH2) was appropriate for this study. Both approaches have been assessed to calculate peak flow estimates with the recommendation to adopt the ReFH2 peak flow estimates and hydrographs for the final design event simulations. Analysis has shown that for the 1% AEP event, the Statistical and ReFH2 peak flow estimates are very similar whereas ReFH2 has much smaller flows for the more frequent design events and higher flows for the larger, less frequent design events. Given the uncertainty surrounding this catchment due to the lack of hydrometric data, and the focus of the study on the more extreme events (1% and 0.1% AEP), it was decided to adopt a more conservative

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approach and use the higher flows produced by the ReFH2 method. The full analysis and justification of the hydrological assessment can be found in Appendix A.

Climate change has been applied to the 1% AEP event with uplifts of 27%, 37%, and 62% applied. These have been taken from the Environment Agency peak river flow map for the Medway Management Catchment for the central, higher, and upper 2080's climate change projections.

3.3.2 Storm duration testing

Storm duration testing has been completed to determine the critical storm duration, resulting in the largest flood extent and highest water levels throughout the modelled study area. Storm durations of 15-hour, 23-hour, and 31-hour were used for this testing. Figure 3-1 shows the TUFLOW MaxMax output, identifying which duration resulted in the highest water levels throughout the model extent.

The 31-hour duration produced the largest flood extent and the highest water levels and therefore this has been adopted for the final design event simulations. For the storm duration testing, the application of the tidal boundary has been included as the potential for tide locking is critical for understanding the flood mechanism impacting the study area.

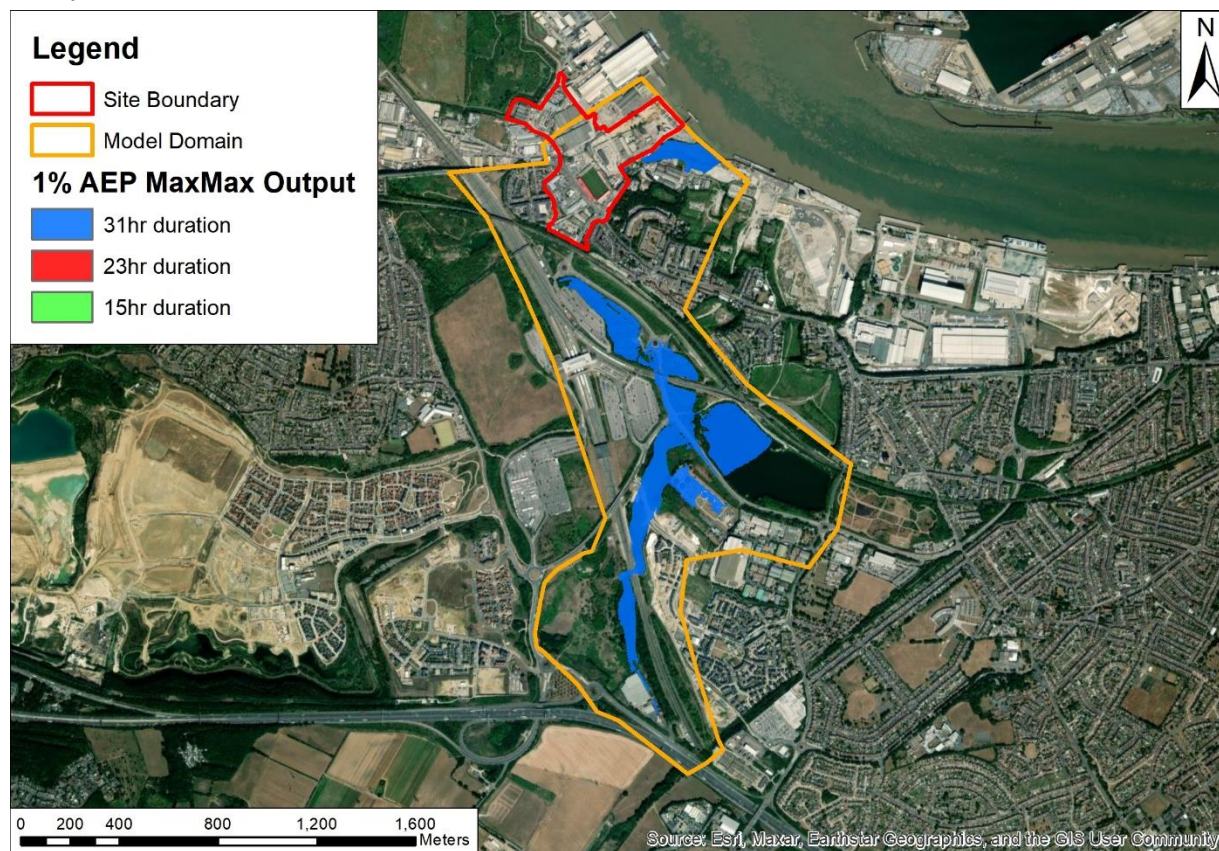


Figure 3-1: Maximum water level storm duration testing

3.3.3 Tidal boundary conditions

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The existing 1D HT tidal downstream boundary (HAT) was replaced with a MHWS curve for Tilbury from the ADMIRALTY TotalTide software, which was smoothed and adjusted from Chart Datum to Ordnance Datum (-3.12) as per industry standard practice.

When applied to the model, the timing of the MHWS curve was adjusted by 58.75 hours so that the tidal peak aligned with the peak of the main fluvial inflow (EBB04) at 27 hours. Over the first tidal cycle water levels have also been adjusted so that they ramp up from the initial water level at the downstream end of the model (-2.62m AOD) into the tidal cycle to aid model stability at the start of the simulations.

To account for the impact of sea level rise during climate change scenarios, the MHWS levels were uplifted by 1.078m (Higher Central allowance) based on the Environment Agency's guidance on Flood risk assessments: climate change allowances. Table 3-2 shows the peak tide levels applied at the downstream boundary for the present day and climate change simulations.

Table 3-2 MHWS peak water levels

MHWS peak water level (mAOD)	MHWS peak water level (mAOD) with Higher Central allowance
3.280	4.358

3.4 2D domain

3.4.1 Topography

Review of the 2015 model indicated new LiDAR of the study area was flown 2018-2019. The base model topography was therefore updated based on the Environment Agency 2022 1m LiDAR DTM Composite which included this updated LiDAR dataset.

3.4.2 2D roughness

Consideration was given to updating the representation of the 2D roughness coefficients. However, a review of the 2015 model found that the 2D roughness representation, based on OS Master Map, was suitable for the purposes of the current study and was therefore maintained unaltered.

3.4.3 1D-2D linkage

The 1D-2D linkages across the model were updated to align with the updates to open channel cross-sections and deactivation markers in the 1D domain. Bank heights across the 1D-2D linkages are defined from the base model LiDAR topography.

3.5 Baseline model results

The updated baseline scenario has been simulated for a range of design events including the 3.33%, 1%, and 0.1% AEP present day events and the 1% AEP event plus climate change with uplifts of 27%, 37%, and 62% to represent the Medway Management Catchment peak river flow allowances.

This section of the report shows the modelled flood depth outputs for the 3.33%, 1%, 1% +27% climate change, and 0.1% AEP events. These are shown in Figure 3-2 to

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Figure 3-5, with the additional design events provided as part of the packaged model deliverables contained in Appendix D. The new flood modelling indicates that there is currently no fluvial flood risk to the site in any design event. The reason there is no flooding to the site is due to the location of the raised road embankments located upstream of the long culvert. Water is stored upstream of the A226 road embankment and is prevented from flowing northwards to the site.

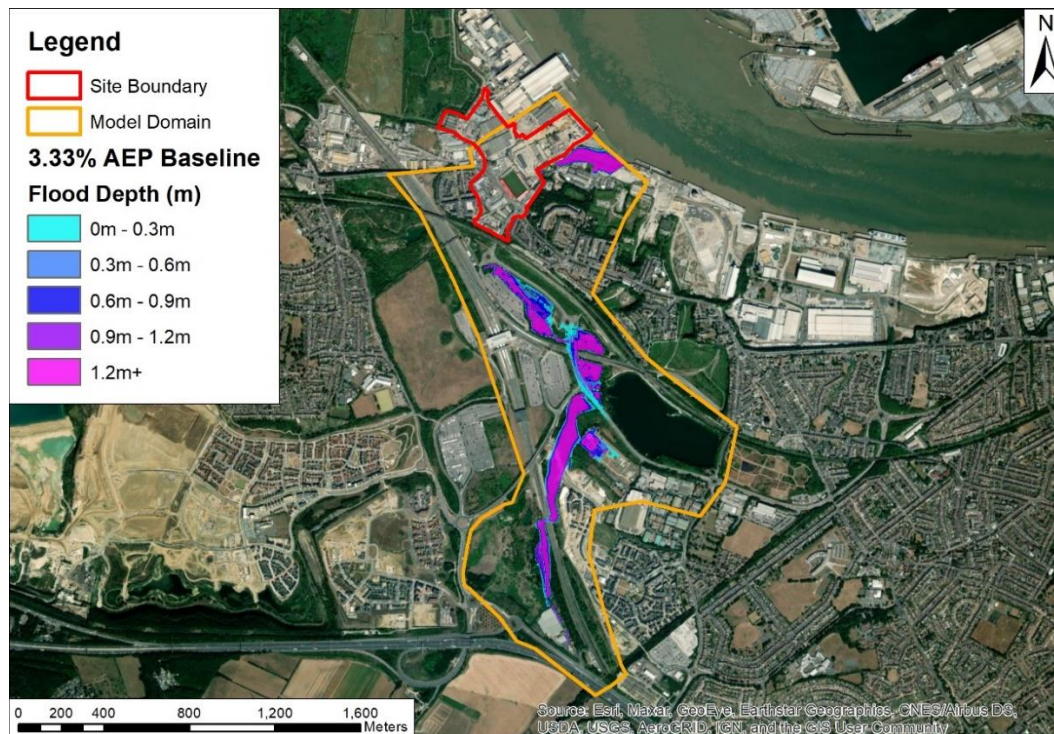


Figure 3-2: 3.33% AEP event baseline flood depth

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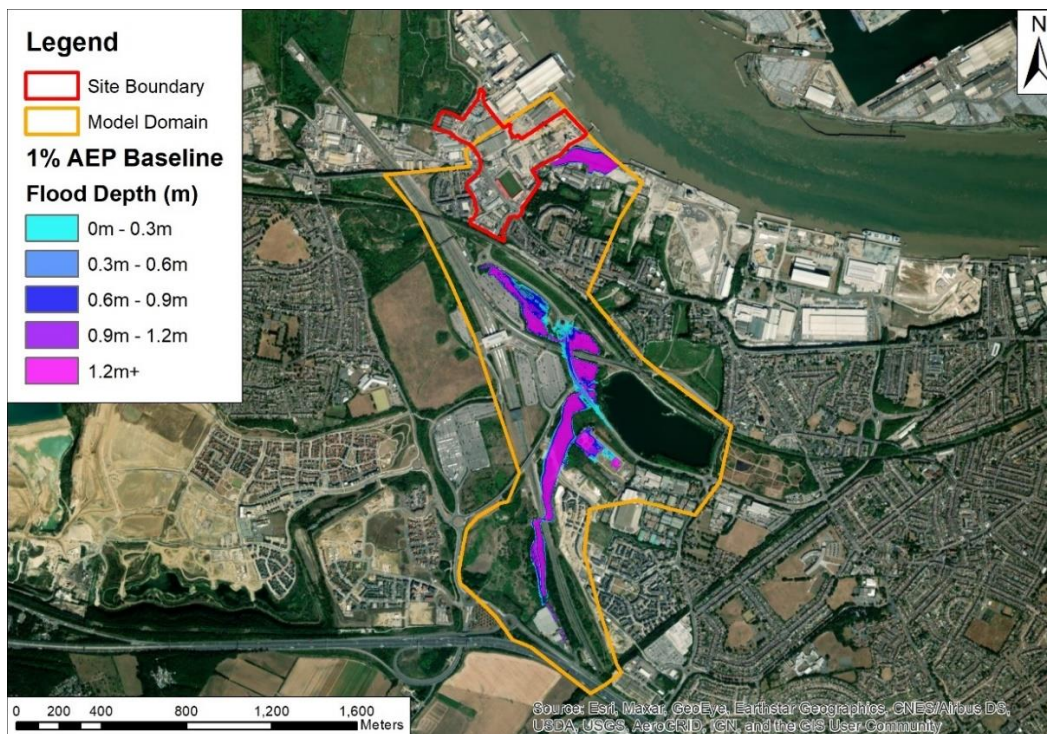


Figure 3-3: 1% AEP event baseline flood depth

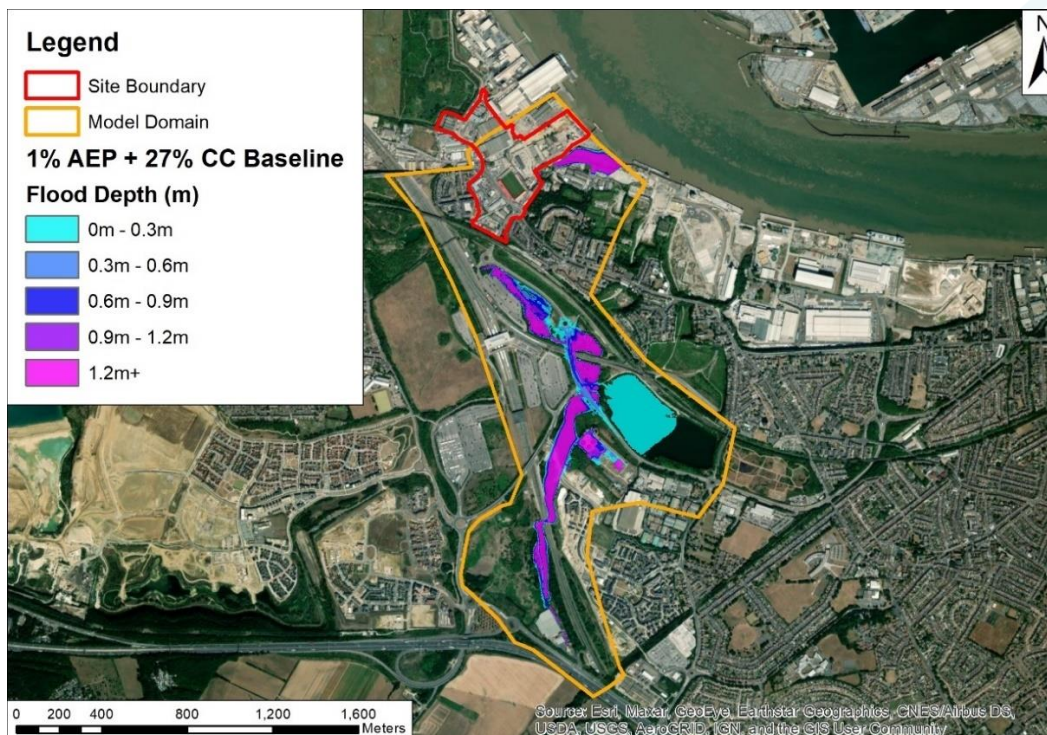


Figure 3-4: 1% AEP event plus climate change (27%) baseline flood depth

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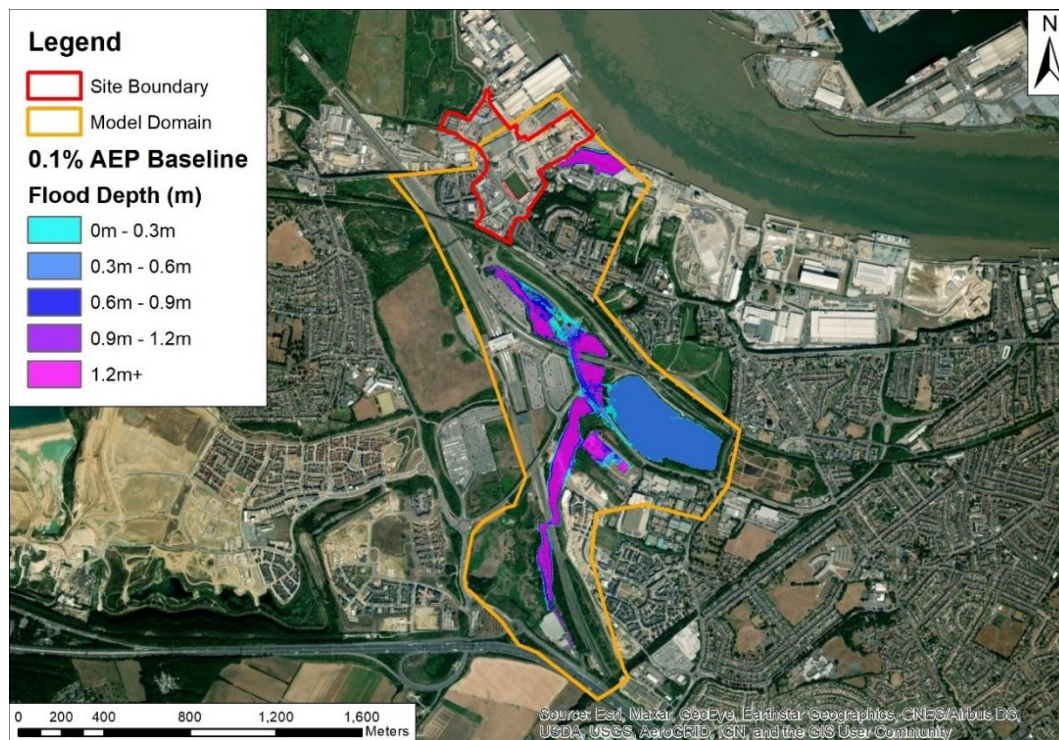


Figure 3-5: 0.1% AEP event baseline flood depth

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4 Culvert daylighting

The Environment Agency response during the pre-application consultation noted that the development is an opportunity to de-culvert and naturalise the river channel, providing environmental enhancement to the site. Therefore, an outline design of daylighting the existing culvert has been developed and this has been tested within the hydraulic model to understand the potential fluvial flood risk constraints.

HLM Architects has produced a concept design showing the location of the proposed daylighted reach along with indicative channel cross-sections so that the channel could be tested within the hydraulic model. The location of the proposed daylighted reach is between Grove Road and the new football stadium, and will consist of an approximate length of 140m. The location of the daylighted reach is shown in Figure 4-1 and is also included in Appendix E along with the channel cross-section profiles.

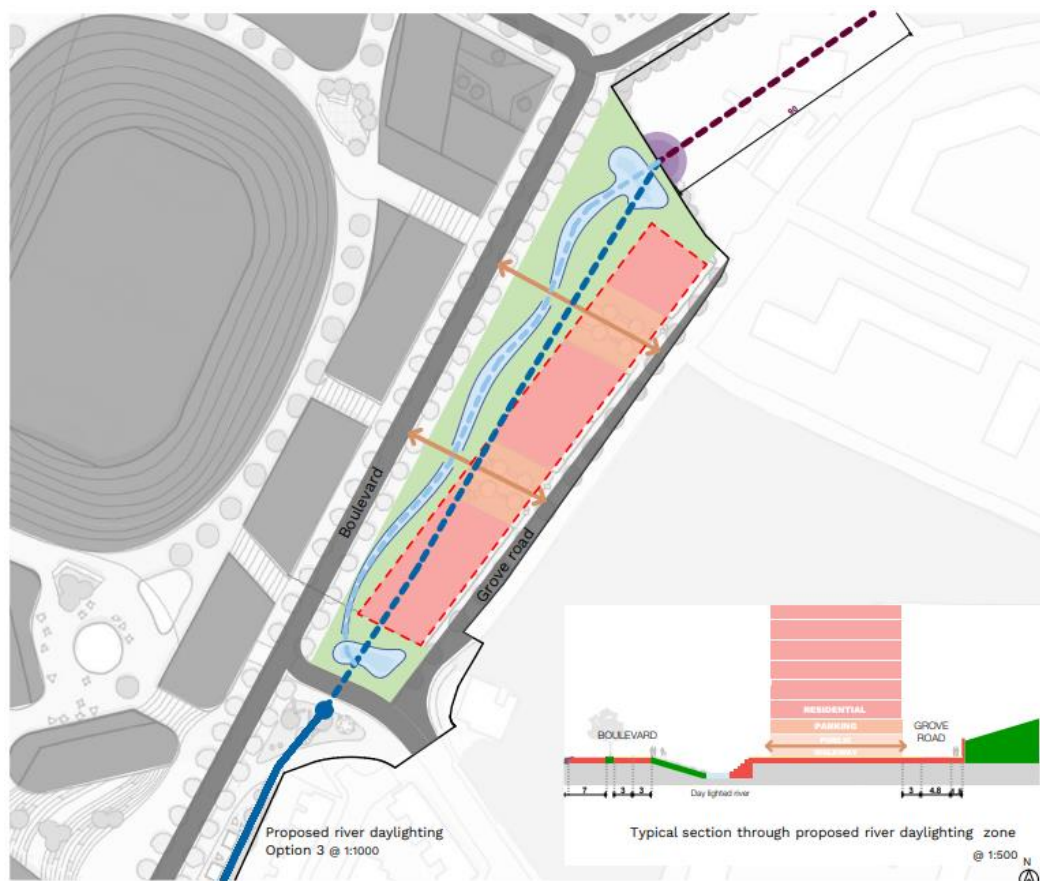


Figure 4-1: Daylighted reach

To represent the daylighted reach as accurately as possible, a 1D-2D linked approach has been adopted with the long culvert cut down and new open channel river sections added into Flood Modeller. In the event of the channel capacity being exceeded, the 1D reach has been linked to TUFLOW to allow spilling into the floodplain with HX boundary conditions applied along the right and left bank locations and along the upstream and downstream faces at the entry and exit of the daylighted reach. Figure 4-2 shows the

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location of the open channel sections and section C-C has been shown in Figure 4-3 for reference.



Figure 4-2: Daylighted channel section locations

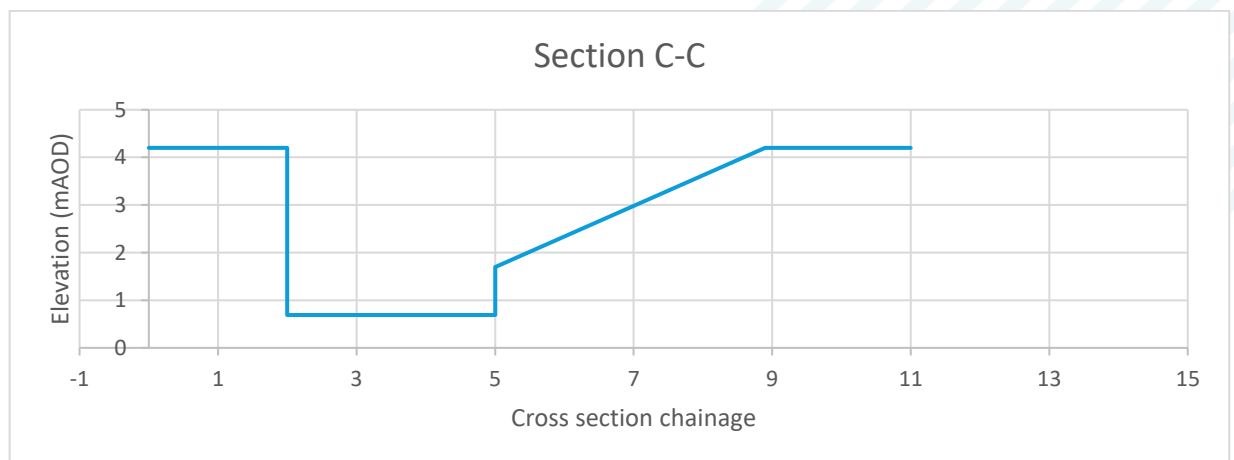


Figure 4-3: Section C-C cross section

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For the representation of the open channel sections in the 1D domain, each channel section has been represented using a Flood Modeller river channel section unit. A consistent approach to the Manning's n roughness coefficients has been adopted with a bed roughness of 0.035 and a bank roughness of 0.05. The exact bed and bank material will need to be confirmed but these values were chosen to reflect a more naturalised river channel as requested by the Environment Agency.

For the 2D domain, the watercourse has been positioned approximately aligned with the PDF design drawing shown in Figure 4-1. The exact location is not considered as important as correctly representing the channel capacity and the top of bank spilling elevations. Figure 4-4 shows the location of the channel as represented within TUFLOW with the node references provided and the bank elevations included. The bank elevations have been specified using a 2D z-line with the elevations matching the top of bank heights specified in the Flood Modeller 1D domain.

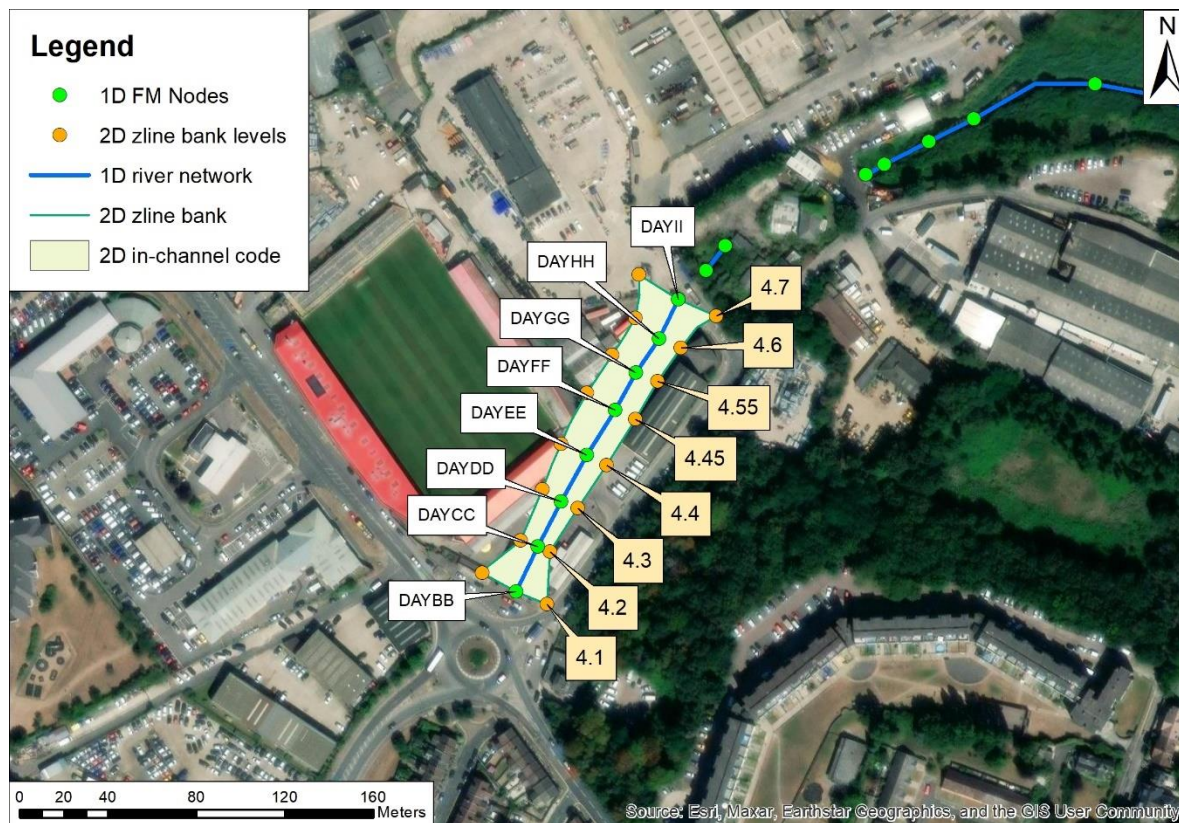


Figure 4-4: Daylighted channel TUFLOW schematisation

Analysis of the model outputs has shown that no spilling will occur from the proposed daylighted channel in any of the design event simulations. This is shown in Figure 4-5 which shows the maximum flood depth outputs for the 0.1% AEP event. All floodwater is contained within channel for all design event simulations. The full suite of events has been provided as part of the packaged model deliverables and can be found in Appendix D.

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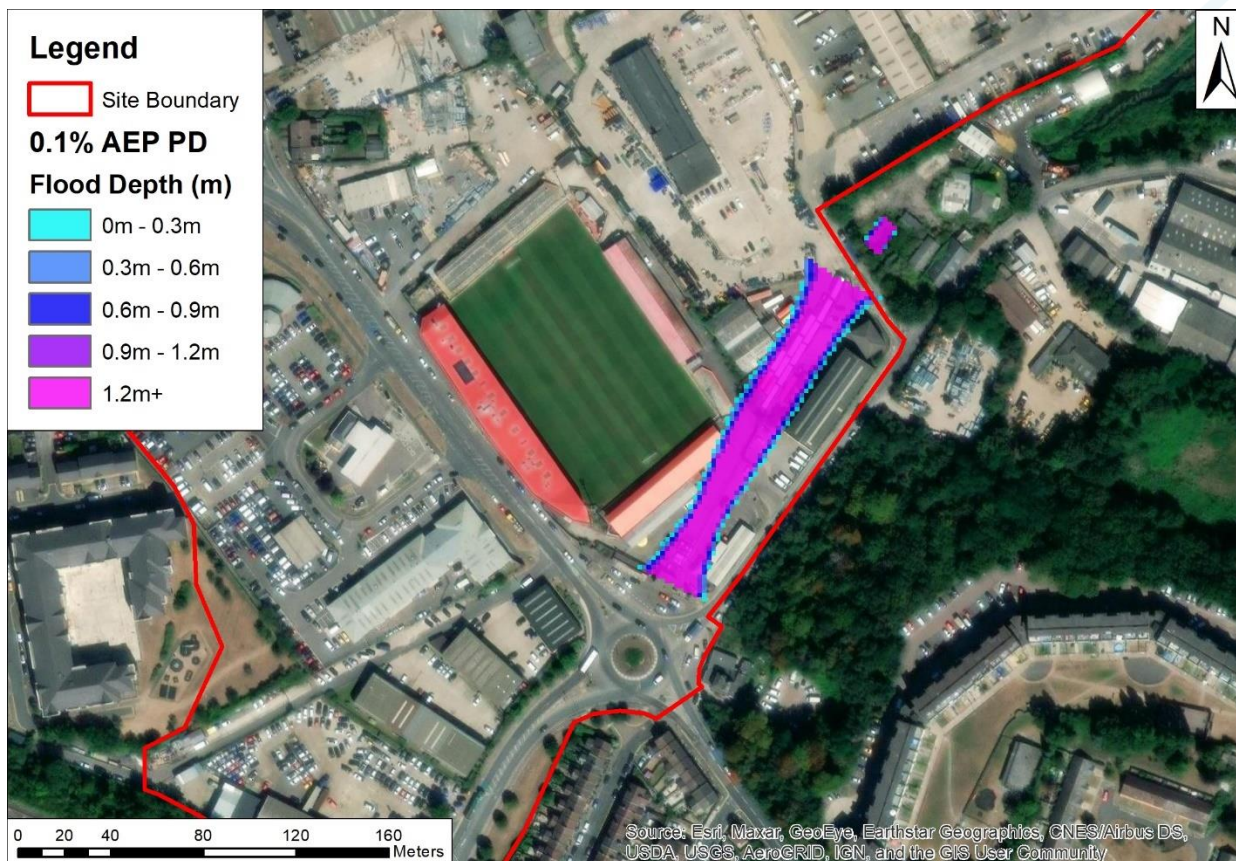


Figure 4-5: Daylighted 0.1% AEP event flood depth

To further demonstrate that spilling will not occur in any of the modelled design events, the maximum water level from the daylighted reach at section B-B has been tabulated and is shown in Table 4-1. This location has been chosen for comparison as it has the lowest top of bank elevations and is therefore most susceptible to out of bank flooding. The bank heights at this location have been set to 4.1mAOD which is well above the maximum modelled water levels shown in Table 4-1.

Table 4-1: Table of maximum water levels within daylighted reach

Design Event AEP	Maximum Water Level (mAOD)
3.33%	3.56
1%	3.57
1% plus climate change (27%)	3.61
1% plus climate change (37%)	3.62
1% plus climate change (62%)	3.64
0.1%	3.62

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5 Robins Creek managed realignment

The 2015 flood modelling included a scenario called 'managed realignment'. This removed the tidal wall separating Robins Creek from the River Thames to allow tidal ingress and installation of a tide flap on the long culvert to prevent the tide backing-up the structure. The Environment Agency requested that this scenario was tested as part of the current modelling study to understand any potential implications for the daylighted reach of channel.

The approach taken in the 2015 study has been reviewed and found to be suitable. This approach has been retained for the current study with the Robins Creek channel sections removed, the tidal wall and outlet structure to the River Thames removed, and two orifice units added at the downstream extent of the culvert that outfalls into Robins Creek. One of the orifice units is flapped representing the flapped outfall that would need to be constructed to prevent the ingress of the tide upstream and the other orifice unit was incorporated to aid with model stability and allow a small amount of backflow.

For the managed realignment scenario, the tidal boundary conditions have been updated so that the tide series starts at 1.3mAOD and continues at this level until it aligns with the natural tide cycle. This has been done to help model stability at the start of the model simulation. For the climate change scenarios, an additional stability measure has been included whereby the bridge unit 1.009Bu which is located at Thames Way (A226) has been modelled with orifice mode enacted. This approach is considered acceptable given the high depths of water being impounded behind the A226 road embankment.

The management realignment results in an increase in water levels through the daylighted reach but, importantly, it does not result in any out of bank flooding in any design event or climate change scenario. Table 5-1 shows the maximum water levels at daylighted section B-B for the managed realignment scenario. This can be directly compared to Table 4-1 and, although the water levels increase, they are not sufficient to cause out of bank flooding.

Table 5-1: Table of maximum water levels within daylighted reach in managed realignment scenario

Design Event AEP	Maximum Water Level (mAOD)
3.33%	3.70
1%	3.71
1% plus climate change (27%)	3.80
1% plus climate change (37%)	3.81
1% plus climate change (62%)	3.82
0.1%	3.76

The modelled flood depth map for the 0.1% AEP event for the managed realignment scenario is shown in Figure 5-1 which indicates that there is no out of bank flooding in this model scenario.

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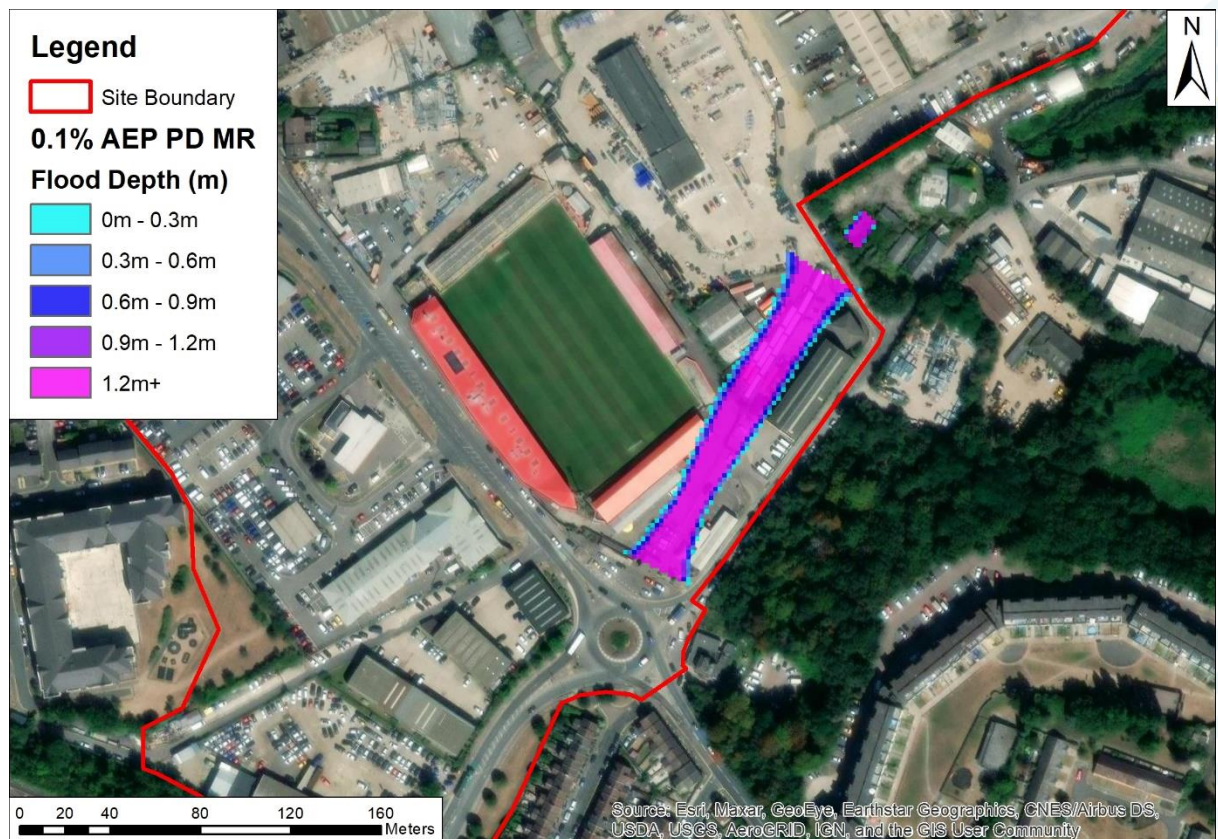


Figure 5-1: 0.1% AEP event daylighted managed realignment scenario flood depth

6 Assumptions, limitations, and uncertainties

6.1 Summary of key assumptions, limitations and uncertainties

Developing a hydraulic model requires the application of simplifications and generalisations. As such, several assumptions were made when building the model. This can lead to model uncertainties and subsequent limitations in the results. Some of the key assumptions, limitations, and uncertainties specific to this study are listed below:

- Hydrology
 - The level / flow gauge located at the entrance to the long culvert is closed and the data is not useful to this study (based on the 2015 study assessment).
 - There is no benefit to continued use of the groundwater level input at the upstream model extent (and conversion to flow in the model) due to numerous limitations to this approach. A fluvial inflow applied to the upstream model extent, varying with design event, is reasonable and no more uncertain than the previous approach.
 - There is insufficient confidence in local gauges being representative for QMED (median annual maximum flood) data transfer. Catchment descriptor estimates are most appropriate due to this.

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- One pooling group to represent growth curves at all locations is appropriate.
- ReFH2 generates a reasonable hydrograph for EBB03 despite any influence of Sawyer's Lake not being accounted for by this method as the watercourse and lake are not included within the hydraulic model.
- The main limitation is the lack of a flow gauge on the study watercourse with which to improve and check the derived estimates. There is no level gauge against which modelled levels could be compared. Lack of detailed flood history information also limits the ability to verify the hydraulic model results based on the derived model inflows.
- Two bridges across the watercourse could not be represented within the model as they were not surveyed as part of the 2013 survey dataset.
 - Springhead Park Bridge which appears to have been constructed after the 2013 survey and 2015 model were completed.
 - The railway bridge across Thames Way and the River Ebbsfleet located between Ebbsfleet International and Sawyers Lake.

In both cases, examination of available LiDAR data, photographs and aerial imagery indicates both bridge decks are likely to be located at much higher elevations than the watercourse and it has therefore been assumed that the bridge soffit levels are likely to have minimal impact on water levels in the modelled events. This could not however be confirmed and the omission of these structures from the model has been noted here as a limitation.

- Internal survey of the long culvert that it is proposed to partially daylight was not available. The path, connectivity and any changes in shape or dimensions are therefore unconfirmed and may not be fully accounted for within the model. The culvert representation has however been improved from the 2015 model as it makes use of the available invert level survey data from cover lifting undertaken as part of the 2013 survey. Topographical survey was collected in 2023 by Reed Geomatics which including lifting the manhole covers of the long culvert. Cover level and silted bed level were collected and, although this information was not used directly within the model, it has been used to sense check the 2013 survey which provides added confidence in its use. The 2023 topographical survey data can be found in Appendix C.
- A second outfall to Robin's Creek was identified from survey photographs close to the outfall of the long culvert. The connectivity and path of this additional connection to Robins Creek could not be confirmed based on the available survey data and may require further investigation as part of any detailed design stage.
- Some oscillations in 1D water levels occur around model node 1.011 iii in some events. This appears to be linked to circulating flow in the 2D domain that re-enters the 1D domain. Attempts have been made to address this using interpolate sections, but the topography is very low-lying and the schematisation of the 1D-2D linkage at this section should be considered a limitation.
- No 2D negative depths occur which indicates a reasonable degree of stability in the 2D domain. The peak cumulative mass error is, however, outside the recommended range of $\pm 1\%$ in the 1% and 0.1% AEP events, and the 1% AEP event plus climate change scenario, at around -2% to -2.75% and occurs through the flood peak. This

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high mass error appears to result from recirculation in the 2D domain within the very confined and relatively low elevation area around the Thames Way Road Bridge at model node 1.015. A realignment of grid orientation, addition of interpolate sections and HX energy loss A Flag of 0.5 were applied which reduced the impact of this issue, which was causing model failure, but could not be fully resolved.

- The combination of the tidal outfall arrangement and tidal boundary conditions result in the watercourse being tidally locked through most of the event length, with only short periods where water is able to drain from the outfall. As a result, water levels drain very slowly through the simulation; however, the use of the relatively long 31-hour storm duration and 96hr event simulation allows for this mechanism to be represented.

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7 Model runs

7.1 Baseline scenario

Run reference	Baseline - EBB1_~e1~_~s1~_047
Purpose of runs:	Baseline scenario to model the 3.33%, 1%, 1% plus climate change (27%, 37%, & 62%) and 0.1% AEP events
TUFLOW file names:	EBB1_~e1~_~s1~_047.tcf EBB_BSL_047.tgc EBB_BSL_047.tbc
Run time:	Simulation time: 96 hours
Flood Modeller file names:	EBB1_1s_2D_JPgW_047BL.DAT EBB1_ReFH2_XX_31hr_MHWS_038.ied EBB1_ReFH2_0030_31hr_MHWS_047BL.ief
Run settings:	TUFLOW version: 2023-03-AB-iSP-w64 Flood Modeller version: VER=5.0.0.7752

7.2 Daylighted post-development scenario

Run reference	Daylighted PD - EBB1_~e1~_~s1~_049_PD1
Purpose of runs:	Daylighted scenario to model the 3.33%, 1%, 1% plus climate change (27%, 37%, & 62%) and 0.1% AEP events
TUFLOW file names:	EBB1_~e1~_~s1~_049_PD1.tcf EBB_PD1_049.tgc EBB_PD1_048.tbc
Run time:	Simulation time: 96 hours
Flood Modeller file names:	EBB1_1s_2D_JPgW_048PD1.DAT EBB1_ReFH2_XX_31hr_MHWS_038.ied EBB1_ReFH2_XX_31hr_MHWS_049PD1.ief
Run settings:	TUFLOW version: 2023-03-AB-iSP-w64 Flood Modeller version: VER=5.0.0.7752

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7.3 Managed realignment scenario

Run reference	Managed Realignment PD - EBB1_~e1~_~s1~_049_PD1_MR
Purpose of runs:	Daylighted scenario to model the 3.33%, 1%, 1% plus climate change (27%, 37%, & 62%) and 0.1% AEP events
TUFLOW file names:	EBB1_~e1~_~s1~_049_PD1_MR.tcf EBB_PD1_049_MR.tgc EBB_PD1_049_MR.tbc
Run time:	Simulation time: 96 hours
Flood Modeller file names:	EBB1_1s_2D_JPgW_049PD1_MR.DAT EBB1_ReFH2_XX_31hr_MHWS_049_MR.ied EBB1_ReFH2_XX_31hr_MHWS_049PD1_MR.ief
Run settings:	TUFLOW version: 2023-03-AB-iSP-w64 Flood Modeller version: VER=5.0.0.7752