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Southend-on-Sea Level 2 SFRA - Tidal and Breach modelling technical note

Draft report

S3 - P01

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This report describes work commissioned by Southend-on-Sea City Council, by an instruction dated 26 May 2026. The Client's representative for the contract was Claire Victory of Southend-on-Sea City Council. Michael Jolley of JBA Consulting carried out this work.

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Abbreviations

1D	One Dimensional (modelling)
2D	Two Dimensional (modelling)
AEP	Annual Exceedance Probability
CFB	Coastal Flood Boundary
DTM	Digital Terrain Model
EA	Environment Agency
ESTRY	One-dimensional solver within TUFLOW (a hydraulic model)
GPU	Graphics Processing Unit
HC	Higher Central
HPC	Heavily Parallelised Computing
LiDAR	Light Detection and Ranging
mAOD	metres Above Ordnance Datum
MHWS	Mean High Water Springs tidal level
SA	Source-Area Boundary
SFRA	Strategic Flood Risk Assessment
ST	Source-Time Boundary
TUFLOW	Two-dimensional Unsteady FLOW (a hydraulic model)
UE	Upper End
UKCP18	United Kingdom Climate Projections 2018

1 Introduction

1.1 Overview

JBA Consulting (JBA) were commissioned by Southend-on-Sea City Council to carry out a Level 2 Strategic Flood Risk Assessment (SFRA) for several sites at risk of tidal flooding across the study area. This technical note describes the coastal modelling undertaken to determine the risk to the sites from extreme water levels and wave overtopping discharges for the present-day (2026) and climate change (2126) epochs.

1.2 General Approach

This study makes use of two existing models to assess the coastal flood risk to the sites. The Environment Agency (EA) 2018 Crouch & Roach and Southend models, both developed by JBA Consulting as part of the Anglian Coastal Modelling project.

Both models are One Dimensional-Two Dimensional (1D-2D) hydrodynamically linked TUFLOW-ESTRY models with defended and undefended configurations. In the undefended scenario, all defences were removed using Triangular Irregular Networks (TINS) within TUFLOW using ground levels at the foot of the raised defence. Both the defended and undefended configurations were used in this study. In addition, three defence breach scenarios were setup and simulated.

The models were updated with a new tidal water level boundary, updated wave overtopping inflows, and new topographic data. The model was simulated for the 3.3%, 0.5%, and 0.1% Annual Exceedance Probability (AEP) tidal events under present day (2026), and future climate change (2126) conditions.

This technical note describes the model updates, data and methodology used.

2 Modelling Approach

2.1 Model domain

The original model domains are shown on Figure 2-1 and stretched from London Gateway Port in the southwest, to the River Blackwater in the northeast.

The Southend model was truncated to only retain the part of the model relevant to the area of interest, from the eastern point of the domain to The Cliffs on the Western Esplanade. Everything to the west of this point was not included as part of this study. The Crouch and Roach model was not truncated as the whole model domain is required to consider the storage of the floodplain. The two models were combined into a single model, and the coastal boundary was modified for stability.

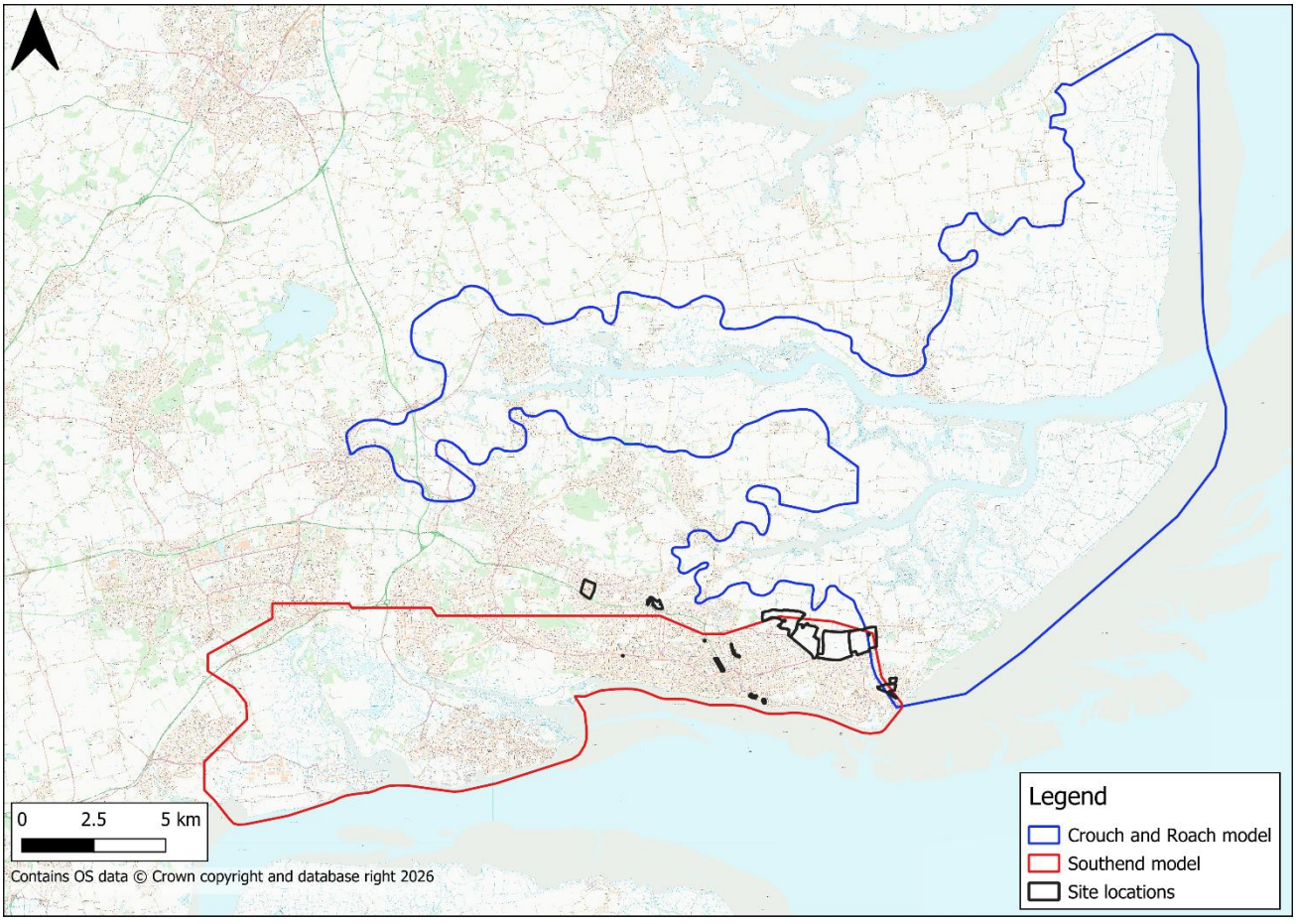


Figure 2-1: Original model domains

The updated model domain is shown on Figure 2-2. The original Crouch and Roach model uses a 10m resolution fixed grid, while the original Southend model uses a 6m resolution fixed grid. The new model retains the 10m grid fixed grid resolution from the Crouch and Roach model.

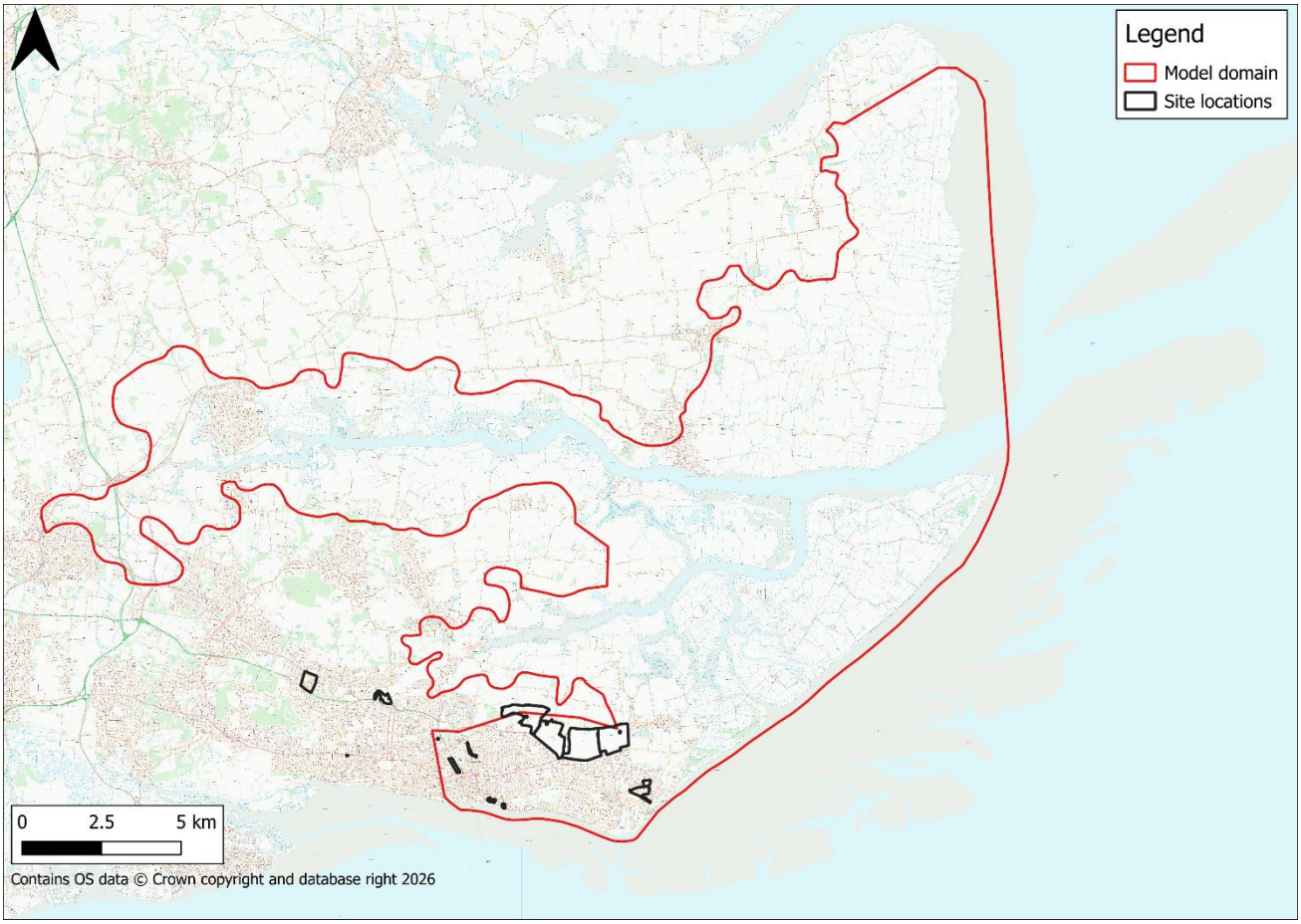


Figure 2-2: New model domain

2.2 Model software

The original TUFLOW models used the TUFLOW Classic solver. Run times for the original Crouch and Roach model exceeded 90-hours. To reduce the model run time, the model was converted to the TUFLOW HPC (Heavily Parallelised Compute) solver. This reduced model run times as it utilises GPU graphics cards.

2.3 Boundary conditions

2.3.1 Tidal boundary

The tidal water level boundary was updated for the 3.3%, 0.5%, and 0.1% AEP present-day (2026) and climate change (2126) events.

The design tidal curves were derived following EA guidance[1] and used the following data:

- The 2018 release of the Coastal Flood Boundary (CFB) extreme sea levels for chainage points 4276, 4280, 4286, 4300, 4304, 4308 and 4312 uplifted using United Kingdom Climate Change Projections 2018 (UKCP18) Higher Central (HC

[1] Environment Agency. (2018). Coastal flood boundary conditions for the UK: Update 2018 SC060064

- 70th percentile) and Upper End (UE - 95th percentile) emissions scenarios to 2126.
- Design astronomical tide using the Mean High-Water Springs (MHWS) at Southend-on-Sea and Holliwell Point.
- Design Surge Shape taken from the closest class A tide gauge at Sheerness

The data used to generate the tide curves is outlined in Table 2-1

The peak of the design surge profile was aligned to coincide with the low tide occurring immediately prior to the maximum peak of the Southend MHWS to generate the tidal profile. The design surge profile was multiplied by a growth factor and added to the Southend and Holliwell MHWS to form a new design tide curve for each event.

The peak water levels for each modelled event are outlined in Table 2-2. An example tide curve is shown on Figure 2-3.

Table 2-1: Data used to generate design tide curves

Location	CFB Chainage	Astro 'MHWS' tide location	Design Surge Shape
Crough and Roach	4276	Holliwell Point	Sheerness
Crouch and Roach	4280	Holliwell Point	Sheerness
Crouch and Roach	4286	Holliwell Point	Sheerness
Crouch and Roach	4300	Southend on Sea	Sheerness
Southend	4304	Southend on Sea	Sheerness
Southend	4308	Southend on Sea	Sheerness
Southend	4312	Southend on Sea	Sheerness

Table 2-2: Design tidal curve peak water levels from CFB point 4312

Event	AEP	Peak water level (mAOD)
2026	3.3%	4.34
2026	0.5%	4.71
2026	0.1%	5.08
2126 (HC)	3.3%	5.41
2126 (HC)	0.5%	5.78
2126 (HC)	0.1%	6.15
2126 (UE)	3.3%	5.78
2126 (UE)	0.5%	6.16
2126 (UE)	0.1%	6.53

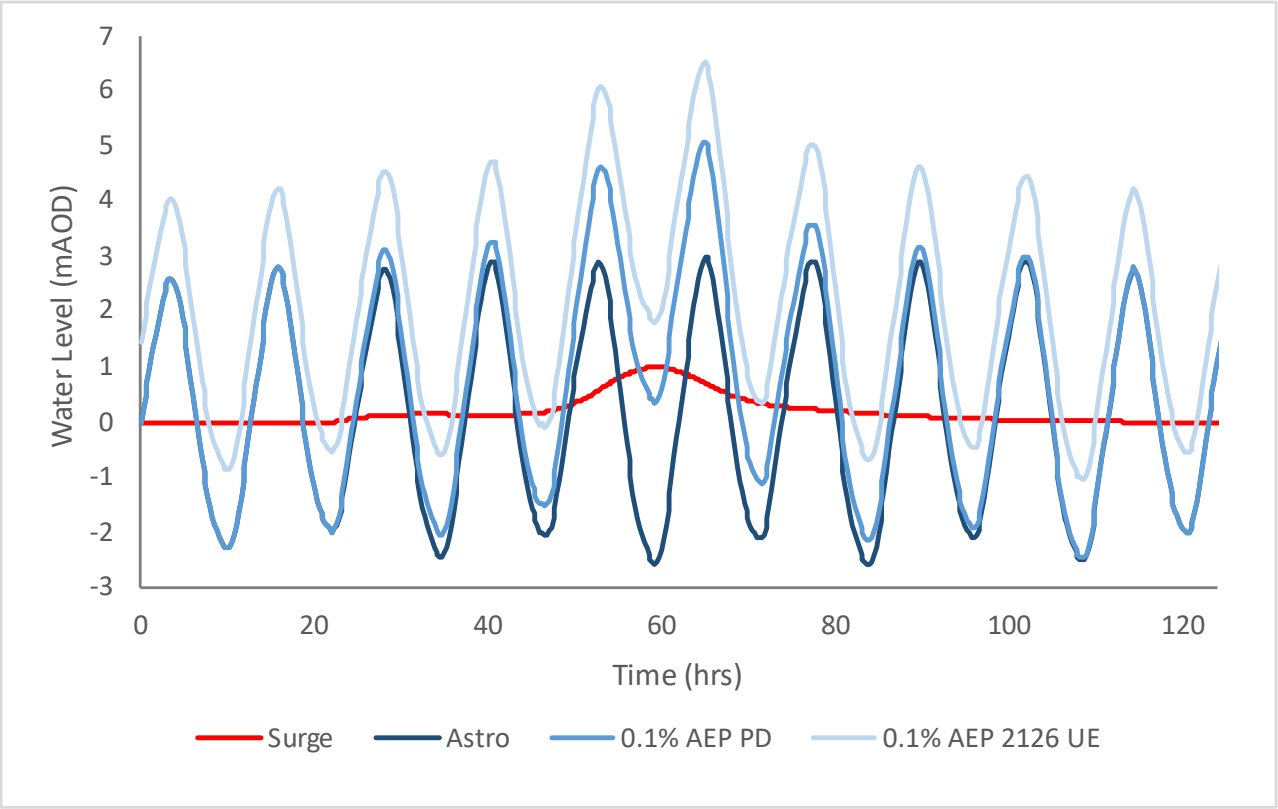


Figure 2-3: Example design tidal curve for CFB point 4312. 0.1% AEP present-day and 2126 UE events

2.3.2 Wave overtopping

Wave overtopping peak rates were not recalculated as part of this study. Wave overtopping inflows north of Havengore Creek are sufficiently far enough away from the sites that they would not be expected to have any impact on the sites, so they are not included in the model. Wave overtopping discharges for the Southend component of the model were updated based on the new tide curves while retaining the same peak overtopping rates. A summary of the existing model overtopping inflows and updates made is provided on Table 2-3.

In the existing modelling, wave overtopping was applied as Source-Time (ST) boundary lines. ST lines are not supported in TUFLOW HPC, so the application of wave overtopping inflows was updated to use Source-Area (SA) polygons using the 'Read GIS SA ALL' command to distribute wave overtopping flows evenly across each model in each SA section.

Table 2-3: Peak overtopping rates for the 0.1% AEP 2126 upper end event in the Southend model.

SA inflow name	Joint Probability ID	0.1% AEP Peak Rate ($m^3/s/m$)	Timeseries updated?
8	136	5.54	Yes
9	135	5.36	Yes

SA inflow name	Joint Probability ID	0.1% AEP Peak Rate ($m^3/s/m$)	Timeseries updated?
10	134	4.58	Yes
11	133	0.98	Yes
12	132	0.69	Yes
13	131	0.02	Yes
14	130	1.43	Yes
15	129	2.16	Yes
16	128	0.27	Yes
17	127	0.22	Yes
18	126	0.18	Yes
19	125	0.00	Yes
20	124	1.09	Yes
21	123	0.33	No
22	122	3.16	No
23	121	1.78	No
24	120	2.30	No
25	119	1.47	No
26	118	1.33	No
27	117	1.32	No

2.4 Digital terrain model

LiDAR for the original Digital Terrain Model (DTM) was provided by the EA and flown between 2010 and 2017. A review of the DTM found differences between the existing DTM and latest EA 2025 1m LiDAR DTM composite dataset. The latest EA 2025 1m LiDAR was used to update the base DTM for the whole model domain, including the offshore areas as this dataset was flown at low tide. In-channel bathymetry for rivers and creeks in the Crouch & Roach portion of the domain were retained from the existing modelling. The model topography from the combined datasets is shown on Figure 2-4. The location of each topography dataset is shown on Figure 2-5.

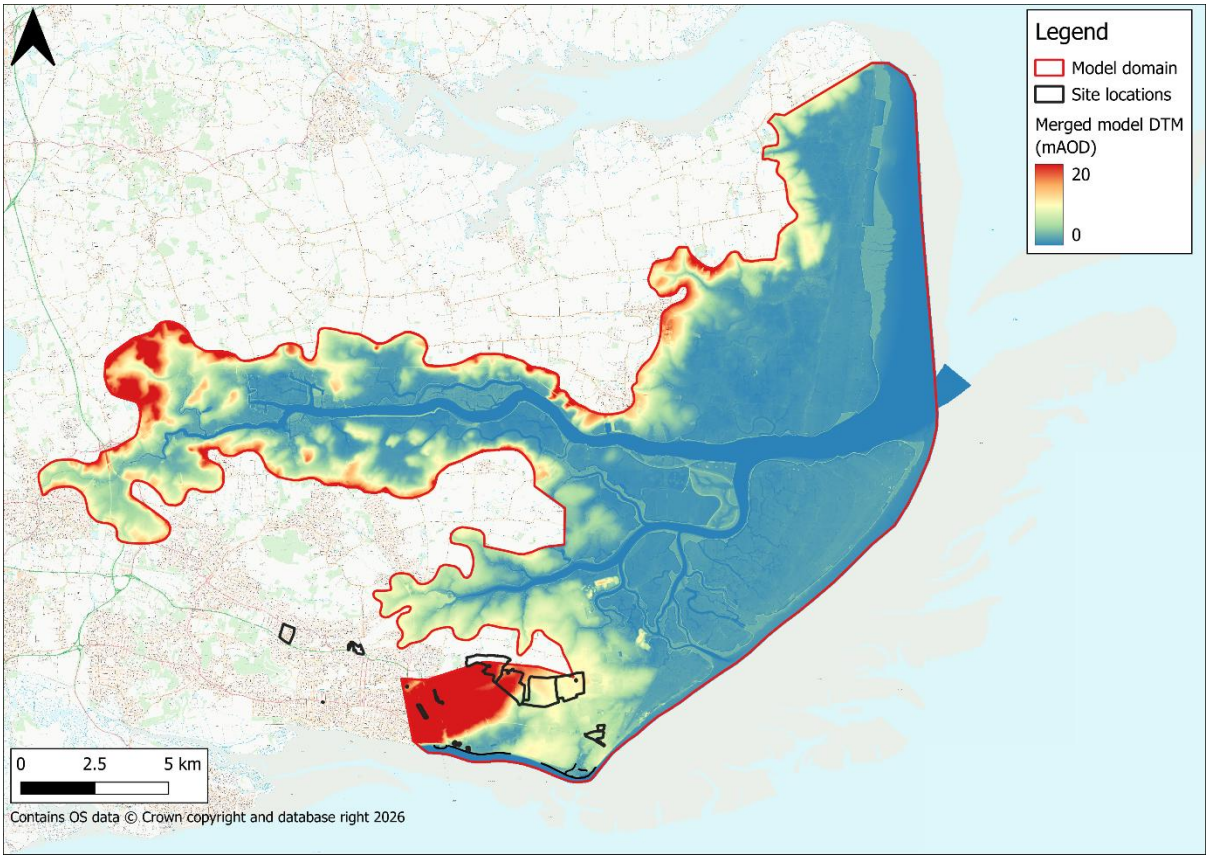


Figure 2-4: Model topography

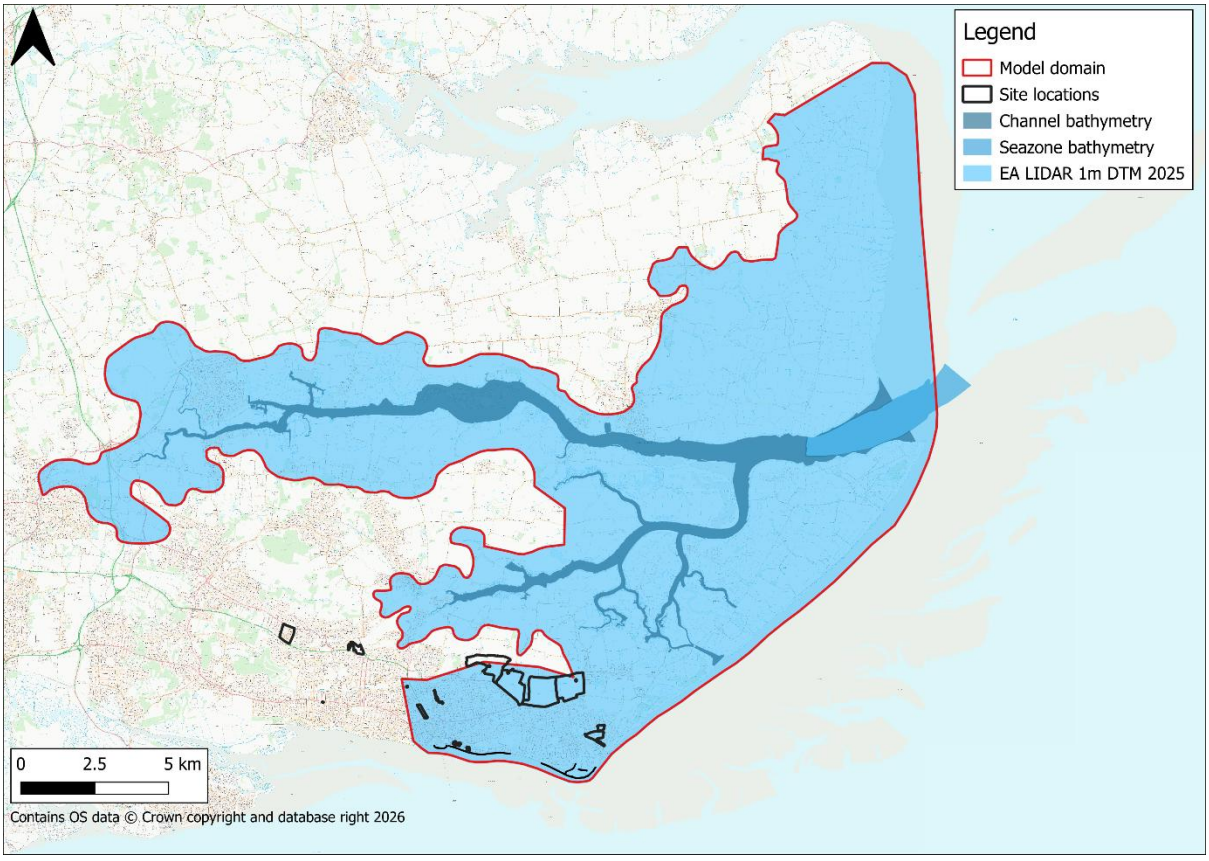


Figure 2-5: Topography dataset locations

2.5 Model topographic roughness

Mannings *n* values (based on Chow, 1959) were used to represent the channel and floodplain. Values for channel roughness were retained from the existing model. Manning's *n* values on the floodplain were based on different land uses.

Table 2-4: Mannings 'n' values

Topographic Category	Material description	Manning's 'n'
10	Default floodplain value	0.030
1	Buildings	0.100
2	Structures	0.100
3	Inland and coastal water	0.030
4	Natural surface and gardens	0.040
5	Manmade surface, roads, and paths	0.025
6	Trees, roughland, and scrub	0.100
7	Marsh, reeds, and saltmarsh	0.046

2.6 Breach modelling

Three breach scenarios were setup to consider the impacts of a defence failure. The three breaches were modelled and simulated in isolation. When a breach occurs, the defence is eroded to a base breach level, taken as the level of the landward toe of the defence. The latest EA breach of defences guidance (LIT 56413)[2] was used to define the breach parameters. Breach locations and base breach levels are outlined in Table 2-5 and shown on Figure 2-6.

Table 2-5: Breach locations

Breach ID	Breach Location	Defence Type	Reason for breach	Base breach level (mAOD)
Breach One	Overtopping reach 10, Adventure Island	Concrete embankment	Wave overtopping risk	1.4
Breach Two	Overtopping reach 15, near Shoebury Common North	Concrete wall	Wave overtopping risk	4.1
Breach Three	Overtopping reach 11, Eastern Esplanade, near Southchurch park	Concrete wall	Worst case scenario	4.5

[2] Environment Agency. 2021. Breach of defences guidance. LIT 56413.

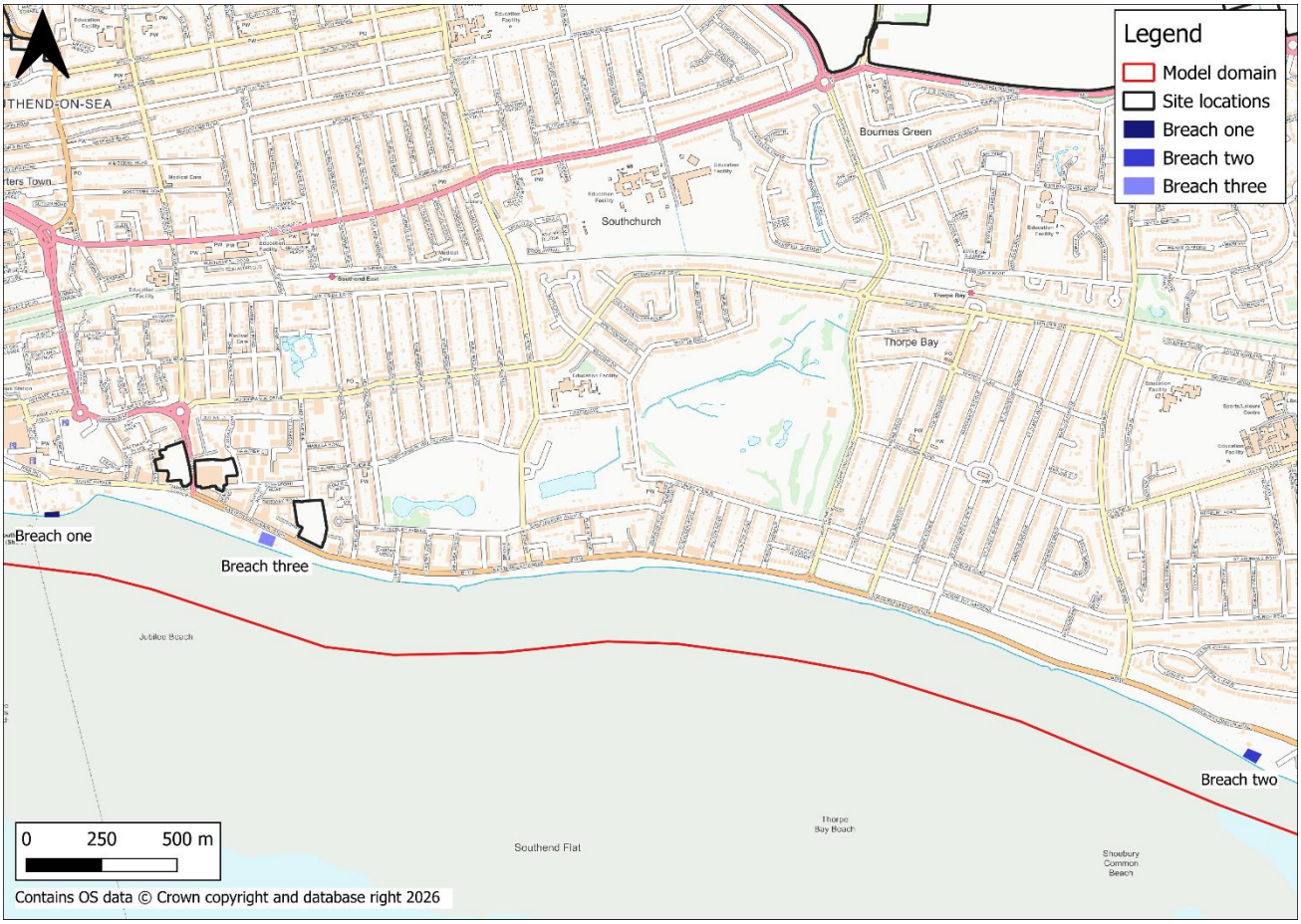


Figure 2-6: Breach locations

2.6.1 Breach trigger level

EA guidance states that in a tidal environment with wave loading, a breach should start either when overtopping begins, or when the extreme water level reaches half of the defence height, whichever occurs first. This means that breaches will trigger at different times for different events. The water level required to breach the defences are outlined in Table 2-6. Breach triggers and trigger times are outlined in Table 2-7 to Table 2-9.

Table 2-6: Breach levels

Breach ID	Crest level (mAOD)	Toe level (mAOD)	Half defence height (mAOD)
Breach One	4.24	1.40	2.82
Breach Two	5.62	4.10	4.86
Breach Three	4.84	4.50	4.67

Table 2-7: Breach one trigger times

Trigger type	Trigger time or level	Events
Water level	2.82mAOD	3.3% 2026
Water level	2.82mAOD	3.3% 2126 HC

Trigger type	Trigger time or level	Events
Water level	2.82mAOD	3.3% 2126 UE
Water level	2.82mAOD	0.5% 2026
Water level	2.82mAOD	0.5% 2126 HC
Water level	2.82mAOD	0.5% 2126 UE
Water level	2.82mAOD	0.1% 2026
Water level	2.82mAOD	0.1% 2126 HC
Water level	2.82mAOD	0.1% 2126 UE

Table 2-8: Breach two trigger times

Trigger type	Trigger time or level	Events
Water level	4.86mAOD	3.3% 2126 HC
Water level	4.86mAOD	3.3% 2126 UE
Water level	4.86mAOD	0.5% 2126 HC
Water level	4.86mAOD	0.5% 2126 UE
Water level	4.86mAOD	0.1% 2126 HC
Water level	4.86mAOD	0.1% 2126 UE
Wave overtopping	62.75hrs	3.3% 2026
Wave overtopping	62.75hrs	0.5% 2026
Wave overtopping	62.75hrs	0.1% 2026

Table 2-9: Breach three trigger times

Trigger type	Trigger time or level	Events
Water level	4.67mAOD	3.3% 2026
Water level	4.67mAOD	3.3% 2126 HC
Water level	4.67mAOD	3.3% 2126 UE
Water level	4.67mAOD	0.5% 2026
Water level	4.67mAOD	0.5% 2126 HC
Water level	4.67mAOD	0.5% 2126 UE
Water level	4.67mAOD	0.1% 2026
Water level	4.67mAOD	0.1% 2126 HC
Water level	4.67mAOD	0.1% 2126 UE

2.6.2 Breach evolution

Breaches are considered instantaneous (use of 0.1 hours breach duration).

2.6.3 Breach width and time to close

Using the EA breach of defences guidance (Table 2-10). The breached defences are classified as 'Open Coast' and 'Reinforced Concrete' in an urban area. Therefore, a defence breach width of 50m and 18-hour time to close was used.

Table 2-10: EA breach of defence guidance parameters

Source	Defence Type	Breach Width (m)	Time to close – urban (hrs)	Time to close – rural (hrs)
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	

2.7 Model simulations

The updated model was simulated for the scenarios and events outlined in Table 2-11.

Table 2-11: Design events

Scenario(s)	Events
Defended Breach One Breach Two Breach Three	3.3% AEP 2026 3.3% AEP 2126 HC 3.3% AEP 2126 UE 0.5% AEP 2026 0.5% AEP 2126 HC 0.5% AEP 2126 UE

Scenario(s)	Events
	0.1% AEP 2026 0.1% AEP 2126 HC 0.1% AEP 2126 UE
Undefended	0.5% AEP 2026 0.5% AEP 2126 HC 0.5% AEP 2126 UE 0.1% AEP 2026 0.1% AEP 2126 HC 0.1% AEP 2126 UE

2.8 Model stability

A summary of stability checks, and model check and warning messages is provided in Table 2-12 and Table 2-13.

Table 2-12: Summary of stability checks

Scenario	Stability checks
Defended	There is a small spike and trough in the maximum water level output grids at the boundary along the River Crouch. This does not propagate through the model. There is one apparent spike in the maximum water level grid around Shoebury Common. This is due to wave overtopping being applied over raised land behind the defence. The final cumulative mass error (ME) for all model events is within the recommended +/-1% limit. However, for a HPC model the mass balance is typically very low so this can be misleading when assessing the performance of a model. The change in volumes (dVol) shows cyclical behaviour consistent with tidal flows and wave overtopping. Design timestep (dt) cycles with the still water boundary. There are small, isolated dips, with the lowest dt upon model startup as the model settles. 0 HPC HCN repeated timesteps 0 HPC NaN repeated timesteps

Scenario	Stability checks
Undefended	There is a small spike and trough in the maximum water level output grids at the boundary along the River Crouch. This does not propagate through the model. There is an additional spike in the maximum water level grid (~150mm) in the northern area of the domain near Tillingham. This is sufficiently far enough away from the sites that it will not have an impact. The final cumulative mass error (ME) for all model events is within the recommended +/-1% limit. The change in volumes (dVol) shows cyclical behaviour consistent with tidal flows. Design timestep (dt) cycles with the still water boundary. There are small, isolated dips, with the lowest dt upon model startup as the model settles. 0 HPC HCN repeated timesteps 0 HPC NaN repeated timesteps
Breach One	There is a small spike and trough in the maximum water level output grids at the boundary along the River Crouch. This does not propagate through the model. The final cumulative mass error (ME) for all model events is within the recommended +/-1% limit. The change in volumes (dVol) shows cyclical behaviour consistent with tidal flows and wave overtopping. Design timestep (dt) cycles with the still water boundary. There are small, isolated dips, with the lowest dt upon model startup as the model settles. 0 HPC HCN repeated timesteps 0 HPC NaN repeated timesteps
Breach Two	There is a small spike and trough in the maximum water level output grids at the boundary along the River Crouch. This does not propagate through the model. The final cumulative mass error (ME) for all model events is within the recommended +/-1% limit. The change in volumes (dVol) shows cyclical behaviour consistent with tidal flows and wave overtopping. Design timestep (dt) cycles with the still water boundary. There are small, isolated dips, with the lowest dt upon model startup as the model settles. 0 HPC HCN repeated timesteps 0 HPC NaN repeated timesteps
Breach Three	There is a small spike and trough in the maximum water level output grids at the boundary along the River Crouch. This does not propagate through the model. The final cumulative mass error (ME) for all model events is within the recommended +/-1% limit. The change in volumes (dVol) shows cyclical behaviour consistent with

Scenario	Stability checks
	tidal flows and wave overtopping. Design timestep (dt) cycles with the still water boundary. There are small, isolated dips, with the lowest dt upon model startup as the model settles. 0 HPC HCN repeated timesteps 0 HPC NaN repeated timesteps

Table 2-13: Summary of check and warning messages

Scenarios	No of checks/warnings	Message	Comments
Defended Breach One Breach Two Breach Three	58 checks prior to simulation	Check 2118 - Lowered SX ZC Zpt by 0.3m to 1D node bed level	This is related to lowering the ground level around culvert openings. Flow through the culverts have been checked for sensibility. There are no culverts with the potential to impact any of the sites, due to this, culvert invert levels were not updated.
Defended Breach One Breach Two Breach Three	85 warnings prior to simulation	Warning 2118 - Lowered SX ZC Zpt by 3.93m to 1D node bed level	This is related to lowering the ground level around culvert openings. Flow through the culverts have been checked for sensibility. There are no culverts with the potential to impact any of the sites, due to this, culvert invert levels were not updated.
Defended Breach One Breach Two Breach Three	7 checks during simulation	Check 1284 - Connecting a 1D H boundary to 2d HX link	This is expected due to the spatially varying tidal boundary.
Defended Breach One Breach Two Breach Three	0 warnings during simulation	-	-
Undefended	2 checks prior to simulation	Check 2118 - Lowered SX ZC Zpt by 0.13m to 1D node bed level	This is related to lowering the ground level around culvert openings. Flow through the culverts have been checked for sensibility. There are no culverts with

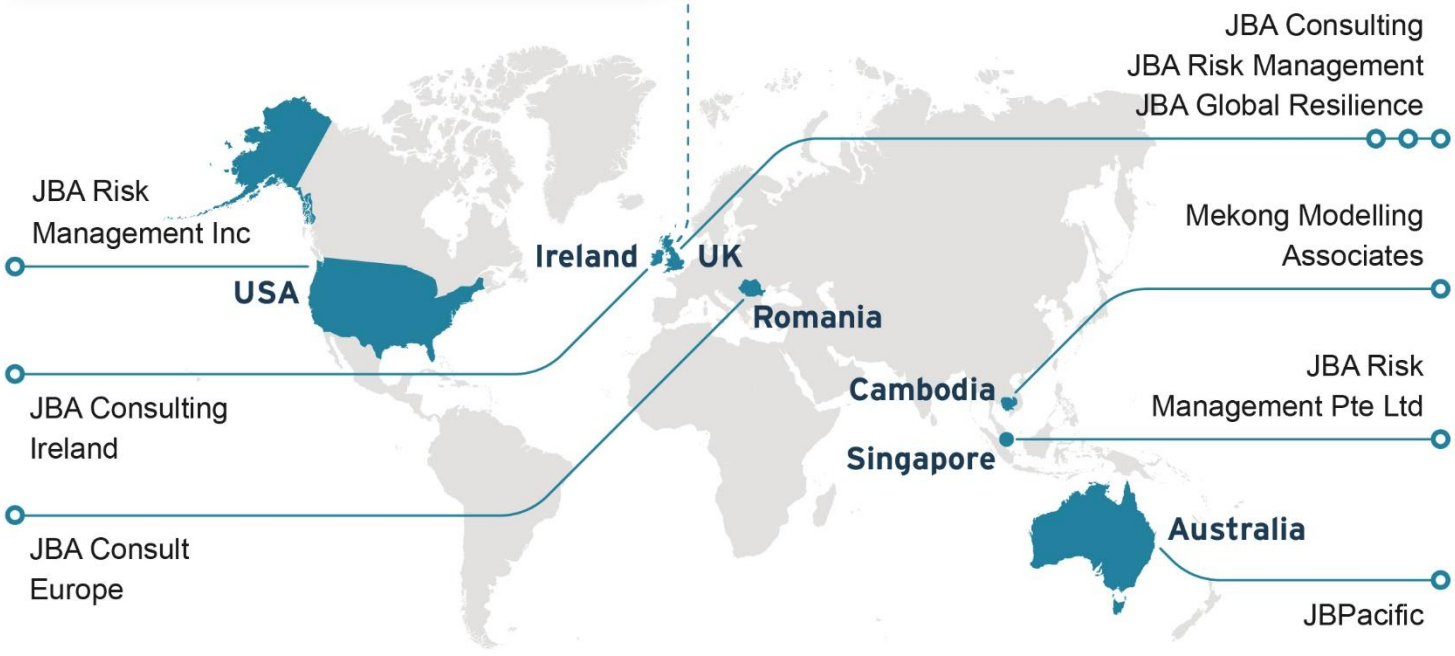
Scenarios	No of checks/warnings	Message	Comments
			the potential to impact any of the sites, due to this, culvert invert levels were not updated.
Undefended	6 warnings prior to simulation	Warning 2118 - Lowered SX ZC Zpt by 1.49m to 1D node bed level	This is related to lowering the ground level around culvert openings. Flow through the culverts have been checked for sensibility. There are no culverts with the potential to impact any of the sites, due to this, culvert invert levels were not updated.
Undefended	7 checks during simulation	Check 1284 - Connecting a 1D H boundary to 2d HX link	This is expected due to the spatially varying tidal boundary.
Undefended	0 warnings during simulation	-	-

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