Appendix A: Hydrodynamic Breach Modelling Methodology

This appendix presents the methodologies used to develop flood outlines, maximum flood depths, hazard ratings and time to inundation maps for the Southend-on-Sea Borough Council SFRA.

Rapid Inundation Modelling

The modelling methodology used for this SFRA uses a 'breach at the peak' approach or 'rapid inundation' approach. Rapid inundation modelling simulates breaches that occur suddenly just before the peak tidal level. As the maximum force and volume of water behind the defences occurs at this point, it was agreed that this would provide the most rapid inundation of the system and correspondingly the most severe hazard and time to inundation results. The results from these scenarios could then be used to determine the minimum time to inundation for vulnerable locations in the flood cell, particularly for the more vulnerable properties located closer to the flood defences.

The total volume of water entering the system will be slightly less, and inundation will be slightly lower in the outlying areas of the flood cell, but the potential flooding in the more vulnerable lower areas close to the breach will be tested more appropriately. This methodology was agreed with the Environment Agency (EA) prior to the commencement of the project.

Flooding from the breach scenario simulated at the peak of the tidal surge results in a greater volume of water surging through the breach with more rapid and higher floodwater velocities simulated, particularly in the vicinity of the breaches. Hence, velocity will now play a larger part in determining the flood hazard category in certain areas.

The modelling carried out for this SFRA was based on the previous modelling undertaken as part of the Thames Gateway SFRA and the City Beach study. It should be noted that although many of these breach locations were previously identified, all of the breach modelling conducted within this study is original and does not use or incorporate any previous modelling.

Topographic Data

A key component in the modelling process is the representation of topography throughout flood prone regions of the study area. For this purpose, a Digital Terrain Model (DTM) was derived for each of the modelled areas. A DTM is a three-dimensional 'playing field' on which the model simulations are run.

The platform used for the generation of the DTM was the GIS software package MapInfo Professional (version 8.5) and its daughter package Vertical Mapper (version 3.1).

The DTM is primarily based on filtered LiDAR data provided by the EA. LiDAR (Light Detection And Ranging) is a method of optical remote sensing, similar to the more primitive RADAR (which uses radio waves instead of light). In this case, the LiDAR surveys return data at a horizontal resolution of 2 metres, 1 metre and 0.25metres (that is, a unique elevation level is given every two/one/0.25 metres in both the north-south and east-west directions). Filtered LiDAR data represents the "bare earth" elevation with buildings, structures and vegetation removed. This information was provided by the EA and was captured at various times (1999, 2002, 2003, 2006 and 2007). The most recent data was used in preference to older data.

The LiDAR data was used to create a DTM grid covering the complete study area.

Flood Cell Definition

Nine breach locations have been identified along the northern bank of the River Thames within the Southend-on-Sea Borough Council administrative area. Details are provided in

Table A-1 and shown in Figure 11 Level 1 SFRA.

Table A-1 Breach Characteristics

Code	Previous	Breach Name	Floodcell	Easting	Northing	Defence Type
SOU01	SOU05	Old Leigh	Hadleigh Marsh	583160	185661	Earth (estuary)
SOU02	N/A	Chalkwell	Chalkwell	585796	185365	Hard (estuary)
SOU03	City Beach Breach 01	Marine Parade	City Beach	588834	185034	Hard (estuary)
SOU04	City Beach Breach 02	Kursaal	City Beach	589174	184919	Hard (estuary)
SOU05	City Beach Breach 03	Southchurch Park	City Beach	589705	184776	Hard (estuary)
SOU06	SOU01	Sh'ness Old Ranges	East Southend	593018	183955	Hard (estuary)
SOU07	SOU03	Sh'ness East Beach	Shoeburyness/Great Wakering	594700	185300	Earth (open coast)
SOU08	SOU02	Sh'ness New Ranges	Shoeburyness/Great Wakering	595445	185998	Earth (open coast)
SOU09/ROC	ROC05	Morrins Point	Shoeburyness/Great Wakering	596298	186654	Earth (open coast)

Code	Breach Width* (m)	Breach Invert Level (mAOD)	Crest Height (m)	Elements	Source of water level info	Peak Level			
						200 Year 2010	1000 Year 2010	200 Year 2110	1000 Year 2110
SOU01	50	3.80	5.7-5.8	N/A	Thames Estuary Extreme Water Levels (2008) - East Canvey Point	4.997	5.473	6.096	6.597
SOU02	20	4.10	5.80	N/A	Thames Estuary Extreme Water Levels (2008) - Leigh node	4.906	5.381	6.003	6.496
SOU03	20	4.7(4.1-old)	5.65	N/A	Thames Estuary Extreme Water Levels (2008) - Southend node	4.755	5.237	5.850	6.336
SOU04	20	2.90	5.61	N/A	Thames Estuary Extreme Water Levels (2008) - Southend node	4.755	5.237	5.850	6.336
SOU05	20	4.6 (3.9-old)	5.86	N/A	Thames Estuary Extreme Water Levels (2008) - Southend node	4.755	5.237	5.850	6.336
SOU06	20	2.00	6.00	N/A	Anglian Region Extreme Tide Levels	4.538	4.894	5.588	5.944
SOU07	200	4.00	5.3-4.3	N/A	Anglian Region Extreme Tide Levels	4.507	4.847	5.557	5.897
SOU08	200	2.00	4.2-5.5	N/A	Anglian Region Extreme Tide Levels	4.496	4.837	5.546	5.887
SOU09/ROC	200	1.80	5.00	N/A	Anglian Region Extreme Tide Levels	4.485	4.827	5.535	5.877

Once the DTM grids and breach locations have been obtained, the flood cell for each model must be defined. The flood cell is the geographical extent of the model; the area of the overall DTM that will be used in the model. While it would be possible to run each of the breach models using all of the derived DTM topographical data, it is far more sensible to define a smaller area on which to run each scenario.

Flood cells are typically defined by considering the topography of the area inland of the breach and the peak levels of the tidal events to be tested. MapInfo can be used to show areas of potential flooding by only displaying areas of the DTM that are below the predicted peak inundation levels in the vicinity of the breach, plus a freeboard. Areas of the DTM that are not shown (that is, areas that are well above the tidal levels of interest) do not need to be considered in the model.

Where the local topography does not clearly define an enclosed flood cell it may be necessary to artificially enclose certain parts of the flood cell. This should only be done for areas that are not near the breach or any important areas of the model, and will typically be outlying or empty areas of the flood cell. For example, estuaries or flat, open fields at the far end of the flood cell. Since the model treats the boundaries of flood cells as 'glass walls' it is vital that any artificial boundaries do not affect levels in the important areas of the flood cell. However, this is typically not an issue in models where the inflows are based on tidal levels rather than a specific volume.

Extreme Water Level Derivation

Water levels were taken from 'Environment Agency: Thames Tidal Defences Joint Probability Extreme Water Levels 2008, Final Modelling Report, April 2008' preferentially where available and appropriate for particular breach locations. Where this study did not cover particular breach locations 'Environment Agency, Anglian Region, Eastern and Central Areas Report on Extreme Tidal Levels, 2007' was used to obtain water level information. Where nodes were present within close proximity to specific breach locations unmodified water levels were used. Where a significant distance was present between the modelled nodes within the Extreme Tidal Levels study and the Southend-on-Sea SFRA breach locations water levels from the Extreme Tidal Levels study were factored based on chainage to provide more realistic water levels.

Climate Change

PPS25 recommended contingency allowances have been applied to the extreme water levels in order to simulate climate change scenarios (100 years of climate change simulated up to 2110).

Breach Modelling

Nine breach locations have been identified along the northern bank of the River Thames within the Southend-on-Sea Borough Council administrative area as shown in Figure 11 SFRA Level 1 and

Table A-1.

To assess flood propagation in events where the flood defences are breached, a hydraulic modelling analysis has been undertaken using the two-dimensional hydraulic modelling software MIKE21-HDFM (Release 2009, Service Pack 3). This section discusses the modelling methodology that has been applied for the hydraulic modelling analysis of the breach events. The choice of model is discussed, the model schematisation is described and the boundary conditions used are presented.

The defences along the Southend-on-Sea coastline are variable in standard. There are lengths of defence that fall below the 1 in 200 year design standard. As such, models including the potential for overtopping as well as breaching have been constructed. These models allow a breach to be forced through a section of chosen defence but also allow overtopping of the defences to occur where the defences are lower than the simulated water level. In addition to this, an overtopping scenario was also run where no breach occurs. This gives a flood water extent from overtopping alone, or 'actual' flood risk.

Model and Software Selection

To achieve the study objectives, the model used to estimate the maximum flood conditions was required to:

- Accommodate the effects of a flood flow (propagation of a flood wave and continuous change of water level);
- Simulate the hydraulics of the flow that breach/overtop the flood defences; and
- Generate detailed information on the localised hydraulic conditions over the flooded area in order to evaluate flood hazard.

MIKE21-HDFM was developed by the Danish Hydraulic Institute (DHI) Water and Environment and simulates water level variations and flows for depth-averaged unsteady two-dimensional free-surface flows. Release 2009, Service Pack 3 was used for this study. It is specifically oriented towards establishing flow patterns in complex water systems, such as coastal waters, estuaries and floodplains using a flexible mesh (FM) approach. The flexible mesh model has the advantage that the resolution of the model can be varied across the model area. The model utilises the numerical solution of two-dimensional shallow water equations.

Model Extent and Resolution

Flexible meshes were developed to define the topography of the land behind the breach, using the MIKE21 program's mesh generator application which creates a mesh of triangular elements covering the entire area prone to flooding. These areas are known as 'flood cells' and generally cover all land that has an elevation below the peak tidal level, with the potential to flood.

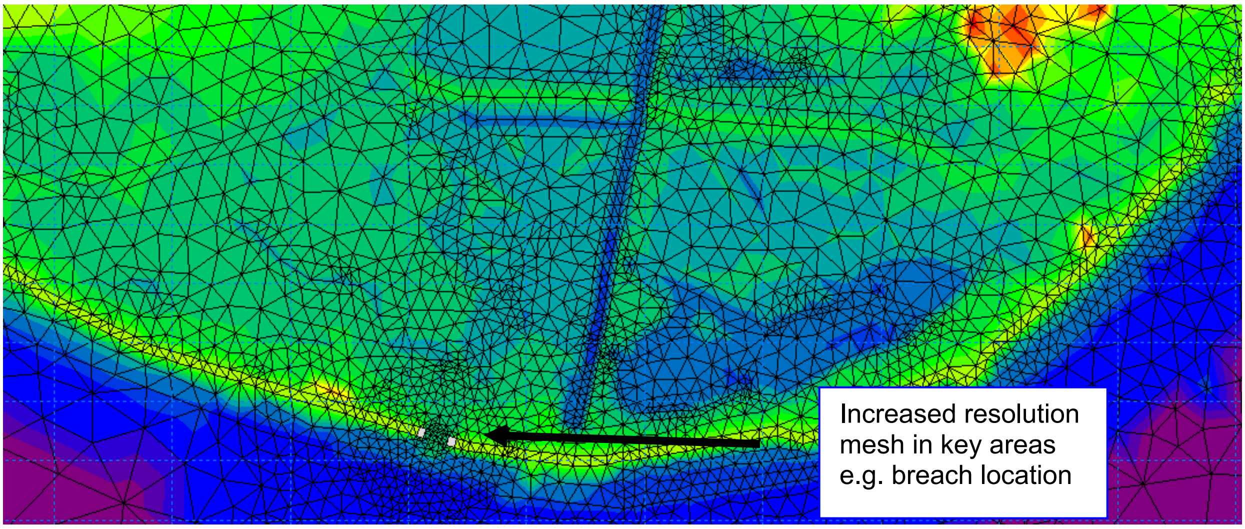
The element size in the mesh is varied throughout the model domain depending upon the complexity of the floodplain, features of interest, and the location of topographic features which have a significant impact on flood propagation. For example, more triangles would be present near a road, wall or bridge and less in areas of open floodplain.

In order to accurately represent the hydraulics around the breaches a comparatively small element size has been specified in the vicinity of the breaches. The breach itself is represented with a minimum of four elements across its width.

By adding 'control lines' during the development of the mesh, the triangles are forced to follow the alignment of the features ensuring the elevations of important features are picked up during the mesh generation. For example, control lines would be placed along each side of a road. In this way, the mesh is 'forced' to follow the road accurately and use level values at very specific points.

Once the final mesh is developed and the triangles generated, elevation values are imported into the mesh at each triangle vertex from the previously created DTM, utilising the LiDAR data. This then provides the 3-dimensional 'playing field' for simulating the breach scenario.

Figure A-1 Example of MIKE 21 HD Flexible Mesh



Breach Specifications

The breach width and exposure duration are determined by the type of defences and the nature of the adjacent water body. Flood defences are categorised as either 'Hard Defences' or 'Earth Embankments'. According to EA guidance (Environment Agency SFRA Guidance[1]) for tidal rivers, the breach width adopted for the above categories is 20 metres and 50 metres respectively for tidal rivers/estuary and 50 metres and 200 metres respectively for open coast.

The land water boundary along Southend-on-Sea is classified as tidal river/estuary to Shoeburyness point and as open coast to the east.

The majority of the breaches simulated in this study involve 'Hard Defences' (20 metre breach). However, there are four breaches where the local defences are 'Earth Embankments' (50 metre breach estuary location and 200 metre breach open coast location).

The repair time required to close a breach is assumed to be 36 hours, covering three tidal cycles. In the hydraulic modelling undertaken for this study, the breach in the flood defence wall occurred prior to the peak tidal level occurring on the second peak and remained open for the remainder of the simulation. This simulation corresponds to approximately three tidal cycles, with the peak level occurring on the second peak, with two slightly smaller peaks either side. This allows any potential overtopping to occur on the first tidal cycle prior to the breach.

Hydraulic Roughness used in Modelling

Hydraulic roughness represents the conveyance capacity of the land or riverbed where flows are occurring. Within the MIKE21 model, hydraulic roughness is defined by the dimensionless Manning's 'n' roughness coefficient.

A number of material roughness classifications have been identified within the study area, for example water; 0.03 (for the river), urbanised; 0.08, rural/non-urbanised land; 0.04, road; 0.02, and rail; 0.03. The

[1] Agency Management System Document: Uncontrolled When Printed [10/01/07]

distribution of these factors has been defined using aerial photography and OS maps in order to vary the conveyance rates throughout the flood cell domain.

Tidal Model Boundary Conditions

Within the MIKE21 model, tidal water level boundary files (in this case located in the River Thames before the breach) are used to provide the important input of water volumes to the mesh. The tidal water level is defined in the river and determines the flow entering the flood cell through the breach.

The water level boundary file consists of real-time tide curves, using the tidal peak levels derived from the report 'Thames Tidal Defences, Joint Probability Extreme Water Levels 2008, Final Modelling Report, Halcrow (for the Environment Agency) and 'Environment Agency, Anglian Region, Eastern and Central Areas Report on Extreme Tidal Levels, 2007'.

Model Simulations Undertaken

The following flood events were simulated for each breach location;

- A tidal flood event with a return period of 1 in 200 years (present day 2010) breach and overtopping;
- A tidal flood event with a return period of 1 in 200 years (with climate change 2110) breach and overtopping;
- A tidal flood event with a return period of 1 in 200 years (with climate change 2110) overtopping only;
- A tidal flood event with a return period of 1 in 1000 years (present day 2010) breach and overtopping;
- A tidal flood event with a return period of 1 in 1000 years (with climate change 2110) breach and overtopping;
- A tidal flood event with a return period of 1 in 1000 years (with climate change 2110) overtopping only.

Breach Time

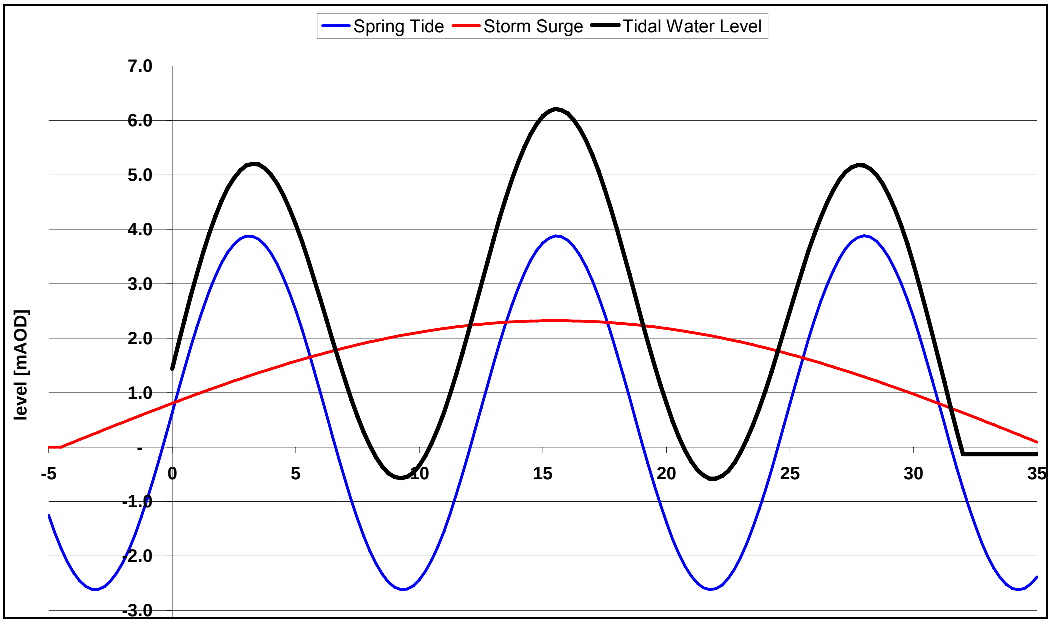
The water levels during a tidal flood event are generated by a summation of the astronomical tide levels and the storm surge residual.

In terms of speed and force of floodwaters, the worst time for a breach to occur is when the maximum hydrostatic force has built up behind the flood defences. Therefore, the modelling undertaken for Southend-on-Sea SFRA was run where the flood defences suddenly breach just before the tidal level on the flood defences at the breach location is at a maximum.

A one hour 'lead-time' was included to ensure that, once the breach had occurred, the water level continued to rise and the volume of water travelling through the breach was slightly higher than exactly at the maximum level time (where the level immediately starts to decline). This was seen as a compromise between the initial flow through the breach and overall volume and impact of the breach (see Figure A-2).

The models were run for 36 hours. This allowed the potential for overtopping before the breach, during the first tidal cycle and ensured water could enter the model through the breach for the second and third tidal cycles.

Figure A-2 Example of Tidal Curve with Breach Time



Modelling Outputs

Modelling analysis presents data to identify the residual risk of flooding from a failure of local defences (through breach or overtopping). The mapping of flood depth, flood hazard and time to inundation within the study area represents an appreciation of the residual risk and provides Southend-on-Sea BC with additional information to enable more detailed consideration of the Sequential Test and PPS25 vulnerability classifications within Flood Zone 3a. Overtopping simulations provide 'actual' flood risk information.

Once the meshes were defined and the models run (by flooding the meshes, through the breaches/overtopping, with the tidal events), three layers were derived for each breach scenario and tidal event, to provide the following deliverables. GIS tasks have been performed using MapInfo Professional (Version 8.5) with the Vertical Mapper spatial analysis add-on (Version 3.1).

Maximum Flood Depth

The maximum flood depth is obtained from the water level achieved at each point in the model, minus the LiDAR topographic level at that point. This has been processed for all scenarios run. Composite depth maps were also created taking the maximum depth where breaches coincided.

Hazard Rating

Flood hazard is a function of both flood depth and flow velocity. Due to this dependence on velocity, it is common during tidal flood events for the maximum flood hazard at a certain location to occur before the maximum floodwater level occurs while floodwaters are flowing and the velocities are higher.

In order to assess the maximum flood hazard during a flood event, the hazard level at each element of the MIKE21 mesh is assessed at every time step of the model simulation.

Each element within the model is assigned one of four hazard categories 'Extreme Hazard', 'Significant Hazard', 'Moderate Hazard', and 'Low Hazard'.

The derivation of these categories is based on Flood Risks to People FD2320 (DEFRA & EA, 2005), using the following equation:

*Flood Hazard Rating = ((v+0.5)*D) + DF*   *Where v = velocity (m/s)*

D = depth (m)

DF = debris factor

The depth and velocity outputs from the 2D hydrodynamic modelling are used in this equation, along with a suitable debris factor. For this SFRA, a precautionary approach has been adopted inline with FD2320; a debris factor of 0.5 has been used for depths less than and equal to 0.25m, and a debris factor of 1.0 has been used for depths greater than 0.25m.

Table A-2 Hazard categories based on FD2320, DEFRA & Environment Agency 2005

Flood Hazard			Description
	HR < 0.75	**Low**	**Caution** – Flood zone with shallow flowing water or deep standing water
	0.75 ≥ HR ≤ 1.25	**Moderate**	**Dangerous for some** (i.e. children) – Danger: flood zone with deep or fast flowing water
	1.25 > HR ≤ 2.0	**Significant**	**Dangerous for most people** – Danger: flood zone with deep fast flowing water
	HR > 2.0	**Extreme**	**Dangerous for all** – Extreme danger: flood zone with deep fast flowing water

A flood hazard rating grid was created for each of the nine breach locations for all flooding scenarios. A composite grid was then created for the entire study area by extracting the maximum flood hazard rating value (where applicable) for each point, considering all nine of the model output grids.

Time to Inundation

As previously stated, a breach was simulated in the models one hour before the peak tidal level. Flows then tended to pass through the breach, inundating the flood cell, for approximately five to six hours, after which the tide level had again retreated well below the breach invert. After another six hours (11 to 12 hours after the breach) the next high tide would again push water through the breach causing further flooding for a further five to six hours.

From examining the results it was decided that the vast majority of land that was inundated by the model was inundated within six hours of the breach occurring. Some of the outlying areas (some distance from the breach) were affected by the second peak and this tended to happen 12 to 16 hours after the breach occurred.

The MIKE21 application 'Data Extraction FM' was used to extract 'snapshots' of the model results Time 0 is set to the time when tidal water enters the breach. This means that the <1 hour band encompasses all areas that are inundated (wet) within the first hour of water travelling through the breach and into the flood cell. Further bands have been produced to show wet cells at: 1-4 hours, 4-8 hours, 8-12 hours, and for each 4 hour interval up to 20 hours. Where overtopping occurred prior to the opening of the breach, this has been classified as such. As overtopping is possible along the frontage due to the variable defence standard, some overtopping will be classified within the time to inundation bands from the breach event.

For each model run, a mesh of polygons was derived in GIS (in this case, MapInfo format), each containing an approximate time of inundation for that triangular element from the model mesh. All empty (zero) elements were then deleted and a 3-dimensional grid file (using the time of inundation as the vertical z-value) was created to define the time to inundation for each model simulation.

These grid files could be used as the final output of the time to inundation process. However, the results could be 'patchy' and complicated in places, mainly due to a finite number of breach locations being used (21 in this case). Ideally, a very high number of breach locations would have been used in the modelling (say, every few hundred metres or more) but this is impractical considering computing power and time that would be required. This should be noted by the reader for all output results, i.e. results are from a discrete number of breach locations and therefore may be subject to change if the breach location were to change.