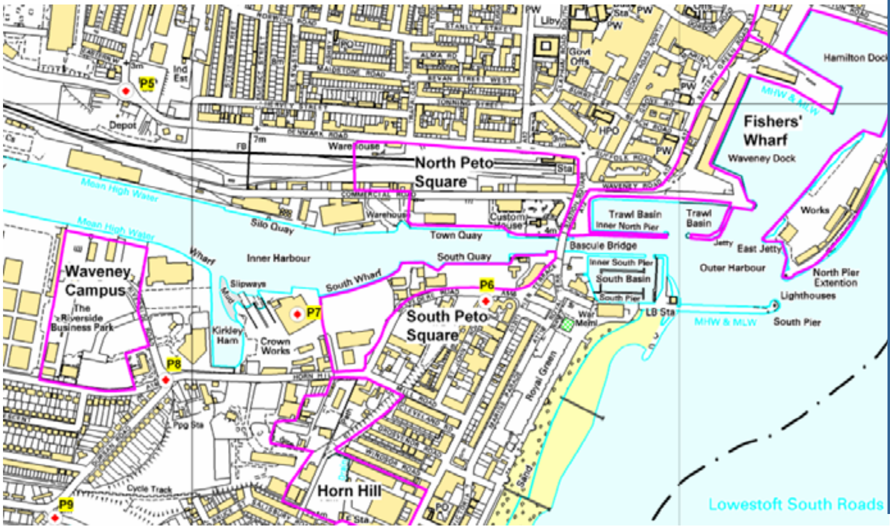
1st East Waterfront Regeneration Co.

Cumulative Land Raising Study

Lake Lothing, 2D Hydraulic Modelling and Defence Assessment

Report

June 2008



Prepared for
1st East Waterfront Regeneration Co.

Revision Schedule

June 2008

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	April 2008	**Draft**	**Nick Martin** Senior Engineer **Maja Klasson** Hydraulic Modeller	**Liz Williams** Senior Consultant	**Jon Robinson** Associate Director
02	June 2008	**Final**	**Nick Martin** Senior Engineer	**Liz Williams** Senior Consultant	

Table of Contents

Formatted: Bullets and Numbering

Executive Summary

1.1.1 Scott Wilson was commissioned by 1st East in March 2008 to conduct a 2-D hydraulic modelling exercise of tidal flows at Lowestoft to investigate the potential impacts on the tidal flood cell arising from a proposed strategic regeneration of the Lake Lothing area incorporating land raising at strategic sites in Lowestoft. It is understood that the land raising scheme is proposed to mitigate potential flood risks and facilitate the regeneration of the Lake Lothing waterfront area.

1.1.2 The Waveney SFRA (prepared by Scott Wilson, 2008) has investigated the flood depths and inundation times associated with overtopping of tidal flows on existing defences around the Lake Lothing area of Lowestoft. The hydraulic model completed as part of the SFRA forms the baseline model for this assessment of tidal flooding after the landscape contour remodelling and associated earthworks have taken place.

1.1.3 An analysis of the existing defences was included as part of this study. It identified many of the defences to be below standard. Options were assessed for each of the sites including improving the existing defences, replacing the defences and land raising. This is included in Annex A of this report.

1.1.4 This report presents the methodology and modelling results for the existing scenario and three post-development scenarios where land raising and contour remodelling have taken place. The modelled flood cell results have been queried to establish the maximum water levels, flow depths and inundation areas for the 1 in 20, 1 in 200 year and 1 in 1000 year plus climate change events (2107) at twelve extraction points to determine any increase in flood risk to surrounding areas.

1.1.5 Three land raising scenarios have been modelled as part of the study. The first scenario looks at the potential impacts on the flood cell from the land raising of four key sites. The second scenario looks at the potential impacts on the flood cell from land raising of these key four sites and an additional four sites. The third scenario was included at the request of the Environment Agency to identify the impacts with the removal of the Horn Hill site on the overall flood cell. This cumulative model aims to identify if the proposed land raising on a strategic basis has any adverse impacts on the surrounding flood cell.

1.1.6 A detailed analysis of the modelling results for the existing and post-development scenarios for all three events was carried out to determine the impact that the two development scenarios would have on existing flood levels. Data was extracted at twelve locations in the flood cell for the existing case and each of the three land raising scenarios. The results showed that changes in flood peak levels were minimal during the two land raising scenarios. In fact, peak water levels generally decreased owing to the added protection and constriction of potential flood water as a result of the land raising. This is discussed further in Section 5.

1.1.7 The overall analysis shows the wide scale land raising of sites in the Lake Lothing flood cell has very little effect (1-2cm) on flood water levels elsewhere within the flood cell. This is because the flows are not restricted at Bascule Bridge so tidal flooding is related to a specific water level, as opposed to a volume.

1.1.8 The Scenario 2 (which included the Horn Hill site) showed marginal increases in flood depth of up to 5cm in some parts of the flood cell. Therefore as part of Scenario 3 the land raising for Horn Hill was removed. The remaining seven sites were land raised and resulted in no increases in flood depth across the flood cell. This suggests the land raising of the Horn Hill site impacted on a flow path that resulted in the increased levels. This site should therefore be treated in isolation. Land raising may still be an option on the Horn Hill site but it would need to look in more detail at the flow path location to ensure this was not affected as part of the sites development.

1.1.9 The modelling demonstrates that the removal of seven sites from the tidal floodplain through land raising has little impact on the remaining flood cell and it can be summarised that these sites do not have a conveyance function for the tidal flows.

1.1.10 Therefore whilst some of the sites at present may be at risk of tidal flooding from a 1 in 20 scenario due to insufficient defences, this study suggests they do not operate as functional floodplain and should instead of Flood Zone 3b be classified as Flood Zone 3a at risk of tidal flooding from a 1 in 20 scenario.

2 Introduction

2.1.1 Scott Wilson was commissioned by 1st East to conduct a 2-D hydraulic modelling analysis of potential impacts on the tidal flood cell of Lake Lothing, Lowestoft as a result of proposed land raising scenarios for several regeneration sites (Figures A1 and A2).

2.1.2 This report does not form a PPS25 Flood Risk Assessment, but is intended as a technical report on the specific aspects of hydraulic modelling undertaken for the proposed development and an assessment of the flood defences in the Lake Lothing regeneration area. The flood defence assessment is included as Annex A at the back of this report.

2.1.3 The proposed land contouring and associated earthworks at the various sites would result in a loss of tidal floodplain. Some of the sites around Lake Lothing were recently classified as functional floodplain in the Waveney SFRA, it was intended that the proposed land raising of these sites would remove them from the functional floodplain and enable their development as part of the regeneration of Lake Lothing.

2.1.4 The Environment Agency has requested that this study be carried out to establish whether the development areas should continue to be defined as functional floodplain, which involved an assessment of off site impacts. The Environment Agency has requested this analysis is carried out for the 1 in 20, 1 in 200 and 1 in 1000 year events inclusive of climate change.

2.1.5 The Waveney SFRA (prepared by Scott Wilson) investigated flood depths and inundation times associated with overtopping of tidal flows on existing defences at Lowestoft. This work has produced a series of flood depth maps presenting the actual flood risk from the existing defences. The hydraulic model used in the SFRA to determine the tidal flood risks to existing land uses has been considered as the baseline model for the assessment of tidal flooding after the two proposed land raising scenarios.

2.1.6 This report presents the methodology and modelling results for scenarios before and after the land raising. The developed models have been queried to establish the maximum water levels, flow depths and inundation areas for the 1 in 20, 1 in 200 year and 1 in 1000 year plus climate change events (2107) at twelve extraction points (per raising scenario) within the flood compartment.

2.1.7 The objective of this cumulative modelling study is to investigate changes in tidal flow characteristics after the proposed land raising via 2-D hydrodynamic modelling. This objective includes the following tasks:

(a) Providing flood-depth maps for nine model scenarios as follows

- 1 in 20 year plus climate change – existing scenario
- 1 in 200 year plus climate change – existing scenario
- 1 in 1000 year plus climate change – existing scenario
- 1 in 20 year plus climate change – first land raising scenario
- 1 in 200 year plus climate change – first land raising scenario
- 1 in 1000 year plus climate change – first land raising scenario

- 1 in 20 year plus climate change – second land raising scenario
- 1 in 200 year plus climate change – second land raising scenario
- 1 in 1000 year plus climate change – second land raising scenario
- 1 in 20 year plus climate change – third land raising scenario
- 1 in 200 year plus climate change – third land raising scenario
- 1 in 1000 year plus climate change – third land raising scenario

(b) Assess the changes in water surface elevations, flood depths and inundation times at ten specified locations.

(c) An assessment of the defences and fluvial consideration to the tidal surge is included in Annex A of this report.

3 Site Description

3.1.1 Tidal flows propagate into the Lake Lothing area of Lowestoft through the Bascule Bridge via a narrow manmade channel approximately 22 metres wide. This tidal inlet dominates the characteristics of tidal flows in the study area. The downstream boundary is formed by the lock gate at Mutford Lock which restricts the tidal propagation west into the Oulton Broads area.

3.1.2 There are existing tidal defences built along the coastline of Lowestoft and around the mouth of Lake Lothing, although the defences around the Lake Lothing inner area tend to be informal defences in the form of quay headings and slipways. Further detail on the existing defences are included in Annex A of this report.

3.1.3 Three land raising scenarios have been modelled as part of the study. The first scenario looks at the potential impacts on the flood cell from the land raising of four key sites. The second scenario looks at the potential impacts on the flood cell from land raising of these key four sites and an additional four sites. The third looks at the same land raising sites as Scenario 2 but with the exclusion of the Horn Hill site. This cumulative model aims to identify if the proposed land raising on a strategic basis has any adverse impacts on the surrounding flood cell. The sites are summarised in Table 3.1.

3.1.4 The first scenario considers the four more advance sites in the area of Lake Lothing, these include Oswald Boatyard, Brooke Marine, Kirkley Waterfront including Waveney campus and South Peto Square. The land raising for this scenario uses the detailed proposed ground contouring for Brooke Marine, Waveney Campus and Oswald Boatyard. A proposed land raising scheme had not been formalised for South Peto Square so it was assumed to be land raised to the 1 in 200 plus climate change water level.

3.1.5 The second modelled scenario includes the land raising of the four sites used in scenario 1 in addition to the proposed land raising of sites at Horn Hill, Peto Square North, Fishers Wharf and the East of England Park including the Power Park. These four additional sites are in the early stages of progression and as such had not considered their ground contouring or defence options. For these sites a worst- case conservative scenario was modelled, assuming land raising to the 1 in 200 plus climate change water level for the entire site boundary.

3.1.6 The third scenario was included following the initial results of the second scenario which identified a slight increase in water level. The Horn Hill was identified as a site potentially blocking a flow path using animations in-house, therefore Scenario 2 was re-run with the exclusion of the land raising for the Horn Hill site to establish if this site was indeed the cause of the increases.

3.1.7 Data was extracted at twelve locations in the flood cell for both existing and land raising scenarios to determine the potential effect the land raising may have on other areas in the flood cell. These extraction points are shown in Appendix A- Figure A4.

Table 3.1 Sites Raised in Modelled Scenarios

Site Name	Scenario 1	Scenario 2	Approx Area (m^2)	Raised Level (mAOD)
Oswald Boatyard	x	x	1,800	4.40
Brooke Marina	x	x	110,000	4.60
Waveney Campus	x	x	55,000	3.30 to 4.20
South Peto Square	x	x	38,000	4.40
North Peto Square		x	66,000	4.40
Horn Hill		x	56,000	4.40
Fishers' Wharf		x	44,000	4.40
East of England Power Park		x	430,000	4.40

4 Modelling Methodology

4.1 Digital Terrain Map (DTM) Generation

4.1.1 A key component of the modelling report is the representation of the topography throughout flood prone areas within the study area. Various data sources were made available, including LiDAR, SAR, topographic survey data and OS maps.

4.1.2 The platform used for the generation of the Digital Terrain Model (DTM) was the GIS package MapInfo Professional (version 8.5) with the addition of Vertical Mapper (version 3.1) to process raster data containing 3D information.

4.1.3 Much of this process had already been carried out as part of the Waveney and Suffolk Coastal SFRA (prepared by Scott Wilson).

4.1.4 The topographical information for the modelling is primarily based on LiDAR data. LiDAR data is provided in three formats; Digital Surface model that includes vegetation and buildings; Digital Terrain model, which is filtered to remove the majority of buildings and vegetation; and a filter which is the difference between the two models.

4.1.5 For the purpose of this study, the filtered LiDAR is used to create a Digital Terrain Model (DTM) to represent the “bare earth” elevation with buildings, structures and vegetation removed. As LiDAR does not provide 100% coverage of an area, and for areas where LiDAR was not available, SAR data was used to fill in any small gaps.

4.1.6 Through the use of the two datasets, the DTM used in hydraulic modelling has the highest resolution possible (i.e. 2m for the LIDAR data and 5m for the SAR data) and inclusion of the survey data ensures accurate representation of the site area.

4.1.7 For the three land raising scenarios, new patches of raised land were created (according to the shape and levels previously discussed), then stamped onto the existing DTM to simulate the theoretical, future topography.

4.2 Flood Cell Definition

4.2.1 Integral to the modelling methodology is the definition of flood cells. Flood cells are typically defined by prominent topographic features (relative to the flood source), which serve to constrain the movement of floodwater. The flood cell defined for this area encompasses the Area of Lake Lothing from the downstream extent of Mutford Lock to the Outer Harbour area and North Sea. Coastal boundaries along North and South Beach are also included in the flood cell to ensure coverage of all pathways into the flood cell. The extent of the flood cell is shown in Figure A3, Appendix A.

4.3 Extreme Water Level Derivations

4.3.1 The extreme tidal levels (1 in 20 year, 1 in 200 year and 1 in 1000 year) associated with each scenario are based on information provided by the Environment Agency, as used in the Waveney SFRA (prepared by Scott Wilson). These levels have been calculated for the year 2000 and do not take into account the effect of climate change. See Table 4.1.

Table 4.1 Peak Tide Levels for Lowestoft (2000)

Location	1 in 20 Year (mAOD)	1 in 200 Year (mAOD)	1 in 1000 Year (mAOD)
Lowestoft	2.75	3.29	3.67

4.4 Climate Change

4.4.1 In the UK the effect of climate change over the next few decades is estimated to result in milder wetter winters and hotter drier summers. An increased frequency of heavy, intense precipitation and storms will lead to different rainfall patterns resulting in changes in peak river flows. The rise in sea levels will increase the duration and magnitude of tide locking affecting all tidal areas. Although the combined effect of climate change and sea level rise at the river catchment scale is uncertain, these factors are expected to have a major influence on the potential for future flooding. Consequently PPS25 requires flood risk studies to consider the potential impacts of climate change on flood risk for the lifetime of proposed developments, considered to be 100 years in this case.

4.4.2 When considering flooding from the sea or tidal sources, allowances for regional rates of sea level rise should be taken into account. The contingency allowances for net sea level rise recommended in PPS25 for Southeast England are tabulated below in Table 4.2. In this case, the predicted sea level rise as a result of climate change over the next 100 years (in this case the 108 years from 2000 to 2107) is approximately 1.02 metres.

Table 4.2 Sea Level Rise Calculations (2000 to 2107)

Region	Net Sea Level Rise (mm/year)			
	1990-2025	2025-2055	2055-2085	2085-2115
Southeast England	4.0	8.5	12.0	15.0

4.4.3 The adjusted tidal peak levels, including climate change, are shown in Table 4.3.

4.5 Project Lifespan

4.5.1 Although the regeneration sites will have a mix of uses, the Environment Agency advocates a conservative approach. Therefore for the purposes of this study we have assumed the project lifespan on residential development, which is classified as a 'more vulnerable' development type within PPS25. Residential developments are normally considered to have a design life of 100 years. Therefore for sites where less vulnerable and water compatible uses are proposed, these hydraulic modelling results present a conservative approach.

4.5.2 In order to calculate the extreme water levels to be used in the modelling, the appropriate sea level rise allowance as shown in Table 4.2 has been applied. The increases in sea level due to climate change were added to present day levels to determine the extreme water levels to be used in the modelling.

Table 4.3 Peak Tide Levels for Lowestoft (2107)

Location	1 in 20 Year (mAOD)	1 in 200 Year (mAOD)	1 in 1000 Year (mAOD)
Lowestoft	3.77	4.31	4.69

4.6 Tide Curve

4.6.1 The MIKE21 hydraulic model requires an extreme tidal curve to be used to represent the changes in water level during each extreme event. The extreme tidal curve for each return period scenario is created from two components; an astronomical tide and a surge residual tide. The astronomical tide is assumed to be independent of the metrological conditions.

4.7 Astronomical Tide

4.7.1 Mean Spring Tidal Water levels were extracted from the Admiralty Tidal Tables and applied to a sine curve with a 12-hour cycle. The published tidal data at Lowestoft has been used.

4.8 Storm Surge Profile

4.8.1 The surge component is simulated by a regular half-sinusoidal water level increase with assumed storm duration of 40 hours. In order to achieve the worst case scenario the storm surge peaks at the same moment as the second astronomical high tide in the simulation.

4.8.2 The water levels during a tidal flood event were generated by a summation of the astronomical tide levels and the storm surge residual. An example of the sea water levels used for the hydraulic modelling analysis is shown in Figure 4.1.

4.9 Model & Software Selection

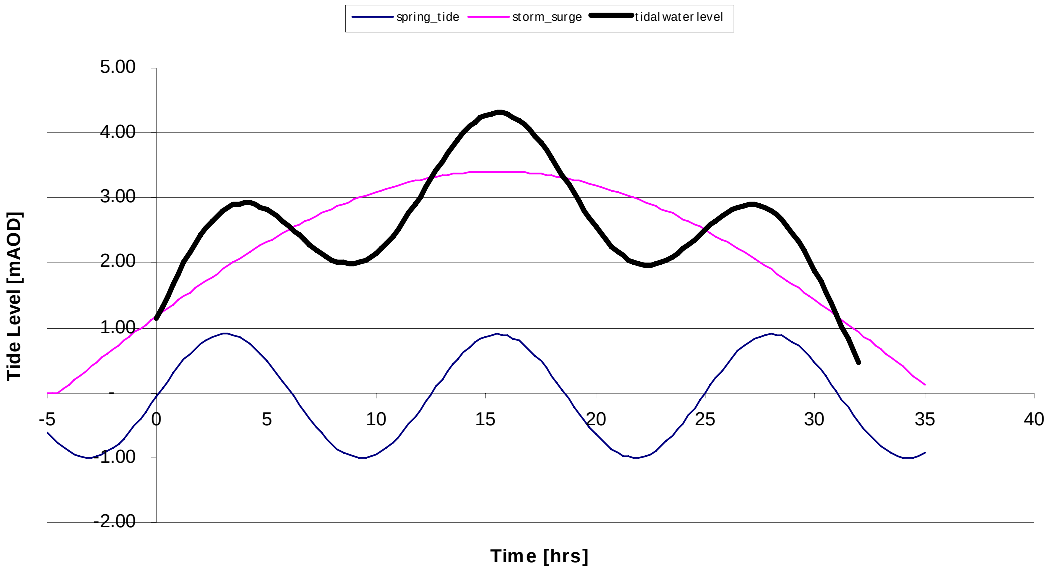
4.9.1 The model used to estimate the maximum flood conditions was required to:

- Accommodate the effects of a flood flow (propagation of a flood wave and continuous change of water level);
- Simulate the hydraulics of overtopping of the flood defences; &
- Generate detailed information on the localised hydraulic conditions over the floodplain area in order to evaluate flood depths.

4.9.2 To investigate the flood propagation resulting from the overtopping of flood defences, the two-Dimensional (2D) hydraulic modelling software MIKE21-HDFM (MIKE21-Hydrodynamic Flexible Mesh Model, 2008 version) has been used.

4.9.3 MIKE21-HDFM simulates water level variations and flows for depth-averaged unsteady two-dimensional free-surface flows. MIKE21 is specifically oriented towards establishing flow patterns in complex water systems, such as coastal waters, estuaries and floodplains. The MIKE21 hydraulic modelling software is developed by the Danish Hydraulic Institute (DHI) Water and Environment. MIKE21-HDFM is a new modelling system based on a flexible mesh approach. The flexible mesh model has the advantage that the model resolution can be varied across the model area. The model utilises the numerical solution of two-dimensional shallow water equations

Figure 4.1 Extreme Tidal Curve with Tidal & Surge Components



4.10 Model Extent & Resolution

4.10.1 For the specific requirements of this investigation, a new MIKE21 flexible mesh has been developed using the MIKE21 program, Mesh Generator. The mesh generator creates a mesh from triangular elements covering the flood cell shown in Figure A3.

4.10.2 Although the same Digital Terrain Model (DTM) and basic flexible mesh concept as that used in the Waveney SFRA, the flexible mesh was vastly redesigned and finalised according to requirements of this study.

4.10.3 The element size in the mesh is varied throughout the model domain depending upon the complexity of floodplain and any topographic features identified as important to flood propagation.

4.10.4 Urban areas and structures within the floodplain have the potential to affect the free flow of floodwater. Embankments, flood defences, significant water courses and other linear features that may be misrepresented by a large element area (2000m^2) have been incorporated into the flexible mesh by creating control-lines parallel to the feature.

4.10.5 By adding control-lines the mesh is forced to follow the alignment of the features ensuring the elevations of important features are picked up during the mesh generation. The control-lines of linear man-made features were schematised by reference to the DTM and 1:25,000 OS maps. The crest levels of linear features, such as secondary flood embankments, road embankments and railway embankments, have been established by interrogation of the DTM. It should be noted that some of the features described above have been identified through a desktop analysis only and have not been verified on the ground.

4.10.6 For this investigation, to facilitate the land raising options within the model, the outlines of each area to be raised were explicitly defined within the updated mesh. This allowed the raised areas to be defined very accurately, as the outlines of the triangular elements within the mesh followed the boundaries of the sites themselves.

4.11 Hydraulic Roughness

4.11.1 Hydraulic roughness represents the conveyance capacity of the vegetative growth, bed and bank material, channel, sinuosity and structures of the floodplain. Within the MIKE21 model, hydraulic roughness is defined by the dimensionless Manning's 'n' roughness coefficient.

4.11.2 Three material roughness classifications were used within the study area: sea, urbanised areas and non-urbanised areas. The assigned hydraulic roughness coefficients for the three defined areas are based on engineering judgement and available literature (e.g. Chow, 1979).

4.11.3 The applied Manning's 'n' roughness coefficients for the sea, urbanised areas and non-urbanised areas were 0.03, 0.07, 0.04 respectively.

4.12 Model Timestep

4.12.1 The model time step interval is very important with respect to the numerical stability of the hydraulic model.

4.12.2 The time step adopted in the MIKE21 models was chosen to ensure stability of the hydraulic models. The stability of the model is defined by two stability criteria, namely the courant number and the CFL stability condition.

4.12.3 In order to ensure numerical stability the courant number was kept smaller than 0.50 during the entire simulation whilst the maximum CFL stability condition was less than 1.0.

4.13 Boundary Conditions

4.13.1 The MIKE21 hydraulic model requires a boundary condition to be defined. This is a time dependent tidal water level boundary located seaward of the area of interest, which replicates the extreme water level during a tidal flood event and provides the important input of water volumes to the model. In this case, the boundary conditions are those of the derived extreme tide curve discussed previously.

4.14 Model Simulations Undertaken

4.14.1 For the hydraulic modelling the flood events analysed were:

- 1 in 20 year plus climate change – existing scenario
- 1 in 200 year plus climate change – existing scenario
- 1 in 1000 year plus climate change – existing scenario
- 1 in 20 year plus climate change – first land raising scenario
- 1 in 200 year plus climate change – first land raising scenario
- 1 in 1000 year plus climate change – first land raising scenario
- 1 in 20 year plus climate change – second land raising scenario
- 1 in 200 year plus climate change – second land raising scenario
- 1 in 1000 year plus climate change – second land raising scenario
- 1 in 20 year plus climate change – third land raising scenario
- 1 in 200 year plus climate change – third land raising scenario
- 1 in 1000 year plus climate change – third land raising scenario

4.14.2 The outputs of the individual model simulations are attached in Appendix A, B and C. These consist of 'difference maps' (maps of the difference in levels between the existing and tested scenarios) and maximum flood depth maps, respectively.

5 Modelling Results

5.1 Result Mapping

5.1.1 The main output of the flood risk modelling is the production of 'difference maps' (maps of the difference in levels between the existing and tested scenarios) and maximum flood depth maps.

5.1.2 Appendix B contains nine difference maps, comparing all three scenarios for each of the three tidal events (1 in 20 year, 1 in 200 year and 1 in 1000 year) against its corresponding existing case.

5.1.3 Appendix C contains 12 depth maps, showing the maximum depth observed for the three tidal events (1 in 20 year, 1 in 200 year and 1 in 1000 year) for each of the four scenarios (existing and the three raising scenarios).

Level Profiles

5.1.4 In order to assess the effects of the land raising scenarios, twelve data extraction points in the flood cell were chosen for each of the raising scenarios. The model results were then queried at each of these locations and compared to those for the existing scenario in order to gauge the impact of the proposals. Details of these locations are shown in Tables 5.1 and Figure A5 for the respective raising scenarios.

Table 5.1 Extraction Points for Land Raising Scenarios

Point	Easting	Northing	Approx Elevation (mAOD)
P1	652,188	292,847	3.6
P2	652,267	292,524	3.3
P3	652,977	292,627	3.6
P4	653,254	293,250	3.0
P5	653,863	293,026	2.7
P6	654,602	292,593	2.4
P7	654,215	292,566	3.1
P8	653,945	292,431	3.2
P9	653,718	292,147	2.2
P10	653,424	291,642	1.9
P11	654,680	292,919	3.0
P12	655,283	293,565	3.7

5.1.5 Sea level profiles at the seaward boundary of the model are comprised of astronomical tide, storm surge and the predicted sea level increase due to climate change in the year 2107. The profiles have a 32-hour duration covering two complete 12-hour tidal periods to ensure that the propagation of tidal flow can reach the whole study area and include a complete high tide and low tide cycle.

5.1.6 The maximum sea water levels for the three tidal events (as shown in Table 4.3) occur at 15:30 in the tidal cycle. This level and time can be used as a reference to assess the magnitude of maximum water level and its time lag between the maximum water level at the seaward boundary and that at the specified locations.

5.2 1 in 20 Year (2107)

5.2.1 Figures D1 to 30 in Appendix D compare the existing and raised scenario events in real time using flood hydrographs (flood level with respect to time) for the twelve extraction points.

5.2.2 The maximum flood levels and maximum flood depths are compared with the existing scenario in Table 5.2 (Scenario 1), Table 5.3 (Scenario 2) and Table 5.4 (Scenario 3),, below.

5.2.3 The times that initial flooding begins to occur and the times that the maximum depth occurs for each group of extraction points are compared with the existing scenario in Table 5.5 (Scenario 1), Table 5.6 (Scenario 2) and Table 5.7 (Scenario 3), below.

Table 5.2 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 1** During the **1 in 20 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 1	Existing	Scenario 1
P1	2.922	-	0.298	-
P2	3.779	3.776	0.469	0.460
P3	3.097	3.096	0.272	0.263
P4	3.778	3.775	0.815	0.813
P5	3.776	3.773	1.053	1.050
P6	3.773	-	1.413	-
P7	3.774	3.772	0.708	0.699
P8	3.648	3.642	0.489	0.484
P9	2.030	2.027	0.363	0.360
P10	2.512	2.507	0.661	0.657
P11	3.772	3.771	0.804	0.803
P12	-	-	-	-

Table 5.3 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 2** During the **1 in 20 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 2	Existing	Scenario 2
P1	2.922	-	0.298	-
P2	3.779	3.776	0.469	0.460
P3	3.097	3.096	0.272	0.263
P4	3.778	3.775	0.815	0.812
P5	3.776	3.774	1.053	1.051
P6	3.773	-	1.413	-
P7	3.774	3.773	0.708	0.699
P8	3.648	3.641	0.489	0.483
P9	*2.030*	*2.055*	*0.363*	*0.387*
P10	*2.512*	*2.542*	*0.661*	*0.692*
P11	3.772	-	0.804	-
P12	-	-	-	-

Table 5.4 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 3** During the **1 in 20 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 3	Existing	Scenario 3
P1	2.922	0.632	0.298	0.052
P2	3.779	3.776	0.469	0.460
P3	3.097	3.096	0.272	0.263
P4	3.778	3.775	0.815	0.812
P5	3.776	3.774	1.053	1.051
P6	3.773	-	1.413	-
P7	3.774	3.773	0.708	0.699
P8	3.648	3.643	0.489	0.485
P9	2.030	2.026	0.363	0.359
P10	2.512	2.506	0.661	0.656
P11	3.772	-	0.804	-
P12	-	-	-	-

Table 5.5 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 1** During the **1 in 20 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 1	Existing	Scenario 1
P1	13:30	-	15:45	-
P2	13:05	13:05	15:45	15:40
P3	14:05	14:10	15:45	15:40
P4	13:35	13:35	15:45	15:40
P5	13:25	13:25	15:45	15:45
P6	13:05	-	13:45	-
P7	13:00	13:00	15:45	15:45
P8	13:40	13:45	15:45	15:45
P9	15:35	15:30	17:50	17:50
P10	15:50	15:50	17:50	17:50
P11	13:35	13:35	15:45	15:45
P12	-	-	-	-

Table 5.6 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 2** During the **1 in 20 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 2	Existing	Scenario 2
P1	13:30	-	15:45	-
P2	13:05	13:05	15:45	15:40
P3	14:05	14:10	15:45	15:45
P4	13:35	13:35	15:45	15:40
P5	13:25	13:25	15:45	15:45
P6	13:05	-	13:45	-
P7	13:00	13:00	15:45	15:45
P8	13:40	13:45	15:45	15:45
P9	15:35	15:30	17:50	17:50
P10	15:50	15:50	17:50	17:50
P11	13:35	-	15:45	-
P12	-	-	-	-

Table 5.7 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 3** During the **1 in 20 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 3	Existing	Scenario 3
P1	13:30	14:20	15:45	15:40
P2	13:05	13:05	15:45	15:40
P3	14:05	14:10	15:45	15:45
P4	13:35	13:35	15:45	15:40
P5	13:25	13:25	15:45	15:45
P6	13:05	-	13:45	-
P7	13:00	13:00	15:45	15:45
P8	13:40	13:40	15:45	15:45
P9	15:35	15:30	17:50	17:50
P10	15:50	15:50	17:50	17:50
P11	13:35	-	15:45	-
P12	-	-	-	-

5.3 1 in 200 Year (2107)

5.3.1 Figures D1 to 30 in Appendix D compare the existing and raised scenario events in real time using flood hydrographs (flood level with respect to time) for the twelve extraction points.

5.3.2 The maximum flood levels and maximum flood depths for each group of extraction points are compared with the existing scenario in Table 5.8 (Scenario 1), Table 5.9 (Scenario 2) and Table 5.10 (Scenario 3), below.

5.3.3 The times that initial flooding begins to occur and the times that the maximum depth occurs for each group of extraction points are compared with the existing scenario in Table 5.11 (Scenario 1), Table 5.12 (Scenario 2) and Table 5.13 (Scenario 3), below

Table 5.8 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 1** During the **1 in 200 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 1	Existing	Scenario 1
P1	4.229	-	0.740	-
P2	4.304	4.304	0.954	0.953
P3	4.304	4.304	0.719	0.719
P4	4.304	4.303	1.341	1.341
P5	4.302	4.302	1.579	1.579
P6	*4.301*	*4.312*	*1.942*	*1.952*
P7	4.301	4.301	1.235	1.222
P8	4.100	4.091	0.942	0.933
P9	3.828	3.800	1.585	1.557
P10	3.832	3.804	1.934	1.907
P11	4.304	4.304	1.337	1.336
P12	4.292	4.292	0.593	0.593

Table 5.9 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 2** During the **1 in 200 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 2	Existing	Scenario 2
P1	4.229	-	0.740	-
P2	4.304	4.297	0.954	0.946
P3	4.304	4.297	0.719	0.712
P4	4.304	4.296	1.341	1.333
P5	4.302	4.295	1.579	1.572
P6	*4.301*	*4.308*	*1.942*	*1.949*
P7	4.301	4.293	1.235	1.215
P8	4.100	4.092	0.942	0.934
P9	*3.828*	*3.838*	*1.585*	*1.595*
P10	*3.832*	*3.842*	*1.934*	*1.945*
P11	4.304	-	1.337	-
P12	4.292	-	0.593	-

Table 5.10 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 3** During the **1 in 200 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 3	Existing	Scenario 3
P1	4.229	3.681	0.740	0.299
P2	4.304	4.296	0.954	0.945
P3	4.304	4.297	0.719	0.711
P4	4.304	4.295	1.341	1.333
P5	4.302	4.294	1.579	1.571
P6	4.301	4.301	1.942	1.942
P7	4.301	4.293	1.235	1.214
P8	4.100	4.083	0.942	0.925
P9	3.828	3.784	1.585	1.541
P10	3.832	3.787	1.934	1.890
P11	4.304	-	1.337	-
P12	4.292	-	0.593	-

Table 5.11 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 1** During the **1 in 200 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 1	Existing	Scenario 1
P1	12:25	-	15:40	-
P2	12:00	12:00	15:40	15:40
P3	13:00	13:20	15:40	15:40
P4	12:35	12:35	15:40	15:40
P5	12:25	12:25	15:45	15:40
P6	04:05	14:00	15:45	15:35
P7	12:00	12:00	15:45	15:40
P8	12:35	12:35	15:50	15:50
P9	14:10	14:10	17:40	17:45
P10	14:20	14:20	17:45	17:45
P11	12:35	12:35	15:45	15:45
P12	14:10	14:10	15:45	15:45

Table 5.12 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 2** During the **1 in 200 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 2	Existing	Scenario 2
P1	12:25	-	15:40	-
P2	12:00	12:00	15:40	15:45
P3	13:00	13:20	15:40	15:45
P4	12:35	12:35	15:40	15:45
P5	12:25	12:25	15:45	15:50
P6	04:05	14:00	15:45	15:35
P7	12:00	12:00	15:45	15:45
P8	12:35	12:35	15:50	15:55
P9	14:10	14:10	17:40	17:40
P10	14:20	14:20	17:45	17:40
P11	12:35	-	15:45	-
P12	14:10	-	15:45	-

Table 5.13 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 3** During the **1 in 200 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 3	Existing	Scenario 3
P1	12:25	13:10	15:40	15:45
P2	12:00	12:00	15:40	15:45
P3	13:00	13:20	15:40	15:45
P4	12:35	12:35	15:40	15:45
P5	12:25	12:25	15:45	15:50
P6	04:05	14:00	15:45	15:35
P7	12:00	12:00	15:45	15:45
P8	12:35	12:35	15:50	15:50
P9	14:10	14:10	17:40	17:45
P10	14:20	14:20	17:45	17:50
P11	12:35	-	15:45	-
P12	14:10	-	15:45	-

5.4 1 in 1000 Year (2107)

5.4.1 Figures D1 to 30 in Appendix D compare the existing and raised scenario events in real time using flood hydrographs (flood level with respect to time) for the twelve extraction points.

5.4.2 The maximum flood levels and maximum flood depths for each group of extraction points are compared with the existing scenario in Table 5.14 (Scenario 1), Table 5.15 (Scenario 2) and Table 5.16 (Scenario 3), below.

5.4.3 The times that initial flooding begins to occur and the times that the maximum depth occurs for each group of extraction points are compared with the existing scenario in Table 5.17 (Scenario 1), Table 5.18 (Scenario 2) and Table 5.19 (Scenario 3), below.

Table 5.14 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 1** During the **1 in 1000 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 1	Existing	Scenario 1
P1	4.676	-	1.108	-
P2	4.677	4.674	1.325	1.322
P3	4.676	4.675	1.040	1.039
P4	4.676	4.674	1.713	1.711
P5	4.675	4.673	1.952	1.950
P6	4.675	4.681	2.316	2.322
P7	4.673	4.671	1.608	1.592
P8	4.530	4.517	1.371	1.359
P9	4.487	4.475	2.244	2.232
P10	4.490	4.477	2.593	2.580
P11	4.680	4.679	1.712	1.711
P12	4.690	4.690	0.986	0.986

Table 5.15 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 2** During the **1 in 1000 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 2	Existing	Scenario 2
P1	4.676	-	1.108	-
P2	4.677	4.651	1.325	1.300
P3	4.676	4.651	1.040	1.016
P4	4.676	4.650	1.713	1.687
P5	4.675	4.648	1.952	1.925
P6	4.675	4.666	2.316	2.307
P7	4.673	4.646	1.608	1.567
P8	4.530	4.510	1.371	1.352
P9	4.487	4.473	2.244	2.230
P10	4.490	4.476	2.593	2.578
P11	4.680	4.678	1.712	1.408
P12	4.690	4.689	0.986	0.284

Table 5.16 Maximum Water Levels and Maximum Flood Depths for Existing and Land Raising **Scenario 3** During the **1 in 1000 Year (2107)** Event

Point	Max Water Level (mAOD)		Max Flood Depth (m)	
	Existing	Scenario 3	Existing	Scenario 3
P1	4.676	4.612	1.108	0.636
P2	4.677	4.650	1.325	1.298
P3	4.676	4.650	1.040	1.014
P4	4.676	4.649	1.713	1.686
P5	4.675	4.647	1.952	1.924
P6	4.675	4.666	2.316	2.306
P7	4.673	4.645	1.608	1.566
P8	4.530	4.493	1.371	1.334
P9	4.487	4.448	2.244	2.205
P10	4.490	4.450	2.593	2.553
P11	4.680	4.678	1.712	1.408
P12	4.690	4.689	0.986	0.283

Table 5.17 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 1** During the **1 in 1000 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 1	Existing	Scenario 1
P1	11:45	-	15:40	-
P2	03:00	03:00	15:40	15:45
P3	12:00	12:45	15:45	15:45
P4	04:00	04:00	15:45	15:45
P5	03:40	03:40	15:45	15:50
P6	03:00	13:15	15:45	15:40
P7	03:00	03:00	15:45	15:45
P8	11:55	11:55	16:15	16:15
P9	13:25	13:25	16:50	16:55
P10	13:35	13:35	16:55	16:55
P11	03:50	03:50	15:45	15:45
P12	13:20	13:20	15:45	15:45

Table 5.18 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 2** During the **1 in 1000 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 2	Existing	Scenario 2
P1	11:45	-	15:40	-
P2	03:00	03:00	15:40	15:55
P3	12:00	12:45	15:45	15:55
P4	04:00	04:00	15:45	15:55
P5	03:40	03:40	15:45	15:55
P6	03:00	13:15	15:45	15:50
P7	03:00	03:00	15:45	15:55
P8	11:55	11:55	16:15	16:25
P9	13:25	13:25	16:50	16:55
P10	13:35	13:35	16:55	17:00
P11	03:50	14:40	15:45	15:35
P12	13:20	14:50	15:45	15:45

Table 5.19 Time of Initial Flooding and Time of Maximum Flood Depth for Existing and Land Raising **Scenario 3** During the **1 in 1000 Year (2107)** Event

Point	Time of Initial Flooding (hh:mm)		Time of Max Flood Depth (hh:mm)	
	Existing	Scenario 3	Existing	Scenario 3
P1	11:45	12:25	15:40	15:55
P2	03:00	03:00	15:40	15:55
P3	12:00	12:35	15:45	15:55
P4	04:00	04:00	15:45	15:55
P5	03:40	03:40	15:45	15:55
P6	03:00	13:15	15:45	15:50
P7	03:00	03:00	15:45	15:55
P8	11:55	11:55	16:15	16:20
P9	13:25	13:25	16:50	17:00
P10	13:35	13:35	16:55	17:05
P11	03:50	14:40	15:45	15:45
P12	13:20	14:50	15:45	15:35

5.5 Discussion

5.5.1 The effects on flood levels as a result of land raising during both of the 1 in 20 year, 1 in 200 year and 1 in 1000 year (2107) events are generally minimal.

5.5.2 The extraction results show a decrease in peak flood levels, albeit by very small amounts (less than one centimetre) as a result of the various constrictions and changes to flood paths caused by the land raising. This is especially pronounced during the Scenario 2 case (highlighted in blue in the tables), where the significant amounts of land raising further reduce peak flooding levels by limiting the tidal influence reaching Lake Lothing. Again, this influence is relatively minor but visible on the many hydrographs contained in Appendix D.

5.5.3 The exceptions to this observation are points 9 and 10 during Scenario 2. In these cases, the peak levels rose by approximately 2.5 centimetres and 3.0 centimetres, respectively. This observation seems largely related to the presence of the Horn Hill land raising and the fact that this raising blocks the flow path that otherwise exists from South Quay and south along St Johns Road and beyond the Horn Hill site itself. When this flow path is blocked, it appears that flood flows travel down to the Durban Road and Birds Lane area (near Points 9 and 10) with more intensity, causing the slight increases in peak levels.

5.5.4 This is further confirmed by the fact that during the 1 in 1000 year (2107) case for Scenario 2, this increase is no longer experienced. This is explained by the fact that, during this case, the tidal levels are high enough to inundate the flow path over the Horn Hill site and the increases at Points 9 and 10 are no longer seen.

5.5.5 During the Scenario 3 the land raising for the Horn Hill site was removed to confirm if this site was responsible for the minor changes experienced in the lower flood return period events. The Scenario 3 tables show these increases are not experienced and there is general trend of lower flood depths across the flood cell. This confirms that a flow path runs through the Horn Hill site, so land raising of the entire site has a potential minor impact on water levels elsewhere in the flood cell. Therefore further development of this site will need to look closely at secondary defence options to ensure any proposed land raising does not impact on this flow path.

6 Summary

6.1.1 The Hydraulic modelling was completed for the 3 land raising scenarios. The first assuming four sites further on in the planning process are land raised according to their proposed ground contouring and site plans. The second assuming the remaining four key sites are land raised to the 1 in 200 year plus climate change water level. The third assumed the same land raising of sites as scenario 2 with the exception of the Horn Hill site which remained at existing ground levels.

6.1.2 The results were analysed at twelve points in the flood cell. The points were located near to the sites and at key points where increases in water level would have been anticipated.

6.1.3 The hydraulic modelling shows a general pattern for all three different scenarios, where the maximum water level experienced at the extraction points decrease after the land raising. In most cases this is minor by 1-2cm which is within the bounds of the model accuracy.

6.1.4 There is a notable increase in the time to inundation and time to peak hazard following the land raising options. This is as great as 10 hours in some cases, and caused by the land raising areas affecting flow paths in the greater flood cell. A 10 hour delay to inundation could improve flood risk evacuation and emergency preparation, therefore in this case the land raising options would have a benefit to the wider flood cell with respect to flood risk.

6.1.5 The removal of the land raising for the Horn Hill site in the Scenario 3 removed all increases in flood depths in the flood cell. This indicates that the previously recorded increases, albeit minor (5cm) were a result of a blocked flow path through the Horn Hill site. Therefore it would be suggested that future development of this site is approached in isolation to the other 7 sites analysed, with more attention required on secondary defence options to ensure flow paths in the flood cell are unaffected.

6.1.6 Planning applications for the sites identified as part of this study should assess the potential for off-site impacts across a wider area as part of a site specific flood risk assessment, with suitable mitigation included as part of any planning applications that are brought forward.

6.1.7 Discussions with the Environment Agency previously suggested that the functional floodplain definition of the Lake Lothing area was related to its function for conveyance of flood flows. The results of this hydraulic modelling show land raising and removal of the seven sites in Scenario 3 from the floodplain do not result in increases in water level elsewhere within the flood cell. This suggests the immediate frontage to Lake Lothing, whilst it may be at risk of flooding from a 1in 20 year scenario (2107) does not convey flood routes as part of a functional floodplain. Therefore the classification of this area as Flood Zone 3a may be more appropriate.

ANNEX A- Flood Defence Assessment

Flood Defence Assessment

Introduction

This study has been carried out to investigate the existing and possibly future provision of strategic defence for the Lake Lothing area and coastline.

The existing defences are generally in a good condition, however, they are not to a high specification and will not withstand increased water depths as a result of climate change.

During the 1953 event, Lowestoft was extensively flooded with water levels recorded at 3.35m AOD. This is significantly higher than many of the quay levels currently surrounding the Lake Lothing area. Consequently, during an event with a similar magnitude, Lowestoft would once again become seriously inundated.

Lake Lothing runs through the centre of Lowestoft from the Bascule-Bridge on the A12 in the east, to Mutford Lock, which divides Lake Lothing from Oulton Broad in the west. The areas surrounding Lake Lothing host significant residential, commercial and industrial developments, as well as an active port ad docklands area.

Except near Mutford Bridge, there are no formal defences protecting these areas. None of the quays around Lake Lothing have floodwalls. The crests of the quay walls are levelled with the paved quays with the inland land levels determining the defence level.

Existing defence types within the Lake Lothing area

River/Seawall

River walls (also known as seawalls when used along open coastline) are protective walls built along the bank/shoreline. They provide protection from high water levels and heavy wave action. The majority of walls are constructed from steel reinforced concrete but can also be constructed from timber and sheet pile walls.

Revetments

Revetments are armouring placed along embankments or natural channel banks to prevent erosion and scour from wave action and/or high flow velocities. The armouring may be constructed from a wide range of materials including concrete, Essex blocks (small rectangular blocks), or rock armouring.

Earth Bunds

Earth bunds, also known as earth embankments, protect an area from flooding by providing a mass of earth, which raises the surrounding land level preventing inundation from a specific direction. Typically the crest of a bund is flat and a minimum of 3m wide. Wider bunds have a reduced risk of breaching, but have greater land take and costs associated with them. Side slopes down from the crest to the natural level of the land should have a gradient of 1 in 3 as a maximum, but the actual slope depends on the material used to construct the bund.

Bunds are constructed from mass fill material, the majority is usually earth, but other bulk fill material, such as aggregates, may be used to form the core. Bunds may be reinforced with piles, concrete retaining wall structures, or sheet pile walls driven through the crest, to provide structural stability, additional resistance to breaching and to raise the level of protection.

Distribution of defences within the Lake Lothing area

A walk over survey has been carried out as part of the assessment, inspecting the defences wherever access could be obtained. The defences have been inspected along the majority of Lake Lothing's shoreline, the coastline in front of the East of England Park and Fishers' Wharf, and the coastline along South Beach. The observations recorded have been presented below in terms of relevance to the eight proposed development sites.

Oswald Boatyard

The upstream end of Lake Lothing is defined by the Mutford Lock, which separates Lake Lothing from Oulton Broad. The lock consists of two sets of double pointing gates and has been surveyed to have a crest level of 2.54m AOD (ref 3). The lock is surrounded by paved areas, which are at a slightly lower elevation. Overtopping and inundating the grounds surrounding the dock may therefore occur during an extreme event. The two gates forming part of the dock can be seen in Photo 0-1 and Photo 0-2.

Southeast of Mutford Lock on the south bank of Lake Lothing, along the bank parallel to Mutford Bridge Road, the frontage consist of a brick wall. This wall extends down to the caravan park. Crest levels of the wall are thought to range between 5.3 – 3.56m AOD (ref 3). An earth embankment extends perpendicular from the brick wall and joins the higher ground of the railway embankment east of the caravan park. The lowest crest level along this embankment has been identified as 2.89m AOD (ref 3).

There are no defences east of Mutford Lock on the north bank of Lake Lothing along to Leathes Ham. This stretch of shoreline benefits by the rising ground elevations adjacent to the north shore, which provide a degree of flood protection for minor events. The shoreline in front of the Oswald Boatyard site is surrounded by higher ground elevations to the north, west and east, with only the southern boundary of the site along Lake Lothing identified as a low lying area.

Photo 0-1 Gate closest to Lake Lothing looking east

Photo 0-2 Gate closest to Oulton Broad looking west

 **Photo 0-3 Undefended areas in front of the Oswald Boatyard site looking west**	 **Photo 0-4 Undefended areas opposite Oswald Boatyard site looking south**

Peto Square North

East of Leathe's Ham towards the Bascuel Bridge, the shoreline is protected by a combination of structures. The majority of the north bank is fronted by steel sheet and timber piling with concrete capping backed by paved concrete areas. The crest levels varies between 2.8m AOD to 3.4m AOD (Ref: 3) The undefended natural beach west of Leathe's Ham is connected to a section of Armorflex revetments between the natural beach in front of Leathe's Ham and the depot south east of Leathe's Ham. These revetments have a crest height of approximately 2.5m AOD and extend approximately 345m along the railway line (ref3).

A small section further east, opposite the Riverside Business Park, is also fronted by revetments with a hollow quay deck and concrete paving behind the defences as seen in Photo 0-7.

 **Photo 0-5 Natural beach in front of railway line, north bank**	 **Photo 0-6 Armorflex revetments, north bank**

Photo 0-7 Revetments with a hollow quay deck north bank

Photo 0-8 Steel sheet piling with concrete capping, north bank

Fishers' Wharf

The north quay frontage east of Bascule Bridge is protected by a combination of steel sheet piling with concrete capping backed by paved areas, combined with areas with slightly raised ground near the inner north pier of the Trawl Basin. Further north in the Waveney Dock area, the banks are protected by steel sheet piling with concrete capping backed by paved concrete. Several undefended pockets are present on the North Pier Extension. Further north the Hamilton Dock shoreline is protected by a combination of concrete walls, steel and timber piling with concrete capping.

Photo 0-9 Raised land behind Trawl Basin

Photo 0-10 Steel sheet piling with concrete capping

Photo 0-11 Concrete wall inside Hamilton Dock

Photo 0-12 Undefended areas inside Waveney Dock along the North Pier Extension

East of England Park

The Lowestoft Ness Seawall provides protection along the northern coastline. The seawall runs between higher grounds north of East of England Park and the northern pier extension opposite Fisher's Wharf. Access could not gained to the northern pier at the time of the survey, the condition and type of the seawall along this strip could therefore not be confirmed. The wall north of Fishers' Wharf consists of a stepped concrete apron backed by a concrete seawall. Armour rocks providing toe protection are located in front of the structure along the southern section to provide additional protection against heavy wave action. Further north the armour rocks are replaced with groynes. A typical cross section of the wall is displayed in Photo 0-14.

Increased water levels are likely to result in greater wave action at the wall, with the potential for accelerated foreshore erosion due to the forces generated by wave reflection. Where the toe of the wall is unprotected, this accelerated foreshore erosion may result in undermining of the wall foundations and hence cause instability of the wall itself in the longer term.

Higher water levels and wave crests could also result in the ground north of the seawall being overtopped, where the ground levels are at a lower level than the wall. An area of low lying ground behind the flood wall, which is linked to the area north of the wall, would act as flow route allowing flood water to enter the East of England Park from the north.

Photo 0-13 Seawall north of Fisherman's Wharf looking south

Photo 0-14 Typical cross-section of seawall

Photo 0-15 Seawall further north with groynes looking south

Photo 0-16 Unprotected seawall toe looking north

South Peto Square

The South Quay frontage east of Bascule Bridge, is protected in a similar manner as the north bank, with a combination of steel sheet and timber piling with concrete capping backed by paved areas. The quay crest at the Yacht Boat Club is at a lower level compared to the surrounding areas. The yacht club is enclosed by a brick wall to the west and further defended by higher ground elevations to the southwest. The effective crest height of the marina is thus determined by the ground elevations and structures surrounding it.

Concrete walls run along the whole length of the South Pier. These cannot be regarded as formal flood defence walls, as the end of the pier is completely open to the sea and there are a number of holes through the walls.

The base of the South Pier is lined with a concrete toe, which joins a stone pitched revetment and concrete capping. This type of defence wall extends along the South Beach until the shoreline joins higher grounds north of Pakefields Cliff.

The South Wharf west of the South Quay is fronted by a concrete wall backed with concrete paved areas. Further west, the shoreline is protected by a combination of steel sheet and timber piling with concrete capping backed by paved areas. This continues until it joins the natural beach west of Riverside Business Park.

The condition of the defences along this stretch was found to vary along the shoreline. Areas with particularly poor condition of the defences were found in front of the South Wharf parallel to Belvedere Road. See Photo 0-20. Partial failure of the defence wall was also observed next to the Bascule Bridge, which can be seen in Photo 0-19.

A difference in crest height was observed between the quay crest along the South Quay and the South Wharf in front of the commercial area north of Belvedere Road, which appear to be at a lower level.

Photo 0-17 Seawall along the South Beach looking south

Photo 0-18 Concrete wall at the base of the South Pier looking north

 **Photo 0-19 Concrete on south bank near Bascule bridge looking west along South Quay**	 **Photo 0-20 Deterioration of defence wall along South Wharf looking east**

Horn Hill

The shoreline and defence structures relevant to the Horn Hill development coincide with those affecting the South Peto Square development. The Horn Hill development is also likely to be affected by the defences in front of the existing ASDA store and the land immediately to the east of ASDA.

The river frontage in front of the ASDA store and the neighbouring site is currently defended by steel sheet piling with concrete capping and land raising following development of this area.

As a result of the land raising, a large difference in quay crest height can now be observed between the low lying South Wharf in front on Belvedere Road, and the quay crests along the raised ADSA-site and the land immediately to the east of ASDA.

Due to the difference in quay crest levels along the shoreline, floodwater is likely to overtop the low-lying South Wharf first and inundate the low-lying areas further south. Floodwater is anticipated to flow towards Horn Hill via the low-lying car park and cycle track underneath Mill Hill Road.

 **Photo 0-21 Affect of land raising at ASDA site looking south**	 **Photo 0-22 Potential flow path towards Horn Hill**

Waveney Campus

The majority of the river frontage within the Kirkley Waterfront area, including the Waveney Campus site, is protected by a combination of steel sheet and timber piling with concrete capping backed by paved areas. Abrupt differences in quay crest levels were observed between different sites within the business park, some in excess of 0.5 meters. The variation in crest levels along the entire stretch between Bascule Bridge and west of the business park is thought to vary between 2.6m AOD to 3.35m AOD, (ref: 3). Raised quay crests with sloping topography towards low-lying grounds inland of the shoreline were also observed within the business park.

An area of undefended land is present immediately to the west of the Riverside Business Park. This area consists of a sand and shingle beach backed by rising ground levels with a crest level of approximately 3.2m OAD, (ref: 3).

Photo 0-23 Sheet piling along Kirkley Water Front

Photo 0-24 Raised quay crest with sloping ground

Photo 0-25 Difference in crest levels

Photo 0-26 Undefended sand and shingle beach

Brooke Marina

The undefended sand and shingle beach west of the Riverside Business Park continues up to the Brooke Business and Industrial Park. From this point onwards, the frontage consists of a steel sheet pile quay backed by a concrete pavement with a crest level of approximately 3.36m AOD (ref 3).

Revetments are used along a short section of the School Road Quay Marina along the south banks of Lake Lothing as seen in Photo 0-29.

An undefended sand and shingle beach lie further west of the School Road Quay, which is backed by an earth embankment with a crest level of approximately 2.5m AOD, (ref 3).

Photo 0-27 Undefended sand and shingle beach east of Brooke Marina looking east

Photo 0-28 Sheet piling with concrete capping in front of Brooke Marina looking west

Photo 0-29 Revetments along School Road Quay looking west

Extreme tidal water levels and resulting water surface elevations

The extreme water levels at Lowestoft, up to the 1 in 200-year event inclusive of the effect of climate change, taken from the *'Report on Extreme Tide Levels: Anglian Region, Central and Eastern Areas'* (Royal Haskoning, 2007), are tabulated below.

Estimates of the effects of climate change on extreme water levels were based on current DEFRA guidelines. These assume a progressive increase in water levels with time. For the East of England, East Midlands, London and South England the increases in peak tidal levels as a result of climate change are predicted as 4mm/year increase during the first 18 years, 8.5mm/year during the next 30 years, 12mm/year during the following 30 years and 15mm/year during the last 22 years. The accumulative effect of which results in a net increase of 1.02m.

Table 0-1 Extreme Water Levels

1 in 20-year [m AOD]	1 in 20-year + climate change [m AOD]	1 in 200-year level [m AOD]	1 in 200-year + climate change [m AOD]
2.75	3.77	3.29	4.31

Based on the tabulated extreme water levels in Table 0-1, hydraulic modelling has been undertaken to investigate the flood risk on all eight sites.

To investigate the affect of partial or complete land raising on the development sites, three model scenarios have been run representing the existing conditions, land raising of the interim 4 sites and land raising on all 8 sites. The resulting maximum water surface elevation resulting from the 1 in 200-yr event inclusive of climate change under the different conditions and proposed land raising levels have been tabulated below.

Table 0-2 Resulting water surface elevations, 1 in 200 year scenario with climate change (2108)

Development area	Proposed land raising levels m AOD	Water level assuming existing conditions m AOD	Water levels assuming interim land raising of 4* sites only m AOD	Water levels assuming land raising of all 8 sites m AOD
Oswald Boatyard*	4.4	4.30	Dry	Dry
Brook Marina*	4.6	4.30	Dry	Dry
Waveney Campus*	3.3 – 4.2	4.30	4.30	4.30
South Peto Square*	4.4	4.30	Dry	Dry
North Peto Square	4.4	4.30	4.30	Dry
Horn Hill	4.4	3.87	3.84	Dry
Fisher's Wharf	4.4	4.31	4.31	Dry
East of England Park	4.4	422 – 4.31	422 – 4.31	Dry

As seen from the above table, land raising on the 4* interim sites would not result in an increase in flood depth elsewhere. Due to only partial land raising at the Waveney campus site, some of the site would experience minor inundation. All development at Waveney Campus is proposed on the higher raised levels with only parking and landscaped areas on the lower levels.

A slightly lower water depth is shown to occur at the Horn Hill site following land raising of the four interim sites. This is expected as the land raising of the South Peto Square, combined with the partial land raising of the Waveney Campus site would significantly restrict the flow paths and volumes of water that may reach the Horn Hill site, offering a form of flood defence to the lower lying land behind it.

Fluvial Considerations

Fluvial floodwater entering the Lake Lothing area is unlikely to be influenced by the change in floodplain storage due to proposed land raising of the development sites. As previously mentioned, the hydraulic modelling was carried out assuming an extreme tidal event. This represents a worst case scenario as it is considered that a fluvial event with a return period of 1 in 100 years, or a combined fluvial flood event and storm surge would result in lower water levels within Lake Lothing than the extreme tidal event. Thus during a fluvial event, exclusion of the development sites from the floodplain will not increase the flood risk within the Lake Lothing area, since land raising during a more extreme event has already been shown not to effect the flood levels within the area.

In addition, due to the magnitude of the extreme tidal levels during an extreme event, seawater would be expected to overtop the floodgates at Mutford Bridge at their current height and drain into Oulton Broad. The difference in height between the predicted water level and the crest height at Mutford dock has been estimated to 1.77m. Thus in the unlikely event a 1 in 200-year tidal event was to coincide with 1 in 100-year fluvial event, flood water flowing down the River Waveney would not be able to contribute to the flood levels within the Lake Lothing area as it would be held back by the tidal inflow.

Flood Defence Options

Upgrade Existing Defences

The first option is to upgrade and repair the existing defences where necessary to the appropriate standard. Upgrading of existing defences may only be applicable along the coastline, as the coastal seawalls north and south of Lowestoft are the only two formal defences present in the Lake Lothing flood cell.

A structural assessment would be required to check for erosion and the condition of the walls prior to any improvement work. If found to be structurally stable, then it would be possible to raise the crest of the walls to ensure the correct level of protection is provided along the entire coastal frontage of Lowestoft.

Improvement work of these defences should be carried out to ensure a minimum crest height of 4.4m AOD plus a 300mm freeboard is provided (this would provide protection to the 1 in 200 year plus climate change scenario). Thus the final crest height should be set at 4.7m AOD. This height should be maintained along the entire length of the defences until the defences are joined up with higher grounds.

In order to reduce the likelihood of failure of the seawall in the future it may also be necessary to provide continuous toe protection. Toe protection would most likely consist of armour units, either rock or concrete, placed along the base of the wall to prevent erosion and undermining of the seawall.

New defences

New defences in terms of floodwalls and earth embankments may be practical where there is sufficient space. A minimum of an eight metre set back distance would be required between the defence structure and any buildings adjacent to the structure for access purposes. The width of the defence structure must also be sufficient to allow access for maintenance. Concrete defence walls can be constructed to withstand long-term exposure to both wave actions and impacts caused by debris. This type of defence walls may therefore be more suitable along the Lake Lothing and Dock areas of the shoreline.

In addition to the buffer zone and access requirements for maintenance, earth embankments should also be constructed with a slope no steeper than 1:3. This would require a large amount of land take. This type of defence structure is therefore unlikely to be suitable in restricted urbanised areas, but may be more suitable in the area around the East of England Power Park. The strength of an earth embankment is also slightly lower when compared to reinforced concrete walls. The alignment and location of earth embankments should be constructed to avoid over exposure of wave actions and impacts from debris. Additional armouring is likely to be required to provide protection from erosion.

Land raising

Land raising or partial land raising may be more suitable for sites with limited space available between site boundaries and the shoreline. The hydraulic modelling carried to investigate the effect of land raising on the proposed regeneration sites has showed that although large areas within the flood cell will effectively be removed from the floodplain, land raising will not result in significant increase in flood levels elsewhere.

Partial land raising will need to be combined with additional defence structures in order to provide the required level of protection stipulated by the EA. This can be achieved by raising the quay crest by the water frontage to a level above the predicted extreme 1 in 200-year tidal level and allow a stepped or sloped gradient to inland areas. This approach may need to be complemented by additional structures to prevent floodwater from low-lying neighbouring sites from entering the development site from alternative pathways.

Partial land raising may also need additional structures to prevent water from overtopping the quay crest, unless areas can be created into the sites for parking and landscaping that are able to flood. A small embankment with a retaining wall with partial raised land could be constructed as part of a river walkway along the frontage of Lake Lothing. This could provide a sufficient level of protection whilst ensuring safe access to the water frontage without shielding off the view of Lake Lothing.

Recommended Options

Oswald Boatyard

Due to small scale of this site, and high ground surrounding the site, land raising the quay crest between the Railway Bridge and Mutford Bridge is likely to be sufficient for providing the required level of protection for the development of this site. An alternative option would be to construct a defence wall along the Lake Lothing frontage tying in to the higher ground on the east and west of the site.

Peto Square North

An embankment with a retaining wall backed up by partial land raising along the water frontage could be constructed to provide a sufficient level of protection whilst providing a pedestrian route in front of North Peto Square. The height of the retaining wall should be constructed at 4.7m AOD and would need to be linked to the higher grounds north of the site and to be connected to the defences in front of Fishes' Wharf. As such land raising near the Bascuel Bridge may be necessary to maintained a continuous defence line of 4.7m AOD between Peto Square North and Fisher's Wharf.

A continuous embankment defence would not be appropriate for this site, as the flow paths into the site are from the south, west and east and the earth embankments as a secondary defence would require significant land take on this site.

Fishers' Wharf

Similarly to the Peto Square North, the proposed pedestrian route along the water frontage can be constructed to form part of the defence by raising the land adjacent to the shoreline, constructing an embankment with a retaining wall along the Lake Lothing frontage. The wall would need to be linked to the defences in front of Peto Square North. The northern part of Fishers' Wharf would either need to be connected to the higher ground west of the site, or extended and linked to potential defences for the East of England Power Park site to prevent flood water overtopping Hamilton Dock to inundate the site.

If the site is defended entirely by land raising it can be viewed as independent to the other sites. However if a proposed hard defence retaining wall with small embankment was viewed as a possibility it would need to collaborate with the East of England Power Park site and Peto Square North for continuity purposes, to ensure the defence protected the site from flooding. A joined up approach for these three sites could also offer an improved standard of protection for existing development with respect to flood risk.

East of England Power Park

The majority of the coastal defences in front of East of England Power Park appear to be at a sufficient level. Raising of the crest level would be necessary in some localised areas to ensure a minimum level of 4.7m AOD is maintained along the entire length of the flood defence wall for the entire flood cell (which would include the area around Hamilton Dock). An earth embankment, either along the southern boundary of East England Power Park or parallel to Hamilton dock may also be necessary to join the defences along Fishers' Wharf to prevent floodwater from Hamilton dock overtopping and inundating the East of England park from the south.

A second earth embankment north of the park may also be necessary to link the flood defence wall to the higher ground west of the site and prevent inundation of the site from the north.

Land raising a site of this size would not be cost effective. Therefore a more suitable option in terms of cost and land take would be to upgrade the existing coastal defences and confer with neighbouring sites to build secondary defences along Hamilton Docks and north of the site to tie into higher areas and prevent floodwater inundation into the site.

South Peto Square

The proposed pedestrian route along the water frontage is recommended to be constructed as an embankment with a retaining wall backed up by raised land. The height of the wall will need to be set to a minimum of 4.7m AOD. This would ensure a sufficient level of protection can be maintained along the water front whilst providing safe public access to the water frontage.

Raising the defences along the South Beach would also be necessary to prevent overtopping of the coastal defence wall. This would prevent floodwater from inundating the area adjacent to the South Basin, which would otherwise flood South Peto Square from the south and southeast.

Horn Hill

As seen from the hydraulic modelling result, flood levels on the Horn Hill site will drop as a result of the partial land raising at the Waveney Campus site and South Peto Square. The third scenario of the hydraulic modelling demonstrates that the Horn Hill site does have a flow path through it, that if raised results in some minor increases in flood depth elsewhere. To ensure this flow path is maintained further detailed modelling of the site may be required, with the cycle path proposed at its existing level to maintain the existing flow paths to the wider flood cell area.

Waveney Campus

It is proposed to only partially raise the site at Waveney Campus. The development will be located on the raised section of the site, with floodwater allowed on the lower areas. The lower areas would be used for less vulnerable uses such as car parking and landscaping.

An alternative would be to construct a pedestrian route along the entire south bank frontage of Lake Lothing. To Brooke Marine in the west and South Peto Square in the east. The height of the wall would need to be set to a minimum of 4.7m AOD. This would ensure that a sufficient level of protection could be maintained along the waterfront whilst providing safe public access to the water frontage. The route will need to be connected to the high lying grounds on Horn Hill Road, which falls outside of the floodplain to prevent floodwater entering from the east. The pedestrian route would also need to be linked to the defences in front of the Brook Marina to prevent floodwater entering from the west.

Brooke Marina

Due to the limited space available within the site, land raising to a level above 4.7m OAD is recommended to ensure the proposed residential developments will remain safe during an extreme tidal event. Land raising to the same extent and level may not be required for the proposed marina as such a development would be classified as water compatible which would not be required to remain dry during an extreme flood event.

Summary and conclusions

Scott Wilson has been commissioned by 1st East to undertake a review of the flood defence provision in the Lake Lothing area, in particular for those sites where land raising may not be provide a complete solution to flooding. This report has been based on the model output of extreme tidal levels and is at this stage restricted to qualitative descriptions of type of defence and suitability only.

A range of flood defences are currently in use within the Lake Lothing area, including concrete seawalls, steel and timber sheet pilling with concrete capping and revetments. The majority of these defences cannot be classified as formal defences since they do not provide sufficient protection to meet the Environment Agency standard of protection, set as the 1 in 200 year extreme water level.

To improver the provision of defences for the proposed regeneration sites within Lowestoft, three options have been investigated, namely: -

- Upgrading existing structures
- Providing new defences
- Land raising

Based on the review of the existing defences, the proposed development plans and space availability, the provision of defences to the stipulated level may be achieved through the following options:

- Oswald Boatyard: Land raising the quay crest or hard defence wall between the Railway Bridge and Mutford Bridge

- Peto Square North: Riverside walkway combined with an embankment with a retaining wall backed up by partial land raising linked to higher grounds north of the site and connected to the defences in front of Fishes' Wharf.
- Fishers' Wharf: Riverside walkway combined with an embankment with a retaining wall backed up by partial land raising, linked to the defences in front of Peto Square North and either linked to higher grounds west of the site, or extended and linked to East of England Park defences.
- East of England Park: Raising crest level of sea wall to ensure a minimum level of 4.7m AOD is maintained along the entire coastline. Construction of an earth embankment, either along the southern boundary of East England Park or parallel to Hamilton Dock to prevent floodwater from Hamilton dock from inundating the site from the south. Construction of a second earth embankment north of the park to prevent floodwater entering the site from the north. Land raising of this site would not be a viable option with respect to cost.
- South Peto Square: Riverside walkway combined with an embankment and retaining wall backed up by partial land raising. Raising the defence height of the coastal defence wall along the south beach to prevent overtopping and inundation from the south and southeast.
- Horn Hill: Further detailed modelling may be required to ensure existing flow paths are not obstructed as part of any land raising. The cycle path should probably be kept at the existing height as it is thought this would form the main flow path through the site in the event of a flood. Land raising may be appropriate for the southern half of the site but this would need to be examined in greater detail as part of any proposed development for the site.
- Waveney Campus: Partial land raising, or part of larger south bank riverside walkway combined with an embankment with a retaining wall backed up by the partially raised land. The route will need to be connected to the high lying grounds on Horn Hill Road and linked to the defences in front of the Brooke Marina.
- Brooke Marina: Land raising to a level above 4.7m OAD for all areas with proposed residential usage.

References

1. Waveney and Suffolk Coastal Draft SFRA, Scott Wilson, 2008
2. NFCDD
3. Estuarial Standard of protection Lowestoft, 2000, Posford Duvivier
4. Sea Defence Survey Data, Posford Duvivier 1999.