MAYOR OF LONDON

Transport for London

Inner Thames Estuary Feasibility Study

Response to Airports Commission Call for Evidence

The Mayor of London's Submission:
Supporting technical documents

23 May 2014

Title: **Inner Thames Estuary Airport Option: Impact Appraisal**

Author: **ABP Marine Environmental Research Ltd**

Purpose of paper:

To detail the results of the high level impact assessment, which is informed by a baseline review (and conceptual understanding), coupled with output from numerical models. The results presented should be considered as preliminary only.

Key messages:

- **The tidal range within the Thames Estuary (the difference in height between high and low water) is expected to be reduced by around 0.04m, relative to a mean spring tidal range of around 6m.**
- **Reclamation works within the estuary to accommodate the airport are predicted to cause localised increases in peak current speeds within the navigation channel and along the northern bank of the estuary, while reduced flows are expected immediately upstream and downstream of the scheme footprint on the south bank. These changes have potential implications for sediment transport within the estuary and for navigation.**
- **The Inner Thames Estuary Option footprint covers approximately 2,099ha of intertidal, transitional and subtidal habitat. The extent of overlap with internationally designated sites is approximately 1,609ha. The predicted indirect habitat losses associated with changes in water levels are estimated to be less than 5% of the direct losses.**

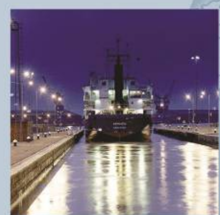
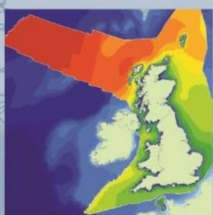
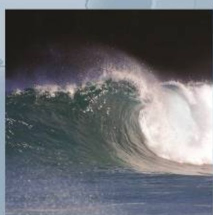
Transport for London

Inner Thames Estuary Airport Option: Impact Appraisal

Report R.2254

May 2014

Creating sustainable solutions for the marine environment

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Inner Thames Estuary Airport Option: Impact Appraisal

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Summary

The Airports Commission (the Commission) was set up in 2012 to take an independent look at the UK's future airport capacity needs. As part of this process it has sought to identify a list of the most credible options for new runway capacity in the UK. In December 2013 the Commission identified two potential sites that were selected for further analysis, namely at Heathrow and Gatwick (Airports Commission, 2013). The Commission also announced that it intended to carry out additional research in respect of the Inner Thames Estuary Option in the first half of 2014.

The Mayor of London Aviation Work Programme is currently co-ordinating a work stream to provide additional information to the Airports Commission with respect to the Inner Thames Estuary Option. ABP Marine Environmental Research Ltd (ABPmer) has been contracted to undertake the following tasks as part of this programme of works:

- A baseline description and high level impact review for waders and waterfowl;
- High level impact assessment; and
- Compensation review.

This report details the results of the high level impact assessment which is informed by a baseline review (and conceptual understanding), coupled with output from existing numerical models of the region. The results presented should be considered as preliminary only. In due course, a more refined modelling approach, supported by a more detailed set of investigations and site data, would need to be considered to support any future planning application.

Preliminary results indicate that the proposed Inner Thames Estuary Option would result in a modification of the tidal signal within the Inner Thames and to some extent in the Medway. Specifically, high water levels on mean spring tides are expected to reduce by up to 0.03m upstream and immediately downstream of the Inner Thames Option footprint and by 0.015m in the Medway. The low water levels are likely to slightly increase (by around 0.01m) in the same area. These changes to high and low water levels yield an overall reduction in the tidal range of 0.01-0.04m. There is also a small phase shift in the propagation of the tidal signal (i.e. a slight alteration of tidal timings) with the Inner Thames Option resulting in a small advancement of the tide by 1-2 minutes.

The proposed Inner Thames Estuary Option would also be expected to result in some modification to the tidal flows, with an increase in depth-averaged flow speeds within the main channel and on the northern shore of the estuary and a reduction in flows immediately upstream and downstream of the footprint. Within the main channel the peak spring flows are expected to increase from approximately 1m/s (~2 knots) by around 20% to 1.2m/s. The area of increased flows is localised, only just extending beyond the footprint of the Inner Thames Estuary Option.

The wave regime is also expected to undergo some modification with the Inner Thames Estuary Option providing shelter to some areas of the Inner Estuary and adjacent coastline from locally generated waves. It is assumed that a suitable design of the reclamation boundary (rock armour) would not result in significant wave reflection.

The predicted changes in the hydrodynamic regime have the potential to affect the existing sediment regime. It is anticipated that, on the whole, the proposed Inner Thames Estuary Option could result in a marginal increase in the on-going export of fine sediment from the estuary. Within the estuary itself, increased flows within the maintained Yantlet Channel could result in the channel widening or deepening, or becoming more self-maintaining in the area adjacent to the Inner Thames Estuary Option footprint, depending on the bed material type.

Increased flows on the north bank of the estuary are likely to result in increased sediment transport from the intertidal areas of parts of Chapman Sands, Marsh End Sand and Southend Flat. On the south bank of the estuary, immediately upstream and downstream of the Inner Thames Estuary Option footprint, the reduced flows (and wave activity upstream) will potentially reduce erosion, and in small areas very local to the footprint may even result in some accretion of fine material. The Inner Thames Estuary Option is also likely to alter the flow directions in the immediate approaches of the Medway, which has the potential to modify the local pattern of sediment transport and channel slope and stability in this area.

The Inner Thames Estuary Option in its current location would result in a direct loss of approximately 2,099ha of intertidal, transitional and subtidal habitat (including grassland and brackish standing water). The extent of overlap with internationally designated sites is approximately 1,609ha. The majority of habitat that would be lost comprises intertidal mud and sandflats, grazing marsh, subtidal sand/ mud and to a lesser extent saltmarsh and brackish standing water. The predicted indirect losses associated with changes in water levels are estimated to be less than 5% of the direct losses of intertidal, transitional and subtidal habitat under the direct footprint of the Inner Thames Estuary Option. Modifications to the morphological and hydrodynamic regime of the estuary will result in additional changes to habitat extent and quality which could have further implications for the species supported by the estuary.

Given the predicted changes in tidal signal, it is not considered likely that the Inner Thames Estuary Option will result in any increase to fluvial flood risk from the ‘backing-up’ of flood waters. In addition, the shelter afforded by the Inner Thames Estuary Option to wave activity is expected to reduce overtopping effects from waves.

The predicted increases in flow speed in the Yantlet Channel associated with the Inner Thames Estuary Option may impact on the navigation of certain vessels (particularly smaller ones) and as such it is likely that a Navigation Risk Assessment would be necessary to support any future planning application. In the area of increased flow speeds, maintenance dredge requirements are unlikely to increase. However, downstream of the Inner Thames Estuary Option where flow speeds slightly reduce, a small increase in dredge requirements may result.

Acknowledgements

The authors would like to thank DP World for providing information on the London Gateway development.

Abbreviations

1D	One-Dimension(al)
2D	Two-Dimension(al)
3D	Three-Dimension(al)
ABPmer	ABP Marine Environmental Research Ltd.
BGS	British Geological Survey
CCO	Channel Coastal Observatory
CD	Chart Datum
CEH	Centre for Ecology and Hydrology
CHaMP	Thames Coastal Habitat Management Programme
Defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EIA	Environmental Impact Assessment
ETM	Estuary Turbidity Maximum
FCDPAG	Flood and Coastal Defence Appraisal Guidance
HW	High Water
IECS	Institute of Estuarine and Coastal Studies
LAT	Lowest Astronomical Tides
LiDAR	Light Detection and Ranging
LW	Low Water
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MSL	Mean Sea Level
ODN	Ordnance Datum Newlyn
OS	Ordnance Survey
PLA	Port of London Authority
Ramsar	International Convention on Wetlands
RMS	Root Mean Square
RSL	Relative Sea Level
SPA	Special Protection Area
TE2100	Thames Estuary 2100 Project
TfL	Transport for London
TotalTide	Tidal prediction program by The United Kingdom Hydrographic Office
UK	United Kingdom
UKCIP	UK Climate Impacts Programme
UKHO	United Kingdom Hydrographic Office

Nomenclature

Hs	Significant Wave Height
m(CD)	Metres Above Chart Datum
mODN	Metres Ordnance Datum Newlyn
Tp	Peak Wave Period

Cardinal points/directions are used unless otherwise stated.
SI units are used unless otherwise stated.

Inner Thames Estuary Airport Option: Impact Appraisal

Contents

Page

Appendix

Tables

Figures

1. Introduction

The Airports Commission (the Commission) was set up in 2012 to take an independent look at the UK's future airport capacity needs. As part of this process it has sought to identify a list of the most credible options for new runway capacity in the UK. During 2013 the Commission received 52 proposals for addressing the UK's airport capacity shortfall, over 40 of which suggested building additional runway infrastructure. These proposals were based on very different visions for the future of the aviation sector.

In December 2013 the Commission identified two potential sites that were selected for further analysis, namely at Heathrow and Gatwick (Airports Commission, 2013). The Commission also announced that it intended to carry out additional research in respect of the Inner Thames Estuary Option in the first half of 2014. On this basis, it will reach a view before the end of the 2014 as to whether such an option would offer a credible proposal for consideration alongside the short-listed options. If so, it will be subject to a similar appraisal and consultation process as for those options, although not necessarily to the same timetable.

The Mayor of London Aviation Work Programme is currently co-ordinating a work-stream to provide additional information to the Airports Commission with respect to the Inner Thames Estuary Airport Option. The overall scope of works is based on the Inner Thames Estuary feasibility studies terms of reference as issued by the Commission (Airports Commission, 2014). ABP Marine Environmental Research Ltd. (ABPmer) has been contracted to undertake the following tasks as part of this programme of works:

1. A baseline description and high level impact review for marine birds;
2. High level impact assessment; and
3. Compensation review.

This report contains a high level impact assessment of the Inner Thames Estuary Option with respect to predicted changes in the hydrodynamics and geomorphology of the estuary with the scheme in place. The wider implications of such changes have been conceptually reviewed in the context of other sea users. The report is structured according to the following main sections:

Section 1:	Provides an introduction to the report;
Section 2:	Outlines previous understanding in relation to potential impacts associated with the Inner Thames Estuary Option;
Section 3:	Provides a conceptual understanding for the physical processes operating within the study area;
Section 4:	Outlines details of the numerical modelling that has been undertaken to inform this project;
Section 5:	Presents a preliminary impact evaluation on the basis of the model outputs and the conceptual understanding of the study area; and
Section 6:	Provides an overall summary and recommendations for further work.

2. Previous Understanding

A high level impact assessment for marine ecological receptors was undertaken in May 2013 (ABPmer, 2013). The report detailed the potential generic impact pathways that could arise as a result of the airport footprint for the following marine ecological receptors:

- Environmental designations;
- Intertidal and subtidal habitats;
- Plankton;
- Fish and shellfish;
- Marine mammals; and
- Seabirds.

In May 2014 (as part of this package of work) this was extended to include a review of the potential impacts to waders and waterfowl that currently occur in the vicinity of the Inner Thames Estuary Option (ABPmer, 2014).

The potential generic impact pathways, associated with the placement of an airport in the Thames Estuary, that have been identified for each of the marine ecology receptors are summarised in Table 1. It should be noted at this stage that there is insufficient detail relating to the airport option, both in terms of scheme design (including any associated infrastructure) and construction methodologies, to determine the detail of the potential impacts. At this stage only operational and construction impacts have been considered as it has been assumed that the infrastructure installed as part of an airport development of this type would permanently remain *in situ* with at most a change of use employed at the end of the lifespan of the project. No attempt has therefore been made to identify potential impact pathways associated with the decommissioning phase of the Inner Thames Estuary Option.

To provide some initial quantification of a number of the potential impacts associated with the Inner Thames Estuary Option an element of high level hydrodynamic modelling has been undertaken. This has included the development of a conceptual understanding of the physical processes operating in the inner estuary (Section 3), hydrodynamic modelling (Section 4) and an interpretation of the model outputs in the context of marine ecology and other sea users (Section 5).

Table 1. Summary of potential impacts to marine ecology receptors

Pathway	Intertidal		Subtidal		Plankton		Fish		Marine Mammals		Seabirds		Waders and Waterfowl	
	C	O	C	O	C	O	C	O	C	O	C	O	C	O
Changes in habitat extent	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Changes in habitat suitability	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Changes in water quality	x	x	x	x	x	x	x	x						
Changes in suspended sediment concentrations	x	x	x	x	x	x	x	x	x		x			
Release of contaminants associated with the dispersion of suspended sediments	x		x		x		x		x		x		x	
Re-deposition of suspended sediment causing localised smothering	x		x		x									
Underwater noise/ vibration			x				x	x	x	x	x	x	x	x
Visual disturbance							x	x	x	x	x	x	x	x
Barrier to movement							x	x	x	x	x	x	x	x
Collision risk									x		x	x	x	x
Physical disturbance by plant and machinery	x													
Discharges and accidental spillages	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Changes in structure and function of biological assemblages		x		x		x								
Introduction of non-native species	x	x	x	x	x									
Key: C Construction O Operational														

3. Conceptual Understanding

3.1 Physical Setting

The Thames Estuary is one of the largest estuaries on the east coast of England, a classic macrotidal funnel-shaped estuary that has been heavily reclaimed and modified over time by anthropogenic influences. The Thames can be broadly defined into the Inner and Outer Estuary, with the Inner Estuary extending upstream from the point of widening at Shoebury Ness (Southend) to the tidal limit at Teddington Weir; see Figure 1. The Thames River, located upstream of Teddington Weir, provides the most significant source of freshwater into the estuary.

The proposed Inner Thames Estuary Option is situated along the south bank within the Inner Estuary, spanning the mudflat and subtidal areas fronting the Isle of Grain, extending approximately 7.9 km in an east-west direction from the mouth of the Medway Estuary (see Figure 1). The development will, by its nature, result in a constriction of the baseline estuary profile. At its furthest extent into the estuary, the proposed reclamation results in a reduction in flow width of approximately 30% at HW (from 7.2km to 4.9km) and around 23% at LW (from 3.8km to 2.9km). Associated reductions to cross-sectional area of flow range between 17 and 23%, dependant on the tidal state. An example of the change in estuary profile as a result of the reclamation is provided in Figure 2.

In total, the Inner Thames Estuary Option covers an area of approximately 2,595 ha of which 1,281 ha is estimated to be reclaimed from the fronting intertidal mudflats, predominantly the wide Yantlet Flats (with smaller areas reclaimed from Yantlet Creek and Grain Spit), and the shallow subtidal adjacent up to a depth of *circa* 5 to 6m below Chart Datum (CD).

Within the footprint of the proposed Inner Thames Estuary Option, the Yantlet Flats extend approximately 1.2 to 1.6 km from the shoreline, with maximum elevations of around 3 m above CD. The flats predominantly comprise muddy sediments, backed by narrow steep shingle with groynes placed along the Allhallows-on-Sea frontage. The intertidal habitats situated within and adjacent to the footprint of the Inner Thames Estuary Option are internationally designated and form part of both the Thames Estuary & Marshes SPA and Ramsar sites.

3.2 Hydrodynamic Regime

3.2.1 Tidal Levels

The Thames Estuary is macrotidal in nature, with a mean spring tide range of 5.2 m at Sheerness, gradually increasing upstream to 6.6 m at London Bridge (United Kingdom Hydrographic Office (UKHO), 2013); see Table 2. This increasing tidal range upstream is attributed to the funnelling effect of the estuary, which has been modified historically by the extent of intertidal reclamation within the estuary and the ‘training’ by the numerous jetty and wharf structures. At the location of the proposed Inner Thames Estuary Option, the mean spring tidal range is expected to be approximately 5.2 m. In addition to variations in tidal range, tidal propagation along the estuary also results in the time of HW being delayed in an upstream direction (e.g. by *circa* 1 hour 20 minutes between Sheerness and London Bridge).

Table 2. Tidal levels for the Thames Estuary

Tidal Level		Sheerness		Tilbury		London Bridge (Tower Pier)	
		m(CD)	m(ODN)	m(CD)	m(ODN)	m(CD)	m(ODN)
Highest Astronomical Tide	HAT	6.30	3.40	7.10	3.98	7.70	4.50
Mean High Water Springs	MHWS	5.80	2.90	6.40	3.28	7.10	3.90
Mean High Water Neaps	MHWN	4.70	1.80	5.40	2.28	5.90	2.70
Mean Sea Level	MSL	3.10	0.20	3.36	0.24	3.67	0.47
Mean Low Water Neaps	MLWN	1.50	-1.40	1.40	-1.72	1.30	-1.90
Mean Low Water Springs	MLWS	0.60	-2.30	0.50	-2.62	0.50	-2.70
Lowest Astronomical Tide	LAT	0.00	-2.90	-0.10	-3.22	-0.20	-3.40
Spring Tidal Range (MHWS - MLWS)		5.20		5.90		6.60	
Neap Tidal Range (MHWN - MLWN)		3.20		4.00		4.60	

(Source: UKHO, 2013)

Previous studies have identified increases in the elevation of high water (HW) within the Thames Estuary over time (e.g. Rossiter (1969) and Bowen (1972)), with these changes magnified upstream from around 1.0 to 1.1 mm/yr for Southend-on-Sea and 6.4 to 6.8 mm/yr for Tower Bridge during the period 1934 to 1969. These recorded changes have been described by Royal Haskoning (2004) as being the likely result of a combination of anthropogenic and natural causes (i.e. sea level rise), whilst Bowen (1972) considered that a large part of the observed increase in tidal range is likely to be due to the effects of embanking the estuary (coastal squeeze).

Before construction of flood defences along the estuary, much of the water entering the Thames spreads laterally to cover mudflats/saltmarshes and occasionally across a wider flood plain. The presence of flood defences has caused a loss of this water storage volume at high tide levels, thus increasing the height of high water contained within the banks. Other contributory artificial causes may include the historic dredging of deeper shipping channels, the damming of tidal creeks and changes to estuary morphology caused by various waterside developments (PLA, 2009). Alternatively, Haigh *et al*. (2009) calculated historical trends in mean sea level (MSL) of 1.21±0.23 mm/yr (between 1933 and 1983) at Southend-on-Sea and 1.58±0.91 mm/year (between 1961 and 1983) at Tilbury. Similarities between changes in HW and MSL with time tend to suggest that increases around Tilbury and further downstream are likely driven by natural changes (i.e. sea level rise), whilst more significant changes further upstream (e.g. in the vicinity of Tower Bridge) are likely to be amplified by anthropogenic change.

More recently, HR Wallingford (2002a) undertook hydrodynamic modelling to assess the potential impacts of the London Gateway development on the tidal regime within the Inner Thames Estuary. The London Gateway development, situated on the north bank of the Thames between Coryton and Mucking Flats (*circa* 8 km upstream of the Inner Thames Estuary Option), is presently in operation but not fully constructed (as of April 2014). During the design phase of the scheme, it was identified that any reclamation on the north side of the river would have an immediate impact upon the course of the main channel as well as upon the effective overall cross-section of the Thames at this point.

Taking this into consideration, the reclamation design was aligned with the main channel, with any reduction in width balanced with an increase in water depth (i.e. dredging to maintain the cross-sectional area of water flow past this reclamation). Results from the London Gateway modelling identified that the combined reclamation and capital dredging would result in small increases in low water (LW) levels (in the order of 20 mm) throughout the estuary, with no predicted change in HW levels (offset by deepening of the channel through dredging). The absence of the deepened channel would have resulted in HW reductions throughout the Inner Thames, and therefore a greater impact on tidal range.

Importantly, it can be considered that a reduction of the estuary cross-section at any given location within the Inner Thames (i.e. through reclamation, which effectively reduces the tidal prism) will result in the slight lowering of HW and raising of LW upstream of that location; thus resulting in a reduced tidal range.

3.2.2 Surge Events (Flood Risk)

Tidal flooding within the Thames Estuary is principally driven by high tide water levels enhanced by a non-tidal (storm) surge component. The incidence and magnitude of surge events is controlled by air pressure and the severity of winds in the North Sea. Positive surges in the North Sea, which result in water level increases, are generated by low air pressure typically combined with strong northerly winds. If the surge component peaks at the same time as high water (particularly spring tides), there will be an increased risk of flooding, unless the flood defences are able to cope with the increased elevation. In February 1953, a tidal surge event lead to an increase of high water at Tower Bridge by approximately 1.9 m (Trafford, 1981), fortunately, however, the surge diminished as it approached London's centre and only minor damage was observed in the capital. Elsewhere along the east coast of England the surge caused loss of life and catastrophic damage.

In order to prevent similar flooding in the future, a series of flood defence schemes were constructed (e.g. tidal barriers, improvements to sea walls and embankments etc.), the majority of which were completed and fully operational by the early 1980s (Lewin and Lavery, 2002). Of these schemes, the Thames Barrier (constructed in 1982) was designed to provide the primary protection to central London from both tidal and fluvial events. For fluvial events, the area upstream of the barrier can be used for flood storage capacity during periods of high freshwater flow.

Prior to 2014 the Thames Barrier had been closed no more than 24 times per year since its completion. However, as a result of prolonged stormy weather across the UK between December 2013 and March 2014 the barrier was closed in excess of 50 times over this 4 month period alone (i.e. more often than the recommended annual safety limits). The closures were required to protect central London from tidal flooding (with a surge), but more frequently from freshwater flooding following periods of significant rainfall. Interestingly, Littlewood and Crossman (2003) identified that the closure of the Thames Barrier for prevention of fluvial flooding (without a surge component) could result in a reflected tidal wave that may raise high water levels downstream of the barrier by around 0.5 m, depending upon the time of closure. In contrast, a small negative wave (depression of water level) is generally recorded propagating upriver.

The regularity of recent closures would tend to suggest an increase in flood risk within the Thames, which will be further enhanced by climate change in the future, specifically (relative) sea level rise and increased winter rainfall (fluvial flooding). As such, any potential influence of the barrier on the local estuary morphology is also expected to increase. These issues are being considered in detail as part of the ongoing Thames Estuary 2100 project.

3.2.3 Tidal Currents

Tidal currents in the Thames Estuary generally show an increasing degree of asymmetry in an upstream direction; i.e. the length of the flood tide shortens in comparison to the ebb, thus resulting in increased flood velocities. Between Southend-on-Sea and Gravesend, i.e. within the section of the estuary where the proposed Inner Thames Estuary Option is present, the maximum ebb velocity of the tide is typically in excess of the flood. At Sheerness, this ebb dominated tidal regime probably results from the large tidal prism held in the Medway Estuary as it joins with the Thames Estuary over the ebb tide through the constricted mouth. In contrast, upstream of Gravesend, flood current velocities are in excess of the ebb, where the tidal velocities reflect the increasing influence of the flood tide (see Table 3).

Table 3. Maximum tidal velocities (spring tide) within the Thames Estuary

Location	Maximum Tidal Velocities (m/s)	
	Flood	Ebb
Sea Reach (Southend)	1.00	1.15
Sea Reach (Middle Blyth)	0.95	0.98
Gravesend Reach	1.25	1.60
Long Reach	1.55	1.35

(Source: IECS, 1995)

3.2.4 Waves

The wave characteristics of the Inner and Outer Thames Estuary differ significantly, in which wind action is the main wave generation process in the Inner Thames Estuary (specifically between Sea Reach and Lower Gravesend Reach). Waves generated offshore are largely dissipated over the Outer Estuary banks and wide intertidal flats (HR Wallingford, 2002b). Numerical modelling for the Thames Estuary 2100 study (HR Wallingford, 2005) determined that within the Inner Estuary, the highest annual significant wave height tends to decrease in an upstream direction from around 1.3 m at Roas Bank (immediately to the east of the proposed Inner Thames Estuary Option) to 0.7 m at East Tilbury.

Another method of wave generation in the estuary is that created by the passage of vessels (e.g. ship wash etc.). Although these are individually of less energy than wind-generated waves, and being isolated events, they may present the largest amplitude waves in more sheltered locations.

3.2.5 Freshwater Flows

The Thames River provides the most significant source of freshwater into the estuary at Teddington, with a mean flow rate of around 90 m^3/s (Defra, 2002). Average freshwater inputs to the Thames are considerably smaller than the tidal discharge within the estuary, with HR Wallingford (2002c) reporting tidal discharges of up to 15,000 m^3/s on both flood and ebb tides (in Lower Hope Reach). The constant exchange of tidal volume in a relatively shallow estuary ensures that the Thames Estuary is generally well-mixed. A longitudinal salinity gradient does, however, exist in the Thames, thus driving mixing to take place at the interface between the river water and seawater.

This mixing generates a weak upstream density current (in addition to the tidal currents) which assists in transporting fine suspended sediments (muds) within the estuary. The near bed residual flows result in the formation of a null point where there is no net movement of water at the bed. During summer freshwater discharges, the null point is generally located along the Gallions, Barking and Halfway Reaches (i.e. in the proximity of Woolwich in the upper Inner Estuary) but variations such as freshwater input will cause the location of the null point to move up or down-estuary (Royal Haskoning, 2004).

It is this process which develops the estuary turbidity maximum (ETM) in the water above the so-called mud reaches. Freshwater flows, salinity gradients and residual currents are expected to have a negligible impact on both local tidal conditions (specifically flows) and sediment transport at the location of the proposed Inner Thames Estuary Option due to its position at the lower end of the Inner Estuary, i.e. considerably downstream of these observed effects.

3.2.6 Climate Change

The proposed Inner Thames Estuary Option for an airport would be expected to be a permanent development, i.e. the airport would be continually maintained into the future for a period of at least 100 years. Influences that might be expected to occur as a result of climate change therefore need to be considered.

Key climate change factors are taken here as changes that might occur to the baseline which relate to mean sea level, freshwater flow (precipitation), winds and waves (i.e. storminess). The primary source of climate change information is the UK Climate Change Impacts Programme (UKCIP) and the most recent predictions are from UKCP09 (Lowe *et al.*, 2009). Climate change predictions are not exact but are based on a range of high, medium and low greenhouse gas emission scenarios using ensemble modelling techniques to help bound the level of uncertainty involved. A medium emissions scenario is considered here as the representative description for climate change and values are quoted in relation to the 95%ile likelihood of non-exceedance of this scenario.

3.2.6.1 Sea level rise

The south coast of England, in general, is still responding to changes during the last 10,000 years, however, there is now further concern relating to sea level rise acceleration resulting from human-induced climate change. Future changes in relative sea level (RSL) are quoted as the net effect of geological adjustments in land levels and the projected absolute changes in mean sea level. Table 4 presents a summary of UKCP09 projections up to 2115 for the medium emissions scenario and at the level of the 95%ile likelihood, and for comparative purposes, the more conservative high emissions scenario with 95%ile likelihood (using 2015 as the base year).

Table 4. Predicted relative sea level rise for the next 100 years

Year	RSL Rise Based On Medium Emissions 95% Scenario (m)	RSL Rise Based On High Emissions 95% Scenario (m)
2015	0.00	0.00
2035	0.12	0.14
2065	0.32	0.39
2115	0.75	0.91

(Source: Lowe *et al.*, 2009)

In general, an increase in RSL may result in a number of effects, such as, displacing the high water mark up the estuary, enabling wave energy to propagate further along the estuary (exposing the estuary margins to greater periods of wave and tidal energy) and increasing potential flood risk. The magnitude of this impact would vary depending upon the rate of predicted sea level rise and the timing relative to the 18.6 year Lunar Nodal Cycle variations, which may have a greater amplitude in the short term (i.e. over the next 10 to 20 years); where there will be a reduction in high water levels by approximately 0.19 to 0.24 m between 2015 and 2024, followed by a period of increasing high water levels (at a similar rate) from about 2025.

More specifically, assessment of the long-term behaviour of the estuary over the next 100 years suggests that the Thames Estuary will be subject to an increased tidal prism and greater cross-sectional areas (ABPmer, 2008). Due to the constraints of the coastal defences placed upon the estuary, which are expected to be largely maintained (hold the line) in the long-term, significant areas of intertidal habitat are predicted to be lost along the length of the Thames as a result of coastal squeeze (some 1,045 ha by 2106).

In addition to changes in intertidal habitats, changes in the hydrodynamic regime may also drive morphological changes in the Inner Thames Estuary, particularly immediately either side of the reclamation for the airport. Further information on future morphological change in the Thames Estuary, more specifically in the vicinity of the proposed Inner Thames Estuary Option, is provided in Section 3.3.

3.2.6.2 Storminess

UKCP09 includes projections of the likely future wind and wave climate. Over the 21st Century, climate change may influence the frequency and magnitude of storms as well as their direction. Within the Outer and Inner Thames Estuary (upstream to approximately the London Gateway), mean annual maximum significant wave heights are projected to increase by up to approximately 0.1 m by 2100, thus representing an increase of *circa* 5 to 10% of the annual significant wave heights in the vicinity of the proposed Inner Thames Estuary Option. This increase has the potential to enhance erosion of the estuary margins, particularly across the intertidal areas at the mouth of the Thames Estuary.

3.2.6.3 Freshwater flow

In addition to sea level rise and storminess, a change to freshwater flow (through precipitation) is considered important to estuarine evolution. Guidance issued by UKCP09 (Lowe *et al.*, 2009) indicates that between 2009 and 2020 summer precipitation will decrease by around 5%, whilst winter precipitation will increase by approximately 10%. No figures are provided for changes in peak freshwater (river) flow by UKCP09 guidance, however, previous Defra guidance (Defra, 2006) suggests that this will increase by 10% between 1990 and 2025.

Whilst the Defra guidance is not based on an equivalent UKCP09 emissions scenario, the outcomes are generally seen as conservative (i.e. more associated with a high emissions scenario). Long-term, the UKCP09 guidance states that peak summer and winter precipitation will decrease by 25% and increase by 30%, respectively, for the period 2080 to 2140. During this period, Defra guidance suggests that peak freshwater flows will increase by 20% relative to 1990 levels. As a consequence of these predicted changes, there are likely to be sustained periods of higher freshwater flows in winter months, and lower freshwater flows in summer months.

Whilst this is not likely to have a major effect on the salinity regime (and hence mixing) in close proximity to the proposed Inner Thames Estuary Option, localised changes in the upper Thames Estuary may occur due to potential changes to the sediment 'null point' within the estuary. Furthermore, increased precipitation and freshwater flow into the Thames is likely to increase the risk of fluvial flooding and modify riverine sediment supply across the catchment, thus potentially displacing the ETM along the Thames.

3.3 Sediment Regime

The following sections detail the components of the physical environment that combine to define the sediment regime of the Thames Estuary, with specific consideration given to the estuary in close proximity to the proposed Inner Thames Estuary Option. The sediment regime also includes the process linkages for each component (i.e. the hydrodynamic and wave processes) that can act as mechanisms for transport and provide the pathways for moving sediments.

Consideration of long-term morphological change in the Thames Estuary (e.g. over the next 100 years) is also provided, largely drawing on from previous studies (e.g. TE2100 and the Outer Thames CHaMP) but also from research undertaken for previous development schemes, particularly the London Gateway.

3.3.1 Seabed Sediment Composition and Distribution

The characteristics of the seabed sediments of the Inner Estuary vary across and along the estuary. Yantlet Flats and Blyth Sands predominantly comprise muddy sediments towards the high water mark, becoming sandy towards the low water mark and with a transition between the two (BGS, 1997). A narrow strip of coarser sediment, mainly shingle, forms the steep beaches at the base of the flood defences backing the intertidal flats. Seabed sediments along the main subtidal channel adjacent to Yantlet Flats principally consist of sand, whilst further upstream (i.e. between Canvey Island and Erith) the channel seabed generally comprises a mixture of sand and gravel. Mean sediment particle size thereafter becomes markedly smaller up-river into the Upper Thames Estuary, with mud predominating. Within the Outer Thames Estuary, intertidal flats are characterised by sediment with high sand content due to the winnowing of fine sediment by wave action (HR Wallingford, 2004).

3.3.2 Sediment Transport

Following a programme of water sampling in the Thames downstream of Gravesend Reach in July 2001, HR Wallingford (2002d) identified a marked concentration gradient with spring tide near-bed levels up to 2,000 mg/l in Lower Hope Reach, decreasing to 1,000 mg/l at Coryton and to less than 100 mg/l at Southend-on-Sea. A similar pattern emerged from the neap tide measurements with values of up to 500 mg/l in Lower Hope Reach and less than 100 mg/l at Southend-on-Sea. They also showed vertical layers on both spring and neap tides, in which bed concentrations were an order of magnitude greater than mid-depth concentrations at high water. At other states of the tide, these differences were several times higher. It is important to note that the ETM is typically located upstream of the mud reaches *circa* 50 km landward of the Inner Thames Estuary Option.

It has been recognised, however, that single point measurements in the estuary may not provide sufficient information on the full complexity of suspended sediment distribution. For example, the presence of wide meanders influences suspended sediment transport. The interaction of these meanders (and the secondary currents set up by them) with the adjacent intertidal mudflats gives rise to a complex suspended sediment regime with large fluxes of sediment moving on and off the mudflats, with subsequent morphological change (HR Wallingford, 2004, Royal Haskoning, 2004). Bed sediments can also change across the section from the outer to inner part of the meander. For example, the meander separating Gravesend Reach and Lower Hope Reach results in secondary currents that move near-bed sediment towards the inside of the meander increasing suspended sediment concentrations relative to the outside of the meander (HR Wallingford, 2002d).

It is estimated that the fluvial sediment input from the River Thames is approximately 150,000 tonnes/yr, with about 20,000 tonnes/yr being further supplied by other tributaries (HR Wallingford, 2006). This fine sediment, in addition to other sediment sources (e.g. eroding intertidal areas within the estuary and the erosion of the London Clay Cliffs) provides material to feed mudflat and saltmarsh development in the vicinity of the Inner Thames Estuary Option (i.e. Yantlet Flats).

As part of the London Gateway development, HR Wallingford (2002e) modelled fine sand transport (median diameter 0.1 mm) in the estuary downstream of Gravesend and found a net spring and neap tide sediment flux out of the estuary (i.e. net export of sediment). Tidal currents transported a majority of the sediments with waves providing negligible influence. These results support the general conclusion that the estuary is ebb-dominated downstream of

Gravesend (in both tidal duration and current velocity) and wave heights are relatively small and have less influence on sediment transport.

3.3.3 Morphological Change in the Thames Estuary

Historic morphological change in the Thames Estuary can be typically divided into two periods. The first, extending from around the middle of the 19th century until around 1970, was a period when many natural morphological changes were masked by extensive anthropogenic activity, such as flood defences, dredging, waterside schemes and developments. The second period, from 1970 to the present day, corresponds with the implementation of legislation to control waterside activities enabling the estuary to (commence a process to) establish a more natural regime (PLA, 2009).

Taking this into consideration, it can be envisaged that morphological changes identified in the estuary post-1970 are far more representative as a baseline to future development than the longer-term development, which must be set within the context of large anthropogenic changes to the estuary. A description of observed historical changes to the subtidal channel and intertidal flats (relevant to the proposed Inner Thames Estuary Option) are provided in the subsequent sections.

3.3.3.1 Subtidal channel

Estuarine channels experience natural periodic shifts in position, which over time, may produce a change in the slope of the intertidal profile and subsequently alter the wave and tidal energy impinging on the shoreline. Natural historic changes in the position and depth of the Thames Estuary subtidal channel are difficult to ascertain because of the influence of dredging and disposal activities. This is demonstrated clearly by two examples:

- Between 1909 and 1928, a major programme of capital dredging took place to improve navigation in the Yantlet Dredged Channel. It was further deepened in 1965 and much of the dredged sediment was deposited in Leigh Channel to the north to encourage flow in the Yantlet Channel (HR Wallingford, 2002f); and
- The navigation channel in Lower Gravesend Reach migrated to the south after dredging was undertaken in 1963/64. The dredged sediment may have been used to close the previous (more northerly) alignment of the navigation channel.

In broad terms, however, the subtidal channel has increased in width between Lower Hope Reach and the eastern tip of Canvey Island as a result of natural and anthropogenic influences since 1820, whilst narrowing between Canvey Island and the Isle of Grain (IECS, 1993). These changes were due to advance or retreat of the adjacent intertidal areas. During a similar period (1834 to 1957/59), HR Wallingford (2003) found that in Lower Hope Reach and Upper Sea Reach (i.e. slightly upstream of the proposed Inner Thames Estuary Option, adjacent to the London Gateway), the deep water channel deepened, accompanied by a shallowing of the subtidal areas fronting Mucking Flats and Blyth Sands between 1920 and 1957/59. These changes are also influenced by the large-scale historic ballast winning and disposal activities in Lower Hope Reach. Overall, since 1920 the deep water channel has deepened significantly in

Lower Hope Reach and Upper Sea Reach and the subtidal areas adjacent to the intertidal flats have shallowed (HR Wallingford, 2003, 2004).

More recently, significant capital dredging has been undertaken within Sea Reach along the Yantlet Channel and within the Outer Estuary navigation channels in order to provide sufficient navigational access to the London Gateway development. In total, *circa* 31.35 Mm^3 of material has been dredged to provide depths within the operational berth pockets of 17.0 m below CD, 14.5 m below CD within the manoeuvring area and along Yantlet Channel (i.e. within the main channel directly fronting the Inner Thames Estuary Option) and approximately 16.5 m below CD in the outer navigation channels.

Numerical modelling undertaken by HR Wallingford (2002g) for the London Gateway development identified that the greatest magnitude of impact resulting from the reclamation and dredging, with respect to sand transport, occurred in the immediate vicinity of the dredged area. A tendency for seabed erosion immediately to the west of the dredged area was identified as a consequence of changes to the flow regime brought about by the development. In contrast, a significant area of mud deposition was predicted to occur at the west end of the berthing and manoeuvring area, i.e. within the dredge pocket and immediately in the lee of the structure, whilst an increase in deposition was also identified at the seaward (northern) end of Mucking Flats with a reduction in deposition near LW along the front of the flats.

With respect to adjacent third parties within this section of the estuary, no significant changes (i.e. deposition and erosion) were predicted within their berths as a result of the development. It is presently predicted that up to 1.94 Mm^3 per annum of maintenance dredging will be required in the manoeuvring areas and berths (combined) for the London Gateway, with an additional volume of approximately 250,000 m^3 from the channel within Sea Reach in order to maintain the required navigational depths.

It should be noted that the capital dredge has only recently finished, and so the predicted volumes have not yet been informed by any significant period of port operation (i.e. the estuary may still be responding to the works). At the time of writing, no maintenance dredging has been undertaken for London Gateway.

3.3.3.2 Intertidal sand and mudflats

Utilising OS maps and subtidal channel surveys, IECS (1995) assessed the observed long-term changes to the intertidal mud and sand flats between Gravesend Point and Whitstable on the south bank and Tilbury as far as Foulness Point on the north bank for the period 1820 to 1988 (ABPmer, 2008); see Figure 1 for locations. Results from this analysis identified that between 1820 and 1940 the area of intertidal on both the north and south banks increased by approximately 484 ha, whilst between 1940 and 1988 there was a total reduction in intertidal area of around 126 ha. This reduction was driven by intertidal losses on the north bank (whilst the south bank was still accreting), which are likely to be attributed to the increased reclamation and industrialisation that took place along the bank during the mid-20th Century.

Additionally, a more recent detailed historical volumetric analysis by HR Wallingford (2006) as part of the Thames Estuary 2100 (TE2100) identified a general increase in intertidal area within the Inner Estuary between Broadness and Southend during the period 1910 to 1995, albeit with some reductions between Coryton and Southend from 1920 to 1985.

The extensive intertidal flats downstream of Gravesend, which are of particular importance to the proposed Inner Thames Estuary Option, can be divided into a number of distinct sections (see Figure 1 for locations). These areas are:

- Yantlet Flats/Grain Spit (south bank) - there was significant accretion along the low water mark fronting St Mary's and Allhallows Marshes between 1820 and 1988 (IECS, 1995). Halcrow (1996) attribute this to the disuse of the wharf upstream resulting in the approach channels not being maintained. HR Wallingford (2002f) noted that the area of Yantlet Flats has increased by approximately 1.76 km^2 (16%), equating to an increase in elevation of approximately 0.02 m/yr over the main body of the flat and 0.3m/yr at the low water mark between 1970 and 1998;

- Blyth Sands (south bank) - generally retreated between 1820 and 1940 and then subsequently extended seawards between 1940 and 1988 (IECS, 1995). HR Wallingford (2002e) noted, however, that the surface of Blyth Sands lowered by an average of 0.01 m/yr between 1970 and 1998. This equates to a decrease in volume of approximately 11% (1.1 km^3) but an increase in area of about 4% (0.26 km^2). HR Wallingford (2006) noted an increase in width over the past century along the western part of Blyth Sands and that the main intertidal area eroded vertically by up to 2 m;

- Southend Flat (north bank) - has suffered erosion to the west of Southend-on-Sea Pier (due to the northward movement of Ray Gut), while the creek systems draining the flats have enlarged and migrated (IECS, 1995). HR Wallingford (2002f) also showed a general loss of intertidal flat volume at Canvey Island and Southend-on-Sea between 1970 and 1998;

- Canvey Island (Chapman Sands, Marsh End Sand, Leigh Sand) (north bank) - the intertidal flats in front of Canvey Island have generally retreated between 1820 and 1988 (IECS, 1995). Prior to 1909, Chapman Sands and Marsh End Sand to the east of Canvey Island were receding westwards, but since 1909 they have generally extended eastwards. The movement of Marsh End Sand has resulted in a northward shift of Ray Gut and erosion of the mudflats (Leigh Sand) to its north-east; and

- Mucking Flats (north bank) - between 1940 and 1988 the southern part of Mucking Flats (adjacent to East Tilbury) advanced as the northern part retreated (IECS, 1995). HR Wallingford (2002f) noted a vertical accretion of 0.1 m/yr for the intertidal area between 1970 and 1988. HR Wallingford (2006) analysed a series of bathymetric charts and concluded that Mucking Flats have increased in area over the last century. As detailed previously, further deposition is predicted to occur across Mucking Flats as a result of the London Gateway development.

Due to the location of the proposed Inner Thames Estuary Option, the development has the potential to have a significant impact upon the Yantlet Flats (which will largely be covered by the footprint of the airport), but also on Blyth Sands and Grain Spit that are positioned immediately upstream and downstream, respectively. In addition, there is potential to change the flow regime along the main channel cross-section, thus potentially influencing the sediment regime within the Yantlet Channel and the intertidal areas on the north side of the estuary immediately opposite the Inner Thames Estuary Option.

3.3.3.3 Future morphological response to climate change

With respect to the future morphological development of the Thames Estuary, an important question is whether the general accretion identified across the intertidal areas will be able to keep pace with potential accelerated sea-level rise. IECS (1995) suggested that under an accelerated rate of sea level rise, a net loss of intertidal surface area would be likely, although vertical accretion may continue on some intertidal surfaces. They envisaged that this net loss would result in a narrowing of the foreshore, leading to reduced attenuation of wave and tidal energy.

It was also suggested that the response of the Thames Estuary to sea level rise over the next 100 years would be to roll-over in a landward direction, i.e. the entire estuary sediment system would transgress landward (PLA, 2009). The difficulty with applying roll-over to the Thames Estuary is the likelihood that sediment movement will be laterally constrained by flood defences and other developments, therefore transgression may have ‘nowhere to go’ upstream because this boundary of the estuary is constrained by Teddington Weir and by existing/future developments. In essence, whilst there is potential for continued accretion across the intertidal areas in the short to medium term, there is a high potential for long-term intertidal losses within the Thames Estuary as a result of its constrained nature.

4. Hydrodynamic Modelling

Existing ABPmer hydrodynamic models have been applied to inform the potential hydrodynamic and geomorphological impacts associated with the Inner Thames Estuary Option. These include a One-Dimensional (1D) model of the entire Thames Estuary and Two-Dimensional (2D) model of the Outer Thames (which includes the proposed development area of the Inner Thames Estuary Option). Table 5 summarises the different impacts that have been assessed and the tool used to inform those assessments. Details of the 1D and 2D models, and the rationale for their use in the preliminary assessment of the impacts, are provided in the following sections.

Table 5. Assessment tools used for high-level impact assessment

Impact to be Assessed	Consideration	Assessment Tool / Information
Tidal regime: Impact on water levels due to the Inner Thames Estuary Option footprint.	Flood risk Habitat Change	1D and 2D models
Tidal regime: Impact on flow speeds	Navigation Effect on sediment regime	2D model
Wave regime		Conceptual understanding from baseline review
Sediment regime	Dredge requirements Erosion of banks Smothering of species	Flows from 2D model and conceptual understanding from baseline review

4.1 1D Numerical Modelling

The existing 1D model of the Thames Estuary was originally setup and calibrated for the Environment Agency TE2100 project (Environment Agency, 2012). The model defines the Thames Estuary as a series of cross-sections extending from Sheerness to the tidal limit at Teddington Lock. The upstream boundary is defined by a mean fluvial discharge from the River Thames, using data obtained from the Centre for Ecology and Hydrology (CEH). The same data source has also been used to provide source inputs from a number of tributaries entering the estuary (including the rivers Lee, Rodding, Brent and Darent). The downstream boundary is driven by time varying water level conditions, representing a mean spring tide. The model was calibrated and validated as part of the TE2100 project (EA, 2012).

For the application of the 1D model in the present study, a small modification was made to extend the downstream section out to a line approximately between Foulness Point, Essex and Birchington on the Kent coast (Figure 3). Following this modification, checks showed the model continued to adequately represent the tidal signal, requiring no further calibration.

Within the 1D model, the Inner Thames Estuary Option has been implemented via a series of modifications to the cross-section profiles (see Figure 2 for an example) along the extent of the proposed development. For this high-level assessment, the extents of the reclamation site were assumed to be vertical walls extending throughout the full water column.

4.2 2D Numerical Modelling

ABPmer' s 2D model of the Outer Thames used in this initial appraisal was originally developed to assess the impacts of proposed Round 2 Offshore Wind Farms. Full details on the original model configuration and calibration can be found in Appendix A of ABPmer (2005).

The model extends from Tilbury at its upstream limit, to Lowestoft in the east and Ramsgate in the south. The model extents are shown in Figure 4. The model grid resolution varies throughout the domain, and in the area of interest is approximately 450m x 800m.

Some modifications were made to the original model to ensure that it was 'fit for purpose'. Specifically:

- Modification of the grid to better represent the features local to the development area, namely an improvement to the land-sea definition around the Isle of Grain and an inclusion of the River Swale to enable flow around the Isle of Sheppey;
- Inclusion of the London Gateway development;
- Modification of the upstream boundary at Tilbury, which was originally tidally driven (discussed in more detail below);
- Modifications of the astronomic forcing applied at the offshore boundaries to improve the amplitude and phasing of the tidal levels upstream of the development area; and
- Reconfiguration of the domain, which originally had ten vertical layers, to run in depth averaged mode to reduce computational simulation times (i.e. original model was Three-Dimensional (3D), but run in 2D for the present study).

The close proximity of the original upstream tidal model boundary at Tilbury, to the footprint of the Inner Thames Estuary Option (approximately 20km) had the potential to moderate the predicted effect of the development, particularly with regard to water levels. The tidal boundary was therefore removed and an artificial straight channel was coupled to the existing model grid. This channel approximately captured the tidal prism (and approximate depth and distance) of the Thames up to its tidal limit at Teddington and enabled the calibration of the water levels to be maintained. A constant discharge of $92m^3/s$ was applied at the upstream extent of the appended channel. This represents the long term average flow of the Thames (Defra, 2002).

These modifications enable the 2D model to be used to assess the impacts of the Inner Thames Estuary Option on the hydrodynamics in the vicinity and downstream of its footprint. The grid resolution of the existing 2D model limits its ability to assess the impact of the Inner Thames Estuary Option upstream of its footprint where the estuary becomes more representative of a narrow channel. Within this area, the 1D model which is designed to simulate the hydrodynamics in rivers, estuaries and channels, provides a more suitable tool for the assessment of water level change in this area. It is recommended that should the project move into a more detailed phase a new model is developed allowing greater resolution of the bathymetry within the narrow meandering sections of the estuary.

The 2D Outer Thames model was previously calibrated against simulated tidal levels and flows at more than ten locations across the model domain (ABPmer, 2005), all of which were seaward of Sheerness. Following the small modifications made to the model and the high level nature of the study, a check on the model calibration was made with respect to a small set of simulated tidal levels, local to the study area. The model performed within a set of prescribed calibration guidelines (ABPmer, 2012), validating its suitability for use in this study. Full details of the model calibration are reported in Appendix A. It is recommended that should the project move into a more detailed phase, a more rigorous calibration exercise on the higher resolution model be undertaken against measured water levels and flows in the vicinity of the footprint of the Inner Thames Estuary Option, as well as upstream and downstream of the development.

Within the 2D model, the Inner Thames Estuary Option has been implemented via the inclusion of ‘thin dams’ around the footprint of the development. These ‘thin dams’ are vertical walls that are aligned with the model grid and extend throughout the full water depth and act as a total blockage to the flow, thus achieving a representation of a reclaimed area. The 2D model has been run over both a mean spring tide and a mean neap tide.

5. Preliminary Impact Evaluation

The high-level assessment of potential impact from the proposed Inner Thames Estuary Option has drawn on the relevant baseline information and results of previous studies (as provided in the Conceptual Understanding, Section 3), along with the outputs from the numerical modelling (as described in Section 4).

The preliminary impact evaluation is focussed on predicted changes in the hydrodynamics (tidal levels, flows and waves) and geomorphology (sediment regime) of the estuary and the wider implications of such changes with regards to flood risk, ecological features and other sea users (navigation and maintenance dredging). The following sections detail the findings of high-level impact assessment for each topic.

5.1 Hydrodynamics and Geomorphology

Results offered here, relating to the potential effects of the proposed Inner Thames Estuary Option, are to be considered as preliminary only. High-level modelling has helped inform these initial considerations but, in due course, a more refined modelling approach, supported by a more detailed set of investigations and site data, would need to be considered to inform the Environmental Impact Assessment (EIA) which would be required to accompany any future planning application.

The location and scale of the proposed Inner Thames Estuary Option has the potential to modify the baseline processes, sediment pathways and overall sediment regime across parts of the Inner and Outer Thames Estuary. The degree and severity of any such alteration remains the subject of a more detailed investigation. However, here, the high-level modelling and conceptual understanding of processes and pathways has helped to develop a preliminary indication of the extent of any near-field and far-field changes to physical processes.

5.1.1 Hydrodynamic Regime

The conceptual understanding of the hydrodynamic regime is described in Section 3.2, which includes consideration of the typical water level elevations and flow speeds encountered across the study area, also offering information on the variation in tidal asymmetry. The results of the modelling assessment, as described in the following sections, have been considered in relation to this conceptual understanding.

The results of the high-level assessment of potential changes to water levels are shown in Figures 5 to 7, whilst Figures 8 and 9 show the potential changes to flow conditions. The assessment covered a period over a mean spring tide, with a tidal range of approximately 5.2m at Sheerness, with Figures 5 and 6 showing the predicted spatial extent of changes to the HW and LW levels and Figure 7 showing changes in water levels (and flows) throughout the tide at discrete locations. In addition, Figure 8 shows the predicted spatial extent of changes to peak spring flood and ebb flow speeds and Figure 9 shows the predicted changes to peak flow directions. Potential changes are shown down to 0.01m for water levels and down to 0.02m/s for flow speeds, which is within the margins of model accuracy for this high-level study.

Results for a mean neap tide reveal a slightly lower magnitude and extent of effect to that seen on a spring tide. As such, only the results for the spring tide are presented here, and discussed in further detail in the following sections.

5.1.1.1 Tidal levels

In respect of tidal levels, the proposed Inner Thames Estuary Option results in a predicted slight reduction in the level of HW immediately downstream (to the east) of the development of a magnitude between 0.02 - 0.03m. Wider reductions to HW level of up to 0.015m are also predicted across the River Medway. No changes in HW level of greater than ±0.01m are predicted downstream/east of a line extending from approximately Sheerness on the Isle of Sheppey to Shoebury Ness (Figure 5).

The results of the assessment also predict a slight increase in the elevation of LW immediately downstream (to the east) of the development, although the extent of this predicted effect is smaller than that predicted at HW. The magnitude of the predicted increase to LW local to the development is up to 0.02m, with no change greater than ±0.01m predicted across the wider study area (including the River Medway) (Figure 5). These results are derived from the 2D model.

Upstream of the proposed development site the Inner Thames Estuary funnels, towards a narrow channel (compared to the more expansive nature of the Outer Thames). Within this area, the 1D model, designed to simulate flows in rivers, estuaries and channels, has predicted a general reduction in HW levels between approximately 0.01 - 0.02m upstream and immediately downstream of the proposed development, with a smaller (<0.01m) increase in LW levels over the same area (Figure 6).

As a result of these changes to HW and LW, the tidal range is shown to reduce following the implementation of the proposed development by between approximately 0.01 to 0.04m within the Thames, and a predicted reduction of up to 0.02m in the River Medway.

These results are consistent with those of a previous study (HR Wallingford, 2002a), for the London Gateway development, which also predicted a reduction in HW and an increase to LW resulting from a reclamation of a section of the Inner Thames Estuary (sited approximately 8km upstream of the Inner Thames Estuary Option, between Coryton and Mucking Flats).

Time-series of modelled water levels for the baseline and scheme scenarios are provided in Figure 7 at two locations; Site C4 which is immediately to the north of the reclamation and C2 which is downstream of the reclamation within the main approaches to the Thames. There is a small phase shift, with the scheme slightly advancing the tide by approximately 1-2 minutes.

5.1.1.2 Tidal currents

In respect of flow speeds, the proposed Inner Thames Estuary Option results in a similar pattern of predicted change on both peak flood and peak ebb tidal conditions (Figures 8 and 9). In both cases, the results predict an increase in depth-averaged flow speeds within the main channel (immediately to the north of the Inner Thames Estuary Option), resulting from the constriction of flow past the reclamation site (as described in Section 3.1).

This predicted increase to peak flow speeds is up to approximately 0.2m/s, or around 20% (with peak baseline ebb flows of approximately 1m/s). A time-series comparing the modelled flow speeds for the baseline and scheme scenarios is provided in Figure 7, at a location immediately to the north of the proposed reclamation (Site C4 as shown in Figure 4). The spatial extent of this predicted increase to peak flows is approximately the length of the reclamation, with the predicted effect extending slightly further under ebb tidal conditions (likely as a result of the slight ebb dominance in this part of the Inner Thames Estuary).

Similar increases to flow speed were inferred for the London Gateway development, again due to reclamation of land constricting the estuary profile. In this case, the associated dredging of the berth pock*et al*ongside the reclamation was found to help maintain the cross-sectional area of flow, resulting in some mitigation of the increased flows.

In addition to the predicted increase in flow speeds in the main channel, adjacent to the reclamation site, there is also a predicted reduction in flow speeds immediately upstream and downstream (to the west and east) of the Inner Thames Estuary Option. Flows in these regions are reduced by the proposed reclamation, which acts to block the previous flow pathways. The predicted reduction in peak flow speeds is up to approximately 0.6m/s in the downstream direction, although this magnitude of effect is highly localised, with reductions across the wider area generally reaching 0.1 to 0.2m/s.

Under both flood and ebb tidal conditions, the extent of this predicted reduction is much greater downstream of the reclamation than upstream, extending as far as the main approach channel to the Thames (Figure 8). A time-series comparing the modelled flow speeds for the baseline and scheme scenarios is provided in Figure 7, at a location downstream of the reclamation, within the main approaches to the Thames (Site C2, as shown in Figure 4). Time-series of flows upstream of the development are not shown because no changes are predicted to occur within the margins of the accuracy of the model.

5.1.2 Wave Regime

The conceptual understanding of the wave regime (Section 3) across the study area identified that due to the presence of the Outer Estuary banks and wide intertidal flats, the predominant wave forcing within the Inner Estuary is from locally generated winds. Whilst the modelling of potential changes to the wave conditions is outside the scope of the present study, some comment is offered here as to the likely effects.

The proposed Inner Thames Estuary Option is likely to shelter areas of the Inner Estuary and the adjacent coastline from locally generated waves (both from wind-generated sources and from ship wash). Depending on the direction of wave approach, areas in the lee of the proposed development will be afforded a degree of shelter by the reclamation site. In addition, the fetch length across the Estuary for winds approaching from the southerly sector will be reduced by the reclaimed land, thus providing a potential reduction in wave energy along sections of Chapman Sands, Marsh End Sand and Southend Flat under certain prevailing wind conditions.

It is considered likely that an assessment of potential changes to the wave regime would be necessary should the project move into a more detailed phase. This assessment would also allow for consideration of the potential for reflection effects from waves impacting on the reclamation site and any likely interaction effects with waves from passing vessels. However, assuming a suitable design of the reclamation boundary (rock armour), reflection would not be expected to be significant.

5.1.3 Sediment Regime

Whilst the modelling of potential changes to the sediment regime is outside the scope of the present study, some comment is offered here as to the likely effects based on the conceptual understanding of the physical processes and how potential changes in flows might affect sediment transport.

Taking a holistic view of the estuary, the Inner Thames Estuary Option has the effect of reducing the overall tidal range, and therefore the volume of water passing in and out of the estuary on a single tide. Assuming that concentrations in the water column are not affected across the entrance then the sediment budget will be reduced. This however will be marginal as most of the sediment in suspension is due to deposition and resuspension within the estuary, where this will not be changed and most of the changes occur in the vicinity of the development where suspended sediment concentrations are lower. The development also tends to locally increase flows, therefore there is potential for a marginal increase in the on-going export of fine sediment, see below.

The conceptual understanding of the sediment regime is detailed in Section 3. This identified that downstream of Gravesend (along the section of the Inner Estuary where the proposed development is sited), the ebb-dominant nature of the tide results in a net export of sediment out of the estuary. Along this part of the Inner Estuary, the dominant forcing mechanism for sediment transport is considered to be from the tidal currents, with wave forces generally providing a negligible influence.

Existing flows within the main channel fronting the proposed development peak at approximately 1.15m/s on the ebb tide, compared to around 1m/s on the flood tide (as described in Section 3). Given the water depths present, these flows are likely to be sufficient to mobilise the dominant sediment types occurring in the channel (mainly sands). Following the implementation of the Inner Thames Estuary Option, the flow speeds in the channel immediately to the north of the development, are predicted to increase by up to 20% (Figure 7 and Figure 8). It is considered likely that this increased flow speed will result in an increased rate of sediment transport from this area on both the flood and ebb state of the tide. In keeping with the conceptual understanding of the baseline environment, the ebb tide is considered to remain the dominant forcing with the Inner Thames Estuary Option in place, thus the general trend for export of sediment will likely continue. The increased flows through the maintained Yantlet Channel, could result in a widening or deepening of the channel, depending on the bed material type or the channel may become more self-maintaining within this section of the estuary.

A similar pattern of increased flow speeds is also predicted over parts of Chapman Sands, Marsh End Sand and Southend Flat, on the north bank of the estuary, opposite the proposed development site (Figure 8). The conceptual understanding of this part of the estuary shows the sediments here are similar in character to those on the south bank of the estuary, being predominantly muddy but becoming increasingly sandy towards the subtidal. The predicted changes of increased flow speed in the main channel is considered likely to result in an increased rate of sediment transport from the intertidal area on both the flood and ebb state of the tide, particularly near to the LW mark, where erosion could result. Changes to flow direction are less marked across the shallow intertidal areas, than within the main channel (Figure 9). Within the main channel, the ebb tide is considered to remain the dominant forcing with the Inner Thames Estuary Option in place, thus the general trend for export of sediment from the Inner Estuary will likely continue.

Downstream of the Inner Thames Estuary Option, the hydrodynamic assessment has predicted a slight reduction in peak flow speeds on both the ebb and flood tides (Figure 8). This predicted decrease in flows is relatively small (<0.1m/s), and the flows speeds are predicted to remain high enough to mobilise the sandy sediment expected in these areas. As such, the likely effect of the proposed development will be to slightly reduce the existing rate of sediment transport in these areas, rather than to turn an erosionary environment into an accretionary one. There are no associated changes to flow direction predicted across the approaches to the main channel, suggesting the direction of sediment transport across this area is likely to remain as in the existing baseline situation.

Outside of the main channel, the high-level assessment has predicted a reduction in flow speeds immediately upstream and particularly downstream of the proposed development (Figure 8). In these locations, which occur mainly across the existing intertidal area, the reduction in tidal current speeds could potentially result in flows that fall below the threshold for sediment mobility, and thus result in increased accretion of fine material. Downstream of the proposed development, the action of waves and their reflection from the end of the reclamation may help to stir up the bed, particularly over the intertidal, helping maintain suspended sediment transport. However, upstream of the Inner Thames Estuary Option the sheltering effect is likely to reduce the potential for sediment transport yet further, causing accretion.

Changes to flow direction are also predicted across the areas immediately adjacent to the proposed development, particularly in the downstream direction (Figure 9). Here the flows are forced around the reclamation site, in contrast to the baseline condition whereby uninterrupted flow pass across the development site. The change in flow direction on both the ebb and flood tides is predicted to be in an anticlockwise direction in proximity to the coastline (and within the immediate approaches to the Medway), switching to a clockwise direction further offshore, towards the main channel. These changes to flow direction tend to increase the flow separation at the mouth of the Medway. This has the potential to change the local pattern of sediment transport, and possibly the location, slope and stability of the channel to the Medway Estuary.

Discussion of the estuary turbidity maximum (ETM) is provided in Section 3.2.5. Based on changes to the tidal conditions considered in this preliminary impact evaluation, the predicted effects are unlikely to impact the location of the ETM More detailed assessment is likely to be required to investigate the effects of different scenarios (including surge tides and high freshwater flows) should the development progress.

5.2 Flood Risk

The results of the high-level hydrodynamic assessment have predicted a small reduction in the levels of HW and small increase in the levels of LW, in close proximity to the Inner Thames Estuary Option footprint (Figures 5 and 6). The predicted reduction infers an overall small reduction in the level of tidal flood risk as a direct result of the development. It is noted here that further assessment of the potential effect considering surge tides and under high river flows and taking account of the effects of climate change will help to provide additional information on flood risk effects as a result of the development.

As described in Section 3, surge events have the potential to increase flood risk, particularly when they coincide with periods of HW. The high-level assessment has identified a small phase shift in the tidal signal upstream of the Inner Thames Estuary Option, whereby the temporal transit of the tide is shifted slightly by the proposed development. Depending on the timing of any surge events (in relation to the tide), this phase shift may have the potential to slightly increase, or reduce, flood risk above the baseline case under certain tidal states. A more detailed surge analysis would help to determine how often surge events coincide with the timing of HW, and the potential for a shift in the tidal phase to increase or decrease flood risk.

The sheltering effect of the Inner Thames Estuary Option is also likely to result in reduced wave heights in the lee of the reclamation site, and where the development interrupts the existing fetch along and across the Inner Estuary. As a result, it is considered likely that potential overtopping effects from waves will also reduce, due to the smaller waves impacting on these sections of the coastline.

In addition, the general lowering of HW levels suggests that the capacity of the Inner Estuary to receive flood waters from fluvial sources will not be reduced by the proposed development. As a result, it is not considered likely that the construction of the Inner Thames Estuary Option will result in any increase to fluvial flood risk from the 'backing-up' of flood waters. Further assessment including a scenario which simulates a closed Thames Barrier would help to provide further detail on the potential effect on fluvial flood waters.

It is noted that present future climate predictions (as summarised in Section 3), suggest a general increase in mean sea-level, along with an increased storminess (resulting in potentially increased wave energy, and a projected increase in winter precipitation) over the next 100-years. These increases are considered likely to outweigh the effects of the predicted reductions in water levels and wave heights, as a result of the proposed development. As such, a general increase in flood risk is expected in the future, although from the results of the high-level preliminary assessment, it is not considered likely that this will be exacerbated by the construction of the Inner Thames Estuary Option.

5.3 Ecological Features

The Inner Thames Estuary Option in its current location would result in a direct loss of approximately 2,099 ha of intertidal, transitional and subtidal habitat (including grassland[1] and brackish standing water). The extent of overlap with internationally designated sites is approximately 1,609ha. The majority of habitat that would be lost comprises intertidal mud and sandflats, grazing marsh, subtidal sand/mud and to a lesser extent saltmarsh and brackish standing water.

There will also be indirect changes to the extent of intertidal and subtidal habitats as a result of changes in the hydrodynamic (water levels) and sedimentary regimes (changes in patterns of sediment erosion and accretion) associated with an Inner Thames Estuary Option. In this respect the outputs of the high level numerical hydrodynamic modelling exercise have been used to determine a possible magnitude of indirect change in habitat extent. The baseline and predicted water levels (with the inclusion of the Inner Thames Estuary Option) have been extracted from the hydrodynamic model and reviewed in the context of the estuary topography. The range of typical slopes at both high and low water have been approximated from bathymetric charts for three sections of the study area which have been defined in relation to the relative changes in high and low water with the scheme in place (Figure 10). The ranges in slopes that have been assumed are:

- Between 1:50 and 1:200 at LW; and
- Between 1:10 and 1:50 at HW.

This is an over-simplification of the range of slopes likely to occur within the study area but the results help to indicate the broad range and magnitude of the potential indirect losses associated with changes in water level.

The predicted changes in high and low water levels assumed for each section can be summarised as:

- Section 1: 0.02m reduction in high water and 0.01m increase in low water; and
- Sections 2 and 3: 0.015m reduction in high water and 0.01m increase in low water.

These estimates are based on the outputs of the numerical modelling (see Section 5.1.1.1) in the context of the margins of accuracy of the numerical model. The change in width of the intertidal zone (according to the ranges in slope applied) has been extrapolated along the respective lengths of high and low water within these zones. The length of the low and high water lines has been approximated on the basis of the Ordnance Survey (OS) Terrain 50 and the OS Boundary-Line datasets respectively.

[1] It should be noted that at this stage the degree of marine influence on the grassland habitats has not been assessed and as such could include areas of terrestrial habitat.

The results of this exercise are summarised in Table 6. The potential changes to intertidal extent as a result of changes in water levels with the airport in place (under the conservative assumptions used in this assessment) are in the order of 70ha. This is equivalent to less than 5% of the direct losses of intertidal, transitional and subtidal losses under the direct footprint of the Inner Thames Estuary Option.

It should be noted that to increase the confidence in this prediction there would be a requirement for better defined recent topographic data with complete estuary coverage, improved resolution within the hydrodynamic models and a fuller consideration of any associated physical / biological changes.

In addition, this estimate does not take account of any indirect losses associated with any additional changes to the morphological or hydrodynamic regime of the estuary (e.g. waves, sedimentation). On the north bank of the estuary, opposite the location of the Inner Thames Estuary Option, for example, the potential for increased erosion, particularly near to the LW mark has been identified (Section 5.1.3).

In contrast in some locations such as outside of the main channel, the high-level assessment has predicted a reduction in flow speeds immediately upstream and particularly downstream of the proposed development. In these locations, which occur mainly across the existing intertidal area, the reduction in tidal current speeds could potentially result in flows that fall below the threshold for sediment mobility, and thus result in increased accretion of fine material. These changes to the physical environment not only have the potential to result in changes to habitat extent but also the species that are supported by these habitats.

Table 6. Indicative indirect intertidal losses from changes in water levels

Section	Lower Estimate of Loss at LW (ha)	Upper Estimate of Loss at LW (ha)	Lower Estimate of Loss at HW (ha)	Upper Estimate of Loss at HW (ha)
1	5	19	2	10
2	2	6	0	1
3	6	22	2	10
Total	12	48	4	21

5.4 Other Sea Users

An initial consideration of potential effects on other sea users is offered here. Due to the preliminary nature of the present study, only those activities that are known to take place in close proximity to the proposed development site are discussed below. Other topics (e.g. aggregate dredging, offshore renewable energy projects, fishing, tourism etc.), along with further assessment of the topics included herein, will likely need to be considered (at least to some degree) as part of any future studies.

5.4.1 Navigation

The main approach channel into the Inner Thames Estuary, providing access to the London Gateway (and beyond, to the Port of London) passes within 0.5km to the north of the proposed development site. Furthermore, the number of marinas located around the Thames Estuary coastline and the presence of a number of small-ship anchorage areas in close proximity to the proposed development, suggest the area is likely to be used by a wide range of vessel types and sizes.

The Inner Thames Estuary Option will partially block the southern limits of the Estuary (Figure 2), resulting in a reduction in the cross-sectional profile. This blockage will reduce the portion of the Inner Estuary that is available for sailing, forcing all vessels transiting the area to use the more northerly extents (which include the main dredged channel). The close proximity of the edge of the reclamation to the main navigation channel has the potential to affect the manoeuvring characteristics of vessels past the airport, for example from boat suction effects, or changes to the vessel squat characteristics. In addition, the constriction of the estuary is predicted to result in an increase in peak depth averaged flow speeds on both the ebb and flood tidal states. These increases of approximately 0.2m/s (0.4 knots) on mean spring baseline flows of 1m/s (2 knots) represent around a 20% increase in peak flows based on this high level assessment and are likely to have an effect on navigation for certain vessels (particularly smaller ones) and, as such, it is likely that a Navigation Risk Assessment would be necessary, should the project proceed to a more detailed phase.

Due to the ongoing requirement for navigational access to the London Gateway, the main channel along Sea Reach (Yantlet Channel), which would pass within 0.5km from the northern limit of the proposed Inner Thames Estuary Option, would need to be maintained over the lifetime of this new port development. As such, the potential impact of the proposed Inner Thames Estuary Option on this channel, i.e. the potential for increased flow velocities and, therefore, a potential for increased erosion (or reduced deposition), requires more detailed consideration.

5.4.2 Maintenance Dredging

The main approach channel for the Thames Estuary passes adjacent to, and immediately north of, the proposed Inner Thames Estuary Option. Due to the ongoing requirement for navigational access to the Inner Thames (including the London Gateway development), the main channel along Sea Reach will need to be maintained.

The predicted effects from the hydrodynamic assessment, and the associated effects inferred on the sediment regime, suggest that the main channel along Sea Reach will be subject to higher flows on both the flood and ebb tides, following construction of the Inner Thames Estuary Option. Flows speeds are predicted to increase by up to 20% immediately to the north of the proposed development. As a result, it is considered likely that this section of the channel will experience higher rates of sediment transport than presently exist, resulting in no increase in the maintenance dredging requirement, or even scour in terms of both width and depth depending on the underlying bed characteristics. Should erosion occur, it is possible the disturbed material could be redeposited in sufficiently slack, existing deposition areas, both up and down estuary. Such areas would include the new berths at London Gateway, even though the hydrodynamics of the location are unlikely to significantly change.

Further offshore, within the approaches to the main channel, the assessment has predicted a slight reduction in peak flow speeds on both the flood and ebb tides. The reduction is likely to be small, with flow speeds remaining sufficient to mobilise the sandy sediment expected within this region. The likely effect is considered to be a small reduction in the overall rate of sediment transport in these areas and a possible redistribution in locations of channel erosion and accretion, possibly affecting the existing maintenance dredging commitment. The changes in hydrodynamics at the entrance to the Medway have the potential to affect the alignment and depths of the main channel to the Medway Ports (Sheerness and Chatham Docks).. Further detailed sediment modelling would be recommended to confirm this potential, and attempt to quantify the volumetric changes that would occur.

6. Summary and Recommendations

The results of the high level impact assessment presented in this report should be considered as preliminary only. In due course, a more refined modelling approach, supported by a more detailed set of investigations and site data collection would need to be undertaken to support any future planning application.

Preliminary results indicate that the proposed Inner Thames Estuary Option would result the following modifications to the existing hydrodynamic regime:

- Reduction in high water levels on mean spring tides by up to 0.03m upstream and immediately downstream of the Inner Thames Option footprint and by 0.015m in the Medway;
- Slight increase in low water levels (by around 0.01m) in the same area;
- Overall reduction in tidal range of 0.01-0.04m;
- Small shift in the propagation of the tidal signal, specifically a small advancement of the tide by 1-2 minutes;
- A localised increase in depth-averaged flow speeds within the main channel (only just extending beyond the along-estuary extent of the Inner Thames Estuary Option). This increase is around 20% of the baseline flows (which peak at just over 1m/s on spring tides);
- A localised increase in flows on the northern shore of the estuary;
- A reduction in flows immediately upstream and downstream of the footprint; and
- Reduced wave activity upstream, particularly on the south bank.

The predicted changes in the hydrodynamic regime have the potential to affect the existing sediment regime. The anticipated affects are:

- A marginal increase in the on-going export of fine sediment from the estuary;
- A widening or deepening of the Yantlet Channel, or more self-maintaining channel in the area adjacent to the Inner Thames Estuary Option footprint, depending on the bed material type;
- Increased sediment transport from the intertidal areas of parts of Chapman Sands, Marsh End Sand and Southend Flat;
- Reduced erosion, or in some small areas very local to the footprint accretion of fine material on the south bank of the estuary; and

- A modified local pattern of sediment transport in the immediate approaches of the Medway which could affect the approach channel slope and stability.

The Inner Thames Estuary Option would result in the following changes to ecological habitats:

- A direct loss of approximately 2099 ha of intertidal, transitional and subtidal habitat (including grassland and brackish standing water), approximately 1609ha of which is internationally designated.

- An indirect loss (associated with changes in water levels) estimated to be less than 5% of the direct losses of intertidal, transitional and subtidal habitat under the direct footprint of the Inner Thames Estuary Option; and

- Additional changes to habitat extent and quality as a result of changes in erosion and deposition patterns which could have further implications for the species supported by the estuary, although these changes would be expected to be considerably smaller than the predicted impacts associated with changes in water levels.

It is not considered likely that the Inner Thames Estuary Option will result in an increase in flood risk.

The key changes which have the potential to impact other sea users are summarised as follows:

- The increased flows in the Yantlet Channel may impact on the navigation of certain vessels (particularly smaller ones); and

- The reduced flows downstream of the Inner Thames Estuary Option footprint may slightly increase dredge requirements in the main channel over a small area and/or affect the Medway approach channel.

Should the project move into a more detailed phase, the following recommendations should be considered:

- Detailed, up to date bathymetry data of the study area to feed into the detailed model and the associated ecological assessment. This includes complete Light Detection and Ranging (LiDAR) coverage to ensure intertidal areas are sufficiently resolved;

- Collation of existing data sets on hydrodynamic and sedimentary regimes followed by a gap analysis. Based on the results, justify and develop a set of detailed field measurements that will support detailed EIA analysis and provide relevant data as input parameters and calibration data for a bespoke suite of models;

- Detailed sediment properties survey to assist model calibration and enhance conceptual understanding of the sediment dynamics of both the subtidal and intertidal areas. This can be undertaken at the same time as sampling for ecological requirements;

- Assessment of existing data to determine historic and on-going trends, particularly in areas that are indicated to be changed by the Inner Thames Estuary Airport Option in this study;

- Development of bespoke hydrodynamic model allowing greater resolution of the bathymetry within the narrow meandering sections of the estuary;

- Rigorous calibration of bespoke hydrodynamic model against surveyed water level and flow data in the vicinity of the Inner Thames Estuary Option footprint;

- Detailed flow modelling (speed and direction) to inform ecological and detailed navigation requirements;

- Wave modelling to inform engineering design;

- Sediment modelling for quantification of potential changes to the intertidal areas and subtidal berth and channel configuration and consequential effects to dredge requirements;

- Surge and climate change effects analysis for more detailed assessment of flood risk and potential for change to the morphological development of the estuary;

- Model run scenarios should include the investigation of surge events, high river flows and a closed Thames Barrier; and

- Navigation Risk Assessment.

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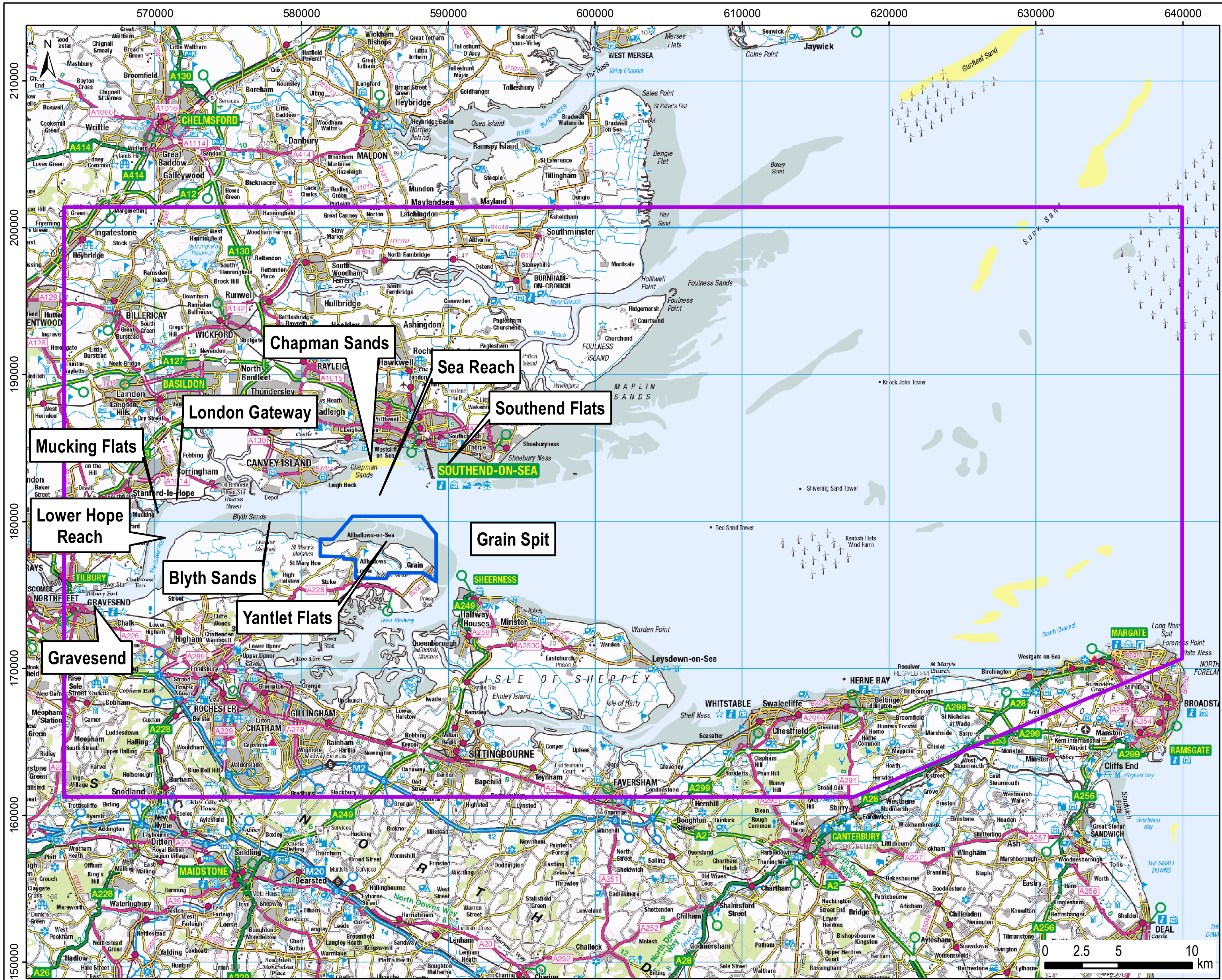
Figures



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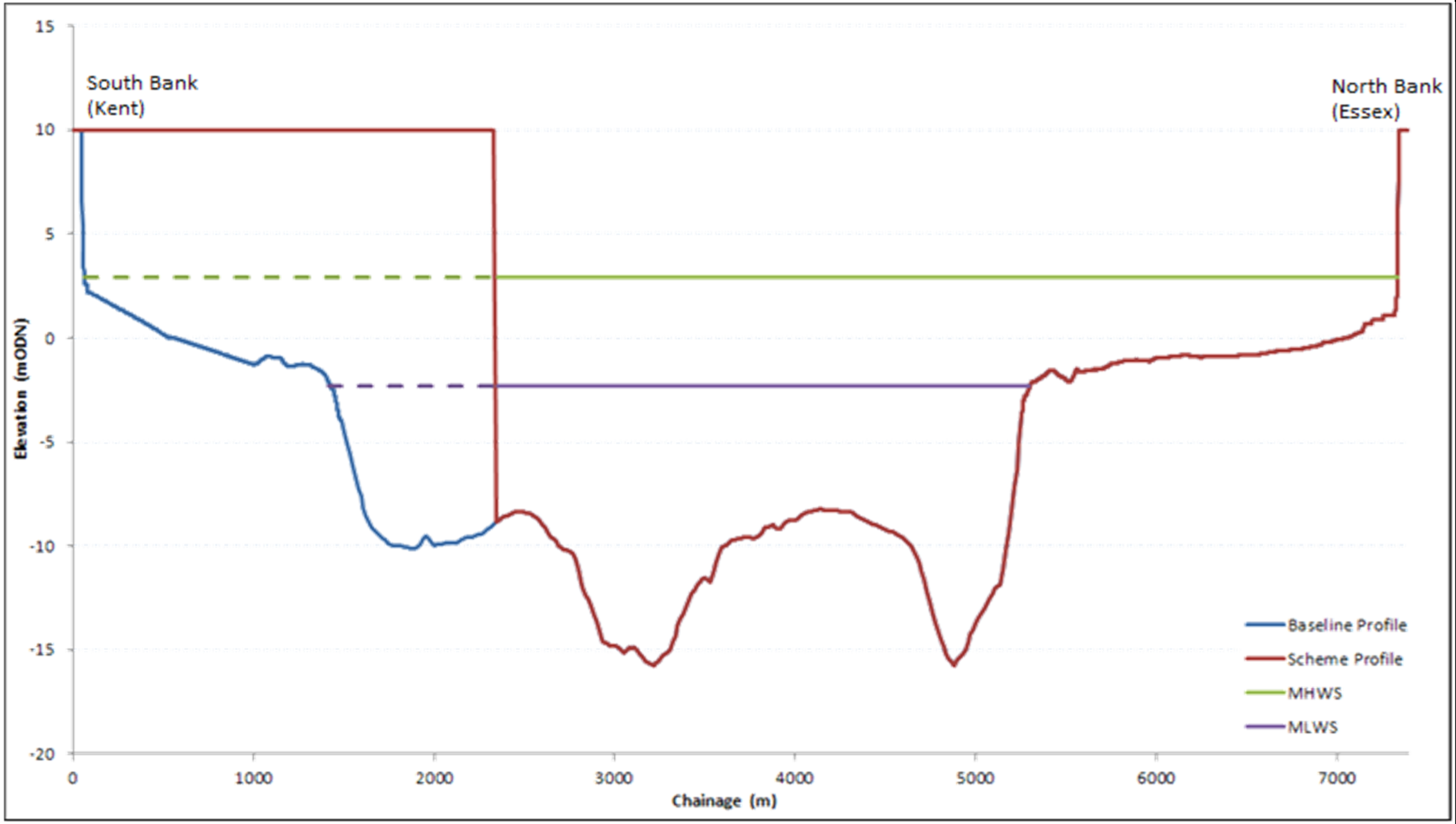
Study Area

Figure 1



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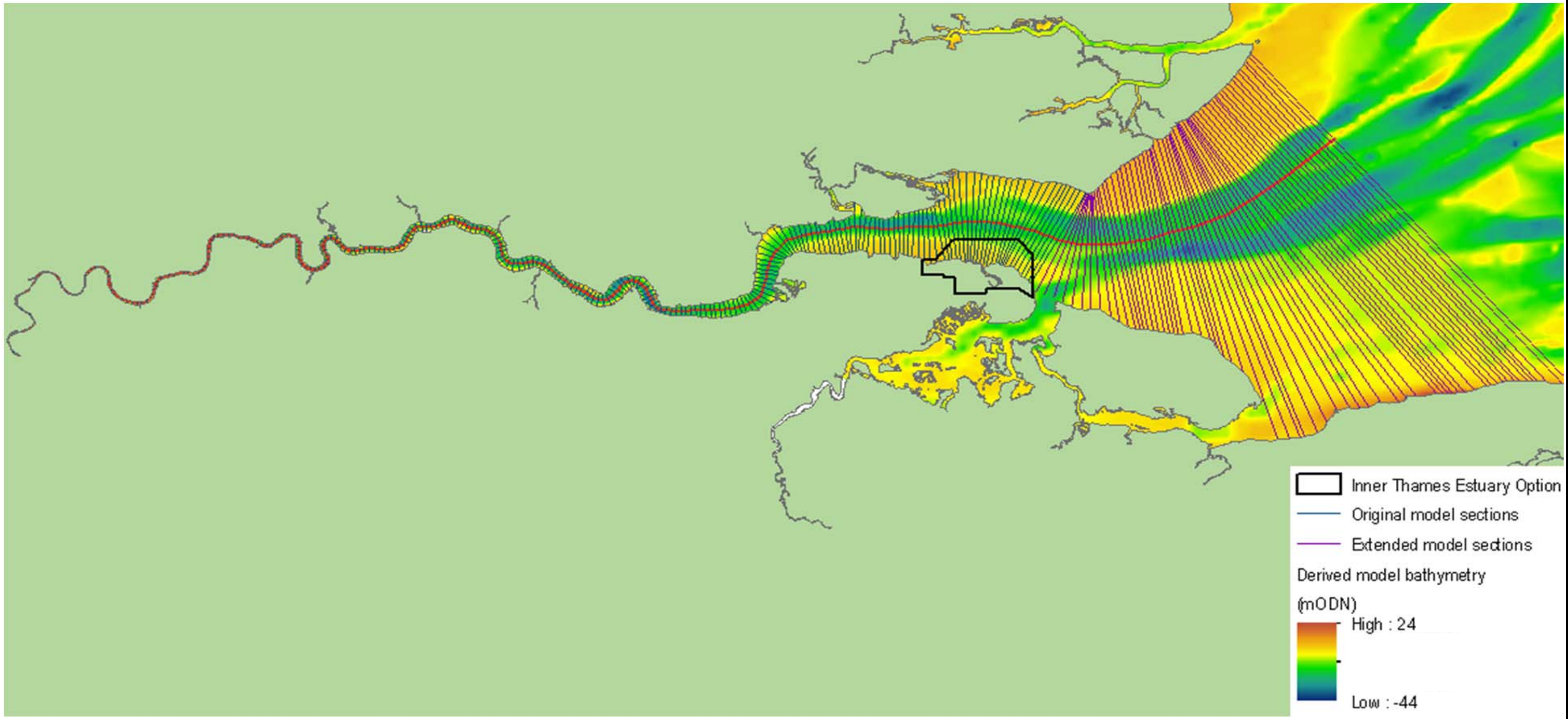
Example Change in
1D Cross-section Profile

Figure 2



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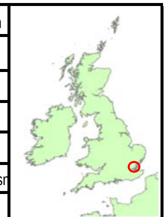

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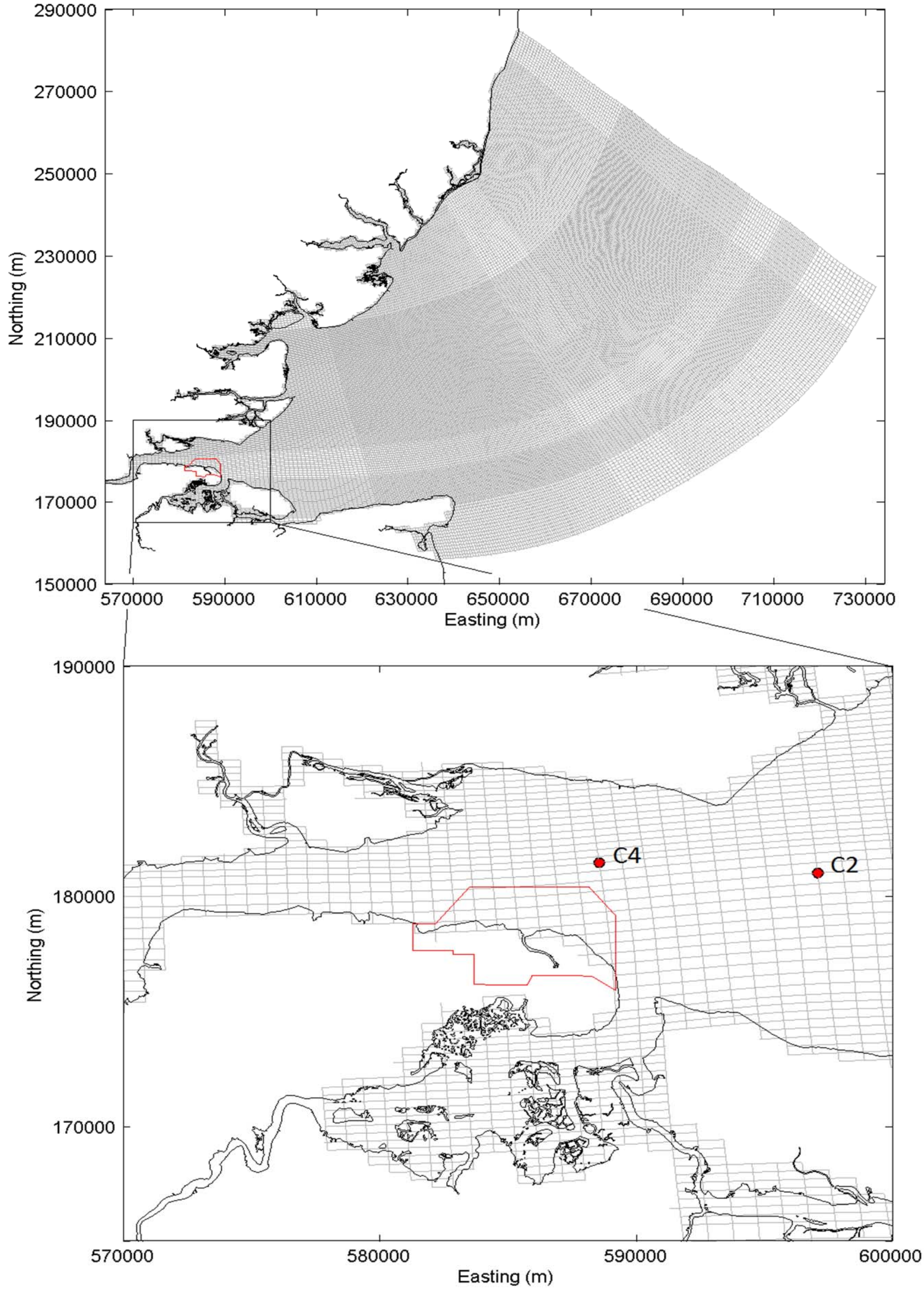
1D Model Extent

Figure 3



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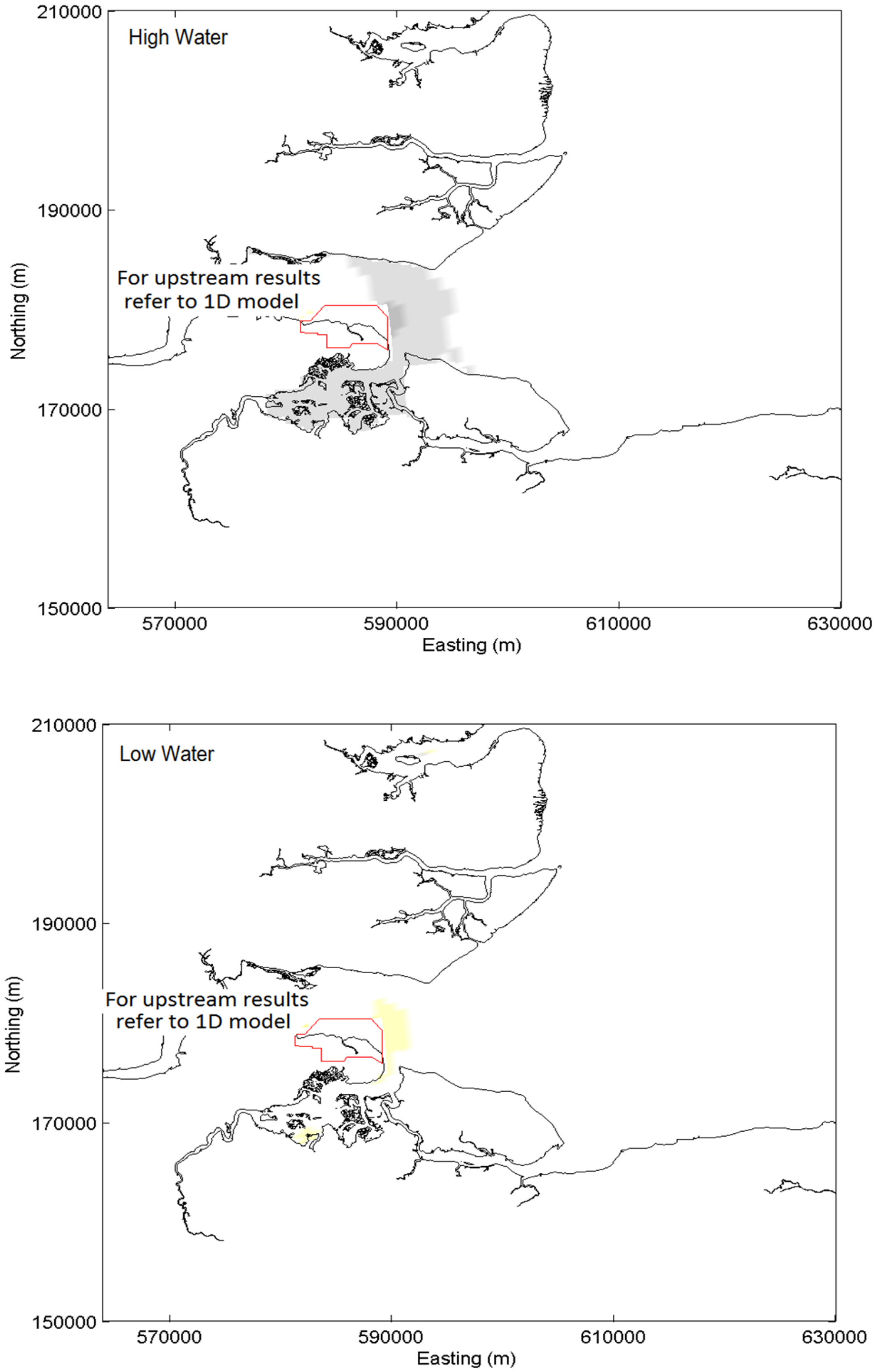
2D Model Extent

Figure 4



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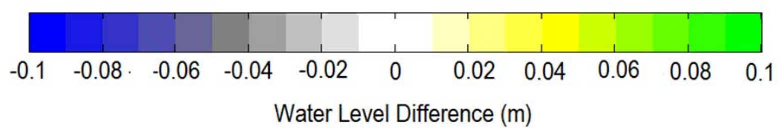

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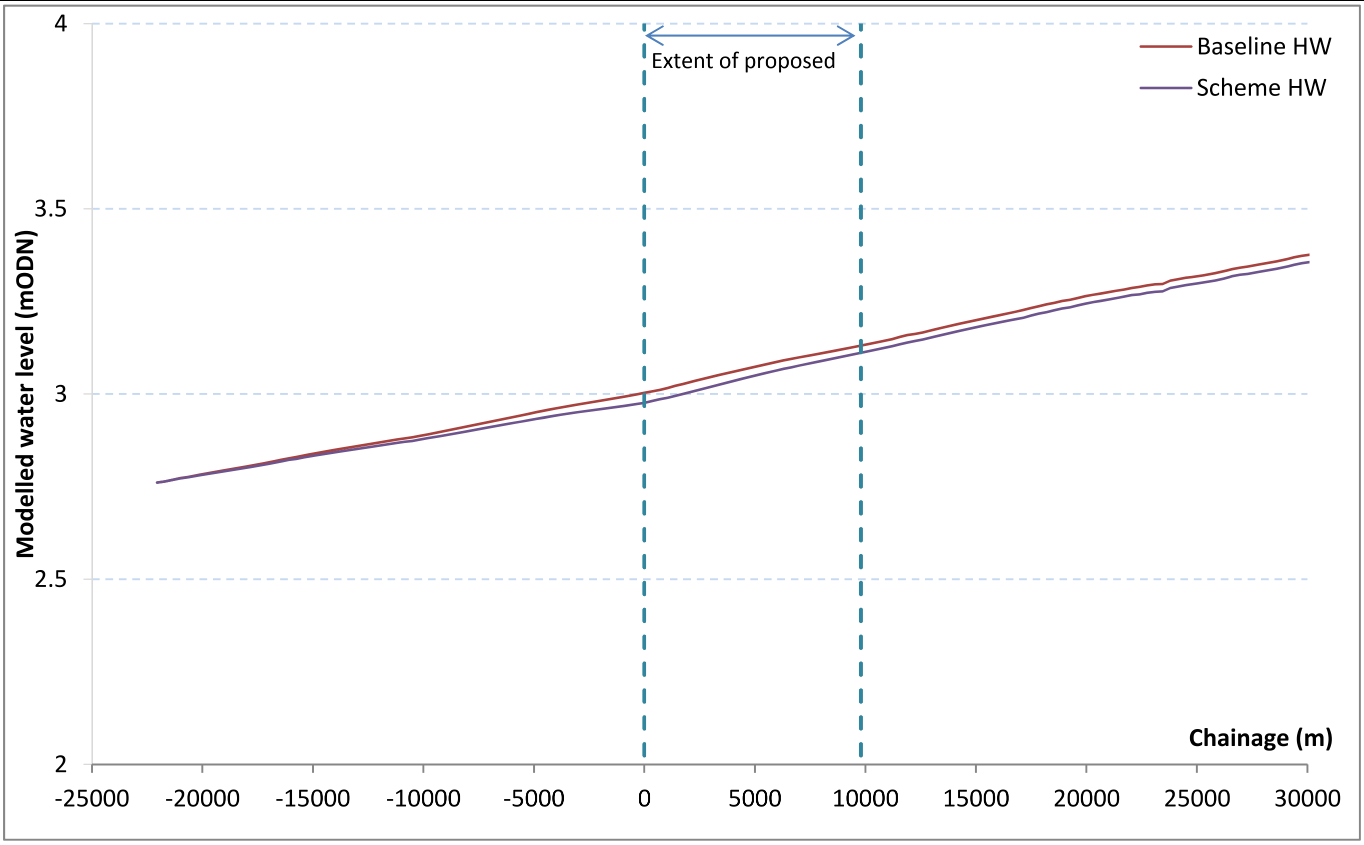
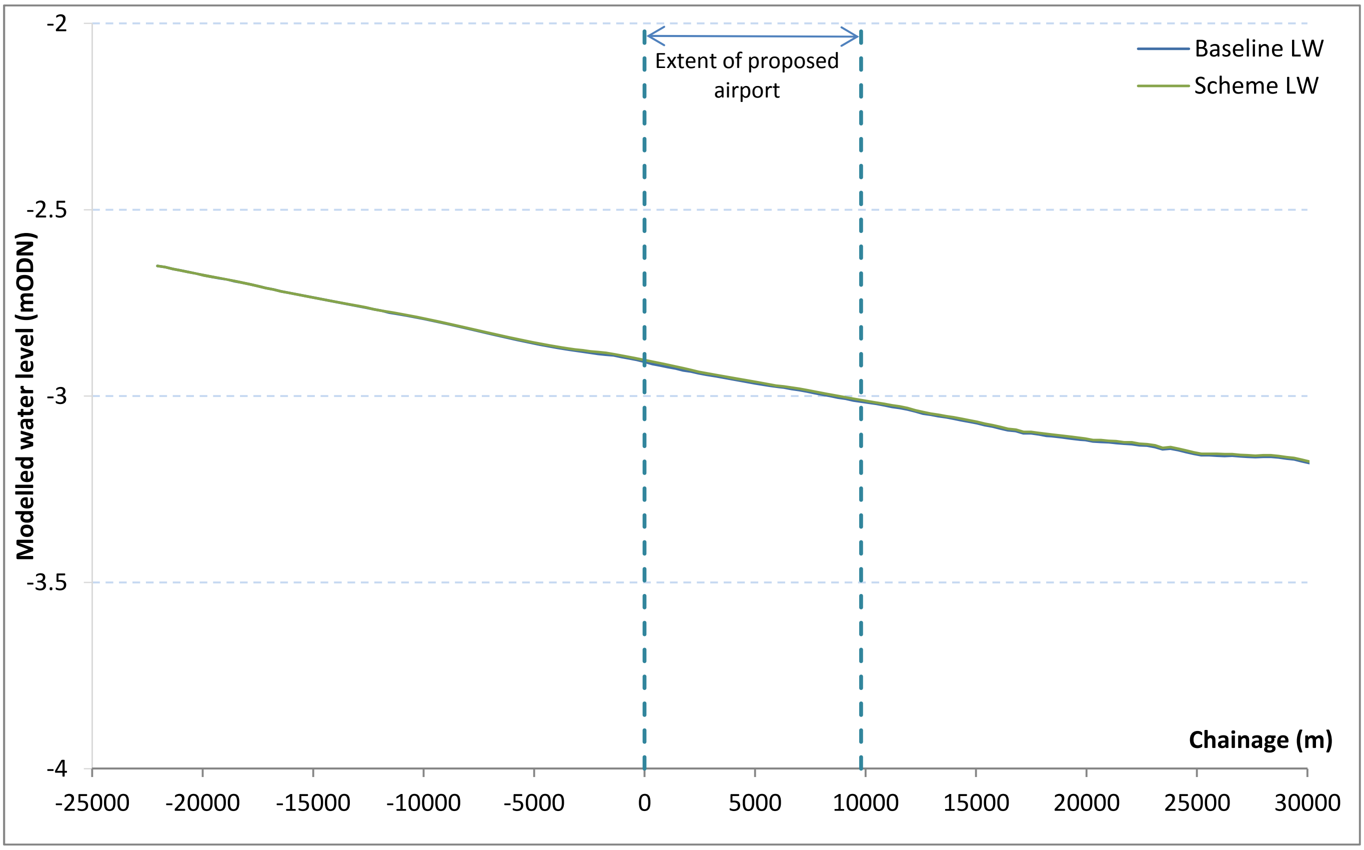
Predicted Changes to Water Levels - 2D Model

Figure 5





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Scale		n/a	
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Chainage given relative to downstream limit of Inner Thames Estuary Option footprint

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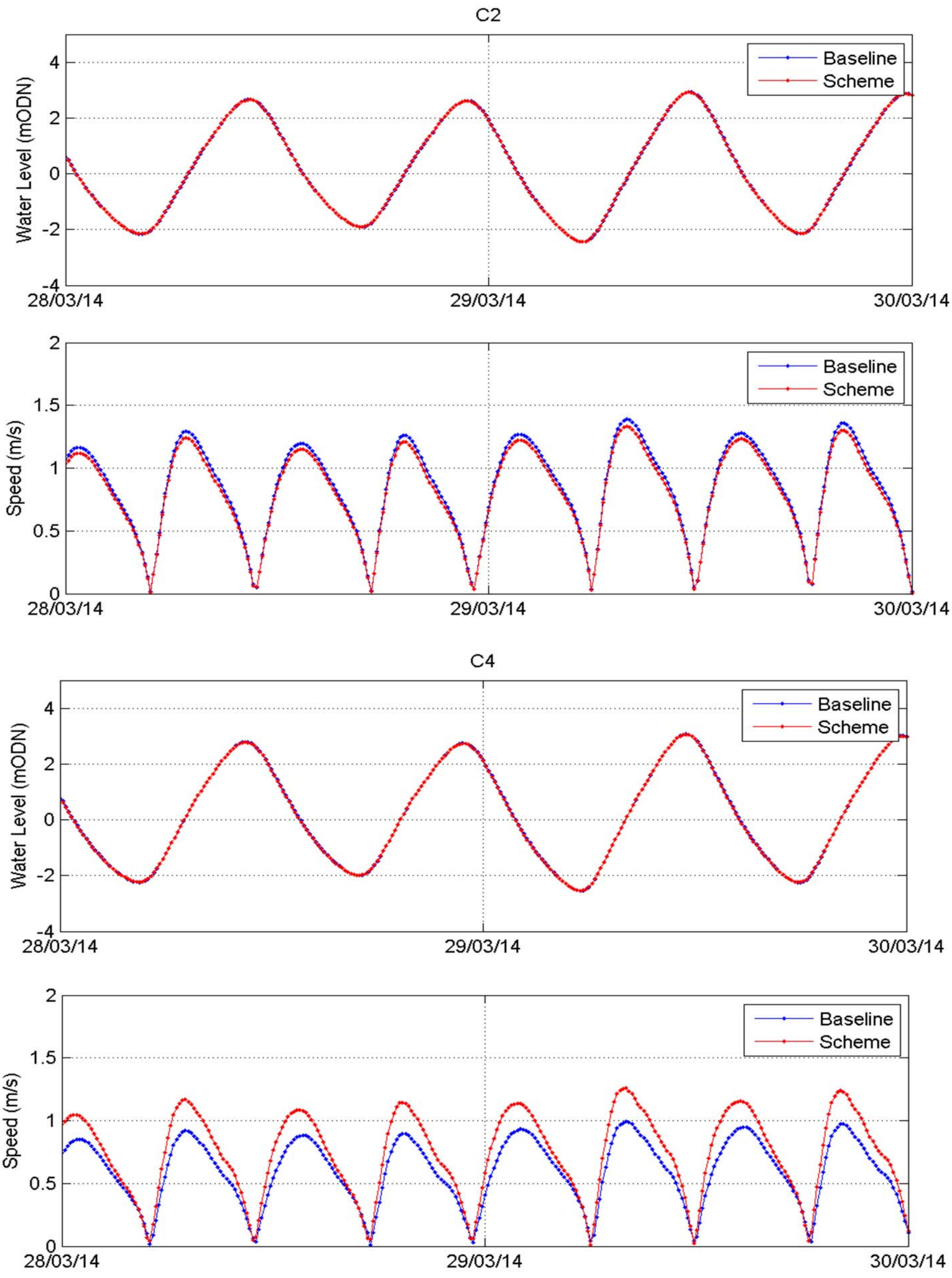
Predicted Changes to Water Levels - 1D Model

Figure 6



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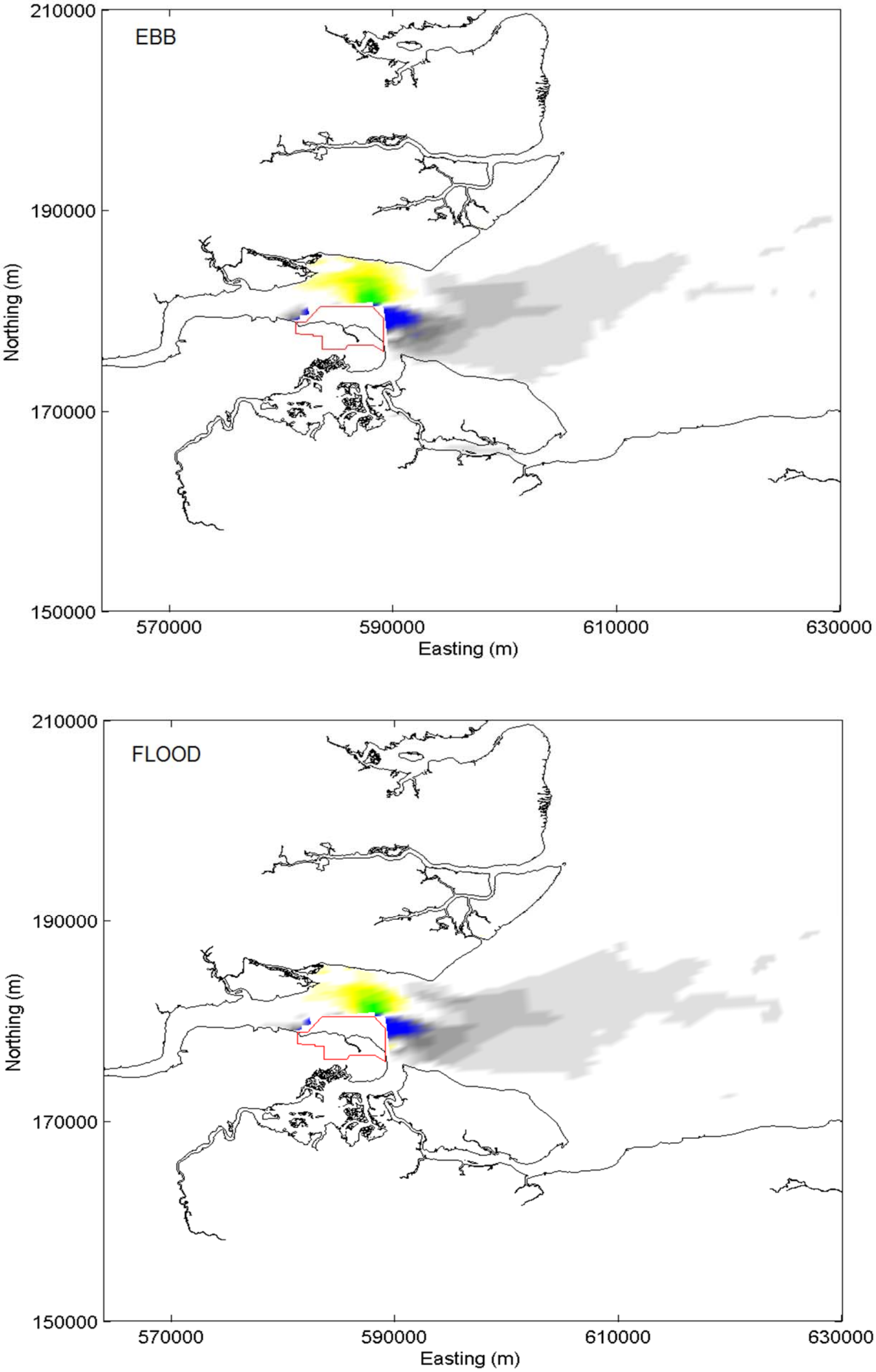
Time-series Comparison Plot of Water Levels and Flows at C2 and C4

Figure 7



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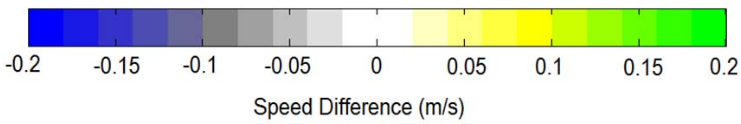

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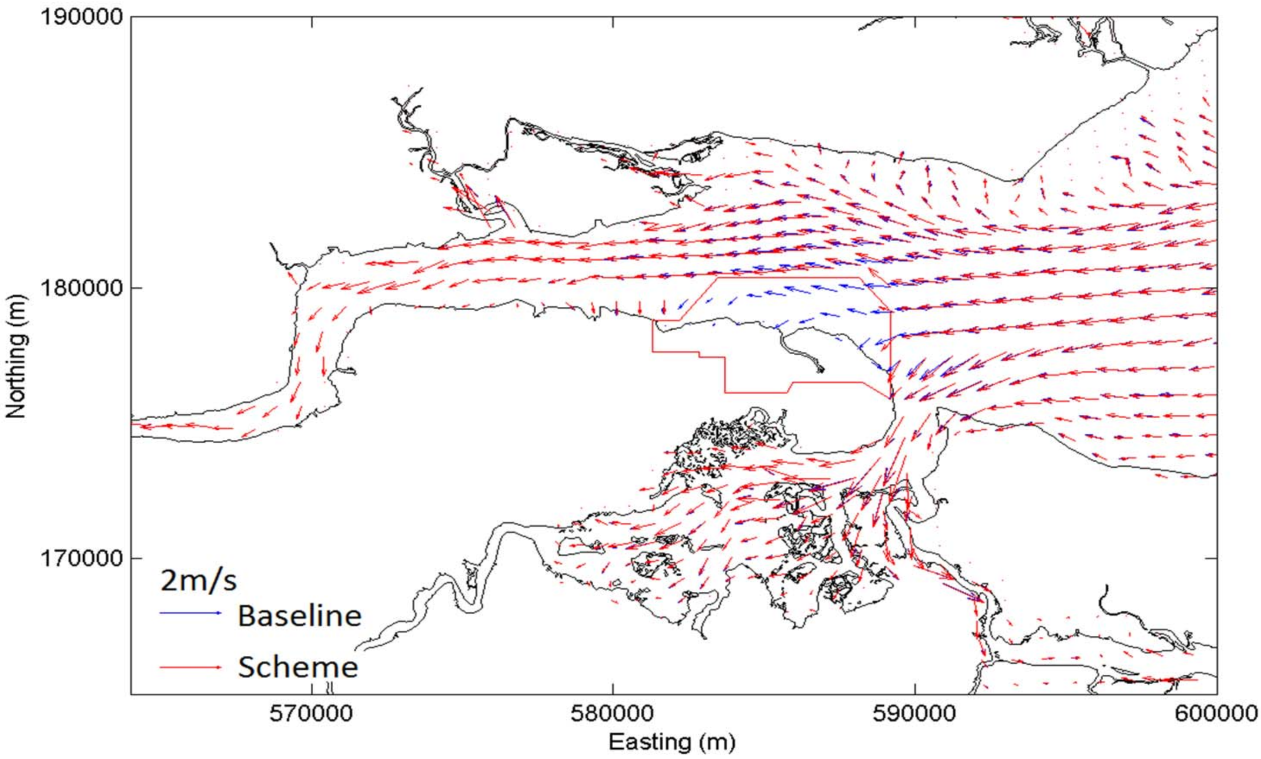
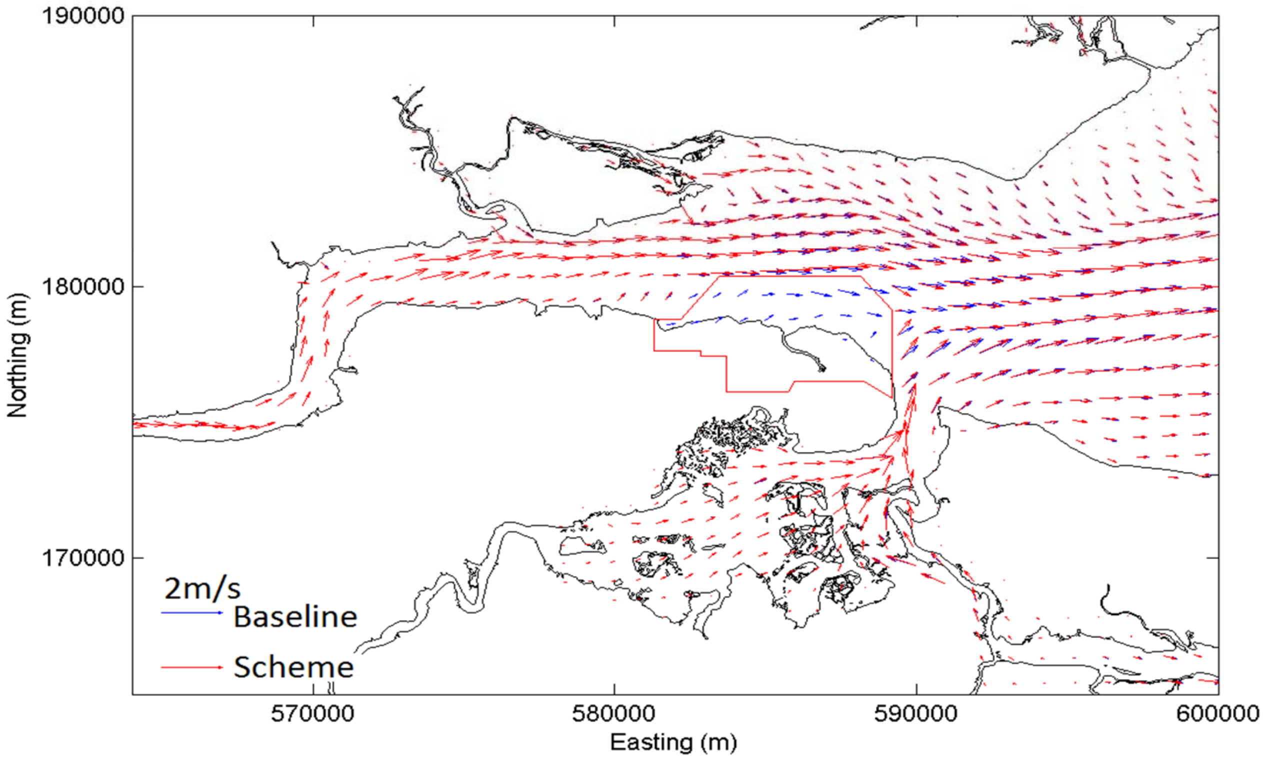
Predicted Changes to Flow Speeds on Peak Ebb and Peak Flood

Figure 8





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Produced by ABPmer			

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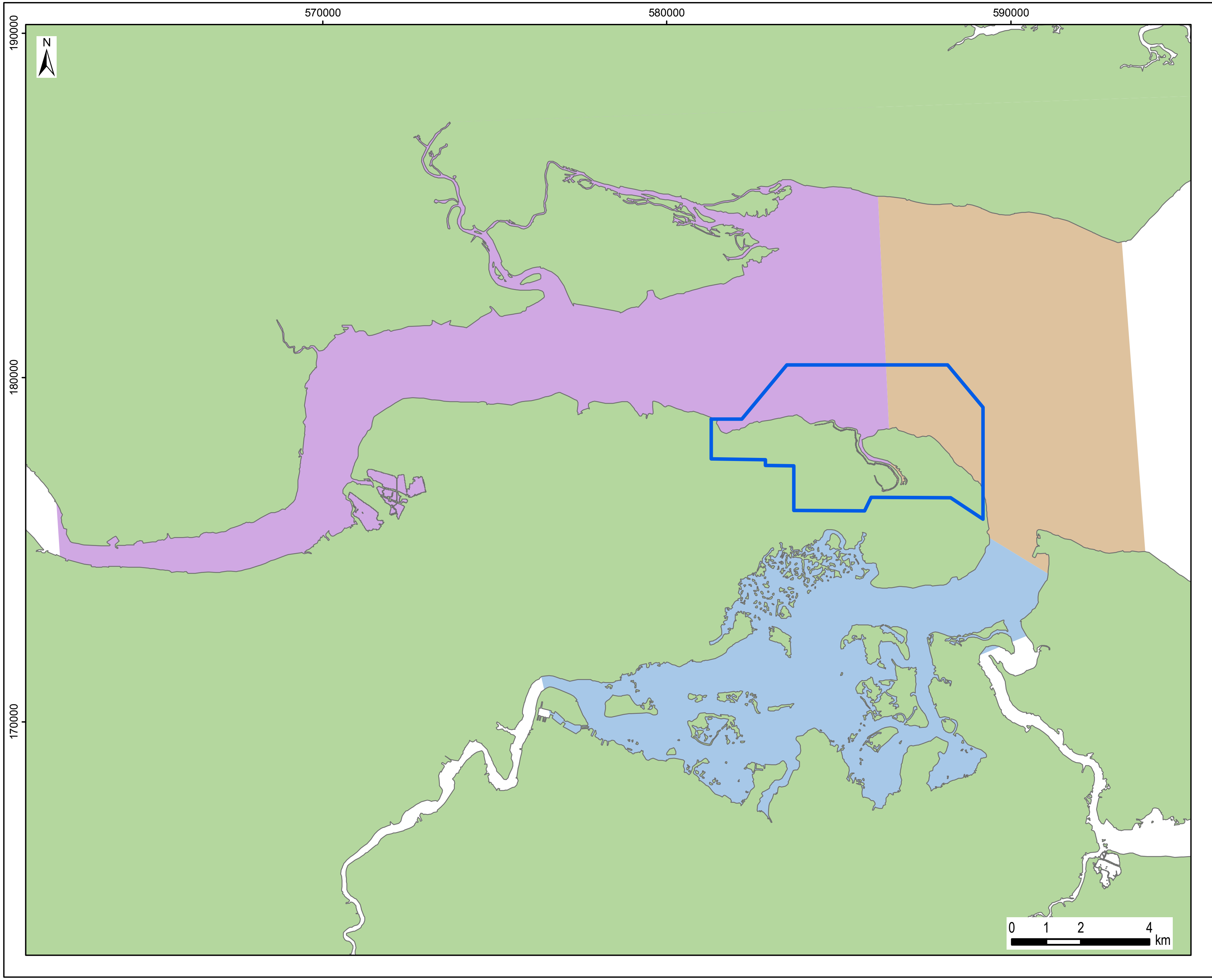
Flow Vector Comparison Plot on Peak Flood and Peak Ebb

Figure 9



Inner Thames Estuary Option

Sections

1

2

3

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4237 Mod_Fig10_Hab_Loss.mxd			
Produced by ABPmer			

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Indirect Habitat Loss Calculations

Figure 10

Appendix A

Model Calibration

A. Model Calibration

A.1 Introduction

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by Transport for London (TfL) to provide a high level review of the suitability of the Inner Thames Estuary Option as part of the Airports Commissions investigation into the UK's future airport capacity needs. The review has a number of aspects including a high level impact assessment. An existing hydrodynamic model, which encompasses the Inner and Outer Thames Estuary, has been modified and used to reproduce water levels and depth averaged current speeds and directions to help evaluate the hydrodynamic and geomorphological impacts associated with the proposed development as part of this assessment.

This appendix provides details on the Two-Dimensional (2D) model applied in this study, including information on model setup and calibration.

A.2 Model Design

ABPmer's existing model of the Outer Thames (which includes the proposed development area of the Inner Thames Estuary Option) was modified for use in this study. The extents of the model are shown in Figure A1. The model has an upstream limit at Tilbury and an offshore limit to the east at Lowestoft and to the south at Ramsgate. The model grid resolution in the area of interest is approximately 450m x 800m. Full details on the original model configuration can be found in ABPmer (2005), Appendix A.

Some modifications to the existing model were required to ensure that it was 'fit for purpose'. Specifically:

- Modification of the grid to better represent the features local to the development area, namely an improvement to the land-sea definition around the Isle of Grain and an inclusion of the River Swale to enable flow around the Isle of Sheppey;

- Inclusion of the London Gateway development;

- Modification of the upstream boundary at Tilbury, which was originally tidally driven. To avoid the introduction of any boundary artefacts which would limit the interpretation of the modelled impact associated with the development (due to the relatively close proximity of this boundary to the development) the tidal boundary was removed and an artificial channel was coupled to the existing model grid. This channel approximately captured the tidal prism (and approximate depth and distance) of the Thames up to its tidal limit at Teddington and enabled the calibration of the water levels to be maintained. A constant discharge of $92m^3/s$ was applied at the upstream extent of the appended channel. This represents the long term average flow of the Thames (Defra, 2002).

- Modifications of the astronomic forcing applied at the offshore boundaries to improve the amplitude and phasing of the tidal levels upstream of the development area; and

- Reconfiguration of the domain, which originally had ten vertical layers, to run in depth averaged mode to reduce computational simulation times.

A.3 Model Calibration

The Outer Thames model was previously calibrated against simulated tidal levels and flows at more than ten locations across the model domain (ABPmer, 2005), all of which were seaward of Sheerness. Given the relatively small modifications made to the model and the high level nature of the study, the recalibration of the model was constrained to a relatively small set of simulated tidal levels, local to the study area (as shown in Figure A2). It is recommended that should further study be required, the modified model undergoes a more rigorous calibration exercise against additional measured water level and flow data around the study area.

In order to represent the range of tidal conditions encountered within the extent of the study area the model was run for a 6 day period, encompassing both mean spring and mean neap tidal levels. The length of the simulation was sufficient to allow initial model start-up instabilities to settle down prior to the neap and spring tides used in the analysis. The model was calibrated against 2 days of spring tides and validated against 2 days of neap tides.

Model calibration was achieved by applying minor corrections to the atmospheric conditions which drive the offshore model boundary. The applied corrections shifted the forcing at the boundary by approximately 20 minutes and modified the amplitude by a 95% scaling.

A.3.1 Guidelines and Metrics

The performance of the model was assessed against a set of metrics defined in an internal model calibration guidance note (ABPmer, 2012). This document brings together all relevant literature and guidance and offers a critique and discussion on best practice standards upon which the derived metrics are based. These metrics provide a comparative measure for the goodness-of-fit between temporal and peak features of the model predictions and measured hydrodynamic parameters. These statistical assessments are accompanied by visual checks.

The model performance metrics used here are:

- Mean surface elevation difference (high and low water level). Calculated as the mean difference (bias) in water level at high and low water (model minus observed value) for a spring and neap tidal period. The mean difference is also expressed as a percentage of the mean tidal range;

- Time adjusted fit in water level. This is the phase correction required to yield the minimum Root Mean Square (RMS) differences between the modelled and observed water levels at all-time steps for a spring and neap tidal period and indicates any phase lag in the model;

In view of the relatively minor modifications made to the model and the high level nature of the study, a detailed calibration of modelled flows was not undertaken.

The best practice standards reported in ABPmer (2012) state recommended values that the model aims to meet; for water levels mean level differences should be within ±0.1m, while the percentage differences should be within 10% of spring tidal ranges and 15% of neap tidal ranges; and water level phasing should be to within ±15 minutes within coastal regions, although this can be relaxed to ±25 minutes within estuaries at the upstream limits.

These standards allow for some discrepancy between modelled and measured data to account for differences in what the model is capturing (parameter values averaged over a grid cell and a time step of ten minutes in this case) against what the data represents (parameter values at a single point in space for a particular point in time). In addition to this, the modeller should consider whether additional discrepancy is acceptable based on any known limitations in the calibration dataset used. Simulated water levels from the admiralty's TotalTide package were used as a calibration dataset in this study. This dataset has a limited temporal resolution (hourly but with sinusoidal curve fitting to derive values at 10 minute intervals) and a limited quoted precision with levels given to one decimal place (i.e. to the nearest 0.1m).

A.3.2 Calibration and Validation of Water Levels

The calibration statistics are presented in Table A1. These statistics should be considered in conjunction with time-series plots of modelled water levels against the TotalTide levels, which are shown in Figure A3. The model was tuned to achieve a good level of agreement with the TotalTide water levels during the spring tide calibration period. It is apparent that on the whole the model captures the amplitude and phasing of the tidal signal as it progresses up-estuary. For the most part the statistics achieve the standards detailed in section 3.1. The only exception to this is in the HW values at Southend On Sea and Sheerness where the modelled levels are 0.11 and 0.12m higher than those from TotalTide, respectively. However this is only 2% of the tidal range and is therefore considered acceptable, especially in view of the fact that levels in TotalTide are only given to the nearest 0.1m.

Table A1. Calibration statistics (spring tides)

Location	Water Level Difference in m and (% of Tidal Range)		Phase Difference (Minutes)
	High Water	Low Water	
Tilbury	-0.06 (-1)	0.02 (0)	-14
Coryton	0.00 (0)	0.02 (0)	-4
Southend on Sea	0.11 (2)	0.08 (2)	-3
Sheerness	0.12 (2)	-0.01 (0)	2
Margate	0.04 (1)	0.05 (1)	-3

Examination of Figure A3 indicates the modelled shape of the tidal curve slightly differs from the symmetrical tidal curve from TotalTide, with the model depicting a slower ebbing of the tide relative to the flood at all sites except Margate. Gauge data at Sheerness viewed in real-time online from the Channel Coastal Observatory (CCO) suggests that the model may provide a more accurate representation than TotalTide. Should a more detailed assessment be required for the Inner Thames Estuary Option, it is recommended that this be investigated in more detail.

The validation statistics are presented in Table A2, and time-series plots of modelled water levels against the TotalTide levels on neap tides are shown in Figure A4. As during the calibration period, the model captures the amplitude and phasing of the tidal signal as it progresses up-estuary during the validation period. Percentage differences in tidal levels are slightly higher on neap tides than on spring tides, in part due to the smaller neap tidal range, but remain less than 10% at all sites. Phase differences are also similar to those derived for the spring tides, except at Margate where the model is 12 minutes early (compared to just 3 minutes early on spring tides). This still lies within the calibration target of 15 minutes and as such it is concluded that the modelled water levels achieve a suitable level of calibration for the model to be applied for the use intended in this study.

Table A2. Validation statistics (neap tides)

Location	Water Level Difference in m and (% of Tidal Range)		Phase Difference (Minutes)
	High Water	Low Water	
Tilbury	-0.05 (-1)	-0.06 (-2)	-18
Coryton	0.07 (2)	-0.12 (-3)	-4
Southend on Sea	0.17 (5)	-0.03 (-1)	-1
Sheerness	-0.01 (0)	0.09 (3)	-3
Margate	0.18 (7)	0.00 (0)	-12

A.3.3 Validation of Modelled Flows

The model has not been calibrated against flow data in this study. However, to ensure that the model is simulating flows of the correct sort of magnitude and direction, peak ebb and peak flood flows on a mean spring tide have been extracted and are plotted in Figure A5. It is apparent that the flood and ebb flows are of comparable magnitude with ebb flows only slightly higher than those on the flood. Highest flows occur offshore of South East of Southend, peaking at around 1.3m/s on the ebb. Directly offshore of Southend flows are slightly lower, being around 1.1m/s. Further upstream at Middle Blyth flows are slightly lower, in general being less than 1m/s. The characteristics of the modelled flows in this region are consistent with reported maximum flows (IECS, 1995) which are quoted in the main report.

A.4 Summary

The modifications made to ABPmer's existing 2D regional model of the Outer Thames Estuary have ensured that the model is fit for the purpose of informing the high level review of the Inner Thames Estuary Option, with the model achieving a suitable level of calibration against synthesised tidal levels and a reasonable agreement with known peak flow speeds. It is recommended that should the project progress to more a detailed phase, the model undergoes a more rigorous calibration procedure against measured water level and flow data.

A.5 References

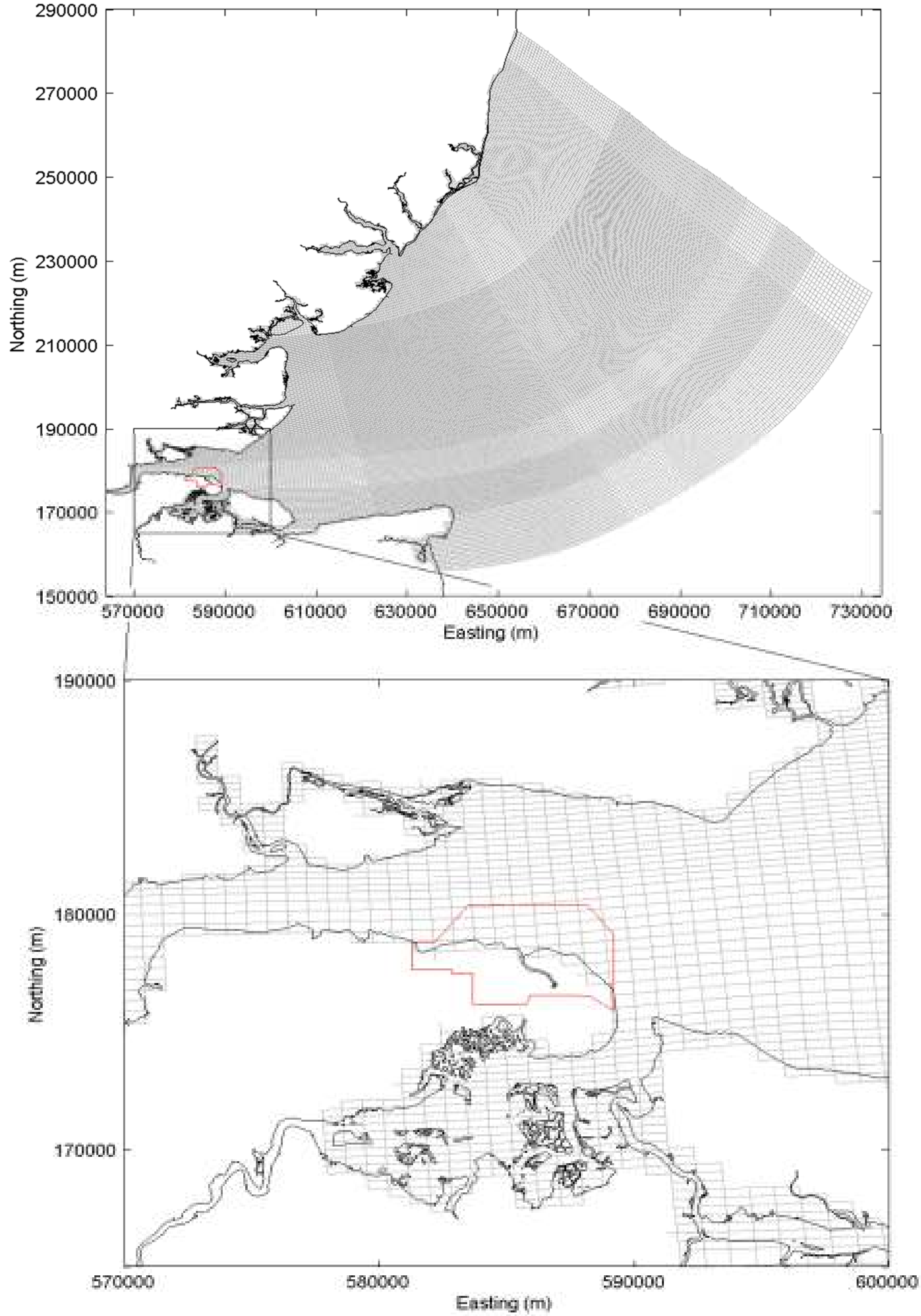
ABPmer (2012). Numerical Model Calibration and Validation Guidance. ABP Marine Environmental Research Ltd, File Note R/1400/112.

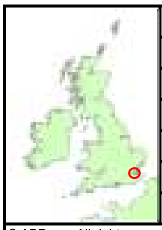
ABPmer (2005). Greater Gabbard Offshore Wind Farm Coastal Process Assessment: Scheme Assessment. ABP Marine Environmental Research Ltd, Report No. R.1224. Appendix A: Regional Model Design, Calibration and Validation 'Greater Gabbard Offshore Wind Farm'.

Defra (2002). Futurecoast. Published by Department for Environment, Food and Rural Affairs on CD-Rom.

IECS (1995). The Thames Estuary: Coastal Processes and Conservation. Report to English Nature by the Institute of Estuarine and Coastal Studies (IECS). Report number: Z035-95-F (a).

Appendix A Figures





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Red outline shows footprint of Inner Thames Estuary Option

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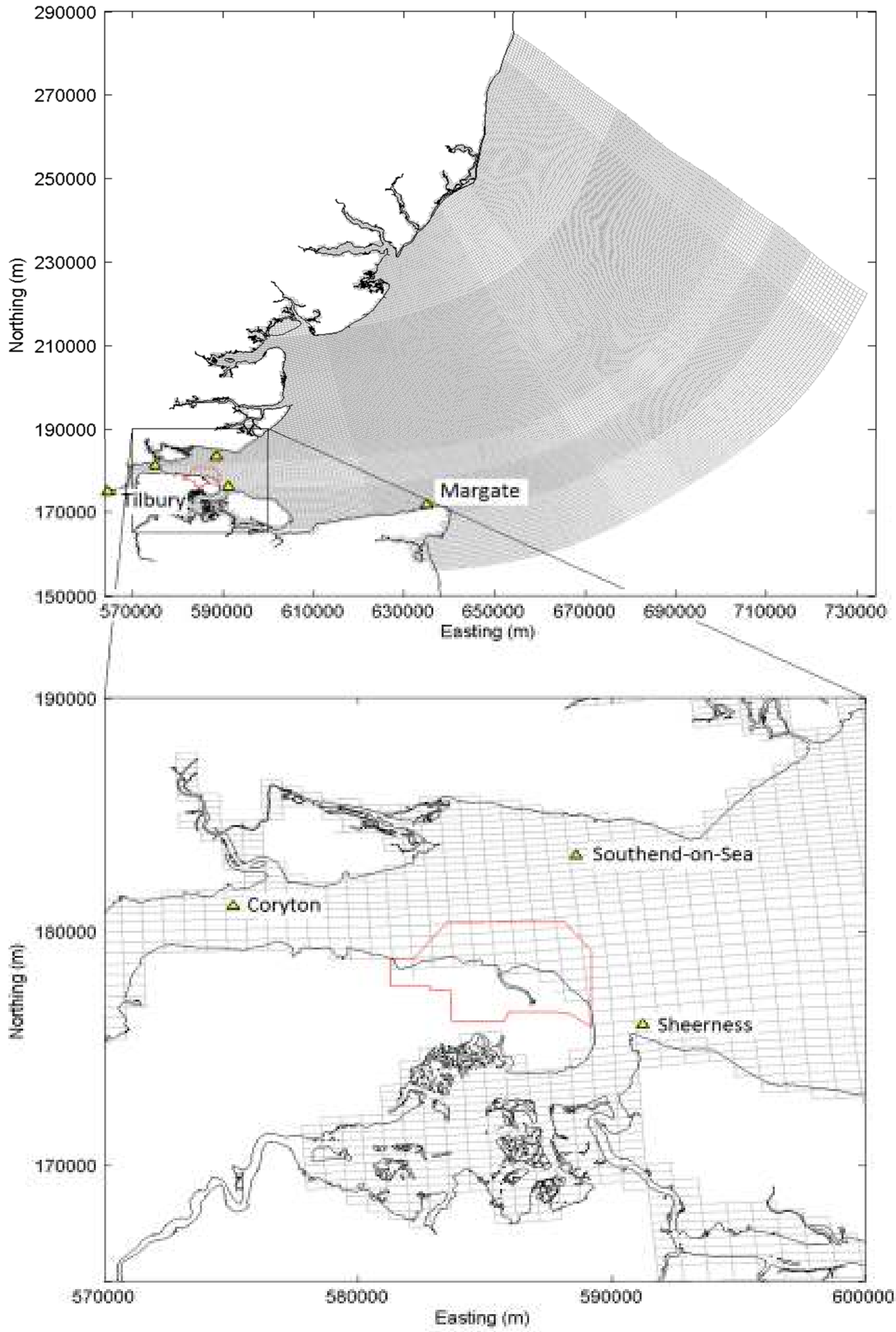
Model Domain

Figure A1



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Produced by ABPmer			

Red outline shows footprint of Inner Thames Estuary Option

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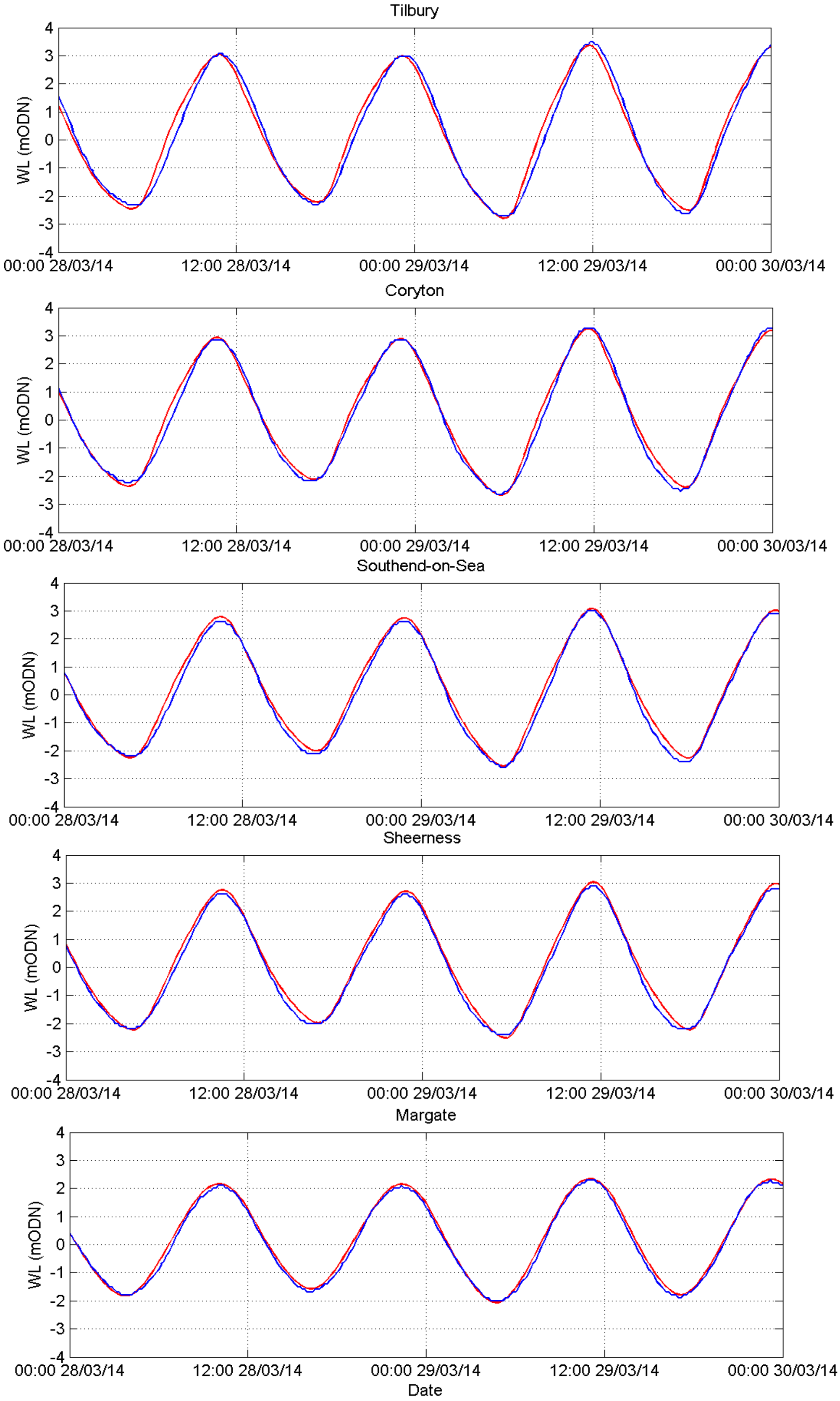
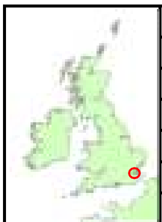
Model Calibration Locations

Figure A2





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Model

Total Tide

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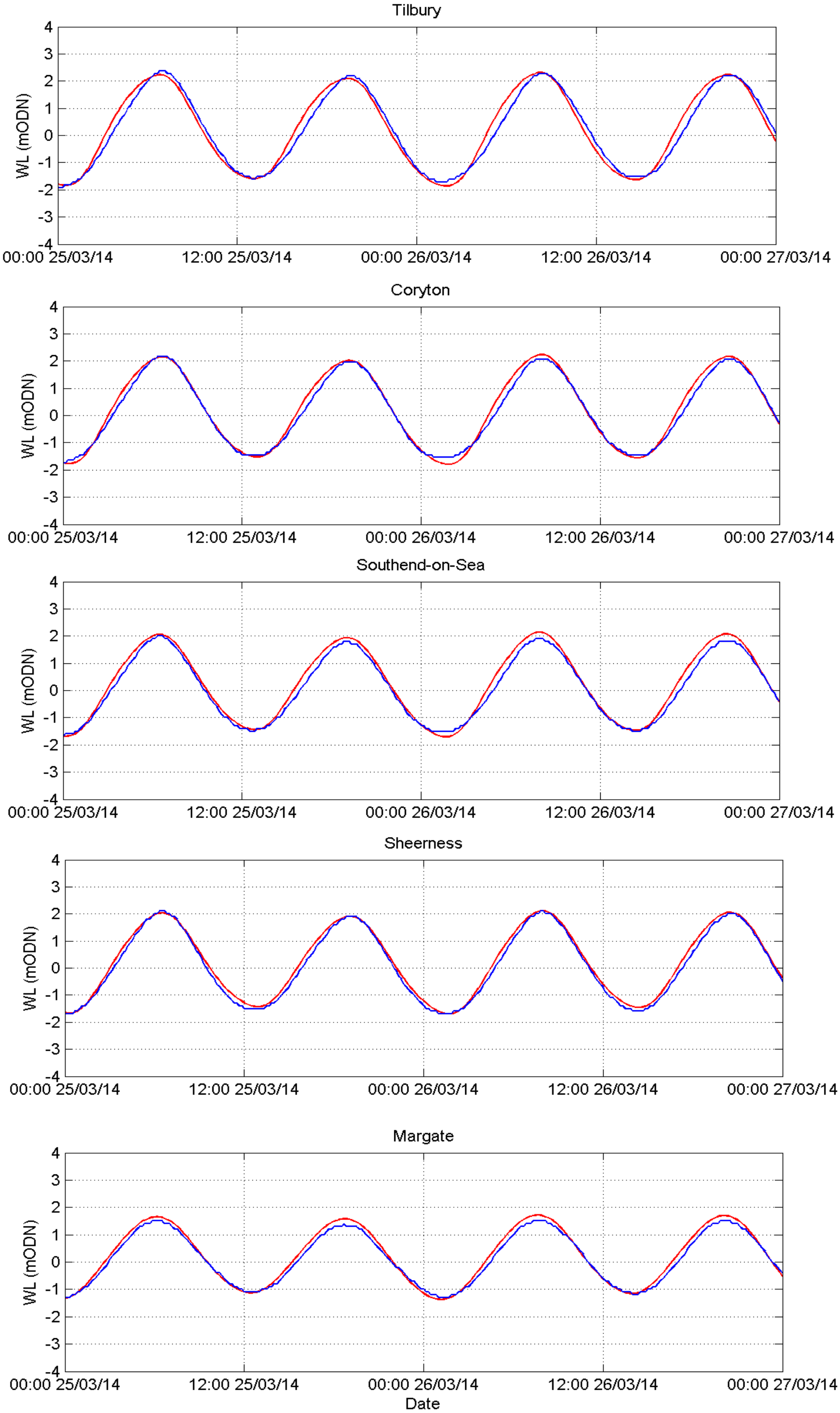
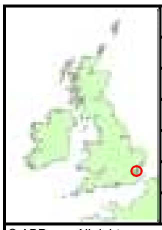
Model Calibration: Water Levels During Spring Tidal Conditions | **Figure A3**





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Model

Total Tide

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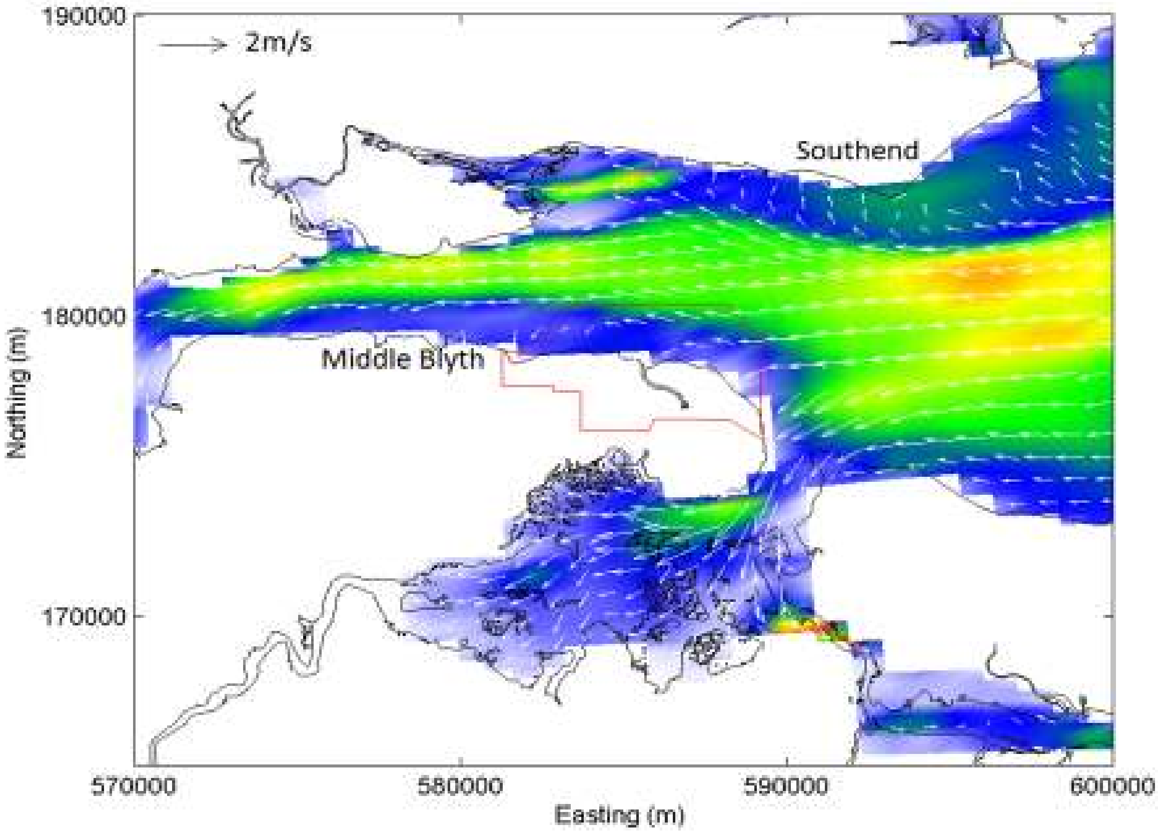
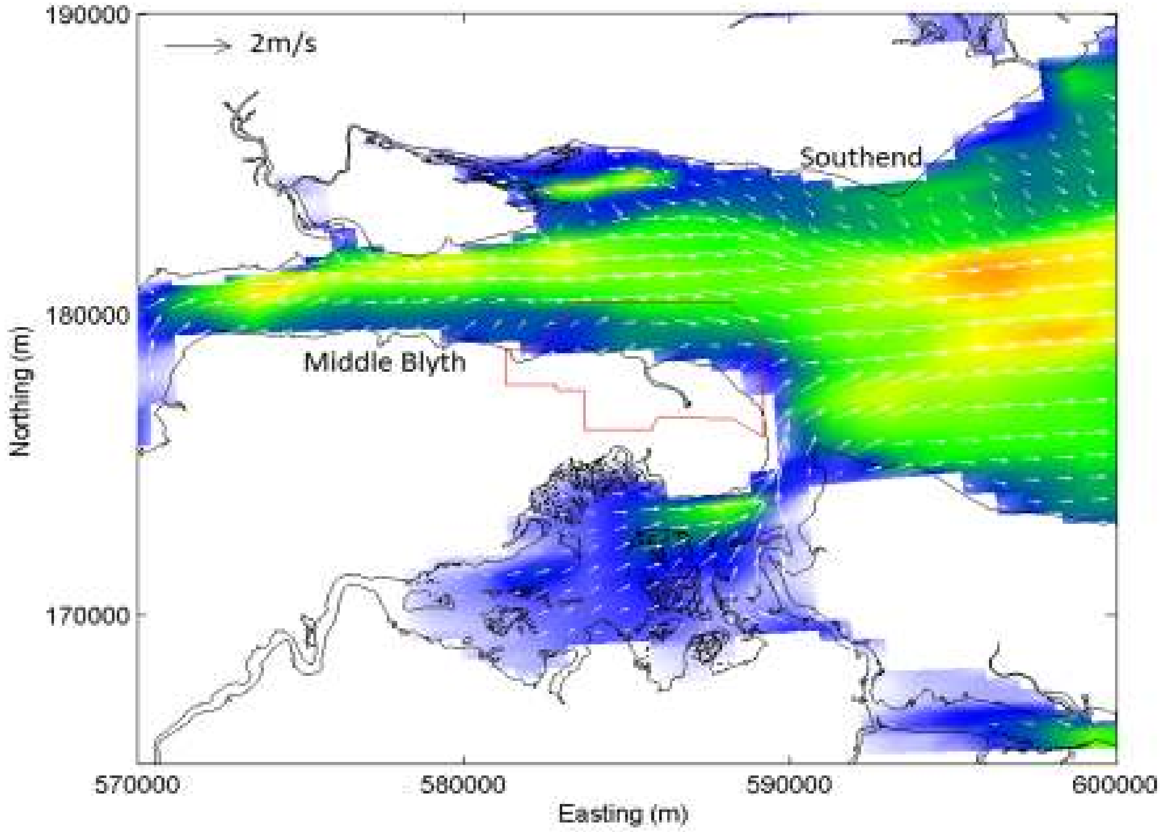
Model Validation: Water Levels During Neap Tidal Conditions

Figure A4





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Peak flows are the maximum flows occurring between low water and high water and high water and low water for the flood and ebb, respectively

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Peak Spring Flows on Flood and Ebb

Figure A5

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