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able marine energy park

Supplementary Environmental Information

Modelling of Final Quay Design (Supplement to Annex 8.1 of ES)

Supplementary Report EX 8.7

June 2012
Revision: 0
JBA Consulting

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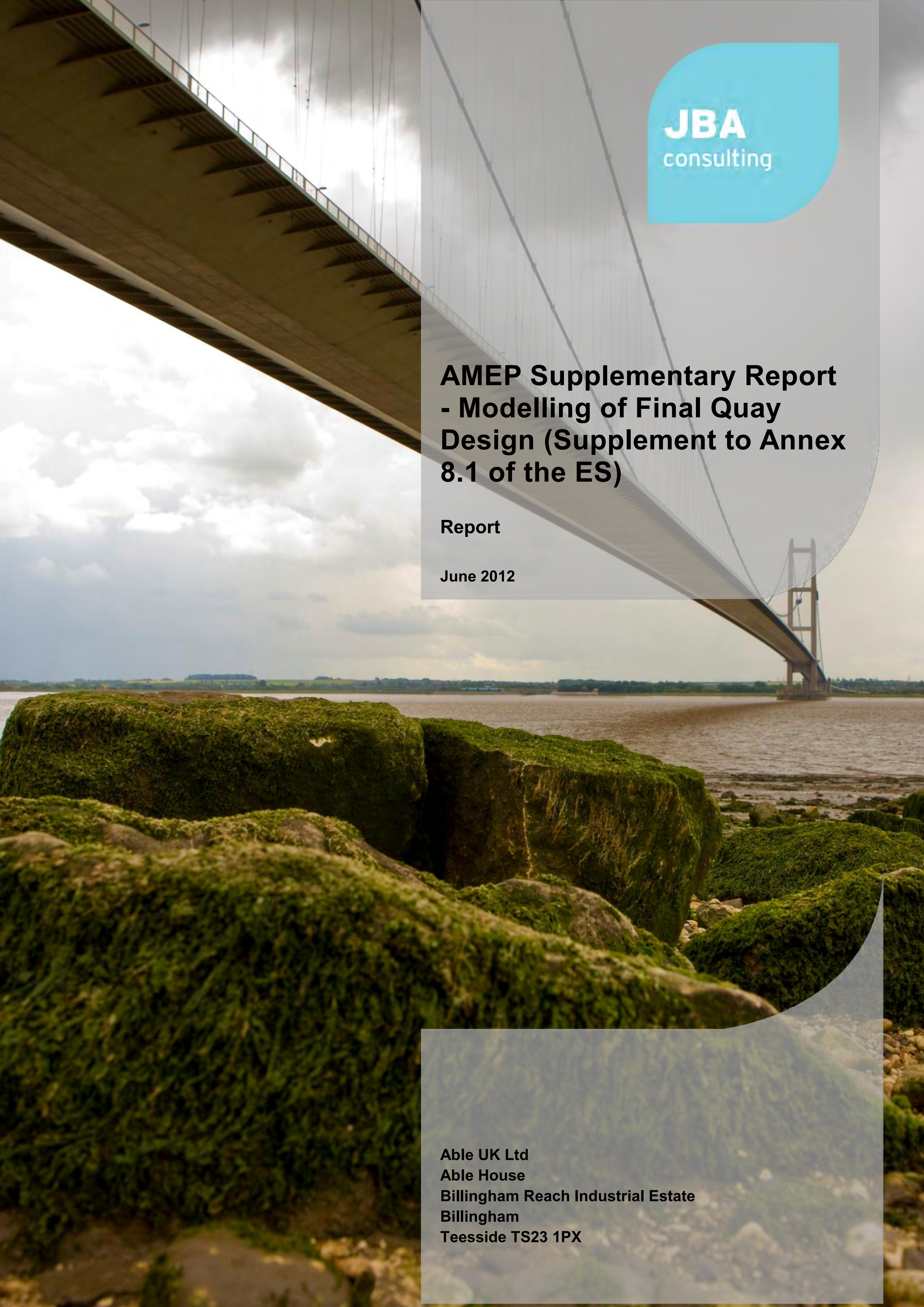

AMEP Supplementary Report - Modelling of Final Quay Design (Supplement to Annex 8.1 of the ES)

Report

June 2012

Able UK Ltd
Able House
Billingham Reach Industrial Estate
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Teesside TS23 1PX

Executive Summary

Able UK Ltd proposes to develop the Able Marine Energy Park (AMEP) on the south shore of the Humber Estuary. The development will include a quay and dredged berthing pockets, approach channel and turning area. An assessment of the potential impacts of a previous design of the marine development on sensitive receptors in the Humber Estuary has been performed by JBA Consulting[1] and this report updates that assessment for the final design.

As part of the final design, inerodible material dredged from the reclamation site is proposed to be disposed at a site offshore of Hawkins Point in the Outer Humber Estuary. An assessment of the potential impacts on sensitive receptors from changes in the hydrodynamic and sedimentary regime due to this disposal is also reported here.

Finally, an impact assessment is performed for the AMEP proposal in combination with other proposed developments for the Humber Estuary to investigate the cumulative impacts.

The potential impacts on sensitive receptors due to the AMEP quay and dredge areas are summarised in the table below.

Table ES1 - AMEP Quay and Dredge Area Impacts

Relevant receptors	Impact due to AMEP quay and dredge areas	Information
EA coastal defences	No impact (after rubble slope mitigation design)	Increased wave heights due to wave reflection along the defence line to the north of the quay are mitigated by rock armour in front of the defence. Increased wave heights due to wave reflection from the south east face of the quay are negligible at the defence. Increased inter-tidal sedimentation due to the presence of the quay is predicted to occur over time and will act to depth-limit waves further, leading to further mitigation of these impacts. No adverse impact is predicted for the north shore defences due to increased wave reflection from the south shore.
Adjacent ports and facilities	Minor impact	Very small quantities of enhanced wave energy can reach adjacent berths during extreme storms but will not affect navigation, partly due to the fact that ships are unlikely to be manoeuvring during such conditions. Wave energy reflected from the southeast face of the quay does not affect the dolphins to the southeast of the quay. The non-cohesive sediment transport modelling suggests annual maintenance dredge rates may increase very slightly at the nearby CPK (5 000-8 000m^3), IGT (2 000-3 000m^3) and HIT (2 000-3 000m^3). This is a minor impact, and it should be noted that results from HR Wallingford's mud transport modelling assessment predicts a beneficial impact (decreased deposition) at all adjacent berths.
Inter-tidal areas	No impact / Impact at inter-tidal areas adjacent to quay assessed elsewhere	Changes in water levels due to the quay and dredge areas are within model uncertainty, and therefore no change is predicted. The potential for wave reflection-induced erosion will be more than offset by the large decreases in current-induced bed shear stress (leading to accretion) in the inter-tidal areas adjacent to the quay. The potential for wave reflection-induced increases in bed shear stress on the north bank inter-tidal area opposite the quay is small for the most extreme storm events from the north and east. Any effect will be dwarfed by the effects of other storm directions. The long-term change to inter-tidal areas adjacent to the quay is assessed in HR Wallingford reports EX8.8, EX8.9 and EX8.10.
Navigation at CPK	Impact assessed elsewhere	The impact on navigation at the CPK from changes in currents due to the AMEP development has been assessed in a simulation exercise that is reported separately (EX14.4).
Centrica intake/outfall, EON intake/outfall	Impact assessed elsewhere	An assessment of the likelihood of accumulated sediment impacting on these receptors has been performed by HR Wallingford (EX8.8).

[1] JBA Consulting (2011) Able Marine Energy Park Estuary Modelling Studies. Report for Able UK Ltd

Relevant receptors	Impact due to AMEP quay and dredge areas	Information
Gas pipelines near Halton Middle	No impact	There is no additional potential for erosion at the location of the pipelines due to the AMEP quay and dredge areas.

The potential impacts on sensitive receptors due to the AMEP capital dredge disposal of inerodible material at the disposal site (HU082) are summarised in the table below.

Table ES2 - Disposal Site Impacts

Relevant receptors	Impact due to disposal of material at proposed site	Information
Inter-tidal areas on estuary north bank	Localised minor impact (north bank inter-tidal area near disposal site), no estuary-wide impact	Two options are appraised: full disposal and a 50% / partial disposal, the latter being the quantity that fills existing depressions in the bed. The change in bathymetry due to material disposal will affect wave direction through changes to the refraction process. For large waves travelling towards the estuary north bank, this will slightly change the existing pattern of wave-induced bed shear stresses at the inter-tidal areas here. The impact is deemed to be minor; in areas of increased wave energy, there will be the potential for development of drainage channels of the form that are observed over the mudflats to the east. This may be a visually significant change, the scale of which would be difficult to predict, however a change to inter-tidal area and volume of sediment is very unlikely. There would be no change in the type of sediment exposed in the area and so no change to habitat. The magnitude of this impact would be greatly reduced if only half of the inerodible material were disposed at HU082.
Sub-tidal and maintenance dredged areas	Minor impact	The change in bathymetry due to the disposed material (full disposal) increases current speeds over the site, and directly to the north and south, by up to 5%. The increase to the north may increase the potential for channel development on the mudflats. Current speeds to the west and east are reduced by up to 5%, which may lead to increased deposition in these areas. The area affected is just under 2% of the area of the Outer Humber Estuary. The change in bathymetry leads to scouring around the edges of the raised bathymetric area. Sediment is deposited to the east of the site, with 4 000m^3 settling in the SDC after 18 days. This volume will not be substantially added to once the thin erodible layer of material adjacent to the disposal site that is scoured away has gone. The impacts for the scenario of half of the inerodible material disposed of at the site are, again, greatly reduced.

The potential impacts on sensitive receptors due to the AMEP development in combination with other proposed developments are summarised in the table below.

Table ES3 - In Combination Impacts

Relevant receptors	Impact due to AMEP quay and dredge areas	Information
North bank inter-tidal area around Hawkins Point	Localised minor impact (north bank inter-tidal area near disposal site), no estuary-wide impact	The changed bathymetry due to the in combination developments in the Outer Humber Estuary (AMEP full disposal at HU082, in combination disposal at HU081, SDC deepening) will lead to very small changes in the wave climate (due to wave refraction), which will lead to a minor localised impact on inter-tidal morphology. This is likely to take the form of localised change across affected soft sediments with channelling possible. The mudflats around Hawkins Point will be subject to potential change in the form of channel development. Any potential new morphology will likely mimic the channels of the mudflats farther to the east.

Estuary-wide inter-tidal areas	No impact	Changes to water levels due to the proposed developments acting in combination are within model uncertainty bounds, and therefore no change is predicted. Potential decreases in current speeds in the Middle Estuary due to all other developments (except the AMEP quay) are offset by potential increases due to the quay. The additional cumulative impact of all in combination developments is negligible (all impacts are local to each development).
Sub-tidal areas	No impact	The cumulative change to current speeds in the Middle Estuary is negligible and this means that the potential impact on bed morphology here is also negligible. In general, in the sub-tidal area, the in combination cumulative impacts at the disposal sites are no greater than those due to the SDC deepening and AMEP full disposal individual impacts.
Gas pipelines near Halton Middle	Minor beneficial impact	The small reduction in current speeds due to the HRBT contribution may be of beneficial impact to the gas pipelines, potentially increasing bed stability and reducing the currently observed erosion here.
Adjacent EA defences, ports and facilities	No impact	There are no impacts on sensitive receptors adjacent to the AMEP due to the cumulative impacts of the in combination developments (i.e. any impacts on these receptors are due to the AMEP development alone).

The EA has provided the applicant with their consultant's assessment of long term morphological change caused by the Project[2]. The assessment infers change from studies undertaken on set-back sites within the estuary, assuming that the quantum of habitat change resulting from the reclamation works will be pro-rata, and opposite to, the quantum of habitat change due to a substantial (808 ha) set back site on Sunk Island.

Modelling morphological change carries high levels of uncertainty. Long term change in the estuary will be dictated by sea level rise which over 100 years will amount to around 1055 mm between 2015 and 2115 using the UKCP09 95% medium emission scenario. On the same basis, over the first 50 years sea level rise is predicted to be 380 mm. The Humber CHaMP uses an assumption that sea levels will rise by 6mm/year between 2000 and 2050 and that this will give rise to a need for 600 ha of new intertidal habitat in order to maintain the habitat at its current quanta.

By contrast to the above, the changes in water levels due to AMEP are predicted to be millimetric and cannot be distinguished from model error. Thus, any impact will be dwarfed by natural change (sea level rise is defined as natural change in the Humber CHaMP). Accordingly, the argument for the applicant to provide compensation for long term morphological change is not substantiated by the project specific modeling.

[2] Deltares (2012) Review EIA documents GPH & AMEP. Memo for the Environment Agency

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
V1 / 8 June 2012		Richard Cram (Able UK)
V2 / 15 June 2012	Additional comments on potential morphology impact due to disposal. Assessment of lower compensation site level added. In combination assessment and executive summary added. Initial comments from Able incorporated.	Richard Cram (Able UK)
V3/ 19 June 2012	Comments from Able incorporated. Submitted as final report.	Richard Cram (Able UK)

Contract

This report describes work commissioned by Richard Cram, on behalf of Able UK Ltd, by an email dated 31 May 2012. Crispian Batstone of JBA Consulting carried out this work.

Prepared by .... Crispian Batstone BEng PhD

Senior Analyst

Reviewed by .... Kevin Keating BEng MSc CEng MICE

Technical Director

Purpose

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JBA is aiming to achieve carbon neutrality.

Contents

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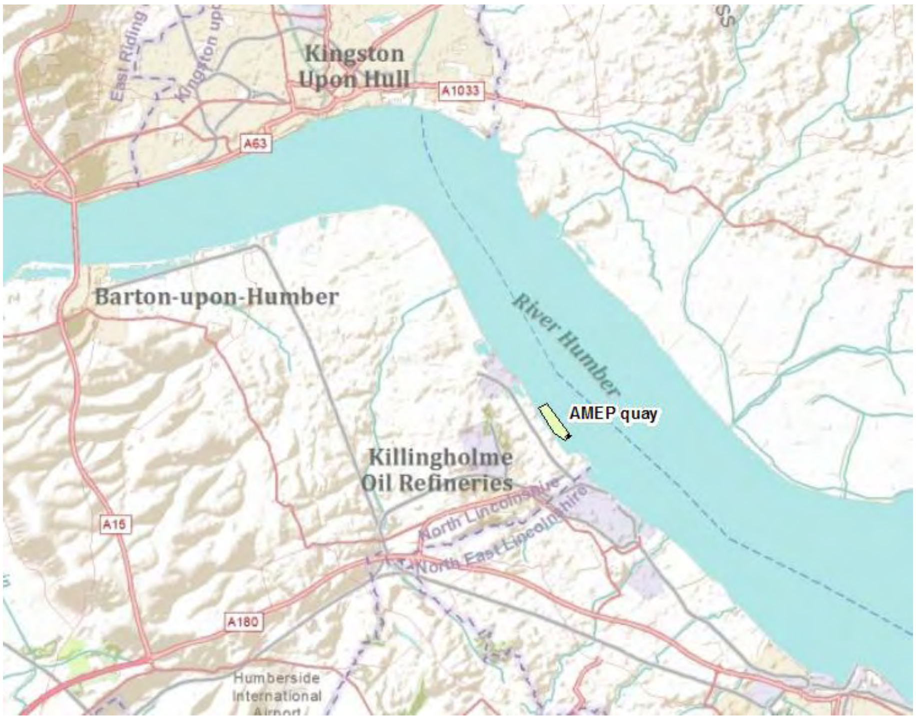
Definitions

AMEP	Able Marine Energy Park
CD	Chart Datum
CHaMP	Coastal Habitat Management Plan
CPK	Previously HST (Humber Sea Terminal)
EA	Environment Agency
ES	Environmental Statement
GPH	Green Port Hull
HIT	Humber International Terminal
HRBT	Hull Riverside Bulk Terminal
HWB	Humber Work Boats
IGT	Immingham Gas Terminal
IOTA	Immingham Oil Terminal Approach
MHWS	Mean High Water Springs
OD	Ordnance Datum
SDC	Sunk Dredge Channel
SKOJ	South Killingholme Oil Jetty
SSC	Suspended Sediment Concentrations

1 Introduction

Able UK Ltd proposes to develop the Able Marine Energy Park (AMEP) on the south shore of the Humber Estuary. The development will include a quay and dredged berthing pockets, approach channel and turning area that will extend from the present defence line at South Killingholme out into the Humber Estuary. The location of the marine development is shown in Figure 1-1.

Figure 1-1: Location of AMEP quay in Humber Estuary (map sources: USGS, FAO, NPS, EPA, ESRI, DeLorme, TANA, other suppliers)



An assessment of the potential impacts of the marine development on sensitive receptors within the Humber Estuary due to changes from present day conditions in hydrodynamic and sedimentary processes was performed by JBA Consulting. This was completed for a preliminary quay configuration and reported, the report hereafter referred to as JBA2011[3]. The preliminary quay configuration is shown in Figure 1-2.

The design of the quay has been changed since this assessment was performed. The 'footprint' of the quay has been reduced, with the frontage line being moved inland by 80m. The final quay configuration is shown in Figure 1-3, with the preliminary design outlined in red. The altered quay design will lead to changes in the impacts described in JBA2011 although it was reported in JBA2011 that the change was likely to reduce the impacts. However, consultees have requested that the impacts of the final quay configuration on the hydrodynamic and sedimentary regime be re-assessed quantitatively. This report provides this updated assessment. The modelling techniques and assessment methodology are the same as that used in JBA2011, though the model grid geometry has been adjusted to incorporate the final quay and dredging area design (numerical models typically solve relevant equations at prescribed intervals in space and time - the grid points refer to the solution points in plan form).

[3] JBA Consulting (2011) Able Marine Energy Park Estuary Modelling Studies. Report for Able UK Ltd

Figure 1-2: Preliminary quay design assessed in JBA2011

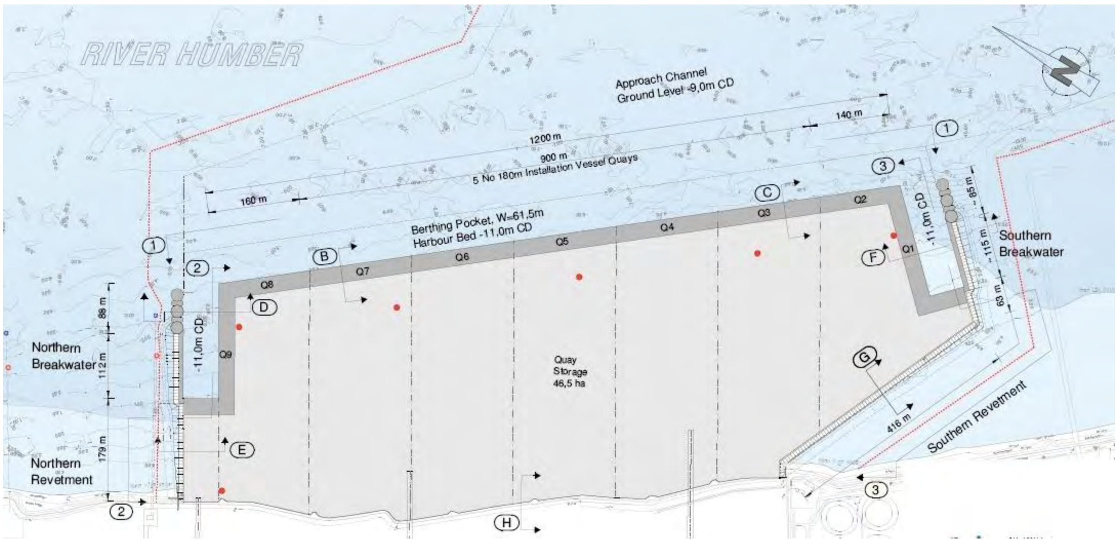
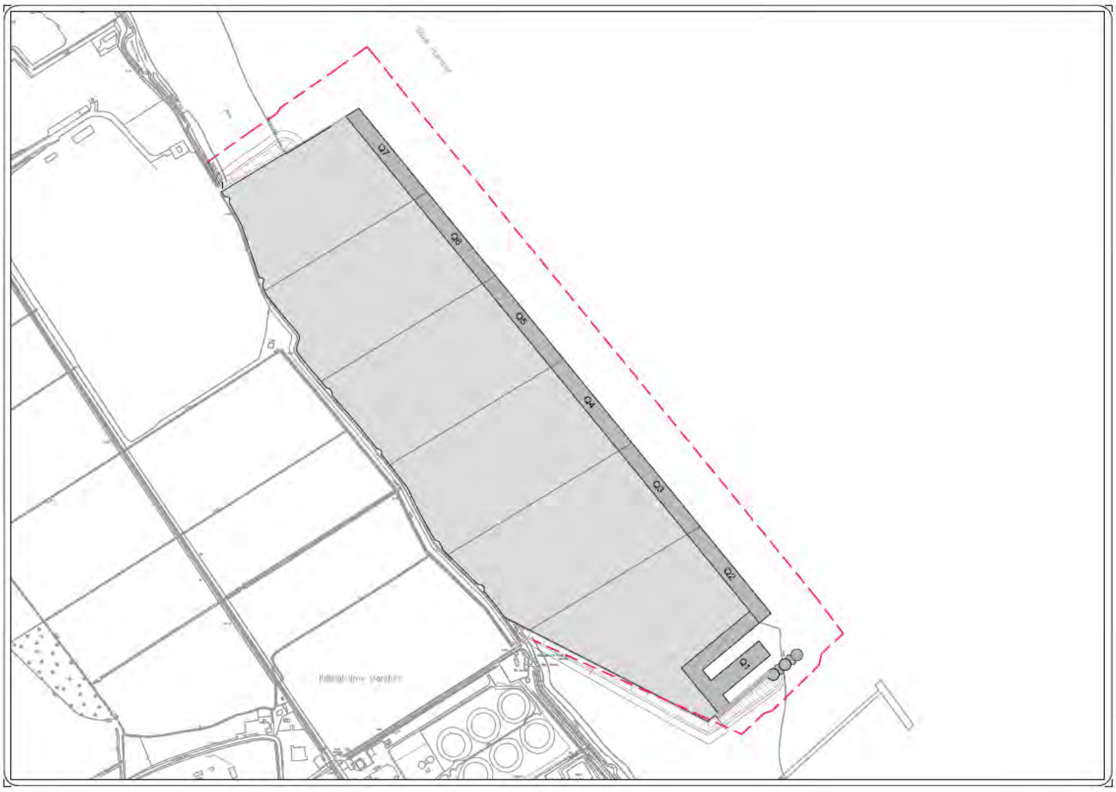


Figure 1-3: Final quay design (preliminary quay outline in red; direction of north is upwards)



During the construction of the AMEP quay, a capital dredge operation will lead to the excavation of an estimated 954 350 m^3 of inerodible clay[4] from the estuary bed. In the absence of alternative beneficial uses, Able has proposed to dispose of this material at the HU082 disposal site in the Outer Humber Estuary, to the south east of Hawkins Point (Figure 1-4). The disposal site is located to the north of the Sunk Dredge Channel (SDC). The bed of this area is largely made up of inerodible boulder clays[5,6,7], where any deposits of erodible sand-sized sediment are

[4] The term inerodible is used throughout this document to describe the boulder clay/glacial till that is to be disposed. The term is used relative to short-term sedimentary processes (on the order of weeks). In reality clay will erode, though slowly over a matter of years. The impact to the estuary sedimentary regime of this slow erosion is not significant compared to background variability.

[5] Van Ormondt, M. and Roelvink, D. (2004) Short-term morphologic modelling of the Humber Estuary with Delft3D

highly localized and typically less than 2cm in thickness. The presence of these clays provides constraint on morphological changes in the Outer Estuary. The SDC is noted to have exhibited a clear 13-year cycle in sedimentation patterns up to the early 1990s. However, since this time the pattern has become less clear. Moreover, minimal maintenance dredging has been required since 2007.

JBA2011 found that the addition of the capital dredge material would not affect the estuarine sediment regime directly, as its inerodible nature would not lead to any changes in local or remote suspended sediment concentrations. However, an assessment of the impacts on hydrodynamics, and subsequent potential changes in the sedimentary regime, due to the change in bathymetry at the site was not provided. This assessment is provided in the current report.

Figure 1-4: Disposal sites in the Outer Humber Estuary

In summary, an updated hydrodynamic and sedimentary regime impact assessment is provided for the AMEP final quay and proposed inerodible material disposal in combination with other proposed developments in the Humber Estuary.

The structure of the remainder of this report is as follows:

Chapter 2: Potential Impacts and Sensitive Receptors. This chapter lists the **potential** impacts that may result from changes in the hydrodynamic and sedimentary regime due to the proposed development. The receptors that are likely to be sensitive to such impacts are also listed.

Chapter 3: Assessment of Final Quay Design. This chapter provides an assessment of impacts on the receptors due to changes in the hydrodynamic and sedimentary regime that are predicted to result from the final AMEP quay design.

Chapter 4: Assessment of Inerodible Material Disposal Impacts. This chapter provides an assessment of impacts on the receptors due to changes in the hydrodynamic and sedimentary regime that are predicted to result from the disposal of inerodible material at the proposed disposal site.

[6] ABPmer (2004). Humber Estuary Shoreline Management Plan – Stage 2. Humber Estuary Data Report. Report R932. Environment Agency North East Region.

[7] ABPmer (2009a) Immingham Oil Terminal Approach Channel Dredging Environmental Statement. Associated British Ports & Total Lindsey Oil Refinery. Report R. 1416.

Chapter 5: In Combination Assessment. This chapter provides an assessment on impacts on receptors due to changes in the hydrodynamic and sedimentary regime that are predicted to result from the AMEP marine development (quay and disposal site) in combination with other proposed developments within the Humber Estuary.

2 Potential Impacts and Sensitive Receptors

2.1 Introduction

The construction of the AMEP quay, dredged areas and disposal of capital dredge at the disposal site will cause changes to the hydrodynamic and sedimentary regime locally, and possibly estuary-wide. These changes may occur in the vicinity of sensitive receptors, potentially having an adverse or beneficial impact on the receptors. This chapter describes the potential changes induced by the development and the impact on receptors that may be sensitive to change.

2.2 Impacts and receptors

The sensitive receptors are listed in Table 2-1, along with how they may be affected. The locations of the receptors in relation to the proposed development are shown in Figure 2-1 to Figure 2-5. Acronyms used are explained below:

- CPK - formally the HST (Humber Sea Terminal)
- HWB: Humber Work Boats
- SKOJ: South Killingholme Oil Jetty
- SDC: Sunk Dredge Channel

Table 2-1: List of *potential impacts* (and sensitive receptors) that may arise from changes to the hydrodynamic and sedimentary regime induced by the development

Potential impacts	Sensitive receptors
Reflection of waves from the AMEP quay, potentially increasing wave energy climate locally	**EA Coastal defences (south and north banks)** Wave energy reflected towards coastal defences from the sides of the quay may increase the overtopping risk behind the defences during storm events. In agreement with the EA, overtopping of coastal defences must not exceed 2 l/s/m for a 1:200-year joint probability wave height/water level storm event in 2033 (covering the lifetime of the Humber Shoreline Management Plan). Due to the orientation of the AMEP quay, storm wave directions that may lead to reflected energy propagating towards the adjacent coastal defences on the south shore are from the north and from the east/south east. Any wave reflection towards the north shore defences may lead to increases in overtopping risk here also. **Inter-tidal areas (south and north banks)** Increases in wave energy climate due to reflections from the quay may lead to increases in the average bed shear stresses experienced in inter-tidal areas (this may affect the inter-tidal areas adjacent to the quay or the area on the north bank opposite the quay). In turn, this may lead to increased erosion at the affected sites. Conversely, areas that will experience a reduction in wave energy due to the blocking nature of the quay may experience increased deposition of sediment. Moreover, variation in sedimentation patterns in front of the coastal defences will dictate wave-breaking behaviour, further influencing flood risk at the defences.
Changes to high/low water levels	**Estuary-wide inter-tidal area** Changes to high and/or low water levels could change the total area of inter-tidal flats available for wildlife habitats.
Changes to the flow regime	**Navigation at adjacent berths (CPK)** Variations to the existing flow regime at adjacent ports, such as the CPK, could affect navigation and the berthing of ships.
Changes to sediment transport patterns brought about by changes to the flow regime	Changes to patterns of erosion and deposition can result from changes to the flow regime. Sensitive receptors are: **Access and berths at adjacent port facilities (CPK, HWB, SKOJ, Immingham Gas Terminal, Immingham port terminals and docks, SDC)** Increased sedimentation can affect access to these adjacent ports and facilities, and could require increases in the required maintenance dredging activities. **Centrica intake/outfall, EON intake/outfall, North Killingholme Pits, Halton Middle gas pipelines** Changes to erosion/deposition patterns could affect the appropriate functioning of these receptors.

Figure 2-1: Sensitive receptors to the immediate north of the AMEP quay

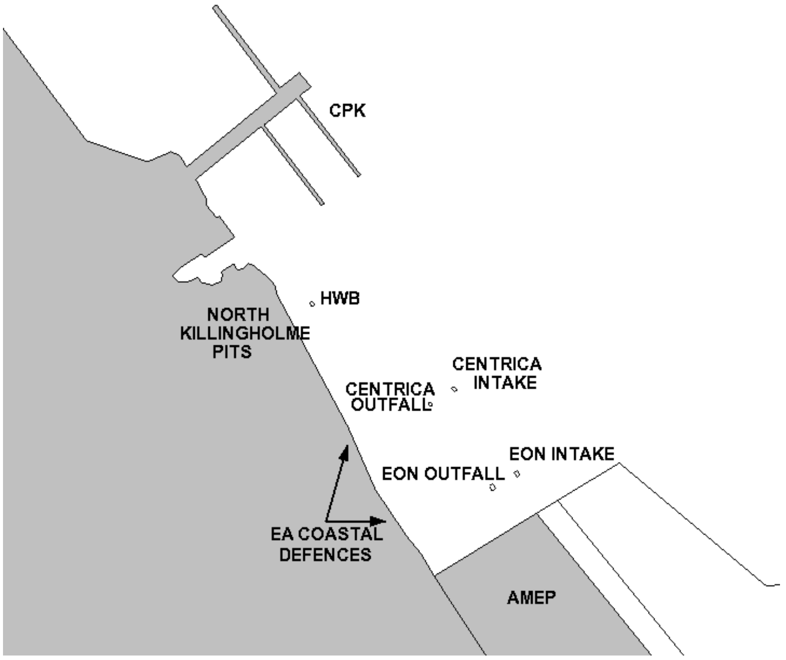


Figure 2-2: Sensitive receptors to the immediate south of the AMEP quay

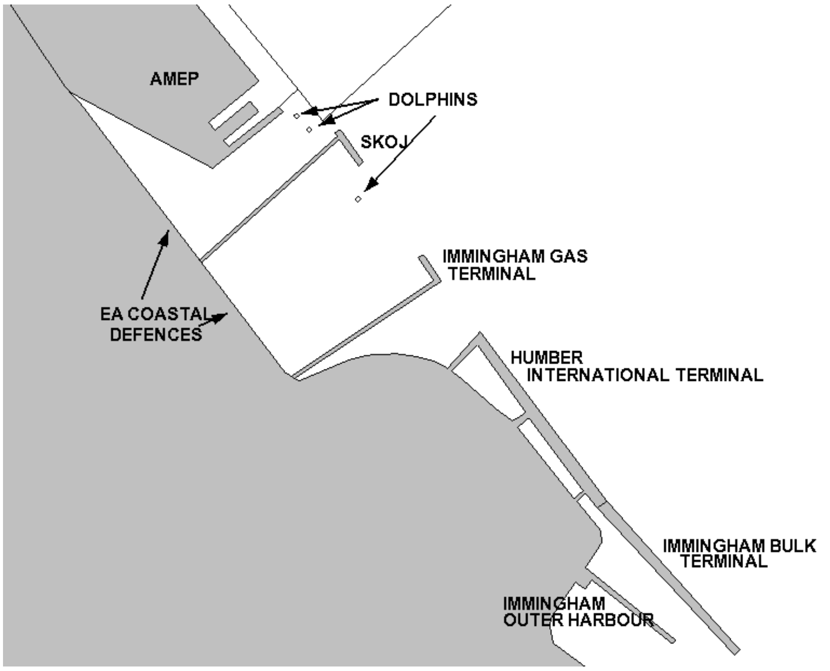


Figure 2-3: Sensitive receptors to the south of the AMEP quay

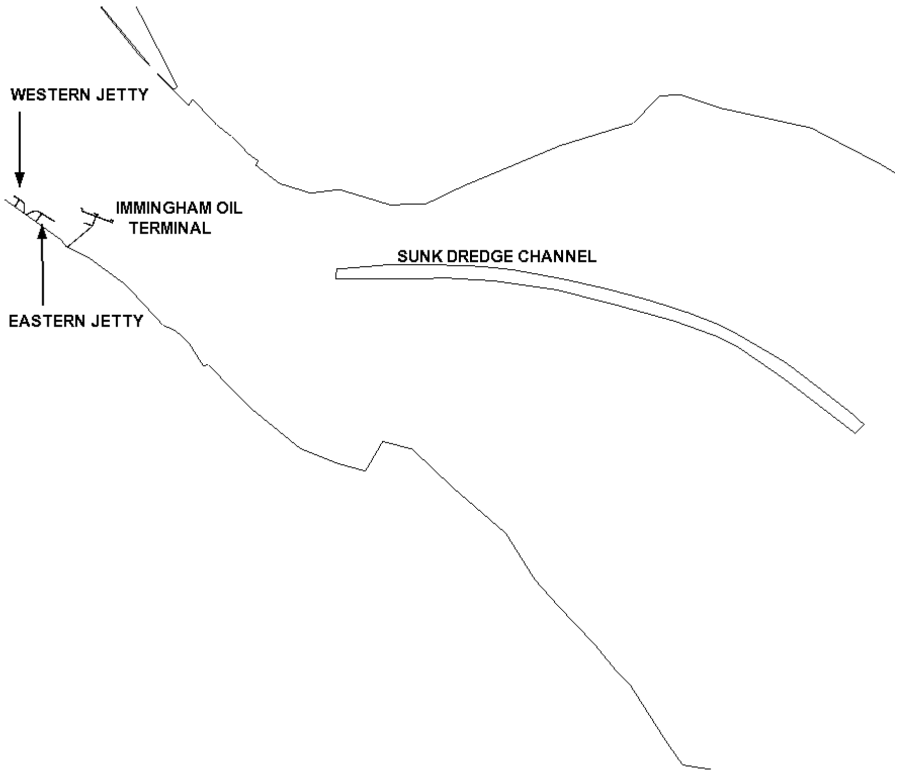


Figure 2-4: Location of gas pipelines along the bottom of the estuary near Halton Middle (AMEP quay is just to the south of the southern extent of the figure)

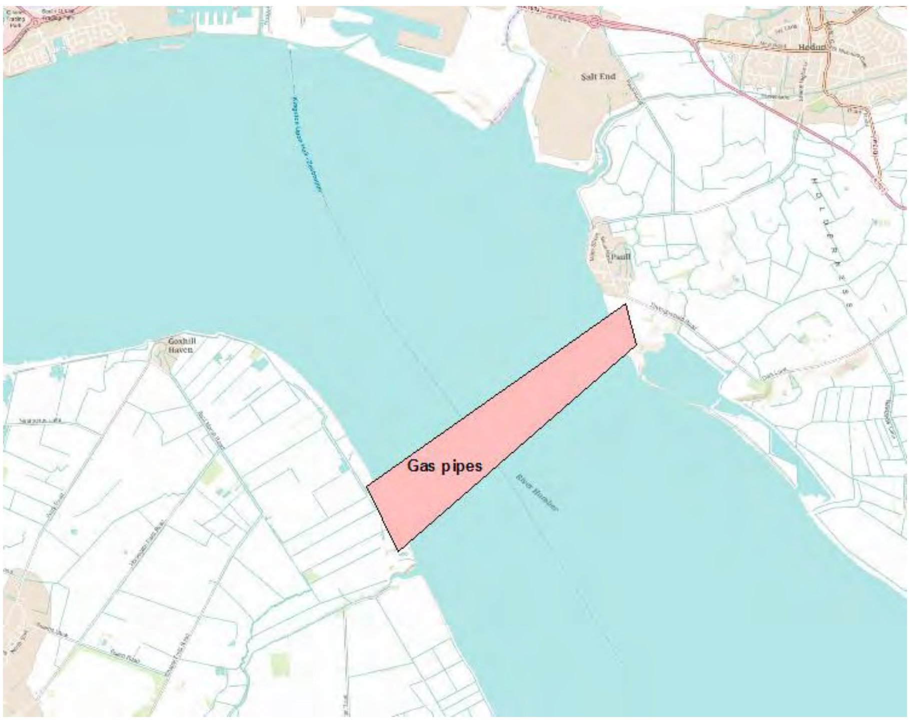
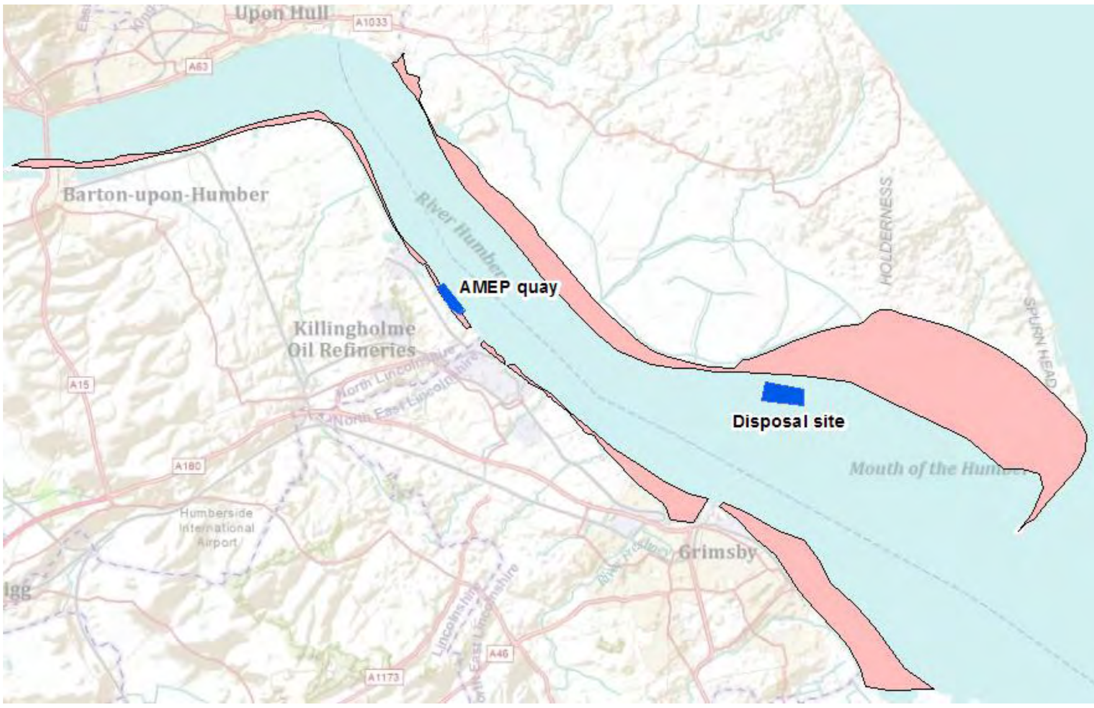


Figure 2-5: Location of inter-tidal areas in the Humber Estuary



3 Assessment of Final Quay Design

3.1 Introduction

An assessment of the impacts on sensitive receptors within the Humber Estuary due to the proposed construction of a previous design of the AMEP quay and dredge areas was presented in JBA2011. The final design of the quay and dredge areas differ from the design assessed in that report. The quantitative assessment of the final proposal is detailed in this chapter. An assessment of the sensitivity of the model results to changes in the site level at the Cherry Cobb Sands compensation site is also presented.

The sensitive receptors and potential impacts due to the proposed scheme are summarised in Table 2-1.

3.2 Assessment methodology

The numerical models developed, calibrated and validated in JBA2011 were used to investigate potential changes in the hydrodynamic and sedimentary regime of the estuary due to the construction of the final quay design and dredge areas. The hydrodynamic and sedimentary processes were simulated by running the appropriate models. Model simulations were performed for the following scenarios:

- Existing bathymetry
- AMEP quay and dredge area, and Cherry Cobb Sands compensation site

Predicted changes in physical processes were calculated by deducting the existing bathymetry simulation results from the simulation of the AMEP quay and dredge area.

Simulations specific to the type of models used are detailed herein.

3.2.1 Waves

The AMEP quay will be exposed to wave action in the Humber Estuary. The adjacent EA maintained coastal defences have been identified as sensitive receptors, with the potential impact of increased flood risk resulting from waves reflecting off the sides of the quay. The design features described below are of relevance to this issue.

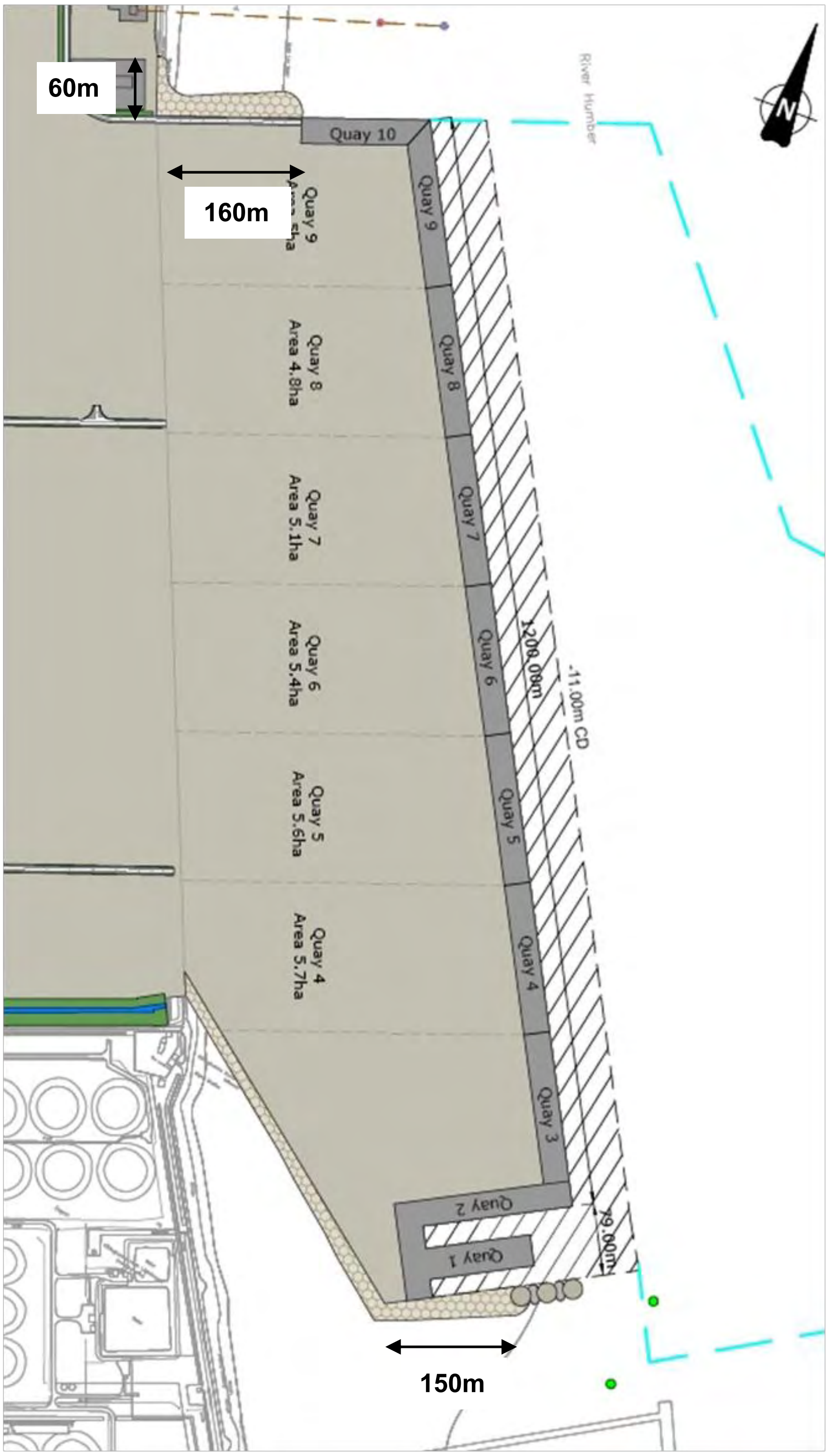
- Along its northwest face the quay consists of rock armour with a 1:4 gradient, which extends from the existing land out 160m (Figure 3-1). The remaining 140m of this face is a vertical wall. Rock armour is also proposed to be placed in front of the existing sloping flood defence, extending from where the quay meets the existing defences, to a distance of 60m along the existing defences to the north west.
- Along the south west and south east faces of the quay rock armour is proposed at a 1:2 gradient. The south east facing side is 150m in length. The remaining 60m consists of a vertical structure.

To model the effects of wave reflection, the CMS-Wave model[8] has been used as described in the methodology presented in JBA2011. Reflection coefficients have been calculated using guidance from the CIRIA/CUR Rock Manual[9]. For the 1:4 rubble slope to the north of the quay a coefficient of 0.2 has been used. For the 1:2 rubble slope to the south of the quay a value of 0.25 has been used. For the vertical sections, a value of 1 has been used.

[8] CMS-Wave is a two-dimensional wave spectral transformation model that employs a finite-difference method to solve the wave action conservation equation. It is a phase-averaged model that simulates diffraction, refraction, reflection, wave breaking, dissipation mechanisms, wave-current interaction and wind-wave generation and growth (Coastal and Hydraulics Laboratory (2008)).

[9] Rock Manual CIRIA C683 (http://www.kennisbank-waterbouw.nl/DesignCodes/rockmanual/)

Figure 3-1: AMEP quay showing extent of rubble armour



Wave reflections due to a 1:200-year joint probability wave height/water level storm in 2033 have been simulated. From ABPmer (2007), at South Killingholme this is represented by a 1.47m wave height and 4.68mOD still water level (21cm of sea level rise is predicted from 1991 using PPS25 guidance). This combination was found to lead to the largest impacts due to wave reflection. Combinations with larger wave heights and reduced still water levels did not produce significant wave reflection due to the greater depth-limiting effect of the lower water level. Furthermore, combinations with lower wave heights, and higher still water levels, did not lead to significant increases in reflected energy due to dissipation at the rubble slope.

As for all other models, the wave model results exhibit considerable uncertainty. JBA is of the opinion that changes below 5~10cm should be treated with caution. However, in line with requests from Regulators, wave height changes at or above 1cm in height are presented.

3.2.2 Hydrodynamics

The CMS-Flow hydrodynamic model was used to simulate the flows associated with a MHWS tidal cycle. This was achieved by specifying a varying water elevation condition at the Spurn Head downstream model boundary, reproducing the MHWS tidal signal observed at this location. An initial period of 5 model days was incorporated into the model simulations in order to allow for transients due to model initial conditions to settle. Water levels and currents were extracted for the model scenarios specified above.

3.2.3 Short-term sedimentary regime

The CMS-Flow model with non-cohesive sediment transport enabled was used to simulate an 18-day period, incorporating a Spring-Neap cycle, for the model scenarios described above. To be consistent with the previous study, a 1m thick erodible layer was specified throughout the estuary, below which bathymetry could not deepen further. The non-cohesive sediment transport model was run twice, using median grain sizes of 0.1mm and 0.2mm, typical of the sand fraction present in the area. It should be noted that given the predominantly muddy nature of the estuary, results of mud transport modelling[10] for the final quay design should be given more weight when assessing the local impacts on the sedimentary regime. As the mud modelling software incorporates a representation of the particular forces affecting finer sediments, the 0.075mm grain size scenario is not repeated here.

3.2.4 Assessment of Cherry Cobb Sands compensation site level

The typical site level within the compensation site is +2.5mOD. A typical reduction of this level to +2.2mOD has been proposed by the developer as approximately 300 000 m^3 of material from within the site will be used to construct a new flood defence wall. A modelling scenario has therefore been performed with the compensation site level reduced to +2.2mOD, in order to examine the potential impacts.

3.3 Impacts

3.3.1 Waves

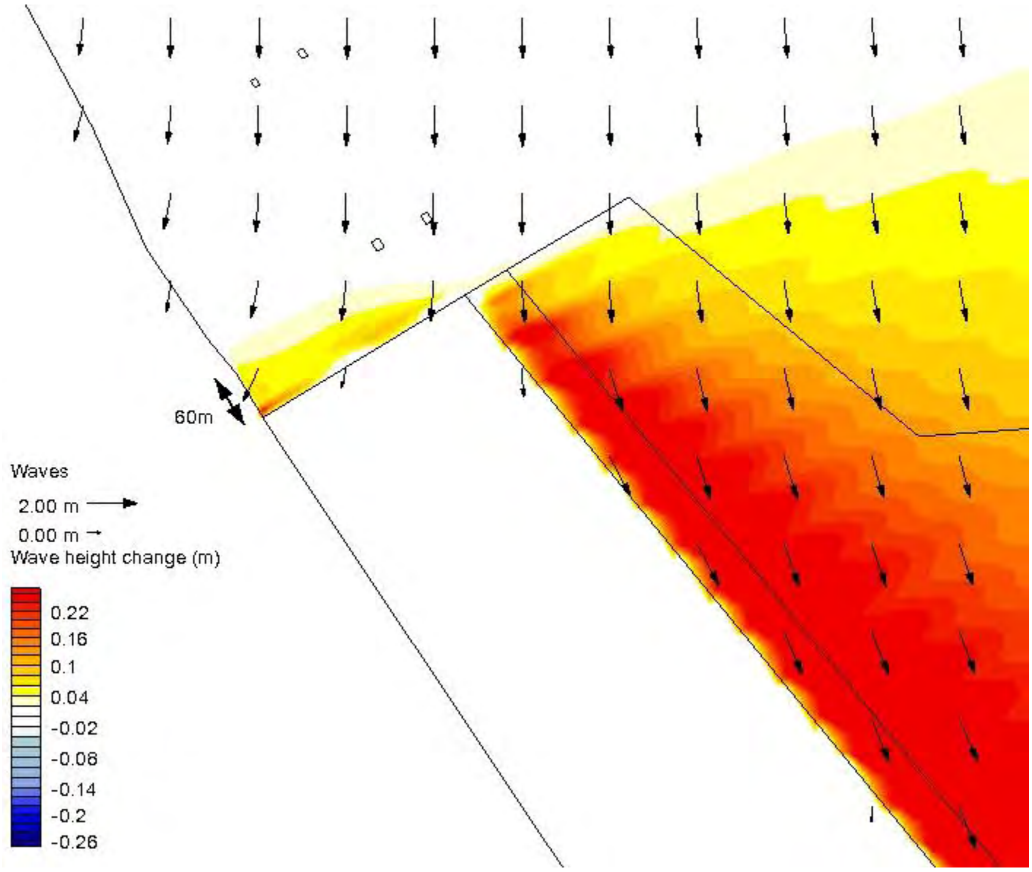
For waves travelling from the north for the 1:200-year storm, there is an increase in wave height at the defence line due to wave reflection from the quay. At this location the model baseline wave height is 1.30m[11]. The increase due to reflected energy is 25cm in the corner where the quay meets the defence line (Figure 3-2). The magnitude of this increase reduces to millimetric and therefore negligible values within 60m along the defence line to the north of the quay.

For comparison with the location of sensitive receptors, refer to Figure 2-1 to Figure 2-4.

[10] HR Wallingford (2011) Able marine Energy Park 3D Mud Modelling. Report EX 6603

[11] The wave height at the seaward end of the quay is 1.47m, consistent with the wave height from the 1:200-year joint probability water level/wave height values published in ABPmer (2007). The model simulates a reduced value at the defence due to the effects of depth-limitation, which is not accounted for in ABPmer (2007).

Figure 3-2: Increase in wave heights due to wave reflection at the north of the quay, during a 1:200 year storm in 2033 with waves from the north

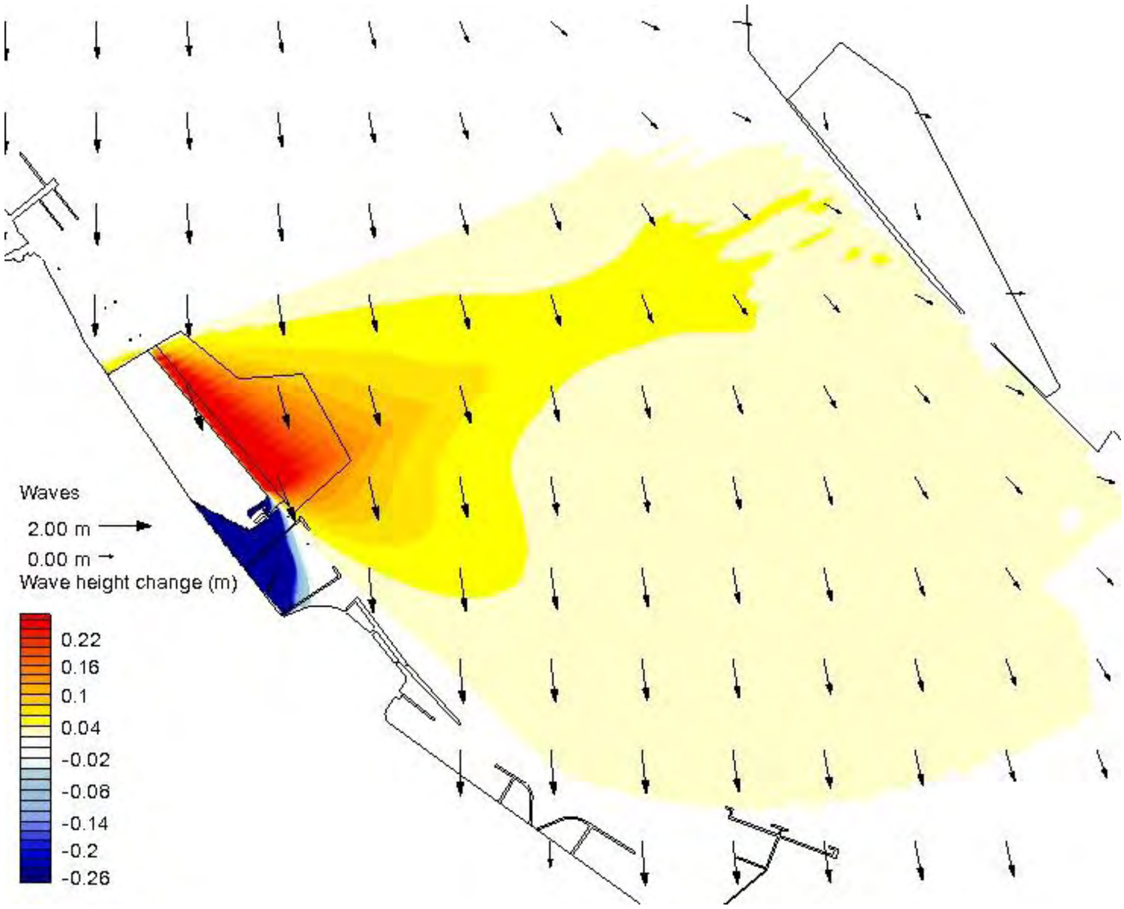


Waves reflect off the vertical wall of the berthing face of the quay. This reflected wave energy travels towards the north shore of the estuary where an increase of 0.02m is observed here (Figure 3-3 - increases in wave height 1700m from the quay are less than 0.06m). However, it should be noted that this 1:200-year extreme scenario is for a northerly storm; this is not an important direction for the north shore which will be more greatly affected by south-westerly storm events.

The reflected energy that reaches the north shore diminishes to negligible values for more frequent storm events. The small increase in wave energy in the centre of the estuary also diminishes for more frequent return periods, and is considered to be negligible in terms of any potential adverse impact.

A small quantity of reflected wave energy can reach the berths of adjacent ports during this extreme event. Such levels would not impact upon navigation, particularly as ships are unlikely to be manoeuvring during such storm events.

Figure 3-3: Estuary wide increase in wave heights due to wave reflection at the north of the quay, during a 1:200 year storm in 2033 with waves from the north



Wave reflection has the potential to lead to impacts at the EA defence to the south of the quay during easterly storms, when waves propagate from the east towards the south east face of the quay. The increase in wave heights at the defence line for a 1:200-year storm in 2033 is <1cm (Figure 3-4). The bathymetry at this location is shallow, causing incident waves to break before reaching the defence line. Therefore, any additional wave energy due to reflection will be lost when the waves break. There is therefore no impact due to wave reflection at the EA defence to the south of the quay. It should be noted that the model does not incorporate bathymetry from 2033, which may consist of raised bed levels due to a change in the sedimentary regime to the south of AMEP[12]. Raised bed levels will act to further depth-limit waves here and mitigate flood risk at the defence.

Reflected wave energy to the south of the quay for the 1:200-year event does not impact upon the dolphins to the southeast. Storms of a more frequent return period also do not produce wave reflections that impact upon these receptors.

Estuary wide increases in reflected wave energy are shown in Figure 3-5. Increases of up to 4cm are predicted at the north shore line. This amount of reflected energy means there is no impact at the north shore, given that wave heights here would be far greater if the storm were from the south-west. The very minor change in wave climate at the north shore will have a negligible impact on those intertidal areas.

The south east face is exposed to the North Sea for a very small arc. This means that there is the potential that it may experience incident swell waves from the open sea, though the possibility is remote. An extreme scenario model simulation was performed, specifying waves directed at the quay from the mouth of the Humber Estuary. Wave heights were set at a very conservative 5m with a 20s period (at the mouth) and a still water level of 4.68mOD. The model predicted that the majority of wave energy would be dissipated before the wave reached the

[12] HR Wallingford (2012) Able Marine Energy Park 3D Mud Modelling: Morphological assessment of changes south-east of development

quay, so that swell wave heights were only of the order of 30cm at the quay. This is consistent with the generally shallow nature of the Outer Humber Estuary, shown in Figure 3-6, which acts to dissipate wave energy from waves propagating into the estuary from the open sea. Reflected wave energy was dissipated within 50m of the south east quay face, and did not impact upon adjacent receptors.

Figure 3-4: Increase in wave heights due to wave reflection at the south of the quay, during a 1:200 year storm in 2033 with wave direction from the east

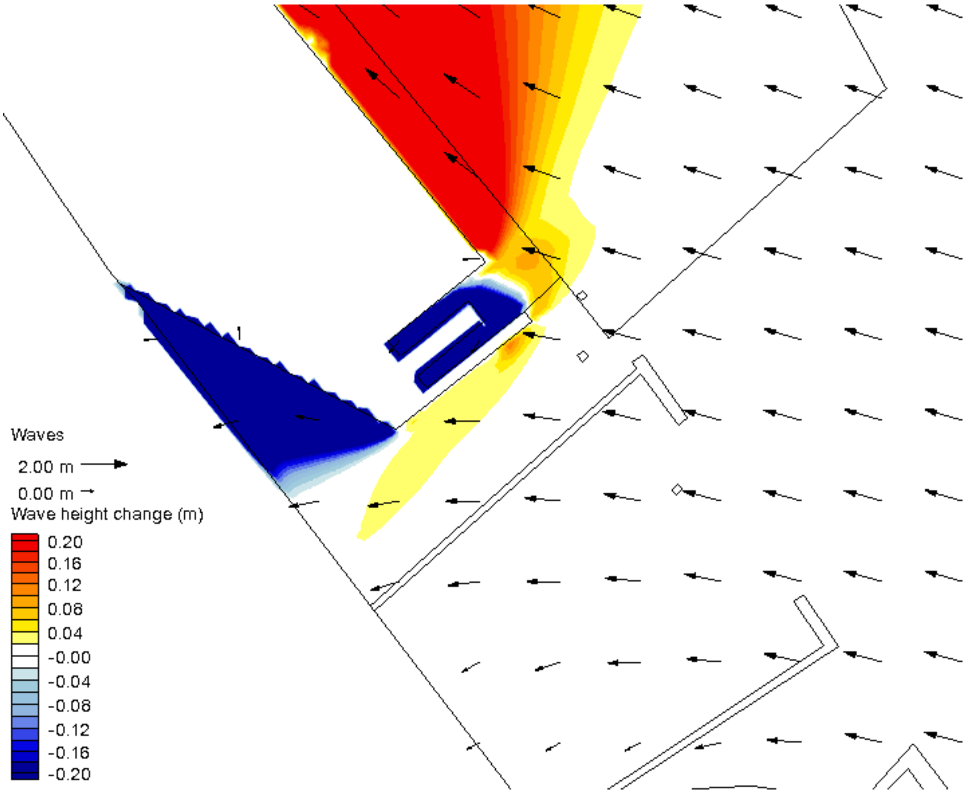


Figure 3-5: Estuary wide increase in wave heights due to wave reflection at the south of the quay, during a 1:200 year storm in 2033 with wave direction from the east

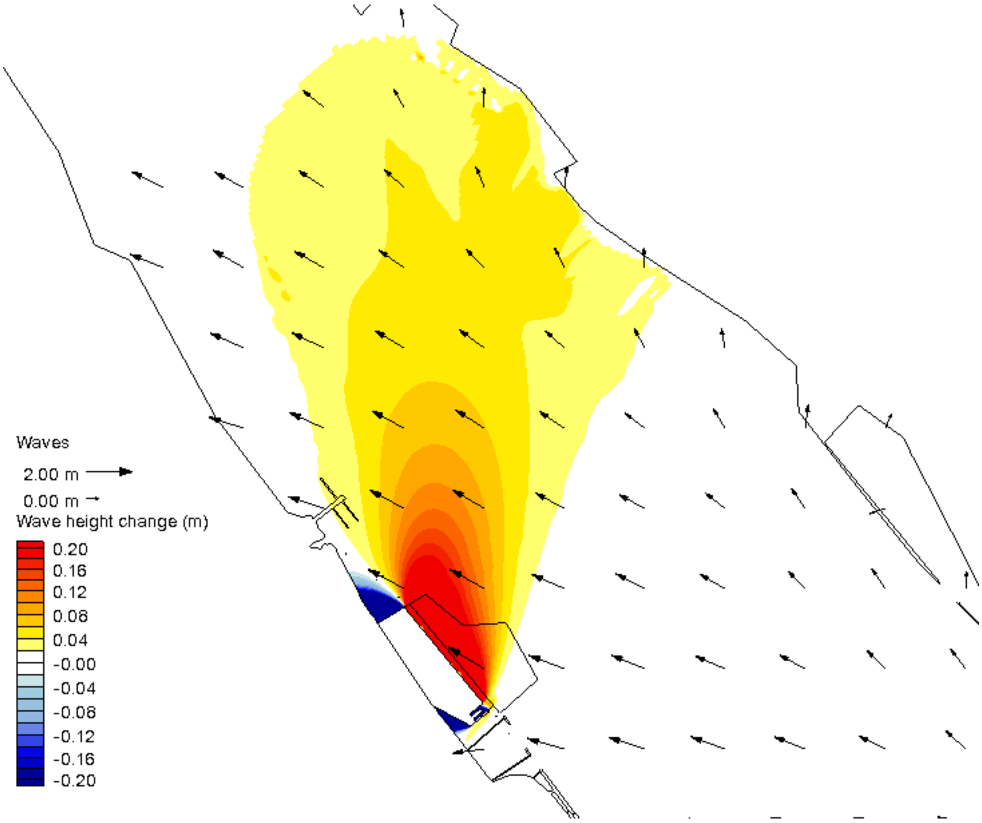
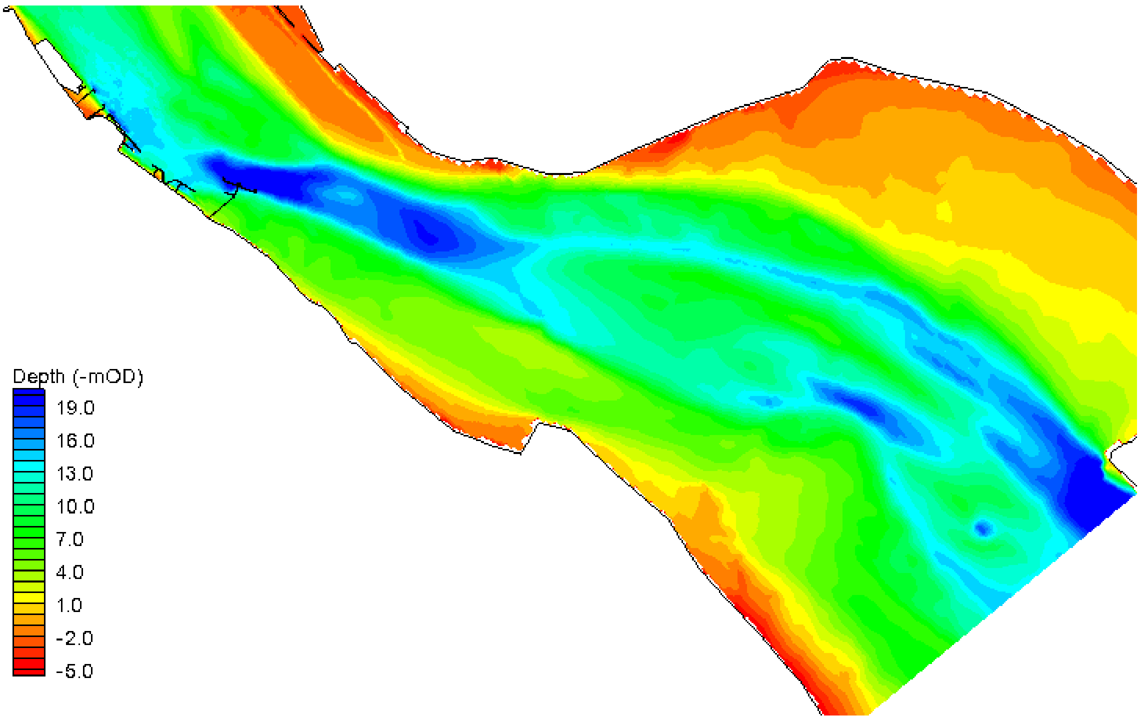


Figure 3-6: Bathymetry of Outer Humber Estuary

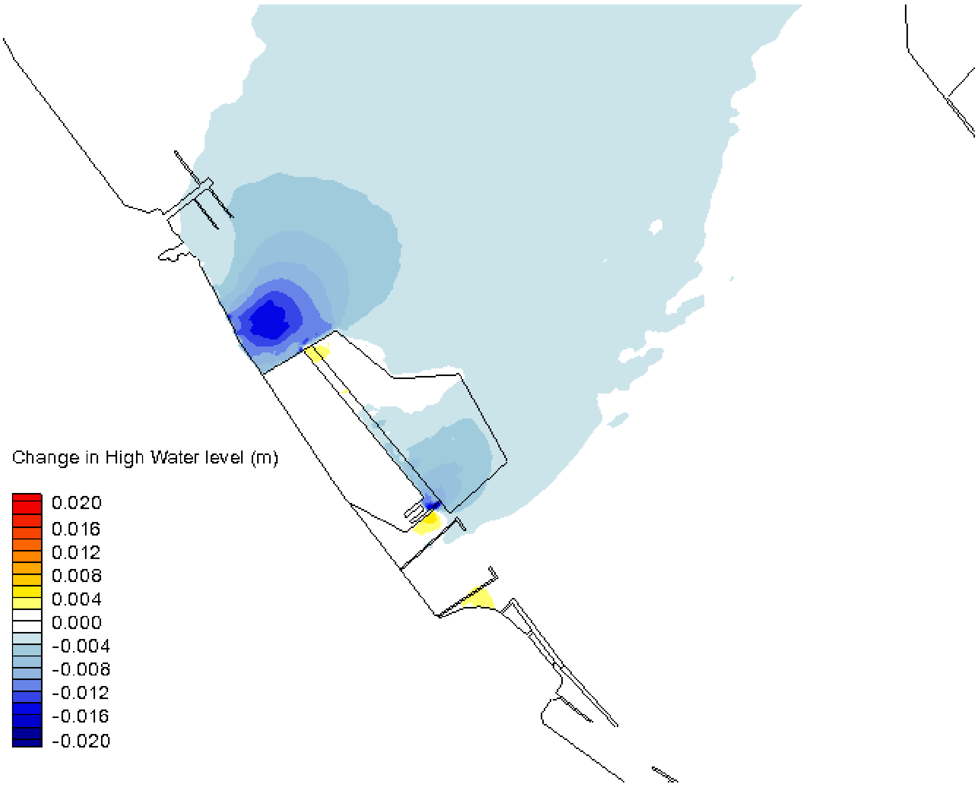


3.3.2 Hydrodynamics

The change in water level due to the scheme is minor and localised. Local changes to MHWS levels of -1.5cm are predicted to the north of the quay due to changes in circulation patterns

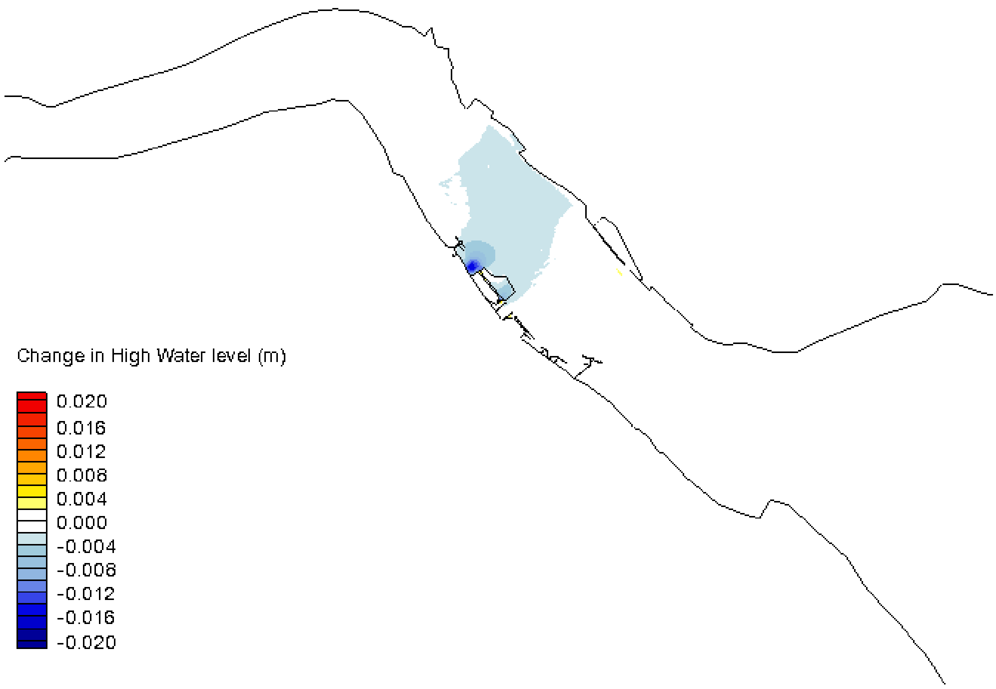
(Figure 3-7). Changes outside of the local area are within model uncertainty bounds, which are deemed to be of the order ± 1cm (Figure 3-8). The predicted estuary-wide change in MHWS level due to the scheme is -0.1cm ± 1cm. Changes to MLWS are similarly small in magnitude. An estuary-wide reduction in MLWS levels of less than 1mm is predicted, with a model uncertainty[13] of ±1cm.

Figure 3-7: Change in High Water level due to the AMEP scheme



[13] Wetting and drying routines in models typically use a minimum depth of water of 0.05m, below which the model cell is specified as being dry. Over the large inter-tidal areas of the Humber Estuary, this parameterisation can lead to even greater uncertainty in model water levels at low tide than at high tide.

Figure 3-8: Estuary-wide change in MHWS level due to the AMEP scheme



Changes to currents are local to the AMEP quay. Reductions from the baseline are observed upstream and downstream in the wake of the quay during flood and ebb flow (Figure 3-9 and Figure 3-10). The large circulation zone predicted in JBA2011 (paragraph 5.17) has now disappeared due to the quay front being moved back 80m towards the shore. During flood MHWS flow a reduction in the currents at the CPK is observed (approximately 18% at Berths 5 and 6; less for the other berths). A navigation modelling study has been performed to assess the impact of this on berthing and unberthing and is reported separately (see Supplementary Report EX14.4[14])

The effect of setting back the quay line inshore from the initial layout is to reduce the change in currents in the middle of the estuary. JBA2011 reported that the narrowing of the channel width at this point in the estuary due to the protrusion of the quay led to increases in current speeds. The final quay design does not protrude into the estuary as much so the impact is reduced.

[14] Able (2012) EX 14.4: Supplementary report: simulation videos & stills

Figure 3-9: Change in peak flows due to the scheme during a flooding MHWS tide

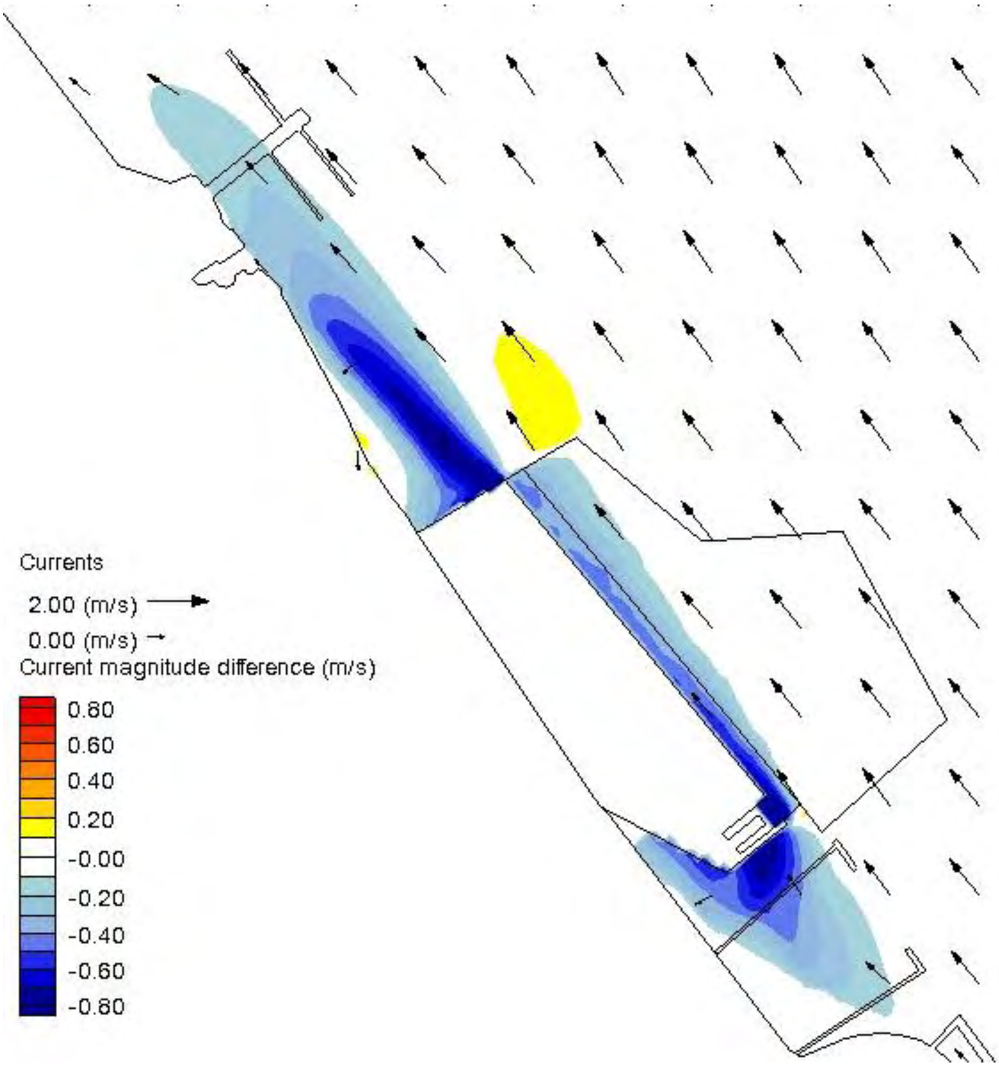
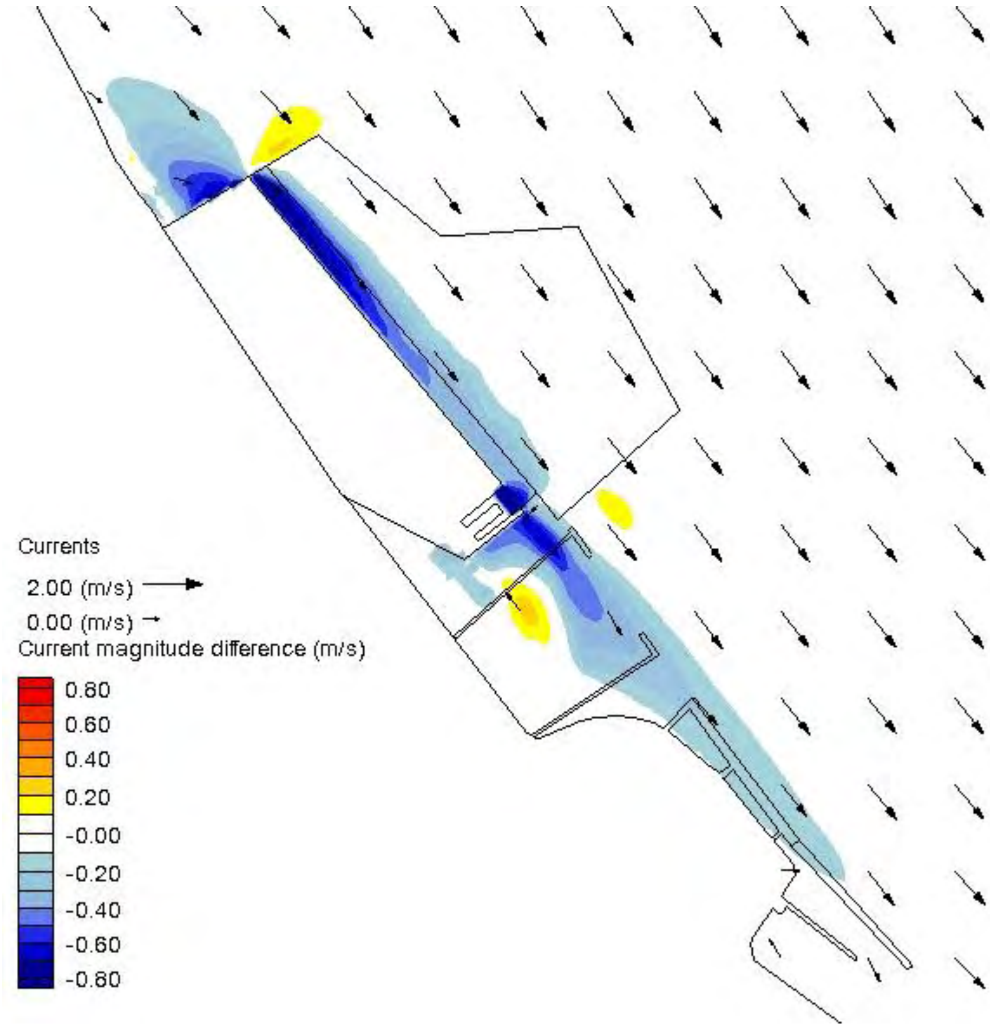


Figure 3-10: Change in peak flows due to the scheme during an ebbing MHWS tide



The changes to currents are manifest in bed shear stresses. During peak flood MHWS flow, bed stresses adjacent to the quay walls to the south east and in the lee of the quay to the north west are reduced (Figure 3-11). In areas where flows are increased, at the corners of the quay, increased bed shear stress is predicted. The increases peak at approximately 20% of the baseline values (which are approximately 3N/m^2 over the location of the dredge area during peak MHWS flood flow). The pattern of change is largely similar for peak MHWS ebb flow, though the decrease in shear stress extends downstream farther. An increase in stress is observed shoreward the SKOJ berth, due to the recirculation pattern produced at the downstream edge of the AMEP quay.

These patterns of potential bed morphology change agree well with the results of the mud modelling study by HR Wallingford[15]. This study predicts accumulation in the areas denoted here as less energetic (blue) and greater potential erosion (depending on the bed material) in areas denoted here as more energetic (yellow/orange) (see their Figure 14 and Figure 15). This provides good validation of the models used in these studies.

The estuary-wide changes to bed shear stress are shown in Figure 3-13 and Figure 3-14. These show that the changes to the bed shear stress are local to the quay. Therefore, the AMEP development will not affect the bed shear stresses, and therefore erosion patterns, where three gas pipelines cross the estuary upstream of AMEP (Figure 2-4).

[15] HR Wallingford (2011) Able marine Energy Park 3D Mud Modelling. Report EX 6603

Figure 3-11: Change in peak bed shear stress due to the scheme for a flooding MHWS tide

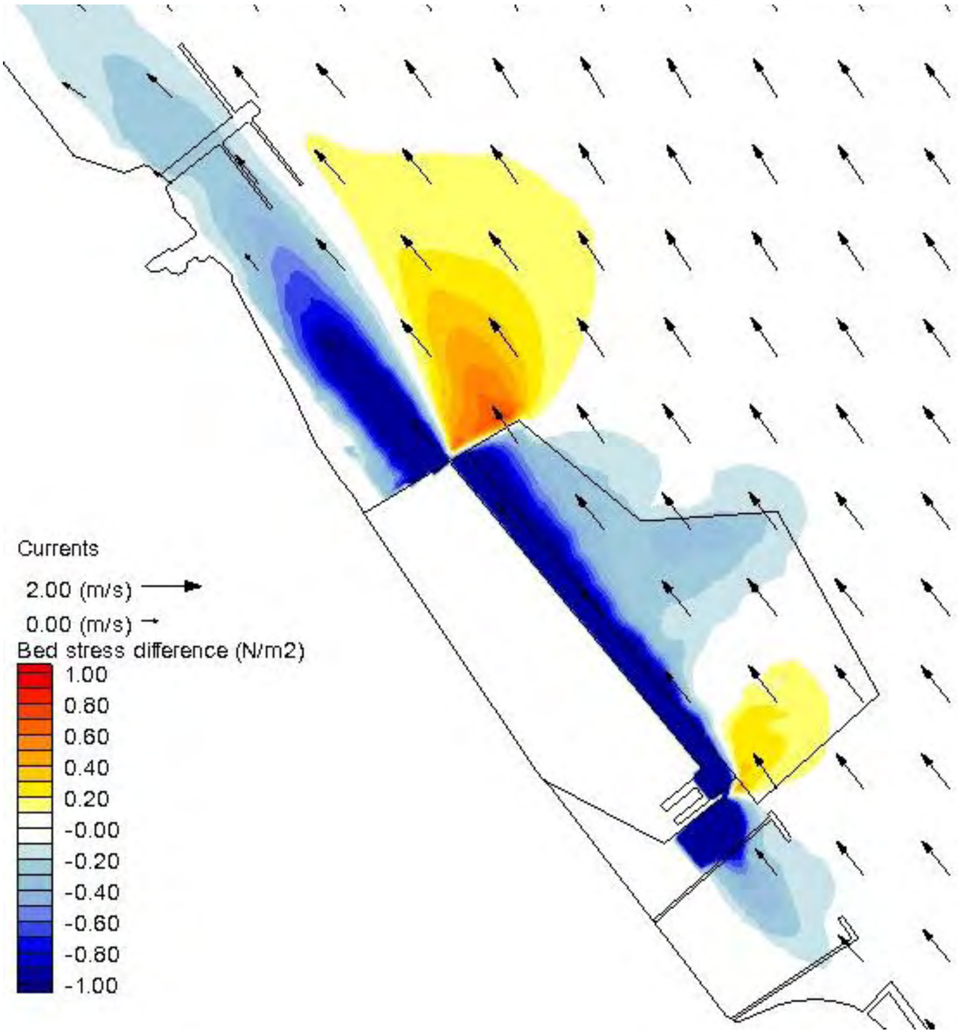


Figure 3-12: Change in peak bed shear stress due to the scheme for an ebbing MHWS tide

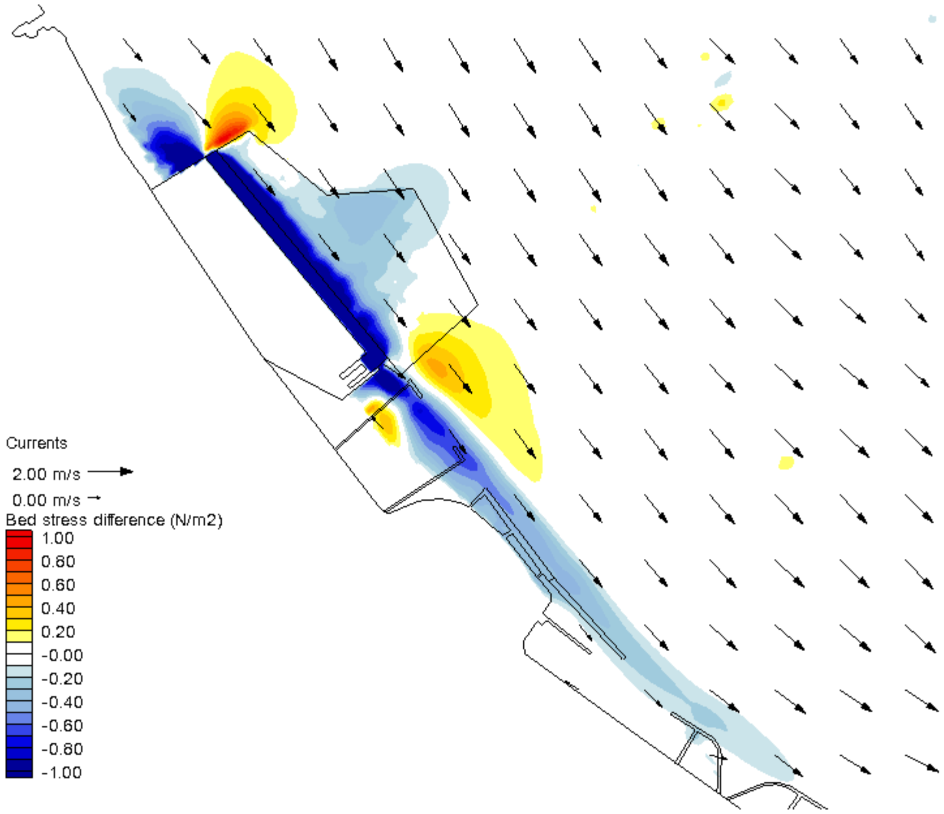


Figure 3-13: Estuary-wide change in peak bed shear stress due to the scheme for a flooding MHWS tide

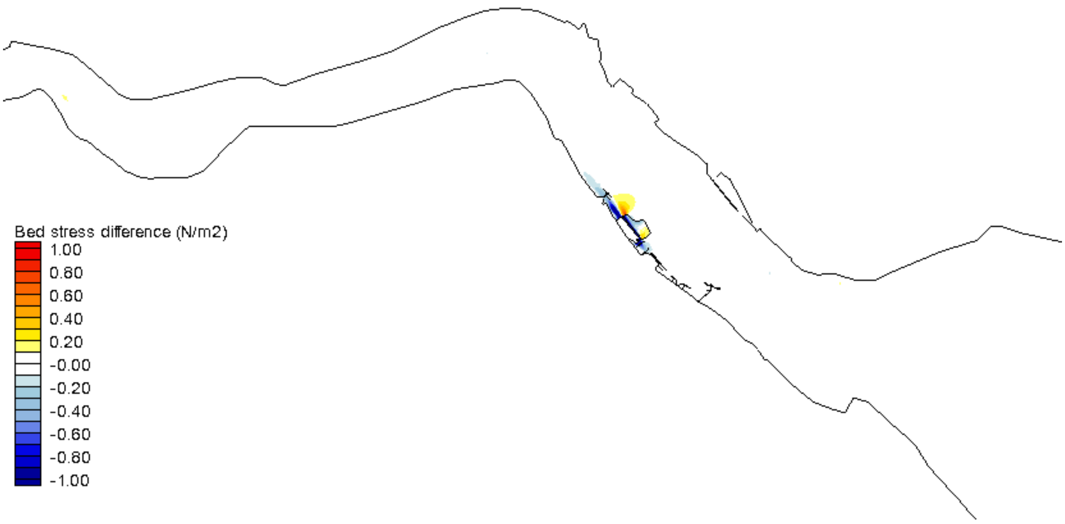
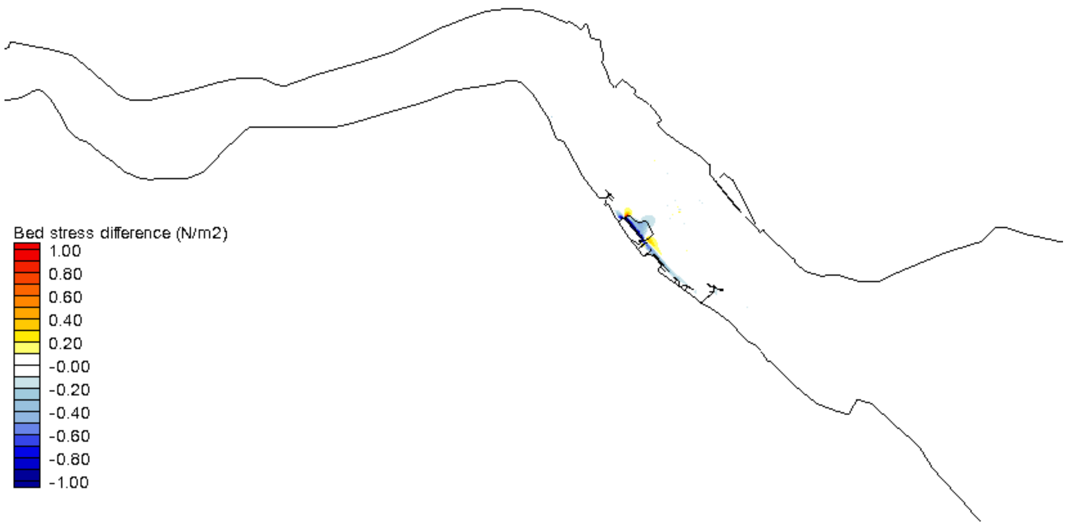


Figure 3-14: Estuary-wide change in peak bed shear stress due to the scheme for an ebbing MHWS tide



3.3.3 Short-term sedimentary regime

The predicted change to the bed morphology from the non-cohesive sediment transport model after simulating 18 days of tidal flows is shown in Figure 3-15. The pattern of predicted change follows that which can be inferred from the bed shear stress predicted changes, and is similar to that predicted for the preliminary quay design (Figure 27 of JBA2011). Scour is predicted around the edges of the dredge area, due to the increased flows and bed shear stresses at these locations. Deposition is predicted in the dredge area as a result of this scour. It is also due to the fact that, as currents are predicted to decrease over the dredge area, the deposition of sediment from the high sediment load in the water will increase. Deposition is also predicted in the less energetic areas to the north west and south east of the quay. However, due to the reduced 'footprint' of the quay in the estuary and the resulting disappearance of the circulation pattern near the CPK, substantial deposition is now not predicted here as was previously the case. However, this result should be treated with caution. Sedimentation is still very likely to occur in this area over decadal timescales.

Erosion is predicted at the SKOJ berth, suggesting that maintenance dredge requirements here may in fact be reduced. Accretion is predicted at the IGT and at the Centrica intake/outfall and EON outfall to the north west. A fuller assessment of the impacts to the sedimentary regime at the Centrica and EON intakes/outfalls is provided by HR Wallingford's mud modelling study (Report EX8.10[16])

It should be noted that the model assumes a non-cohesive erodible layer of 1m thickness. This is therefore a conservative approximation of the conditions at the site, at which the bed material exhibits some cohesive properties and the depth to the inerodible clay layer varies considerably and can be less than 1m. The results of HR Wallingford's mud modelling study, as well as their analysis of the impact of HIT on the intertidal area fronting Killingholme Marshes, are potentially more useful to understanding these local effects.

The patterns of predicted change after 18 simulated days allow for a linear extrapolation of the change after 365 days, providing an estimate of the change to annual maintenance dredge requirements. It should be noted that the uncertainty associated with such a linear extrapolation is very large. Table 3-1 provides the extrapolated predicted changes to annual maintenance dredge volumes at nearby facilities due to the changes to the short-term sedimentary regime brought about by the AMEP quay and dredge areas. The volumes are smaller than for the preliminary quay design (refer to Table 10 in JBA2011) due to the reduced size and impact of the quay. The uncertainty associated with these volumes is large, and for all adjacent sites (except the Centrica and EON outfalls and intakes) HR Wallingford's mud modelling study predicts decreases in annual maintenance dredge requirements. The potential variability in the

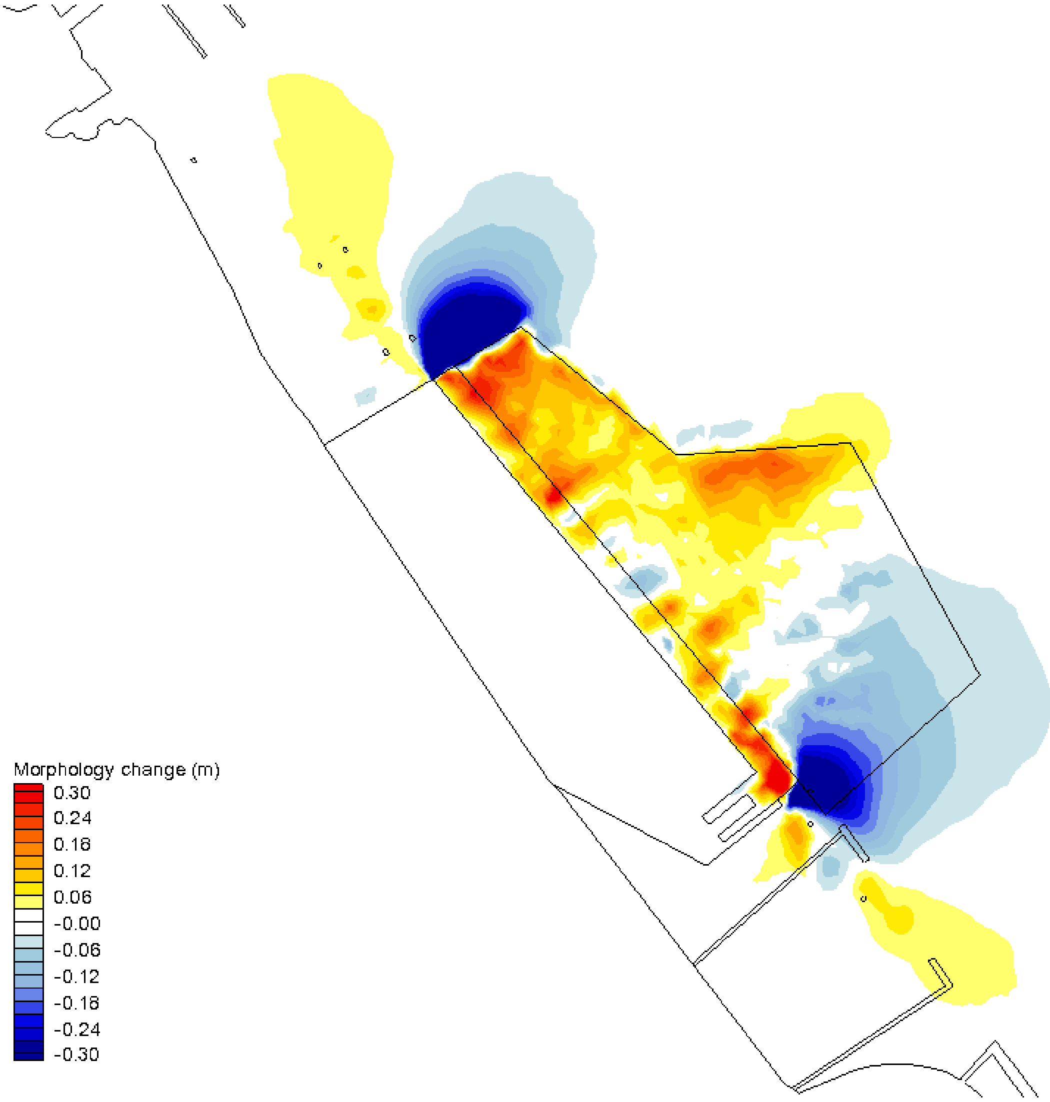
[16] HR Wallingford (2012) Ex 8.10. Explanatory note. Able Marine Energy Park 3D Mud Modelling: Morphological assessment of changes south-east of development

maintenance dredge volumes are considered in much greater detail in Supplementary Report EX8.6[17]. For other sites in the Humber Estuary that are not included in the table, the short term modelling predicts no change in dredging requirements due to the AMEP quay and dredge areas (e.g. Immingham Outer Harbour, HWB, SDC, etc.).

Table 3-1: Predicted changes to annual maintenance dredge volumes at nearby facilities due to the AMEP quay

Facility	Predicted change to annual maintenance dredge volumes (m3)	
	Median grain size = 0.1mm	Median grain size = 0.2mm
AMEP berths	740 000	300 000
CPK	8 000	5 000
SKOJ	-8 000	-6 000
Immingham Gas Terminal	3 000	2 000
Humber International Terminal	3 000	2 000
Immingham Bulk Terminal	-2 000	-1 000

Figure 3-15: Difference in model morphology change after 18 days (scheme minus baseline) (red is deposition, blue is erosion)

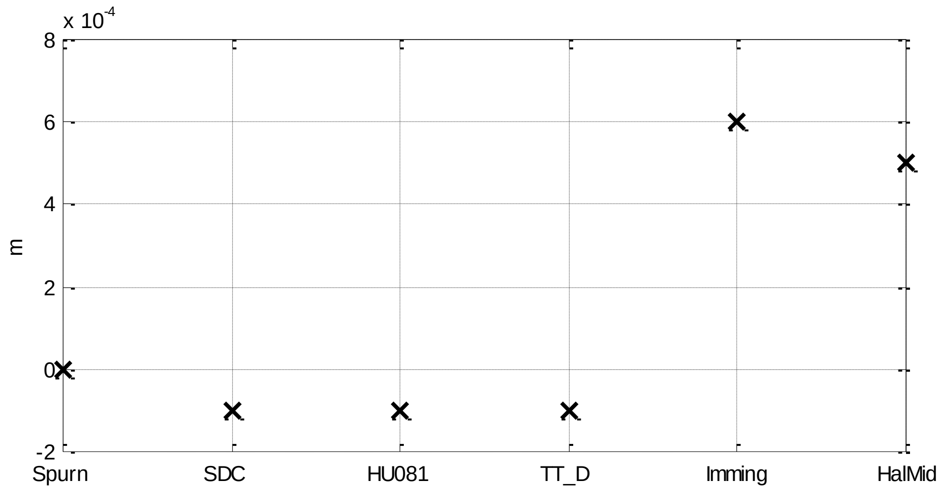


[17] HR Wallingford (2012) Ex 8.6 Explanatory note. Assessment of maintenance dredging requirements

3.3.4 Impacts of reduced compensation site level

The reduction in the level of the compensation site from +2.5mOD to +2.2mOD represents an increase in storage volume of 300 000m^3 during high Spring tide. However, the model predicts that this increase in storage leads to a slight increase in HW in the Middle Estuary around Immingham and Halton Middle of 0.5mm (Figure 3-16). Given that the model uncertainty in water levels is ±1cm, the realism of this prediction is extremely low. Moreover, this change is local to the estuary adjacent to the compensation site, reducing in magnitude farther upstream and downstream. Therefore, the model hydrodynamics can be assumed to be insensitive to this change in compensation site level.

Figure 3-16: Simulated water levels for the Outer and Middle part of the Humber Estuary



3.4 Discussion of results

The EA has provided the applicant with their consultant's assessment of long term morphological change caused by the Project[18]. The assessment infers change from studies undertaken on set-back sites within the estuary, assuming that the quantum of habitat change resulting from the reclamation works will be pro-rata, and opposite to, the quantum of habitat change due to a substantial (808 ha) set back site on Sunk Island.

Modelling morphological change carries high levels of uncertainty. Long term change in the estuary will be dictated by sea level rise which over 100 years will amount to around 1055 mm between 2015 and 2115 using the UKCP09 95% medium emission scenario. On the same basis, over the first 50 years sea level rise is predicted to be 380 mm. The Humber CHaMP uses an assumption that sea levels will rise by 6mm/year between 2000 and 2050 and that this will give rise to a need for 600 ha of new intertidal habitat in order to maintain the habitat at its current quanta.

By contrast to the above, the changes in water levels due to AMEP are predicted to be millimetric and cannot be distinguished from model error. Thus, any impact will be dwarfed by natural change (sea level rise is defined as natural change in the Humber CHaMP). Accordingly, the argument for the applicant to provide compensation for long term morphological change is not substantiated by the project specific modeling.

For a 1:200-year storm in 2033, for waves travelling from the north, the model predicts an increase in wave heights of 25cm on top of a 1.3m wave to the immediate north of the quay along the defence line. This reduces rapidly with distance to the north to negligible values within 60m. As described in JBA2011, the 1:4 rock armour slope in front of the defence at this point is more than adequate to limit overtopping to below 2 l/s/m (the 1:200-year overtopping limit agreed with the EA). For this storm severity in 2033 for waves travelling from the east and impacting on the southeast of the quay, the model predicts no impact on the EA defences to the south of the quay. The inter-tidal areas to the north and south of the quay are expected to be areas of accretion over decadal timescales and this will cause estuary bed levels to be raised locally. This has not been included in the modelling due to the large uncertainty involved in estimating

[18] Deltares (2012) Review EIA documents GPH & AMEP. Memo for the Environment Agency

the quantity of build up. However, the raised bed levels will generally act to further depth-limit waves and mitigate any increase in wave heights due to wave reflection from the AMEP quay.

During the 1:200-year storm, wave reflection from the berthing face of the quay leads to increases in wave height at the north shore of 4cm. However, this impact is of little or no consequence given that the north shore is not exposed to large waves during northerly and easterly storms (storm directions of relevance to the issue of wave reflection from the AMEP quay); south westerly storm events will be more significant to this receptor and these are unaffected by AMEP

The wave reflection modelling has shown that reflected wave energy is predicted in the inter-tidal area to the north and south of the quay, for an extreme storm scenario. More typical reflected wave energy experienced at these locations will be far less than that shown, and is likely to be mostly if not wholly dissipated by the rock armour incorporated into the quay design. During storm events, the increase in wave energy due to reflection in these areas may lead to increased bed shear stresses over those of the baseline. This suggests that the quay may lead to increased erosion in these inter-tidal areas through this process. However, the areas affected are areas that will experience significant reductions in current-induced bed shear stress, as the quay will block tidal flow. Increased deposition over the baseline will be the dominant change in these areas. Reflected wave energy during storms may lead to temporary erosion of these areas, but they would soon be replenished during calm periods.

The offshore receptors to the north and south of the quay (e.g. dolphins to south east) are not impacted by wave reflection issues.

The changes to the flow and short-term sedimentary regimes due to the quay and dredge area are substantially reduced from those predicted for the preliminary design in JBA2011. Small increases in annual maintenance dredge requirements are predicted for the CPK, IGT and HIT. However, this is contrary to the results of HR Wallingford's mud modelling study (Ex 8.6), which predicts decreased deposition (and therefore a beneficial impact) at all adjacent berths. The results of the mud modelling study are perhaps more reliable, given the greater proportion of muddy sediment within this area of the Humber Estuary.

3.5 Summary of impacts

A summary of potential impacts and the sensitive receptors that they may affect due to the final AMEP development are listed in Table 3-2.

Table 3-2: A summary of the potential impacts on sensitive receptors due to the final AMEP development

Relevant receptors	Impact due to AMEP quay and dredge areas	Information
EA coastal defences	No impact (after rubble slope mitigation design)	Increased wave heights due to wave reflection along the defence line to the north of the quay are mitigated by a new rubble structure slope in front of the defence. Increased wave heights due to wave reflection from the south east face of the quay are negligible at the defence. Increased inter-tidal sedimentation due to the presence of the quay will occur over time and will act to depth-limit waves further, leading to further mitigation of these impacts. No adverse impact is predicted for the north shore defences due to increased wave reflection from the south shore.
Adjacent ports and facilities	Minor impact	Very small quantities of enhanced wave energy can reach adjacent berths during extreme storms but will not affect navigation, partly due to the fact that ships are unlikely to be manoeuvring during such conditions. Wave energy reflected from the southeast face of the quay does not affect the dolphins to the southeast of the quay. The non-cohesive sediment transport modelling suggests annual maintenance dredge rates may increase slightly at the nearby CPK (5 000-8 000m^3), IGT (2 000-3 000m^3) and HIT (2 000-3 000m^3). This is a minor impact, though it should be noted that results from HR Wallingford's mud transport modelling assessment predicts a beneficial impact (decreased deposition) at all adjacent berths.
Inter-tidal areas	No impact / impact at inter-tidal areas	Changes in water levels due to the quay and dredge areas are within model uncertainty, and therefore no change is predicted. The potential for wave reflection-induced erosion will be more than

Relevant receptors	Impact due to AMEP quay and dredge areas	Information
	adjacent to quay assessed elsewhere	offset by the large decreases in current-induced bed shear stress (leading to accretion) in the inter-tidal areas adjacent to the quay. The potential for wave reflection-induced increases in bed shear stress on the north bank inter-tidal area opposite the quay is small for the most extreme storm events from the north and east. Any effect will be dwarfed by the effects of other storm directions. The long-term change to inter-tidal areas adjacent to the quay is assessed in HR Wallingford reports EX8.8, EX8.9 and EX8.10.
Navigation at CPK	Impact assessed elsewhere	The impact on navigation at the CPK from changes in currents due to the AMEP development has been assessed in a simulation exercise that is reported separately (EX14.4).
Centrica intake/outfall, EON intake/outfall	Impact assessed elsewhere	An assessment of the likelihood of accumulated sediment impacting on these receptors has been performed by HR Wallingford (EX8.8)
Gas pipelines near Halton Middle	No impact	There is no additional potential for erosion at the location of the pipelines due to the AMEP quay and dredge areas.

4 Assessment of Inerodible Material Disposal Impacts

4.1 Introduction

As part of the AMEP capital dredge, an estimated 954 350m^3 of inerodible[19] material will be dredged. Following consultation with the Marine Management Organisation, Able UK have proposed to dispose of this clay material at the HU082 disposal site in the Outer Humber Estuary (Figure 4-1). To dump all of this material at this site would lead to a bed level rise over the entire site to around -5.3mCD (-9.2mOD). The existing bathymetry for this site is approximately sloping down from the northern edge (-5.5mCD) to the southern edge (-7.3mCD) which is also the northern edge of the Sunk Dredged Channel (SDC). Subject to the identification of other beneficial use for some of the material, a second proposal is to dispose of only some dredged material at this site: enough to fill in the local natural bathymetric depressions within the disposal site creating a smoother bed that slopes from a high point north of the disposal site to the SDC. This would allow approximately 460 000m^3 of inerodible material to be disposed here, with the remainder disposed of to land.

Figure 4-1: Disposal sites in the Outer Humber Estuary

The proposed change in bathymetry at the HU082 site may impact upon the hydrodynamic and sedimentary regime within the Humber Estuary. Flow paths could be altered, leading to changes in water levels that may impact upon the size of inter-tidal area in the estuary. Changes in tidal current speeds and directions are unlikely to affect shipping, but may affect inter-tidal and sub-tidal morphology. The baseline flow paths that transport sediment through the area could be altered, leading to variations in where sediment settles. Changes in the sedimentary regime could increase maintenance liabilities at sensitive sites within the estuary, for example SDC or at port facilities. The likelihood and magnitude of these potential impacts is assessed in this chapter.

The inter-tidal areas to the north of the HU082 disposal site, to the west and east of Hawkins Point on the north shore, are sensitive receptors. These areas are exposed to relatively large wave energy due to waves propagating into the estuary from the North Sea. Such waves travel over the proposed disposal site before reaching the inter-tidal areas. Therefore, changes to

[19] See footnote 4 in chapter 1.

bathymetry at the disposal site may lead to changes in the wave climate experienced at these receptors. Changes to wave-related flood risk behind the defence line on the north shore will be negligible: the large water depths that will exist during storms mean that, over the length of the defence line changes to waves due to the proposed bathymetric alterations will be negligible. However, for more frequent wave activity during times of low waters, the wave-related bed shear stress climate experienced at the inter-tidal areas may be affected. This in turn may affect the local morphology. The potential for such morphological changes is also assessed in this chapter.

A summary of relevant sensitive receptors and the potential impacts are given in Table 4-1.

Table 4-1: List of receptors sensitive to potential impacts from inerodible material disposal

Sensitive receptor	Potential impact
Inter-tidal areas and habitats	Impacts on water levels and flow regimes at these sites may lead to increased/decreased inter-tidal area and changes to accretion/erosion patterns. Changing bed levels at the disposal site may affect the wave climate, leading to changes in wave energy reaching the inter-tidal areas.
Sub-tidal areas, maintained dredged areas (SDC, ports)	Impacts on flow regimes may lead to changes in estuary sedimentation patterns and morphology that could affect maintenance dredging requirements.

4.2 Site characteristics

The Humber Estuary is characterised by relatively fast currents and high levels of suspended sediment concentrations. The bed morphology is naturally very dynamic, with changes occurring over varying period lengths such as short period storms, the Spring/Neap cycle, seasonal and decadal. Moreover, a 13-year natural cycle in channel morphology in the Outer Estuary has been observed[20].

The disposal site is located within the Outer Humber Estuary, immediately to the north of the SDC. The bed of this area is made up of inerodible boulder clays, where any deposits of erodible sand-sized sediment are highly localized and typically less than 2cm in thickness[21,22,23]. The presence of these clays provides a constraint on morphological changes in the Outer Estuary. The SDC is noted to have exhibited a clear 13-year cycle in sedimentation patterns up to the early 1990s. However, since this time the pattern has become less clear. Moreover, minimal maintenance dredging has been required since 2007.

To the north of the disposal site the large inter-tidal area is made up of mudflats. These are characterised by a complex network of channels and gullies (Figure 4-2), the arrangement and positions of which are relatively stable over time. The inter-tidal areas are shown in Figure 4-3, denoted as the areas shoreward of the MLWS red line.

[20] Gameson, A L H, 1982, 'Physical characteristics', In: The quality of the Humber Estuary 1961-1981, edited by Gameson, ALH, Humber Estuary Committee.

[21] Van Ormondt, M. and Roelvink, D. (2004) Short-term morphologic modelling of the Humber Estuary with Delft3D

[22] ABPmer (2004). Humber Estuary Shoreline Management Plan – Stage 2. Humber Estuary Data Report. Report R932. Environment Agency North East Region.

[23] ABPmer (2009a) Immingham Oil Terminal Approach Channel Dredging Environmental Statement. Associated British Ports & Total Lindsey Oil Refinery. Report R. 1416.

Figure 4-2: Network of mudflat channels on mudflats to the north of the disposal site in the Humber Estuary

Figure 4-3: MLWS line (red) in the Outer Humber Estuary

4.3 Assessment methodology

The numerical models developed in JBA2011 were used to investigate potential changes in the hydrodynamic and sedimentary regime of the estuary due to the disposal of inerodible material at the disposal site. The original model grid resolution at the disposal site was 160m. This was improved to 25m to enhance model accuracy here. The hydrodynamic and sedimentary processes were simulated by running the appropriate models. Model simulations were performed for the following scenarios:

- Existing bathymetry
- A raised bed elevation within the disposal site to -5.3mCD everywhere, increasing the volume of inerodible material within the site by 954 350m^3 (full disposal) in combination with the AMEP quay.
- A sloping bed in the disposal site, increasing the volume of inerodible material within the site by 460 000m^3 (half disposal) in combination with AMEP quay.

Predicted changes in physical processes were calculated by deducting the existing bathymetry simulation results from those of the altered bathymetry simulations.

Simulations specific to the type of models used are detailed herein.

4.3.1 Waves

Changes to wave climate due to disposal of inerodible material at the proposed site were investigated by using the spectral wave model, CMS-Wave. A simulation was performed to examine the changes to typical wave conditions for the region. Waves travelling in from the estuary mouth were specified. This direction is most relevant when considering the source of greatest wave energy in relation to the orientation of the sensitive receptors (inter-tidal areas) to the disposal site (at Hawkins Point wave direction is observed from the south east for only 34%of the time). Wave heights were set so that the height of waves incident at Hawkins Point was 1m. This represents a relatively typical wave height (a return period of approximately 1 month), given that the 1-year wave height here is 1.76m[24]. A mean wave period of 4s was used. This wave period corresponds to the typical wave height of 1m, using the relationship between extreme wave heights and associated wave periods reported in the EA Humber Estuary extreme wave heights report[24] (during the 15-year data period from which these extreme wave heights were derived, there were no instances of wave heights of approximately 1m being associated with periods significantly larger than 4s).

The average water level of 0mOD was specified. Wave heights in the relatively shallow Humber Estuary are depth dependant. Therefore, the sensitivity of the simulated wave heights on the inter-tidal area was assessed by specifying two additional model runs: one with a water level of 3.2mOD and another with a level of -2.8mOD, representing MHWS and MLWS at Grimsby respectively.

4.3.2 Hydrodynamics

The CMS-Flow hydrodynamic model was used to simulate the flows associated with a MHWS tidal cycle. This was achieved by specifying a varying water elevation condition at the Spurn Head downstream model boundary, reproducing the MHWS tidal signal observed at this location. An initial period of 5 model days was incorporated into the model simulations in order to allow for transients due to model initial conditions to settle. Water levels and currents were extracted for the bathymetric scenarios specified above.

4.3.3 Short-term sedimentary regime

The CMS-Flow model with non-cohesive sediment transport enabled was used to simulate an 18-day period, incorporating a Spring-Neap cycle, for the bathymetric scenarios described above. Given the boulder clay nature of the disposal site and surrounding area an erodible layer of only 2cm thickness was specified for the region. This accuracy of this assumption may reduce farther away from the disposal sites, particularly approaching the mudflats to the north. Therefore, the results of the modelling in these areas will be characterised by greater uncertainty. The two disposal sites, HU081 and HU082, were set to be inerodible. The non-cohesive sediment transport model was run using a median grain size of 0.1mm, typical of the sand fraction found throughout the area.

As for the Humber Estuary as a whole, the complex nature of this area means that the modelling results of the sediment transport and morphology change are informative rather than being highly accurate. Limitations that should be considered include the absence of the representation

[24] ABP R&C (1999) The Humber tidal database and joint probability analysis of large waves and high water levels - Annex I. R.810. Report for the Environment Agency

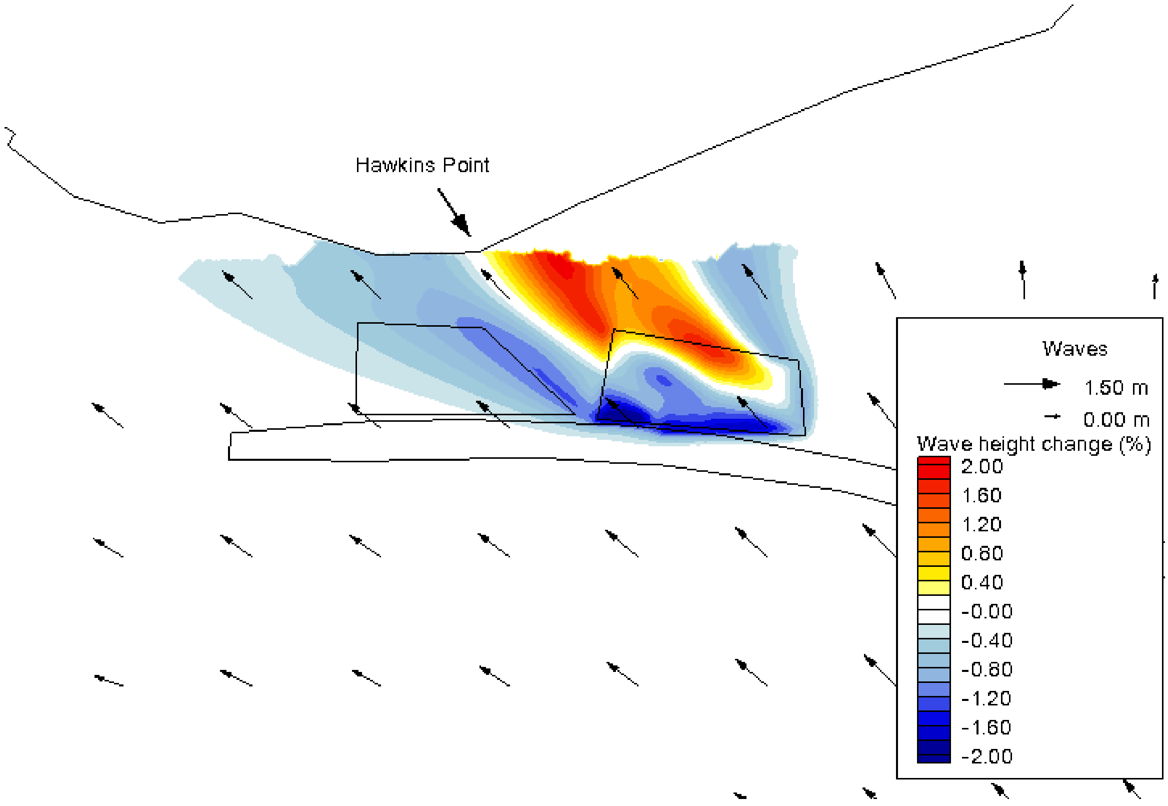
of cohesiveness between sediment particles, which is restrictive for modelling the inter-tidal mudflats. Also, the depths and volumes of erodible material are likely to vary over the domain, the values of which would require a comprehensive monitoring program to determine. Sediment transport is inherently uncertain and the results of these simulations should not be used in isolation. More reliance should be given to the interpretation of the potential impacts on morphology due to changes in waves and currents (provided in section 4.5).

4.4 Impacts

4.4.1 Waves

The impacts on waves have been investigated by running the wave model for typical wave conditions, with and without the disposal site bathymetry changes. The predicted percentage change in wave heights from the 1m waves travelling from the south east are shown in Figure 4-4 (the 0mOD water level means that inter-tidal areas to the east and west of Hawkins Point are above the water line). Changes of up to ±2% in wave height are predicted along the north shore line, covering a length of approximately 4km. These differences are due to the change in how waves refract due to the change in bathymetry at the disposal site. The sub-tidal bathymetry changes are in deep water (relative to the wave characteristics) and consequently no loss of the baseline wave energy occurs through depth-induced wave breaking. The baseline wave energy is not increased; it is simply distributed along the coastline slightly differently.

Figure 4-4: Percentage change in wave heights due to full disposal of inerodible material at the proposed disposal site



The magnitude of this effect increases with decreasing water level, as the waves respond to the bed to a greater degree. For the MLWS simulation, the wave height change can be up to 4% in magnitude. Conversely, during times of high water the effect is reduced. For the MHWS simulation, the wave height change is below 0.5%. Therefore, during extreme storm conditions the water level will be high enough so that changes to flood risk at the defence line due to this effect will be negligible.

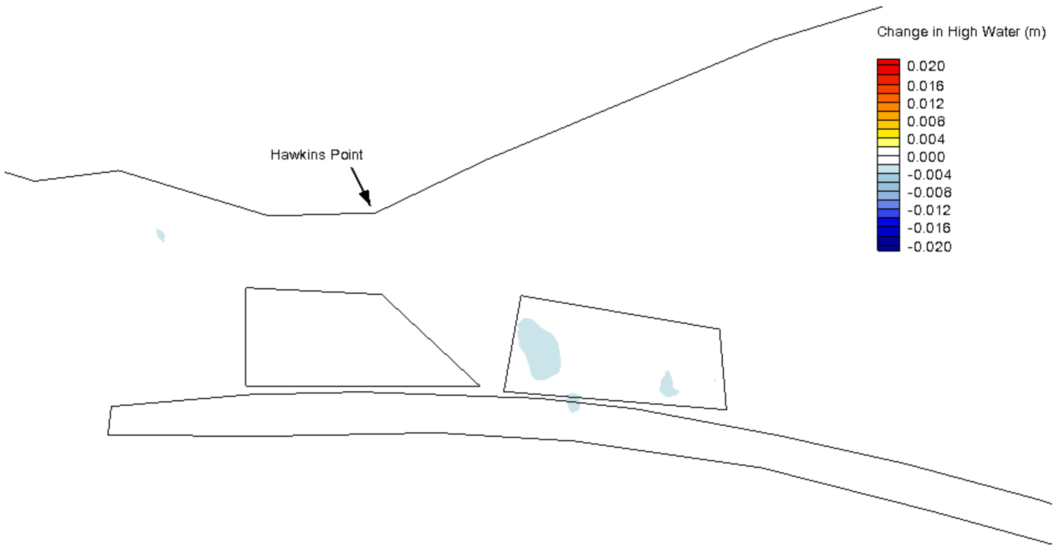
However, over long term timescales the effect may manifest in modest morphological changes in the inter-tidal areas, due to the change in wave-induced bed shear stress. The changes presented in Figure 4-4 reveal a slightly more energetic zone to the east of Hawkins Point, and a slightly reduced wave energy zone to the west. The locations of these increased/decreased wave energy zones will vary depending on wave direction. In areas of increased wave energy, there will be the potential for development of drainage channels of the form that are observed over the mudflats to the east. This may be a visually significant change, the scale of which would be difficult to predict, however a change to inter-tidal area and volume of sediment is very unlikely. There would be no change in the type of sediment exposed in the area and so no change to habitat.

This effect on the wave climate by the change in bathymetry at the disposal site is substantially reduced for the scenario of half disposal.

4.4.2 Hydrodynamics

The change to MHWS water levels due to full disposal is shown in Figure 4-5. The only change is a local decrease of 2mm in the vicinity of the disposal site. This is within the model uncertainty of ± 10mm, therefore no changes to estuary water levels are predicted.

Figure 4-5: Change in MHWS levels due to full disposal at the disposal site



The changes to peak MHWS flood and ebb currents due to the full disposal are shown in Figure 4-6 and Figure 4-7 respectively. The full disposal will raise bed levels at the disposal site, so that there is a decrease in the cross-sectional area through which the tidal current flows. This leads to an increase in the magnitude of current over the disposal site for both flood and ebb tide phases, denoted by the yellow shading in the figures. The increases are approximately 0.06m/s, which represent an increase of 5% on the baseline flow. Increased flow is predicted just to the north and south (including in the SDC) of the disposal site.

In the areas to the west and east of the disposal site there is a considerable expansion in the cross-sectional area through which tidal flow travels. Therefore, there is a decrease in current speeds here, highlighted by the blue contours in the figures. These areas of expansion lead to reductions in the flow speed of approximately 5% from the baseline. The area affected (approximately 2Mm^2), shown in the figures, is less than 2% of the area of the Outer Humber Estuary (approximately 150Mm^2).

As bed shear stresses here are determined by currents, these patterns of change are manifest in the stresses also. Increased stresses are observed over the disposal site and to the north and south (including in the SDC). This is likely to lead to scouring of the disposed material and a very gradual flattening of the mound, over a period of months and years. The extension of increased currents to the north of the site provides an increase in the potential for localised channel development in this area. Decreased stresses are predicted to the west and east, which provide the potential for increased sediment deposition here.

Figure 4-6: Change in peak flood flow for a MHWS tide due to full disposal at the disposal site

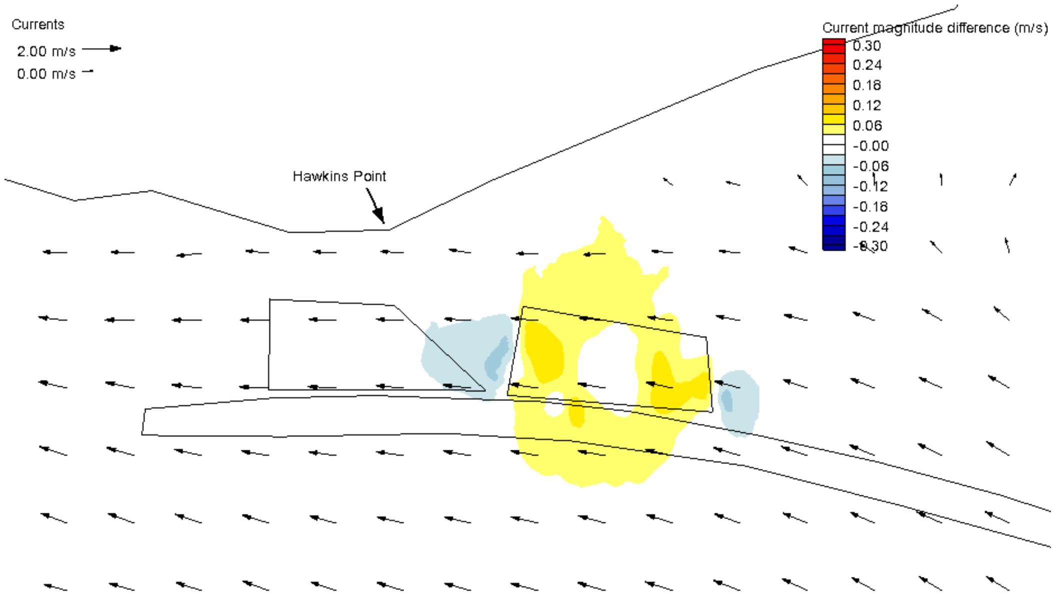
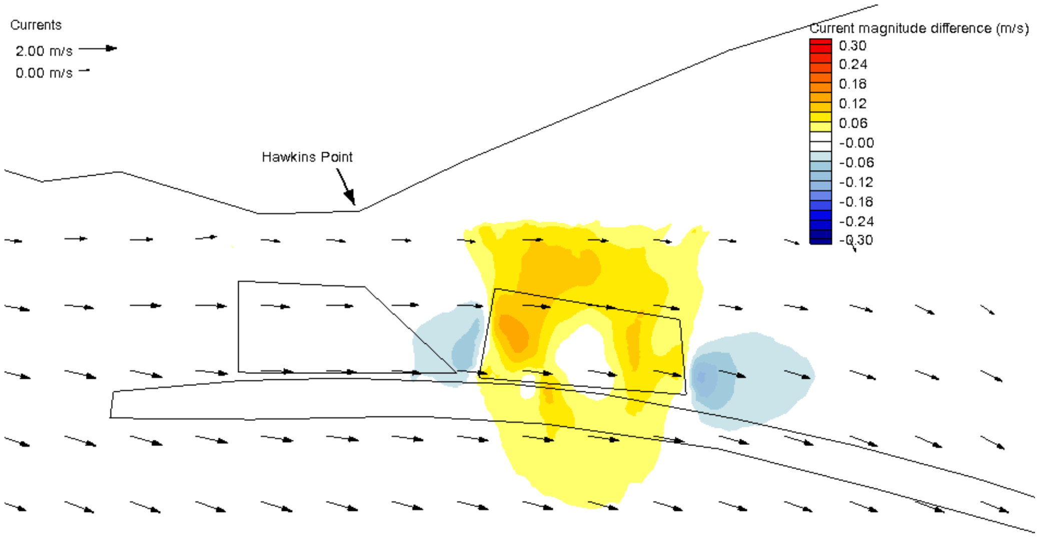


Figure 4-7: Change in peak ebb flow for a MHWS tide due to full disposal at the disposal site



The corresponding changes to MHWS currents due to the half disposal scenario for flood and ebb flows are shown in Figure 4-8 and Figure 4-9 respectively. The patterns of predicted change are similar to those for the full disposal site, though significantly reduced in magnitude. The changes are only of the order of 2% and are highly localised at the disposal site. The impacts on bed shear stresses are similarly reduced for the half disposal scenario over that of the full disposal scenario.

Figure 4-8: Change in peak flood flow for a MHWS tide due to half disposal at the disposal site

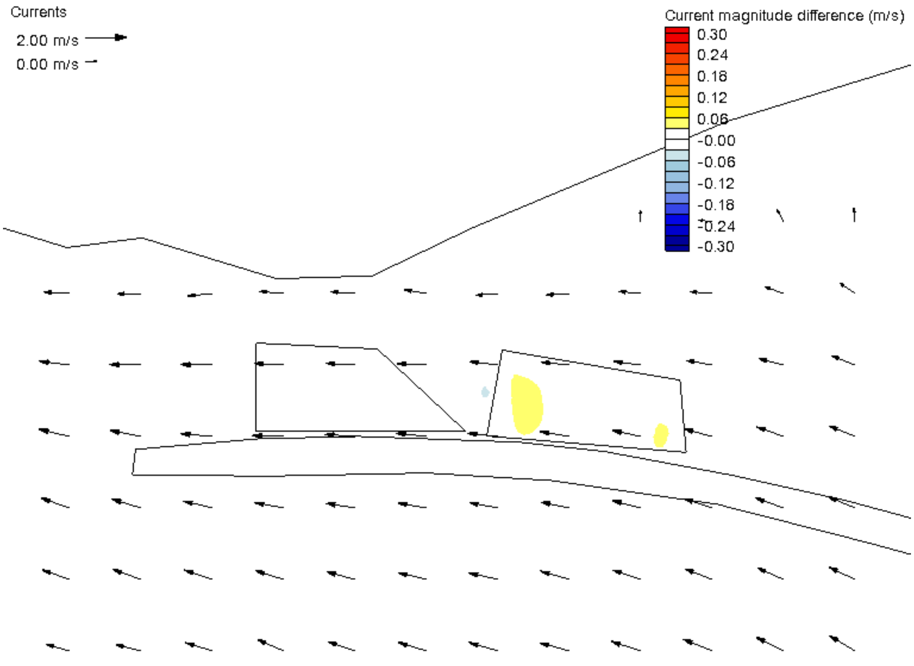
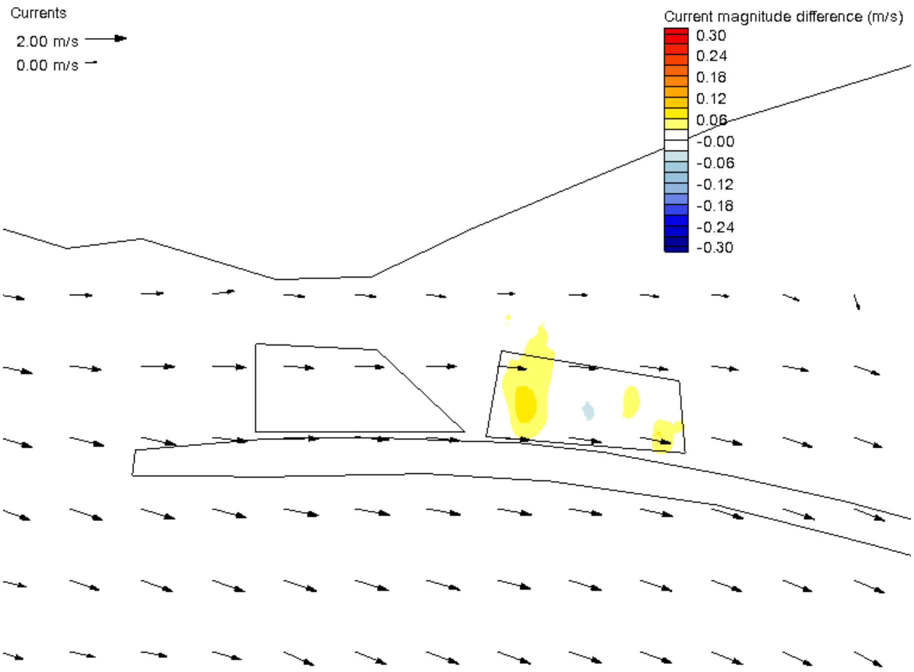


Figure 4-9: Change in peak ebb flow for a MHWS tide due to half disposal at the disposal site



4.4.3 Short-term sedimentary regime

The predicted change to the estuary bed morphology after 18-days (incorporating a Spring-Neap tidal period) for the existing bathymetry is shown in Figure 4-10. A general pattern of erosion is predicted (indicated by the light blue contour), with sediment being shifted towards the less energetic areas of the inter-tidal flats and the shallow spoil grounds of Middle Shoal to the south of the SDC. This general erosion does not extend into the inter-tidal mudflats. The indented nature of the deposition/erosion pattern at the sub-tidal/inter-tidal interface highlights the potential for selective channel development, which is observed along the north bank mudflats.

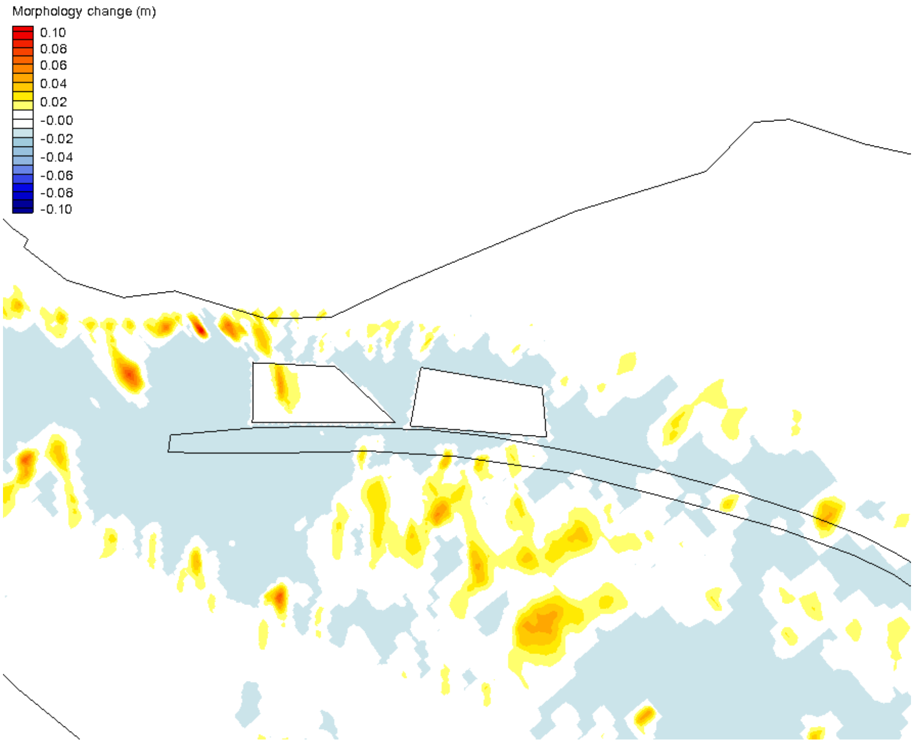
General erosion is predicted throughout the SDC, which is in keeping with the fact that the SDC has required minimal maintenance dredging since 2007[25].

The change after 18 days to this baseline bed morphology due to the full disposal scenario is shown in Figure 4-11. Highly localised scour of the erodible material around the edges of the block of inerodible material is predicted by the model (rounding of the edges of the 'inerodible' material is also likely but not simulated by this model; this effect will involve such small quantities that it would cause negligible impact on the local sedimentary regime). This small quantity of sediment is predicted to settle to the east of the disposal site in the area of reduced current flows. Some sediment is predicted to settle in the SDC. This quantity is small (approximately 4 000 m^3) and will not be substantially added to once the erodible material around the disposal site has been transported away.

The corresponding change due to the half disposal scenario is shown in Figure 4-12. As the impact on currents is greatly reduced over the full disposal scenario, the impact on the sedimentary regime is similarly small. Compared to natural variability and model uncertainty, there is no significant change predicted to the local sedimentary regime.

Though some small deposits of sediment are predicted to accumulate in the SDC, the quantity is negligible compared with historical dredging records[25]. These show that there was only 1 year between 1969 and 2005 where maintenance dredging volumes were below 500 000m^3. Moreover, maintenance dredging requirements resulting from the proposed deepening of the SDC are predicted[26] to similarly dwarf this result, being in the region of 1-8 million m^3.

Figure 4-10: Estuary bed morphology after an 18-day non-cohesive sediment transport simulation, with a 2cm erodible layer specified (existing bathymetry)



[25] ABP (2011) Harbour Master's Report 2011 for the Humber Harbour Area

[26] ABPmer (2009). Immingham Oil Terminal Approach Channel Dredging Environmental Statement. Associated British Ports & Total Lindsey Oil Refinery. Report R. 1416.

Figure 4-11: Change due to full disposal scenario to predicted estuary bed morphology after 18-days

Figure 4-12: Change due to half disposal scenario to predicted estuary bed morphology after 18-days

4.5 Summary of impacts

A summary of the impacts that are predicted for the disposal of the AMEP capital dredge inerodible material at the proposed site are given in Table 4-2.

Table 4-2: Potential impacts on receptors due to the disposal of inerodible material at the proposed disposal site

Relevant receptors	Impact due to disposal of material at proposed site	Information
Inter-tidal areas on estuary north bank	Localised minor impact (north bank inter-tidal area near disposal site), no estuary-wide impact	Two options are appraised: full disposal and a 50% / partial disposal, the latter being the quantity that fills existing depressions in the bed. The change in bathymetry due to material disposal will affect wave direction through changes to the refraction process. For large waves travelling towards the estuary north bank, this will slightly change the existing pattern of wave-induced bed shear stresses at the inter-tidal areas here. The impact is deemed to be minor: in areas of increased wave energy, there will be the potential for development of drainage channels of the form that are observed over the mudflats to the east. This may be a visually significant change, the scale of which would be difficult to predict, however a change to inter-tidal area and volume of sediment is very unlikely. There would be no change in the type of sediment exposed in the area and so no change to habitat. The magnitude of this impact would be greatly reduced if only half of the inerodible material were disposed at HU082.
Sub-tidal and maintenance dredged areas	Minor impact	The change in bathymetry due to the disposed material (full disposal) slightly increases current speeds over the site, and directly to the north and south, by up to 5%. The increase to the north may increase the potential for channel development on the mudflats. Current speeds to the west and east are slightly reduced by up to 5%, which may lead to increased deposition in these areas. The area affected is less than 2% of the area of the Outer Humber Estuary. The change in bathymetry leads to scouring around the edges of the raised bathymetric area. Sediment is deposited to the east of the site, with 4 000m^3 settling in the SDC after 18 days. This volume will not be substantially added to once the thin erodible layer of material adjacent to the disposal site that is scoured away has gone. The impacts for the scenario of half of the inerodible material disposed of at the site are greatly reduced.

5 In Combination Assessment

5.1 Introduction

As part of the Environmental Impact Assessment process, it is necessary to understand potential impacts that could be brought about by a proposal acting in combination with other proposed developments within the study area. The potential 'in combination' impacts on hydrodynamic and sedimentary processes within the Humber Estuary are reported herein. For the 'in combination' assessment, the proposed developments that are considered are:

- Hull Riverside Bulk Terminal (HRBT)[27]: this proposal involves the construction of a jetty with a dredged area to accommodate berthing ships near Hull. Dredging of the entrance to Halton Middle from Whitebooth Road to a depth of -7mCD is proposed;
- Green Port Hull (GPH): this proposal extends the former Quay 2005 proposal at the entrance to Alexandra Dock at Hull. The facility is to include a new quay and dredged berthing pockets;
- Grimsby Ro-Ro berth[28]: this proposal involves the construction of a roll-on roll-off facility at Grimsby Docks, consisting of a floating pontoon, dredged berthing area and approach channel. The berth is to accommodate vessels too large to enter the existing locks at Grimsby;
- Immingham Oil Terminal Approach (IOTA)[29]: this proposal involves a large dredging operation to deepen the SDC and other areas in order to allow passage of larger ships through to the middle estuary;
- EA's flood risk management strategy[30] with numerous managed realignment sites; and
- Routine maintenance dredging[31].

The proposed locations of these developments are highlighted in Figure 5-1.

The EA's Humber Estuary flood risk management strategy includes the provision for constructing numerous managed realignment sites. These are in varying states of design and preparation, and so no specific proposed site has been included in the assessment. However, the qualitative in combination impacts are considered.

An EIA scoping report for Phase IV of the HST facility, involving the dredging of extra berths, was published for consultation in August 2006. However, the application process has not been taken further. Therefore, the proposed development it is not considered here. Also, the deployment of the Neptune Proteus prototype tidal stream generator near to Albert Dock is not considered, given that such a small device would have negligible impact on the estuary-wide physical processes.

The Marine Management Organisation has proposed that the inerodible material arising from the capital dredging associated with the above developments is placed in disposal site HU081, to the west of HU082, the proposed site for the AMEP capital dredge disposal. A disposal volume of 1 336 961m^3 (including a 30% bulking factor) at this site is proposed to account for the likely total volume of inerodible sediment resulting from the capital dredge operations for these developments. This would raise bed levels throughout the site to -5.27mCD, approximately an average rise of 1.6m over an area of 90ha.

An assessment of the potential impacts of these developments in combination with the AMEP proposal is provided in this chapter.

[27] ABPmer (2010) Hull Riverside Bulk Terminal Environmental Statement, ABPmer

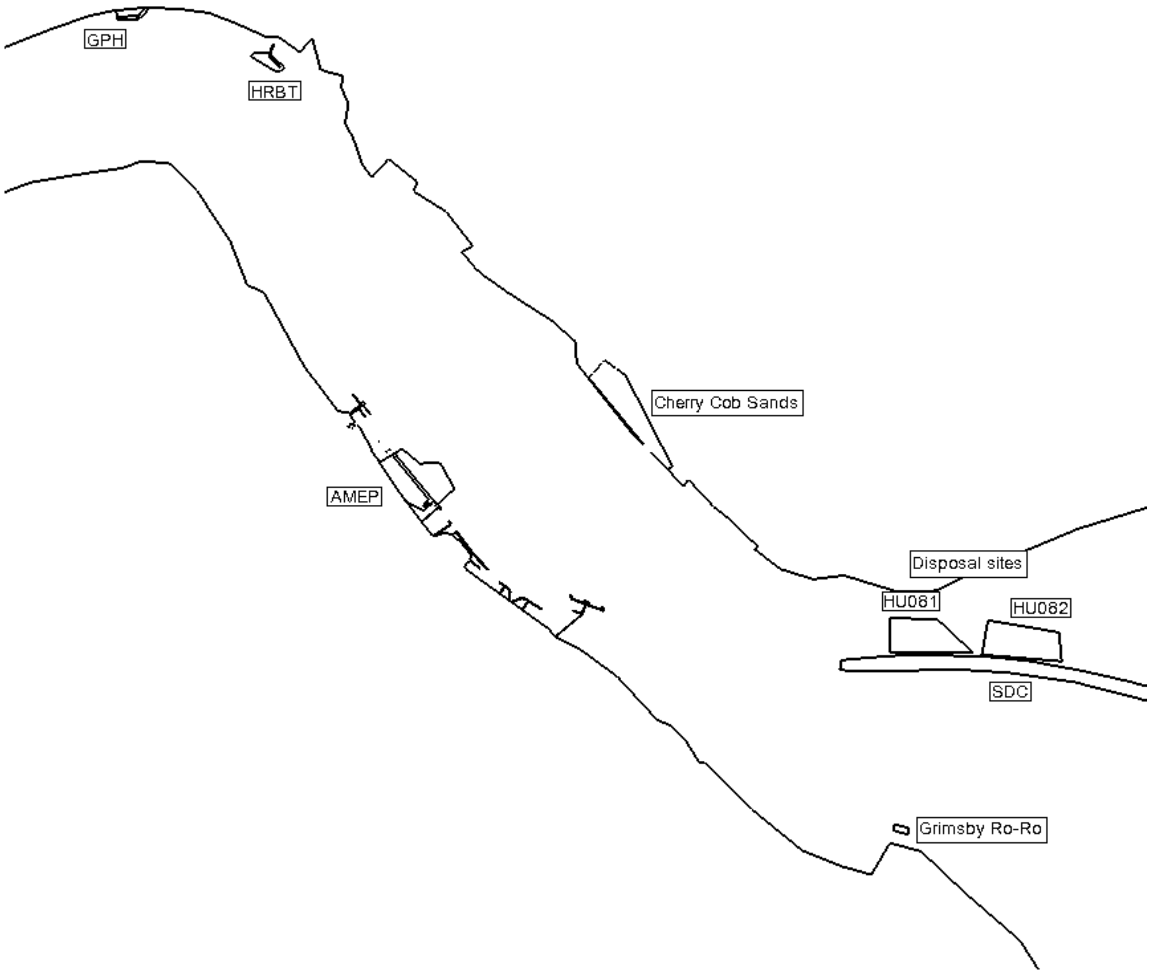
[28] ABPmer (2009b) Grimsby RO-RO Berth Environmental Statement. R.1506. ABPmer

[29] ABPmer (2009a). Immingham Oil Terminal Approach Channel Dredging Environmental Statement. Associated British Ports & Total Lindsey Oil Refinery. Report R. 1416.

[30] Environment Agency (2008) The Humber flood risk management strategy: planning for the rising tides. Environment Agency, Leeds

[31] ABP Humber Estuary Services (2008) Humber maintenance dredging baseline document. ABP Humber Estuary Services, Hull

Figure 5-1: Locations of proposed developments and sites relevant to in-combination assessment



5.2 Summary of existing in combination assessments

5.2.1 HRBT

The in-combination assessment completed for the HRBT development considered the cumulative impacts of HST Phase IV, the Quay 2005 proposal, and the IOTA SDC deepening. The cumulative impact on water levels and tidal range was found to be minor/not significant, characterised by a small decrease in low water levels, leading to an increase in inter-tidal area of 1.8ha between Grimsby and Ferriby Sluice, caused by the HRBT alone. No impacts on surge levels were predicted.

In terms of currents, the effects were deemed to be localised to each development and no impact was predicted estuary-wide.

The in combination impacts on sedimentary regime were found to be dominated by the HRBT, and very localised to the development. Though the impacts were found to be minor adverse locally, generally the pattern of coarse sediment transport was predicted not to change. The impacts of the highly localised and small changes to suspended sediment concentrations were found to be insignificant estuary-wide, when compared to the background variability.

In summary, it was determined that the inclusion of the additional developments made little difference to the impacts caused by the HRBT alone.

5.2.2 Grimsby Ro-Ro

With regards to the estuary hydrodynamics and sedimentary regime, a specific in combination modelling exercise was not undertaken. This was because the Environmental Statement (ES) found that the extent and magnitude of the impacts from the relatively small Ro-Ro development were insignificant compared with those of the other developments (IOTA and HRBT).

5.2.3 IOTA

The in combination assessment provided in the IOTA Environmental Statement found that there was little evidence of any significant interaction between the proposed developments (HRBT, Quay 2005 and Grimsby Ro-Ro). No changes to water levels were predicted and changes to low water levels were found to be local to the HRBT. Impacts to sedimentation patterns were predicted to be focussed around the vicinity of the individual schemes. Predicted changes in the estuary were found to be dominated by the HRBT. Overall, due to the large background variability, the cumulative effects of all the considered schemes were found to be minor.

5.2.4 GPH

The in-combination assessment for GPH was the only one to include a representation of the AMEP proposal. However, their assessment assumed the preliminary design of the quay, which exhibited a larger footprint in the estuary than the submitted proposal. The effects of the Grimsby Ro-Ro development were considered to be minor and highly localised, and were therefore not considered in the estuary-wide in combination assessment.

The assessment predicted that, without the preliminary AMEP design, all of the proposed developments (GPH, HRBT, HST Phase IV, IOTA) would lead to a minor cumulative impact on water levels. The low water level was predicted to reduce by 0.8cm between Grimsby and Ferriby Sluice, resulting in a minor increase in inter-tidal area of 1.8ha. This small/negligible change in water levels was considered to represent a minor adverse impact with respect to sub-tidal habitats and a minor beneficial impact with respect to inter-tidal habitats. It was speculated that the AMEP would neutralise this change in water levels. No impacts on surge levels were predicted.

The in-combination assessment for all developments excluding AMEP, predicted a minor cumulative impact in flow speeds in the Middle Estuary (between Hull and Immingham). This would take the form of a small reduction in flow speeds, which would be beneficial or adverse depending on the receptors it would affect.

Note: This is contrary to the findings of the HRBT Environmental Statement in combination assessment, which found no large scale impact. However, this used the Quay 2005 proposal instead of the GPH proposal.

Inclusion of the preliminary AMEP was postulated to lead to an overall increase in flow speeds throughout the Middle Estuary, due to the narrowing of the estuary brought about by the AMEP. Given that this increase was predicted to occur in an area of substantial recent natural bed movement, the cumulative impact was assessed to be moderate adverse, with the potential for greater longer-term instability of the estuary bed.

In terms of the sedimentary regime, the Middle Estuary was predicted to exhibit potentially increased bed stability as a result of the developments excluding the preliminary AMEP. This was assessed to be a minor beneficial impact, with the minor adverse impact of potential increases in dredging requirements at Halton Middle. With the preliminary AMEP included, increased bed mobility was predicted for the Middle Estuary, which was classified as an adverse impact leading to large uncertainty in longer term impacts.

In summary, excluding the AMEP, the developments were predicted to lead to a minor impact on the estuary, with the greatest impact due to the HRBT development. With the preliminary AMEP included, the cumulative adverse impact was considered to be moderate, albeit with large uncertainty.

5.3 Assessment methodology

The modelling assessment has been performed using the models and methods described in the previous chapters, developed in JBA2011, for the relevant hydrodynamic and short-term sedimentary processes. In order to assess the cumulative impacts of the proposed developments, the outputs from the following model scenarios were compared:

- In combination: AMEP quay and dredge area, Cherry Cobb Sands compensation site, **full** disposal at HU082, GPH, HRBT, Grimsby Ro-Ro, IOTA, disposal at HU081;
- AMEP alone: AMEP quay and dredge area, Cherry Cobb Sands compensation site, **full** disposal at HU082

* Existing conditions.

5.4 Impacts

5.4.1 Waves

All in combination developments are sufficiently small (at an estuary scale) and distant to each other, that there will be no cumulative change to the wave climate as a result of their construction.

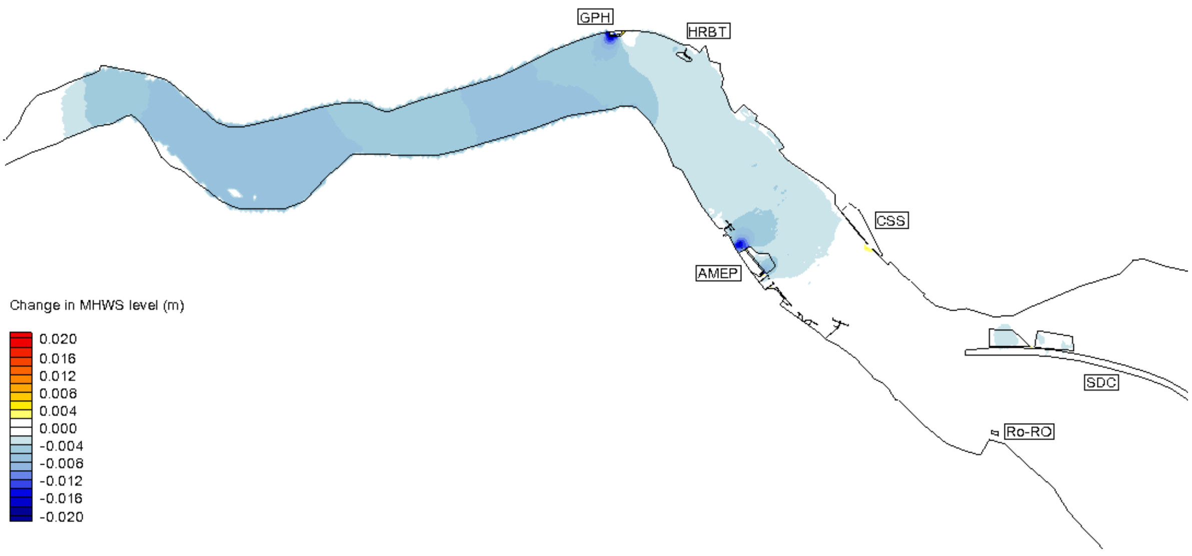
5.4.2 Hydrodynamics

The predicted change to MHWS levels due to all proposed developments is shown in Figure 5-2. The GPH and HRBT lead to reduced levels upstream of 5mm. The GPH and HRBT Environmental Statements do not report such changes in high water level (negligible change is predicted), highlighting the differences that can arise depending upon which validated hydrodynamic model is used. Consideration of model uncertainty, estimated to be ±10mm for water levels, has to be recognised when interpreting the model results.

The estuary-wide change to MLWS levels due to all developments is less than +2mm. Again, this result differs from the results of the GPH in combination assessment, which reports a change of -8mm between Grimsby and Ferriby Sluice. The differences are due to different models being used and, once again, highlight the need for caution when interpreting very small changes predicted within any particular model.

Given that the predicted changes are within model uncertainty bounds, the modelling predicts negligible change to water levels due to all proposed developments acting in combination.

Figure 5-2: Change in MHWS level due to in combination developments



For all developments acting in combination the change in peak MHWS flood and ebb currents are shown in Figure 5-3 and Figure 5-4. The dredged areas of the AMEP, GPH and HRBT all lead to reductions in currents from the baseline. Areas of constriction lead to increased currents. These are the area between the GPH quay and the south bank, the AMEP quay and the north bank, the entrance to CSS and the raised bed levels at the two disposal sites. The increase in speeds at GPH of approximately 5% is the same magnitude as that reported in the GPH Environmental Statement[32]. However, given that a different model has been used for this study,

[32] ABPmer (2011) Green Port Hull Environmental Statement. ABPmer

which has gone through a separate calibration and validation process, the representation of hydrodynamics will not be exactly the same.

The in combination assessment in the GPH Environmental Statement reports that, with all developments except the AMEP, there is a small estuary-wide decrease in flow speeds. It is reported that, with the preliminary AMEP design, this impact becomes a cumulative increase in flow speeds in the Middle Estuary. In the present study, the AMEP-only model simulation predicts an average increase of 0.01m/s in peak MHWS flow currents, from the edge of the AMEP dredge area to approximately three quarters of the distance towards the north bank. This is due to the narrowing of the estuary resulting from the presence of the quay. When the in combination developments are included, this increase reduces to zero. This result is consistent with the findings of the GPH Environmental Statement, given that the final AMEP quay has a smaller 'footprint' than that of the preliminary design assessed in that report.

In summary, the increase in current speeds due to AMEP is offset by the reduction in current speeds due to the other developments. Therefore, in terms of the estuary-wide impacts on currents from all developments in combination there is negligible change and no impact.

The in combination current impacts near to the Halton Middle gas pipelines are characterised by a small decrease due to the HRBT dredged area. This will give a minor beneficial impact, potentially offsetting observed erosion at this location.

The impacts of changes at the disposal sites north of the SDC are assessed in section 5.5.

Figure 5-3: Change in peak MHWS flood currents due to all developments acting in combination

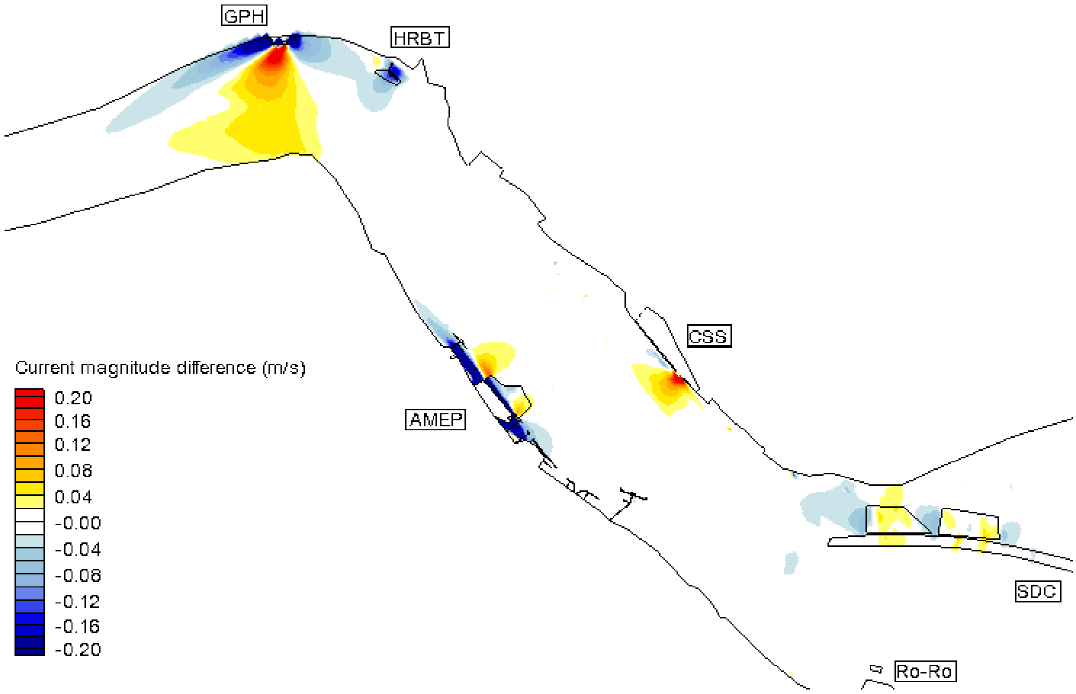
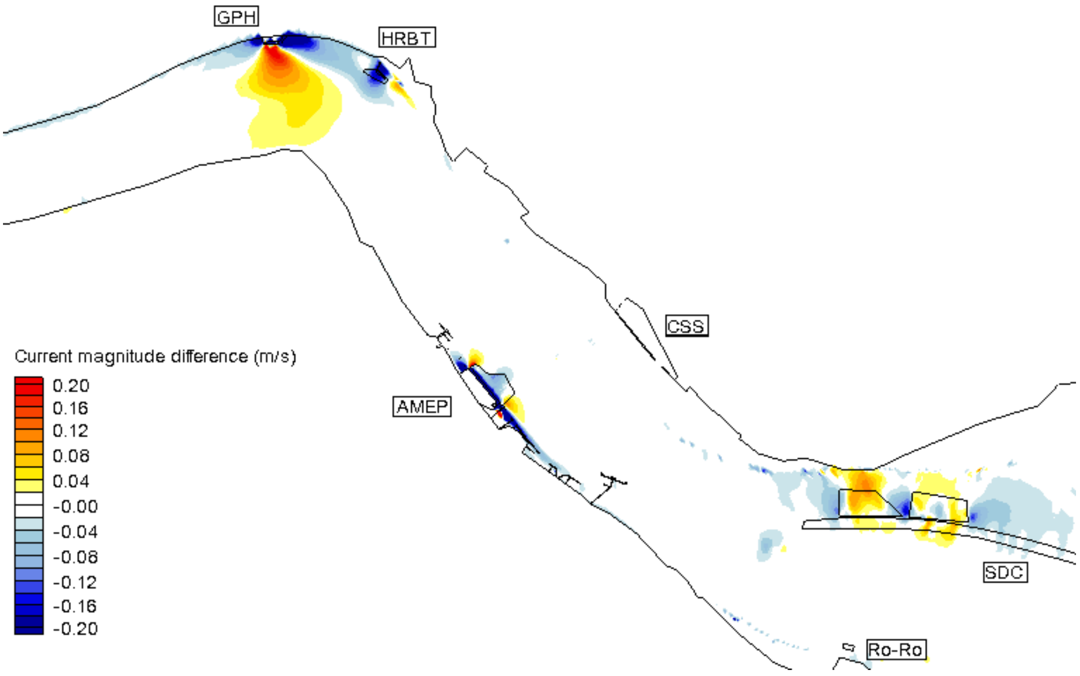


Figure 5-4: Change in peak MHWS ebb currents due to all developments acting in combination



In terms of estuary-wide water levels, the in combination impacts of the potential construction of managed realignment sites are most likely to be dominated by such sites. This is due to the expansion of the inter-tidal area provided by such sites. Therefore, the impacts will be beneficial in terms of providing more inter-tidal area and habitats, and helping to offset potential sea level rise and the consequential increase in flood risk.

Changes to flow regimes due to such sites will be local to the site entrance; an estuary-wide impact on currents will be negligible.

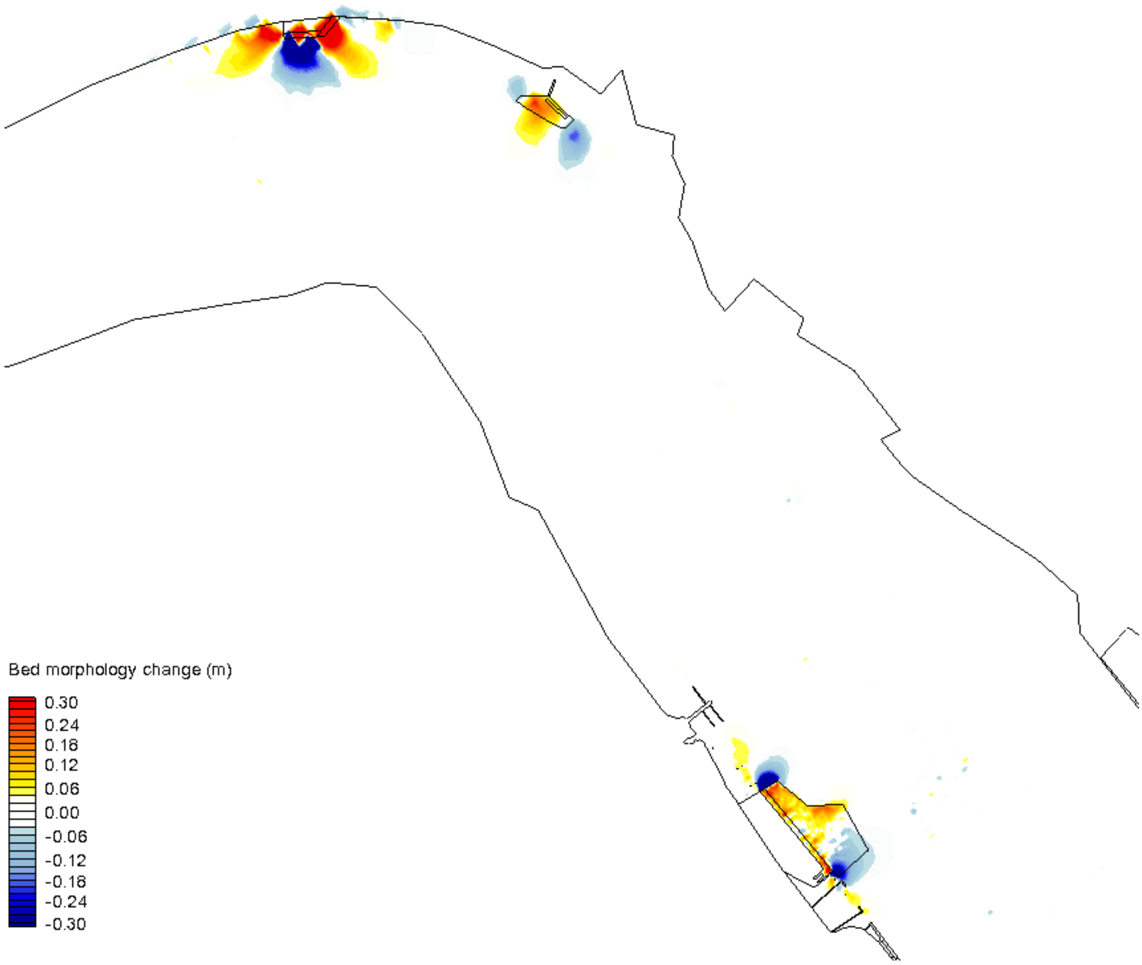
5.4.3 Short-term sedimentary regime

The predicted estuary bed change due to all in combination developments after an 18-day non-cohesive sediment transport model simulation is shown in Figure 5-5. This model simulation assumed a median grain size of 0.1mm (typical sand-sized grains) and a 1m deep erodible layer in the Middle Estuary and upstream (see JBA Consulting (2011b)). The Outer Estuary was assumed to be largely inerodible (a 2cm thick erodible layer was specified here). The model shows that short-term bed change is localised to each individual development, with deposition resulting in the berthing areas and potential scour around these due to flow being drawn towards the deeper pockets.

The type of sediment transport model used here is not suitable to be used to predict the longer term sedimentary regime, due to the massive uncertainties involved in the technique. The longer term impact can be inferred from the potential changes to the current regime. As the cumulative impact on currents in the Middle Estuary is negligible, it follows that there will be negligible impact on bed stability and natural morphology change due to all in combination developments.

Changes to flow regimes, and therefore the sedimentary regime, due to additional managed realignment sites will be local to the site entrance; an estuary-wide impact on the sedimentary regime will be negligible.

Figure 5-5: Change in bed level after 18 days for in combination developments



5.5 Impacts at disposal sites

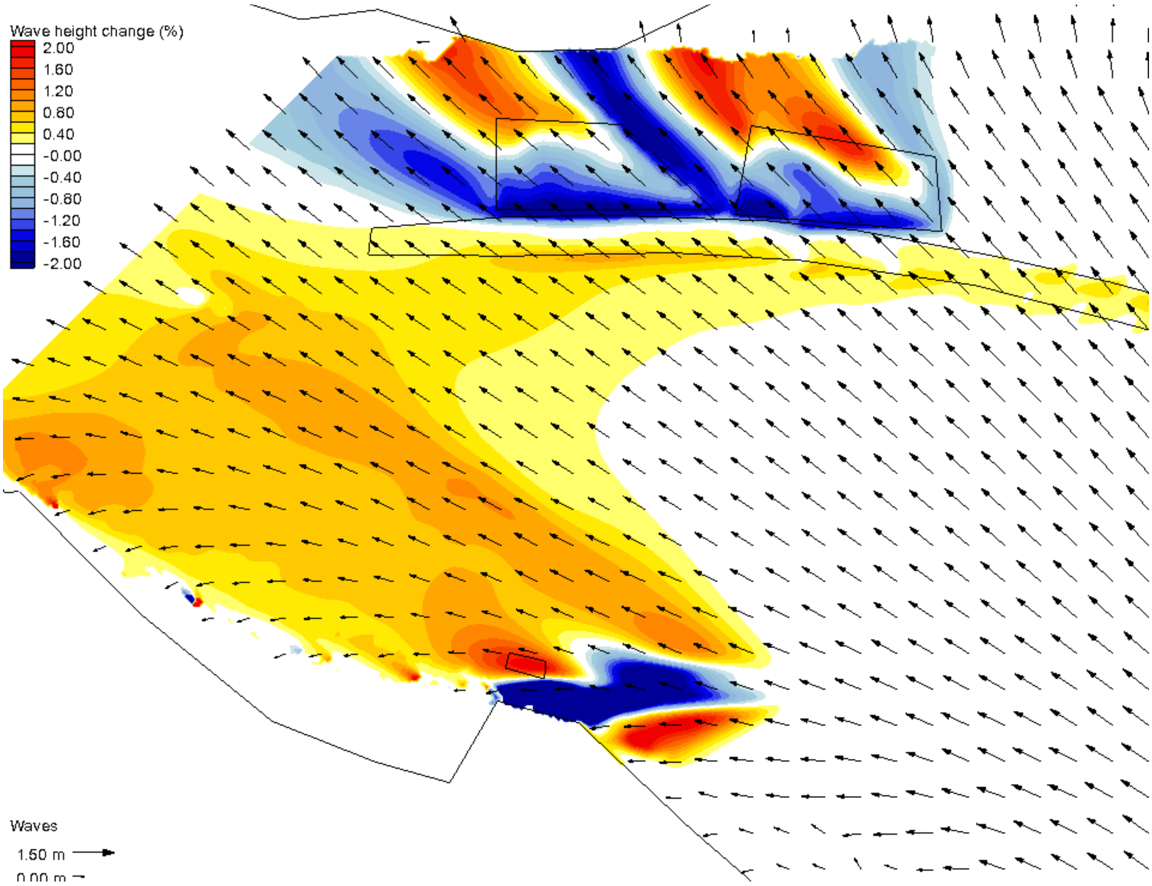
5.5.1 Waves

The potential change in wave heights due to full disposal of AMEP material at the HU082 disposal ground, disposal of in combination material at the HU081 disposal ground, and dredged areas of the SDC (immediately south of the disposal sites) and Grimsby Ro-Ro berth (close to the south shore) approach is shown in Figure 5-6. This is for a 1m significant wave height, of 4s period travelling from the south east at a water level of 0mOD (refer to section 4.3.1 for more information on wave climate here).

The magnitude of the impact on waves reaching the north shore inter-tidal areas is greater than for the AMEP full disposal scenario alone (Figure 4-4). This is due to the greater change in bathymetry from the in combination disposal at HU081 and the deepening of the SDC. The magnitude of potential change is of the order of 2-3% for this water level; this will increase with lower water levels and decrease with higher water levels (section 4.4.1). The impact will be an increase in the potential for channel development on the mudflats to the north, of greater magnitude than that due to the AMEP-only disposal at HU082 (section 4.4.1).

The wave climate over the Outer Humber Estuary is slightly affected by the Grimsby Ro-Ro berth dredged area. These changes are unlikely to affect bed mobility in the deeper areas of the estuary, but potentially may impact upon inter-tidal morphology on the south shore.

Figure 5-6: Percentage change in wave heights due to full disposal of AMEP inerodible material at the proposed disposal site (HU082), in combination development disposal at HU081, and increased depth areas of the SDC and Grimsby Ro-Ro approach



5.5.2 Hydrodynamics

Changes to local water levels at the disposal sites are negligible.

The changes to peak MHWS flood and ebb currents due to the in combination developments (AMEP full disposal at HU082, in combination disposal at HU081, SDC deepening) are shown in Figure 5-7 and Figure 5-8 respectively. Increases in flow speed are observed over the disposal sites where the bed levels have been raised, reducing the cross sectional area through which tidal water travels. The areas to the sides of the raised bed levels, representing areas of cross-sectional area expansion, are characterised by reductions in flow speeds. The magnitudes of change can reach 5%.

In the AMEP full disposal only scenario, increases in current speed in the vicinity of the disposal site can extend north onto the edges of the inter-tidal mudflats (section 4.4.2). The change in the flow regime brought about by the additional change in bathymetry, due to the in combination developments disposal at the HU081 site, appears to mitigate this impact. However, the model suggests that increases in currents to the north of the in combination disposal site may reach the inter-tidal areas around Hawkins Point. This will increase the potential for channel development on the mudflats here. The magnitude of the impact will be very difficult to predict. The decrease in flow speeds to the east and west of the disposal sites may lead to increased sedimentation in these areas.

Figure 5-7: Change in peak MHWS flood currents due to in combination developments at the disposal grounds

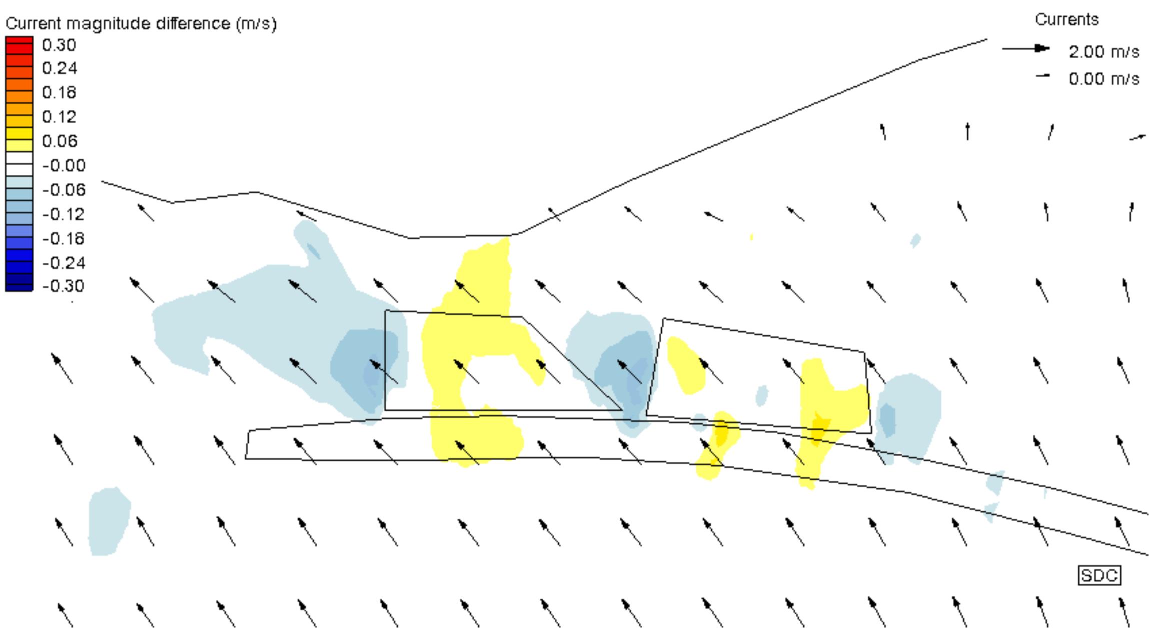
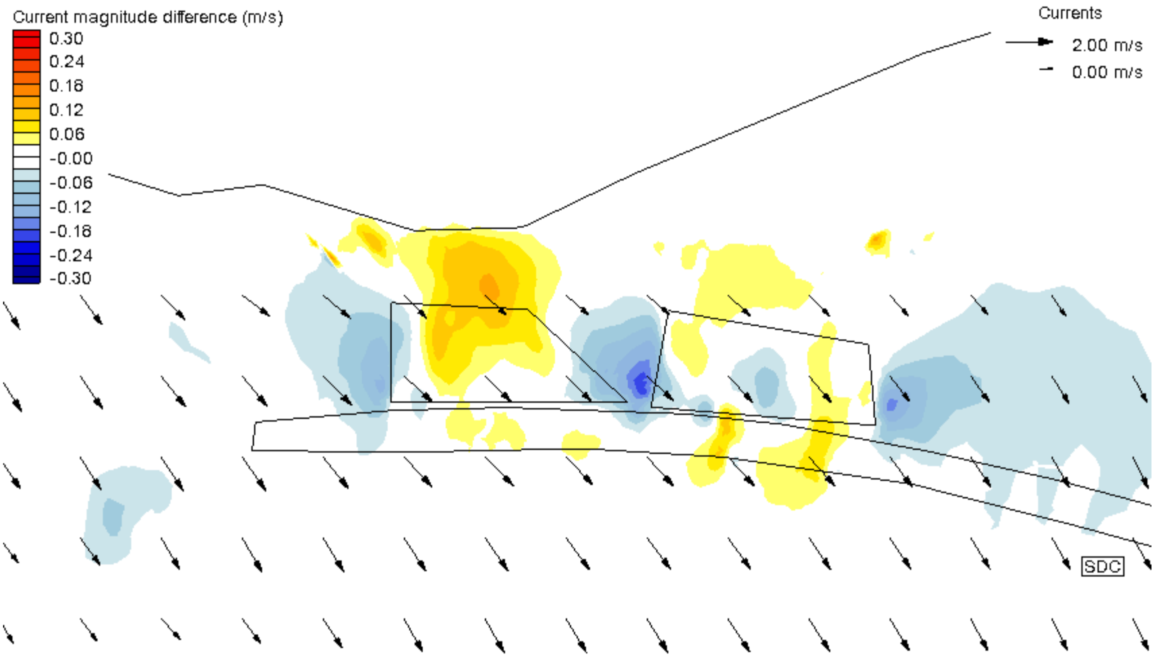


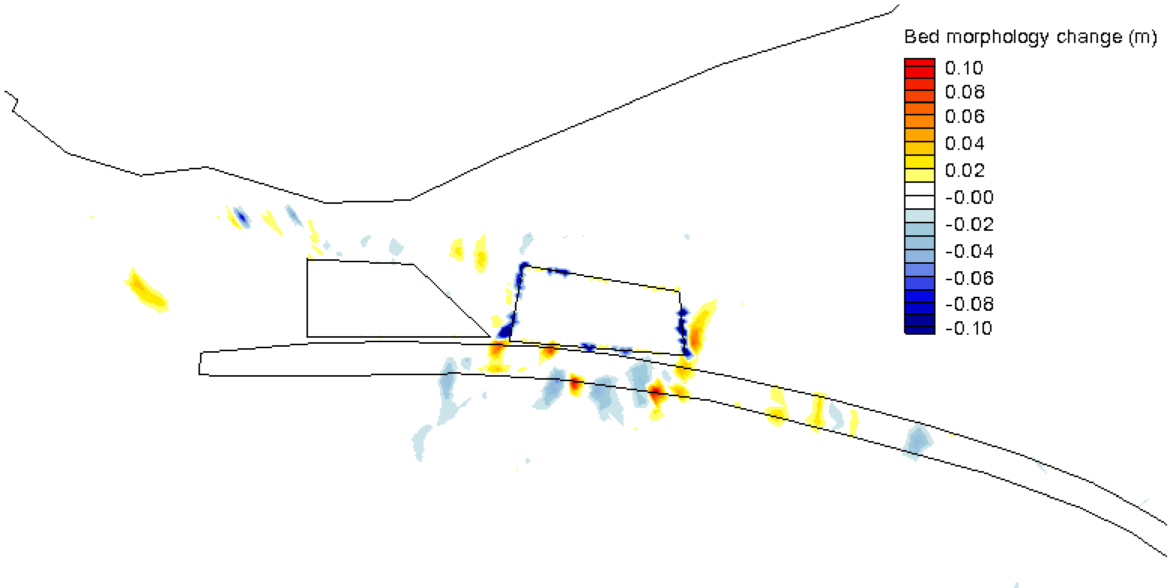
Figure 5-8: Change in peak MHWS ebb currents due to in combination developments at the disposal grounds



5.5.3 Short-term sedimentary regime

The predicted change to bed levels due to the in combination developments (AMEP full disposal at HU082 is simulated) around the disposal sites after 18 days is shown in Figure 5-9. These changes are due to a model simulation that assumes the estuary bed is inerodible below 2cm, with a top layer of non-cohesive sand sized sediment. Given that there is considerable uncertainty in the depth of the actual erodible layer and cohesiveness of the sediment in the area (the inter-tidal area to the north is characterised by mudflats) the results should be interpreted with considerable uncertainty. Changes are similar to those due to the AMEP full disposal alone (Figure 4-11). There is an increase in the material deposited within the SDC; a result that is consistent with the findings of the IOTA Environmental Statement, which states that the SDC deepening will lead to increased sedimentation within the channel. There are no patterns of large scale change predicted; rather the model suggests localised shifting of non-cohesive material.

Figure 5-9: Change in bed level after 18 days due to in combination developments at the disposal sites



As described, the results of the sediment transport modelling should not be taken in isolation, due to the uncertainties involved in the method. The predicted changes to the hydrodynamic processes infer impacts on the sediment regime that are not captured by the model, likely due to model limitations. In general, the in combination cumulative impacts at the disposal sites appear of a slightly larger magnitude to those due to the AMEP full disposal only scenario. This appears to be due to the addition of the bathymetric change at the HU081 disposal site, as well as the presence of a deeper SDC.

5.6 Summary of in combination impacts

A summary of the potential impacts that are predicted for in combination developments is provided in Table 5-1.

Table 5-1: Potential impacts on receptors due to in combination developments

Relevant receptors	Impact due to AMEP quay and dredge areas	Information
North bank inter-tidal area around Hawkins Point	Localised minor impact (north bank inter-tidal area near disposal site), no estuary-wide impact	The changed bathymetry due to the in combination developments in the Outer Humber Estuary (AMEP full disposal at HU082, in combination disposal at HU081, SDC deepening) will lead to very small changes in the wave climate (due to wave refraction), which will lead to a minor localised impact on inter-tidal morphology. This is likely to take the form of localised change across affected soft sediments with channelling possible. The mudflats around Hawkins Point will be subject to potential change in the form of channel development. Any potential new morphology will likely mimic the channels of the mudflats farther to the east.
Estuary-wide inter-tidal areas	No impact	Changes to water levels due to the proposed developments acting in combination are within model uncertainty bounds, and therefore no change is predicted. Potential decreases in current speeds in the Middle Estuary due to all other developments (except the AMEP quay) are offset by potential increases due to the quay. The cumulative impact of all in combination developments is negligible (all impacts are local to each development).
Sub-tidal areas	No impact	The cumulative change to current speeds in the Middle Estuary is negligible and this means that the potential impact on bed

		morphology here is also negligible. In general, in the sub-tidal area, the in combination cumulative impacts at the disposal sites are no greater than those due to the SDC deepening and AMEP full disposal individual impacts.
Gas pipelines near Halton Middle	Minor beneficial impact	The small reduction in current speeds due to the HRBT contribution may be of beneficial impact to the gas pipelines, potentially increasing bed stability and halting the currently observed erosion here.

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