

Annex 4.4

Consideration of the Main Design Alternatives


(Able UK)



ABLE MARINE ENERGY PARK CONSIDERATION OF THE MAIN DESIGN ALTERNATIVES

NOVEMBER 2011

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APPROVAL & REVISION REGISTER

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Checked by:	R.Cram		24/11/2011
Approved by:	R. Cram		28/11/2011

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1 INTRODUCTION

1.1 GENERAL

1.1.1 This report has been produced in accordance with The Infrastructure Planning (Environmental Impact Assessment) Regulations 2009 Schedule 4 Part 1 Section 18, to record;

"(a)n outline of the main alternatives studied by the applicant and an indication of the main reasons for the applicant's choice, taking into account the environmental effects."

1.1.2 It is noted that the Regulations do not compel an applicant to consider a range of alternative designs and assess each before adopting whichever has the least environmental effect; the obligation is limited to the reporting of the main alternatives that have been considered and the main reasons for the applicant's choice.

1.1.3 The alternative designs considered for the compensation site are discussed in Volume 2 of the Environmental Statement (ES).

1.2 SITE LOCATION


1.2.1 The proposed development is located in an area known as Killingholme Marshes on the south bank of the Humber Estuary between the Humber Sea Terminal (HST) and ABP Immingham Port. It is approximately 2 km from the village of North Killingholme to the west, and 3.3 km from Immingham to the south. The boundary of the site lies partially within the Humber Estuary, which is protected under both national and European law, including the EC Habitats Directive (92/43/EEC).

1.2.2 The site comprises the following development areas:

- Existing terrestrial land - 270 ha
- Existing intertidal area - 31.5 ha
- Existing subtidal area - 13.5 ha

1.2.3 The western boundary of the development is defined by Rosper Road, which provides direct access to the A160, part of the trunk road network. Beyond Rosper Road lies the Total Oil Refinery and Conoco Philips refinery and combined Heat and Power Plant. The eastern boundary of the existing territorial area is marked by the existing flood defence wall, beyond which lies the Humber Estuary.

1.2.4 The intertidal and subtidal areas are located within the Humber Estuary and extend from the existing tidal defences to the edge of the deep water channel that serves the HST.

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2 QUAY: FORM OF CONSTRUCTION

2.1 INTRODUCTION

2.1.1 The total quay frontage will be 1 279 m in length and will be aligned outside the western edge of the existing dredged channel that provides access into HST. The quay will be a solid berth structure with a combi-pile front wall. The tubular piles will be tied back with flap anchors that fix the piles in position near their top. This front wall will return at the southern end of the quay and tie into a rock revetment that will extend from the line of the existing flood defences.

2.1.2 A piled relieving slab will be constructed behind the front wall and will enable a range of plant including large dock cranes, up to 1 600 tonne capacity, to operate anywhere on the quay.

2.2 ALTERNATIVE QUAY DESIGNS

Fitness for Purpose

2.2.1 It is axiomatic that the design needs to be fit for the purposes of the marine energy sector. Whilst this is an emerging sector, it is already characterised by large, heavy components that require heavy lift transporters and substantial cranes to manoeuvre them. It is also evident that the sector requires extensive laydown areas close to quays for storage and pre-assembly prior to export. These considerations have significantly influenced the choice of quay design.


Yorkshire Forward Studies 2009

2.2.2 Alternative quay configurations for the site were initially studied in 2009 by Mott MacDonald, on behalf of Yorkshire Forward and were informed by discussions with potential investors. Initially suspended finger piers and jetties were considered. The benefit of a pier and jetty arrangement, illustrated in *Figure 2.1 (AME-01152 A)*, is that it would reduce the direct loss of the existing mudflat and subtidal habitat. The retained habitat may however lose its functional value as a food larder for the SPA assemblage given the level of disturbance that might arise.

2.2.3 These narrow structures are not, however, fit for the purposes of the offshore sector, as they provide very limited space for the transport, manoeuvring, handling and pre-assembly of OWTs, and for the laydown of large and heavy products being imported and exported. For these practical reasons it was discounted.

2.2.4 To address the need to provide large areas adjacent to the berths, a suspended slab was considered. The benefit of this arrangement, illustrated in *Figure 2.2 (AME-01153 B)*, is that it would prevent the actual loss of the existing mudflat and subtidal habitat below the suspended quay. The habitat would however lose its functional value to both flora and fauna given that it would be in permanent shade.

2.2.5 As the quay must support heavy mobile plant and that plant will need to operate over wide areas of the quay, the design loads for the suspended quay will be very significant, around 20T/m². A suspended deck does not therefore provide a commercially viable form of construction over such a large area.

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2.2.6 Reclaiming land from within the estuary is the only viable means of providing a facility suitable for the offshore energy sector.

2.3 ALTERNATIVE QUAY LAYOUTS

2.3.1 Alternative quay alignments have been subject to assessment using hydrodynamic computer modelling. Estuaries are complex systems and such models help to inform decision-making but are unlikely to predict environmental impacts precisely; professional judgement is also necessary.

2.3.2 Initial hydrodynamic modelling undertaken by JBA Consulting demonstrated that the impacts of the Project on the Estuary were relatively local to the new quay. The most significant local impact was a change to the local sedimentary regime that gave rise to the potential for significantly increased maintenance dredging at nearby berths.

2.3.3 Alternative quay alignments have therefore been considered to balance the following considerations:

- Capital dredging works.
- Maintenance dredging works at the new quay
- Minimising adverse changes to sedimentation patterns at nearby berths.
- Changes to accretion patterns in the vicinity of the existing outfalls and intakes.

2.3.4 Initial hydrodynamic studies by JBA Consulting used a non-cohesive sediment transport model to assess the impact of the project on maintenance dredging. These preliminary studies were based on a quay alignment that followed a line connecting the South Killingholme Oil Jetty to Berths 5 and 6 at Humber Sea Terminal ('the preliminary layout'), as illustrated in drawing AME-05017, refer to Annex 1.

2.3.5 Whilst the bed of the Humber Estuary comprises a broad range of material from muds, to sands and cobbles and also in some areas chalk bedrock, the non-cohesive sediment transport computer programme is limited to having a single median grain size within the model. In order to understand the sensitivity of the model to this specific parameter, computations were undertaken with five alternative grain sizes for the estuary bed; 0.3 mm, 0.2 mm, 0.15 mm, 0.1 mm and 0.075 mm. Generally, as the grain size reduces, the maintenance dredge requirement increases. To avoid generating transparently unrealistic results for the lowest grain size modelled using this particular model, the estuary bed was defined as non-erodible at a depth of 10 cm with the 0.075mm grain size.

2.3.6 The predicted increases in annual maintenance dredge volumes determined from the non-cohesive transport model are detailed in Table 1.

Table 1: Predicted Increases in Annual Maintenance Dredge Volumes (m³) due to the Preliminary Quay Design (refer to drawing AME-05017), **Using a Non-Cohesive Computer Model**

DREDGING LOCATION	D50= 0.075mm	D50= 0.1mm	D50= 0.15mm	D50= 0.2mm	D50= 0.3mm
HST berths	320 000	110 000	80 000	27 000	20 000
South Killingholme Oil Jetty	0	0	0	0	0
Immingham Gas Jetty	26 000	2 800	2 700	700	600
Humber International Terminal	17 000	4 400	3 200	1 200	1 100
Immingham Bulk Terminal	16 000	5 600	2 500	1 400	700
AMEP approach area & berths	720 000	1 300 000	800 000	430 000	280 000

- 2.3.7 The model results showed a high risk of a significant increase in maintenance dredging at two receptors to the north of AMEP; HST and the power stations' cooling water plant. To mitigate this effect, JBA Consulting investigated the benefit of introducing a large chamfer at the north end of the quay to determine whether this would significantly improve flows around the quay and thereby reduce the impact of sedimentation at these receptors. Their assessment is included in Annex 2 of the report. The modelling indicated that the chamfer would give rise to a significant benefit compared to the preliminary quay design. It also showed that incorporating a narrow suspended quay at the northern end of the solid quay reduced the potential benefit of the chamfer, though still offered an improved outcome compared to the original layout.
- 2.3.8 Further analysis of the original quay layout with the suspended deck was reported by JBA and concluded that it would still have a 'negative impact' on the power stations' infrastructure, refer to Annex 3.
- 2.3.9 In order to assess the potential for mitigating predicted adverse effects on the power stations' infrastructure by setting the quay face closer to the land, JBA Consulting further modelled the quay at both 15m and 30 m west of its position in the preliminary layout so that it did not project as far into the estuary. In both cases the solid quay was modelled,
- with a 200 m chamfer and,
 - with a 200 m chamfer and a narrow suspended section of quay.
- 2.3.10 The results of this assessment are reported in Annex 4. The analysis concentrated on model predictions of bed shear stress levels throughout the tidal cycle. Briefly, where bed shear stress values are below 0.2N/m², deposition will occur; where they are above 0.5N/m² erosion will occur. In all quay configurations, the period of time that bed shear stress levels exceeded 0.5N/m² reduced significantly whilst periods of potential sedimentation (where the local shear stress dropped below 0.2N/m²) showed less change. The overall conclusion reached was that,

"(t)he results suggest only local and short term potential sedimentation regardless of quay design, at worse there should only be localised sedimentation at the E.ON outfall for a short period around the neap tide. Conditions 30 m offshore from the intakes/outfalls are

conductive to keeping fine material in suspension exhibiting considerable excess shear stress beyond that needed to mobilise unconsolidated fine sediment. However, it should be remembered that the spatial pattern of shear stress shows a sharp reduction in the vicinity of the intakes/outfalls (see JBA File Note 17). Hence the shear results are sensitive to the accuracy of the modelling process around the intakes and outfalls and will be influenced by the model resolution and the assumption of a fixed bathymetry across the area. Potential shoreline sedimentation in the vicinity of the proposed quay will cause a change in the shear stress pattern across the area and will result in changes in the shear stress predictions around the intakes and outfalls made above”.

- 2.3.11 The alternative that resulted in the least impact on sedimentation process had the quay alignment set back 30 m relative to the preliminary layout and incorporated a chamfer on its northern elevation. This is illustrated as *Iteration 1* on drawing AME-05017, refer to Annex 1.
- 2.3.12 Following a technical review of the non-cohesive modelling by HR Wallingford, it was decided that a cohesive transport model was also needed to improve understanding of the impacts of the quay on nearby berths and infrastructure. HR Wallingford subsequently undertook this non-cohesive modelling ('mud modelling').
- 2.3.13 Mud modelling was initially undertaken on the configuration illustrated as *Iteration 2* on drawing AME-05017, refer to Annex 1; quay setback 30 m relative the preliminary layout, chamfer and suspended quay. The capital dredge for this option is estimated to be 1.7M m³. The modelling predicted the changes to maintenance dredge requirements that are detailed in Table 2.

Table 2: Existing and Predicted Changes to Annual infill Estimates for Design Iteration 2, Using a Cohesive Sediment Transport Model (Dry Tonnes/year)

Location	Existing (No development)		Change (with development of Iteration 2 design)	
	Lower Estimate	Upper Estimate	Lower Estimate	Upper Estimate
Humber Sea Terminal	204 800	540 000	6 000	17 000
AMEP Berthing Pocket	-	-	239 200	640 000
AMEP Dock	-	-	16 800	44 000
AMEP Chamfer Pocket	-	-	87 600	241 000
Region Inshore of Power Station Infrastructure	-	-	143 200	381 000
South Killingholme Oil Jetty	44 400	135 000	29 200	80 000
Immingham Gas Terminal	29 600	83 000	22 800	60 000
Humber International Terminal	290 000	771 000	48 000	135 000
Immingham Bulk Terminal	512 000	1 356 000	-34 800	-71 000

Note: 1 Dry Tonne = 2m³

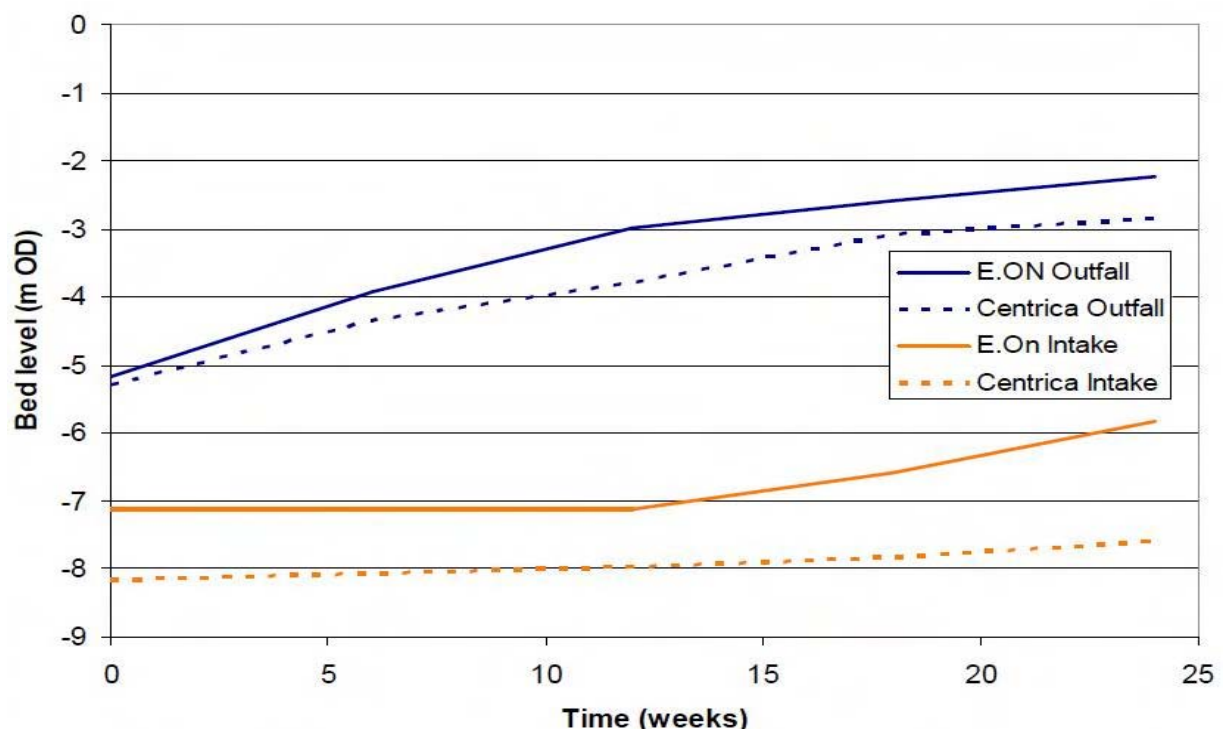
2.3.14 The assessment of this design also found:

- significant deposition accumulating over both power station outfalls, but little deposition over the intakes;
- reduction in suspended sediment concentrations at the intakes, and
- by reference to the HIT reclamation site downstream of AMEP and using professional judgement, a potential increase in bathymetric levels to the north of the quay over an area of 10-15 ha.

2.3.15 In order to improve understanding of the longer term morphological change along the routes of the power stations' infrastructure, the sediment transport model was run for an extended duration with the model bathymetry updated iteratively. Predictions of bed levels were thus obtained for conditions pertaining 24 weeks after construction (the model assumes the construction is instantaneous).

2.3.16 The long term modelling predicted accretion at the Centrica and Eon outfalls of 2.5 m and 2.9 m respectively; at the intakes the accretion was assessed to be 0.5 m and 1.3 m respectively. The model showed the intertidal areas to be still accreting at the end of the 24 week period. This is illustrated in Figure 2.3 below.

Figure 2.3: Long Term changes in bed Levels at the Centrica and Eon Intake and Outfalls



Source: Annex 8.3: 3D Mud Modelling

2.3.17 As the impacts of this option were still deemed to be significant with respect to maintenance dredging of adjacent berths and on power station infrastructure, a further option was investigated with the quay set a further 50 m towards the land relative to the Iteration 2 layout (or 80 m towards the land relative to the preliminary layout modelled by JBA). The revised quay configuration is illustrated as Iteration 3 on drawing AME-05017; the chamfer is omitted.

- 2.3.18 The capital dredge for this option is estimated to be around 1.9M m³ as the estuary bed begins to rise towards the land causing an increase in the berthing pocket dredge. The predicted changes to maintenance dredge requirements compared to existing are detailed in Table 3.

Table 3: Existing and Predicted Changes to Annual infill Estimates for Design Iteration 3, using a Cohesive Sediment Transport Model (Dry Tonnes/year)

Location	Existing (No development)		Change (With development of the iteration 3 design)	
	Lower Estimate	Upper Estimate	Lower Estimate	Upper Estimate
Humber Sea Terminal	204 800	540 000	-10 000	-25 000
AMEP Berthing Pocket	-	-	234 000	585 000
AMEP Dock	-	-	17 000	42 000
Region Inshore of Power Station Infrastructure	-	-	94 000	234 000
South Killingholme Oil Jetty	44 400	135 000	-18 000	-46 000
Immingham Gas Terminal	29 600	83 000	-2 000	-4 000
Humber International Terminal	290 000	771 000	-19 000	-48 000
Immingham Bulk Terminal	512 000	1 356 000	-30 000	-74 000

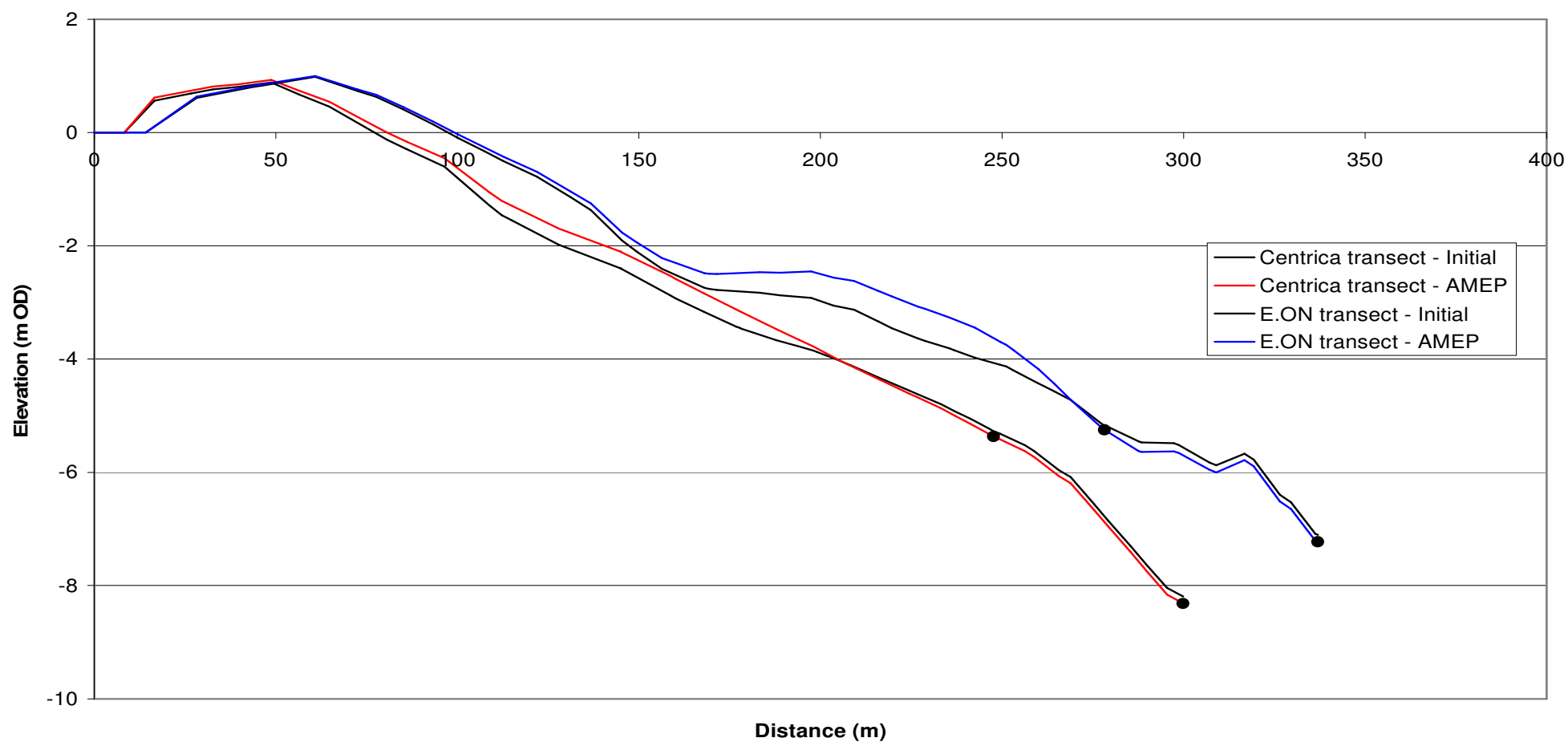
Note: 1 Dry Tonnes = 2m³


- 2.3.19 The results in Table 3 show that the Iteration 3 design does not give rise to any predicted increase in maintenance dredging at adjacent berths, provides significant reductions in sedimentation effects in the region of the power station infrastructure and also results in modest reductions in maintenance dredging to the berthing pocket.
- 2.3.20 Suspended sediment concentrations at the cooling water intakes are reduced compared to existing levels as was the case with Iteration 2.
- 2.3.21 Figure 2.4 shows predicted sedimentation along the Centrica and Eon intake-outfall lines with the final quay design for the model simulation with no waves. After a single 14-day spring-neap cycle, no sedimentation is predicted over the intake or outfall locations. Inshore of the outfalls, however, approximately 0.5m (assuming a dry density of 500 kgm⁻³) is deposited onto the E.ON transect, with 0.3-0.4m deposition being predicted on the Centrica transect.
- 2.3.22 Iteration 3 was chosen as the final quay alignment as it reasonably balanced the need for capital dredging and the predicted maintenance dredging impacts.

2.4 QUAY WALL ANCHORAGE

- 2.4.1 The proposed design has tubular piles tied back with flap anchors that fix the piles in position near their top. These anchors rely on the passive resistance of the quay backfill material.

Figure 2.4: Transects showing model predicted sedimentation along intake/outfall lines after a 14 day Spring/Neap cycle



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2.4.2 An alternative anchoring system that was considered were vertical driven anchor piles and tie rods. However, this method required an extra set of tubular piles to be driven and tie rods to be fixed to the front and anchor wall.

2.4.3 One advantage of the flap anchors is that only one set of piles will require driving thus reducing the noise impact of the piling.

3 DREDGING

3.1 INFILLING

3.1.1 The existing intertidal area between the existing flood defence and the new quay will be filled with sea or estuary dredged material. The upper sections of fill, approximately 1m, will comprise imported stone that will provide a permeable heavy-duty pavement for operational plant.

3.1.2 Consideration was given to the use of the capital dredge material as infill material. However, the vibrocore investigation undertaken within the dredge box revealed that the proposed dredge arising's would not be suitable. Alternative sources of fill material are to come from either licensed sites and/or sunk dredged channel capital dredge if the projects are undertaken simultaneously.

3.2 DREDGING

3.2.1 To enable vessel access to the operational quay and allow berthing alongside its length over a commercially viable tidal range, capital dredging will be required from three distinct areas:


- Berthing Pocket
- Approach Channel
- Turning Area

3.2.2 The dredge depth was originally proposed as -9.0mCD across all three areas, however, taking into consideration emerging designs for new generation wind turbine installation vessels, an operational draught of 10m has been adopted. Accordingly, the berthing pocket dredge depth was increases to a maintained -11mCD with an initial over-dredge to competent material to provide a firm foundation for jack up vessels.

3.2.3 Consideration was given to constructing discrete foundation pads in the berthing pocket for jack-up vessels but this option was considered too restrictive to the future use of the quay.

4 LIGHTING

4.1.1 To allow for 24 hours operation sufficient lighting will be provided to enable personnel to access, egress and carry out their work safely and to identify any hazards or obstacles in the workplace. Accordingly, external lighting over the quay frontage will comprise 50m towers that will be fitted with directional luminaires to limit spill outside the working areas. Over the operational areas of the quay (notionally taken to be that area within 50m of the quay edge), the lighting will provide average luminance of 50 lux, with a minimum of 20 lux. Elsewhere, on the storage areas behind the quay,

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lighting will be designed to provide an average luminance of 30 lux with a minimum of 5 lux.


- 4.1.2 An option for using 30m high lighting towers was investigated and required a total of 93 columns across the entire site. This option required 72 new lighting columns and associated foundations to be installed.
- 4.1.3 However, by using 50m columns it is possible to reduce the number of lighting columns required to 30 within the main site. Within the supply chain 30m high columns would still be used however these are currently already in place and in use as part of an extant planning permission.
- 4.1.4 It is not only more economical to use the 50m columns but also it decreases the visual impact created by 30m columns.

5 DRAINAGE

5.1 SURFACE WATER

Pumping Station

- 5.1.1 The site lies within the Killingholme Marshes drainage catchment, which is within the North East Lindsey Drainage Board (NELDB) district. The North Killingholme, South Killingholme and Killingholme Marsh's catchment are currently subjected to tide locking on each tide cycle, and during intense events the flood plains inter-connect to form a complex hydraulic regime. An existing outfall lies within the footprint of the proposed quay.
- 5.1.2 Able UK commissioned JBA Consulting to a feasibility report to identify and assess potential locations for the pumping station and associated watercourses. After consideration of the all constraints and proposed development 4 alternative routes have been identified and assessed. Details of each route are shown in Figures 5.1-5.4 and summarised below.
- **Route A:** Pumping station located north of the quay, watercourse traverses the site northeast-southwest (*Figure 5.1*);
 - **Route B:** Pumping station and watercourse as per Route A, but a booster pumping station to raise bed levels downstream and create a more manageable watercourse (*Figure 5.2*).
 - **Route C:** Pumping station north of the proposed quay, watercourse follows northern site boundary to west of the site. Watercourse runs parallel to western boundary (*Figure 5.3*).
 - **Route D:** Pumping station located to the south of the proposed quay. Watercourse doglegs through site to meet southern end of Route B (*Figure 5.4*).
- 5.1.3 The assessment of these options concluded the following:
- Route A may present additional siltation problems due to the proposed bed level, north of the proposed quay, being 127mm lower than the invert of the existing gravity outfall and represents the largest amount of earthworks.

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- Route B results in a bed level at the River Humber defences of 1.325m some 900mm above the existing gravity outfall invert. This route represents the highest level of capital and operating expenditure.
- Route C would expose the E-ON cooling pipes within an open channel. This is based upon an existing concrete cover slab in the bed of the channel protecting the pipes. This proposed route would require additional deepening at this location and therefore require a diversion of the pipes.
- Route D would provide the shortest route, reduced earthworks and provide a similar bed level at the River Humber defences to the existing gravity outfall invert. The layout of the proposed quay may require amendment at the site of the proposed pumping station and land ownership issues would require resolving between the two developers and the NELDB. This route represents the lowest level of capital and operating expenditure.

5.1.4 In accordance with the above Route D has been adopted.

Sustainable Urban Drainage System (SUDS)

5.1.5 PPS25 states that surface water from a developed site should, as far as is practicable, be managed in a sustainable manner to mimic the surface water flows arising from the site prior to the proposed development. Developers are encouraged to use SUDS for surface water disposal.

5.1.6 However, findings from previous ground investigations undertaken on parts of the site indicate that the ground generally consists of:

- Made ground up to 3 metres deep in some locations;
- Alluvium and clay to depths exceeding 15 metres;
- Groundwater strikes at various levels in some boreholes; and
- Groundwater levels which may be influenced by tide levels in the Humber Estuary.

5.1.7 The Flood Risk Assessment, as undertaken by JBA Consulting, presented in Annex 13 states: "impermeable clay ground conditions are not suitable for infiltration drainage. The existing site is drained by the Killingholme Marshes Drainage System: a network of open watercourse channels under the control of the North East Lindsey Drainage Board. It is therefore appropriate and consistent with PPS25 to discharge surface water from the development to the Killingholme Marshes Drainage System."

5.2 FOUL WATER / SEWAGE

5.2.1 Foul water drainage from buildings will fall by gravity into pumping stations distributed throughout the site. These will pump the foul effluent through rising mains into the adopted foul water drainage system operated and maintained by Anglian Water.

5.2.2 Alternative solution considered was the installation of package treatment facilities such as Klargesters. These were deemed inappropriate for the scale of the facility.

Figure 5.1: Route A



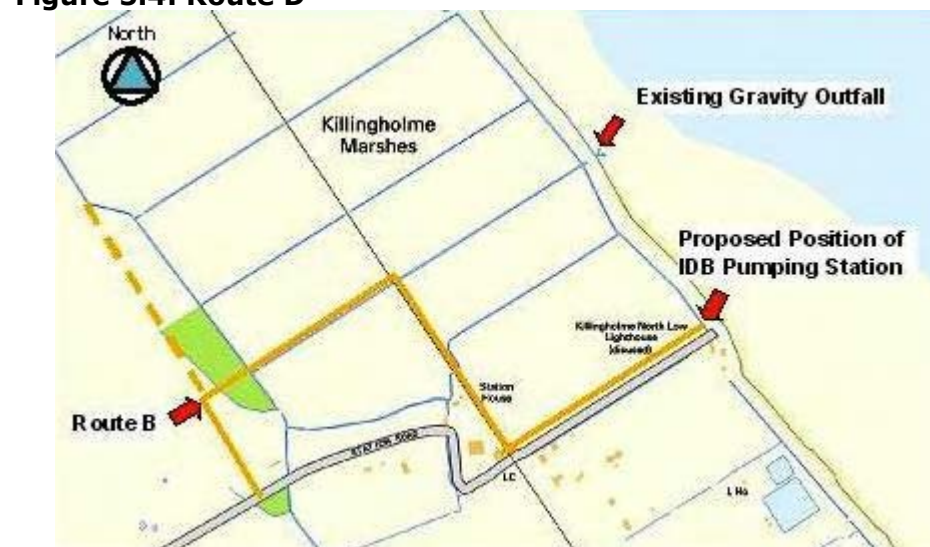
Figure 5.2: Route B




Figure 5.3: Route C



Figure 5.4: Route D




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6 BUILDINGS

6.1 GREEN ROOFS

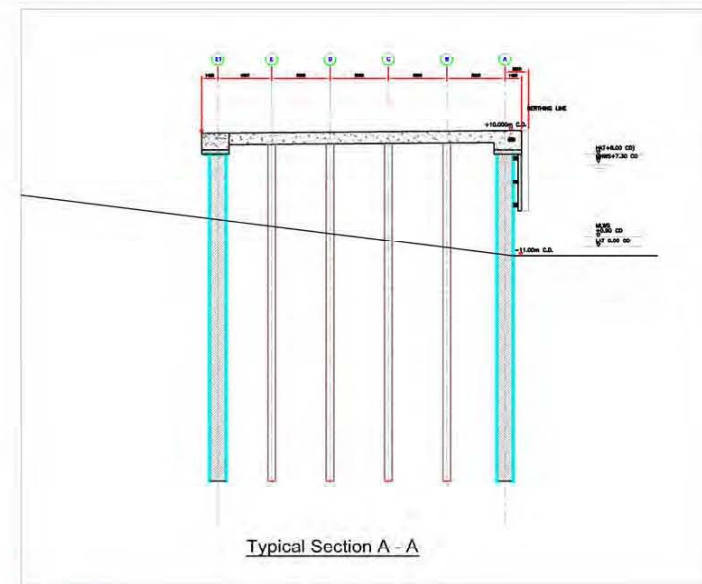
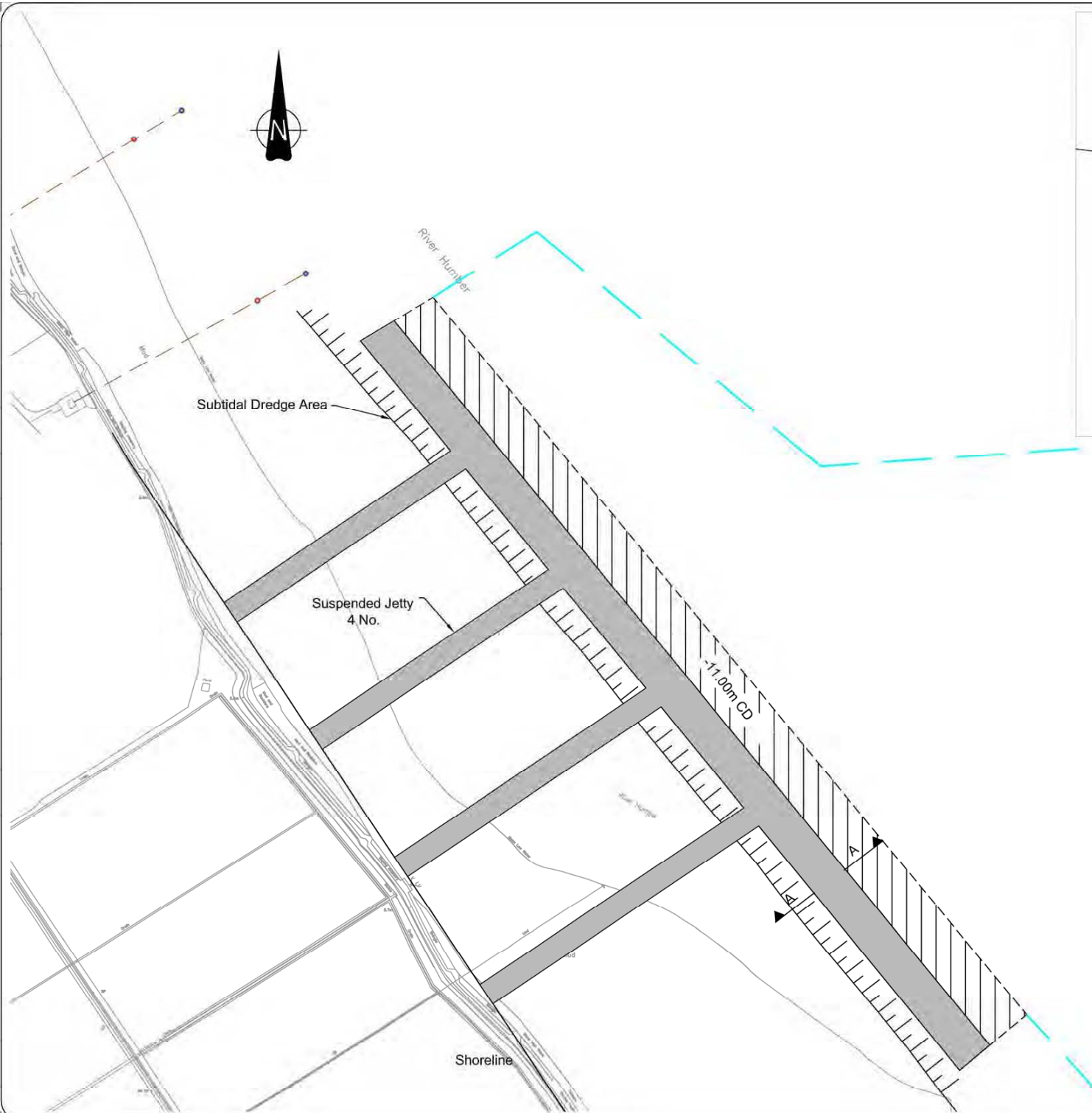
- 6.1.1 The site is proposed to have several large warehouse type buildings with small offices attached. Green roofs were considered on the larger structures as potential roosting/loafing areas for birds. However the idea was dismissed at an early stage as the lightweight steel structures would need significant reinforcement to be able to withstand the extra weight from the soils required.

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FIGURES

FIGURE 2.1: Pier & suspended Jetty Alternative – AME-01152 A

FIGURE 2.2: Suspended Deck Alternative – AME-01153 B



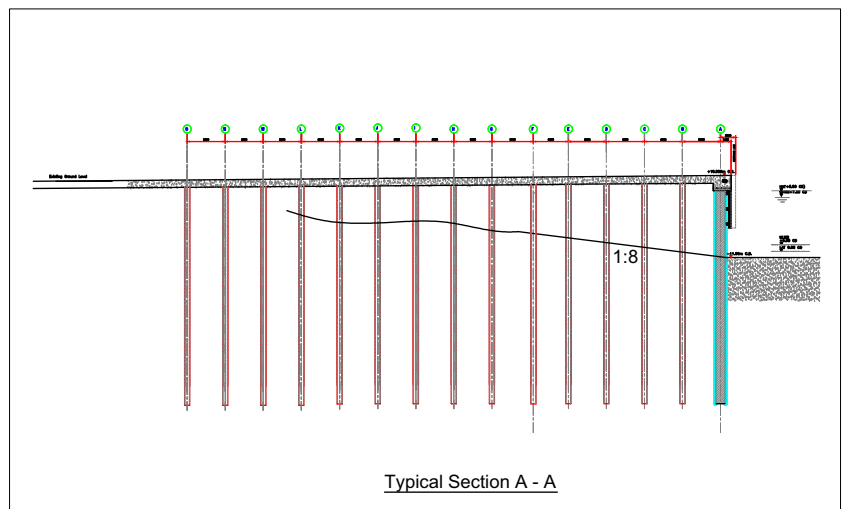
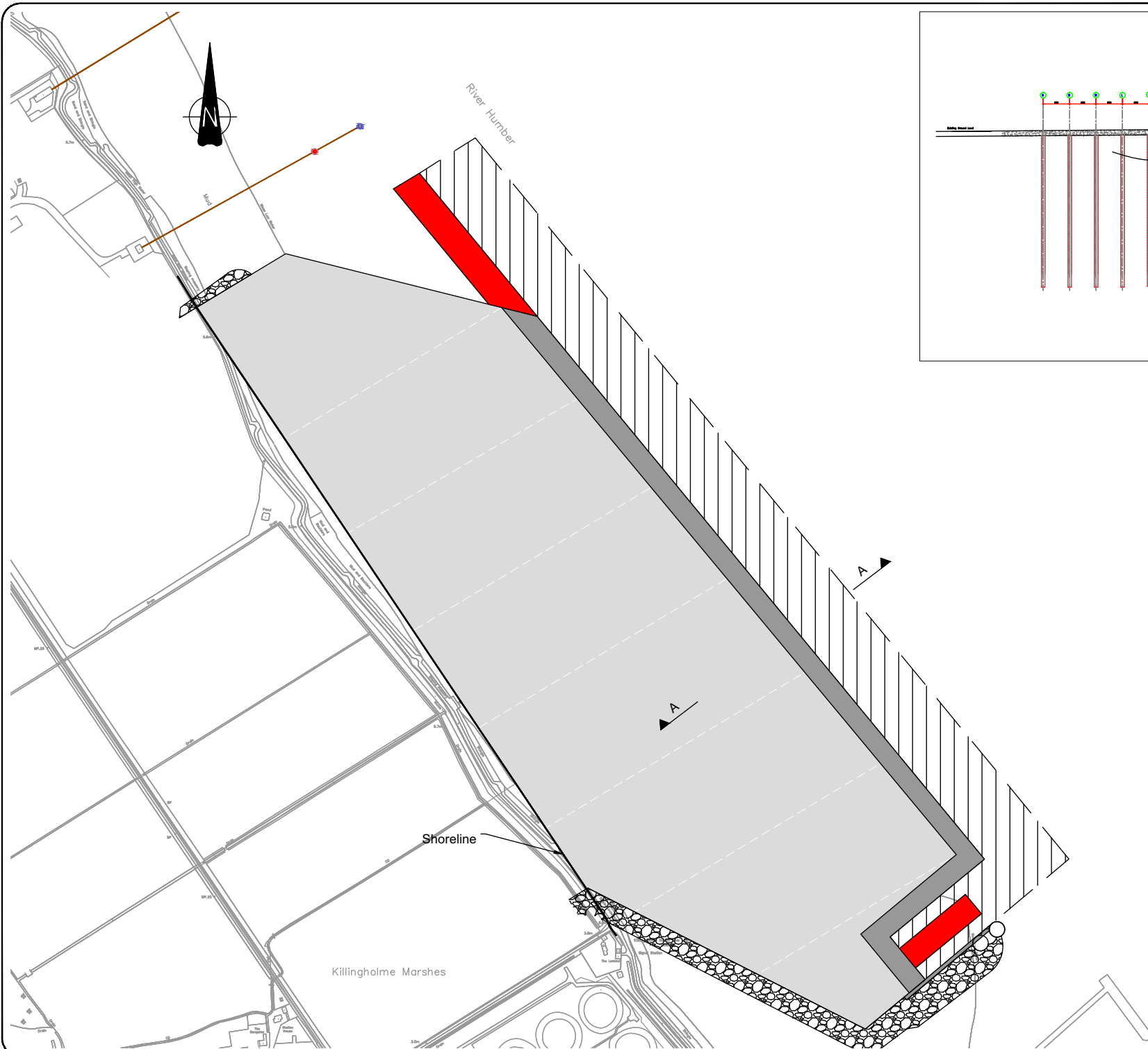
KEY					
		Piled Concrete Deck			
Rev	Date	Comments	Drw	Chk	App
A	14/04/2011	Preliminary Issue	JH	RC	RC

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Project:	ABLE Marine Energy Park
Client:	ABLE UK Ltd
Title:	Figure 2.1 Pier & Jetty Alternative

PRELIMINARY			
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Drawing No.	AME - 01152	Revision:	A



KEY					
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B	23/06/11	General	PP		
A	14/04/2011	Preliminary Issue	JH	RC	
Rev	Date	Comments	Drw	Chk	App



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Project:	ABLE Marine Energy Park
Client:	ABLE UK Ltd
Title:	Figure 2.2 Suspended Deck Alternative

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Date	14/04/2011	14/04/2011	14/04/2011
Drawing No.	AME - 01153		Revision: B

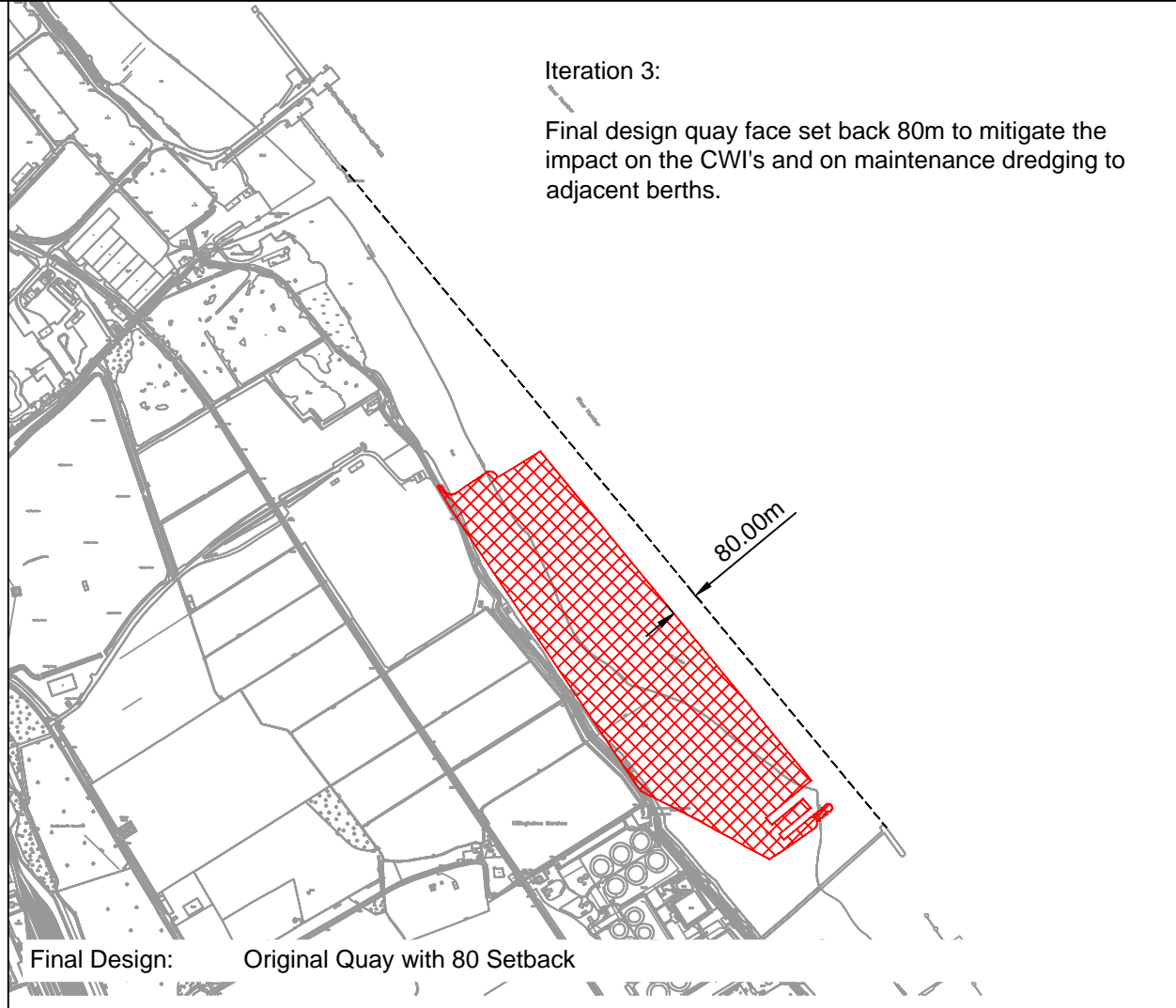
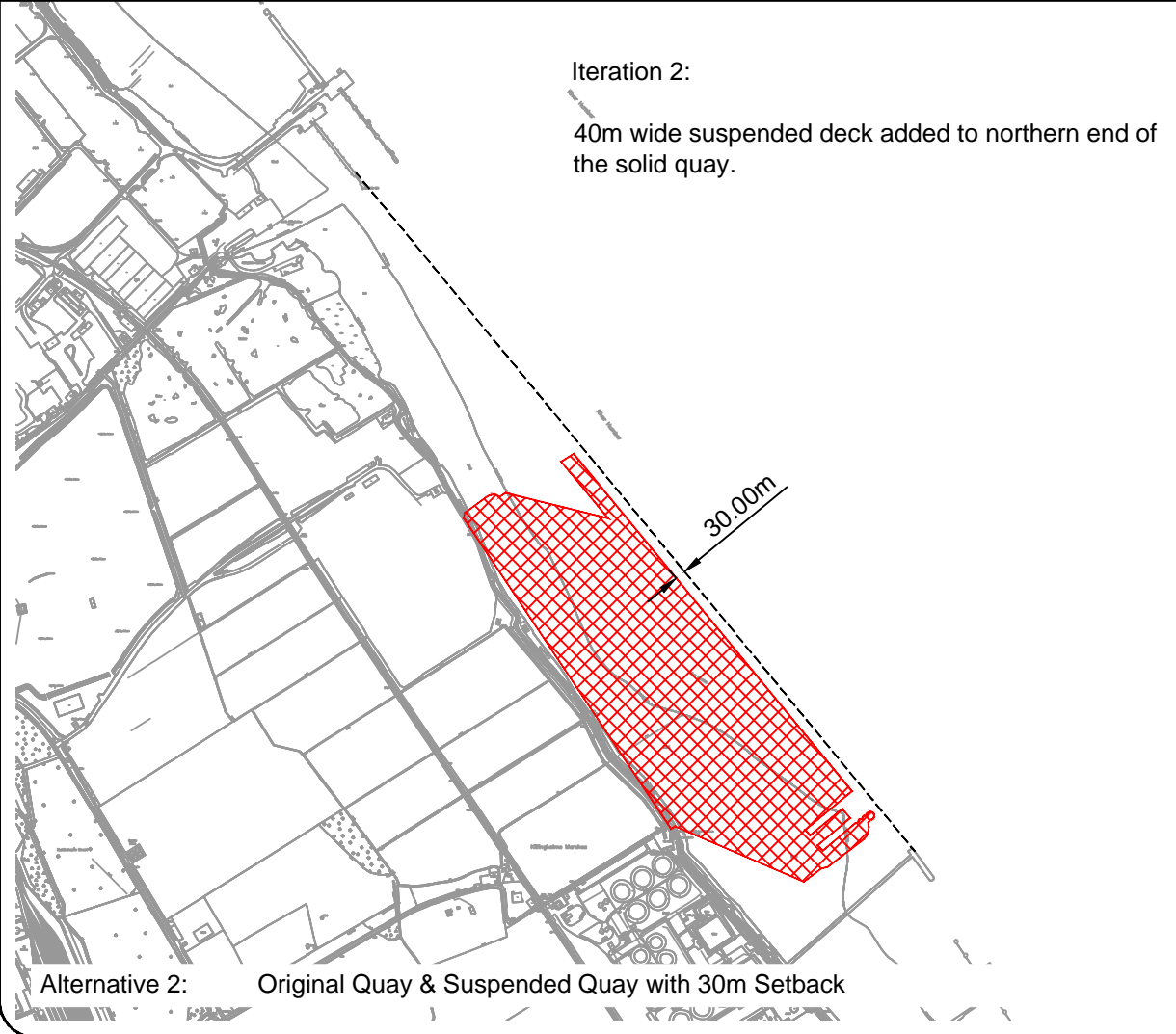
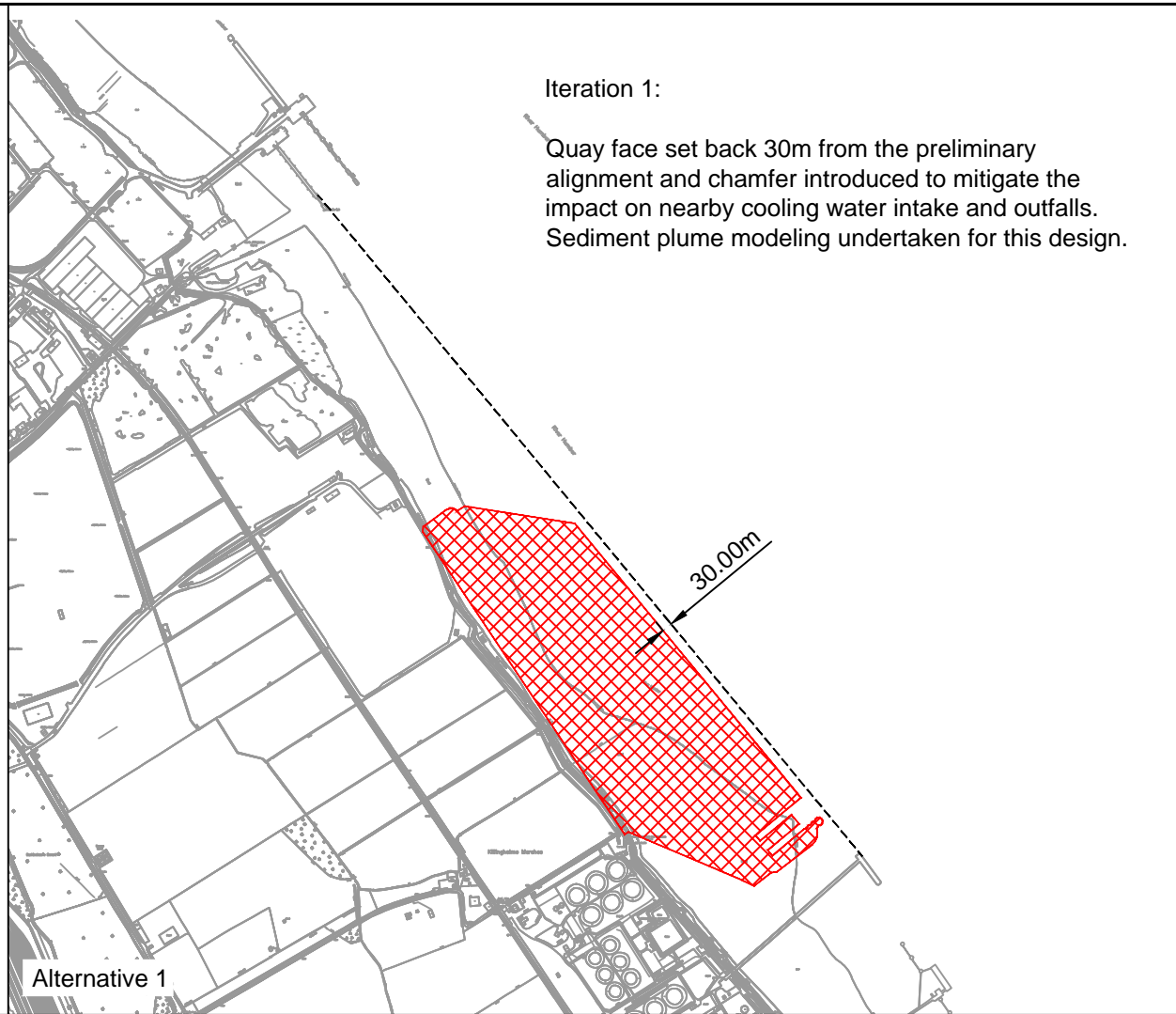
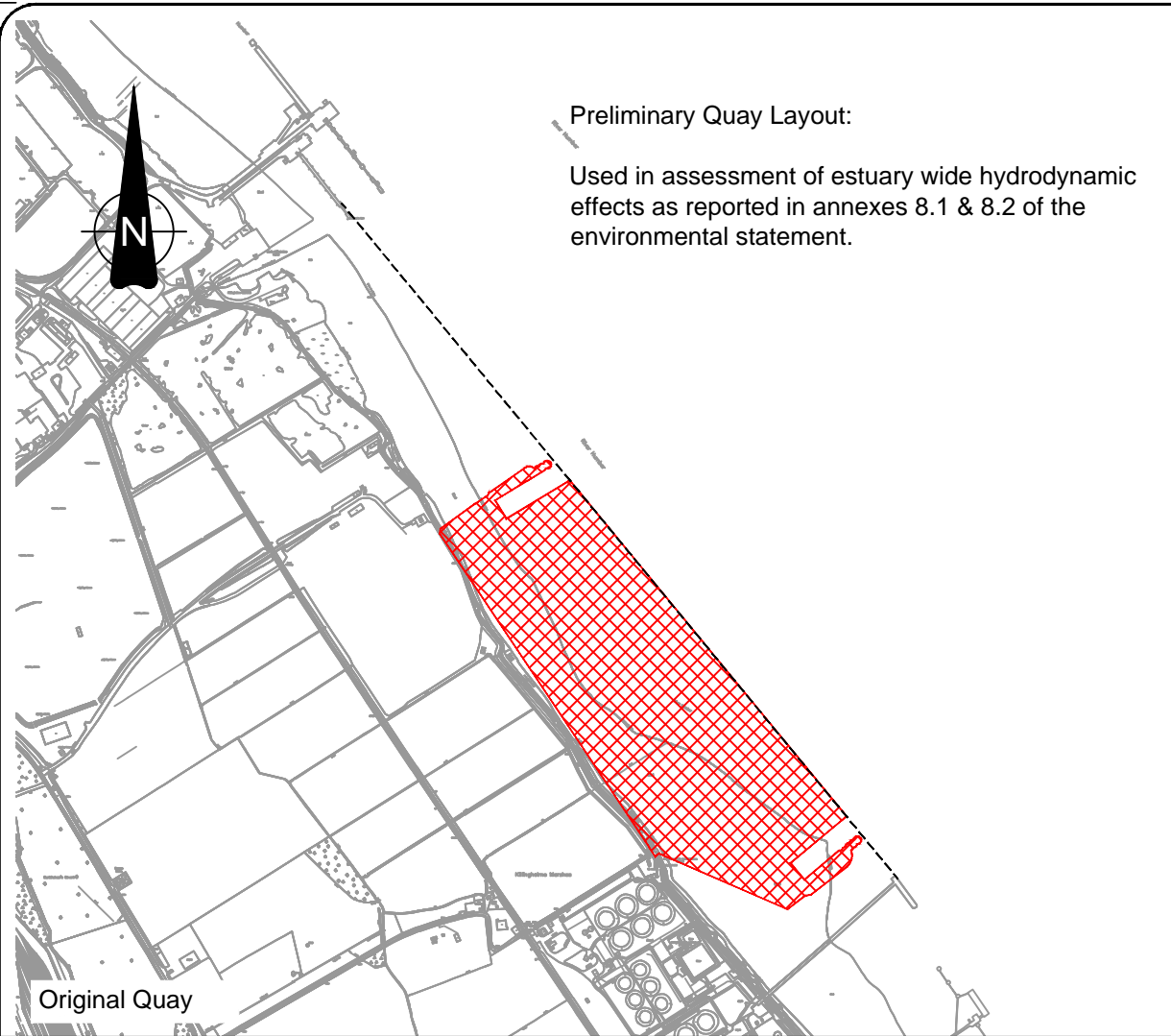


**ABLE MARINE ENERGY PARK
CONSIDERATION OF THE MAIN
ALTERNATIVE DESIGN**

NOV 2011

ANNEX 1

Drawing AME-05017 C



KEY

Notes:

1. This drawing shows the evolution of the design as the environmental impacts were assessed and mitigation introduced.

C	01/12/11	General Amendments	JH	RC	RC
B	01/11/11	Text Added	JH	RC	RC
A	30/09/11	Preliminary Issue	RK	RC	RC
Rev	Date	Comments	Drw	Chk	App




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Project:	ABLE Marine Energy Park
Client:	ABLE UK Ltd
Title:	Quay Design Iterations

PRELIMINARY

Scale:	Drawn	Checked	Approved
1:20,000@A3	R Keirl	R Cram	R Cram
Date	30/09/2011	30/09/2011	30/09/2011
Drawing No.	AME - 05017		Revision: C

	<p>ABLE MARINE ENERGY PARK CONSIDERATION OF THE MAIN ALTERNATIVE DESIGNS</p>	<p>NOV 2011</p>
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ANNEX 2

JBA Consulting

ST Model and Chamfer Further Results

JBA Project Code 2010s4456
Contract Humber Estuary Quay Design Modelling
Client Able UK Ltd.
Day, Date and Time 11th May 2011
Author C Batstone
Subject ST model and chamfer further results

Purpose

This note describes refined estimates of maintenance dredging rates for AMEP and nearby facilities, after completion of work suggested by external review performed by HR Wallingford.

In addition the note contains diagrams showing impacts of the quay on currents with a focus on impacts to the north of the site. Impacts for the original design, a chamfer edge and a chamfer edge with a suspended deck are shown.

Maintenance dredging rates

The Sediment Transport model was run for various median sediment grain sizes for an 18-day spring-neap cycle. The model was run with the original (i.e. no chamfer) scheme in place and also without. In this way it is possible to deduce the differences in the model-simulated sediment transport regime due to the scheme. The additional accumulations due to the scheme after the 18-day run were multiplied by 20 to provide an estimate of the increase in annual accumulations. This provides a conservative estimate as it assumes sediment will accumulate at a constant linear rate throughout the year, whereas a dynamic equilibrium is more likely going to be reached before the end of the year (assuming the accumulation is not dredged during the year).

The predicted increases in maintenance dredge rates for the AMEP facility and adjacent ports are provided below. The model predicts negligible increases in maintenance dredge volumes for facilities farther from the scheme than those given in the table. The sediment distribution characteristic of the Humber varies greatly with location and time. Therefore it is not possible to provide single estimates in terms of likely accumulations, but rather ranges of potential accumulations covering the overall sediment distribution of the Humber. The actual values are likely to lie within the ranges given. Note that no increase in accumulation is predicted to occur at the SKOJ as the model predicts increased erosion at this location for all sediment sizes.

Table 1: Predicted increases in annual maintenance dredge volumes due to the original quay design (m³)

Dredging location	D50=0.075mm	D50=0.1mm	D50=0.15mm	D50=0.2mm	D50=0.3mm
HST berths	320 000	110 000	80 000	27 000	20 000
South Killingholme Oil Jetty	0	0	0	0	0
Immingham Gas Jetty	26 000	2 800	2 700	700	600
Humber International Terminal	17 000	4 400	3 200	1 200	1 100
Immingham Bulk Terminal	16 000	5 600	2 500	1 400	700
AMEP approach area & berths	720 000	1 300 000	800 000	430 000	280 000

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Author C Batstone
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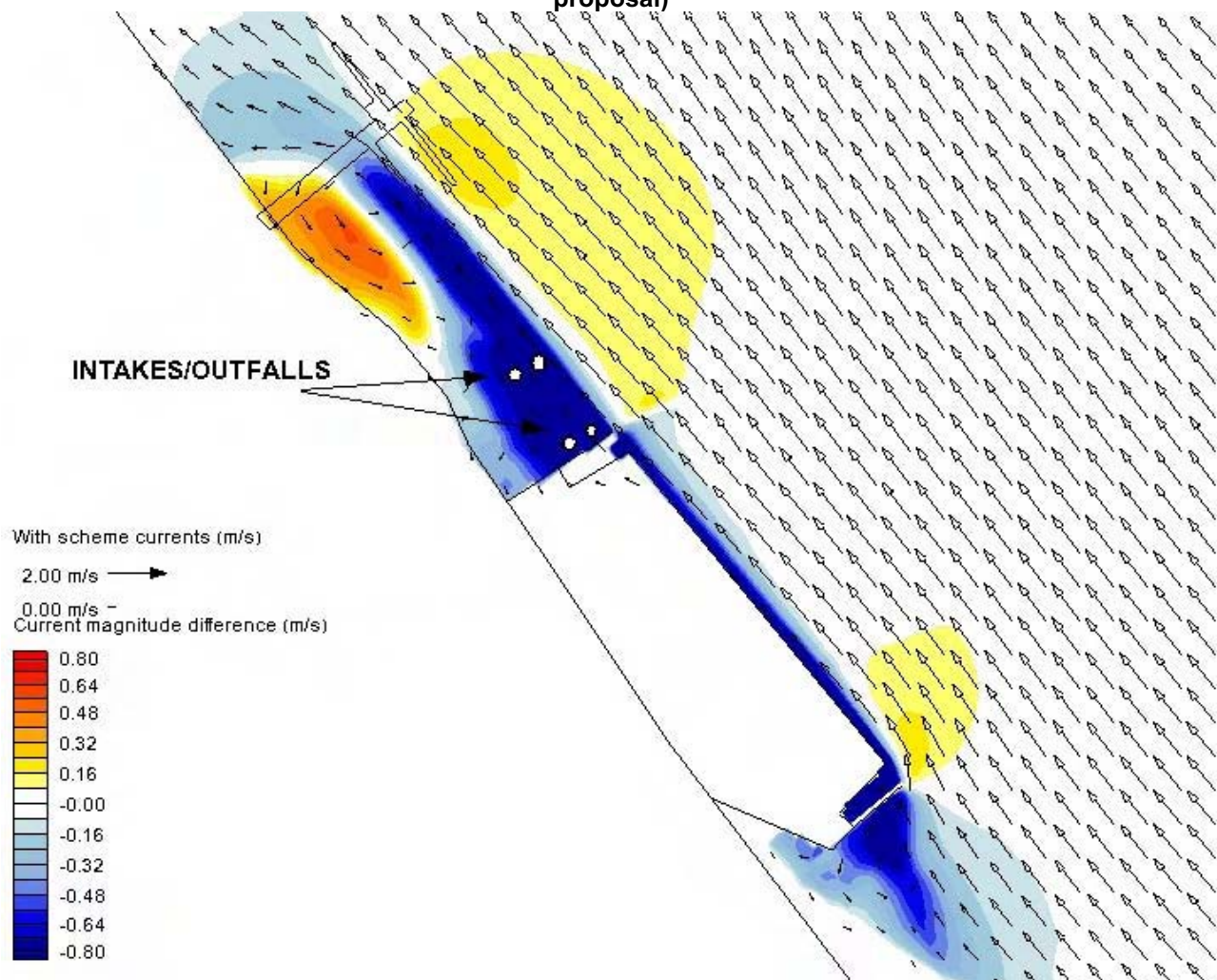
Impacts to the north of the AMEP scheme

The protrusion of the proposed quay into the estuary will affect hydrodynamic flow during flooding and ebbing tides. During flooding tides, the original proposal (with northern edge breakwater), leads to a significant recirculation pattern near to the HST to the north of the quay. This is shown in Figure 1, which depicts the change in magnitudes of the currents due to the scheme (contours) along with the currents related to the scheme simulation (arrows). This recirculation pattern is likely to have a significant impact on the sediment regime in the area and also on maritime activities at the HST.

Figure 2 shows the same plot for the scheme with a chamfer edge on the northern end of the quay. There is a large reduction in the impact of the quay to the point that changes to baseline currents at the HST due to the quay are effectively negligible in terms of maritime activities.

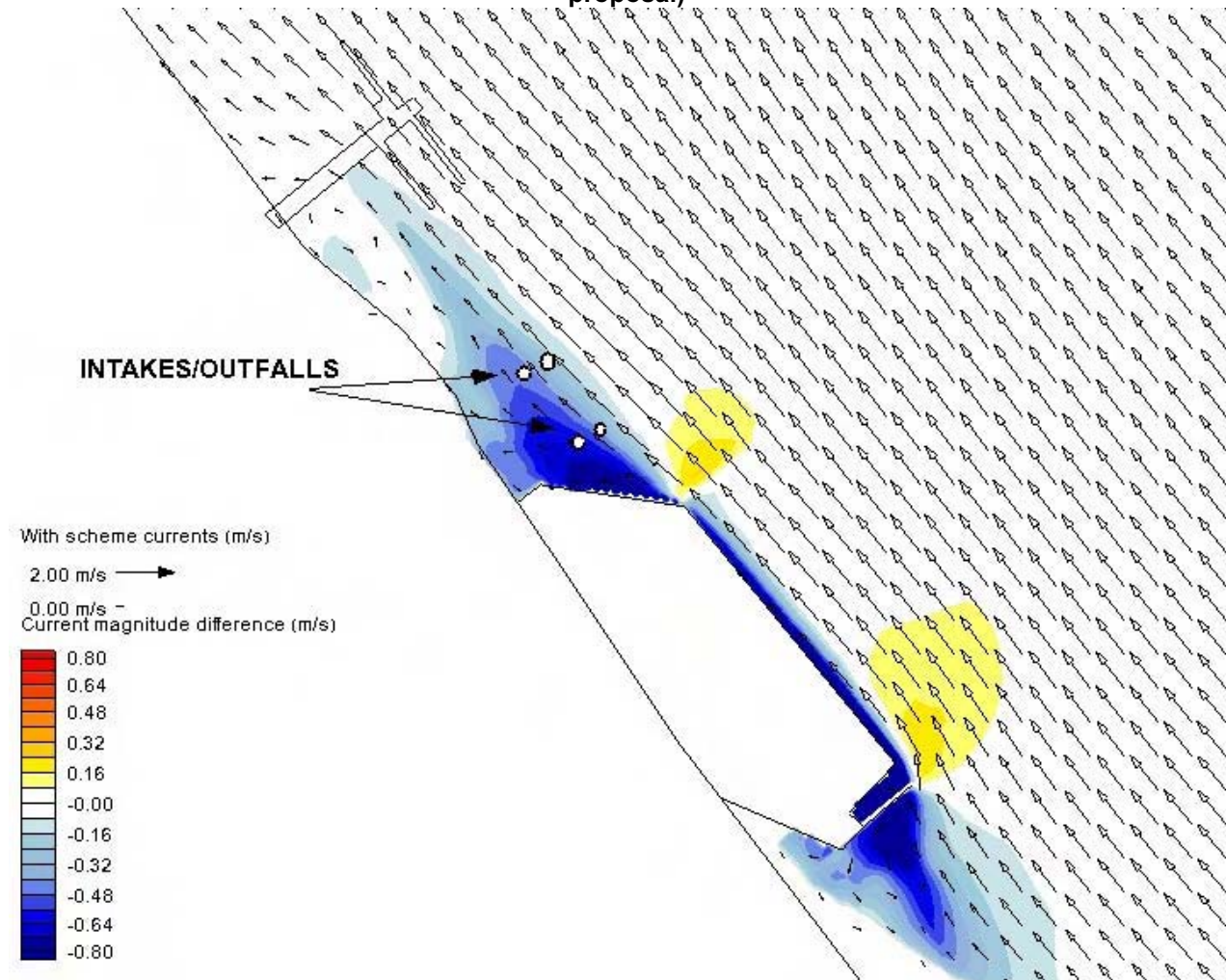
Figure 3 shows the same plot again for the scheme with a chamfer edge and a suspended deck protruding to the north-west from the quay frontage. The additional drag force of the piles supporting the suspended deck lead to a larger impact on current magnitudes to the north over the scheme with just the chamfer edge. However the impacts are not as great as for the original proposal with northern edge breakwater.

Figure 1: Change in current magnitudes due to the scheme for peak MHWS flood flows (original proposal)



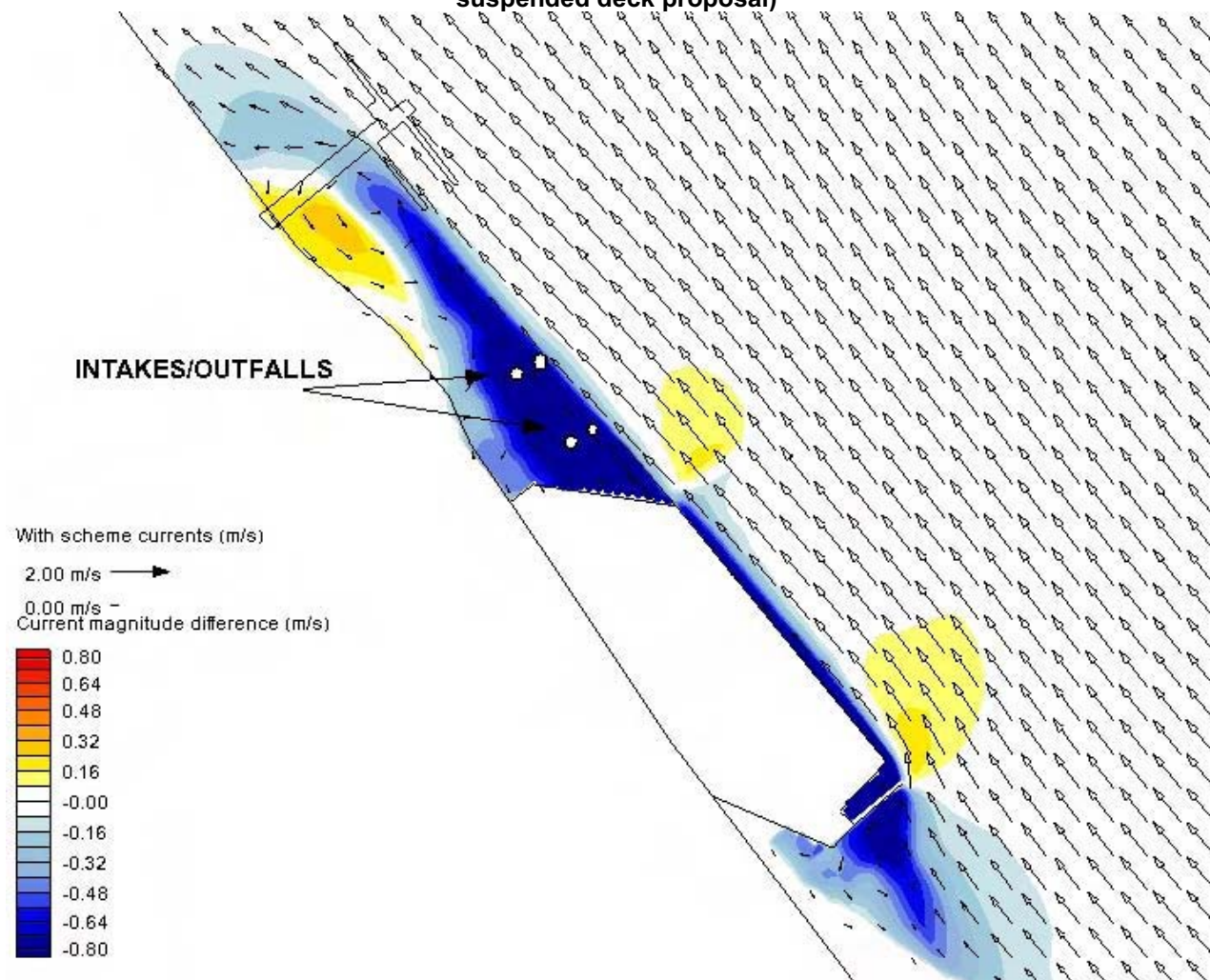
JBA Project Code 2010s4456
Contract Humber Estuary Quay Design Modelling
Client Able UK Ltd.
Day, Date and Time 11th May 2011
Author C Batstone
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Figure 2: Change in current magnitudes due to the scheme for peak MHWS flood flows (chamfer proposal)



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 Contract Humber Estuary Quay Design Modelling
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Figure 3: Change in current magnitudes due to the scheme for peak MHWS flood flows (chamfer with suspended deck proposal)



	<p>ABLE MARINE ENERGY PARK CONSIDERATION OF THE MAIN ALTERNATIVE DESIGN</p>	<p>NOV 2011</p>
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ANNEX 3

JBA Consulting

MEP Chamfer Quay Sedimentary Impacts

JBA Project Code	2010s4456
Contract	Humber Estuary Quay Design Modelling
Client	Able UK Ltd.
Day, Date and Time	31 st May 2011
Author	C Batstone
Approved by	K Keating
Subject	File Note 17: MEP chamfer quay impacts on sedimentary regime

Synopsis

This file note describes the modelled patterns of likely erosion/deposition throughout the tidal cycle for the existing and MEP chamfer quay scenarios (this scenario is characterised by a reduction of 200m from the northern edge of the quay frontage and the replacement of the northern berthing pocket with a chamfer edge). These results reveal the likely impact of the quay on the sedimentary regime. Results from a scenario with a suspended deck positioned in front of the chamfer are also included.

Analysis

Figure 2 to Figure 25 show the bed shear stresses at hourly snapshots throughout a MHWS tidal period for the existing (left column) and MEP chamfer quay (right column) scenarios (this MEP scenario does not include a suspended deck). The locations of the HST and power station intakes and outfalls are also denoted (the 2 intakes are 70m farther offshore than the 2 outfalls). The contours show the threshold below which deposition is likely to occur (0.2 N/m^2) and the threshold above which erosion is likely to occur (0.5 N/m^2)¹. Only these contour lines are shown to delineate areas of likely deposition and erosion during the tidal cycle. The intermediary zone (yellow contour) is an area where the suspended material load is not increased by entrainment of bed material.

It can be seen that, for the existing case, the outfalls and intakes are located within an area of likely erosion for the majority of the time during the flood flow leading up to High Water (HW). For the MEP chamfer quay scenario the erosion/deposition delineation is farther offshore and therefore closer to these locations. The intakes are located in areas characterized by likely erosion, with the outfalls only partially, for most of the lead-up time to HW. After the tide turns (at HW+1 hour) there appears a significant acceleration of flow (and therefore increased bed shear stresses) in the vicinity of the outfalls/intakes for the MEP quay scenario over the existing scenario. This increase in potential for more erosion in the MEP quay scenario is brief, and both scenarios reveal likely erosion at these locations through the rest of the ebb tide.

Figure 26 to Figure 49 show the corresponding plots for a MHWN tidal period. In this situation, during flood flow, the intakes are located within an area of likely erosion for the existing scenario, with the outfalls only just so. As with the MHWS situation the MEP quay leads to the erosion/deposition delineation being moved farther offshore, so that for a MHWN tide the outfalls are predominantly within an area of likely deposition during the flooding tide. The intakes in this case are only just within an area of likely erosion. The intakes/outfalls for the MEP quay scenario appear to experience only slightly shorter periods of likely erosion during the ebb tide than in the existing scenario.

Figure 50 shows the water level throughout the MHWS tide to the north of the MEP quay. **Figure 51** shows the corresponding bed shear stresses at the E.ON outfall (south-western most location on previous diagrams) and intake (south-eastern most location on previous diagrams). The stresses for the scenarios of existing situation, MEP chamfer quay, and MEP chamfer quay with suspended deck are presented (**Figure 1** shows the suspended deck set-up, which is characterized by a suspended deck extending along the frontage in front of the chamfer edge). The thresholds for deposition (0.2 N/m^2) and erosion (0.5 N/m^2) are shown on the graphs.

The stresses for the existing scenario throughout the tidal cycle are significantly above the 0.5 N/m^2 threshold for likely erosion for most times at both outfall and intake. The stresses are reduced in the MEP chamfer quay scenario. Whereas stresses at the intake are above the likely erosion threshold for most of the flood period in this scenario, stresses at the outfall are within the erosion/deposition equilibrium zone. For the MEP chamfer quay with suspended deck scenario the bed stresses at these locations remain in the likely deposition zone ($<0.2 \text{ N/m}^2$) throughout the entire flooding tide period. At all locations for all scenarios the stresses rise above the likely erosion threshold (0.5 N/m^2) for the majority of the ebb tide period.

Corresponding plots for the MHWN tide are shown in **Figure 52** and **Figure 53**. In the existing scenario the outfall and intake are within the likely erosion zone for the majority of the tidal flow. For the MEP chamfer

¹ Ormond, M. van & Roelvink, D. (2004) Short-term morphologic modelling of the Humber Estuary with Delft3D, WL|Delft Hydraulics, Delft, Netherlands

JBA Project Code	2010s4456
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quay scenario the intake is within the erosion/deposition equilibrium zone during flood flow, and the erosion zone for most of the ebb tide. However the outfall remains in the likely deposition zone during flood flow, only briefly experiencing likely erosion during the ebb tide. Both locations remain well within the likely deposition zone for the flood tide for the MEP chamfer quay with suspended deck scenario. During ebb tide for this scenario the stresses at the outfall do not rise above the likely erosion threshold.

Summary

It appears that the MEP chamfer quay option as proposed will have a negative impact on the sedimentary regime at the nearby outfalls and intakes to the north of the quay. The outfalls nearer to shore are more sheltered from flooding currents by the quay than the intakes, and so are likely to experience greater accumulation. The intake and outfall nearest the HST, being farthest from the quay, will be impacted the least. The results suggest that the MEP chamfer quay with suspended deck scenario will lead to greater sheltering of the intakes and outfalls during flooding flow, leading to greater time over the tidal cycle for deposition here.

The bed shear stress plots highlight values due to predictable tidal currents. Not shown are stresses due to stochastic wave activity. Waves will increase the bed shear stress, leading to suspension of bed material. This process at the E.ON intake and outfall may be increased by the presence of the chamfer, leading to reflected waves travelling back in their direction and increasing the local wave activity. The suspended deck option would likely decrease the wave-induced bed shear stress climate as it would shelter the intake/outfall from large waves from the south-east.

Figure 1: Location of suspended deck for MEP chamfer quay with suspended deck scenario

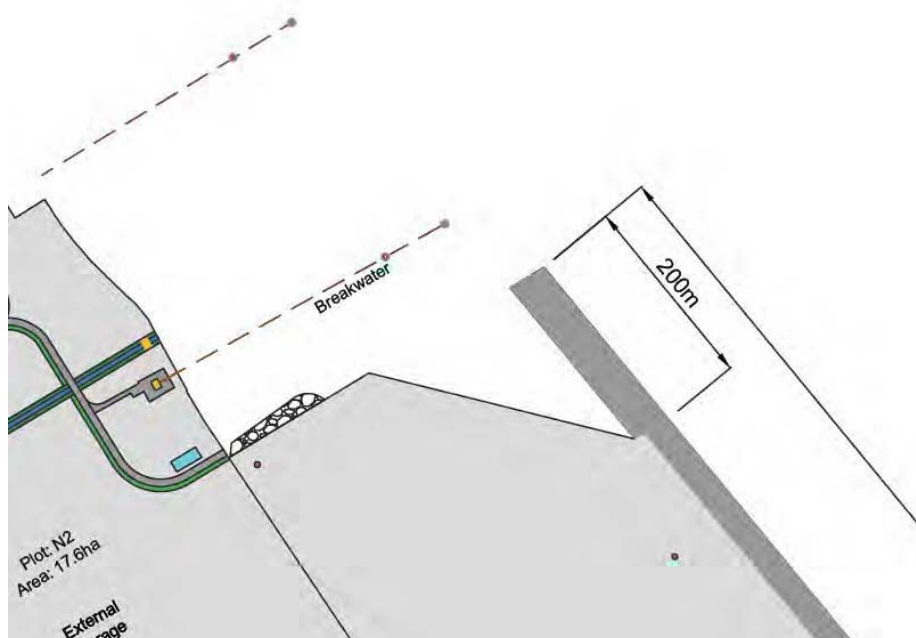


Figure 2: Existing, MHWS, HW-5

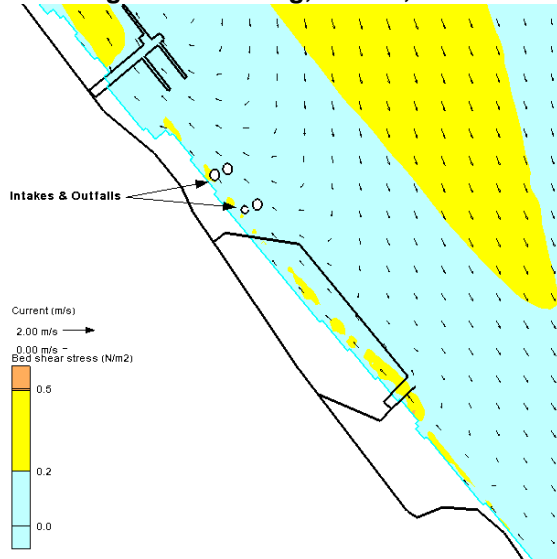


Figure 3: MEP chamfer quay, MHWS, HW-5

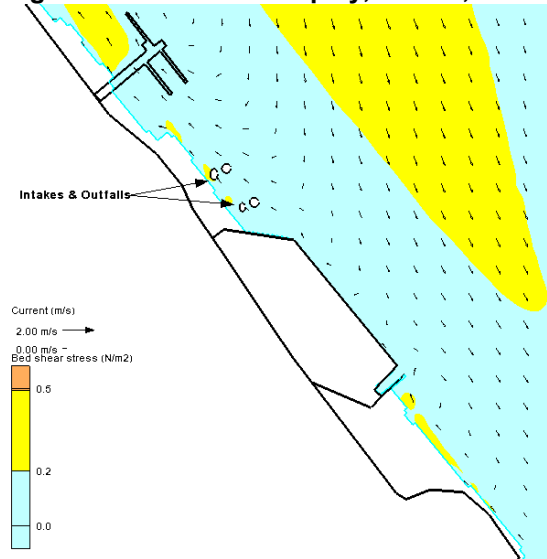


Figure 4: Existing, MHWS, HW-4

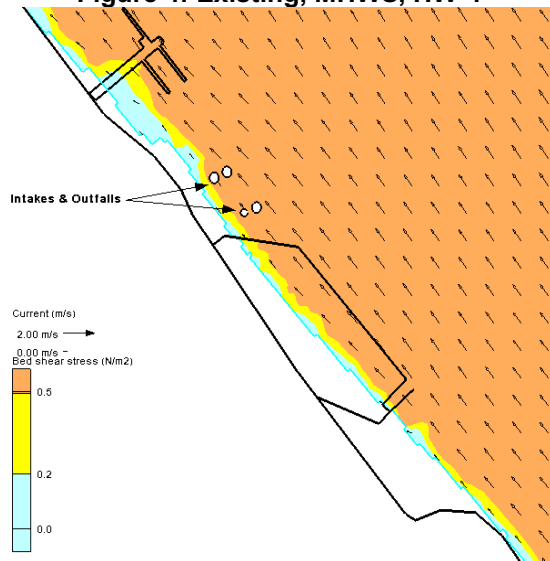


Figure 5: MEP chamfer quay, MHWS, HW-4

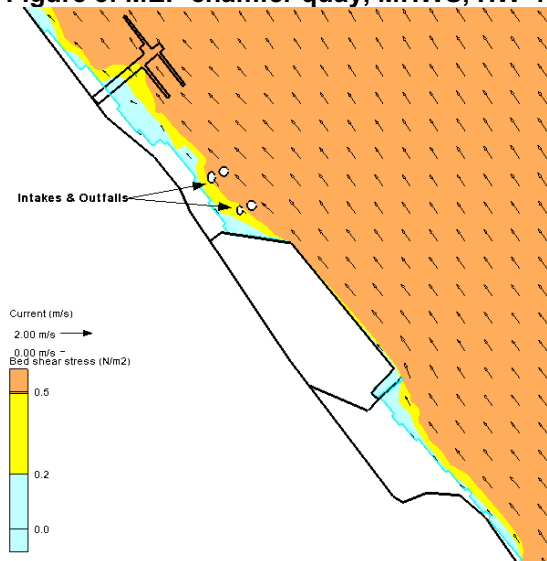


Figure 6: Existing, MHWS, HW-3

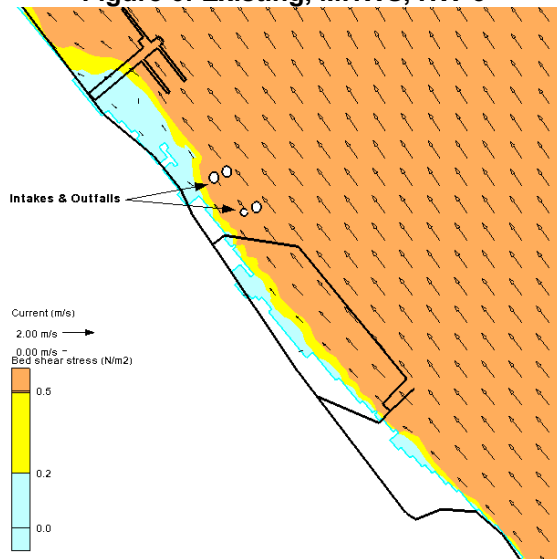


Figure 7: MEP chamfer quay, MHWS, HW-3

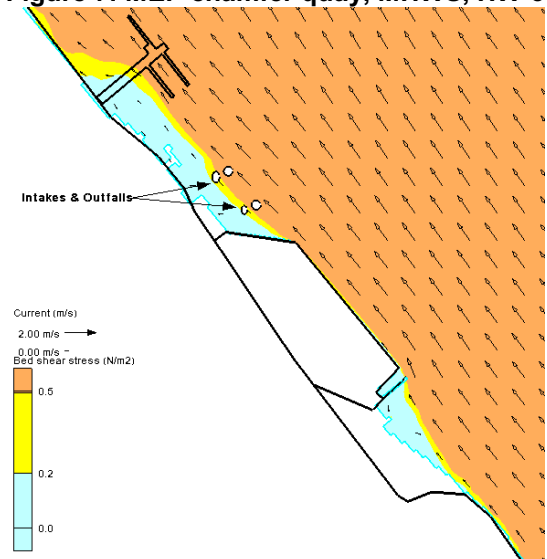


Figure 8: Existing, MHWS, HW-2

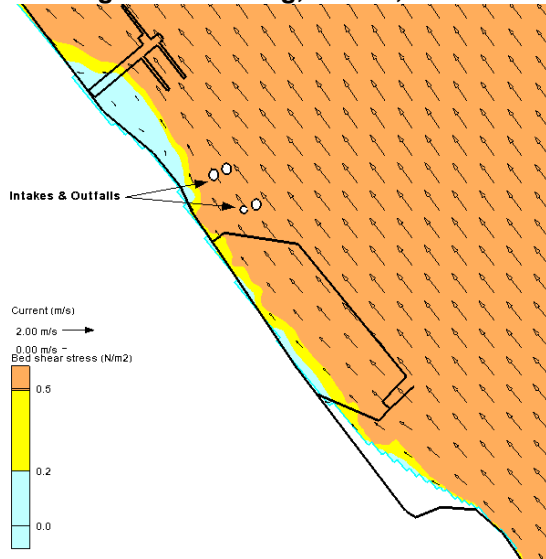


Figure 9: MEP chamfer quay, MHWS, HW-2

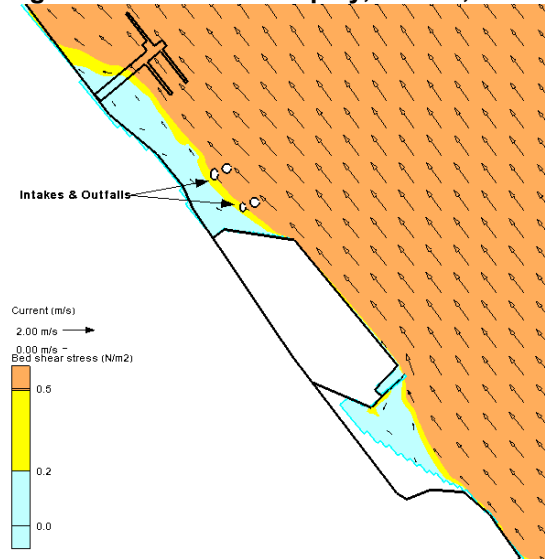


Figure 10: Existing, MHWS, HW-1

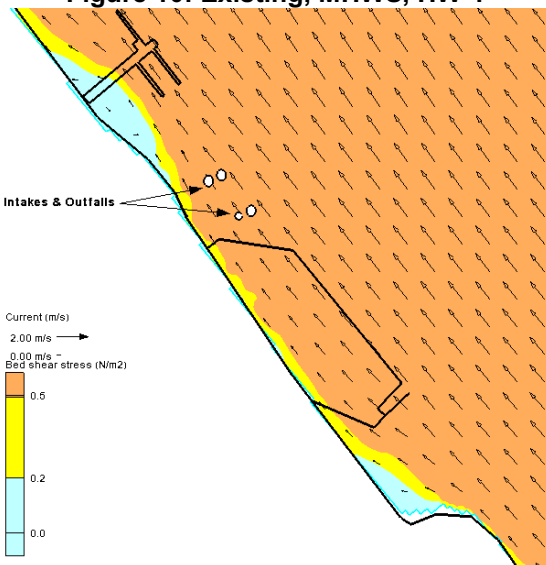


Figure 11: MEP chamfer quay, MHWS, HW-1

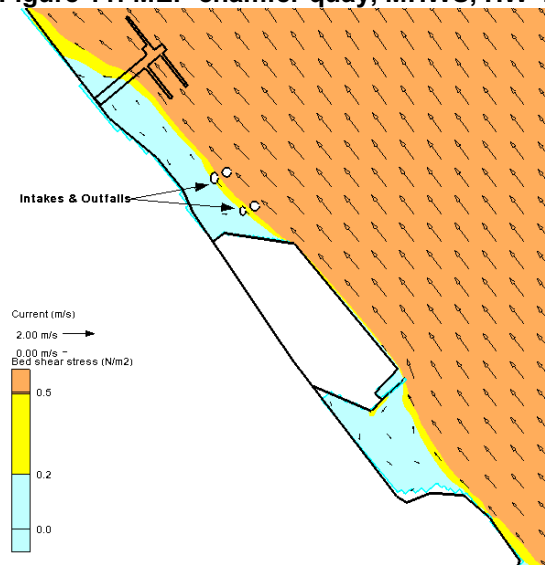


Figure 12: Existing, MHWS, HW

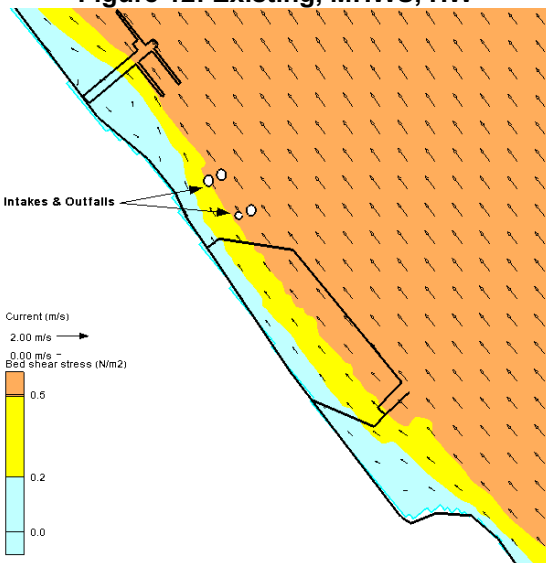


Figure 13: MEP chamfer quay, MHWS, HW

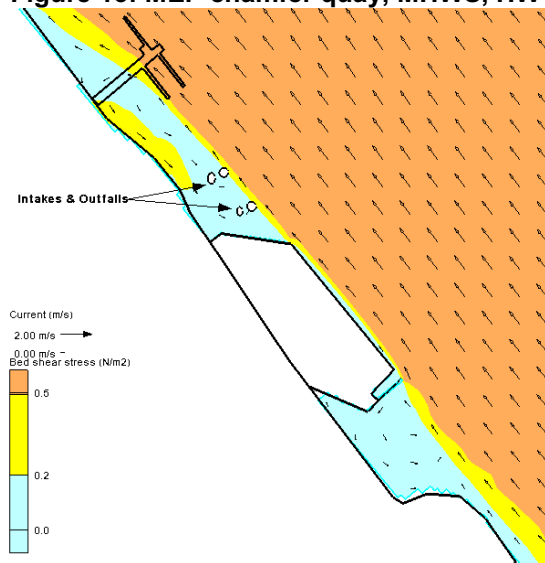


Figure 14: Existing, MHWS, HW+1

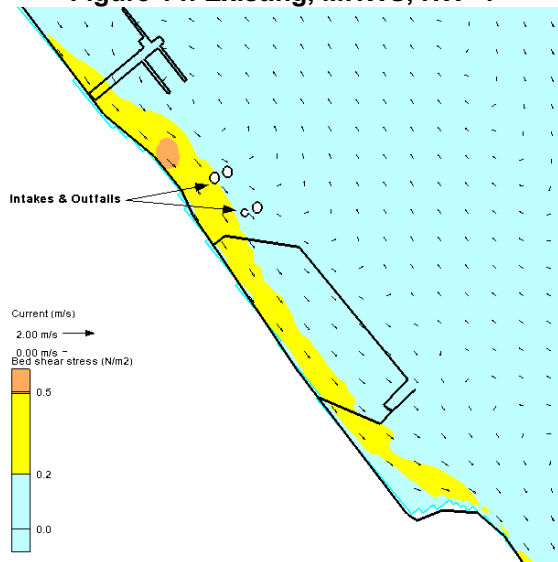


Figure 15: MEP chamfer quay, MHWS, HW+1

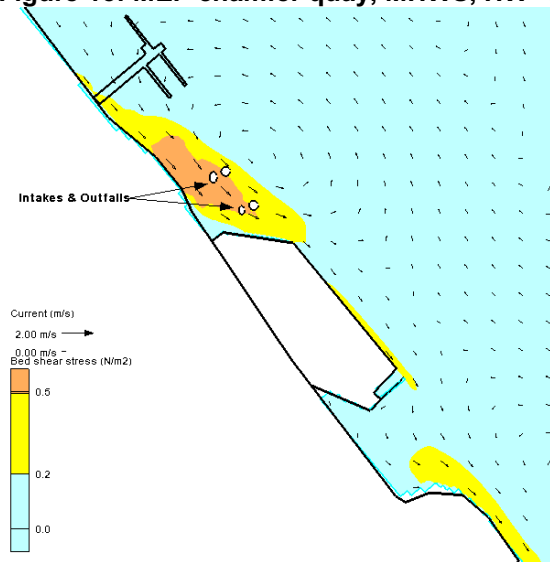


Figure 16: Existing, MHWS, HW+2

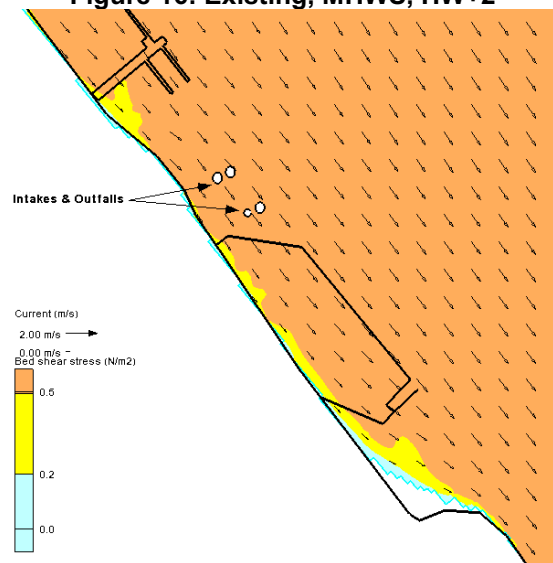


Figure 17: MEP chamfer quay, MHWS, HW+2

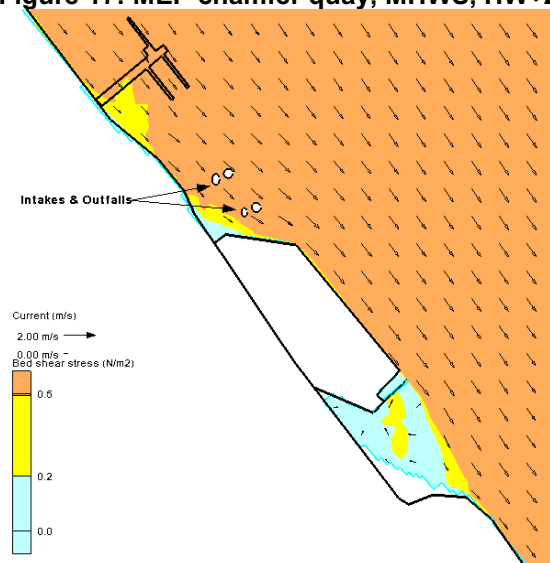


Figure 18: Existing, MHWS, HW+3

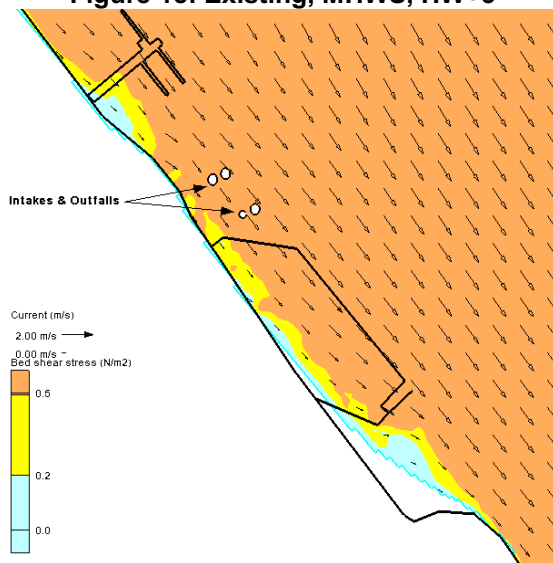


Figure 19: MEP chamfer quay, MHWS, HW+3

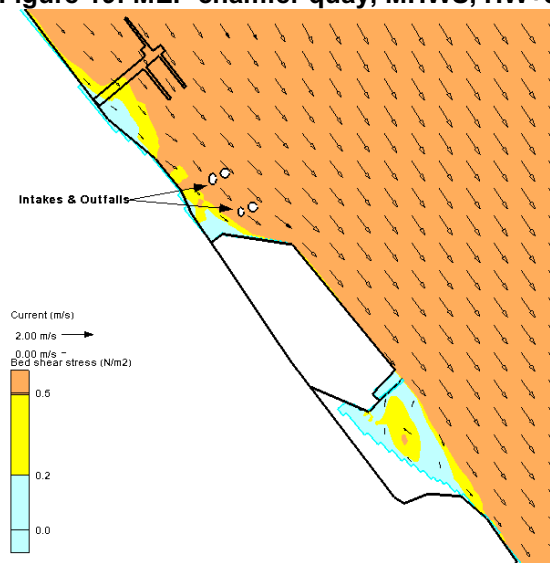


Figure 20: Existing, MHWS, HW+4

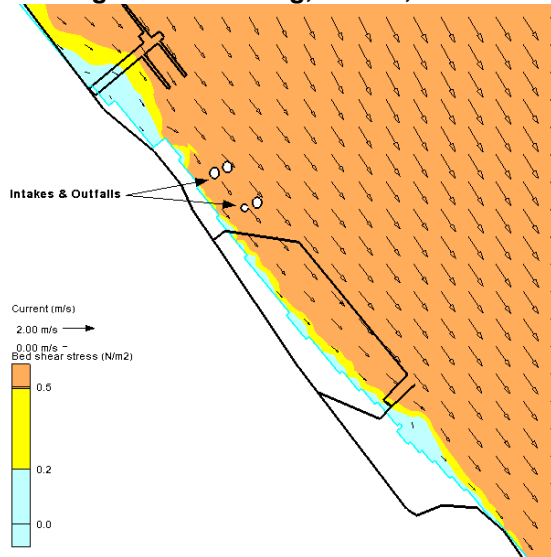


Figure 21: MEP chamfer quay, MHWS, HW+4

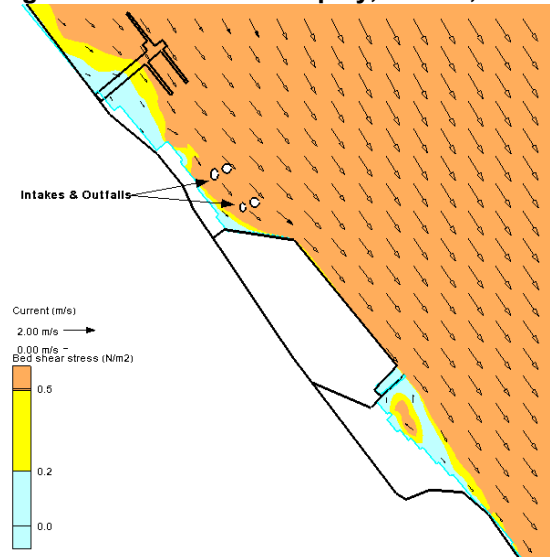


Figure 22: Existing, MHWS, HW+5

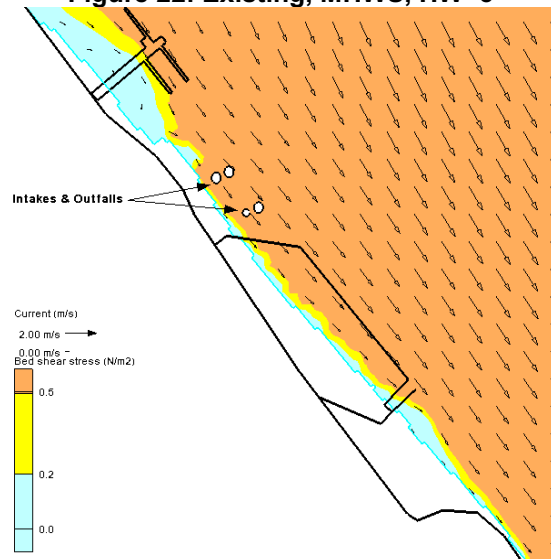


Figure 23: MEP chamfer quay, MHWS, HW+5

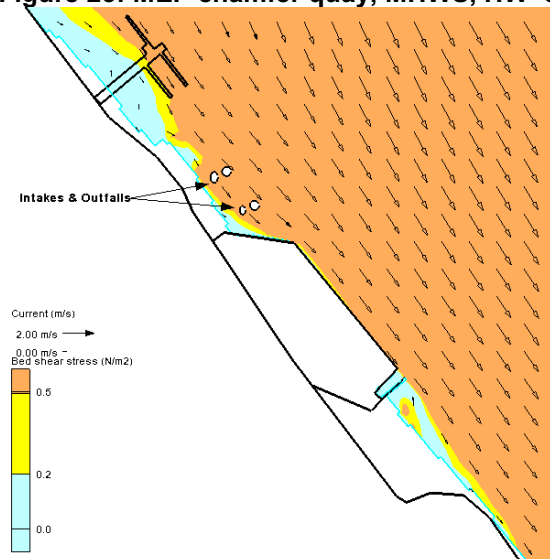


Figure 24: Existing, MHWS, HW+6

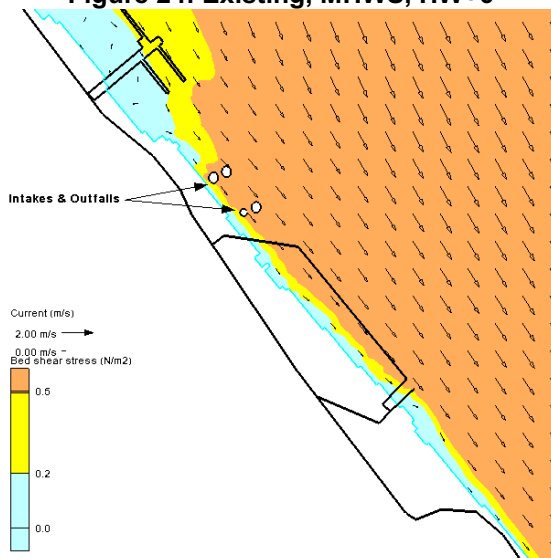


Figure 25: MEP chamfer quay, MHWS, HW+6

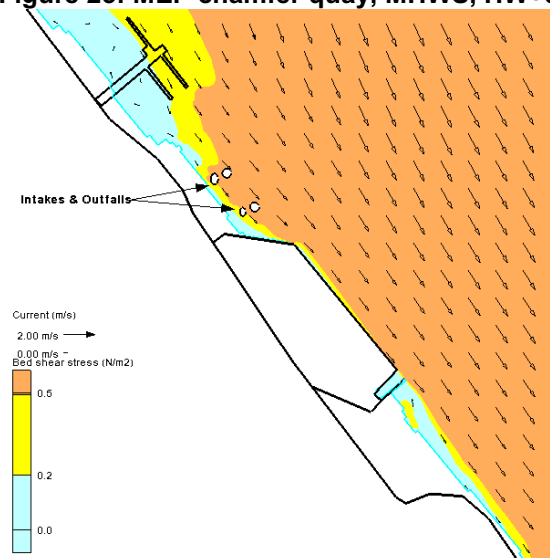


Figure 26: Existing, MHWN, HW-5

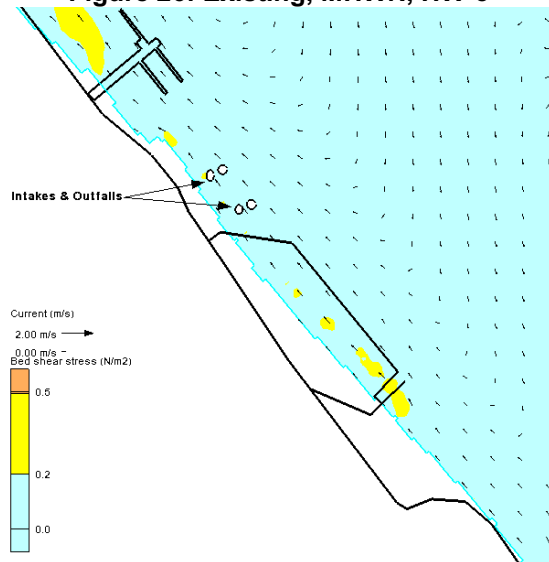


Figure 27: MEP chamfer quay, MHWN, HW-5

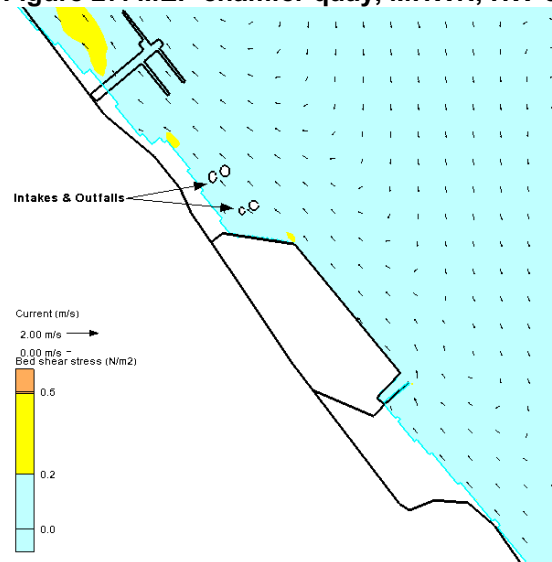


Figure 28: Existing, MHWN, HW-4

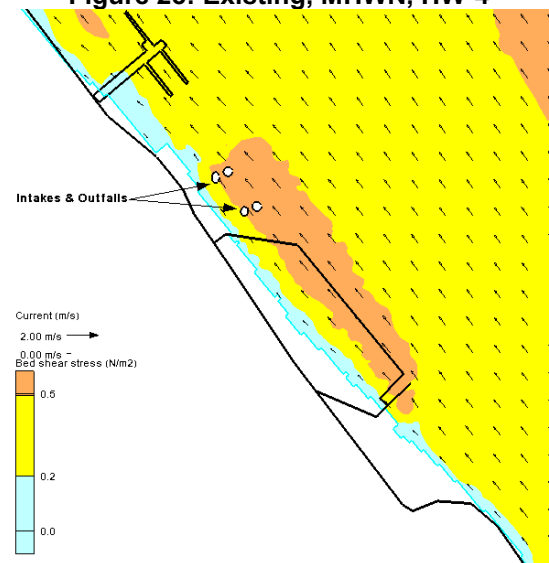


Figure 29: MEP chamfer quay, MHWN, HW-4

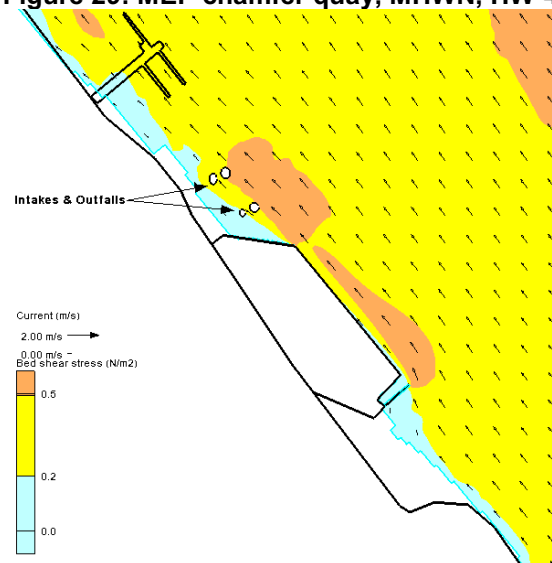


Figure 30: Existing, MHWN, HW-3

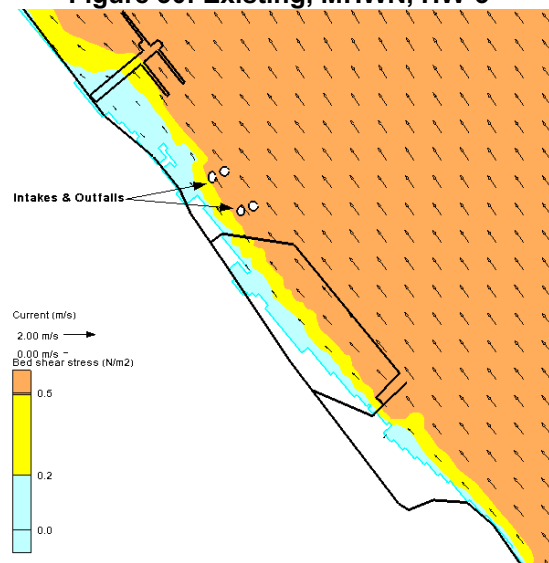


Figure 31: MEP chamfer quay, MHWN, HW-3

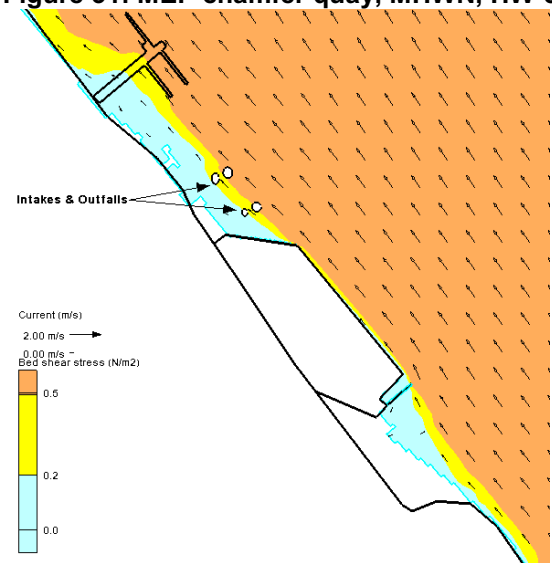


Figure 32: Existing, MHWN, HW-2

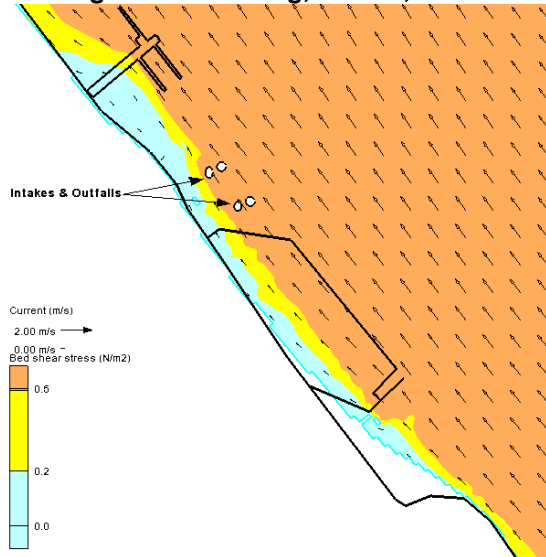


Figure 33: MEP chamfer quay, MHWN, HW-2

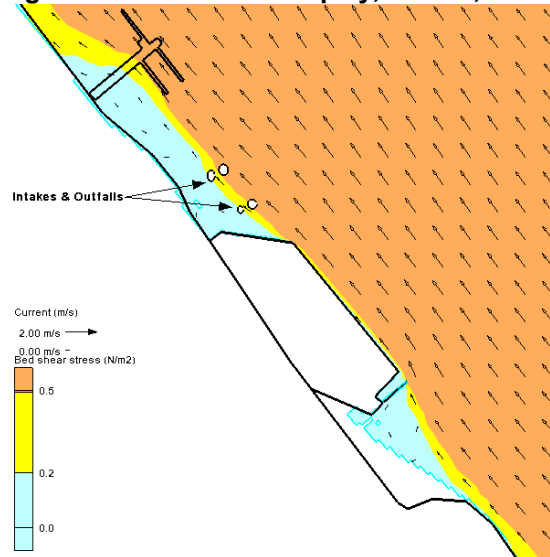


Figure 34: Existing, MHWN, HW-1

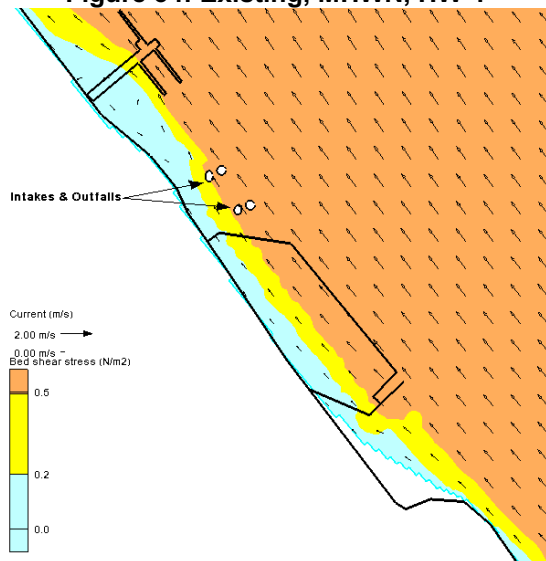


Figure 35: MEP chamfer quay, MHWN, HW-1

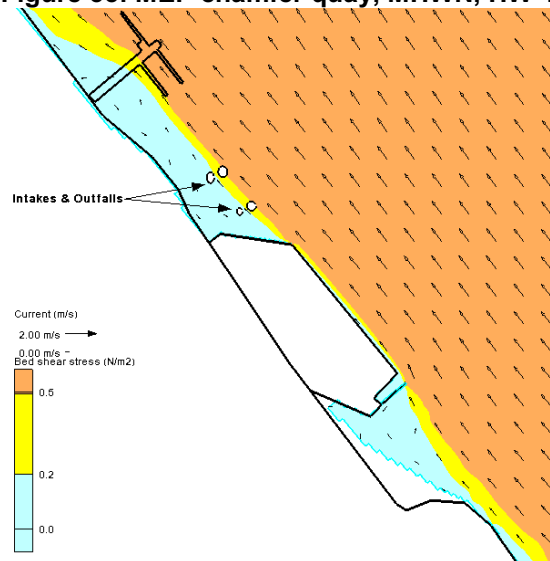


Figure 36: Existing, MHWN, HW

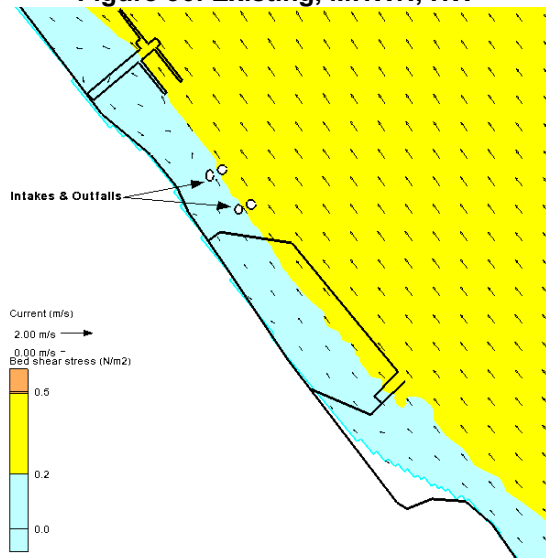


Figure 37: MEP chamfer quay, MHWN, HW

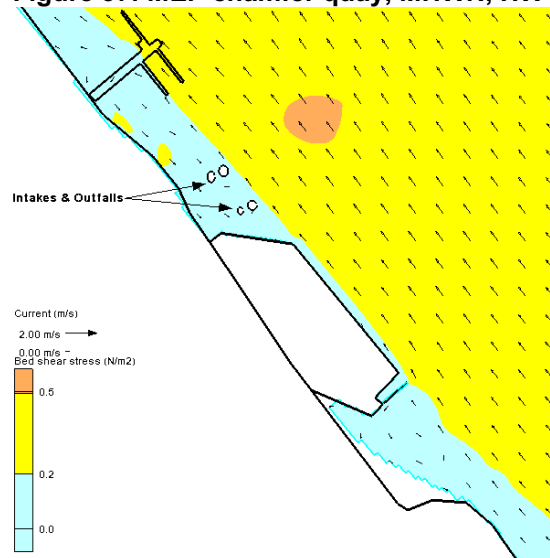


Figure 38: Existing, MHWN, HW+1

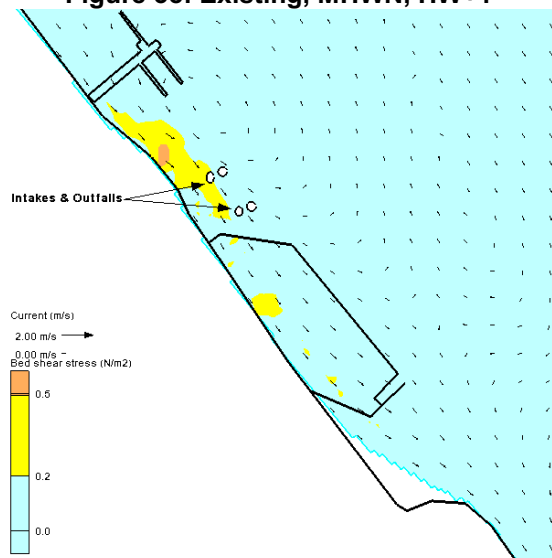


Figure 39: MEP chamfer quay, MHWN, HW+1

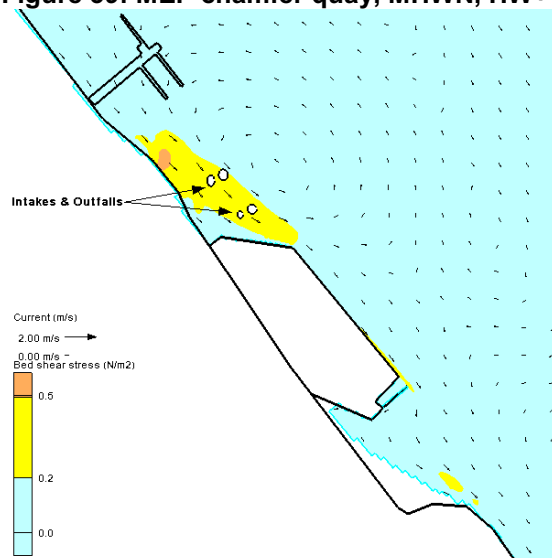


Figure 40: Existing, MHWN, HW+2

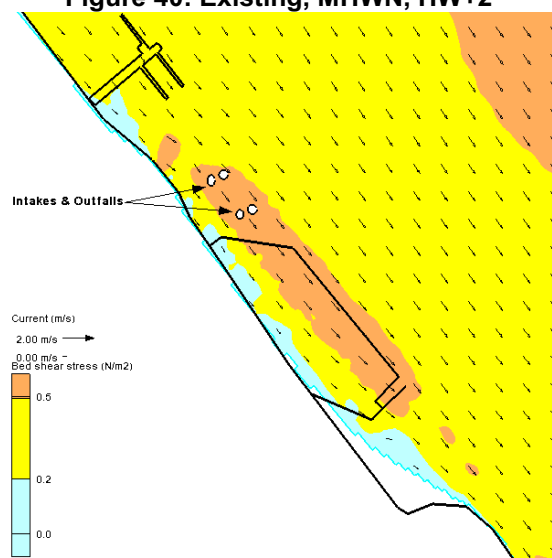


Figure 41: MEP chamfer quay, MHWN, HW+2

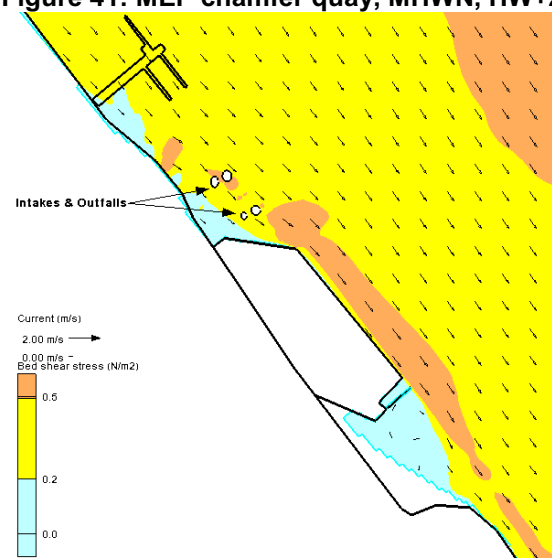


Figure 42: Existing, MHWN, HW+3

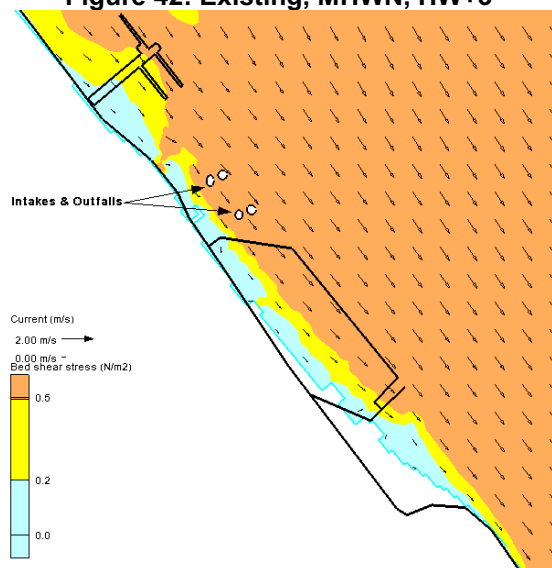


Figure 43: MEP chamfer quay, MHWN, HW+3

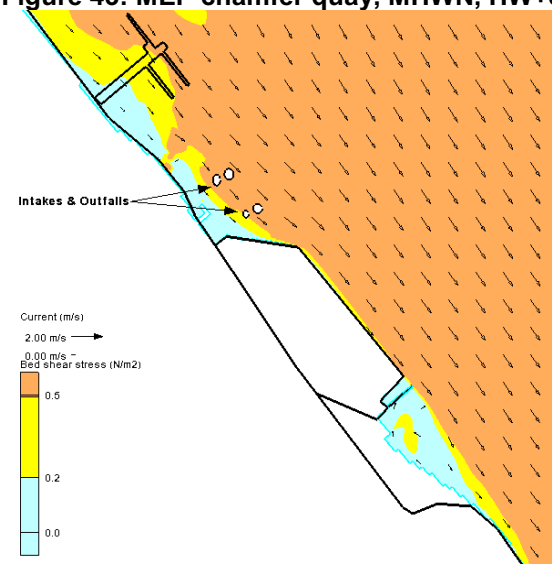


Figure 44: Existing, MHWN, HW+4

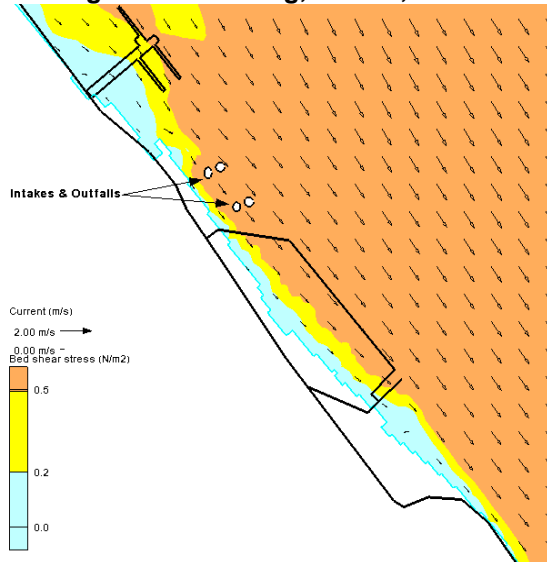


Figure 45: MEP chamfer quay, MHWN, HW+4

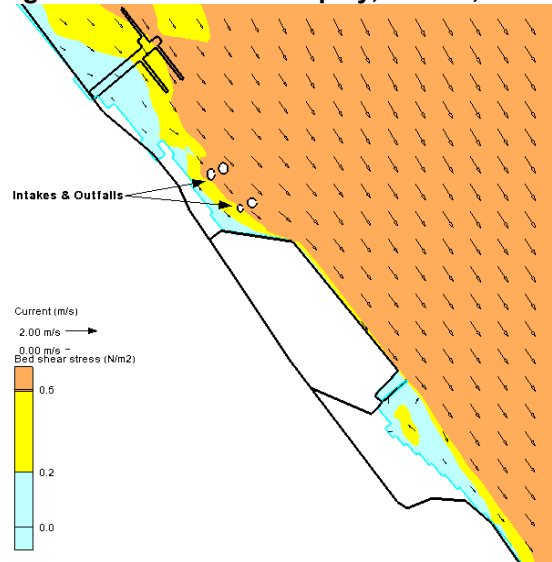


Figure 46: Existing, MHWN, HW+5

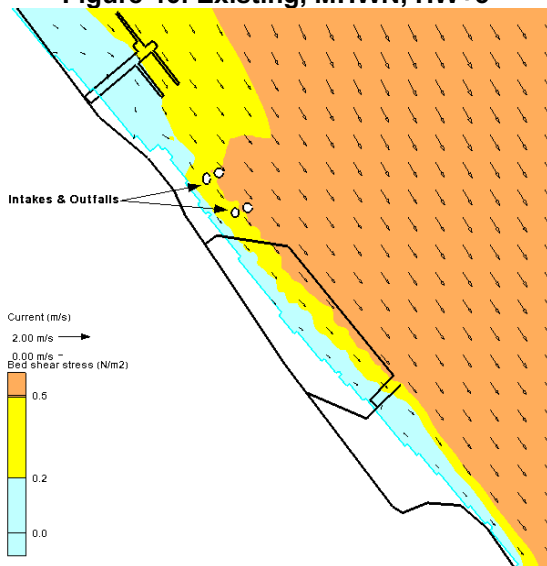


Figure 47: MEP chamfer quay, MHWN, HW+5

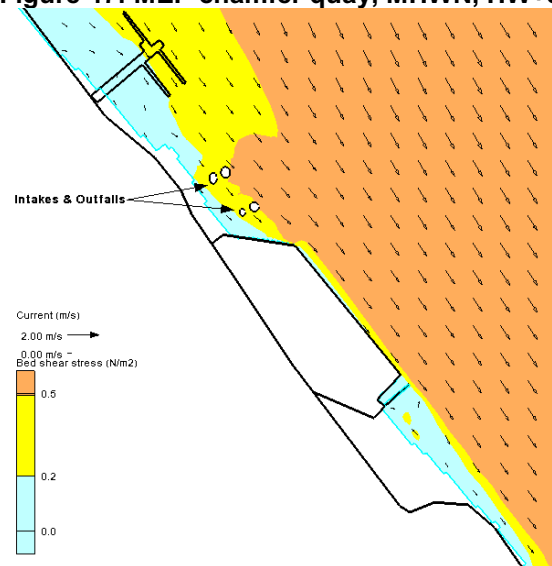


Figure 48: Existing, MHWN, HW+6

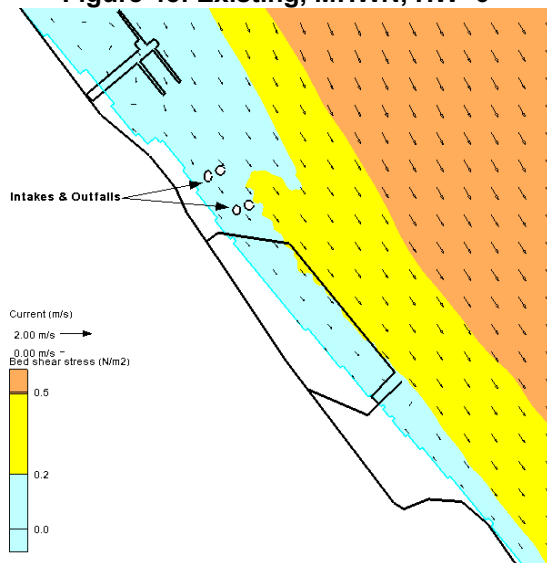


Figure 49: MEP chamfer quay, MHWN, HW+6

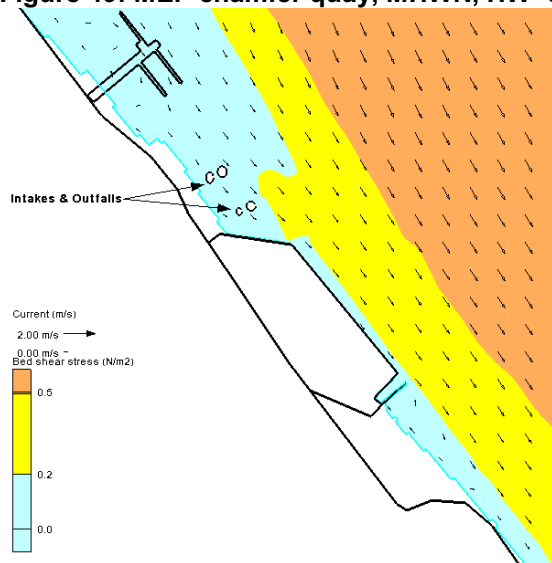


Figure 50: Model MHWS water level at E.ON intake

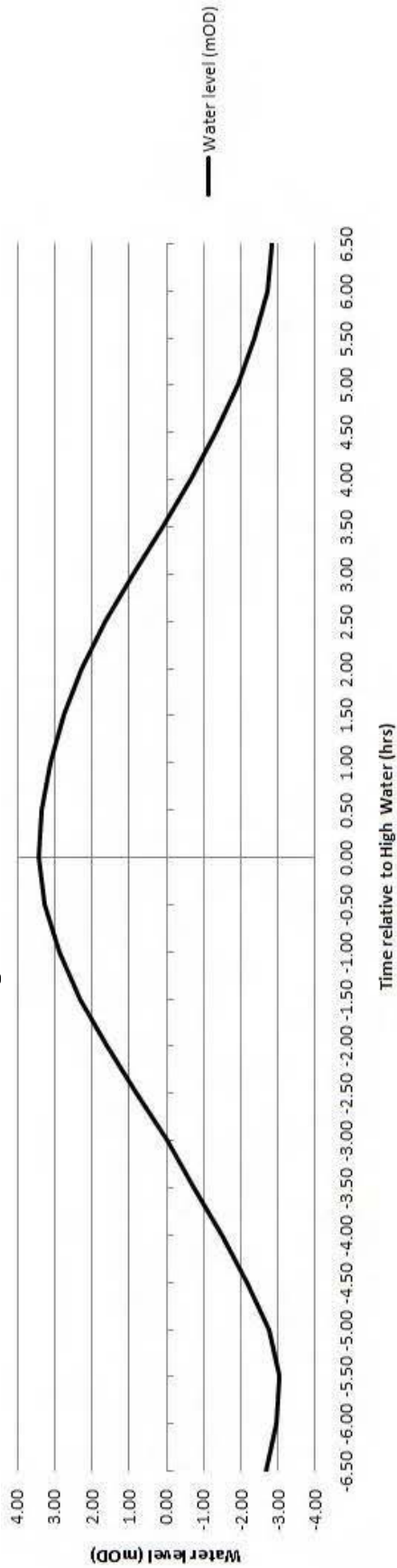


Figure 51: Bed shear stresses associated with Figure 50 at E.ON intake/outfall for various scenarios

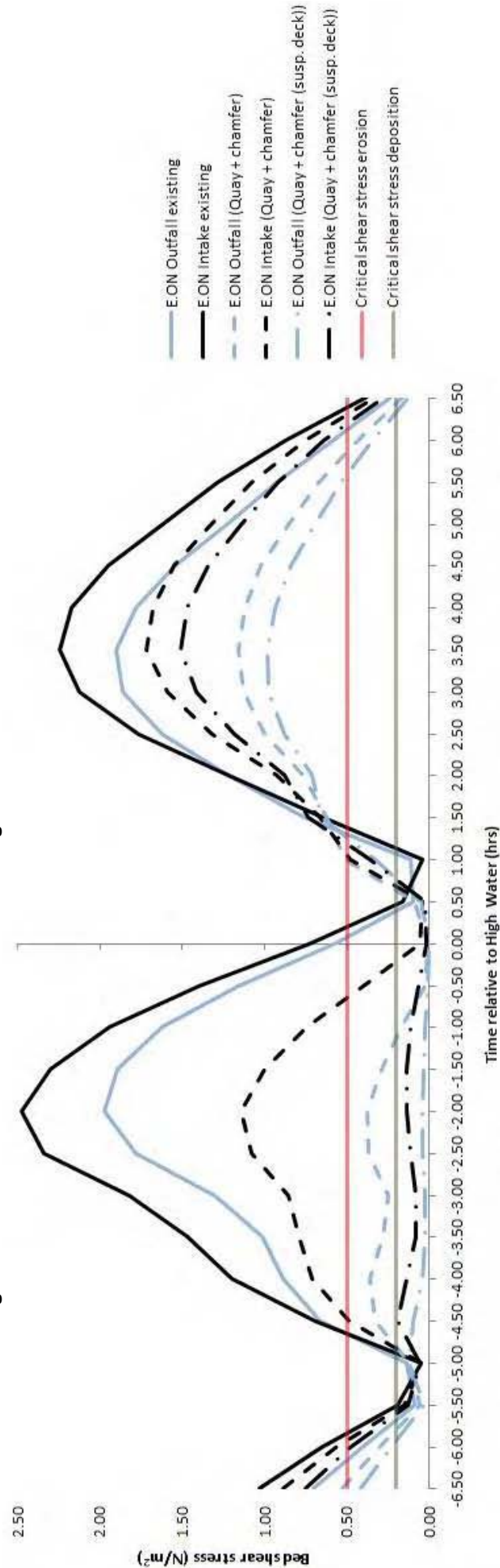


Figure 52: Model MHWN water level at E.ON intake

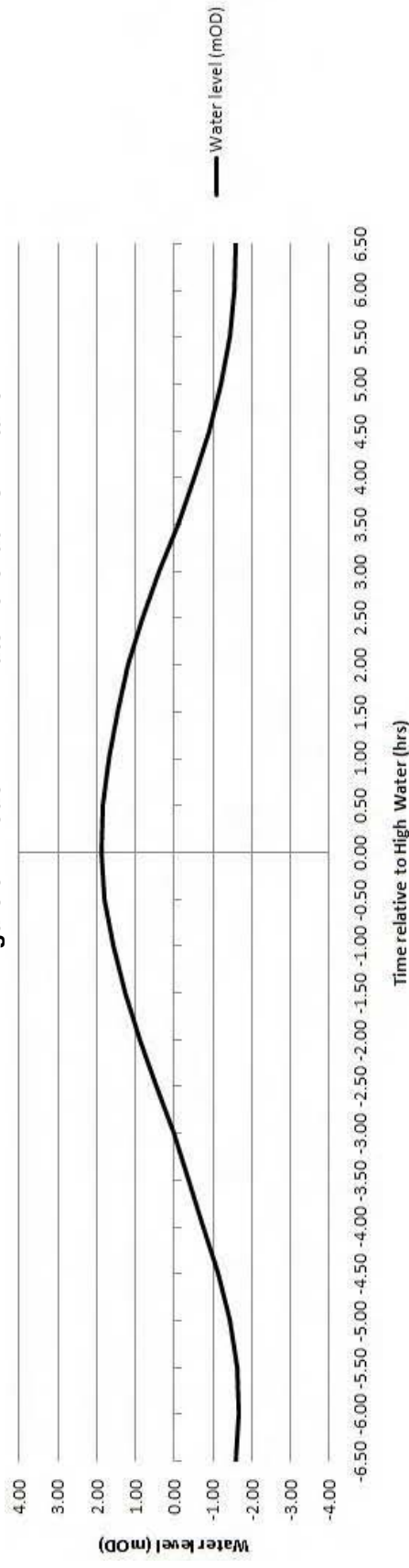
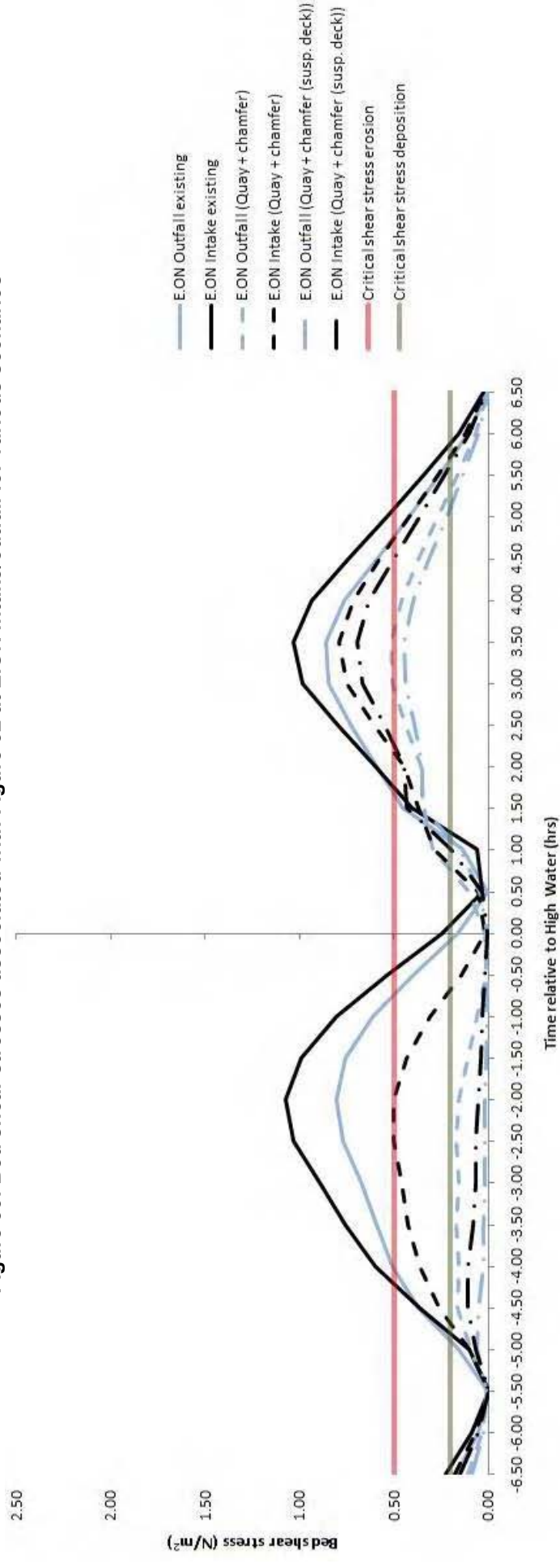



Figure 53: Bed shear stresses associated with Figure 52 at E.ON intake/outfall for various scenarios



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ANNEX 4

JBA Consulting

6 Scenarios Mitigation Modelling Assessment

JBA Project Code 2010s4456
Contract Humber Estuary Quay Design Modelling
Client Able UK Ltd.
Day, Date and Time 17th June 2011
Author C Batstone & G Heritage
Reviewed by K. Keating (JBA), John Harris (Hydraulics Research Wallingford)
Subject File note 18: 6 scenarios mitigation modelling assessment

Synopsis

This file note provides the results from HD model runs for various mitigation scenarios to address the potential for increased accumulation to the north of the AMEP quay.

Methodology

The HD model was run for a range of scenarios as listed below:

1. Existing: the existing bathymetry and no quay;
2. Chamfer, original quay line: a chamfer is present on the northern edge of the quay, beginning 1km from the south-eastern edge of the quay frontage with a 45 angle from the frontage line. The frontage position (quay line) is as originally planned;
3. Chamfer, 15m retreated quay line: as scenario 2, with the quay line (and dredge pocket) set back 15m towards the shoreline;
4. Chamfer, 30m retreated quay line: as scenario 2, with the quay line set back 30m towards the shoreline;
5. Chamfer + suspended deck, original quay line: as scenario 2, with a 200m long suspended deck added to increase the length of the quay frontage to 1.2km;
6. Chamfer + suspended deck, 15m retreated quay line: as scenario 5, with the quay line set back 15m towards the shoreline;
7. Chamfer + suspended deck, 30m retreated quay line: as scenario 5, with the quay line set back 30m towards the shoreline.

Bed shear stresses were extracted from the model runs at 30 min sample intervals for both the MHWS and MHWN tidal cycle simulations. The shear stresses were extracted at the locations of the Centrica intake and outfall, the EON intake and outfall and a position 30m directly offshore from the EON intake. Bed shear stresses from the model were extracted at this latter position as this represented the location where the EON intake could potentially be moved to.

The bed shear stresses over a tidal cycle are summarised as follows:

1. Flood excess: this is the sum of the bed shear stress excess values over the 0.5 N/m^2 erosion threshold for the flood tide (e.g. if all 12 samples during the flood tide = 2 N/m^2 , then the flood excess would be = 12×1.5).
2. Flood deficit: this is the sum of the bed shear stress deficit values over the period of the flood tide. The bed shear stress deficit value at a time is defined as the amount by which the stress drops below the 0.2 N/m^2 deposition threshold.
3. Ebb excess: this is calculated as 1 for the ebb period of the tide.
4. Ebb deficit: this is calculated as 2 for the ebb period of the tide.

Erosion thresholds were set according to the reviewed values for silts used in the Short-term morphologic modelling of the Humber Estuary with the Delft3D model (Van Ormondt, M. & Roelvink, D. 2004). These values are similar to those found by Amos et al (1998) in the estuary and the more general review of Black et al (2002). It should be recognised, however, that a single threshold representation of a complex set of suspended grain sizes is an approximation of reality.

A comparison of these values between the various mitigation scenarios indicates how the bed shear stress (and consequently the sedimentary) regimes are likely to change at the intake/outfall locations.

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Results: E.ON intake

Table 1 and Table 2 summarise the impacts on the bed shear stress regime at the E.ON intake. The least impact is predicted for no suspended deck, with the quay line moved back 30m. With no deck and the quay line in the original position the flood excess value drops by half from the existing scenario for MHWS (a larger drop is predicted for MHWN), suggesting a significant potential for increased deposition. Of the suspended deck options, moving the quay line back 30m leads to much less impact than having it at the original quay line, a scenario which leads to the largest predicted impact and greatest potential for increased deposition.

Table 1: EON intake (MHWS): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	11.3	0.2	10.9	0.0
Chamfer, original quay line	5.7	0.3	9.1	0.0
Chamfer, 15m retreated quay line	7.4	0.3	9.7	0.0
Chamfer, 30m retreated quay line	9.3	0.2	10.4	0.0
Chamfer + suspended deck, original quay line	3.4	0.3	7.8	0.0
Chamfer + suspended deck, 15m retreated quay line	5.6	0.3	8.5	0.0
Chamfer + suspended deck, 30m retreated quay line	8.3	0.3	9.4	0.0

Table 2: EON intake (MHWN): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	2.7	0.3	2.1	0.3
Chamfer, original quay line	0.7	0.4	1.4	0.3
Chamfer, 15m retreated quay line	1.3	0.3	1.6	0.3
Chamfer, 30m retreated quay line	2.0	0.3	1.8	0.3
Chamfer + suspended deck, original quay line	0.1	0.4	1.0	0.3
Chamfer + suspended deck, 15m retreated quay line	0.6	0.4	1.2	0.3
Chamfer + suspended deck, 30m retreated quay line	1.6	0.3	1.5	0.3

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Results: E.ON outfall

These results are summarised in Table 3 and Table 4. Significant impact on the bed shear stress regime at the E.ON outfall is predicted for all scenarios, particularly during the flood tide, with the no deck/30m set-back quay line scenario causing the least impact.

Table 3: EON outfall (MHWS) Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	7.8	0.2	8.3	0.0
Chamfer, original quay line	1.4	0.3	5.1	0.0
Chamfer, 15m retreated quay line	2.2	0.3	5.6	0.0
Chamfer, 30m retreated quay line	3.1	0.2	6.3	0.0
Chamfer + suspended deck, original quay line	0.1	0.4	3.4	0.0
Chamfer + suspended deck, 15m retreated quay line	0.8	0.3	4.0	0.0
Chamfer + suspended deck, 30m retreated quay line	1.8	0.3	4.7	0.0

Table 4: EON outfall (MHWN): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	1.2	0.3	1.4	0.3
Chamfer, original quay line	0.0	0.5	0.3	0.4
Chamfer, 15m retreated quay line	0.0	0.5	0.4	0.4
Chamfer, 30m retreated quay line	0.0	0.4	0.6	0.4
Chamfer + suspended deck, original quay line	0.0	0.7	0.0	0.4
Chamfer + suspended deck, 15m retreated quay line	0.0	0.6	0.1	0.4
Chamfer + suspended deck, 30m retreated quay line	0.0	0.5	0.2	0.4

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Results: Centrica intake

These results are summarised in Table 5 and Table 6. The scenarios set back by 30m lead to the least predicted impact at the intake, with the quay line farther out leading to significant impact predicted. Sediment transport modelling of the 30m set-back scenarios will help to elucidate whether the reduction in the bed shear stresses predicted at this location are significant in terms of long-term potential for increased accumulation.

Table 5: Centrica intake (MHWS): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	11.0	0.2	10.2	0.1
Chamfer, original quay line	6.3	0.3	7.5	0.1
Chamfer, 15m retreated quay line	7.4	0.3	7.7	0.1
Chamfer, 30m retreated quay line	8.5	0.2	7.9	0.1
Chamfer + suspended deck, original quay line	5.0	0.3	7.1	0.0
Chamfer + suspended deck, 15m retreated quay line	6.4	0.3	7.4	0.0
Chamfer + suspended deck, 30m retreated quay line	7.7	0.3	7.7	0.1

Table 6: Centrica intake (MHWN): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	2.5	0.3	1.9	0.3
Chamfer, original quay line	0.8	0.4	1.1	0.4
Chamfer, 15m retreated quay line	1.2	0.3	1.1	0.4
Chamfer, 30m retreated quay line	1.6	0.3	1.2	0.4
Chamfer + suspended deck, original quay line	0.4	0.4	1.0	0.3
Chamfer + suspended deck, 15m retreated quay line	0.9	0.4	1.1	0.4
Chamfer + suspended deck, 30m retreated quay line	1.3	0.3	1.1	0.4

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Results: Centrica outfall

Table 7 and Table 8 summarise the results of the predicted impacts on the bed shear stress regime at the Centrica outfall. Significant impacts are predicted for all scenarios, with the no deck/30m set-back option leading to the least predicted impact. Sediment transport modelling of all scenarios will help to elucidate whether the predicted decreases in bed shear stresses at these locations will lead to potential increases in accumulation at this location.

Table 7: Centrica outfall (MHWS): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	7.2	0.1	9.0	0.0
Chamfer, original quay line	2.7	0.2	7.1	0.0
Chamfer, 15m retreated quay line	3.4	0.2	7.4	0.0
Chamfer, 30m retreated quay line	4.0	0.2	7.7	0.0
Chamfer + suspended deck, original quay line	1.3	0.3	6.6	0.0
Chamfer + suspended deck, 15m retreated quay line	2.1	0.3	6.9	0.0
Chamfer + suspended deck, 30m retreated quay line	3.0	0.2	7.3	0.0

Table 8: Centrica outfall (MHWN): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	1.0	0.3	1.6	0.3
Chamfer, original quay line	0.0	0.4	0.9	0.3
Chamfer, 15m retreated quay line	0.1	0.4	1.0	0.3
Chamfer, 30m retreated quay line	0.2	0.4	1.1	0.3
Chamfer + suspended deck, original quay line	0.0	0.5	0.8	0.3
Chamfer + suspended deck, 15m retreated quay line	0.0	0.4	0.9	0.3
Chamfer + suspended deck, 30m retreated quay line	0.0	0.4	1.0	0.3

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Results: 30m offshore from E.ON intake

These results are summarised in Table 9 and Table 10. If the E.ON intake were moved 30m offshore, then the no deck quay moved 30m inshore is predicted to lead to no increased accumulation at this location. The addition of the suspended deck at this 30m inshore line leads to minimal impact on the bed shear stress regime. The suspended deck at the original quay line scenario is predicted to lead to significant impact on the bed shear stress regime at this location.

Table 9: 30m offshore from EON intake (MHWS): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	13.1	0.2	12.6	0.0
Chamfer, original quay line	8.9	0.3	11.4	0.0
Chamfer, 15m retreated quay line	11.1	0.2	12.0	0.1
Chamfer, 30m retreated quay line	13.1	0.2	12.7	0.1
Chamfer + suspended deck, original quay line	7.4	0.3	10.4	0.0
Chamfer + suspended deck, 15m retreated quay line	10.2	0.3	11.3	0.0
Chamfer + suspended deck, 30m retreated quay line	12.5	0.2	12.3	0.0

Table 10: 30m offshore from EON intake (MHWN): Shear stress integrated over flood and ebb tides.

	Flood excess	Flood deficit	Ebb excess	Ebb deficit
Existing	3.5	0.3	2.6	0.3
Chamfer, original quay line	1.9	0.3	2.1	0.3
Chamfer, 15m retreated quay line	2.7	0.3	2.3	0.3
Chamfer, 30m retreated quay line	3.5	0.2	2.6	0.3
Chamfer + suspended deck, original quay line	1.3	0.3	1.8	0.3
Chamfer + suspended deck, 15m retreated quay line	2.4	0.3	2.1	0.3
Chamfer + suspended deck, 30m retreated quay line	3.3	0.2	2.4	0.3

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Summary

The analysis reveals that opportunities for sedimentation (where the local shear stress drops below 0.2 Nm^{-2}) generally occur under neap tide conditions (e.g. Tables 4 & 8). Both the Centrica and E.ON outfalls are potentially affected. The opportunity for sedimentation occurs mostly on the flood tide, although in the case of the E.ON outfall this period can extend across to the ebb flow too (Table 4). Calculation of the overall shear stress balance across the flood-ebb cycle (Table 11) reveals that all of the mitigation scenarios fail to prevent potential sedimentation at the E.ON outfall under neap conditions. This is most pronounced for the chamfer with suspended deck and original quay line (here the Centrica outfall is on the threshold of possible sedimentation too). The best option is the chamfer with a 30m retreated quay line.

Looking at the longer-term shear stress variation between spring and neap tides it is clear that the spring tide shear stress levels are well in excess of the 0.5 Nm^{-2} threshold level for erosion. As such, despite some potential for consolidation of the neap cycle deposits, the predicted neap tide sedimentation is likely to be re-suspended preventing long-term sediment accumulation.

Table 11. Neap tide shear stress imbalances promoting sedimentation at the intake and outfall sites.

	E.ON intake	Centrica intake	E.ON outfall	Centrica outfall	30m Offshore of outfalls
Existing					
Chamfer, original quay line			-.6		
Chamfer, 15m retreated quay line			-.5		
Chamfer, 30m retreated quay line			-.2		
Chamfer + suspended deck, original quay line			-.1.1	0	
Chamfer + suspended deck, 15m retreated quay line			-.9		
Chamfer + suspended deck, 30m retreated quay line			-.7		

The results thus suggest only local and short term potential sedimentation regardless of quay design, at worse there should only be localised sedimentation at the E.ON outfall for a short period around the neap tide. Conditions 30 m offshore from the intakes/outfalls (Tables 9 & 10) are conducive to keeping fine material in suspension exhibiting considerable excess shear stress beyond that needed to mobilise unconsolidated fine sediment. However, it should be remembered that the spatial pattern of shear stress shows a sharp reduction in the vicinity of the intakes/outfalls (see JBA File Note 17). Hence the shear results are sensitive to the accuracy of the modelling process around the intakes and outfalls and will be influenced by the model resolution and the assumption of a fixed bathymetry across the area. Potential shoreline sedimentation in the vicinity of the proposed quay will cause a change in the shear stress pattern across the area and will result in changes in the shear stress predictions around the intakes and outfalls made above.

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Amos, C. L., Brylinsky, M., Sutherland, T. F., O'Brien, D., Lee, S., and Cramp, A. (1998). The stability of a mudflat in the Humber estuary, South Yorkshire, UK. *J. Geol. Soc. (London)*, 139, 25–44.

Black, K.S., Tolhurst, T.J., Hagerthey, S.E., and Paterson, D.M., (2002) Working with Natural Cohesive Sediments. *Journal of Hydraulic Engineering*, January, Vol. 128 (1), 2-8

Van Ormondt, M. & Roelvink, D. (2004). Short-term morphologic modelling of the Humber Estuary with Delft3D. Report to the Environment Agency, UK.

JBA File Note 17: MEP chamfer quay impacts on sedimentary regime