5 HYDRODYNAMIC AND SEDIMENTARY REGIME

5.1 Introduction

5.1.1 This section of the ES describes the existing environment for the hydrodynamic and sedimentary regimes of the Tees estuary and the potential effects associated with the construction and operational phases of the proposed scheme. It includes:

- A description of the methodology and studies that were undertaken to inform the EIA process.
- A description of the existing environment based on available data and the studies undertaken.
- An assessment of potential effects based on the studies undertaken for the EIA.

5.1.2 There are no proposals to decommission the port terminal and, therefore, decommissioning is not relevant to this chapter of the ES.

5.2 Policy and consultation

National Policy Statement for Ports

5.2.1 The assessment of potential effects on the hydrodynamic and sedimentary regimes has been made with reference to the NPS for Ports (Department for Transport, 2012). The particular assessment requirements relevant to the hydrodynamic and sedimentary regimes / coastal processes, as presented within the NPS for Ports, are summarised in **Table 5-1**.

Consultation

5.2.2 A summary of the responses received in the PINS Scoping Opinion (January 2014) (**Appendix 4.1**) and through consultation under Section 42 of the Planning Act 2008 (September 2014) of relevance to the hydrodynamic and sedimentary regimes is presented in **Table 5-2**.

Table 5-1 Summary of NPS for Ports requirements with specific regard to coastal processes

NPS requirements	NPS reference
Where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures.	Section 5.3.4
The ES should include an assessment of the effects on the coast. In particular, applicants should assess: • the impact of the proposed project on coastal processes and geomorphology, including by taking account of potential impacts from climate change. If the development will have an impact on coastal processes, the applicant must demonstrate how the impacts will be managed to minimise adverse impacts on other parts of the coast; and • the implications of the proposed project on strategies for managing the coast, as set out in Shoreline Management Plans, any relevant marine plans, River Basin Management Plans and capital programmes for maintaining flood and coastal defences.	Section 5.3.5
The decision-maker should not normally consent new development in areas of dynamic shorelines where the proposal could inhibit sediment flow or have an impact on coastal processes at other locations. Impacts on coastal processes must be managed to minimise adverse impacts on other parts of the coast. Where such proposals are brought forward, consent should only be granted where the decision-maker is satisfied that the benefits (including need) of the development outweigh the adverse impacts.	Section 5.3.9

Table 5-2 Summary of comments in the PINS Scoping Opinion and received during consultation under Section 42 of the Planning Act 2008 with regard to the hydrodynamic and sedimentary regimes

Consultation Comment	Response / Section of the ES in which the comment has been addressed
Scoping Opinion (January 2014)	
Secretary of State	
The physical scope of the assessment should be clarified in the ES. It will be important to carefully justify the physical area for this assessment.	**Section 5.3**
The applicant is advised to ensure that existing data sources to be drawn upon are relevant to the development and is up to date and representative of the existing baseline. Where data is not recent, justification should be provided in the ES to demonstrate how it remains relevant.	**Section 5.3**
Full copies of all reports from which data is drawn are to be provided in the ES.	**Appendix 5.1**
The ES should provide the calibration and validation methods and copies of the modelling report.	**Appendix 5.2**

Consultation Comment	Response / Section of the ES in which the comment has been addressed
The approach to wave modelling (which is dependent on the quay option to be selected) needs to be agreed with the MMO.	The approach to wave modelling has been discussed at consultation meetings. Wave modelling has been undertaken for both proposed options of quay construction. **Section 5.6**
Effects resulting from sediment dispersion relating to quay construction are to be assessed as part of the EIA.	**Section 5.5**
The ES should provide an assessment of the impact on hydrodynamics and sedimentary processes resulting from maintenance dredging works that are intended to be carried out. The ES should include details of the proposed deposit locations for the spoil dredged as part of maintenance works.	**Section 5.6**
Natural England	
Natural England would welcome detailed information on how the deepened estuary channel may act as a sediment trap, intercepting fine sediment and reducing the level of deposition at the intertidal areas of Seal Sands and South Gare and Coatham Sands SSSI. A potential hypothesis for decline of SPA birds in the estuary is a shift from fine sediments to coarse marine ones. The potential impact on sediment flows should be examined in detail.	**Section 5.6**
MMO	
The MMO concurs with the description of likely impacts set out in Section 5.1 of the Scoping Report.	Noted
TELEMAC-3D and SEDPLUME are suitable for the modelling proposed but the ES must include calibration and validation methods and also the modelling reports.	Noted (see **Appendix 5.2**)
The Scoping Report states that maintenance dredging may be required and that this will be assessed during the EIA. The EIA must also assess the potential to alter the sediment regime and cause additional sedimentation which could increase dredging operations at other locations in the vicinity.	**Section 5.6**
The MMO welcomes the commitment to assess sediment dispersion (or retention) from the offshore disposal sites and to assess and quantify the potential for release of sediment into the Tees estuary including through the dewatering of Bran Sands lagoon.	Noted

Consultation Comment	Response / Section of the ES in which the comment has been addressed
Some of the reports referenced in the Scoping Report could be considered to be out of date. If they are to be relied upon, the ES must justify why the reports remain valid and should include copies of the reports as appendices.	The results of modelling work undertaken for previous projects were not used to inform this EIA. Validated models have been refined to model the predicted effects of the proposed harbour facilities. The modelling results are appended to the ES (**Appendix 5.1 and 5.2**).
Two offshore disposal sites have been identified that could potentially accept the dredged material. TY160 has previously received quantities that would be similar to the proposed scheme. TY150 did receive over 1 million tonnes in 1999 but since then has only received 74,903 tonnes in total. The EIA must assess the fate of any material disposed at sea, in particular, whether and how this would be dispersed.	**Section 5.5**
Section 42 responses (September 2014)	
MMO	
Paragraph 5.3.2 states numerical modelling from NGCT has been used and that the calibration and validation is still valid. Justification of how the data is still valid should be provided given the age of the data. The MMO would also expect the model to include new projects and applications for a CIA as it is not clear that the model has been updated to reflect changes in the estuary.	The results of modelling work undertaken for previous projects were not used to inform this EIA. There have been no significant developments within the Tees estuary which could impact upon the validity of the model. The model mesh was refined in the area of interest around the proposed port terminal. The CIA has included relevant consented projects that have not yet been implemented.
Paragraph 5.3.3 states implications of predicted changes will be assessed in terms of significance of the potential impacts on various environmental parameters, but does not note impacts on erosion and accretion; this paragraph should be clarified.	Noted; this has been amended within **Section 5.3**
When using reports that are not current (e.g. NGCT and QEII ESs) a justification for why the results are still valid should be included in the ES. The MMO would also expect modelling reports to be included as appendices to the ES for cross referencing.	The results of modelling work undertaken for previous projects were not used to inform this EIA. Validated models have been refined to model the predicted effects of the proposed harbour facilities. The modelling results are appended to the ES (**Appendix 5.1**).
The MMO would expect full details of sediment plume modelling to be included in the ES i.e. calibration, validation, increase in suspended sediment data.	**Section 5.5 and Appendix 5.2**
The MMO would like to review the modelling that was used to calculate the 8,000m^3 increase of sediment in chart area 9	Please refer to **Appendix 5.1** which contains the modelling report.

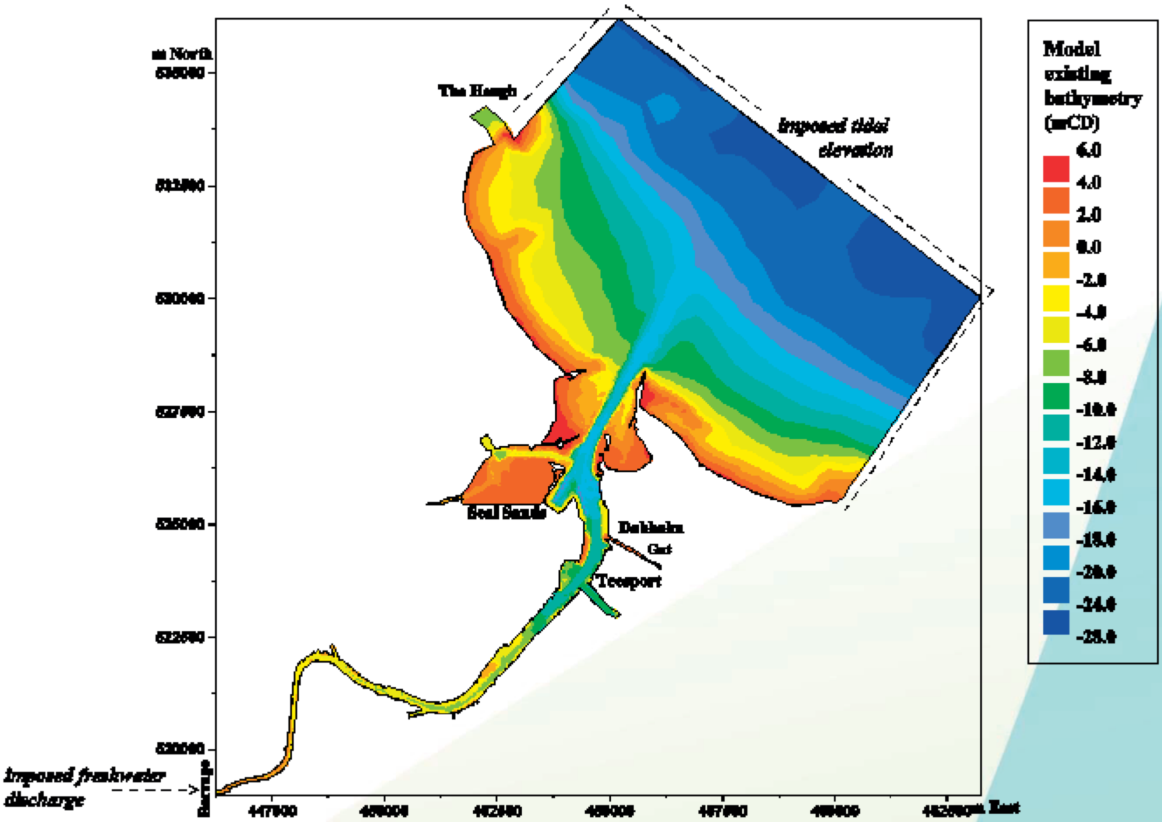
Consultation Comment	Response / Section of the ES in which the comment has been addressed
It will be necessary to assess whether the works will affect any other part of the Tees estuary in terms of sedimentation or increased erosion (outside of Chart area 9).	**Section 5.6**
The ~~applicant has stated if no alternative uses for~~ dredged material can be found, then all dredged material will be disposed of offshore. The applicant should ensure that if this is the case (or unknown at the time of submission) the EIA should assess the impacts of all material being disposed offshore.	Proposals for alternative uses of dredged material are set out in **Section 3**. Section 3 also sets out the proposed use of dredged material within the habitat enhancement proposals. The proposed scheme includes offshore disposal of dredged material for which no practicable alternative use is currently available. The predicted impacts associated with this are set out in **Section 25.**
Natural England	
Further clarity regarding the infill rate of 100,000m^3 per year is required. Is this the amount of material that will need to be maintenance dredged from the YPL dredge footprint each year? If so, 80,000m^3 of mud would be lost from the system, which could have been destined for Bran Sands or Seal Sands.	**Section 5.6**. There would be no effect on the rate of sediment input into the Tees as a result of the proposed scheme.
A full assessment of impacts due to dredging will be needed in the ES.	**Sections 5.5 and 5.6**
The impacts from increased wave height should be given due consideration even though the impact is low.	**Sections 8.6 and 9.6**
The PER states Chart area 8 has an annual infill rate of 84,000m^3, but Paragraph 5.4.20 suggests an infill rate of 100,000m^3 for the development footprint which is smaller than the whole of chart area 8. Further clarity on this is required.	The text within **Section 5.4** has been clarified to address this point.

5.3 Methodology

Study area

5.3.1 The study area for the assessment of hydrodynamic and sedimentary effects of the proposed scheme encompasses the tidal Tees estuary between Teesmouth and the Tees Barrage and Tees Bay, incorporating the existing dredged material disposal sites. The domain for the numerical modelling represents the study area for this aspect of the EIA and is shown in **Figure 5-1**.

Figure 5-1 Numerical modelling domain for the hydrodynamic and sedimentary studies



Methodology

5.3.2 The assessment of the hydrodynamic and sedimentary effects of the proposed scheme is based on numerical modelling tools first established and calibrated in support of the EIA for the consented (but not yet constructed) NGCT. This suite of modelling activities included tidal flow modelling, wave modelling, sediment transport, bed change modelling and modelling of sediment plume released from construction activities. The calibration effort put into these modelling tools means that the modelling suite is well calibrated and additional data collection and model validation was not considered necessary for the studies undertaken to support the proposed scheme. The calibration and validation reports are included within the ES at **Appendix 5.2**.

5.3.3 For the EIA process for the harbour facilities, new modelling studies were undertaken (as described in this chapter) based on refinement of the modelling tools which were originally set up for the NGCT scheme. The findings of these studies (undertaken specifically for the proposed harbour facilities) are presented within this chapter.

5.3.4 New data on bed sediment types anticipated to be dredged for the proposed scheme has been used in defining the detail of the dredging activity and to inform the modelling of the release of sediment during the dredging and disposal.

5.3.5 It should be noted that the implications of any predicted changes to / effects on the physical regime of the estuary (e.g. sediment accretion / erosion) were assessed in terms of the significance of the potential impact on various environmental parameters (e.g. marine ecology, water quality, fisheries, etc.) and the findings are set out in the appropriate chapters of the ES.

5.4 Existing environment

Historical context

5.4.1 Prior to the mid-19th century the Tees estuary was a wide, shallow estuary bordered by extensive wetlands and had tidal ingress for approximately 44km from the mouth. Since this time, the estuary has undergone substantial anthropogenic changes as the channel was trained, land was reclaimed and the channel deepened to its present depth.

5.4.2 Anthropogenic activities over the last 150 years have resulted in an estuary that is essentially a narrow 'canalised' channel bordered near the estuary mouth by sandy intertidal areas partly trained by various historic training works. Within this area, a remnant of the originally large Seal Sands, covering approximately 140ha, is divided from the other intertidal areas by Seaton Channel. Intertidal areas of 300ha remain at the estuary mouth. Approximately 15% of the intertidal area calculated for the pre-1800 situation remains.

5.4.3 The most recent major anthropogenic influence on the Tees estuary has been the construction of the Tees Barrage in the mid-1990s. The barrage (at Blue House Point) has truncated the tidal section (approximately 16.5km into the former estuary) and has reduced the tidal volume upstream of South Gare by about 7% (ABPmer, 2002).

Tides and water level

5.4.4 The tide at the mouth of the Tees estuary is observed to be very close to sinusoidal in shape with ranges of 4.6m and 2.3m for mean spring and neap tides respectively (UKHO, 2006). Mean High Water Spring (MHWS) tidal levels at the mouth of the Tees estuary are 5.50m above CD and 2.65m above OD respectively. The other tidal parameters of the estuary mouth are summarised in **Table 5-3** (ABPmer, 2002).

5.4.5 The variation between the astronomical maximum and minimum and the highest and lowest levels recorded indicate that the level can be influenced by meteorological effects, such as winds, surge and waves.

Table 5-3 Tidal levels for the Tees estuary

Description	Level (m CD; '+' indicates above CD, '-' indicates below CD)
Highest recorded water level	+6.86
Highest astronomical tide	+6.10
Mean high water spring tide	+5.50
Mean high water neap tide	+4.30
Mean sea level	+3.20
Mean low water neap tide	+2.00
Mean low water spring tide	+0.90
Lowest Astronomical Tide	0.00
Lowest recorded water level	-0.38

Fluvial flow

5.4.6 The River Tees has its source approximately 160km from the sea on Cross Fell in the Pennines and drains a catchment of 1,932km^2. The main freshwater input to the estuary is measured at Low Moor. HR Wallingford (1992) calculated the long term monthly mean flows for the period 1981 to 1988, which ranged from 9m^3/s in summer to 30m^3/s to 40m^3/s in winter. Lewis et al (1998), also looked at the flows at Low Moor and presented a long term average flow of 20m^3/s, a maximum recorded flow of 563m^3/s, a minimum of less than 3m^3/s and a 10% exceedence flow of about 47m^3/s.

5.4.7 The fluvial flow is further regulated by the Tees Barrage which is operated to maintain upstream water levels and prevent the upstream penetration of saline water. The flow through the Barrage is, therefore, very unlike the natural flow especially as the flows are no longer continuous.

Density effects

5.4.8 The regulated freshwater flow (as a result of the Barrage) enters the estuary and partially mixes with saline water entering through the estuary mouth. This partial mixing, the reduced tidal volume (and currents) and the associated longitudinal salinity gradient both contribute to a density driven gravitational circulation. This effect is a result of the density changing the vertical profile of the flow such that the ebb tide flows are strongest at the surface whereas the flood tide flows are more evenly spread through depth. The tidally averaged current tends, therefore, to be seawards in the surface waters and landwards in the waters closer to the bed.

5.4.9 In the Tees estuary, under many circumstances this effect becomes dominant such that continuous near-bed upstream (flooding) flows are observed. These effects are important in supplying sediment to the estuary from offshore (the main sediment supply).

Waves

5.4.10 Wave conditions in the Tees estuary are a combination of offshore swell and locally generated wind waves. The direction from which swell can enter the estuary is limited by the North Gare and South Gare breakwaters. The majority of offshore swell in the region has been found to come from a northerly direction (HR Wallingford, 2002).

5.4.11 An analysis of wind speeds observed at South Gare between 1999 and 2005 undertaken as part of the studies for the NGCT (HR Wallingford, 2006) shows the most common winds are from the south-west (210°N to 270°N) but the most common large wind events (> 40 m/s) are from the north.

5.4.12 From the wave climate observed at the waverider buoy north of Tees North Buoy the return periods for significant wave heights were calculated (**see Table 5-4**) (HR Wallingford, 2006).

Table 5-4 Calculated wave return periods at waverider buoy locations

Return period (years)	Significant wave height (Hs (m))
0.1	3.87
1	6.03
10	8.63
50	10.69

5.4.13 In the Tees estuary and around the site of the proposed scheme, only remnants of the swell wave energy combined with short period local wind waves (including those for winds from the south-west) occur due to the limitation in the penetration of swell waves into the estuary as a result of the North Gare and South Gare breakwaters.

Sediment

5.4.14 In general, suspended sediment concentrations are low within the estuary and within Tees Bay. The highest observed values tend to occur on spring tides. This relationship is not strong, but the extreme values are also attributed to either high rainfall or storm events. In general, the suspended sediment concentrations appear to be dominated by freshwater inputs above Middlesbrough Reach and marine influences further downstream.

5.4.15 In the vicinity of the proposed scheme, suspended sediment concentrations are, for the most part, less than 20mg/l with short-term peaks from 40mg/l to 80mg/l. In terms of the tidal sequence, the highest suspended sediment levels occur close to high water. After storm periods, higher concentrations of suspended sediment have been noted around the Shell Jetty, but with little penetration further up the estuary. On other occasions the reverse has been true, thus the effect of storm events is not consistent within the estuary.

5.4.16 Historic bed sampling results in the vicinity of the proposed scheme show bed sediments in the area to comprise predominantly (65% to 70%) silt, with some (20%) clay and the remainder sand and gravel

(Halcrow, 1991). These observations match the particle size distribution results from bed grabs undertaken in this vicinity for previous studies (Royal Haskoning, 2009).

5.4.17 The sources of material into the Tees estuary system are fluvial inputs coming through the Tees Barrage, material entering from Tees Bay and any industrial inputs. These inputs are in addition to material eroded from the estuary bed. Of these sources, the main source of material is that entering the estuary from Tees Bay. This material comes in on the flood tide, particularly during times when concentrations in Tees Bay are raised by the resuspension of material from the sea bed during storm events. The coarser material, mostly sand, is then able to settle out in the lower estuary, whereas the finer material is drawn further up the estuary by the gravitational circulation.

5.4.18 Within the system, the driving forces for sediment transport are the tidal flows, density driven currents, wave induced currents, vessel induced forces and resuspension of material by dredging operations.

5.4.19 Maintenance dredging information from PD Teesport (pers. comm., reported in HR Wallingford, 2006) suggests that out of the 1.35 million m^3 of sediment that is dredged annually, 250,000m^3 is mud. Of the remainder, 80% is clean, fine sand (approximately 880,000m^3) and 20% silty sand (approximately 220,000m^3). Assuming the silty sands have 15% to 35% fines content, the total fine material input is 280,000m^3 to 330,000m^3 per year.

5.5 Prediction of potential effects during construction

Sediment release during dredging

5.5.1 As described in **Section 3**, an enclosed grab is proposed to dredge the contaminated sediments present within the dredge footprint during both Phase 1 and Phase 2 (see **Section 7.4**). The dredging required for the sands and gravels, clay and mudstone deposits during Phase 1 and Phase 2 would be undertaken by a TSHD, CSD or backhoe dredger.

5.5.2 The main issues which have the potential to arise with regard to sedimentation during the construction phase are:

- Increased turbidity due to release of sediments into the water column during the dredge.
- The effects of fine sediment run-off from the fill material used in the quay construction (this is relevant to the solid quay structure only).

5.5.3 A larger rate of sediment release would be anticipated from the TSHD or the CSD in comparison with the backhoe and enclosed grab. This is due to the larger production rate of the TSHD and CSD compared with the backhoe, combined with the potential for overflow of the dredged material within the hopper in order to increase the density of material taken to the disposal site. Material arising from the backhoe remains close to its in-situ density and so allowing the material to overflow out of the hopper in order to increase the density of material (thereby reducing the water content) is not required. There would be virtually no sediment release from the enclosed grab method, as this is a specialist technique that is specifically used to limit the release of sediment into the water column during dredging as much as possible (e.g. when sediments to be dredged are known to be contaminated).

5.5.4 Sediment plume modelling tests have been carried out for the proposed scheme to predict the effects of dredging associated with all potential dredge methods (with the exception of an enclosed grab, due to the fact that there is negligible sediment release from an enclosed grab). The modelling used two sets of flow results to examine the fate of fine material dispersed into the water column during dredging of the berth pocket and approach channel for TSHD, CSD and backhoe dredgers. The low freshwater flow, spring tide flow simulation was used to demonstrate the maximum extent of the sediment plume and the high freshwater flow, neap tide conditions was used to show a minimal dispersion case.

5.5.5 The modelled simulation of the average excess concentration and deposition due to the use of a TSHD and CSD dredger at the proposed development site for both sets of flow results are shown in **Figures 5-2 to 5-7**. The modelling includes sediment release at the dredger drag head and overflow from the hopper. Overflow typically provides the largest sediment release rate from a barge loaded from a CSD. A backhoe dredger would produce an effect at least an order of magnitude lower.

5.5.6 The simulations indicate a significant difference in excess concentrations from one side of the navigation channel to the other, with the most dispersion along the main direction of flow on the eastern side of the estuary. Furthermore, the highest amounts of deposition are predicted in the immediate area of the dredging operation. The deposition indicated within the proposed dredged area would be likely to be re-dredged as part of the capital dredging operations. The footprint of the effect of dredging for high river flow, neap tide conditions would be considerably smaller than that for low river flow, spring tide conditions. The findings of the sediment plume modelling are discussed in greater detail below.

5.5.7 The simulations for the CSD predict that mean elevated suspended sediment concentration increases above 10mg/l are confined to an area 500m upstream and downstream of the dredger. Mean concentration increases of more than 500mg/l are predicted at the location of the dredging activity only. Immediately upstream and downstream of the dredging location, deposition of tens of millimetres is predicted, while tens of centimetres of sediment deposition is predicted in the vicinity of the barge itself. Elsewhere within the estuary (up to 1.5km either side of the dredge location), fine sediment deposition over the simulation period is predicted to be a maximum of a few millimetres.

5.5.8 The simulation results for the backhoe dredger predict that an area of elevated suspended sediment concentrations in the range of 10mg/l to 50mg/l would be confined to the immediate area of the dredger, with no wider effects within the estuary. Sediment deposition of a maximum of a few millimetres is predicted up to 1.5km upstream and downstream of the dredger.

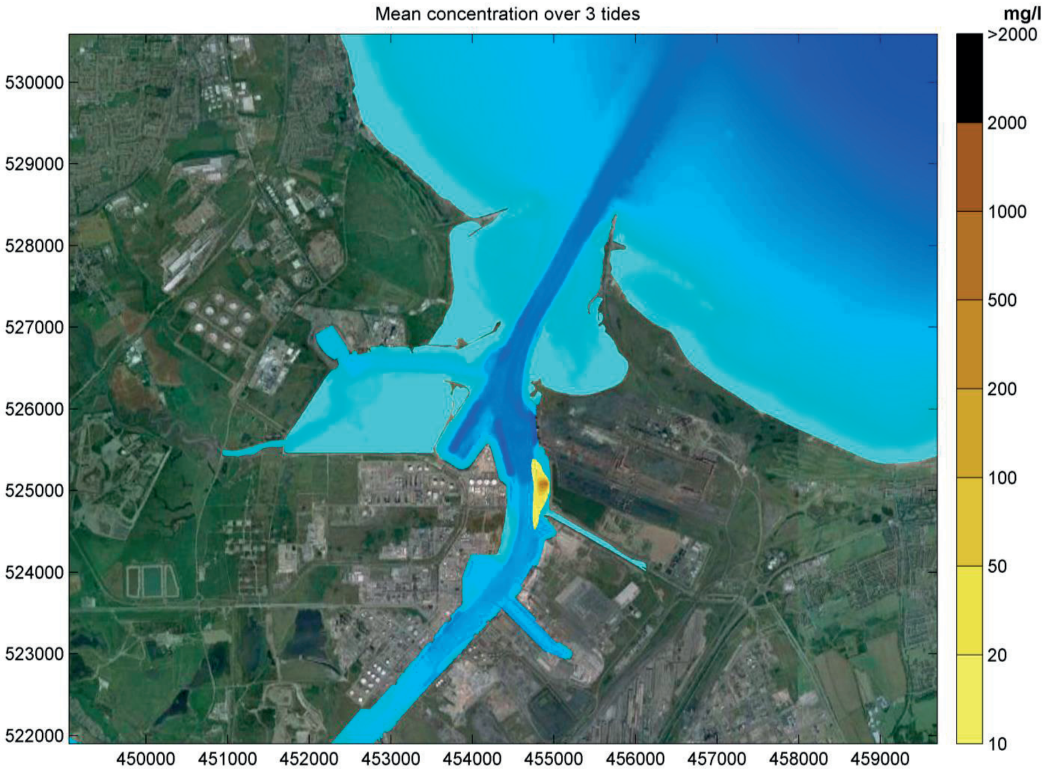
5.5.9 The simulations for the TSHD show that an area of elevated suspended sediment concentration, in the range of 10mg/l to 50mg/l above background may be anticipated in the channel, 1km either side of the dredging works. Larger excess concentrations are predicted in the immediate area of the dredger, at up to 200mg/l of suspended sediment. Fine sediment deposition is predicted to be a maximum of a few millimetres at a distance of approximately 2km either side of the dredge footprint, while deposition at the dredge location is predicted to be 10 to 20mm.

5.5.10 During simulations for all dredge methods, no average increase in suspended sediment concentration is shown over the intertidal areas, leading to a prediction of negligible sediment being able to deposit on the intertidal areas.

Sediment release during disposal

5.5.11 Following a consideration of alternative uses for the dredged material (see **Section 3**), it is proposed that a maximum of 230,000m^3 of clay, 385,000m^3 of mudstone and 326,000m^3 of sand and gravel, would be disposed of at the capital dredged material disposal site in Tees Bay (Tees Bay C).

Figure 5-2 Simulated sediment release from CSD dredging in spring tide, low river flow conditions a) average increase in suspended sediment concentration b) deposition after 3 tides of dredging



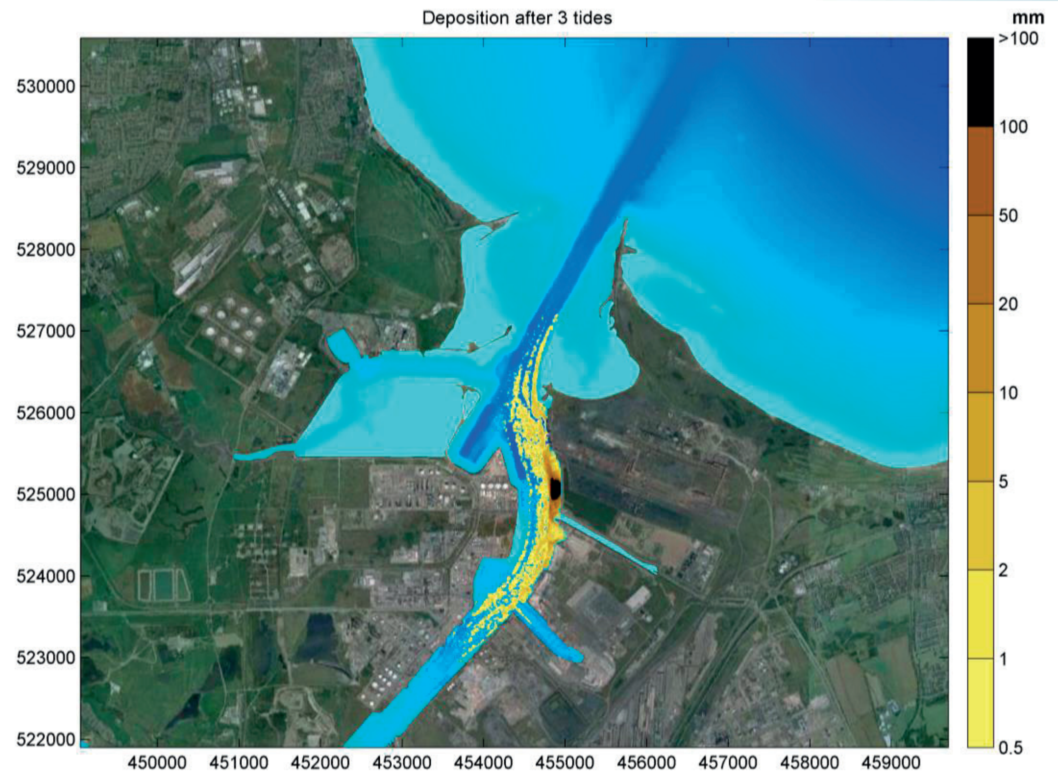
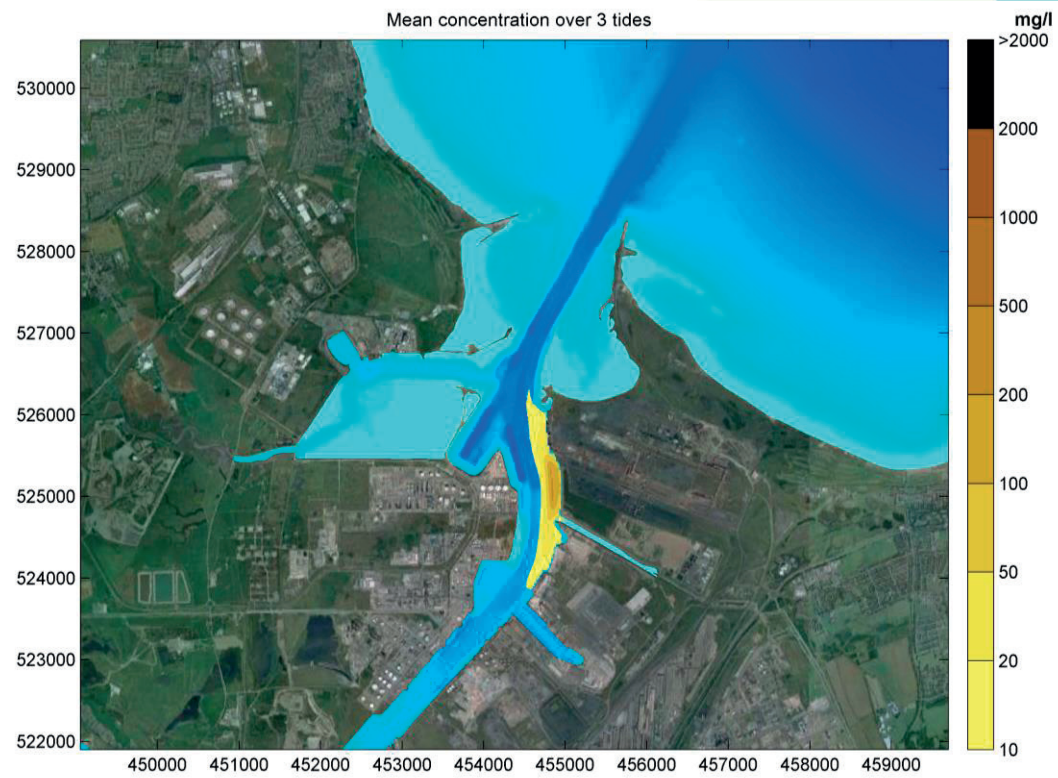


Figure 5-3 Simulated sediment release from TSHD dredging in spring tide, low river flow conditions a) average increase in suspended sediment concentration b) deposition after 3 tides of dredging



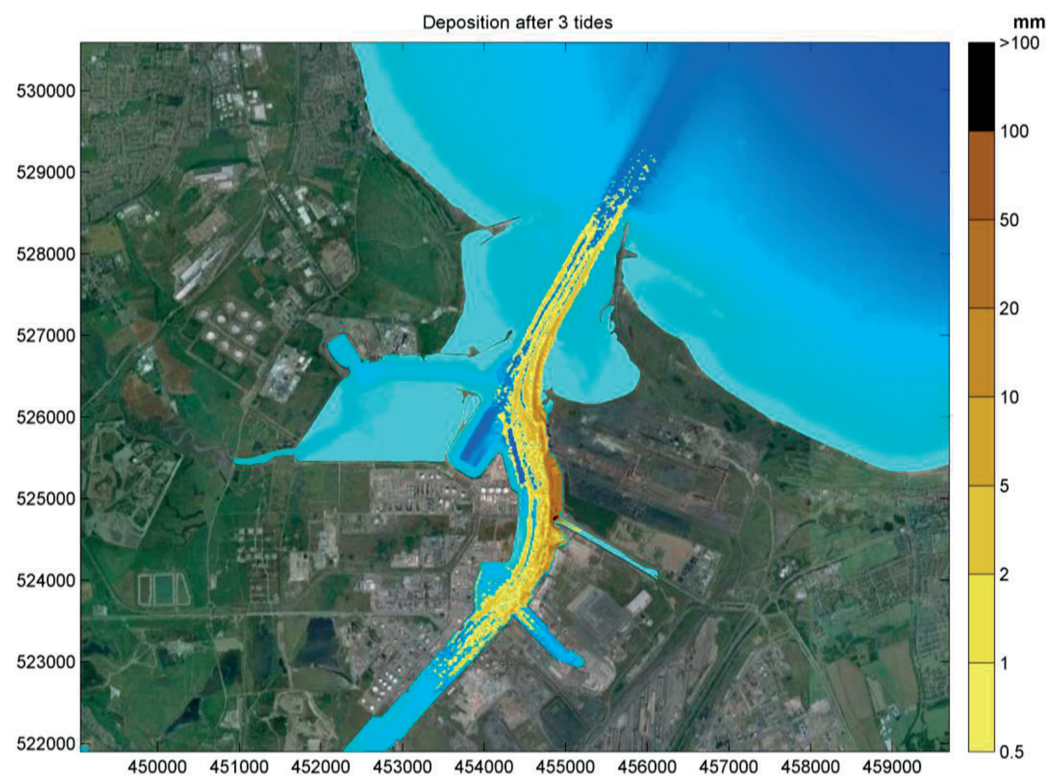


Figure 5-4 Simulated sediment release from backhoe dredging in spring tide, low river flow conditions a) average increase in suspended sediment concentration b) deposition after 3 tides of dredging

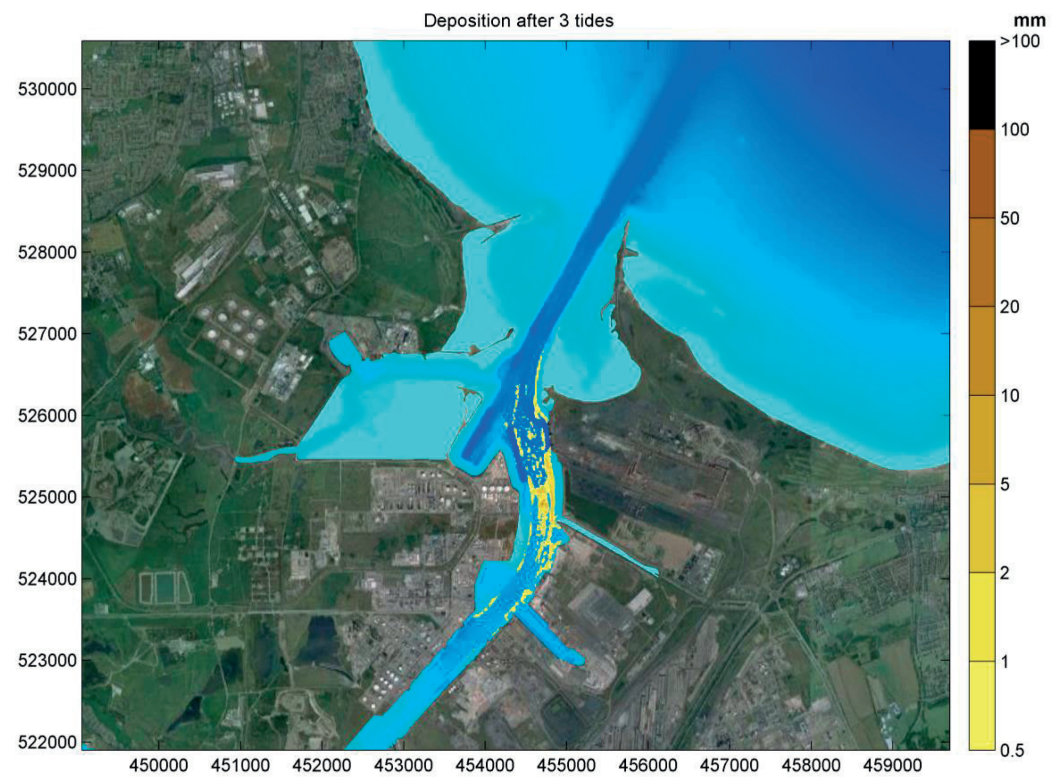
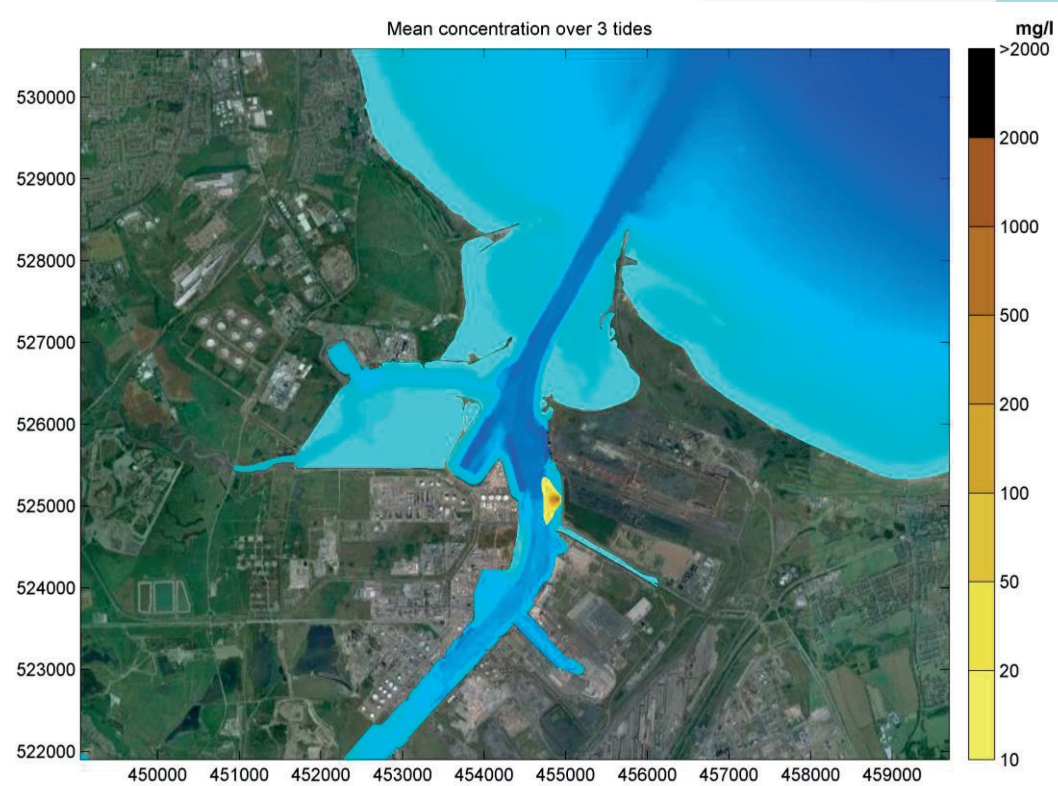


Figure 5-5 Simulated sediment release from CSD dredging in neap tide, high river flow conditions a) average increase in suspended sediment concentration b) deposition after 3 tides of dredging



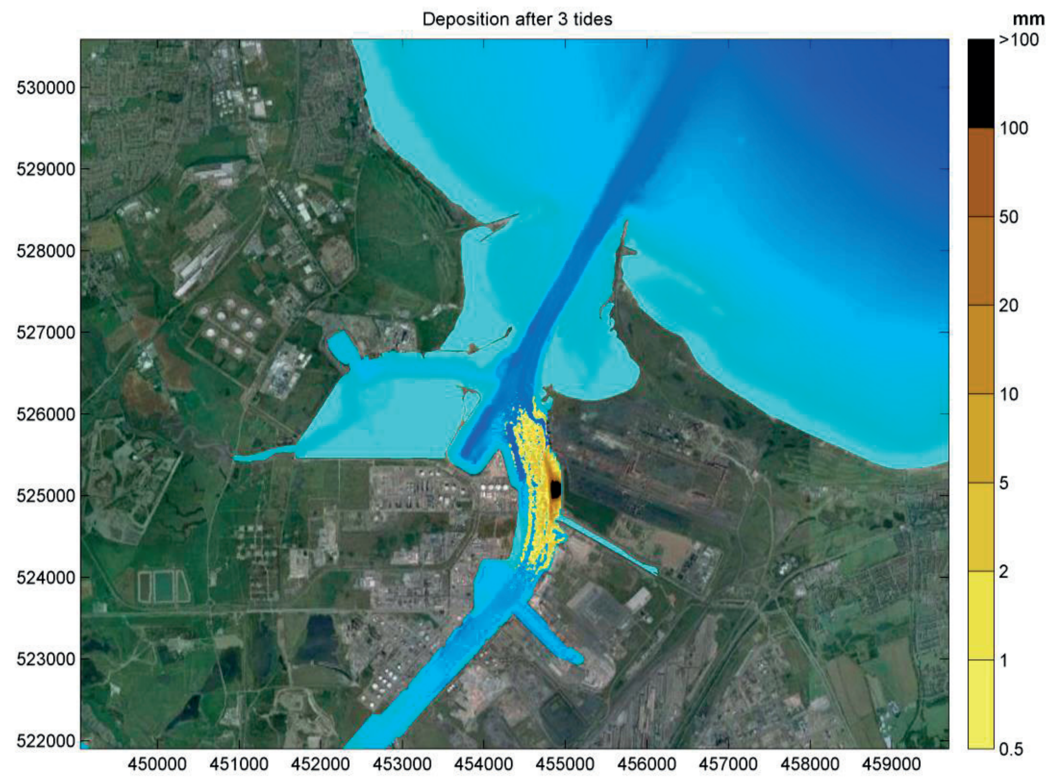
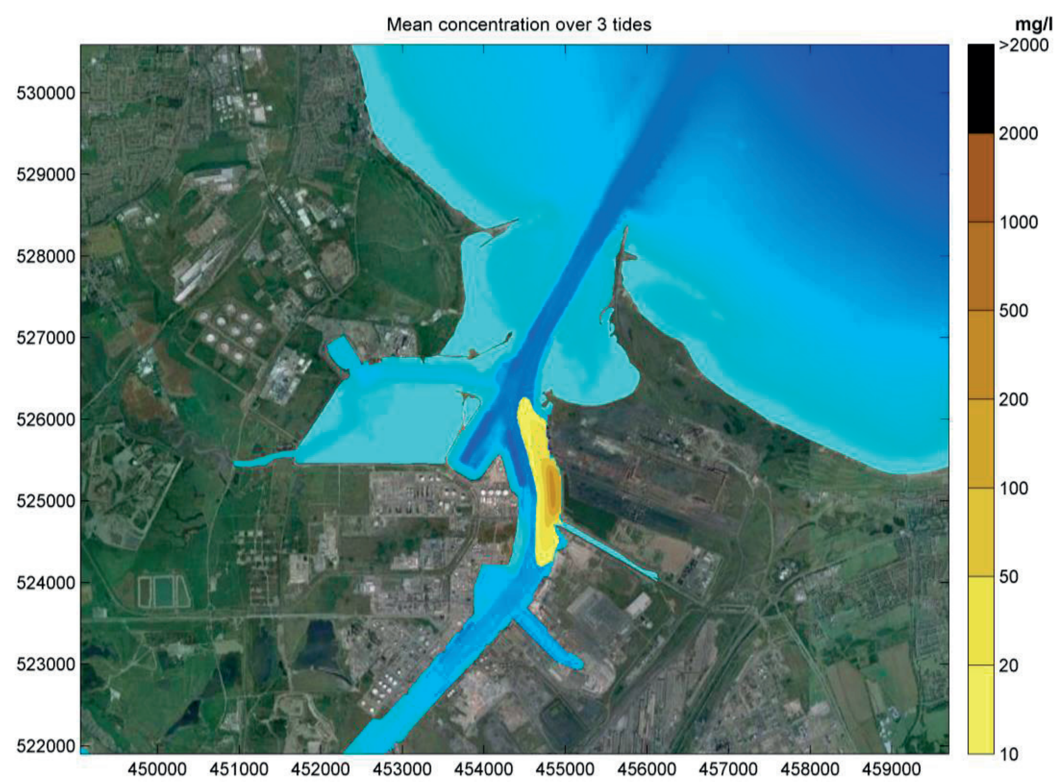
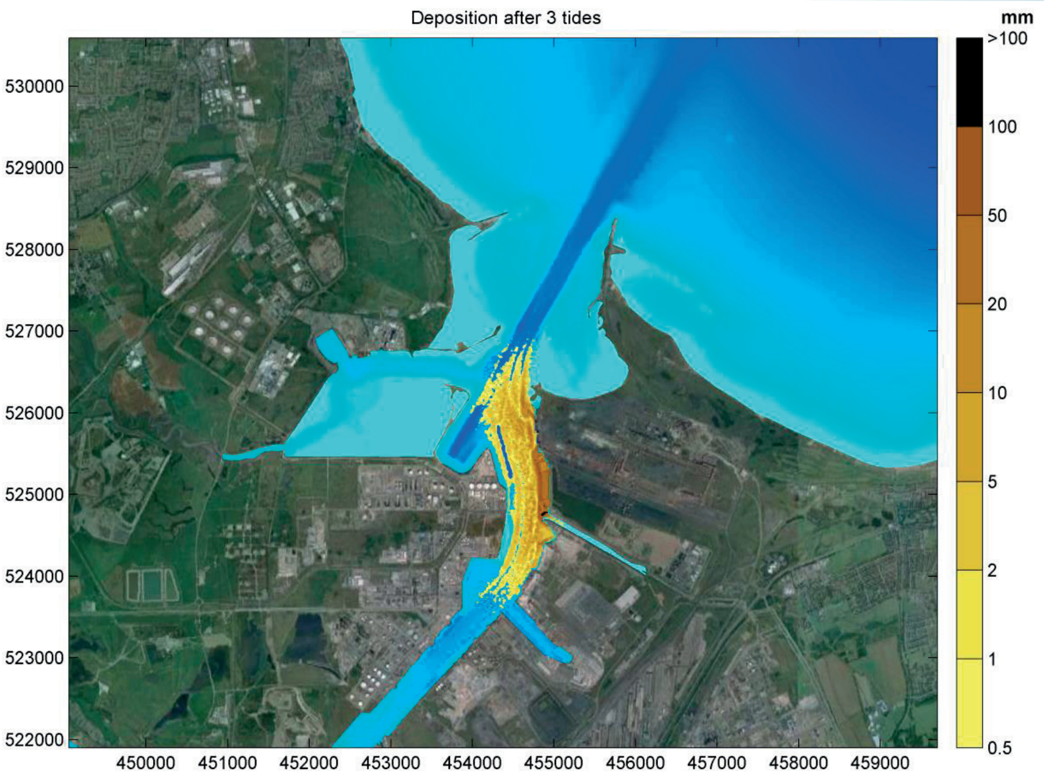


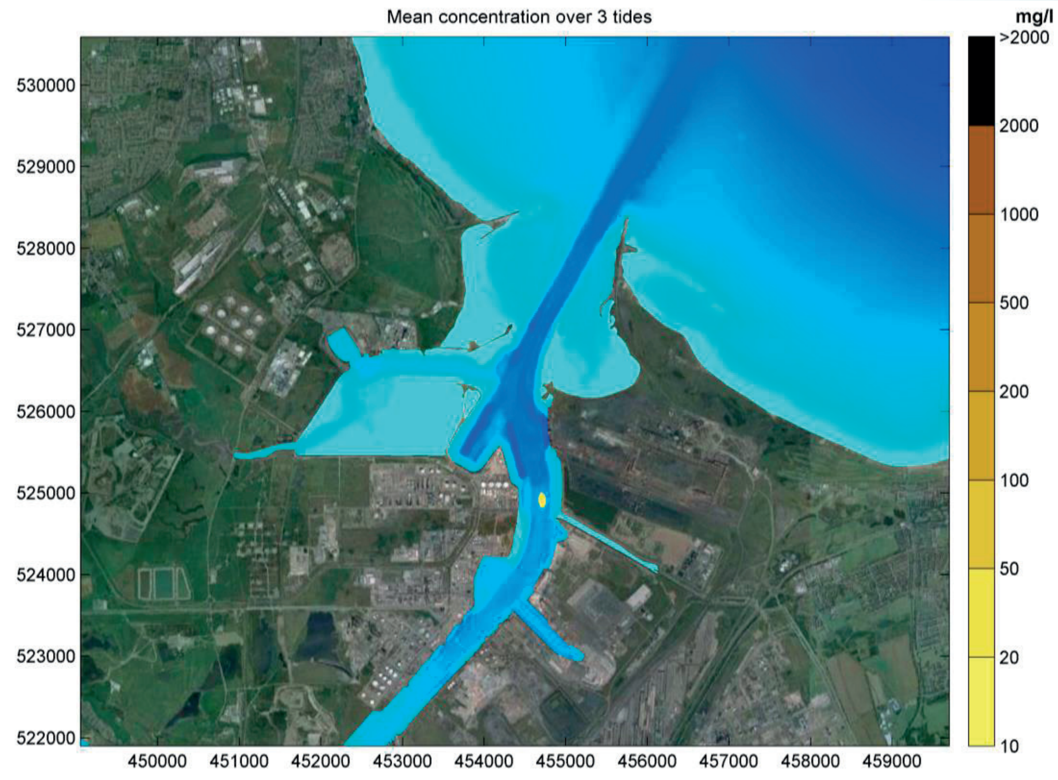
Figure 5-6 Simulated sediment release from TSHD dredging in neap tide, high river flow conditions a) average increase in suspended sediment concentration b) deposition after 3 tides of dredging

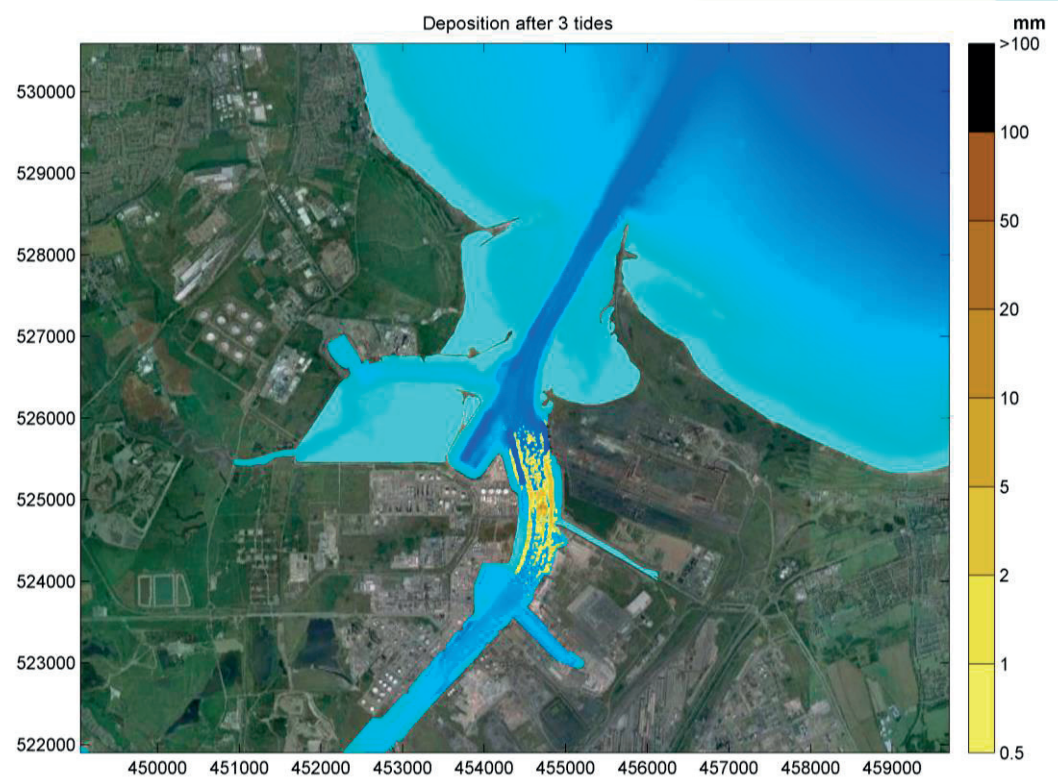




Deposition after 3 tides
mm
>100
100
50
20
10
5
2
1
0.5
530000
529000
528000
527000
526000
525000
524000
523000
522000
450000
451000
452000
453000
454000
455000
456000
457000
458000
459000

Figure 5-7 Simulated sediment release from backhoe dredging in neap tide, high river flow conditions a) average increase in suspended sediment concentration b) deposition after 3 tides of dredging





Royal HaskoningDHV

5.6 Prediction of potential effects during operation

Changes in tidal and density driven hydrodynamics

5.6.1 A TELEMAC-3D flow model was established to simulate currents in the Tees estuary and Tees Bay. The model was calibrated against extensive current measurements made at 11 Acoustic Doppler Current Profiler (ADCP) transects distributed throughout the study area.

5.6.2 TELEMAC-3D is a state-of-the-art finite element flow model, originally developed by LNHE Paris, which uses a completely unstructured grid enabling the accurate simulation of water movement in complex shaped areas. TELEMAC-3D also includes vertical layers, enabling three-dimensional flow structures in the river to be accurately represented. Distribution of salinity, and its evolution, is also included to represent density driven flows and stratification effects.

5.6.3 The model's upstream limit is the Tees Barrage, extending approximately 6.5km offshore in Tees Bay and covering an area of approximately 80km^2. The mesh resolution varies from 800m at the seaward model boundary, to 50m over most of the estuary, and 30m in narrow sections.

5.6.4 The model has been used to simulate the proposed scheme, comprising the proposed dredging and both the open and solid quay options for the completed (Phases 1 and 2) quay, on the baseline (existing) case.

5.6.5 Simulation of the effects of the open quay structure has been included by representation of the additional drag force of the piles on the flow. For the solid quay option, the structure has been included as a solid block in the model setup. Both forms of construction were investigated to provide a view on the sensitivity of the flow regime to the form of construction of the port terminal.

5.6.6 Results from the flow modelling studies, predicted effect on depth average flows, are presented in **Figures 5-8 to 5-11**. In these figures, the currents at time of peak ebb and peak flood with the two forms of quay construction are compared with the baseline case.

5.6.7 It is considered that the majority of the effects illustrated in **Figures 5-8 to 5-11** are a function of the capital dredging, with currents predicted to be reduced within the deepened areas. The results show that the spatial extent of the effect due to the open structure is similar to that of the solid quay structure.

5.6.8 Some current speed increases are predicted on the shoreline adjacent to the works for the solid quay structure (at the Redcar Bulk Terminal frontage on the ebb tide and adjacent to Dabholm Gut during the flood tide), suggesting that the dredging is predicted to draw some of the flow to the south side of the estuary; although such effects are shown to be relatively localised to the proposed works. The current speed increases predicted for the solid quay structure are not predicted for the open quay structure. It is considered that this is due to the drag effect of the piles, further slowing the flow along the quay line compared to less frictional effect of the solid quay structure. At the time of the peak ebb tide, an area of current speed increase is shown to the rear of the open structure. This is associated with changes to the position of the eddy generated at the site of the open structure, by the interaction of ebbing flow exiting Dabholm Gut with that in the main estuary. In this area of speed increase, the magnitude of change is less than 0.1m/s, therefore erosion of the bed is unlikely.

5.6.9 Away from the immediate area of the proposed scheme, the modelling work has predicted that the effect of the works is insensitive to the form of the port terminal (i.e. open quay or solid quay structure).

Figure 5-8 Change in depth average currents due to dredging and open quay structure at time of peak ebb tide, spring tide, low river flow

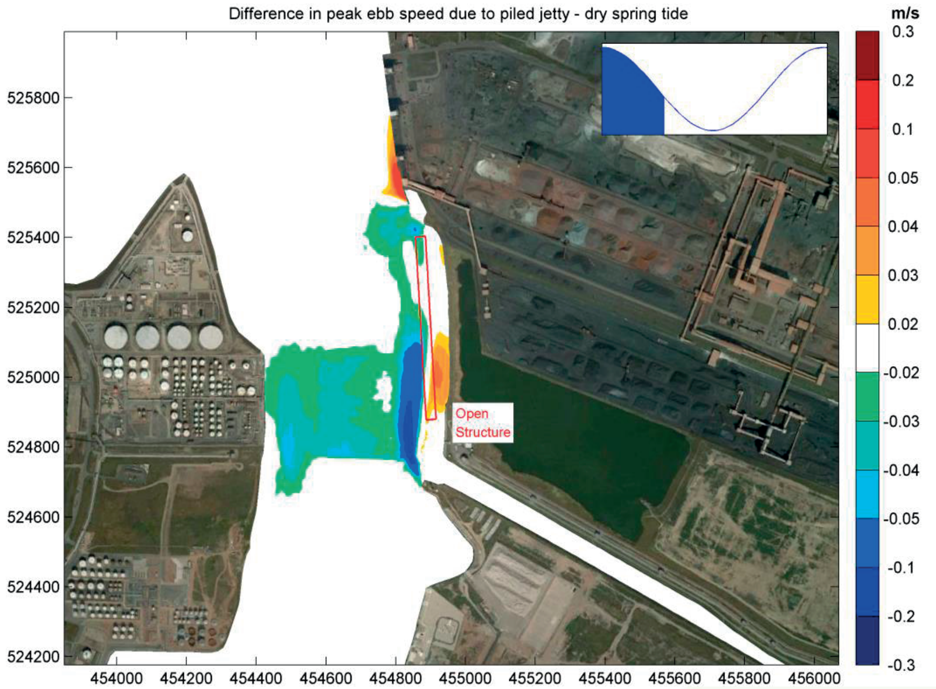


Figure 5-9 Change in depth average currents due to dredging and the solid quay structure at time of peak ebb tide, spring tide, low river flow

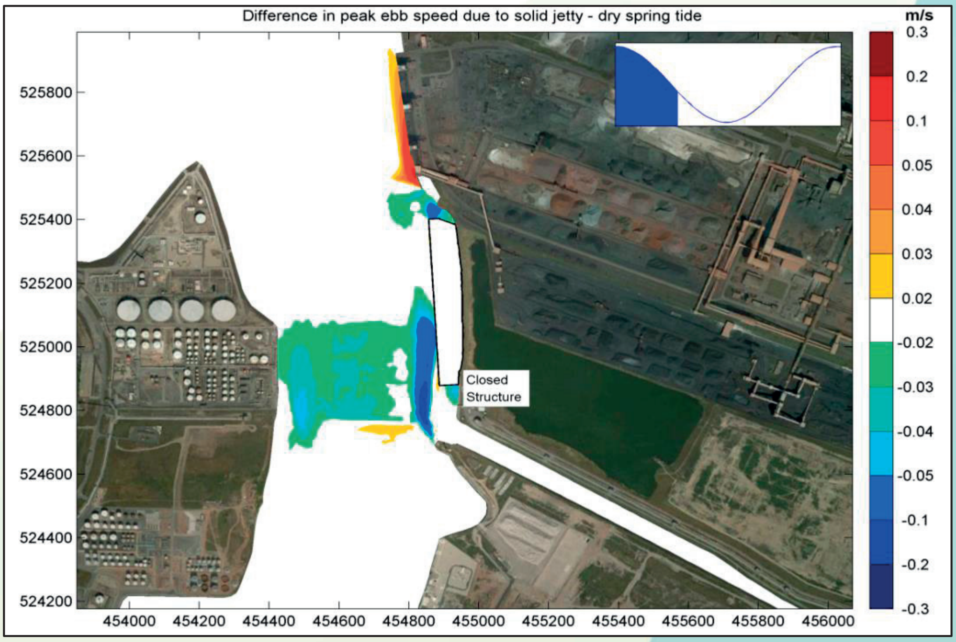


Figure5-10 Change in depth average currents due to dredging and the open quay structure at time of peak flood tide, spring tide, low river flow

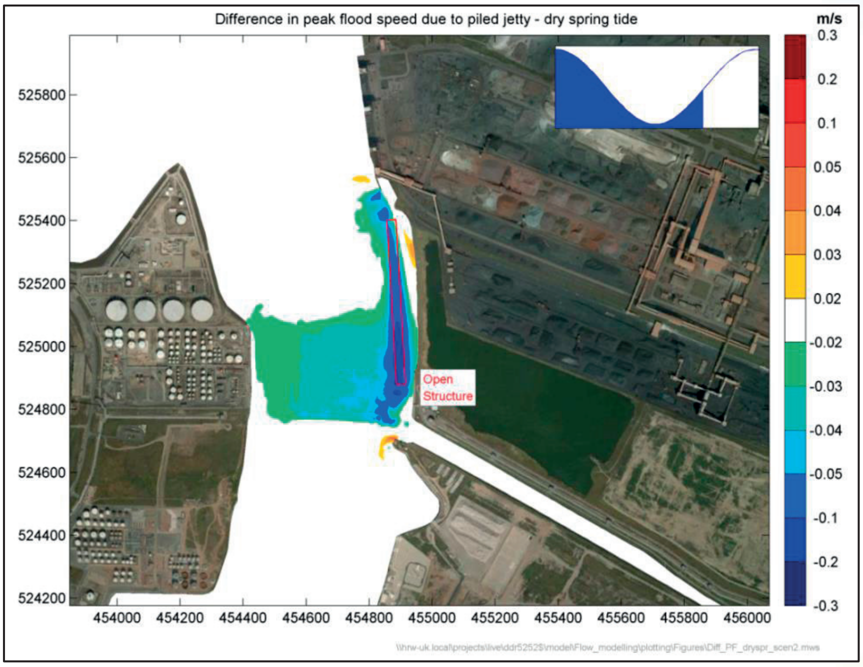
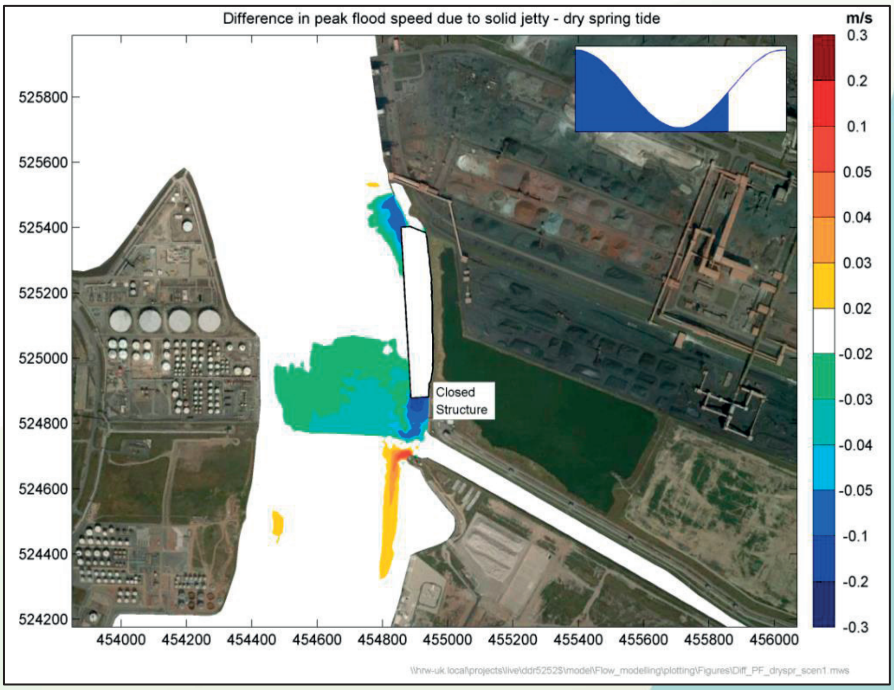


Figure 5-11 Change in depth average currents due to dredging and the solid quay structure at time of peak flood tide, spring tide, low river flow



5.6.10 As the density driven flows are an order of magnitude slower than the tidal flows, any effect of the proposed scheme on these flows can be expected to be significantly less than the effects described above.

5.6.11 The limited area of dredging required for the proposed scheme suggests that there would be a negligible effect on tidal propagation and water levels. Phase 2 would represent the maximum effect of the proposed scheme, with Phase 1 having an effect over a small spatial extent compared with the complete (Phase 1 and 2) scheme.

Changes in wave propagation

5.6.12 Given that no capital dredging of the approach channel is proposed between the location of the proposed scheme and the mouth of the Tees, no effect on the penetration of waves into the Tees estuary is anticipated. The primary focus of the wave modelling study was, therefore, to predict changes in wind generated wave conditions due to the change of the form of the coastline associated with the two options for the proposed port terminal. An open quay structure would have little effect on waves, although the proposed dredged slope and new revetment to the rear of the structure may have an effect. A solid quay structure would change the wave conditions locally due to increased wave reflections.

5.6.13 In order to model the wave transformation within the Tees estuary, a local SWAN (Simulating WAves Nearshore) numerical wave model has been used. SWAN is a third generation wave model representing the following processes acting on a complete directional wave spectrum.

5.6.14 Simulations of the effect of the proposed dredging and both options for the quay were undertaken for three return period winds from two directions anticipated to generate waves from the SW and three return period for incoming waves from Tees Bay.

5.6.15 Wave modelling has been undertaken at both mean high water spring tide and mean low water spring tide to show the sensitivity of the modelled impacts to water level.

5.6.16 The results presented in **Figures 5-12 (a to h) to 5-13 (a to h)** show a relatively localised predicted effect on existing wave heights. The open quay structure is predicted to fully transmit wave energy through to the shore protection behind the proposed quay. The shore protection would have similar reflection characteristics to the existing shoreline and, therefore, no increase in wave energy is predicted within the estuary.

5.6.17 For return period winds of less than 5 years, no effect due to the open quay structure is predicted. The proposed dredging is not predicted to change the overall pattern of wave conditions throughout the estuary. The only differences evident in the results are shown in **Figure 5-12 (e and h)** where there is a highly localised strip of increased wave heights predicted (in the range of 0.03m to 0.1m) adjacent to the open quay structure. This small increase in wave height is considered to be a result of the dredging required for the proposed scheme. No increases in wave energy over the designated intertidal areas at Teesmouth are predicted, 5.6.18 The vertical face of the solid quay structure is considered to have higher reflection properties than the existing shoreline and, therefore, less wave energy would be absorbed following construction of the solid quay structure. Hence, it can be seen that the effect of the solid quay structure in reflecting wave energy towards the north provides localised increases in significant wave height in the range 0.05m to 0.1m. No increases in wave energy over the designated intertidal areas at Teesmouth are shown, although some increases of very low magnitude may occur on the narrow spits located to either side of Seaton Channel. Phase 1 in isolation would have a lesser effect than the complete (Phase 1 and 2) development.

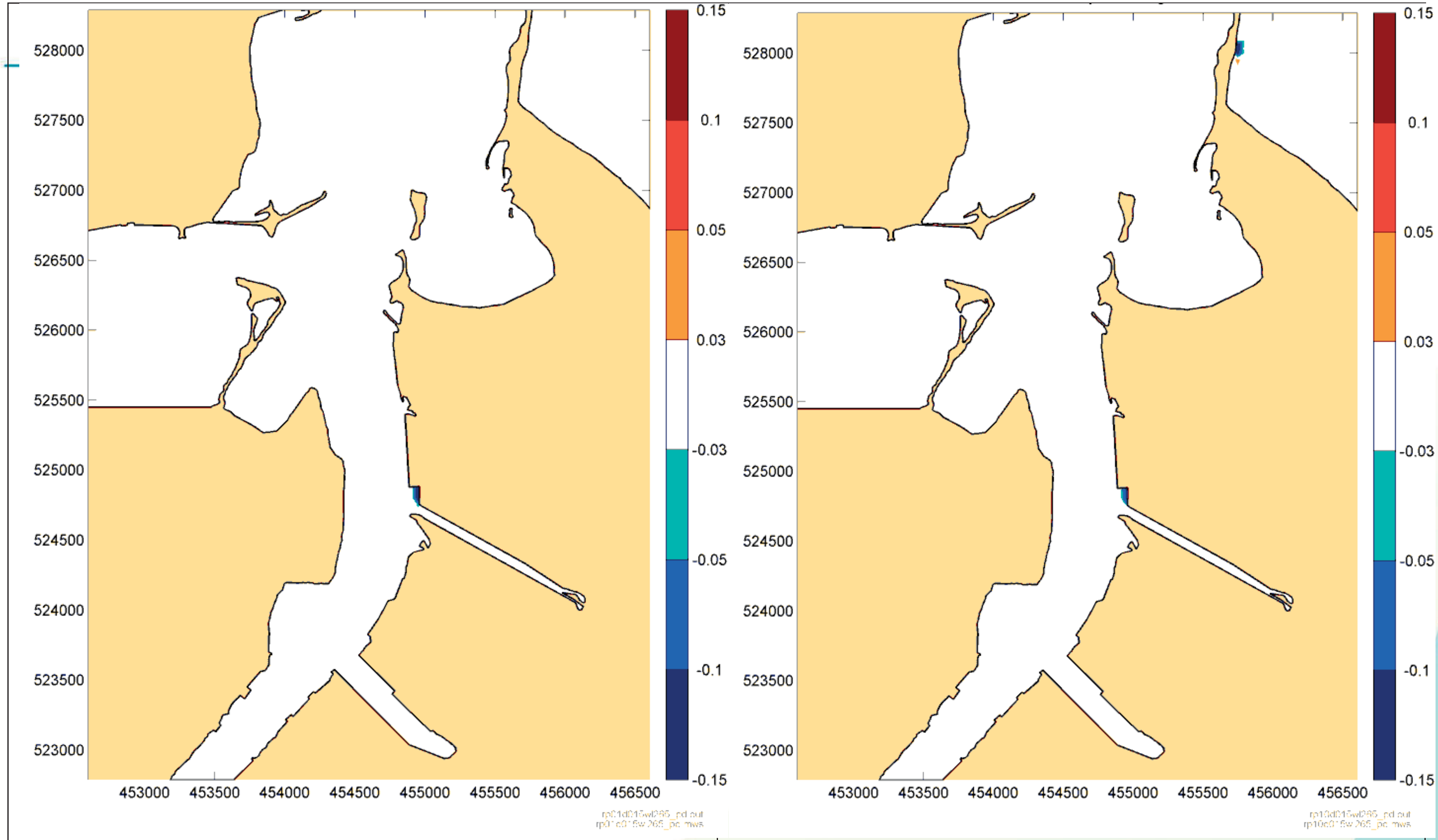
Changes to the local sediment regime including sedimentation in the dredged areas

5.6.19 Given that the proposed dredging does not include any changes to the outer sections of the approach channel, the proposed scheme does not have the potential to have a significant effect on the amount of sediment imported to the Tees from offshore (identified to be the largest sediment input). Furthermore, no changes to sediment transport in the predominantly sandy areas around Teesmouth are expected and so no effect on sand transport is anticipated. However, cohesive sediment transport modelling was undertaken for the proposed scheme. This was concerned with potential increased infill in the berth pocket, new dredged approaches and extended area of -14.1m CD channel.

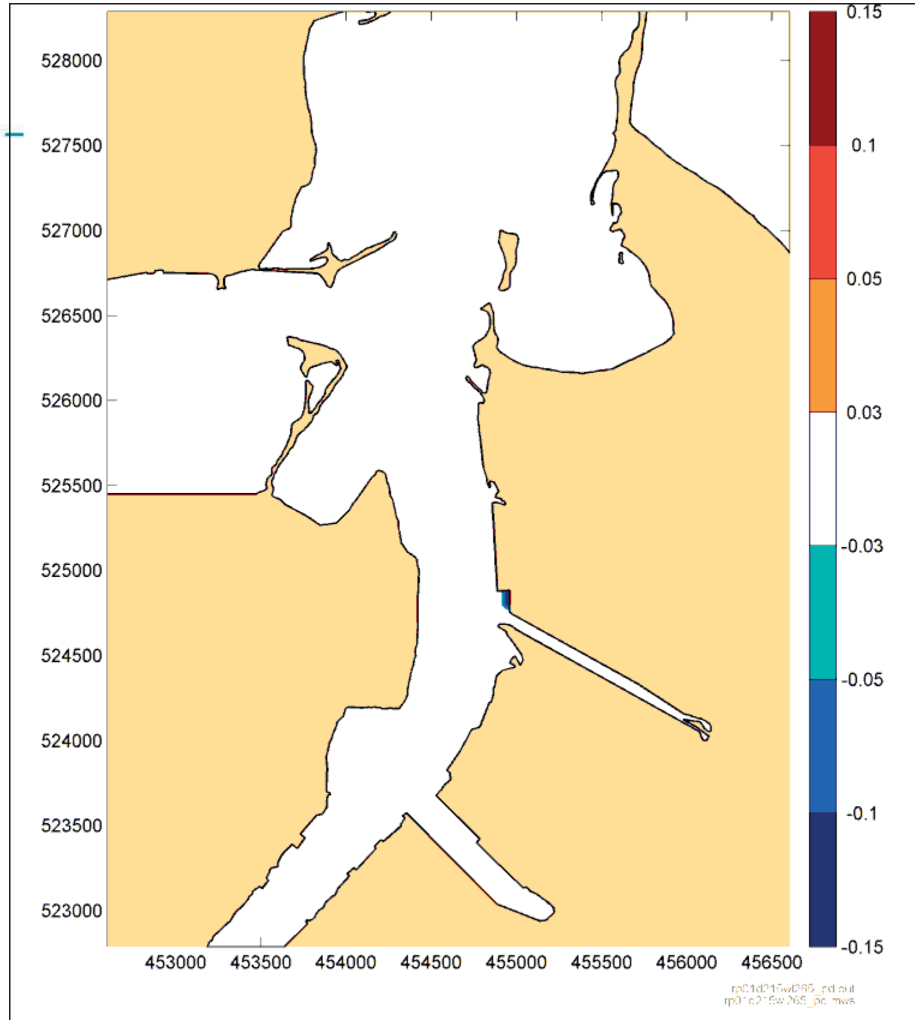
5.6.20 The baseline situation for sediment transport in the Tees as a whole is an average total infill rate of approximately 800,000m^3 per year. This total has reduced from historical levels due to the effects associated with the Tees Barrage.

5.6.21 Within the estuary and approaches the areas of current maintenance dredging are divided into a series of Chart areas (**Figure 5-14**). The proposed port terminal is located within Chart area 8. This Chart area has had an average annual infill rate of approximately 84,000m^3 per year since the Tees Barrage was constructed in 1995. Bed sampling undertaken by Bridgland (shown in Halcrow, 1991) indicates that, in Chart area 8, 83% of the material dredged is in the fine silts and clay fractions. The most significant source of this fine material is marine sources. Fine sediment moved into suspension during storm periods is brought into the estuary by density induced, landward, near-bed flows. Once within the estuary, wave and tidal energies reduce and the material settles. Within the estuary reaches of the Tees (Chart areas 1 to 9), total fine sediment infill has been in the range 100,000 to 600,000m^3 per year, with an average of 300,000m^3 per year.

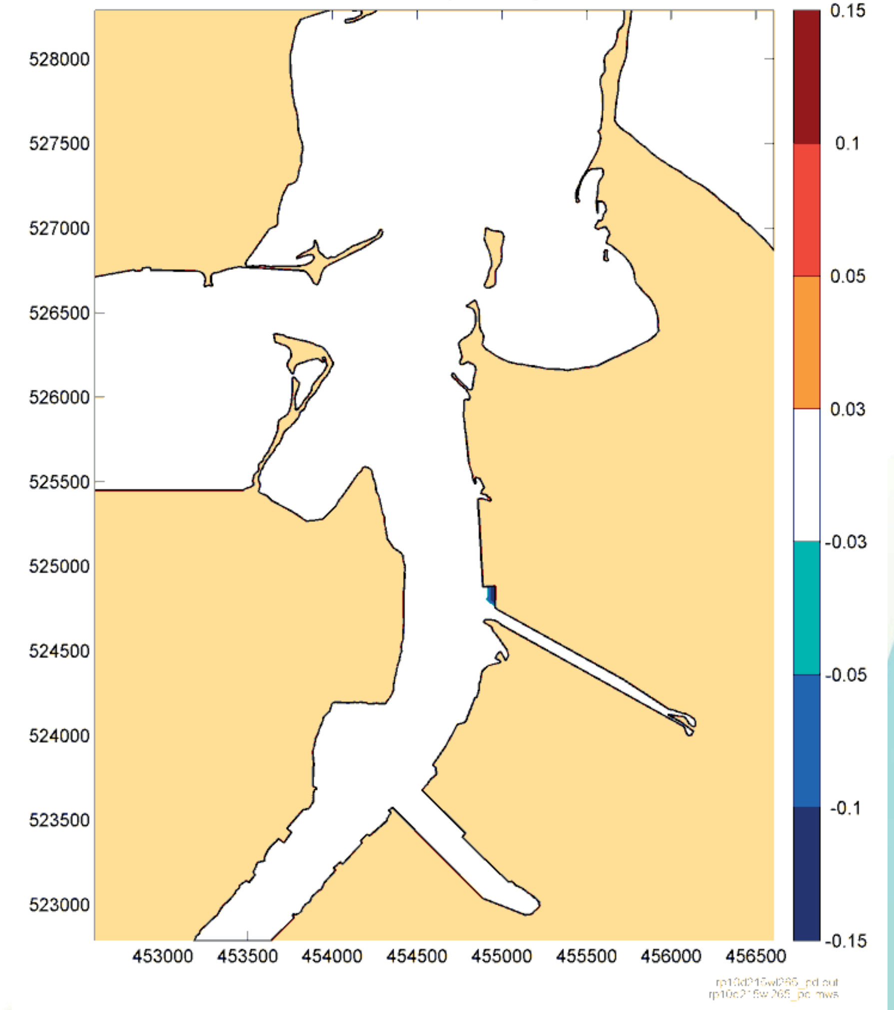
Figure 5-12 Change in wave height (m) due to dredging and open quay structure



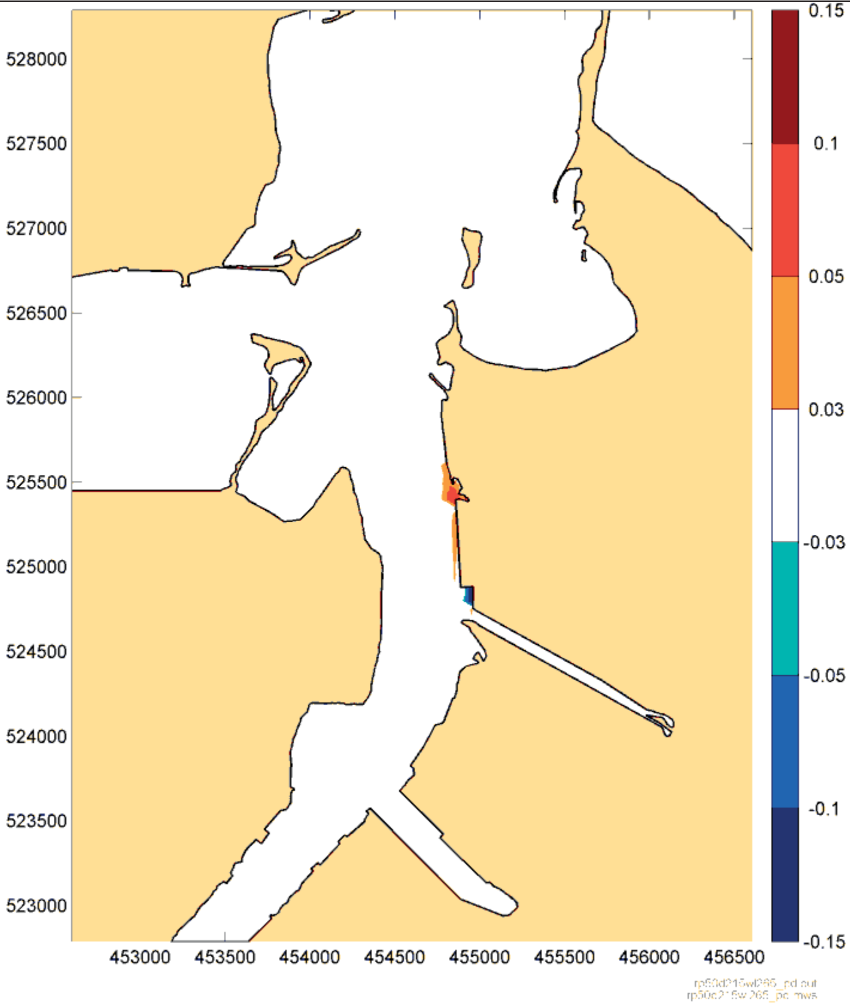
a. Change in wave height (m) due to dredging and open quay at high water, 0.1 year return period wind from 15°	b. Change in wave height (m) due to dredging and open quay at high water, 1 year return period wind from 15°



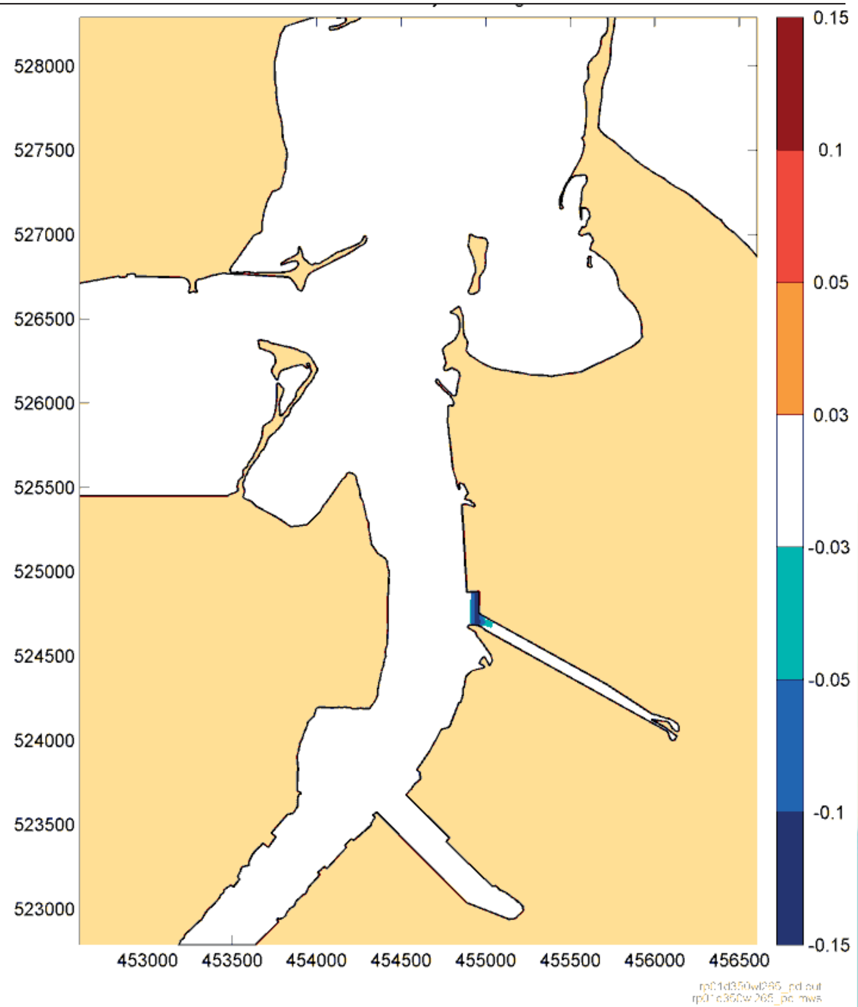
c. Change in wave height (m) due to dredging and open quay at high water, 0.1 year return period wind from 215°



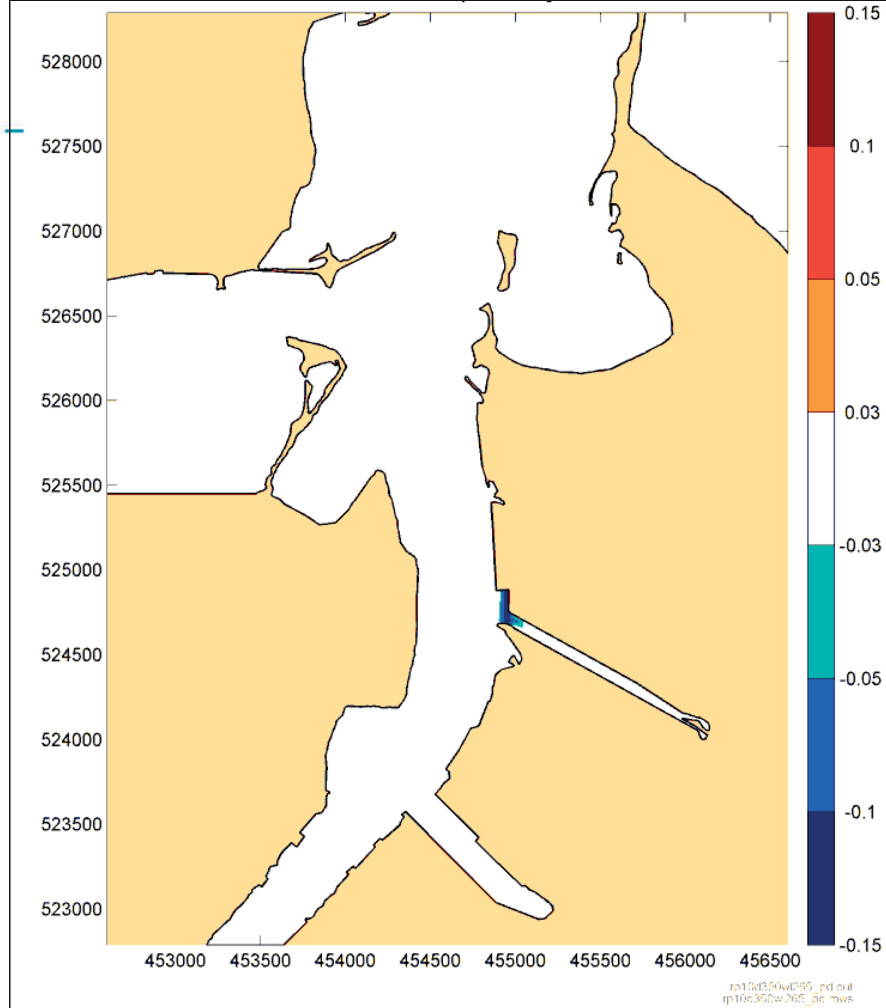
d. Change in wave height (m) due to dredging and open quay at high water, 1 year return period wind from 215°

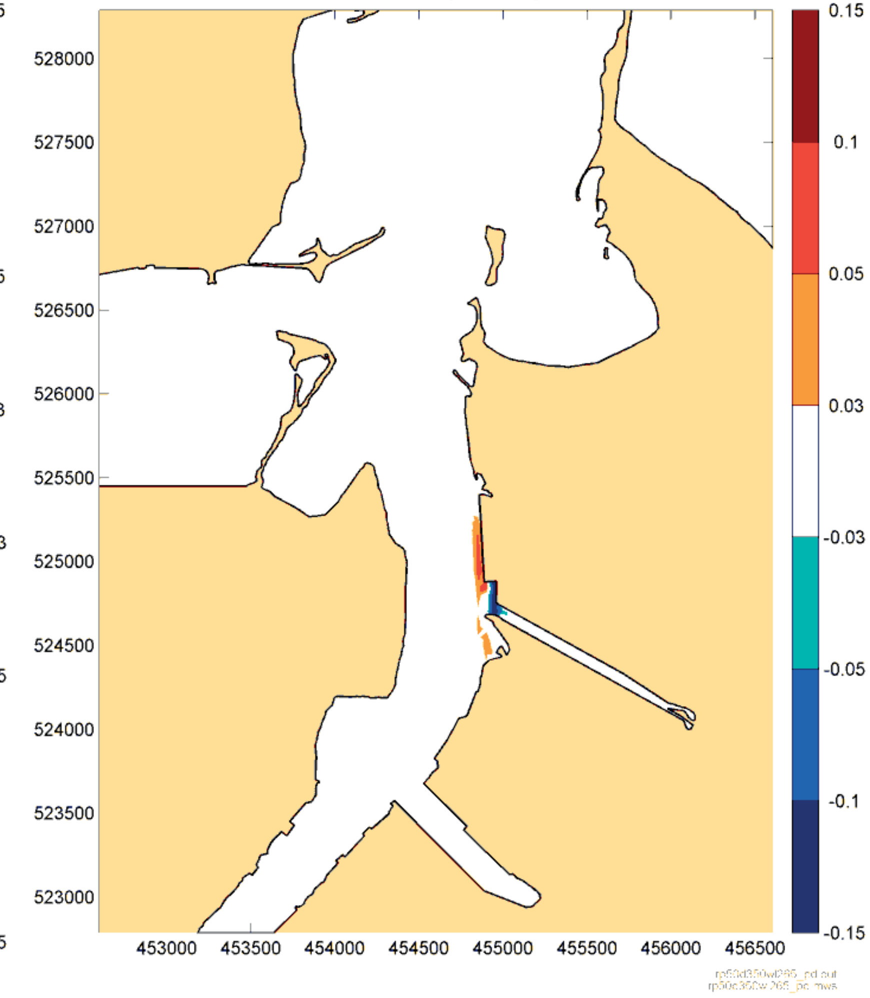


e. Change in wave height (m) due to dredging and open quay at high water, 5 year return period wind from 215°



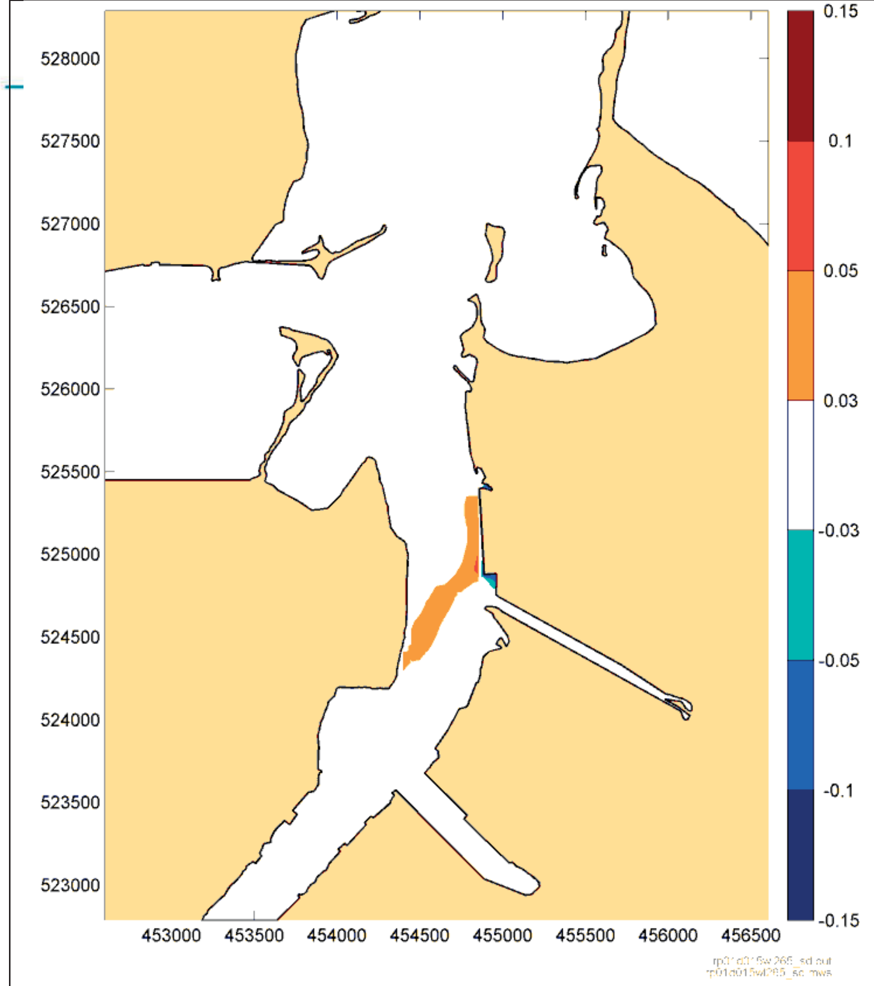
f. Change in wave height (m) due to dredging and open quay at high water, 0.1 year return period wind from 350°

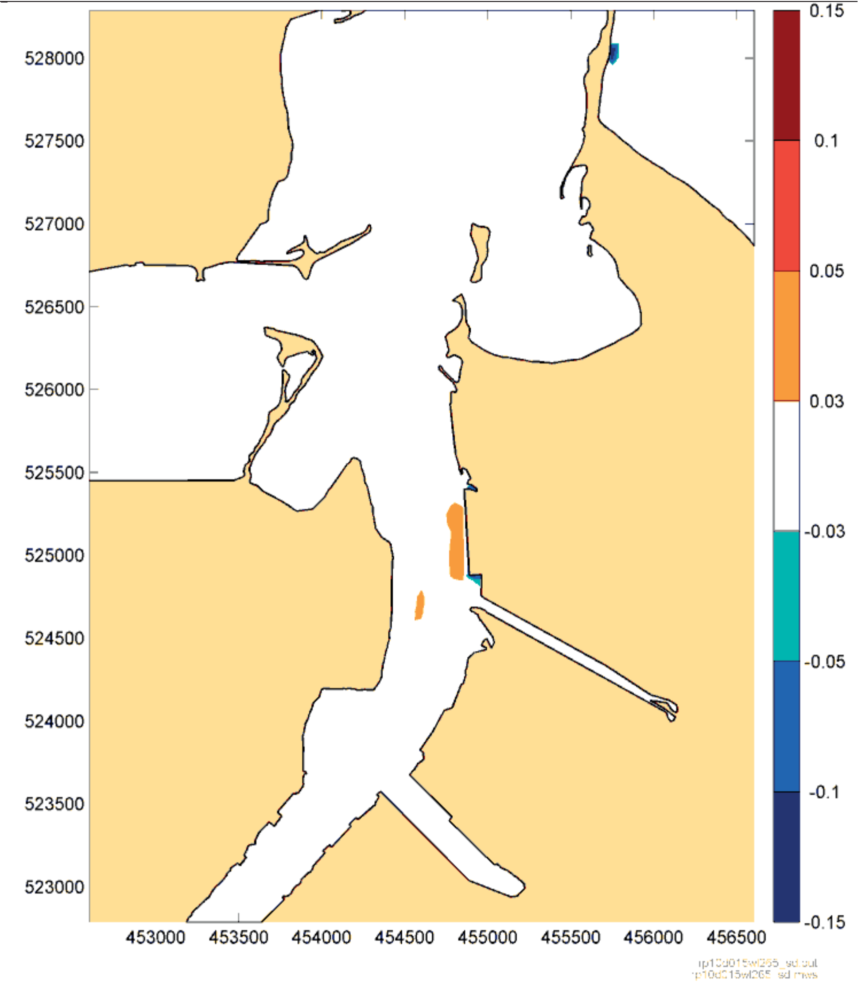




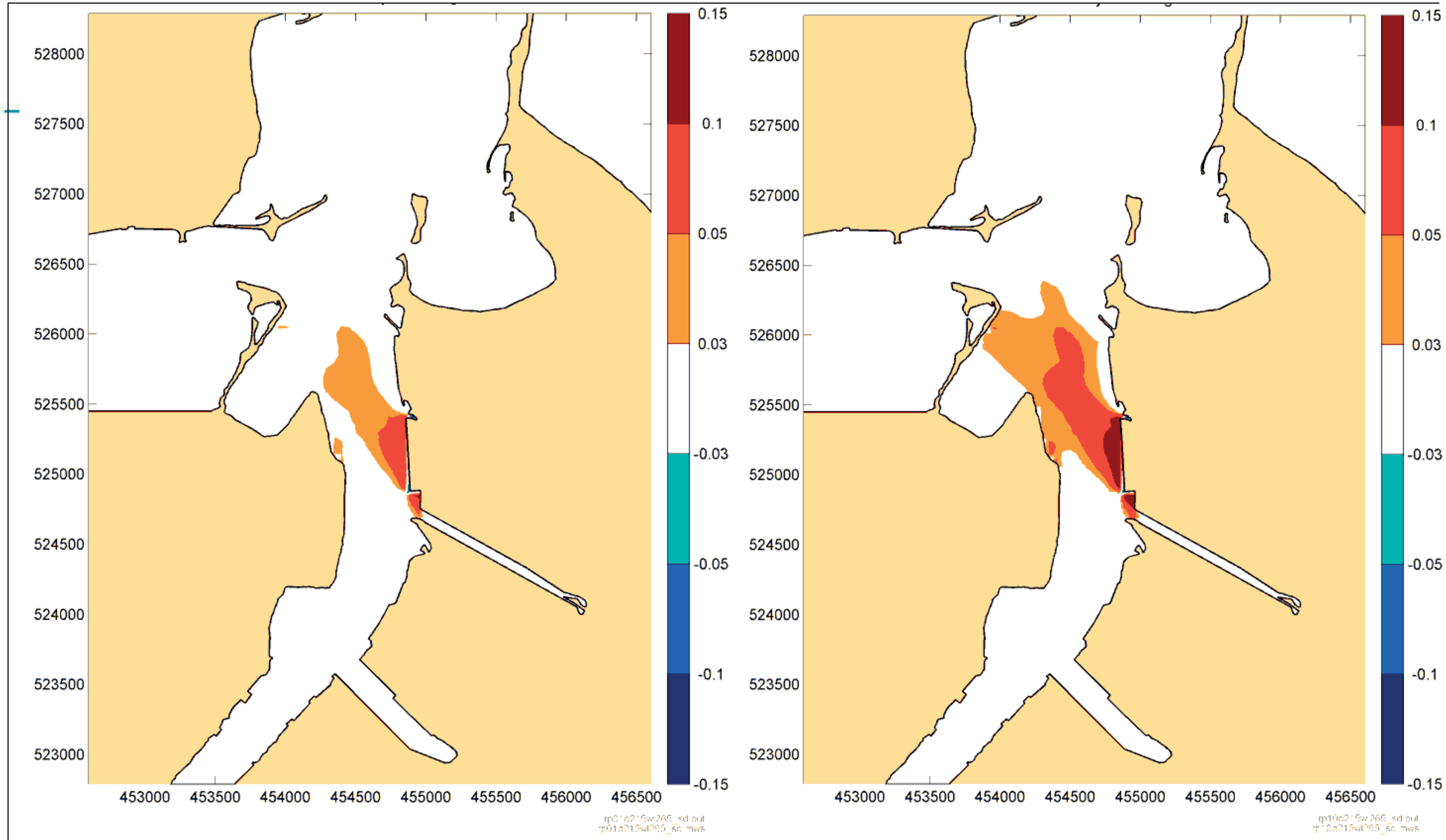
g. Change in wave height (m) due to dredging and open quay at high water, 1 year return period wind from 350°	**h. Change in wave height (m) due to dredging and open quay at high water, 5 year return period wind from 350°**

Figure 5-13 Change in wave height (m) due to dredging and solid quay structure

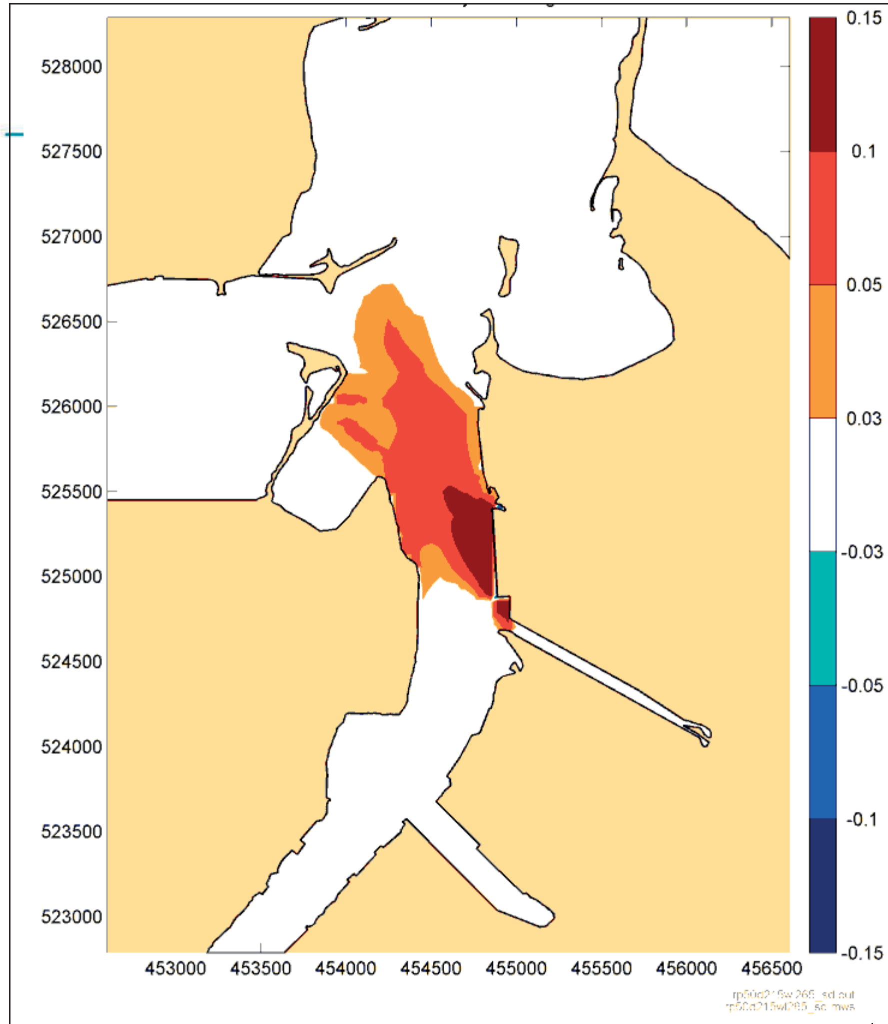




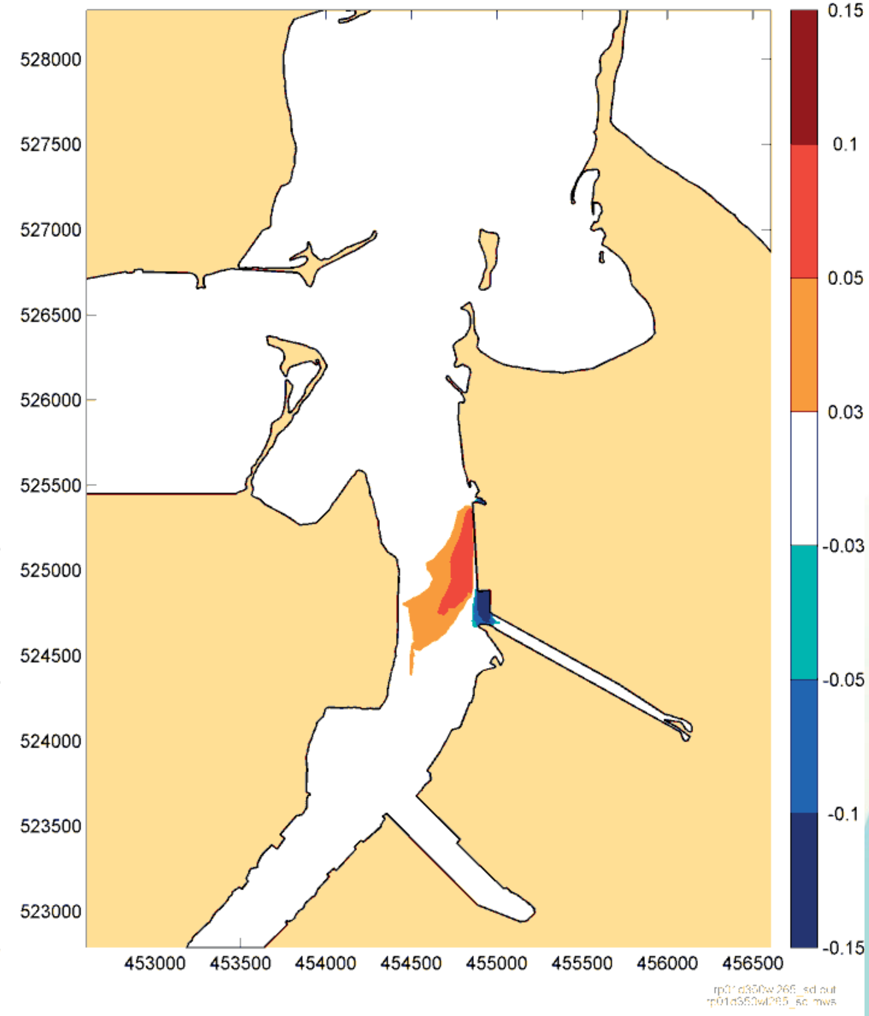
a. Change in wave height (m) due to dredging and solid quay at high water, 0.1 year return period wind from15°	b. Change in wave height (m) due to dredging and solid quay at high water, 1 year return period wind from 15°



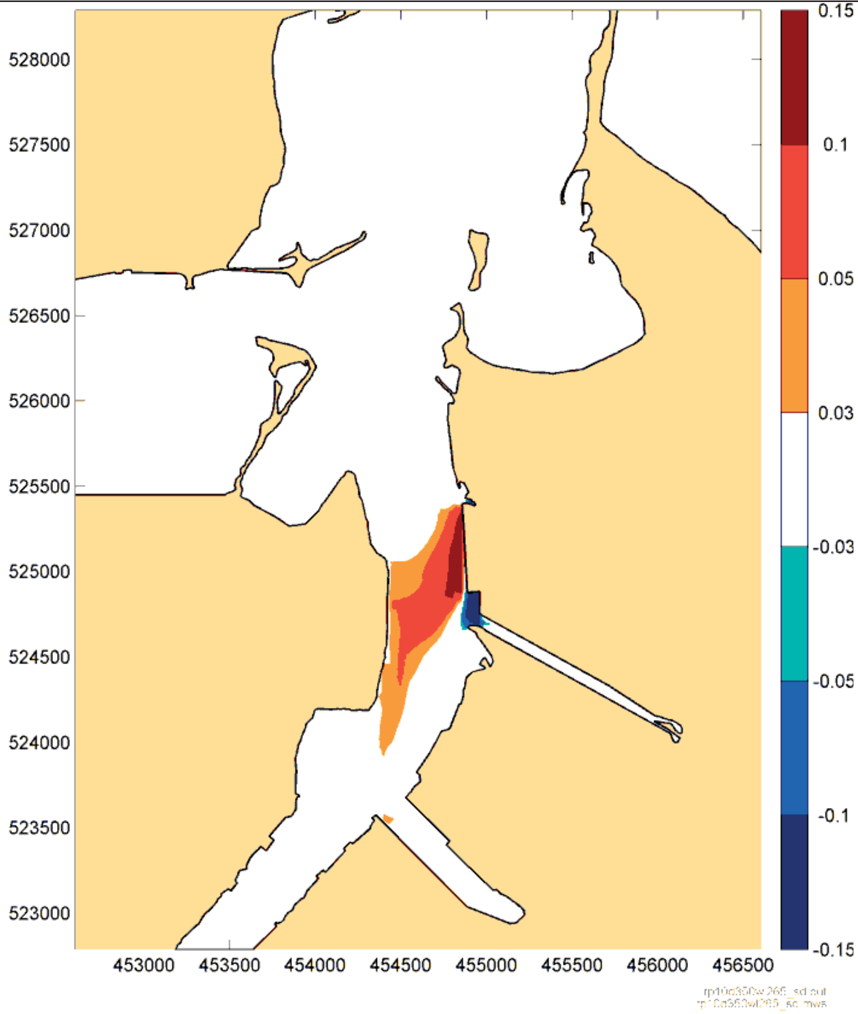
c. Change in wave height (m) due to dredging and solid quay at high water, 0.1 year return period wind from 215°	d. Change in wave height (m) due to dredging and solid quay at high water, 1 year return period wind from 215°



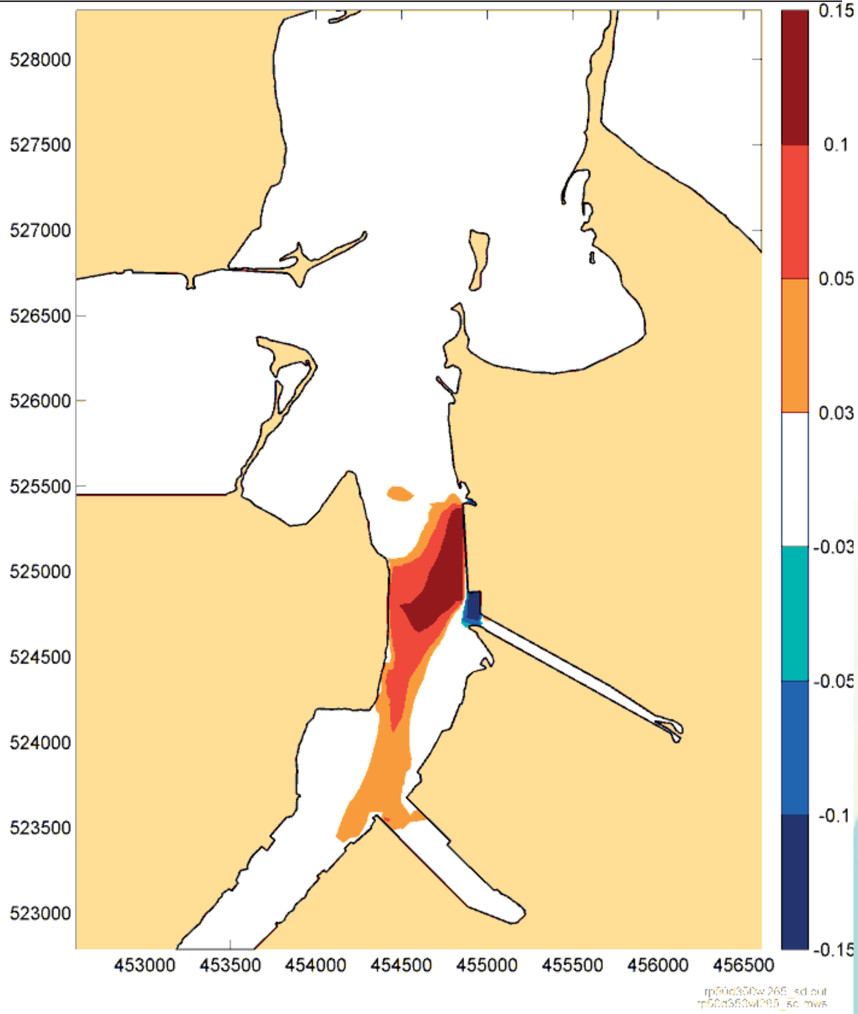
e. Change in wave height (m) due to dredging and solid quay at high water, 5 year return period wind from 215°



f. Change in wave height (m) due to dredging and solid quay at high water, 0.1 year return period wind from 350°

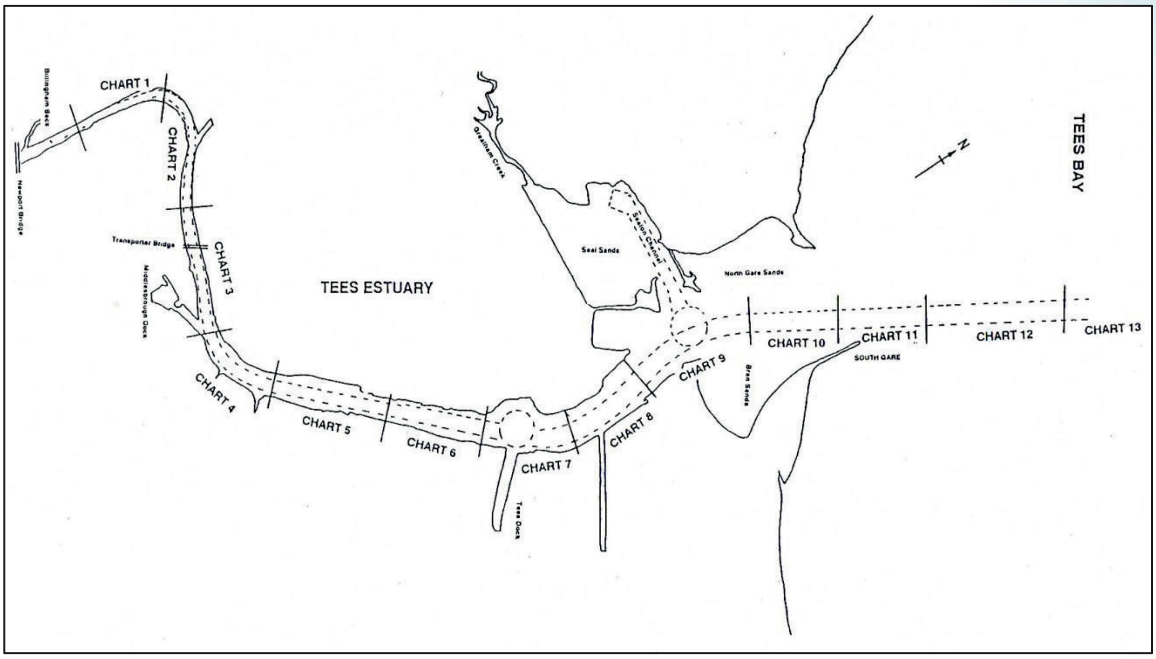


g. **Change in wave height (m) due to dredging and solid quay at high water, 1 year return period wind from 350°**



h. **Change in wave height (m) due to dredging and solid quay at high water, 5 year return period wind from 350°**

Figure 5-14 Tees estuary and approach Chart areas



5.6.22 The modelling undertaken for the hydrodynamic studies shows the effect of the proposed dredging on the import of fine sediment and the potential infill rate in the proposed dredged areas associated with both quay configuration options for the proposed port terminal.

5.6.23 The model simulated an existing (i.e. baseline) overall import of fine sediment of 430,000m^3 into Chart areas 1 to 9, which is within the range observed since the Tees Barrage was installed. In Chart area 8, the model predicted an existing 88,000m^3 per year of fine sediment infill, which is very close to the observed annual average value (84,000m^3). All infill predictions were made assuming a representative density of 500kg/m^3.

5.6.24 The results for the post-development cases show a negligible effect on the overall import of fine sediment into the estuary (less than 0.5%). This is to be expected because the width and depth of the channel at the entrance to the estuary would be unchanged by the proposed scheme; so the potential for changes to the amount of sediment imported though this route is also unchanged.

5.6.25 At the study site in Chart area 8, the infill rate is predicted to reduce by 2 to 3% for the two quay configurations compared to baseline conditions. This effect is associated with a small increase in fine sediment infill in Chart area 9 (approximately 1%). These changes are extremely small and are well within any natural variability in infill associated with, for example, variation in duration of storm wave conditions during any given year. No changes were predicted in other zones of the estuary.

5.6.26 In the berth pocket and approaches for the proposed port terminal, the average infill rates are predicted to be 5,100m^3 per year for the solid quay structure and 5,900m^3 per year for the open quay structure. This calculation includes the foreshore surrounding the facility, as these areas may also act as a sediment supply into the berth pocket. It is for this reason that the solid quay structure (which removes some foreshore) has less infill predicted than the open quay structure.

5.6.27 Overall, therefore, the effect of the proposed scheme is to result in a localised redistribution of sediment deposition in response to predicted changes in current speeds. It is predicted that this very small change in the overall fine sediment regime would not require any alteration in the present frequency of, or methodology used for, maintenance dredging and no effect on sediment supply to intertidal areas throughout the Tees estuary would occur. Consequently, no effect on the morphology of intertidal areas is predicted.

5.7 Summary

5.7.1 The hydrodynamic and sediment transport modelling undertaken predicts that the effects of the proposed works on tidal currents and waves would be relatively small and local to the proposed scheme. No change in the supply of fine sediment from offshore is predicted and the predicted accumulation of sediment within the berth pocket and the section of the approach channel to be dredged represents a redistribution of material that currently settles within the lower estuary only. As a result, no effect on the overall sedimentary regime of the Tees estuary is predicted.

5.7.2 A summary of the predicted effects of the proposed scheme on the hydrodynamic and sedimentary regime is provided in **Table 5-5**.

Table 5-5 Summary of predicted effects of the proposed scheme on the hydrodynamic and sedimentary regime

Predicted effect	Consequence
Construction phase	
Sediment release during dredging	*Summary of effect*
The simulations indicate a significant difference in excess concentrations from one side of the navigation channel to the other, with the most dispersion along the main direction of flow on the eastern side of the estuary.	
Enclosed grab	• There would be virtually no sediment release from the enclosed grab method.
CSD	• Mean elevated suspended sediment concentration increases above 10mg/l are confined to an area 500m upstream and downstream of the dredger. Mean concentration increases of more than 500mg/l are predicted at the location of the dredging activity only.
Backhoe dredger	• An area of elevated suspended sediment concentrations in the range of 10mg/l to 50mg/l would be confined to the immediate area of the dredger, with no wider effects within the estuary
TSHD	• An area of elevated suspended sediment concentration, in the range of 10mg/l to 50mg/l above background may be anticipated in the channel, 1km either side of the dredging works. Larger excess concentrations are predicted in the immediate area of the dredger, at up to 200mg/l of suspended sediment.

Predicted effect	Consequence
Sediment deposition	*Summary of effect*
The highest amounts of deposition are predicted in the immediate area of the dredging operation. The deposition indicated within the proposed dredged area would be likely to be re-dredged as part of the capital dredging operations. Negligible sediment is predicted to deposit on the intertidal areas.	
CSD	• Immediately upstream and downstream of the dredging location, deposition of tens of millimetres is predicted, while tens of centimetres of sediment deposition is predicted in the vicinity of the barge itself. Elsewhere within the estuary (up to 1.5km either side of the dredge location), fine sediment deposition over the simulation period is predicted to be a maximum of a few millimetres.
Backhoe	• Sediment deposition of a maximum of a few millimetres is predicted up to 1.5km upstream and downstream of the dredger.
TSHD	• Fine sediment deposition is predicted to be a maximum of a few millimetres at a distance of approximately 2km either side of the dredge footprint, while deposition at the dredge location is predicted to be 10 to 20mm.
Operational phase	
Change in tidal density drive hydrodynamics	• Currents are predicted to be reduced within deepened areas. • The spatial extent of the effect due to the open structure is similar to that of the solid quay structure. • Some current speed increases are predicted on the shoreline adjacent to the works for the solid quay. • An area of increased current speed is predicted to the rear of the open structure on the ebb tide, however this is less than 0.1m/s so erosion of the bed is unlikely. • Away from the immediate area of the proposed scheme, the effect of the works is insensitive to the form of port terminal. • A negligible effect on tidal propagation and water levels is predicted.
Change in wave propagation	• No effect on penetration of waves into the Tees estuary is anticipated. • No increase in wave energy is predicted within the estuary for the open quay. • A relatively localised effect on existing wave heights within the estuary is predicted for the solid quay option (in the range 0.05m to 0.1m). • No increases in wave heights over the designated intertidal areas at Teesmouth are shown.

Predicted effect	Consequence
Change to local sediment regime in dredged areas	• No potential for effect on the amount of sediment imported to the Tees from offshore. • The proposed scheme would result in a localised redistribution of sediment deposition due to change in current speed. • This very small change would not result in any alteration in the present frequency of maintenance dredging. • No effect on morphology of intertidal areas predicted.