REPORT

South Bank Quay

Hydro-dynamic and sedimentary plume modelling

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1 Introduction

Royal HaskoningDHV has been commissioned by Tees Valley Combined Authority to undertake a numerical modelling exercise to inform the Environmental Impact Assessment (EIA) that is being prepared as part of the South Bank Quay project.

This report describes the numerical modelling study, and the approach to the modelling is summarised below:

- **Hydrodynamic modelling**: An existing 2D North East Regional Tidal Model built in MIKE21-HD was used to provide boundary conditions for an existing 3D Tees Estuary Tidal Model built in MIKE3-HD. The latter model was updated with new bathymetry data and its mesh was refined around the site of the proposed scheme. The model was re-calibrated and then further verified using the acoustic doppler current profiler (ADCP) data newly collected as part of a Metocean Survey undertaken by Partrac in July 2020. The updated and verified 3D model was then used to characterise baseline conditions and predict potential local and estuary-wide changes in hydrodynamics caused by the proposed scheme.

- **Dispersion modelling**: The updated and verified 3D Tees Estuary Tidal Model was used to predict movement of suspended sediment from the proposed dredging and disposal activities by coupling with a sediment plume model built in MIKE3-MT software. The sediment plume model was run for the entire 4-month dredging and disposal schedule.

- **Wave modelling**: Since the site is well sheltered from North Sea swell waves, it is locally-generated wind waves that are of more significance to the proposed scheme. To demonstrate this understanding of the baseline wave conditions, an established Tees Bay Wave Model built in MIKE-SW was used to transform extreme offshore waves (1 in 1 year and 1 in 100 year) to the site. In addition, extreme value analysis was undertaken for extreme wind conditions in the Tees Estuary. Locally-generated waves caused by extreme winds were then hindcast using the Tees Bay Wave Model.

Figure 1.1 shows the project area of the proposed scheme, as well as the wider study area used for consideration of hydrodynamics and sedimentary processes. The wider study area: (i) extends approximately 18 kilometres offshore to encompass the offshore disposal site Tees Bay C; (ii) covers Hartlepool Headland in the north and Redcar in the south; and (iii) includes the whole of the River Tees up to the Tees Barrage, which is the tidal limit. The proposed scheme at South Bank Wharf is situated approximately 6 km upstream from the mouth of the Tees Estuary.

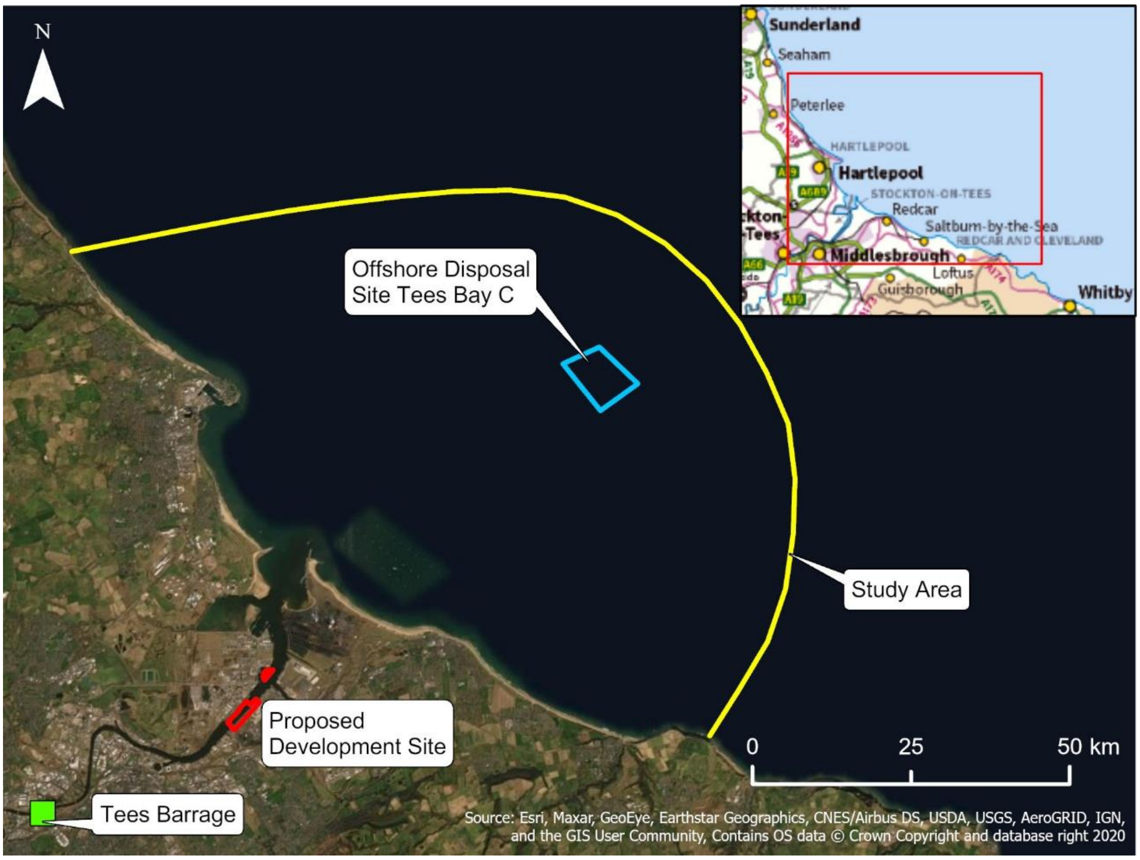

Figure 1.1: Proposed Development Site and Wider Study Area

2 Hydrodynamic 2D/3D Model Update and Recalibration

This chapter of the report describes the update and recalibration of the 2D and 3D Hydrodynamic Model for the South Bank Wharf project.

2.1 Model Description

The two-dimensional MIKE21/3 hydrodynamic (HD) model previously developed, calibrated and verified by RHDHV for a recent Tees Dock project (Northern Gateway, No. 1 Container Operation, Vessel Navigation Assessment, 2017) was taken as the basis for the new South Bank Wharf HD model. It was refined and updated specifically for the South Bank Wharf project. It has been recalibrated to establish a detailed description of the water levels and currents, focusing on the study area along South Bank Wharf and Tees Dock Turning Area as shown in **Figure 2.1**.

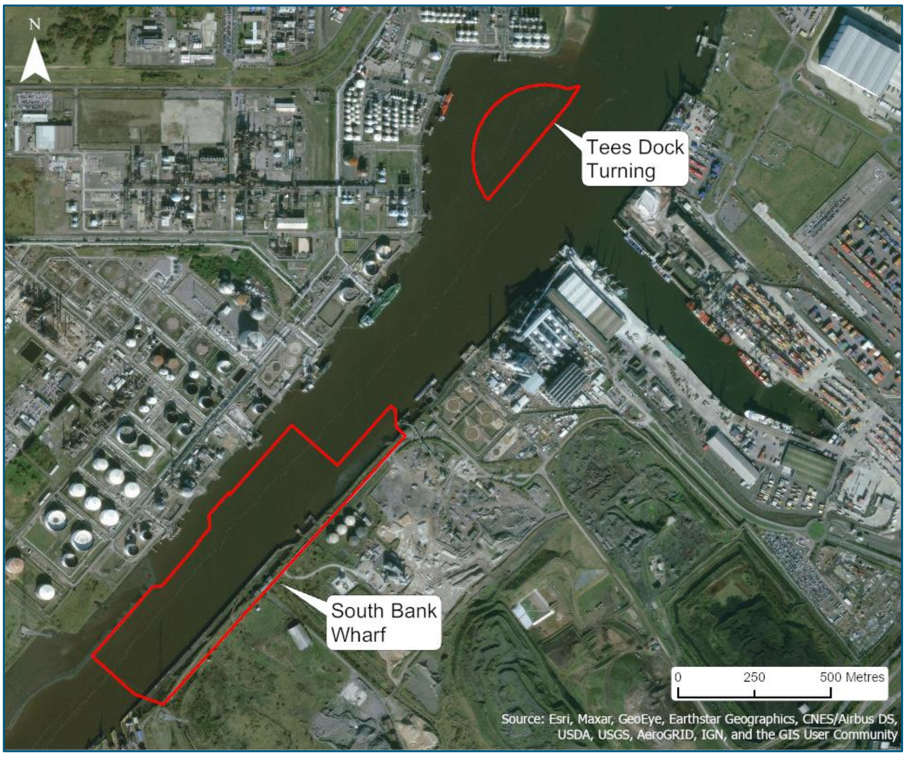

Figure 2.1: Proposed Development Site - South Bank Wharf and Tees Dock Turning Circle

The MIKE21/3 software was developed by the Danish Hydraulic Institute (DHI). The software has a proven track record and is widely used in many similar studies worldwide. The MIKE21/3-HD hydrodynamic module can be used to solve both two-dimensional (2D) and three-dimensional (3D) problems. The 2D model is based on the nonlinear shallow water equations using depth-averaged conditions. The 3D the model is based on the three-dimensional numerical solution and can provide hydrodynamic information for different water depths. The main advantages of this model are:

- The flexible triangular mesh of MIKE21/3-HD provides accurate boundary fitting for an area with complicated geometry, for example around South Bank Wharf and the Tees Dock Turning Area.

- The flexible mesh enables the model to use a coarser grid in the offshore area and the areas further away from proposed development site but a finer mesh in the areas of greatest interest. This approach enables higher computational efficiency whilst still maintaining sufficient accuracy of mesh coverage in areas of greatest interest in the present study.

- The software allows for a quadrangular mesh covering the River Tees to be seamlessly linked into the overall triangular mesh covering the remaining study area, enabling important fluvial flows from the River Tees to be incorporated.

2.2 2D Model Extent

The north to south extent of the model covers the area between North Shields, approximately 50km to the north, and Flamborough Head, approximately 100km to the south of South Bank Wharf. It also covers the River Tees up to the Tees Barrage. The offshore boundary follows the predominant north-south tidal stream orientation and extends 35km offshore in the north and narrows down to 16km offshore in the south.

2.3 Model Bathymetry

The bathymetry was updated with the latest available data sets and consists of several data sources that are listed below. **Figure 2.2** and **Figure 2.3** show the MIKE21-HD model extent and the bathymetric survey data points that have been loaded into the model.

The following bathymetry data sets have been updated in the model:

- Bathymetric Surveys of the Tees approach channel, Tees Dock, Tees Dock Turning Area, River Tees up to Tees Barrage (PD Ports)

The following bathymetry data sets have been newly incorporated into the model:

- Bathymetric Nearshore Surveys between Sunderland to Flamborough Head (Cell One Regional Coastal Monitoring Programme)
- Lidar data covering the mudflats near South Bank Wharf (Environment Agency)

The following bathymetry data sets are unchanged in the model:

- Bathymetric Survey in Hartlepool and around Redcar (Environment Agency)
- River Tees cross sections (Environment Agency)
- C-map data covering offshore areas (Hydrographic Office)

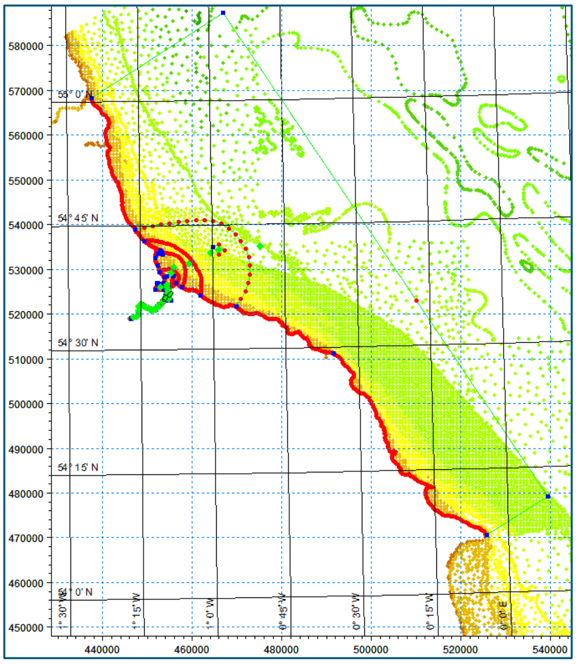

Figure 2.2: Model extent and bathymetry points

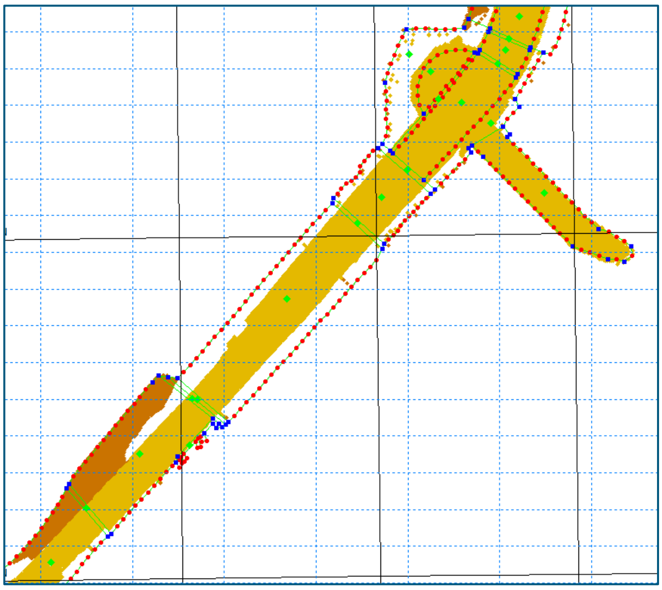

Figure 2.3: Bathymetry points in study area

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2.4 Model Mesh Resolution

2.4.1 Triangular Mesh

The model domain was divided into areas of different grid resolution as shown in **Figure 2.4**. A triangular mesh was generated between offshore areas up to the Tees Dock Turning Area with the resolution shown in **Table 2-1**. A quadrangular mesh was generated for the Tees River, from the Tees Dock Turning Area to the South Bank Wharf study area and up to the Tees Barrage, see 2.4.2. Elsewhere a triangular mesh was used.

Table 2-1: Mesh Resolution

Mesh Area	Mesh resolution (m^2)	Approx. Max mesh size (m)
Offshore areas	500,000	700
Intermediate areas	50,000 to 5,000	225 to 75
Tees Dock Turning Area	500	25
South Bank Wharf Study Area	quadrangular	20 x 20
River Tees	quadrangular	50 x 50

The grid is finest in the area which covers the South Bank Wharf study area to give better definition as this area is of most interest in terms of the hydrodynamic outputs for the Environmental Impact Assessment. The mesh becomes gradually coarser moving away from the study area to the most offshore areas being the coarsest resolution.

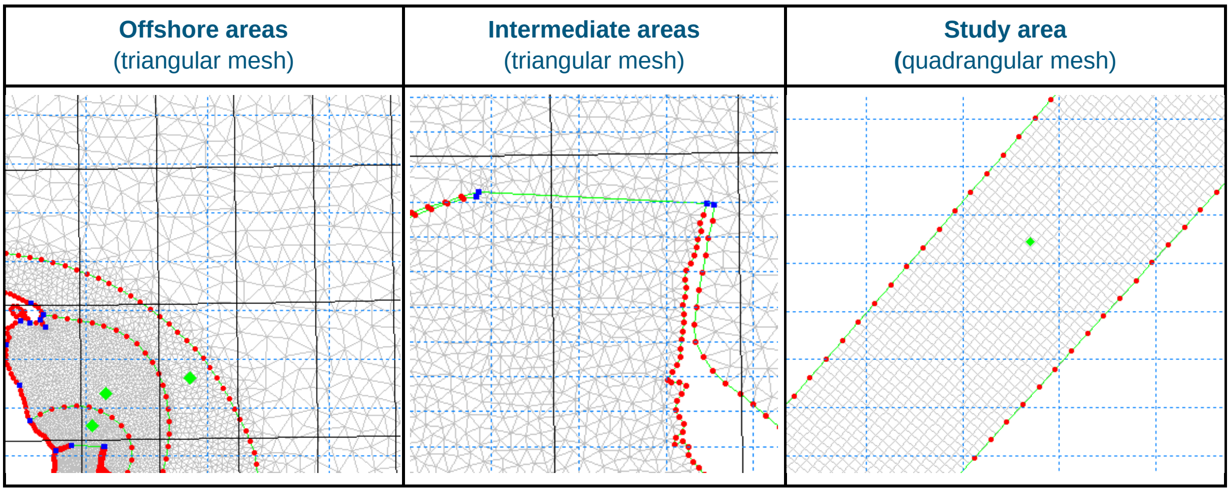
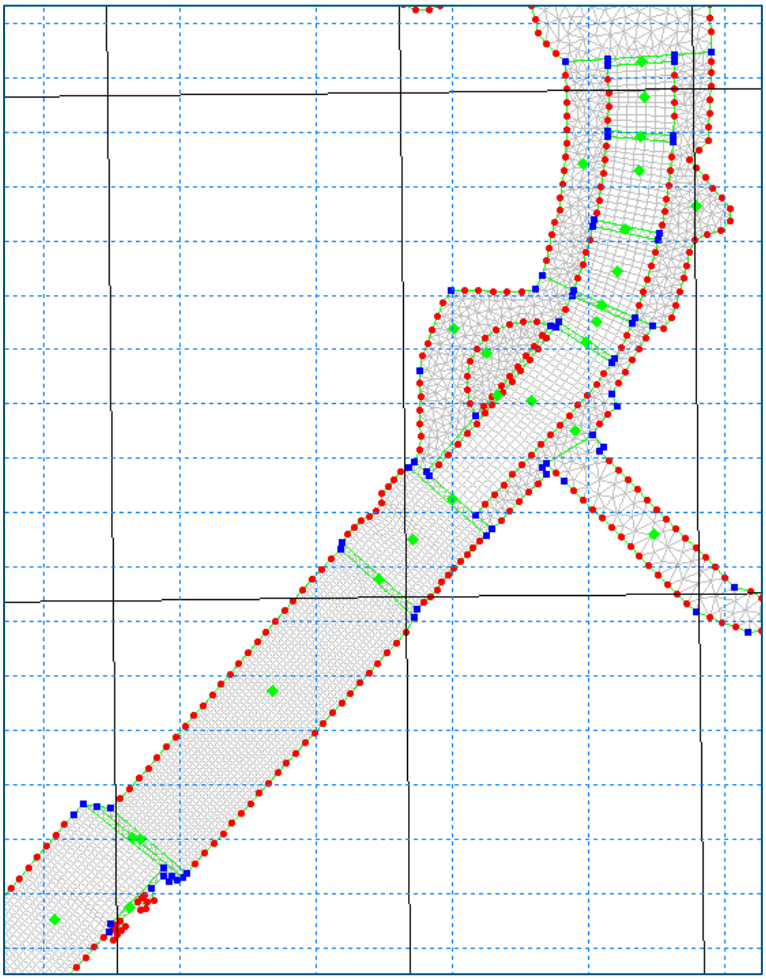


Figure 2.4: Triangular Mesh Resolution examples

2.4.2 Quadrangular Mesh

Due to the importance of fluvial flows from the River Tees, a quadrangular mesh of the river channel up to the tidal limit was seamlessly linked into the triangular mesh covering the wider study area. The quadrangular mesh is defined by its mesh size in flow direction as well as in transversal direction to the flow



as illustrated in **Figure 2.5**.

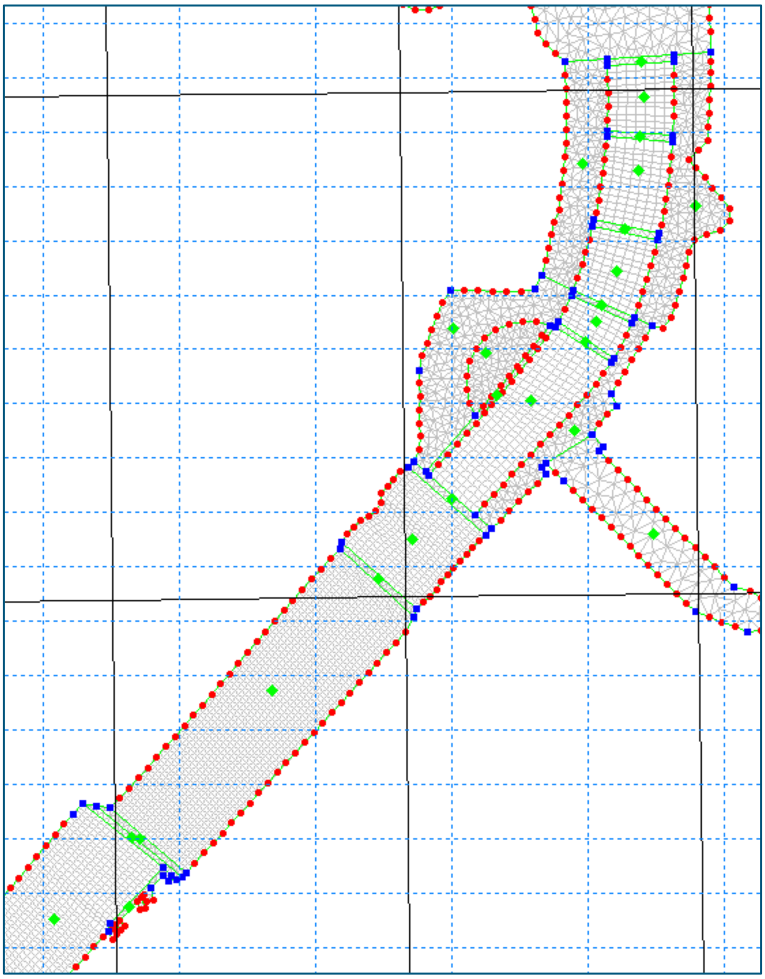


Figure 2.5: Seamless link between triangular and quadrangular mesh of the River Tees

2.5 Model Boundaries

Open model boundaries are set to drive the flow conditions in the model. This model is driven by three sets of open boundary data and one closed boundary as illustrated in **Figure 2.6**.

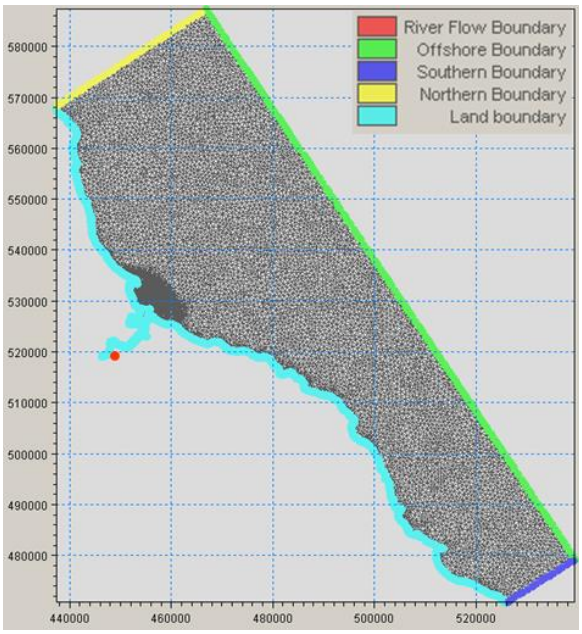


Figure 2.6: Model boundaries

The northern and southern model boundaries are varying tidal elevation boundaries using predicted tidal data. The tides are predicted by using a formula developed from the information from Tide Tables (tidal harmonics and phase lag information) for the required time periods. The northern boundary uses the tide gauge at North Shields which is one of the National Oceanographic Centre's A-Class tide gauges.

The southern model boundary at Flamborough Head is also a varying tidal elevation boundary. However, due to the fact that the nearest and suitable tide gauge to Flamborough Head is Whitby (also one of NOC's A-Class tidal gauges) it was necessary to modify the tidal phase to take into account the geographical distance of 55km between Whitby and the actual model boundary at Flamborough Head.

The third open boundary is the river flow boundary at the River Tees Barrage, which is based on the time series river flow gauge data recorded by the Centre for Ecology & Hydrology (CEH) at Low Moor and Leven Bridge for the required time periods. The location of the two river flow gauges are shown in **Figure 2.7**.

The offshore boundary running parallel to the shoreline and parallel to the predominant direction of the tidal currents along the coast is set as a closed boundary. This setting assumes that no significant flow runs across the offshore boundary into and out of the model domain. Therefore, care was taken in the model set-up and calibration process to ensure that the offshore boundary (distance to shore and orientation) satisfies this assumption.

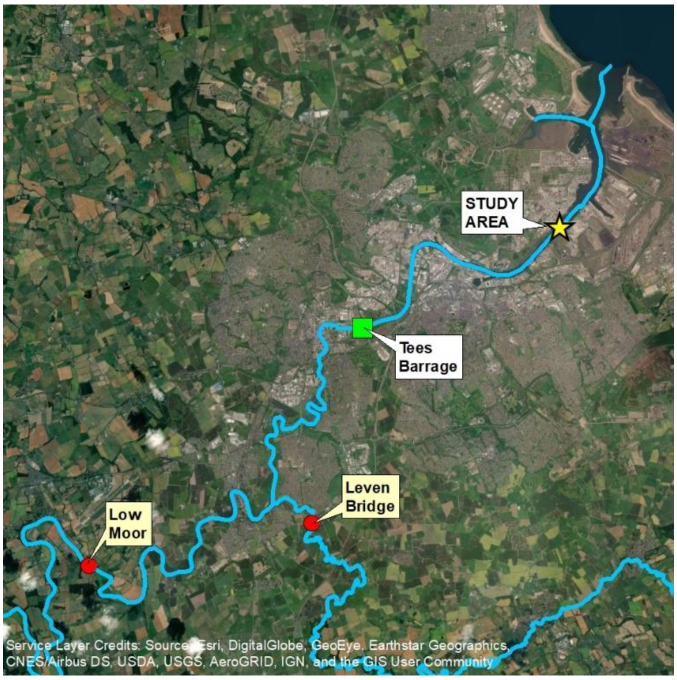


Figure 2.7: Location of River Flow Gauge Stations at Low Moor and Leven Bridge

2.6 2D/3D Model Recalibration

The model recalibration process had to determine satisfactory model performance in respect of two parameters, namely water level and tidal currents.

The following measured data were provided previously by PD Ports:

- Water level data at the Tees Dock Tide Gauge for the time period between 22nd to 30th April 2005.
- Tidal current data for ADCP transects captured by a vessel mounted instrument in the River Tees for the time period between 22nd to 30th April 2005.
- Tidal current data for ADCP data collected using a bed frame located near the Tees Dock Turning Area for the time period between 24th January to 23rd February 2017.

The location of the Tees Dock Tide Gauge is shown in **Figure 2.8**.

There are three ADCP transect locations in the River Tees that are relevant to this study, namely T9 (upstream of the site), T8 (at the site itself) and T11 (downstream of the site). For the purpose of model verification, a point was placed at the centre of each transect to extract modelled time series data at these locations and then compared to the data measured along the ADCP transect. The three ADCP 2005 transects and the ADCP 2017 point are shown on **Figure 2.9**.

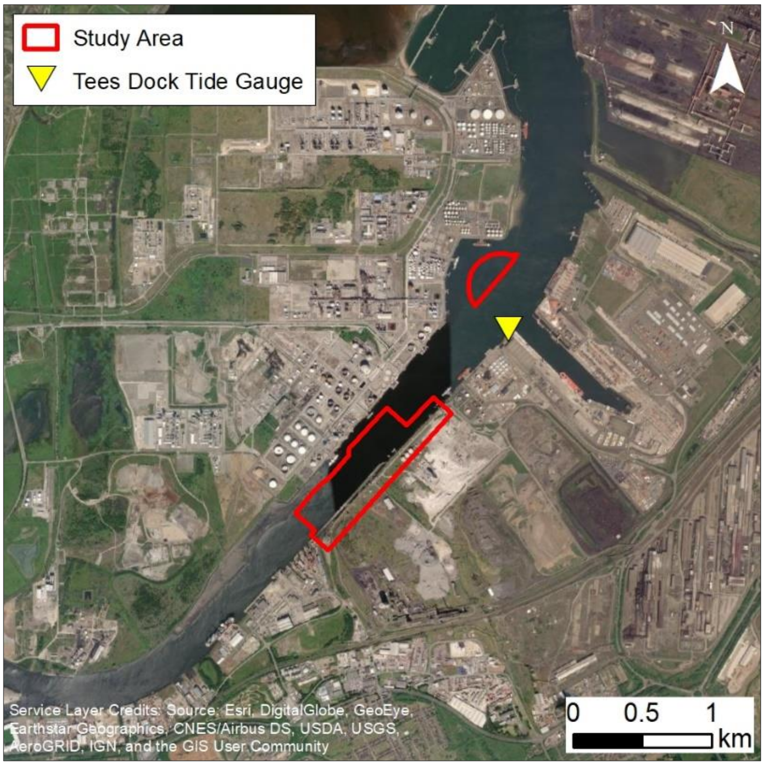


Figure 2.8: Location of the Tees Dock Tide Gauge

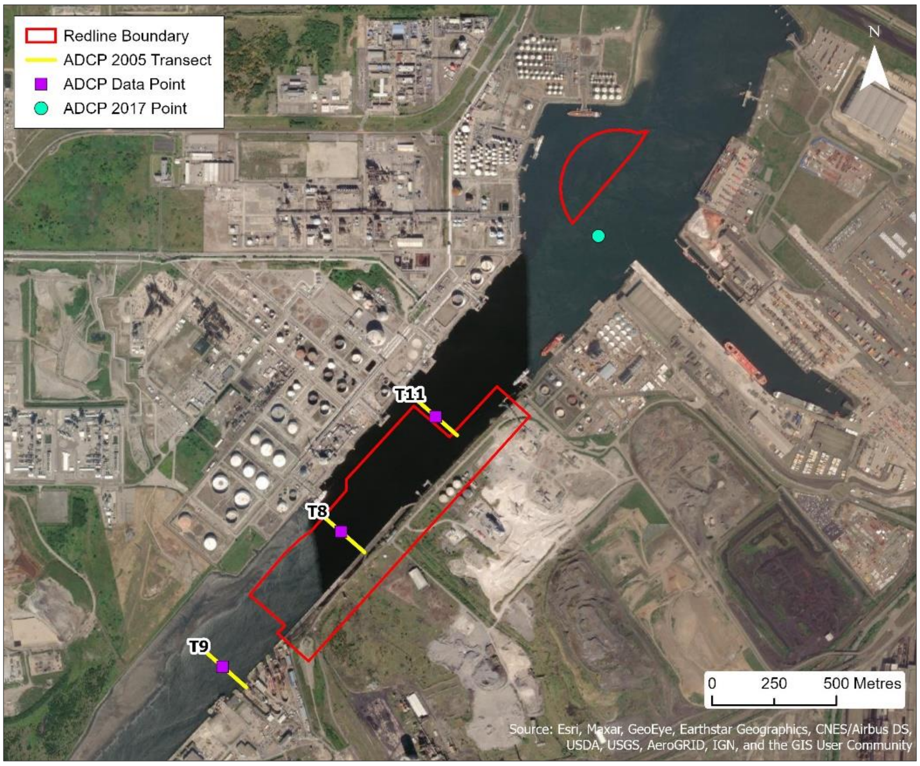


Figure 2.9: ADCP 2005 transect and ADCP 2017 point in the River Tees

2.7 Recalibration Comparison

The South Bank Wharf 2D HD model was recalibrated against RHDHV's Tees Dock 2D HD model that has previously been calibrated against 2005 water level and tidal current data. The purpose of the recalibration is to show that the refinement of the model mesh and updates of the bathymetry still produces the same results. A recalibration run was undertaken for the time period of 22nd to 30th April 2005 with high river flows, combined from two river flow gauge stations, namely Low Moor and Leven Bridge (**Figure 2.7**).

Figure 2.10 shows good agreement was obtained between the measured and both modelled tidal data. There is virtually no difference in tidal level between the Tees Dock and South Bank Wharf 2D HD models.

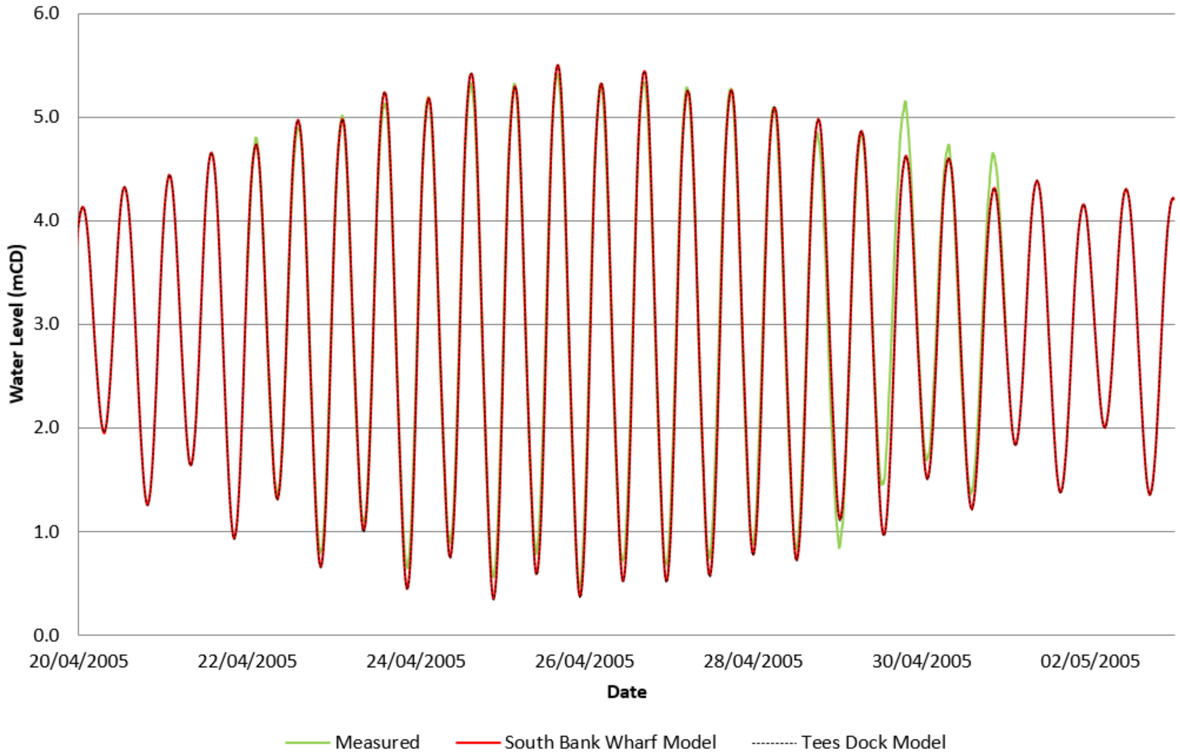


Figure 2.10: Comparison of Measured and Modelled Tidal Elevation at Tees Dock Tide Gauge between 22nd to 30th April 2005

However, as pointed out during the previous study, the modelled lower tides are slightly under predicted. Around the 29/30th April a "spike" in the measured data can be seen and the modelled data does not match it well. This discrepancy can be explained by **Figure 2.11** that overlays long-term predicted harmonic tidal data on the previously plotted modelled and measured datasets. It shows that the modelled and predicted harmonic tidal levels match well with each other on those days and it is therefore likely that during the time period of the "spike" a real-time surge occurred which was captured by the measured data.

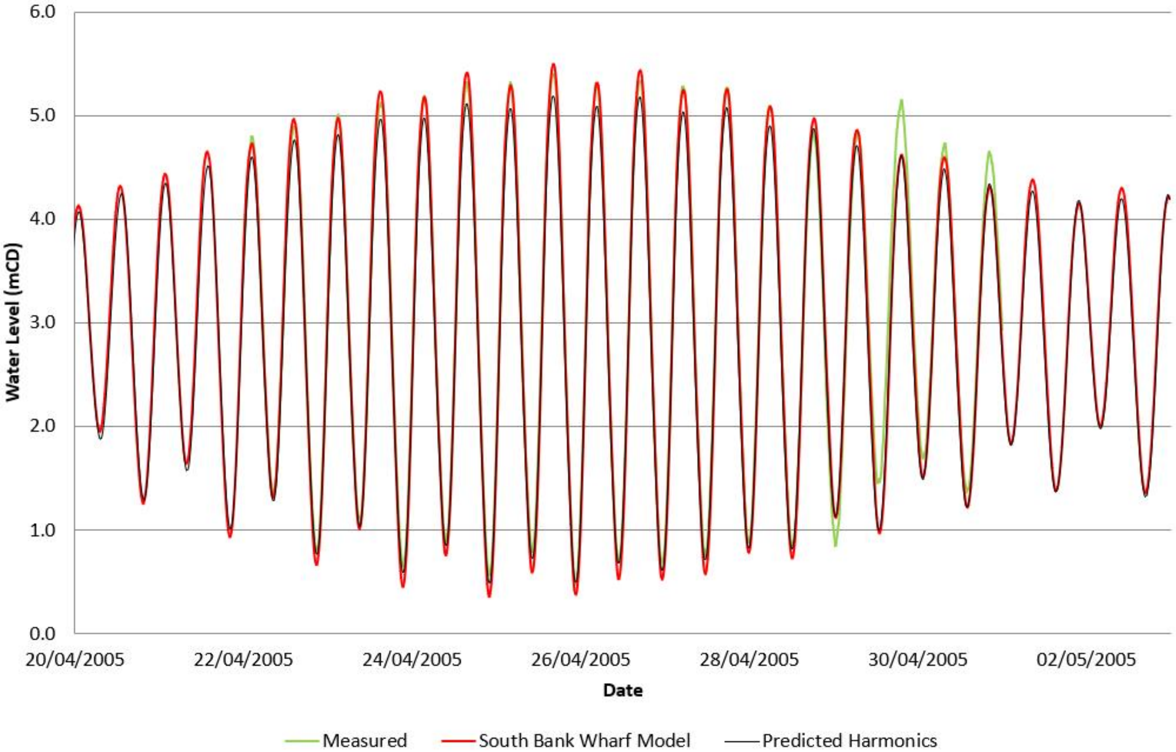


Figure 2.11: Comparison of Measured, Modelled and Predicted Tidal Elevation at Tees Dock Tide Gauge between 22nd to 30th April 2205

Figure 2.12 to **Figure 2.14** show a comparison between the measured and modelled current speed and the current direction of both, the previous Tees Dock model and the new South Bank Wharf, for the recalibration run. The three ADCP transects T9, T8 and T11, which are relevant for this project, are presented here. It is worth noting that due to the nature of the 2005 ADCP data collection the measured points shown on the plots are approximately 5-10 metres away from the modelled data point. Considering that there are uncertainties over whether or not the measured 2005 data is depth-averaged, it agrees reasonably well with the both modelled data.

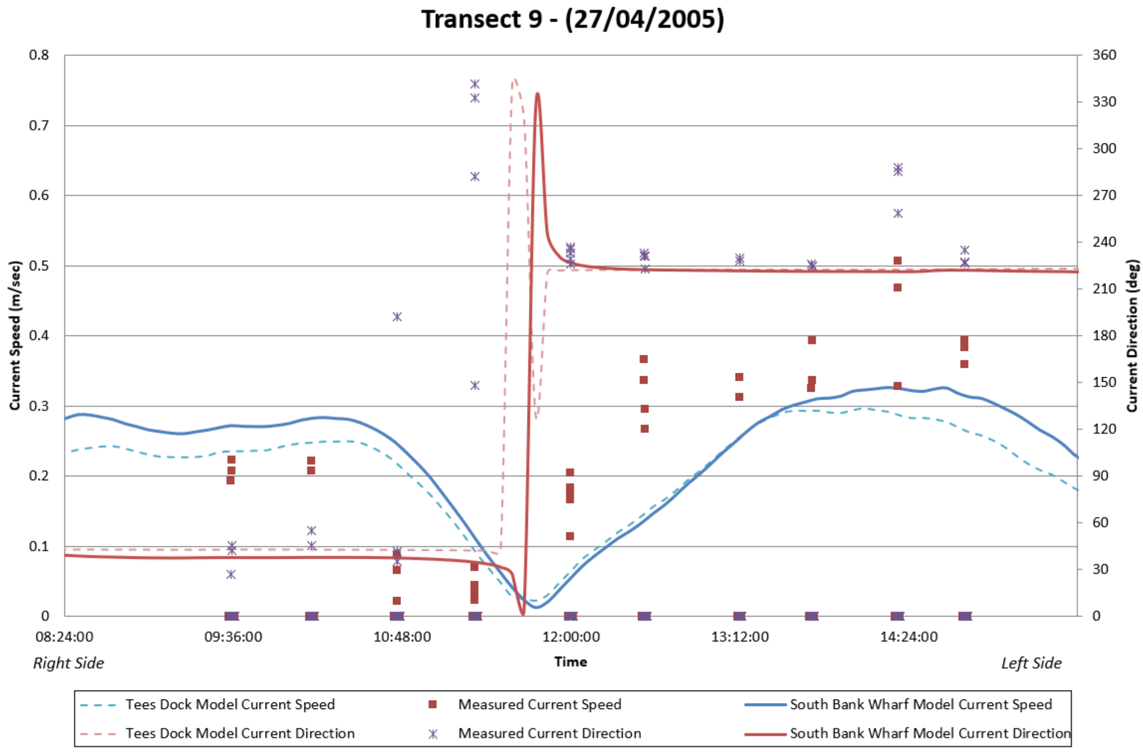


Figure 2.12: Comparison of Measured and Modelled Current Speed and Direction at Transect 9 on 27th April 2005

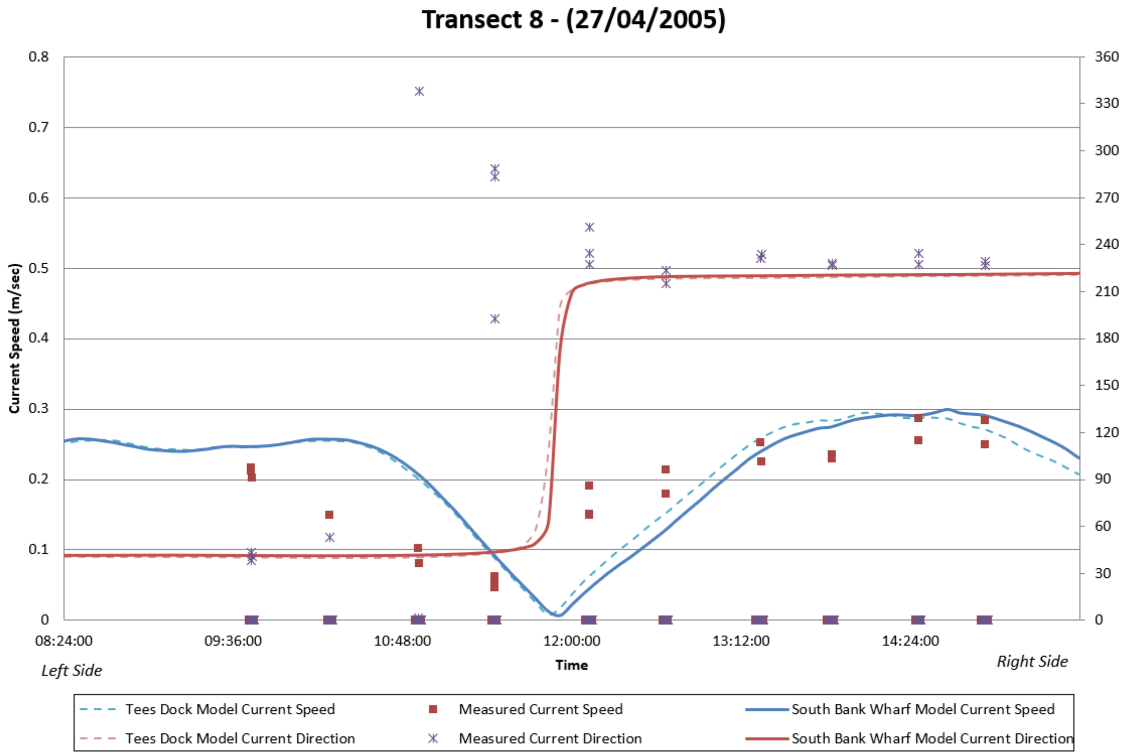


Figure 2.13: Comparison of Measured and Modelled Current Speed and Direction at Transect 8 on 27th April 2005

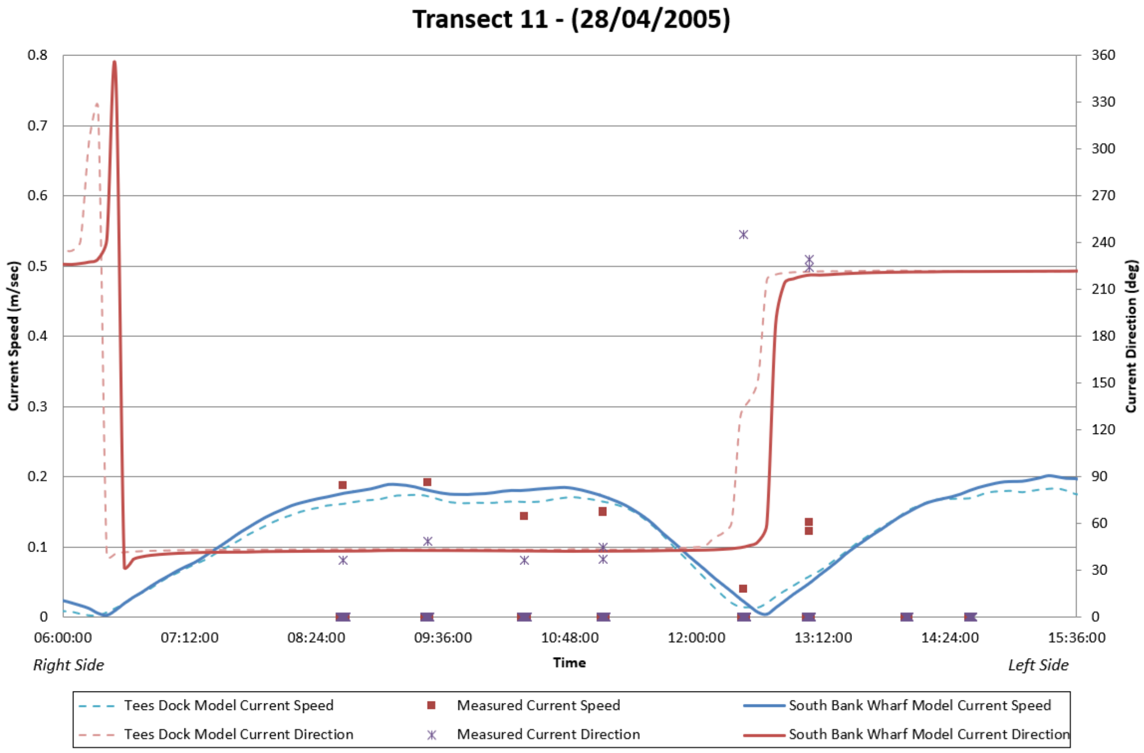


Figure 2.14: Comparison of Measured and Modelled Current Speed and Direction at Transect 11 on 28th April 2005

The Tees Dock 2D HD model was also developed into a 3D HD model which was calibrated against the ADCP 2017 data collected near the Tees Dock Turning Area. This 3D HD model is covering the smaller extent from the Tees Estuary mouth to the Tees Barrage, shown in **Figure 2.15**. The purpose of the recalibration against the 2017 ADCP data is to show that the refinement of the model mesh and updates of the bathymetry still produces the same results. A recalibration run was undertaken for the time period of 6th to 23th February 2017 with high river flows.

The comparison of the measured and modelled results for the previous Tees Dock and latest South Bank Wharf model are presented in **Figure 2.16** to **Figure 2.18**. They show a very good agreement for current speed and direction near the sea bed, the middle of the water column and the water surface.

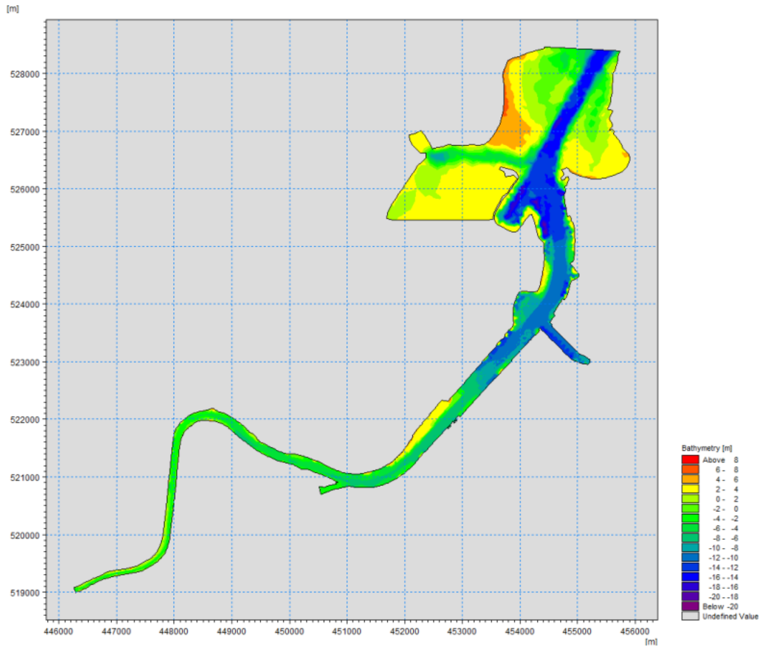


Figure 2.15: Tees Dock 3D HD Model Extent

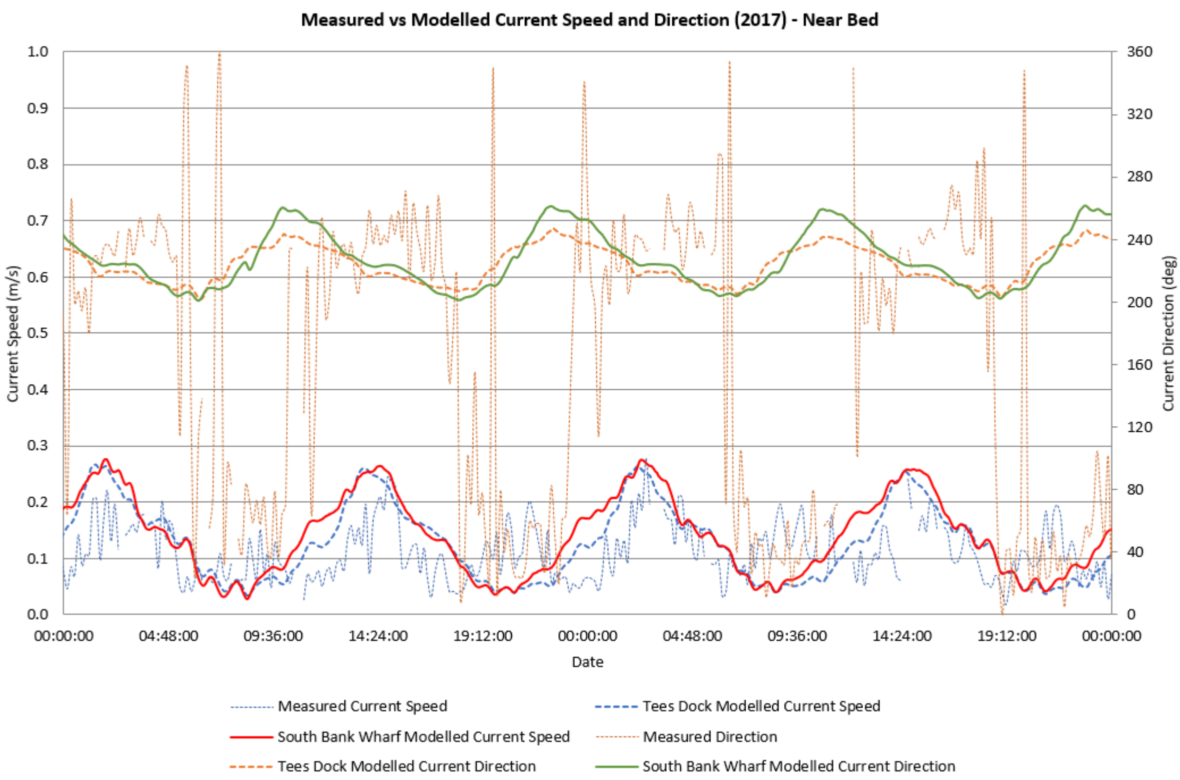


Figure 2.16: Comparison of Measured and Modelled Current Speed and Direction near bed

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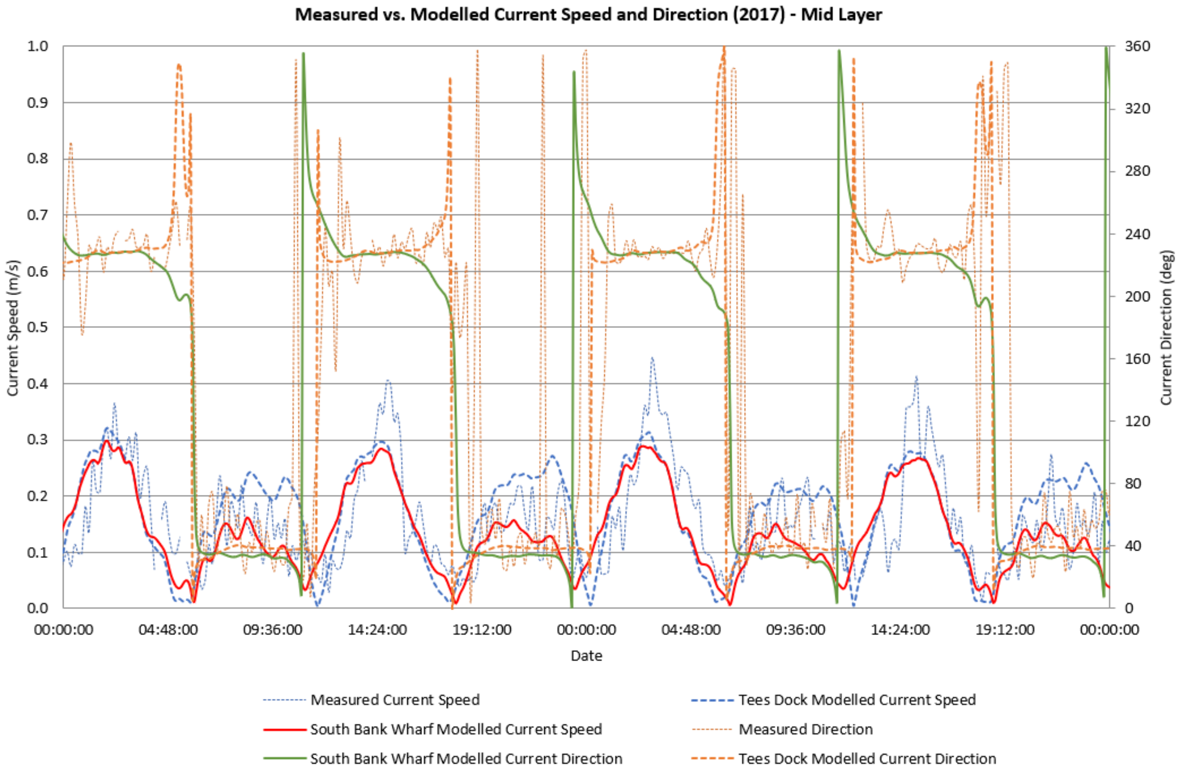

Figure 2.17: Comparison of Measured and Modelled Current Speed and Direction for mid water column

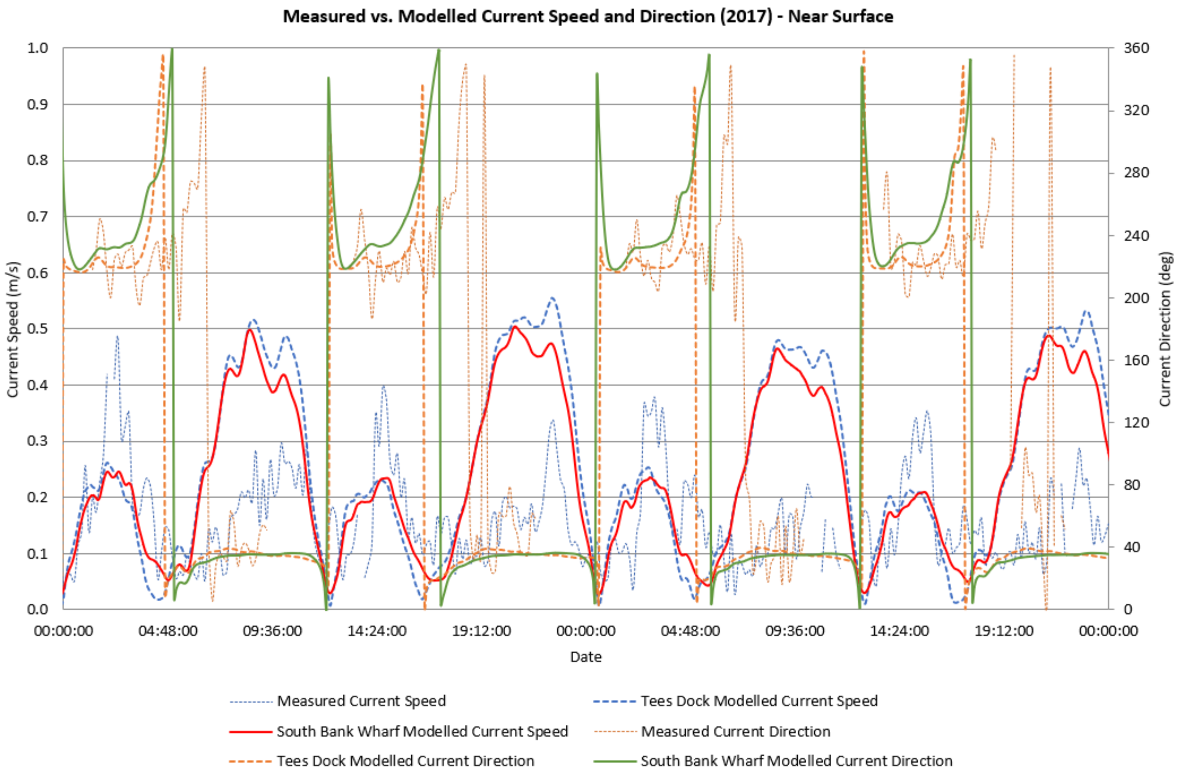

Figure 2.18: Comparison of Measured and Modelled Current Speed and Direction near water surface

3 Hydrodynamic 3D Model Extension and Verification

This chapter of the report describes the set-up and verification of the extended 3D Hydrodynamic Model for the South Bank Wharf project.

3.1 Model Description and Extent

For the South Bank Wharf project, the previously constructed three-dimensional Tees Dock HD Model, described in Section 2, has been extended further offshore to include the offshore disposal site Tees Bay C.

The 3D Model (MIKE3-HD) has been set up as a smaller, so-called 'nested', model within the larger 2D HD model. This is because the 3D model simulates the hydrodynamics in three dimensions, i.e. the water depth is divided up into a number of layers, which makes the model run a lot slower. In order to speed up computation, the 3D HD Model extent has been reduced in size which is illustrated in **Figure 3.1**.

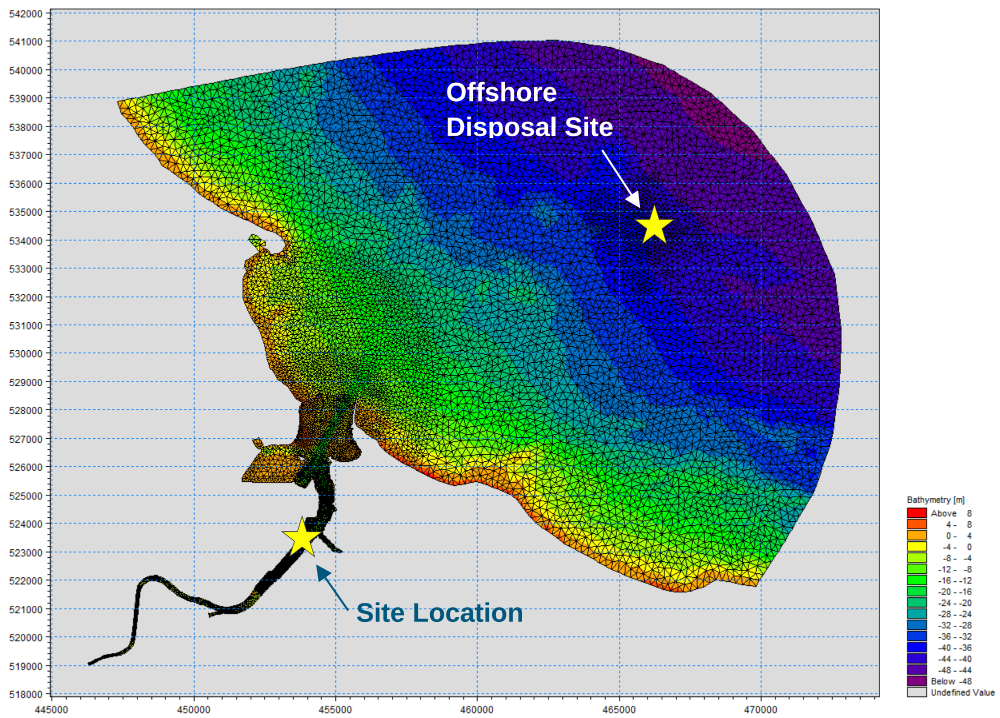

Figure 3.1: Extended 3D Model Domain

The model verification process had to determine satisfactory model performance in respect of two parameters, namely water level and tidal currents. The following measured data was collected as part of the Metocean study and provided by Partrac:

- Water level data at the Tees Dock Tide Gauge for
  a Spring Tide on 24th July 2020 and a Neap Tide on 30th July 2020
- Tidal current data for ADCP transects captured by vessel mounted instrument in the River Tees for a Spring Tide on 24th July 2020 and a Neap Tide on 30th July 2020

The location of the Tees Dock Tide Gauge and the ADCP transects are shown in **Figure 3.2Figure 2.8**.

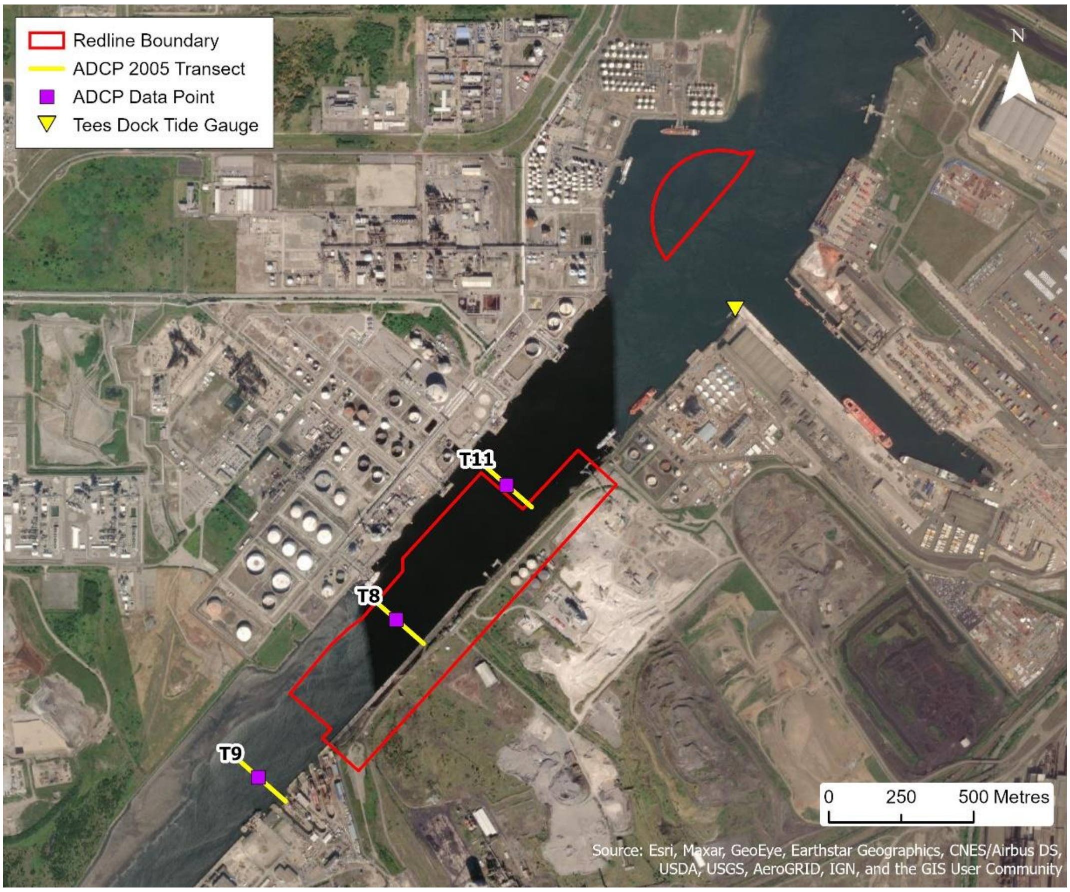

Figure 3.2: Location of Tees Dock Tide Gauge and ADCP Transects

The vessel mounted ADCP data for this study has been measured along the same transect locations in the River Tees as for the previous Tees Dock study. ADCP data has been recorded along three transects, namely T9 (upstream of the site), T8 (at the site itself) and T11 (downstream of the site). For the purpose of model verification, a point was placed at the centre of each transect to extract modelled time series data at these locations and then compared to the data measured along the ADCP transect. The transects and the data point locations are shown on **Figure 3.2Figure 2.9**.

3.2 Model Boundaries and Settings

The South Bank Wharf 3D HD Model is driven by two boundaries. Firstly, the offshore boundary is derived from the larger 2D HD model and uses a water level varying in time and along the boundary. The other boundary is located upstream the River Tees at the Tees Barrage and uses a constant discharge flow.

During the ADCP data collection, salinity measurements were also undertaken in the centre of the river channel. **Figure 3.3** shows a typical salinity profile during spring and neap tide. The salinity profile shows that the rate of salinity through the water column varies depending on the water depth. The deeper the water, the higher the salinity rate. This is because fresh water and salt water are mixing in this area. Fresh water that flows down the river from the Tees Barrage is lighter than sea water and therefore ‘floats’ on top of the salt water that flows into the Tees estuary from the sea.

Due to this, the function of salinity has been applied in the model. The rate of salinity at the offshore boundary has been set to 35 PSU and at the river boundary, the Tees Barrage, the rate has been set to zero PSU.

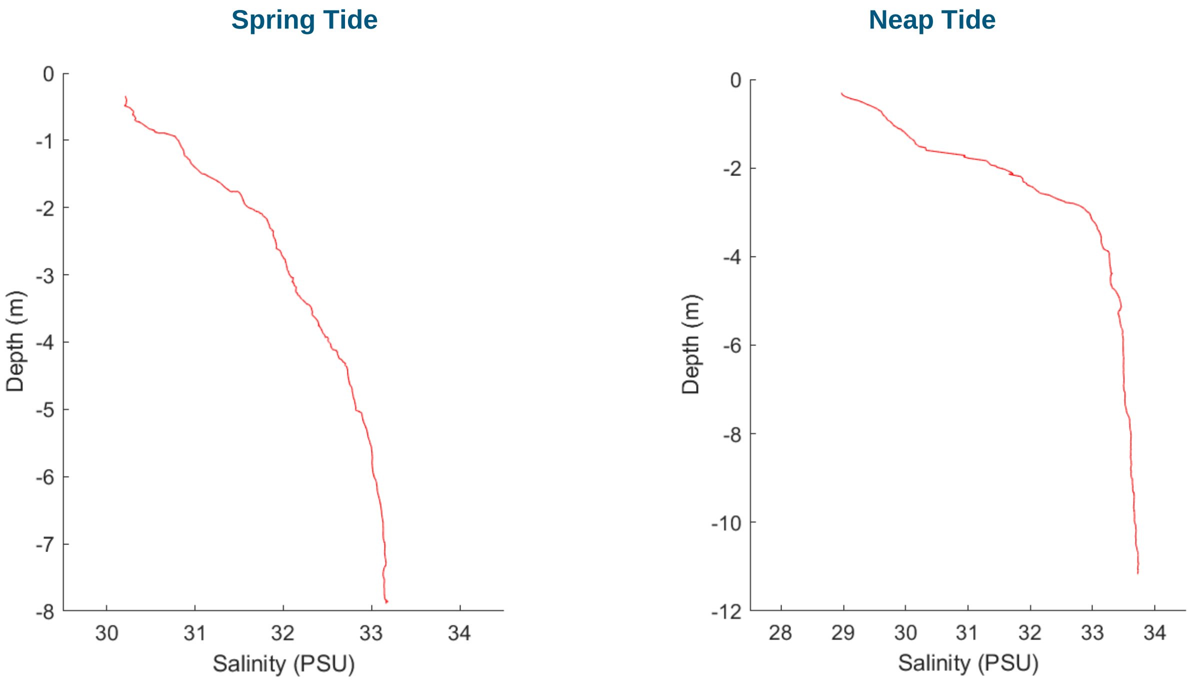

Figure 3.3: Typical salinity profile during spring and neap tide

The 3D HD model has been configured with 10 layers in order to differentiate between the current speeds throughout the water column, e.g. near the sea bed, in the middle of the water column and near the water surface.

The 3D HD verification model has been run for a full spring-neap tidal cycle, specifically covering the periods where the ADCP data has been recorded on the 24th July 2020 (Spring Tide) and on 30th July 2020 (Neap Tide).

3.3 3D Model Verification

Figure 3.4 to **Figure 3.9** show a comparison of the measured and modelled current speed and direction at ADCP transects T9, T8 and T11 during a spring tide and neap tide respectively for near seabed, mid layer and near water surface. There is a reasonably good agreement between the measured and modelled data. It is worth noting that due to the nature of the ADCP data collection the measured points shown on the plots are approximately 5-10 metres away from the modelled data point.

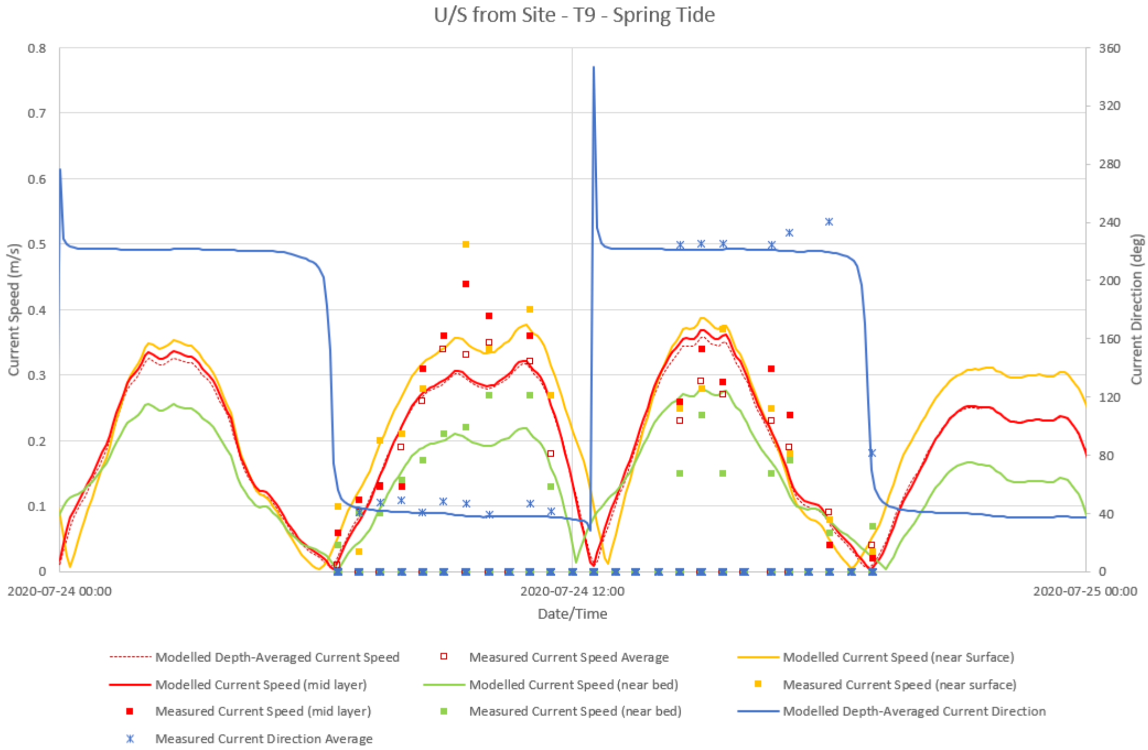

Figure 3.4: Comparison of measured and modelled current speed and direction at ADCP transect T9 upstream of the site during Spring Tide

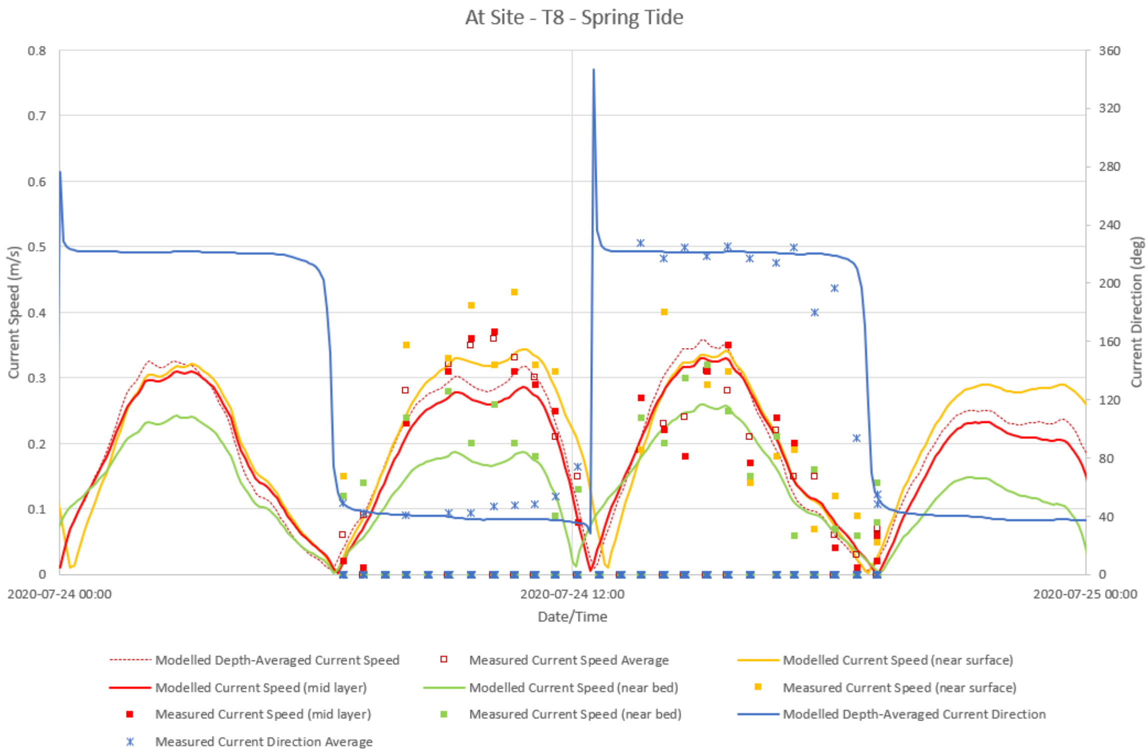

Figure 3.5: Comparison of measured and modelled current speed and direction at ADCP transect T8 at the site during Spring Tide

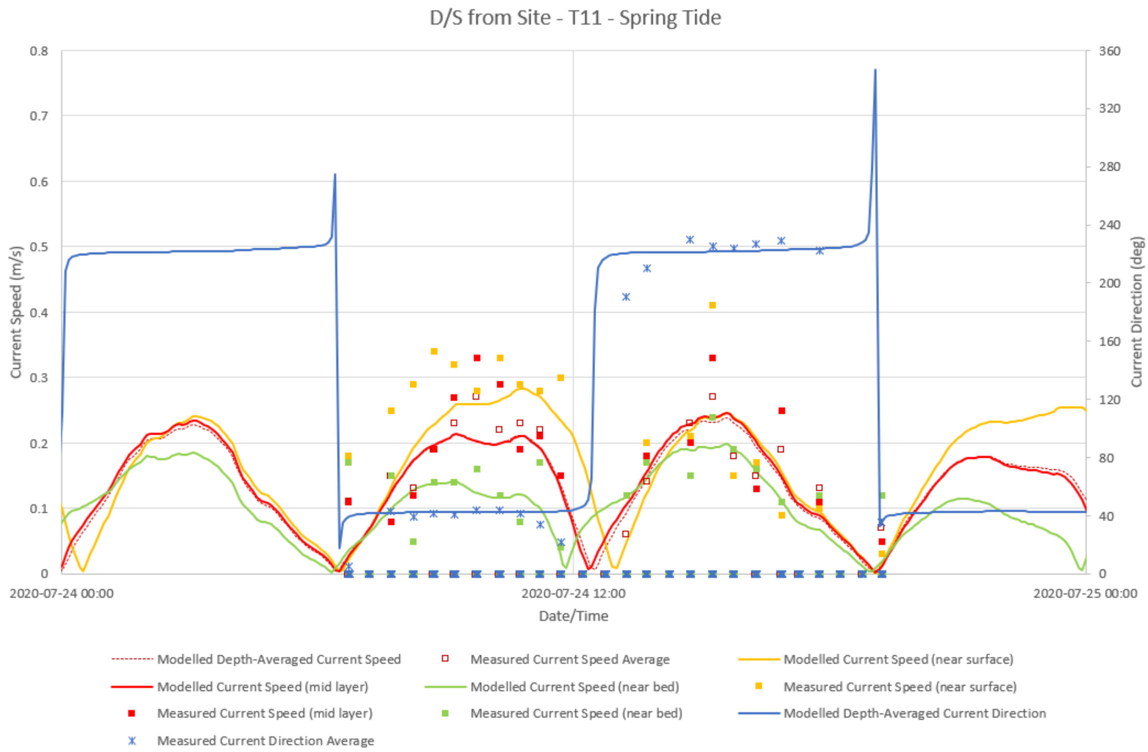

Figure 3.6: Comparison of measured and modelled current speed and direction at ADCP transect T11 downstream of the site during Spring Tide

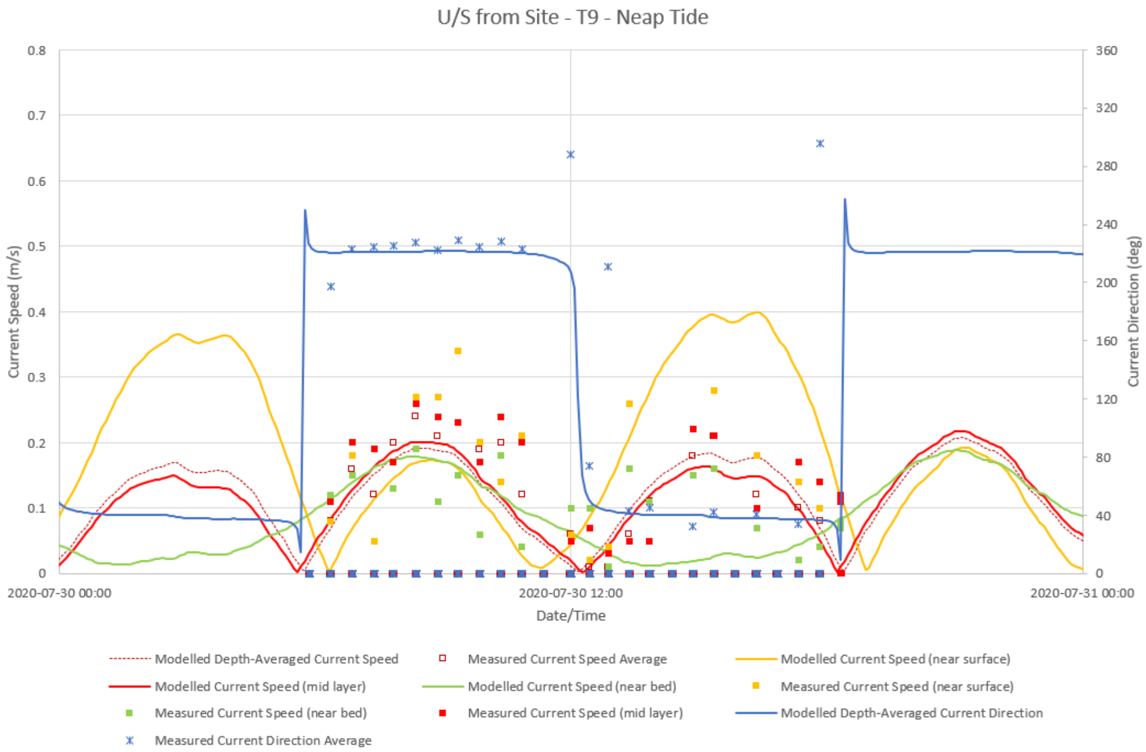

Figure 3.7: Comparison of measured and modelled current speed and direction at ADCP transect T9 upstream of the site during Neap Tide

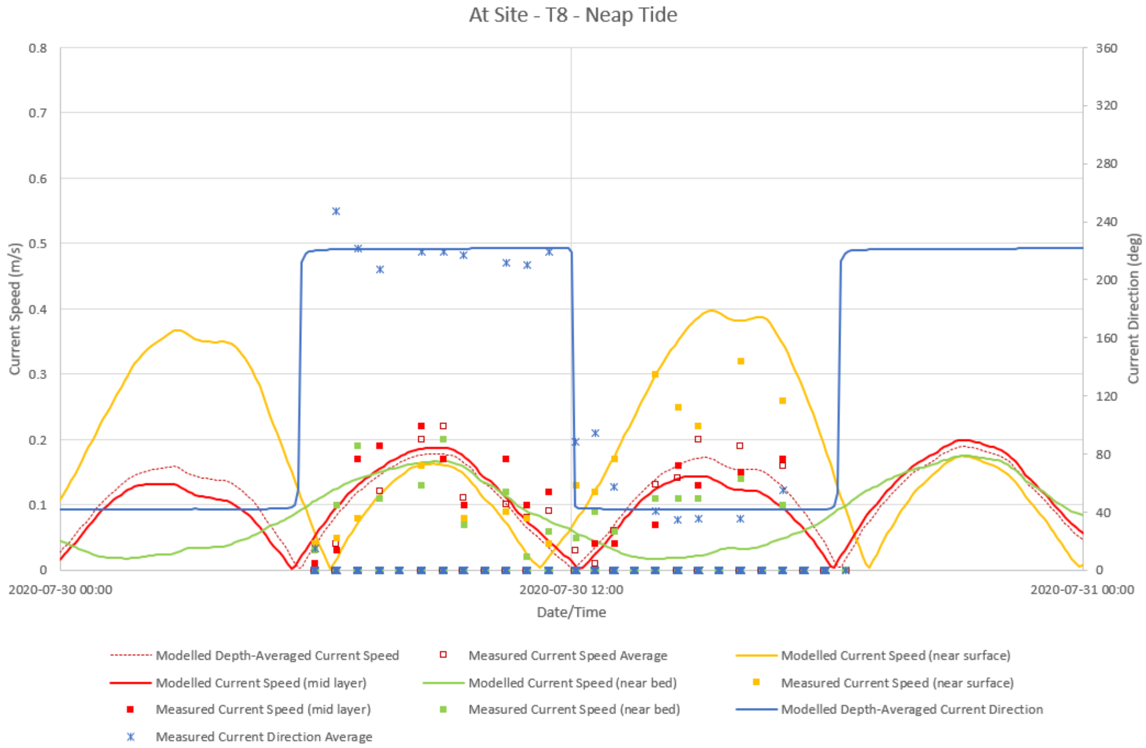

Figure 3.8: Comparison of measured and modelled current speed and direction at ADCP transect T8 at the site during Neap Tide

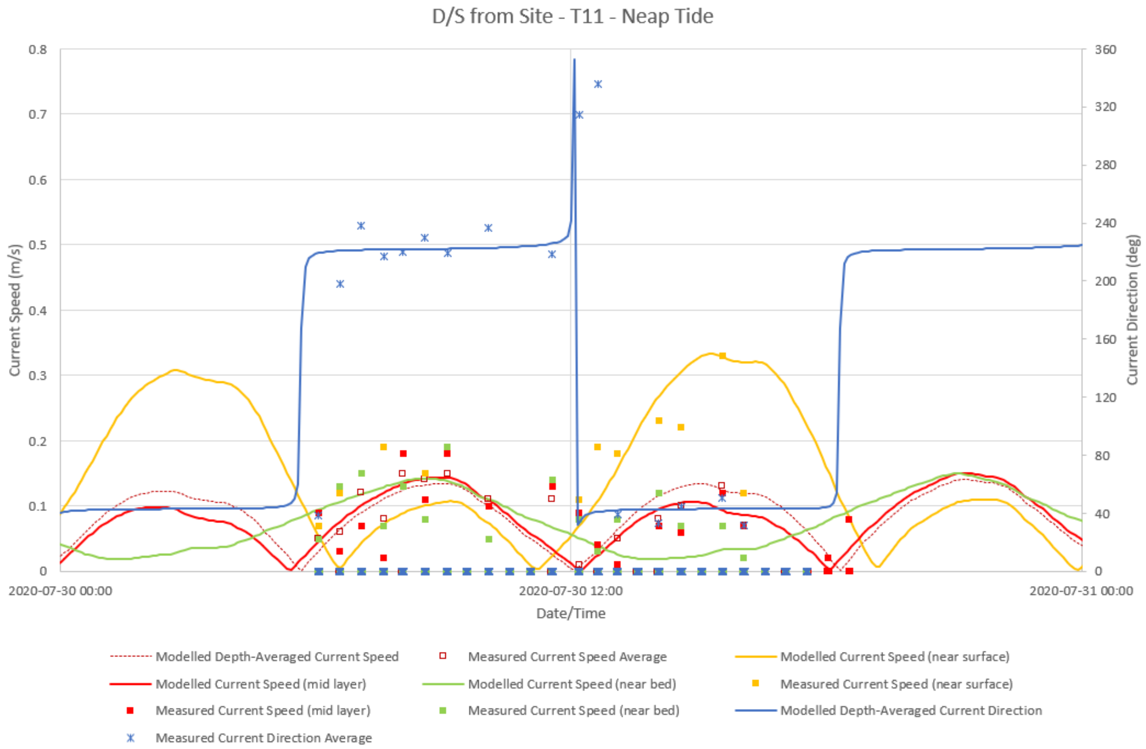

Figure 3.9: Comparison of measured and modelled current speed and direction at ADCP transect T11 downstream of the site during Spring Tide

4 3D HD Model Setup for Baseline and Scheme

4.1 Background

This section of the report describes the setup of a number of 3D HD model runs to determine the present hydrodynamic conditions at the project site and compare those to the simulated hydrodynamic conditions with the new scheme in place.

The 3D HD model simulations have been run for the following two scenarios:

- **Baseline** with present bathymetry
- **Scheme** with present bathymetry and with proposed scheme incorporated, including deepened channel and berth pocket in front of South Bank Wharf, set back South Bank Wharf new quay wall, and deepened part of Tees Dock Turning Area.

The baseline and scheme 3D HD models are based on the model described in Section 3 of this report.

Figure 4.1 and **Figure 4.2** show the model bathymetry for the baseline and scheme run respectively.

The input river flows that are applied at the Tees Barrage model boundary have been sourced from the National River Flow Archive. There are two River Flow Stations relevant to the project site, namely Tees at Low Moor and Leven at Leven Bridge.

For the purpose of determining the hydrodynamic conditions under the baseline and with the new scheme in place, the daily mean river flow has been applied at the Tees Barrage model boundary. This mean daily river flow has also been used in the dispersion model discussed in Section 5 of this report.

However, for the purpose of informing the engineering design, two further river flows have been used in the model simulation to establish the hydrodynamic conditions under more extreme water flows, namely median annual flow (QMED) and 1 in 100 year return period river flow.

Each simulation has been run under the following river flow conditions:

- Mean daily river flow of 20 m^3/s
- QMED river flow of 457 m^3/s
- 1 in 100 year river flow of 739 m^3/s

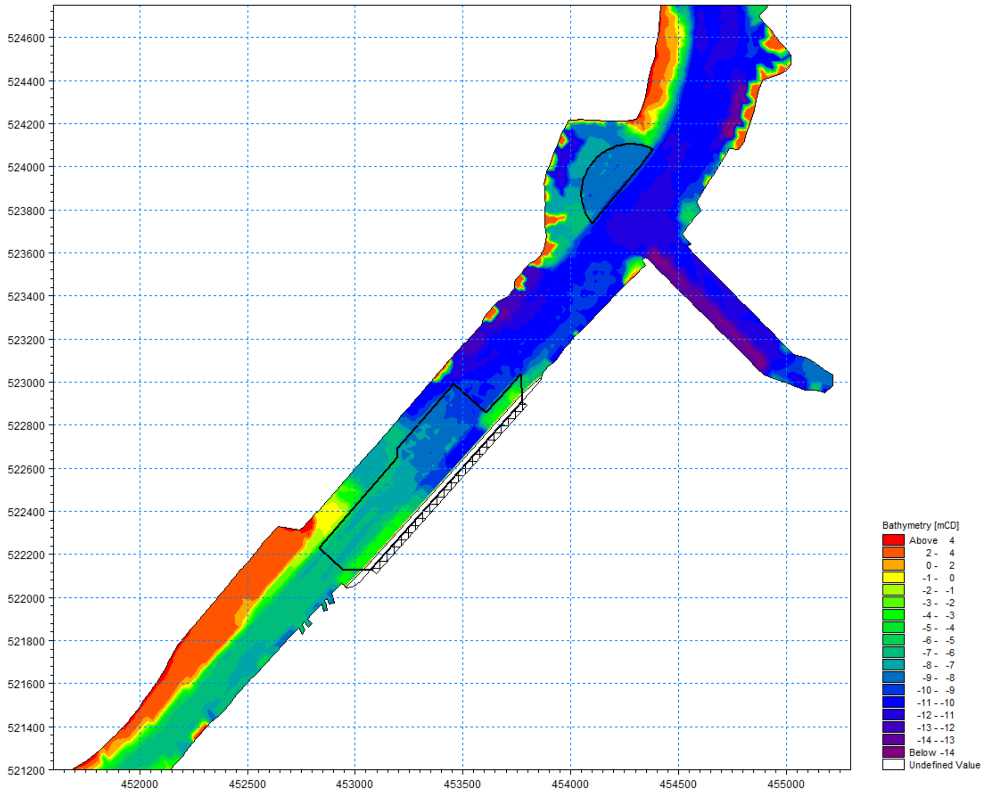

Figure 4.1: Model Baseline Bathymetry

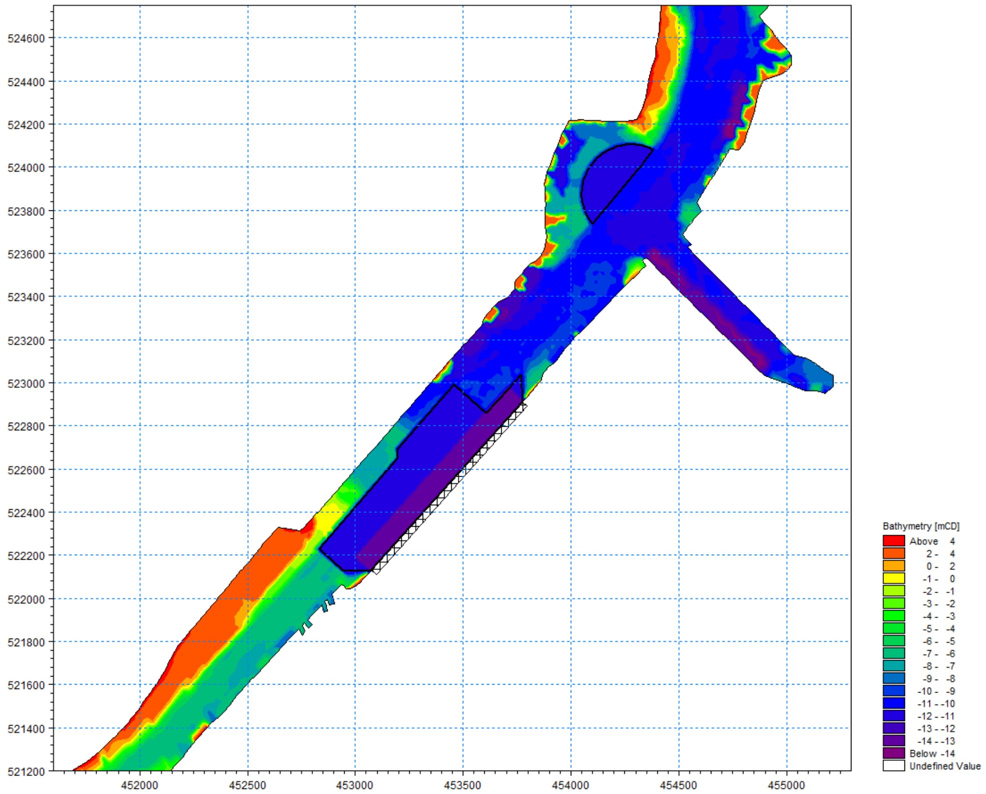

Figure 4.2: Model Scheme Bathymetry

4.2 Model Results

This section of the report presents the model results of the hydrodynamic simulations for the ‘Baseline’ and ‘With Scheme’ scenarios. Each simulation has been run under the three river flows mentioned in section 4.1 and are discussed separately in the following report sections. For each scenario, plots showing the current speed contours and current direction are described and plots showing the current speed difference between the ‘Baseline’ and ‘With Scheme’ scenario are also presented.

For the simulations run under the mean daily river flow, plots for peak flood and peak ebb under a spring tide and neap tide have been presented. However, for the simulations run under the QMED and the 1 in 100 year river flow, only plots for peak ebb have been presented for spring and neap tides. Due to the much higher river flows coming from the Tees Barrage under these scenarios, the water flowing into the estuary during a rising tide is considerably weakened and therefore no peak flood event is noticeable.

Figure 4.3 and **Figure 4.4** show the water level and current speeds under each river flow for spring and neap tide respectively at the site. Under the mean daily river flow, two current peaks can clearly be seen, one coinciding with the flood (rising) tide and the other with the ebb (falling) tide. Under the QMED and 1 in 100 year river flows, only one peak can be seen which coincides with the ebb (falling) tide.

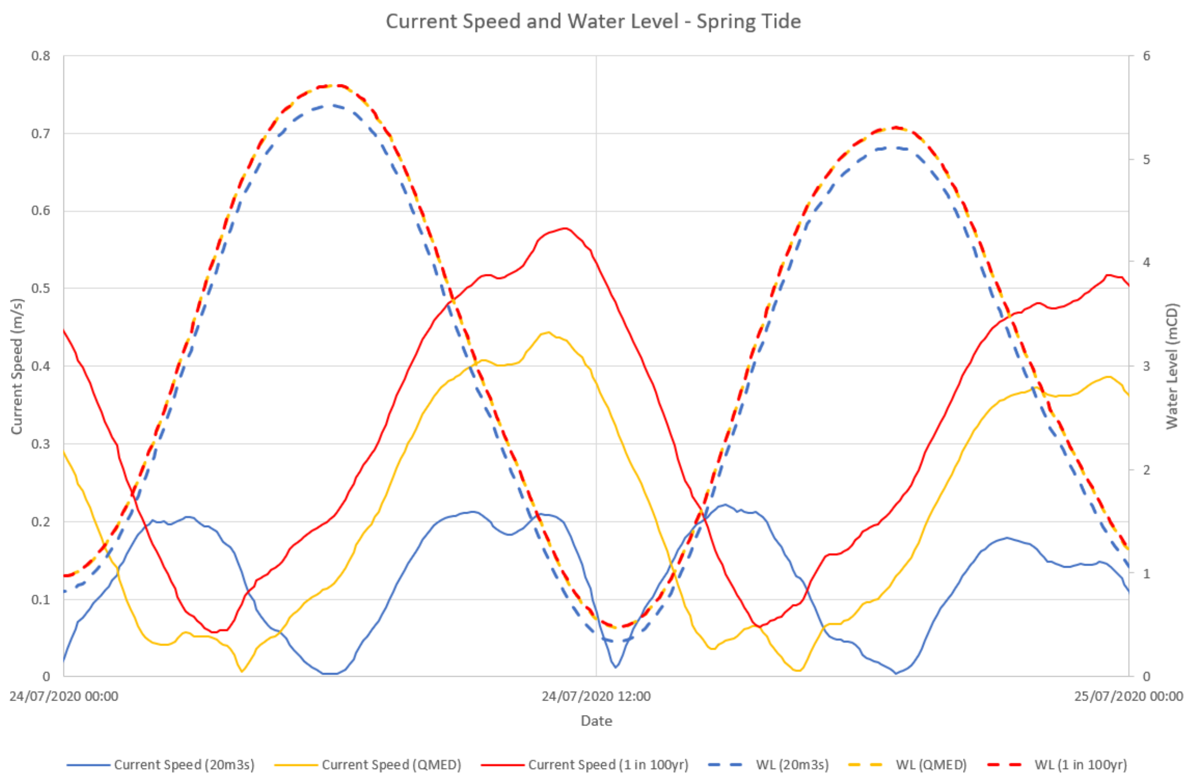

Figure 4.3: Current Speed and Water Level during Spring Tide at Site

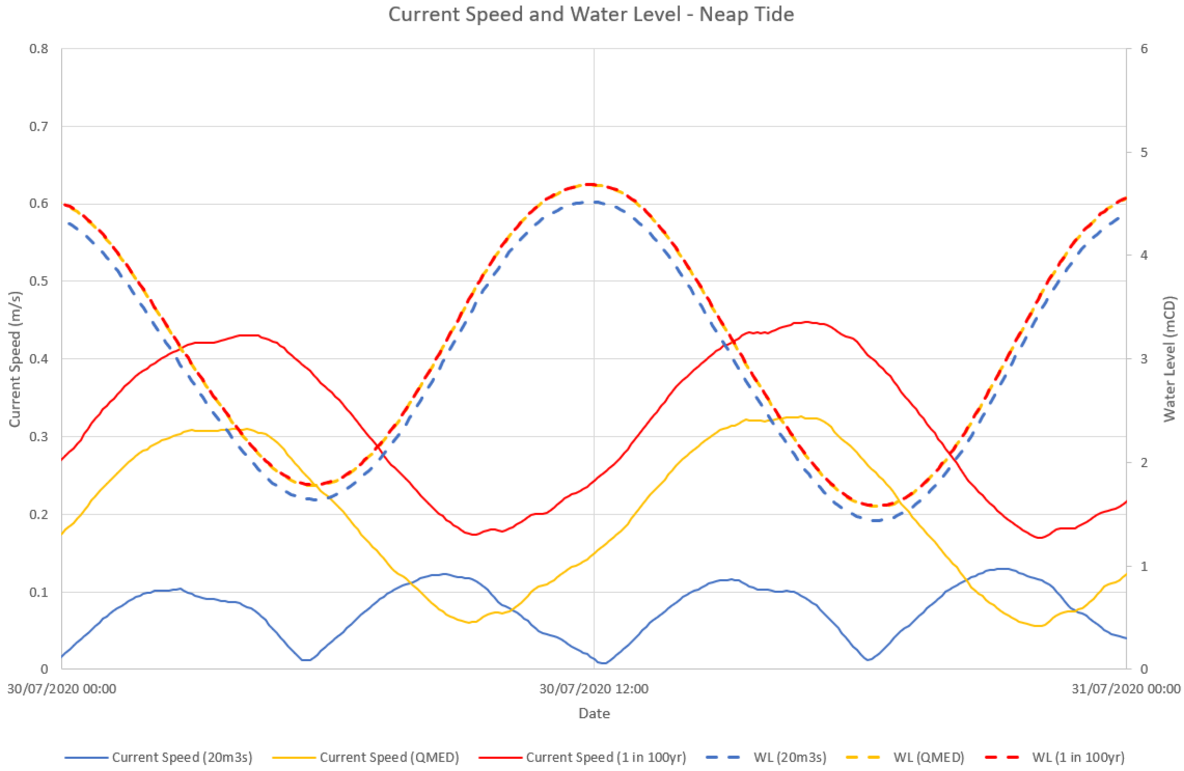

Figure 4.4: Current Speed and Water Level during Neap Tide at Site

4.2.1 Mean daily river flow

Numerical modelling of hydrodynamic currents during both neap and spring tides was undertaken, each with a mean daily river flow (20 m^3/s) through the Tees Barrage. **Figure 4.5** and **Figure 4.6** show the peak current speeds during the flood and ebb phases of a neap tide with a mean daily river flow for the 'Baseline' scenario, whilst peak current speeds during corresponding phases of a spring tide with a mean daily river flow are shown in **Figure 4.7** and **Figure 4.8**. These plots confirm the findings of the measured data, showing maximum current speeds greater on the spring tides than the neap tides and a tendency for ebb dominance during neap tides and flood dominance during spring tides. Note that the layout of the proposed scheme is shown on these figures for context only (these model runs represent the baseline conditions without the scheme in place).

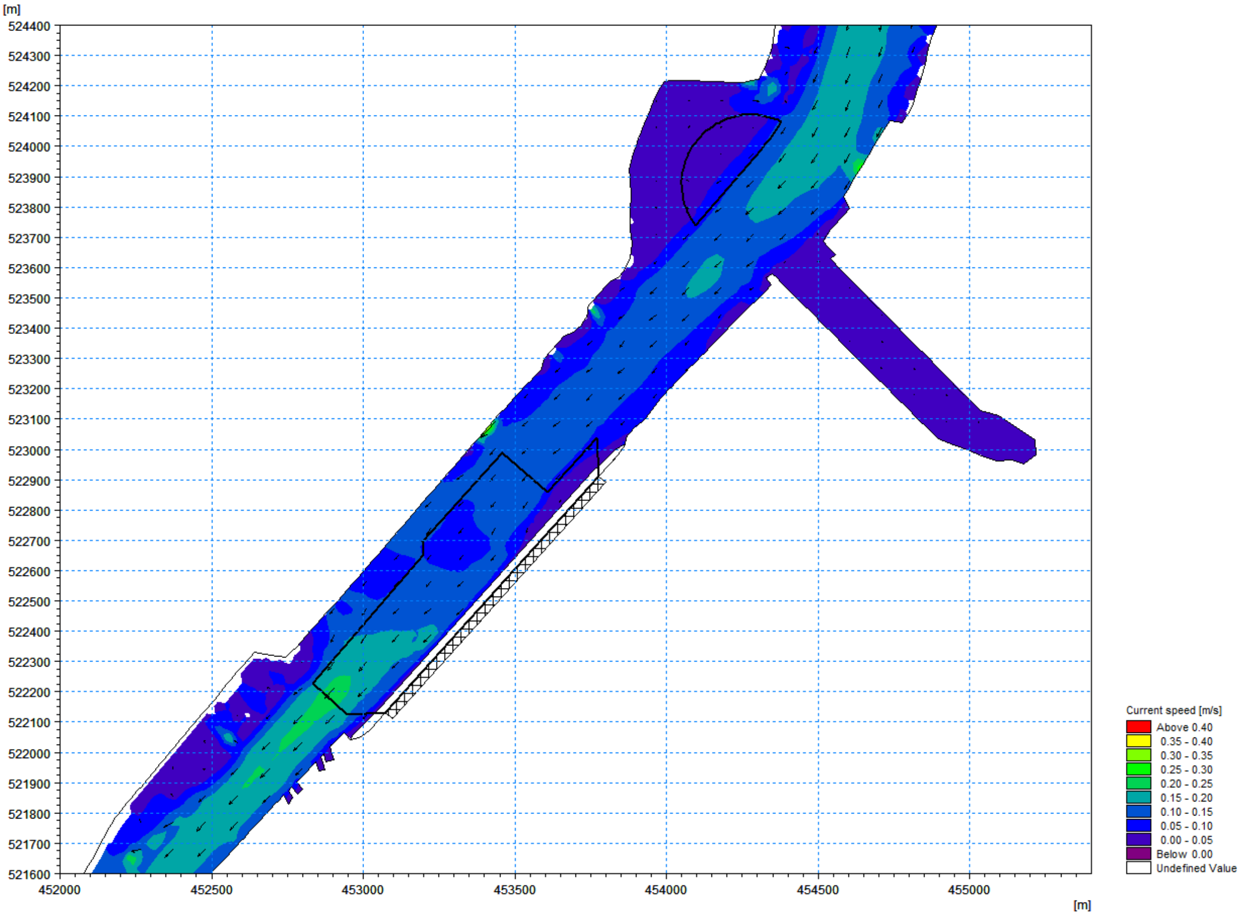

Figure 4.5: Peak current velocities during the flood phase of a neap tide with mean daily river flow - baseline

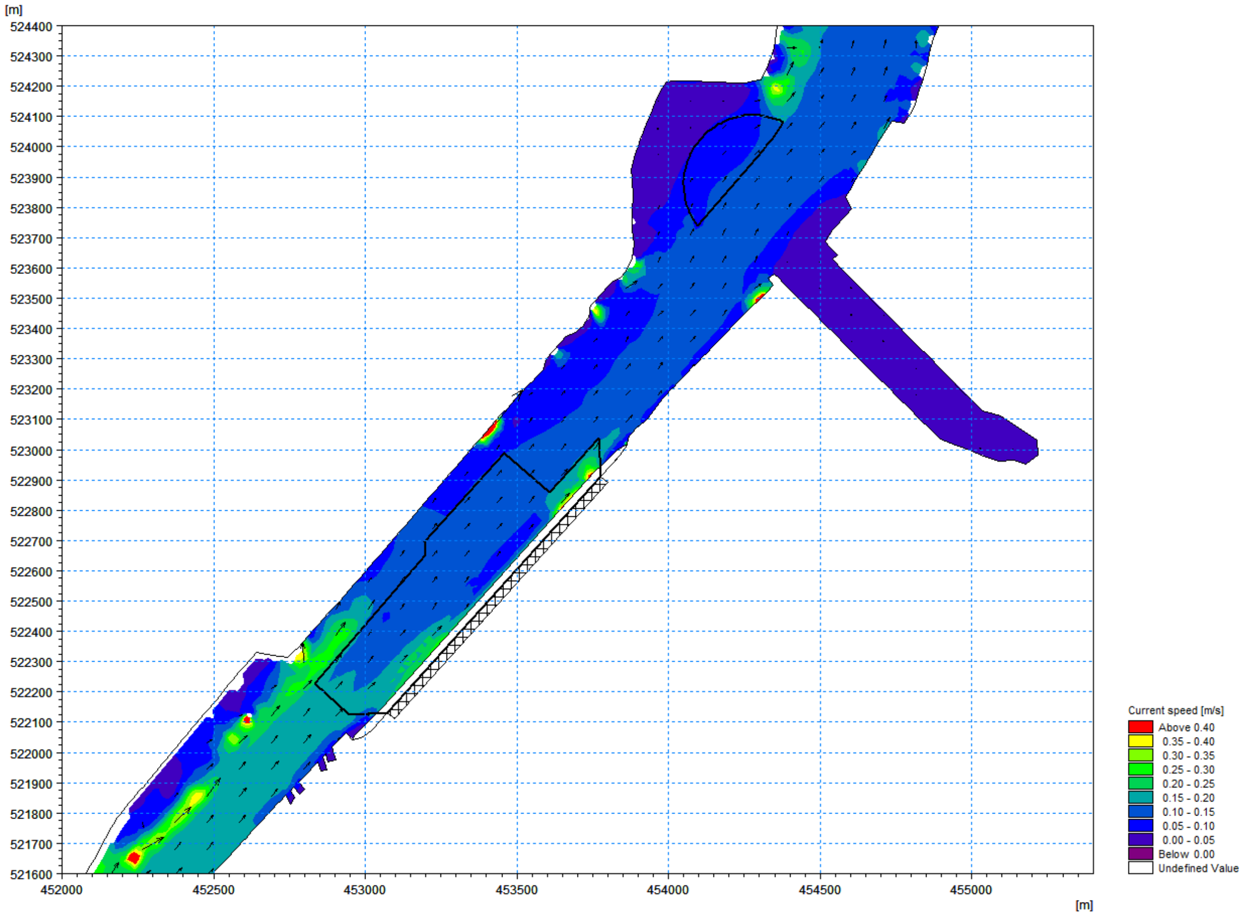

Figure 4.6: Peak current velocities during the ebb phase of a neap tide with mean daily river flow - baseline

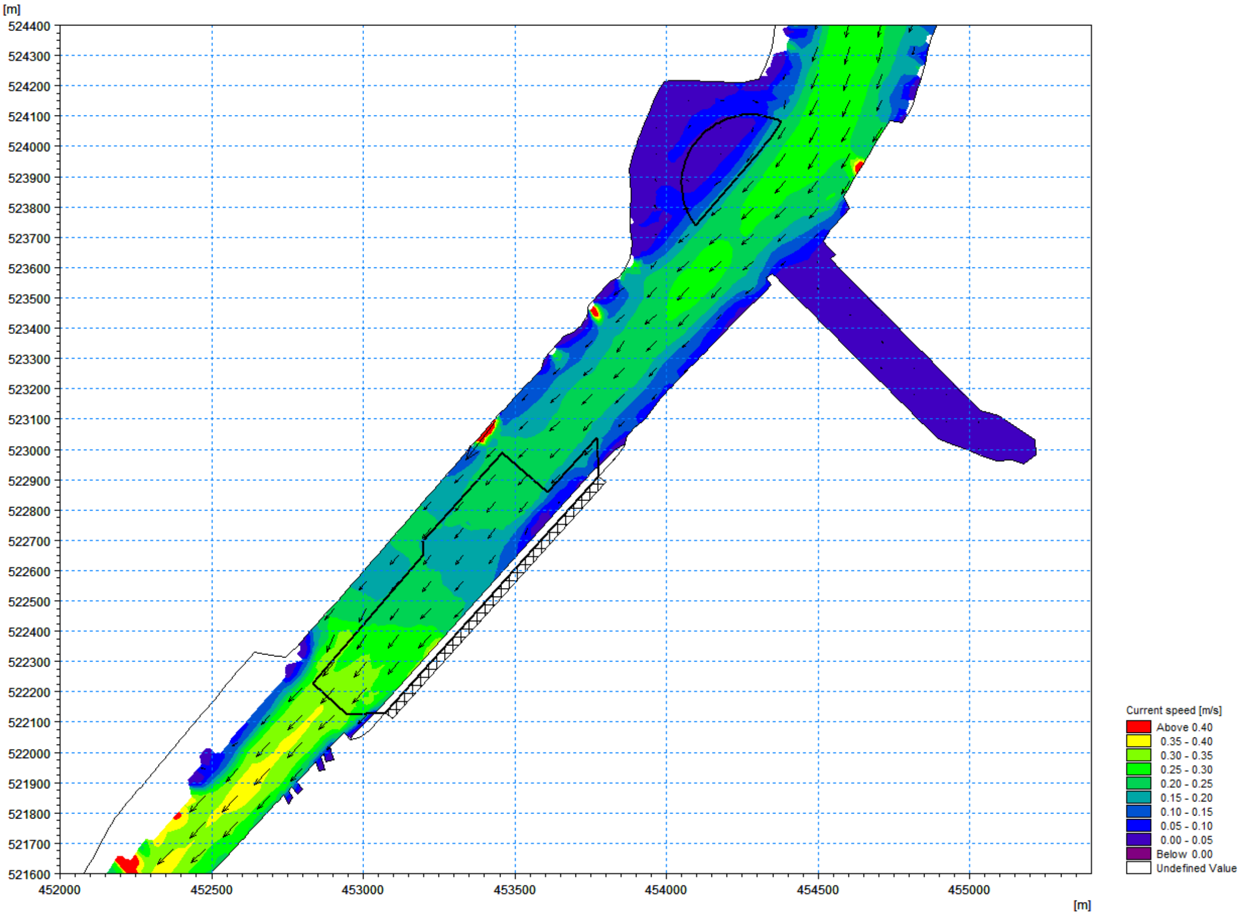

Figure 4.7: Peak current velocities during the flood phase of a spring tide with mean daily river flow - baseline

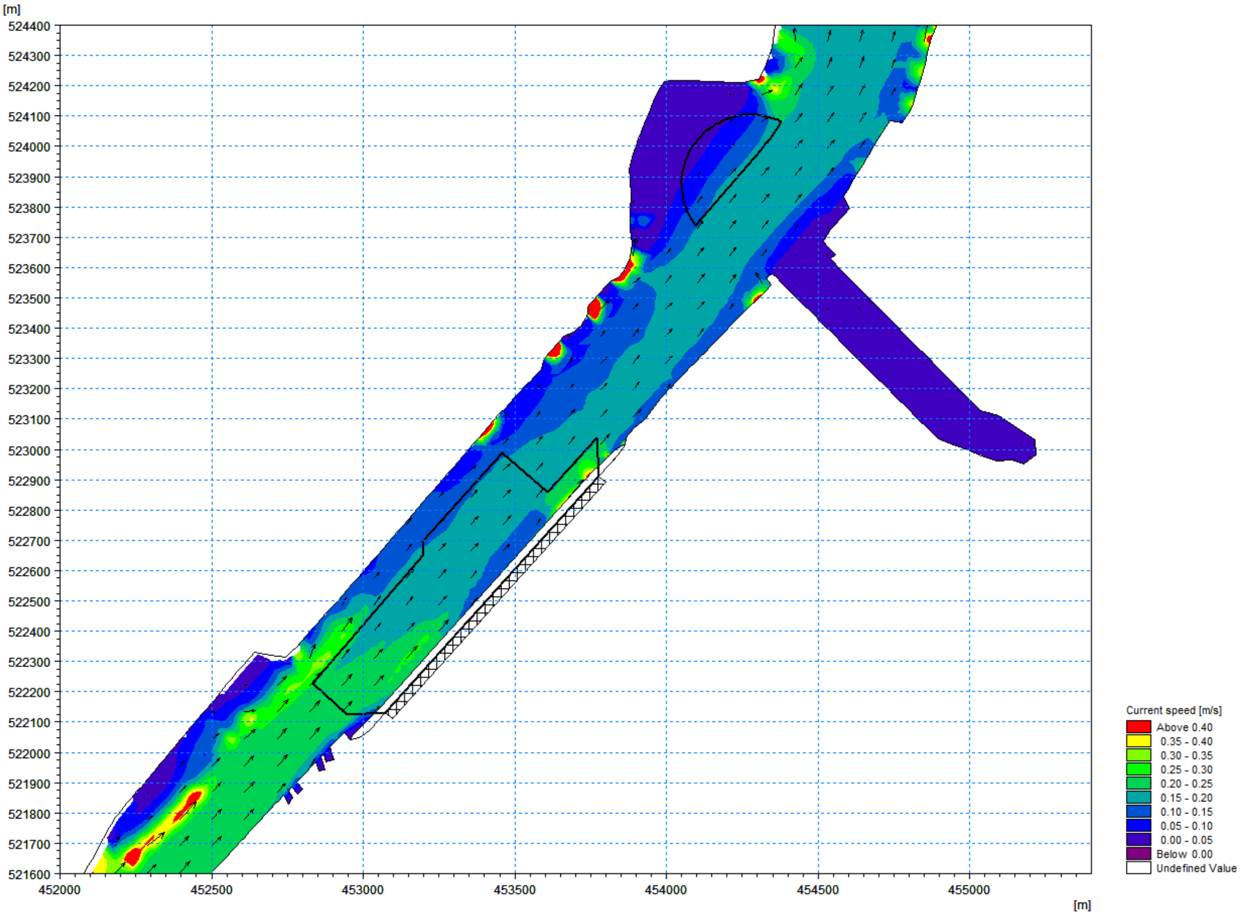

Figure 4.8: Peak current velocities during the ebb phase of a spring tide with mean daily river flow - baseline

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Figure 4.9 and **Figure 4.10** show the ‘with scheme’ effects for peak current speeds during the flood and ebb phases of a neap tide with a mean daily river flow, whilst peak current speeds during corresponding phases of a spring tide with a mean daily river flow are shown in **Figure 4.11** and **Figure 4.12**. The general baseline tendencies, showing maximum current speeds being greater on the spring tides than the neap tides and an ebb dominance during neap tides and flood dominance during spring tides, remain unaffected by the scheme.

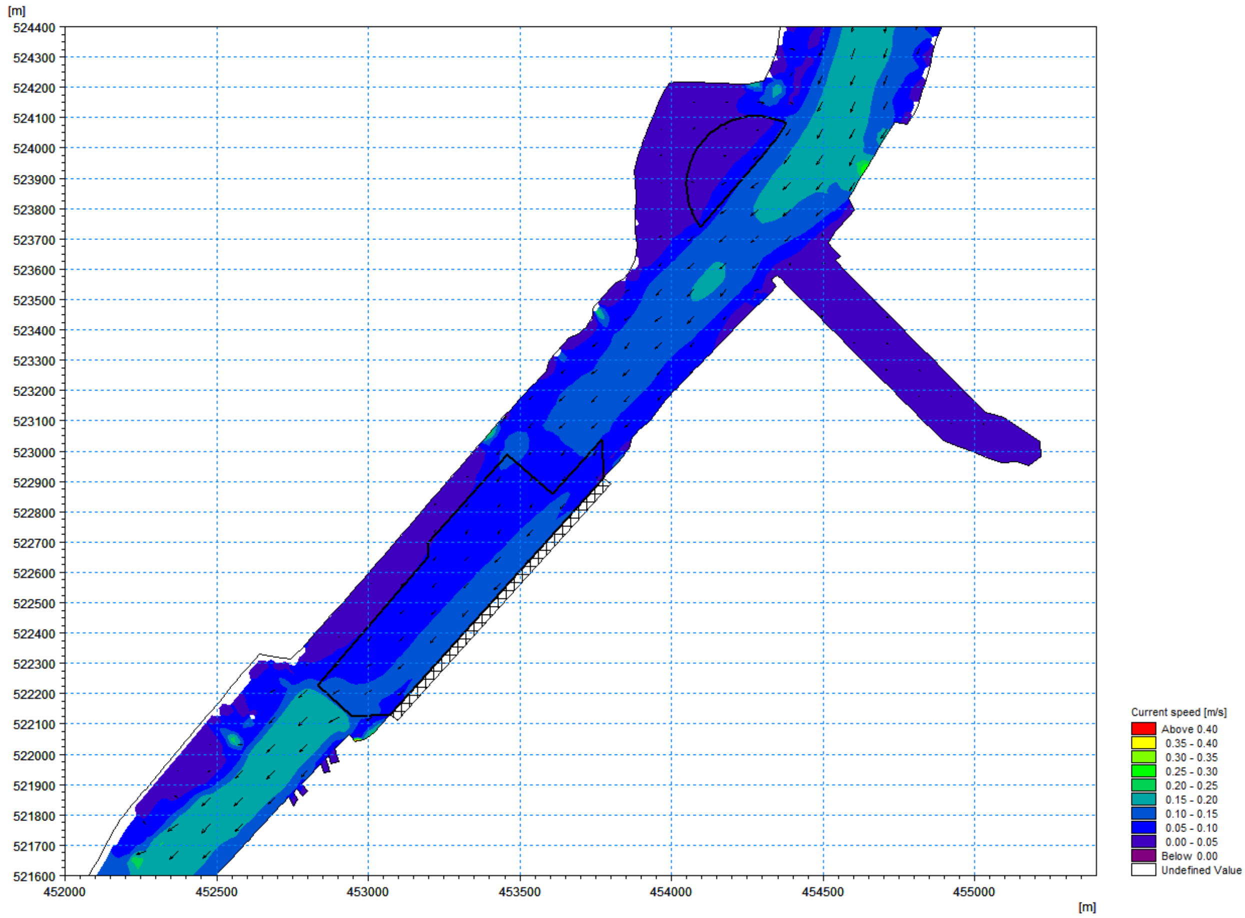

Figure 4.9: Peak current velocities during the flood phase of a neap tide with mean daily river flow – with scheme

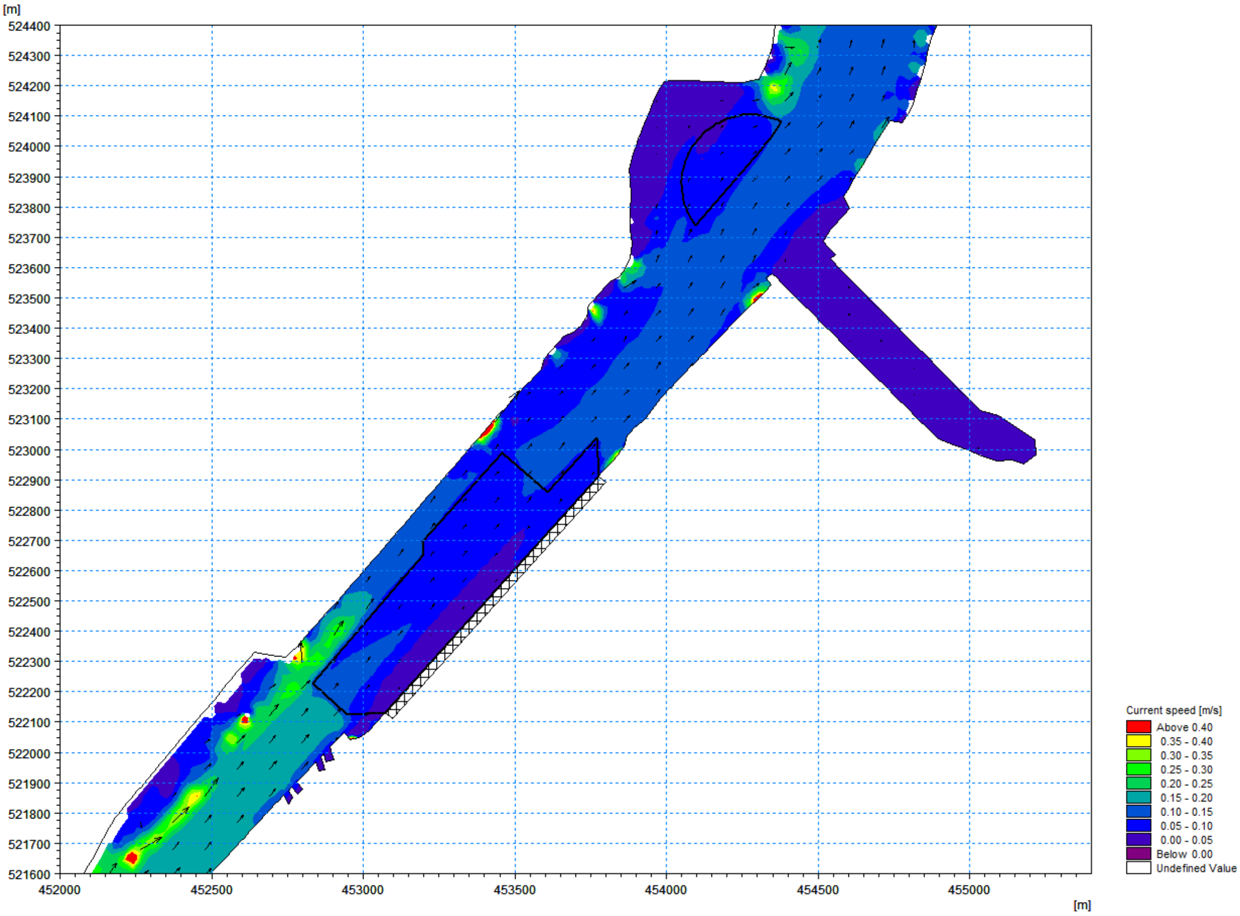

Figure 4.10: Peak current velocities during the ebb phase of a neap tide with mean daily river flow – with scheme

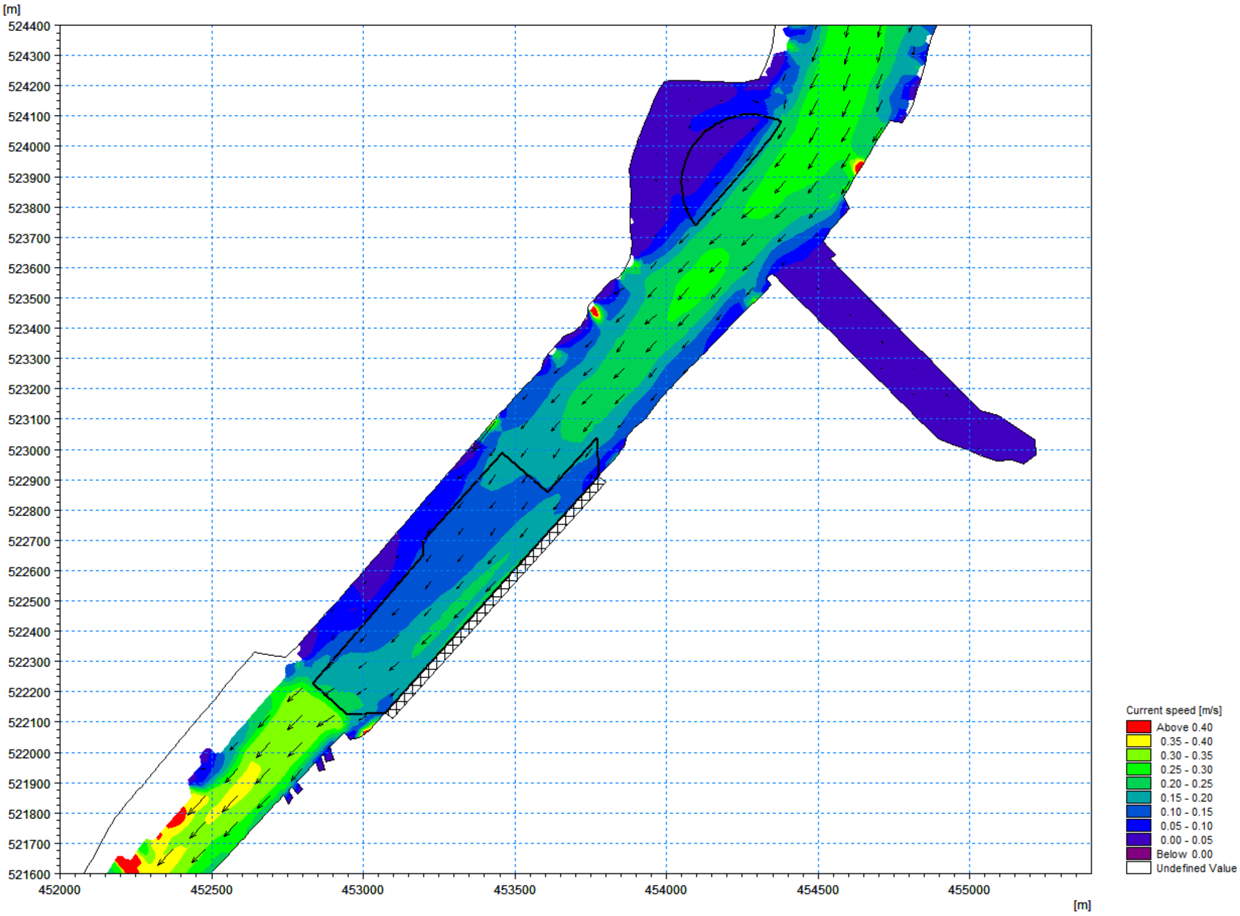

Figure 4.11: Peak current velocities during the flood phase of a spring tide with mean daily river flow – with scheme

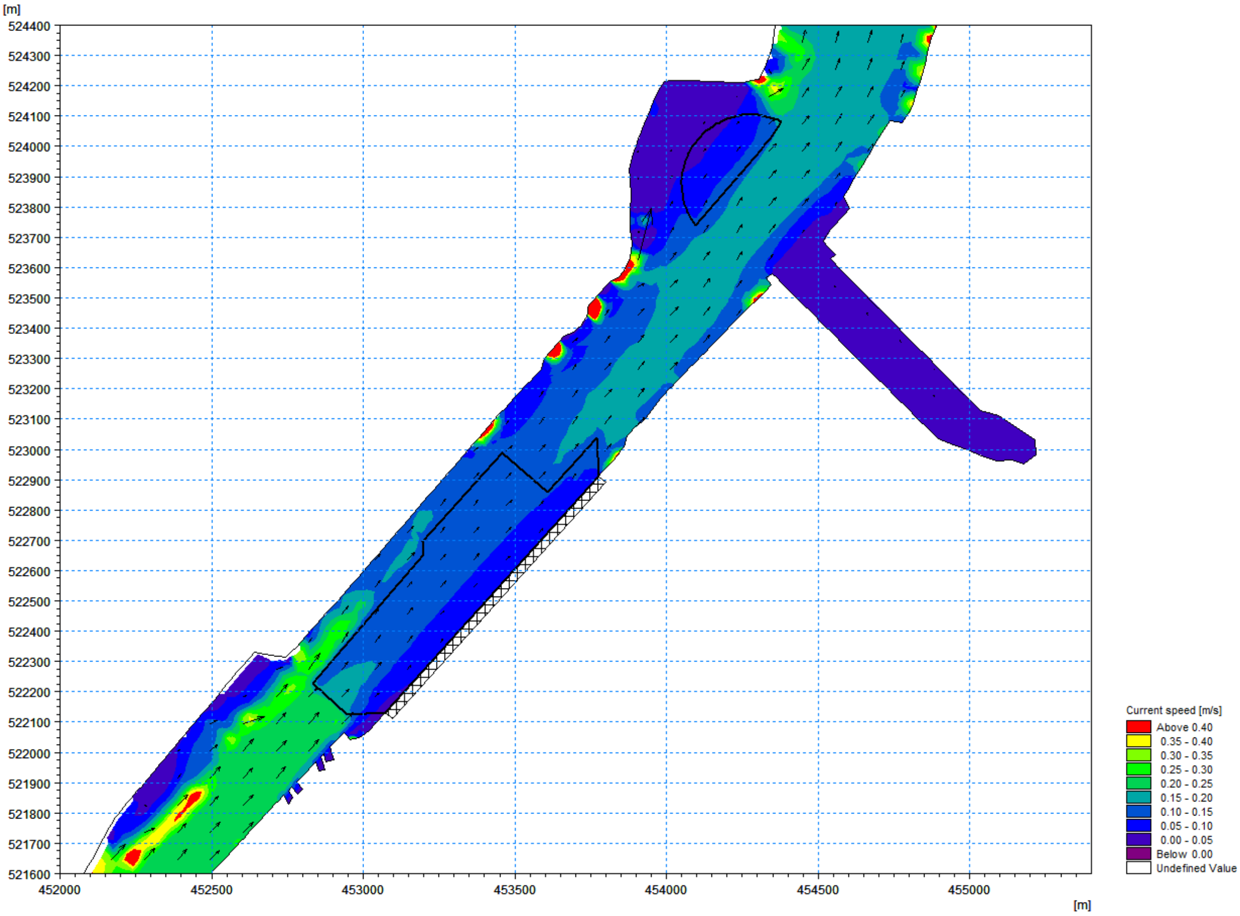

Figure 4.12: Peak current velocities during the ebb phase of a spring tide with mean daily river flow – with scheme

The ‘with scheme’ conditions have been compared against the baseline conditions and the resulting difference plots in **Figure 4.13** to **Figure 4.16** show the changes in peak current speeds on the ebbing and flooding phases of neap and spring tides, respectively. The implications of these changes are discussed in **Section 6 (Hydrodynamic and Sedimentary Processes)** of the EIA Report.

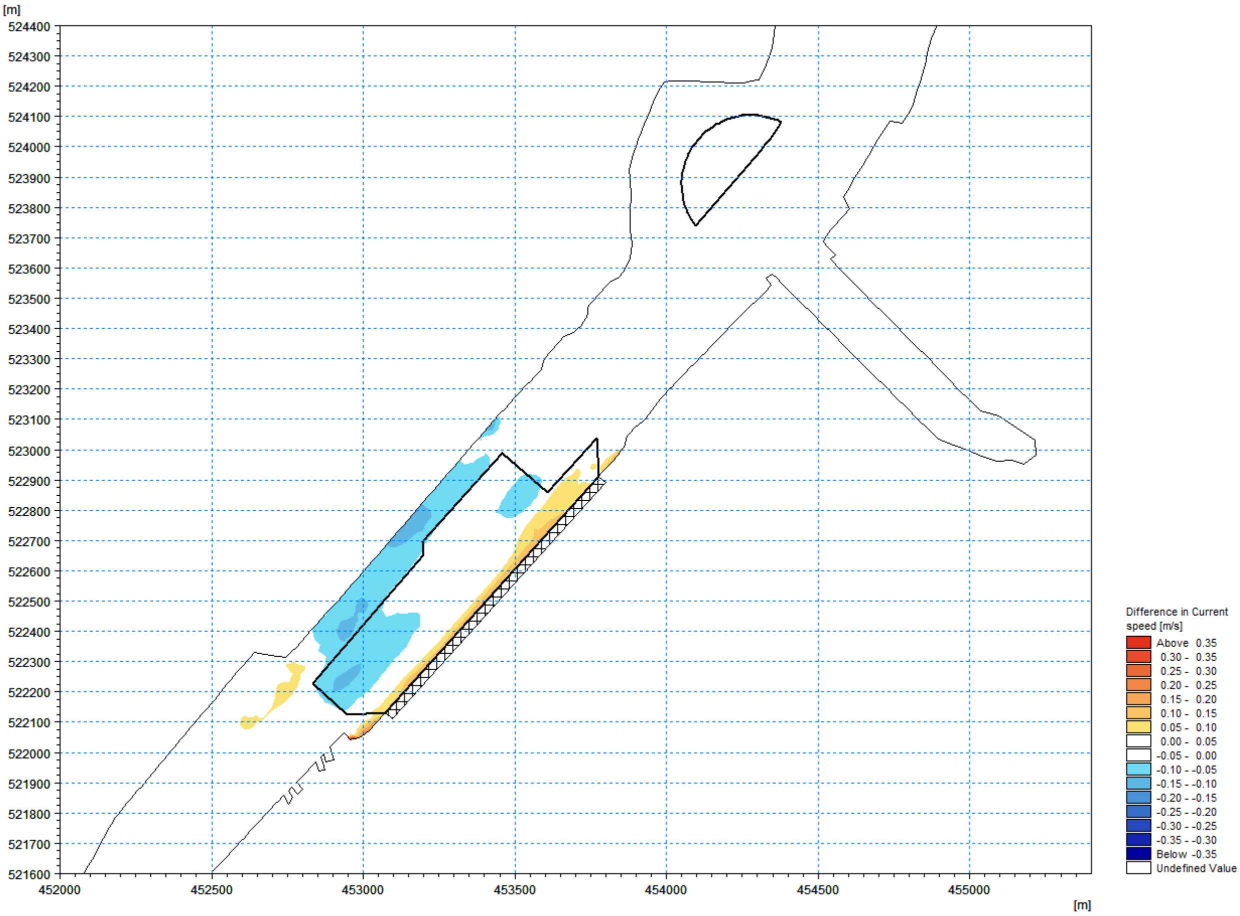

Figure 4.13: Change in peak current velocities due to the scheme during the flood phase of a neap tide with mean daily river flow

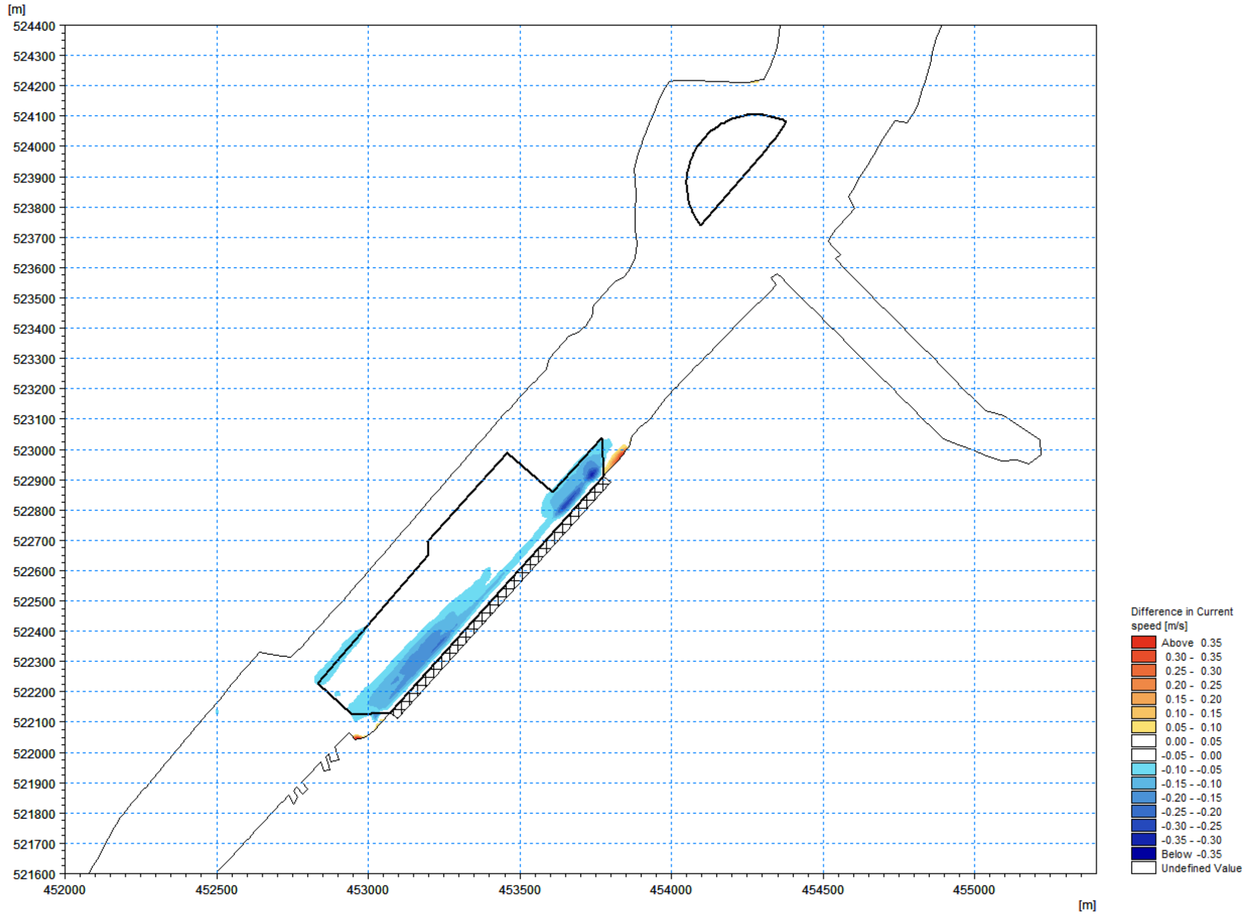

Figure 4.14: Change in peak current velocities due to the scheme during the ebb phase of a neap tide with mean daily river flow

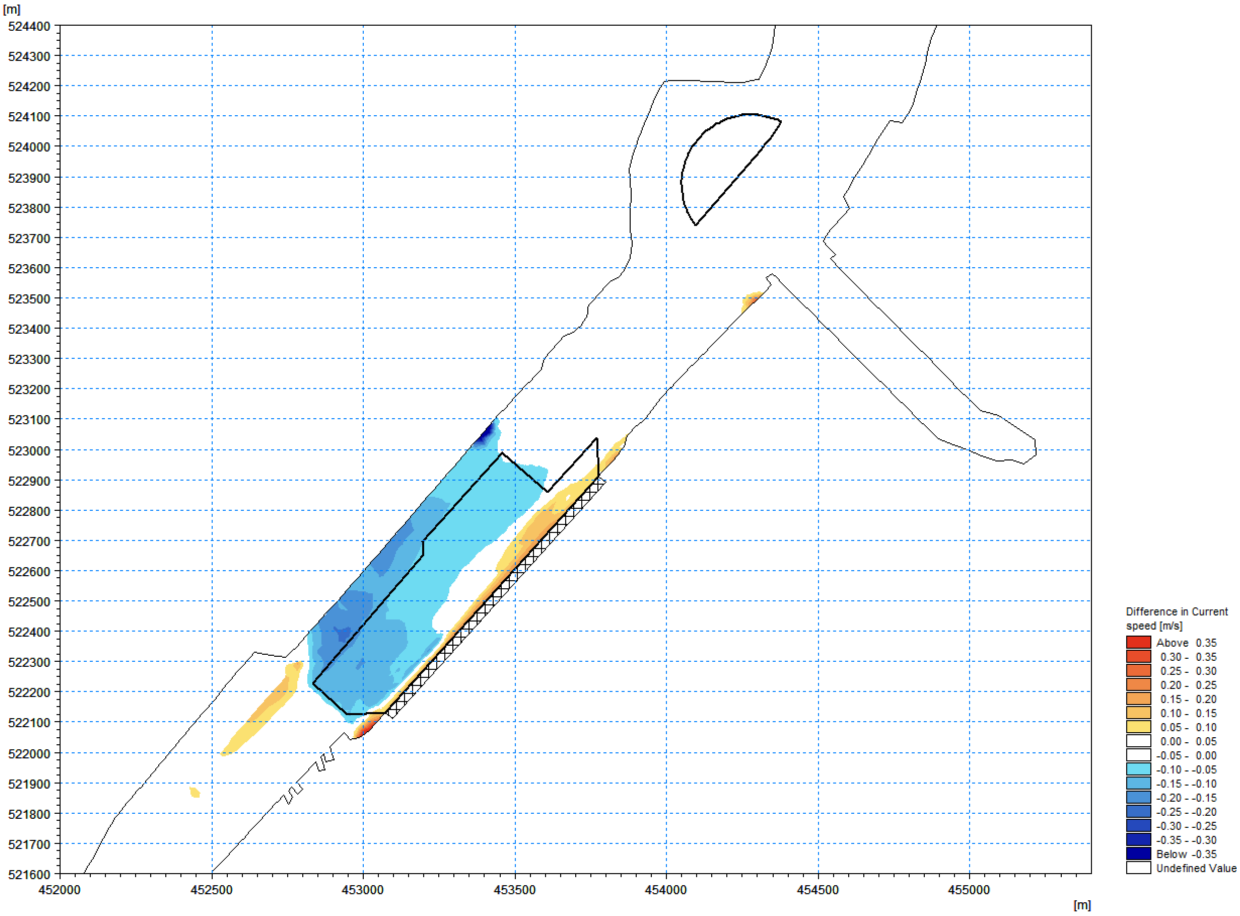

Figure 4.15: Change in peak current velocities due to the scheme during the flood phase of a spring tide with mean daily river flow

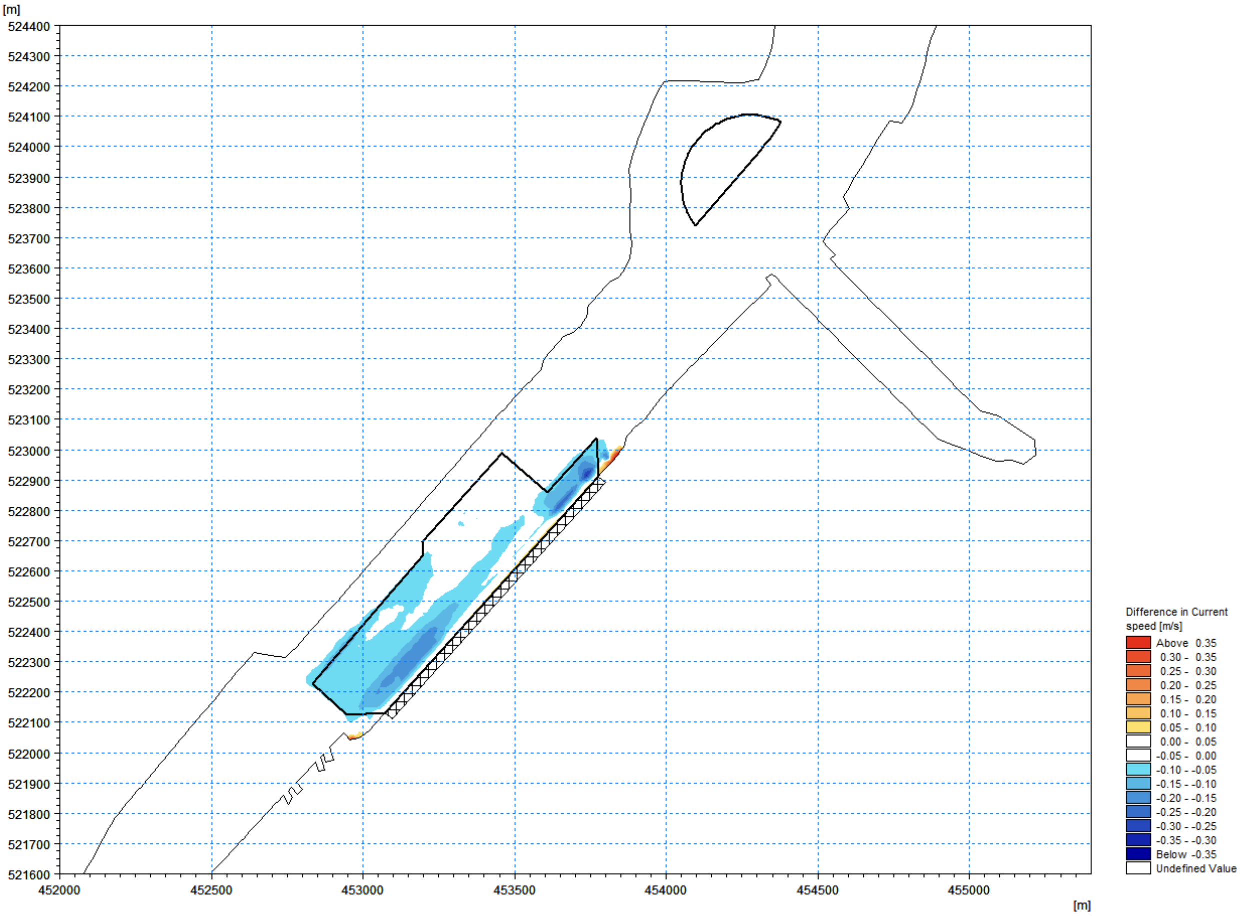

Figure 4.16: Change in peak current velocities due to the scheme during the ebb phase of a spring tide with mean daily river flow

4.2.2 QMED river flow

Numerical modelling of hydrodynamic currents during both neap and spring tides was undertaken, each with a QMED river flow (457 m^3/s) through the Tees Barrage. **Figure 4.17** and **Figure 4.18** show the peak current speeds during the ebb phase of a neap tide and spring tide respectively for the 'Baseline' scenario. Note that the layout of the proposed scheme is shown on these figures for context only (these model runs represent the baseline conditions without the scheme in place).

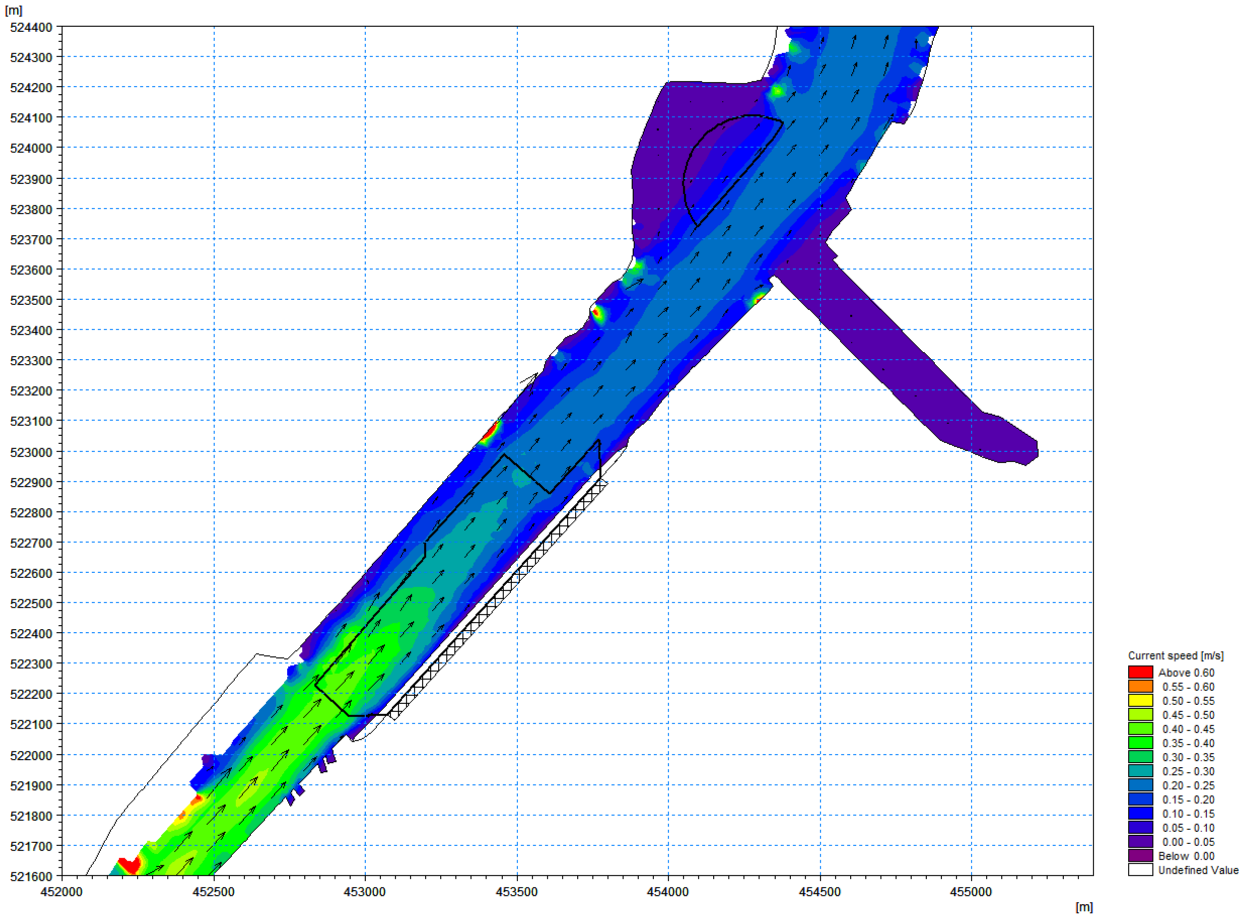

Figure 4.17: Peak current velocities during the ebb phase of a neap tide with QMED river flow - baseline

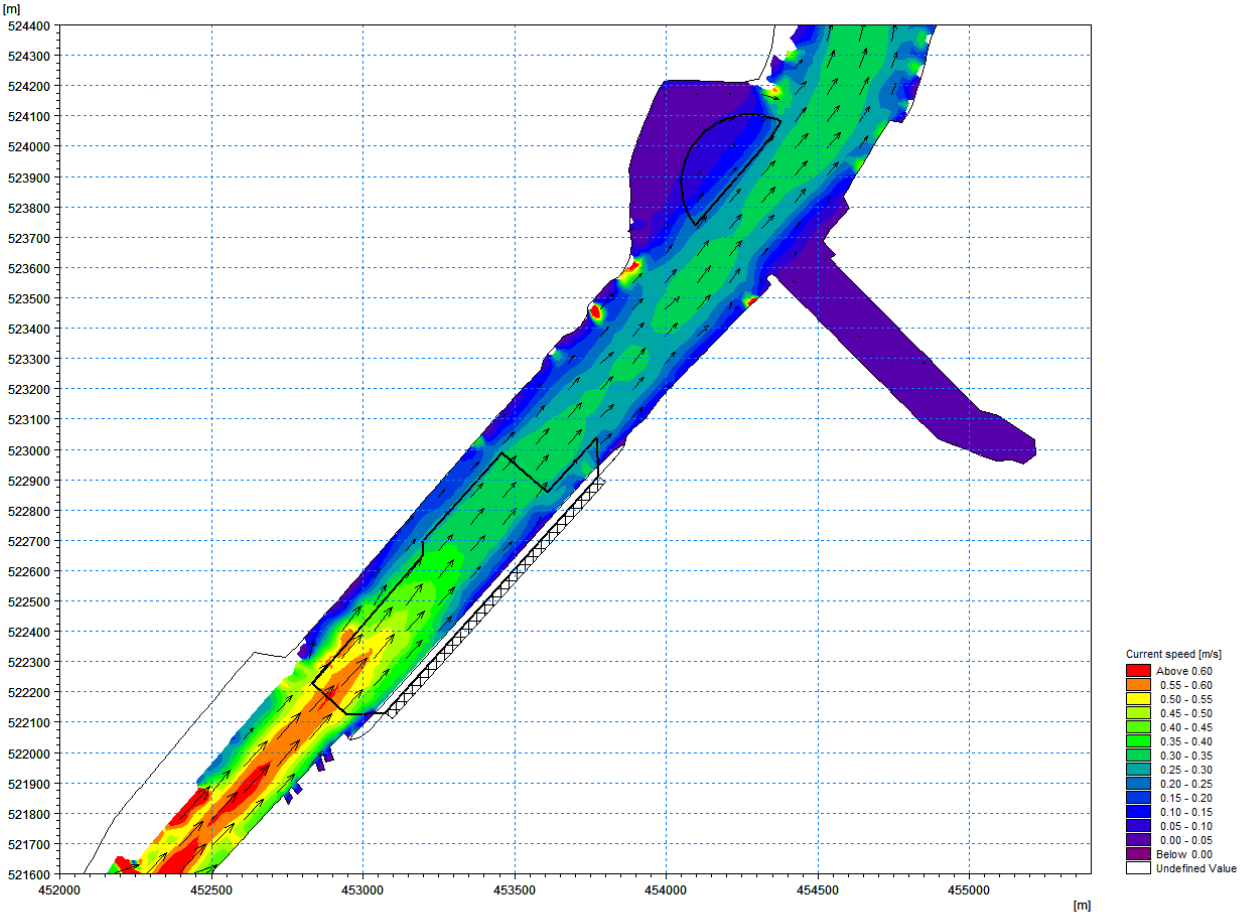

Figure 4.18: Peak current velocities during the ebb phase of a spring tide with QMED river flow – baseline

Figure 4.19 and **Figure 4.20** show the 'with scheme' effects for peak current speeds during the ebb phases of a neap and spring tide respectively with a QMED river flow. The general baseline tendencies under the QMED scenario remain unaffected by the scheme.

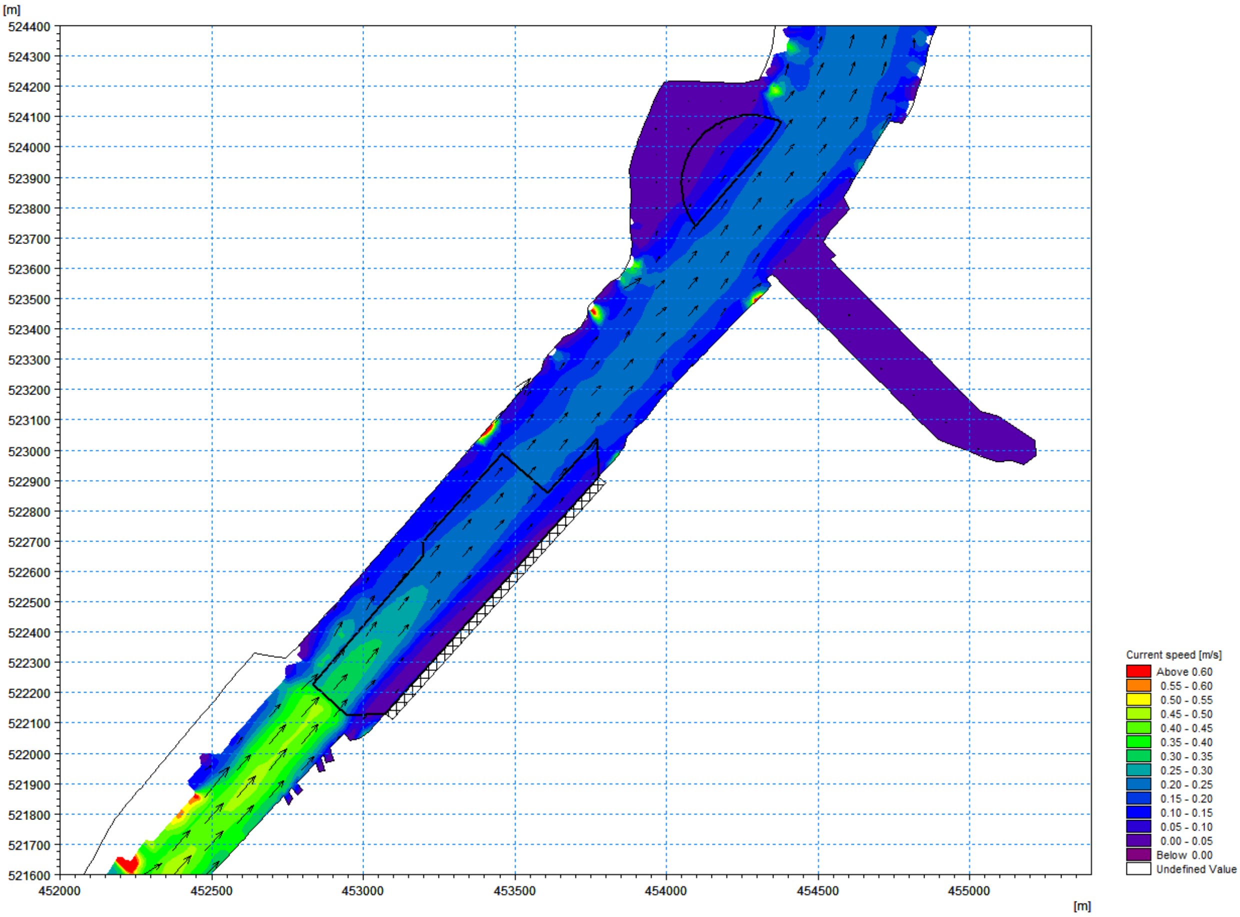

Figure 4.19: Peak current velocities during the ebb phase of a neap tide with QMED river flow – with scheme

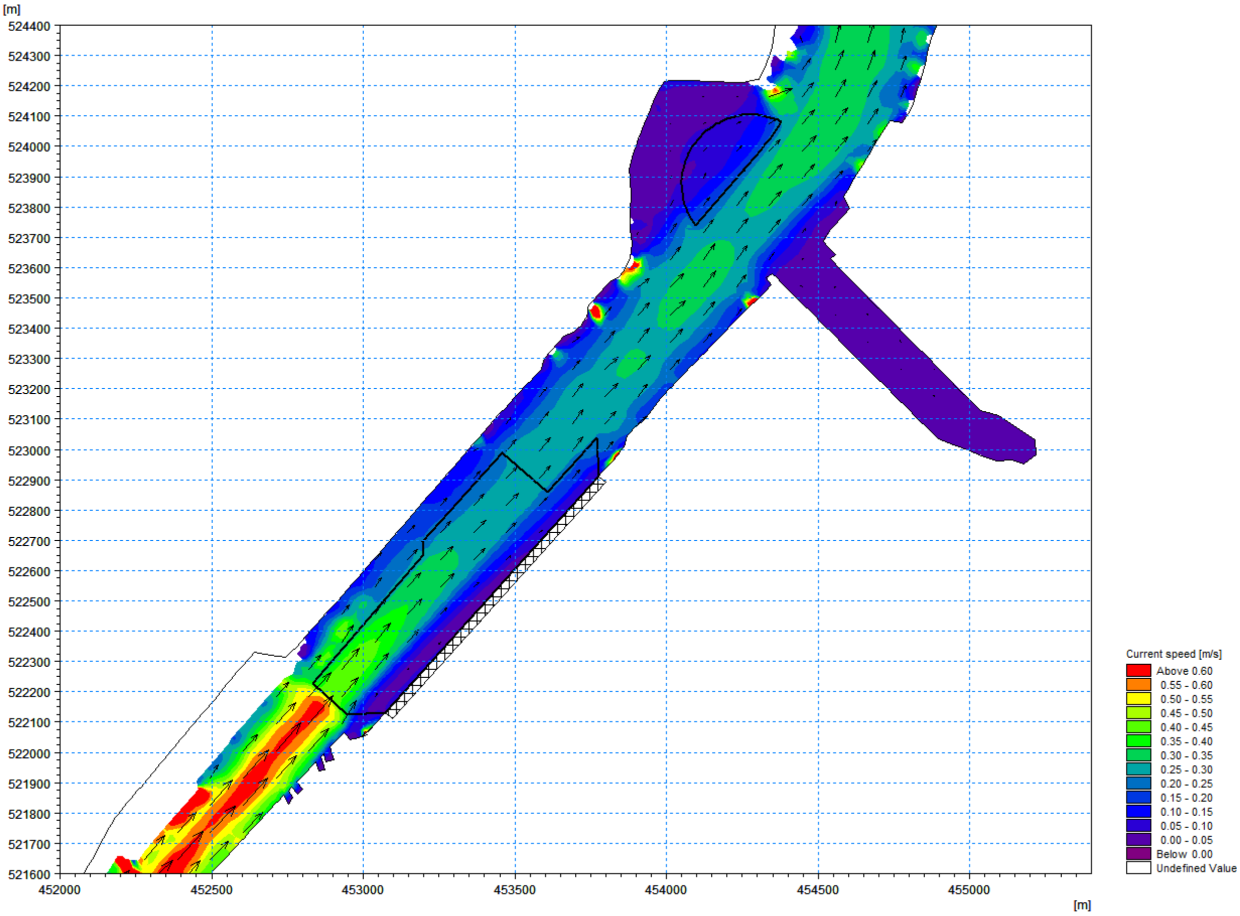

Figure 4.20: Peak current velocities during the ebb phase of a spring tide with QMED river flow – with scheme

The 'with scheme' conditions have been compared against the baseline conditions and the resulting difference plots in **Figure 4.21** and **Figure 4.22Figure 4.16** show the changes in peak current speeds on the ebbing phases of neap and spring tides, respectively. These changes remain largely confined to the river reach of the South Bank Wharf.

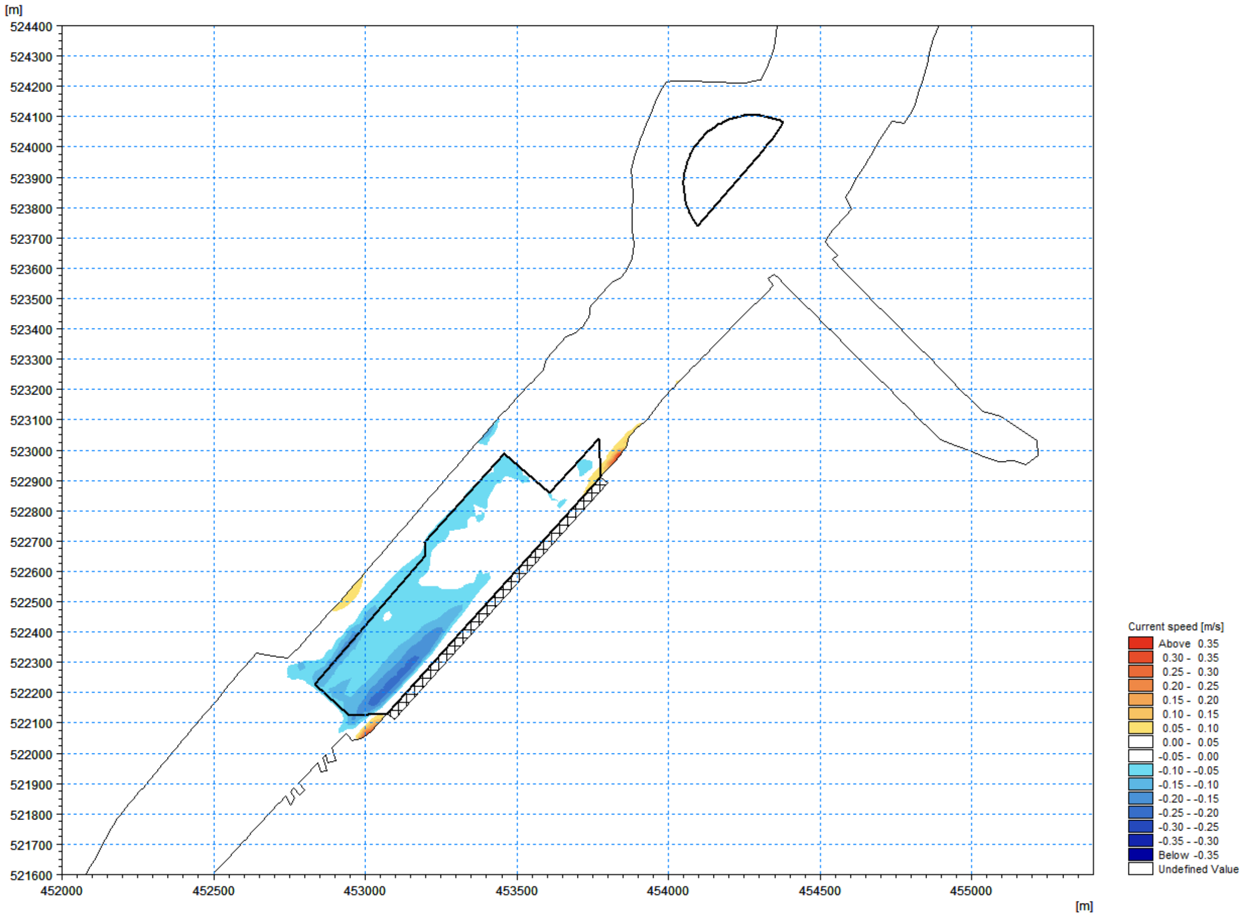

Figure 4.21: Change in peak current velocities due to the scheme during the ebb phase of a neap tide with QMED river flow

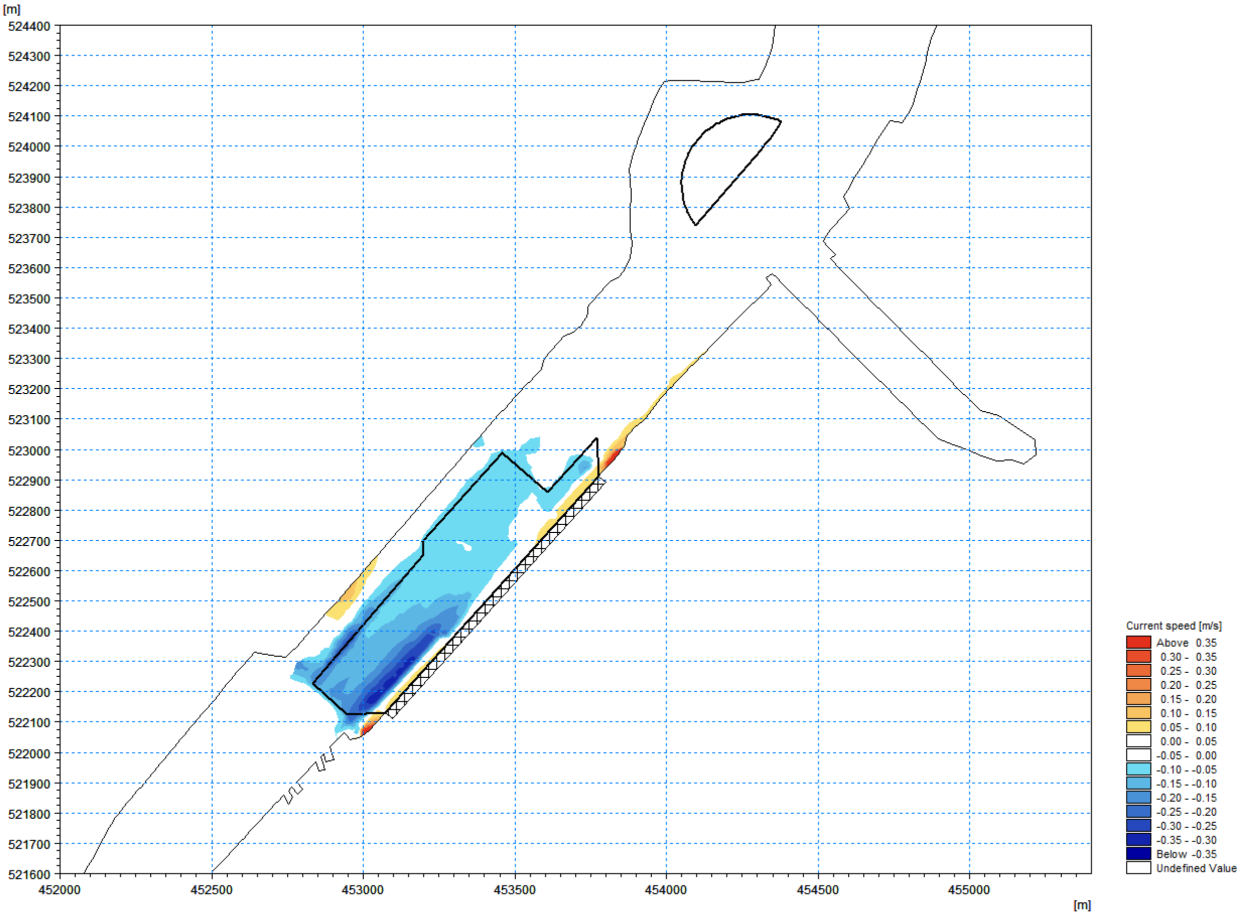

Figure 4.22: Change in peak current velocities due to the scheme during the ebb phase of a spring tide with QMED river flow

4.2.3 1 in 100 year river flow

Numerical modelling of hydrodynamic currents during both neap and spring tides was undertaken, each with a 1 in 100 year river flow (739 m^3/s) through the Tees Barrage. **Figure 4.23** and **Figure 4.24** show the peak current speeds during the ebb phase of a neap tide and spring tide respectively for the 'Baseline' scenario. Note that the layout of the proposed scheme is shown on these figures for context only (these model runs represent the baseline conditions without the scheme in place).

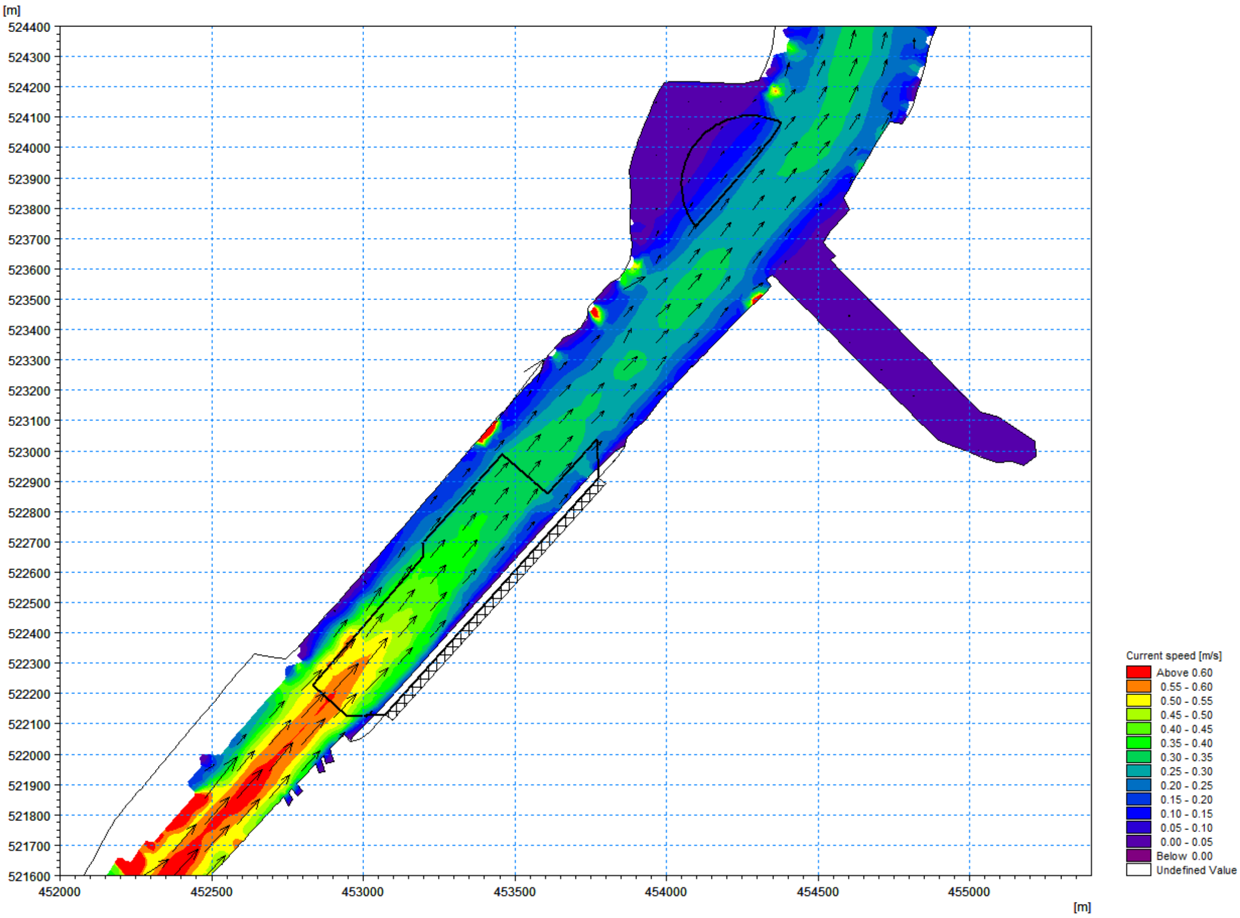

Figure 4.23: Peak current velocities during the ebb phase of a neap tide with 1 in 100 year river flow - baseline

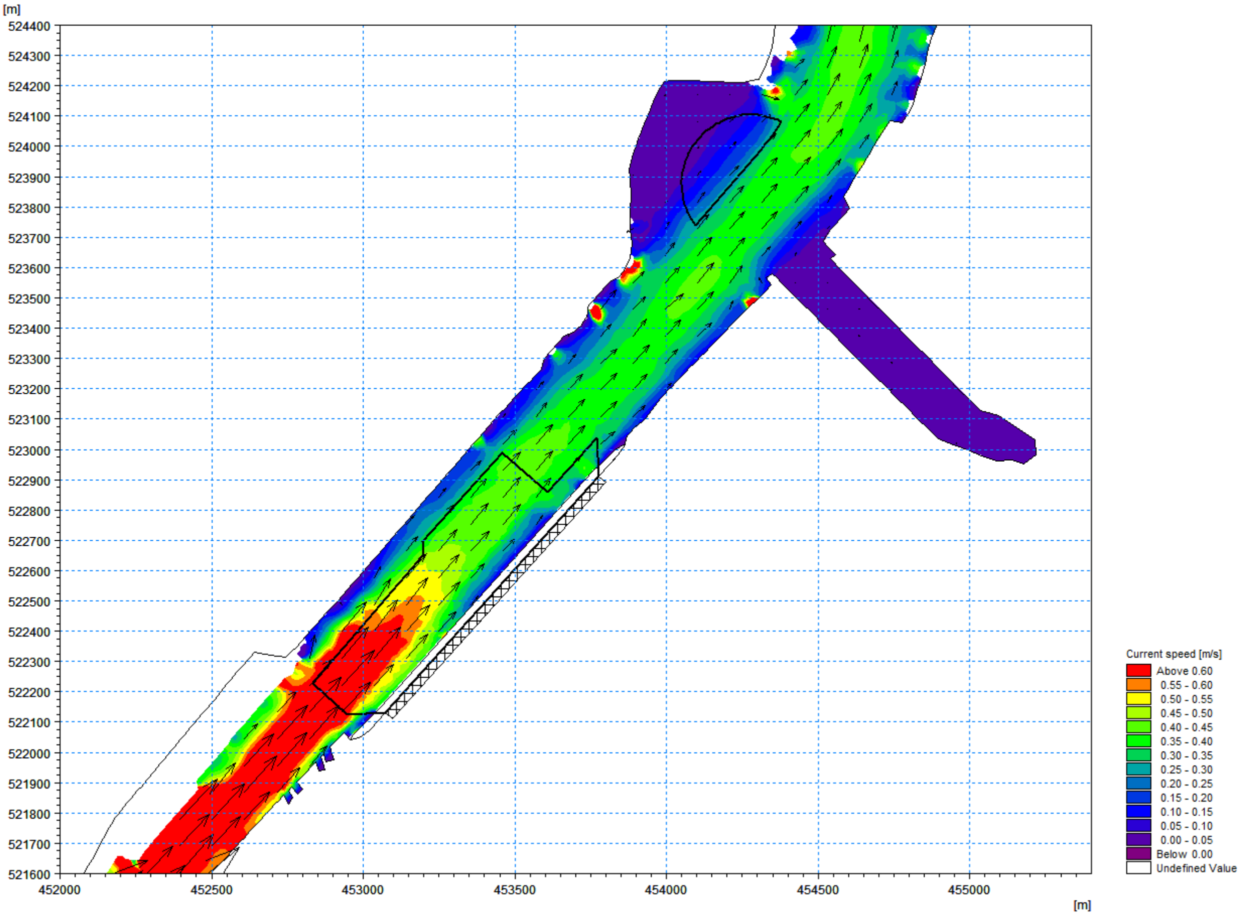

Figure 4.24: Peak current velocities during the ebb phase of a spring tide with 1 in 100 year river flow – baseline

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Figure 4.25 and **Figure 4.26** show the ‘with scheme’ effects for peak current speeds during the ebb phases of a neap and spring tide respectively with a 1 in 100 year river flow. The general baseline tendencies under this extreme flow condition remain unaffected by the scheme.

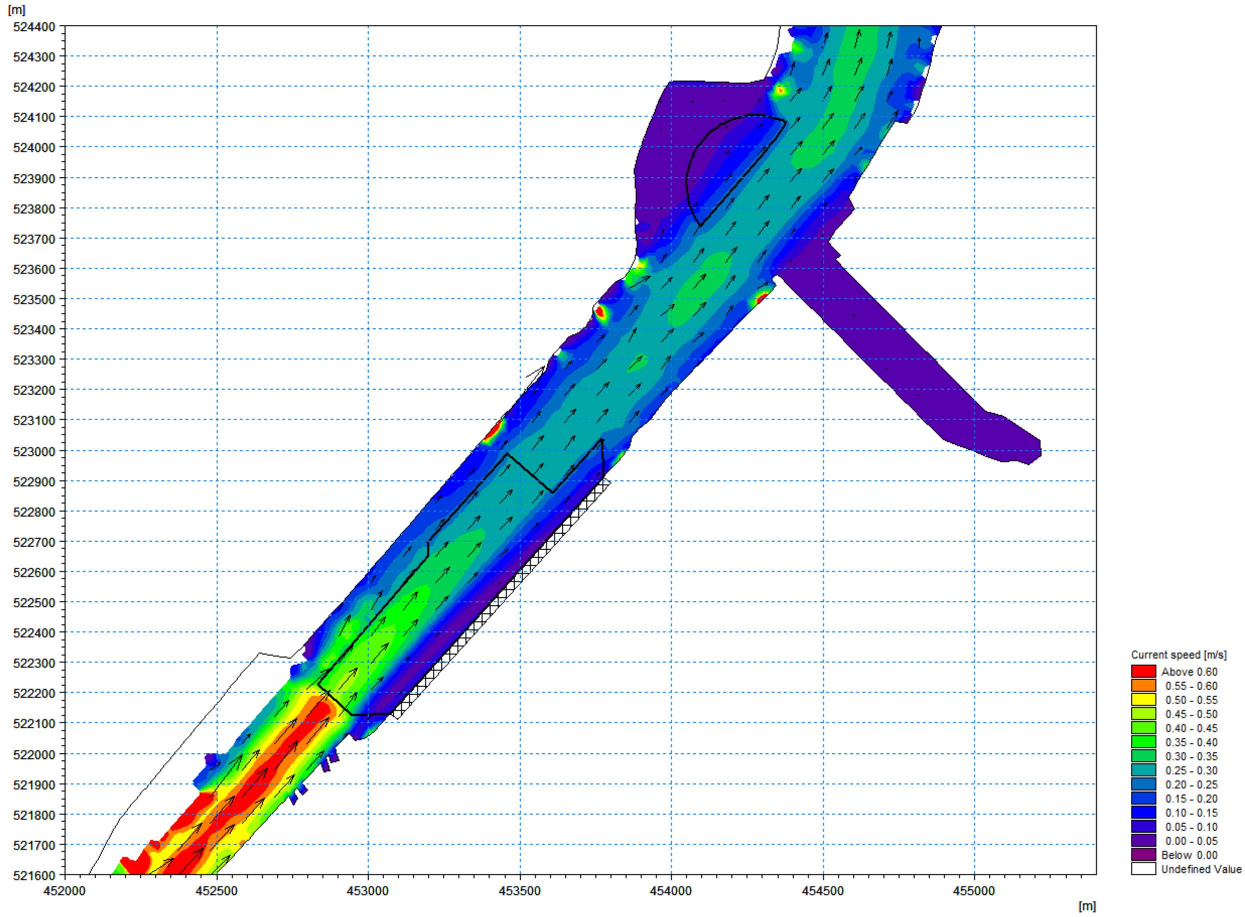

Figure 4.25: Peak current velocities during the ebb phase of a neap tide with 1 in 100 year river flow – with scheme

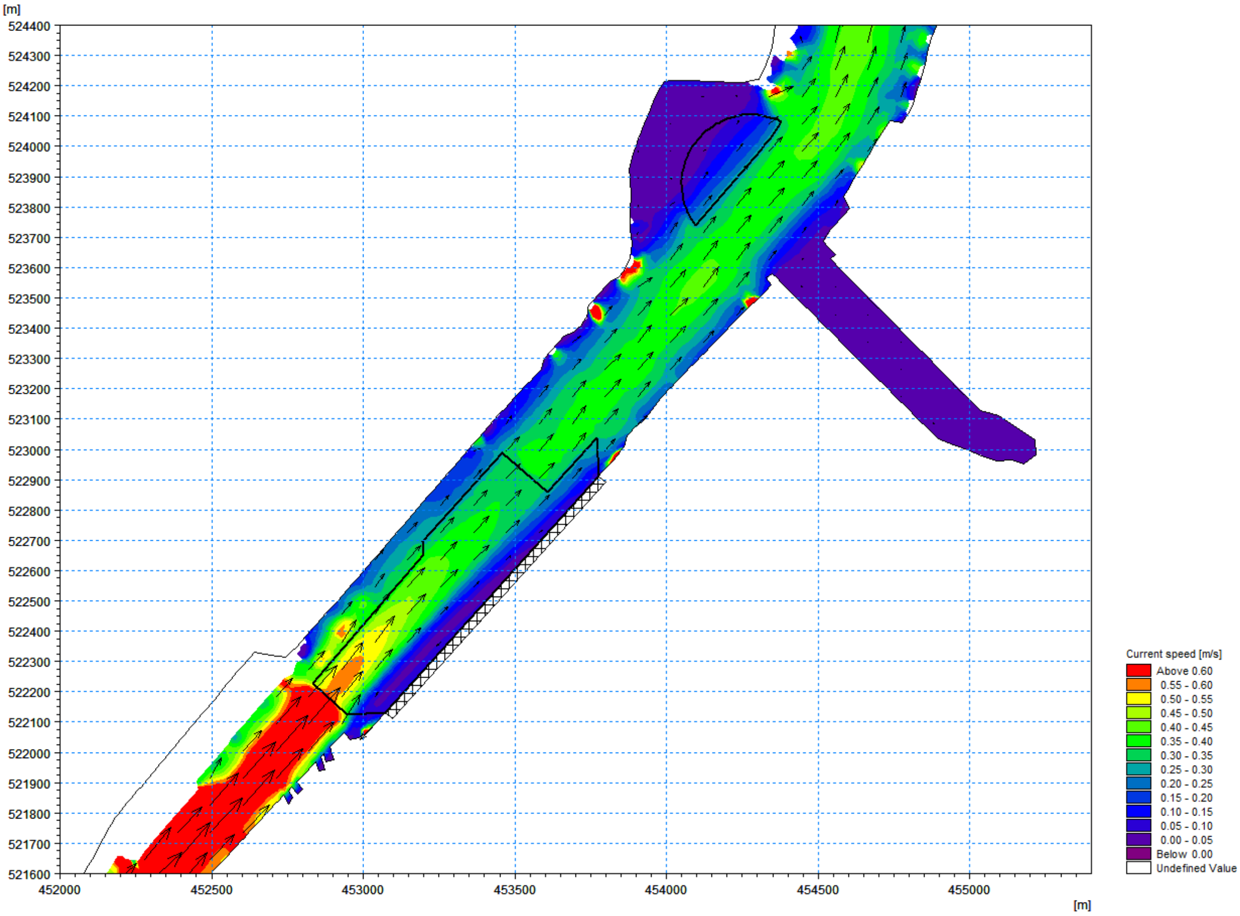

Figure 4.26: Peak current velocities during the ebb phase of a spring tide with 1 in 100 year river flow – with scheme

The ‘with scheme’ conditions have been compared against the baseline conditions and the resulting difference plots in **Figure 4.27** and **Figure 4.28Figure 4.16** show the changes in peak current speeds on the ebbing phases of neap and spring tides, respectively. These changes remain largely confined to the river reach of the South Bank Wharf even under this extreme river flow scenario.

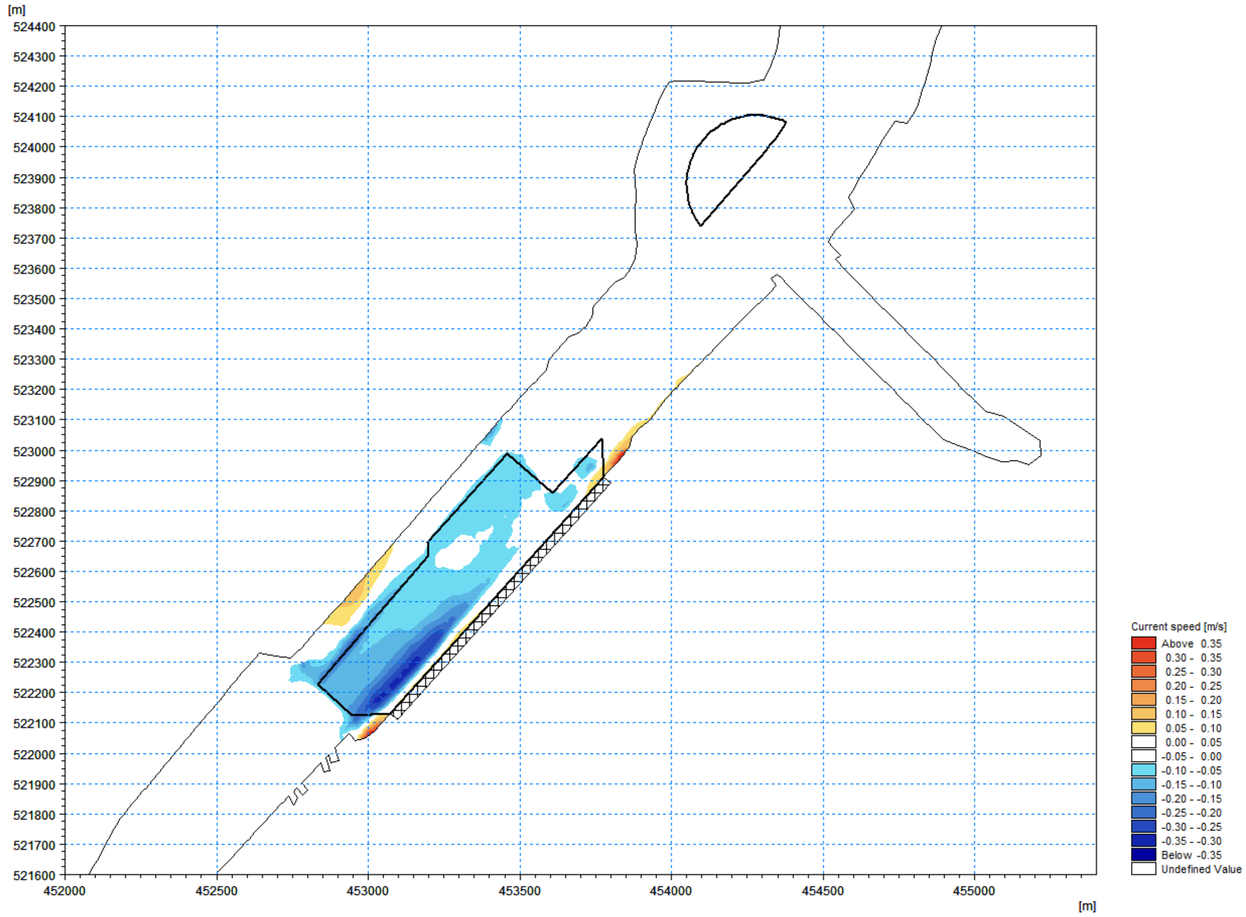

Figure 4.27: Change in peak current velocities due to the scheme during the ebb phase of a neap tide with 1 in 100 year river flow

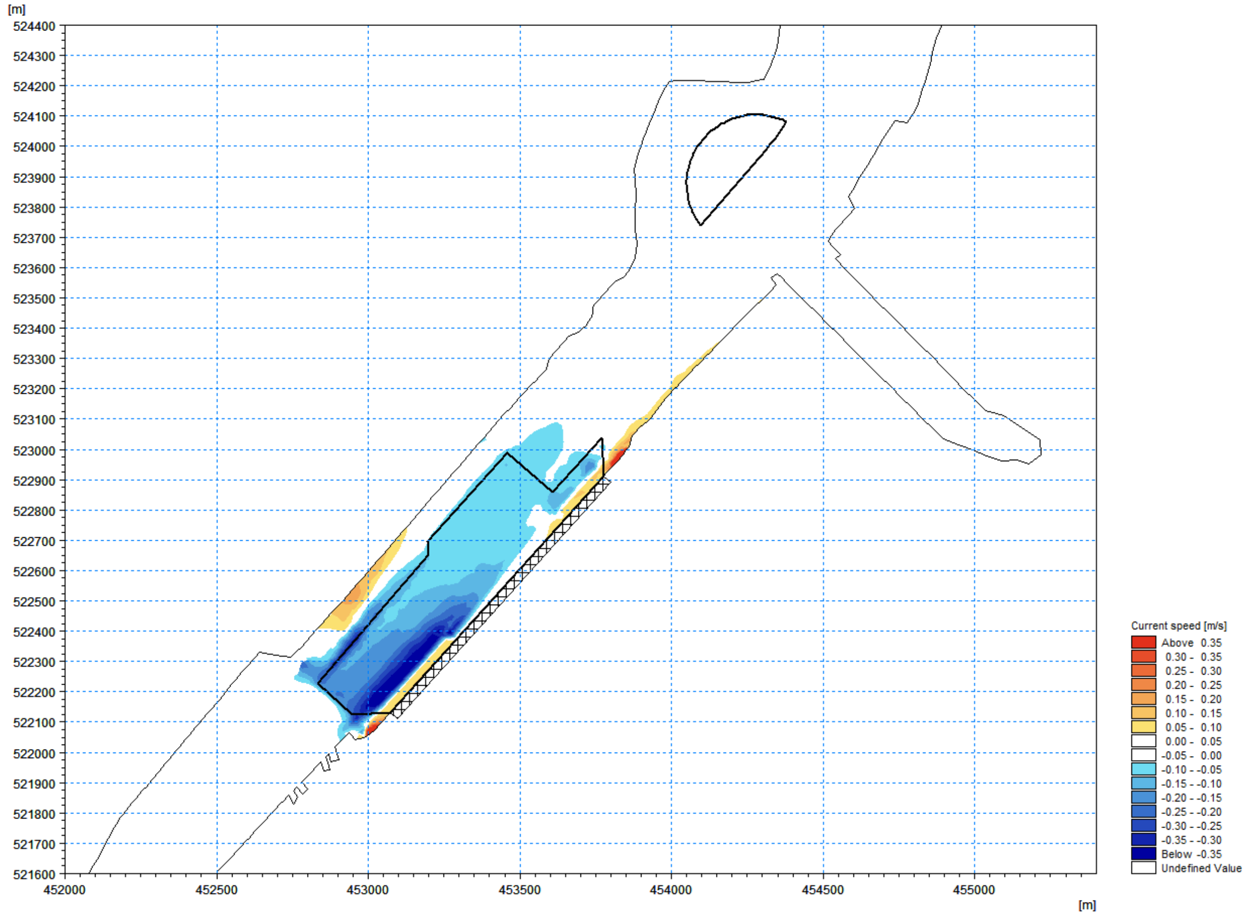

Figure 4.28: Change in peak current velocities due to the scheme during the ebb phase of a spring tide with 1 in 100 year river flow

4.3 Conclusions

The principal findings from the numerical hydrodynamic modelling are:

- The proposed new quay alignment and capital dredging to deepen the Tees Dock turning circle and approach channel and to create a berth pocket will not significantly affect the existing baseline hydrodynamic conditions under any of the three different river flow scenarios considered.

- There will be flow newly occurring in the area of the new quay because it is being set-back from the existing riverbank, but even the peak flows in this area will be low.

- Elsewhere, there will be a general small magnitude reduction in baseline flows varying during different phases of the tidal cycle, but always remaining largely within the reach immediately opposite the new quay. This reduction in baseline flows is caused by both a slight widening of the channel (due to the new quay alignment) and the local deepening of the bed due to the capital dredging.

- The reductions in baseline current speeds in these areas may lead to a slight increase in deposition of sediment. In the main channel the deposition will require periodic dredging to maintain the design depths.

- There is no measurable change caused by the capital dredging at the Tees Dock turning circle.
- There are no estuary scale effects on baseline hydrodynamic conditions.

5 Dispersion Model

5.1 Background

This section of the report describes the sediment dispersion modelling exercise that was undertaken to investigate the suspended sediment transport effects of the proposed dredging of the channel and the berth pocket in front of the new quay wall, as well as the deepening of parts of the Tees Dock turning area. The sediment transport model was built in MIKE3-MT software developed by DHI.

The set-up, calibration and application of the hydrodynamic 3D model (MIKE3-HD) is described in this report in Section 3.

5.2 Sediment Data

Available soil data indicates that it is expected that the dredging material consists of different soil types. A summary of the expected dredging soil types based on the ground investigation data (Definitive Feasibility Study Basis of Design - PC1084-RHD-SB-ZZ-RP-Z-1303) is presented in **Table 5-1**. A distinction is made between soft and hard material because it is expected to influence the choice of dredging equipment to be deployed.

Table 5-1: Soil Types to be dredged

Soil type	Stratum	Top to bottom levels (mCD)	Description
Soft soil material	Tidal Flat Deposits	+2 to -2	Loose to medium dense grey brown very clayey slightly gravelly SAND
	Glacial Till	-2 to -11	Stiff (locally firm) red brown sandy gravelly CLAY of low plasticity. Gravel is fine to coarse subangular and consists of sandstone, quartzite and mudstone
Hard soil material	Mercia Mudstone Group	-11 and deeper	Red brown highly weathered MUDSTONE weak with occasional deposits of gypsum

Based on the ground investigation data, for the sediment dispersion modelling, the following particle size distribution of the two soil types has been adopted as shown in **Table 5-2**.

Table 5-2: Particle size distribution for dredged soil types

Sediment Category	Sediment Size (mm)	Soft material	Hard material
Silt/Clay	0.031	70%	20%
Fine Sand	0.13	10%	5%
Medium Sand	0.3	5%	-
Coarse Sand	1.3	5%	-
Gravel/Cobble	2	10%	75%

5.3 Dispersion Model Setup

The sediment dispersion model built in MIKE3-MT is coupled with the 3D hydrodynamic model built in MIKE3-HD. The computational mesh of MIKE3-MT is identical to the MIKE3-HD mesh described in Section 4 of this report.

The dredging layout for the South Bank dredging scope is shown in **Figure 5.1**. The river channel in front of the South Bank Wharf as well as part of the Tees Dock Turning Area will be dredged to a level of -11mCD. The berth pocket in front of the new quay has a design bed level of -13.6mCD, but the dredge volumes considered in the dispersion model include an extra two metres of dredge material down to a bed level of -15.6mCD to allow for a rock blanket to be installed in the berth pocket.

The sediment dispersion model has been run for a four-month period to cover the full duration of the dredging schedule. Due to the uncertainty of the time when the dredging will take place, the worst scenario in terms of the tides has been chosen, and the model has been run for the period of March to June in which spring tides are slightly higher.

The sediment dispersion model has been setup with 4 layers in order to differentiate between suspended sediment concentrations throughout the water column, e.g. near the sea bed and near the water surface.

In order to simulate the sediment dispersion close to natural conditions, wave disturbance effect has been included in the MIKE3-MT model. Wave condition of 1m and 4.9 sec (Tz) has been chosen in the model settings.

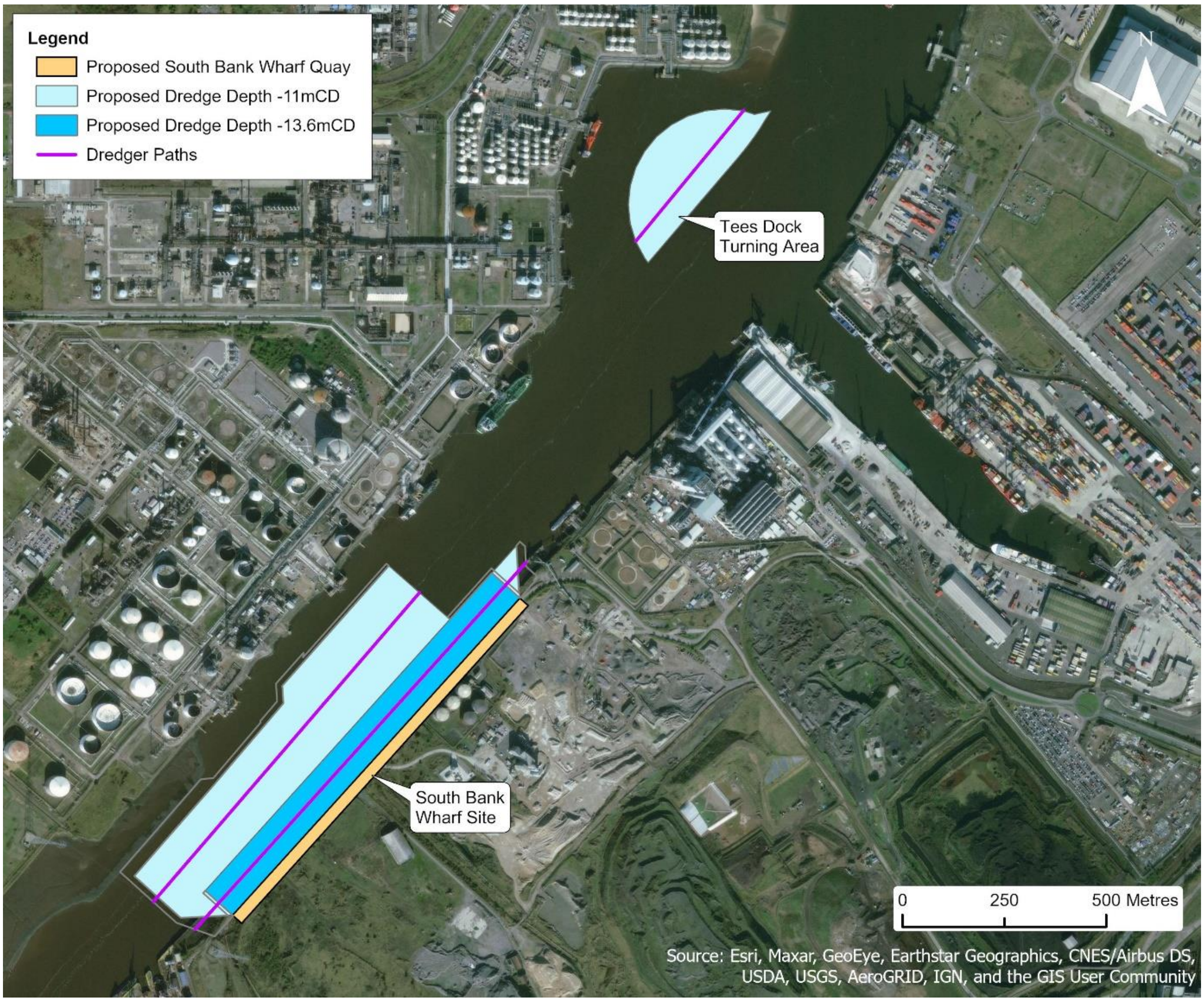

Figure 5.1: Dredging Layout

5.4 Dredging Methodology and Schedule

The dredging method, dredging schedule and details of the sediment release settings for the sediment plume dispersion model are described in this section.

5.4.1 Dredging Method

The sediment will be dredged using two types of dredgers. The soft soil material below a depth of -5mCD will be dredged by using a Trailing Suction Hopper Dredger (TSHD), and a Backhoe Dredger (BHD) will be used to dredge material above this level. The hard soil material will also be dredged by the BHD because the TSHD cannot deliver sufficient cutting power.

All dredged material will be taken to the "Tees Bay C" offshore disposal site which is approximately 18km (or 10 nautical miles) away from the South Bank Wharf site. This is shown in **Figure 5.2**

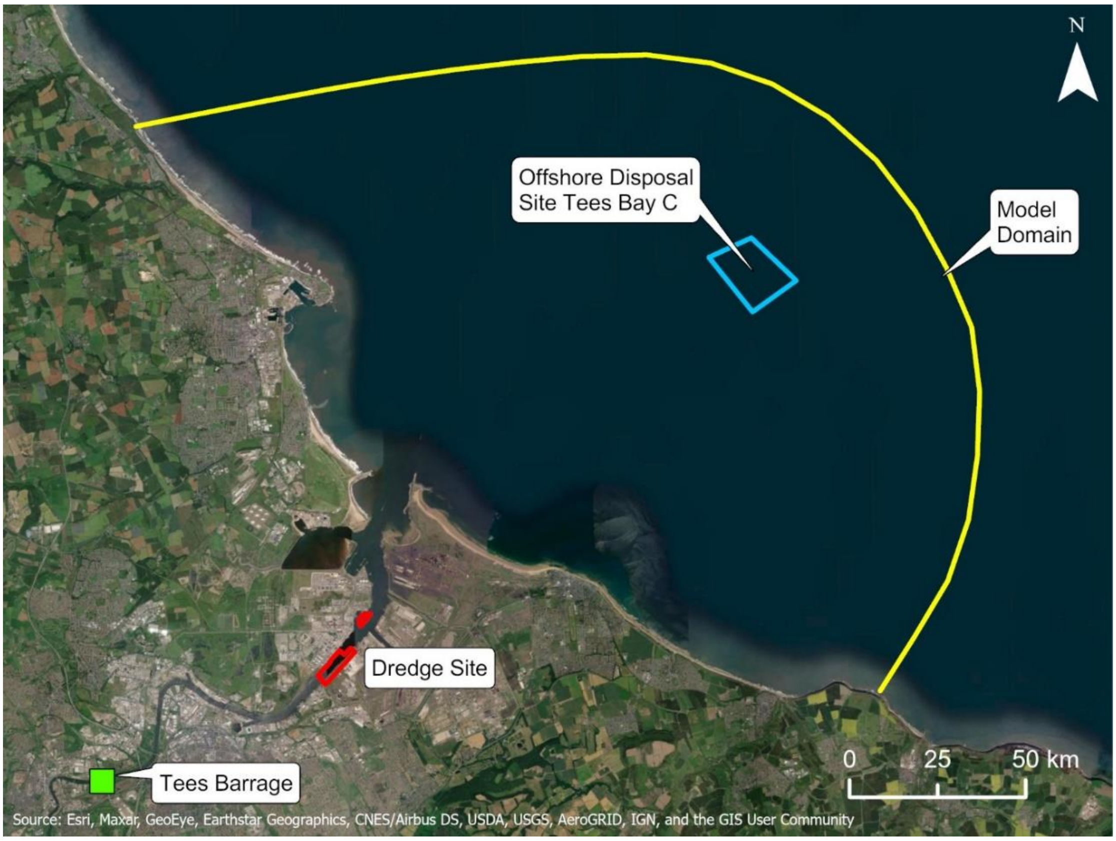

Figure 5.2: South Bank Wharf Dredge Site and Tees Bay C Offshore Disposal Site

5.4.2 Dredging Schedule

The dredging schedule and quantity for the BHD and TSHD are described in **Table 5-3**. The dredging will begin with the BHD removing the soft soil material above a level of -5mCD, followed by the TSHD and the BHD working in parallel on dredging the soft soil material below the level of -5mCD, and then the BHD will remove the hard material to the required bed level.

A total of 1.8 million m^3 of bed material will be dredged over a period of 17weeks. The simulation covers the entire dredging period and the movement of dredgers and transport barges were tracked for the processes of dredging, sailing, disposal and downtime for bad weather, refuelling, and equipment maintenance.

Figure 5.3 and **Figure 5.4** show the sediment release schedules for the dredgers at the South Bank Wharf site and Tees Dock Turning Area, and at the offshore disposal site respectively. The dredging schedule will start with the BHD dredging the soft material above -5mCD at South Bank Wharf for 3.7 weeks, followed by the TSHD and BHD working in parallel dredging soft material below -5mCD which will take 3.7 weeks. Then the BHD will start dredging the hard material at the site for 8.6 weeks. After this time the BHD and TSHD will then be working in parallel again to dredge the material from the Tees Dock Turning Area which will take 0.7 weeks. This means that the whole dredging campaign will take 17 weeks to complete.

The disposal schedule will follow the same pattern as the dredging schedule in that the barge filled by the BHD will sail to the offshore disposal site, as well as the TSHD sailing to the offshore disposal site once its full capacity has been reached.

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Table 5-3: Dredging Schedule Overview

	South Bank Wharf Channel and Berth Pocket				Turning Circle	
	TSHD (soft) below -5mCD	**BHD (soft)** - below -5mCD	**BHD (soft)** above -5mCD	**BHD (hard) Bottom**	**TSHD (soft)** below -5mCD	**BHD (soft)** below -5mCD
Vessel load (m^3)	3429	1652	1652	1520	3429	1652
Dredge time (minutes)	75	123	123	286	75	123
Sailing time empty (minutes)	50.0	54.5	54.5	54.5	50.0	54.5
Sailing time loaded (minutes)	54.55	60.0	60.0	60.0	54.55	60.0
Discharging time (minutes)	10	10	10	10	10	10
Operational to service hours (%)	83.3%	71.4%	71.4%	71.4%	83.3%	71.4%
Total dredging cycle time (minutes)	**189.55**	**123.1**	**123.1**	**285.9**	**189.55**	**123.1**
Effective operation hours per week	**140**	**120**	**120**	**120**	**140**	**120**
Number of trips to offshore disposal site per week	**44.3**	**58**	**58**	**25**	**44.3**	**58**
Cycle production (m3/week)	**151,961**	**96,596**	**96,596**	**38,282**	**151,961**	**96,596**
Dredging volume (m3)	**568,577**	**361,423**	**360,000**	**330,000**	**103,933**	**66,067**
Dredging time (weeks)	**3.7**	**3.7**	**3.7**	**8.6**	**0.7**	**0.7**

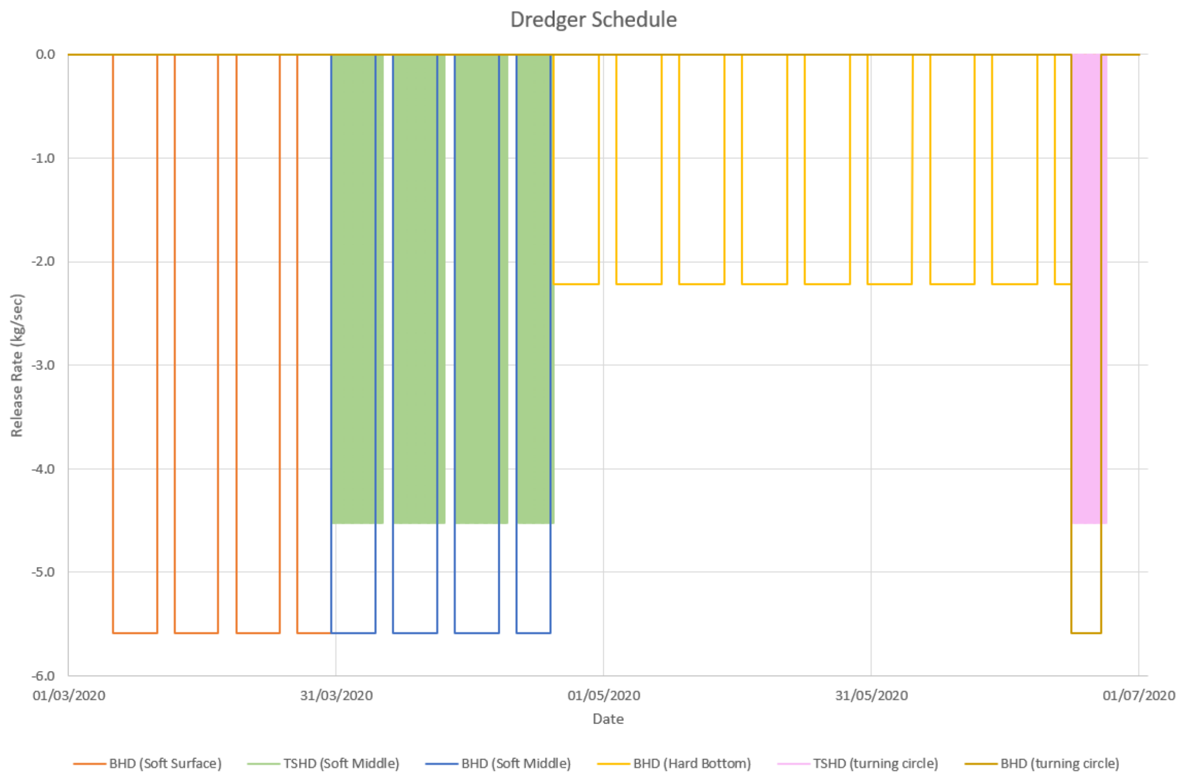

Figure 5.3: Sediment release schedule for dredger

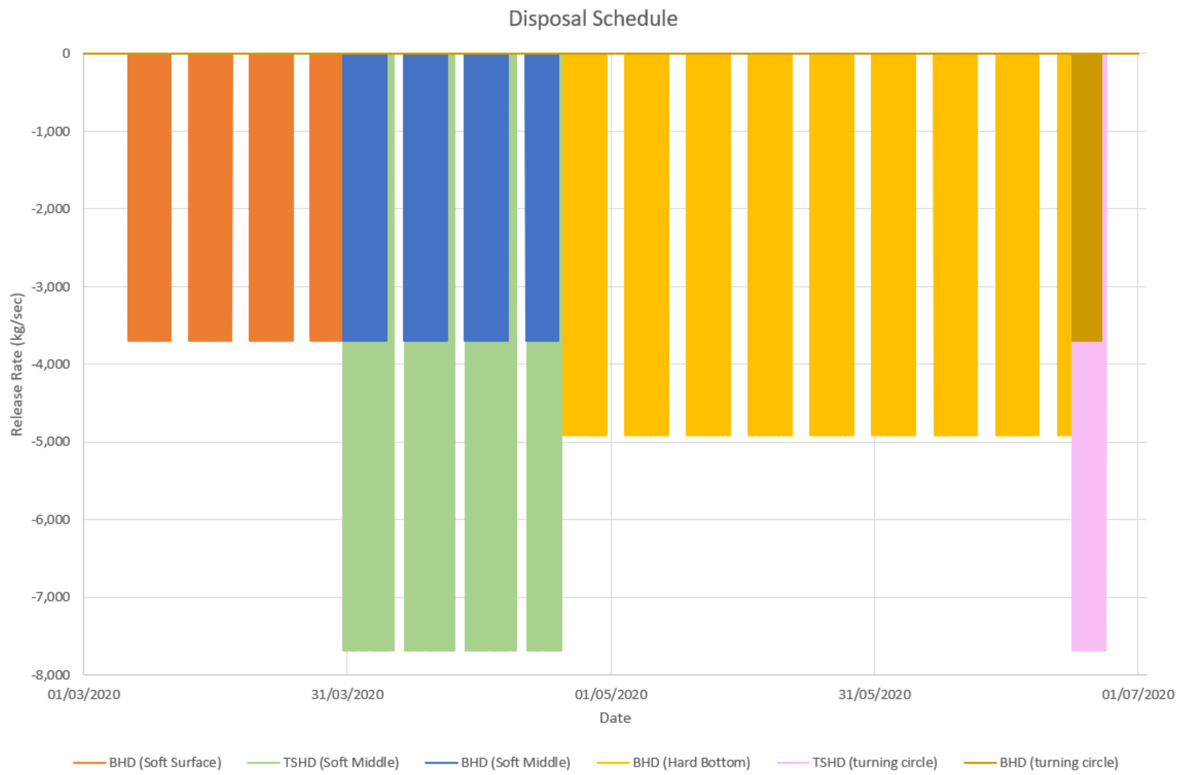

Figure 5.4: Sediment release schedule at offshore disposal site

5.4.3 Sediment Release Assumptions

The following assumptions have been made for the simulation of sediment plumes arising from dredging and offshore disposal.

At any one time at least one dredger, or for some of the dredging period two dredgers, are scheduled to be in operation and will operate at full capacity. The dredgers will release material along a single line along the channel, the berth pocket and part of the Tees Dock Turning Area. At the offshore disposal site, the dredger will release material in the centre of the site. This adopted method for material release is a conservative approach. The dredger will actually move around the dredging area and disposal site along multiple lines which means the sediment release will be more dispersed and thus the sediment concentration will be less.

5.4.4 Sediment Property Representation

The five sediment fractions, critical bed shear stresses and fall velocities used in the sediment dispersion model to represent bed sediments are shown in **Table 5-4**. The critical bed shear stress and fall velocities were calculated using the SandCalc software developed by HR Wallingford.

Table 5-4: Sediment settling velocity and critical bed shear stress

Sediment Grading Type	Sediment Size (mm)	Settling Velocity (m/s)	Critical Shear Stress (N/m^2)
Silt/Clay	0.031	0.000554	0.0847
Fine Sand	0.13	0.00935	0.1548
Medium Sand	0.3	0.0372	0.2025
Coarse Sand	1.3	0.135	0.657
Gravel/Cobble	2	0.1734	1.166

5.5 Backhoe Dredging and Disposal Cycle

This section describes the backhoe dredge and disposal cycle for the different soil types and depth layers.

5.5.1 Soft surface layer at South Bank Wharf

The backhoe dredger will dredge 360,000 m^3 of soft surface layer material above a level of -5mCD at the South Bank Wharf site. The dredger will operate continuously filling a barge, with two barges being in operation sailing back and forth to the offshore disposal site. The dredger disperses sediment into the water column at a sediment release rate of 5.6 kg/s. The sediment loss rate (the so-called 'S-factor') is taken as 25kg/m^3 for the Backhoe which follows the CIRIA Guidance (2000).

The backhoe will dredge for 123 minutes to load one barge, the barge will then sail for 60 minutes to the disposal site, discharge for 10 minutes with a discharge sediment rate of 3,705kg/s. The barge will then take 55 minutes to sail back to site. The total transport time of the barge takes 125 minutes.

The backhoe will take 3.7 weeks to complete this part of the schedule. The backhoe works on 71.4% operational working hours, which allows for downtime due to bad weather, refuelling, and equipment maintenance.

5.5.2 Soft middle layer at South Bank Wharf

Once the backhoe dredger has removed the soft middle layer, the backhoe will dredge 361,423 m^3 of soft middle layer material below a level of -5mCD at the South Bank Wharf site. The dredger will operate continuously filling a barge, with two barges being in operation sailing back and forth to the offshore disposal site. The dredger disperses sediment into the water column at a sediment release rate of 5.6 kg/s. The sediment loss rate (the so-called 'S-factor') is taken as 25kg/m^3 for the Backhoe which follows the CIRIA Guidance (2000).

The backhoe will dredge for 123 minutes to load one barge, the barge will then sail for 60 minutes to the disposal site, discharge for 10 minutes with a discharge sediment rate of 3,705kg/s. The barge will then take 55 minutes to sail back to site. The total transport time of the barge takes 125 minutes.

The backhoe will take 3.7 weeks to complete this part of the schedule. The backhoe works on 71.4% operational working hours, which allows for downtime due to bad weather, refuelling, and equipment maintenance. In parallel to the backhoe, the TSHD will also remove soft middle layer material; details on this can be found in Section 5.5.1.

5.5.3 Hard bottom layer at South Bank Wharf

Once the backhoe dredger and TSHD have removed the soft middle layer, the backhoe will dredge 330,000 m^3 of hard bottom layer material at the South Bank Wharf site. The dredger will operate continuously filling a barge, with two barges being in operation sailing back and forth to the offshore disposal site. The dredger disperses sediment into the water column at a sediment release rate of 2.2 kg/s. The sediment loss rate (the so-called 'S-factor') is taken as 25kg/m^3 for the Backhoe which follows the CIRIA Guidance (2000).

The backhoe will dredge for 286 minutes to load one barge, the barge will then sail for 60 minutes to the disposal site, discharge for 10 minutes with a discharge sediment rate of 4,913kg/s. The barge will then take 55 minutes to sail back to site. The total transport time of the barge takes 125 minutes.

The backhoe will take 8.6 weeks to complete this part of the schedule. The backhoe works on 71.4% operational working hours, which allows for downtime due to bad weather, refuelling, and equipment maintenance.

5.5.4 Soft middle layer at Tees Dock Turning Area

Once the backhoe dredger has at the South Bank Wharf site, the backhoe will dredge 66,067 m^3 of soft middle layer material below a level of -5mCD at the Tees Dock Turning Area. The dredger will operate continuously filling a barge, with two barges being in operation sailing back and forth to the offshore disposal site. The dredger disperses sediment into the water column at a sediment release rate of 5.6 kg/s. The sediment loss rate (the so-called 'S-factor') is taken as 25kg/m^3 for the Backhoe which follows the CIRIA Guidance (2000).

The backhoe will dredge for 123 minutes to load one barge, the barge will then sail for 60 minutes to the disposal site, discharge for 10 minutes with a discharge sediment rate of 3,705kg/s. The barge will then take 55 minutes to sail back to site. The total transport time of the barge takes 125 minutes. Therefore, one dredge cycle takes 248 minutes.

The backhoe will take 0.68 weeks to complete this part of the schedule. The backhoe works on 71.4% operational working hours, which allows for downtime due to bad weather, refuelling, and equipment maintenance. In parallel to the backhoe, the TSHD will also remove soft middle layer material; details on this can be found in Section 5.5.2.

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5.6 TSHD Dredging and Disposal Cycle

This section describes the TSHD dredge and disposal cycle for the different dredge locations.

5.6.1 Soft middle layer at South Bank Wharf

The TSHD will dredge 568,577m^3 of soft middle layer material below a level of -5mCD at the South Bank Wharf site. The dredger will operate for 75 minutes to load to full capacity, during which time it disperses sediment into the water column at a sediment release rate of 4.5kg/s. The sediment loss rate (the so-called 'S-factor') is taken as 15kg/m^3 for the Backhoe which follows the CIRIA Guidance (2000).

The TSHD will dredge for 75 minutes to load, then sail for 50 minutes to the disposal site, discharge for 10 minutes with a discharge sediment rate of 7,690kg/s. The TSHD will then take 55 minutes to sail back to site. The total dredge and transport cycle take 190 minutes.

The TSHD will take 3.7 weeks to complete this part of the schedule. The TSHD works on 83.3% operational working hours, which allows for downtime due to bad weather, refuelling, and equipment maintenance. In parallel to the TSHD, the backhoe will also remove soft middle layer material; details on this can be found in Section 5.4.2.

5.6.2 Soft middle layer at Tees Dock Turning Area

The TSHD will dredge 103,933m^3 of soft middle layer material below a level of -5mCD at the Tees Dock Turning Area. The dredger will operate for 75 minutes to load to full capacity, during which time it disperses sediment into the water column at a sediment release rate of 4.5kg/s. The sediment loss rate (the so-called 'S-factor') is taken as 15kg/m^3 for the Backhoe which follows the CIRIA Guidance (2000).

The TSHD will dredge for 75 minutes to load, then sail for 50 minutes to the disposal site, discharge for 10 minutes with a discharge sediment rate of 7,690kg/s. The TSHD will then take 55 minutes to sail back to site. The total dredge and transport cycle take 190 minutes.

The TSHD will take 0.7 weeks to complete this part of the schedule. The TSHD works on 83.3% operational working hours, which allows for downtime due to bad weather, refuelling, and equipment maintenance. In parallel to the TSHD, the backhoe will also remove soft middle layer material; details on this can be found in Section 5.4.4.

5.7 Results of Dispersion Model

5.7.1 Background

The model simulations account for the movement of dredgers and transport barges (including dredging, sailing, disposal and downtime) so that sediment releases have been made near continuously throughout the river dredging operations (except for allowed periods of downtime) from along the centre line of the dredged areas, running along the axis of the river channel, and also on a periodic basis from a single point in the centre of the offshore disposal site. The overall river dredging, and offshore disposal operations may be considered as four stages in the following sequence:

1. BHD working to dredge the upper soft material (above -5m CD) in the berthing pocket and river channel
2. BHD and TSHD working in parallel to dredge the middle soft material (below -5m CD) in the berthing pocket and river channel
3. BHD working to dredge the bottom hard material in the berthing pocket and river channel
4. BHD and TSHD working in parallel to dredge the material in the Tees Dock turning circle

Results from the sediment dispersion modelling are discussed in turn for the river dredging and offshore disposal activities. Note that all the modelling plots in following sections show the elevations in suspended sediment concentration (SSC) or sediment deposition due to these activities above baseline levels.

For SSC and sediment deposition, two types of analysis were undertaken:

- 'Timestep' analysis was undertaken based on an animation of plots created at 5-minute timesteps (intervals) throughout the entire 4-month period covered by the dredging and disposal simulations in the model. This interpretation is summarised more fully in in **section 6 (Hydrodynamic and Sedimentary Processes)** of the Environmental Statement (ES).

- Maximum 'zone of influence' plots (presented in following sections) show the maximum values and spatial extents of enhancement in SSC or deposition on the bed from any stage of the river dredging or offshore disposal operations during the relevant stage of the dredging programme. It is important to note that this type of figure does not represent a plume or deposition that would occur at any one point in time (such plumes or deposition are shown in the animated timestep plots). Rather, this type of figure shows the maximum areas of the river channel or offshore area that will become affected by a plume or deposition at some point during the 4-months of dredging or disposal activities (in some areas this will be on a single occasion, in other areas it will be on multiple occasions) and the maximum magnitude of change that will be experienced at that point.

Unless otherwise stated, all SSC plots show in following sections are from the near-bed layer of the 3D model. This is taken as the worst case in terms of SSC enhancement, but the effects described below generally exist throughout the water column but are of lesser magnitude with progression from the near-bed through the water column to the water surface (near-surface layer).

5.7.2 River Dredging

During Stage 1 of dredging (with the BHD working to dredge the upper soft material (above -5m CD) in the berthing pocket and river channel), the model simulates releases over time, moving from the south-western end of the dredging transect to the north-eastern end.

The maximum 'zone of influence' plot for Stage 1 (shown in **Figure 5.5**) shows peak concentrations of SSC (up to a few hundred mg/l) are confined to the release points along the dredging transect at the proposed development site. Further upstream and downstream of the areas directly dredged, the SSC enhancement drops markedly (typically below 50mg/l a short distance from the point of dredging, and at the peripheries below 20mg/l) before merging with low background concentrations that characterise the baseline conditions.

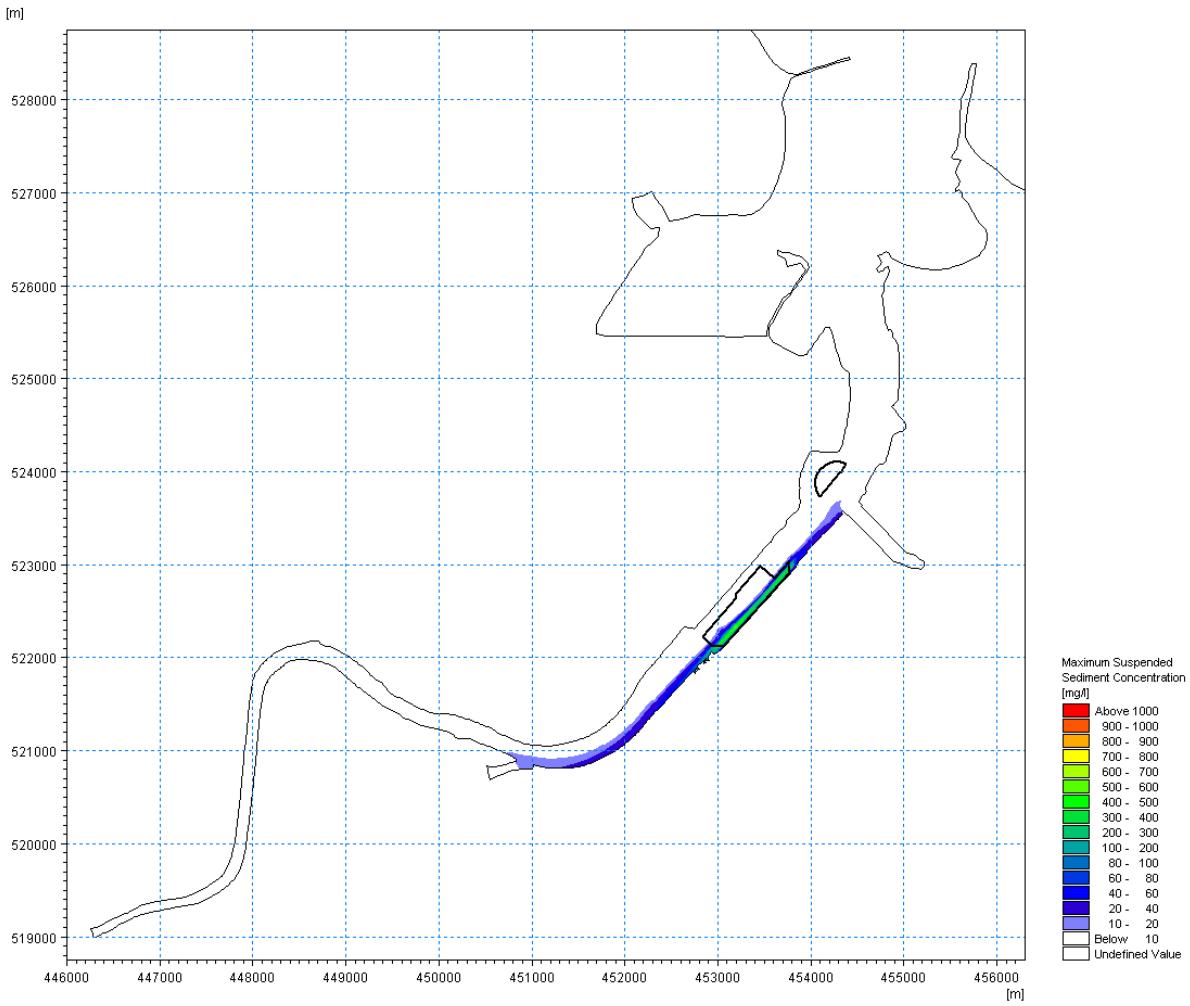

Figure 5.5: Maximum enhanced suspended sediment concentrations arising from dredging activities during Stage 1 of the capital dredging programme

During Stage 2 of the dredging activity (with the BHD and TSHD working in parallel to dredge the middle soft material (below -5m CD) in the berthing pocket and river channel), the model simulates releases over time, moving from the south-western end of each of two parallel dredging transects to the north-eastern end.

The maximum 'zone of influence' from Stage 2 of the dredging activities is shown in **Figure 5.6**. This shows that during Stage 2 of the dredging, broadly similar patterns to those observed in Stage 1 are anticipated, although: (i) the lateral extent of the plume (at low concentrations) becomes slightly greater; (ii) the extent of the plume across the river channel becomes wider; and (iii) at times two plumes are created by the in-parallel dredging activities. Despite these subtle differences, maximum concentrations of SSC (up to a few hundred mg/l) remain confined to the release points along the dredging transects at the proposed development site. Further upstream and downstream of the areas directly dredged, the SSC enhancement drops markedly (typically below 50mg/l a short distance from the point of dredging, and at the peripheries below 20mg/l) before merging with low background concentrations that characterise the baseline conditions.

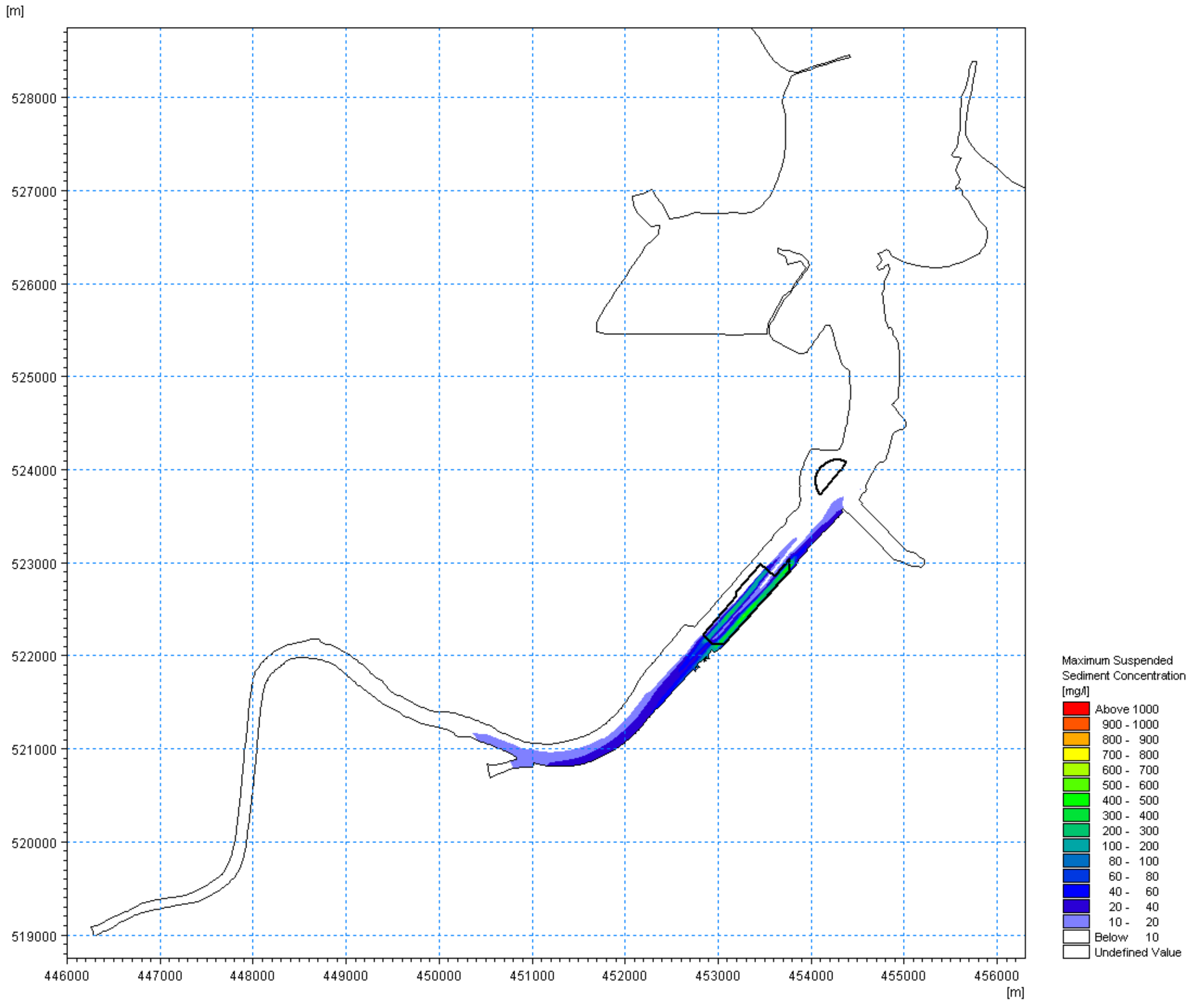

Figure 5.6: Maximum enhanced suspended sediment concentrations arising from dredging activities during Stage 2 of the capital dredging programme

During Stage 3 of the dredging activity (with the BHD working to dredge the bottom hard material in the berthing pocket and river channel), the model simulates releases over time, moving from the south-western end of the dredging transect to the north-eastern end.

The maximum 'zone of influence' from Stage 3 of the dredging activities is shown in **Figure 5.7**. This shows that during Stage 3 of the dredging, the maximum plume extent and maximum SSC values within the plume are much lower than experienced during both Stage 1 and 2 of the dredging (note the slight plume shown in the mid channel is a remnant of the Stage 2 dredging, which has not fully dissipated before Stage 3 commences). During Stage 3, the maximum extent of the plume is confined to within the length of the proposed quay and covers only a very narrow width of the channel, at very low peak concentrations.

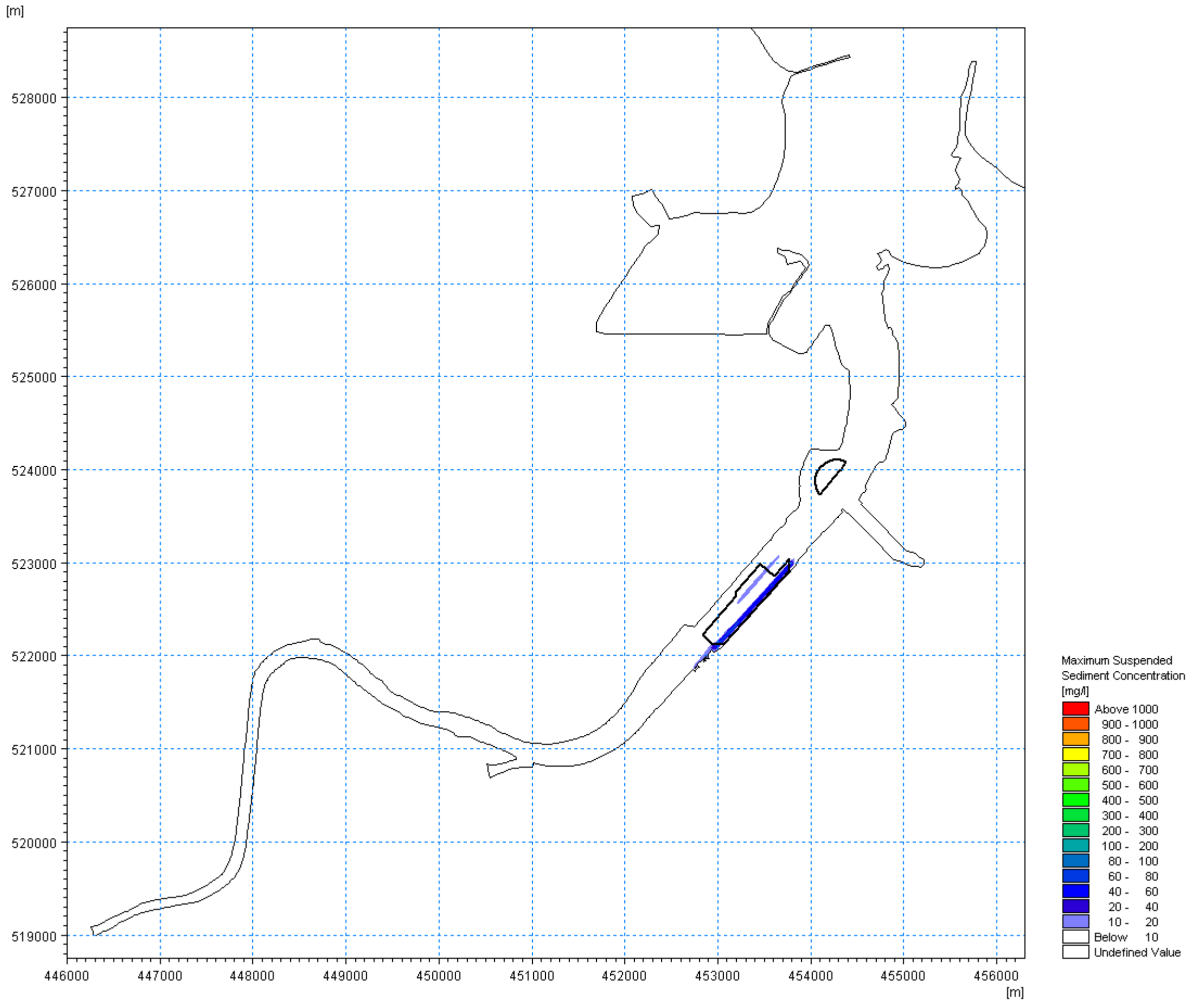

Figure 5.7: Maximum enhanced suspended sediment concentrations arising from dredging activities during Stage 3 of the capital dredging programme

During Stage 4 of the dredging activity (with the BHD and TSHD working in parallel to dredge the material in the Tees Dock turning circle), the model simulates releases over time, moving from the south-western end of each of two parallel dredging transects to the north-eastern end.

The maximum 'zone of influence' from Stage 4 of the dredging activities is shown in **Figure 5.8**. This shows that during Stage 4 of the dredging, the plume is created at the turning circle and along parts of the north bank of the river. As with previous stages, the maximum SSC concentrations remain local to the point of dredging within the turning circle (up to a few hundred mg/l). Further upstream and downstream of the areas directly dredged, the SSC enhancement drops markedly (typically below 50mg/l a short distance from the point of dredging, and at the peripheries below 20mg/l) before merging with low background concentrations that characterise the baseline conditions.

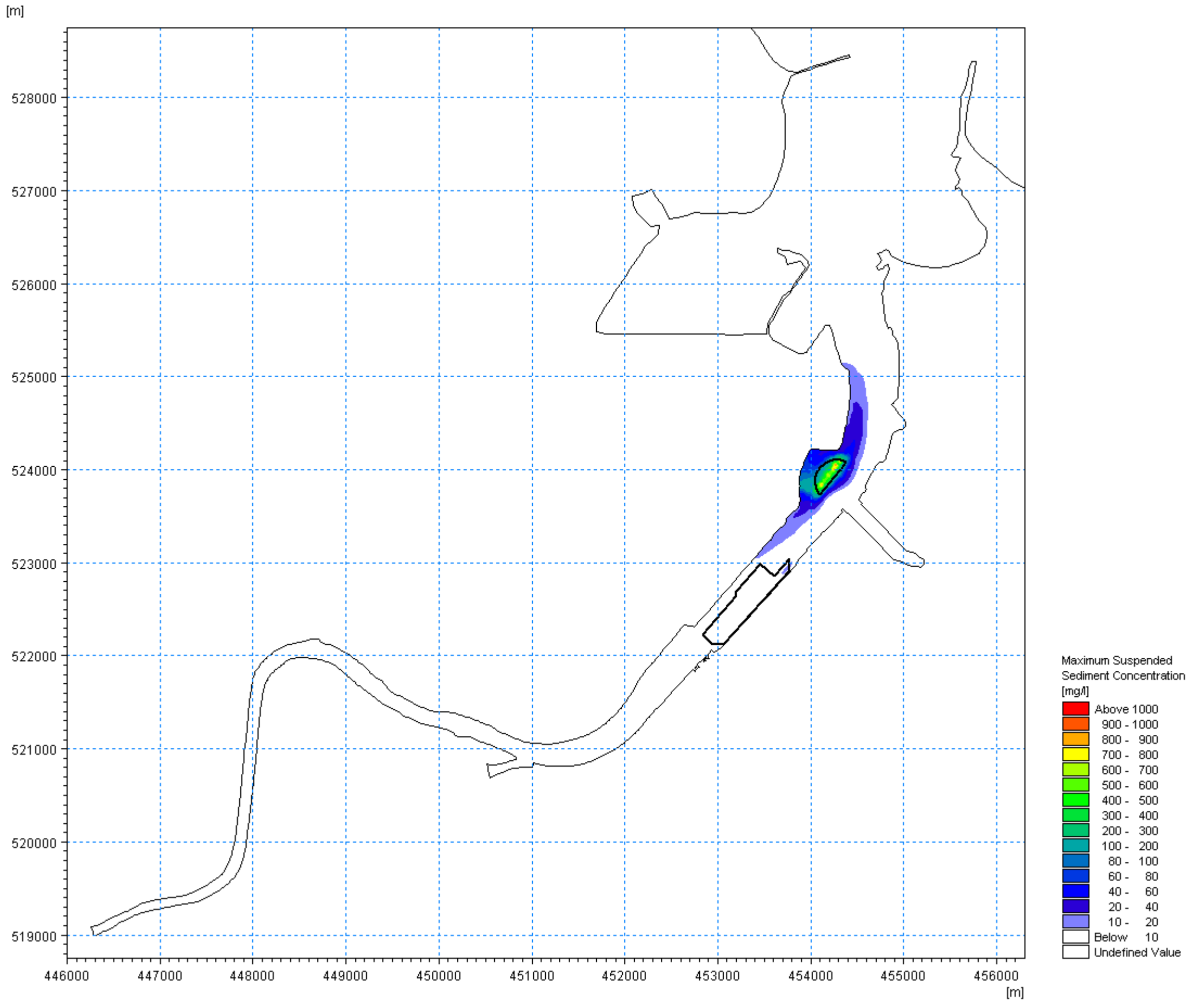

Figure 5.8: Maximum enhanced suspended sediment concentrations arising from dredging activities during Stage 4 of the capital dredging programme

The combined maximum 'zone of influence' from Stages 1 - 4 inclusive of the dredging activities has been plotted in **Figure 5.9** for the near-bed layer of the water column and in **Figure 5.10** for the near-surface layer. These figures demonstrate that near-surface effects are generally slightly lower than near-bed effects, and that during the 4 months of dredging, all plume effects are confined to within the river reaches that extend between Middleborough Dock/Transporter Bridge at the upstream end and the Oil Terminal on the north bank at the downstream end.

Furthermore, all plumes associated with dredging of the berthing pocket and river channel in the vicinity of the new quay are confined to the right bank (south of centre line) portion of the channel's width, whilst all plumes associated with dredging of the turning circle are confined to the left bank (north of centre line) portion of the channel's width in the reaches that they respectively affect.

No plume effects (and by implication no deposition effects) of a significant level above background values will occur beyond these reaches.

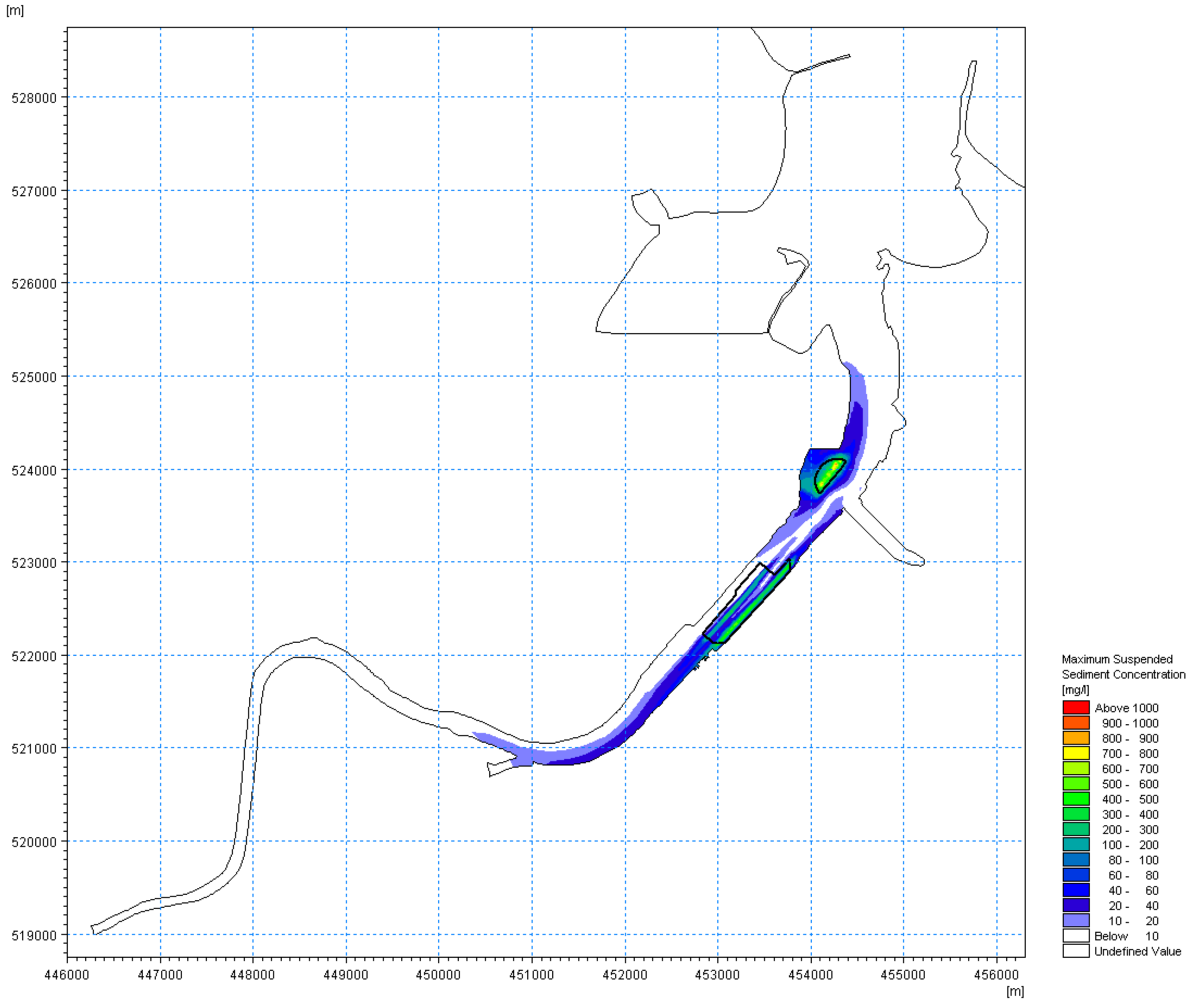

Figure 5.9: Maximum enhanced suspended sediment concentrations (near-bed layer) arising from dredging activities during Stages 1 - 4 inclusive of the capital dredging programme

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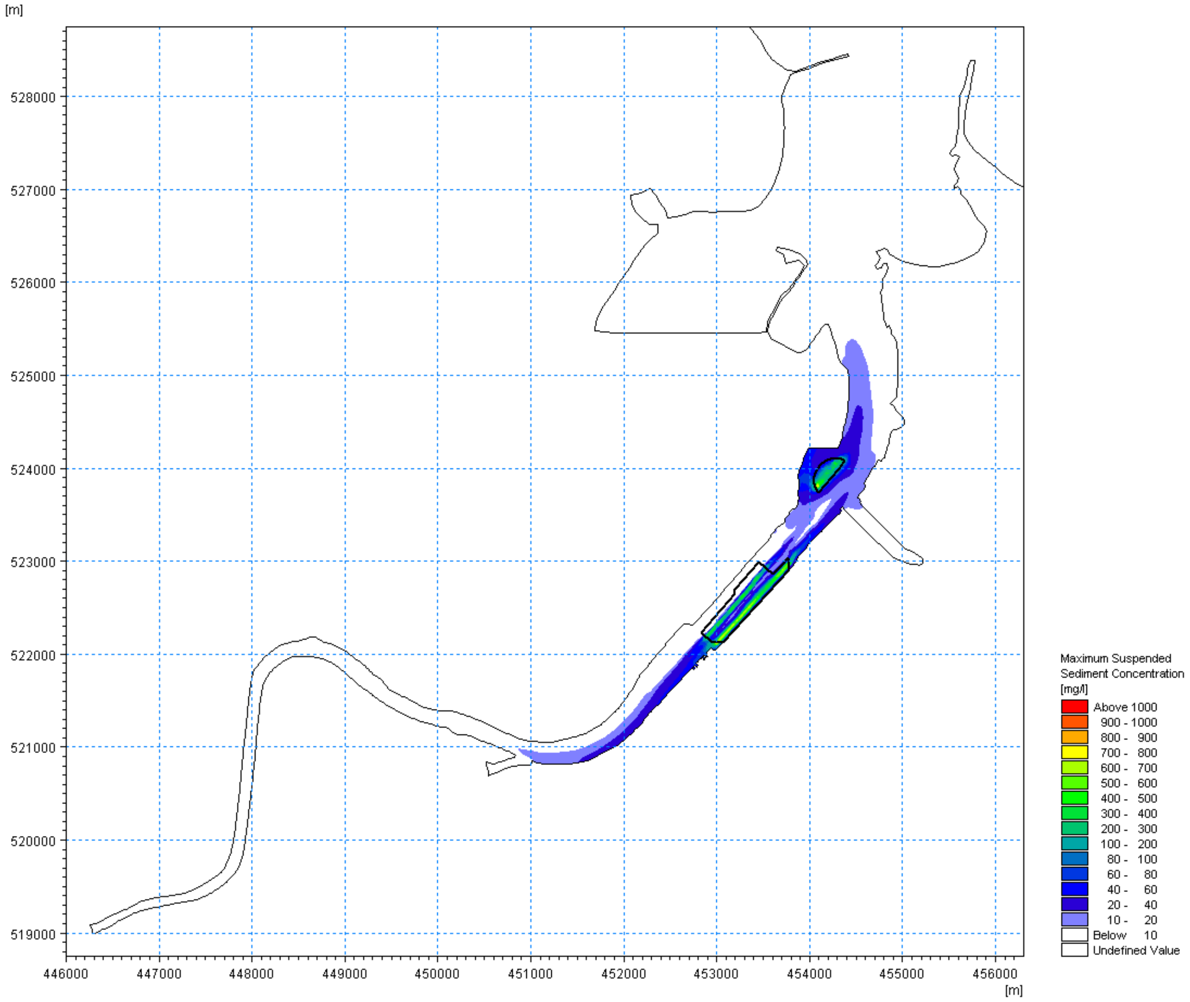

Figure 5.10: Maximum enhanced suspended sediment concentrations (near-surface layer) arising from dredging activities during Stages 1 - 4 inclusive of the capital dredging programme

Figure 5.11 shows the maximum changes in river bed thickness caused by the deposition of sediment from the plumes created by river dredging. It can be seen that much of the sediment falls to the bed within the dredged areas (from where it will be re-dredged to achieve the necessary bed depths), whilst the deposition that occurs in other parts of the river is much lower, typically less than 5cm, within the same area of river that is affected by the zone of influence from the sediment plumes.

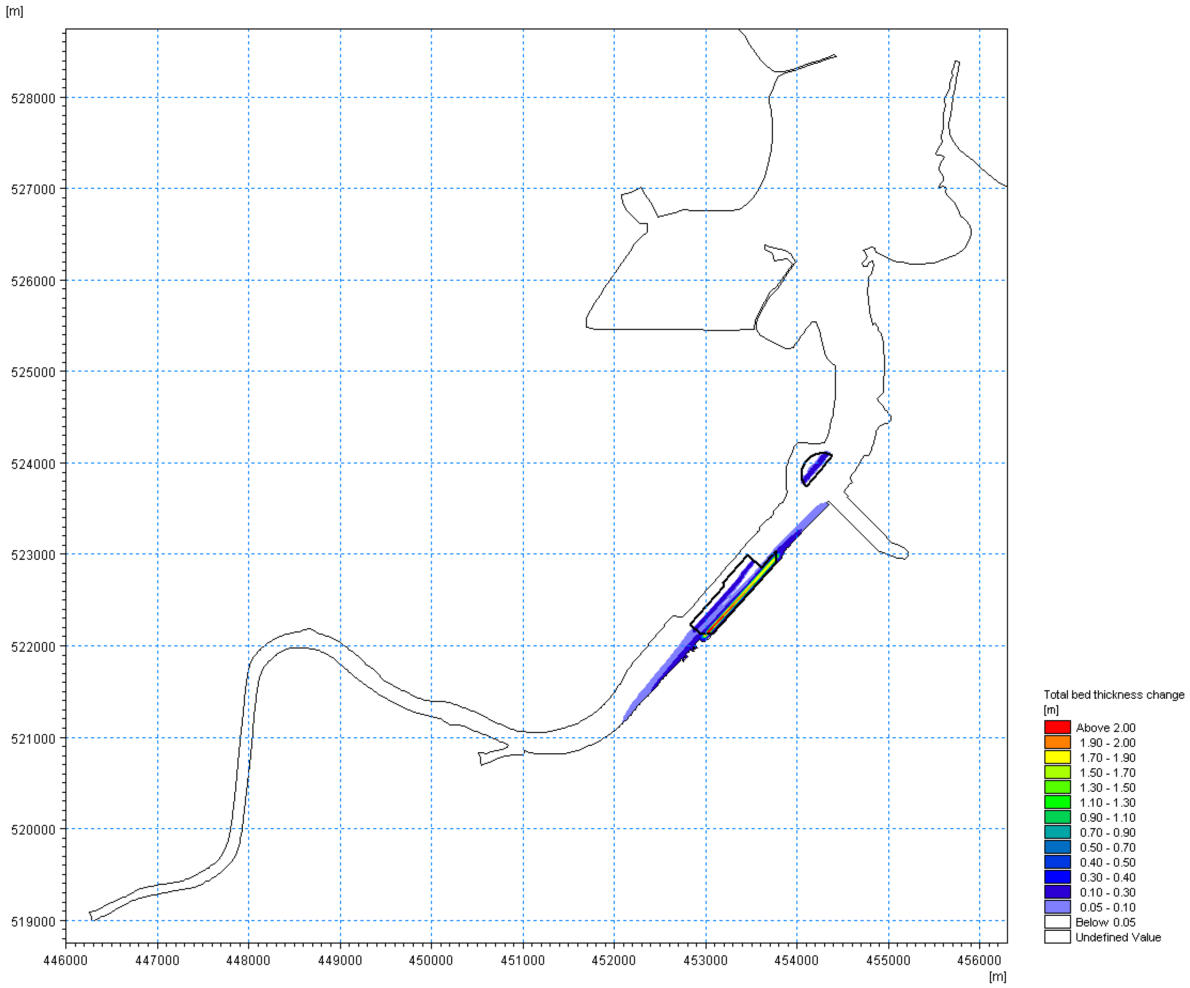

Figure 5.11: Maximum river bed thickness change due to sediment deposition arising from dredging activities during Stages 1 - 4 inclusive of the capital dredging programme

To further investigate these SSC and deposition effects upon receptors of water quality, marine ecology and navigation, timeseries plots of changes throughout the dredging programme have been extracted from the model at a series of points within the affected river reaches. Results and interpretation of these timeseries plots is presented in appropriate sections of the ES.

5.7.3 Offshore Disposal Site

The offshore disposal site is located within a water depth of around 43.5m, approximately 18km from the proposed development site and around 12km from the mouth of the river at its nearest point. The site is licensed for the disposal of dredged sediment and is routinely monitored as part of a national programme. Therefore, plumes arising from disposal activities and subsequent sediment deposition is unlikely to be of concern within the licensed area, or in immediately adjacent sea bed areas.

The maximum ‘zone of influence’ from combined disposal activities during Stages 1 - 4 inclusive of the dredging programme has been plotted in **Figure 5.12** for the near-bed layer of the water column. It should be noted that this represents a worst case whereby all disposal activities have occurred in the model at a single release point and the potential for coalescence of subsequent depositional plumes is greatest. In reality subsequent disposals will be at different parts of the release site and so the zone of influence is likely to be slightly broader in width and shorter in length, and certainly at lower maximum concentrations than shown in the worst case. Nonetheless, it can be seen that SSC values are elevated by the greatest amount at the release point (by up to several thousand mg/l), reducing to more typically a few hundred mg/l within a few km of the upstream and downstream boundaries. At the extremities of the plume extent, there are wide zones of relatively low SSC values (<100mg/l).

Figure 5.13 shows the maximum changes in sea bed thickness caused by deposition of material from the sediment plume for this worst case. It can be seen that much of the sediment falls to the bed within the disposal area (under the scenario of all releases at a single point), forming a mound on the sea bed. Deposition to the west and east of the disposal site is negligible, whilst to the south and north covers a similar zone to the sediment plume. In reality, disposals will be at different points within the licensed area, and so such a pronounced mound will not form and deposition on the sea bed to the north and south of the site will be much lower than this worst case.

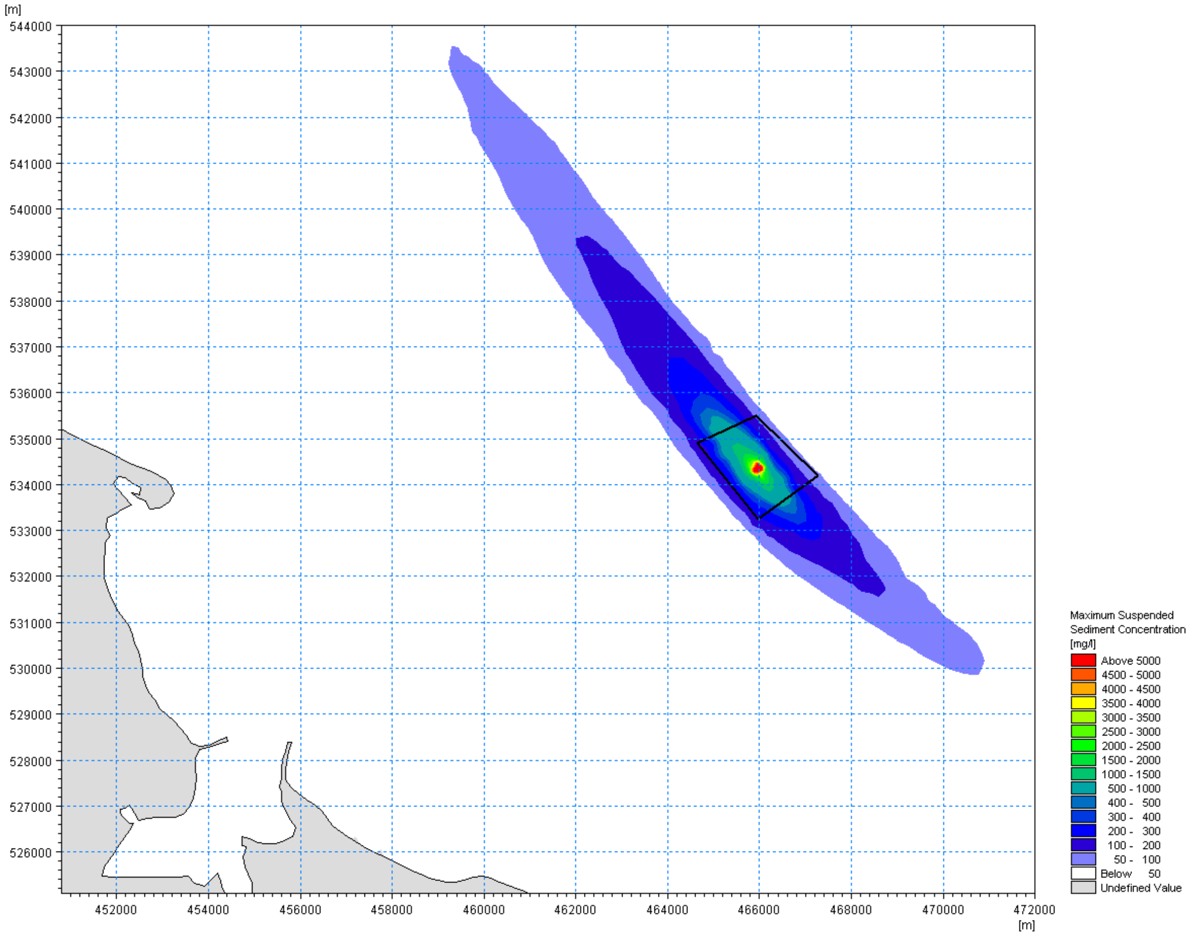

Figure 5.12: Maximum enhanced suspended sediment concentrations (near-bed layer) arising from disposal activities during Stages 1 - 4 inclusive of the capital dredging programme

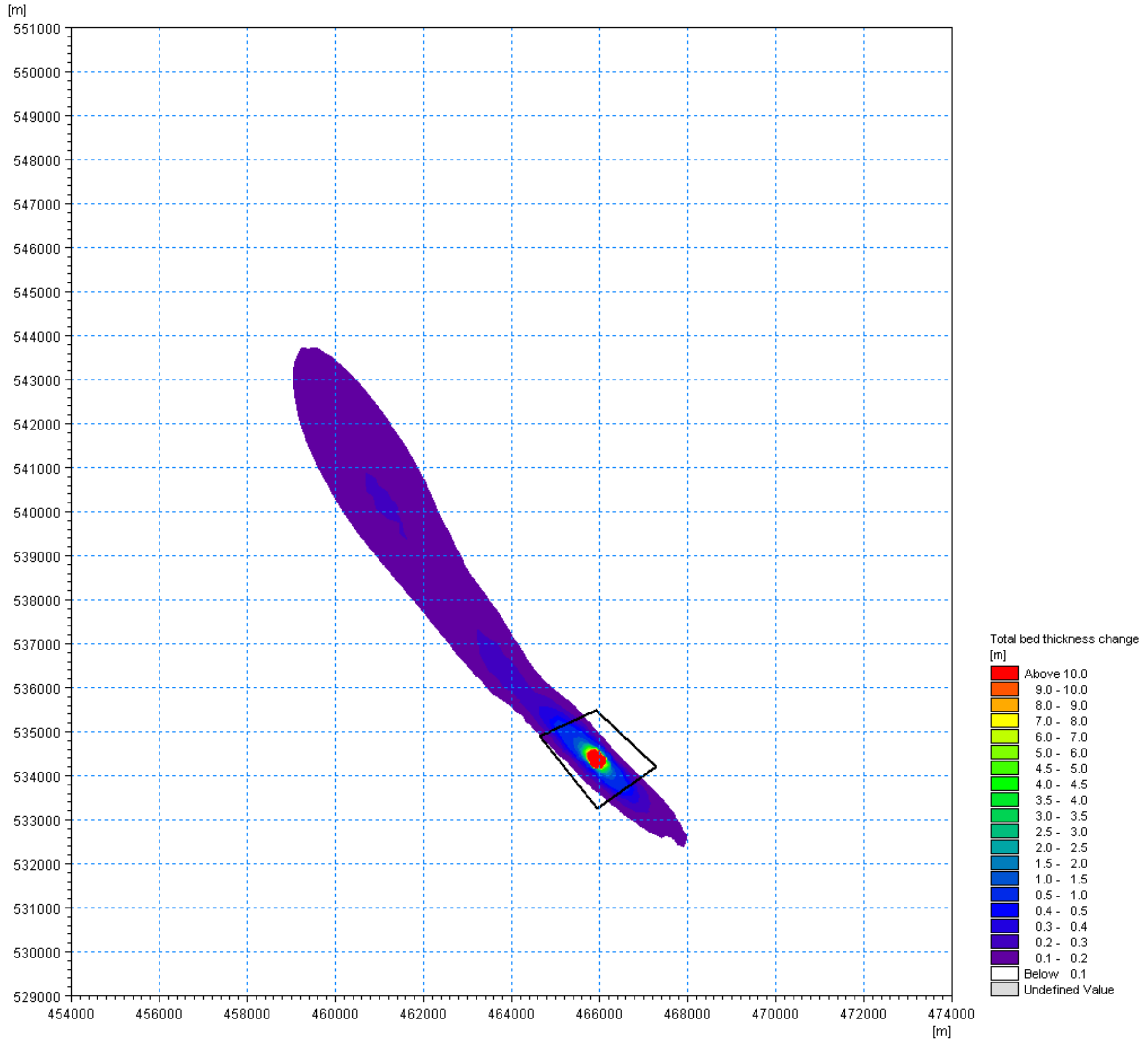

Figure 5.13: Maximum river bed thickness change due to sediment deposition arising from dredging activities during Stages 1 - 4 inclusive of the capital dredging programme

5.8 Conclusion

The river dredging and offshore disposal activities will both cause plumes of sediment to form close to the release point of material into the water column. These plumes will disperse under wave and current action and all sediment particles suspended in the water column will eventually settle to the river or sea bed, causing deposition.

During dredging, there will be release of sediment particles from the deliberate physical disturbance to the river bed and, more significantly, from overflow when dredged material is loaded into the dredger's hopper (for TSHD) or the transport barge (for BHD). Such releases will be ongoing through each dredging cycle until the dredging activity ceases due to downtime (e.g. adverse weather, vessel maintenance) or at scheduled breaks between stages of dredging activity. During offshore disposal, a single hopper load will near-instantaneously deposit material at the surface of the water column on each disposal visit.

Once a plume is generated, the highest SSC values will be recorded at the point of river dredging or offshore disposal, but these concentrations reduce rapidly after cessation of the activity. At distances away from the

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point of sediment release, the enhanced SSC values are considerably lower because the coarser material falls relatively rapidly to the bed, with only the finer proportions being retained in suspension, becoming advected away from the point of release by the prevailing currents. At the peripheries of each plume, the enhanced SSC values will be barely distinguishable from the background levels.

During some stages of the dredging and disposal activities, most notably when both TSHD and BHD are working in parallel, there could be instances where two separately formed plumes coalesce to form one (spatially) larger plume. However, the same principles of dispersion by prevailing currents applies, with peak concentrations remaining close to the point of release of the material for a short duration after its release before diminishing thereafter.

The plume effects arising from the river dredging are characterised by a short-lived localised increase in SSC by a few hundred mg/l at the point of dredging activity, followed by a general dispersion in spatial extent and reduction in concentration over following hours. Since the dredging is a near-continuous operation, the plume effects will be observed throughout much the 4-month period, but at varying extents during the four different stages. During Stages 1-3 the dredging-related plume effects will be largely confined to the channel areas south of the centreline of the river and in reaches between Middlesbrough Dock and Tees Dock. During Stage 4 the dredging-related plume effects will be largely confined to the channel areas north of the centreline of the river and in reaches between North Tees Works Oil Refinery and the Oil Terminal. Other than within the dredged areas, sediment deposition on the river bed will be of very minor magnitudes, in areas covering the same spatial extent as the sediment plumes. Where this occurs in the river channel or at jetties, it will subsequently be dredged as part of ongoing maintenance dredging regimes, whilst material deposited back into the newly dredged areas will be re-dredged during the capital works in order to achieve the desired design depths.

The plume effects arising from the offshore disposal similarly show peak concentrations at the point of release, but because a larger volume of material is near-instantaneously disposed, the peak concentrations are typically a few thousand mg/l at the point of disposal activity. Plumes become advected by tidal currents along the principal axis of tidal flow (north-west to south-east), diminishing in magnitude over a few hours after disposal. Just beyond the boundaries of the disposal site, the maximum sea bed deposition can be up to 0.5m, but this is in water depths that are approximately 43.5m. Furthermore, this represents a worst case of all material being deposited at a common point within the disposal site, whereas in reality deposits will be spread around various locations within the site's boundaries and thus this maximum potential change is highly unlikely to occur in practice.

Overall, the changes in SSC and sediment deposition arising from the river dredging and offshore disposal activities are very much in-keeping with those experienced by similar activities in other areas, which has been the subject of considerable industry-wide monitoring and assessment.

6 Wave Model and Extreme Wind Condition

The South Bank Wharf site is well sheltered from North Sea waves due to its location being well upstream the River Tees, so local wind-generated waves would be of more significance at the site. In order to understand the wave conditions at the site and confirm the above assumption, a MIKE21-SW spectral wave model has been setup and the effect of two types of waves has been investigated, namely local generated waves under extreme wind and extreme swell waves from the North Sea.

6.1 Wind Data

Initially, two wind speed data sets have been collected for this study. The first was frequency tables based on 24-year (1996-2019) recorded data at Loftus provided by UK Met Office, and the other was 9 month (October 2019 - July 2020) time series data recorded at Tees Dock provided by PD Ports. **Figure 6.1** shows the locations of the two wind recording stations, Loftus and Tees Dock. To compare the wind speed between the two stations, the third dataset, time series data recorded at Loftus for the same period of the Tees Dock dataset was acquired from UK Met Office.

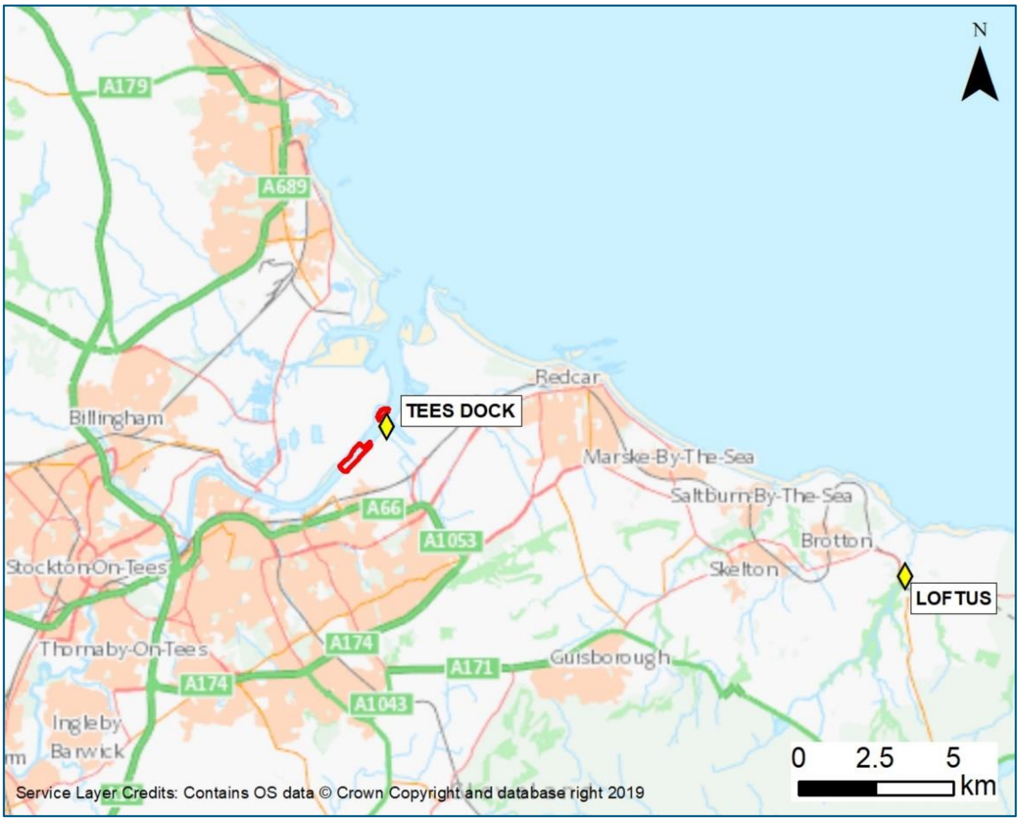

Figure 6.1: Location of wind recording stations at Loftus and Tees Dock

Figure 6.2 and **Figure 6.3** present wind roses for data recorded at Tees Dock and Loftus. It should be noted that both wind roses were derived from 9-month data. Nevertheless, it can be seen that wind direction at Tees Dock is influenced by local topography and the data shows two pre-dominant wind directions of southwest and northeast and calmer (wind speed below 1m/s) periods.

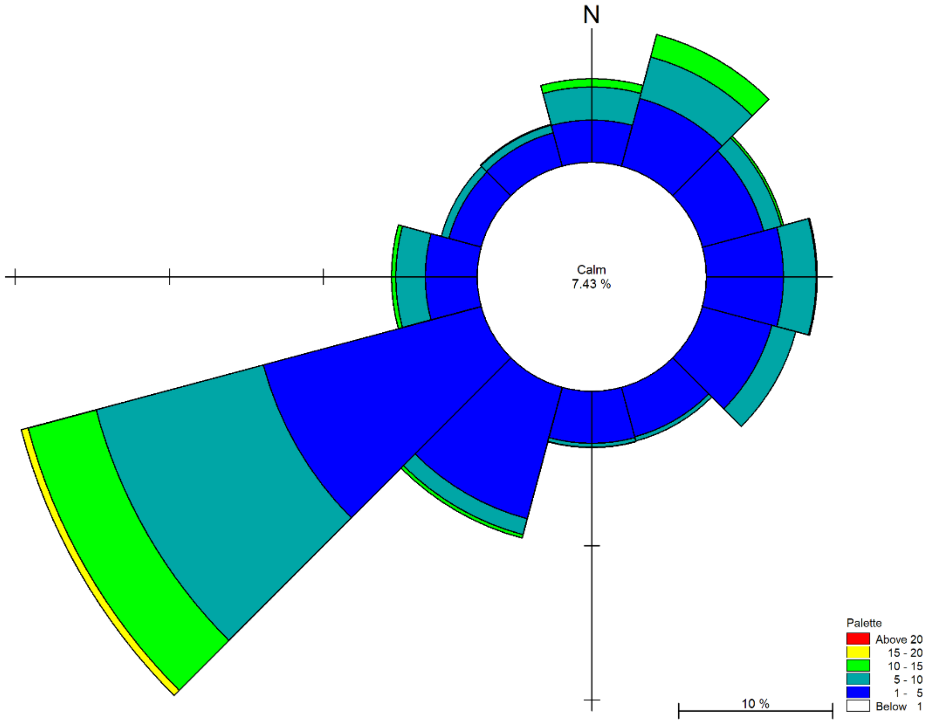

Figure 6.2: wind rose based on recorded data at Tees Dock (October 2019 – July 2020)

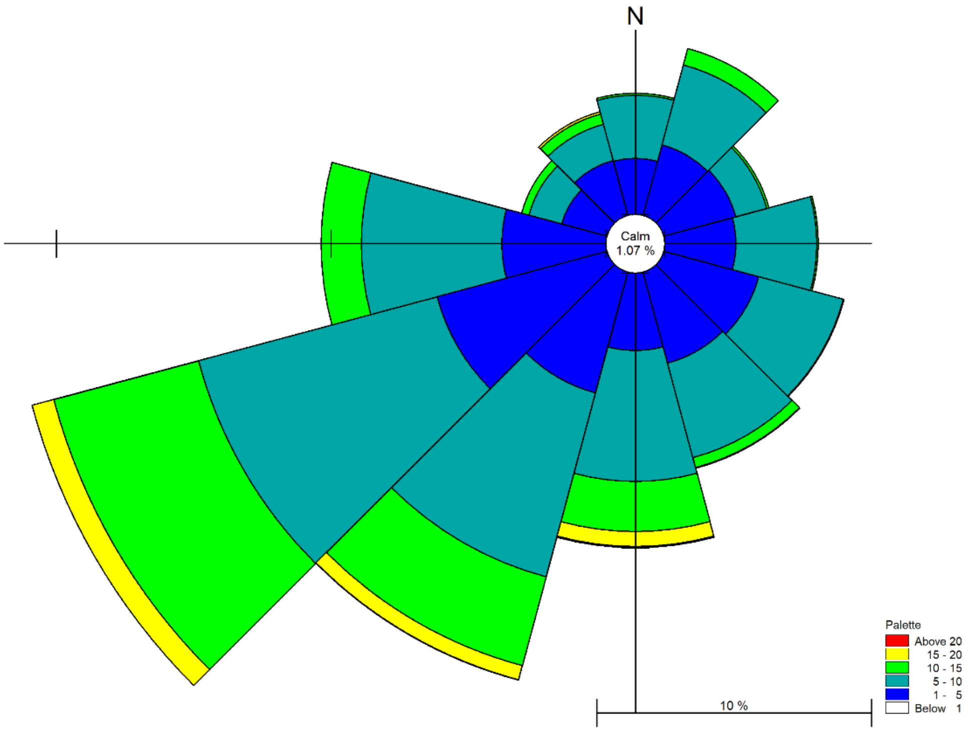

Figure 6.3: wind rose based on recorded data at Loftus (October 2019 – July 2020)

A correlation between the wind speed recorded at both wind stations has been derived based on the overlapping period of 24/10/2019 to 13/07/2020. The focus of this exercise was on the two main concerned wind direction sectors, Southwest and Northeast, due to the geographical orientation of the Tees Estuary mouth and the River Tees. The obtained correlations are:

$$y = 0.89x \ \ for\ wind\ from\ southwest$$

$$y = 1.18x \ \ for\ wind\ from\ northeast$$

where: y is wind speed at Tees Dock and x is wind speed at Loftus.

The above correlation demonstrates that wind speed is lower at Tees Dock when wind comes from Southwest and stronger when wind comes from Northeast. This is supported by the topography around the Tees Valley. **Figure 6.4** and **Figure 6.5** illustrate this correlation.

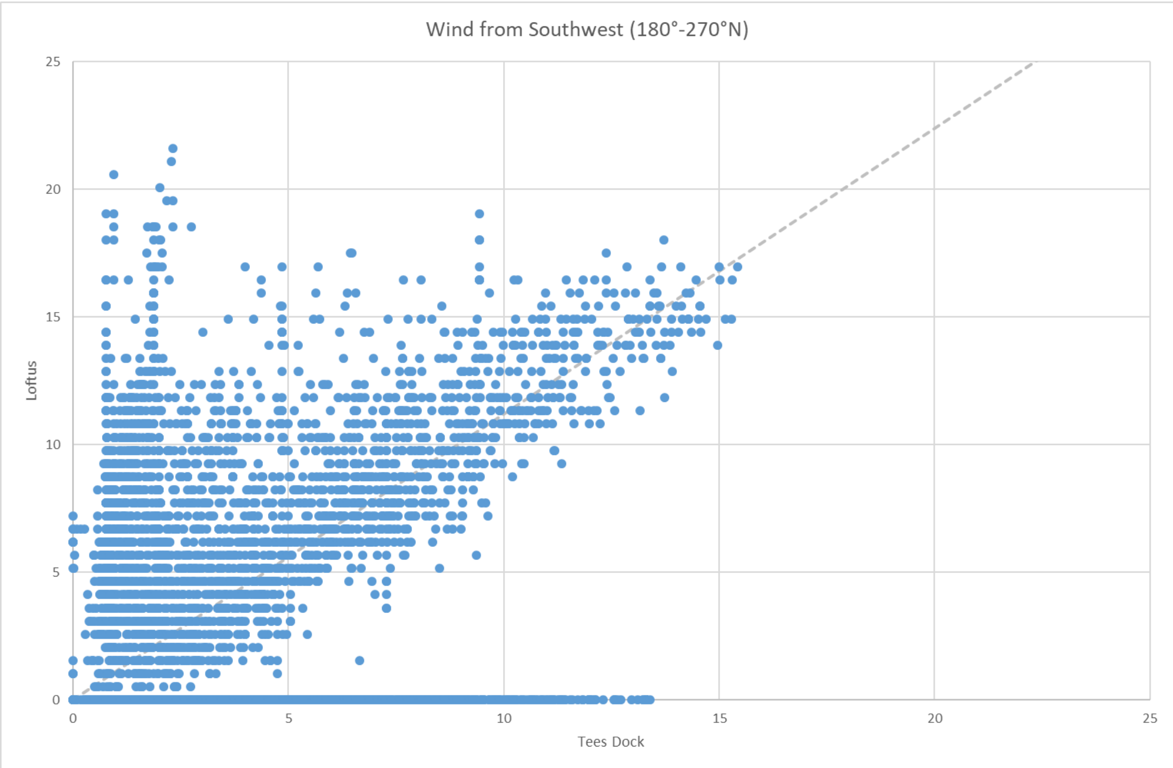

Figure 6.4: Correlation of wind speed between Loftus and Tees Dock for Southwest

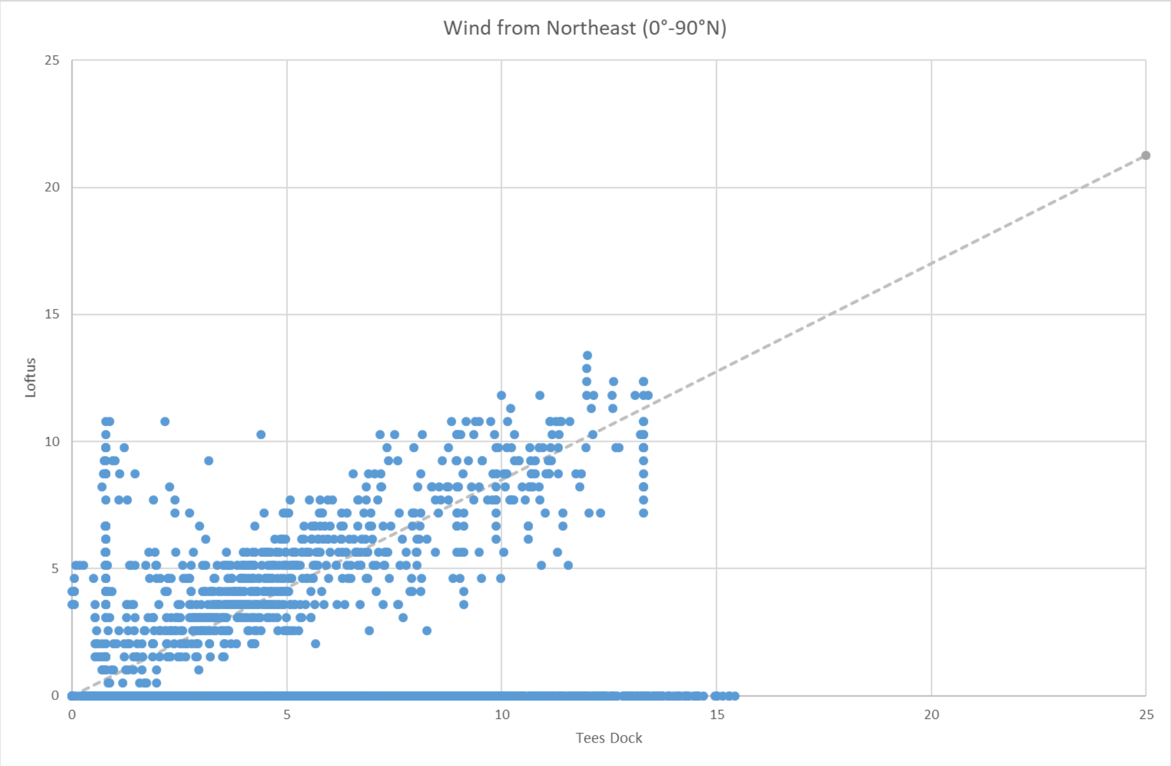

Figure 6.5: Correlation of wind speed between Loftus and Tees Dock for Northeast

6.2 Extreme Wind Conditions

Extreme value analysis has been carried out based on 24-year wind frequency data recorded at Loftus. The wind frequency data is presented in **Table 6-1** and illustrated in a wind rose plot of **Figure 6.6**.

In-house extreme value analysis software, EXTREME, was used. Both Weibull and Gumbel distribution methods were tested and the Gumbel distribution method was chosen as it provides better fitting to the data. The derived extreme wind speeds are presented in **Table 6-2**.

Table 6-1: Wind frequency recorded at Loftus (mean hourly wind speed; all year; 1996 – 2019)

Mean Wind Speed (m/s)	346- 0	16-45	46-75	76-105	106-135	136-165	166-195	196-225	226-255	256-285	286-315	316-345	Total
<0.1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
0.1 - 2.0	0.4	0.3	0.3	0.3	0.7	0.9	1.1	1.3	1	0.5	0.5	0.5	**7.9**
2.1 - 4.0	1.5	1.5	1.3	1.3	1.7	1.7	1.8	3.1	3.5	2	1.5	1.9	**22.7**
4.1 - 6.0	1.2	1.1	1.1	1.6	1.8	1.7	2.5	3.1	3.9	2.8	1.4	1.4	**23.8**
6.1 - 8.0	0.9	0.6	0.6	1	1.2	1.4	2.6	2.8	3.7	2.4	1.2	1	**19.4**
8.1 - 10.0	0.5	0.2	0.3	0.4	0.6	0.7	1.9	1.9	2.8	1.7	0.8	0.7	**12.6**
10.1 - 12.0	0.3	0.1	0.1	0.2	0.2	0.3	1.1	1.1	1.7	1	0.4	0.5	**7**
12.1 - 14.0	0.1	0	0	0.1	0.1	0.1	0.7	0.5	0.9	0.4	0.2	0.3	**3.5**
14.1 - 16.0	0	0	0	0	0	0.1	0.3	0.2	0.4	0.2	0	0.1	**1.4**
16.1 - 18.0	0	0	0	0	0	0	0.1	0.1	0.2	0.1	0	0	**0.5**
18.1 - 20.0	0	0	0	0	0	0	0	0	0.1	0	0	0	**0.2**
20.1 - 22.0	0	0	0	0	0	0	0	0	0	0	0	0	**0.1**
>22.0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**4.9**	**3.9**	**3.9**	**5**	**6.3**	**6.9**	**12.2**	**14.2**	**18.2**	**11**	**6**	**6.4**	**100**

Note: wind speed was measured at 10m above ground.

Table 6-2: Extreme wind speed at Loftus (unit: m/s)

Return Period	0°N	30°N	60°N	90°N	120°N	150°N	180°N	210°N	240°N	270°N	300°N	330°N
1	17.05	16.00	14.81	16.13	15.47	19.57	22.19	22.56	24.23	20.70	18.65	19.52
5	20.48	19.50	17.79	19.22	18.34	23.53	26.02	26.55	28.38	24.34	22.27	23.27
10	21.95	21.01	19.07	20.56	19.57	25.24	27.66	28.27	30.17	25.91	23.82	24.89
20	23.42	22.51	20.35	21.89	20.80	26.94	29.31	29.99	31.96	27.48	25.38	26.51
50	25.37	24.50	22.04	23.65	22.43	29.20	31.49	32.27	34.33	29.55	27.44	28.64
100	26.85	26.01	23.32	24.98	23.67	30.90	33.14	33.99	36.12	31.12	29.00	30.26
200	28.32	27.51	24.60	26.31	24.90	32.61	34.78	35.71	37.91	32.68	30.55	31.88
1,000	31.74	31.01	27.57	29.40	27.77	36.57	38.61	39.70	42.06	36.32	34.17	35.63

Note: extreme wind speeds are based on mean hourly data at 10m above ground

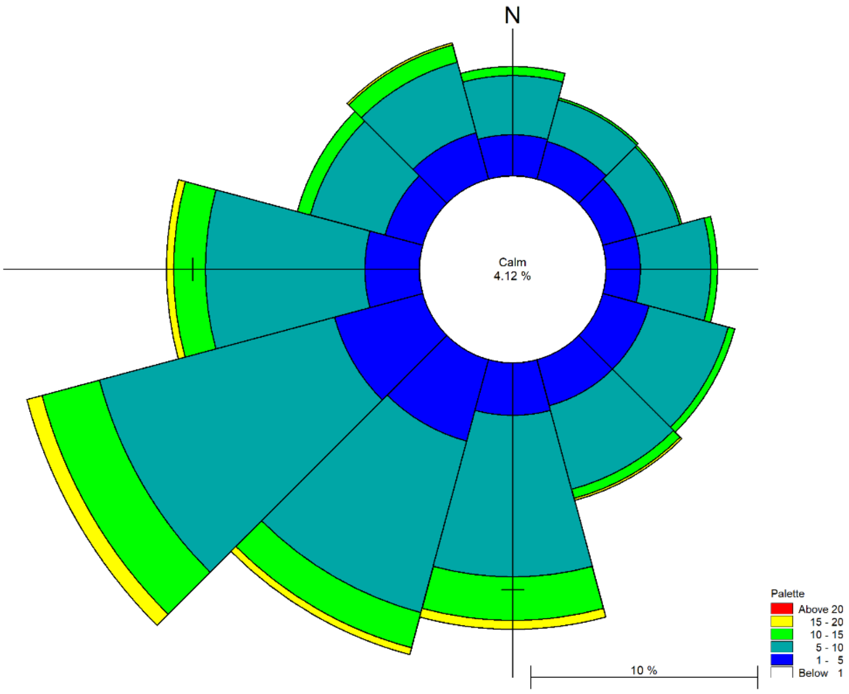

Figure 6.6: wind rose based on recorded data at Loftus (1996 – 2019)

6.3 Model Setup

A MIKE21-SW spectral wave model has been setup using the same geographical extent as the MIKE3-HD model. The model extent and bathymetry are shown in **Figure 6.7**. The MIKE21-SW model mesh was build using flexible mesh (for full details refer to Section 2.4). In summary the greater the detail of the mesh the more precise the calculations, but the longer the processing time that is needed for each simulation. Hence areas furthest offshore have the coarsest mesh whilst areas closest to the study area have the finest, most detailed mesh. The different mesh resolutions are shown in **Figure 6.8**.

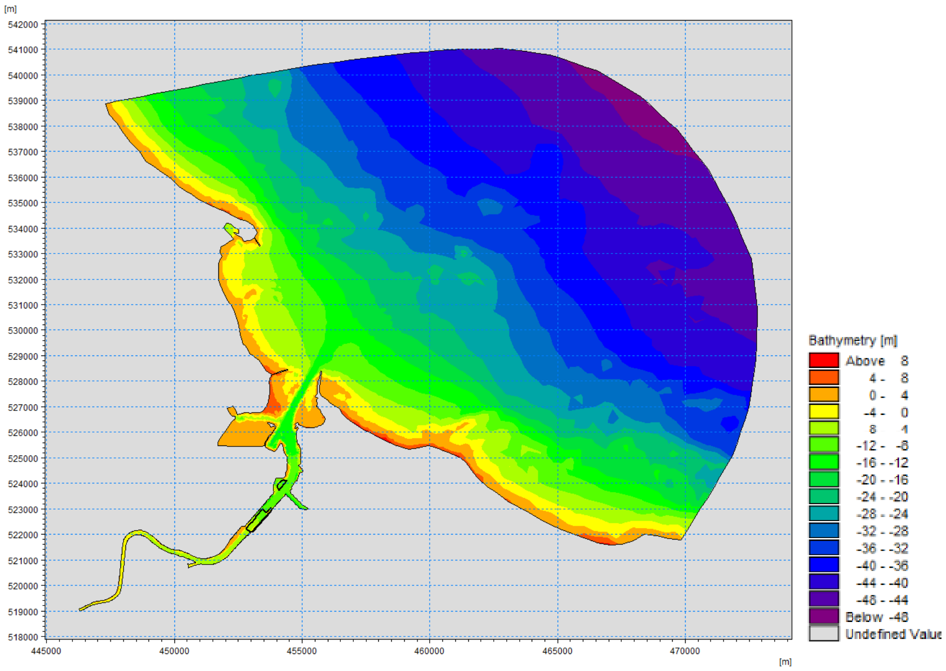

Figure 6.7: MIKE21-SW Model extent and bathymetry (Study area shown in black)

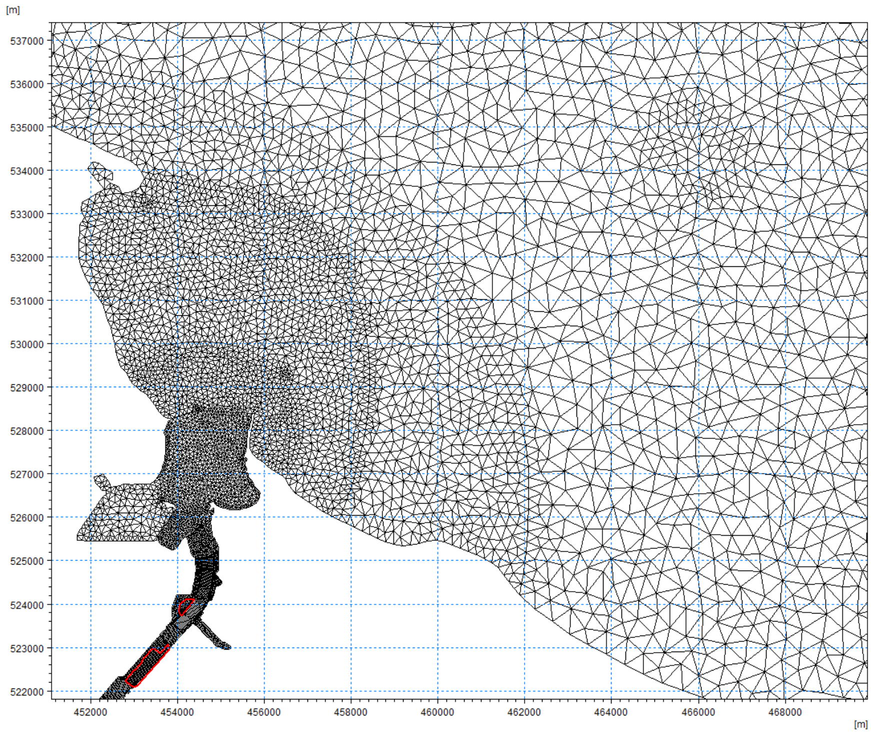

Figure 6.8: MIKE21-SW Model mesh (Study area shown in red)

MIKE21-SW is a new generation spectral wind-wave model based on unstructured meshes. The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. For this wave model, the Directional Decoupled Parametric Formulation was chosen together with SPM73 Wind Generation Formula. Adopted model settings are listed in **Table 6-3** below.

Table 6-3: MIKE21-SW Model Settings

Description	Adopted Settings
Basic Equations	Spectral formulation: Directionally decoupled parametric formulation Time formulation: Quasi stationary formulation
Spectral Discretization	Discretization type: 360 degree rose Number of directions: 36
Wind Forcing	Wind generating formula: SPM73
Bottom Friction	Model: Nikuradse roughness, kn Constant value: 0.04m

The following simulations have been undertaken for two types of waves: a) Swell waves and b) Locally generated waves.

For the swell wave simulations, swell wave conditions were obtained from the 2018 Environment Agency's dataset, i.e. the Coastal Flood Boundary Conditions (CFB). The Environment Agency's CFB study provides offshore wave conditions around the UK coast. The output point gl1674 was chosen as the closest to the South Bank Wharf study area and is shown in **Figure 6.9**.

The swell wave simulations have been undertaken for the return period of 1 in 100 year with and without confidence height. The water level of the Highest Astronomical Tide (HAT) has been chosen for the simulations. **Table 6-4** lists the model runs undertaken for swell waves from North Sea.

Table 6-4: MIKE21-SW model simulations for extreme swell waves from North Sea (offshore wave conditions and water levels)

Return Period	Wave Height (Hs)	Wave Period (Tz)	Wave Direction (deg)	Water Level (mCD)
100	4.13	12.00	North	HAT: 6.05
100	4.33*	12.00	North	HAT: 6.05

* Includes confidence height of +0.2m

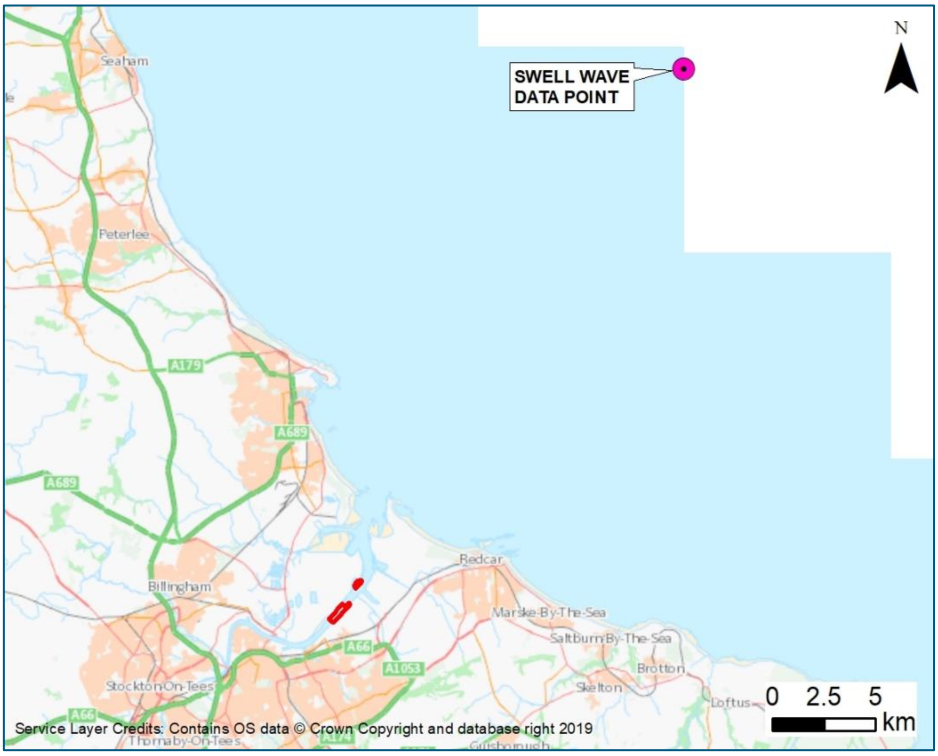

Figure 6.9: Location of Environment Agency's CFB swell wave data point

For the locally generated wave, the extreme wind speeds have been derived based on the wind data analysis discussed in Section 6.1. The water level of the Highest Astronomical Tide (HAT) has been chosen for the simulations.

Table 6-5 lists the model input data for locally generated waves.

Table 6-5: MIKE21-SW model simulations for local generated waves under extreme wind

	Wind Speed* (m/s)			Water Level (mCD)
Return Period	**0°N**	**30°N**	**210°N**	
1	20.12	18.88	20.08	HAT: 6.05
100	31.68	30.69	30.25	HAT: 6.05

Note: the wind speed factors were applied for using wind data recorded at Loftus at Tees Dock described in Section 6.1.

6.4 Wave Model Results

This section presents the wave model results of the two sets of simulations for a) swell waves from North Sea, and b) locally generated waves.

6.4.1 Swell Waves

Figure 6.10 and **Figure 6.11** show the propagation of the swell waves (1 in 100 year from North) into the Tees Estuary and the study area respectively.

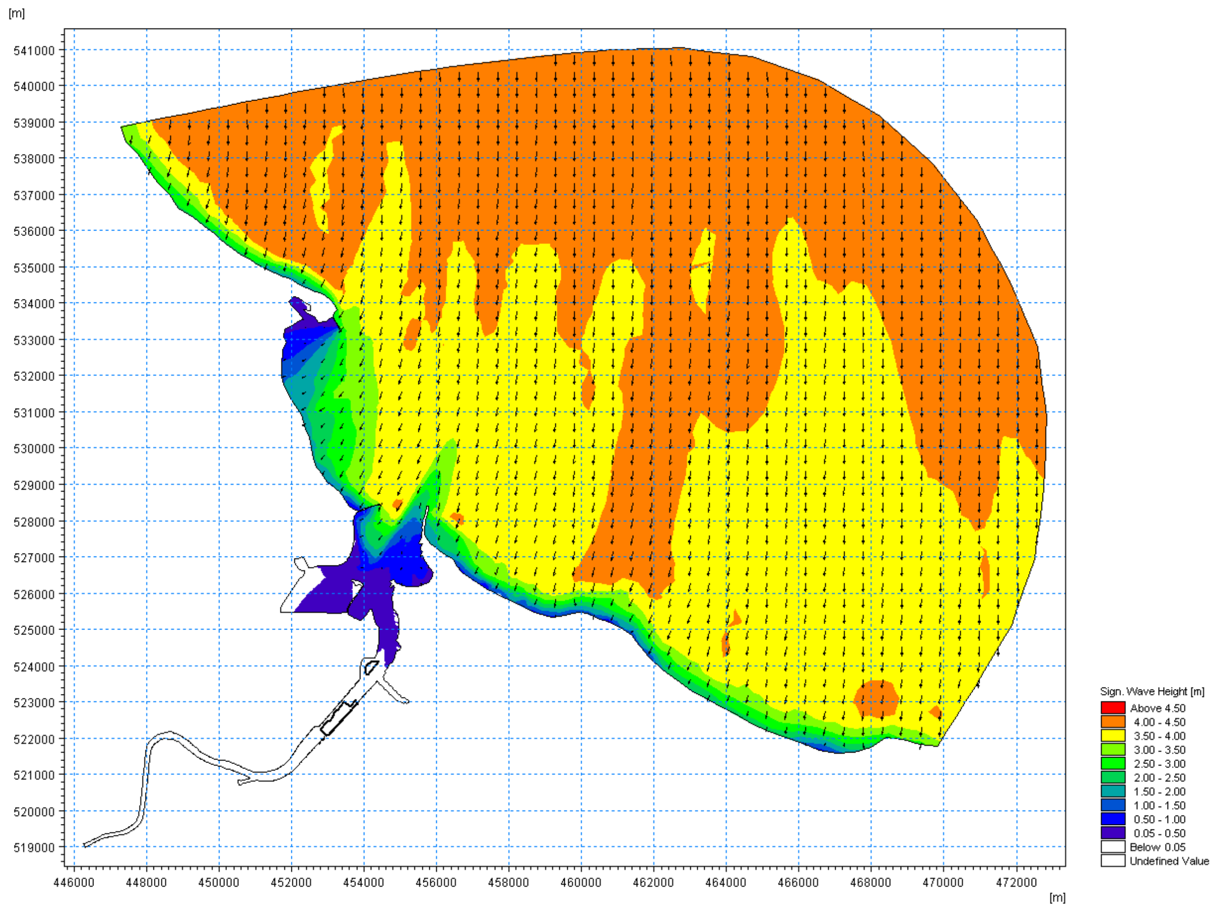

Figure 6.10: Swell Waves for 1 in 100 year return period coming from North (Tees Bay)

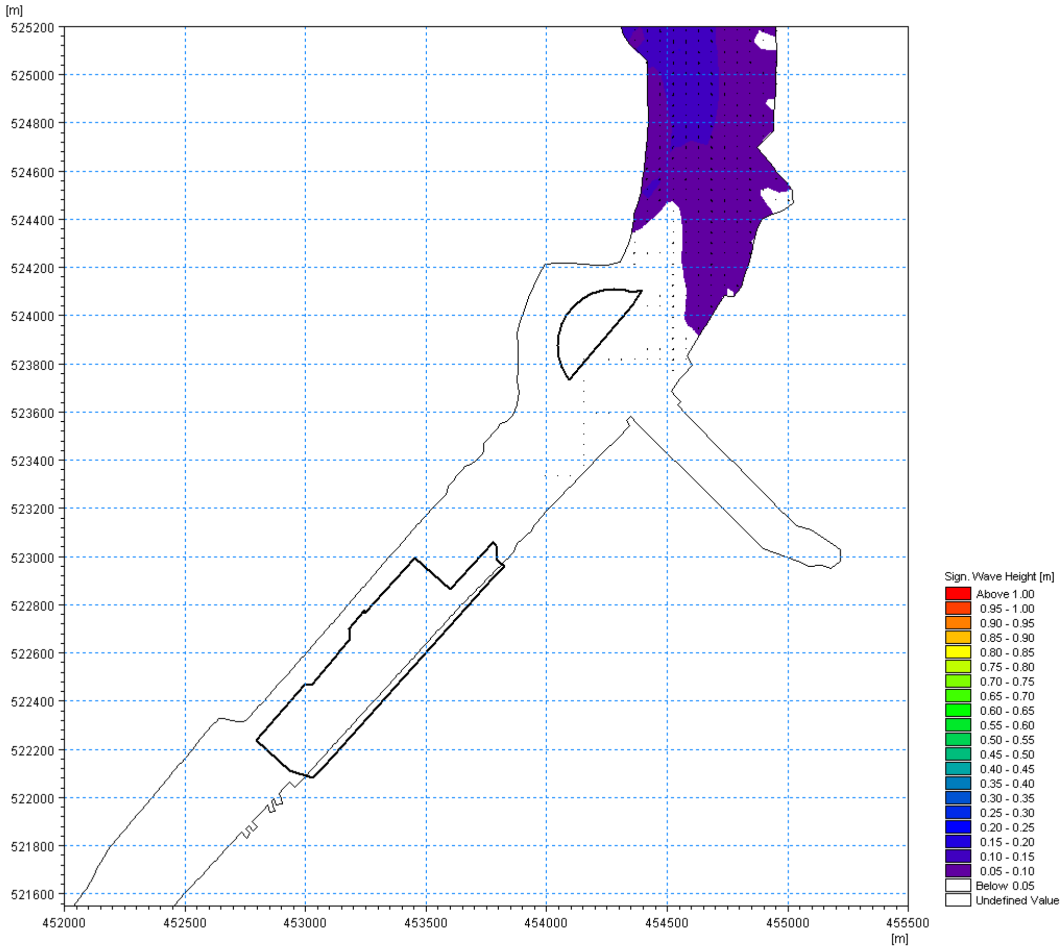

Figure 6.11: Swell Waves for 1 in 100 year return period coming from North (Study Area)

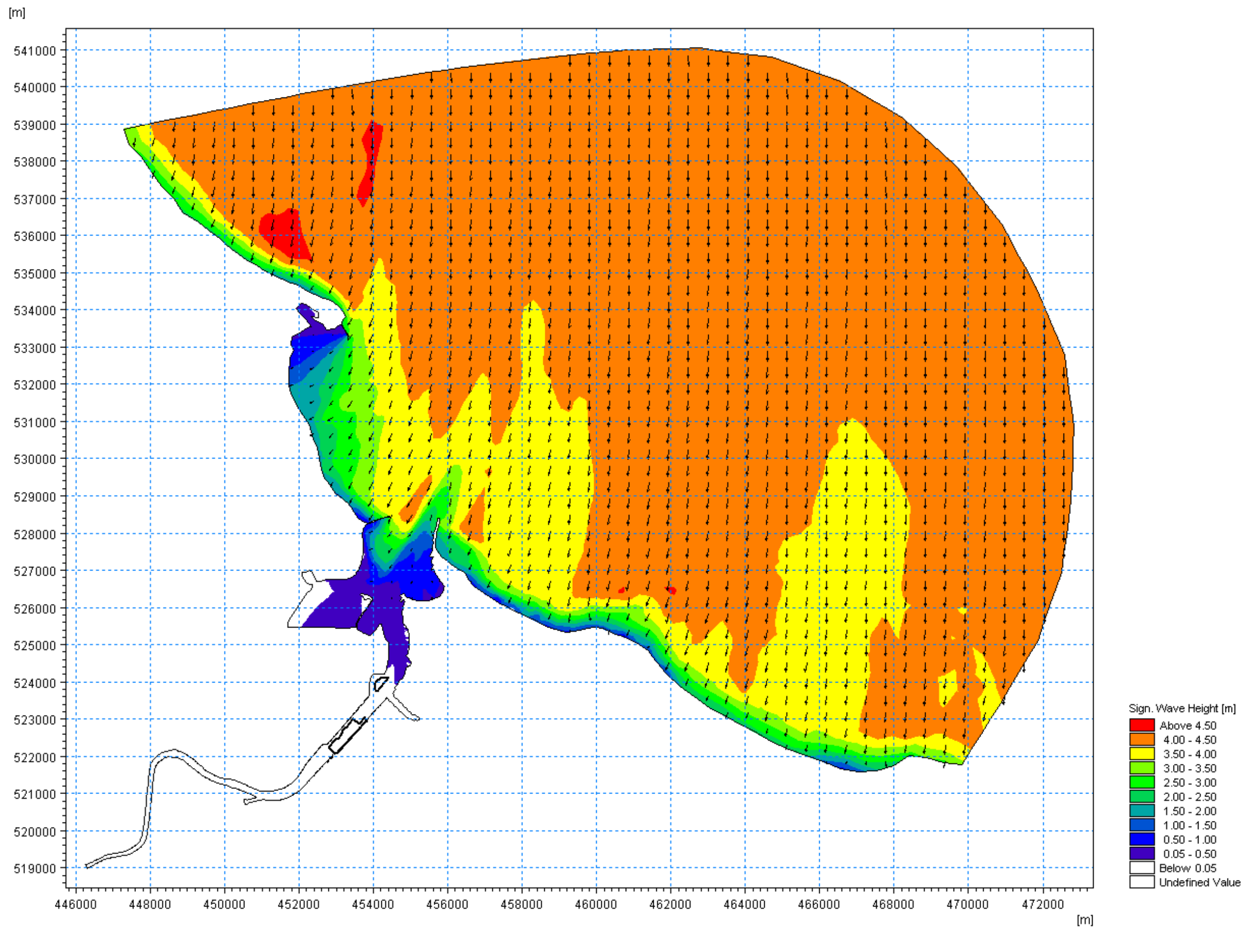

Figure 6.12: Swell Waves for 1 in 100 year return period coming from North with confidence height (Tees Bay)

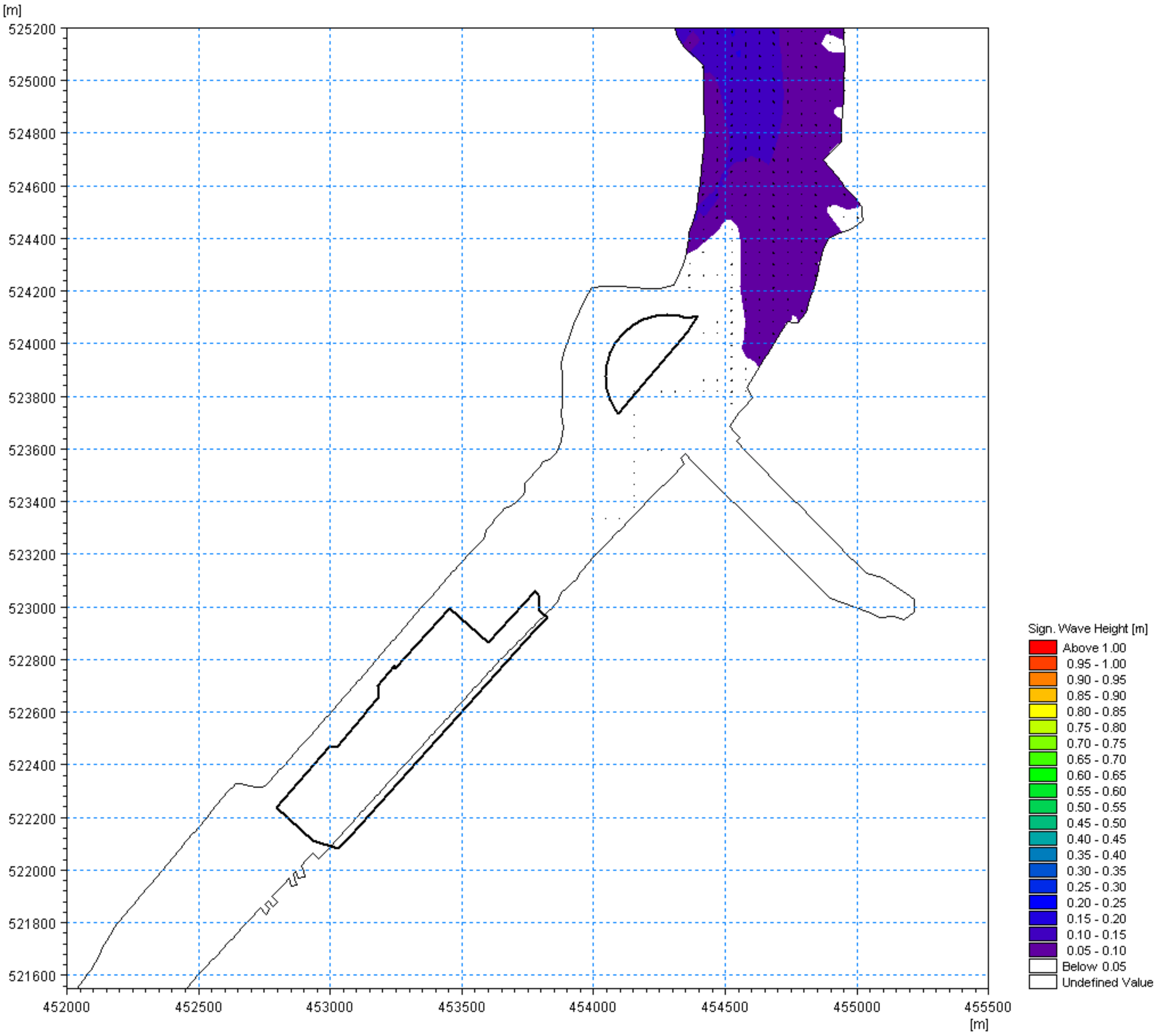

Figure 6.13: Swell Waves for 1 in 100 year return period coming from North with confidence height (Study Area)

6.4.2 Locally generated Waves under extreme wind

Figure 6.14 to **Figure 6.25** show the locally generated waves for 1 in 1 year and 1 in 100 year return periods with wind coming from North (0°N), North-North-East (30°N) and South-South-West (210°N) for the River Tees and the study area respectively.

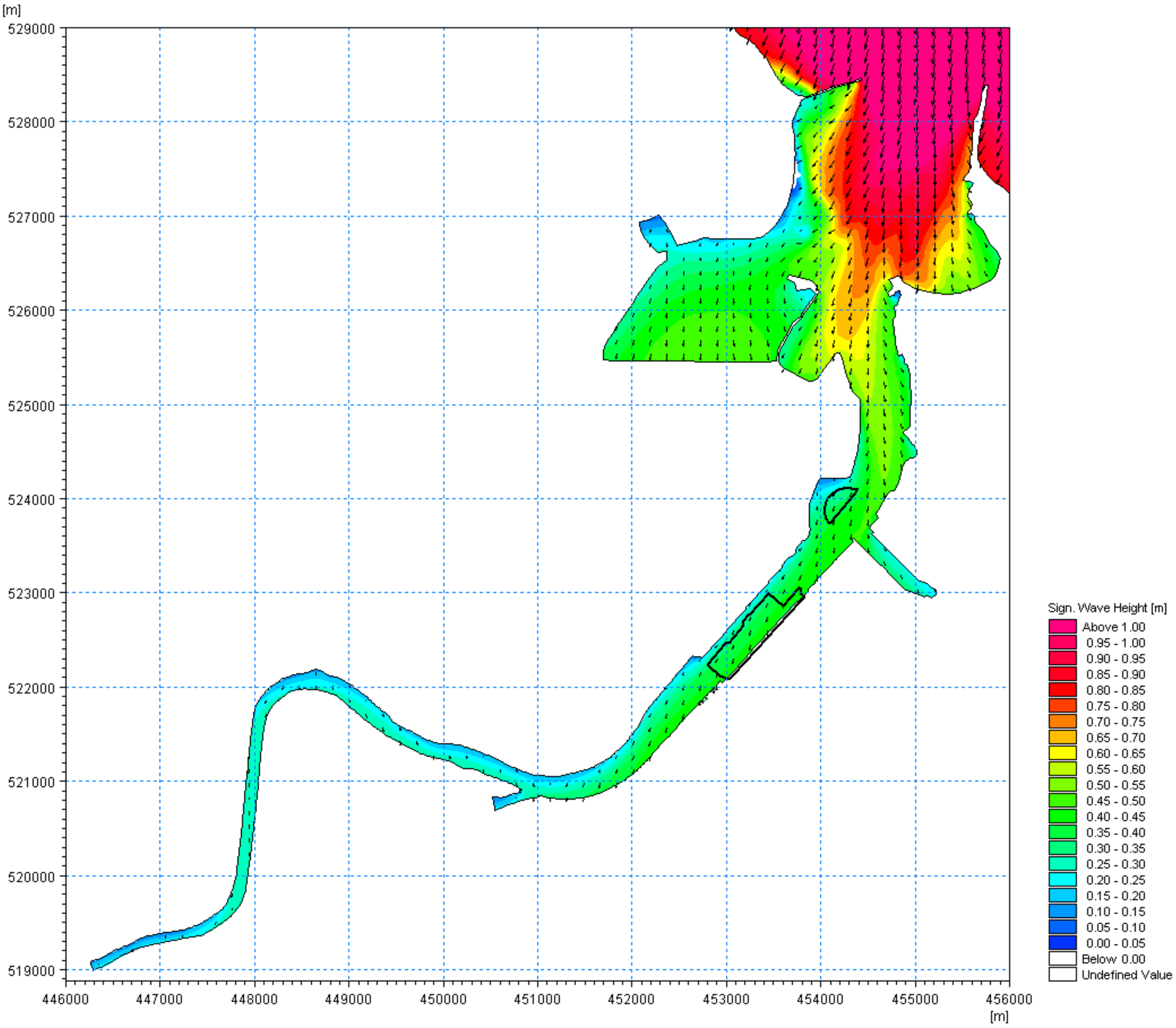

Figure 6.14: Locally generated waves for 1 in 1 year return period coming from North (0 deg N) (River Tees)

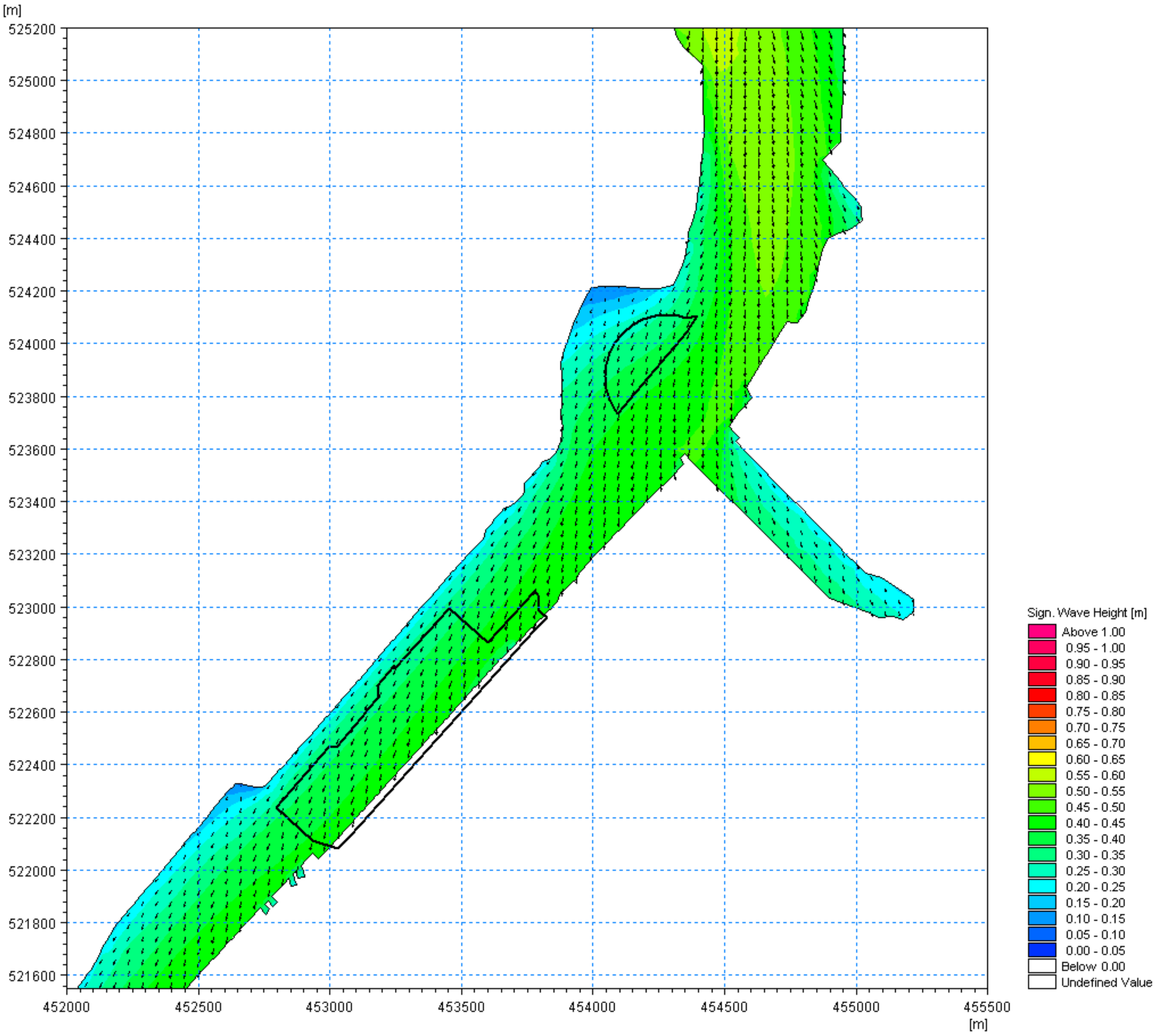

Figure 6.15: Locally generated waves for 1 in 1 year return period coming from North (0 deg N)) (Study Area)

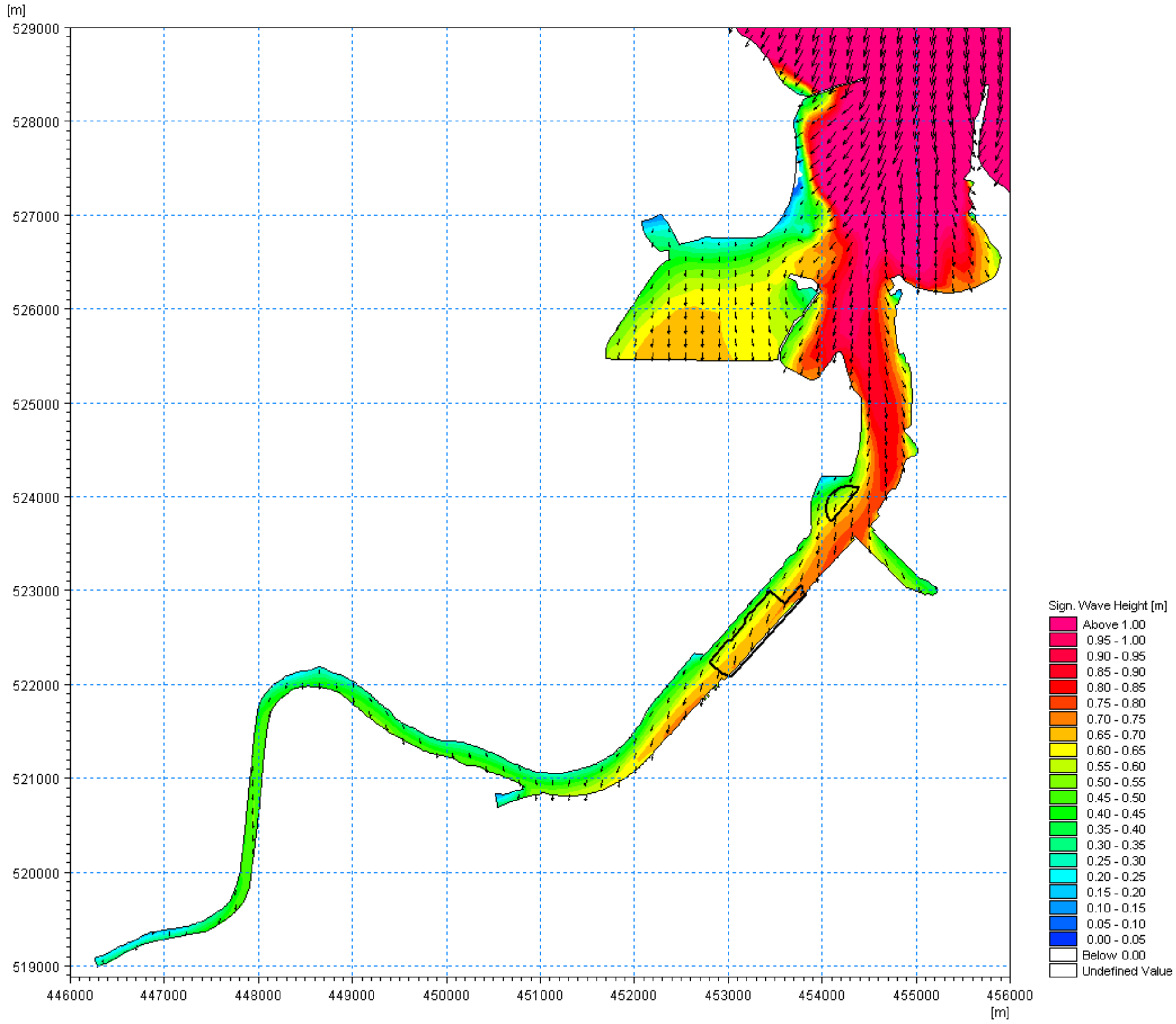

Figure 6.16: Locally generated waves for 1 in 100 year return period coming from North (0 deg N) (River Tees)

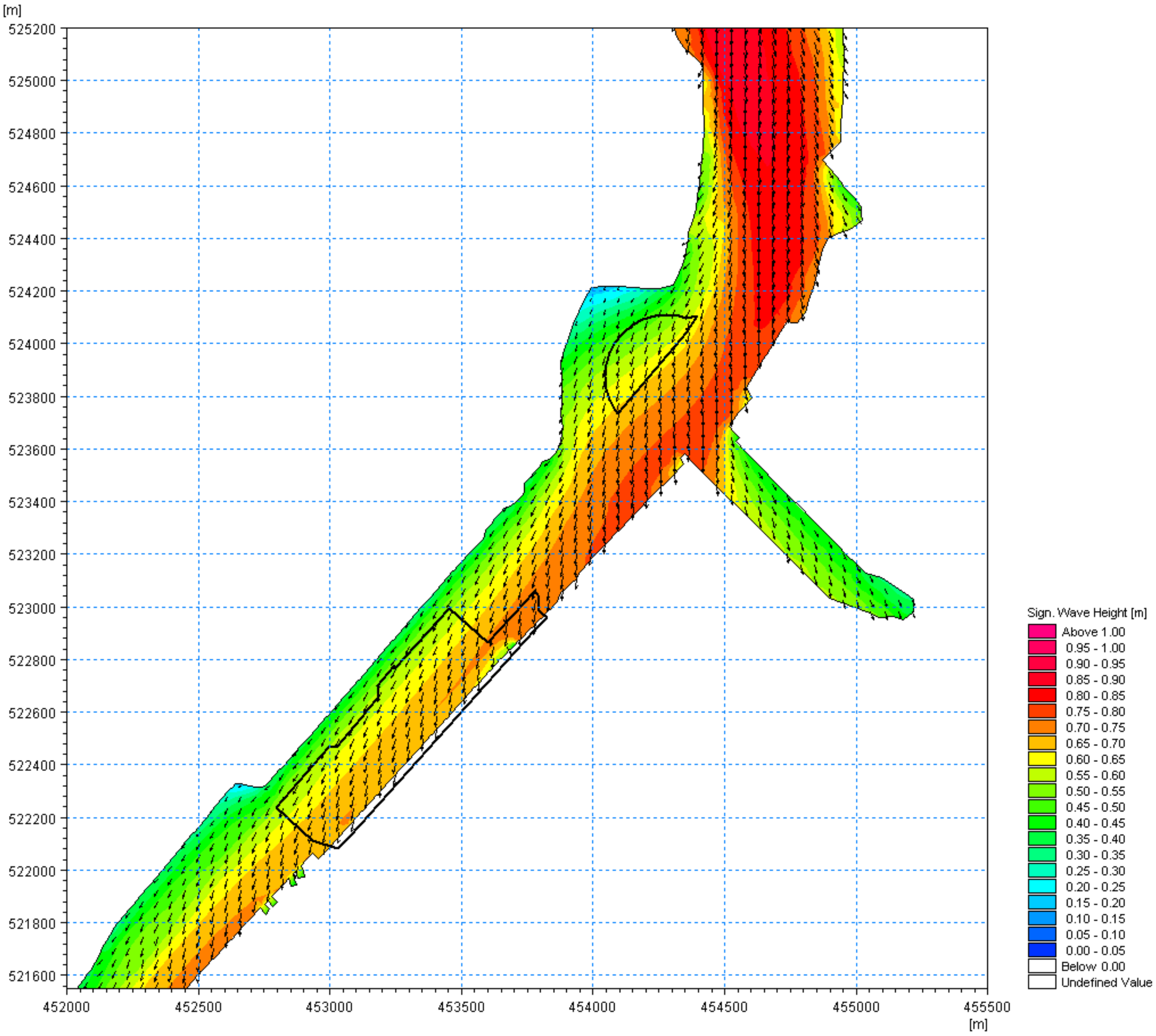

Figure 6.17: Locally generated waves for 1 in 100 year return period coming from North (0 deg N) (Study Area)

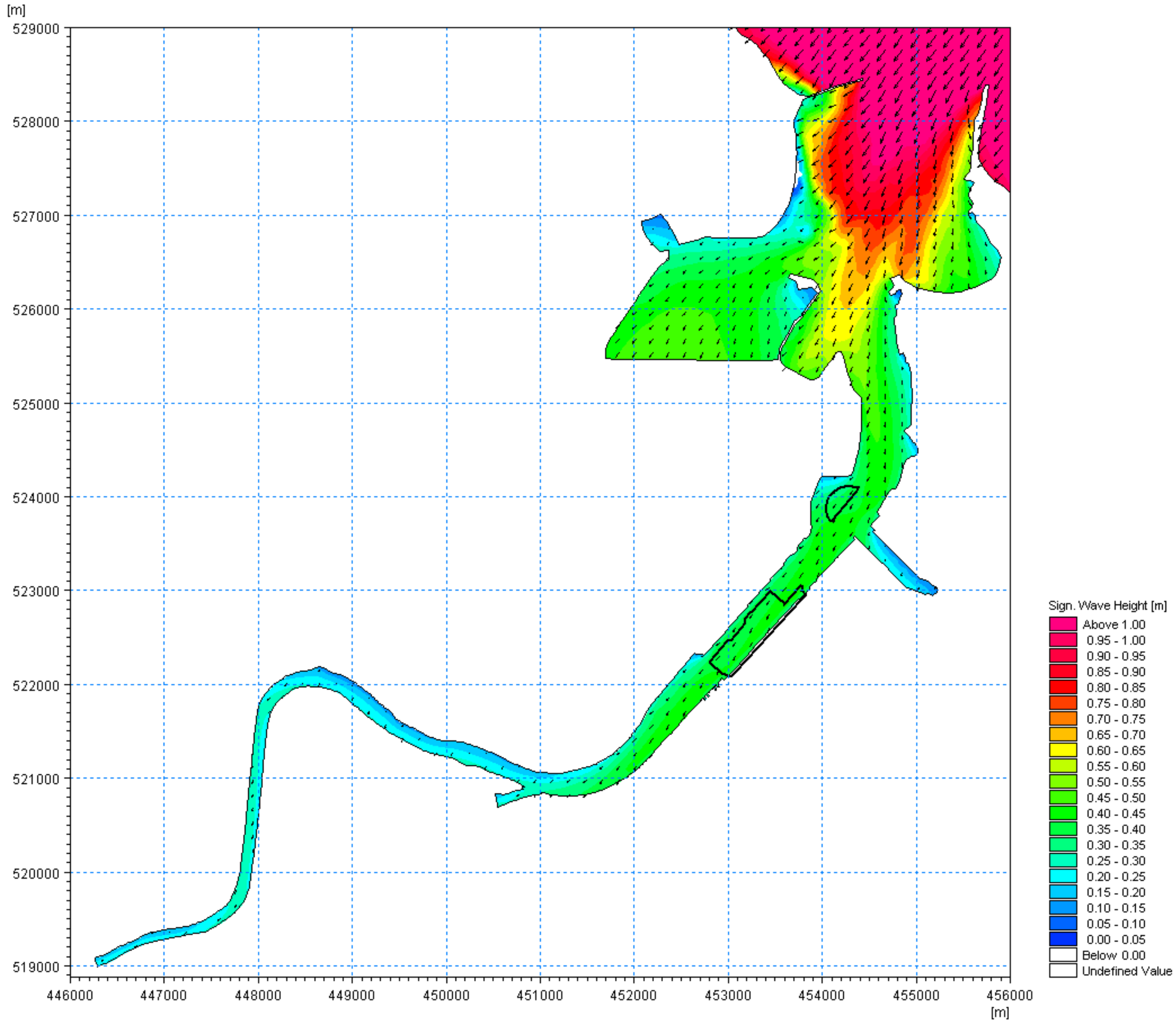

Figure 6.18: Locally generated waves for 1 in 1 year return period coming from North-North-East (30 deg N) (River Tees)

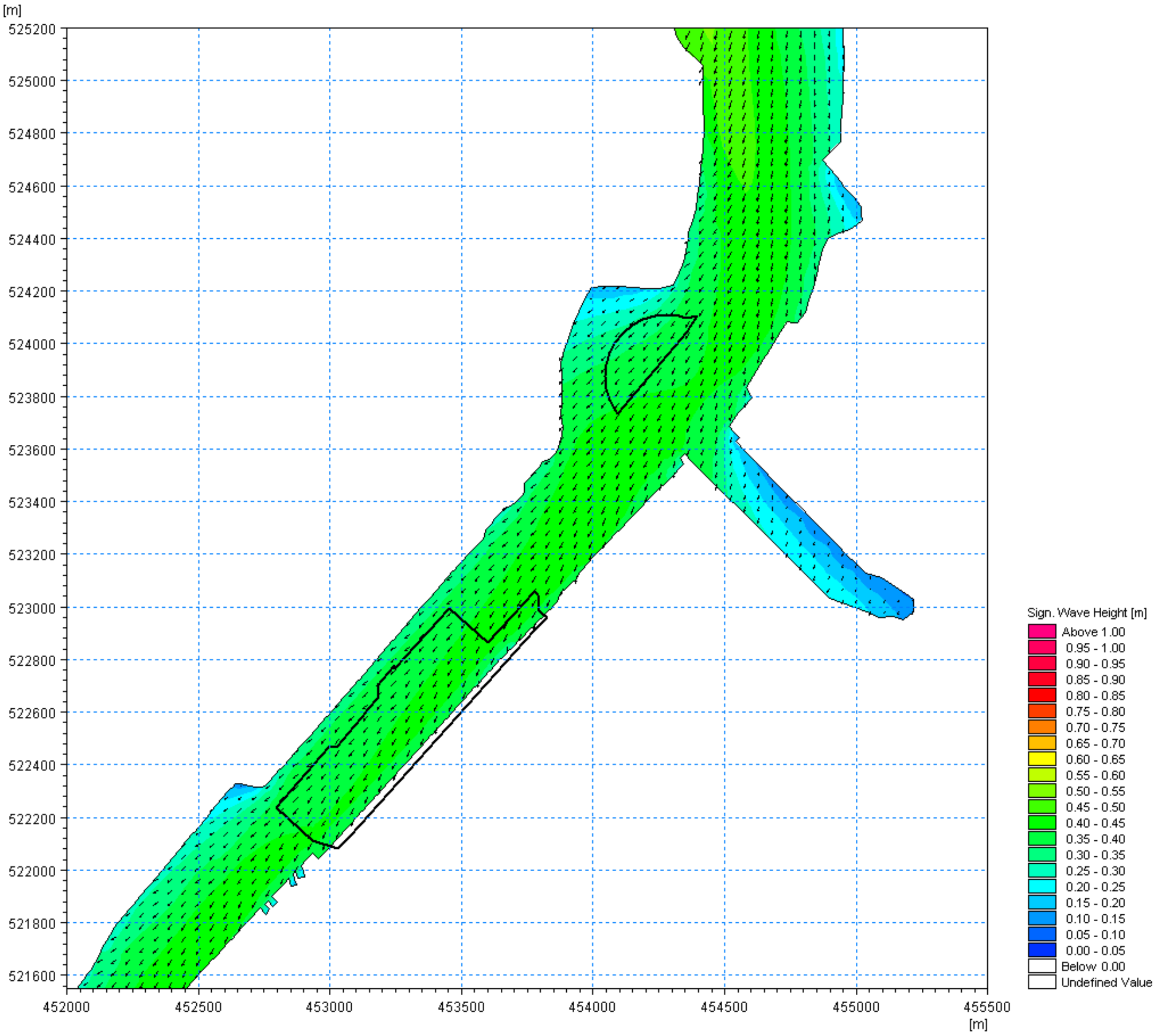

Figure 6.19: Locally generated waves for 1 in 1 year return period coming from North-North-East (30 deg N) (Study Area)

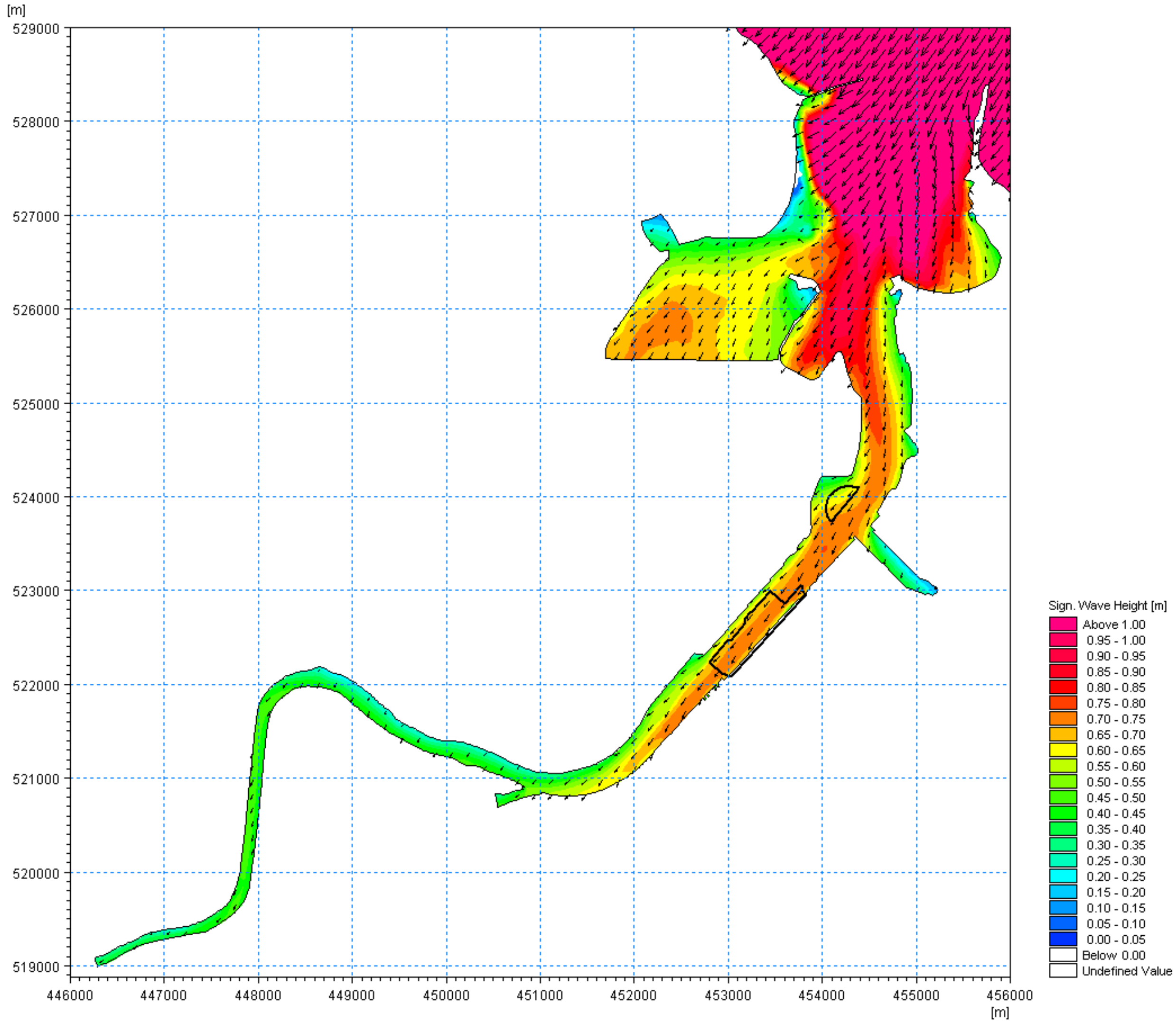

Figure 6.20: Locally generated waves for 1 in 100 year return period coming from North-North-East (30 deg N) (River Tees)

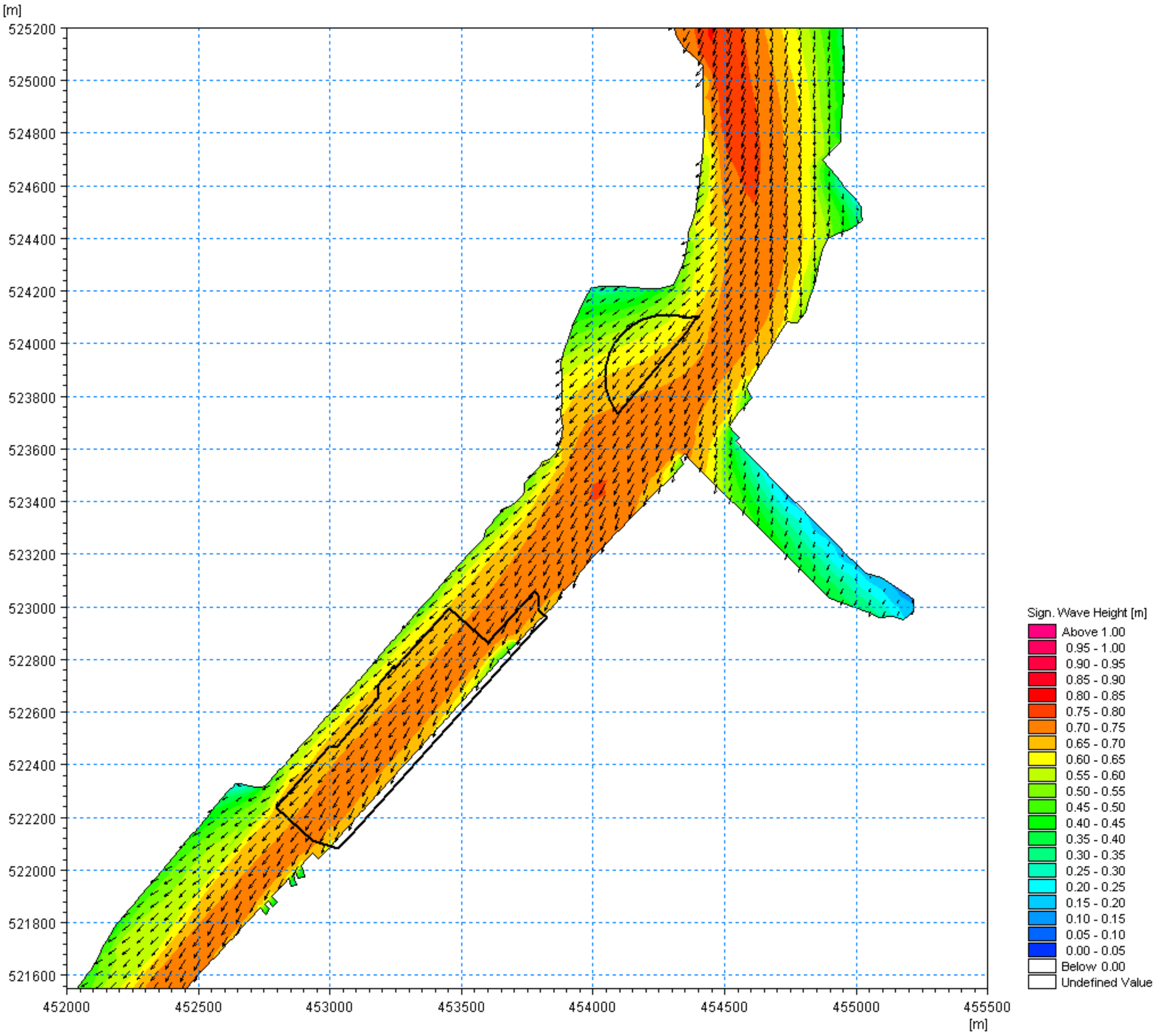

Figure 6.21: Locally generated waves for 1 in 100 year return period coming from North-North-East (30 deg N) (Study Area)

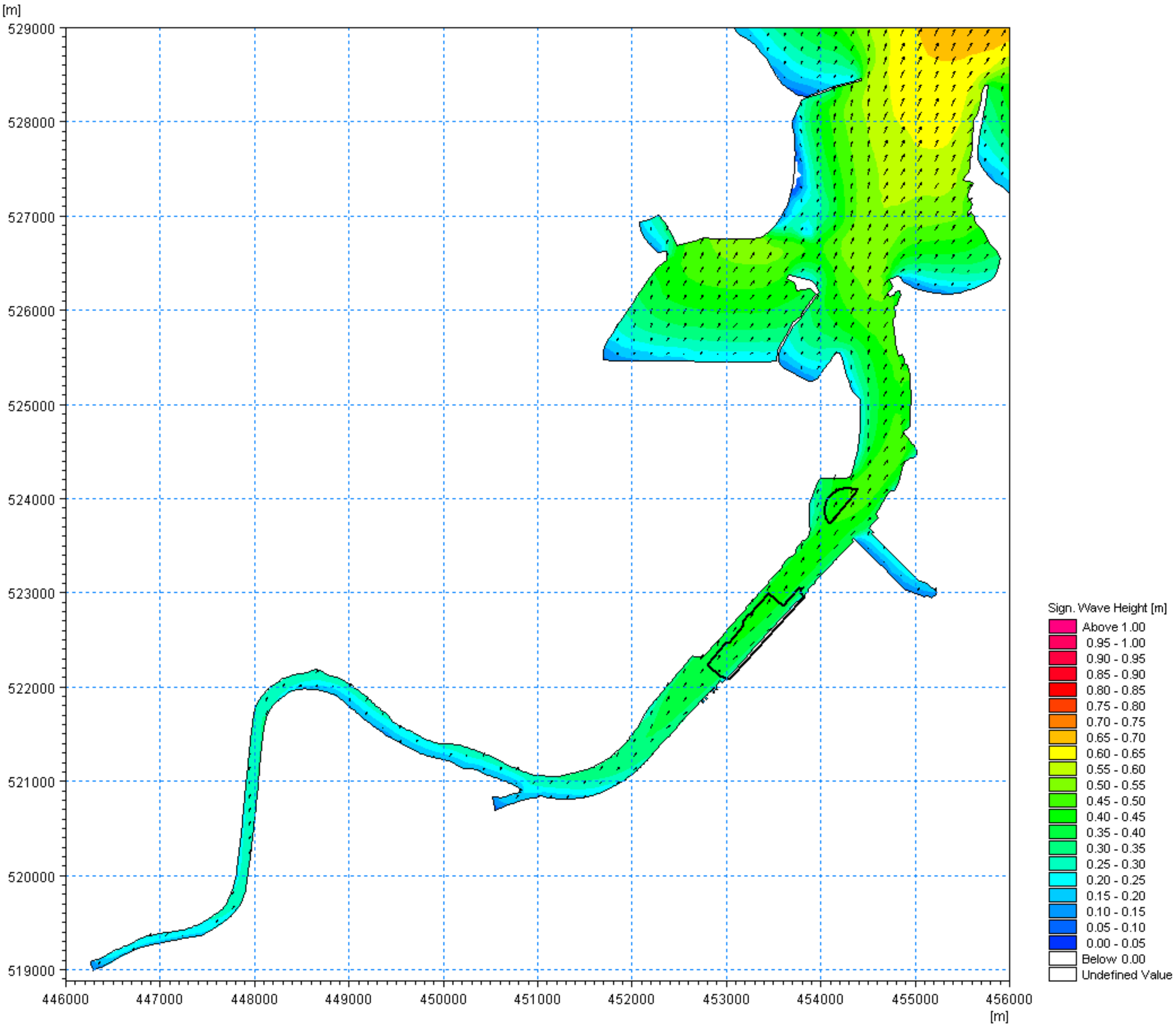

Figure 6.22: Locally generated waves for 1 in 1 year return period coming from South-South-West (210 deg N) (River Tees)

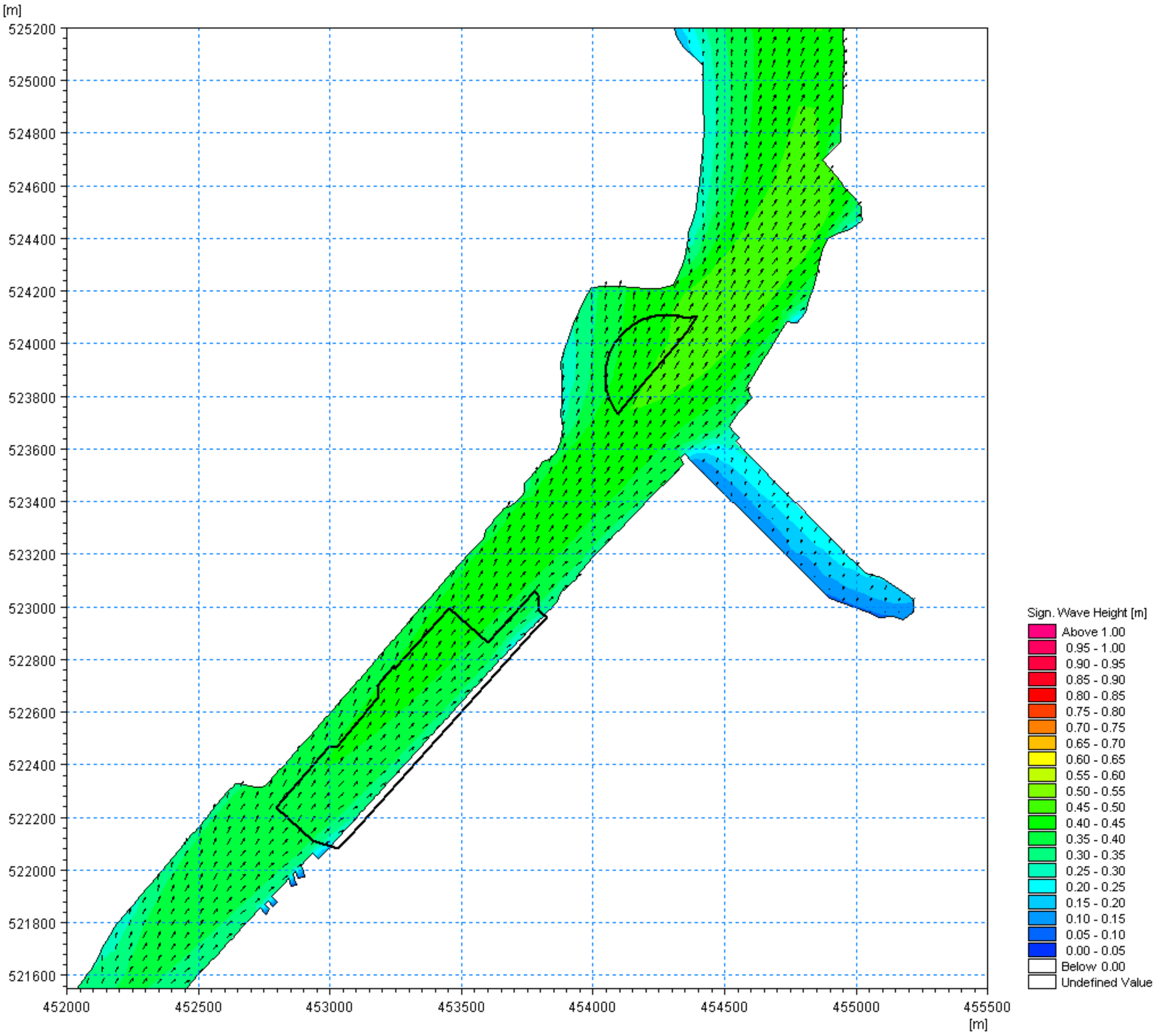

Figure 6.23: Locally generated waves for 1 in 1 year return period coming from South-South-West (210 deg N) (Study Area)

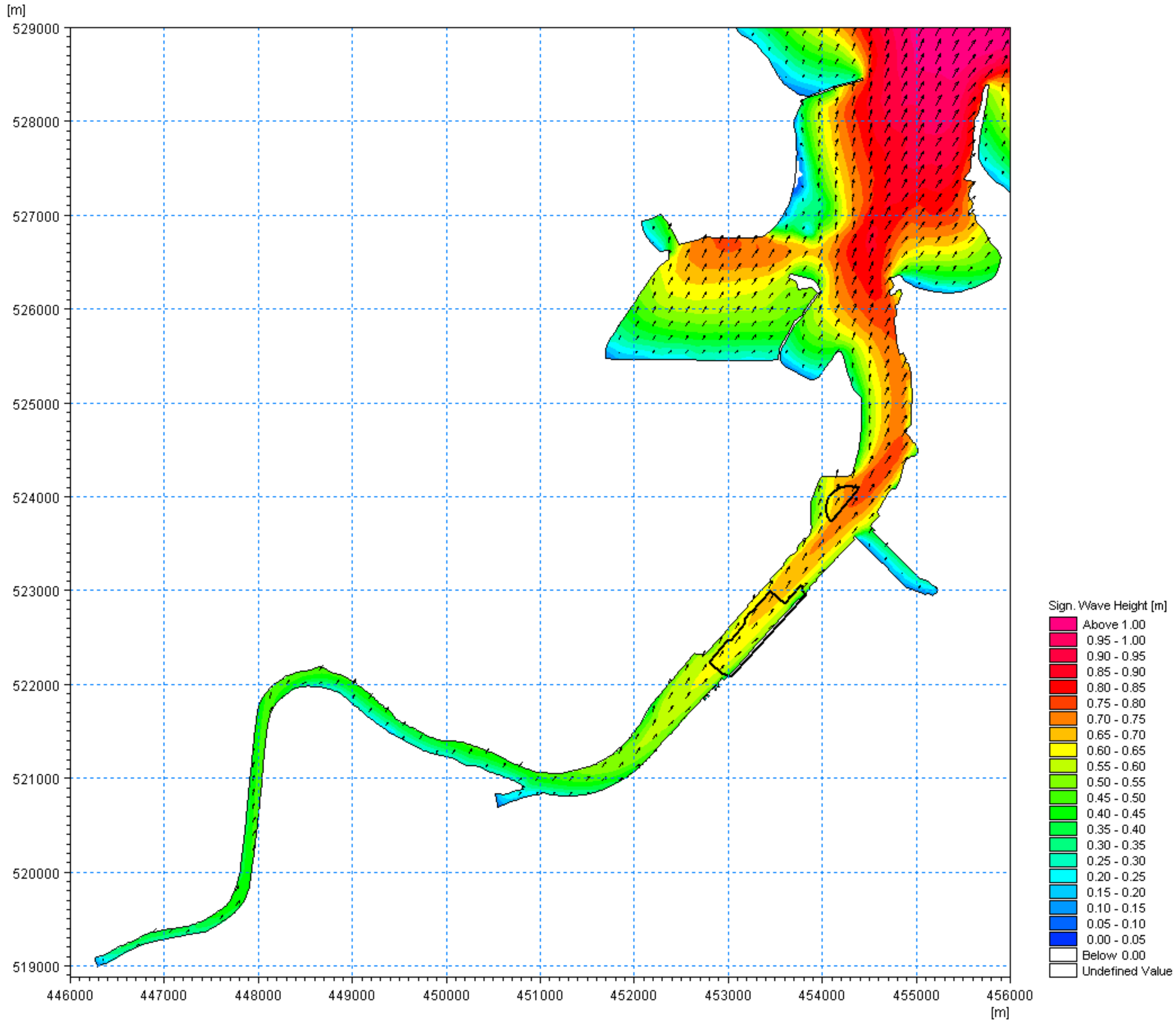

Figure 6.24: Locally generated waves for 1 in 100 year return period coming from South-South-West (210 deg N) (River Tees)

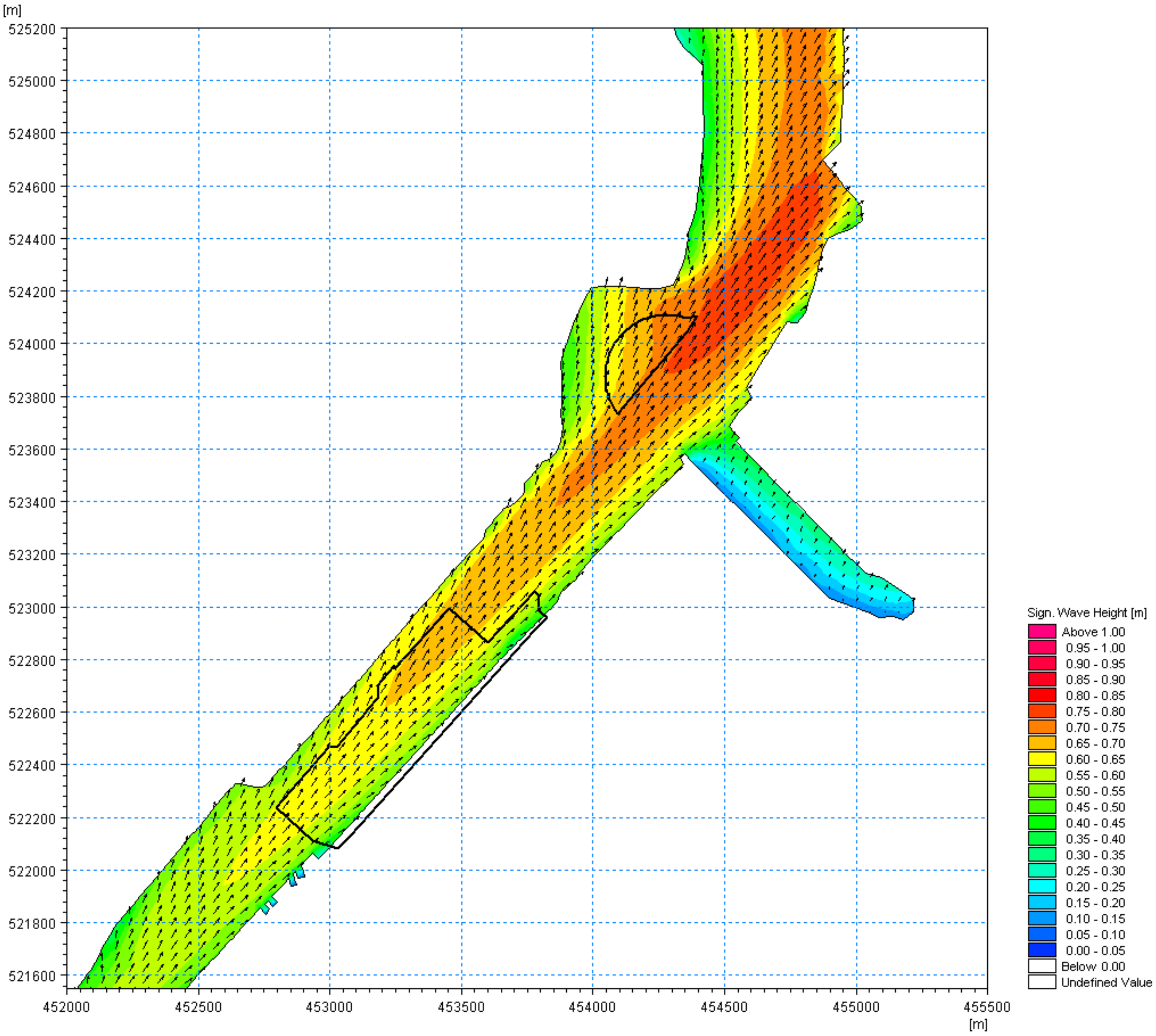

Figure 6.25: Locally generated waves for 1 in 100 year return period coming from South-South-West (210 deg N) (Study Area)

6.5 Conclusions

The wave model results show that the South Bank Wharf site is well sheltered from North Sea waves because swell waves can hardly reach the site. The swell waves that reach the area just downstream of Tees Dock and the Tees Turning Area reach at magnitude of about 0.05m to 0.1m. The swell waves of any significance only reach up to the estuary mouth.

The wave model results also show that locally generated waves under extreme wind are of more significance at the South Bank Wharf site. The wind waves can reach a height of 0.3m to 0.4m for a 1 in 1 year return period and 0.5m to 0.7m for a 1 in 100 year return period.