The London Resort Development Consent Order

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Environmental Statement
Volume 2: Appendices

Appendix 17.4 – Hydrodynamic and Sedimentation Assessment

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Planning Act 2008
The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009
Regulation 5(2)(a)
The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017
Regulation 12(1)

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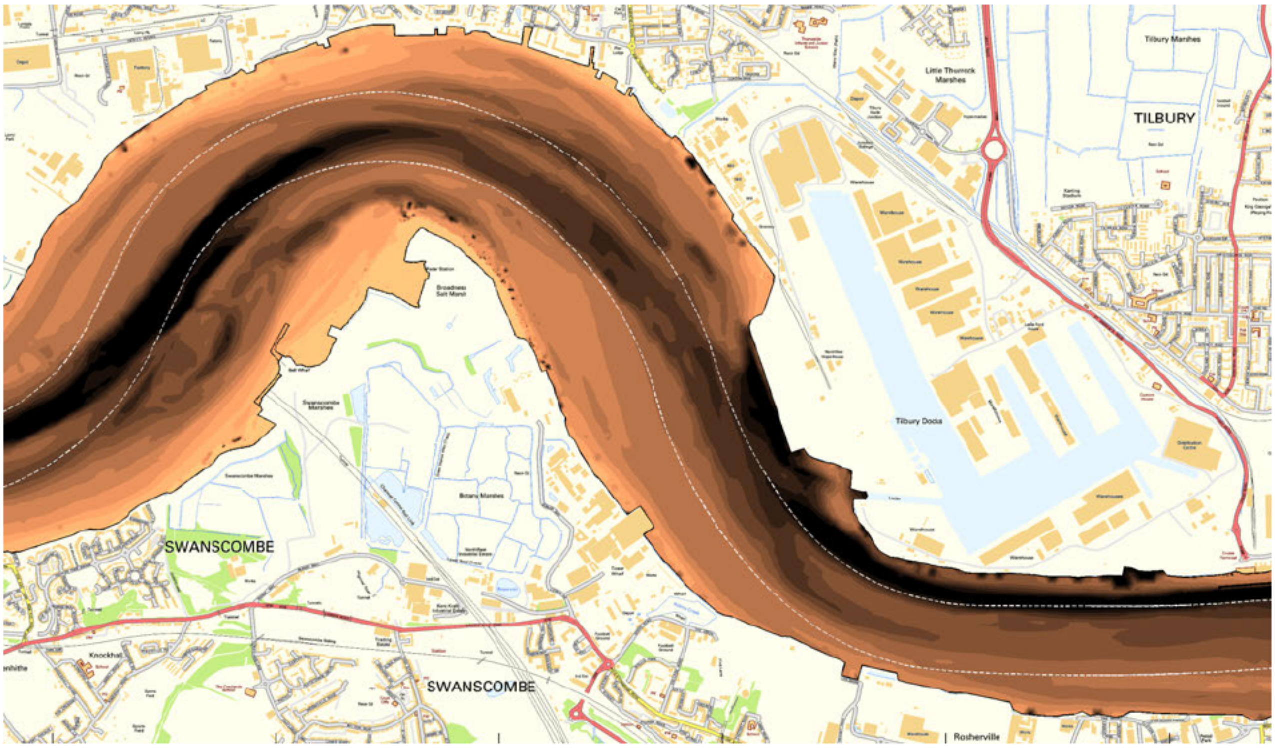
The London Resort

Hydrodynamic and sedimentation assessment



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Project director	Tom Matthewson

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Summary

The London Resort is located on the Swanscombe Peninsula in North Kent in the Thames Estuary. Visitor access to the site is proposed from the River Thames and marine facilities are proposed at the site and at Tilbury to allow a ferry to operate to and from the resort. HR Wallingford has been commissioned to assess of the hydrodynamic and sedimentation impacts of the proposals – with implications for coastal processes, intertidal morphology, navigation, marine ecology and fish passage.

An options study has been completed by Buro Happold to look at river access to the site. The options considered have included refurbishment of Bell Wharf with or without navigational dredging or a floating RO-RO facility extending from Bell Wharf. A pontoon to allow mooring of Thames Clipper types vessels is also proposed for all options. Additionally some setting back of the riverbank line in the northern and eastern sections of the site is proposed to allow the creation of new intertidal habitat to compensate for the intertidal potentially impacted by the development.

This report assesses the predicted impacts of the proposed works at Tilbury, the habitat creation and the three options for the passenger access at Bell Wharf on the hydrodynamic and sedimentation regimes of the tidal Thames.

Hydrodynamics

Of the proposed options for the Swanscombe ferry terminal site, Option C including a dredged area has the largest hydrodynamic effect although it should be noted at none of the options have any effect beyond the immediate vicinity of the structures. The greatest footprint of change is shown as 700 m (Option C).

The habitat creation areas being relatively high in the tidal frame do not include much tidal volume so any effect of the flow passing in and out of the area is small. Some flow speed increases are shown at the openings themselves and some areas of speed reduction can occur on the foreshore adjacent to the habitat areas. The pattern of change is similar for all options considered.

At Tilbury, the proposed pontoons act to impede the flow and reduce currents to either side of the structure. The effect is localized to be within 600 m of the proposed pontoons during the flood tide and within 200 m during the ebb.

The predicted minor effects of the development on tidal currents means that any effect on tidal propagation or maximum water levels will be negligible.

Sedimentation

The very limited impacts predicted for the hydrodynamics are carried forward into the prediction of effects on sediment transport and erosion/deposition. No discernible effect is seen on suspended sediment concentration for all the options studied. At Swanscombe the various structures result in a potential change to the distribution of sediments increasing the proportion of the 5 mm size in a small area NE of White's Jetty.

A coarsening of the bed sediment under the passenger pontoon should be expected.

If the dredging associated with Option C is take forward an annual infill rate of up to 29,700 m^3 per year is predicted. This is a precautionary total as the rate will reduce as the dredged area fills and vessel effects will also resuspend settled fine sediment.

No effects on the erosion or deposition patterns are seen on the intertidal areas near the Swanscombe site although in the medium term some effect of the flow in and out of the habitat creation areas is likely, creating small drainage channels.

The four habitat areas on the east of the peninsula are more successful in receiving fine sediment than the two on the west. This suggests the eastern sites will be quicker to provide functioning intertidal habitat although noting their height in the tidal frame means this process may still take some time.

At the Tilbury site only limited effects on erosion and deposition and bed substrate are predicted and these are in the immediate area of the proposed pontoon and the existing landing stage. No changes to the pattern of erosion and deposition are predicted on the intertidal areas to the north of the pontoon site.

Contents

Figures

Tables

1. Introduction

The London Resort is located on the Swanscombe Peninsula in North Kent in the Thames Estuary (see Figure 1.1:). Visitor access to the site is proposed from the River Thames and marine facilities are proposed at the site and at Tilbury to allow a ferry to operate to and from the resort. HR Wallingford has been commissioned to assess of the hydrodynamic and sedimentation impacts of the proposals – with implications for coastal processes, intertidal morphology, navigation, marine ecology and fish passage.

An options study has been completed by Buro Happold to look at river access to the site. The options considered have included refurbishment of Bell Wharf with or without navigational dredging or a floating RO-RO facility extending from Bell Wharf. A pontoon to allow mooring of Thames Clipper types vessels is also proposed for all options. Additionally some setting back of the riverbank line in the northern and eastern sections of the site is proposed to allow the creation of new intertidal habitat to compensate for the intertidal potentially impacted by the development.

The scale and nature of the structures, the project location and the proposed dredging indicate that hydrodynamic and sedimentation modelling is required to robustly support an environmental impact assessment as has been done for similar scale projects throughout the tidal River Thames including the nearby Tilbury2 port development (Port of Tilbury, 2018).

Figure 1.1: London Resort location plan

Source: London Resort Environmental Impact Assessment Scoping Report, June 2020

This report includes three further sections; **Section 2** summarises the data used for the study. **Section 3** describes the setup of the hydrodynamic model and the predictions of the effects with the development in place. The sedimentation modelling is described in **Section 4**.

2. Received data

2.1. Proposed scheme

Details of the options were provided by Buro Happold in the following drawings:

0042936-LR-DG-BUR-DCO-000-0 - Masterplan - HRW Opt_A

0042936-LR-DG-BUR-DCO-000-0 - Masterplan - HRW Opt_B

0042936-LR-DG-BUR-DCO-000-0 - Masterplan - HRW Opt_C

0042936-LR-DG-BUR-DCO-000-0 - Masterplan - HRW Tilbury.

2.2. Existing structures

Information on the existing structures was assessed from the structural report on the jetties (Eastwood and Partners, 2013) and photographs taken by APEM during their bed sampling site survey (25th-26th August 2020, two examples below).

These inputs were used to estimate the number, size and shape of the piles in the existing structures as input to the modelling.

Figure 2.1: White's Jetty

Source: APEM (2020)

Figure 2.2: Piles under Bell Wharf

Source: APEM (2020)

2.3. Bed sediments

Physical data from surface sediment samples collected by APEM was received (APEM , 2020). The data is summarised in Table 2.1. Figure 2.3 and Figure 2.4 present the data in terms of pie charts of the proportions of gravel, sand and silt/clay. The variable nature of the bed sediments at the Swanscombe site is seen. At Tilbury, a more consistent picture of a mix of sand and fine sediments is seen other than at one location further into the channel which has coarser sediment as might be expected in a higher current environment.

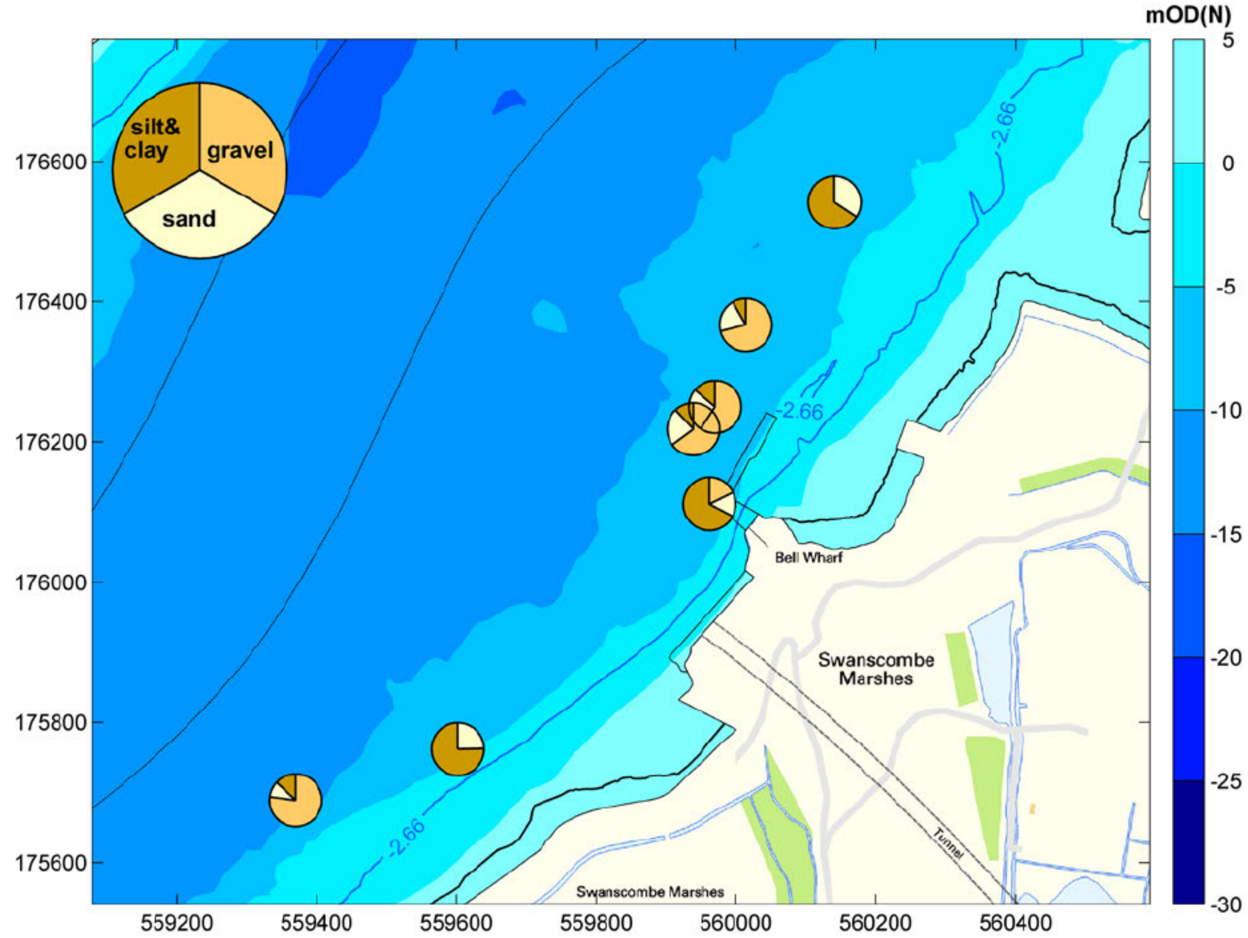

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Figure 2.3: Observed surface sediment composition at Swanscombe site

Source: APEM (2020)

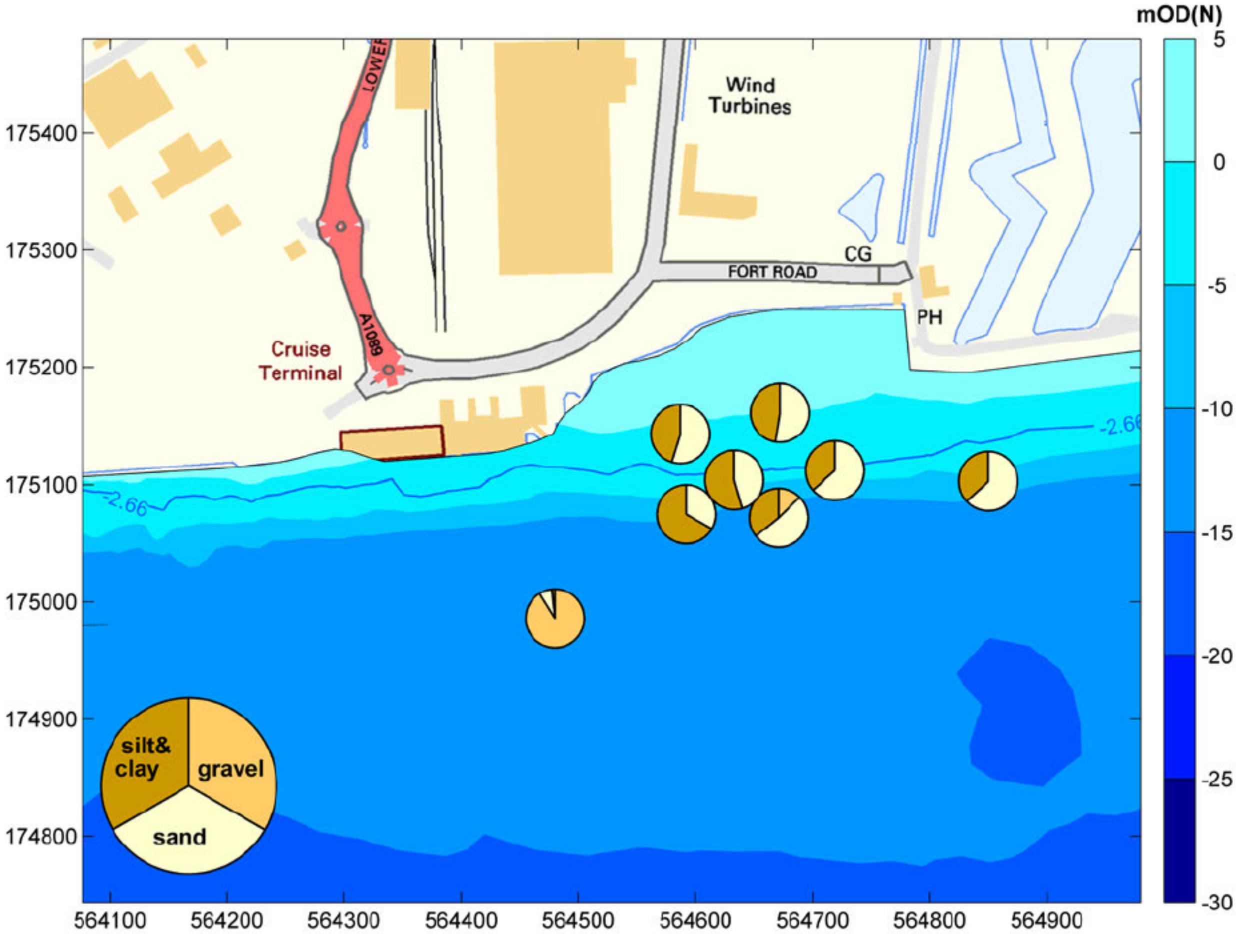

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Figure 2.4: Observed surface sediment composition at Tilbury site

Source: APEM (2020)

Table 2.1: Sediment sampling results

Station ID	Location	Sample date	Decimal Minutes		Visual description pre-analysis	d10 (µm)	d50 (µm)	d90 (µm)	%Gravel (>2 mm)	%Sand (63 µm – 2 mm)	%Mud (<63 µm)
			Latitude	Longitude							
1	Swanscombe	26/08/2020	51° 27.462	0° 17.554	Gravelly mud	23.4	26145.2	41456.0	77.1	9.8	13.1
2	Swanscombe	26/08/2020	51° 27.497	0° 17.756	Sandy mud	0.6	16.0	250.1	0.0	24.7	75.3
8	Swanscombe	26/08/2020	51° 27.754	0° 18.087	Gravelly mud	23.9	7280.6	55676.7	59.3	26.8	13.9
10	Swanscombe	26/08/2020	51° 27.68	0° 18.076	Slightly gravelly mud	2.8	20.4	4960.2	17.7	15.0	67.3
11	Swanscombe	26/08/2020	51° 27.737	0° 18.059	Gravelly mud	34.7	11739.5	39465.9	64.9	23.2	11.9
12	Swanscombe	26/08/2020	51° 27.816	0° 18.128	Gravelly mud	89.2	8669.0	29369.1	71.1	20.7	8.2
13	Swanscombe	26/08/2020	51° 27.908	0° 18.242	Sandy mud	2.2	25.0	339.5	0.0	34.3	65.7
14	Tilbury	25/08/2020	51° 26.995	0° 21.943	Gravel	3046.3	17489.9	36421.7	91.1	7.2	1.7
15	Tilbury	25/08/2020	51° 27.078	0° 22.040	Mud	3.7	68.4	148.1	0.0	54.8	45.2
16	Tilbury	25/08/2020	51° 27.056	0° 22.078	Mud	2.8	46.0	156.7	0.0	45.5	54.5
17	Tilbury	25/08/2020	51° 27.041	0° 22.042	Mud	1.7	23.0	156.3	0.0	33.3	66.7
18	Tilbury	25/08/2020	51° 27.086	0° 22.114	Mud	3.8	65.7	148.6	0.0	52.5	47.5
19	Tilbury	25/08/2020	51° 27.059	0° 22.153	Mud	4.8	92.0	173.4	0.0	63.6	36.4
20	Tilbury	25/08/2020	51° 27.038	0° 22.111	Slightly gravelly mud	4.4	115.5	5901.2	12.6	51.7	35.7
21	Tilbury	25/08/2020	51° 27.051	0° 22.266	Mud	3.7	107.4	234.9	0.0	63.2	36.8

Source: APEM (2020)

2.4. Suspended sediment

The view of a dynamic sedimentary environmental is confirmed by measurements of total sediment flux made at a set of transects throughout the tidal Thames in September 2004 (HR Wallingford, 2006a). At the nearest Transect to the project site spring tide observations showed approximately 65,000 Tonnes of sediment passing through the section during each tidal phase. This total fell to approximately 20,000 Tonnes during neap tides. Figure 2.5 shows the time history of instantaneous discharge and sediment flux at the section in Gravesend Reach east of the development site. Maximum sediment fluxes of 6,000 kg/s are shown for both the ebb and flood tidal phases.

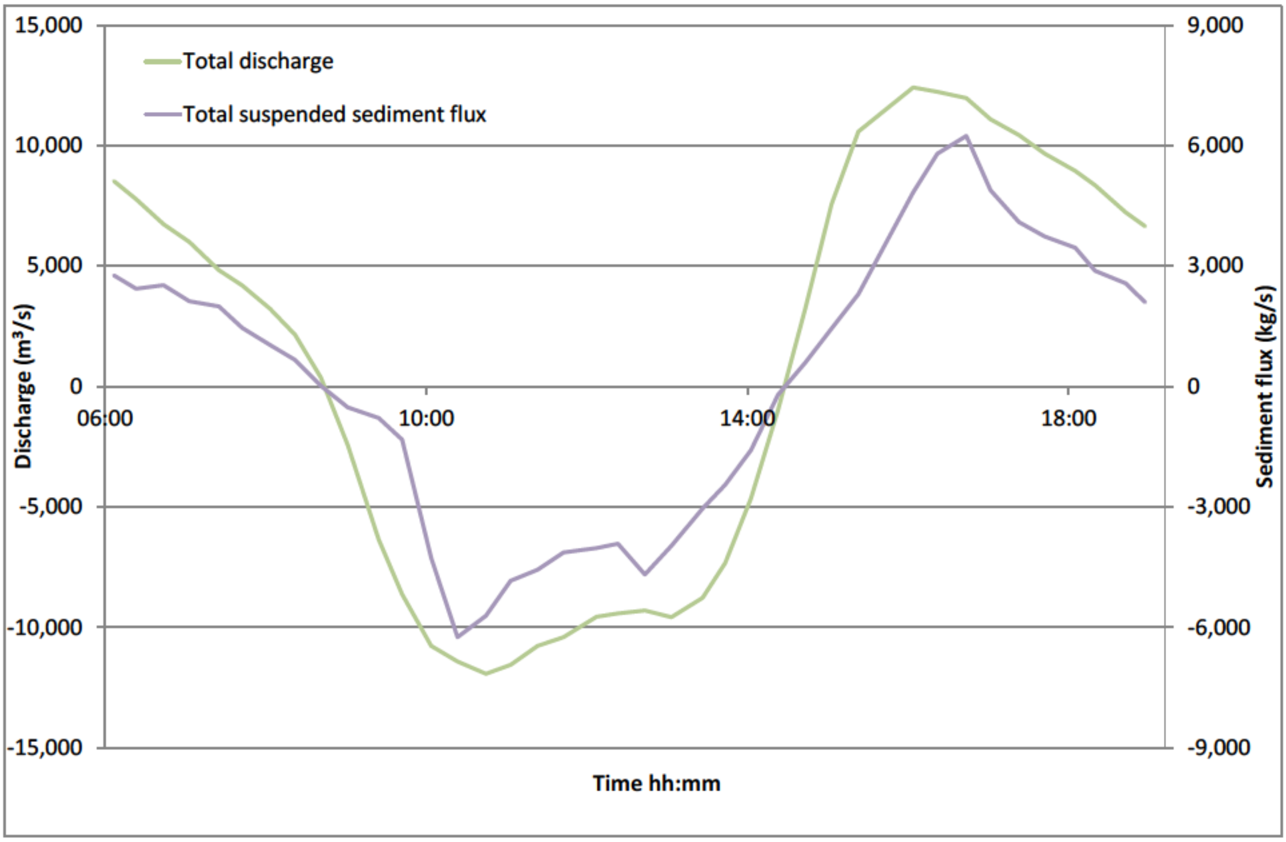


Figure 2.5: Total spring tide water discharge and sediment flux measured in Gravesend Reach, September 2004

Source: HR Wallingford (2006b)

2.5. Intertidal bathymetry and land topography

Part of the project design was to create intertidal habitat by lowering some of the existing embankments along the present bank line and reprofiling some of the area of land behind the embankment such that it becomes intertidal. To provide additional bathymetry and topography data in the proposed areas of habitat creation, the 2019 composite LiDAR Digital Terrain Model (DTM) was acquired from the Defra data portal (https://environment.data.gov.uk/DefraDataDownload/?Mode=survey).

This data was collected at a time when the water surface was at approximately +1.5 m OD(N) so only the upper intertidal were measured. The DTM is intended to represent the land level and excludes vegetation, buildings, etc. As the existing intertidal levels are a key parameter in developing a sustainable new habitat the DTM should be ground-truthed against land based surveying methods as part of the detailed design of the habitat creation.

According to the LiDAR DTM the foreshore fronting the existing embankment is at 3 to 4 mOD(N), higher on the eastern end of the site (Figure 2.6). This puts the levels at around the level of mean high water spring tide (MHWS) of 3.44 mOD(N). Looking at aerial imagery from Google Earth this area includes a mix of areas of saltmarsh and high mudflat as might be expected relatively high in the tidal frame.

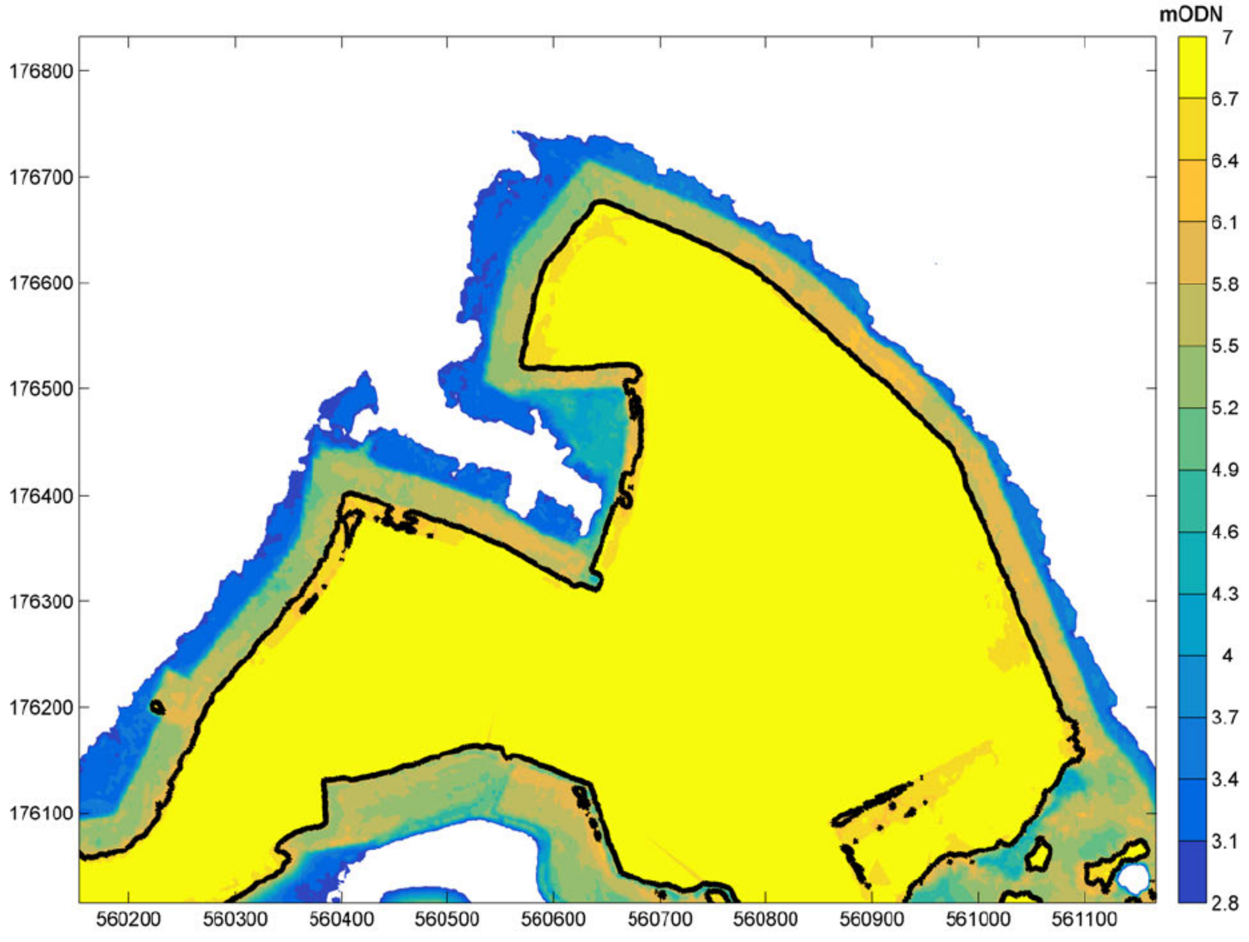


Figure 2.6: Existing topography based on LiDAR DTM

3. Hydrodynamic modelling

3.1. Choice of model

A requirement of this study was to obtain knowledge of the local tidal flow regime via a hydrodynamic assessment for both existing and proposed scenario. Knowledge of the flow environment was obtained based on the Thames Base model, a numerical flow model of the whole Thames Estuary set up by

HR Wallingford in partnership with the Environment Agency (EA) and the Port of London Authority (PLA) to assist the two organisations with their regulatory responsibilities.

The modelling suite used for the Thames Base model is TELEMAC, originated by EDF-LNHE. The location of the development between sharp bends in the river at Broadness and Stoneness suggests 3D flows will be important. Furthermore, modelling fine sediment requires good representation of near bed processes. These factors indicate the modelling should be undertaken in 3D. TELEMAC-3D solves the 3D Navier-Stokes flow equations making the hydrostatic pressure assumption (i.e. no significant vertical flow accelerations) using a finite element solution method on an unstructured triangular grid. This triangular grid allows the model mesh resolution to continually vary in space resulting in good representation of existing and proposed features.

3.2. Calibration and validation

The model was initially established and successively validated against a wide set of tidal level, current and total discharge data in 2001 (HR Wallingford, 2004). The model was subsequently validated against the estuary-wide survey undertaken in late 2004 as part of the EA's TE2100 studies (HR Wallingford, 2006b). A further bathymetric update and validation exercise was undertaken for the PLA in 2009 (HR Wallingford, 2009).

For both the calibration and validation exercises the model accuracy has been assessed based on the Mean Absolute Error (MAE) which gives a view of the average 'goodness of fit' of the simulated hydrodynamics compared with those observed. The MAE for the model representation of the tide curve is in the range 3-4% of the tide range and the MAE of the total water discharge has been calculated as in the range 6-12% of the peak discharge.

For the purposes of assessing the modelled currents, a level of accuracy of 12% based on the maximum MAE for tidal discharge would provide a precautionary view of the uncertainty. For example maximum currents could be in the range 1.05-1.35 m/s for a predicted maximum current of 1.2 m/s.

3.3. Bathymetry

The bathymetry database of the Thames Base numerical model was developed from the bathymetric data published by the Port of London Authority (PLA). All depths were reduced to a common flat datum of Ordnance Datum Newlyn (OD(N)) from the Chart Datum which constantly changes to reflect the local lowest tide levels. At the Tilbury site OD(N) is 3.12 m above Chart Datum whereas at the proposed Swanscombe passenger terminal site OD(N) is 3.2 m above Chart Datum.

The bathymetry data was combined with the LiDAR DTM data to provide a continuous bathymetry/ topography dataset up to 7.0 mOD(N), approximately the level of Highest Astronomical Tide (HAT).

3.4. Mesh

The model domain is the whole tidal Thames from Teddington to Southend-on-Sea. To represent the bathymetry and flows the model uses an unstructured triangular grid which allows the model mesh resolution to continually vary in space resulting in good representation of features such as the various existing or proposed marine structures as well as the riverbank line. A minimum mesh size of 5 m has been used (Figure 3.1). In the vertical 7 equally spaced layers have been employed for the present study.

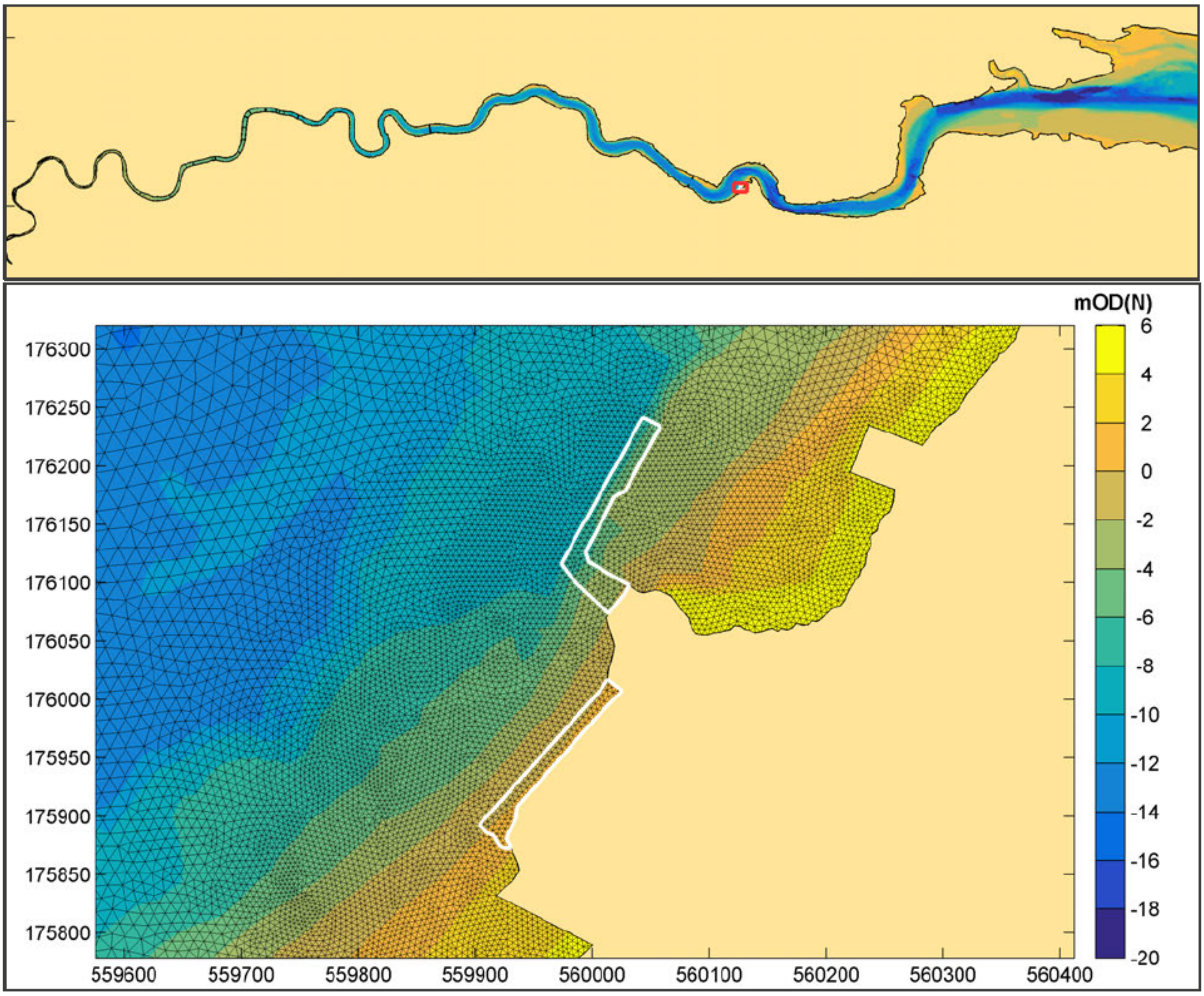


Figure 3.1: Model mesh for existing layout in the area of White's jetty and Bell Wharf

3.5. Boundary conditions

The simulations required the imposition of landward and seaward boundary conditions.

Currents in the area are primarily driven by the tide and even large fluvial flows do not significantly influence the magnitude of currents at this site. To simulate the range of currents and through-tide water levels which occur in the area, a hydrodynamic simulation was undertaken including a 14 day spring-neap cycle to model a full range of tide ranges.

Data for the seaward tidal elevation boundary came from those observed at the Port of London Authority's tide gauge on Southend Pier. The freshwater flow data for the landward boundary was calculated from the gauged flow at Kingston (http://nrfa.ceh.ac.uk/data/station/meanflow/39001).

For the simulated period, the tidal boundary conditions used the neap tide to spring tide period of 20th September to 5th October 2004. To provide representative conditions the imposed river input was the annual mean fluvial flow (65 m^3/s).

3.6. Piles and pontoons

The development includes piles at various locations with various sizes, and two floating pontoons. The computational effort required to model these features in detail would be considerable therefore two simplified methods were applied to represent the effect of the structures on the passing flow.

3.6.1. Piles

The influence of piles on the flow is included in the model by adding extra turbulent drag within each model cell within the piled region using the following equation:

$$F_{u,v} = -0.5 * N * D * C_D * U_{norm} \qquad \text{(Eq. 1)}$$

Where:

$F_{u,v}$ = drag in the X and Y direction

N = total number of piles in the jetty

D = diameter of the piles (m)

C_D = a drag coefficient related to the shape of the pile; for square piles C_D = 2.0 (Mutlu Sumer and Fredsøe, 2006)

U_{norm} = depth averaged current flow speed (m/s).

F_u and F_v are then included implicitly within the hydrodynamic momentum equations used by the model.

3.6.2. Pontoons

Floating pontoons were included in the model by applying additional pressure to the free surface of the 3D hydrodynamic model, depressing the water surface to a level equivalent to the draft of each pontoon.

3.7. Layouts considered

Four layouts have been considered comprising the baseline (existing) condition and the three development options.

3.7.1. Baseline

The existing layout of the site was modelled as a baseline against which to compare the hydrodynamics of the options. At the Swanscombe site the structures considered were Bell Wharf and White's Jetty. The structures as implemented in the model are shown in Figure 3.2. At the Tilbury site the proposed terminal is located immediately east of the exiting landing stage pontoon. This pontoon was modelled with a draft of 2.0 m.

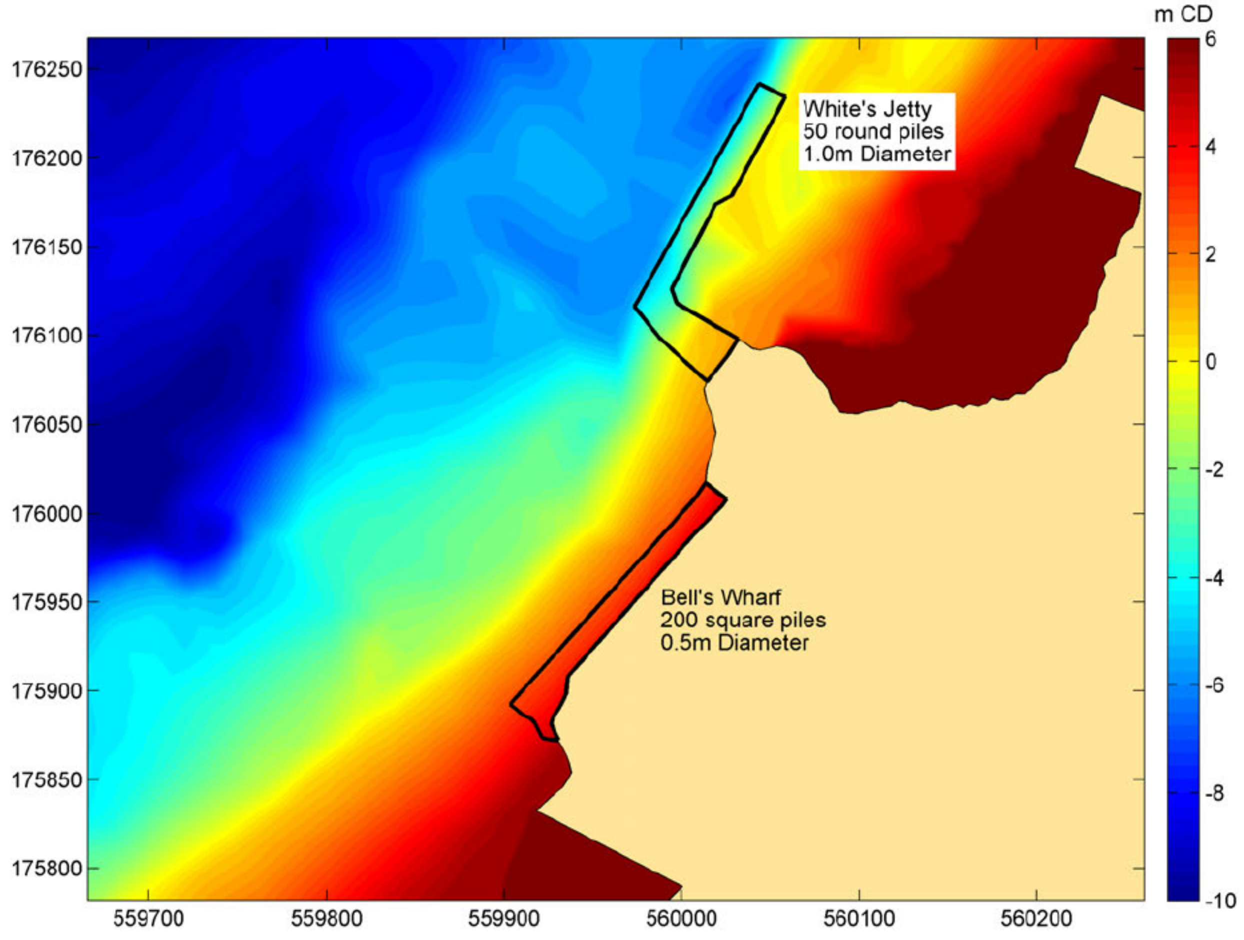


Figure 3.2: Baseline case layout

3.7.2. Option A

Option A (Figure 3.3) introduced:

- a RO-RO pontoon with 1.0 m draft, located further in the river to avoid the need for dredging;
- A set of 2 m diameter mooring piles to the NE of the RO-RO pontoon;
- A set of 1 m diameter piles SE of the RO-RO to support the linkspan bridge to the pontoon;
- A piled ferry terminal structure;
- A passenger pontoon with draft 1.0 m held by two piles of 0.9 m diameter.

Bell Wharf and White's Jetty remained in the layout unchanged from the baseline simulation.

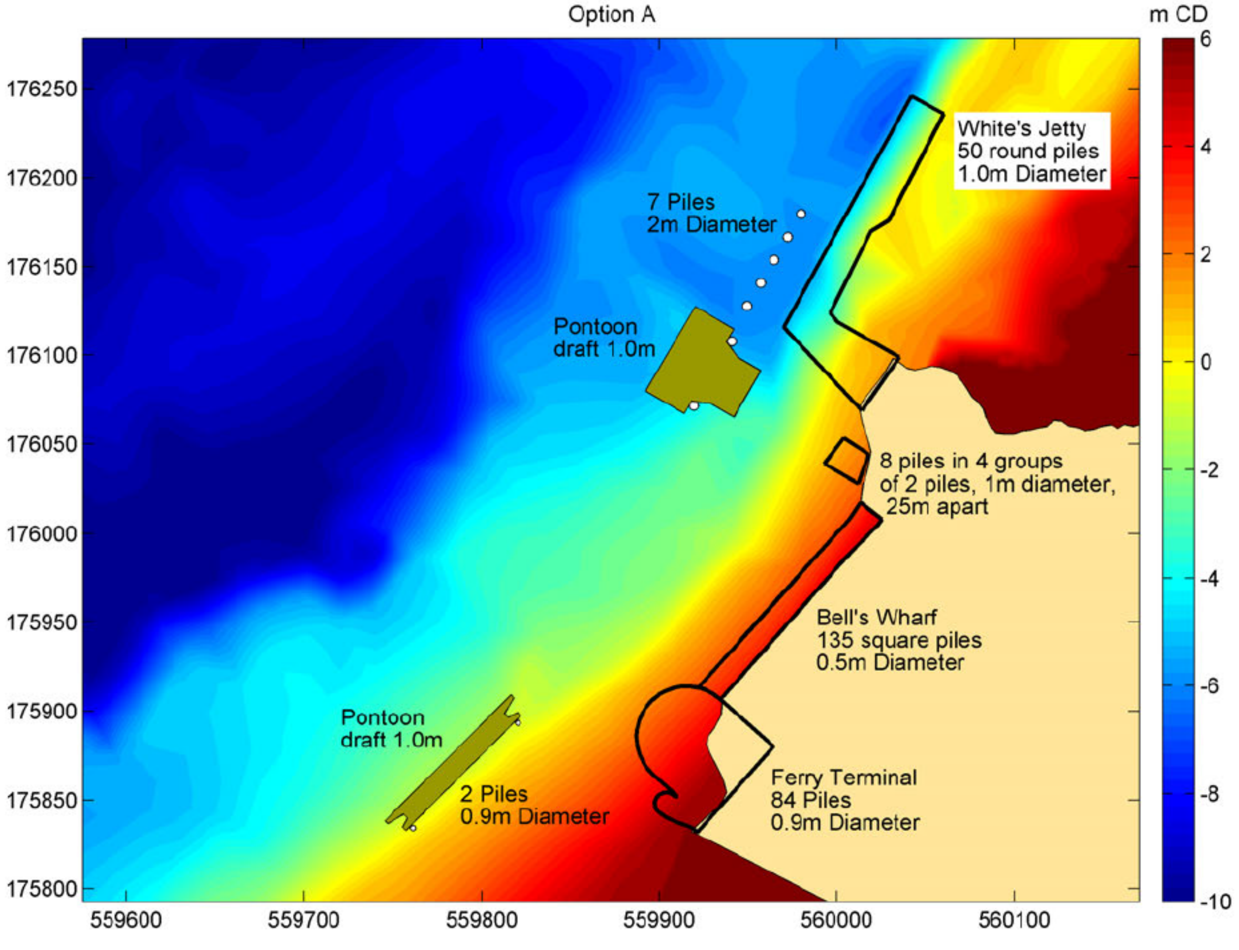


Figure 3.3: Option A layout

3.7.3. Option B

Option B (Figure 3.4) introduced:

- A piled ferry terminal structure;
- A passenger pontoon with draft 1.0 m held by two piles, 0.9 m diameter.

Bell Wharf and White's Jetty remained in the layout unchanged from the baseline simulation.

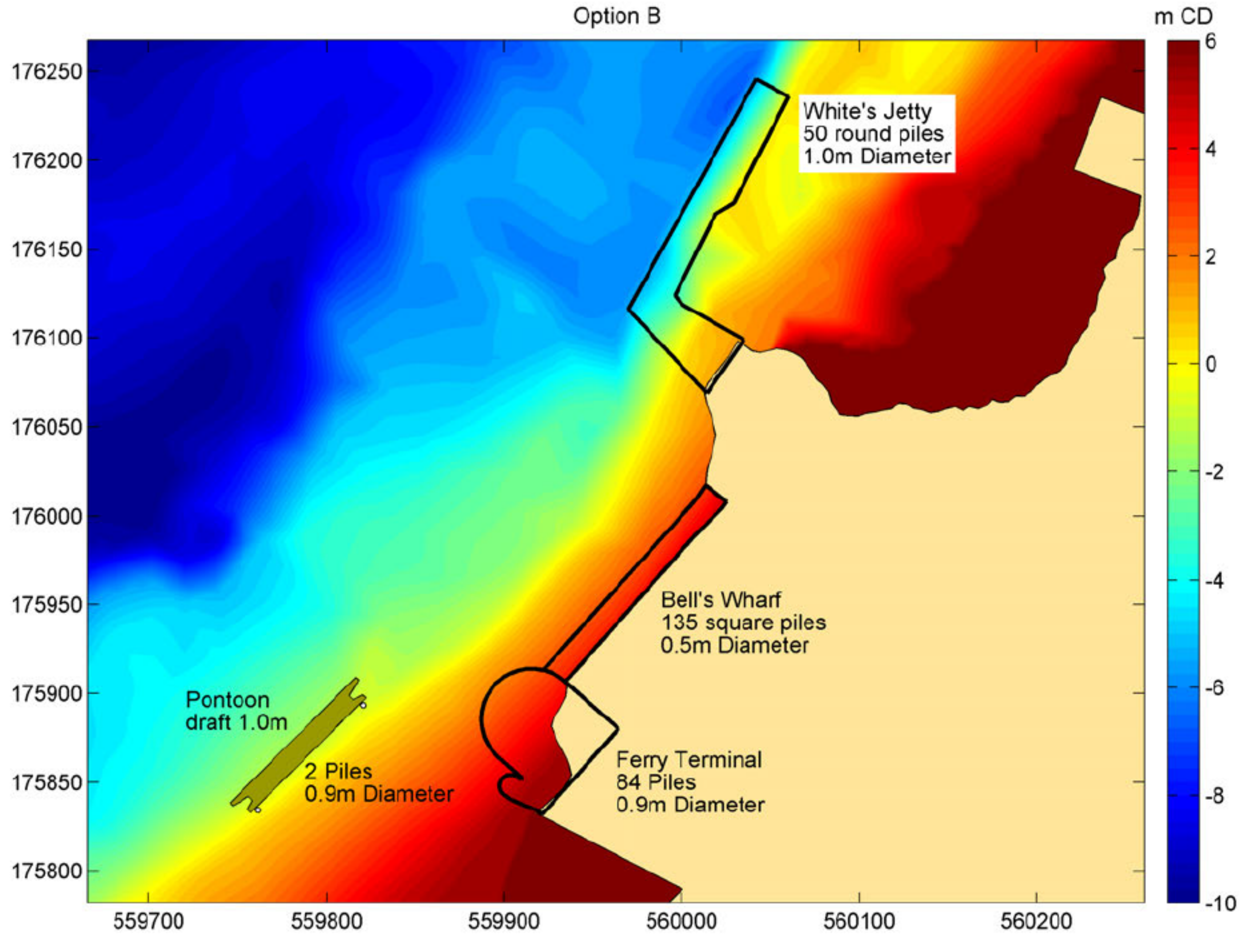


Figure 3.4: Option B layout

3.7.4. Option C

Option B (Figure 3.5) introduced:

- A piled ferry terminal structure;
- A passenger pontoon with draft 1.0 m held by two piles, 0.9 m diameter;
- A dredged area to -4 m CD to allow navigational access to Bell Wharf.

Bell Wharf and White's Jetty remained in the layout unchanged from the baseline simulation.

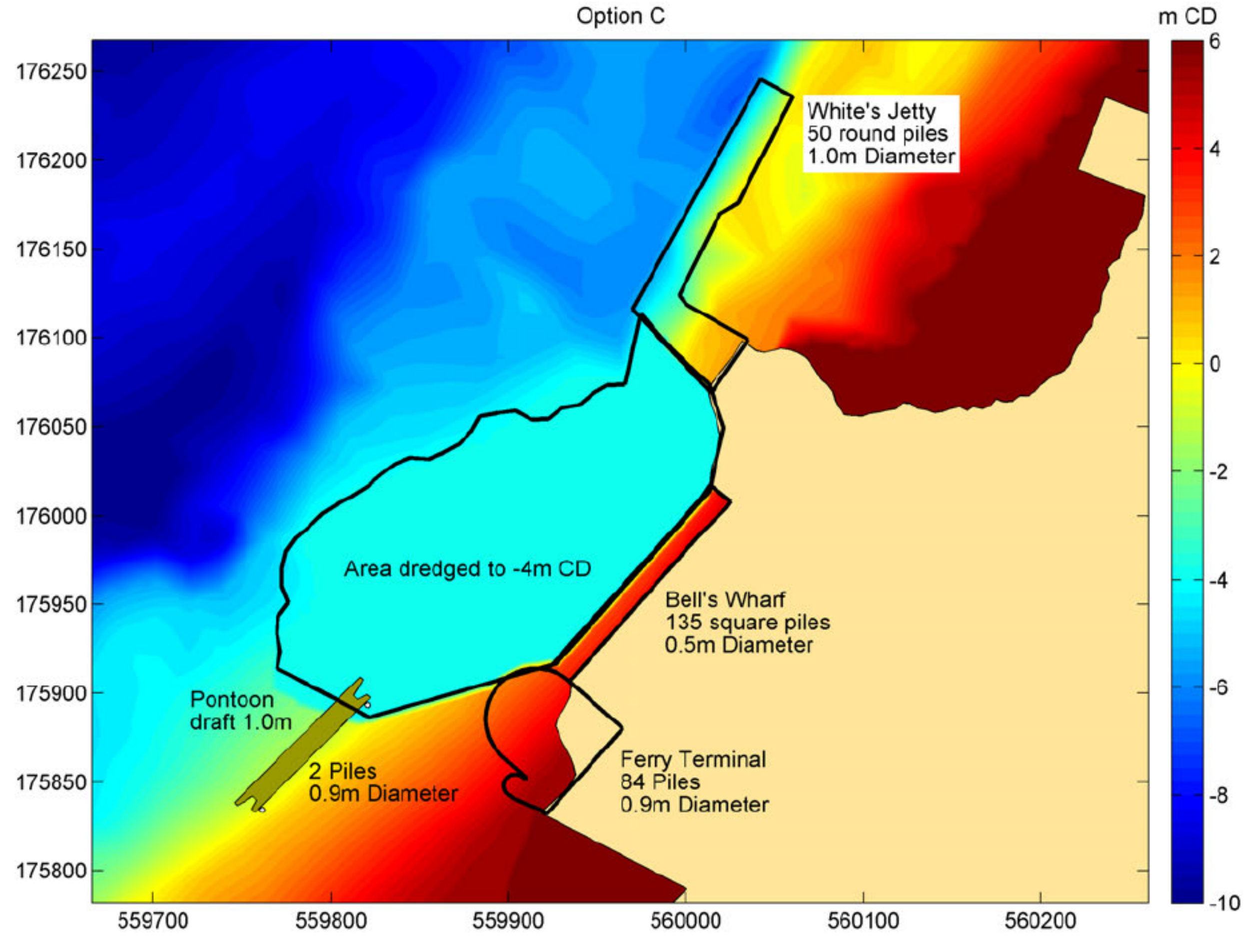


Figure 3.5: Option C layout

3.7.5. Tilbury (all options)

The proposed passenger terminal at Tilbury was modelled identically for all three options. A set of pontoons with a 1 m draft were modelled which were held in place by eight, 0.9 m diameter piles. Figure 3.6 shows proposed the arrangement of the pontoons. It also shows the pontoons fully occupied by 9 ferries although as these ferries will be constantly coming and going, they were not included in the simulation.

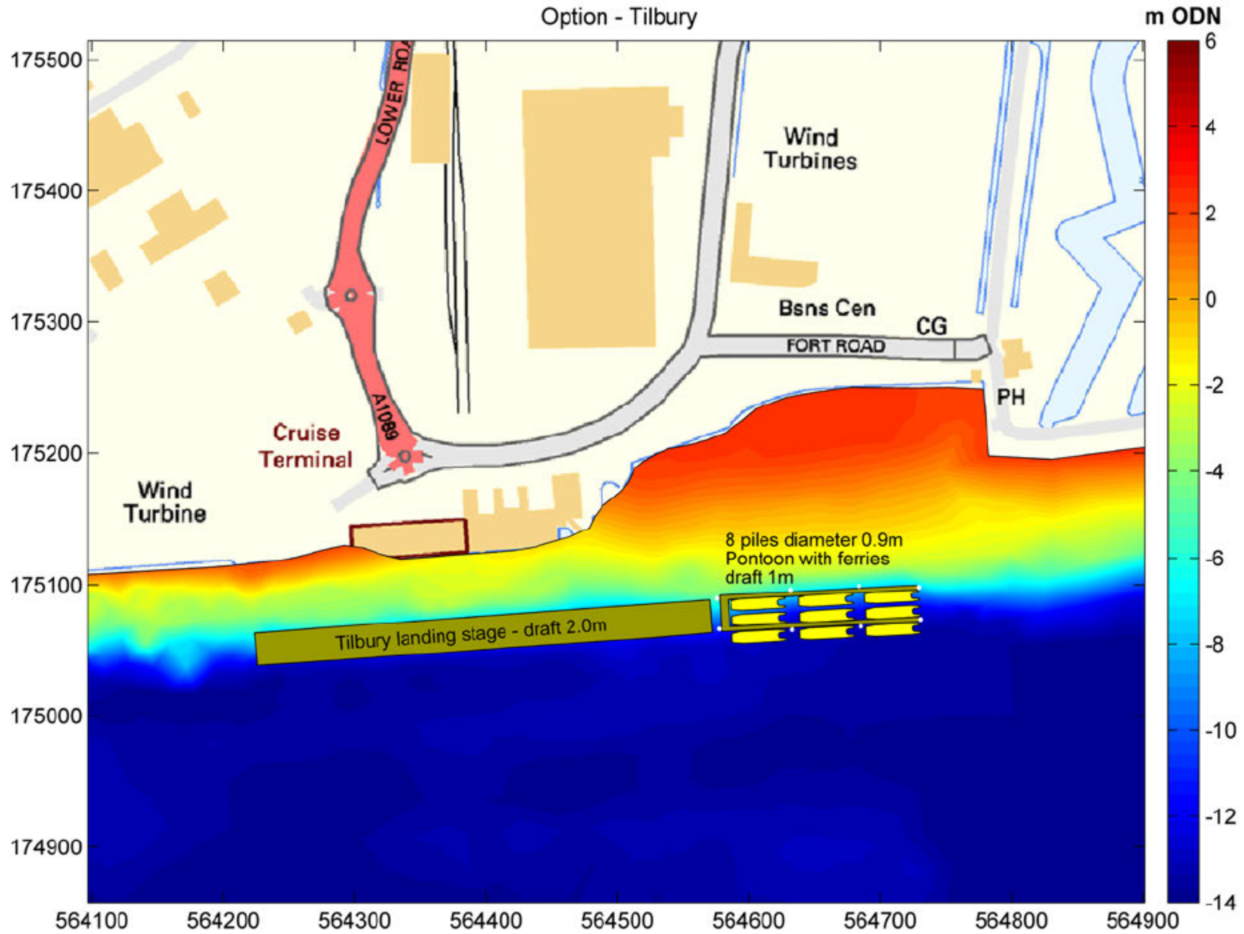


Figure 3.6: Tilbury terminal layout

3.7.6. Habitat creation

As part of the project creation of intertidal habitat is proposed. The final area and layout of the habitat creation areas is subject to detailed design but for the purposes of impact assessment approximately 2.0 ha of intertidal habitat were included in the modelling for all options. Six embayed areas of setback were modelled as shown in Figure 3.7. For each, the area behind the existing riverbank was lowered to +3.34 mOD(N), breaches were made in the riverbank line with a residual amount of the existing riverbank line kept in place to minimise waves in the setback area and so encourage sedimentation. The chosen level od 3.34 mOD(N) is broadly consistent with that of the foreshore fronting the habitat areas to avoid deleterious effects on the foreshore.

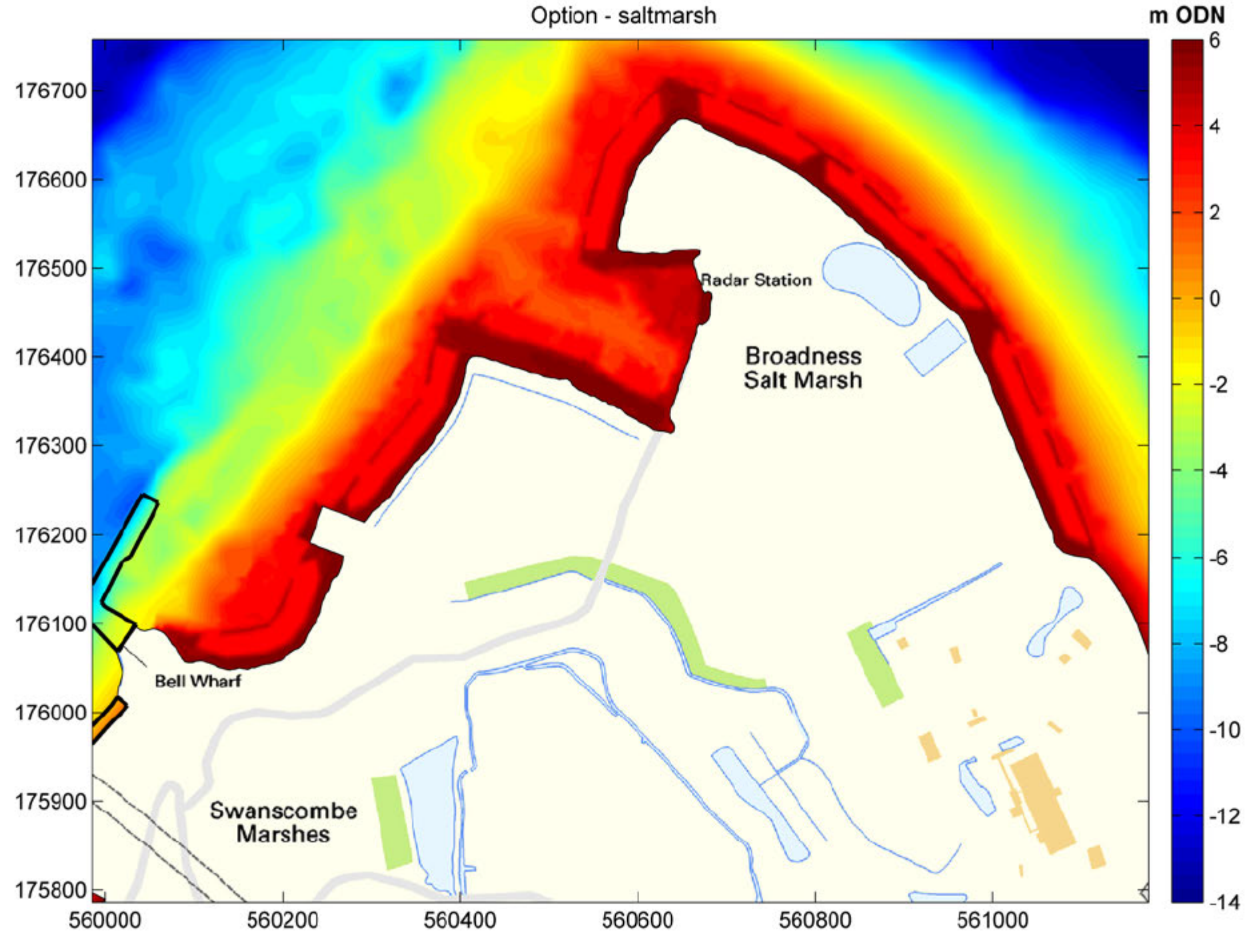


Figure 3.7: Habitat creation layout

3.8. Results

Model results were chosen to allow assessment of the magnitude and footprint of any impacts on the hydrodynamic regime of the tidal Thames and aid the choice of a preferred option for the Swanscombe site. These outputs are also suitable for onward impact assessments such as those for coastal processes, marine ecology and fisheries.

The outputs from the modelling include:

- Spatial plots of peak flood and peak ebb currents for the hydrodynamic conditions under consideration;
- Spatial plots of change to peak flood and peak ebb currents for the hydrodynamic conditions under consideration.

3.8.1. Baseline

The baseline model results against which the results for the options are calculated are presented in Figure 3.8 to Figure 3.11. To show the overall footprint of effect of the options the results from the 3D model are plotted as differences in the calculated depth average currents. To demonstrate the largest footprint of effect the results are shown as differences at the times of maximum ebb and flood currents.

Figure 3.8 and Figure 3.9 show the results for the Swanscombe site and habitat creation areas. Figure 3.10 and Figure 3.11 show the results at the proposed Tilbury passenger terminal site.

Currents around Swanscombe are complex with a large eddy formed during the flood tide at the proposed ferry terminal site and a similarly large eddy formed at the site of the habitat creation during the ebb tide. This means that at the Swanscombe ferry terminal site the currents will be towards the NE most of the time. An ebb tide eddy at Stone Ness is also evident across the river from the proposed passenger pontoon site. There is some evidence in Figure 3.8 for the effect of the piles at White’s Jetty in reducing currents but less evidence during the flood tide, when the currents are lower. Maximum peak currents of more than 2 m/s (4 knots) are shown mid-channel at both the times of peak ebb and flood tide.

At Tilbury, the currents are almost exactly rectilinear with flood and ebb currents going in the opposite directions. Peak current magnitudes approaching 2 m/s are seen for both tidal phases.

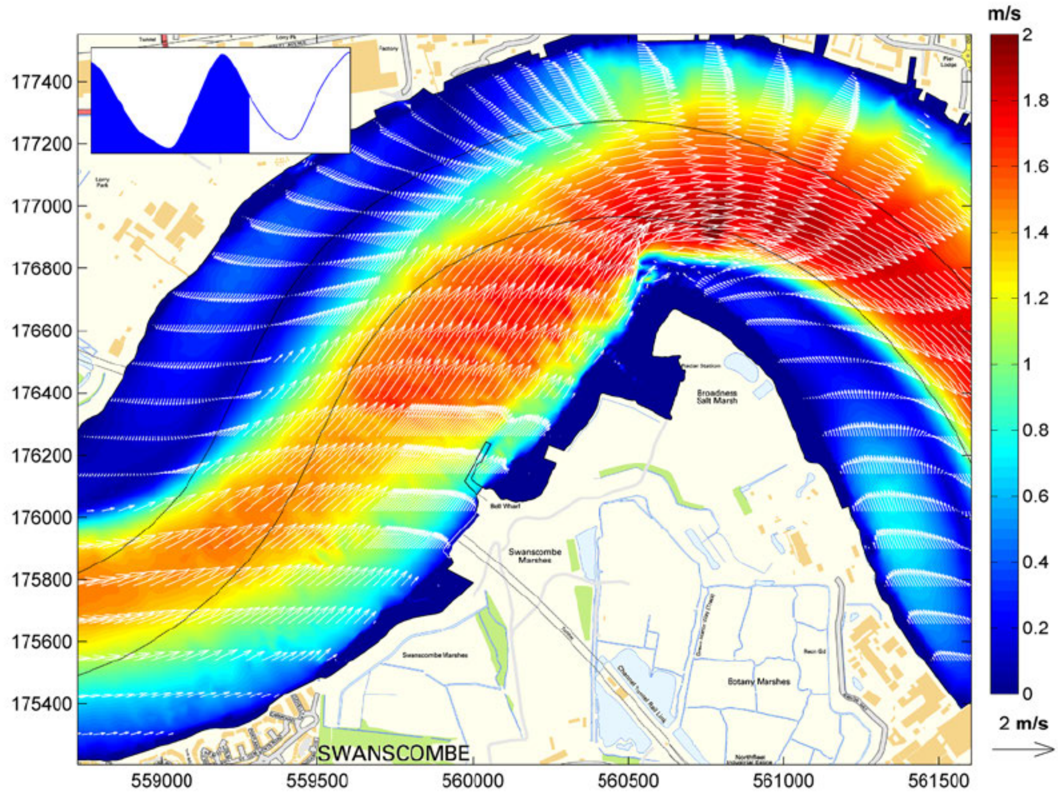


Figure 3.8: Current magnitude at time of peak ebb tide at Swanscombe site, Baseline

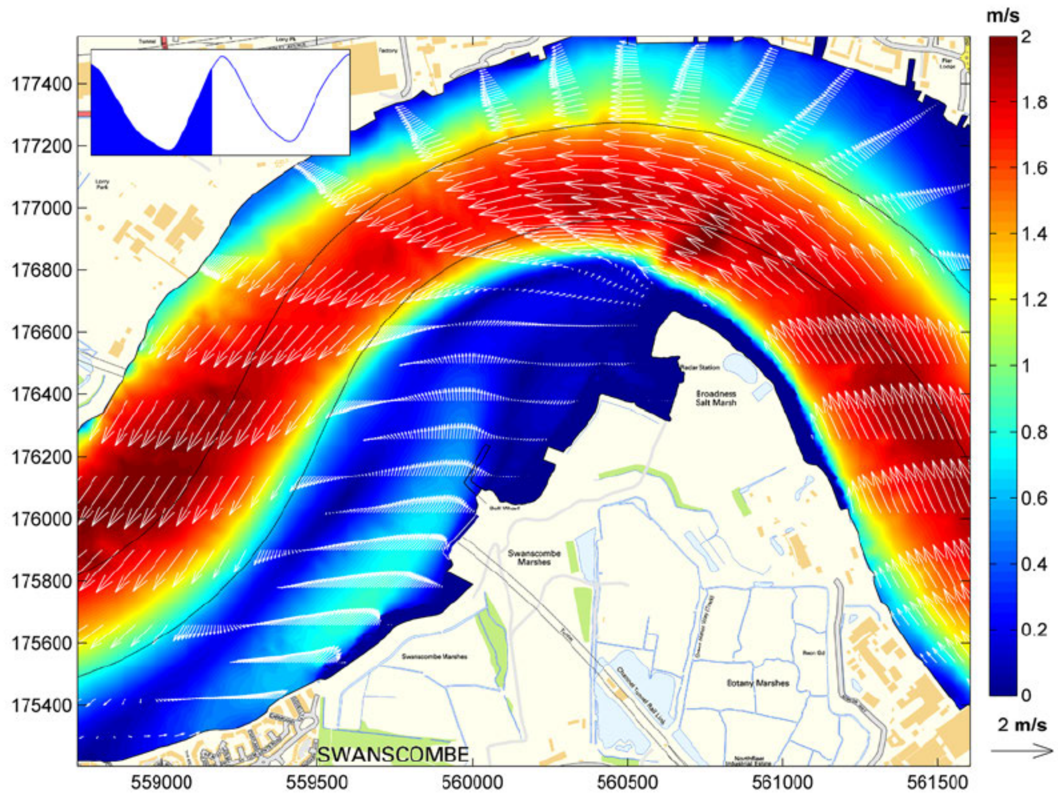


Figure 3.9: Current magnitude at time of peak flood tide at Swanscombe site, Baseline

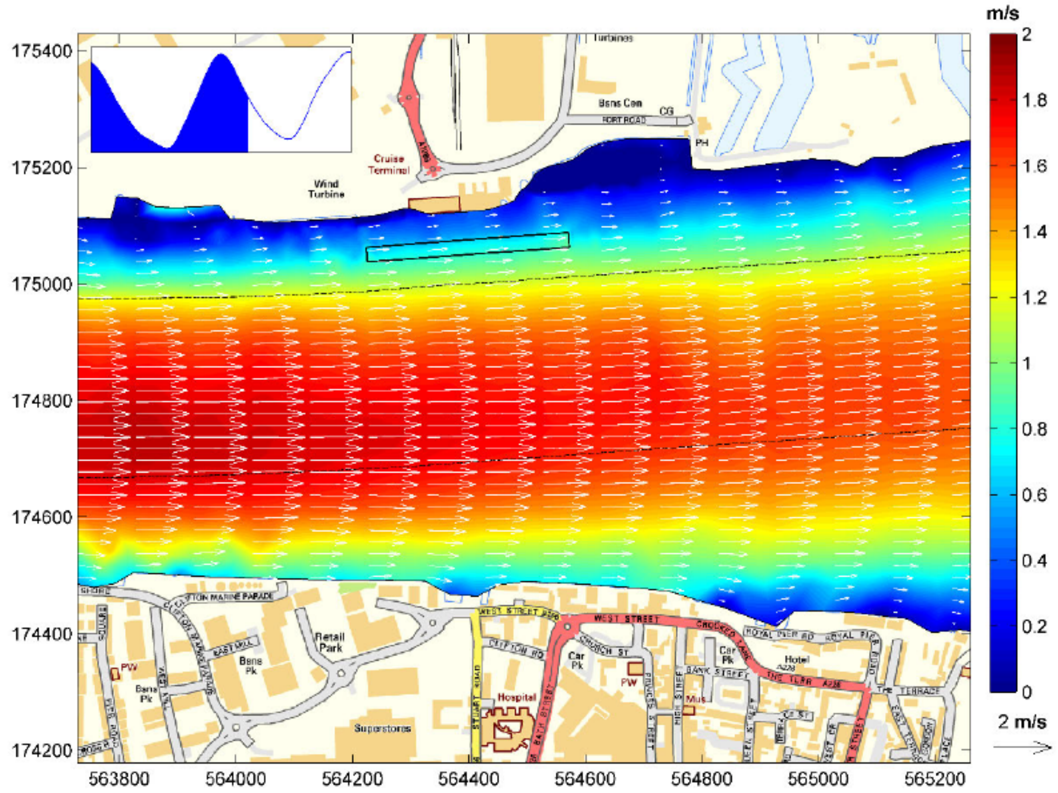


Figure 3.10: Current magnitude at time of peak ebb tide at Tilbury site, Baseline

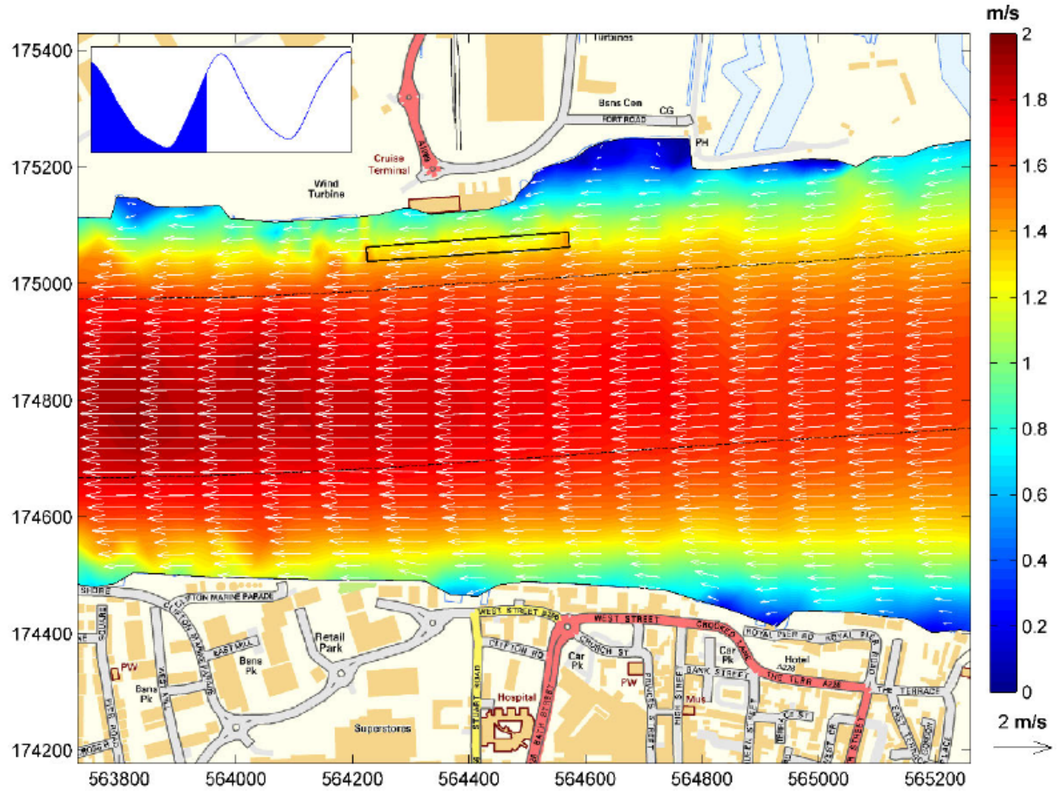


Figure 3.11: Current magnitude at time of peak flood tide at Tilbury site, Baseline

3.8.2. Option A

Figure 3.12 and Figure 3.13 show the difference in depth averaged current magnitude at the time of peak ebb and flood tide. To aid the assessment of the impacts of these changes on intertidal areas a bed level contour at Mean Low Water Spring tide (MLWS, -2.66 mOD(N)) is included in blue and the existing riverbank line is shown in black.

To show the full area of any effect, all changes in current magnitude greater than 0.05 m/s have been plotted. Bearing in mind the high baseline currents in the area (> 2 m/s) this level of change is unlikely to result in a noticeable change e.g. on patterns of erosion or deposition however it is useful to show the overall footprint of the effect of the works.

At the time of peak ebb tide (Figure 3.12) speed reductions greater than 0.05 m/s are predicted over a distance of 800 m around the site of the Swanscombe ferry terminal. The area of larger changes in currents which might have an effect on other estuary processes (e.g. morphology) is smaller with, speed reduction reductions greater than 0.1 m/s over a distance of 400 m. These effects are due to the introduction of blockage to the passing flow by the two pontoons (RO-RO and passenger pontoon) and drag effect of the piles.

Small spots of speed increase are shown by the new breaches out of the habitat creation areas. This is likely due to the water flowing out of the habitat creation areas as they dry out.

The model predictions at the time of peak flood tide (Figure 3.13) show a reduced footprint of change due to lower baseline currents at the ferry terminal site during the flood tide. Speed reductions greater than 0.05 m/s are predicted over a distance of 600 m with speed reductions greater than 0.1 m/s over a distance of 300 m.

Small spots of speed increase by the new breaches into the habitat creation areas are predicted as for the ebb tide result. However as the time of peak flood is closer to high water when the habitat areas are flooded these small areas of increase are surrounded by areas of speed decrease due to the interaction of the passing flow with that entering the habitat areas and the increased flow cross sectional area present when the habitat areas are inundated. However these effects are limited to the immediate area of the habitat areas.

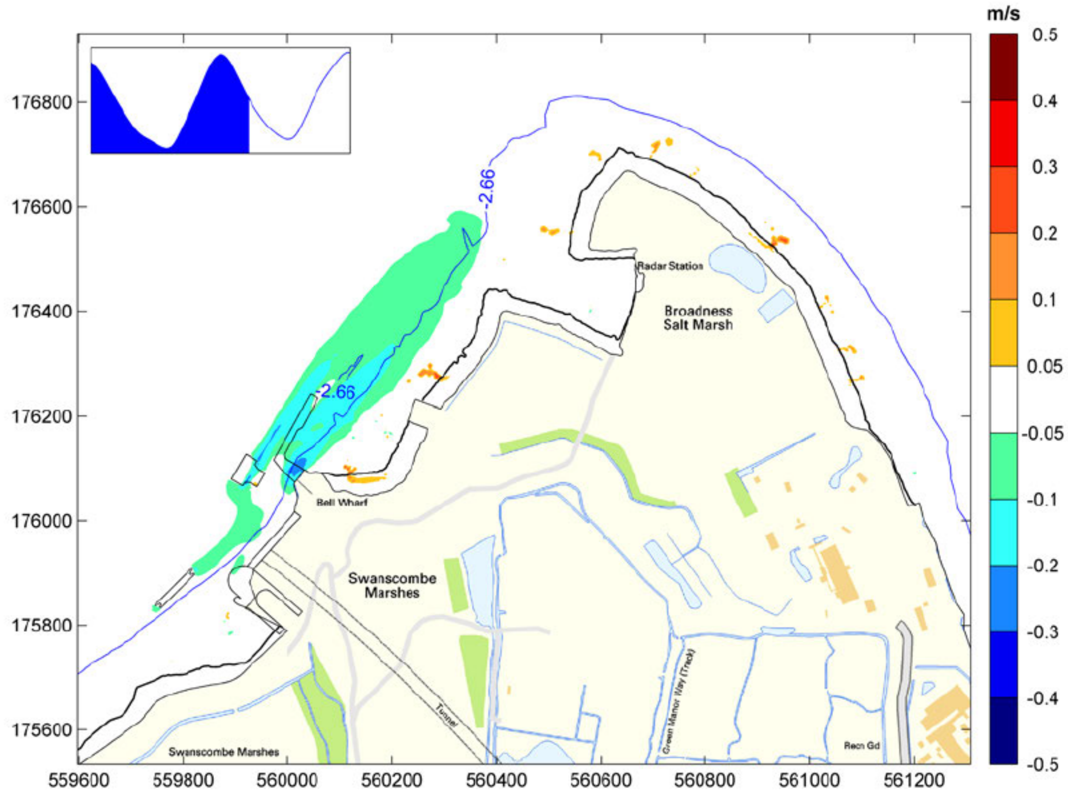


Figure 3.12: Difference in current magnitude at time of peak ebb tide at Swanscombe site, Option A

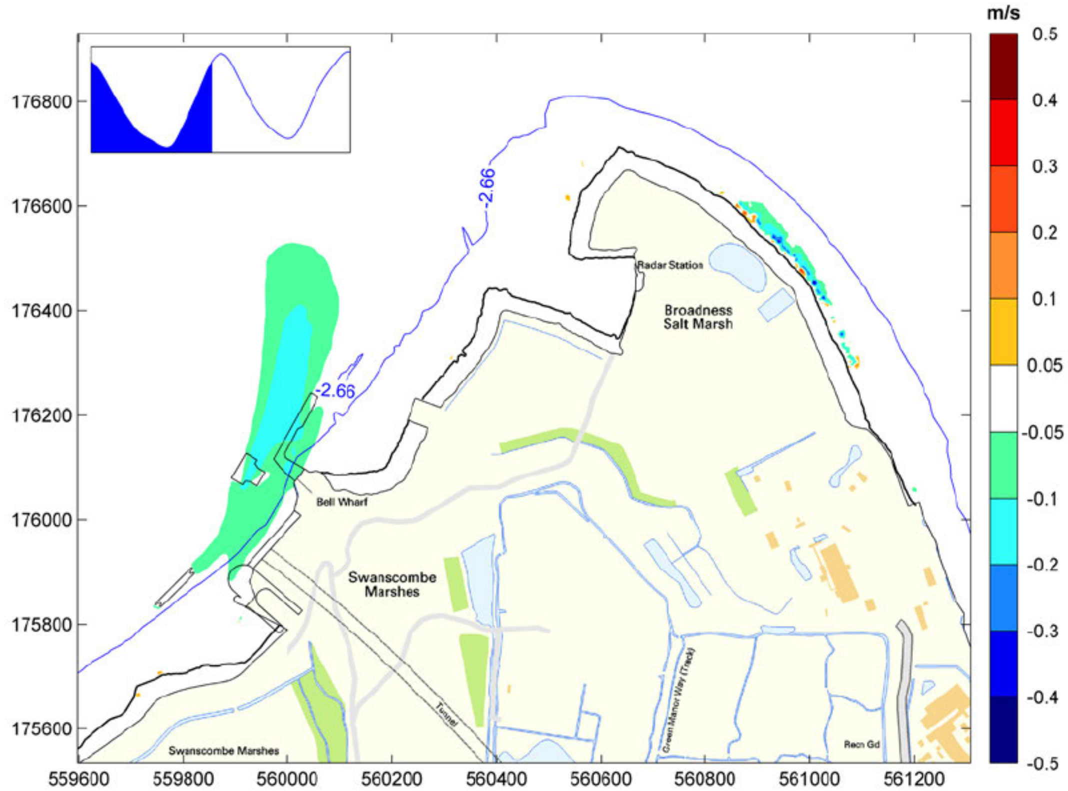


Figure 3.13: Difference in current magnitude at time of peak flood tide at Swanscombe site, Option A

3.8.3. Option B

Without the RO-RO pontoon the effect of Option B on hydrodynamics is noticeably reduced as shown by Figure 3.14 (ebb tide) and Figure 3.15 (flood tide).

At the time of peak ebb tide speed reductions greater than 0.05 m/s are predicted over a distance of 400 m around the Swanscombe ferry terminal site. The area of larger changes in currents which might have an effect on other estuary processes is much smaller with only small spots of speed reduction greater than 0.1 m/s seen close to White's Jetty. As for Option A, small spots of speed increase are shown by the new breaches out of the habitat creation areas.

The model predictions at the time of peak flood tide (Figure 3.15) show speed reductions greater than 0.05 m/s predicted over a distance of 400 m with no speed reductions greater than 0.1 m/s shown. A very similar pattern of changes is shown at the habitat creation sites with spots of speed increase by the new breaches into the habitat creation areas surrounded by areas of speed decrease.

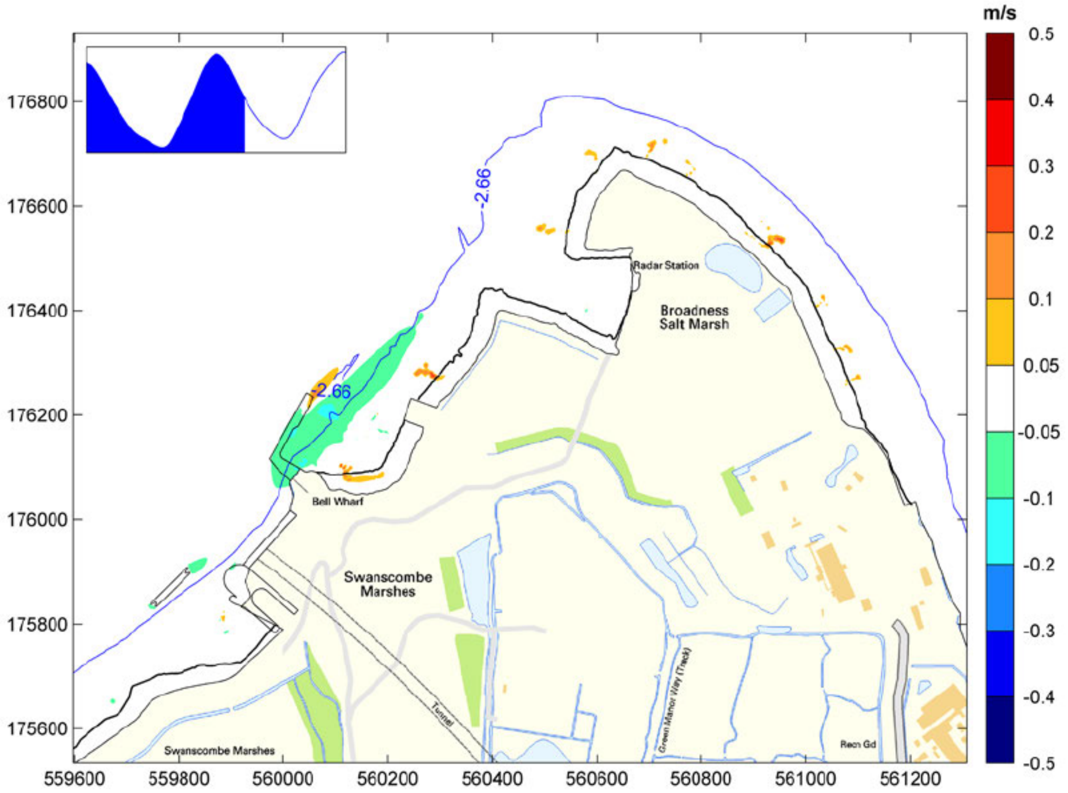


Figure 3.14: Difference in current magnitude at time of peak ebb tide at Swanscombe site, Option B

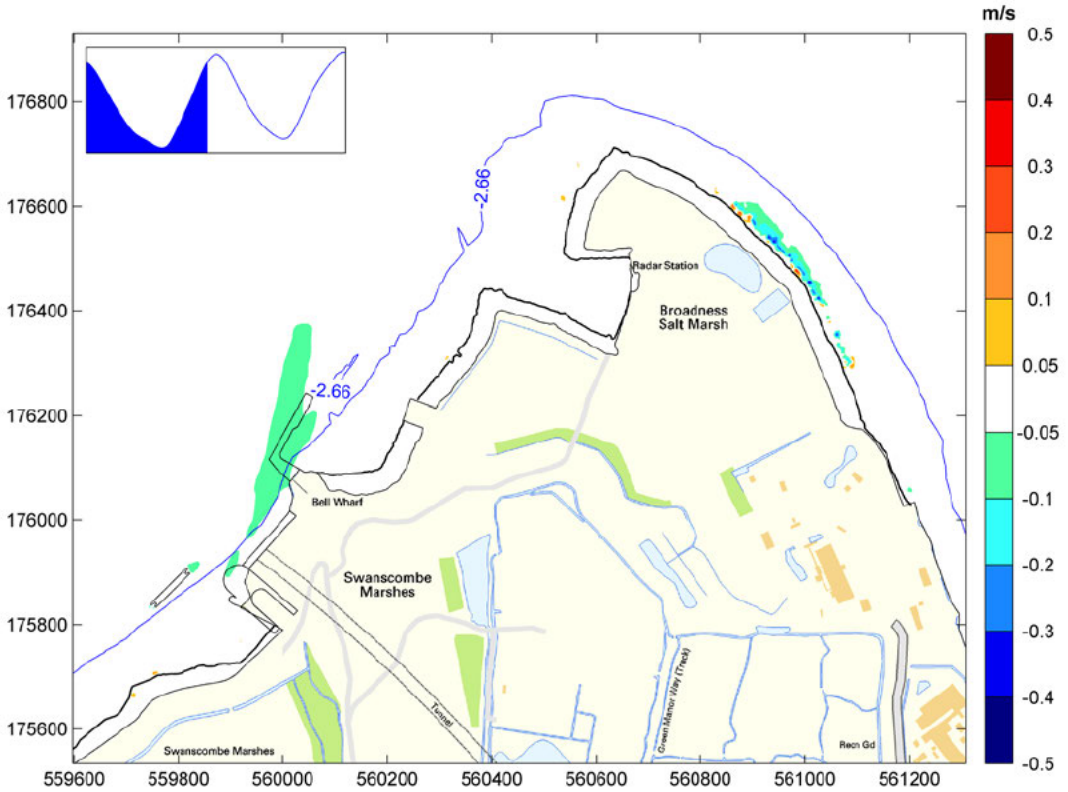


Figure 3.15: Difference in current magnitude at time of peak flood tide at Swanscombe site, Option B

3.8.4. Option C

Option C is similar to Option B but includes dredging to allow navigational access to Bell Wharf. This addition results in an area of speed reduction over the increased water depth in the dredged area. At the time of peak ebb tide (Figure 3.16) speed reductions greater than 0.05 m/s are predicted over a distance of 700 m around the site of the Swanscombe ferry terminal site. The area of larger changes in currents which might have an effect on other estuary processes is restricted to the immediate are of the dredging, extending from the new passenger pontoon to White's Jetty. Within this area some areas of speed reduction greater than 0.2 m/s are shown. The pattern of current changes at the habitat creation sites is the same as for Options A and B.

The model predictions at the time of peak flood tide (Figure 3.17) show speed reductions greater than 0.05 m/s over a distance of 600 m and speed reductions greater than 0.1 m/s over a distance of 500 m, extending from the dredged area towards the NW of White's Jetty. A small area of speed increase greater than 0.05 m/s is shown further into the channel which is most likely due to a very small change to the position of the centre of the eddy at this stage of the tide. However the change is considered too small to have any consequences for morphology or navigation. The pattern of current changes at the habitat creation sites is the same as for Options A and B.

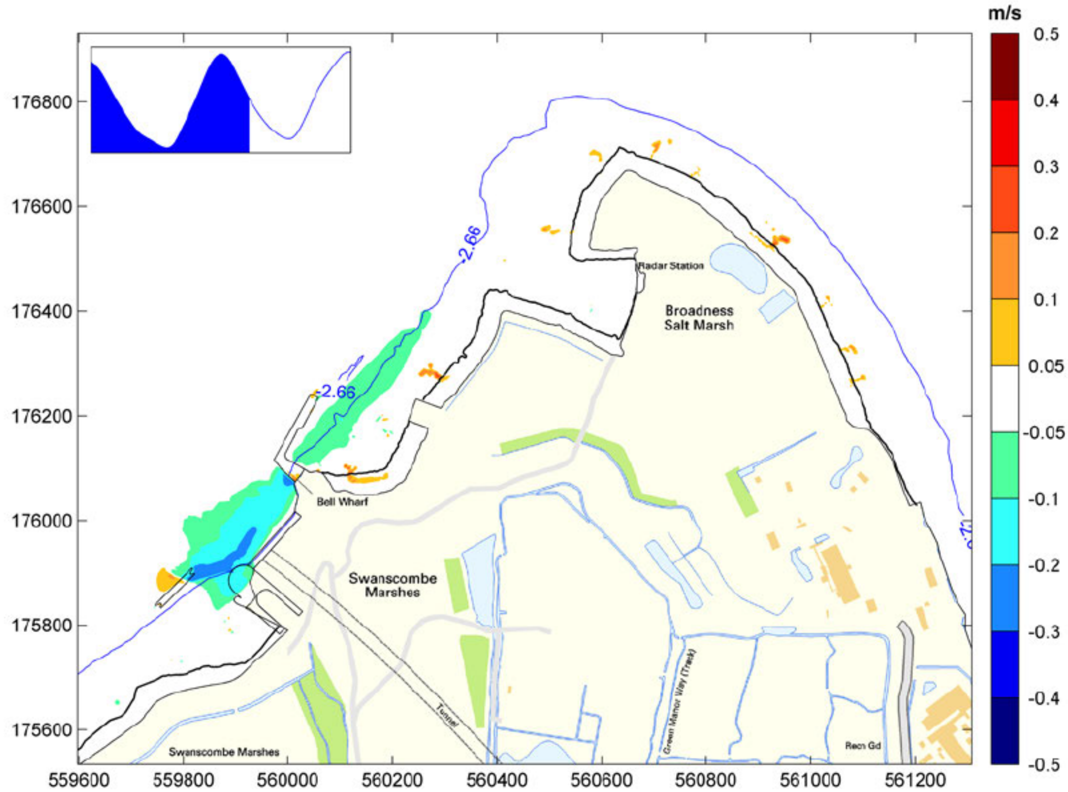


Figure 3.16: Difference in current magnitude at time of peak ebb tide at Swanscombe site, Option C

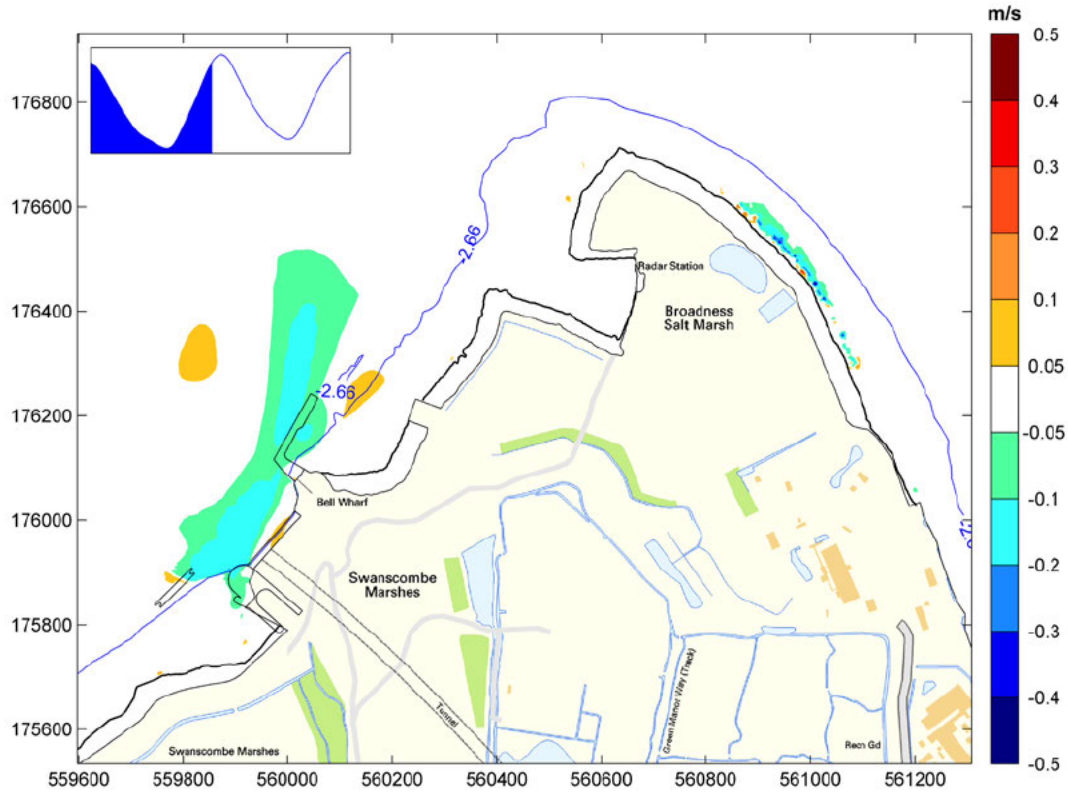


Figure 3.17: Difference in current magnitude at time of peak flood tide at Swanscombe site, Option C

3.8.5. Tilbury

At the Tilbury ferry terminal site the effect on the currents of the blockage of the new pontoons would be expected to be small as the pontoons have a small draft and are in line with the existing landing stage structure. The anticipated small effect of the development is shown in the model predictions in Figure 3.18 (peak ebb tide) and Figure 3.19 (peak flood tide). At the time of peak ebb an area of speed reduction is shown east of the new pontoons extending less than 200 m. A patch of speed increases greater than 0.05 m/s is shown to the north of the new pontoon. This is not expected to have any effect on the morphology as shown by the sediment modelling below (Figure 4.27).

At the time of peak flood tide (Figure 3.19) only speed reductions are predicted, and these are mostly confined to the area under the existing landing stage structure.

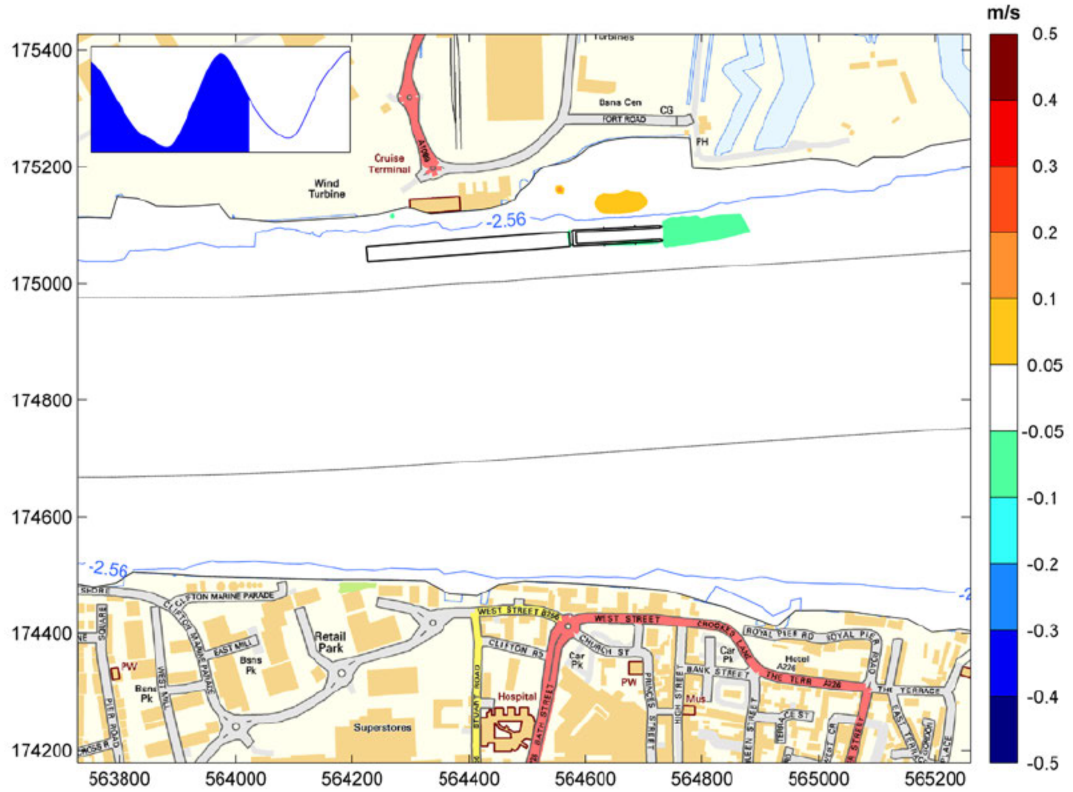


Figure 3.18: Difference in current magnitude at time of peak ebb tide at Tilbury site, all options

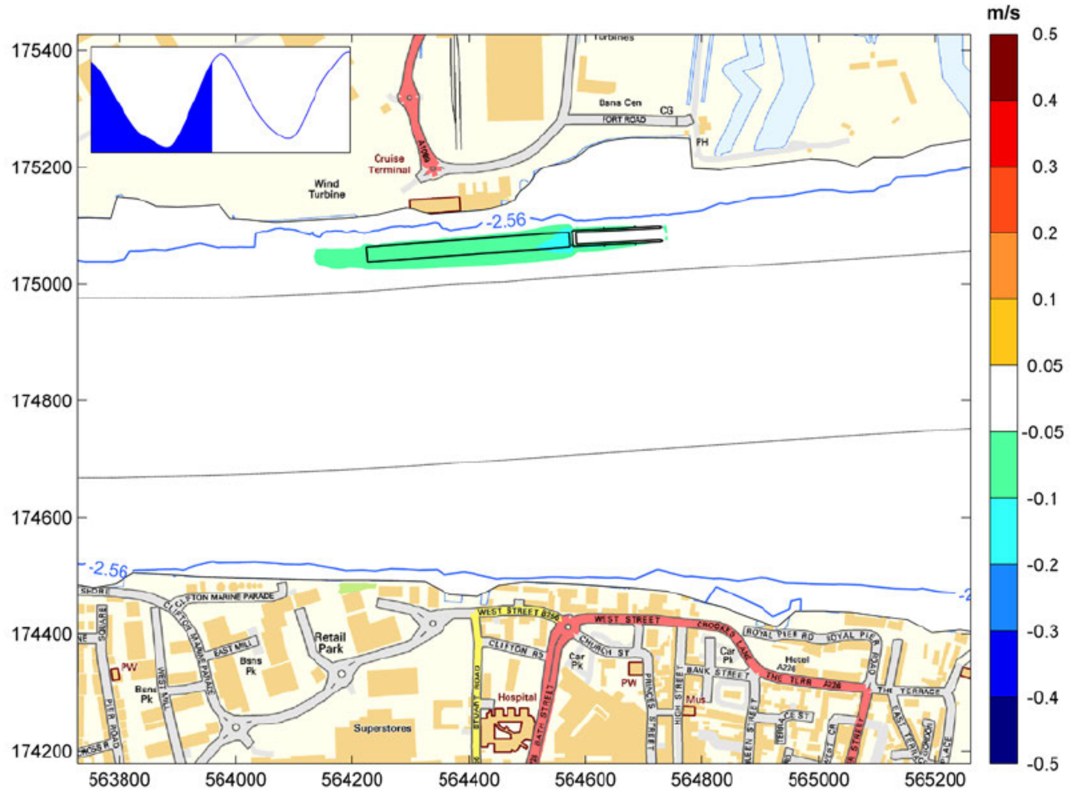


Figure 3.19: Difference in current magnitude at time of peak flood tide at Tilbury site, all options

3.8.6. Summary

None of the options have any hydrodynamic effect beyond the immediate vicinity of the structures. Of the proposed options for the Swanscombe ferry terminal site Option C, including a dredged area has the largest effect on hydrodynamics. The greatest footprint of change is 700 m (Option C).

The habitat creation areas being relatively high in the tidal frame do not include much tidal volume so any effect of the flow passing in and out of the areas is small. Some speed increases are shown by the modelling at the openings themselves and, as shown during the peak flood tide results, some areas of speed reduction can occur on the foreshore adjacent to the habitat areas. The pattern of change is the same for all options considered.

At Tilbury, the proposed pontoons act to impede the flow and reduce currents to either side of the structure. The effect is localized to be within 600 m of the proposed pontoons during the flood tide and within 200 m during the ebb.

4. Sedimentation modelling

4.1. Choice of model

To simulate fine cohesive (muddy) sediment transport, the TELEMAC-3D modelling was repeated including the transport of fine sediments. Coupling of TELEMAC-3D with mud transport is required in areas of high suspended sediment concentration such as the study area due to the suspended sediment concentration being high enough to influence the hydrodynamics via changes to density.

4.2. Boundary and initial conditions

Initial conditions for the simulations were required for fine sediment both in suspension and on the bed. The imposed initial conditions comprised a variation in depth averaged suspended sediment concentration ranging from 30 mg/l at Southend-on-Sea to a maximum of more than 500 mg/l near Crossness (approximately the estuarine turbidity maximum) then decreasing back below 100 mg/l in the upper Tideway. This distribution of fine sediment was enhanced by an initial 0.1 m layer of mud on the channel bed in the area from Gravesend to Woolwich. This bed material was intended to quickly erode and provide additional suspended sediment concentration in the muddiest reaches.

The boundary conditions were 30 mg/l at Southend-on-Sea and 0 mg/l for the river flow entering the tideway at Teddington.

4.3. Calibration and validation

HR Wallingford has been applying TELEMAC-3D coupled with fine sediment transport in the Thames at various times since a model was established in 2005 for the Environment Agency's TE2100 programme. The model was calibrated against the sediment flux data at a series of transects between Southend-on-Sea and central London such as that shown in Figure 2.5. The calibration of the model is reported in Baugh and Littlewood (2005). The validation of the model refined in the study area is shown in Figure 4.1 and Figure 4.2. These two plots compare the simulated and observed total sediment flux through sections at Gravesend Reach (Transect 10) and in Long Reach (Transect 9).

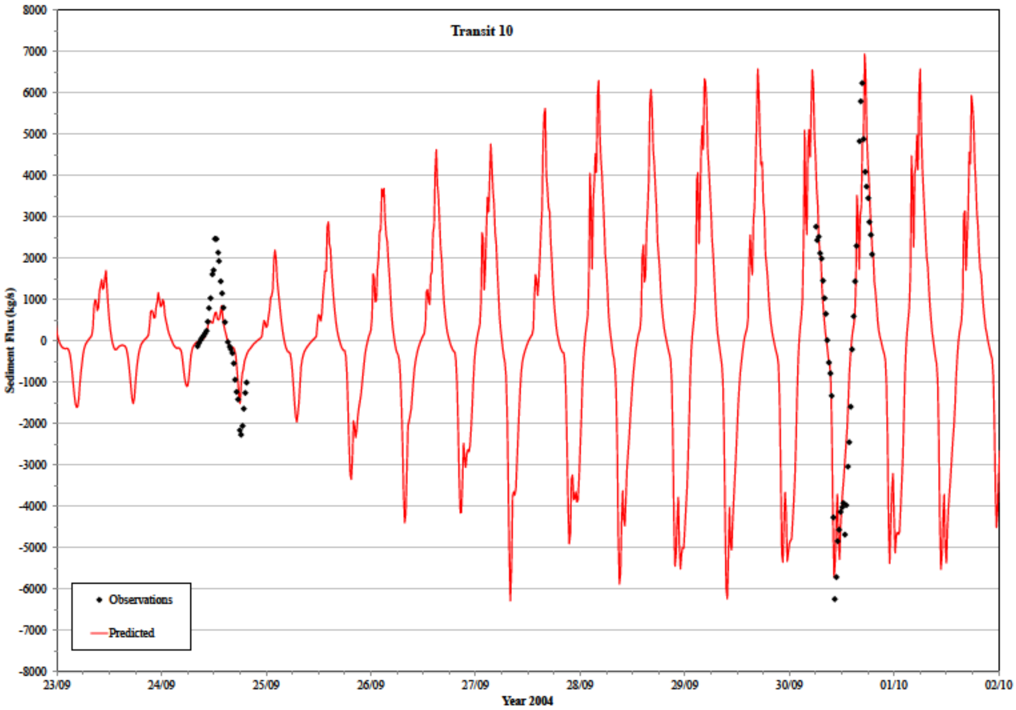


Figure 4.1: Comparison of observed and predicted total fine sediment flux at a transect in Gravesend Reach

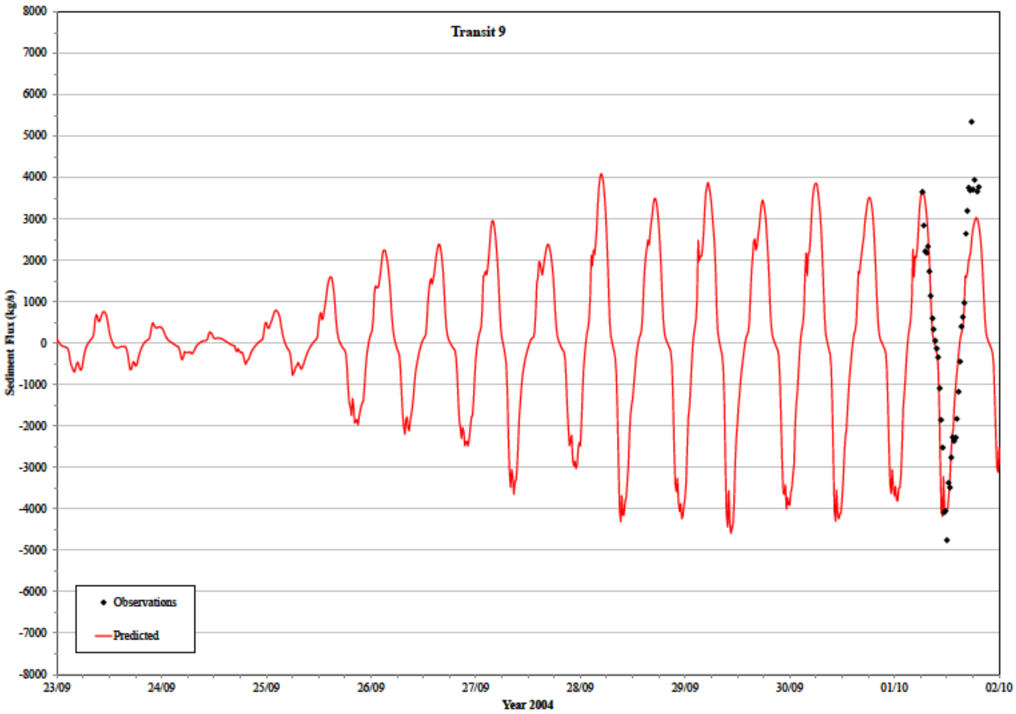


Figure 4.2: Comparison of observed and predicted total fine sediment flux at a transect in Long Reach

4.4. Results

The results of the simulations for the mud transport model are presented in a number of ways to inform the impact assessment:

- Bed type schematization based on maximum bed shear stress;
- Changes to maximum bed shear stress;
- Pattens of mean and maximum suspended sediment concentration;
- Patterns of erosion and sedimentation;
- Changes to patterns of erosion and sedimentation;
- Annualized sedimentation rates in areas which may require maintenance dredging.

The bed type schematization provides a first-order assessment of the implications of the predicted currents for the bed sediments and morphology of the area by analysis of the type of bed material that would be expected for the bed shear stress generated by the currents alone.

The bed shear stress is the force of the passing flow on the riverbed and is used as a measure of the potential for the bed to be eroded or to allow sediment moving as bed load or in the water column to settle onto the bed. To allow comparison of the results the predicted peak bed shear stresses have been coloured according to the type of material that would be expected to be present for the given peak bed shear stress.

For lower values of peak bed shear stress two colour bandings were used; one for bed shear stress low enough to allow long term accretion (build up) of fine sediment on the bed; and a second colour band for bed shear stresses which would allow some fine sediment deposition. For higher values of bed shear stress three bandings were used based on the critical stress required to mobilise sediments of diameter 5 mm, 10 mm and 20 mm.

The figures are coded to the following colours:

- Orange - Bed Stress values allowing fine sediment accumulation;
- Yellow - Bed stress values allowing occasional fine sediment accretion;
- Blue - Bed stress values appropriate for sand and gravel up to 5 mm;
- Pink - Bed stress values appropriate for gravels 5 mm – 10 mm;
- Purple - Bed stress values appropriate for gravels 10 mm – 20 mm;
- Red - Bed stress values appropriate for gravels 20 mm+.

In reality the riverbed is likely to be stronger than that predicted by consideration of sediment size alone. The presence of cohesive sediments would also be expected to reduce sediment movement. Allowing for the above caveats, this simple methodology is considered to be a useful tool to investigate where the bed may experience a change in currents sufficient to allow a change in the bed material, either by a reduction in peak bed shear stress allowing finer sediments to settle or an increase in peak bed shear stress reducing the proportions of finer sediment settling or potentially winnowing out finer sediment from the bed.

4.4.1. Baseline

The results for the sediment modelling of the baseline case are presented in Figure 4.3 to Figure 4.8.

The bed material schematisation at Swanscombe (Figure 4.3) shows that a mix of sediments would be expected to be present with bed shear stresses low enough to allow fine sediment accretion along the riverbank, bed shear stresses increasing towards the channel and the bed material to be expected becomes coarser up to gravels in the range 10 – 20 mm. In the area of the development fine sediment is indicated along the riverbank and under Bell Wharf with the remainder of the development area likely to comprise a mix of sand and gravel up to a diameter of 5 mm. At the Tilbury site the channel is shown as gravel 5-10 mm; close to the pontoons sand and fine gravel is predicted. Close to the river bank some fine sediment settling is predicted.

The baseline suspended sediment concentration (SSC) is shown by Figure 4.5 and Figure 4.6. The area is well known as a location of high SSC as indicated by the plots. Maximum depth averaged SSC of more than 1 kg/m^3 (1000 mg/l) are shown although it should be remembered that significant differences in SSC from surface to bed occur – most of the fine sediment will be expected to be found close to the seabed. The time averaged SSC (Figure 4.6) was calculated over the whole spring-neap cycle (noting the highest SSC would be expected during the spring tide period). Depth averaged values of the order of 0.3 kg/m^3 (300 mg/l) are shown confirming the view of the site as one of high fine sediment fluxes.

The baseline prediction of patterns of bed level change are shown for the Swanscombe area in Figure 4.7 and around the Tilbury site in Figure 4.8. It should be noted that these patterns of bed change assume the bed can erode and supply additional material – as such it is a precautionary view of the fine sediment supply to the development site. The high currents at the site shows very fine sediment can deposit in a limited number of areas – the largest being between the channel and the riverbank line at Swanscombe. At the ferry terminal site itself little bed change is shown. Similarly the intertidal areas fronting the habitat creation areas are shown to be, in general, stable.

At the Tilbury site (Figure 4.8) some accumulation of sediment is shown on the intertidal areas to the north of the proposed pontoon site. Any fine sediment in the area south of the pontoon site is predicted to erode.

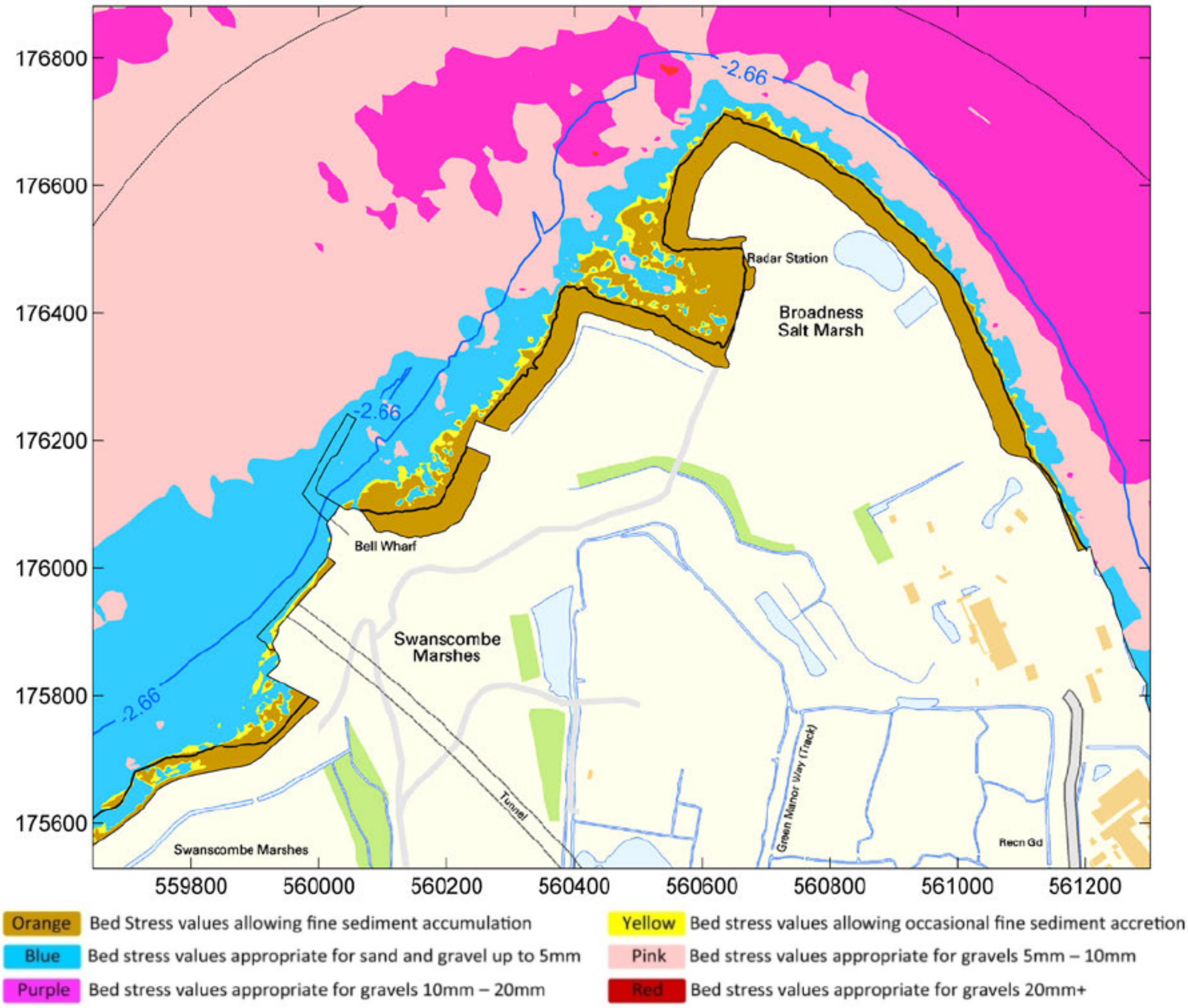
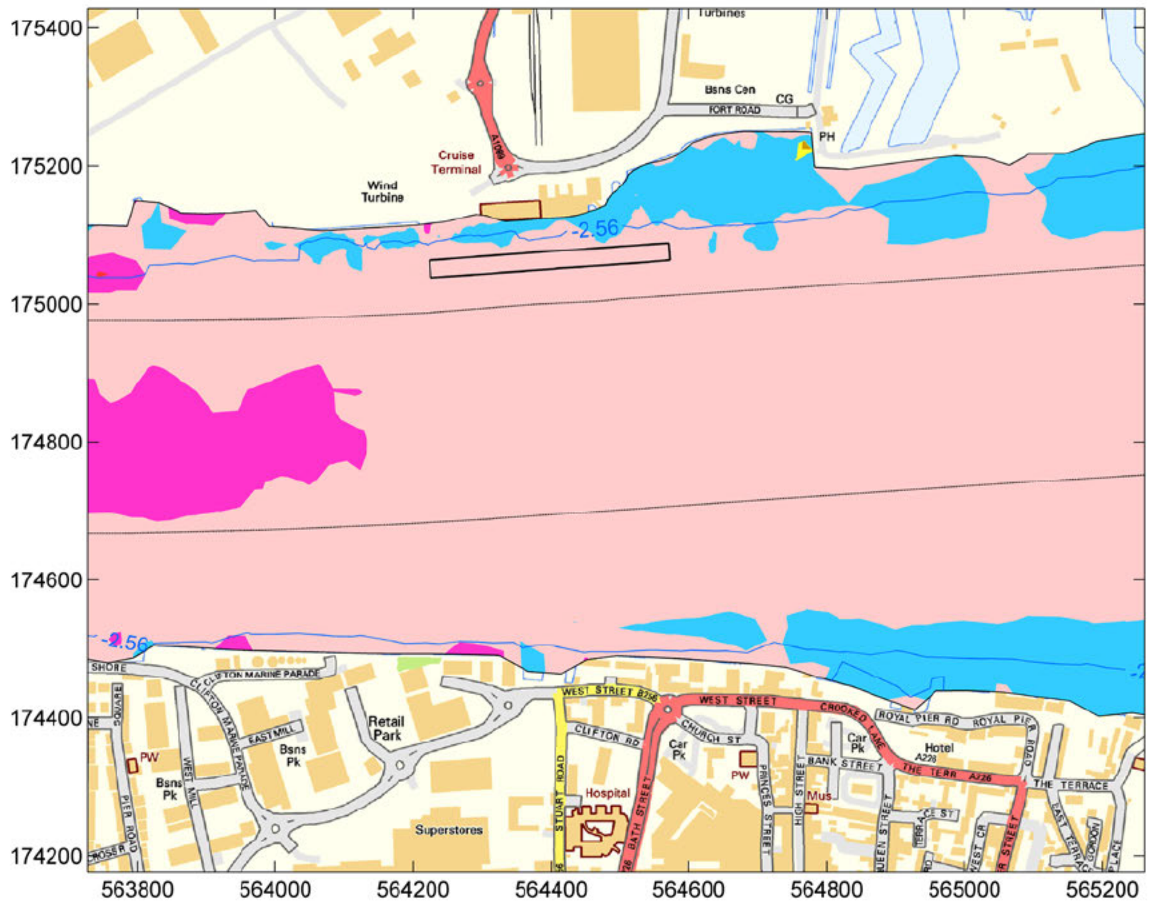


Figure 4.3: Bed types schematization, Baseline



Orange	Bed Stress values allowing fine sediment accumulation	Yellow	Bed stress values allowing occasional fine sediment accretion
Blue	Bed stress values appropriate for sand and gravel up to 5mm	Pink	Bed stress values appropriate for gravels 5mm – 10mm
Purple	Bed stress values appropriate for gravels 10mm – 20mm	Red	Bed stress values appropriate for gravels 20mm+

Figure 4.4: Bed types schematization at Tilbury, Baseline

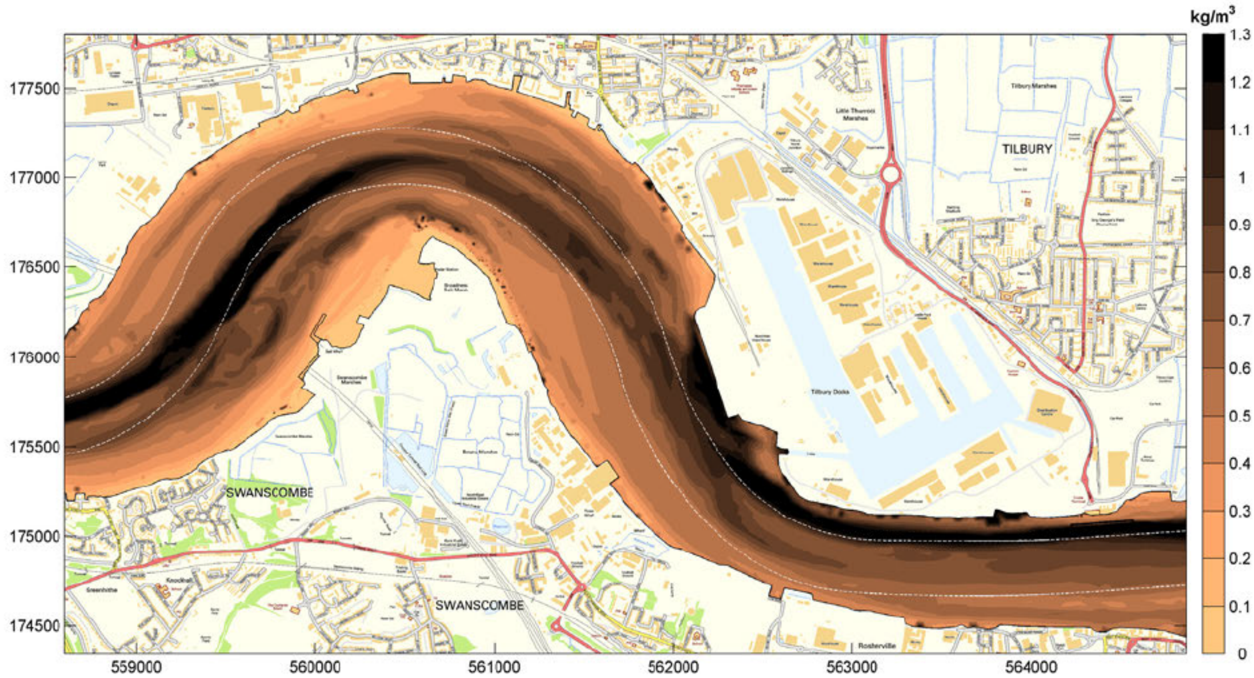


Figure 4.5: Maximum depth averaged suspended sediment concentration, Baseline

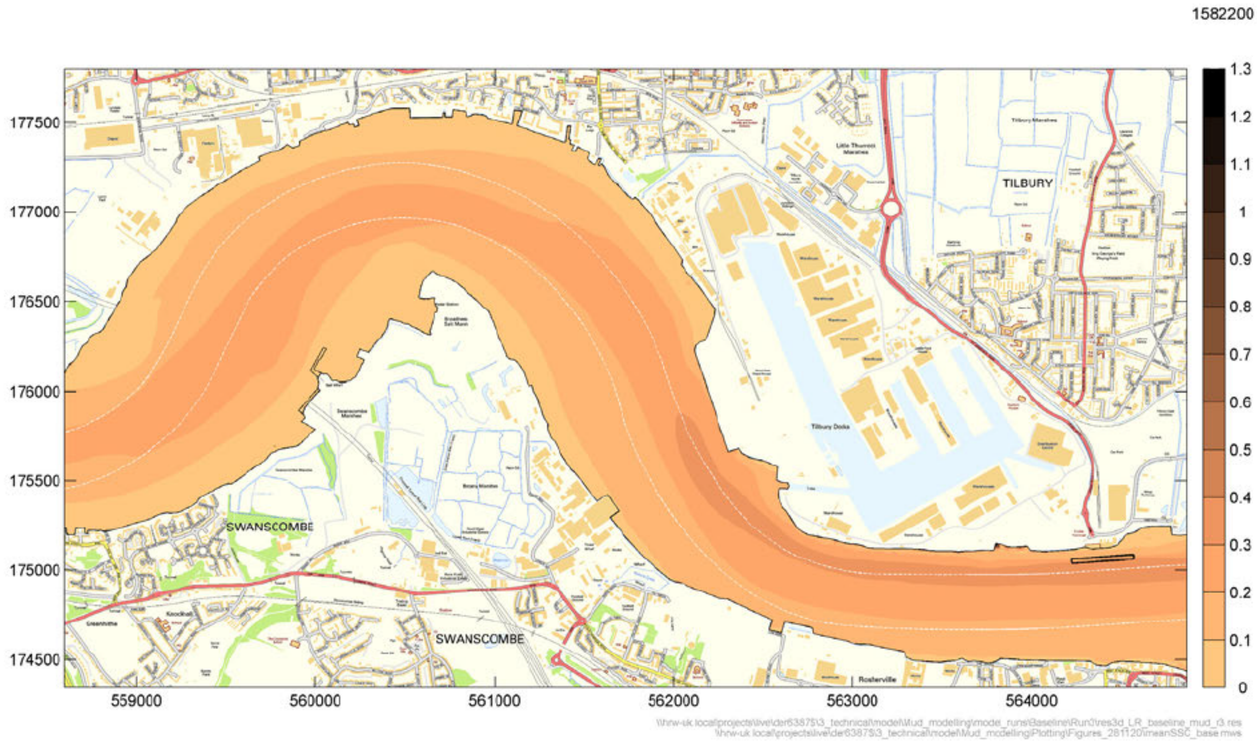


Figure 4.6: Mean depth averaged suspended sediment concentration, Baseline

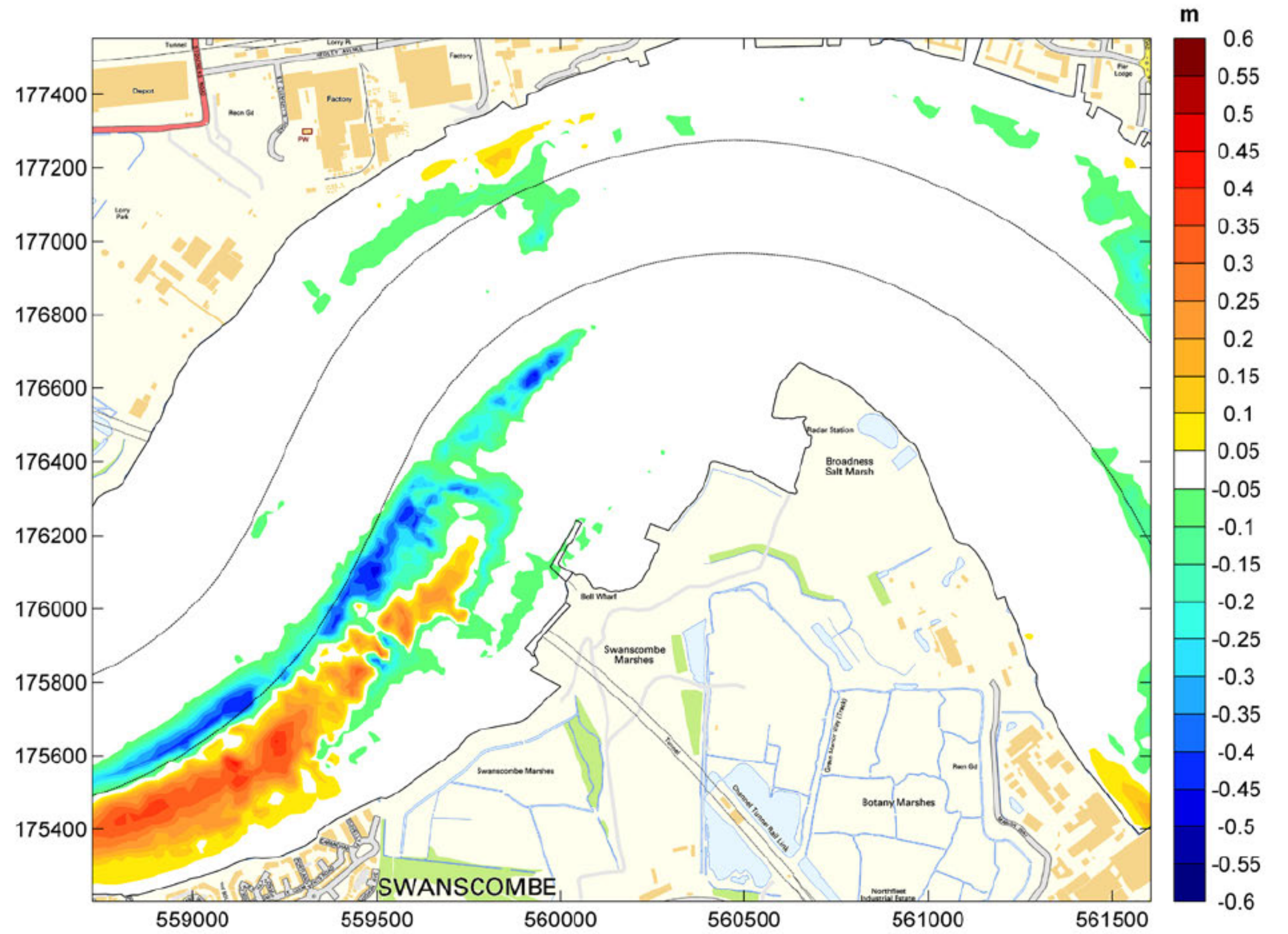


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Figure 4.7: Predicted patterns of erosion and deposition at Swanscombe, Baseline

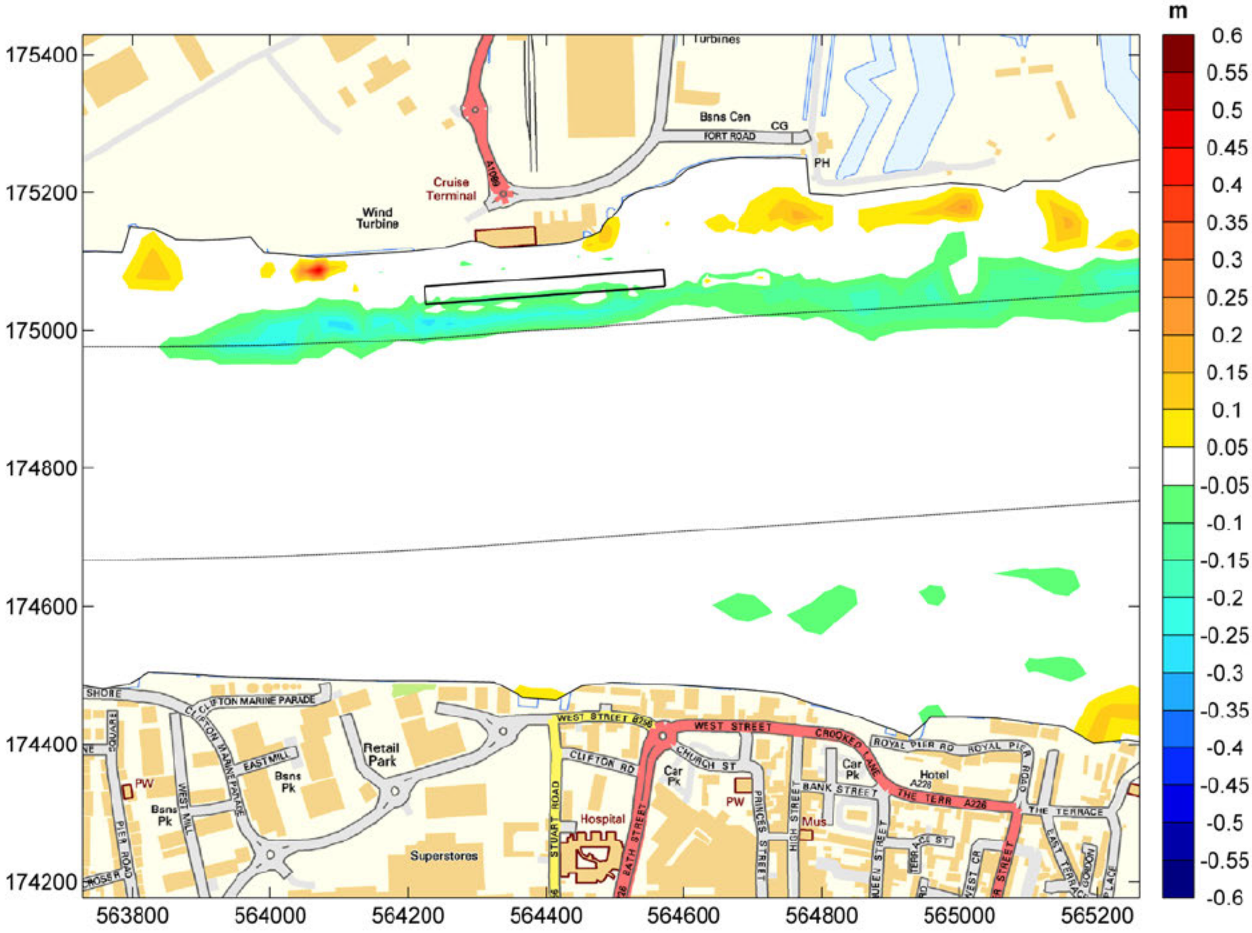


Figure 4.8: Predicted patterns of erosion and deposition at Tilbury, Baseline

4.4.2. Option A

The bed schematisation plot for Option A (Figure 4.9) shows a potential coarsening of the bed material under the passenger pontoon at the SW of the site. This is due to the increased bed shear stress caused by the low minimum water depths under the pontoon. Any bed change here will depend on what sediment is already present. North-east of the RO-RO the contour delimiting the 5 mm gravel is slightly moved towards the bank line. This is illustrated by Figure 4.10 which shows a reduction in peak bed shear stress NE of White's Jetty. Other than these areas of change Figure 4.10 indicates an increase in peak bed shear stress at the entrances to the habitat creation areas and odd spots of reduced peak bed shear stress in the areas around the entrances.

The maximum and mean SSC for Option A as plotted in Figure 4.11 and Figure 4.12 are almost identical to the baseline case. As might be expected for a development of the scale proposed no widespread effect on the fine sediment regime of the area is anticipated.

The maximum SSC plotted on Figure 4.11 shows the four habitat creation sites on the east of the peninsula are more able to receive SSC carried in with the tide than the two sites on the west of the peninsula. This is likely to be due to the flood tide eddy that means any flow has to pass through an area of low currents before it can supply sediment to the habitat areas. During this transit more of the fine sediment is likely to have already been deposited.

The implications of the development for patterns of erosion and deposition are shown by Figure 4.13. Care should be taken on these plots of change as a positive change could equally well represent a reduction in erosion as an increase in deposition. Figures such as Figure 4.13 should be considered bearing in mind the prediction of the baseline bed change as shown by Figure 4.7. In this case the site of the RO-RO pontoon shows as a positive change however in Figure 4.7 the area is seen as an area of potential erosion; hence this prediction is a reduction in the potential for erosion rather than deposition. This view matches the bed schematisation shown in Figure 4.9 which indicates the peak bed shear stresses as too high to allow fine sediment accumulation at the RO-RO pontoon site.

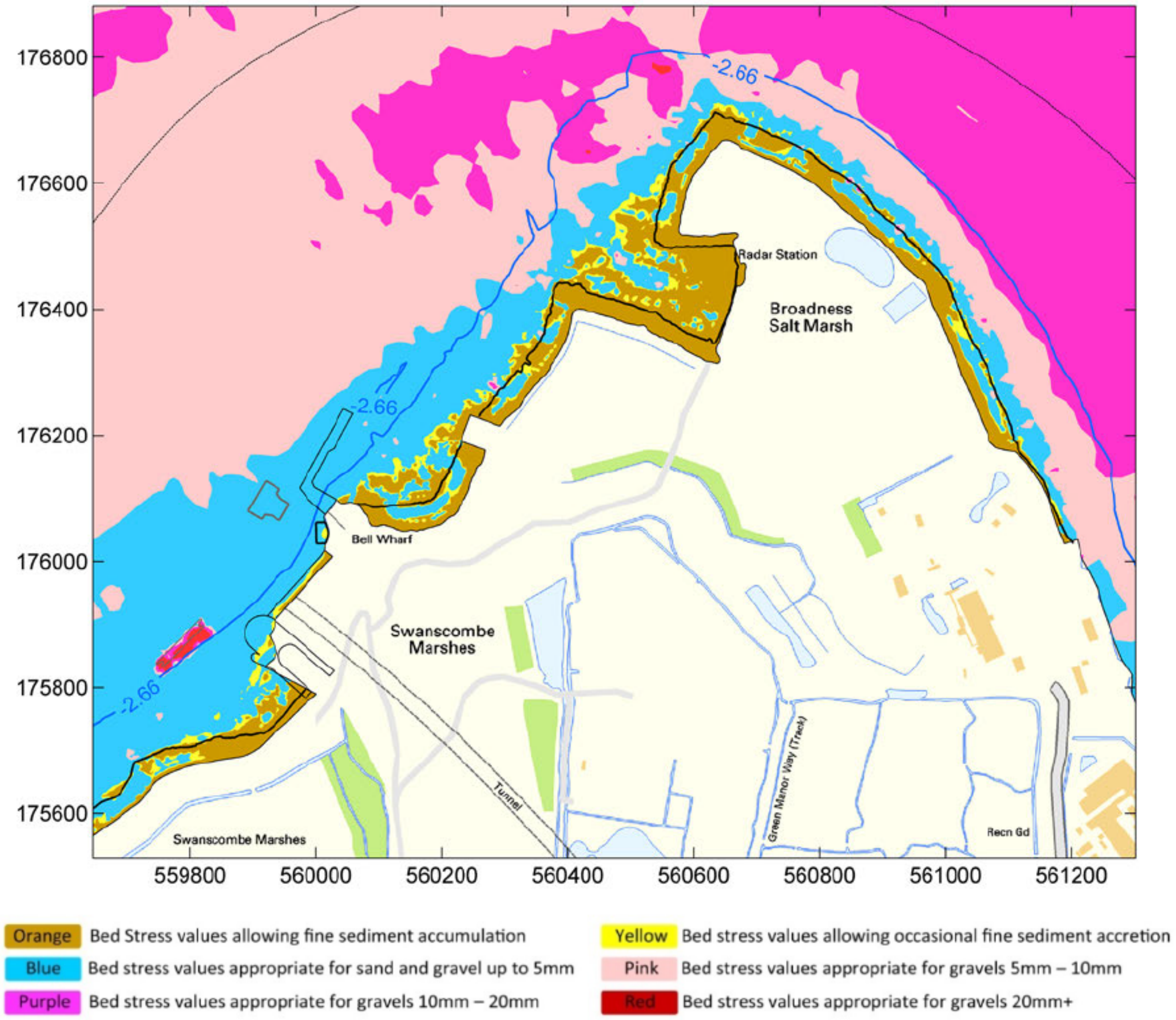


Figure 4.9: Bed types schematization, Option A

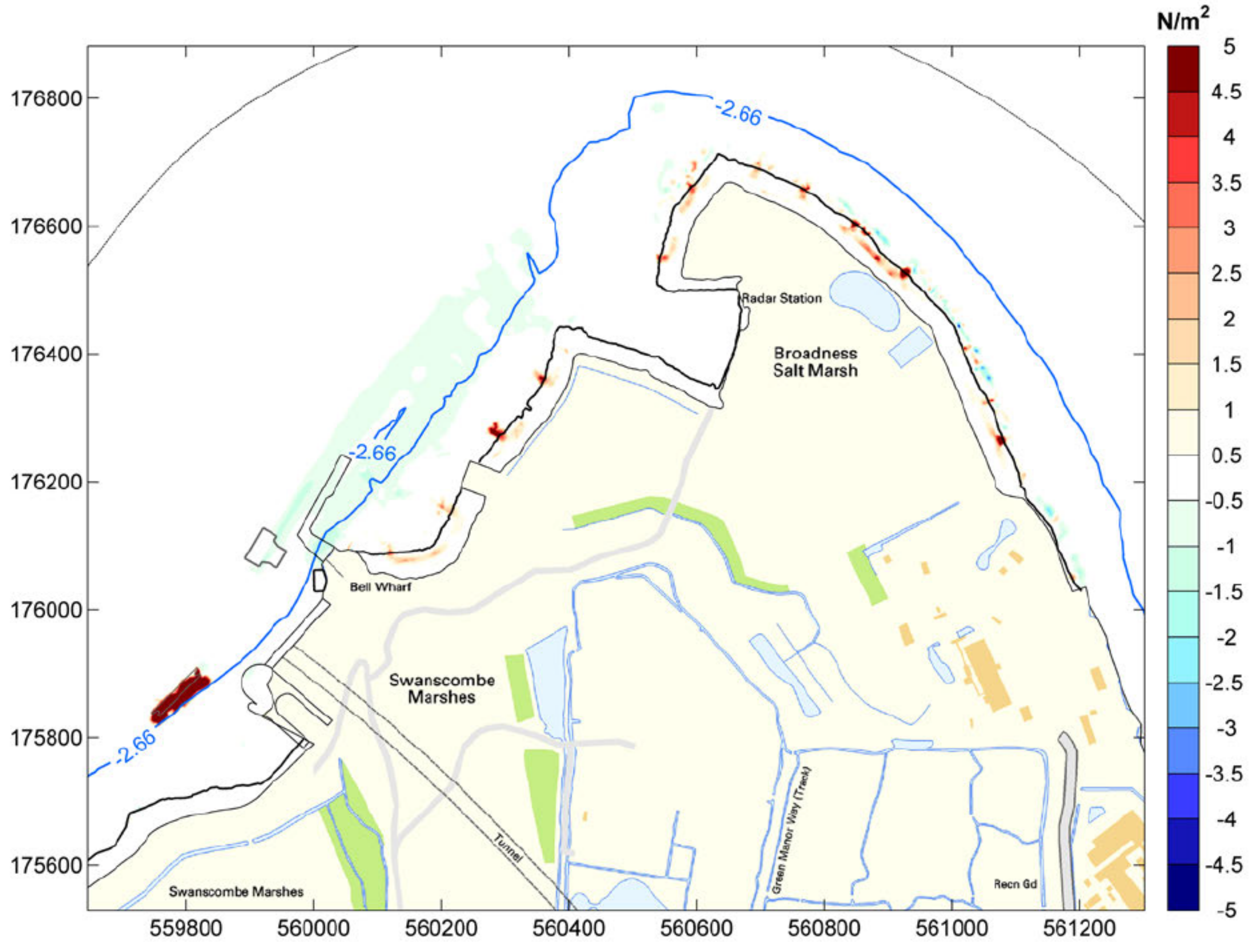


Figure 4.10: Predicted change to maximum bed shear stress, Option A

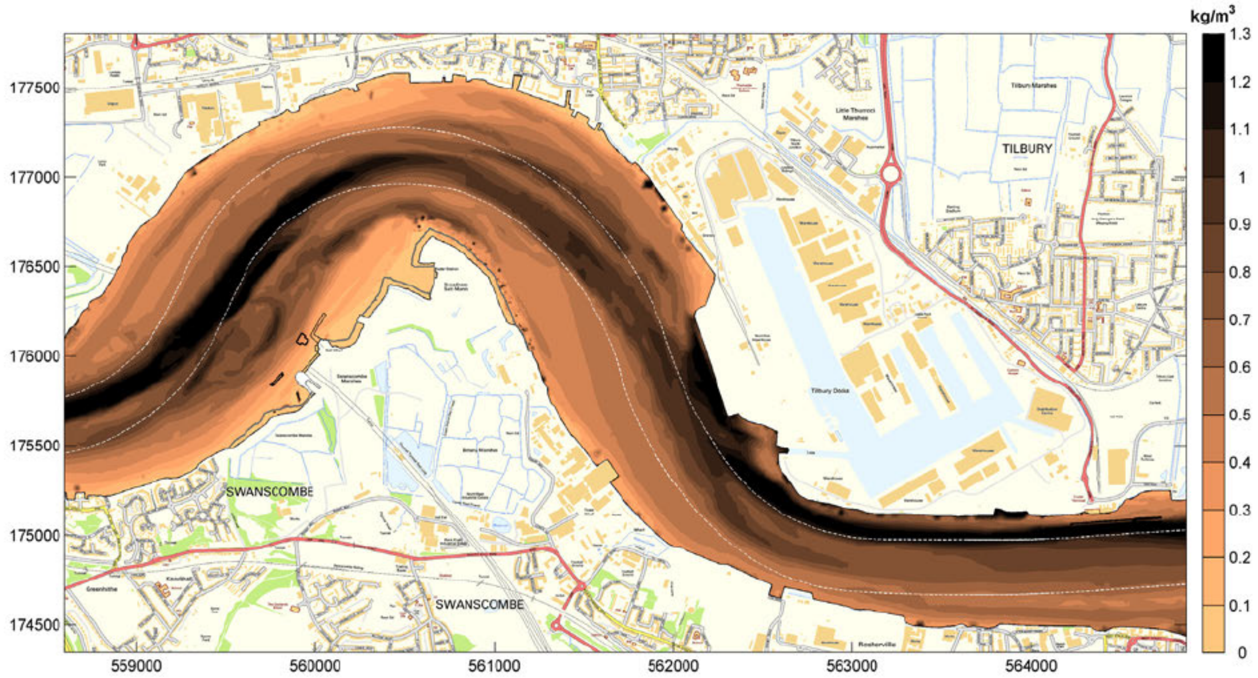


Figure 4.11: Maximum depth averaged suspended sediment concentration, Option A

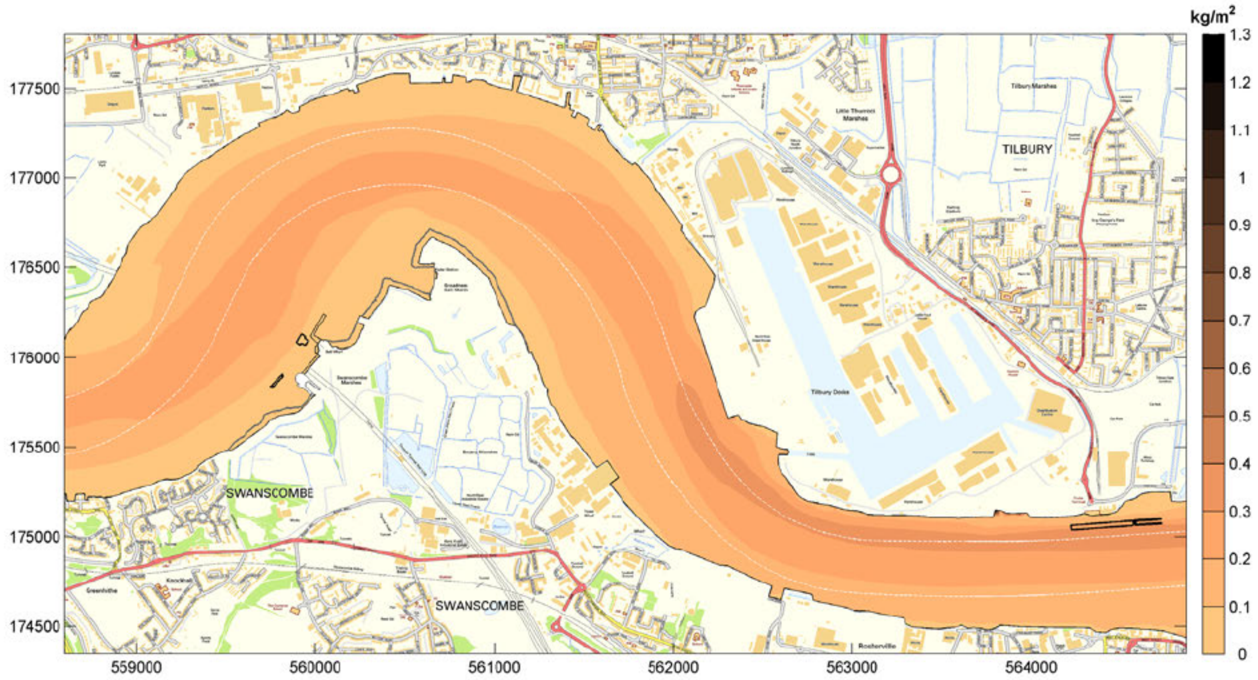


Figure 4.12: Mean depth averaged suspended sediment concentration, Option A

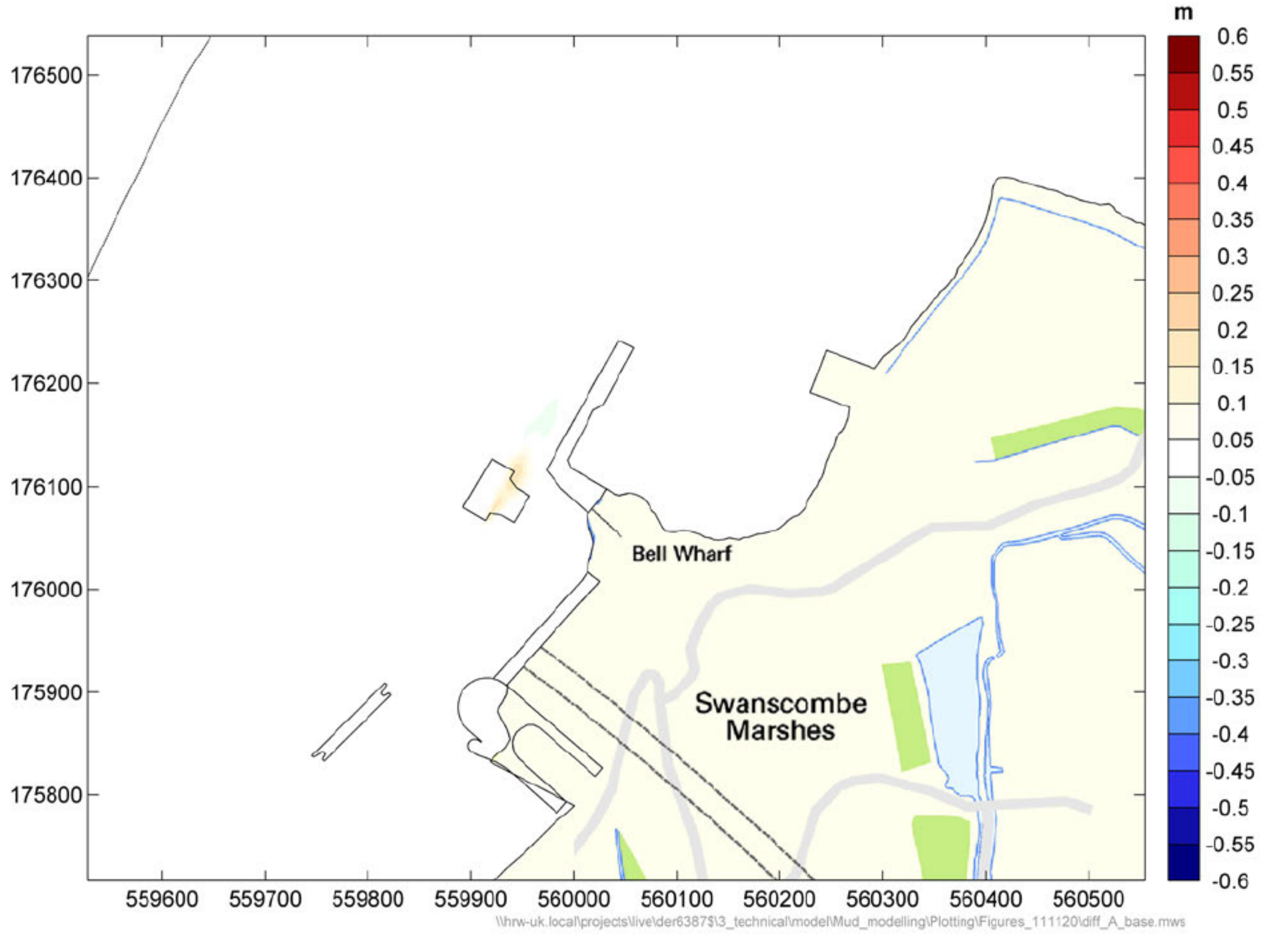


Figure 4.13: Predicted changes to patterns of erosion and deposition, Option A

4.4.3. Option B

The sedimentation modelling results are shown for Option B in Figure 4.14 to Figure 4.18.

As indicated by the hydrodynamic modelling the effect of Option B on peak bed shear stress (Figure 4.15) and hence on bed material schematisation (Figure 4.14) is a reduced version of the effect of Option A.

The results show a small area of riverbed to the NE of White's Jetty may experience an increase in the presence of finer gravel (<5 mm). The effects at the passenger pontoon and at the habitat creation areas are the same as seen for Option A.

As for Option A no effect on the levels of SSC is predicted for Option B (Figure 4.16 and Figure 4.17).

The reduced impact on the hydrodynamics for Option B is reflected in a reduced impact of the patterns of bed change. Almost no change is seen, there is small area with an increase in potential erosion under White's Jetty, but this is not considered as a significant change.

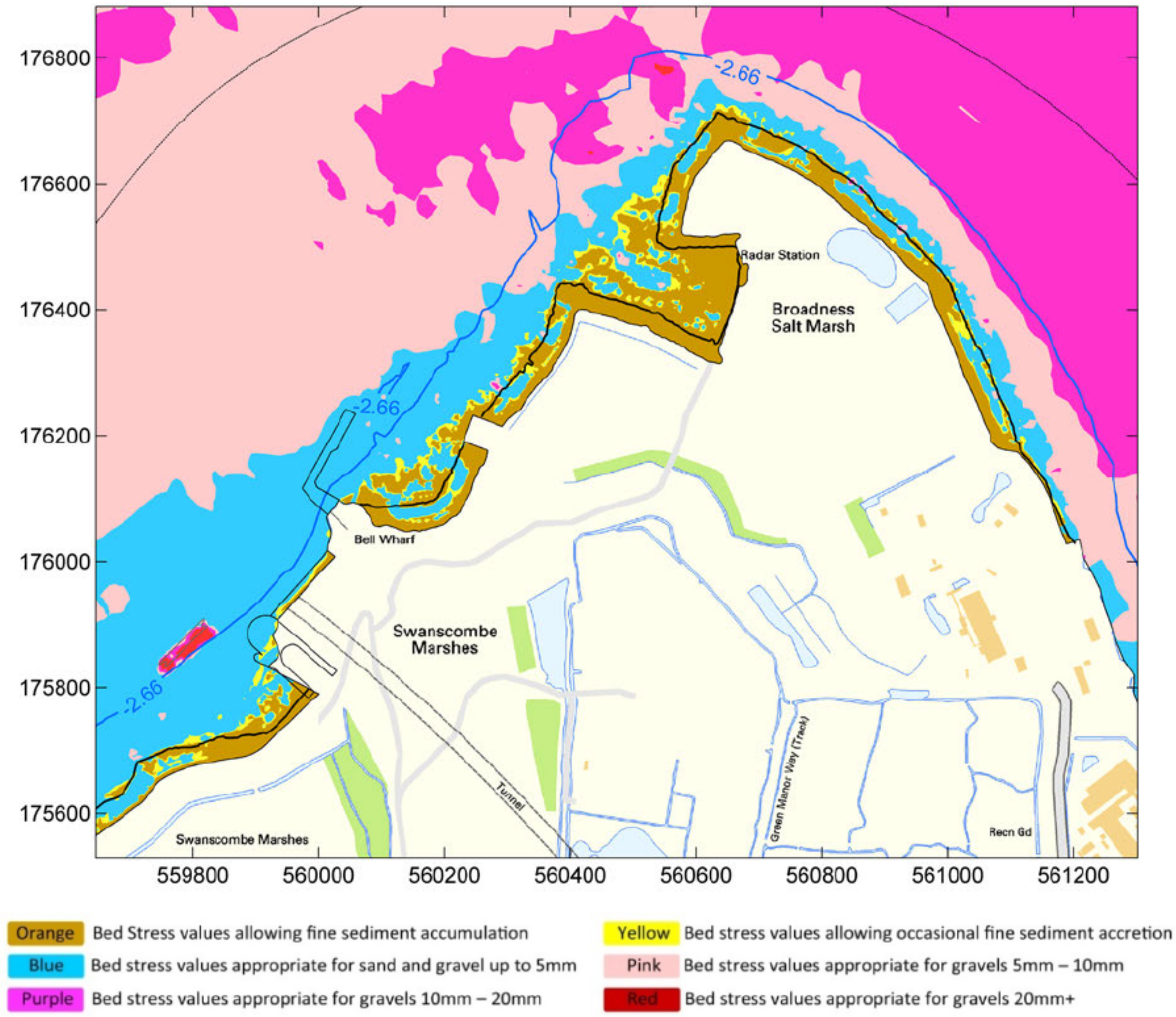


Figure 4.14: Bed types schematization, Option B

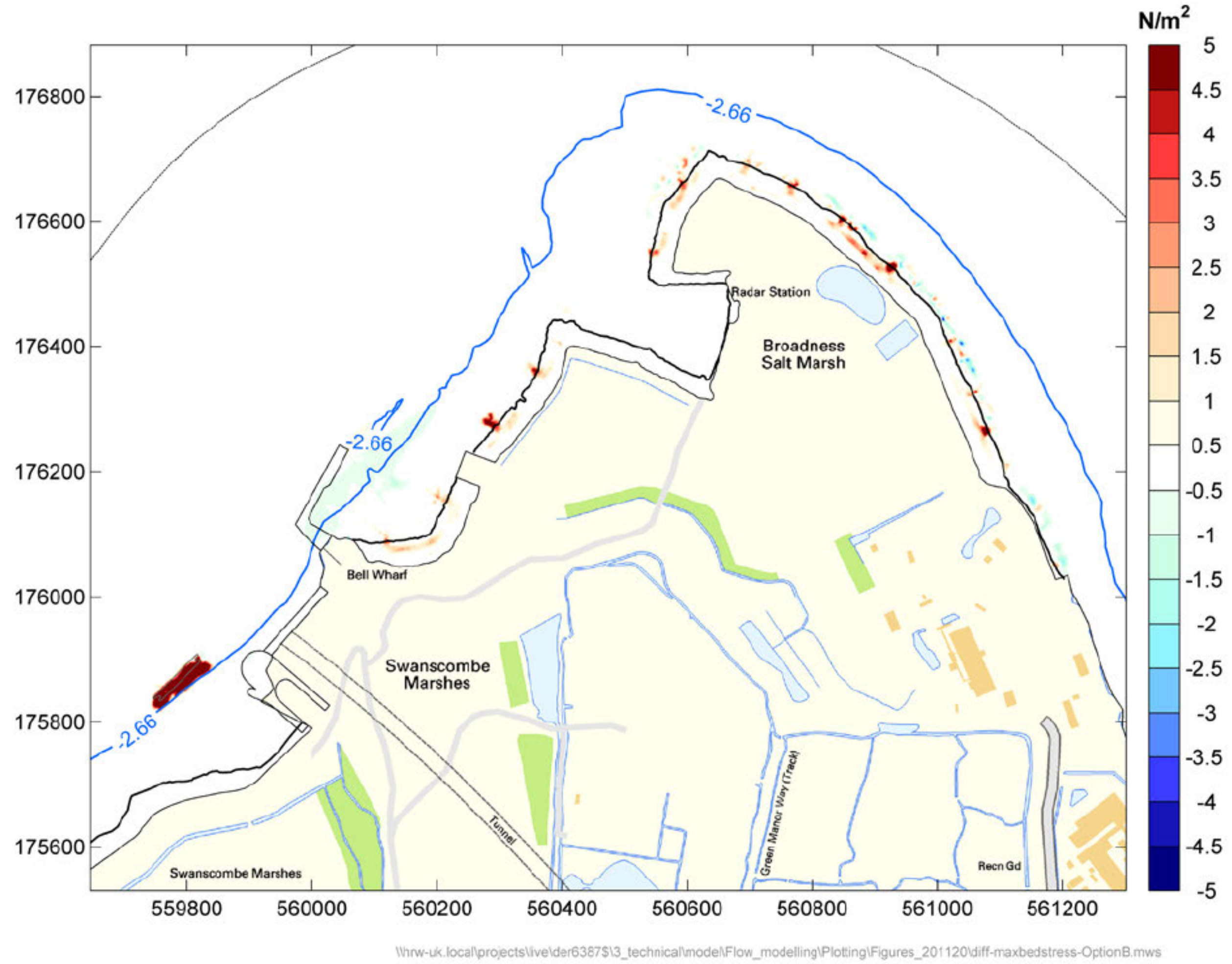


Figure 4.15: Predicted change to maximum bed shear stress, Option B

Figure 4.16: Maximum depth averaged suspended sediment concentration, Option B

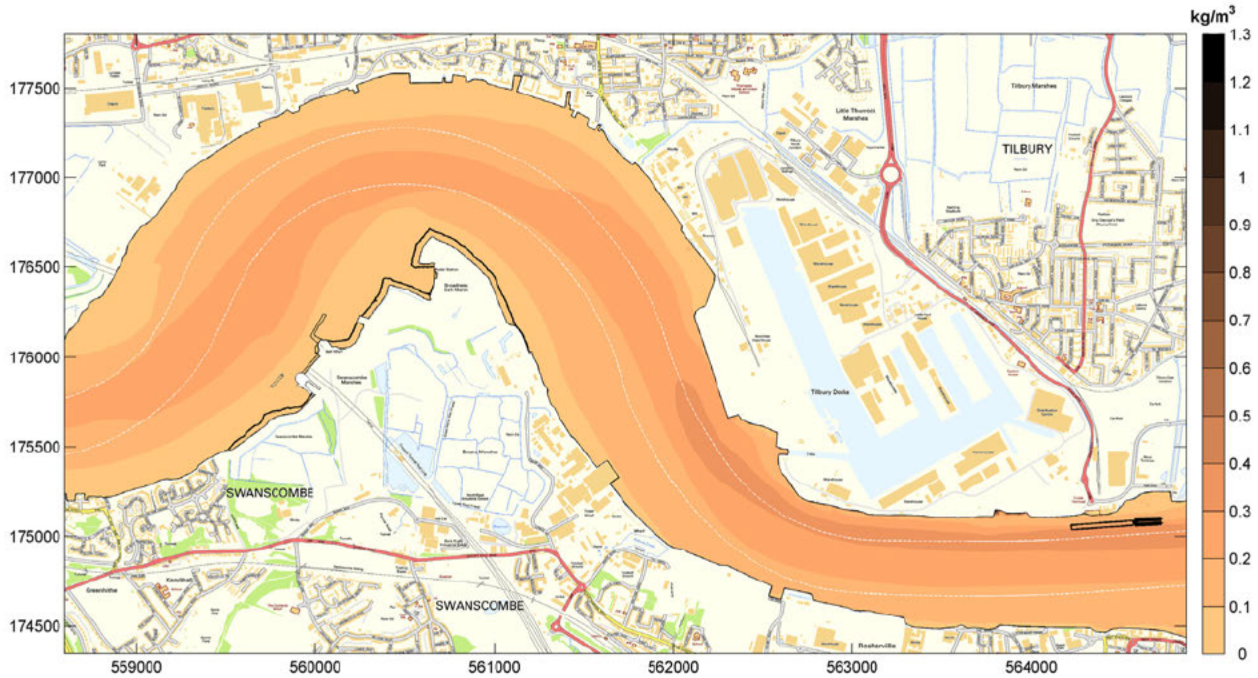


Figure 4.17: Mean depth averaged suspended sediment concentration, Option B

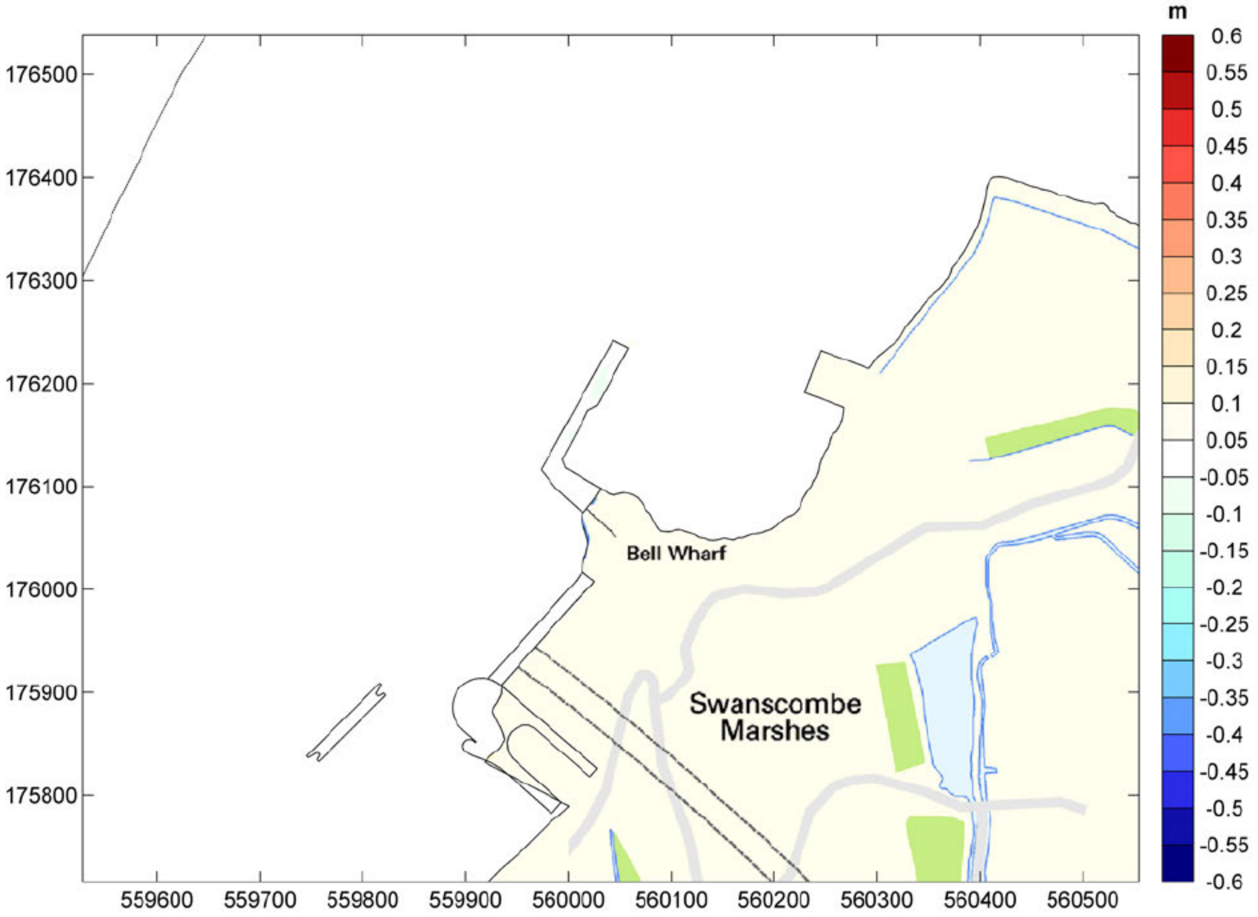


Figure 4.18: Predicted changes to patterns of erosion and deposition, Option B

4.4.4. Option C

The dredging associated with Option C reduces the peak bed shear stress in the dredged area (Figure 4.20) which suggests a risk of fine sediment accumulation (Figure 4.19). The dredging also has an effect on the bed shear stress at the passenger pontoon with a small additional area of coarsening predicted extending west from the NE corner of the pontoon. NE of White's Jetty the extent of the effect is reduced compared to both Option A and B. At the habitat creation areas the changes in bed shear stress are the same as for the other options.

Option C has no discernible effect on SSC (Figure 4.21 and Figure 4.22).

The risk of sediment accumulation in the dredged area is shown by the plot of changes to the pattens of erosion and deposition (Figure 4.23). A proportion of this change is a reduction of the erosion shown in the baseline conditions (Figure 4.7), however the change is sufficient to allow accumulation of fine sediment. The total volume of accumulation in the dredged area for Option C over the spring-neap cycle simulated was 1179 m^3. If this continued for a whole year it would be an annual rate of 29,700 m^3/year. This is a precautionary estimate as the infill rate would be expected to reduce as the dredge area filled. Furthermore the forces in the bed due to vessels operating in the dredged area would be expected to resuspended sediment and reduce this infill total.

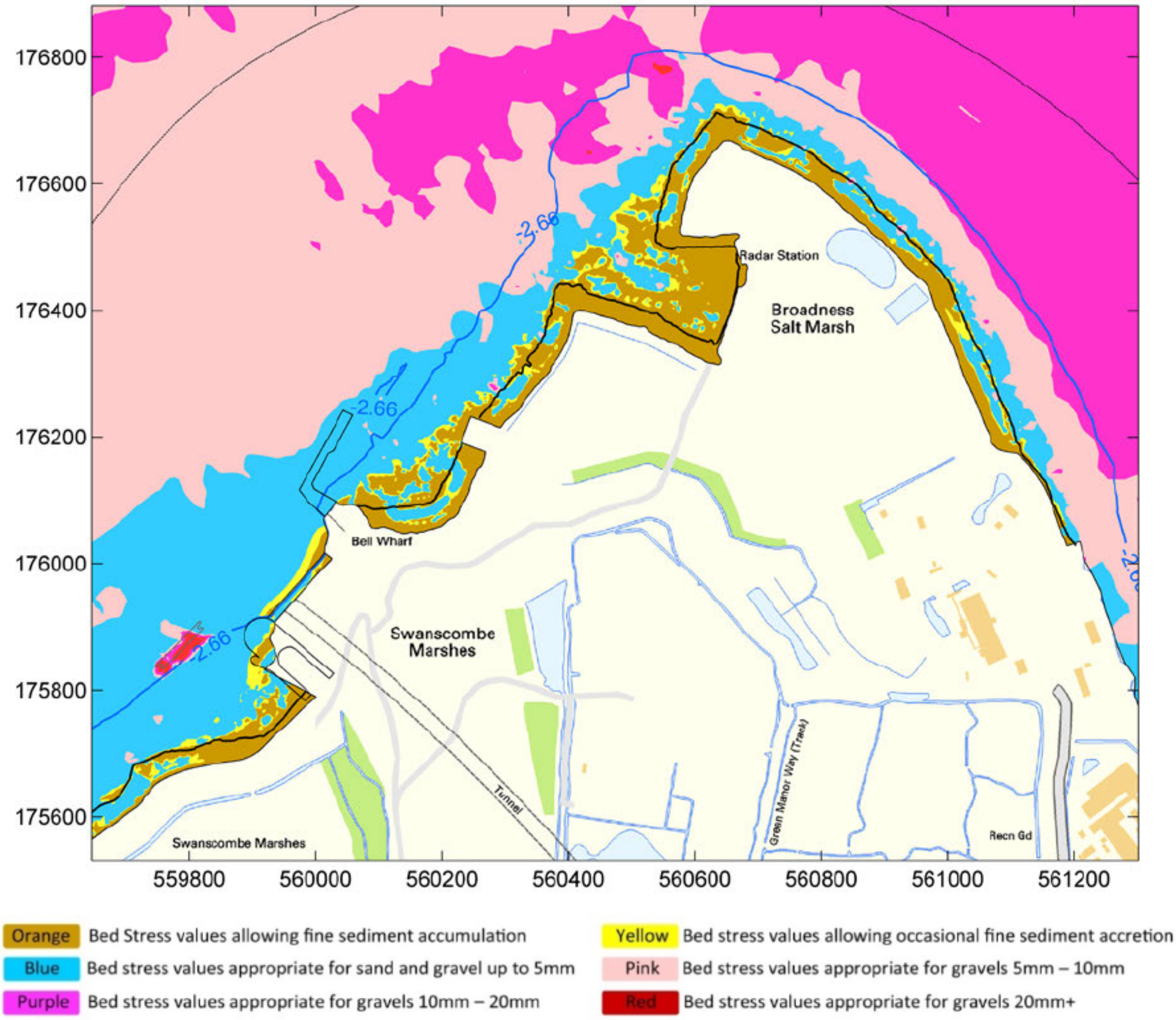


Figure 4.19: Bed types schematization, Option C

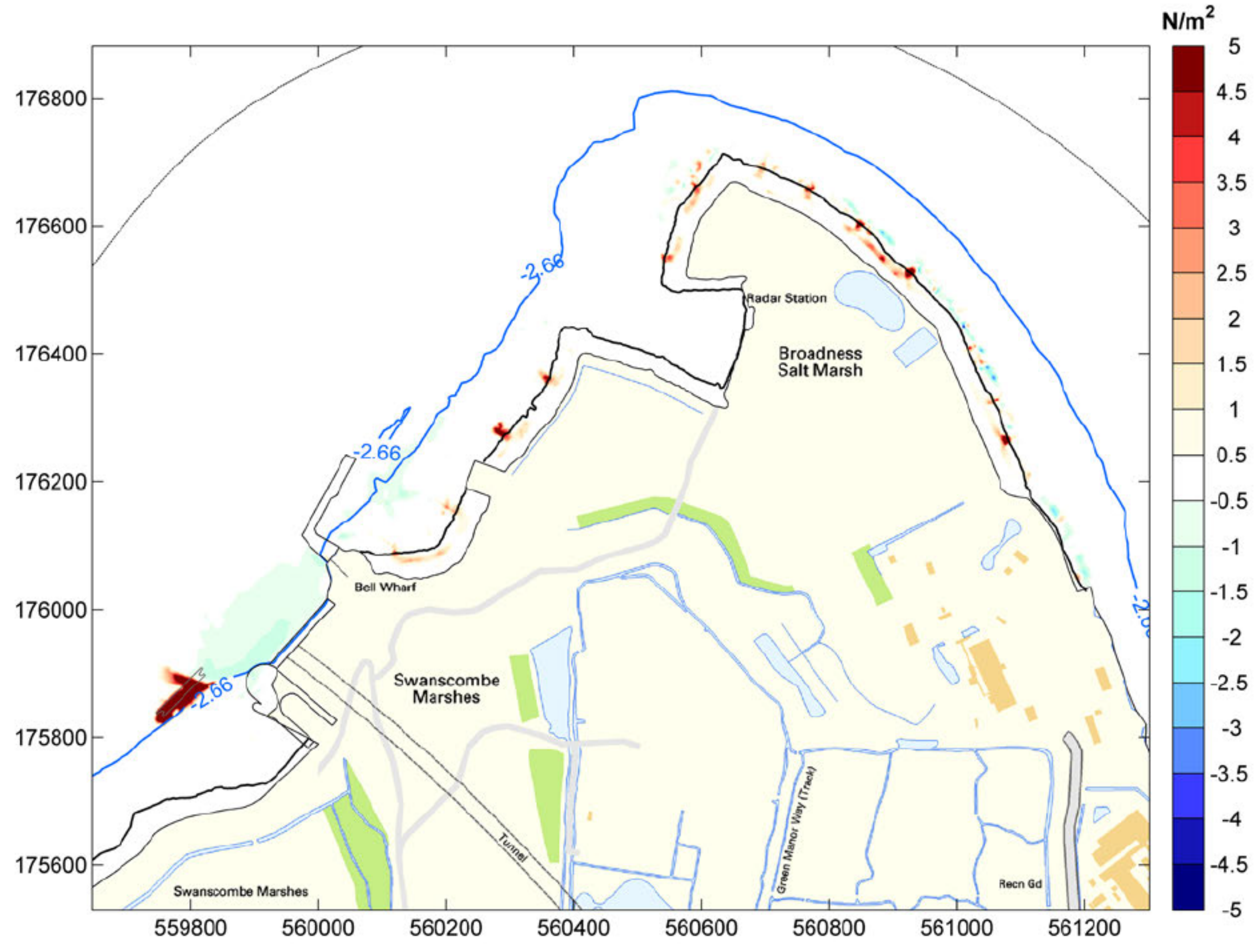


Figure 4.20: Predicted change in maximum bed shear stress, Option C

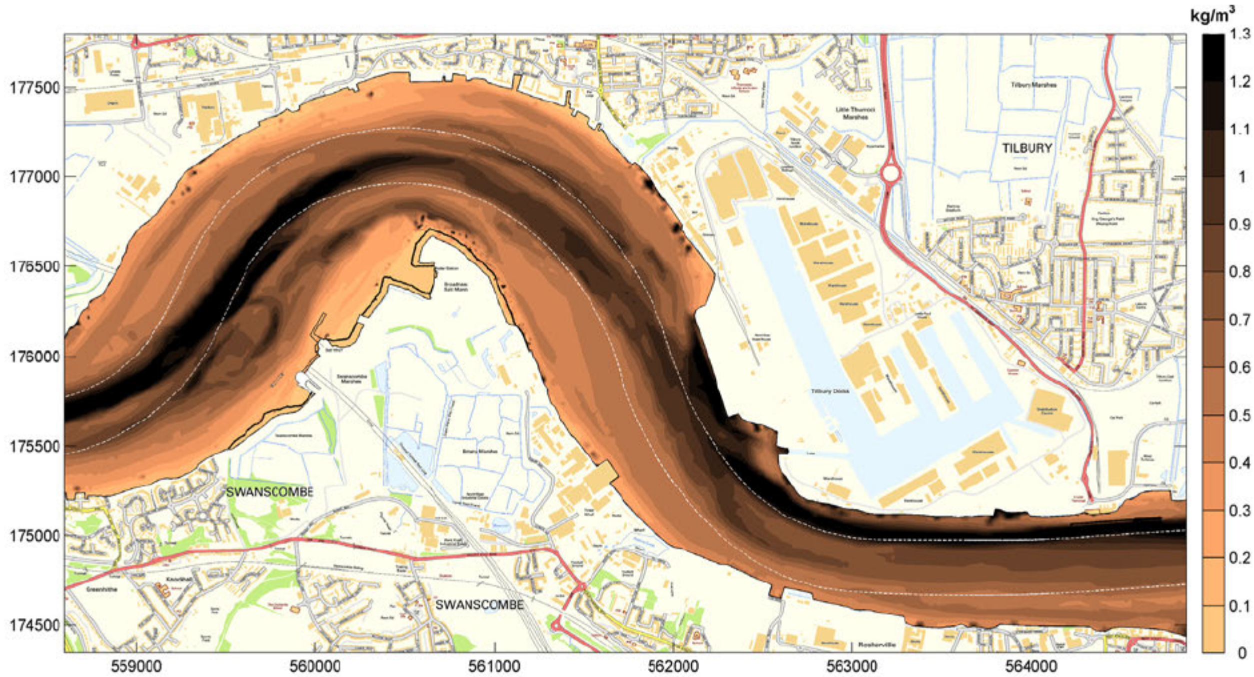


Figure 4.21: Maximum depth averaged suspended sediment concentration, Option C

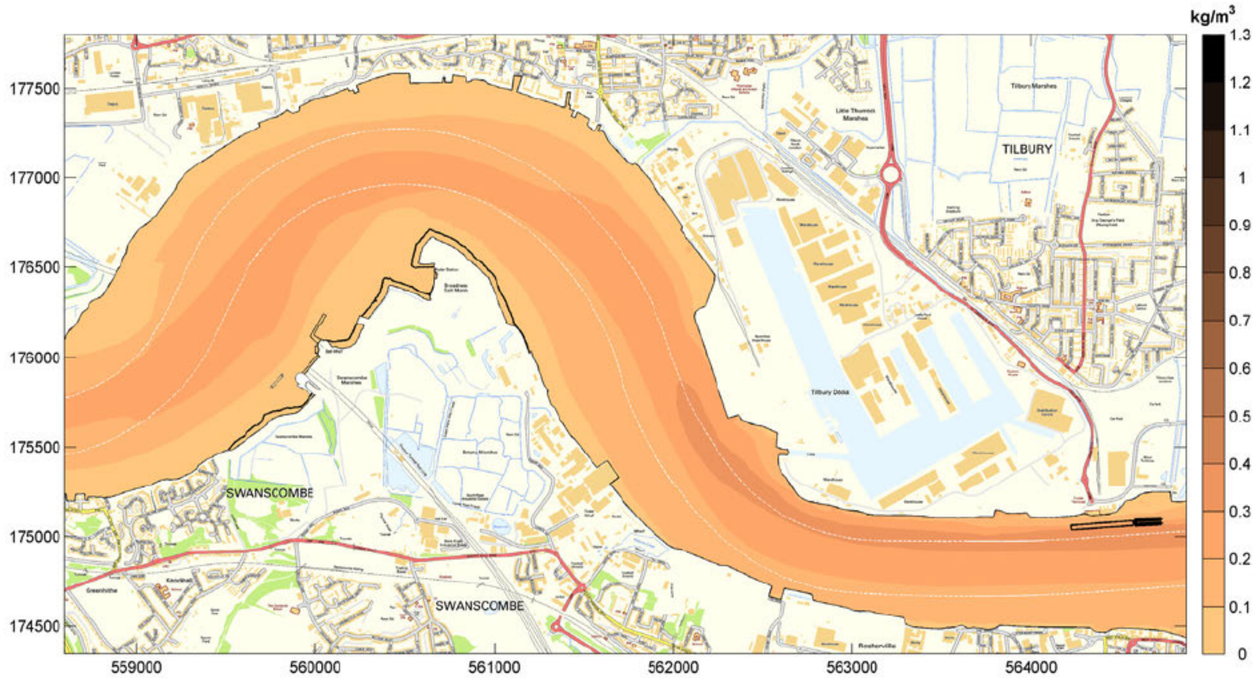


Figure 4.22: Mean depth averaged suspended sediment concentration, Option C

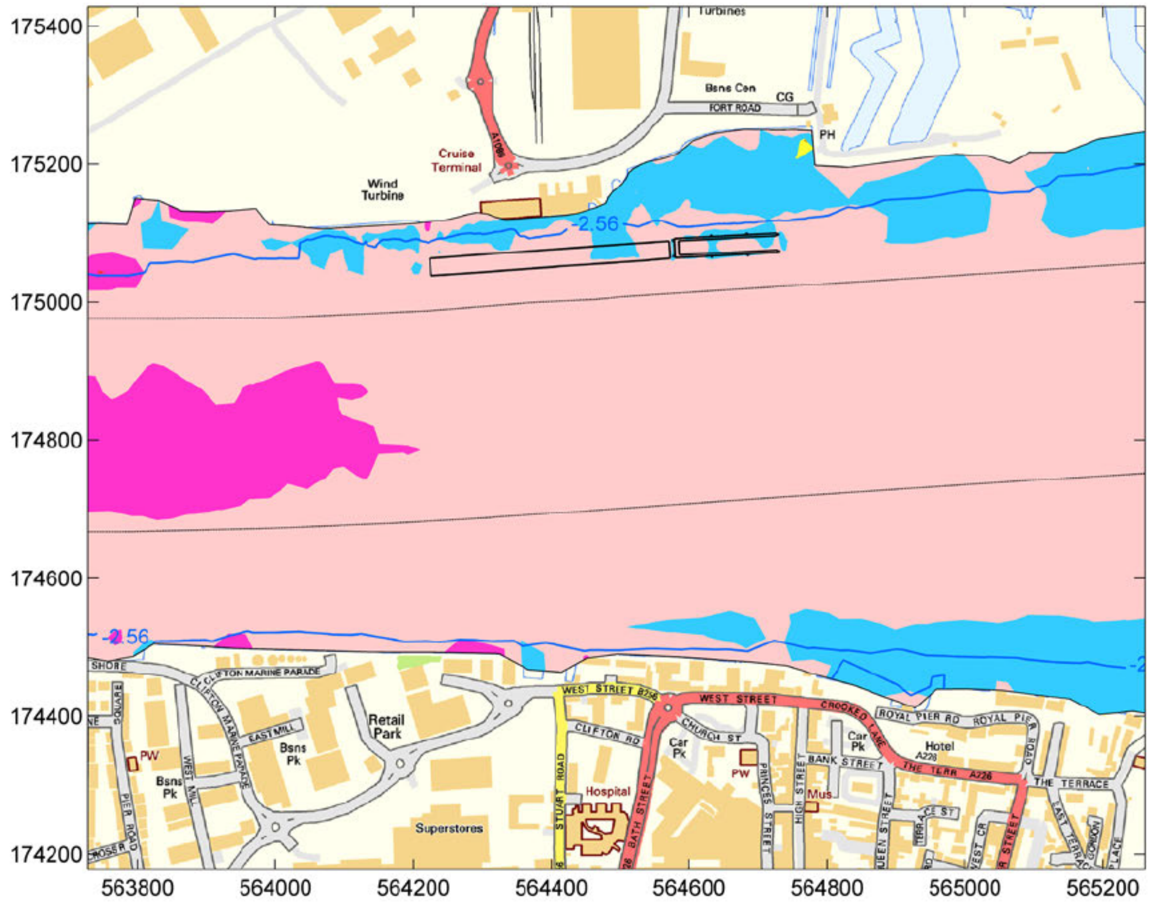
Figure 4.23: Predicted changes to patterns of erosion and deposition, Option C

4.4.5. Tilbury

At the Tilbury passenger pontoons the broad pattern of bed types seen in the baseline (Figure 4.4) with gravel in the channel, sand and gravel in the area between the pontoons and the riverbank line (Figure 4.24). There is a small shift north in the contour for gravel 5 – 10 mm but otherwise there is no change in the bed substrate expected. The change in peak bed shear stress (Figure 4.25) is confined to the area under the proposed outermost pontoon and the existing landing stage.

The predicted pattern of bed changes as seen in Figure 4.26 shows a decrease in the area with a tendency towards erosion along the southern face of the proposed pontoon and the existing landing stage. In one or two areas this change pushes the situation to a potential for accretion. The predicted changes to the pattern of erosion and deposition as shown on Figure 4.27 confirms the general movement of the situation to reduce erosion or even allow a small amount of accretion. Bearing in mind the bed material type shown in Figure 4.24 a long term accumulation of sediment in this area is considered unlikely.

Figure 4.27 indicates no change in the pattern of erosion or deposition on the intertidal areas adjacent to the pontoon.



Orange	Bed Stress values allowing fine sediment accumulation	Yellow	Bed stress values allowing occasional fine sediment accretion
Blue	Bed stress values appropriate for sand and gravel up to 5mm	Pink	Bed stress values appropriate for gravels 5mm – 10mm
Purple	Bed stress values appropriate for gravels 10mm – 20mm	Red	Bed stress values appropriate for gravels 20mm+

Figure 4.24: Bed types schematization, all Options

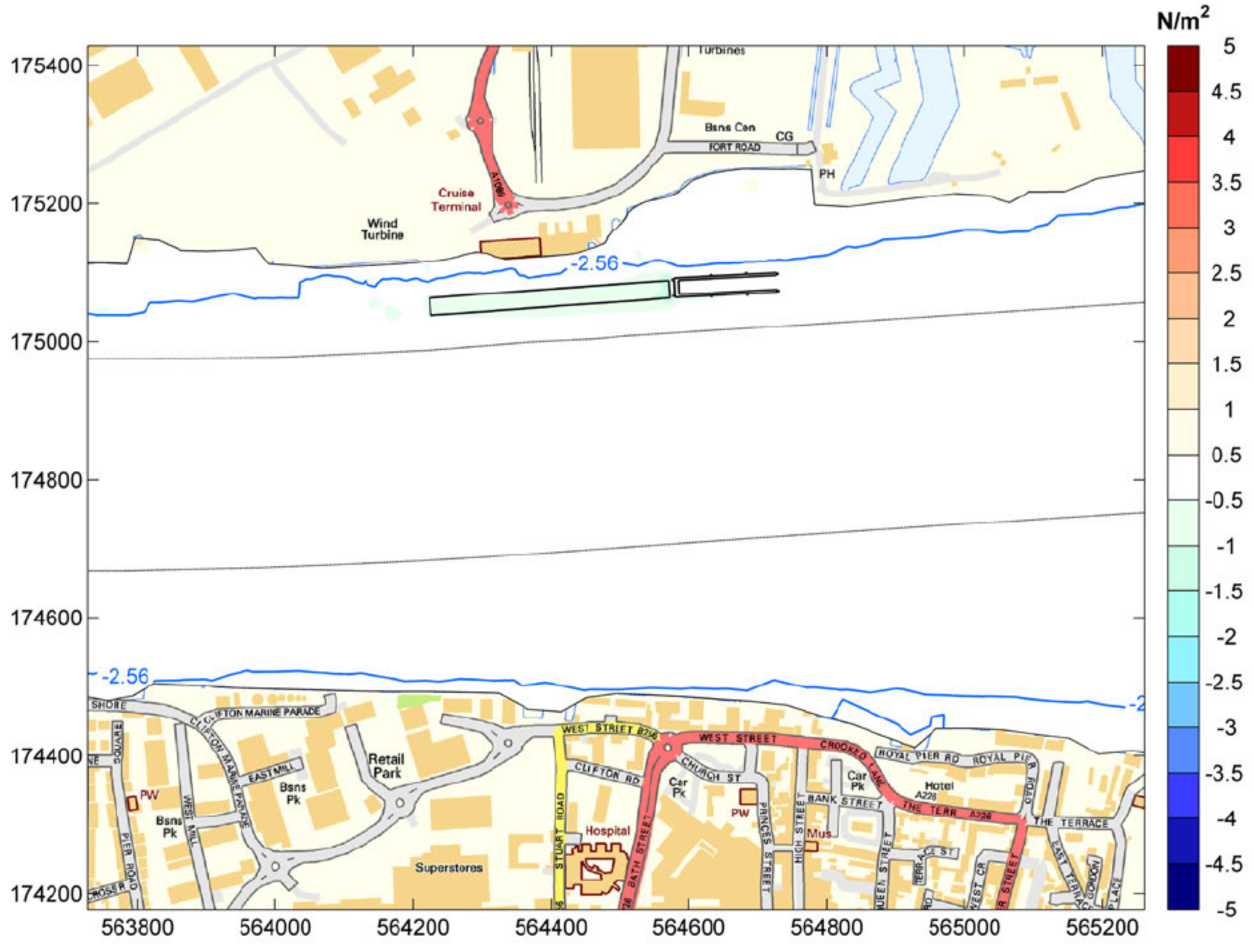


Figure 4.25: Predicted change in maximum bed shear stress, all Options

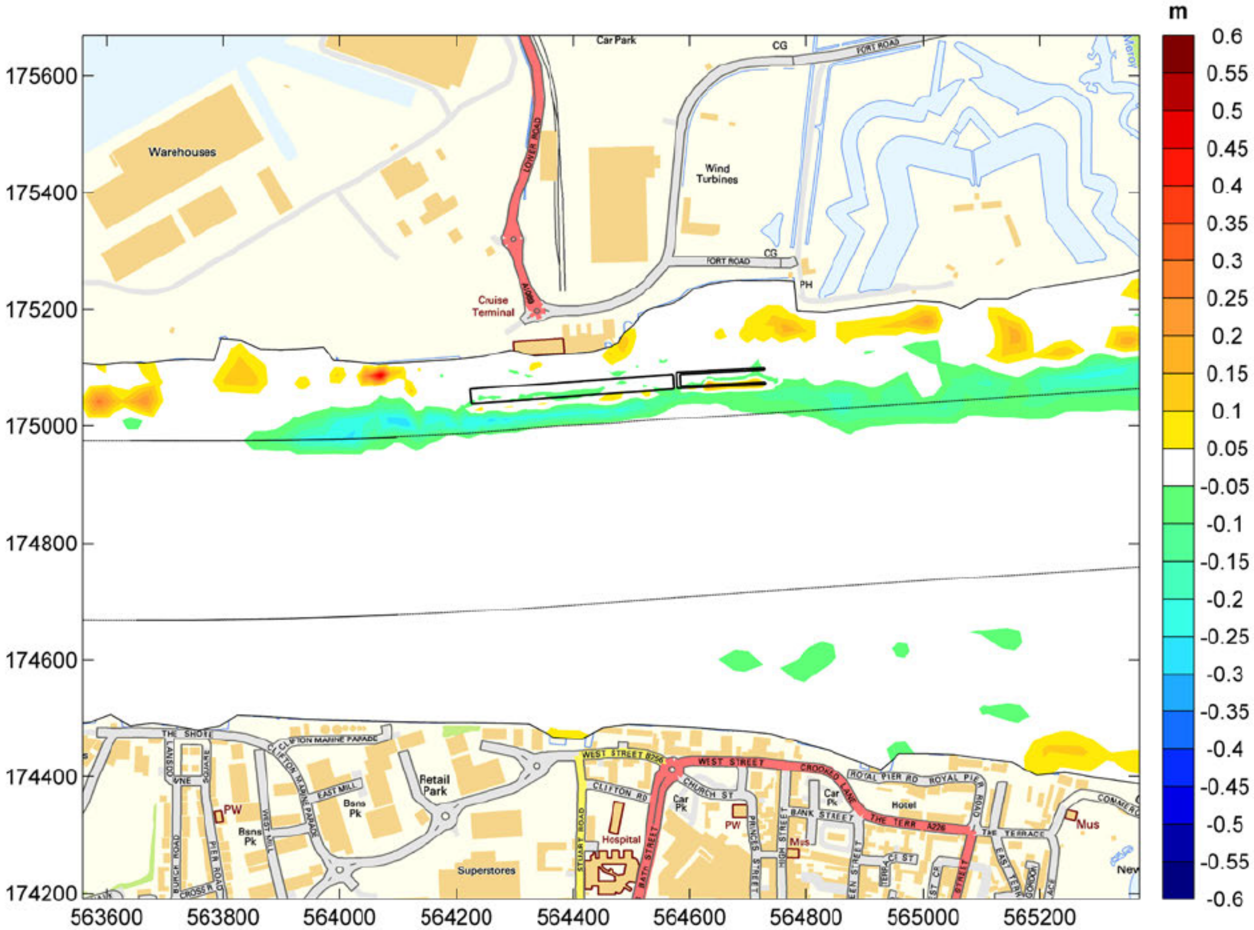


Figure 4.26: Predicted patterns of erosion and deposition at Tilbury, all Options

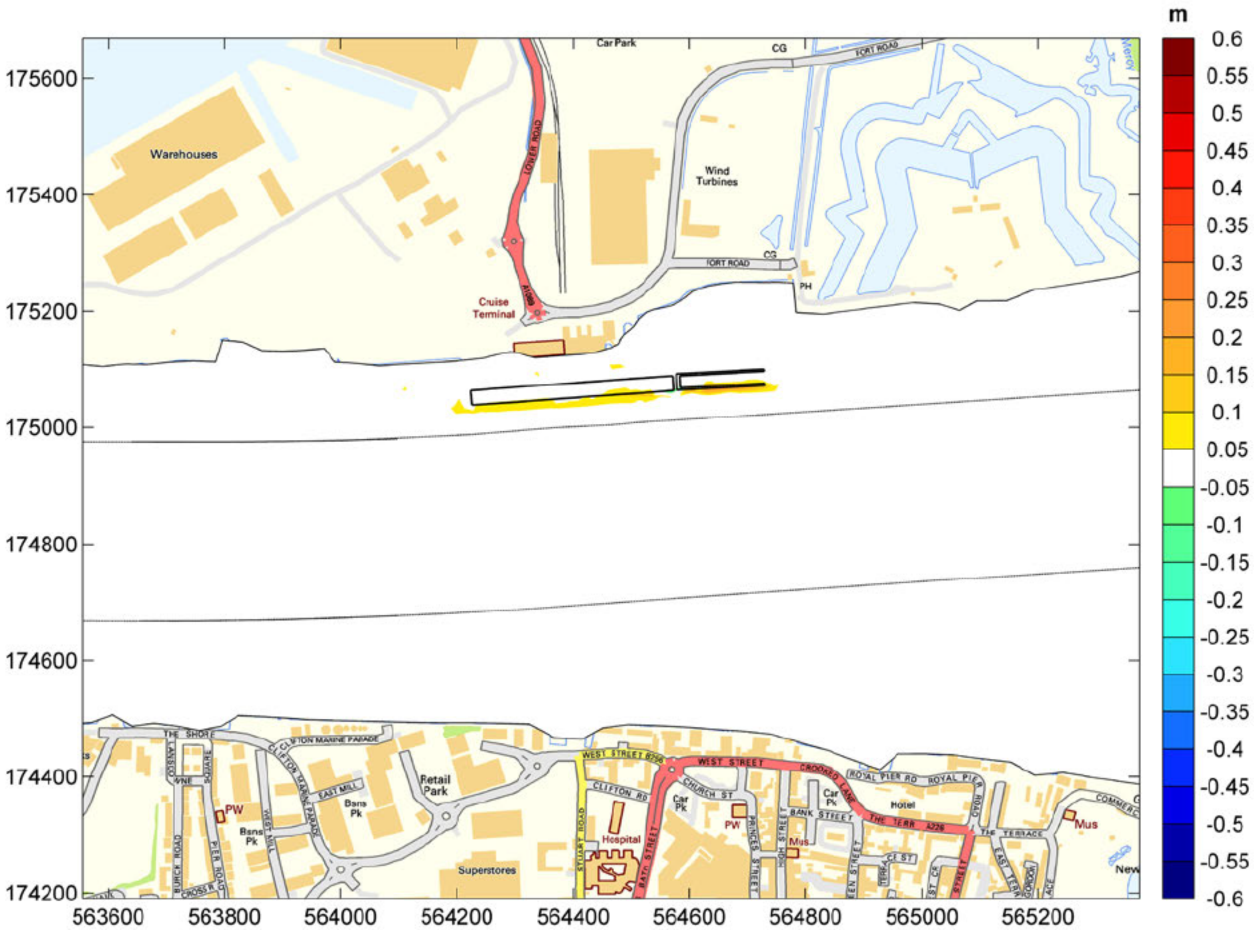


Figure 4.27: Predicted changes to patterns of erosion and deposition at Tilbury, all Options

4.4.6. Summary

The very limited impacts predicted for hydrodynamics are carried forward into the prediction of effects on sediment transport and erosion/deposition. No discernible effect is seen on suspended sediment concentration for all the options studied. At Swanscombe the various structures result in a potential change to the distribution of sediments increasing the proportion of 5 mm gravel in the area NE of White's Jetty.

A coarsening of the bed sediment under the passenger pontoon may occur depending on the nature of the existing bed in this area.

If the dredging associated with Option C is taken forward an annual infill rate of up to 29,700 m^3 per year is predicted. This is a precautionary total as the rate will reduce as the dredged area fills and vessel effects will also resuspend fine sediment.

No effects on the erosion or deposition patterns are seen on the intertidal areas near the Swanscombe site although in the medium term some effect of the flow in and out of the habitat creation areas is likely, creating small drainage channels.

The four habitat areas on the east of the peninsula are more successful in receiving fine sediment than the two on the west. This suggests the eastern sites will be quicker to provide functioning intertidal habitat; although noting their height in the tidal frame this process may still take some time.

At the Tilbury site only limited effects on erosion and deposition and bed substrate are predicted and these are in the immediate area of the proposed pontoon and the exiting landing stage. No changes to the pattern of erosion and deposition are predicted on the intertidal area to the north of the pontoon site.

5. Inputs to WFD assessment

Further assessments of the hydrodynamic and sedimentation effects of the works are required as part of the WFD assessment.

5.1. Total and net water flux

For the WFD assessment and in calculating chemical concentrations from the marine construction activities APEM use a standard tool that requires an estimate of net water flow rate / net tidal flux at the site of the potential sediment releases associated with the marine works.

As input to this assessment the total water flow was calculated through two sections, one landward and one seaward of the site of the Swanscombe ferry terminal. At each section, the total flow in the flood or ebb tide direction were integrated over the simulated 14 day spring neap cycle. These values were then divided by the duration of the simulation to give an average daily water discharge in the flood and ebb tide directions. The difference in the flood and ebb total discharges provides an estimate of the net discharge. The calculated values are quoted to the nearest 1,000 in Table 5.1 below.

This net discharge would be expected to vary seasonally due to variation in the river inputs to the estuary, meteorological effects and mean sea level in the Southern North Sea.

Table 5.1: Total and net discharges near the project site

	Gravesend Reach		Long Reach	
	Flood tide	Ebb tide	Flood tide	Ebb tide
Total discharge over modelled spring neap cycle (m^3)	3,842,614,000	4,100,243,000	2,844,184,000	3,057,145,000
Average discharge per day (m^3/day)	270,250,000	288,369,000	200,031,000	215,008,000
Net discharge over modelled spring neap cycle (m^3)	257,628,000 (ebb)		212,960,000 (ebb)	
Average net discharge per day (m^3/day)	18,119,000 (ebb)		14,977,000 (ebb)	
Net discharge (m^3/s)	210 (ebb)		173 (ebb)	

5.2. Sediment release during construction activities

The WFD assessment also required an estimate of the excess suspended sediment concentrations due to the likely construction activities. As described in Section 2.4 the area is one of high background fine sediment fluxes with 65,000 Tonnes of sediment passing through the section during each spring tidal phase. Maximum sediment fluxes of 6,000 kg/s are shown for both the ebb and flood tidal phases (Figure 2.5). In the context of this high level of sediment movement the sediment released from the construction activities will be a very small excess contribution therefore a desk based assessment was undertaken rather than detailed modelling.

The desk assessment comprised two parts, estimation of the potential sediment release rate from the construction activities (kg/s) and calculation of the variation in suspended sediment concentration at a distance from the works.

5.2.1. Sediment source

Two activities are considered; dredging by backhoe dredger and piling.

Dredging

The detailed dredging method has not been defined so a reasonable worst case has been assumed as a backhoe bucket of 10 m^3 capacity. The sediment dredged is assumed to contain 40% fine sediment (with a potential to be released) as found in the bed grabs (Section 2.3). A general rule of thumb assumes 5% of material from the bucket is lost during the excavation into the bed, raising the bucket and placement of the sediment in a barge. Using an assumed density of in-situ material of 1600 kg/m^3 this proportion suggests up to 800 kg could be lost during each excavation operation, of this 320 kg would be fine sediment. Much of the fine sediment may be bound together into chunks and fall back to the seabed quickly but as a precautionary case this is ignored, and all the fine sediment is assumed to disperse away with the passing current. With an assumption of an average of 6 m of water depth at the dredging site and 60 s per dredging activity this amount of sediment released by the dredger becomes a sediment source of 0.89 kg/s/m.

Piling

Making a precautionary assumption of 2 m diameter tubular piles each of which is completed in 3 hours.

The fine sediments displaced by the pile and disturbed in the surrounding may be disturbed and released into suspension. As a precautionary estimate it may be assumed that all the fine sediment in an area extending 1 m around the pile and to a depth of 1 m may be released. Using the same sediment properties and water depth as above the release rate for this process would be between approximately 0.15 kg/s/m and 0.8 kg/s/m depending on if the pile is hollow or solid.

5.2.2. Sediment dispersion

A desk method for estimating the maximum concentration C_{max} at a distance x from a sediment source is based on (Fischer et al, 1979).

$$C_{max} = \frac{M}{u\sqrt{4\pi DT}} = \frac{M}{u\sqrt{4\pi D\frac{x}{u}}}$$

M is the mass release per unit depth and *M/u* is the source term released into a unit volume of water (the water is passing with a speed *u*). C_{max} is at the centre of the sediment plume, *T=x/u* is the time that elapses as the plume travels from its release point to the point at *x* m away. As the current speed is much bigger than the dispersion, it is reasonable to ignore the longitudinal dispersion and *D* is the lateral dispersion coefficient, given by *D=0.015H.u*,* where H is the water depth.

Using this approach ana reasonable maximum for depth average currents in the area of 1 m/s, the excess suspended sediment concentration due to the backhoe dredging is approximately 175 mg/l at 10 m away and falling to 18 mg/l at 100 m away. For the piling, the excess suspended sediment concentration at 10 m from the activity is in the range 30-165 mg/l failing to the range of 3-17 mg/l at 100 m away, depending on if the pile is hollow or solid.

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HR Wallingford, Howbery Park, Wallingford, Oxfordshire OX10 8BA, United Kingdom
tel +44 (0)1491 835381 fax +44 (0)1491 832233 email info@hrwallingford.com
www.hrwallingford.com