5 Coastal Hydrodynamics and Geomorphology

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5.1 *Introduction*

Coastal developments such as Eastside have the potential to change the local hydrodynamic conditions (i.e. the wave climate, water flows, currents, etc) with knock-on effects to the local sediment transport patterns and the coastal geomorphology (i.e. the seabed, the beaches, etc).

This chapter of the Environmental Statement (ES) describes the potential impacts of the proposed Eastside development on coastal hydrodynamic conditions and geomorphology. The Town Planner's Scoping Opinion (Government of Gibraltar (GoG), 2005 - see Appendix A) identifies the need to address a range of issues relating to Eastside, including:

- The current tidal range and the potential for future sea level rise;
- Wave conditions and measures for dissipating wave energy;
- Storm surges and measures to protect the development from surges;
- Impact of structures on sediment transport and distribution along the coastline and measures to protect structures from coastal erosion;
- Infilling of dredged seabed areas (i.e. borrow pits) used to provide a source of reclamation material;
- Cumulative impacts of Eastside in combination with the effects of other plans or projects (see Section 4.10).

The following sections summarise the extensive coastal hydrodynamics and geomorphology studies undertaken to inform the Environmental Impact Assessment (EIA) process (including detailed numerical modelling to assess impacts). The numerical modelling studies were conducted by Delft Hydraulics and are appended to the ES as a series of three reports concerning Flow Conditions (Appendix B), Wave Conditions (Appendix C) and Coastal Morphology (Appendix D).

It should be noted that the cumulative impacts of Eastside in combination with the Government's proposals for beach works are not considered in this section of the ES for the reasons identified in Section 4.10.

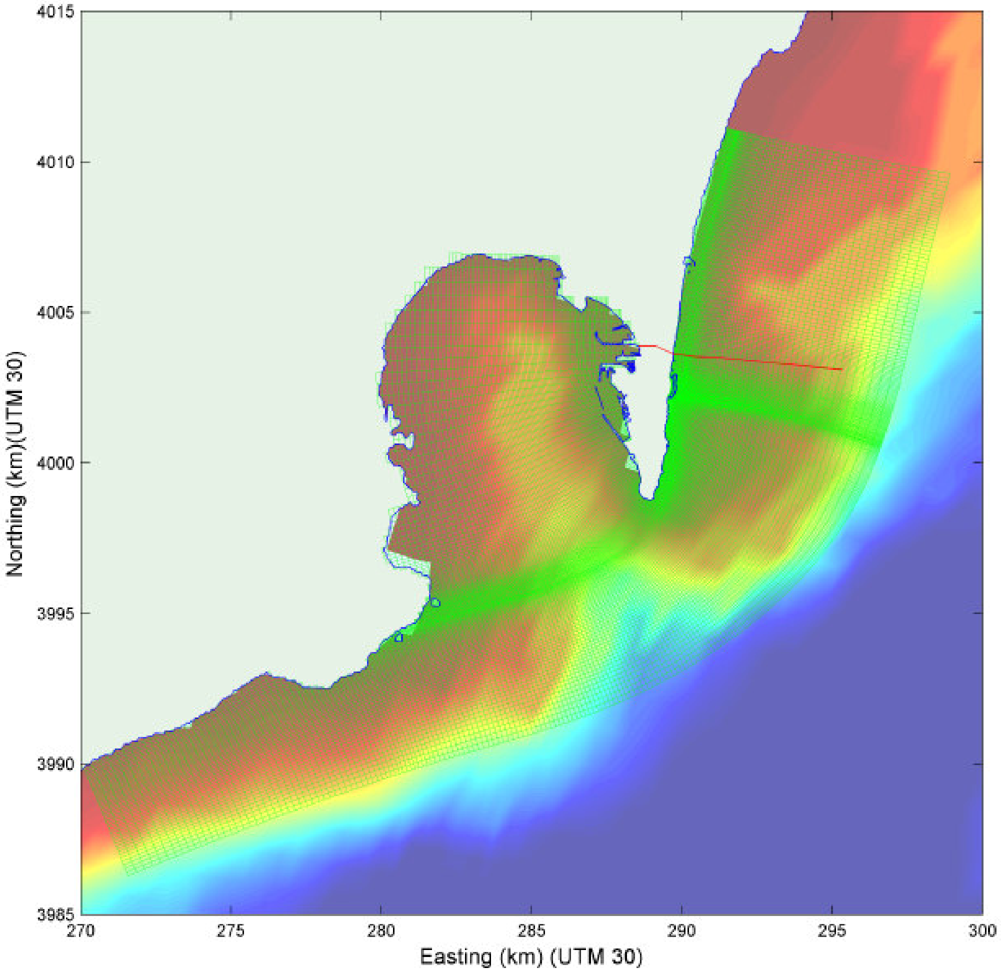
5.2 *Assessment Methodology*

5.2.1 *Modelling Approach – Hydrodynamics*

A range of one-dimensional (1D) and two-dimensional (2D) numerical models were used to inform the EIA process. The choice of modelling approach was based on an assessment of the hydrodynamic conditions at the Eastside development site and how they are influenced by large-scale processes such as density exchange currents, tides and wind.

It was found that although the hydrodynamics of the Strait of Gibraltar are very complex, the flow around the Eastside development site is less complicated. Field measurements using Acoustic Doppler Current Profiling (ADCP) gave no indication of significant velocity gradients in the vertical dimension (i.e. no water stratification due to density differences) and indicated that the local flows result from the combined effects of southbound residual currents, tidal currents and wind effects. Since there are no indications that the flow fields in the direct vicinity of Eastside show a complex three-dimensional behaviour, the hydrodynamics of the east side of Gibraltar were schematized with a 2-Dimensional Horizontal (2DH) modelling approach. To avoid effects of boundary conditions on the hydrodynamics in the area of interest, a modelling domain was chosen which also covers part of the waters south-west of Gibraltar and the waters north-east of the port of Atunara in relatively shallower water depths (see Figure 5.1).

Figure 5.1 Wider Modelling Area



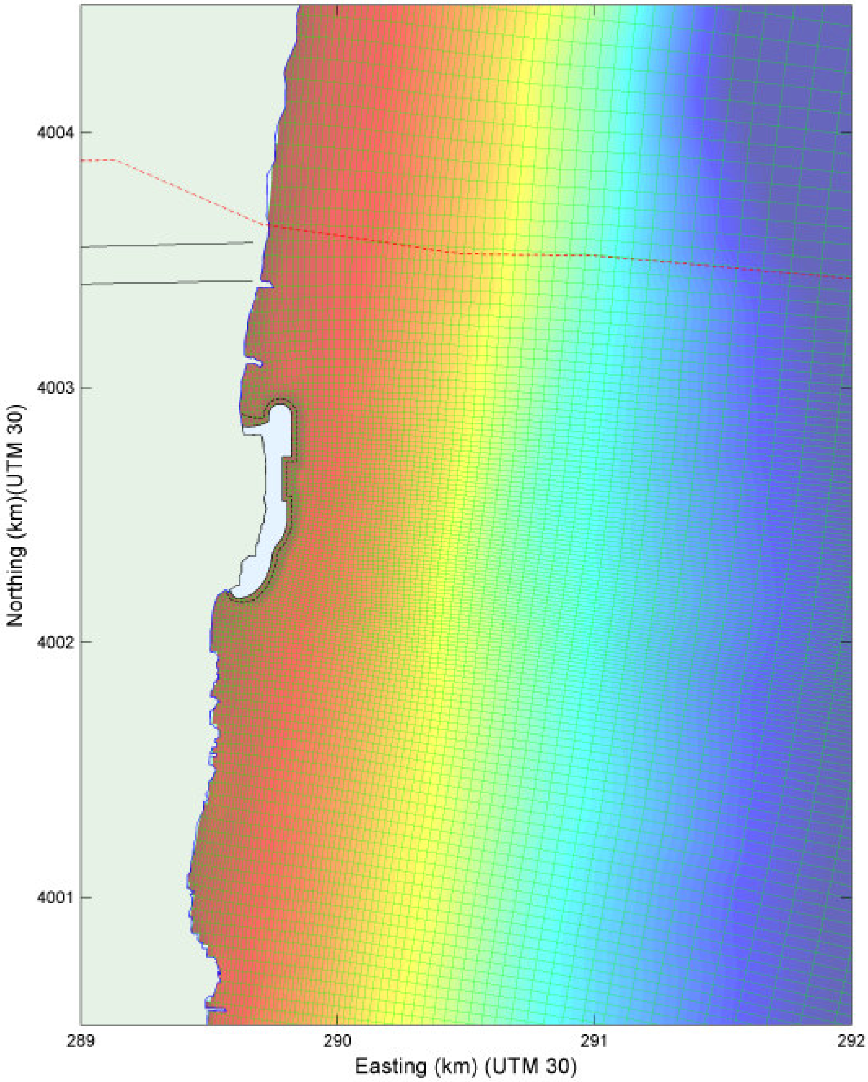
For the modelling of flushing and pollutant dispersion the model was switched to a three dimensional mode to take local three-dimensional effects such as dispersion and effluent induced density differences into account. To resolve the dispersion processes near the scheme and around the dredging locations, flow fields have to be computed which predict possible formation of eddies. For adequately resolving eddies and sharp velocity gradients a high resolution flow model is required: therefore a horizontal resolution of about 10m to 20m was defined in the relevant project areas (e.g. the areas near the scheme and the dredging areas).

The size of the grid cells varies from 150m by 300m near the west boundary of the model to approximately 15m by 15m near the scheme. Figure 5.2 shows the computational grid in the project area on top of the local bathymetry. The model runs from about 25 km south-west of Gibraltar to about 5km north-east of Gibraltar and covers the northern coastal slope of the Strait of Gibraltar up to a depth of about 400m. In this area two grid variants were used:

- A grid representing the existing situation, with grid lines following the present coastline; and

- A grid representing the development, with grid lines following the contours of the development. The permanently dry areas of the development are not included as cells in this grid.

Figure 5.2 Eastside Development Modelling Area



5.2.2 *Modelling Approach – Geomorphology*

For the prediction of the morphological impact of Eastside, the shoreline model UNIBEST-CL+ was used. In this model the cross-shore movement of a single line representing the coastline is computed from longshore gradients in the net longshore sediment transport.

Longshore sediment transport is calculated from wave and flow data obtained from wave and flow modelling results presented in Appendices B and C (thus including longshore variation in wave conditions) and sediment transport formula included in the Unibest model. Seaward and landward movements are termed accretion and erosion respectively. Further details of the Unibest model are given in Appendix D.

For details near structures the model DELFT3D provided additional information for the coastal impact assessment. In this model 2DH (2-Dimensional Horizontal) sediment transport patterns and seabed changes are computed.

For the prediction of the infill rates of dredged areas the model DELFT3D was applied. Sediment transport and (initial) erosion-accretion patterns were computed, on the basis of which the infill rates were estimated.

Dredging induced sediment plume dispersion and deposition was also simulated using the DELFT3D model. In this assessment the combined effect of flows, waves and morphology were simulated to predict the dredging induced sediment plume behaviour.

5.2.3 *Assessment Methodology*

The models have been run to demonstrate the worst-case scenarios for all potentially significant environmental impacts based on realistic design and construction parameters as far as can be reasonably identified and/or predicted.

5.2.4 *Impact Significance*

In order to classify the significance of predicted impacts, and to provide a consistent framework for considering and evaluating impacts, the following terminology has been adopted:

- Negligible - the impact is not of concern;
- Minor adverse - the impact is undesirable but of limited concern;
- Moderate adverse - the impact gives rise to some concern but it is likely to be tolerable (depending on its scale and duration);
- Major adverse - the impact gives rise to serious concern; it should be considered as unacceptable unless unavoidable by best practicable means;
- Minor beneficial - the impact is of minor significance but has some environmental benefit;
- Moderate beneficial - the impact provides some gain to the environment; and
- Major beneficial - the impact provides a significant positive gain.

5.3 *Baseline Conditions*

5.3.1 *Large-Scale Conditions*

The sea at the east side of Gibraltar is the most western part of the Mediterranean Sea and is called the Alboran Sea. The waters in this area are relatively deep close to shore: on average the sea-floor slope is 1:50 from the shore up to a depth of 100m, and then becomes steeper. At around 10km from the shore, water depths exceed 500m.

South of Gibraltar is the Strait of Gibraltar, a narrow sea passage between Spain and Morocco that forms the only connection between the Gulf of Cadiz (Atlantic Ocean) and the Mediterranean Sea. The Strait of Gibraltar is about 60km long, with Europa Point at the east end, and the west end in the Atlantic between Trafalgar and Espartel. The width of the Strait of Gibraltar varies between 44km and 14km, and the bathymetry is very irregular with a minimum depth of about 300m and maximum depths exceeding 900m.

The main processes causing flow in the Strait of Gibraltar are density exchange currents, tides and wind. In addition and especially at the east side of Gibraltar, currents may be affected by large-scale circulations in the Mediterranean, such as the Alboran Gyres.

5.3.2 *Eastside Study Area Conditions*

The east side of Gibraltar is mainly characterised by a continuous southbound current, with tidal currents with magnitudes of about 0.3m/s superimposed, depending on the phase of the spring-neap tidal cycle.

Two series of 1-month ADCP measurements approximately 2km south-south-east of the Eastside development site confirmed the flow behaviour. Both series of measurements recorded a clearly dominant south-going current which only turns northward in the period from three hours before high water to high water. During most tidal cycles the maximum current velocity was between 0.4m/s and 0.7m/s.

The measured vertical current profiles showed no indication of variations in flow magnitude and direction. The vertically uni-directional behaviour of the measured currents indicates that there is no significant stratification in the coastal waters within the project area (0m to 50m water depth). The reader should refer to Appendix B for more details.

5.3.3 *Tides*

The vertical tide (water levels) is predominantly semi-diurnal around Gibraltar. Tidal levels at the Eastside development site and the surrounding study area have been determined using published tidal data sources and an analysis of ADCP data. Table 5.1 presents tidal levels in metres Above Ordnance Datum (mAOD). The tidal range at the project site is only slightly less (about 2 cm) than the range at Gibraltar Port. The future tidal range due to sea level rise is predicted in the range 0.2m to 0.7m over the next 100 years, with a mean value of 0.5m. The reader should refer to Appendix B for more details.

Table 5.1 Tide Levels

Tide Level	**Eastside, Gibraltar study data (mAOD)**	**Government of Gibraltar data (mAOD)**	**Admiralty Tide Tables data 2006 (mAOD)**
Highest astronomical tide	1.0	1.0	1.0
Mean high water springs	0.9	0.9	0.9
Mean high water	0.7	-	-
Mean high water neaps	0.6	0.6	0.6
Mean sea level	0.4	0.4	0.4
Mean low water neaps	0.3	0.3	0.3
Mean low water	0.1	-	-
Mean low water springs	0.0	0.0	0.0
Lowest astronomical tide	-0.2	-0.2	-0.2

5.3.4 *Wave Conditions*

Various offshore wave and wind data have been used to determine the wave climate including nine years of buoy measurements (Mar de Alboran buoy located at 36º 13.931'N 5º 3.071'W, 1997-2005), seven years of wave analysis data (European Centre for Medium-range Weather Forecasting (ECMWF) model data, 3rd generation wave model (WAM), 1999-2005), and seven years of analysis of High Resolution Limited Area Model (HIRLAM) wind data from the Puertos del Estado operational wave model (1999-2005).

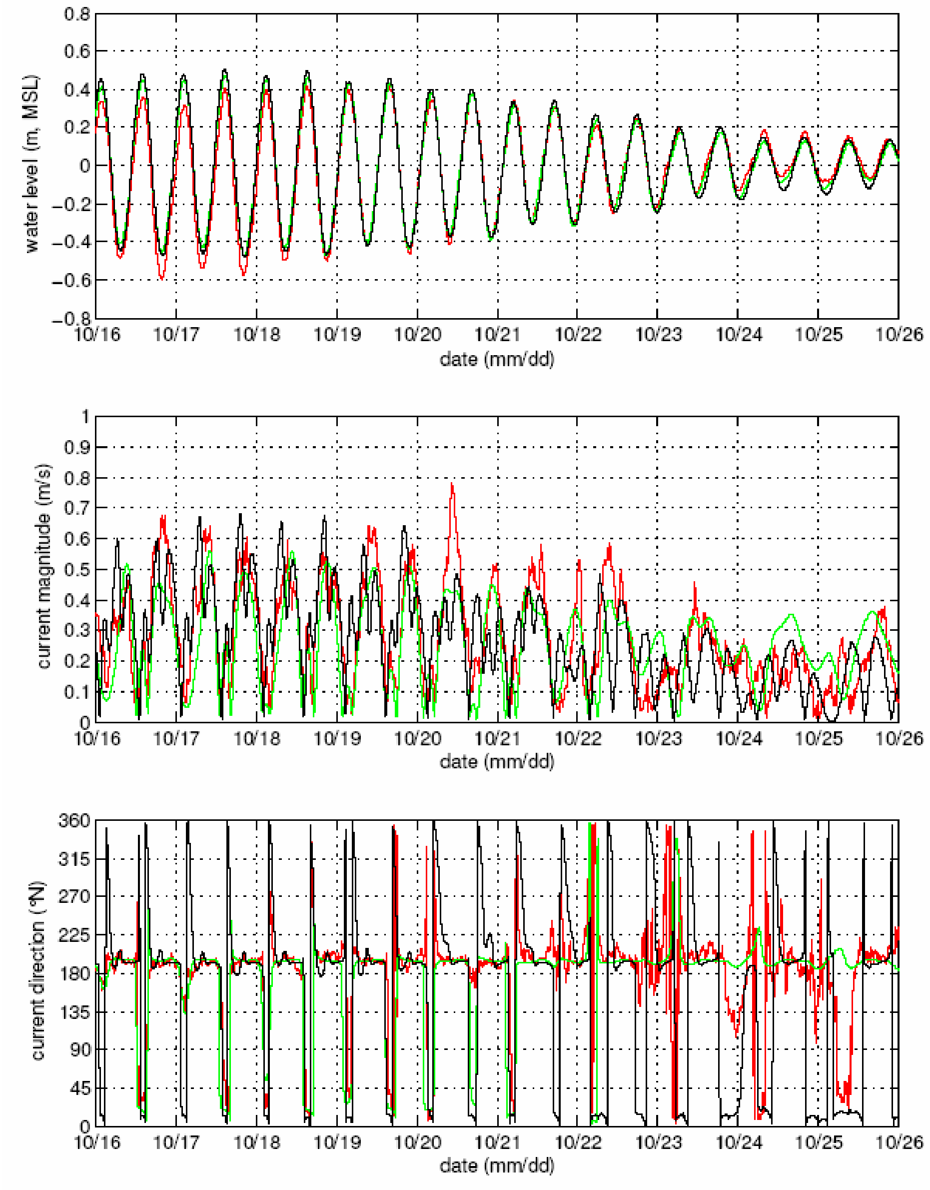
Analysis of this data revealed that the yearly offshore climate in this region is characterised by about 50% of waves from the west and about 25% from the east, and the rest by generally mixed seas with waves reaching Gibraltar from east and west simultaneously. This wave climate will generally lead to double peaked spectra with a western and an eastern component. Waves with peak periods longer than 10 seconds can come from both directions. The reader should refer to Appendix C for more details.

5.3.5 *Currents*

The current flows for the east coast of Gibraltar and surrounding waters were identified as part of the numerical modelling study for the EIA process. In addition, the current flows were calibrated using ADCP current and water level measurement data within the Gibraltar Flow Model (a detailed depth-averaged (2DH) hydrodynamic flow model based on the Delft 3D-FLOW model).

Figure 5.3 (overleaf) shows an example of the ADCP (in red), hindcast (in green) and numerical model (in black) datasets for water levels, current magnitude and current direction. Current speeds of up to 7-8m/s can occur, depending partially on the state of the tide. Around neap tide the wind driven currents can be of the same order of magnitude as the tidal currents, so that relatively larger deviations can be expected between the measured and modelled tidal currents.

Figure 5.3 Water Level, Current Magnitude and Current Direction Data



5.3.6 *Storm Surges*

Storm surge behaviour for the Eastside development site and surrounding area has been determined using published data supported by storm surge calculations.

Table 5.2 presents extreme water levels in mAOD for various return periods taking into account tides, wind, atmospheric pressure and sea level rise.

The reader should refer to Appendix B for more details.

Table 5.2 Extreme Water Levels (source: EBG, 2006)

	1:1 Return Period	**1:10 Return Period**	**1:100 Return period**
Tide (MHWS = +0.9mAOD)	0.9	0.9	0.9
Wind / atmospheric pressure	0.1	0.2	0.3
Sea level rise	0.5	0.5	0.5
Total water level (mAOD)	1.5	1.6	1.7

5.3.7 *Coastal Morphology Features*

The study area for morphology includes the coastline of Gibraltar and the coast of Spain up to La Atunara harbour. The coastline at the east side of Gibraltar is relatively straight and changes only in orientation to the north near La Atunara harbour in Spain. Gibraltar's east coast is oriented about 97ºN and the coast north of La Atunara harbour is 105ºN.

The characteristic features along the coast (from north to south – see Figures 5.4 and ES.2) are:

- La Atunara harbour protruding approximately 300m into the sea;
- Sandy beach between La Atunara harbour and the border between Gibraltar and Spain;
- Sandy beach between the border and the rubble tip area - Eastern Beach;
- Two groynes along Eastern Beach protruding about 50m into the sea;
- Rubble tip area protruding on average about 200m into the sea;
- Sandy beach - Catalan Bay;
- Rocky coast between Catalan Bay and Sandy Bay with a moderately steep profile;
- Sandy beach - Sandy Bay; and
- Rocky coast south of Sandy Bay with a steep profile.

5.3.8 *Shoreline Profiles*

The satellite images in Figure 5.4 give an overview of coastline behaviour over a period of 14 years (1991 - 2005). It can be seen that the rubble tip was extended in the period between 1991 and 2001. This does not appear to have had a significant impact on the adjacent beaches (Catalan Bay and Eastern Beach).

Slight localised changes can be distinguished at Catalan Bay. For the years 1991, 1992 and 2005 the shorelines are very similar. In 2001 there was an overall reorientation of the bay which was probably temporary and which may have been caused by the conditions immediately prior to the 2001 picture (e.g. a long period of persistent waves from relatively southerly directions). Such relatively rapid changes and seasonal fluctuations in wave conditions are not uncommon in small bays, such as Catalan Bay. The shoreline position of 2005 indicates that the changes in 2001 were temporary.

In a similar way to Catalan Bay, there were minor changes in orientation along Eastern Beach, but no long-term changes in the coastline can be distinguished. The difference in the coastlines of 1991 and 2005, for example, is very small. It is therefore expected that changes in beach width are caused by changes in wind and wave climate.

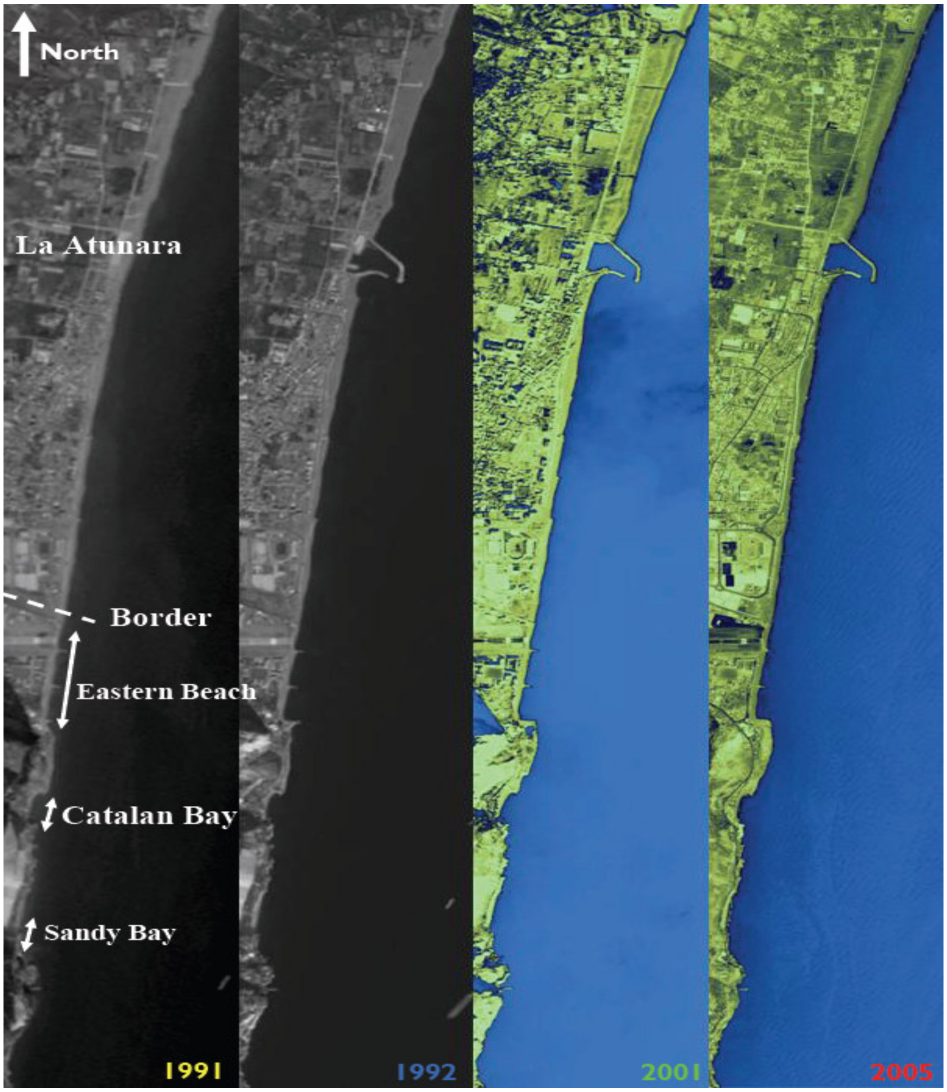
La Atunara harbour was constructed in 1992. Even though this harbour forms an interruption of the longshore transport in the area, shoreline changes with time around La Atunara harbour are small. The shorelines in 2001 and 2005 are almost identical. Local to the south of the harbour, the shoreline seems to have moved landward in the period between 1991 and 2005. A slight tendency towards erosion south of Atunara harbour can be identified between 1991 and 2001.

This may be a leeside effect of interruption of a south-going transport by the harbour breakwaters. However, the occurrence of a net south-going transport is not clearly confirmed by accretion north of the harbour.

Considering the negligible sand accumulation north of La Atunara harbour in a period of 14 years and the observations south of the harbour, the net longshore transport near La Atunara harbour is concluded to be negligible and, if it does exist it tends to be southward directed.

North of La Atunara the beach becomes wider and beach slopes are gentler.

Figure 5.4 Geomorphology Changes 1991-2005



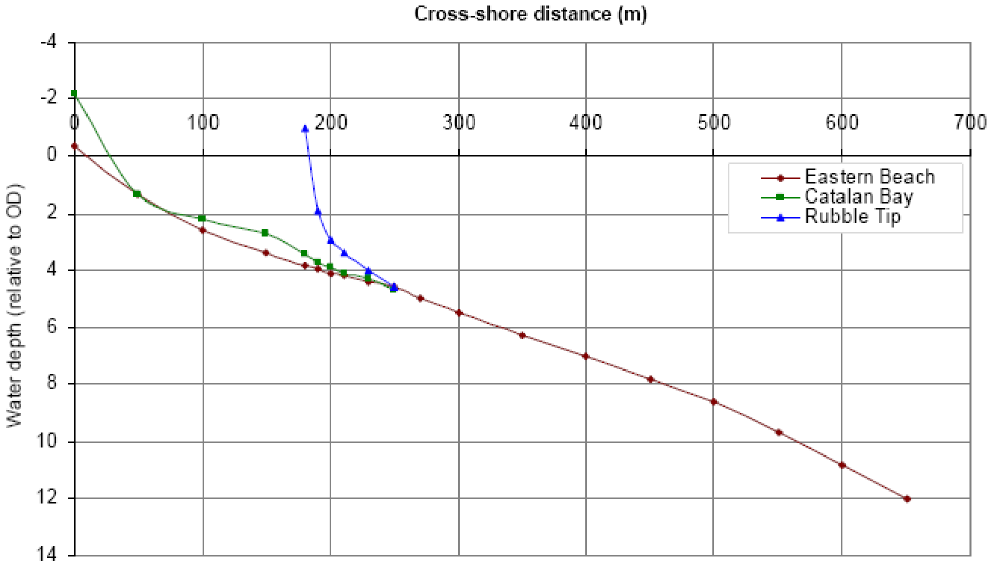
Over larger time scales, the Gibraltar coast appears to have been fed with sand from the north; however no historical evidence for this has been found. The bay shapes of the coast further north of La Atunara confirm that (at least in the past) the net transport in the area north of La Atunara was directed southwards. It cannot be firmly distinguished from the satellite images whether this net southward transport is still present today. As it was indistinguishable in the most recent period (2001-2005) it was concluded that the shoreline behaviour around La Atunara harbour confirms that the net transport in the study area is negligible. The conclusion of a negligible net transport along the studied area of the Gibraltar was also drawn in Delft Hydraulics (2000) on the basis of considerations related to the two groynes at Eastern Beach combined with longshore transport computations.

Bathymetric surveys give a consistent picture of the coastal (beach) profiles over time. Survey plots also show that morphological activity is small in the deeper parts of the profiles along the east Gibraltar coast. Coastal profile changes with time can be observed mainly in the zone between 0mAOD and -10mAOD, with the most dynamic part of the profile between 0mAOD and -6mAOD.

5.3.9 *Cross-Shore Profiles*

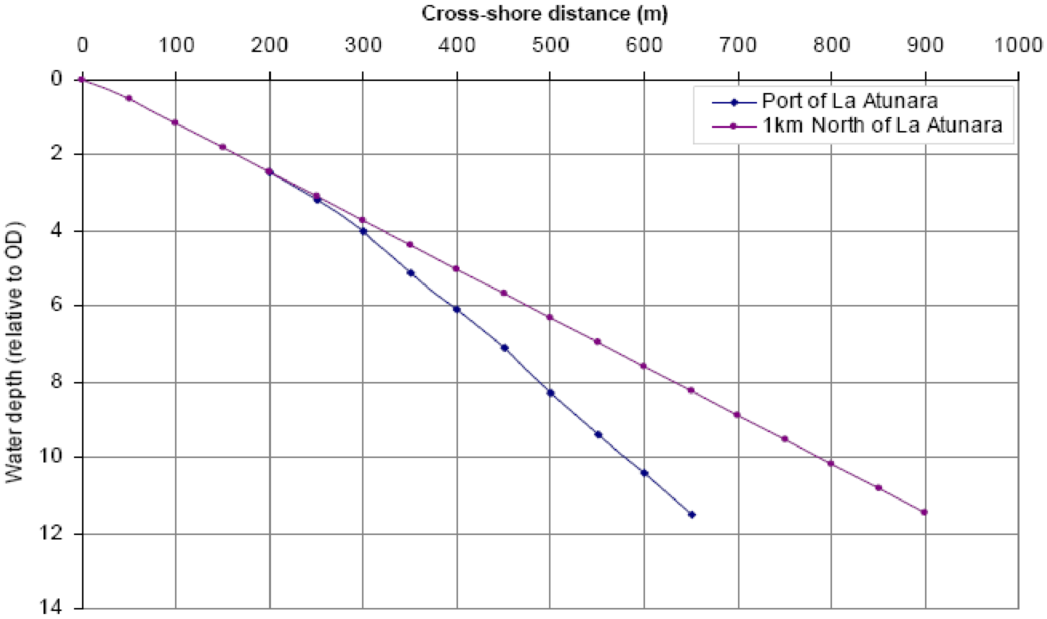
The cross-shore profile of the eastern Gibraltar coast (Figure 5.5) can be characterised by three representative profiles for Catalan Bay, Eastern Beach and for the rubble tip.

Figure 5.5 Characteristic Cross-Shore Profiles for Eastern Gibraltar



Cross-shore profiles north of Eastern Beach are relatively uniform up to the harbour at La Atunara, where there is a small change in profile. North of La Atunara harbour the cross-shore profile gradually changes to a gentler slope. Two characteristic profiles can therefore be distinguished for the Spanish coast (Figure 5.6).

Figure 5.6 Characteristic Cross-Shore Profiles for the Spanish Coast



5.3.10 *Beach and Seabed Sediments*

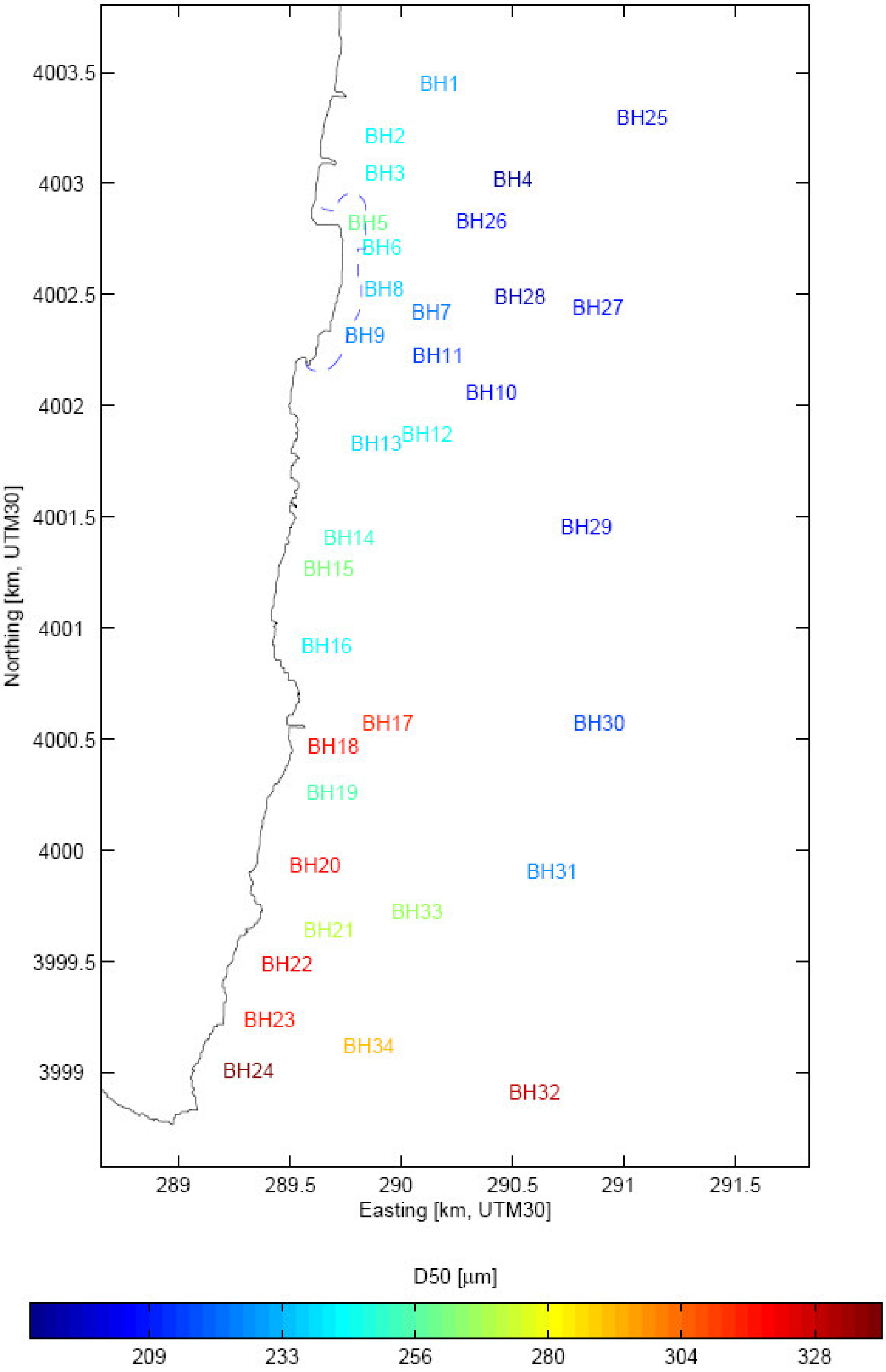
The grain diameters of the fractions on the beaches are reported by GoG (date unknown) as:

- D_{15} = 0.17mm;
- D_{50} = 0.28mm; and
- D_{85} = 0.54mm.

Boskalis Westminster (2005) and Fugro (2000) describe the sediment at the beaches as fine to medium grained sand with low silt contents. The sediment fall velocity of this sand is estimated at 0.035m/s.

Fugro (2000) concluded that sand offshore is poorly graded, is loosely packed in the top layer and very dense at two metres below the surface. The sediment offshore is of a similar size to the beach sediment (see Figure 5.7).

Figure 5.7 Characteristic D_{50} Grain Sizes for Seabed Sediment at various Borehole (BH) Locations



5.4 Predicted Impacts

5.4.1 *Construction Phase: Impact of Sediment Plume Deposition*

Dredging and associated marine works (e.g. reclamation and rock armouring) can cause large-scale releases of sediment into the water column, causing sediment transport and deposition on the seabed. Although sediment deposition does not necessarily adversely affect coastal geomorphology (i.e. the bathymetry), it can alter the physical properties of the sediment such as particle sizes and can have both direct (e.g. smothering) and indirect (e.g. on recruitment processes) impacts on the marine ecological receptors exposed to it (see Chapter 9).

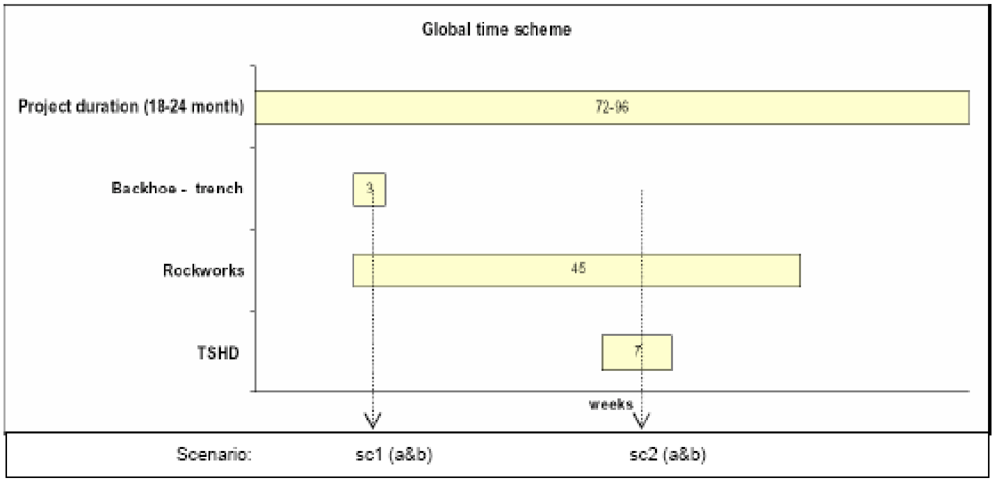
It should be noted that the nature and scale of the proposed dredging from the borrow areas (using a trailing suction hopper dredger (TSHD)) is likely to be similar to that undertaken at the southern borrow area for The Island project on the west side of Gibraltar.

The dredging and marine works that are likely to take place for Eastside comprise the following key activities that can generate sediment plumes:

- Dredging trenches for sea defences by a backhoe dredger (BHD) and placing material on the seabed by a split hopper barge (SHB);
- Placement of rock for the sea defences, mainly by a side stone dumping vessel (SSDV); and
- Dredging of sand from the borrow area(s) and placement of sand for land reclamation by TSHD.

An indicative timeframe for these activities is shown in Figure 5.8.

Figure 5.8 Indicative Timeframe of Key Dredging and Marine Works



Two impact scenarios were used to assess the dredging and reclamation activities during the construction phase of Eastside (identified as sc1 and sc2 in Figure 5.8).

The impact assessment scenarios for Eastside were:

- Dredging and works for the trenches and sea defences (see sc1a and sc1b in Figure 5.8 and Figure 7.3a in Appendix D); and
- Dredging and land reclamation works (see sc2 in Figure 5.8 and Figure 7.3b in Appendix D).

The two impact scenarios were modelled for spring and neap tide conditions including waves, without wind influences. Scenario sc2a was also modelled with two typical wind conditions (wind direction west-south-west at speed of 10 m/s and wind direction east-north-east at speed of 10 m/s) because this scenario represented the worst case impact since it had the longest duration.

The following paragraphs for this impact assessment report the worst case impacts for each scenario (i.e. sc1a, sc1b, sc2a and sc2b,) in terms of the resulting thickness of deposited sediment after the completion of the considered construction works considered by each scenario.

Table 5.3 sets out the figures presenting the worst case model results that can be referenced in Appendix D.

Table 5.3 Figure References for Appendix D

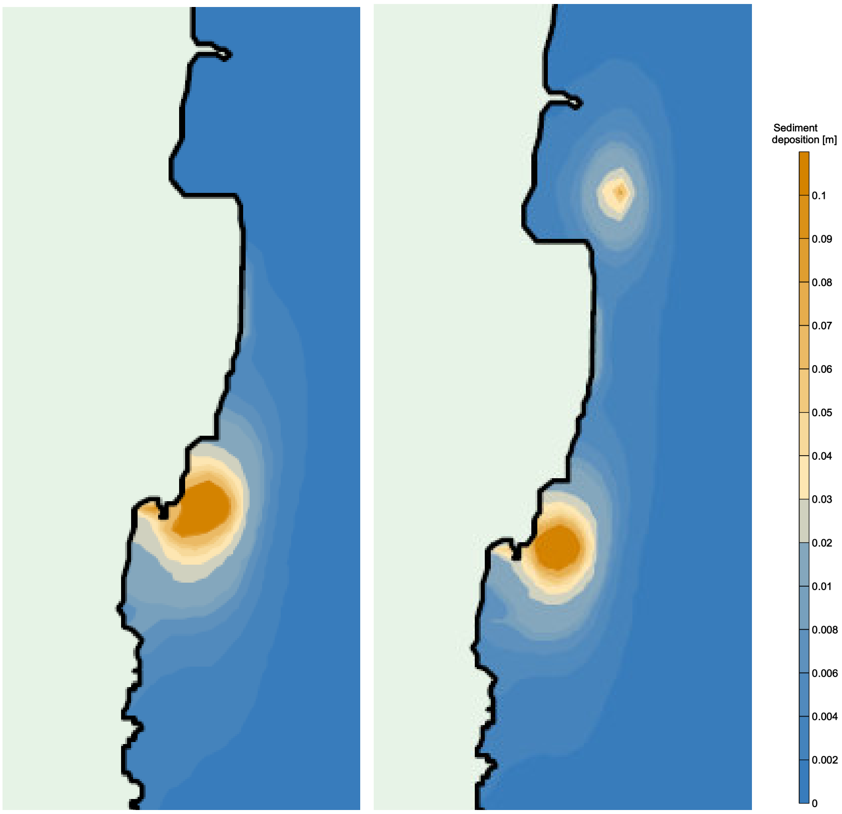
Figure Info / Impact Scenario	sc1a	sc1b	sc2a	sc2b
Layout and sediment plume sources	7.3a	7.3a	7.3b	7.3b
Sediment deposition (increase in m)	7.8	7.13	7.18	7.23

Scenario sc1 - the dredging and works for the trenches and sea defences - represents the BHD dredging activities in combination with the SHB construction of the trenches, and includes SSDV activities. This scenario is subdivided into sc1a for the construction of the southern part of the sea defence and sc1b for the construction of the northern part of the sea defence. The following assessment is based on the worst case conditions arising during a spring tidal cycle.

The model predicts that for sc1a, the expected maximum thickness of deposited sediment is above 0.1m locally around the trench dredging and the sea defence placement locations at Eastside (see Figure 5.9). Elsewhere, deposition is not significant.

The findings for sc1b were very similar to the results of sc1a but were generally moved 500m northwards (see Figure 5.10). This change to the location of the impact reflects a similar movement of the trench and sea defence works under this impact scenario.

Figure 5.9 (left) Maximum Expected Sediment Deposition Thickness for sc1a
Figure 5.10 (right) Maximum Expected Sediment Deposition Thickness for sc1b



Scenario sc2 – the dredging and land reclamation works - represents the dredging of sand from one borrow area and the placement of the material at the reclamation site, and includes SSDV activities working on the sea defence. This scenario is subdivided into sc2a for dredging at the northern borrow area (total duration = seven weeks) and sc2b with dredging from the southern borrow area (total duration = seven weeks). The following assessment is based on the worst case conditions arising during a neap tidal cycle.

The model predicts that for sc2a, the expected maximum thickness of deposited sediment is above 0.1m in and around the northern borrow area. This is due to the relatively high sediment release rates during dredging for seven weeks using a THSD (see Figure 5.11). In addition, deposited sediment is above 0.1m locally at Eastside due to reclamation works. Elsewhere, deposition is not significant.

Sc2b would have similar effects to sc2a but the maximum thickness of deposited sediment is above 0.1m in and around the southern borrow area (see Figure 5.12). This change to the location of the impact reflects a similar dredging operation but at a different borrow area location. In addition, deposited sediment is above 0.1m locally at Eastside due to reclamation works. Elsewhere, deposition is not significant.

When sc2a is modelled with a west-south-west wind direction at 10m/s, the sediment deposition covers a larger water area across the Spanish border (compared to the sc2a situation without wind) because it extends further northward. Similarly, with sc2a modelled with an east-north-east wind direction at 10m/s, the sediment deposition covers a larger water area (compared to the sc2a situation without wind) by extending southward.

The following generic conclusions can be drawn from the modelling:

- The maximum expected sediment deposition thickness is below 0.1m for wide areas in and around THSD dredging works at the northern and southern borrow areas;
- The maximum expected sediment deposition thickness is above 0.1m for local areas at Eastside for trenching and reclamation works;
- The impact (as extent of sediment deposition >0.1m) associated with sc2 is more than the impact associated with sc1 due to the relatively long duration of dredging and the sediment release rates by the TSHD; and
- Wind influences modelled for sc2 show that the area affected by sediment deposition increases with wind speed, extending in the direction of the wind.

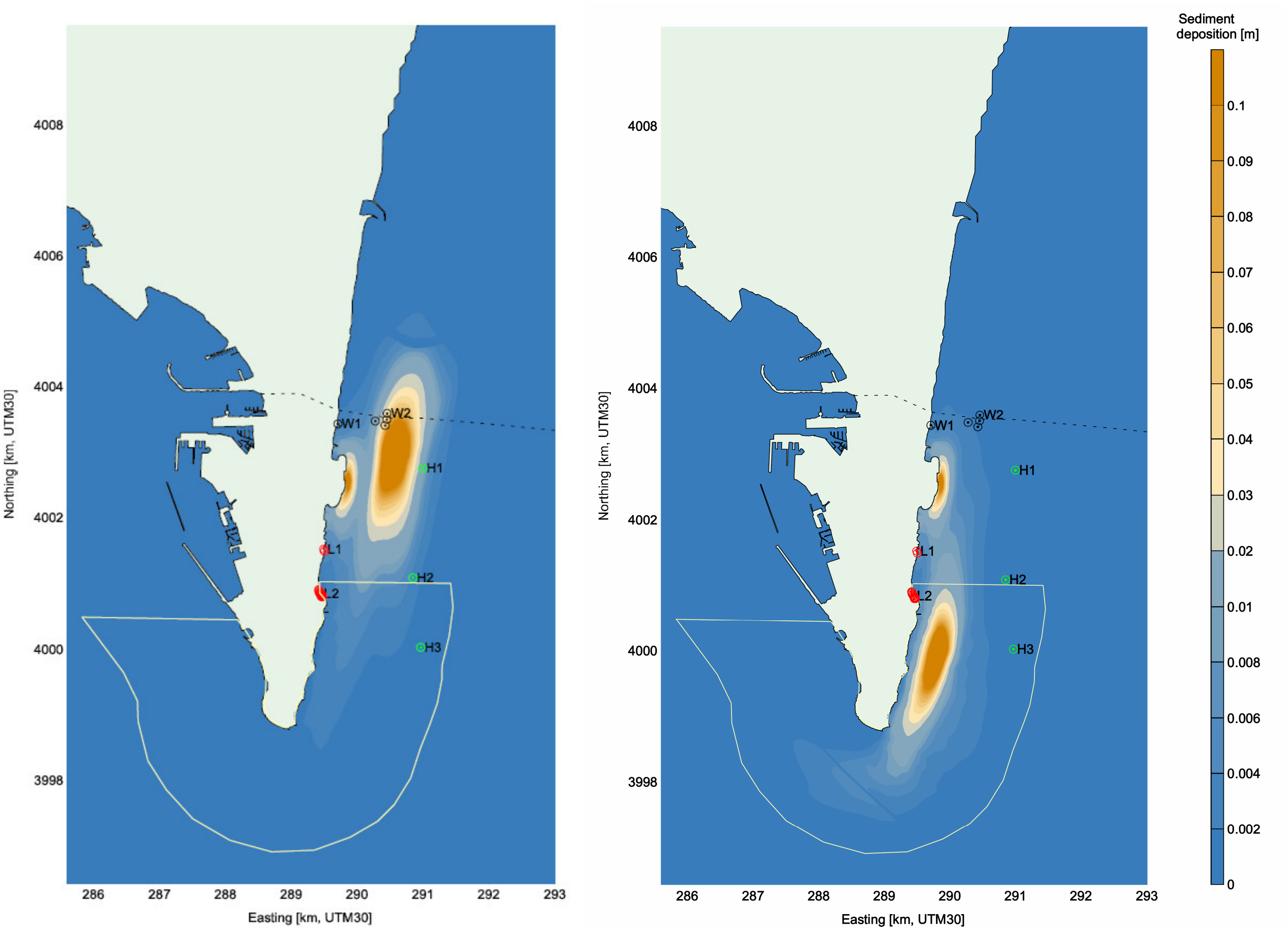
In terms of impacts on overall coastal geomorphology, the proposed dredging and other works will generally create low levels of sediment deposition (i.e. millimetres) in the coastal waters off eastern Gibraltar. The modelling results indicate that although the seabed in and around the northern and southern borrows areas can be affected by localised deposition of over 0.1m of sediment, the shoreline is largely unaffected, except at the land reclamation area for Eastside. Increases of this magnitude are to be expected around activities involving large dredging equipment such as a TSHD since it is in the nature of this dredging activity to release sediment.

Using the criteria for assessing the significance of impacts defined in Section 5.2.4, the following conclusions can be drawn:

- There will be a negligible impact on the seabed bathymetry of areas beyond the northern and southern borrow areas and Eastside;
- There will be a minor adverse impact on the seabed bathymetry of the northern and southern borrow areas and Eastside affected by sediment deposition above 0.1m; and
- The impact on seabed bathymetry decreases with distance from the dredger at the borrow areas and decreases very rapidly with distance from the reclamation areas at Eastside.

To reduce the magnitude and scale of impacts associated with dredging and reclamation, mitigation measures should be considered (see Section 5.5).

Figure 5.11 (left) Maximum Expected Sediment Deposition Thickness for sc2a
Figure 5.12 (right) Expected Sediment Deposition Thickness for sc2b



5.4.2 *Operation Phase: Impact on Tides*

Eastside could affect tide levels as a result of bathymetric and hydrodynamic changes caused by marine works and the dredging required at the two borrow areas (see Figure 4.20).

The impact of the scheme on tide levels was investigated with a numerical flow model to predict the impact of Eastside on high and low water levels during a spring tide. The impact of the scheme on the tidal levels was assessed by comparing the present situation (i.e. without the Eastside development) with the future situation (i.e. with the Eastside development). Modelling predicted that the impact of the scheme on tidal water levels will be negligible, with magnitudes of change of less than 5mm above and below existing levels, and only in the very near vicinity of the Eastside development site.

The impact of dredging works on the tidal water levels was estimated by implementing a new bathymetry in the flow model, in which the sea-bed was lowered in accordance with the expected deepening of the sea-bed at the northern and southern borrow areas. In the model, the seabed was lowered by 0.9m at the northern borrow area and by 0.4m at the southern borrow area to incorporate dredging Figure 5.13 shows the maximum impact of the dredging on the water level at low water.

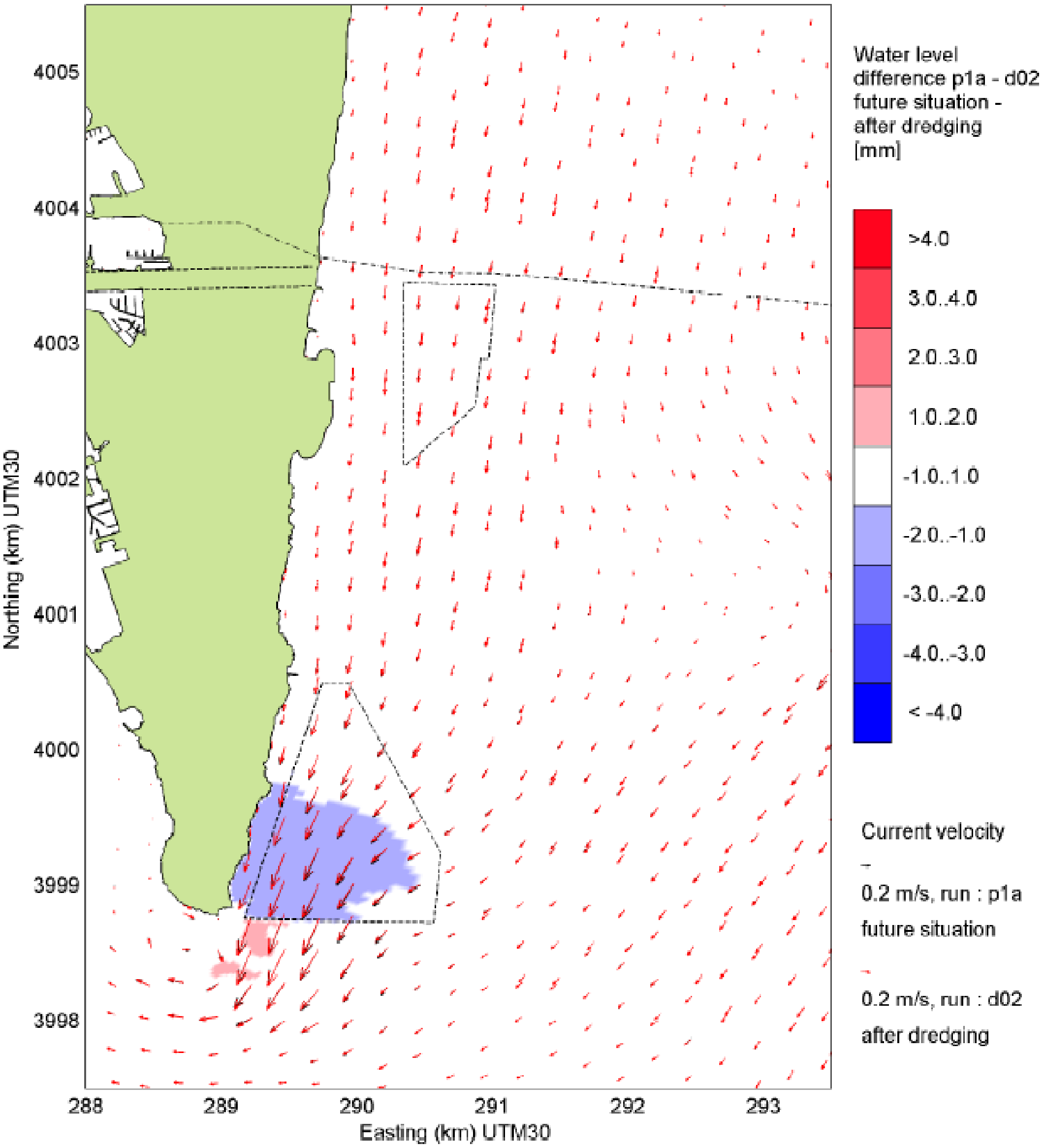
Numerical modelling predicted the impact of the dredging on tidal water levels at the northern borrow area to be less than 1mm, which is negligible.

Numerical modelling predicted the impact of the dredging on tidal water levels at the southern borrow area to be less than 3mm, which is negligible. Spatially, the impact is limited in scale to a water area generally east and partially south of Europa Point.

Using the criteria defined in Section 5.2.4, it can be concluded that the impact of Eastside on tidal water levels is negligible.

The reader should refer to Section 4 of Appendix B for more details.

Figure 5.13 Tidal Level Changes at MLWS due to Dredging at the Southern Borrow Area



5.4.3 *Operation Phase: Impact on Storm Surge Conditions*

The impact of the scheme on storm surges (as water levels and currents) was investigated with a numerical flow model for the 1:1, 1:10 and 1:100 return periods for three wind directions (east, east-north-east and east-south-east).

Storm surge water level changes were found to be limited to an area within the direct vicinity of the Eastside development and are predicted to be less than 2cm for all storm conditions. During winds from the east, Eastside has negligible impact on water levels because the wind is directed perpendicular to the coast. During winds from the east-north-east and east-south-east, water levels can change by up to 2cm, but only in extreme wind conditions.

Storm surge currents were found to be concentrated in the vicinity of the Eastside development. Current speeds are predicted to:

- Decrease up to 0.5km to the north of the site;
- Decrease up to 0.75km to the south of the site;
- Increase up to 0.3km offshore of the site, particularly at north east and south east corners of the development, by up to 3m/s; and
- Change elsewhere by no more than 0.1m/s.

Overall, the impact is predicted to be negligible because only small magnitude changes to water levels and currents are predicted in the vicinity of the site, even during extreme storm conditions (see Figures 5.14 and 5.15).

Figures 5.14 Storm Surge Water Level during 1:100 Year ENE Wind

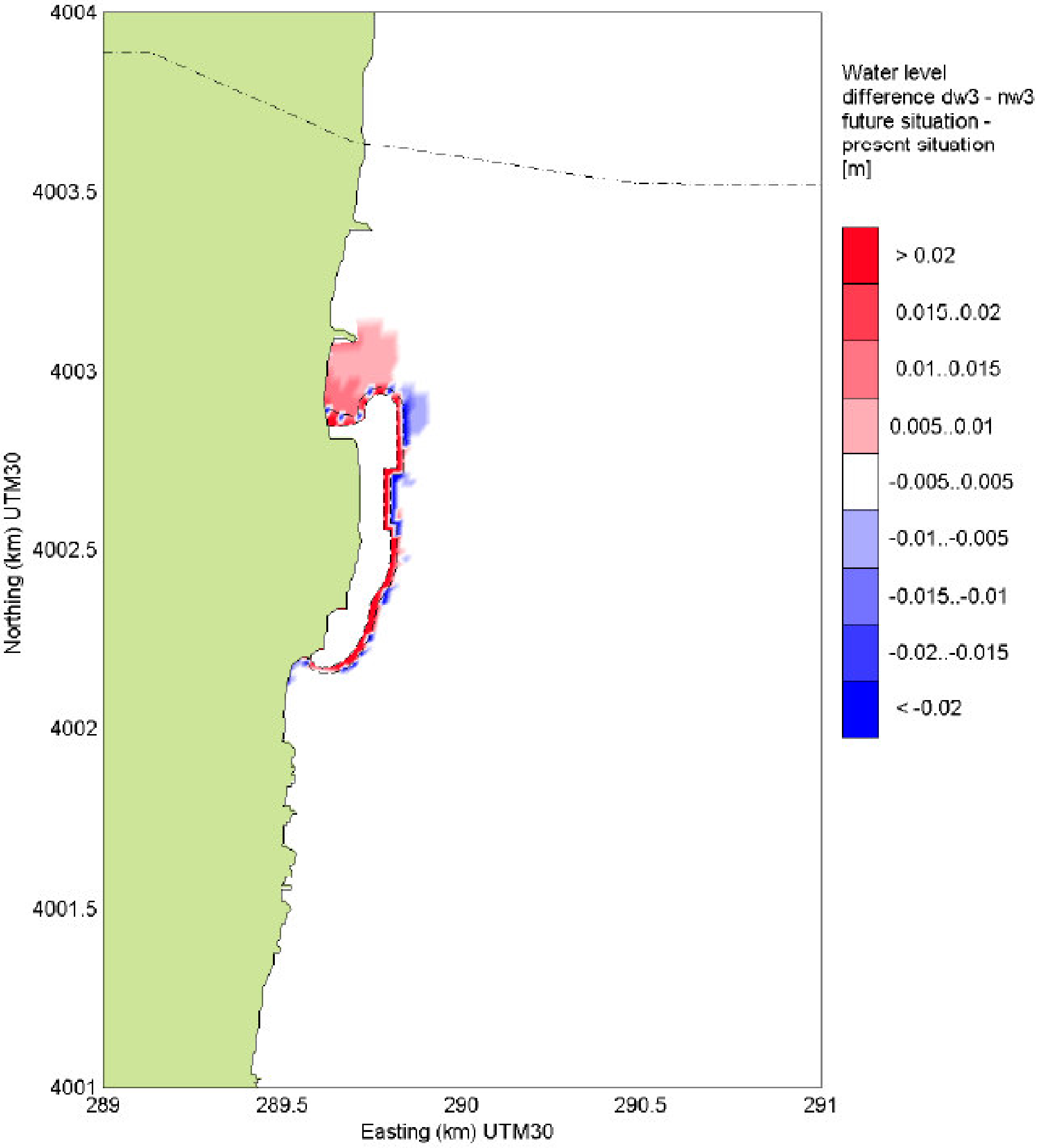
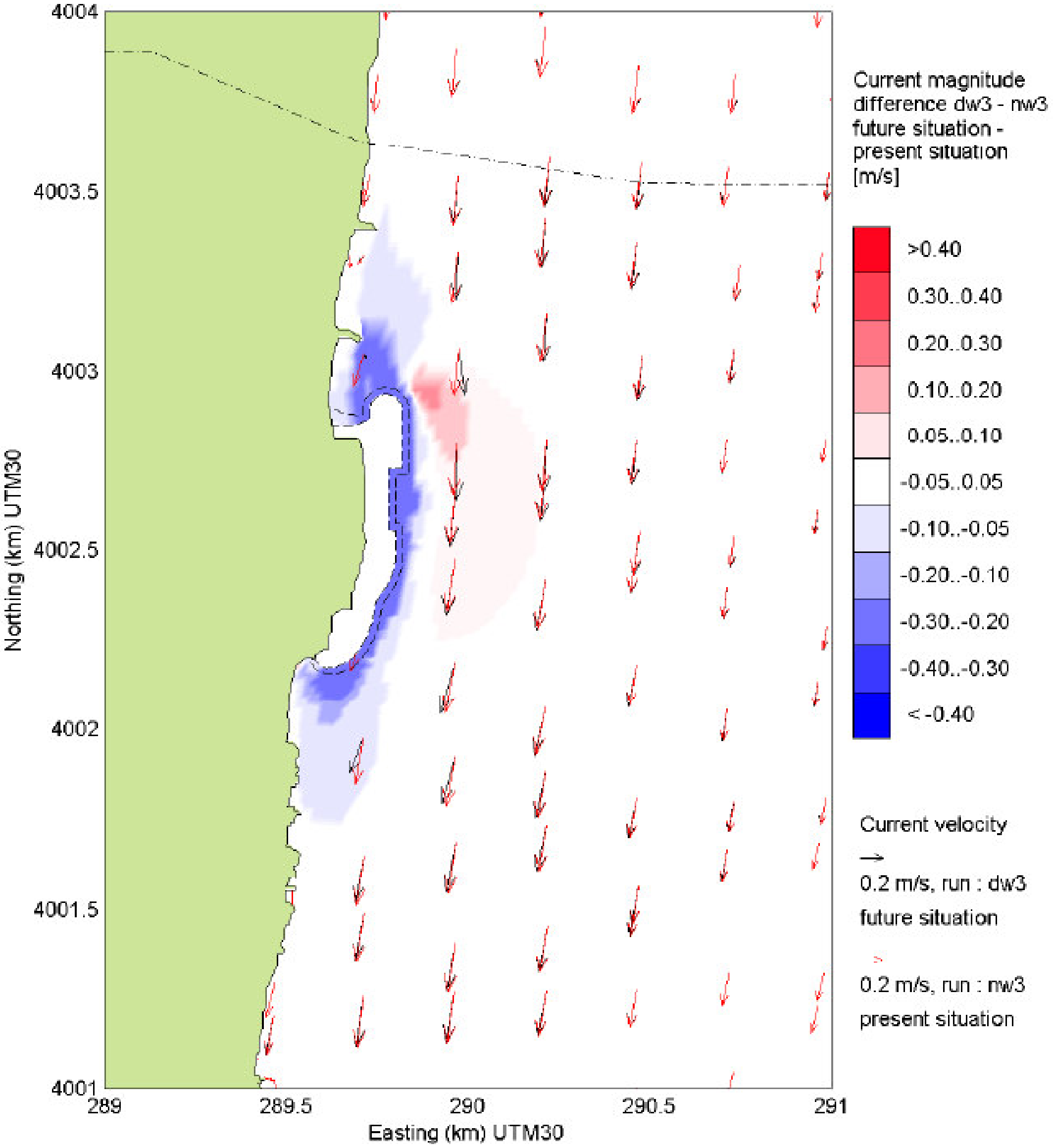


Figure 5.15 Storm Surge Water Level and Current Speed Changes during 1:100 Year ENE Wind



5.4.4 *Operation Phase: Impact on Currents*

The impact of Eastside on hydrodynamic flow patterns (i.e. tide and wind driven currents) was assessed using numerical modelling. The numerical model was run for a typical spring-neap cycle with and without the proposed development to predict the impact of the scheme on the current magnitudes along the east coast of Gibraltar and in neighbouring waters.

The following impact scenarios were assessed:

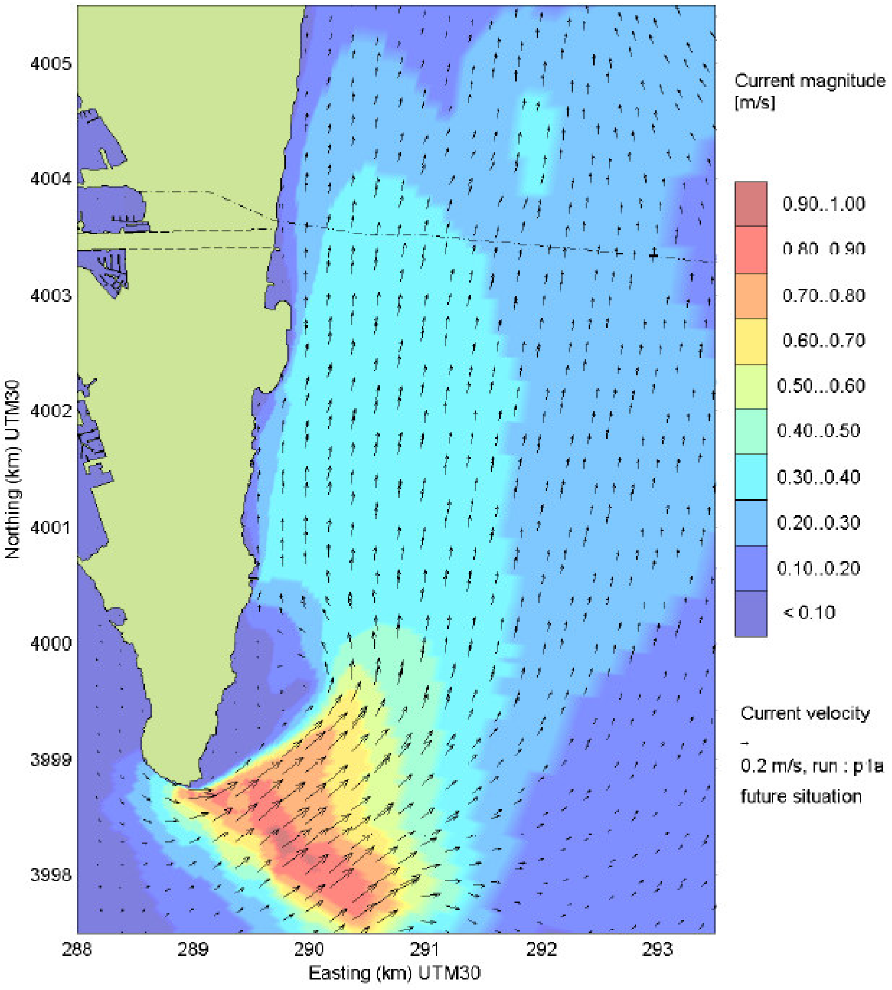
- No wind;
- Wind east-north-east at 10m/s; and
- Wind west-south-west at 10m/s.

In addition, the impacts associated with changes to the bathymetry as a result of dredging were considered.

Under the no wind scenario, the numerical modelling predicts that:

- The currents remain mostly north-south oriented (i.e. parallel to the coast) and circumvent the Eastside development (e.g. see Figure 5.16);
- The currents follow the outline of the development smoothly, and no significant flow acceleration is predicted, implying no detachment and eddying of water flows;
- Current velocities are weak in the corners of the Eastside development with Eastern beach (<0.05m/s) and Catalan Bay (<0.1m/s);
- Current velocities reach 0.4m/s close to the development on spring tides;
- The effect of the development on flow patterns is limited to a coastal section from 500m north to 500m south of the development, where current velocities reduce from up to 0.4m/s to less than 0.2m/s (see Figures 6.13a to 6.13l in Appendix B); and
- Variations to the flow patterns off Europa Point occur as a result of small differences in flow conditions around the Eastside development and bathymetric differences due to dredging from the southern borrow area.

Figure 5.16 Example of North-flowing Current Changes under the No Wind Scenario



Under the east-north-east wind at 10m/s scenario, the numerical modelling predicts general flow patterns with similar characteristics as the no wind scenario. The wind increases south-going currents by about 0.1m/s and decreases the north-going currents equally during a spring tide. During neap tides the wind effects are somewhat more pronounced and cause changes of about 0.2m/s. The effect of the development on flow patterns is limited to a coastal section similar to the no wind scenario (i.e. about 500m south and 500m north of the Eastside development site (see Figures 6.15a to 6.15l in Appendix B)), although differences are slightly larger to the south of the development because the wind direction reinforces southbound currents. Variations to the flow patterns off Europa Point are similar to the no wind scenario.

Under west-south-west wind at 10m/s scenario, the numerical modelling predicts that the general flow behaviour along the east coast of Gibraltar is changed only slightly. North-going currents are about 0.1m/s stronger and south-going currents are slower by about 0.1m/s for spring tides and 0.2m/s for neap tides. As a result, the timing of high water and low water slack conditions is slightly changed by about 30 minutes. The effect of the development on flow patterns is limited to coastal section about 200m south and 500m north of the Eastside development site (see Figures 6.17a to 6.17l in Appendix B)).

The impact of dredging works on the flow patterns was estimated by implementing a new bathymetry in the numerical model, in which the sea-bed was lowered in accordance with the expected deepening; that is, the sea-bed in the northern borrow area was lowered by 0.9m in the northern borrow area and by 0.4m in the southern borrow area. In both cases, the modelling predicted limited effects on flow patterns. In the northern borrow area, currents are not affected. In the southern borrow area flow directions and velocities are slightly different around low water - up to 0.05m/s to 0.1m/s during spring tides.

In summary, the numerical modelling results identified that:

- Current patterns along Gibraltar's east coast are mainly tide driven with a north-south orientation, so strong winds affect current velocities more than directions;
- The effects of the Eastside development on the flow patterns are limited to a coastal section from 500m to the south of the development to about 500m north of the development;
- The Eastside development does not induce recirculation zones (i.e. eddies) in the lee of the development;
- Along the Eastside development, flow velocities will reach 0.4m/s to 0.5m/s;
- Areas with weak currents are predicted to form just north and south of the Eastside development;
- The impact of the development on current velocities gradually decreases with the distance away from the development, and depends on the tidal phase;
- In the hours after high water, a large eddy would form to the north-east of Europa Point, causing strong current magnitudes (over 0.8m/s during spring tides) and current gradients in the southern borrow area, although changes to the eddy formation caused by the proposed development and deepening of the southern borrow area are expected to lie within the band of natural variations;
- Increased water depths in the northern and southern borrow areas due to dredging will not lead to any significant effects on the flow conditions.

Using the criteria in Section 5.2.4, it is concluded that the impact of Eastside on tide and wind driven currents would be negligible for most of Gibraltar's eastern coastal waters (including the borrow areas) except for the waters around the Eastside development site where the predicted changes to flow velocities are considered to be minor adverse impacts.

5.4.5 *Operation Phase: Impact on Wave Conditions*

The offshore wave conditions have been transformed to the nearshore waters of the Gibraltar's east coast using the wave propagation model SWAN (Simulating Waves Nearshore). Model simulations have been carried out with and without the proposed Eastside development to show the impact of the scheme on the annual wave conditions.

Figures 5.17 and 5.18 present the mean wave climate for five locations at the -8mAOD depth line computed with and without the proposed Eastside development. Comparing the figures, it can be concluded that:

- In the most northerly location (about 600m north of the development site) there is no significant effect of the development on waves from all directions;
- Immediately north of the development only waves from southerly directions are affected, but the effect is a very limited shift in wave direction and a small reduction in wave height;
- To the east of the development there is no visible effect on waves from easterly directions, and there is a small reduction in wave height and a shift to slightly more easterly directions for waves from south and south-easterly directions; and
- Immediately south of the development (and further south) there is no significant effect on waves.

In summary, beyond a distance of about 500m to the north and about 200m to the south of the development site the impact of the development on the normal wave conditions is negligible. In addition, assuming that the borrow areas will be dredged uniformly the impact of the dredging is expected to be negligible because the changes in water depth and slope will be relatively small compared to the existing situation.

Figure 5.17 Nearshore Wave Roses without the Eastside Development

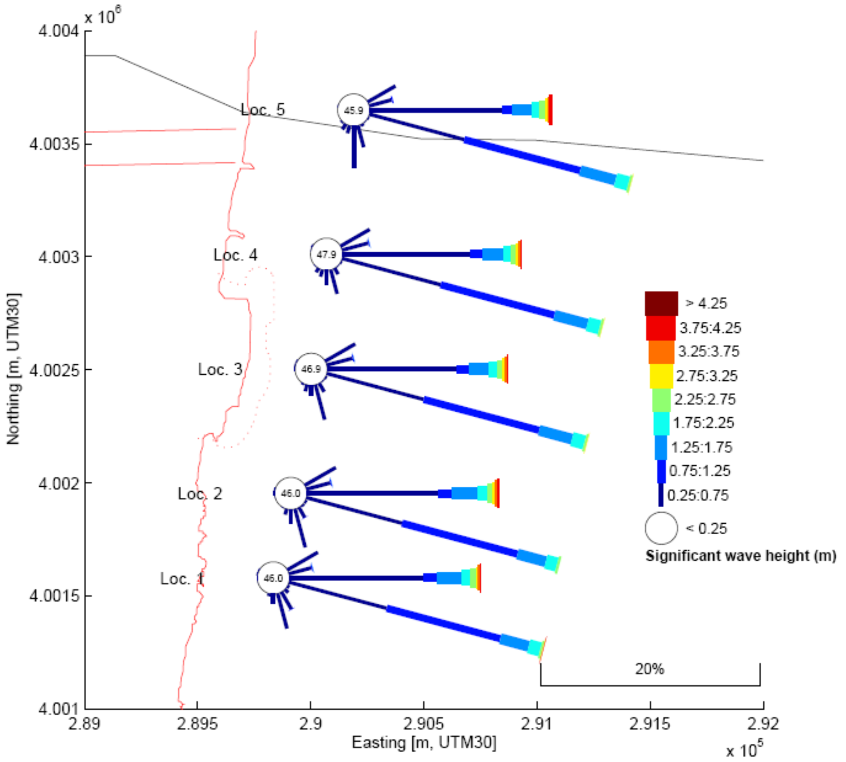
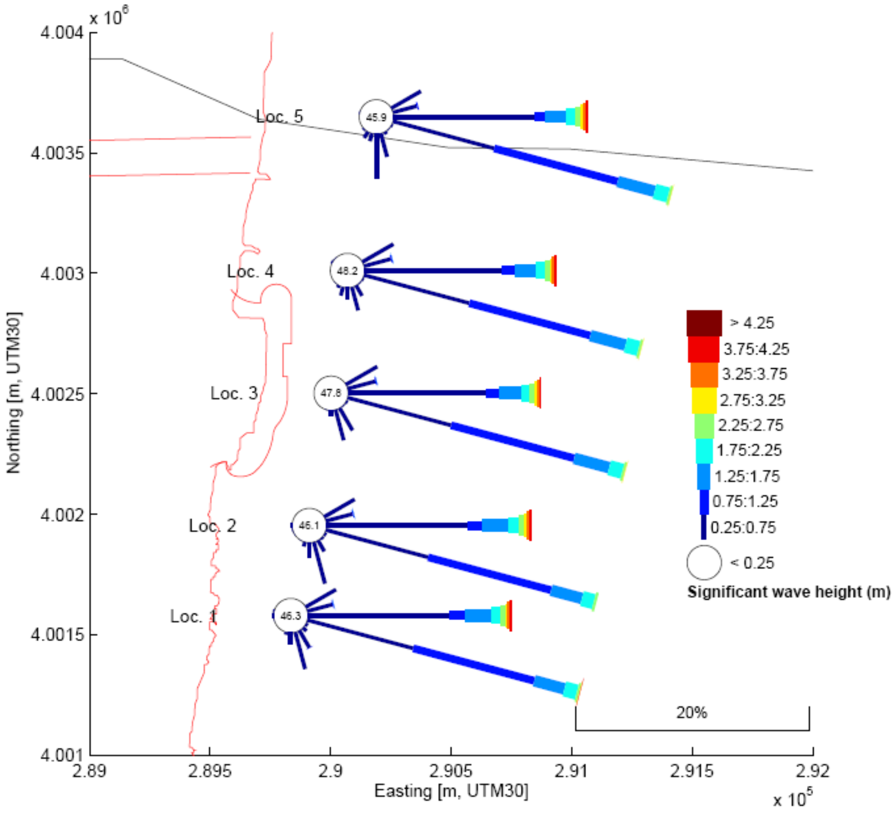


Figure 5.18 Nearshore Wave Roses with the Eastside Development



5.4.6 *Operation Phase: Impact on Beach Morphology*

It is possible that the construction of Eastside could interrupt the along-shore sediment transport, cross-shore sediment transport, cross-shore profiles and offshore sediment movement characteristics of this stretch of coast.

The results of the numerical modelling are summarised below and are presented in more detail in Section 5 of Appendix D.

With the Eastside development in place, the main geomorphology changes are expected to be caused partly by re-orientation of the shoreline of Eastern Beach and Catalan Bay. In the first years after construction the re-orientation effect is dominant. Accretion is predicted against the development at Eastern Beach and Catalan Bay, establishing a new equilibrium shoreline orientation within some (approximately 1 or 2) years. Due to this effect the shielded areas between the northern and southern extensions of the development and the coastline are expected to accrete sediment. The maximum computed seaward displacement of the coastline adjacent to Eastside is 60 to 70 metres for Eastern Beach (with respect to the initial coastline) and 20 to 30 meters for Catalan Bay. This sediment in the accreting zone originates from sections of Eastern Beach and Catalan Bay at some distance from the development, inducing an erosion of 15 to 25 metres just south of the central groyne at Eastern Beach and about 5 to 10 meters at the southern end of Catalan Bay.

The morphological impact on the second section of Eastern Beach (north of the central groyne) is much smaller and consists of a maximum accretion of at most some meters near the central groyne and a shoreline retreat of similar magnitude near the northern groyne.

No significant shoreline re-orientation is predicted north of the northern groyne of Eastern Beach or south of Catalan Bay.

The magnitude of alongshore beach re-orientation after five years is shown in Figure 5.19.

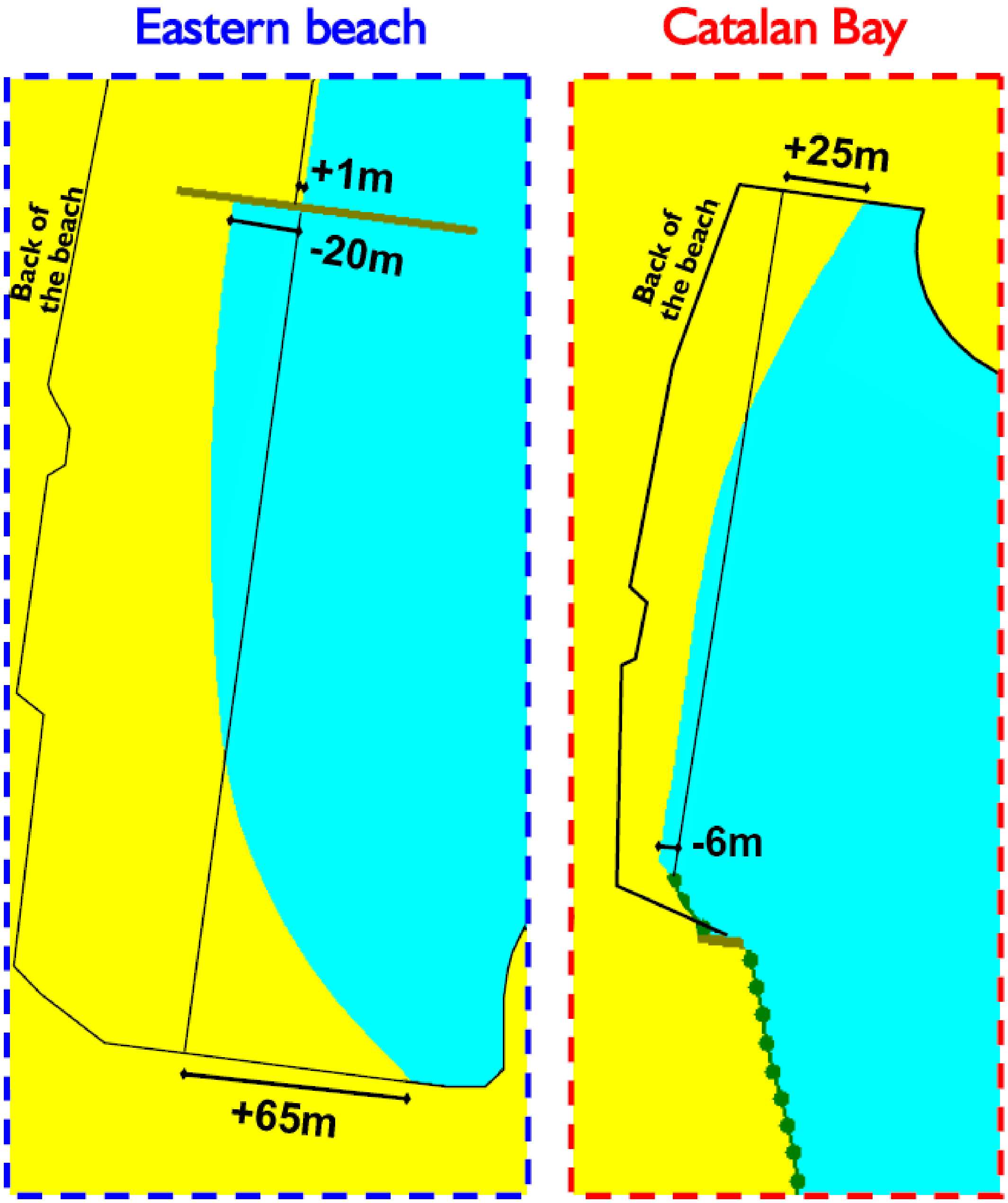
In terms of cross-shore profiles, the modelling predicts:

- No significant change of the beach slopes for the beaches of Eastern beach and Catalan Bay directly adjacent to Eastside;
- Some permanent offshore sand loss for the beaches of Eastern beach and Catalan Bay directly adjacent to Eastside; and
- A slight reduction of cross-shore beach storm response fluctuations for the beaches of Eastern beach and Catalan Bay directly adjacent to Eastside.

In summary, the impacts on beach geomorphology are expected to be:

- Major adverse impact due to beach erosion just south of the central groyne of Eastern Beach and at the southern end of Catalan Bay;
- Moderate adverse impact due to beach erosion just south of the northern groyne of Eastern Beach;
- Moderate beneficial impact due to beach accretion at the southern end of Eastern Beach and the northern end of Catalan Bay, directly south and north of Eastside respectively (if a wider beach is considered to be a desirable morphological quality); and
- No significant impact is predicted south of Catalan Bay (eg Sandy Bay) or north of Eastern Beach's northern groyne (eg Spanish beaches).

Figure 5.19 Impact on Coastal Geomorphology after 5 Years due to Beach Re-orientation as a Response to Long-shore Sediment Transport Changes



5.4.7 *Operation Phase: Impact on Seabed Morphology*

It is possible that the construction of Eastside could affect seabed morphology as a result of infilling at the borrow areas and infilling or scouring around Eastside (see Figure 5.20). [Note: this impact assessment excludes the effects on beach morphology discussed in Section 5.4.6.]

Seaward of the proposed development, some scour is predicted, mainly caused by wave breaking and flow contraction, to a magnitude of vertical erosion amounting to about 0.2 – 0.5m after 1 year. Southwest and northwest of the proposed development, small-scale sedimentation is expected due to wave shielding, to a magnitude amounting to about 0.2 – 1.0 m after 1 year. At some distance north from the proposed development at some locations small isolated spots of change (sedimentation as well erosion) are indicated by the model. These are related to very small changes in the development of rip currents for both situations (model sensitivity), and are not relevant for the overall coastal impact. The net effect of these sedimentation and erosion spots is negligible.

Infill rates at the borrow areas are predicted to cause relative morphological changes (after 1 year) in and around both borrow areas. For both areas, the edges become smoother, erosion takes place just outside the borrow areas, and deposition occurs just inside the borrow areas.

The infill rate of the northern borrow area is very limited. Estimated volumes of total deposited sediment in this borrow area after 1 year range from 50 – 500 m3, which corresponds to an average (over the entire borrow area) deposition of 1 mm at most. However, the main deposition is expected to be close to the edges. It is concluded that the infill rate is very small because the deepening is relatively small compared to the total water depth (approximately 6%) and sediment transport in this location is very small.

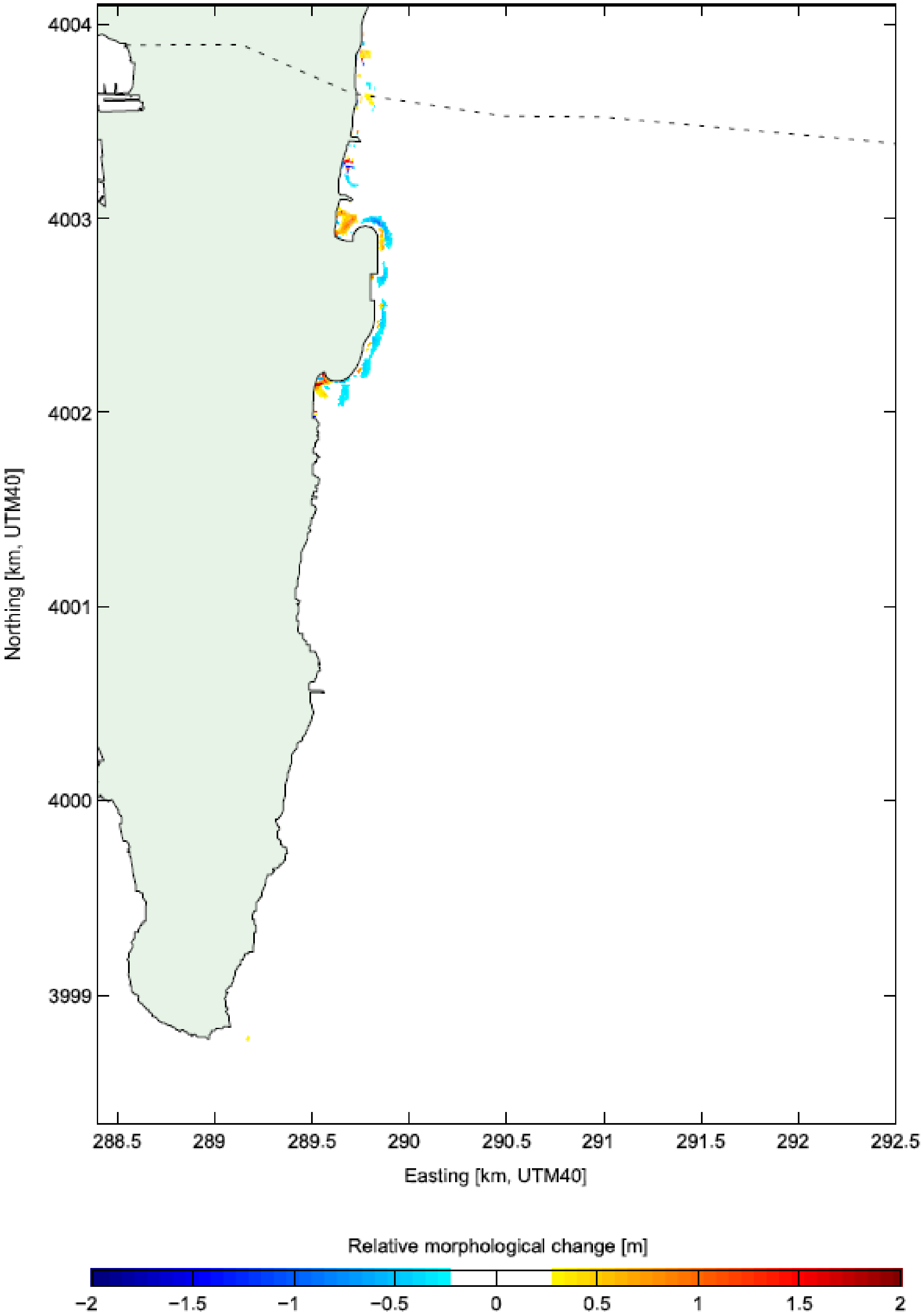
A higher infill rate is predicted for the southern borrow area because of larger sediment transport in this location. It is estimated that the total amount of deposited sediment ranges from 1,400 – 12,000 m^3 after 1 year, corresponding to 1 – 8 mm sedimentation, which is higher than for the northern borrow area. Nevertheless, the infill rate of the southern borrow area is low.

For both borrow areas, most sedimentation is expected in the western parts of the areas, because the relative deepening is largest in the western parts and the sediment transport is larger in more shallow water. Due to the low percentage of sand trapping by the borrow areas any adverse (erosion) effect on the surrounding seabed is predicted to be a very slow process. In addition, since the main part of these effects occur well below the closure depth, any effects of sand re-distribution around the borrow pits on the coast are expected to be very small.

The results of the numerical modelling are presented in detail in Section 6 of Appendix D. The significance of the impacts is summarised below:

- Minor adverse impact on the seabed seawards of Eastside where erosion and deposition of 0.2 and 0.5m is predicted;
- Minor adverse impact on the seabed south-west and north-west of Eastside (i.e. at Catalan Bay and Eastern Beach) where erosion and deposition of 0.2 and 1.0m is predicted;
- Negligible impact on the seabed within the northern borrow area where infilling corresponds to an average sedimentation of 1mm over the entire borrow area. However, a higher magnitude of infilling is expected to occur close to the edges;
- Negligible impact on the seabed within the southern borrow area where infilling corresponds to an average sedimentation of 1mm to 8mm over the entire borrow area. However, a higher magnitude of infilling is expected to occur close to the edges; and
- Negligible impact on the seabed around the borrow areas. The magnitude of erosion on the seabed surrounding the borrow areas is predicted to be very small due to the low percentage of sand trapping by the borrow areas.

Figure 5.20 Impact on Seabed Morphology around the Eastside Development



5.5 Mitigation Measures

5.5.1 *Construction Phase: Impact of Sediment Plume Deposition*

To reduce the magnitude and scale of impacts associated with dredging and reclamation, the following mitigation measures should be considered and implemented in a practicable and cost-effective manner as part of the contract awarded for the marine works for Eastside. To reduce sediment suspension – and associated deposition - from the TSHD (CIRIA, 2000):

- Optimise trailing velocity, suction head and pump discharge with respect to one another to reduce sediment losses around the draghead;
- Try to reduce water intake by the suction head to increase sediment density and reduce need for overflowing;
- Apply return flow method if the TSHD has this facility to increase sediment density and reduce overflowing; and
- Avoid unnecessary overflowing through operational method.

5.5.2 *Operation Phase: Impact on Wave Conditions*

There is a risk (rather than a definite impact) that the wave field surrounding the borrow areas may be more significantly affected if dredging creates a significantly uneven seabed resulting, for example, in a deep channel or pit. It is estimated that unevenness of +/-2.5m may result in local bottom variations of up to 5m which are significant at 20m water depth and could be expected to affect the wave field. Normal tolerances for TSHDs - the type of equipment needed to conduct the works - depend on various factors including local variations in the subsoil, the dredger and the sea state during dredging. Also, there is limited control over the track of the TSHD's draghead since it simply follows the TSHD. An average figure for unevenness is in the order of approximately +/- 1m.

On the basis of the above, it would appear necessary to recommend that the contract specification for the dredging works includes a clause that requires the contractor to avoid dredging practices that will create a significantly deep channel or pit (in terms of tolerances) in order to avoid this risk.

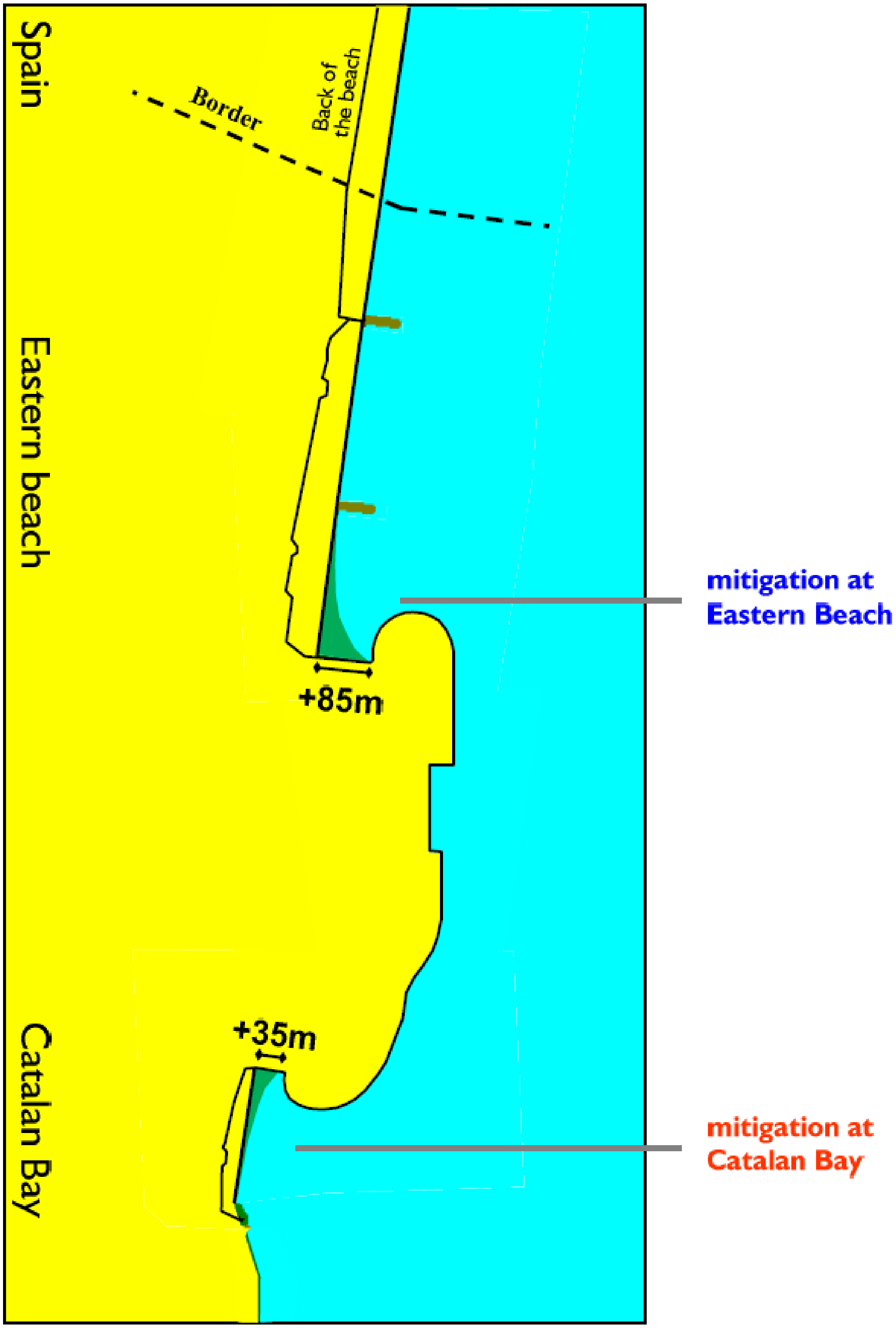
5.5.3 *Operation Phase: Impact on Beach Morphology*

At the time of preparing the ES, a confirmed design and programme for GoG's beach improvement works was not available and therefore the following mitigation measures have not taken these works into account.

The impacts of Eastside can be mitigated by means of regular nourishment of the eroding spots indicated in Figure 5.21. To minimise offshore sand loss, it would be preferable to carry out relatively small-scale nourishment operations.

However, from an operational point of view and in order to avoid local rapid shoreline retreat rates due to re-orientation of the shorelines in the first years after construction of Eastside, an alternative approach would be to create the equilibrium shape of the beach in one initial sand nourishment operation immediately after construction of the planned development, as illustrated in Figure 5.21. In this way the predicted erosion further along the beaches (due to the alongshore re-distribution of sand) can be prevented. The total required volume of sand for this initial nourishment is about 30,000 to 60,000 m^3 north of the planned development (Eastern Beach) and 20,000 to 30,000 m^3 south of the planned development (Catalan Bay). If this mitigation option is chosen, it should be noted that material sourcing could have an environmental impact, which may require further assessment.

Figure 5.21 Proposed Mitigation Measure for Beach Morphology



A potential disadvantage would be that the shoreline is shifted forward at an earlier stage, and as a result cross-shore losses will be relatively large. In the overall seaward shifted state of the beaches as indicated in Figure 5.21 the offshore losses should be expected to be somewhat larger, since a larger overall seaward shift of the coastal profile tends to result in a larger offshore sand loss.

It should be noted that Figure 5.21 only shows mitigation of the most adversely affected areas immediately north and south of Eastside. Some slight erosion is also predicted south of the northern groyne on Eastern Beach, and this can be mitigated with small nourishment.

As a result of the ongoing offshore loss some regular re-nourishment will be required. It is also recommended that monitoring will be implemented and some maintenance be anticipated for the beach north of the northern groyne. The shoreline model has suggested that cross-border effects are predicted to be negligible. However, it is possible that small changes in shoreline trends could be masked by inaccuracies in the shorelines derived from the satellite pictures. Therefore, although there is no evidence to support the supposition, it is possible that a very small northwards transport (some thousands of m^3/yr at most) could be present, but which was not detected on the basis of the shoreline analysis. Even if such a northerly transport were to exist the impact of the planned development on this area would be minimal. Given the above, it is recommended to monitor the beach just south of the border after construction of the planned development. A low-maintenance solution which would provide a contingency measure to avoid any possible cross-border impact might involve the placement of a sand buffer north of the northern groyne at Eastern Beach. If a buffer were to be placed the behaviour of the buffer should be monitored and some re-nourishment (on average some thousands of m^3/year at most) should be anticipated. If this mitigation option is chosen, it should be noted that material sourcing could have an environmental impact, which may require further assessment.

5.6 Residual Impacts

5.6.1 *Construction Phase: Impact of Sediment Plume Deposition*

Even with these measures in place, it is unlikely that predicted impacts will be reduced significantly since modern dredging equipment tends to work very efficiently, for example, in terms of the accuracy of the draghead, increasing the density of the sediment pumped into the hopper and avoiding unnecessary overflowing. Accordingly, there will be:

- A negligible residual impact on the seabed bathymetry of areas beyond the northern and southern borrow areas and Eastside; and
- A minor adverse residual impact on the seabed bathymetry of the northern and southern borrow areas and Eastside affected by sediment deposition above 0.1m.

5.6.2 *Operation Phase: Impact on Beach Morphology*

With mitigation in place a negligible residual impact will remain on beach geomorphology.

5.7 Cumulative Effects

5.7.1 *Construction Phase: Cumulative Effect of Sediment Plume Deposition*

The cumulative effect of Eastside in combination with other plans or projects (see Section 4.10) has been assessed for sediment plumes by using the same approach as described in Section 5.4.

The Both Worlds Project is not expected to involve dredging and reclamation that coincides with the dredging and reclamation for Eastside, and therefore no cumulative effect is predicted.

Accordingly, no mitigation measures are recommended and therefore there will be no residual cumulative effect.

5.7.2 *Operation Phase: Cumulative Effect on Tides*

The cumulative effect of Eastside in combination with other plans or projects (see Section 4.10) has been assessed for tides by using the same approach as described in Section 5.4.

Given the findings of Section 5.4 for Eastside and because of the very limited size of the Both Worlds Project, no cumulative effects on the tidal levels are predicted.

Accordingly, no mitigation measures are recommended and therefore the residual cumulative effect will be negligible too.

5.7.3 *Operation Phase: Cumulative Effect on Storm Surge Conditions*

The cumulative effect of Eastside in combination with other plans or projects (see Section 4.10) has been assessed for storm surge conditions (water levels and currents) by using the same approach as described in Section 5.4.

Given the findings of Section 5.4 for Eastside and because of the very limited size of the Both Worlds Project, no cumulative effects on storm surge levels and storm surge currents are predicted.

Accordingly, no mitigation measures are recommended and therefore the residual cumulative effect will be negligible too.

5.7.4 *Operation Phase: Cumulative Effect on Currents*

The cumulative effect of Eastside in combination with other plans or projects (see Section 4.10) has been assessed for hydrodynamic flow patterns (i.e. currents) by using the same approach as described in Section 5.4.

Given the findings of Section 5.4 for Eastside and because of the very limited size of the Both Worlds Project, no cumulative effects on currents are predicted.

Accordingly, no mitigation measures are recommended and therefore the residual cumulative effect will be negligible too.

5.7.5 *Operation Phase: Cumulative Effect on Wave Conditions*

The cumulative effect of Eastside in combination with other plans or projects (see Section 4.10) has been assessed for waves by using the same approach as described in Section 5.4.

Considering the small scale of the Both Worlds project at Sandy Bay its own impact on the normal wave climate will be very small and limited to a small part of Sandy Bay only; hence, there will be no cumulative effect of the Both Worlds project in combination with Eastside.

On the basis of the above, it is concluded that the cumulative effect on waves is negligible. Accordingly, no mitigation measures are recommended and therefore the residual cumulative effect will be negligible too.

5.7.6 *Operation Phase: Cumulative Effect on Beach Geomorphology*

The cumulative effect of Eastside in combination with the Both Worlds Project (see Section 4.10) has been assessed for beach geomorphology by using the same approach as described in Section 5.4.

For the Both Worlds project (see Section 4.10), the seaward extension is very small and does not create a noticeable wave shielding effect on Sandy Bay beach or any other beach. It also does not form a noticeable interruption of current and sediment transport patterns. Predictions made for the planned development at Eastside are not affected by the Both Worlds Project and so any cumulative effect on beach morphology over the impact caused by Eastside alone is expected to be negligible. Accordingly, no mitigation measures are recommended and therefore the residual cumulative effect will be negligible too.

5.7.7 *Operation Phase: Cumulative Effect on Seabed Morphology*

The cumulative effect of Eastside in combination with the Both Worlds Project (see Section 4.10) has been assessed for seabed morphology by using the same approach as described in Section 5.4.

The cumulative effects of the Both Worlds project are expected to be negligible, as the scale of this development is very small compared to the proposed Eastside development.

Given the above predictions, no mitigation measures are recommended and a negligible residual cumulative effect is predicted.

5.8 Transboundary Effects

5.8.1 *Construction Phase: Transboundary Effect of Sediment Plume Deposition*

The transboundary effect of Eastside has been assessed for sediment plumes by using the same approach based on two scenarios as described in Section 5.4.1.

The model predicts negligible sediment deposition for sc1a and sc1b. The expected maximum thickness of deposited sediment is above 0.1m locally around locations at the Eastside development (see Figures 5.9 and 5.10). Elsewhere, deposition is not significant.

The model predicts that for sc2a (dredging at the northern borrow area), the expected maximum thickness of deposited sediment is above 0.1m just across the border in water depths of around 15m. This is due to the relatively high sediment release rates during dredging for seven weeks using a THSD (see Figure 5.11). Deposition is not significant further into Spanish water.

The model predicts negligible sediment deposition for sc2b since most of the deposition occurs in and around the southern borrow area (see Figure 5.12).

In terms of impacts on coastal geomorphology, the proposed dredging and other works will generally create low magnitude levels of sediment deposition (i.e. millimetres) in Spanish waters. The modelling results indicate that although the seabed in 15m of water just across the border can be affected by high magnitude sediment deposition above 0.1m (sc2a), the shoreline is not significantly affected. The model also shows that the greater impacts tend to occur during a spring tidal cycle.

Since there is no quantified deposition standard for sediment, an impact assessment on geomorphology has to be made on a qualitative basis. Accordingly, it is suggested that:

- There will be a minor adverse transboundary effect on the seabed bathymetry in Spanish waters directly north of the northern borrow areas where sediment deposition above 0.1m may occur in 15m of water; and
- The impact on seabed bathymetry elsewhere in Spanish waters will be negligible or not significant.

To reduce the magnitude and scale of transboundary effect associated with dredging and beach nourishment, mitigation measures should be considered. The mitigation measures described in Section 5.5 cover the dredging works.

Even with these measures in place, it is unlikely that the residual transboundary effect will be reduced significantly since modern dredging equipment tends to work very efficiently, for example, in terms of the accuracy of the draghead, increasing the density of the sediment pumped into the hopper and avoiding unnecessary overflowing.

Accordingly, there will be a minor adverse residual transboundary effect on the seabed bathymetry in Spanish waters directly north of the northern borrow areas where sediment deposition above 0.1m may occur in 15m of water.

5.8.2 *Operation Phase: Transboundary Effect on Tides*

The transboundary effect of the Eastside development has been assessed for tides by using the same approach as described in Section 5.4. Numerical modelling predicts that the impact of Eastside on tidal water levels will be negligible. For example, Figures 4.2a and 4.2b in Appendix B show that impacts on tidal levels is restricted to the vicinity of the Eastside development.

On the basis of the above presented simulations and analysis it is concluded that the transboundary effect on the tidal water levels along the Spanish coast is negligible.

Accordingly, no mitigation measures are recommended and therefore the residual transboundary effect will remain as negligible.

5.8.3 *Operation Phase: Transboundary Effect on Storm Surge Conditions*

The transboundary effect of Eastside has been assessed for storm surge conditions by using the same approach as described in Section 5.4. Numerical modelling predicts that the impact of the Eastside development on storm surges will be limited to 500m north of the site and therefore should not affect storm surge levels and currents in Spanish waters. For example, reference to Figures 5.5a to 5.5c, Figures 5.6a to 5.6c, Figures 5.7a to 5.7c, Figures 5.8a to 5.8c, Figures 5.9a to 5.9c and Figures 5.10a to 5.10c in Appendix B indicate that storm surge conditions in Spanish waters will not be affected within the range of -0.05m/s to 0.05m/s.

On the basis of the above, it is concluded that the transboundary effect on storm surge conditions is predicted to be negligible. Accordingly, no mitigation measures are recommended and therefore the residual transboundary effect will remain as negligible.

5.8.4 *Operation Phase: Transboundary Effect on Currents*

The transboundary effect of Eastside has been assessed for tide and wind driven currents by using the same approach as described in Section 5.4.

Numerical modelling predicts that the impact of Eastside on currents in the Spanish waters is expected to be limited to approximately 500m north of the Eastside development and to be negligible in Spanish waters. For example, reference to Figures 6.13a to 6.13l (no wind), 6.15a to 6.15l (east-north-east wind at 10m/s) and Figures 6.17a to 6.17l (west-south-west wind at 10m/s) in Appendix B indicate that the current magnitudes in Spanish waters will not be affected within the range of -0.05m/s to 0.05m/s.

On the basis of the above, it is concluded that the transboundary effect on currents is predicted to be negligible. Accordingly, no mitigation measures are recommended and therefore the residual transboundary effect will be negligible too.

5.8.5 *Operation Phase: Transboundary Effect on Wave Conditions*

The transboundary effect of Eastside has been assessed for waves by using the same approach as described in Section 5.4. Since Eastside will only affect the normal wave conditions over a spatial area extending about 500m to the north and about 200m to the south of the proposed development, with the magnitude of the changes in wave conditions decreasing with the distance from the development, the transboundary effect on wave climate is predicted to not influence the wave climate in Spanish waters.

On the basis of the above, it is concluded that there will be no transboundary effect on waves. Accordingly, no mitigation measures are recommended and there will be no residual transboundary effect.

5.8.6 *Operation Phase: Transboundary Effect on Beach Morphology*

The transboundary effect of Eastside has been assessed for beach geomorphology by using the same approach as described in Section 5.4.

It is possible that the construction of Eastside could interrupt the along-shore sediment transport, cross-shore sediment transport, cross-shore profiles and offshore sediment movement characteristics of the Spanish coast.

The results of the numerical modelling are summarised below and are presented in more detail in Section 5 of Appendix D.

As described in Section 5.4, with Eastside in place, no significant impact is predicted north of Eastern Beach's northern groyne. Accordingly, no transboundary effect is predicted for Spain's coast.

Although transboundary effects are predicted to be negligible, modelling suggests that it is possible that small changes in shoreline trends could be masked by inaccuracies in the shorelines derived from the satellite pictures. Therefore, although there is no evidence to support the supposition, it is possible that a very small northwards transport (some thousands of m^3/yr at most) could be occurring, but is not detected on the basis of the shoreline analysis. Even if such a northerly transport were to exist, the impact of Eastside to the beaches north of Eastern beach's northern groyne would be minimal.

Given the findings of Section 5.4 concerning the impact of the Eastside development to the north of the northern groyne at Eastern Beach, it would be prudent to monitor Eastern Beach just south of the border after construction of Eastside and decide on placement of a sand buffer if year-to-year erosion is observed (which would indicate the existence of a small net northward transport).

If a buffer were to be placed the behaviour of the buffer should be monitored and some renourishment (on average some thousands of m^3/year at most) should be anticipated.

With mitigation in place, there is expected to be a no residual transboundary effect on beach geomorphology.

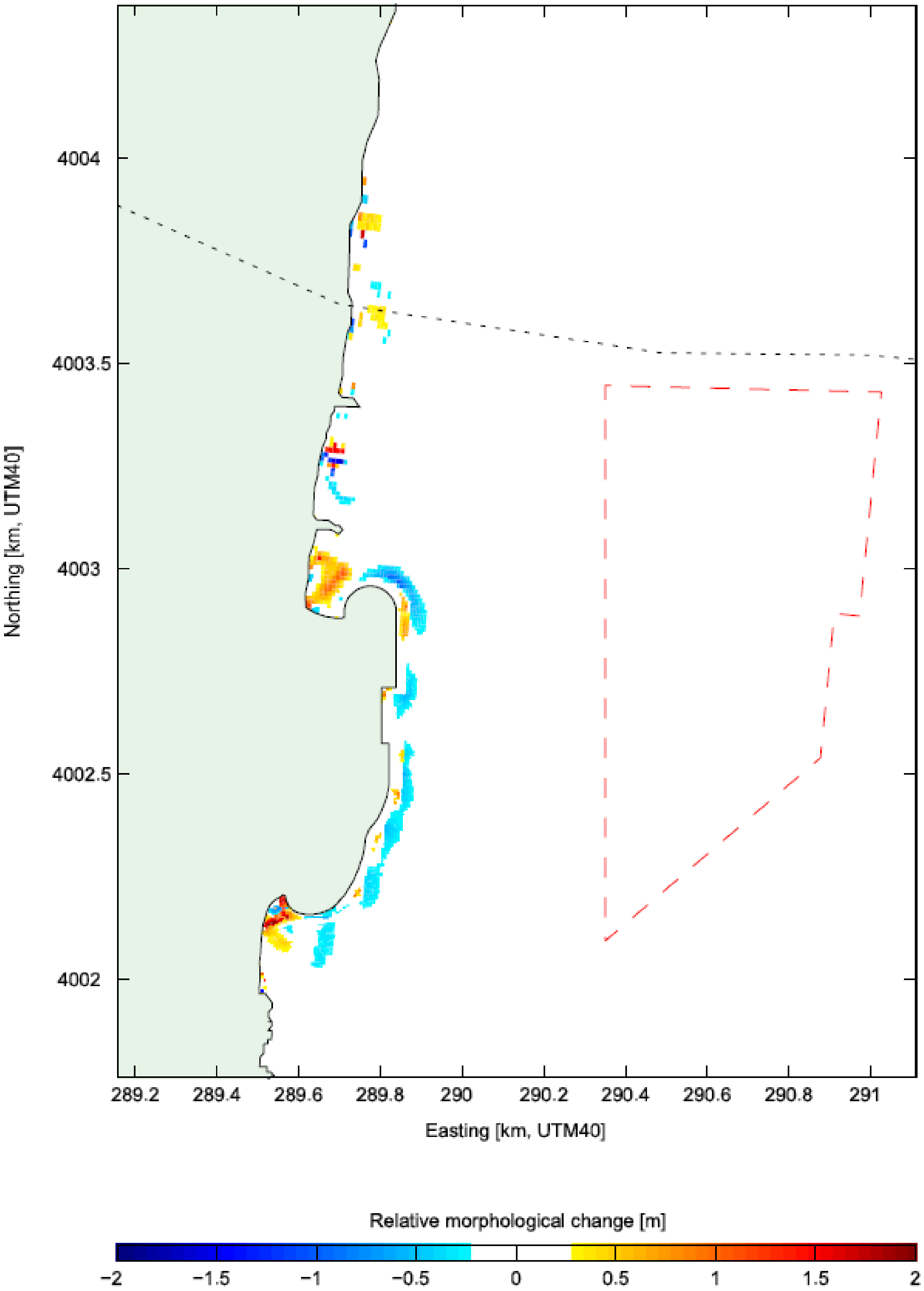
5.8.7 *Operation Phase: Transboundary Effect on Seabed Morphology*

The transboundary effect of Eastside has been assessed for seabed morphology by using the same approach as described in Section 5.4.

In summary, the impacts associated with Eastside (see Section 5.4 and Figure 5.22 overleaf) are predicted to cause negligible morphological impacts within Spanish waters and therefore a negligible transboundary effect is predicted.

Given the above predictions, no mitigation measures are recommended and a negligible residual transboundary effect is predicted.

Figure 5.22 Impact on Seabed Morphology between Eastside and Spain



5.9 Uncertainty

The results of the modelling studies are valid given the applied assumptions and conditions. It should be noted, however, that when there is a (significant) change in these assumptions, the results may change. For example, it is possible that small changes in shoreline trends (that have informed the model assumptions for coastal geomorphology) could be masked by inaccuracies in the shorelines derived from the satellite pictures. Uncertainty has been addressed by using the best available data to inform the modelling.

5.10 Summary

This chapter has assessed the potential impacts, cumulative effects and transboundary effects of Eastside on coastal hydrodynamics and geomorphology.

During construction, the principal impact concerns the deposition of sediment released and dispersed during dredging and how it may affect the seabed's bathymetry.

Generally, sediment deposition will only be significant in the vicinity of the proposed development at Eastside. Nevertheless, mitigation has been recommended to minimise unnecessary sediment discharges during dredging.

During operation, impacts on tide, storm surge, current, wave and seabed conditions are predicted to be negligible or not significant. The principal impact concerns beach morphology which is predicted to change as a response to Eastside to the extent that mitigation is recommended in the form of beach nourishment and maintenance.