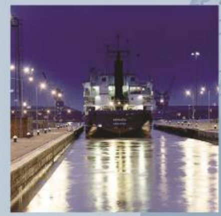
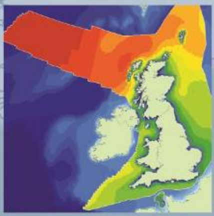
Dun Laoghaire Harbour Company

Cruise Berth, Dun Laoghaire Harbour: Wave, Tide and Sediment Plume Modelling

Report R.2307

October 2014

Creating sustainable solutions for the marine environment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Abbreviations

2D	Two-dimensional
ABPmer	ABP Marine Environmental Research Ltd
BBSG	Burford Bank Spoil Ground
BGS	British Geological Survey
CD	Chart Datum
DHI	Danish Hydraulic Institute
DLH	Dun Laoghaire Harbour
DLHC	Dun Laoghaire Harbour Company
DSD	Directional Standard Deviation
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
FM-HD	Flexible Mesh Hydrodynamics
HAT	Highest Astronomical Tide
Hs	Significant Wave Height
HW	High Water
INFOMAR	INtegrated Mapping FOr the Sustainable Development of Ireland's MArine Resource
LAT	Lowest Astronomical Tide
LW	Low Water
mDir	Mean Wave Direction
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	US National Oceanic and Atmospheric Administration
NTSLF	National Tide and Sea Level Facility
PT	Particle Tracking
RMS	Root Mean Square
Ro-Ro	Roll On Roll Off
SAC	Special Area of Conservation
SSC	suspended sediment concentration
SW	Spectral Waves
Tp	Peak Spectral Wave Period
TS	Timeseries
TSHD	Trailing Suction Hopper Dredger
TT	TotalTide
UKCP09	United Kingdom Climate Projections 09
UKHO	United Kingdom Hydrographic Office

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

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1. Introduction

The Dun Laoghaire Harbour Company (DLHC) is seeking consent to develop a new cruise liner terminal within Dun Laoghaire Harbour (DLH), Ireland. In addition to new onshore facilities, the development will require a new piled mooring jetty to be constructed and capital dredging works will be undertaken to deepen and widen the approach channel to both the harbour and the berth.

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by DLHC to provide an assessment of the identified potential impacts of the proposed development on the marine physical environment. Waterman Moylan is advising DLHC in relation to the proposed development and has provided the engineering input to this assessment. This report is intended to inform the relevant sections of an Environmental Impact Statement (EIS) being developed by DLHC to support its application for planning consent.

The marine components of the proposed development considered within this report are collectively referred to herein as 'the Scheme' and known details are outlined in Section 1.1. Details of the Scheme scenarios actually assessed are provided for each impact type in later sections, which assess the potential impacts. The study area for the impact assessment is defined in Section 1.2.

A summary of the present day (baseline) marine environment within the study area is provided in Section 2. This information provides the environmental context within which potential impacts are assessed. Information is provided for a range of physical parameters, including:

- Water depth (Section 2.2);
- Water levels (Section 2.3);
- Winds (Section 2.4);
- Waves (Section 2.5);
- Currents (Section 2.6); and
- Sediments and Water Quality (Section 2.7).

Potential impacts during the construction phase of the Scheme are assessed in Section 3. Potential impacts during the operational phase of the Scheme are assessed in Section 4. A summary of these assessments is provided in Section 5.

The assessments in this report quantify the likely nature, magnitude, duration and extent of the potential impacts. Assessments in significance to particular sensitive receptors are considered in other reports and in the project Environmental Impact Statement.

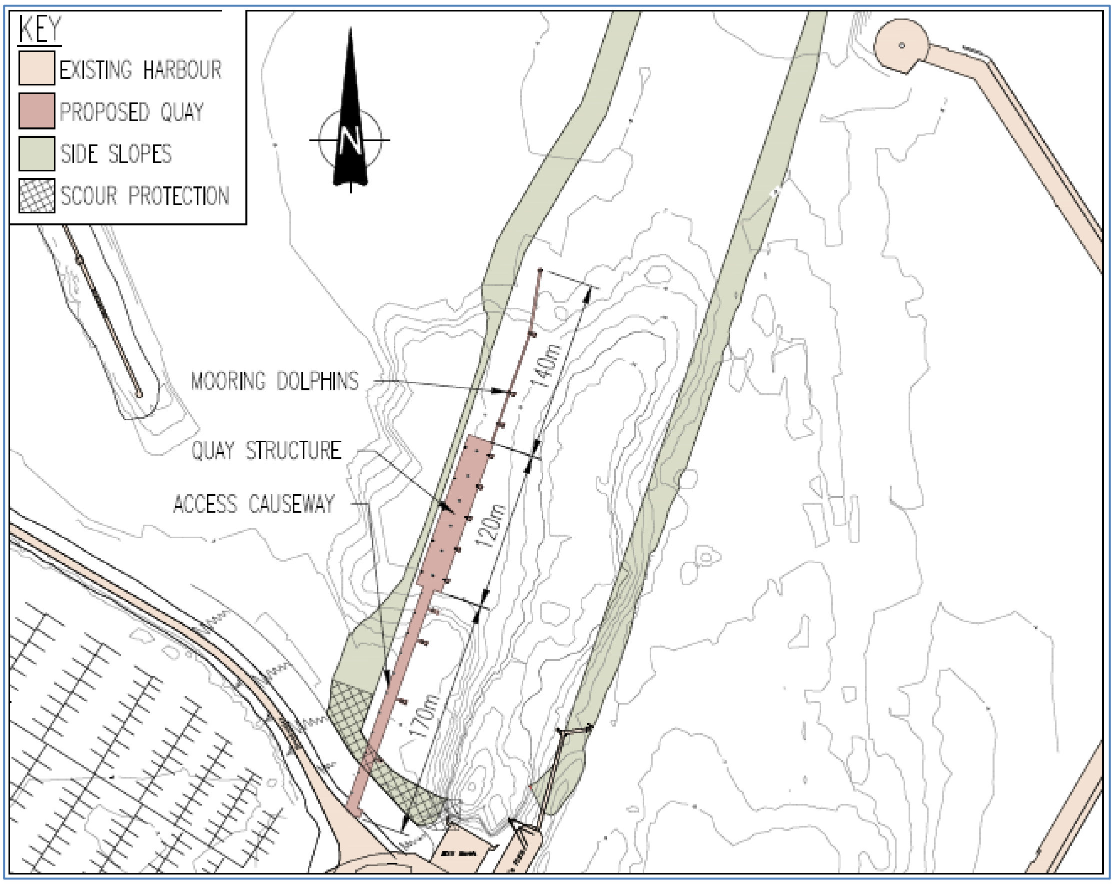
1.1 Description of the Scheme

The proposed development includes a new mooring jetty and capital dredging works to deepen and widen the approach channel to both the harbour and the berth. These marine components are collectively referred to herein as 'the Scheme'. Known details are described in more detail in the following sections.

Realistic worst case scenarios for the purposes of Environmental Impact Assessment (EIA) are dependent upon the nature of the impact being considered. As such, realistic worst case scenario details for individual assessments are provided at the beginning of each scheme impact assessment reported in Sections 3 and 4. The scenarios are based on the following known details but may also include other (realistic worst case) assumptions.

1.1.1 Cruise Terminal Jetty

A new jetty will be constructed in DLH, extending approximately 420 m north-northwest into DLH from the shore to the west of the existing high-speed ferry Ro-Ro berth (see Figure 1). Above the water, the jetty will have a solid deck along most of its length (300 m) and smaller walkways will provide further access to the mooring dolphins (a further 121 m). In the water below, the jetty deck will be supported by a number of metal piles. The mooring dolphins may be either a single large monopile or an arrangement of nine smaller diameter piles in a square grid, subject to confirmation following the results of further geotechnical investigations.



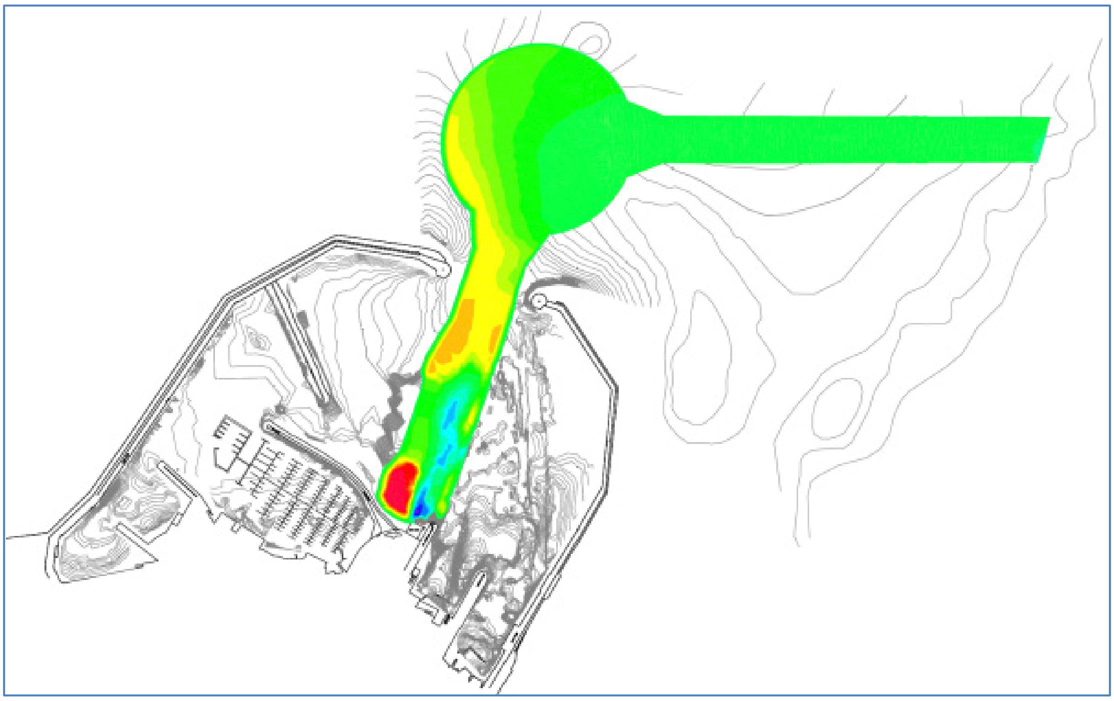
(Image Courtesy of Waterman Moylan)

Figure 1. Schematic Outline of the Proposed Cruise Terminal Jetty

1.1.2 Dredged Approach Channel

A navigation channel will be dredged to a target depth of 10.5 m below local chart datum (CD, see Section 2.3). The channel includes an offshore approach to DLH from the east, a turning circle immediately outside the DLH entrance and an approach channel from the DLH entrance to the new jetty. The majority of the dredging operation will likely be undertaken by a medium sized trailing suction hopper dredger (TSHD), supported by a smaller barge capable of water injection dredging and ploughing if and where needed.

The footprint of the area to be dredged is shown in Figure 2. The overall footprint also includes for a slope of 1:5 to be cut between the footprint of the main dredged area and the surrounding seabed level to ensure slope stability, preventing slumping of material back into the dredged channel.



VOLUMETRIC ANALYSIS						
NUMBER	MINIMUM LEVEL	MAXIMUM LEVEL	COLOUR	AREA	VOLUME	OVERALL CUT/FILL
1	-7.00	-6.50		985.529m2	172.240m3	CUT = 710,622m³
2	-6.50	-6.00		3365.808m2	1556.525m3	
3	-6.00	-5.50		2093.177m2	2869.346m3	
4	-5.50	-5.00		1117.496m2	3504.601m3	
5	-5.00	-4.50		992.106m2	4044.750m3	
6	-4.50	-4.00		11590.197m2	7627.388m3	
7	-4.00	-3.50		24610.838m2	17614.128m3	
8	-3.50	-3.00		20501.715m2	27679.677m3	
9	-3.00	-2.50		25778.204m2	39160.688m3	
10	-2.50	-2.00		30044.945m2	53419.445m3	
11	-2.00	-1.50		52303.409m2	74604.696m3	
12	-1.50	-1.00		65072.373m2	105582.144m3	
13	-1.00	-0.50		135697.529m2	154263.194m3	
14	-0.50	0.00		97693.695m2	218523.001m3	
15	0.00	0.50		7918.729m2	8831.782m3	FILL = 19,723m³
16	0.50	1.00		6033.955m2	5647.642m3	
17	1.00	1.50		4728.456m2	2979.073m3	
18	1.50	2.00		2818.259m2	966.106m3	
19	2.00	2.50		578.999m2	566.111m3	
20	2.50	3.00		383.442m2	337.927m3	
21	3.00	3.50		188.104m2	219.372m3	
22	3.50	4.00		182.194m2	124.810m3	
23	4.00	4.50		123.289m2	45.574m3	
24	4.50	5.00		42.027m2	4.805m3	
25	5.00	5.50		0.428m2	0.000m3	
						NET CUT = 690,899m³

(Image Courtesy of Waterman Moylan)

Figure 2. Footprint of the Dredged Approach Channel and Thickness of Sediment to Remove

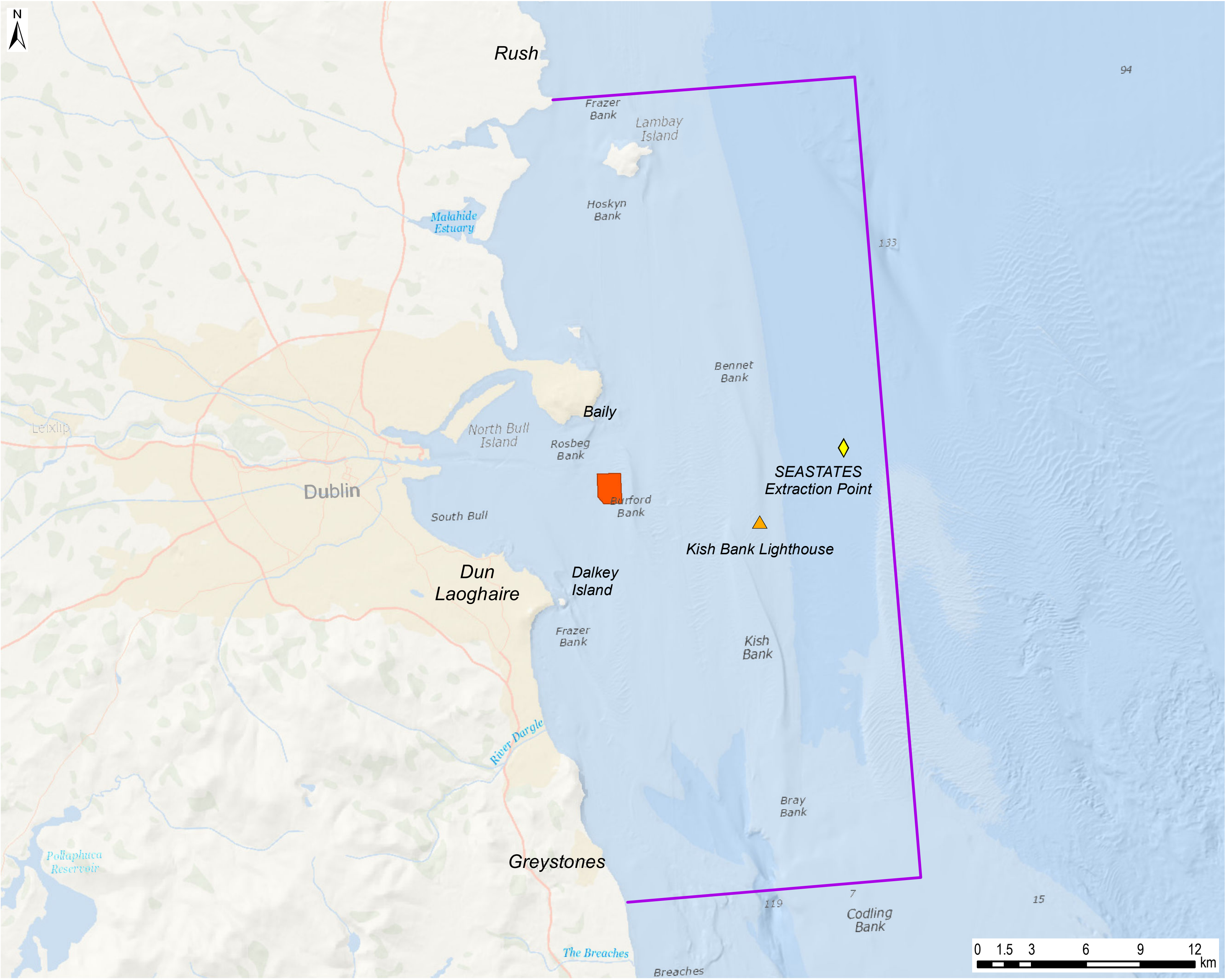
The net cut material will be disposed of at Burford Bank Spoil Ground (BBSG) in outer Dublin Bay (see Figure 3). The TSHD will transit from DLH to the BBSG and release the accumulated dredged material relatively quickly from its hopper to the seabed via large doors on the bottom of the hull.

1.2 The Study Area

The 'study area' is defined as the spatial extent within which the assessment of potential impacts of the Scheme is undertaken, and is shown in Figure 3. The position and extent of named locations referred to in the assessment are also shown. The study area also corresponds to the extent of the numerical models used to inform the present study (see Appendix A).

This study area has been chosen so that it encompasses:

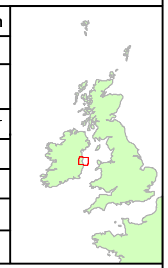
- All of the relevant potential impact source locations (DLH and BBSG);
- More than one tidal ellipse from the relevant impact source locations (the distance travelled by water over the course of one tidal cycle);
- A sufficient distance offshore to obtain robust offshore wave boundary conditions (outside of the influence of the various offshore banks);
- The major banks offshore of Dublin Bay (Burford Bank and Kish Bank) which are likely to significantly affect local tidal processes and wave propagation into Dublin Bay; and
- Relevant designated areas (e.g. Dublin Bay Special Area of Conservation, SAC) which are potentially sensitive receptors for onward use of the results of the present study.



Study Area Extent

Burford Bank Spoil Ground

Date	By	Size	Version
Sep 14	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 29N		
Projection	Transverse Mercator		
Scale	1:300,000		
QA	TAP		
Fig_ModelExtents_DataOutputs.mxd			
Produced by ABPmer			



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ABP mer marine environmental research

Location and Extent of the Study Area

Figure 3

2. Baseline Characterisation

This section provides a summary of the present day conditions experienced within the study area (defined in Section 1.2 and Figure 3). The information in this section provides the context within and against which the potential impacts of the scheme are subsequently assessed. Information is provided about:

- The regional setting;
- Water depth;
- Water levels;
- Winds;
- Waves;
- Currents; and
- Sediments and water quality.

Information is mainly provided for the present day condition. The presently predicted effects of climate change are also summarised. Climate change scenarios are not explicitly used or considered in relation to the assessment, other than to provide additional context regarding the range of natural variability

2.1 Regional Setting

The study area is located on the east coast of the Republic of Ireland, within the Irish Sea on the North East European continental shelf. The study area represents only a very small part of the whole Irish Sea.

Water depths in central parts of the Irish Sea are typically 50 to 100 m, shoaling upwards at the margins to the surrounding coastlines.

Tidal water levels vary semi-diurnally throughout the Irish Sea. Mean tidal ranges within the Irish Sea vary greatly, from approximately 2 m at the north and south margins, to 8 m at the easterly margin in Liverpool Bay. Storm surges may occasionally raise or depress water levels (typically by 10's of centimetres but up to more than 1 m in infrequent extreme cases) from that expected due to the tide alone.

The region is frequently exposed to strong winds associated with weather systems coming from the Atlantic. Winds predominantly come from westerly or south-westerly directions. Stronger winds also tend to come from the predominant wind directions although intermediate strength winds can also frequently come from south-easterly and north-easterly directions.

Offshore facing aspects of the study area are exposed to a range of intermediate fetch lengths (100 to 200 km) for wave generation within the Irish Sea. In combination with the wind climate, this leads to a directionally dependant extreme wave climate. Waves developed over even longer fetches from the north Atlantic can also enter the Irish Sea from St Georges Channel to the south.

Charts from the British Geological Survey (BGS, 1990) show surficial seabed sediments in the general region of the study area are predominantly sandy, becoming progressively coarser to the south (gravelly sands and sandy gravels) and finer to the north (muddy sands and sandy muds). A wide range of sediment types are found elsewhere in the Irish Sea associated with local variation in water depth, wave exposure and current speed.

2.2 Water Depth

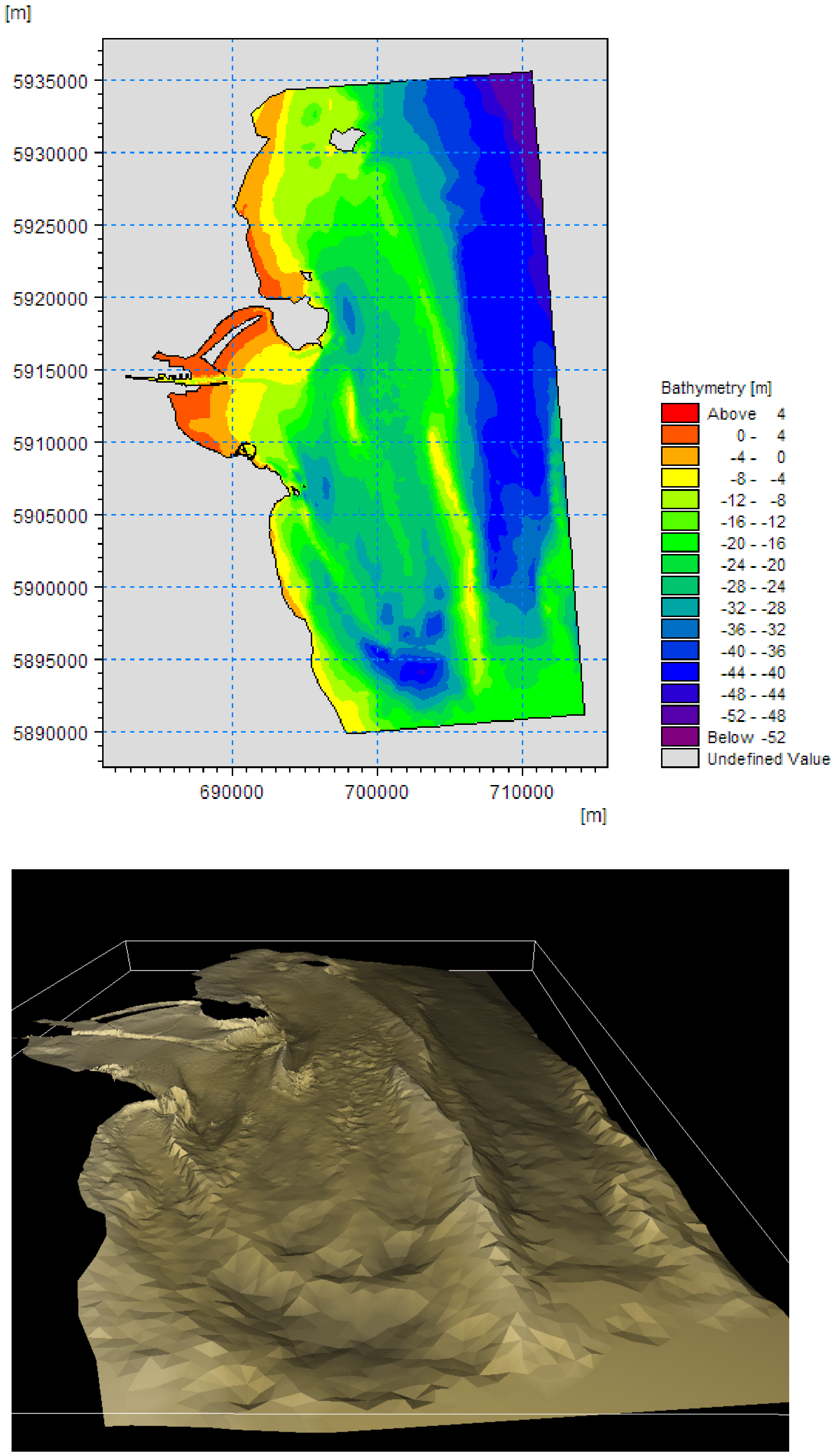
2.2.1 Sources of Water Depth Data

Sources of water depth data within the study area include:

- Swath bathymetry survey data for the majority of the study area from the INtegrated Mapping FOr the Sustainable Development of Ireland's MArine Resource (INFOMAR) programme (http://www.infomar.ie/);
- Additional gridded bathymetry data from within DLH and the dredged footprint from DLHC;
- Charted water depths (Admiralty Charts: 1468, Arklow to the Skerries Islands; 1415, Dublin Bay; 1447, Dublin and Dun Laoghaire); and
- Aerial images from Google Earth providing qualitative bathymetric/topographic information in intertidal parts of Dublin Bay.

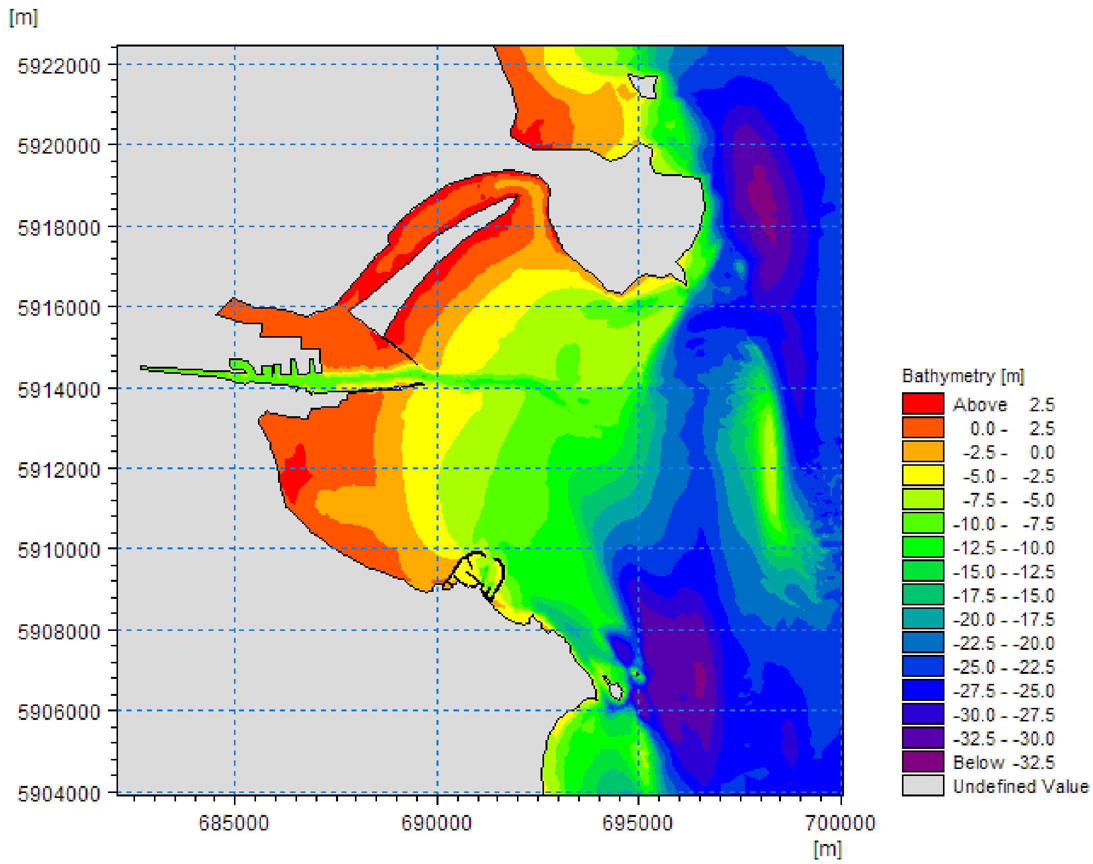
2.2.2 Overview of Water Depths

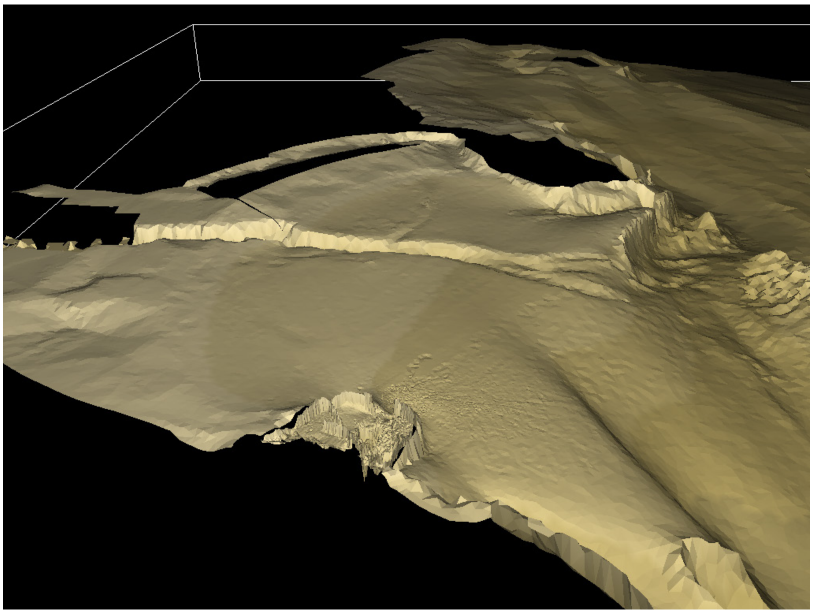
The bathymetry of the main study area is shown in Figure 4. The bathymetry of Dublin Bay is shown in Figure 5. The bathymetry of DLH is shown in Figure 6. Water depth is presented (as a negative value according to the convention of the modelling software) relative to the local chart datum (mCD) which is approximately equivalent to the lowest astronomical tidal water level (see Section 2.3). A summary of key information is provided below.



N.B. Depths are shown as negative in the top image due to the conventions of the modelling software.
Vertical exaggeration of 3D image x40.

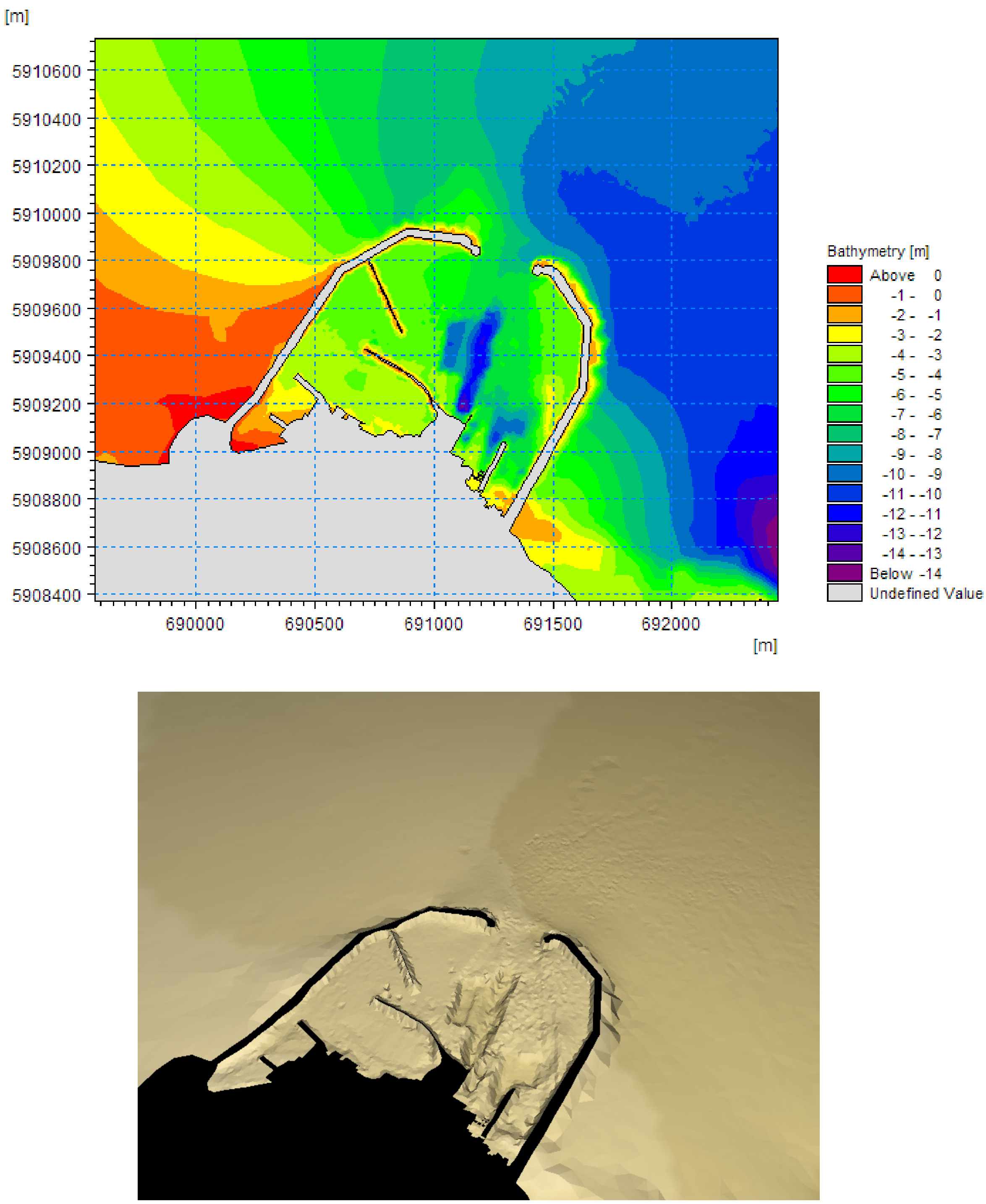
Figure 4. Water Depth in the Study Area (mCD)





N.B. Depths are shown as negative in the top image due to the conventions of the modelling software.
Vertical exaggeration of 3D image x40.

Figure 5. Water Depth in Dublin Bay (mCD)



N.B. Depths are shown as negative in the top image due to the conventions of the modelling software.
Vertical exaggeration of 3D image x5.

Figure 6. Present Day Water Depth in Dun Laoghaire Harbour (mCD)

2.2.3 Water Depths Offshore

With reference to Figure 4:

- Open water depths on the eastern margin of the study area, offshore of Kish Bank, are typically ~40 mCD;
- Open water depths are slightly greater (~50 mCD) at the north-east margin, representative of typical regional water depths in the central Irish Sea;
- Cooling Bank is a more dispersed feature located offshore and to the south of Kish Bank, leading to shallower water depths (~20 mCD) at the south-east margin;
- Kish Bank is a linear sand bank feature aligned broadly parallel to the adjacent coastline and tidal axis. The main body of the bank is 18 km long and 2 km wide. Minimum water depths along the crest of the bank are ~3 to 4 mCD;
- Kish Bank also extends north to the Skerries as Benne Bank. Minimum water depths along the crest of the bank are ~15 mCD; and
- Open water depths between Kish Bank and outer Dublin Bay or Burford Bank are typically ~20 to 25 mCD.

2.2.4 Water Depths in Dublin Bay, Burford Bank and Burford Bank Spoil Ground

With reference to Figure 4 and Figure 5:

- Burford Bank is a linear sand bank feature aligned broadly parallel to the adjacent coastline and tidal axis. Minimum water depths along the crest of the bank are ~4 to 5 mCD;
- Burford Bank Spoil Ground is located immediately inshore of the northern half of Burford Bank. Water depths within the spoil ground extent are typically ~15 to 20 mCD;
- Water depths decrease suddenly from ~25 mCD offshore to 5 to 12 mCD inshore in Dublin Bay, along a line approximately between Baily and Dalkey Island. The sudden change is a result of the underlying hard-geology. The slope is more abrupt in the northern part of Dublin Bay;
- Within Dublin Bay water depths shoal gradually towards the west;
- Inner Dublin Bay, around the entrance to Dublin Port, is characterised by extensive shallow gradient intertidal sand flats. An area of stabilised material (North Bull Island) is present to the north of the port and the intertidal area behind it is only partially flooded during intermediate tidal ranges; and
- A navigation channel into Dublin Port is maintained at 7.8 mCD by dredging. The position of the channel and the surrounding intertidal areas is stabilised by large groynes (Bull Wall to the north and the Great South Wall to the south).

2.2.5 Water Depths In and Around Dun Laoghaire Harbour

With reference to Figure 6:

- Water depths in the approaches to DLH are typically 8 to 10 mCD;
- Water depths reduce to 6 mCD at the harbour entrance;

- Water depths in the outer harbour are typically 4 to 5 mCD;
- Water depths in the recreational/inner harbour are typically 2.5 to 4 mCD;
- A deeper navigation channel extends from the harbour entrance to the fast ferry berth (typically 10 to 12 mCD but locally up to 15 mCD at the berth). This channel is the result of previous dredging and local scour from the wash of the ferry; and
- Areas of locally shallower water depths due to historic siltation are also observed in the Inner Harbour, Old Harbour, in the vicinity of the Royal St George and National Yacht Clubs, and in some localised areas along the East Pier harbour breakwater.

2.2.6 Potential Effects of Climate Change on Water Depth

Climate change is expected to raise mean water levels in the study area by between 0.3 m and 0.4 m by the period 2081 to 2100, relative to levels during 1986 to 2005, according to published findings by the European Environment Agency, for a medium low emissions scenario. Regional scale assessments of isostatic movement that include higher levels of conservatism are available from UKCP09, and suggest a rise at 0.6m to 0.7m over the same period.

This represents only a small relative change in total water depth at most locations in the study area. The change in mean water level is less than the normal and frequently occurring tidal variation in water level and total water depth.

2.3 Water Levels

2.3.1 Sources of Water Level Data

Sources of water level data within the study area include:

- Tide gauge observations at Dublin Port;
- Tide gauge observations in Dun Laoghaire harbour;
- Tide gauge observations at Kish Bank Lighthouse;
- Admiralty Tide Tables (Admiralty, 2014) for Dublin Port;
- Tidal water level predictions for Dublin Port (Admiralty TotalTide Software); and
- Tidal water level predictions made by the tidal model developed for the present study (see Appendix A).

2.3.2 Overview of Water Levels

Tidal water levels vary predictably as a result of the gravitational influence of the sun and the moon and the shape of the tidal basin. Non-tidal factors such as regional patterns of air pressure and wind can result in a surge, causing the water surface to vary (up or down) from the otherwise expected tidal level.

2.3.3 Water Levels in the Study Area

Coincident measurements of total water levels at Dublin Port and Dun Laoghaire (including tidal and non-tidal components) are compared directly in Figure 7. The figure shows that the data closely follow a nearly 1:1 slope and with a strong degree of correlation (R^2 = 0.9984).

Therefore, because instantaneous water levels at these two locations are expected to be the same at any given time, tidal and non-tidal water level information for Dublin Port are equally valid for Dun Laoghaire. This is to be expected, considering the relatively short distance between the two locations.

Similar analysis of measured data from Dublin Port and Kish Bank Lighthouse tide gauges shows that during known periods of low non-tidal influence at Dublin Port, water levels at the two locations compare closely. Differences are sometimes observed at low water due to an apparent drying of the Kish Bank Lighthouse gauge at approximately the level of low water springs. Non-tidal residuals at Kish Bank Lighthouse are typically larger than coincident values at Dublin Port or DLH, likely due to its more exposed location in deeper water. Therefore, tidal water level information for Dublin Port is considered to be equally valid for the location of Kish Bank Lighthouse and locations in-between including Dublin Bay and the BBSG. This is again to be expected, considering the relatively short distance between these locations.

Water levels have been measured nearly continuously at Dublin Port for a relatively long time (~66 years from 1948 to present). Harmonic analysis of these data can be used to separate tidal and non-tidal contributions to the measured (total) water level. The standard statistics of tidal water levels for Dublin Port are provided from Admiralty Tide Tables (Admiralty, 2014) in Table 1. As shown above, these values are also valid for Dun Laoghaire, Dublin Bay and the BBSG.

Table 1. Tidal Water Levels in the Study Area

Tidal Level		Water Level (mCD)
Highest Astronomical Tide	HAT	4.6
Mean High Water Springs	MHWS	4.1
Mean High Water Neaps	MHWN	3.4
Mean Sea Level	MSL	2.41
Mean Low Water Neaps	MLWN	1.5
Mean Low Water Springs	MLWS	0.7
Lowest Astronomical Tide	LAT	0.0
Levels applicable for Dublin Bay and offshore to Kish Bank Lighthouse		

(Source: Admiralty, 2014)

Timeseries of tidal, non-tidal and total water levels at Dublin Port are compared directly in Figure 8. The figure shows that, in the short example period, high and low total water levels frequently deviate by up to ~0.2 to 0.3 m from the tidal value due to the non-tidal contribution. Based on a longer period of observed data from the nearby stations of Bangor, Northern Ireland, and Holyhead, Wales, (18 and 42 years, respectively), more extreme surge conditions (the top 1% of observed skew surges, as reported by the National Tide and Sea Level Facility, NTSLF, http://www.ntslf.org) can cause a high water to be up to 0.8 to 1 m higher than the expected tidal level.

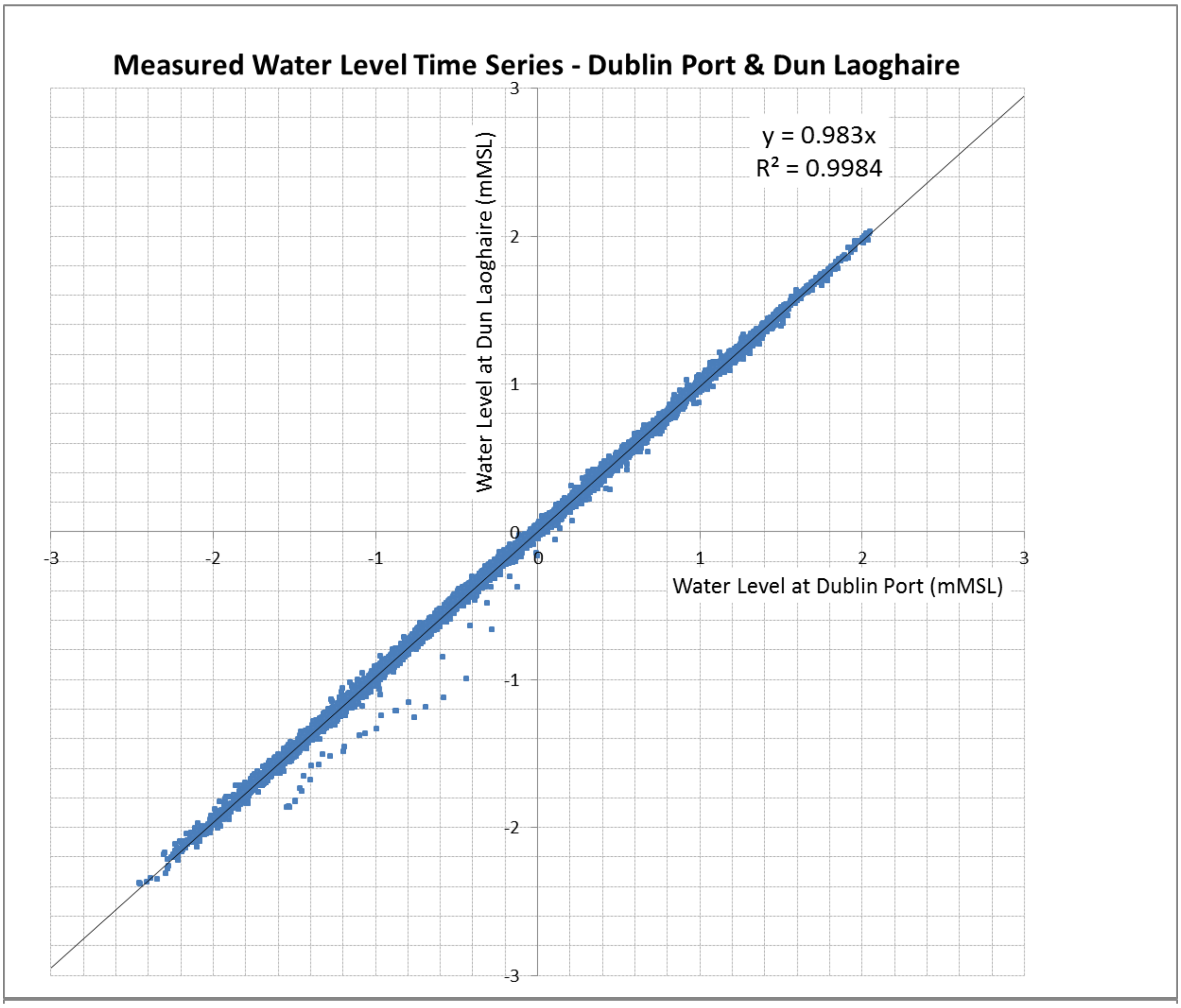


Figure 7. Comparison of Coincident Measured Total Water Levels at Dublin Port and Dun Laoghaire Tide Gauges

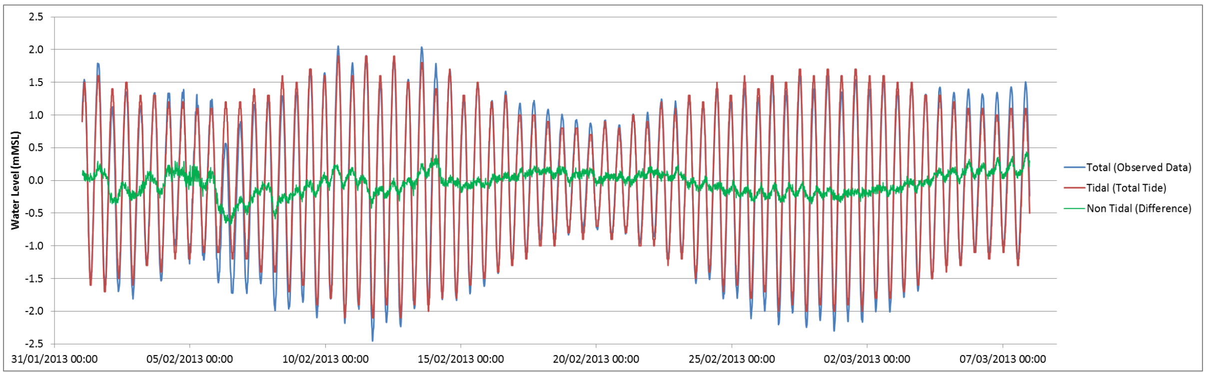


Figure 8. Comparison of Total, Tidal and Non-Tidal Water Levels at Dublin Port

2.3.4 Potential Effects of Climate Change on Water Levels

Climate change is expected to raise mean water levels in the study area (see Section 2.2.6 for further information) but is not expected to measurably alter tidal range or behaviour.

2.4 Winds

2.4.1 Sources of Wind Data

Sources of wind data within the study area include:

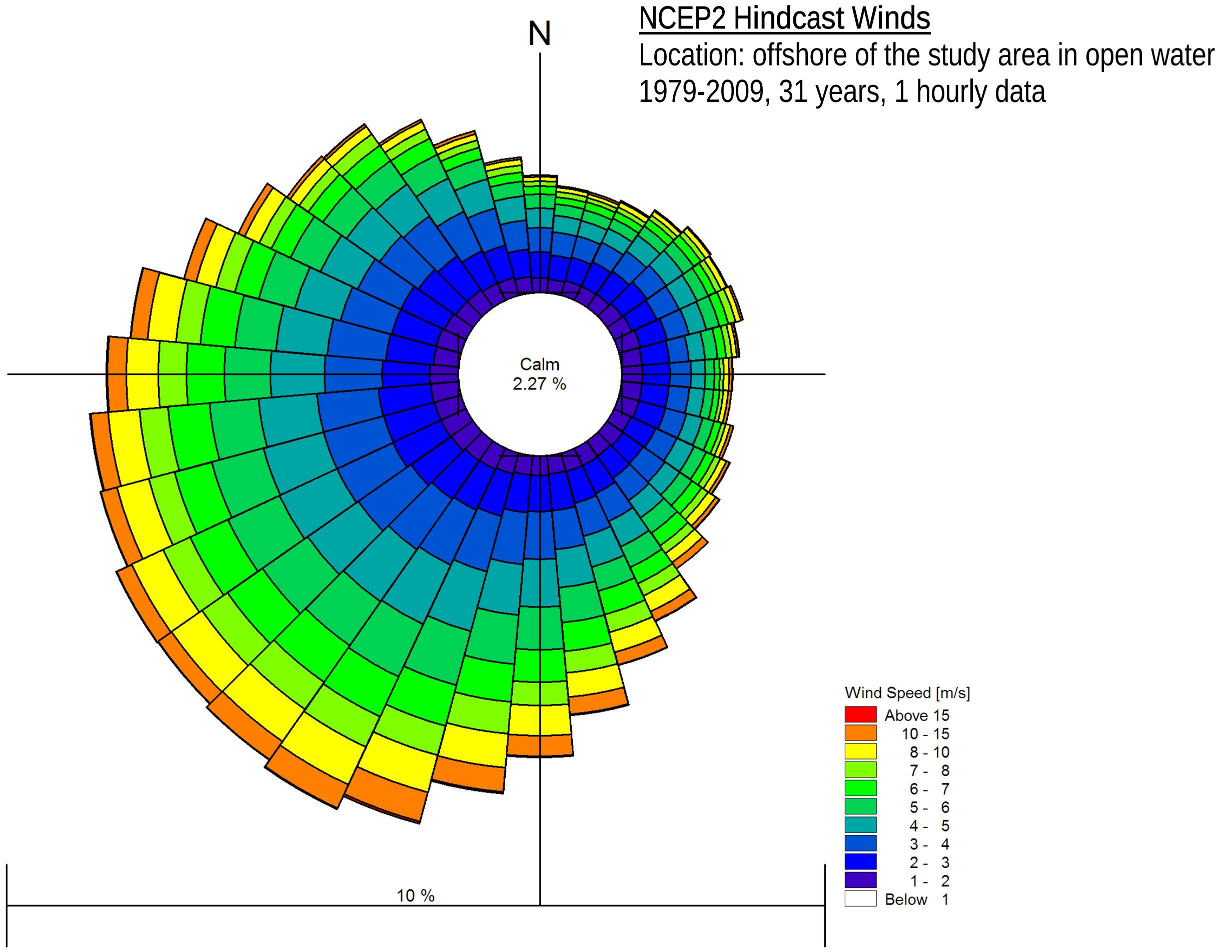
- Weather station observations at Dublin Airport; and
- Hindcast winds from the NCEP Reanalysis-2 model.

2.4.2 Overview of Winds

The wind climate is not of direct relevance to the assessments undertaken in this report, as wind is not a transport mechanism for the potential impacts identified. However, the wind climate (along with other factors) will influence the wave climate and (non-)tidal water level and current regimes both outside and inside of DLH, which are of more direct relevance.

Wind roses of measured winds at Dublin Airport (from June 2005 to August 2014, 9 years) and hindcast winds for a nearby offshore location by NCEP2 (from January 1979 to December 2009, 31 years) are provided in Figure 9. Differences in the detail of the directional distribution of wind climate described by the two data sources may be due to a variety of factors including differences in data type, geographical location and potentially localised wind bias effects at the location of the Dublin Airport anemometer. The figures are however in general agreement that winds in the study area predominantly come from westerly or south-westerly directions. Stronger winds also tend to come from the predominant wind directions although intermediate strength winds can also frequently come from south-easterly and north-easterly directions.

With regard to short wind fetches, it is also reasonable to assume that the wind climate for certain areas within DLH may be further affected by local sheltering from breakwaters, jetties and other buildings.



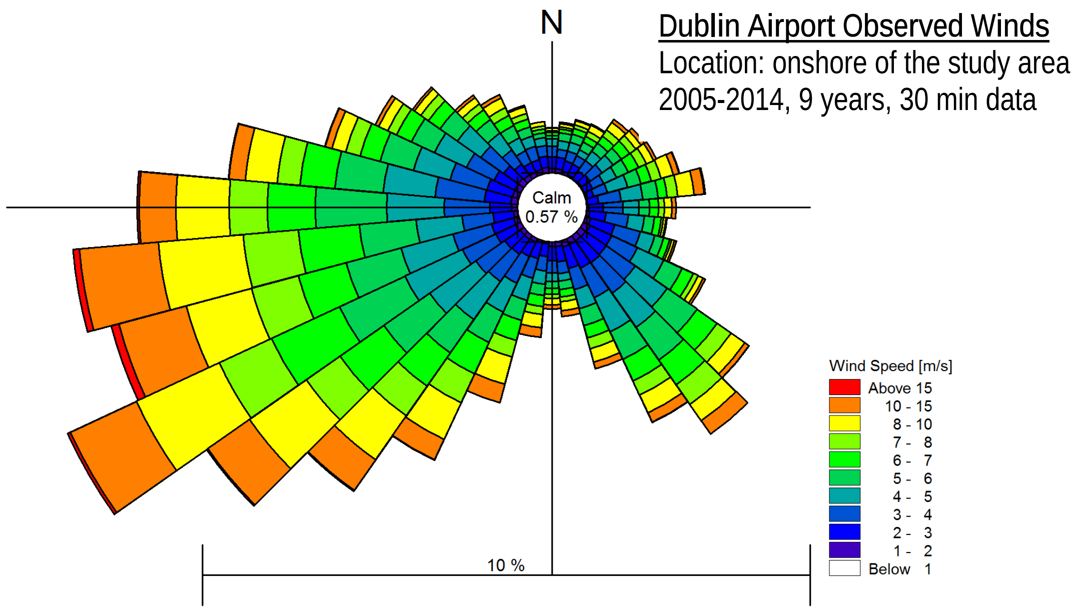


Figure 9. Wind Climate

2.4.3 Potential Effects of Climate Change on Winds

Climate change is expected to generally increase the frequency of more energetic (storm) events which may alter the long term statistics of the wind climate. There is, however, a great deal of uncertainty relating to the quantification of this potential effect on what are inherently episodic events. For the purposes of the present study, the range of typical and extreme wind conditions considered are also likely to encompass a suitable range of conditions under a climate change scenario.

2.5 Waves

2.5.1 Sources of Wave Data

Sources of wave data within and nearby to the study area include:

- Hindcast waves (1979 – 2009) and derived extreme wave climate at the offshore edge of the study area, from the wave model developed for the present study (see Appendix A and Appendix B);
- Spatial distribution of wave parameters within the study area for a discrete range of wave scenarios, predicted by the wave model developed for the present study (see Appendix A and Appendix B);
- Observations of wave parameters by the Marine Institute M2 buoy; and
- Observations of wave parameters by the Dublin Bay buoy.

2.5.2 Overview of Waves

The fetch dependant and so directional nature of wave climate offshore within the Irish Sea was discussed in Section 2.1. The position and aspect of Dublin Bay within the Irish Sea, and the position and aspect of DLH within Dublin Bay, further increase the directional dependency of wave climate at these locations.

A long time series of wave conditions at the offshore edge of the study area (offshore of Kish Bank) was undertaken as part of the present study to characterise the offshore wave climate (reported in Appendix B). A wave rose summarising the offshore wave climate is shown in Figure 10. The wave rose shows that, offshore of Kish Bank at the offshore edge of the study area:

- Waves most commonly come from south south-easterly directions (from long fetches in this direction from the Bristol Channel, Approaches to the English Channel, the Bay of Biscay and the North Atlantic);
- The largest waves also come from these directions;
- A secondary peak is evident from the east north-east, corresponding to the relatively long fetch in this location from Liverpool Bay and the south-west Irish Sea; and
- Waves from fetch limited directions (south-west clockwise through to north north-west to the Irish coast, and to the east to Anglesey) are typically limited in height (1 to 2 m or less).

The wave model (described in Appendix A) was used to transform offshore wave conditions into Dublin Bay and DLH for a range of return periods (probabilities of non-exceedance) and coming directions. The model also includes for the wind speed associated with the return period condition (in the same direction). Patterns of waves within Dublin Bay are provided in Figure 11 for a subset of offshore wave coming directions at the 1:1 year return period for a MHWS water level. The images show that:

- When offshore waves and winds come from south-west clockwise through northerly directions, Dublin Bay is relatively protected by its orientation, shape and the resulting relatively short fetches in these directions;
- Waves from all other directions are able to enter the bay to a variably greater extent. The greatest exposure is to waves from the east;
- Inshore of the ledge at the entrance to Dublin Bay (inshore of Burford Bank), wave heights visibly decrease due to the shallower water depth;
- Waves are reduced in height when obliquely crossing the relatively shallow water of Burford Bank; and
- Waves are refracted within Dublin Bay, especially coming from north and north-easterly, and south-east to southerly directions offshore.

Not shown on these images, waves are also reduced in height crossing the relatively shallow water of the other various offshore banks (Kish Bank, etc.).

Patterns of waves around and inside of DLH are provided for the same set of conditions in Figure 12. The images show that:

- The area surrounding the harbour is similarly exposed to waves as described for Dublin Bay above;
- Strong gradients in wave height can develop near to the entrance to DLH under certain conditions due to wave sheltering from the breakwaters and the position of the coastline to the south;
- For most wind/wave directions, including the most frequently occurring conditions, the harbour is sheltered from waves. Waves within the harbour are then typically the result of local wind fetch only (Hs up to 0.3 m); and
- Additional wave energy can enter from outside of the harbour from north, clockwise through south-easterly directions. The additional wave energy will tend to mainly influence the western and central parts of the outer harbour.

Wave and wind coming direction are the dominant controls on the patterns described above. Similar regional and local patterns are observed for other return periods and water levels, with some minor local variation in magnitude and direction.

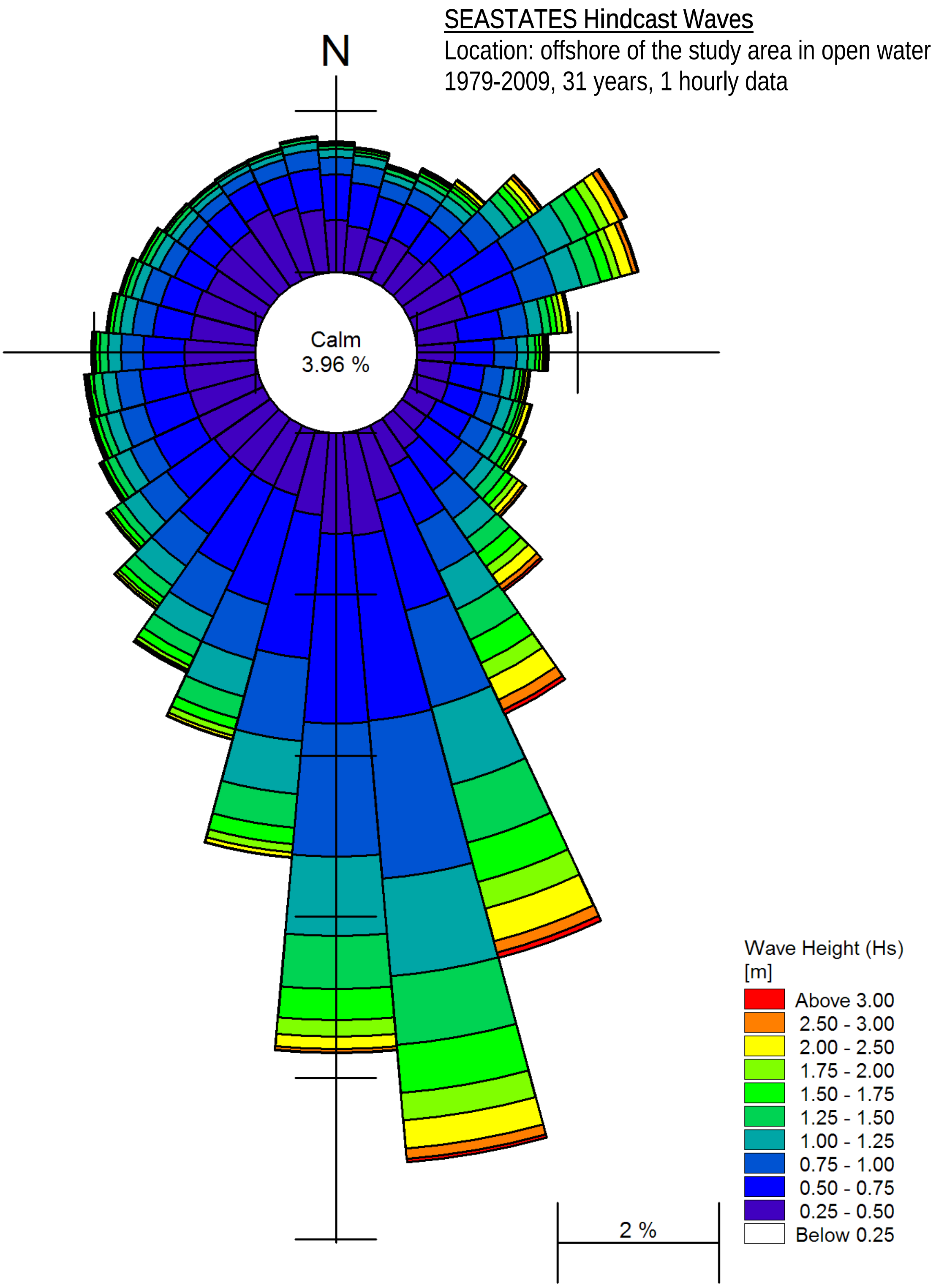
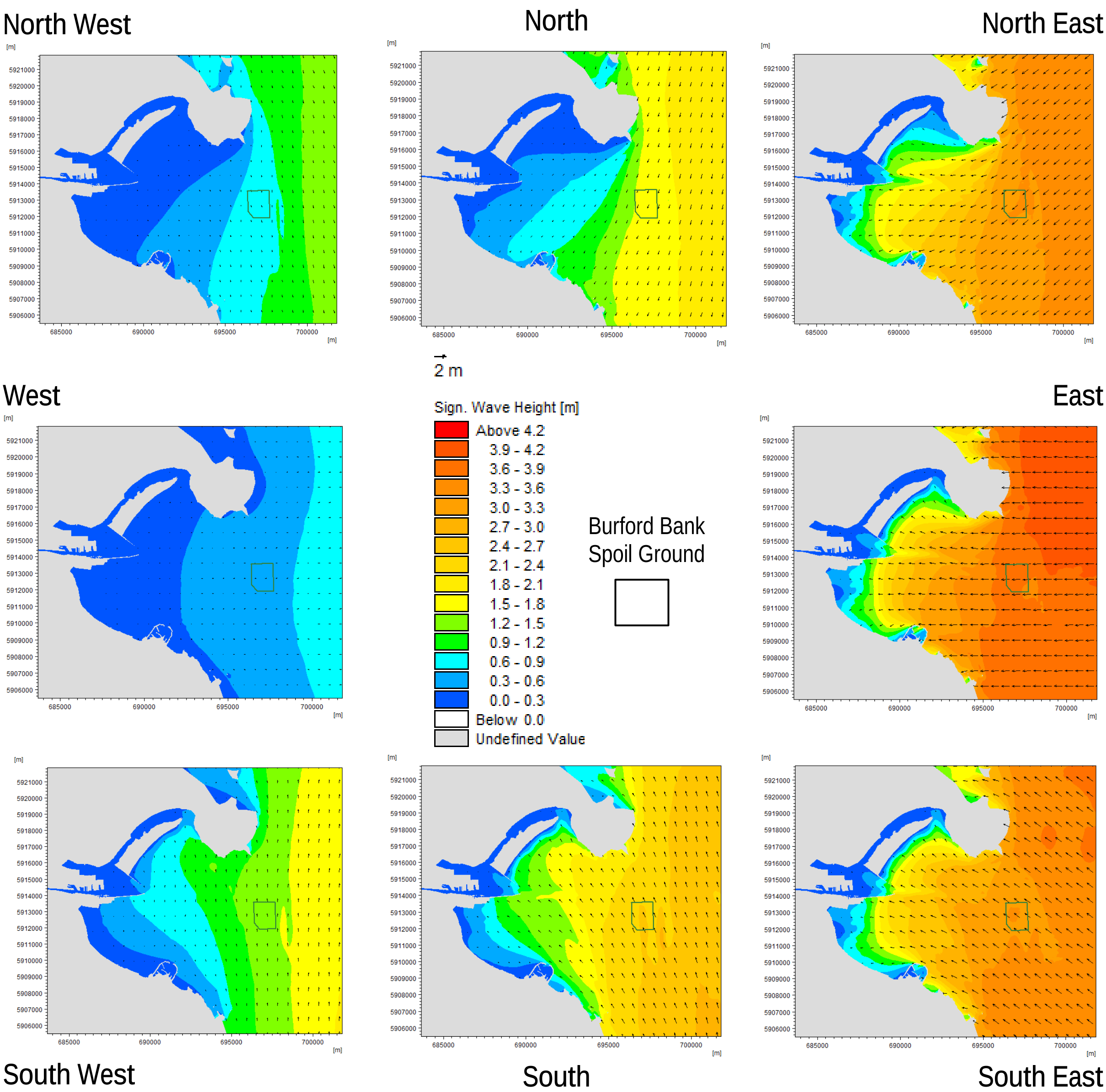
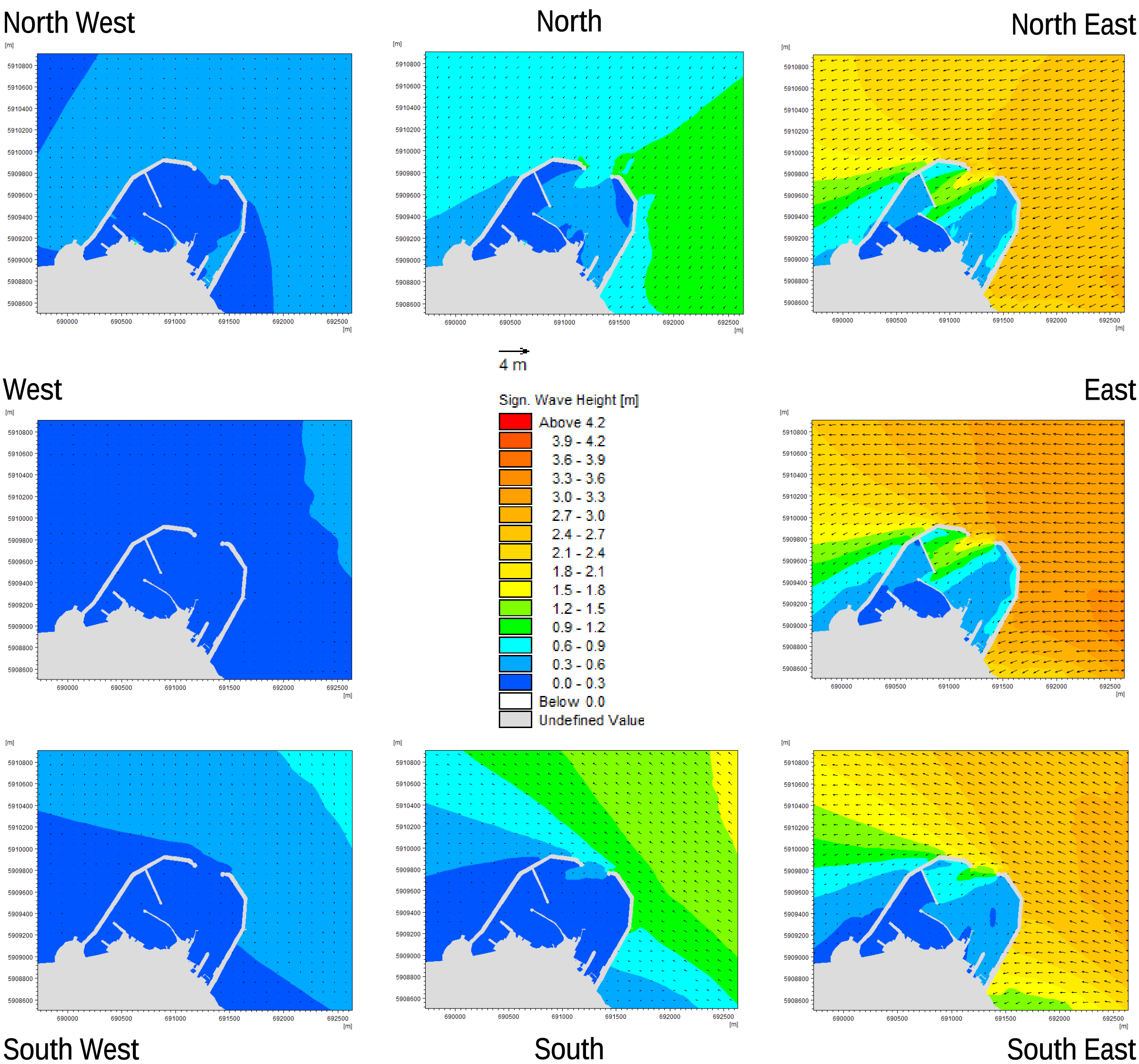


Figure 10. Offshore Wave Climate



Conditions shown for a range of offshore wave and local wind coming directions.

Figure 11. Dublin Bay Baseline Wave Conditions (1:1 Year Return Period, MHWS)



Conditions shown for a range of offshore wave and local wind coming directions.

Figure 12. Dun Laoghaire Harbour Baseline Wave Conditions (1:1 Year Return Period, MHWS)

2.5.3 Potential Effects of Climate Change on Waves

As described in relation to winds, climate change is expected to generally increase the frequency of more energetic (storm) events which may alter the long term statistics of the wave climate. There is, however, a great deal of uncertainty relating to the quantification of this potential effect on what are inherently episodic events. For the purposes of the present study, the range of typical and extreme wave conditions considered are also likely to encompass a suitable range of conditions under a climate change scenario.

2.6 Currents

2.6.1 Sources of Current Data

Sources of current speed and direction data within the study area include:

- Spatial distribution of tidal current speed and direction, predicted by the tidal model developed for the present study (see Appendix A);
- Regional tidal atlas (Du Port & Buttress, 2010);
- Chart of co-speed contours for peak depth averaged current speed on an average spring tide (BGS, 1990);
- Previous current profiler surveys at Burford Bank informing an application for a spoil disposal licence;
- Previous drogue tracking surveys and other direct observations made in DLH informing the EIS for the fast ferry terminal and the inner harbour breakwaters;
- Previous modelling work informing the EIS for the fast ferry terminal and the inner harbour breakwaters.

2.6.2 Overview of Currents

Tidal currents vary predictably in relation to tidal processes (as described in relation to water levels, see Section 2.3). Non-tidal factors resulting in a surge can modify the speed and direction of currents from the otherwise expected tidal pattern. In addition to regional patterns of tidal and non-tidal forcing, current speed and direction are also locally affected by the shape and proximity of coastlines and shallow or complex bathymetry.

The results of the tidal model have been compared with the other data sources listed above (see Appendix A). The different data sources were found to be suitably consistent and in agreement with each other. The tidal model results provide the widest spatial and temporal extent of consistent data and are representative of all data sources, so are used to inform the following baseline characterisation.

Patterns of tidal currents within the central study area and at DLH predicted by the tidal model are shown for mean spring and mean neap tidal conditions in Figure 13 to Figure 16. A summary of key information is provided below.

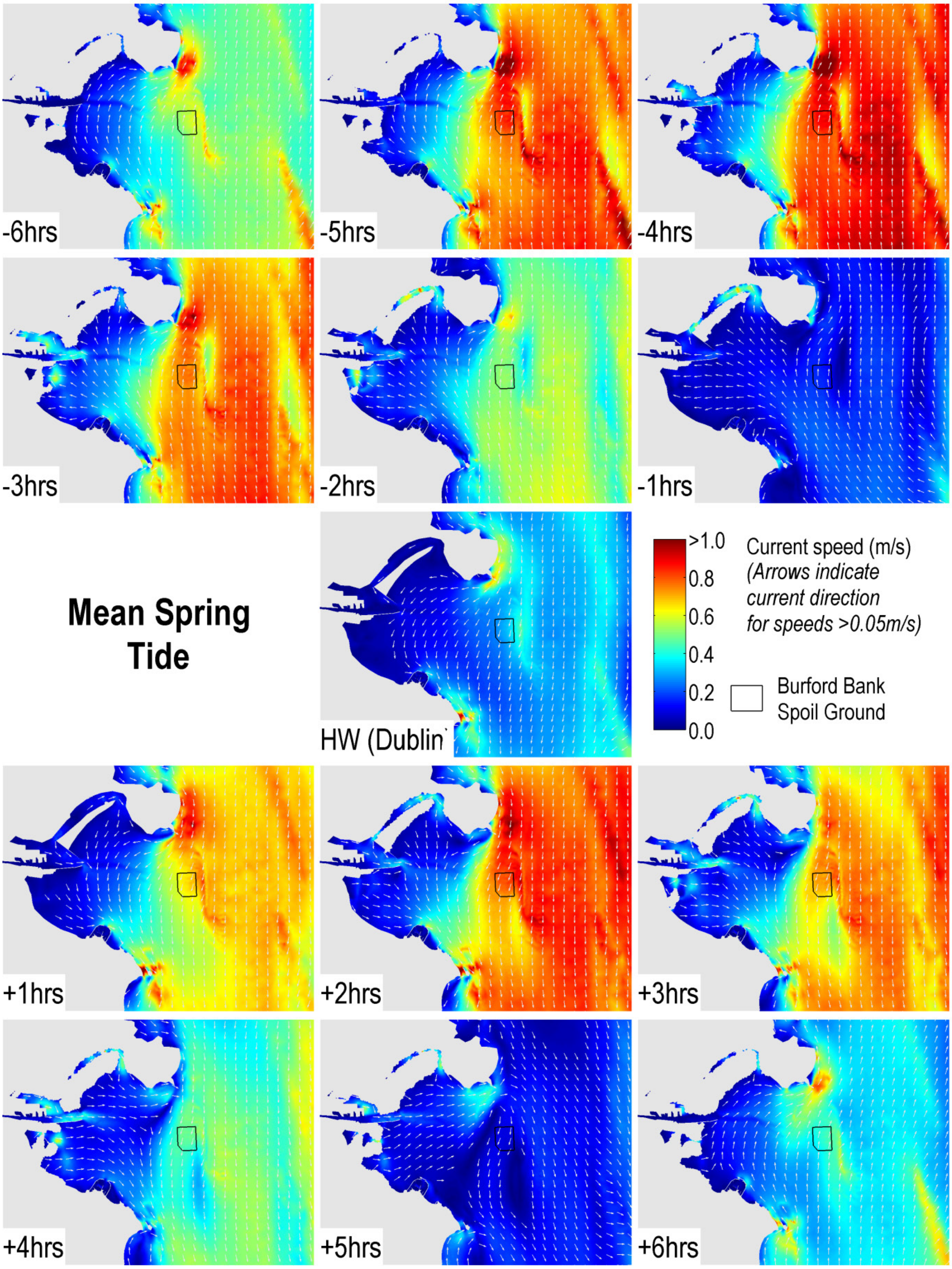


Figure 13. Mean Spring Tidal Currents in the Region of Dublin Bay

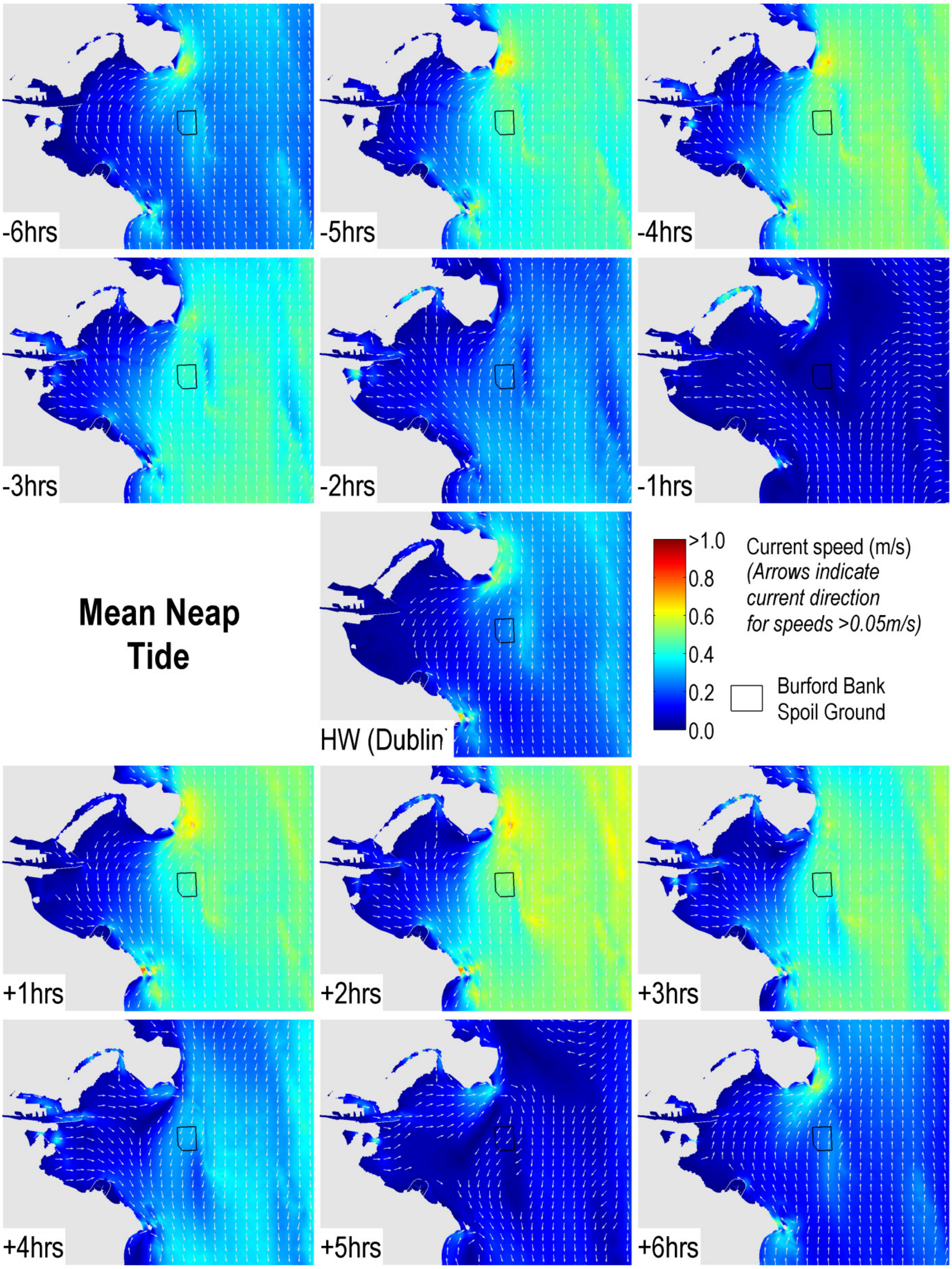


Figure 14. Mean Neap Tidal Currents in the Region of Dublin Bay

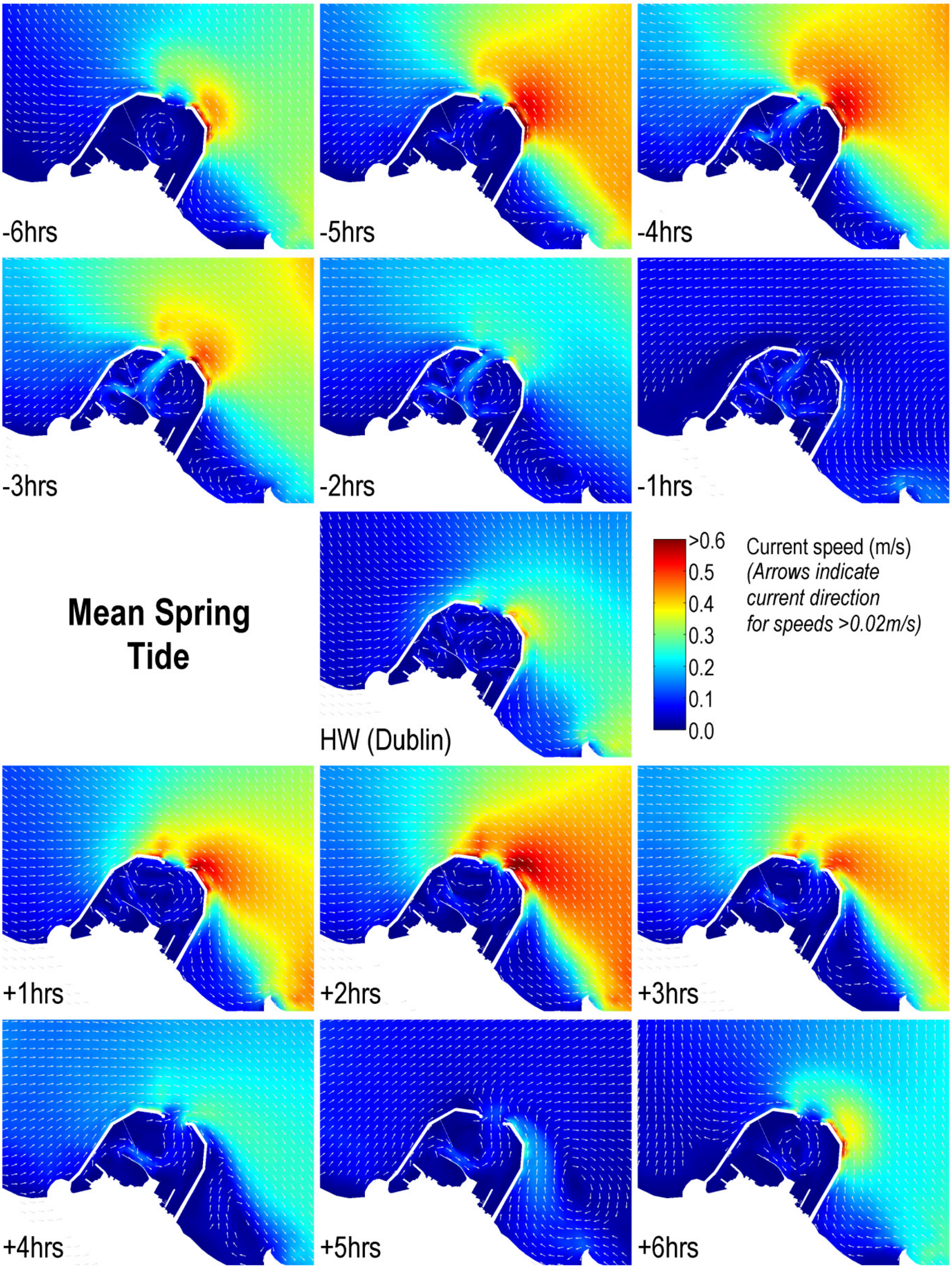


Figure 15. Mean Spring Tidal Currents in the Region of Dun Laoghaire Harbour

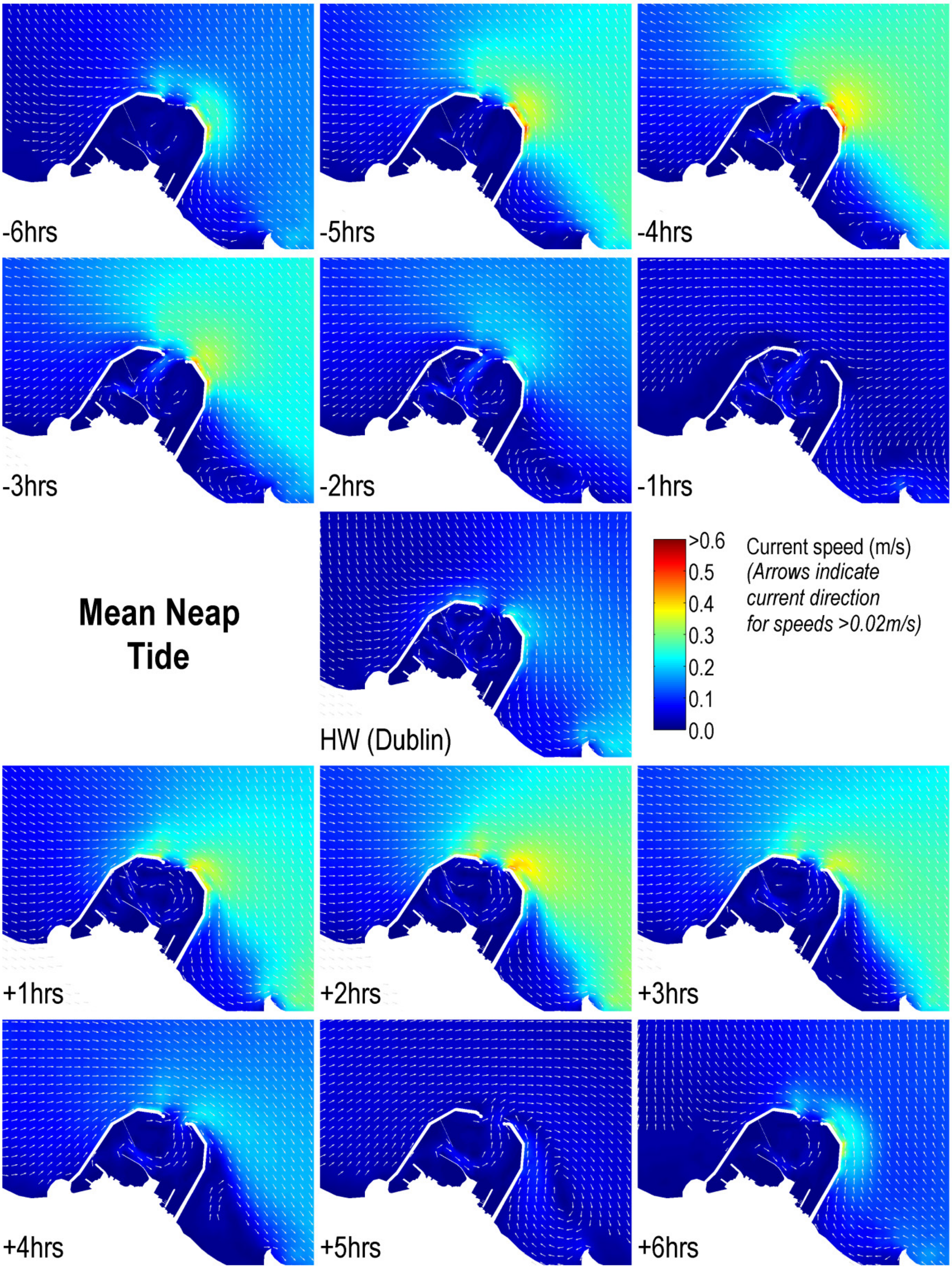


Figure 16. Mean Neap Tidal Currents in the Region of Dun Laoghaire Harbour

2.6.3 Tidal Currents Offshore

With reference to Figure 13 and Figure 14:

- Flood tide currents are directed to the north and ebb tide currents to the south;
- On a mean spring tide, typical peak current speeds offshore are ~0.7 to 1.0 m/s;
- On a mean neap tide, typical peak current speeds offshore are ~0.35 to 0.6 m/s;
- Kish Bank has a local effect on currents. During periods of higher current speed, current speeds are reduced over the crest and in the lee of the bank, with some minor localised deflection of current direction. During periods of weaker current speed (throughout neaps or around the time of flow reversal during springs) current speeds can instead be locally increased on the bank while current direction is more strongly deflected towards shallower water; and
- Spring flood tide current speeds (to the north) appear to be slightly greater than the following ebb in Figure 13 whilst neap ebb tide current speeds (to the south) appear to be slightly greater than the preceding flood in Figure 14. This is mostly accounted for by periodic differences in the range of consecutive flood and ebb tides in the timeseries used to create these images. In practice, the peak current speed is more similar for flood and ebb tides with a more similar range.

2.6.4 Tidal Currents in Dublin Bay, Burford Bank and Burford Bank Spoil Ground

With reference to Figure 13 and Figure 14:

- Tidal current speeds and directions at Burford Bank and the BBSG are similar to that described for offshore locations in Section 2.6.3;
- Burford Bank has a similar local effect on currents to that described for Kish Bank in Section 2.6.3;
- There is a relatively sudden change (reduction) in peak current speed at the edge of Dublin Bay, inshore of the BBSG. The change is attributed to the orientation and shape of the Bay relative to the regional coastline and tidal axis, whereby offshore currents are only weakly deflected around the sharp headlands and also experience additional friction in the relatively shallow water of Dublin Bay. As such, the change in current speed is also generally coincident with the step in bathymetry at the entrance to Dublin Bay (described in Section 2.2);
- On a mean spring tide, typical peak current speeds within Dublin Bay are ~0.2 to 0.4 m/s on flood tides (to the north, following the contours and shape of the bay) but ~0.2 m/s or less on ebb tides (generally to the south but not necessarily following the shape of the bay);
- On a mean neap tide, typical peak current speeds within Dublin Bay are ~0.1 to 0.3 m/s on flood tides (to the north) but ~0.1 m/s or less on ebb tides (to the south);
- The asymmetry in current speed between flood and ebb tides is due to the asymmetry in the orientation and shape of the Bay relative to the regional coastline and tidal axis. Flood currents from the south deflect through a relatively smaller angle (~45°) at Dalkey Island to enter the Bay whilst ebb currents from the north cannot readily turn

through the greater angle at Baily (~90°) and so tend to bypass the Bay almost entirely;

- The asymmetry in current speed results in a strong northerly residual transport of water around the bay from DLH, along the intertidal and nearshore area, around Baily and then in an offshore direction; and
- Localised patterns of stronger flow are associated with discharge from Dublin Port constrained by the breakwaters and dredged navigation channel.

2.6.5 Tidal Currents In and Around Dun Laoghaire Harbour

With reference to Figure 15 and Figure 16:

- The breakwaters surrounding DLH present an obstruction to both flood and ebb currents that would otherwise flow parallel to the adjacent coastline. The deflection of this flow offshore results in flow acceleration outside the entrance to the harbour, extending to the north and east. Current speeds occurring near to DLH entrance are typically ~0.35 to 0.5 m/s (maximum ~0.6 m/s) on a mean spring tide, or ~0.2 to 0.35 m/s (maximum ~0.4 m/s) on a mean neap tide;
- Current speeds in most of DLH are typically only slight (~0.02 to 0.05 m/s) during spring and neap tides;
- During flood tides, a relatively strong and narrow current (~0.1 to 0.25 m/s) is developed between the main harbour entrance and the entrance to the inner harbour. The strongest flow speeds are at the entrances. The strength and location of these features is consistent with the results both of previous observations and of modelling of the harbour (EIS Ltd, 1997);
- During ebb tides, a relatively weaker and more dispersed current (~0.05 to 0.1 m/s) is developed between the entrance to the inner harbour and the main harbour entrance, via the north-eastern part of the outer harbour. The strongest flow speeds are at the entrances. The strength and location of these features is consistent with the result of previous observations made and modelling of the harbour (PH McCarthy & Partners, 1993 & EIS Ltd, 1997); and
- Characteristic weak recirculating flow patterns are set up within the harbour on both flood and ebb tides.

2.6.6 Non-Tidal Currents

Non-tidal contributions to currents may result from regional scale meteorological effects (changes in air pressure and wind stress applied over large areas) that can affect the tidal range and/or the duration of a flood or ebb period. Both of these effects, either alone or in combination, can change the rate at which water volume is moved within the tidal basin (or in and out of DLH), resulting in modifications to current speed and direction throughout the region and throughout the full water column.

Smaller scale non-tidal contributions may also result from local scale wind stress, resulting in wind blown currents. Such currents are only set up where sufficient fetch is available (a sufficient distance over which the wind can blow) and tend to be confined to a relatively thin layer of surface water (tens of centimetres to a few metres, depending on the wind speed and fetch). Given sufficient fetch, wind blown currents are typically ~3% of the wind speed and in approximately the same direction, e.g. a strong but frequently occurring wind speed of 10 m/s might produce a wind-blown surface current of up to 0.3 m/s, decreasing rapidly to the regional condition with depth below the water surface.

Additional sensitivity tests (not explicitly reported) have been undertaken using the tidal model to quantify the effect of a range of typical and extreme wind speeds and directions on the reported patterns of tidal currents. The additional effect of winds may locally slightly enhance or weaken the strength of already relatively weak currents but does not alter the overall patterns of flow and circulation.

2.6.7 Potential Effects of Climate Change on Currents

Climate change within the operational lifetime of the Scheme is expected to raise mean water levels but is not expected to measurably alter tidal range. The relative difference in total water depth will be negligible at most locations (less than the normal tidal variation in water depth). As a result, little or no change in patterns of tidal currents is expected in the wider study area.

In the long term, an increase in total water depth might conceptually reduce current speeds within DLH as the tidal prism (volume of water exchanged tidally with Dublin Bay) will remain similar, but the cross-sectional area through which the volume is passing will have increased. This difference is however likely to be negligible in comparison to the effect of other development activities, siltation and dredging works within the harbour.

2.7 Sediments and Water Quality

2.7.1 Sources of Sediments and Water Quality Data

Sources of sediment and water quality data within the study area include:

- Seabed sediment cores (observed vertical thickness of sediment type) collected within and outside DLH as part of the geotechnical survey for the proposed development;
- Grain size analysis of seabed sediment samples taken from the seabed cores as part of the geotechnical survey for the proposed development;
- Surficial seabed type information from various navigation charts (Admiralty Charts: 1468, Arklow to the Skerries Islands; 1415, Dublin Bay; 1447, Dublin and Dun Laoghaire);
- Regional charts of surficial seabed type (BGS, 1990); and
- Water quality monitoring in Dublin Port (Briciu-Burghina *et al*., 2014).

2.7.2 Overview of Sediments

Regional scale charts of surficial seabed type show that sediments in the majority of the study area are predominantly sands (observed to be fine to medium sands at DLH). At the regional scale, seabed sediments become progressively coarser to the south of the study area (gravelly sands and sandy gravels) and finer to the north of the study area (muddy sands and sandy muds).

Seabed sediments immediately outside and within DLH are predominantly fine to medium sands although localised deposits of silt and finer material have accumulated in some areas as a veneer over the sand. A more detailed description of such a silty deposit in the footprint of the dredged channel is given in Section 3.1. It is likely, and generally shown on navigational charts, that similar deposits are present in other parts of the harbour not regularly exposed to disturbance by stronger currents.

It is expected that a locally increased proportion of finer sediment would be found in surface sediments within and around the BBSG in Dublin Bay, associated with previously deposited and consolidated dredge spoil from the surrounding harbours.

The asymmetry in tidal current speeds between flood (stronger to the north) and ebb (weaker to the south) tides within Dublin Bay (described in Section 2.6.4) will lead to a net transport pathway for sediment either as bedload or in suspension (due to wave action) along the DLH coastline and then generally northerly across Dublin Bay. Active transport of fine to medium sands due to tidal currents alone is only likely to occur around the time of peak current speeds during relatively large tides (current speeds > ~0.3 to 0.4 m/s). Sediment is likely to be more frequently mobilised by wave action in the relatively shallow water of the Bay and transported then by tidal currents (long term net direction to the north). Currents speeds progressively reduce towards the north-west corner of Dublin Bay, resulting in bedload transport convergence, net accretion of sediment and the large volume of sand accumulated on the Dublin Bay frontage.

2.7.3 Overview of Water Quality

Mapped statistics of naturally occurring suspended sediment concentration (SSC) in surface waters, measured over an 8 year period by ocean colour satellites, are available from Dolphin *et al*. (2011). A summary of the reported climatological mean, standard deviation and maximum values of surface SSC in the central Irish Sea and in the outer part of the study area are summarised in Table 2. It is noted that the main source of SSC offshore is sediment resuspension at the seabed. Lower in the water column and especially closer to the seabed, SSC is therefore expected to be higher than the values shown in Table 2. Vertical gradients in SSC will be more pronounced during or shortly after active sediment resuspension events. During a storm event that is locally sufficient to stir and resuspend the seabed sediment, very nearbed SSC of hundreds or thousands of mg/l would be expected.

Table 2. Surface Water Suspended Sediment Concentration

Suspended Sediment Concentration	Offshore Dublin Bay		Central Irish Sea	
	Winter	Summer	Winter	Summer
Climatological Mean (mg/l)	10	4	5	1
Standard Deviation (mg/l)	5	1	3	1
Maximum (mg/l)	30-50	5	10	2

(Source: Dolphin *et al*, 2011)

No other site specific data are available to better quantify spatial or temporal variability in SSC within the study area. It is, however, noted that levels of SSC are expected to be generally higher in shallow coastal waters than in open water (as reported above for the Irish Sea and offshore of Dublin Bay). Local sources of SSC potentially include:

- Background SSC in water from regional or offshore sources (typically ~5 mg/l but up to tens of mg/l);
- Episodic local resuspension of sediment from the seabed by waves and/or currents in intermediate and shallow water (typically tens or hundreds of mg/l during storms but potentially hundreds or thousands of mg/l very close to the seabed); and
- Sediment suspended in river outflow (e.g. the River Liffey exiting through Dublin Port, (daily mean values from ~2 to 15 mg/l observed over a 7 month period in 2010/2011, Briciu-Burghina *et al*., 2014).

3. Potential Scheme Impacts (Construction Phase)

3.1 Potential Impacts During the Construction Phase

The construction phase of the proposed development includes the installation of the new jetty and the capital dredging works.

In the present study, potential impacts during the construction phase relate to effects of the various dredging activities, namely:

- Water quality: Increase in suspended sediment concentration due to dredging;
- Seabed: Deposition of resuspended sediment affecting water depth; and
- Seabed: Deposition of resuspended sediment affecting seabed sediment type.

Potential impacts are separately assessed for:

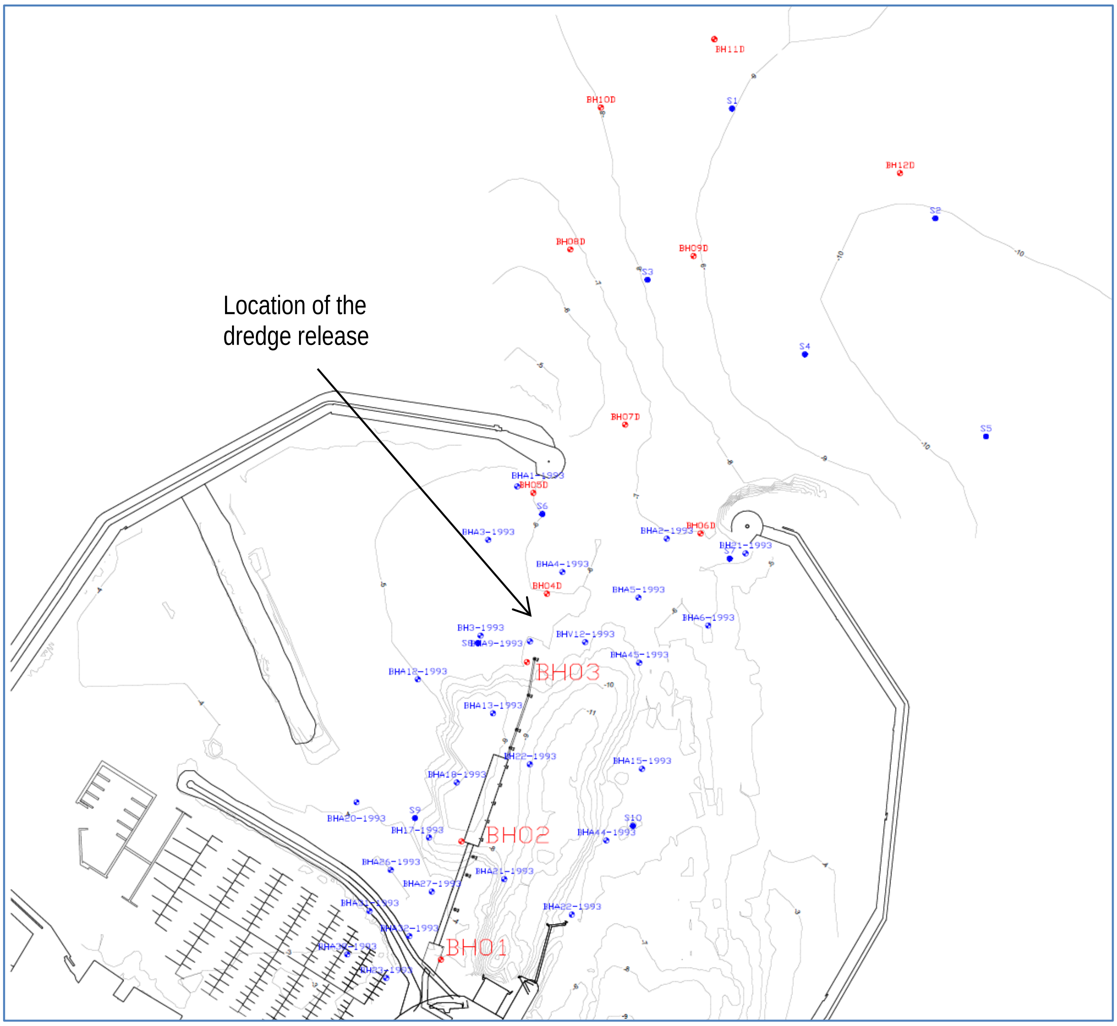
- Dredging inside Dun Laoghaire Harbour;
- Dredging outside Dun Laoghaire Harbour; and
- Spoil disposal at BBSG.

Potential impacts to wave and tidal regimes from the installed infrastructure are considered in relation to the operational phase (see Section 4). Partial potential impacts caused by less than the total amount of installed infrastructure during construction can be approximated on a proportional basis.

Piles for the jetty and mooring dolphins will be hammered into position and so this activity will cause negligible sediment disturbance. The potential impacts of a much higher rate and volume of sediment disturbance in the same location are considered in relation to dredging. The potential impacts of piling activities are therefore not separately considered.

Present water depths within the footprint of the dredged channel are accurately known from recent high-resolution bathymetric surveys (see Section 2.2). Based on these data, Figure 2 also shows the local thickness of material that will need to be either cut or filled to achieve the target water depth of 10.5 mCD. It is noted that, although only dredging (cutting) is required in most locations, some of the cut material will also be used to partially fill the local depression adjacent to the high-speed ferry dock, which is presently deeper than the target water depth. The total volume of material to be cut (710,622 m^3) and filled (19,723 m^3), and hence also the net volume to cut (690,899 m^3) is calculated by integrating the volumes shown in Figure 2.

Seabed core samples have been collected at a number of locations inside and outside of the harbour (Figure 17) as part of a geotechnical survey to inform the engineering design of the proposed development (IGSL, 2014). The majority of the cores within the dredged channel footprint indicate that the seabed sediments from the present seabed surface to the target depth of the dredge are dominantly 'sandy'. Only two cores within the harbour, (BH01 and BH02, approximately within the footprint of the new jetty) indicate a thin veneer of 'silty' material to be present (2.0 and 1.5 m thick at these locations, respectively), overlying the sandy material. Borehole BH03, also within the dredged channel in the harbour but closer to the entrance, indicates no silty layer to be present at that location. Assuming a linear variation in the thickness of the silty layer along the dredged channel between these three borehole locations, in conjunction with the reported thickness of sediment to be cut from these areas (Figure 2), it is estimated that 60,000 m³ (8.7%) of the total material dredged (cut) will be silty.



(Image Courtesy of Waterman Moylan)

Figure 17. Location of Available Seabed Core Samples

Sediment grain size analysis has been undertaken for sediment samples taken from the various borehole cores (IGSL, 2014). Representative grain size distributions are provided in Table 3 for sandy and silty sediment types. There is some minor variation in the exact proportion of the different grain sizes present; however, the sandy sediment type does typically contain no measurable proportion of silt or fines. Representative settling velocities for individual sediment grains and erosion thresholds for redeposited sediment in reasonable quantities are also provided from Soulsby (1997) on the basis of standard equations and relationships for these empirical parameters.

Table 3. Grain Size Distribution of the Characteristic Local Sediment Types

Grain Size Interval		Proportion by Mass* (%)		Representative Settling Velocity** (m/s)	Representative Erosion Threshold** (N/m²)
		'Sandy'	'Silty'		
Medium Sand	(150 – 300 μm)	50	20	0.03	0.15
Fine Sand	(63 – 150 μm)	50	36	0.01	0.12
Silt	(18 – 63 μm)	0	20	0.001	0.06
Fines	(<18 μm)	0	24	0.0001	0.04

(*Source: IGSL, 2014; ** Source: Soulsby 1997)

The realistic worst case description of dredging within the harbour for the purposes of the following assessments is:

- A medium sized trailing suction hopper dredger (TSHD) based on the Boskalis 'Shoalway' (Boskalis, 2014). Hopper capacity 4500 m^3, loaded draught 6.8 m, able to overspill and with hull mounted doors for sediment disposal, 11 kn laden steaming speed, 0.9 m diameter single suction pipe with changeable drag head;
- Dredging/release of sediment at a single location (indicated in Figure 17) representative of the end of the proposed jetty in the central harbour and in the path of the stronger incoming flood tidal currents. Also representative of the location of a relatively large localised volume of 'silty' seabed material to be cut (see Table 3, bathymetric feature visible in Figure 2);
- Actual dredging occurs for thirty minutes during each dredging cycle;
- The action of the drag-head is represented by sediment being released at 2 m above the seabed throughout the dredging period, including all grain size fractions present;
- Overspilling occurs during the last five minutes of the dredge (only once the hopper is full). Overspilled sediment laden water exits from the bottom of the vessel and is assumed to be fines and silt only;
- The rate of sediment disturbance/release is estimated using the commonly applied S-Factors presented in Kirby and Land (1991) for a medium size TSHD. The total S-Factor rate is 15 kg/m^3 dredged, of which 4 kg/m^3 dredged is associated with the drag head and 11 kg/m^3 dredged is associated with overspill (only whilst overspilling). A representative dredging rate of 2.16 m^3/s has been estimated, taking account of the hopper volume, duration of dredging and assumed differences in the bulk density of the material *in situ* (~1500 kg/m^3) and following dredging in to the hopper (~1300 kg/m^3). The resulting rates of sediment disturbance/release are 8.67 kg/s associated with the drag head and 23.83 kg/s associated with overspill;
- The dredger then spends 60 minutes not dredging (representative of transiting to the spoil ground, depositing the load and returning to the harbour) before beginning the next dredging cycle;
- Each dredging cycle (dredge and spoil disposal) therefore takes 1.5 hours – a conservative minimum time frame which maximises the potential risk of cumulative SSC effects within the harbour and also includes for a wide range of tidal conditions on any given day; and

- In order to provide a conservative representation of repeated dredging cycles over a range of tidal conditions, 76 dredging cycles are repeated continuously (24/7) at this rate over a 5 day period starting on mean spring and ending on mean neap tidal conditions. It is noted that the total volume of silty material 'dredged' in this scenario is greater than the total volume of silty material present in the dredged footprint.

The realistic worst case description of dredging outside of the harbour for the purposes of the following assessments is largely the same as for dredging within the harbour (described above), except:

- Dredging/release of sediment at a single location representative of the centre of the turning circle, immediately outside of the entrance to DLH; and
- The sediment being dredged outside of DLH is all 'sandy' (see Table 3) i.e. no silt or fines content.

The realistic worst case description of spoil disposal for the purposes of the following assessment of impact on SSC is:

- Consistent with the dredging cycle described above. Following dredging, the dredger takes 30 minutes to transit to the BBSG, 5 minutes to deposit the spoil load and then 25 minutes to transit back to the harbour to start the next dredge cycle (total duration 1.5 hours);
- The position of release within the spoil ground is randomly varied for each dredge cycle;
- A full hopper load (4,500 m^3) of 'sandy' or 'silty' spoil is deposited during each cycle, equivalent to 1,993,630 kg dry sediment (based on an assumed bulk density of 1300 kg/m^3, sediment mineral density of 2650 kg/m^3 and seawater density of 1029 kg/m^3);
- It is assumed that 10% of the total load (199,363 kg) will enter suspension directly as the passive phase, at the depth of the vessel hull, over a 5 minute period;
- The remaining 90% of sediment mass is released directly to the seabed so does not immediately contribute to SSC. Sediment mass impacting the seabed will result in a small amount of suspended sediment. Sediment falling away from the dumped load will also occur throughout the water column. Both of these suspended sediment components are assumed to be released close to the surface as this is the worst case. Therefore all sediment released into suspension is assumed to be within the 10% described in the previous bullet point.; and
- Once deposited, 100% of the sediment mass remains available for further transport, should local tidal conditions exceed the threshold for erosion. In practice, only a smaller amount from the surface of main mass of deposited sediment might be remobilised at any given time.

3.2 Potential Impact on Water Quality (Suspended Sediment Concentration)

3.2.1 Conceptual Basis

Dredging operations may place sediment into suspension, increasing suspended sediment concentration (SSC) locally as a result of:

- Direct disturbance by the dredger drag head at the seabed;
- Releasing or overspill of excess sediment laden water from the dredger hopper; and/or
- Dumping of the dredged sediment load at the designated disposal ground.

Sediment resuspension by drag head disturbance or overspill will place sediment directly into suspension at the location of the source (nearbed and at the bottom of the dredger hull, respectively). The rate and duration of the release, and hence the total mass of sediment resuspended, will depend on the dredger type and the nature of the sediment being dredged.

Dumping of the dredged material will most likely occur over a relatively short time period (5 minutes or less) via large doors in the bottom of the dredger hopper. The majority (approximately 90%) of the sediment load will descend to the seabed as a single unit, behaving as a density flow. This portion is termed the dynamic phase of the plume. The rate of descent of the dynamic phase through the water column is rapid (in the order of several metres per second) relative to the normal settling rate for the individual grains that comprise it. After impacting the seabed (in a footprint estimated to be similar to the area of the vessel), the dynamic phase of the plume will spread radially under gravity, aided or opposed by any significant bed slopes that are present. Sediment will be gradually deposited to the bed as the density flow loses energy with time and distance.

The remainder of the sediment released will form a more dispersed plume, termed the passive phase, that will settle instead at the rate of the individual grains (see Table 3). Sediment grains shed from the dynamic phase of the plume during its descent also join the passive phase.

Sediment placed into suspension by dredging or spoil disposal will directly lead to an increase in SSC, which would negatively affect this measure of water quality. Sediment in suspension will be passively advected as a plume from the point of release by any currents that are present. At the same time, the plume will be subject to dispersion by naturally occurring turbulence that will increase the area of the effect but with a corresponding decrease in the level of SSC through dilution. The amount of sediment in suspension will also decrease over time as individual grains settle downwards under gravity and are re-deposited to the seabed. Hence, levels of elevated SSC will be greatest at the time and location of the release but will decrease, becoming negligible over time.

Dredging within harbours and disposal of dredged sediments in the coastal environment are normal operations. In response to general environmental and commercial concerns, modern dredging equipment and methodologies have been developed over time to maximise the efficiency and accuracy of the removal of sediment whilst minimising unintended resuspension.

Maintenance and capital dredging operations have been undertaken historically within DLH and Dublin Port, using local sites such as the BBSG for spoil disposal. The BBSG is a licensed spoil disposal ground which has been identified as suitable and has been used for this specific purpose since 1996. Prior to this, since the 1960's, spoil was also disposed in a nearby location. In addition to general (historical) anecdotal evidence, the potential impacts of spoil disposal at this general location have been objectively assessed in a number of previous EIS reports and have consistently been found to present no likely significant impacts with regard to a range of potentially sensitive receptors.

As a result, the impact of dredging operations such as those proposed are generally and normally characterised as a localised, short-duration (temporary) increase in SSC within the sediment plume, initially exceeding background levels but returning to background levels within a matter of minutes to hours, depending on the nature of the sediment being dredged or deposited.

3.2.2 Approach to the Assessment

The plume dispersion model (described in Appendix A) was used to simulate continuous dredging and disposal over a 5 day timeseries of tidal conditions, including individual tides of mean spring and mean neap range.

The following construction scenarios were simulated according to the realistic worst case scenarios described in Section 3.1:

- Dredging of silty sediments within Dun Laoghaire Harbour (in conjunction with silty spoil disposal at the Burford Bank Spoil Ground); and
- Dredging of sandy sediments outside of Dun Laoghaire Harbour (in conjunction with sandy spoil disposal at the Burford Bank Spoil Ground).

Dredging and spoil disposal activities (for the corresponding sediment type) are included in the same scenario (model simulation) to realistically assess the likelihood of any potential cumulative impacts. Results are presented below for representative example periods during mean spring and mean neap tidal range tides.

3.2.3 Impact of Dredging Within Dun Laoghaire Harbour

Example images showing local increases in instantaneous SSC as a result of continuous dredging operations within DLH are provided in Figure 18 to Figure 25.

Collectively, the figures illustrate typical distributions of SSC as a result of continuous dredging of silty sediments within the harbour, taking account of differences in the tidal condition (peak flood, peak ebb and high and low water slack conditions, for mean spring and mean neap tidal ranges). All of the images have been chosen so that a dredging operation is underway (a sediment plume release is actively being introduced at the location identified in Figure 18). Sufficient previous dredging cycles had been completed, prior to each of the conditions illustrated, for the results to have reached a dynamic equilibrium.

With reference to Figure 18 to Figure 25, and to other underlying model results (not shown):

- As expected, the greatest increase in SSC is at the location of the dredger during dredging. The typical increase in SSC at this location is in the order of hundreds to thousands of mg/l;

- The increase in SSC reduces rapidly to tens or hundreds of mg/l within 50-100 m of the active dredger as the sand component (typically 56% of the disturbed sediment mass) is rapidly redeposited to the seabed, within a matter of minutes from release;
- The more disperse plumes evident in the images (typically <5 mg/l but locally 25 to 200 mg/l) are caused by the silts and fines which remain in suspension for a longer time;
- Silts tend to redeposit to the seabed (ceasing to contribute to SSC) within approximately 1.5 hours from the time of release, hence, up to two 'silt' plumes can be present in the harbour at any given time;
- Fines that stay within the relatively shallow water of the harbour tend to redeposit to the seabed (ceasing to contribute to SSC) within ~6 to 9 hours from the time of release, hence, up to six 'fine sediment' plumes can be present in the harbour at any given time;
- Fine sediment plumes may become widely dispersed throughout the inner and outer harbour; and
- For most of the tidal cycle, most of the material in fine sediment plumes tends to accumulate in the recirculating flow patterns in the outer harbour (identified in Section 2.6.5 and visible in Figure 15 and Figure 16). For a brief time at the end of the following ebb tide, some (but not all) of the plume may be ejected out of the harbour and advected north-west into Dublin Bay. SSC of these ejected plumes in the very near vicinity of DLH may be the same as reported above for inside the harbour (typically <5 mg/l but locally 25 to 200 mg/l). Further than 2 km from DLH, SSC is diluted by rapid dispersion to <5 mg/l. Tidal asymmetry also described in Section 2.6.5 will progressively advect the highly dispersed sediment plume around the bay and eventually offshore. The full extent of these plumes at the example timesteps during a mean spring tide are also shown in Section 3.2.5.

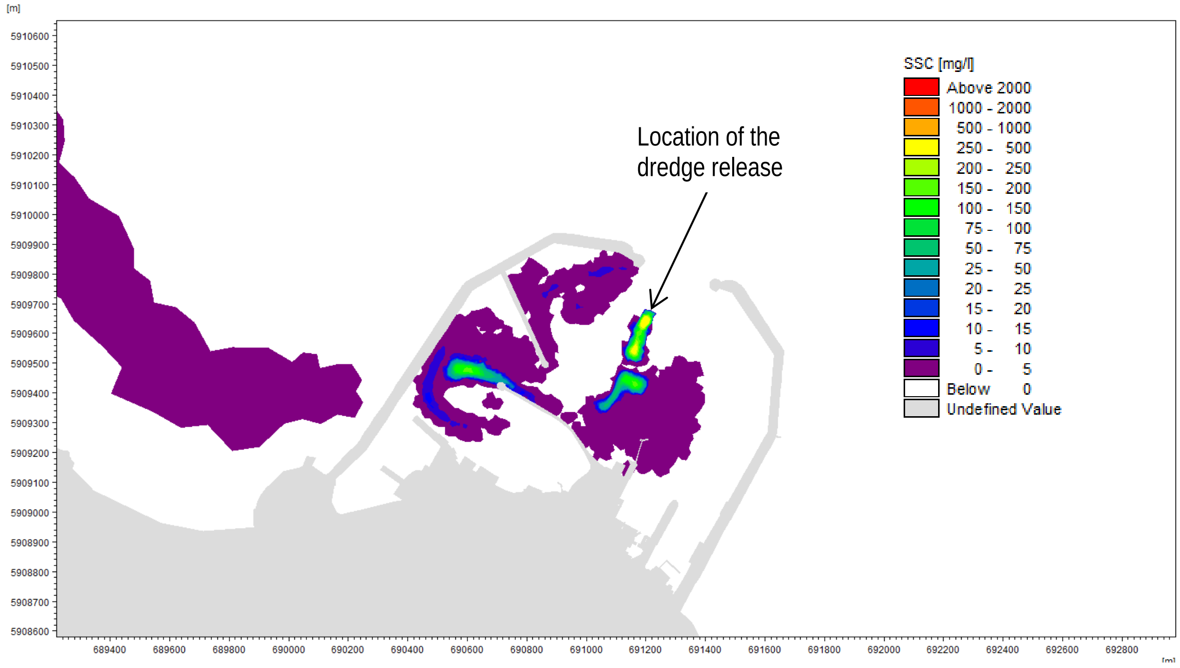


Figure 18. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Spring Tide, Peak Flood Currents)

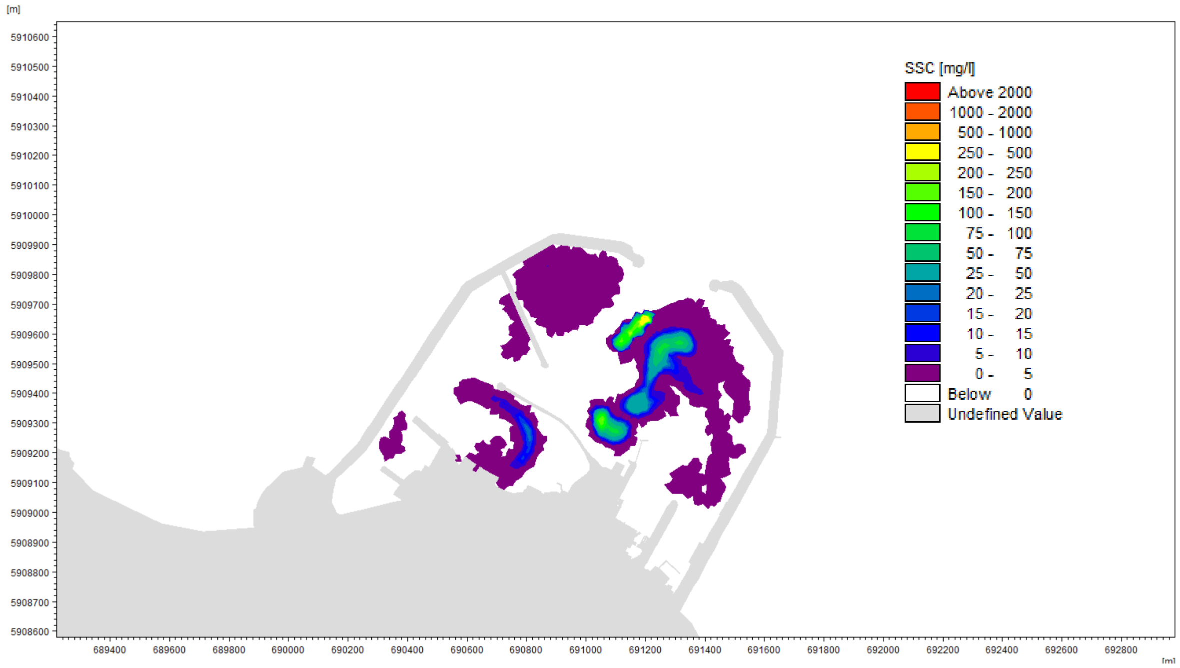


Figure 19. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Spring Tide, High Water Slack)

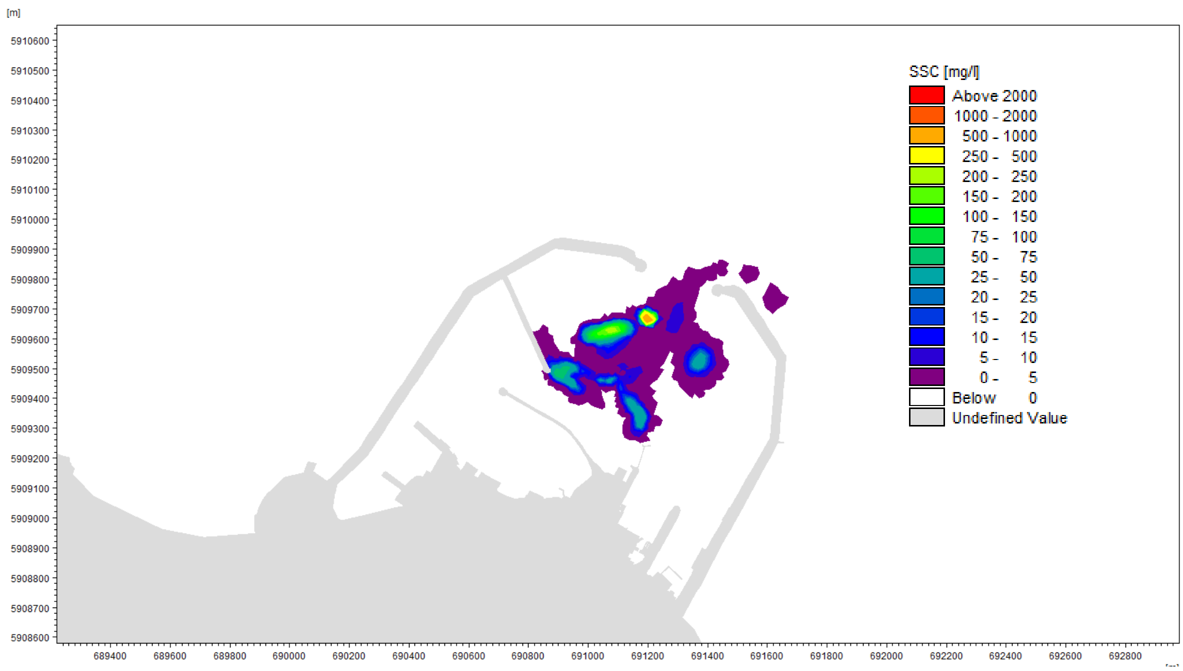


Figure 20. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Spring Tide, Peak Ebb Currents)

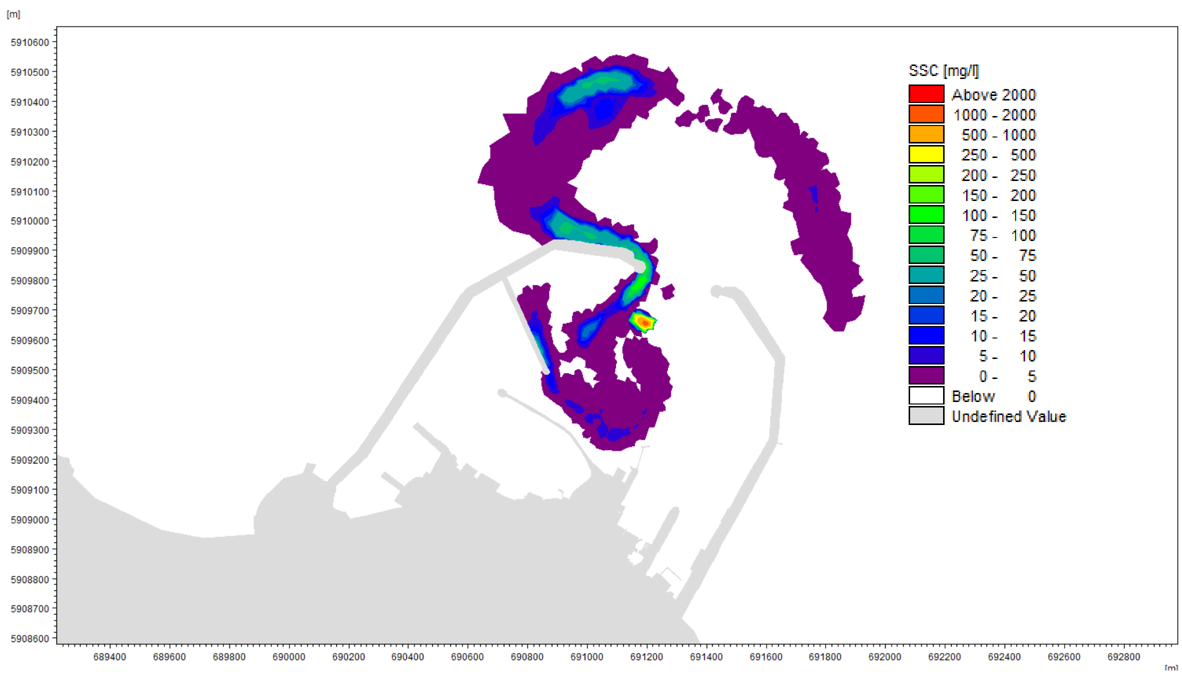


Figure 21. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Spring Tide, Low Water Slack)

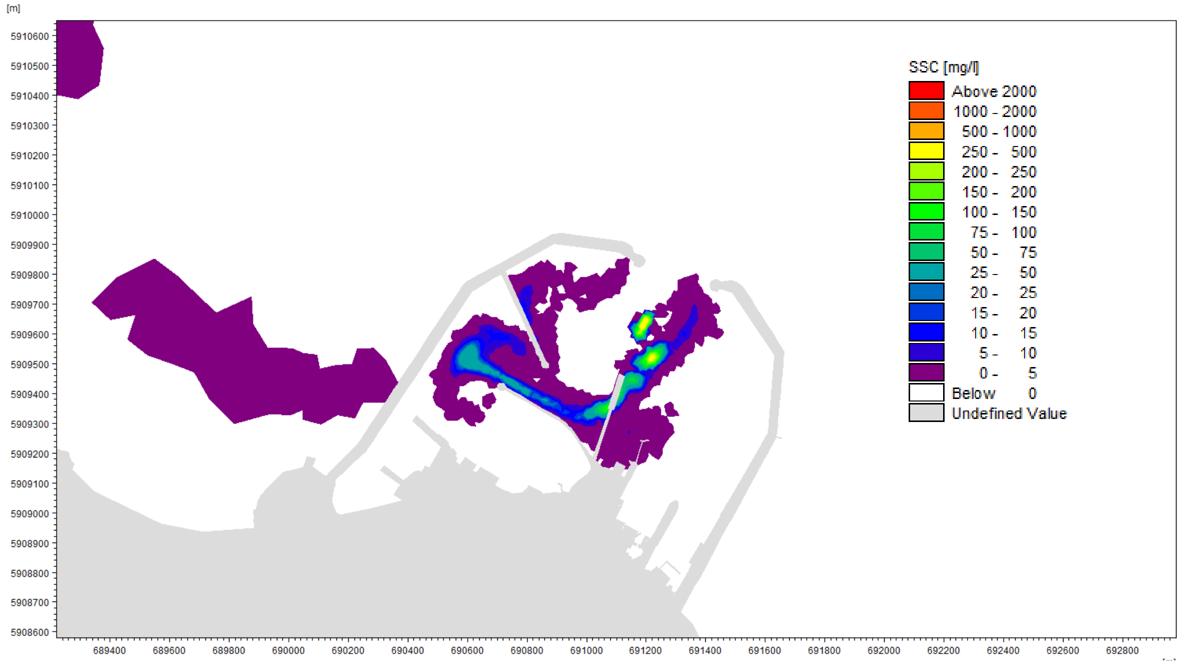


Figure 22. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Neap Tide, Peak Flood Currents)

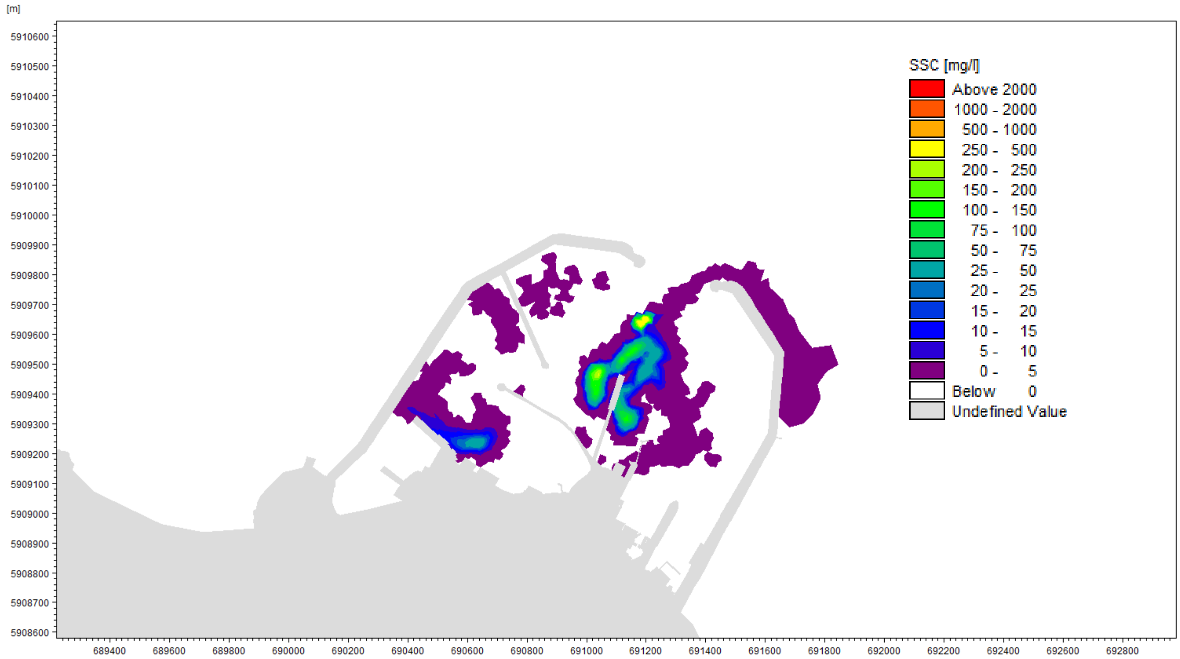


Figure 23. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Neap Tide, High Water Slack)

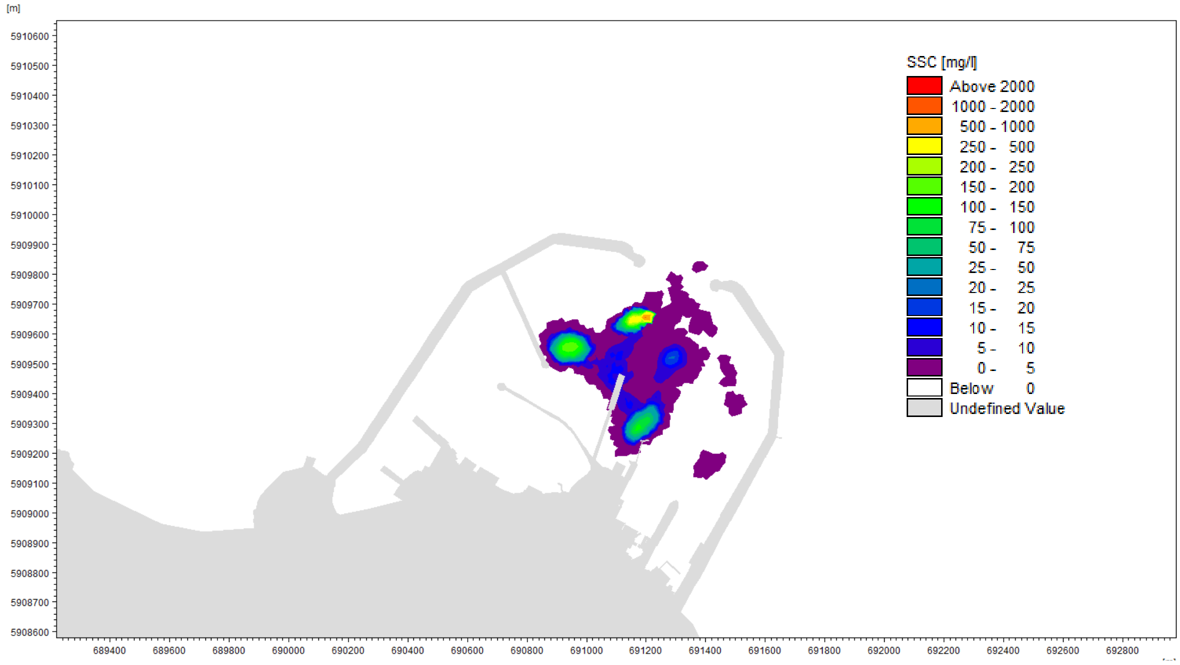


Figure 24. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Neap Tide, Peak Ebb Currents)

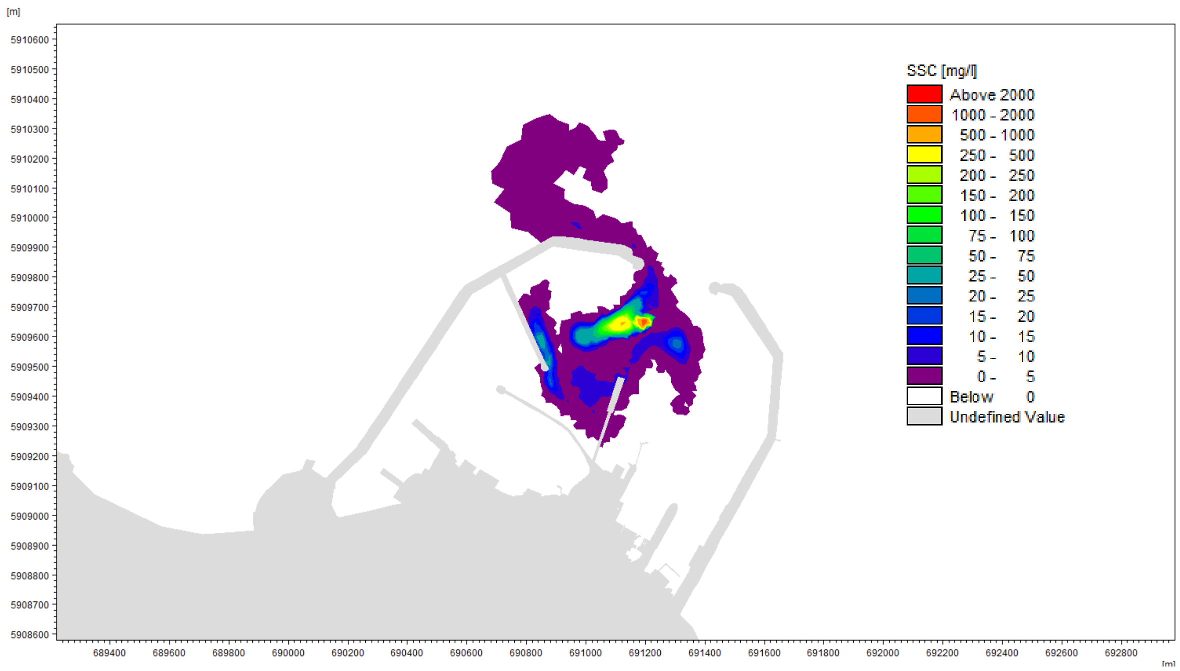


Figure 25. Increase in SSC Resulting from Continuous Dredging of Silty Sediment in Dun Laoghaire Harbour (Neap Tide, Low Water Slack)

3.2.4 Impact of Dredging Outside of Dun Laoghaire Harbour

Example images showing local increases in instantaneous SSC as a result of continuous dredging operations outside of DLH are provided in Figure 26 to Figure 29.

Collectively, the figures illustrate typical distributions of SSC as a result of continuous dredging of sandy sediments outside the harbour, taking account of differences in the tidal condition (peak flood, peak ebb and high and low water slack conditions, for a mean spring tidal range). All of the images have been chosen so that a dredging operation is underway (a sediment plume release is actively being introduced). All of the (spring tide) images include for at least nine completed dredging cycles, prior to the cycle underway (shown in the images).

With reference to Figure 26 to Figure 29, and to other underlying model results (not shown):

- As expected, the greatest increase in SSC is at the location of the dredger during dredging. The typical increase in SSC at this location is in the order of hundreds to thousands of mg/l;
- The increase in SSC reduces rapidly to tens or hundreds of mg/l within 50-100 m of the active dredger as sand (100% of the disturbed sediment mass) is rapidly redeposited to the seabed, within a matter of minutes from release;
- There is no measurable increase in SSC at locations further than 100 m from the dredger during dredging, or at any location more than a short time following the end of active dredging; and
- The patterns shown for mean spring tidal conditions also apply to mean neap and other intermediate tidal conditions.

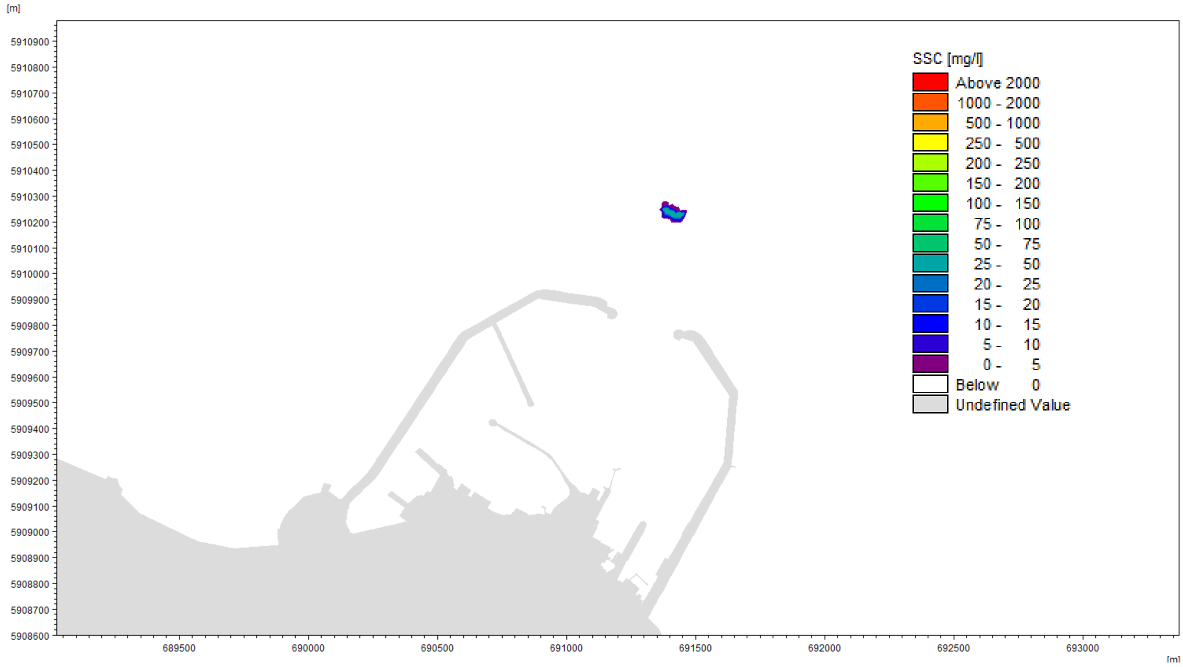


Figure 26. Increase in SSC Resulting from Continuous Dredging of Sandy Sediment outside Dun Laoghaire Harbour (Spring Tide, Peak Flood Currents)

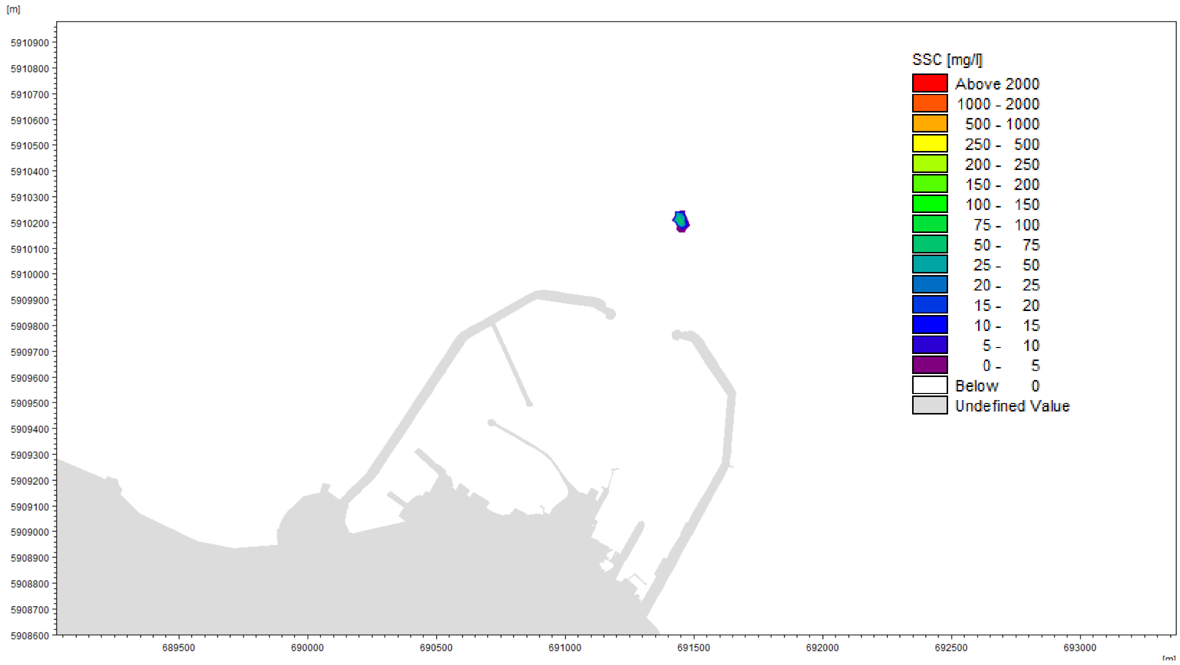


Figure 27. Increase in SSC Resulting from Continuous Dredging of Sandy Sediment outside Dun Laoghaire Harbour (Spring Tide, High Water Slack)

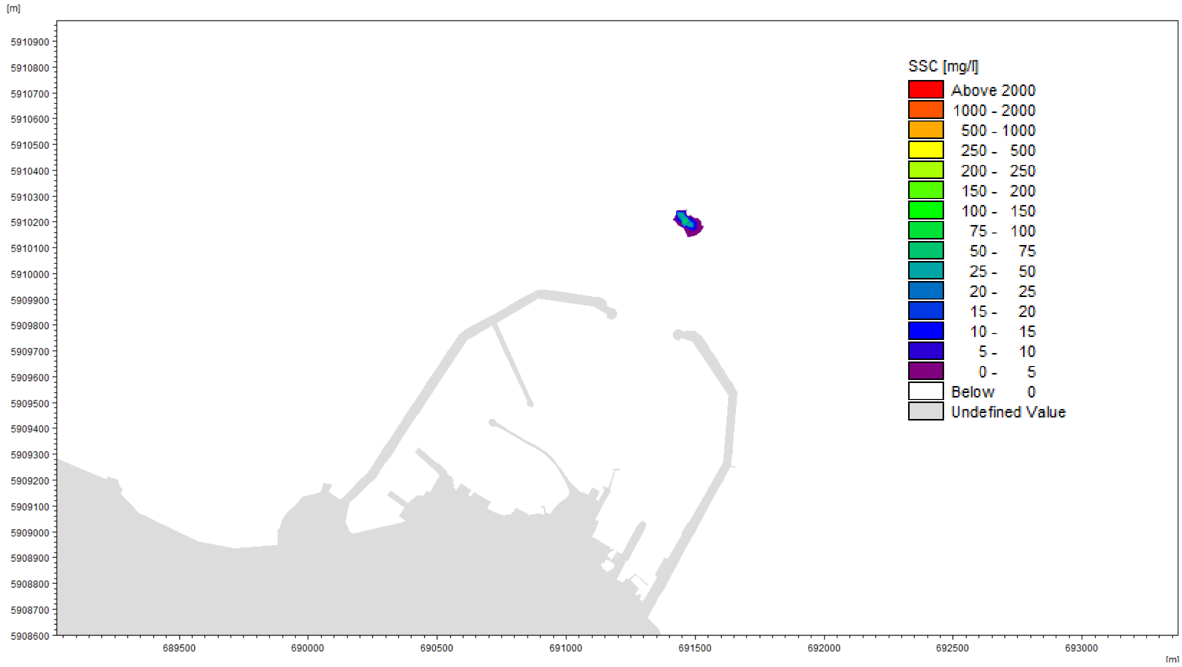


Figure 28. Increase in SSC Resulting from Continuous Dredging of Sandy Sediment outside Dun Laoghaire Harbour (Spring Tide, Peak Ebb Currents)

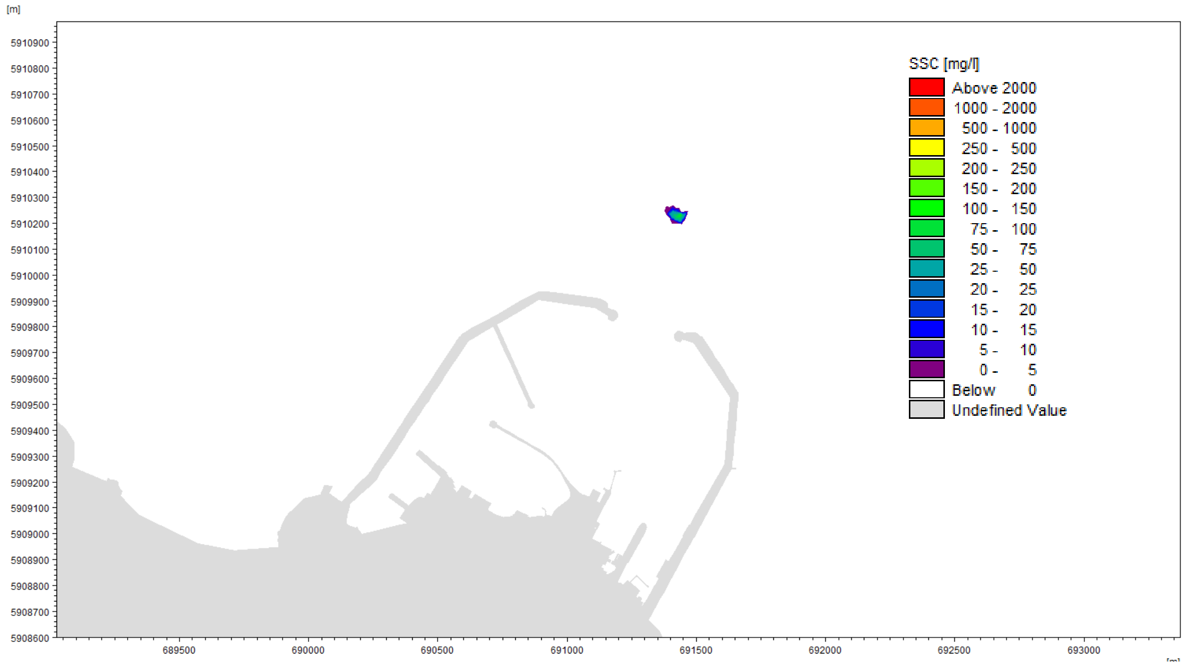


Figure 29. Increase in SSC Resulting from Continuous Dredging of Sandy Sediment outside Dun Laoghaire Harbour (Spring Tide, Low Water Slack)

3.2.5 Impact of Silty Spoil Disposal at Burford Bank Spoil Ground

Example images showing local increases in instantaneous SSC as a result of continuous spoil disposal operations at the BBSG, in conjunction with continuous dredging of silty sediments within DLH, are provided in Figure 30 to Figure 33.

Collectively, the figures illustrate typical distributions of SSC as a result of continuous dredging of silty sediments within the harbour and disposal at the nearby spoil ground, taking account of differences in the tidal condition (peak flood, peak ebb and high and low water slack conditions, for a mean spring tidal range). Consistent with Figure 18 to Figure 25 previously shown in Section 3.2.3, all of the images have been chosen so that a dredging operation is underway in DLH (a sediment plume release is actively being introduced). All of the images include for at least 9 completed dredging cycles, prior to the cycle underway (shown in the images).

With reference to Figure 30 to Figure 33, and to other underlying model results (not shown):

- As expected, the greatest increase in SSC is at the location of spoil disposal. The typical increase in SSC at this location is in the order of thousands of mg/l;
- Initially, the plume is confined to a small footprint with increases in SSC reducing rapidly to tens or hundreds of mg/l within 50-100 m of the plume centroid;
- The sand component (typically 56% of the resuspended sediment mass) is rapidly redeposited to the seabed, in the order of 15 to 30 minutes from release;
- The more disperse plumes evident in the images (typically <5 mg/l but locally 25 to 200 mg/l) are caused by the silts and fines which remain in suspension for a longer time;
- Silts tend to redeposit to the seabed (ceasing to contribute to SSC) within ~7 to 12 hours from the time of release;
- Fines will likely remain in suspension in the order of days or weeks from the time of release, however, it is expected that the plume will be dispersed to negligible levels of SSC over such time periods;
- Fine sediment plumes from the BBSG will be carried along the (approximately north-south) tidal axis and are not expected to enter Dublin Bay. Over longer time-scales, any sediment that remains in suspension will be taken gradually north and then offshore, in the direction of residual tidal flow; and
- The plume footprints from sequential spoil releases and the dredging in DLH have little or no potential to overlap and so cumulative impacts are not likely.

The above observations relate to the 10% of all material that is resuspended in the upper water within the passive plume phase. A conceptual estimate of the extent, duration and magnitude of the potential impact of silty sediment in the dynamic plume phase is provided below:

- Duration of effect in the water column - order of seconds to minutes;
- Duration of effect at the seabed - order of seconds to minutes;
- Extent of effect in the water column - order of tens of metres (both laterally and vertically); and
- The dynamic plume phase is essentially a solid mass of seabed sediment material, which cannot be assigned a meaningful measure in terms of SSC.

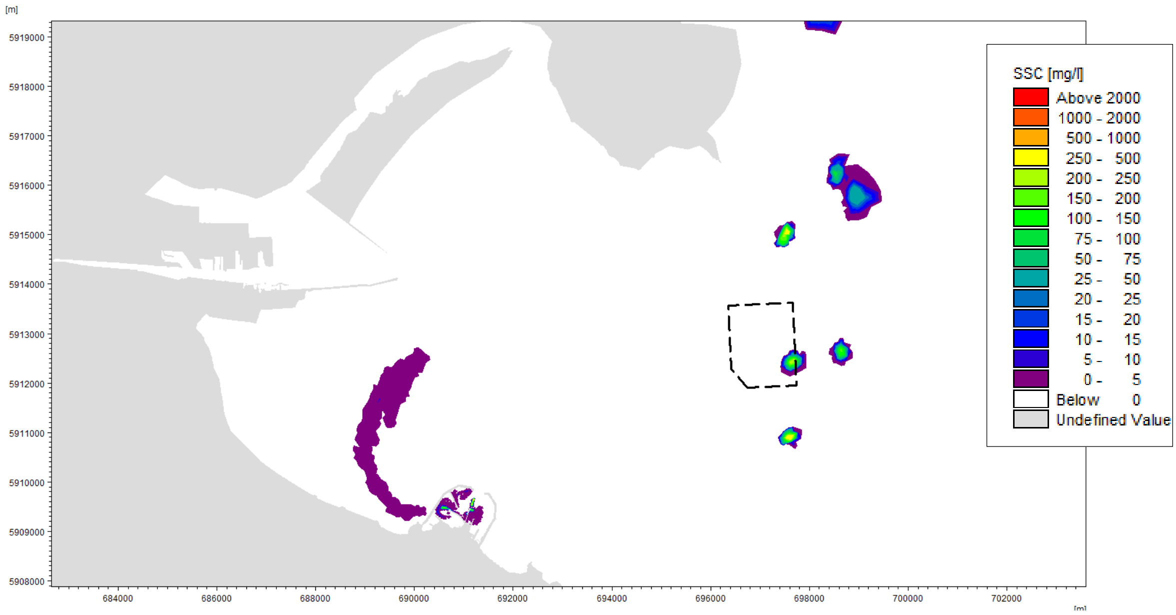


Figure 30. Increase in SSC Resulting from Continuous Dredging of Silty Sediment inside Dun Laoghaire Harbour and Subsequent Disposal at Burford Bank Spoil Ground (Spring Tide, Peak Flood Currents)

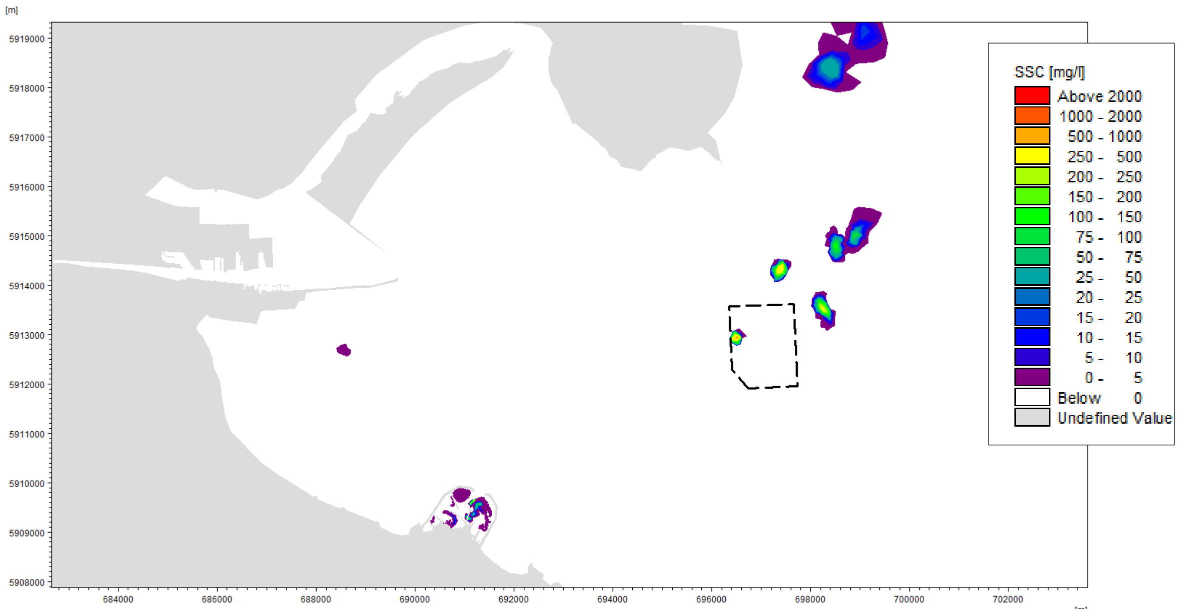


Figure 31. Increase in SSC Resulting from Continuous Dredging of Silty Sediment inside Dun Laoghaire Harbour and Subsequent Disposal at Burford Bank Spoil Ground (Spring Tide, High Water Slack)

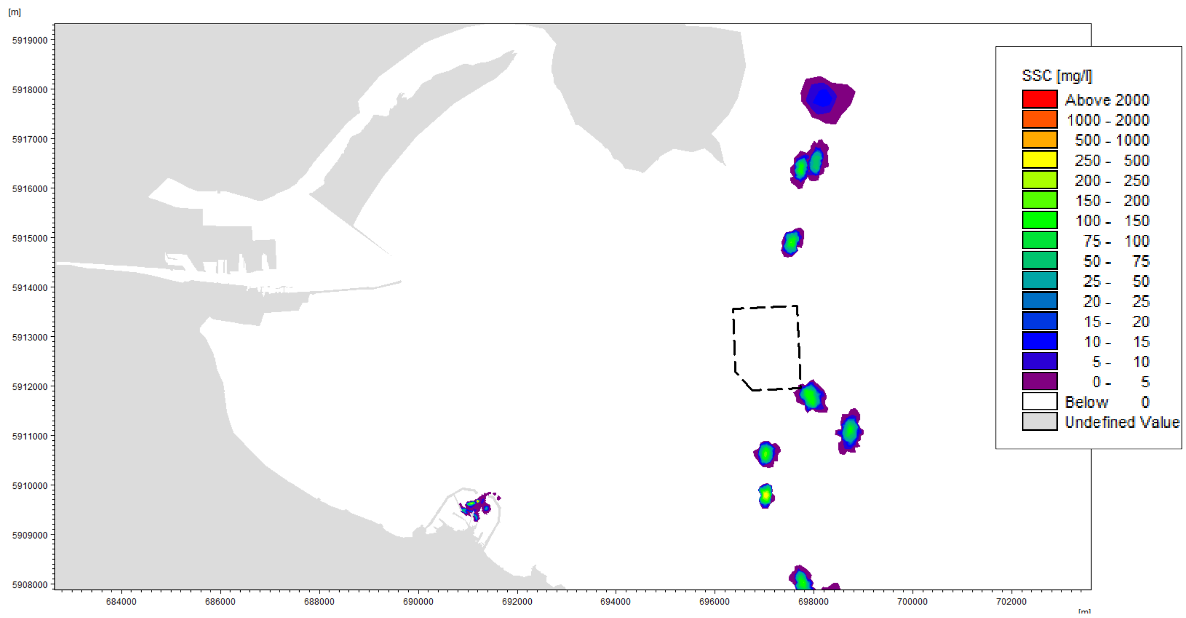


Figure 32. Increase in SSC Resulting from Continuous Dredging of Silty Sediment inside Dun Laoghaire Harbour and Subsequent Disposal at Burford Bank Spoil Ground (Spring Tide, Peak Ebb Currents)

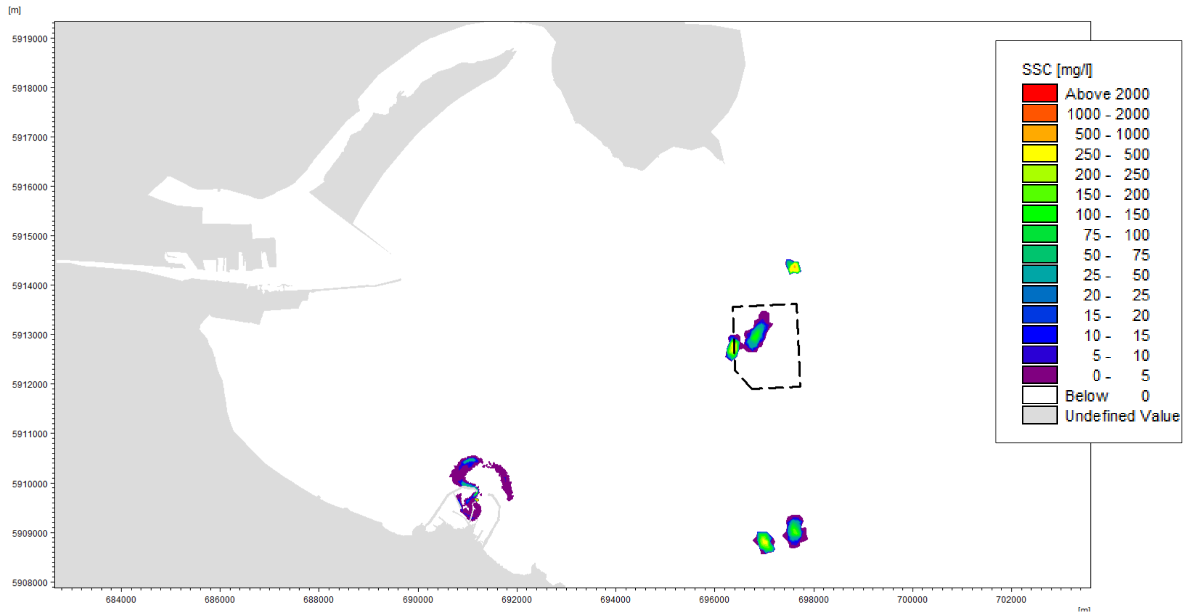


Figure 33. Increase in SSC Resulting from Continuous Dredging of Silty Sediment inside Dun Laoghaire Harbour and Subsequent Disposal at Burford Bank Spoil Ground (Spring Tide, Low Water Slack)

3.2.6 Impact of Sandy Spoil Disposal at Burford Bank Spoil Ground

Sandy sediments placed into suspension were shown to deposit relatively rapidly to the seabed (ceasing to contribute to SSC) when dredging outside of DLH in Section 3.2.4, and for the sand fraction when depositing silty spoil at the BBSG in Section 3.2.5, resulting in only a localised and temporary effect on SSC. A similar pattern of effect is reported by the models for the passive phase during sandy spoil disposal, i.e.:

- As expected, the greatest increase in SSC is at the location of spoil disposal. The typical increase in SSC at this location is in the order of thousands of mg/l;
- Initially, the plume is confined to a small footprint with increases in SSC reducing rapidly to tens or hundreds of mg/l within 50-100 m of the plume centroid;
- All sediment placed in suspension is rapidly redeposited to the seabed (leaving no further impact on SSC), in the order of 15 to 30 minutes from release; and
- Sediment plumes at the BBSG therefore do not persist until the following spoil disposal event and so there is no potential for cumulative effects.

The potential impact of sandy sediment in the dynamic plume phase is the same as provided in Section 3.2.5 for silty sediments.

3.3 Potential Impact on the Seabed (Sediment Deposition)

3.3.1 Conceptual Basis

Dredging operations may place sediment into suspension, which may then be redeposited to the seabed in other locations, leading to a thickness of deposition and potentially also a change in sediment type. As outlined in Section 3.2.1, sediment may be disturbed as a result of:

- Direct disturbance by the dredger drag head at the seabed;
- Releasing or overspill of excess sediment laden water from the dredger hopper; and/or
- Dumping of the dredged sediment load at the designated disposal ground.

Once in suspension, a first order estimate of the minimum time required for individual sediment grains to redeposit to the seabed can be made on the basis of the theoretical settling velocity for the given grain size (see Table 3) and the vertical distance to the seabed from the point of release. In practice, naturally present turbulence in moving water may keep sediment in suspension for longer than this minimum period.

The dispersive nature of sediment plumes means that the minimum time from release to deposition will result in the greatest potential thicknesses of sediment accumulation, but also the smallest potential area. Relatively more extensive deposits might also occur, but with a proportionally smaller average thickness.

3.3.2 Approach to the Assessment

The plume dispersion model (described in Appendix A) was used to simulate continuous dredging over a 5 day timeseries of tidal conditions, including individual tides of mean spring and mean neap range.

The following construction scenarios were simulated according to the realistic worst case scenarios described in Section 3.1:

- Dredging of silty sediments within Dun Laoghaire Harbour (in conjunction with silty spoil disposal at the Burford Bank Spoil Ground);
- Dredging of sandy sediments outside of Dun Laoghaire Harbour (in conjunction with sandy spoil disposal at the Burford Bank Spoil Ground); and
- Disposal of all dredged material at the Burford Bank Spoil Ground.

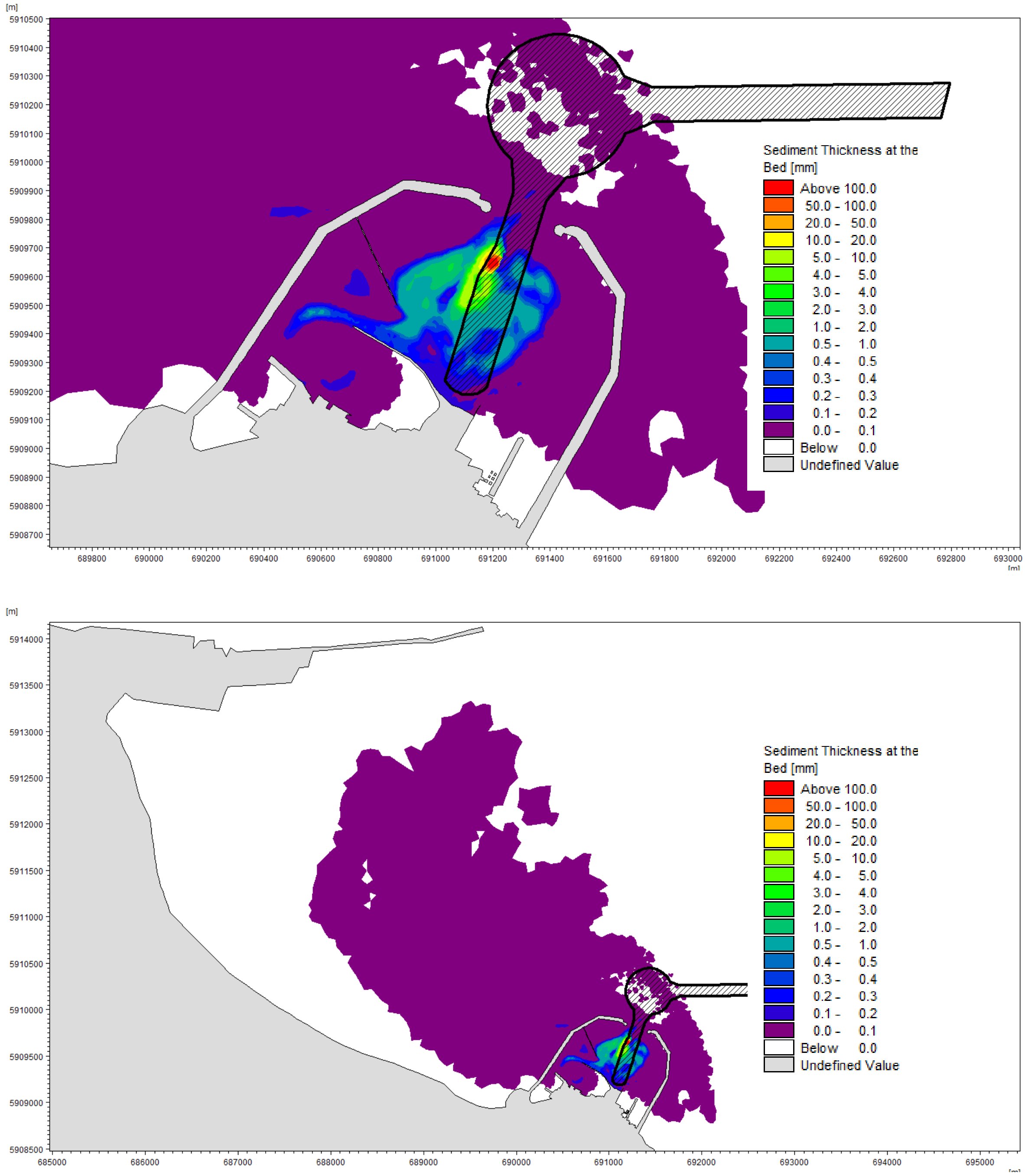
The total volume of silty material 'dredged' by the number of dredging cycles simulated (76) corresponds to more than the total volume of silty sediment present in the dredged footprint. The final result was scaled proportionally to reflect the difference.

3.3.3 Impact of Dredging Within Dun Laoghaire Harbour

The thickness of sediment deposition as a result of continuous dredging of the total volume of silty sediments within DLH, with sediment disturbance/release occurring at one location only, is shown in Figure 34

With reference to the images and to the underlying model results:

- The greatest apparent thickness of sediment deposition is at the location of the dredger. This corresponds to the medium and fine sands which are deposited rapidly to the seabed (within approximately 10 m or less of the release point). In the model, this accumulation is artificially concentrated in this location. In practice, the sand fraction would be more widely dispersed (within the footprint of the dredged area) and any deposits of sediment within the dredged footprint that are above the target dredged depth would be removed by subsequent dredging;
- Intermediate thicknesses of sediment (typically 0.3 to 0.8 mm but up to 5 to 10 mm within 150 m of the release) result from the more dispersed settlement of silts and fines. In practice, these will also be more widely dispersed and so of a smaller thickness locally;
- As a result of the typical current speeds in this part of the harbour (~0.05 to 0.1 m/s), the majority of the silt content is deposited within ~270 to 540 m of the release, i.e. within the harbour;
- A proportion of the fines will be distributed widely throughout the harbour, settling in negligible thicknesses of less than 0.1 mm; and
- A proportion will also be transported out of the harbour and deposited in negligible thicknesses of less than 0.1 mm elsewhere in the surrounding coastal or offshore environment.



N.B. The black hatched area indicates the footprint of the dredged channel

Figure 34. Sediment Deposition Thickness Resulting from Dredging of All Silty Sediment in Dun Laoghaire Harbour (Single Release Location)

The actual proportion of fines staying in or leaving the harbour cannot be accurately predicted. However, by releasing all possible sediment only at a single location in the scenario results described above, the reported thicknesses (typically 0.3 to 0.8 mm but up to 5 to 10 mm) represent a conservative estimate of the maximum local thicknesses that can be expected within 150 m of the dredge footprint.

At least a thin silt or fine sediment veneer is expected to be naturally present throughout most of the harbour. As such, the redeposited sediment would be of a similar type to the surrounding seabed, resulting in no measurable change to the seabed texture or sedimentary characteristics.

3.3.4 Impact of Dredging Outside of Dun Laoghaire Harbour

Resuspended sandy sediments will redeposit to the seabed rapidly (within ~10 m of the release and so mainly within the dredge footprint). Any sediment redeposited within the dredged footprint to a level above the target dredged depth would be removed by subsequent dredging. Because of the small spatial scale (10 m), the thickness of sediment deposition outside of the dredged channel footprint cannot be more accurately modelled, but is expected to be reasonably small.

The redeposited sediment would be of a similar type to the surrounding seabed, resulting in no measurable change to the seabed texture or sedimentary characteristics.

3.3.5 Impact of Spoil Disposal at Burford Bank Spoil Ground

The thickness of sediment deposition at the BBSG as a result of depositing the total volume of all (sandy and silty) sediments from the dredged footprint at a series of random locations evenly over one tidal cycle is shown in Figure 35.

With reference to the image and to the underlying model results:

- The greatest thickness of sediment deposition is within the BBSG extent (~40 to 80 mm). The majority of this sediment corresponds to the mixture of sediment types in the dynamic phase of each deposit made, and to the sand fraction of the passive plume phase which will settle relatively rapidly and typically within or near to the extent of the spoil ground;
- A secondary area of deposition is visible outside of the spoil ground extent (~3 to 10 mm thickness) where silts and some fine sands are transported for a short period of time by tidal currents prior to settling out; and
- A larger area of negligible deposition thickness (typically 0.1 to 0.3 mm but locally up to 1 mm) is also visible where fines are transported northwards by residual currents before being deposited.

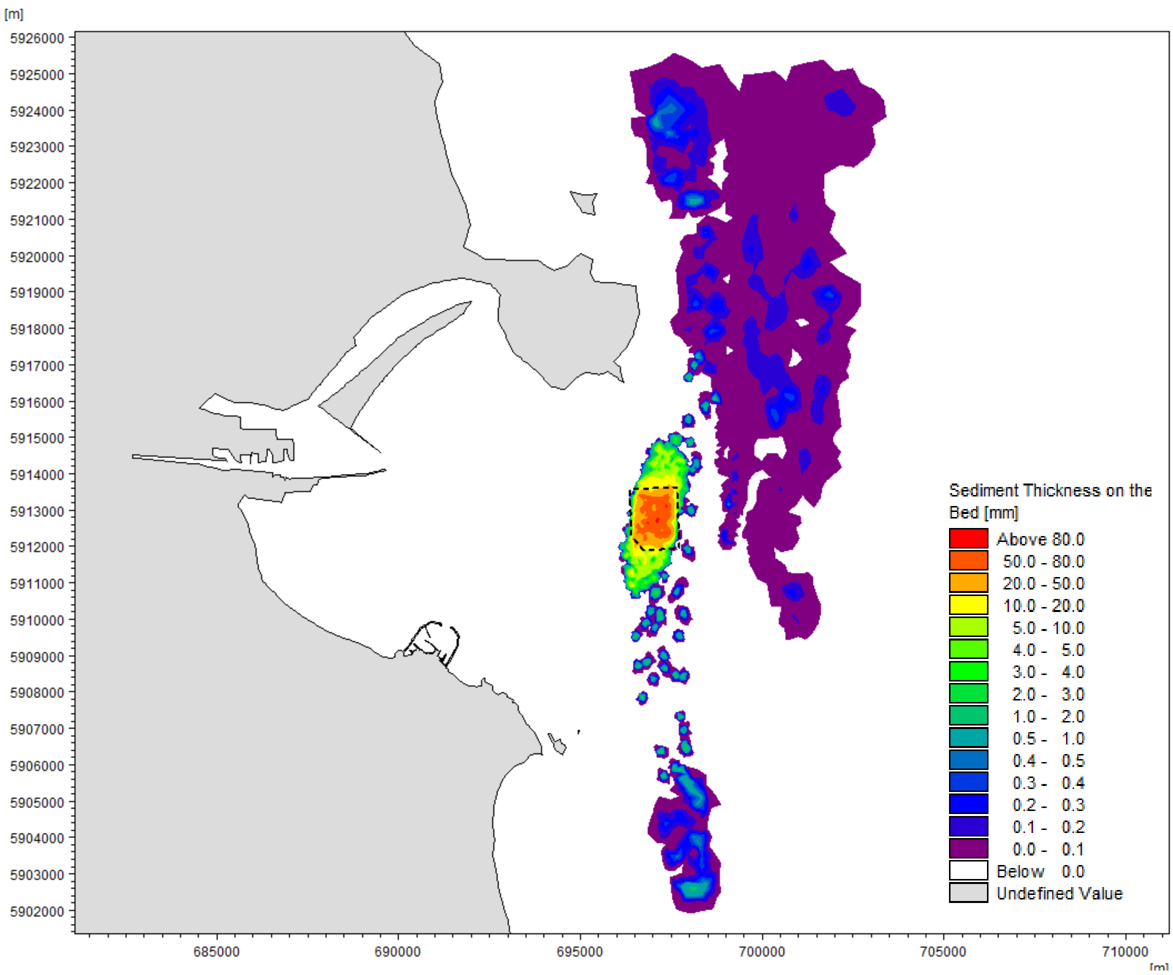


Figure 35. Sediment Deposition Thickness Resulting from Deposition of All Sandy and Silty Sediment at the Burford Bank Spoil Ground

4. Potential Scheme Impacts (Operational Phase)

4.1 Potential Impacts during the Operational Phase

The operational phase of the proposed development follows completion of construction works and includes for the presence of the new jetty and dredged channel under a range of operating conditions.

Potential impacts during the operational phase relate to the effect of the jetty piles and dredged channel on patterns of:

- Water levels;
- Currents;
- Waves; and
- Sediment transport and deposition.

With or without the Scheme present, all of the above features of the marine environment are subject to natural variability, both spatially within the study area, and on a range of timescales (summarised in Section 2). The relative impact of the Scheme on these features is assessed

Due to the relatively small current speeds present in and around DLH, the potential effects of, or viability due to wave-current interaction are not significant and are therefore scoped out of this study.

Due to the absence of significant sources of fresh water input to DLH or the immediate surrounding area, the potential effect of spatial gradients in temperature and salinity (affecting water density and stratification) are not significant and are therefore scoped out of this study.

The potential impact of the mooring dolphins on waves and currents within the harbour relates to the blockage that they present locally. Potential differences in the magnitude of potential impacts are therefore principally related to differences in the total cross-sectional area of blockage presented by each of the two options. For an example water depth of 10 m, a single 3 m monopile will present a face area of 30 m^2 whereas nine 1 m diameter monopiles will present 90 m^2; i.e. the multiple pile option presents three times more blockage potential than the single pile option. The multiple pile option is therefore the (relative) worst case for assessment. Potential impacts of the single pile option are expected to be of a proportionally lesser magnitude and extent.

The realistic worst case description of the jetty for the purposes of the following assessments is:

- For the main jetty: 60 vertical piles, 0.914 m diameter, extending from the water surface to the seabed;
- For the approach jetty: 44 vertical piles, 0.762 m diameter, extending from the water surface to the seabed; and
- For the 8 mooring dolphins: 72 vertical piles (9 piles per dolphin), 1 m diameter, extending from the water surface to the seabed, each dolphin pile group in a square grid configuration with 3 m separation between pile centres.

The locations of these piles, in addition to the existing piles associated with St Michaels Pier and the fast ferry berth, are shown in Figure 36.

The realistic worst case description of the dredged channel during the operational phase is

- A maintained water depth of 10.5 mCD within the footprint shown in Figure 2; and
- The extent and angle of slopes between the dredged footprint and surrounding seabed are also represented.

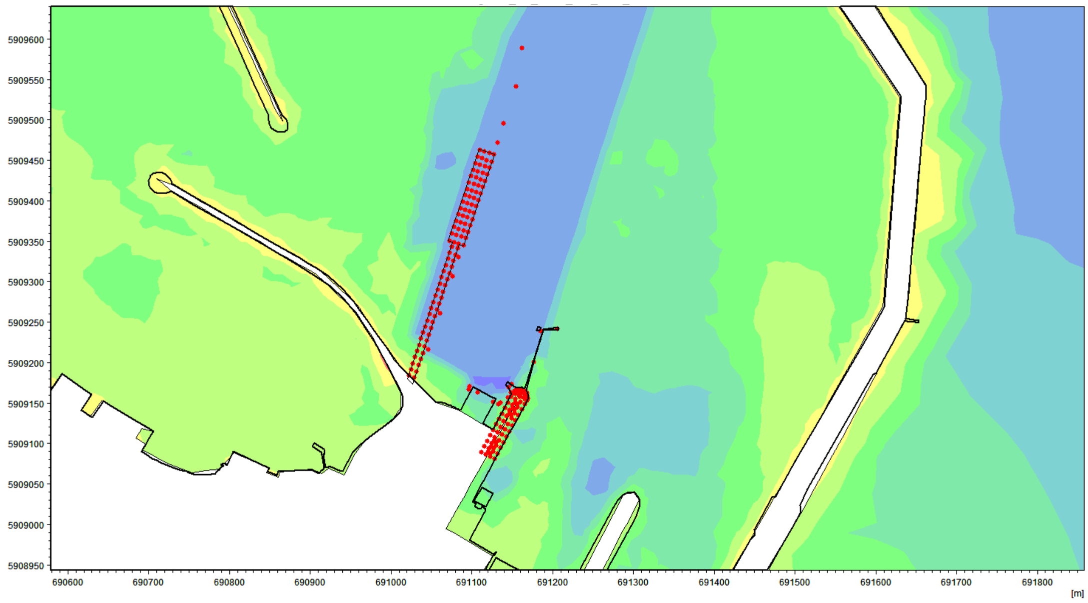


Figure 36. Locations of Existing and New Scheme Piles Simulated in the Tide and Wave Models

4.2 Potential Impact on Water Levels

4.2.1 Conceptual Basis and Impact

It is reasonably assumed that the Scheme has no potential to measurably affect regional tidal processes or the normal exchange of water volume between DLH and Dublin Bay.

Therefore, tidal and non-tidal water levels will not be affected by the presence of the Scheme.

4.3 Potential Impact on Currents

4.3.1 Conceptual Basis

The piles associated with the new cruise terminal jetty have the potential to individually reduce current speed locally. Whilst individual piles of the size being installed are unlikely to result in a measurable impact, the potential combined impact of the array of piles is less certain and so is assessed numerically in this section.

The dredged channel most notably represents an increase in local water depth within its footprint. The cross-sectional area of the harbour entrance will increase but there will be no measurable change in the tidal prism of the harbour. Therefore, the speed of currents through the harbour entrance might be slightly reduced.

Patterns of currents within the harbour or in the vicinity of the approach channel outside of the harbour might potentially change locally in speed or direction in response to the local increase in flow depth and cross section, with a corresponding reduction in friction in these areas.

4.3.2 Approach to the Assessment

The tidal model (described in Appendix A) was used to simulate a 10-day timeseries of tidal conditions, including individual tides of mean spring and mean neap range.

The following development scenarios were simulated:

- A 'Baseline' scenario (without the Scheme and using present day bathymetry);
- A realistic worst case 'Scheme' scenario (with the new piled jetty and dredged channel in place); and
- A 'dredge only' scenario (with only the dredged channel in place).

The results of the Baseline scenario were subtracted from the results of the Scheme scenario to quantify absolute differences in currents (and water levels), as a direct result of the Scheme, throughout the study area and at all timesteps in the simulation period.

The results of the dredge only scenario were subtracted from the results of the Scheme scenario to quantify the relative contribution of the new piled jetty to the absolute differences in currents identified above, throughout the study area and at all timesteps in the simulation period.

Results are presented below for representative example periods during mean spring and mean neap tidal range tides.

4.3.3 Impact of the Piled Jetty

The piles of the cruise terminal jetty and dolphins will have no measurable impact on current speeds (>0.01 m/s) or directions (>5°) at any time or location (other than possibly localised wake effects within a few diameter lengths of individual piles, not resolved by the model).

4.3.4 Impact of the Dredged Channel

The presence of the dredged channel is shown to have a small effect on local patterns of tidal currents in Figure 37 to Figure 43.

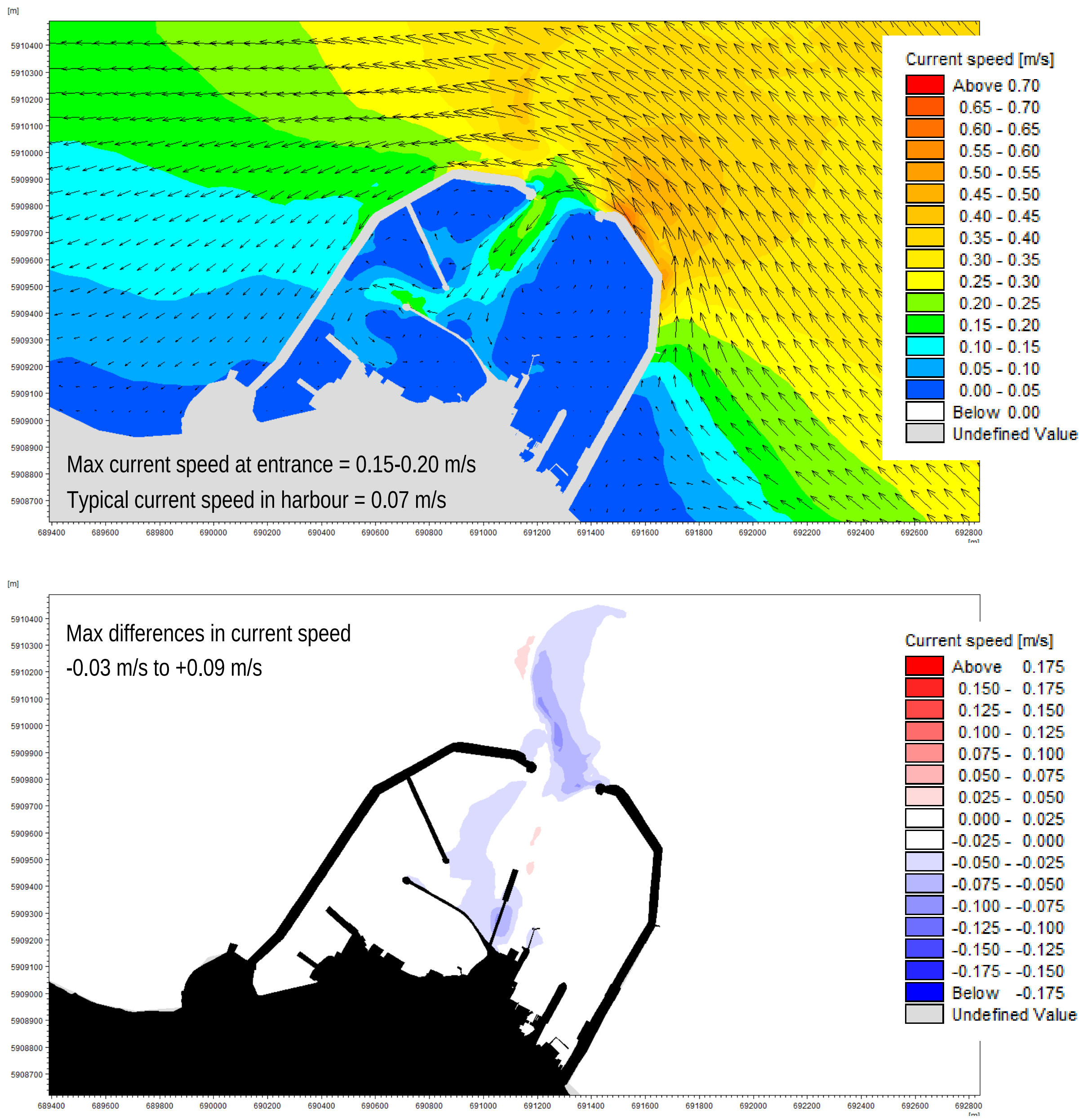


Figure 37. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW-3hr, Peak Flood).

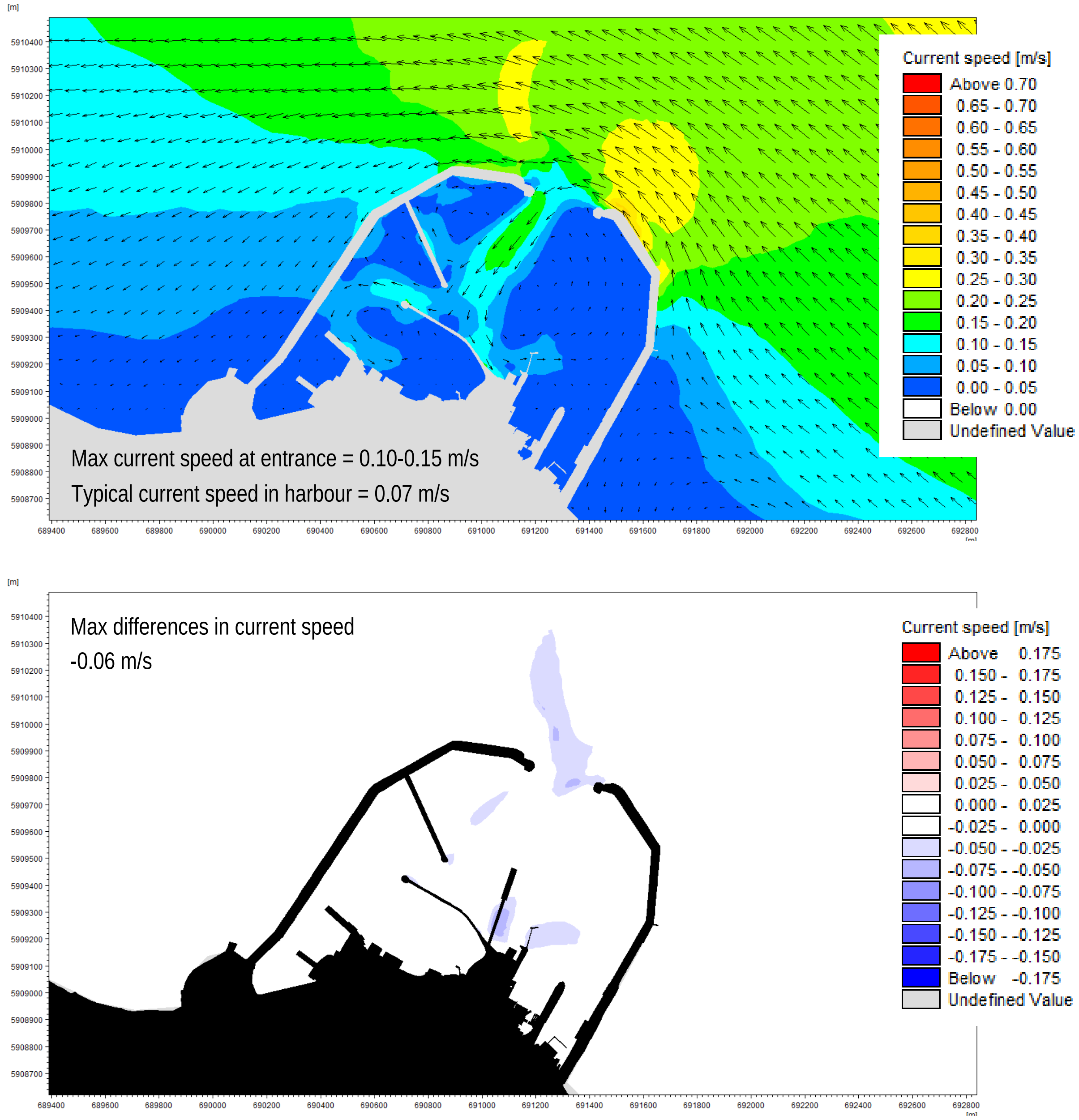
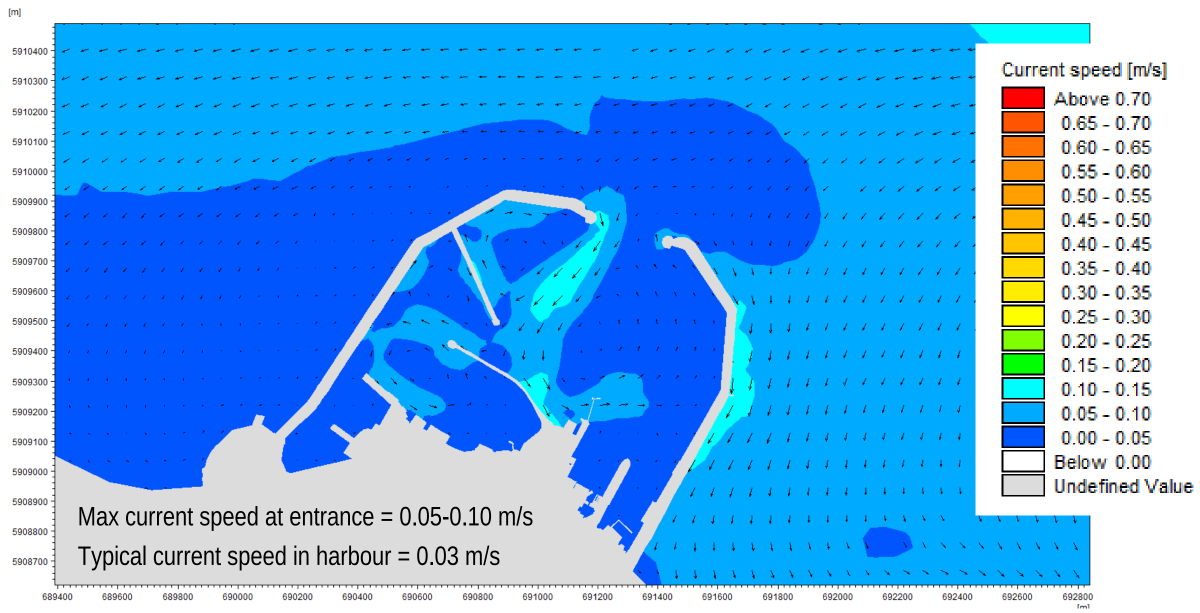


Figure 38. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW-2hr, Flood)



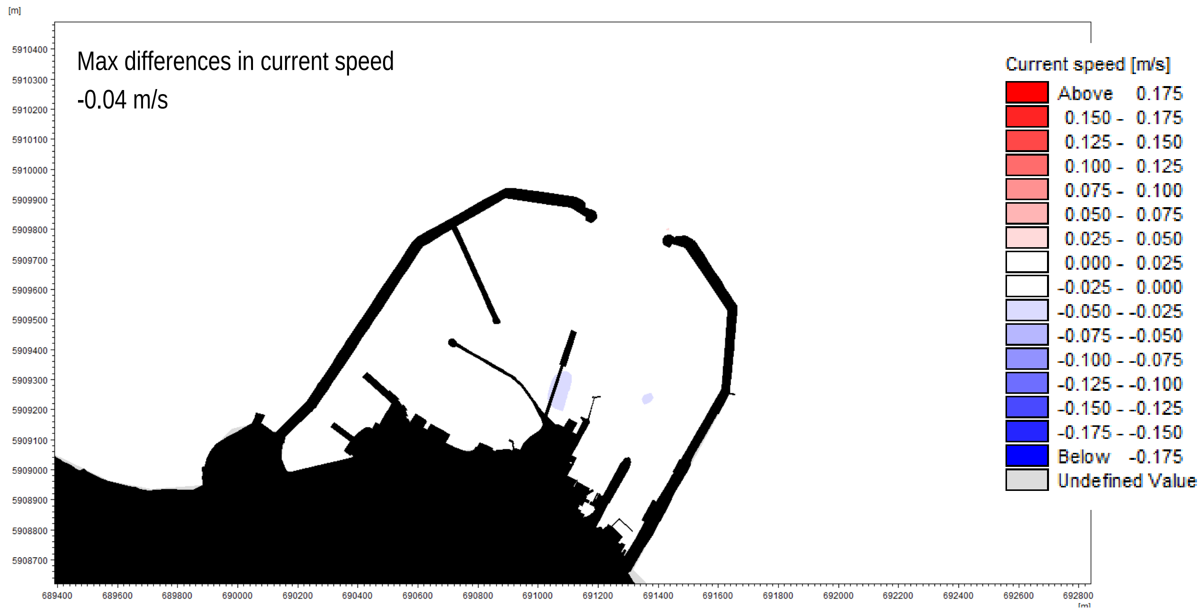


Figure 39. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW-1hrs, Flood)

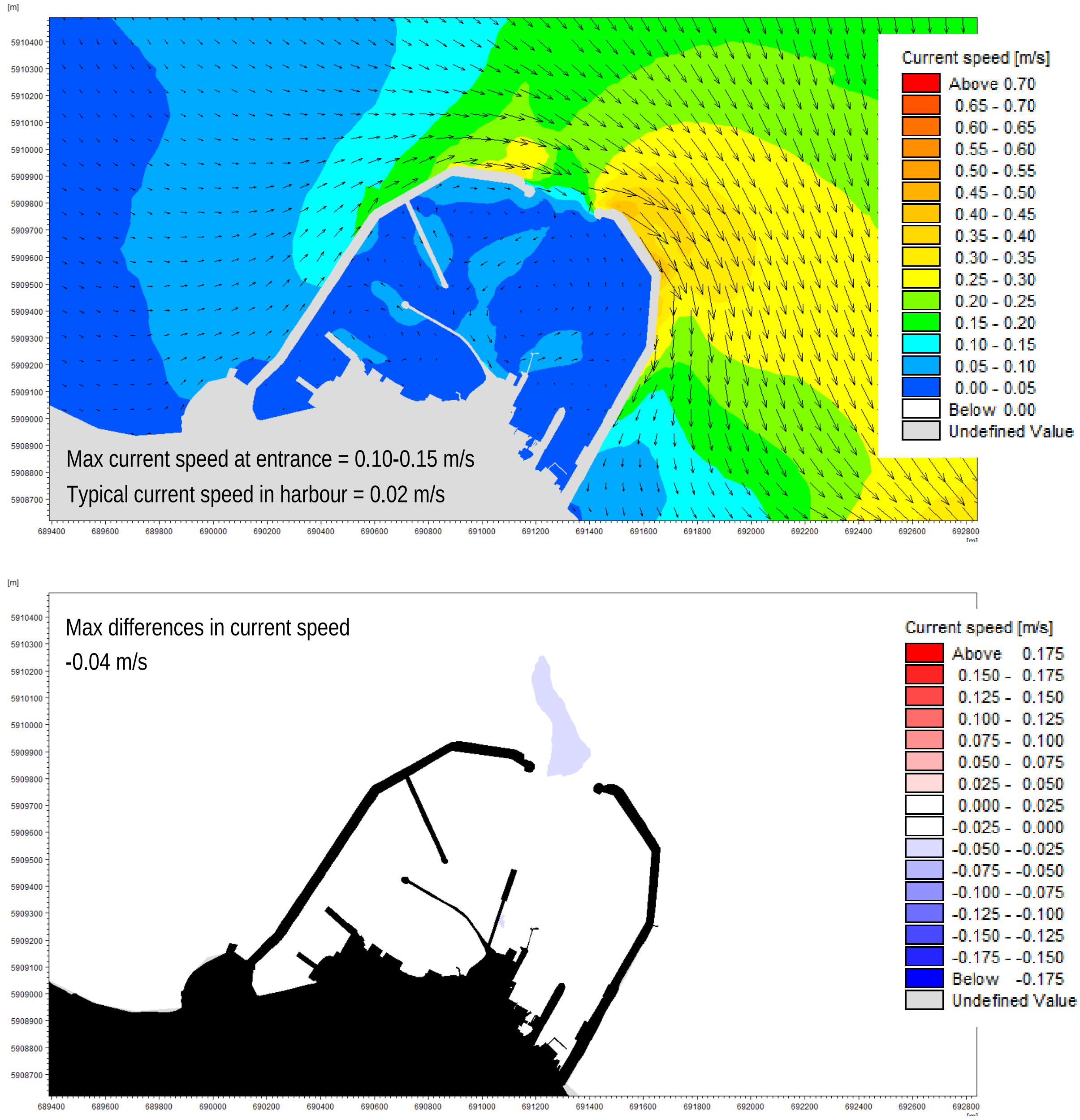


Figure 40. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW Slack)

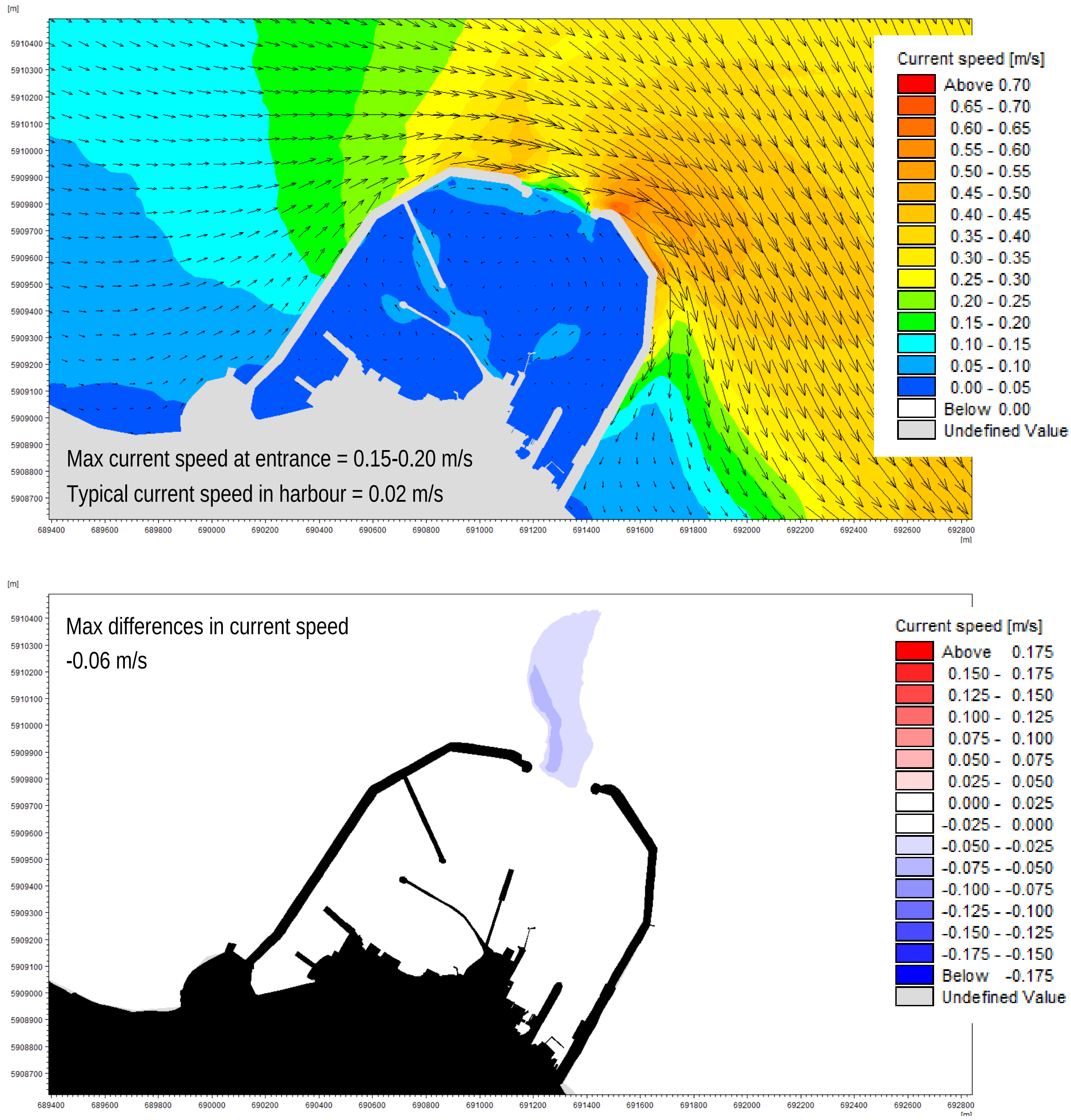


Figure 41. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW+1hrs, Ebb)

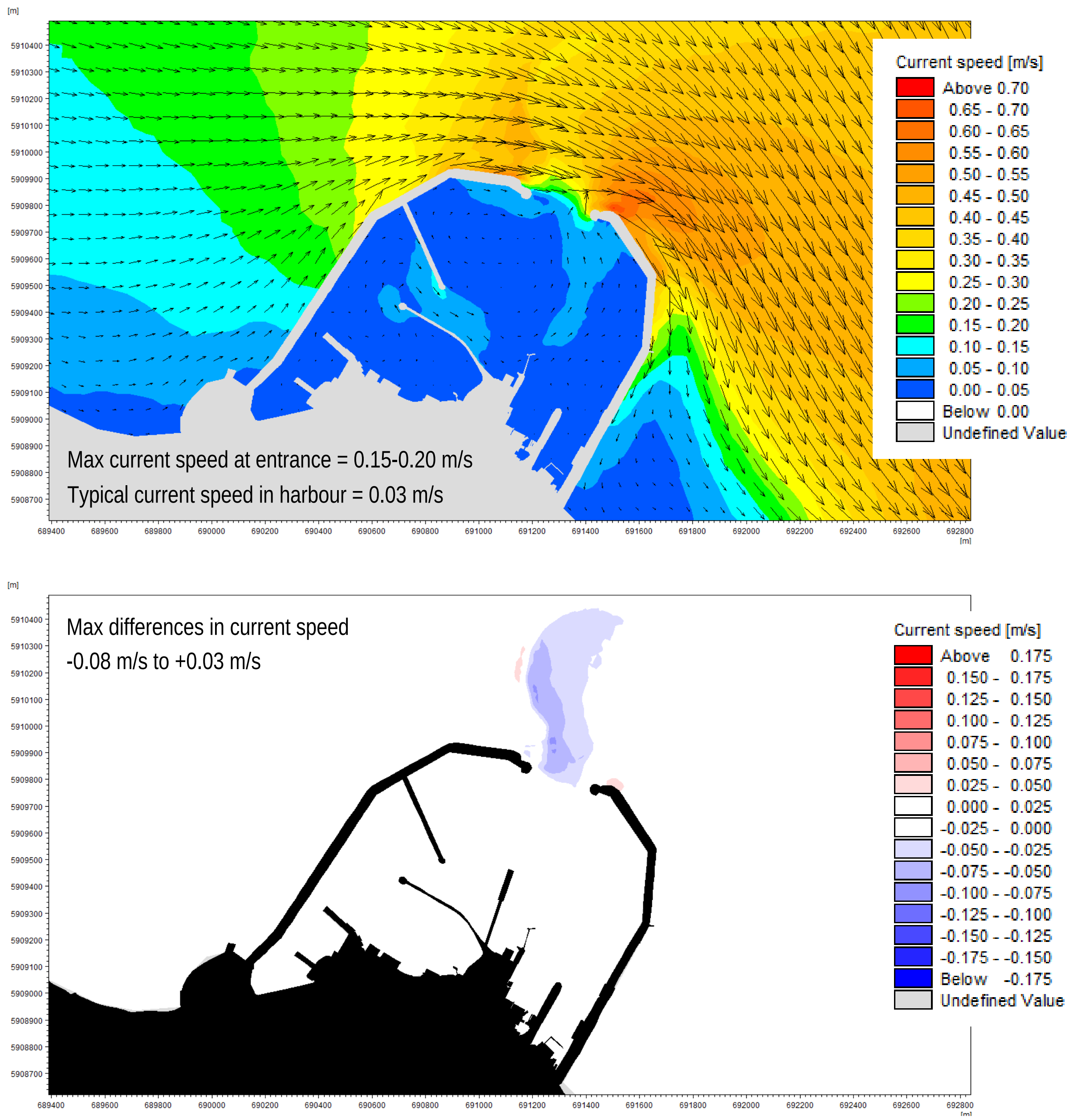


Figure 42. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW+2hrs, Ebb)

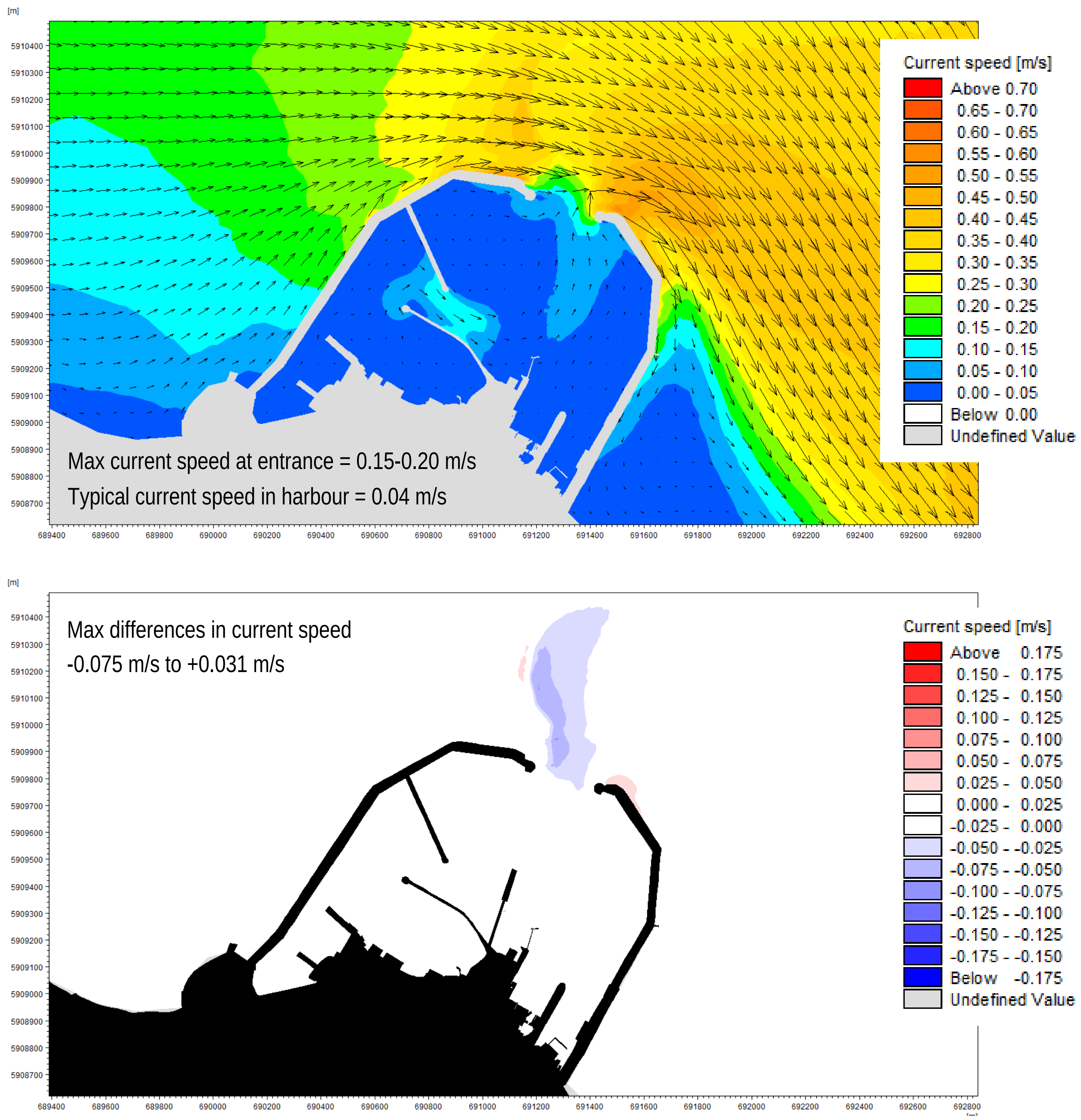


Figure 43. Baseline Tidal Current Speed (Top) and Difference in Current Speed (Bottom) as a Result of the Scheme (Mean Spring Tide, HW+3hrs, Peak Ebb).

The effect is typically a reduction in local flow speed (in the order ~0.03 to 0.1 m/s). The greatest magnitude effects occur within the turning circle, immediately outside of the DLH entrance. The effect is likely caused by the relative increase in water depth, increasing the cross section through which the water may flow.

Effects on neap tides follow a similar pattern but with a smaller absolute magnitude.

The absolute magnitude of the differences is relatively small and causes no significant change to the orientation of flow outside of the DLH entrance, or to the patterns of recirculation within DLH.

4.3.5 Overall Impact of the Scheme

The overall impact of the Scheme on currents is associated almost entirely with the impact of the dredged channel as described above.

4.4 Potential Impact on Waves

4.4.1 Conceptual Basis

The piles associated with the new cruise terminal jetty have the potential to individually block, scatter or reflect incident waves locally. Whilst individual piles of the size being installed are unlikely to result in a measurable impact, the potential combined impact of the array of piles is less certain and so is assessed numerically in this section.

It is, however, noted that measurable reflection or blockage of wave energy is markedly reduced or absent altogether when the wave length is more than approximately 5 times the diameter of the obstruction (Sumer and Fredsøe, 1997). The typical pile diameter used in the Scheme is up to 1 m. In this case, only waves less than 5 m in length (corresponding to a wave period of only ~0.5 to 1 s and therefore likely of relatively small height) would interact measurably with the piles. The largest dolphin monopile diameter being considered is 3 m which may interact with waves up to 15 m in length (wave period ~1.5 to 2 s) although the number of dolphins and the total area of waves potentially affected by them is small. All other waves will simply bypass the piles with little or no modification.

The dredged channel most notably represents an increase in local water depth within its footprint. Conceptually, more wave energy might potentially enter the harbour through a deeper entrance channel. However, water depths surrounding the harbour and approach channel (typically ~6 to 8 mCD) are already less than the target dredge depth and so waves at the entrance will already have been subject to shoaling and other shallow water effects. It is therefore unlikely that the dredged channel will allow a greater total amount of wave energy into the harbour than the baseline case.

The increase in local water depth within the dredged channel footprint and also the change in local seabed slope at its margins might potentially cause different patterns of wave refraction. Modified refraction patterns of waves in the dredged approach channel and turning circle outside of the harbour might potentially increase or decrease the total wave energy entering the harbour. Modified refraction patterns of waves in the dredged channel inside the harbour and harbour entrance might distribute wave energy differently within the harbour, potentially increasing or decreasing local wave exposure. The particular orientation and linear nature of the dredged channel sections, in addition to the directional nature of the predominant wave climate in Dublin Bay, means that such effects caused by the Scheme are likely to be directionally variable.

4.4.2 Approach to the Assessment

The wave model (described in Appendix A) was used to simulate a range of representative wave and corresponding wind conditions within Dublin Bay. The full range of conditions tested included 288 discrete wave/wind/water level scenarios:

- Wind and wave coming directions from 0 to 350°N in 10° increments.
- Wave parameters (Hs and Tp) and associated wind speeds representative of the 10:1, 1:1, 1:10 and 1:50 year return period conditions for each coming direction, as established at the offshore edge of the study area (see Appendix A and Appendix B); and
- All wave conditions were tested using representative low and high water levels (MLWS and MHWS, respectively).

The following development scenarios were simulated for all wave/wind/water level scenarios:

- A 'Baseline' scenario (without the Scheme and using present day bathymetry);
- A realistic worst case 'Scheme' scenario (with the new piled jetty and dredged channel in place); and
- A 'dredge only' scenario (with only the dredged channel in place).

The results of the Baseline scenario were subtracted from the results of the Scheme scenario to quantify absolute differences in water level, as a direct result of the Scheme, throughout the study area and for all conditions tested.

The results of the dredge only scenario were subtracted from the results of the Scheme scenario to quantify the relative contribution of the new piled jetty to the absolute differences in water level identified above, throughout the study area and for all conditions tested.

The results are summarised below including examples of frequently occurring conditions, extreme conditions and conditions resulting in the greatest absolute impact.

4.4.3 Impact of the Piled Jetty

The piles of the cruise terminal jetty and dolphins will have no measurable impact on wave height (>0.05 m), period (>0.1 s) or direction (>5°) within the range of conditions tested at any time or location (other than possibly localised wake effects affecting only relatively small waves within a few pile-diameter lengths of individual piles, not resolved by the model).

4.4.4 Impact of the Dredged Channel

The modified water depth in the dredged channel affects patterns of wave refraction both inside and outside of the harbour, but only under certain conditions (certain offshore wave coming directions). Considering the results of all wave/wind/water level conditions simulated, the magnitude of change in wave height (the primary effect) is directionally dependant as follows:

- No measurable differences >±0.05 m in local wave height (i.e. no impacts) are predicted to occur either inside or outside of the harbour when waves and/or winds come from the fetch limited sectors within Dublin Bay (140°N clockwise through 0°N at the harbour entrance);
- Measurable differences in local wave height (>±0.05 m under 10:1 to 1:50yr conditions) only occur when waves come from 0°N clockwise through 140°N at the harbour entrance;
- Relatively larger differences (>±0.1 m under 10:1 to 1:50yr conditions) occur when waves come from 65°N through 125°N at the harbour entrance; and
- Peak differences for all return periods occur when waves come from 80°N through 90°N at the harbour entrance.

Figures showing the spatial distribution of the effect of the Scheme on wave height are provided on the following pages for the example scenarios listed in Table 4.

Table 4. Wave Scenarios Presented in More Detail

Scenario Number	Wave/Wind Return Period (years)	Wind and Wave Coming Direction Offshore / Wave Coming Direction at DLH (°N)	Tidal Water Level	Description
S1	10:1	60 / 85	MHWS	Worst direction for impacts: typical storm wave condition
S2			MLWS	
S3	1:1	60 / 85	MHWS	Worst direction for impacts: severe wave condition
S4			MLWS	
S5	1:50	60 / 85	MHWS	Worst direction for impacts: extreme wave condition
S6			MLWS	
S7	1:50	240 / 230	MHWS	Predominant wind coming direction at Dublin Airport
S8			MLWS	
S9	1:50	170 / 120	MHWS	Predominant wave coming direction offshore and secondary predominant wind coming direction at Dublin Airport
S10			MLWS	

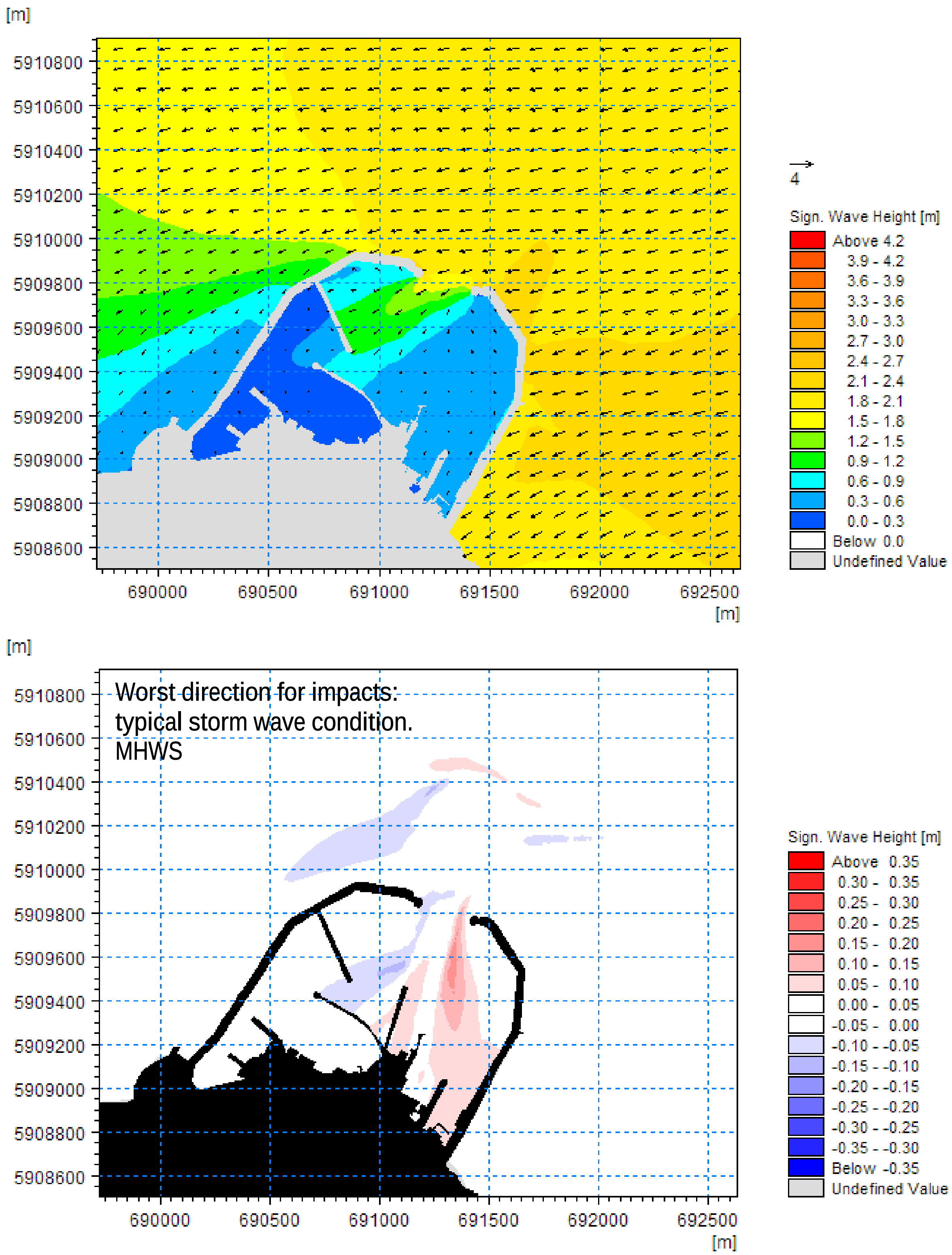


Figure 44. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S1 [10:1, 60/85, MHWS])

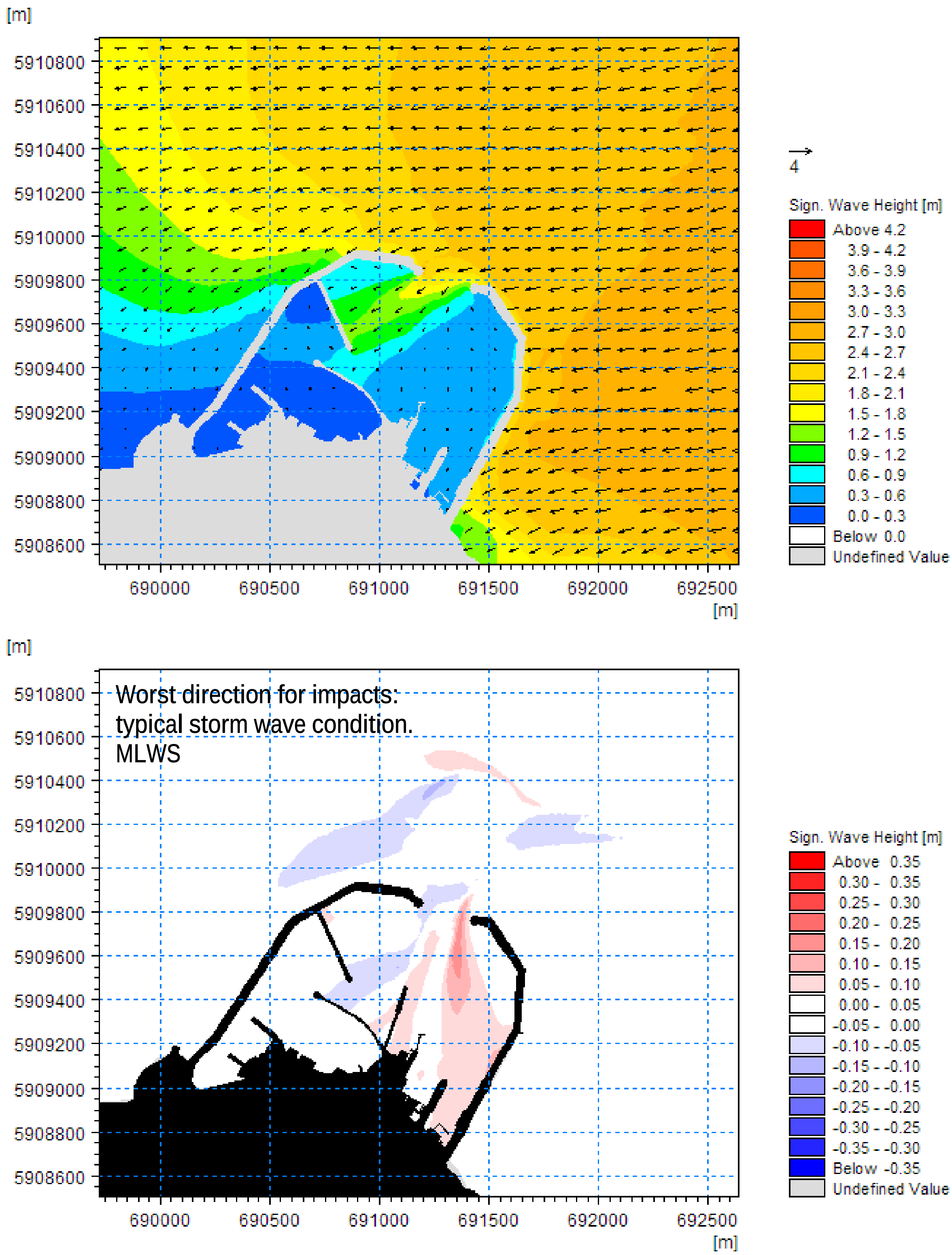


Figure 45. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S2 [10:1, 60/85, MLWS])

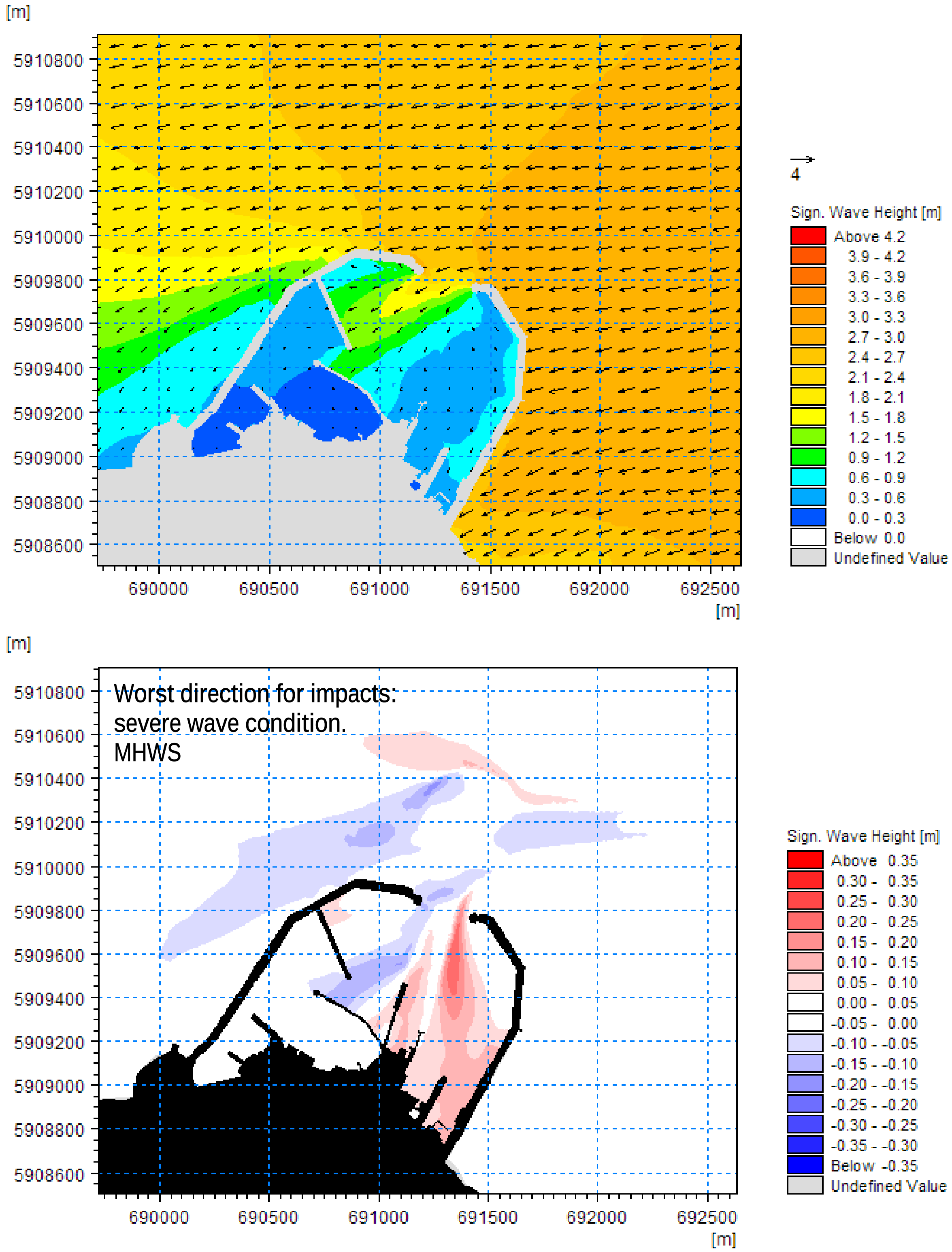
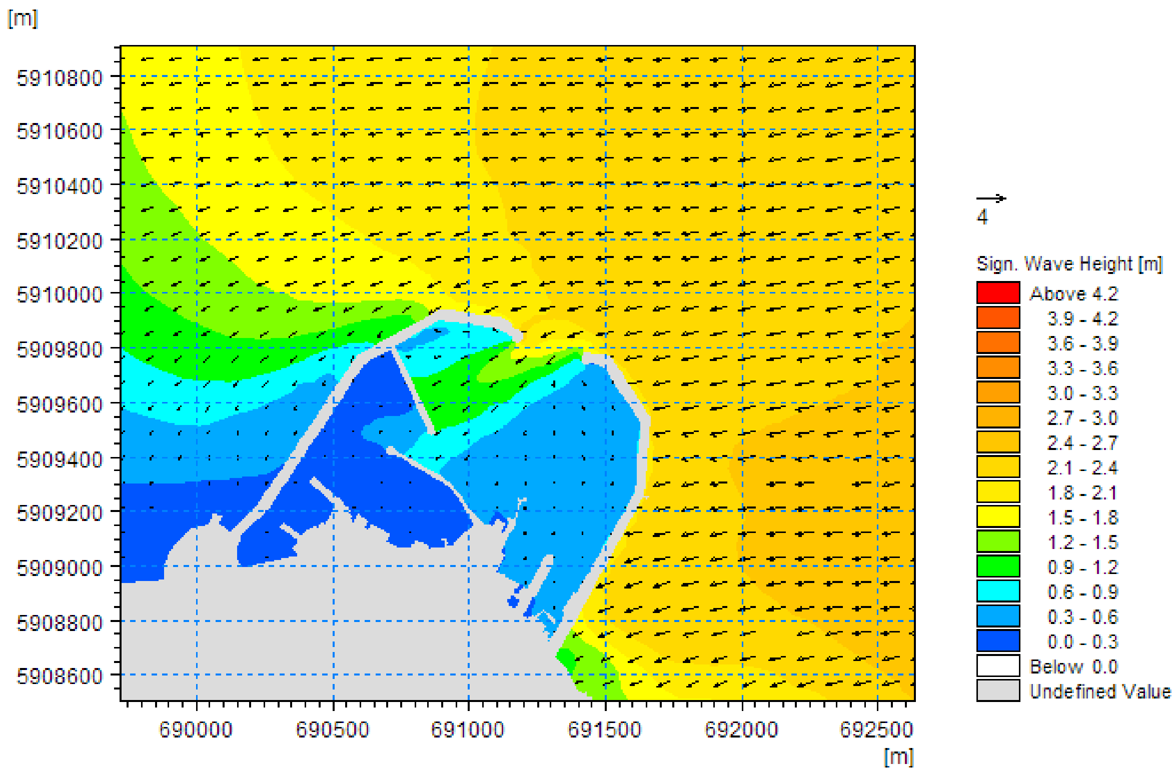


Figure 46. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S3 [1:1, 60/85, MHWS])



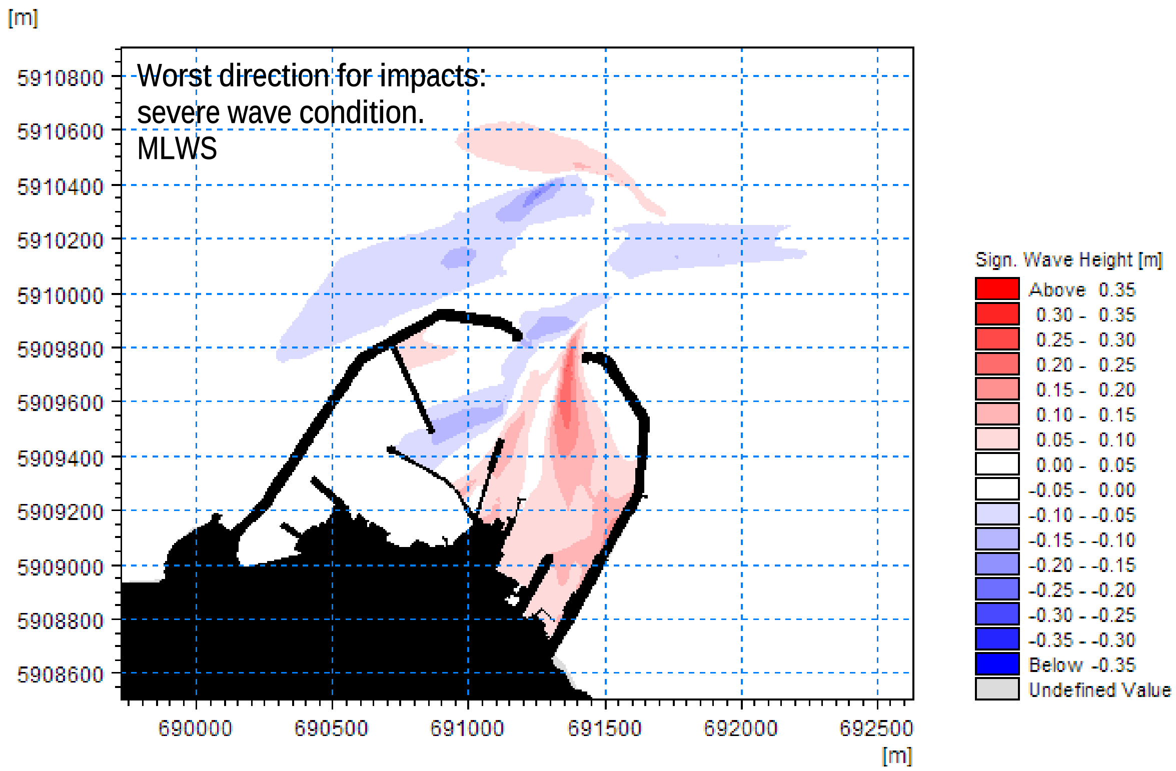


Figure 47. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S4 [1:1, 60/85, MLWS])

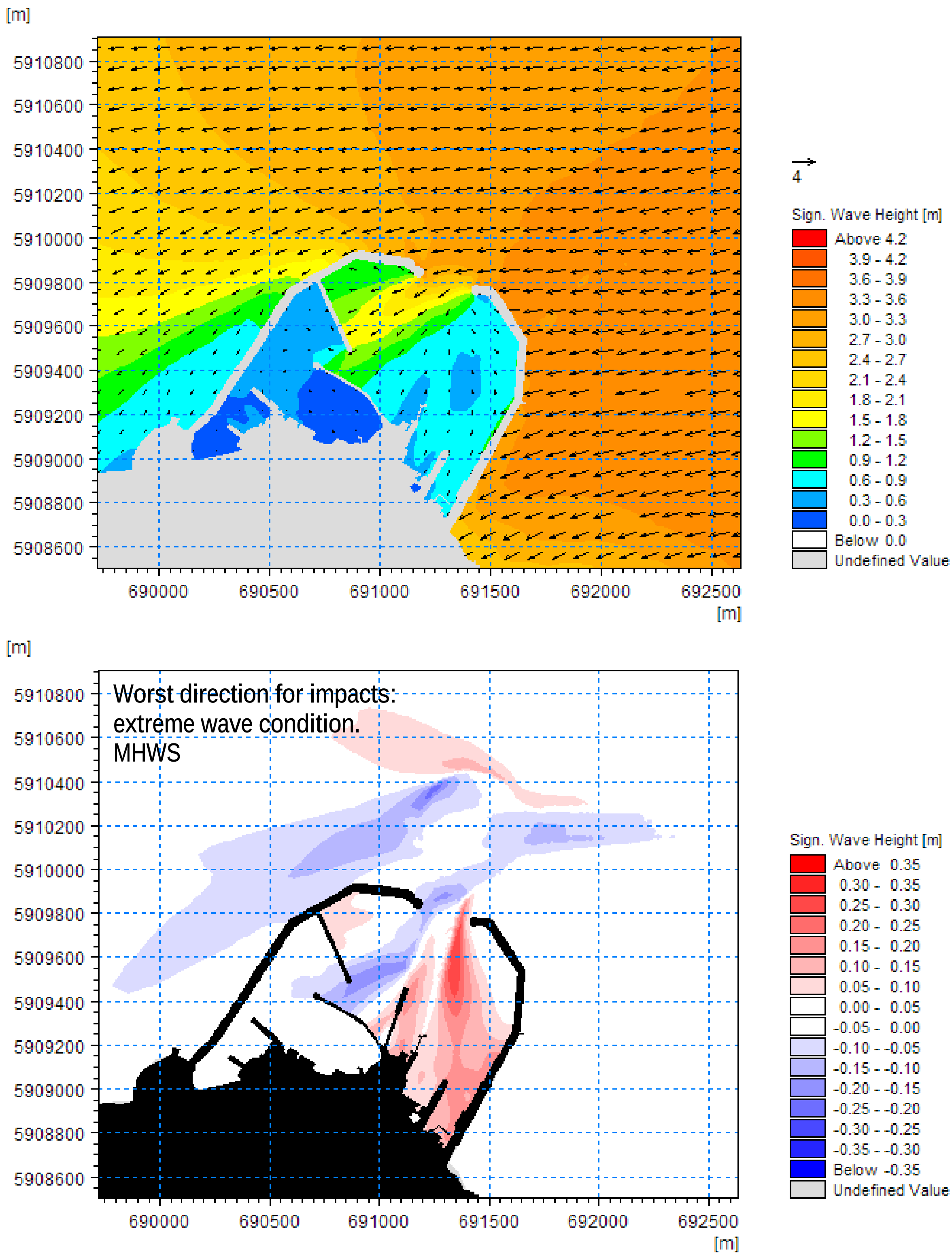


Figure 48. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S5 [1:50, 60/85, MHWS])

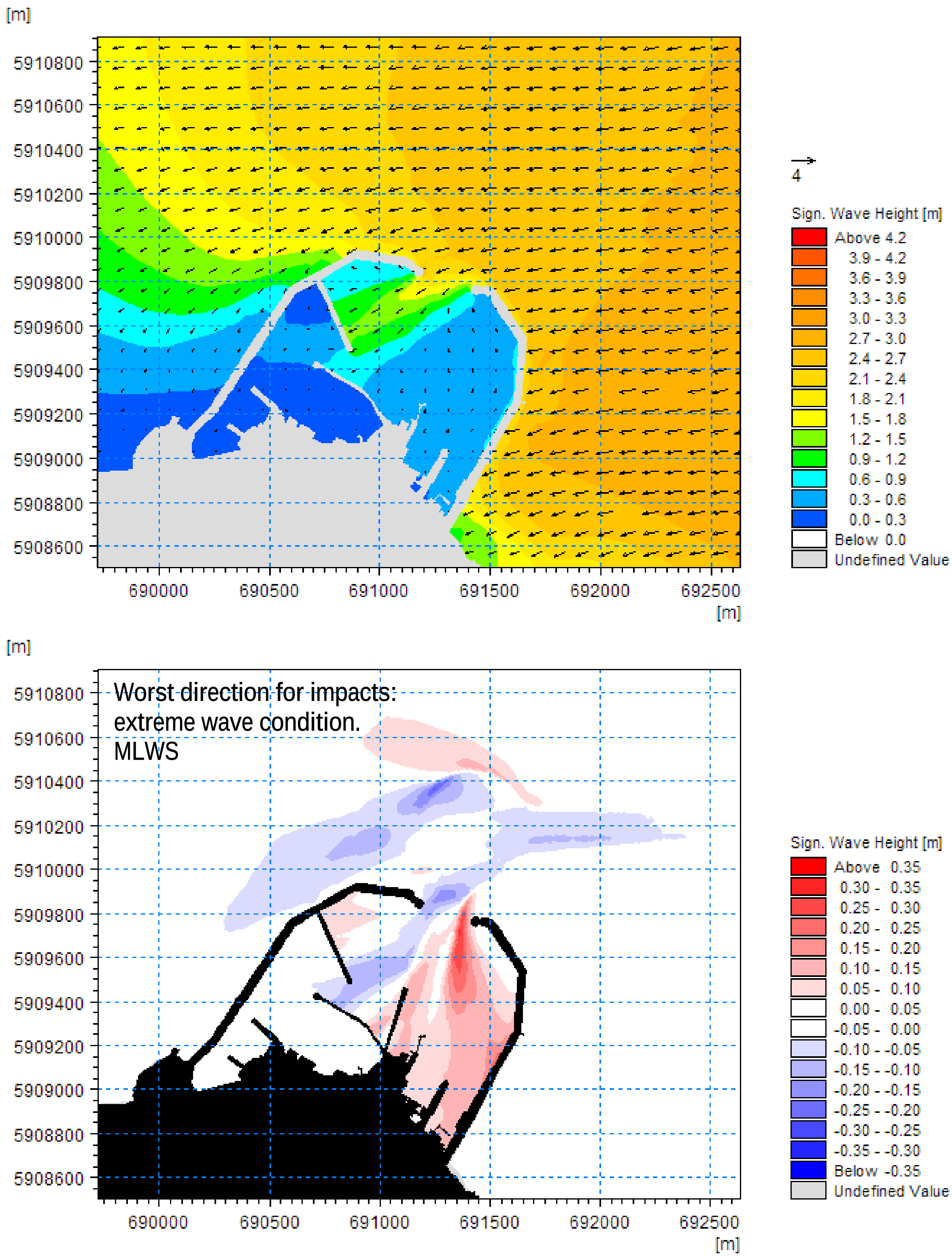


Figure 49. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S6 [1:50, 60/85, MLWS])

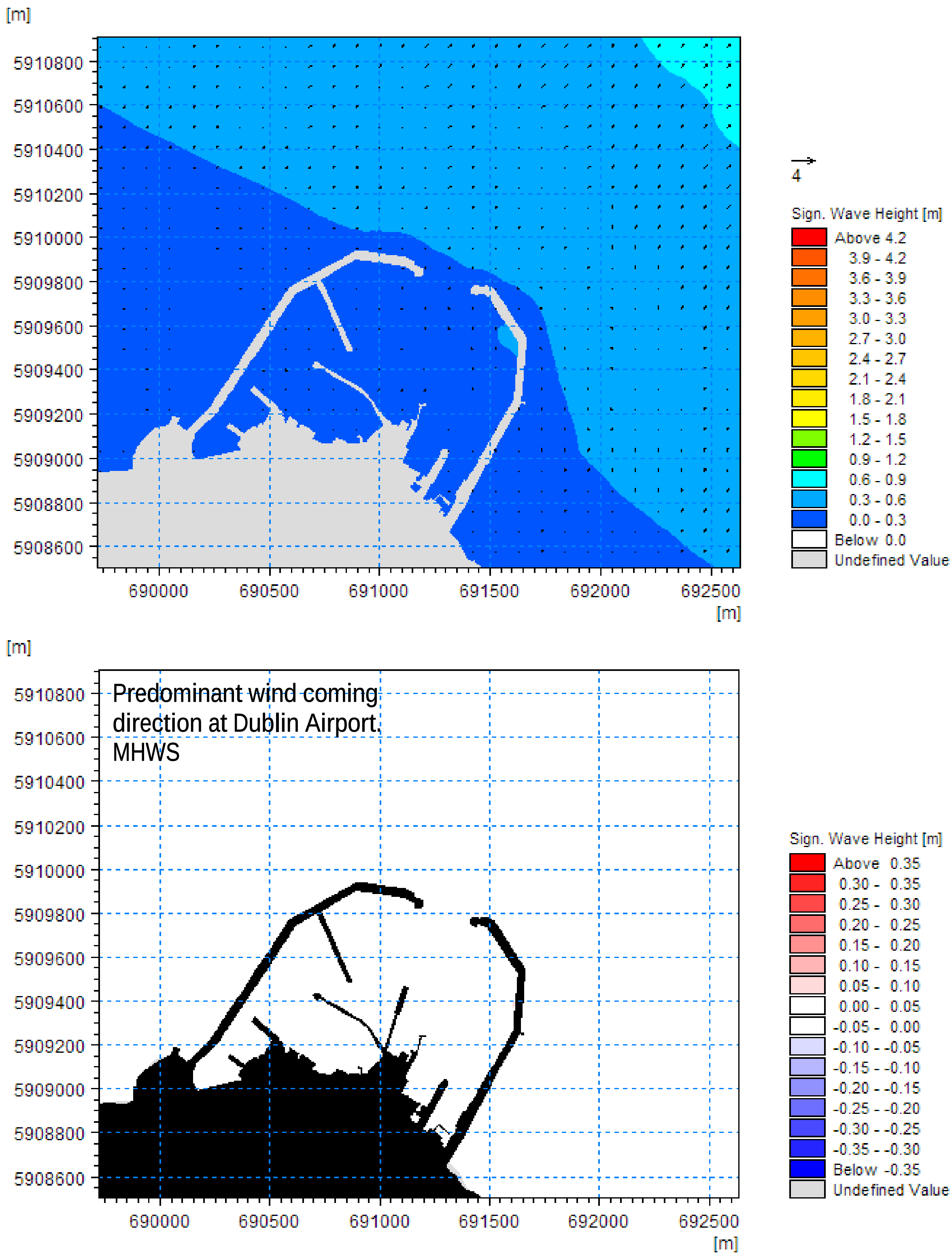


Figure 50. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S7 [1:50, 240/230, MHWS])

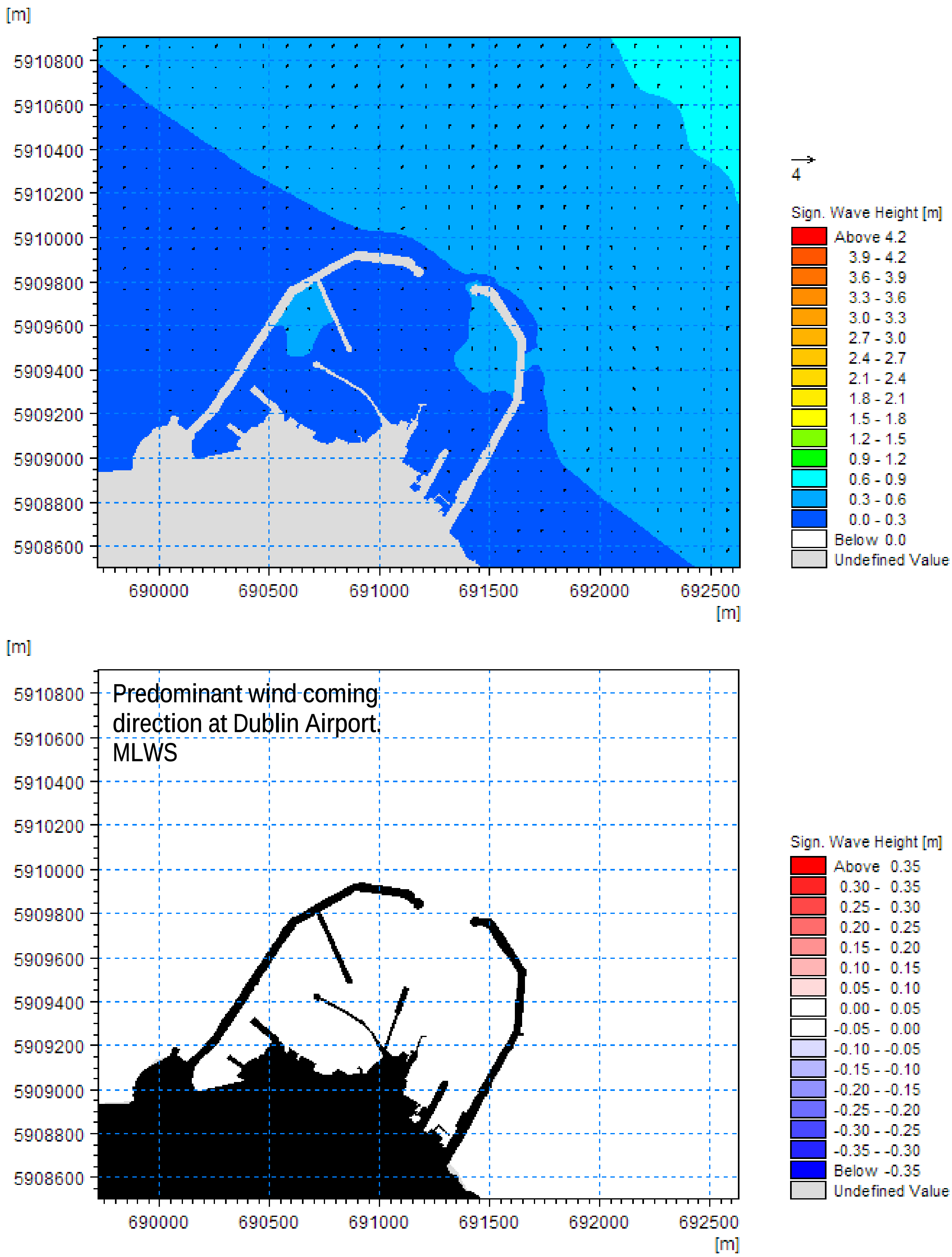
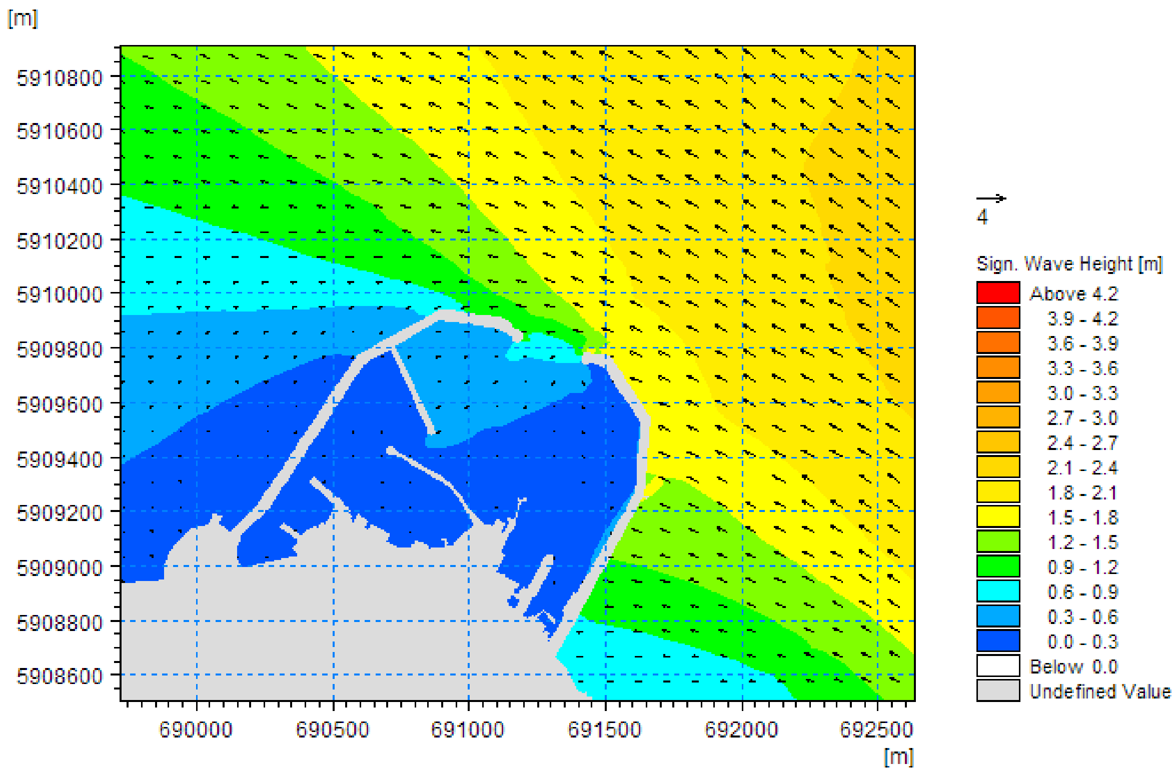


Figure 51. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S8 [1:50, 240/230, MLWS])



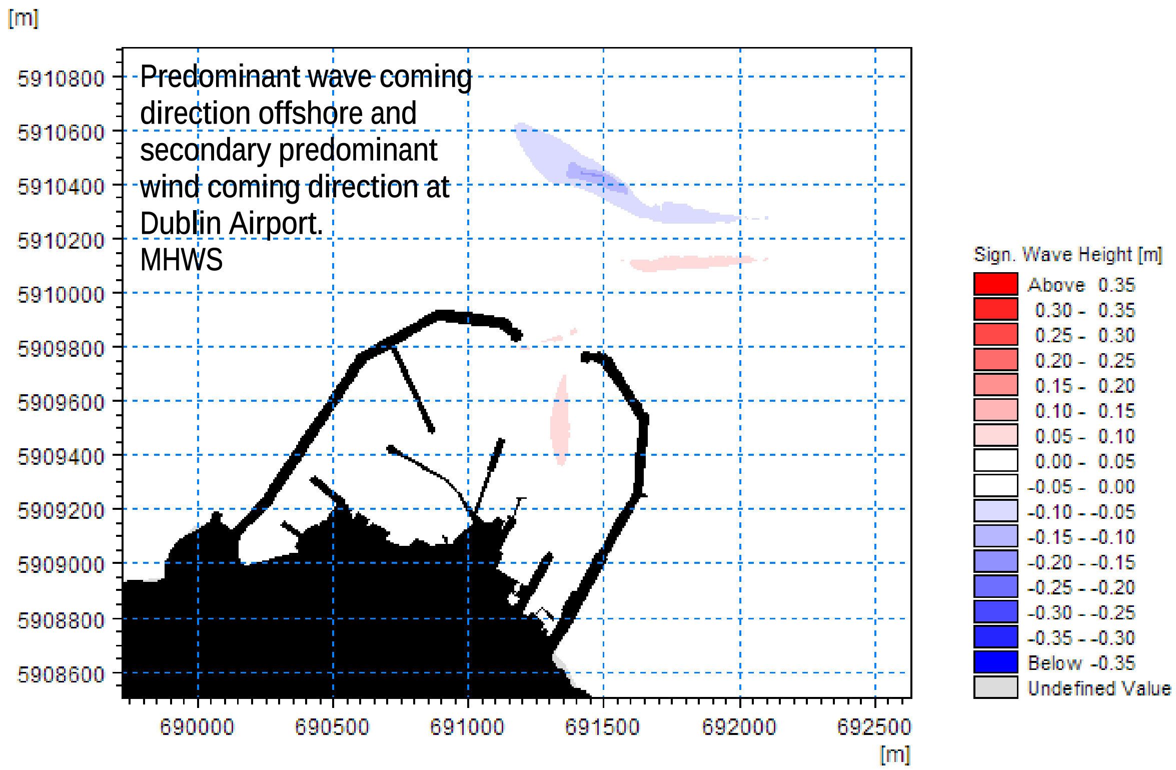
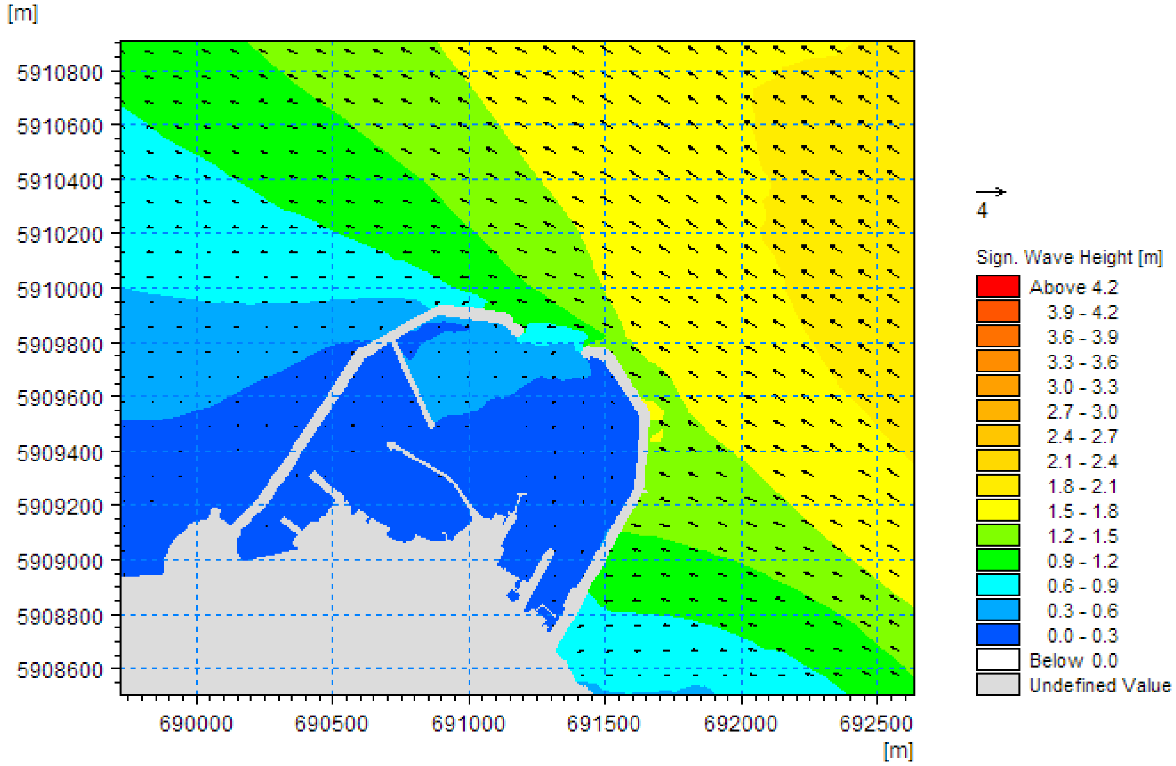


Figure 52. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S9 [1:50, 170/120, MHWS])



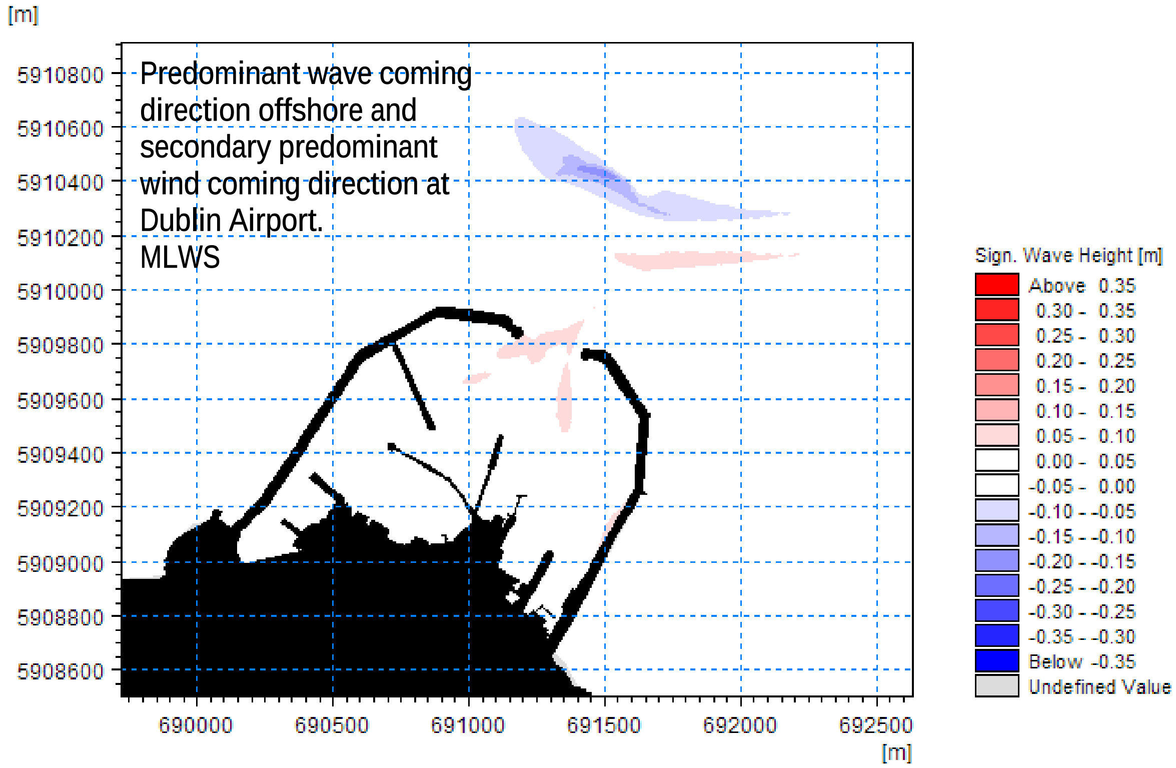


Figure 53. Baseline Significant Wave Height (Top) and Difference in Significant Wave Height (Bottom) as a Result of the Scheme (Scenario S10 [1:50, 170/120, MLWS])

As shown in the preceding figures, when measurable differences are apparent, the following general patterns of change are consistently observed:

- A reduction in wave height and possibly also steepness inside of the harbour between the main entrance and the entrance to the inner harbour, to the west of the dredged channel;
- A reduction in wave height and possibly also steepness outside of the harbour within the turning circle and dredged approach channel;
- An increase in wave height and possibly also steepness inside of the harbour in the eastern part of the harbour and along the dredged channel to the new jetty and existing Ro-Ro berth;
- An increase in wave height and possibly also steepness outside of the harbour to the north of the turning circle;
- Wave heights in the north western harbour and the inner harbour are not measurably affected (>±0.05 m) under any of the wave conditions tested;
- The magnitude of the difference in wave height varies with the nearshore wave coming direction, but the pattern (of ± change) and the spatial distribution of the impact remains broadly similar;
- Impacts on wave period in all locations and under all wave conditions tested are negligible (<±0.1 s); and
- Impacts on wave direction relate to refraction caused by the change in bathymetry in the footprint of the dredged channel. Absolute differences in mean wave coming direction locally are however relatively minor (typically <±1°, maximum ±4°) in all locations and under all wave conditions tested.

4.4.5 Overall Impact of the Scheme

The overall impact of the Scheme on waves is associated almost entirely with the impact of the dredged channel (see Section 4.4.4).

4.5 Potential Impact on Sediment Transport and Deposition

4.5.1 Conceptual Basis

Baseline patterns of sediment transport, including erosion, transportation and deposition are described in Section 2.7. These patterns of sediment transport are the combined and net result of the baseline wave and current regimes, local water depths and the nature of the seabed sediments (described in Sections 2.5, 2.6, 2.3 and 2.7 respectively). The relative contribution of waves and currents to the rate and direction of sediment transport varies greatly in the baseline, both spatially and temporally in relation the episodic nature of storm events and to tidal (and non-tidal) current behaviour.

It is noted that waves in intermediate water depths (such as in DLH) act to stir and mobilise seabed sediments *in situ* but do not tend to cause measurable directional transport. The transport of mobilised sediments (rate and direction) is rather controlled by the local speed and direction of currents. The rate of instantaneous sediment transport can be increased on occasion by the additional action of waves that are sufficiently large to have an influence at the seabed.

4.5.2 Approach to the Assessment

Long term patterns of net sediment transport cannot be predicted with sufficient certainty to assess the potential impact directly. This assessment instead considers the potential impact of the Scheme on the variables controlling sediment transport (i.e. currents, waves, water depth and sediment type) in order to assess the extent to which the range of baseline variability might be altered.

4.5.3 Impact of the Piled Jetty

The piles of the cruise terminal jetty and dolphins will have no measurable impact on tidal current speed or direction (Section 4.3.3), or wave height, period or direction (Section 4.4.3). Therefore, the piles will also have no measureable impact on patterns of sediment transport within the harbour or elsewhere in the study area.

Localised wake effects (potentially also in conjunction with the wash from large vessels manoeuvring within the harbour) may result in limited local scouring of seabed sediments from around the base of individual piles. The potential for scouring of the new jetty piles is the same as the present day potential for the piles already installed elsewhere in the harbour and so does not present a new type of impact.

4.5.4 Impact of the Dredged Channel

The dredged channel will have little or no measurable effect on patterns of tidal current speed and or direction (Section 4.3.4), and only localised effects on wave height (but not wave period or direction) under certain regional wave conditions (Section 4.4.4).

When and where wave heights are potentially locally increased by the Scheme in and around DLH, the potential for sediment resuspension and therefore the rate of sediment transport may be increased relative to the baseline condition for the duration of the event. Conversely, a reduction in wave height may reduce the potential for sediment resuspension and therefore the rate of sediment transport relative to the baseline condition for the duration of the event.

Although wave heights may be relatively increased or decreased locally as a result of the Scheme, the resulting absolute wave heights remain within the range of normally expected wave conditions within the harbour. As such, the general potential for resuspension of sediments by waves locally is not considered to be measurably changed from baseline conditions. The relative potential for fine sediment accretion or erosion may vary slightly in a few localised areas corresponding to those of greatest impact on wave height.

Because patterns of tidal currents will not change from the baseline condition, the overall rate and direction of potential sediment transport are not expected to measurably change as a result of the Scheme.

The distribution of sediments (the position and thickness of accumulations of silty material) within the harbour will continue to vary naturally due to baseline processes. Any contribution of the Scheme during the operational phase will be relatively small.

More direct impacts of sediment deposition associated with dredging during construction of the scheme are considered in Section 3.3.

4.5.5 Overall Impact of the Scheme

The overall impact of the Scheme on sediment transport is mainly associated with the impact of the dredged channel on local wave height (see Section 4.5.4). Localised scour effects may occur in relation to the piles.

5. Summary of Impacts

5.1 Summary of Potential Scheme Impacts (Construction Phase)

5.1.1 Potential Impact on Water Quality (Suspended Sediment Concentration)

Impact of dredging within Dun Laoghaire Harbour:

- Dredging of the silty or sandy material within DLH will result in a localised and temporary increase in SSC at the location of the dredger, whilst dredging is occurring, in the order of hundreds or thousands of mg/l;
- Resuspended sands will be redeposited (no longer contributing to SSC) in the order of minutes;
- Silts will be redeposited in the order of a few hours from the end of dredging;
- Fines may persist in suspension in the order of hours to a day within DLH, leading to an increase in SSC throughout the harbour (typically <5 mg/l but locally 25 to 200 mg/l); and
- Fine material in suspension at a similar concentration may also exit DLH towards the end of the ebb tide and will then be advected north-west towards Dublin Bay, but will rapidly disperse (within ~2 km) to negligible levels <5 mg/l.

Impact of dredging outside of Dun Laoghaire Harbour:

- Dredging of the sandy material outside of DLH will result in a localised and temporary increase in SSC at the location of the dredger, whilst dredging is occurring, in the order of hundreds or thousands of mg/l;
- Resuspended sands will be redeposited (no longer contributing to SSC) in the order of minutes; and
- Any plumes are therefore unlikely to advect more than a few tens of meters from the dredger and so will not affect SSC within DLH.

Impact of Spoil Disposal at Burford Bank Spoil Ground:

- Disposal of silty or sandy material at the BBSG will result in a localised and temporary increase in SSC at the location of the dredger, whilst the release is occurring, in the order of hundreds or thousands of mg/l;
- The majority of the sediment load (~90% of the mass) will likely fall directly to the seabed as a coherent unit or gravity flow, without entering into suspension;
- The remaining 10% will enter suspension in the water column or near-bed, either directly, or shed from the main sediment mass;
- Sandy sediments placed in suspension will settle out within 15 to 30 minutes from release;
- Silty sediments placed in suspension will settle out within ~7 to 12 hours from the time of release;

- Fines will likely remain in suspension in the order of days or weeks from the time of release, however, it is expected that the plume will be dispersed to negligible levels of SSC over such time periods; and
- Fine sediment plumes from the BBSG will be carried along the (approximately north-south) tidal axis and are not expected to enter Dublin Bay. Over longer time-scales, any sediment that remains in suspension will be taken gradually north and then offshore, in the direction of residual tidal flow.

5.1.2 Potential Impact on the Seabed (Sediment Deposition)

Impact of dredging within Dun Laoghaire Harbour:

- Resuspended sands will be deposited rapidly, within ~ 10 m of the dredger or dredging footprint. Sediments deposited back into the dredging footprint that are above the target dredge depth will be removed by subsequent dredging;
- Resuspended silts might be transported up to 250 to 500 m from the dredged channel before being deposited with a worst case (maximum) resulting thickness predicted in the order of 10 mm, but typically less;
- Fine sediments are distributed widely throughout the harbour and may also settle to the seabed but the predicted thickness is very small (<1 mm); and
- At least a thin silt or fine sediment veneer is expected to be naturally present throughout most of the harbour. As such, the redeposited sediment would be of a similar type to the surrounding seabed, resulting in no measurable change to the seabed texture or sedimentary characteristics.

Impact of dredging outside of Dun Laoghaire Harbour:

- Resuspended sandy sediments will redeposit to the seabed rapidly (within ~10 m of the release and so mainly within the dredge footprint);
- Any sediment redeposited within the dredged footprint to a level above the target dredged depth would be removed by subsequent dredging. Because of the small spatial scale (10 m), the thickness of sediment deposition outside of the dredged channel footprint cannot be more accurately modelled, but is expected to be reasonably small; and
- The redeposited sediment would be of a similar type to the surrounding seabed, resulting in no measurable change to the seabed texture or sedimentary characteristics.

Impact of spoil disposal at Burford Bank Spoil Ground:

- The actual thickness of sediment accumulation locally within the spoil ground will depend upon the patterns of release made by the dredger; and
- A fully randomised release scenario including the total volumes of silts and sands from the whole dredge indicates up to 80 mm thickness of accumulation (on average) within the spoil ground, ~3 to 10 mm in a secondary area of deposition outside the site along the tidal axis and a wider area of negligible thickness (typically 0.1 to 0.3 mm but locally up to 1 mm) where fines are transported northwards by residual currents before being deposited.

5.2 Summary of Potential Scheme Impacts (Operational Phase)

5.2.1 Potential Impact on Water Levels

Impact of the Scheme:

- It is reasonably assumed that the Scheme has no potential to measurably affect regional tidal processes or the normal exchange of water volume between DLH and Dublin Bay.

5.2.2 Potential Impact on Currents

Impact of the piled jetty:

- The piles of the cruise terminal jetty and dolphins will have no measurable impact on current speeds (>0.01 m/s) or directions (>5°) at any time or location (other than possibly localised wake effects within a few diameter lengths of individual piles, not resolved by the model).

Impact of the dredged channel:

- The effect is typically a reduction in local flow speed (in the order ~0.03 to 0.1 m/s). The greatest magnitude effects occur within the turning circle, immediately outside of the DLH entrance. The effect is likely caused by the relative increase in water depth, increasing the cross section through which the water may flow; and
- The absolute magnitude of the differences is relatively small and causes no significant change to the orientation of flow outside of the DLH entrance, or to the patterns of recirculation within DLH.

5.2.3 Potential Impact on Waves

Impact of the piled jetty:

- The piles of the cruise terminal jetty and dolphins will have no measurable impact on wave height (>0.05 m), period (>0.1 s) or direction (>5°) within the range of conditions tested at any time or location (other than possibly localised wake effects affecting only relatively small waves within a few pile-diameter lengths of individual piles, not resolved by the model).

Impact of the dredged channel:

- The modified water depth in the dredged channel affects patterns of wave refraction both inside and outside of the harbour, but only under certain conditions (certain offshore wave coming directions);
- No measurable differences >±0.05 m in local wave height (i.e. no impacts) are predicted to occur either inside or outside of the harbour when waves and/or winds come from the fetch limited sectors within Dublin Bay (140°N clockwise through 0°N at the harbour entrance);

- Measurable differences in local wave height (>±0.05 m under 0.1 to 50yr conditions) only occur when waves come from 0°N clockwise through 140°N at the harbour entrance;
- Relatively larger differences (>±0.1 m under 0.1 to 50yr conditions) occur when waves come from 65°N through 125°N at the harbour entrance;
- Peak differences for all return periods occur when waves come from 80°N through 90°N at the harbour entrance;
- A reduction in wave height and possibly also steepness inside of the harbour between the main entrance and the entrance to the inner harbour, to the west of the dredged channel;
- A reduction in wave height and possibly also steepness outside of the harbour within the turning circle and dredged approach channel;
- An increase in wave height and possibly also steepness inside of the harbour in the eastern part of the harbour and along the dredged channel to the new jetty and existing Ro-Ro berth;
- An increase in wave height and possibly also steepness outside of the harbour to the north of the turning circle;
- Wave heights in the north western harbour and the inner harbour are not measurably affected (>±0.05 m) under any of the wave conditions tested;
- Impacts on wave period in all locations and under all wave conditions tested are negligible (<±0.1 s); and
- Impacts on wave direction relate to refraction caused by the change in bathymetry in the footprint of the dredged channel. Absolute differences in mean wave coming direction locally are however relatively minor (typically <±1°, maximum ±4°) in all locations and under all wave conditions tested.

5.2.4 Potential Impact on Sediment Transport and Deposition

Impact of the piled jetty:

- The piles of the cruise terminal jetty and dolphins will have no measurable impact on patterns of sediment transport within the harbour or elsewhere in the study area; and
- Localised wake effects (potentially also in conjunction with the wash from large vessels manoeuvring within the harbour) may result in limited local scouring of seabed sediments from around the base of individual piles. The potential for scouring of the new jetty piles is the same as the present day potential for the piles already installed elsewhere in the harbour and so does not present a new type of impact.

Impact of the dredged channel:

- Localised long term rates of erosion and accumulation, locally affecting the nature or thickness of seabed sediments, may vary slightly in those areas affected by impacts on wave height; and
- The distribution of sediments (the position and thickness of accumulations of silty material) within the harbour will also continue to vary naturally due to baseline processes. Any contribution of the Scheme during the operational phase will be relatively small.

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Appendices

Appendix A

Model Design, Setup, Calibration and Validation

A. Model Design, Setup, Calibration and Validation

A set of numerical models were developed for this project using the 'MIKE by DHI' software suite, developed by the Danish Hydraulic Institute (DHI). A two-dimensional (2D) depth-averaged, modelling approach utilising a flexible mesh was undertaken for this study, using the following modules:

- Tidal model: MIKE 21 Hydrodynamic (FM-HD);
- Wave model: MIKE 21 Spectral Waves (SW); and
- Plume dispersion model: MIKE 21 Particle Tracking (PT).

The tide and wave models are used to provide a description of the baseline environment within the study area. The tidal model also provides the flow field information that underpins the plume dispersion model. All three models are used in the assessment of potential scheme impacts.

The MIKE modelling suite undergoes continuous development with updates regularly released by DHI. This project uses the current version available at the time of the project commencement (MIKE 2014; Released December 2013).

A description of the model mesh design and data inputs is provided in Section A.1.

The tidal model is typically used in the present study to simulate a time series of tidal water levels and currents. The ability of the model to realistically simulate conditions in a time series mode that are representative of those observed across the study area is therefore important and so this model is subject to calibration and validation. A description of the model design and setup is provided in Section A.2.

The wave model is typically used in the present study to transform discrete wave conditions from an offshore location into Dublin Bay and DLH, in conjunction with the effect of wind. The ability of the model to simulate a particular time series of consecutive observed wave conditions is not a requirement of the present study and so calibration and validation of the wave model against time series data is not undertaken. A description of the model design and setup is provided in Section A.3.

The plume dispersion model simulates the advection and dispersion of discrete particles within a flow field. In the present study, the flow field is provided by the (separately calibrated and validated) tidal model which is considered to be suitable for this purpose. Other design aspects of the model (particle behaviour, etc.) are chosen on the basis of standard approaches and other assumptions which are stated where relevant. Therefore, detailed calibration and validation of the plume model against time series data is not undertaken. A description of the plume model design and setup is provided in Section A.4.

A.1 Mesh Design

A.1.1 Mesh Extent and Resolution

A single model mesh was developed for all modelling in the present study. This is appropriate as the requirements for mesh extent and grid resolution are similar for each aspect of the study. A flexible mesh design is used, typically comprising a series of interlocking triangular elements of gradually varying sizes. Using a flexible mesh allows greater control over local mesh resolution, orientation and the inclusion of coastline details.

The model mesh extent was (in part) chosen in order to satisfy the requirements of each model type being used. The model mesh extent is also equivalent to the study area. Other reasons for the particular choice of extent are discussed in Section 1.2 of the main report.

The extent of the model mesh is the same as the study area for the present study (shown in Figure 3 of the main report). Details of the mesh for the regional scale and detail within Dublin Bay and Dun Laoghaire Harbour (DLH) are shown in Figure 54, Figure 55 and Figure 56, respectively. The model has three open boundaries with the north, west and south boundaries having a distance of 16.6 km, 44.4 km and 16.4 km respectively. The model grid extends approximately:

- 3 km north of Lambay Island (Co. Dublin) at the northern boundary;
- 3 km south of Greystones (Co. Wicklow) at the southern boundary; and
- 10 km east of Kish Bank at the eastern (offshore) boundary.

The model grid resolution is:

- 470 m in offshore areas;
- 80 m across Dublin Bay and Burford Bank; and
- 10 m to 15 m within DLH.

Graduated stages of intermediate grid resolution are applied between these general areas.

Within DLH, two small localised areas of the mesh (the footprint of piles for St Michaels Pier and the new cruise terminal jetty) use quadrangular (four-sided) instead of triangular (three-sided) elements. This provided greater control over the position, size and orientation of these elements, in order to achieve an even spatial distribution, but also to correctly position and confine the effect of piles in these areas.

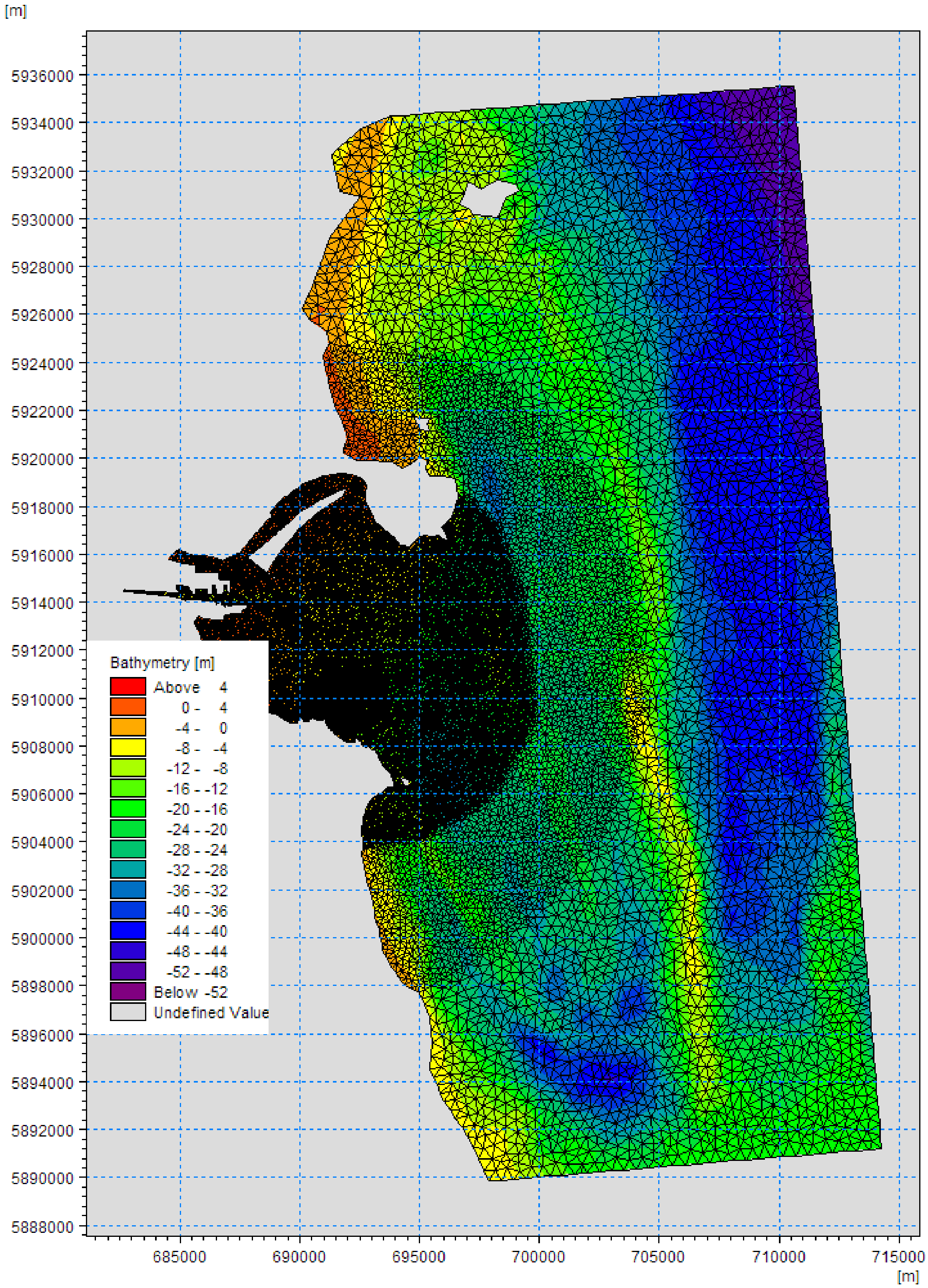


Figure 54. Model Mesh Extent and Offshore Detail

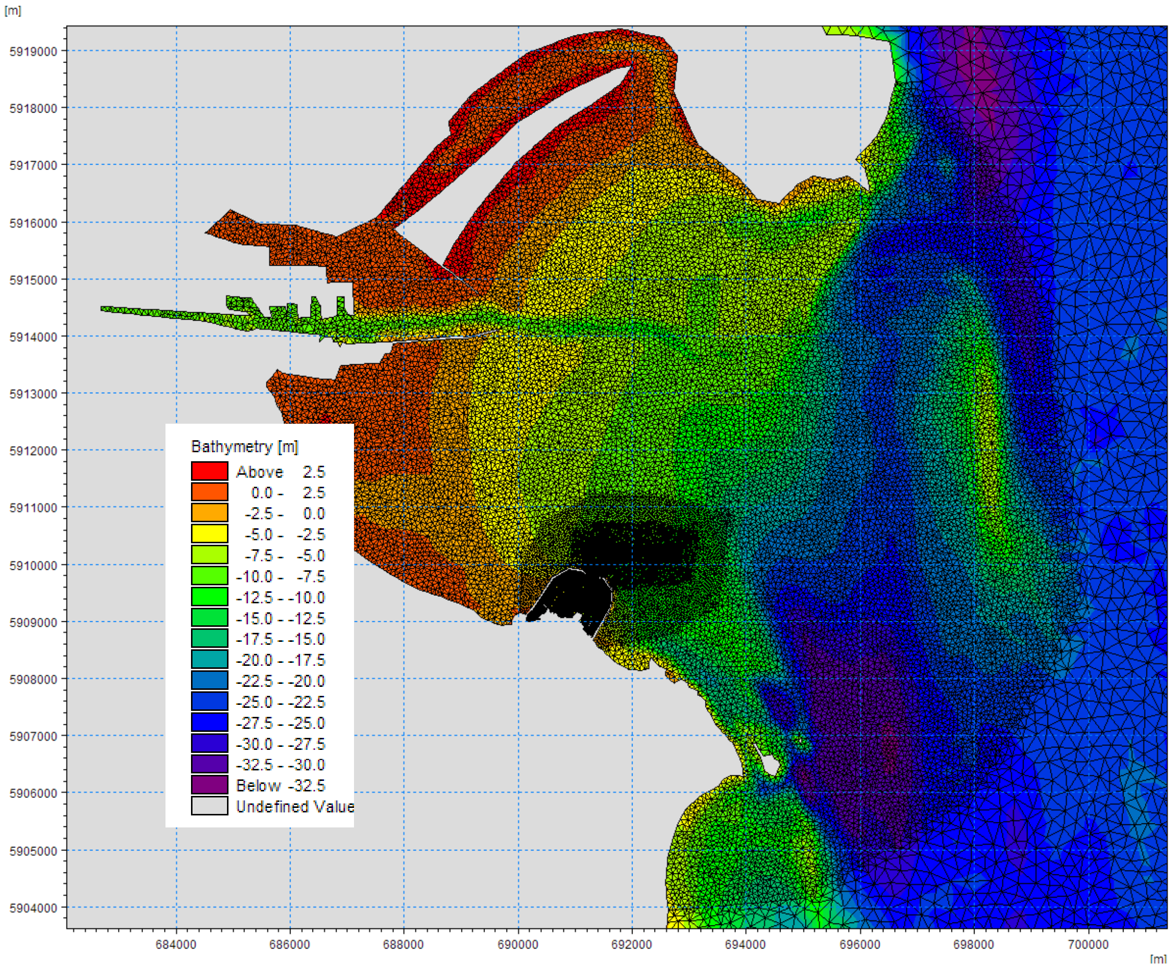
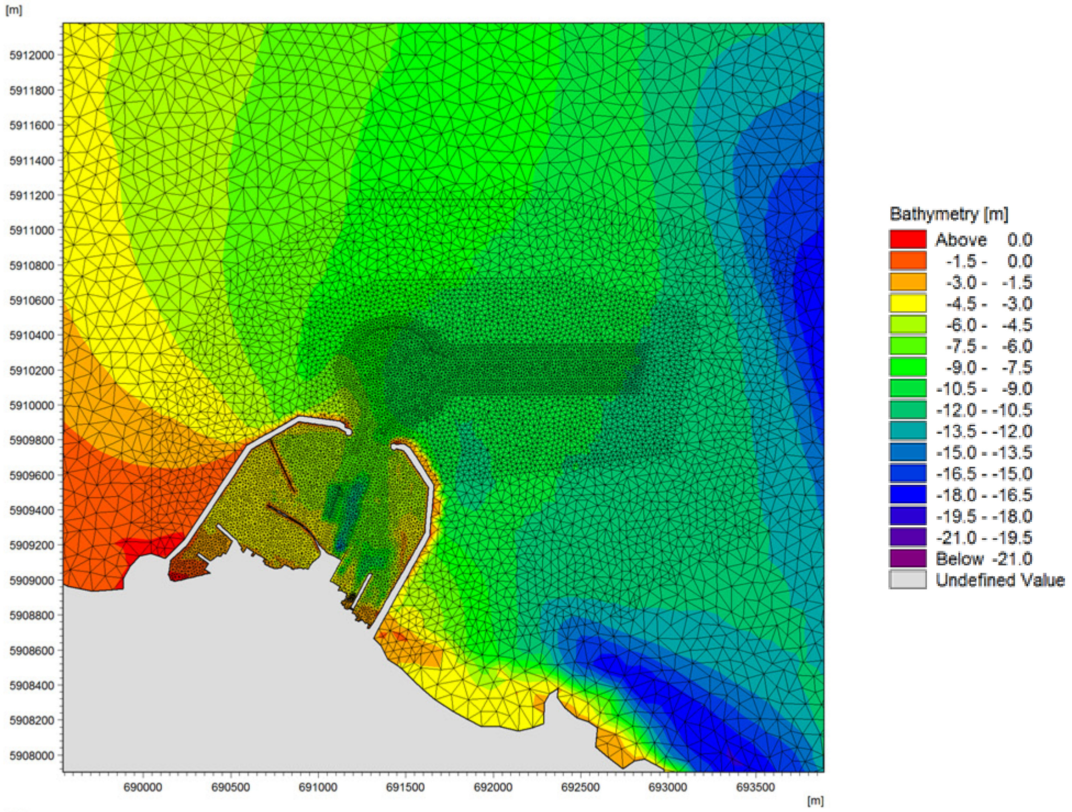


Figure 55. Detail of the Model Mesh Within Dublin Bay



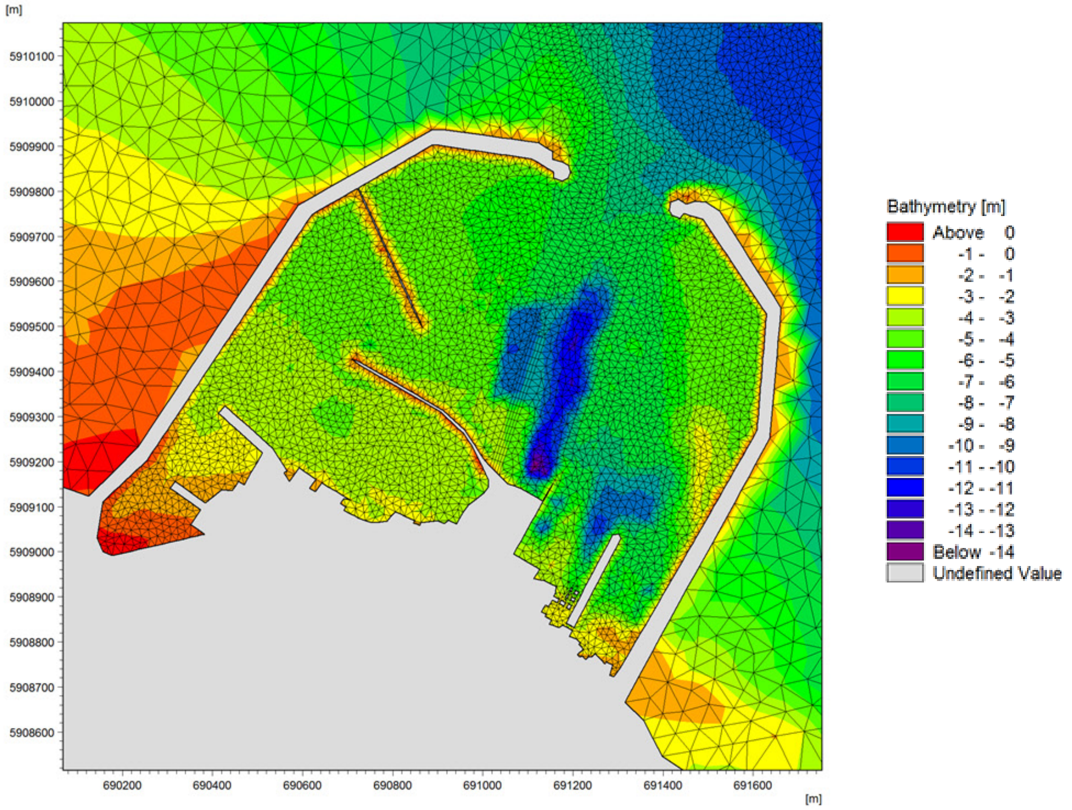


Figure 56. Detail of the Model Mesh Within Dun Laoghaire Harbour

A.1.2 Coastline Definition

The coastline position data used to define the majority of the land boundary in the model mesh outside of DLH was obtained from ESRI ArcGIS and is representative of the position of mean high water springs. Final positioning of the coastline also utilised aerial imagery from Google Earth to ensure that all intertidal areas were included in the model.

The land boundary of the mesh within DLH was obtained from GIS data sources. The land boundary is that of the hard coastline only, i.e. including breakwaters, quay walls, sheet piling etc. There are currently areas of pier deck supported by piles within the harbour that appear as land from an aerial perspective, such as Saint Michael's Pier and the exiting RO-RO loading ramp. In the model, these structures, adjacent to and including the new cruise terminal jetty, are more correctly represented only by the piles on which they are supported (see Section A.2.1.4).

A.1.3 Bathymetry

The model bathymetry was collated from several datasets, including recent swath bathymetry survey data (public sources and provided by the client) and digitised chart information.

Multibeam swath bathymetry survey data collected between 2003 and 2009 was obtained from the online portal hosted by the 'INtegrated mapping FOr the sustainable development of Ireland's MArine Resource' (INFOMAR) project. The surveys provide quality-checked high-resolution bathymetry data for the majority of the mesh extent including offshore areas, Kish and Burford Banks, Dublin Bay and DLH at a spatial resolution of up to 5 m. All of the individual surveys had been reduced to a consistent datum (local LAT) by INFOMAR. The data were found to be suitably de-conflicted (overlapping areas of data are similar without notable offset) and were found to compare closely in spot checks against lower resolution bathymetric charts. These data are considered to be the best-available. The extent of the swath data used is shown in Figure 57.

In areas where high resolution survey data was not available, depth information was digitised from navigation charts from the United Kingdom Hydrographic Office (UKHO). These data were mostly used to fill data gaps near the northern and southern extents of the mesh, and in the intertidal areas of Dublin Bay.

The high-resolution survey data and the digitised charted data were then interpolated to the model mesh using a nearest neighbour linear interpolation method. In most areas, the density of the bathymetry data is much higher than the mesh resolution and so the interpolated bathymetry of the model mesh closely matches the input bathymetry data.

Following initial interpolation of the mesh bathymetry, some localised manual editing of bathymetry was required where charted data was sparse, such as within and around the channel north and inshore of Bull Island and at Sandymound Strand, south of Dublin Port. Additional manual edits were required near to the southern boundary where locally steep gradients in bathymetry were manually smoothened out from the coastline to the 20m contour in order to stabilise the model and reduce the presence of jetting of flow speeds into the domain on the flooding tide.

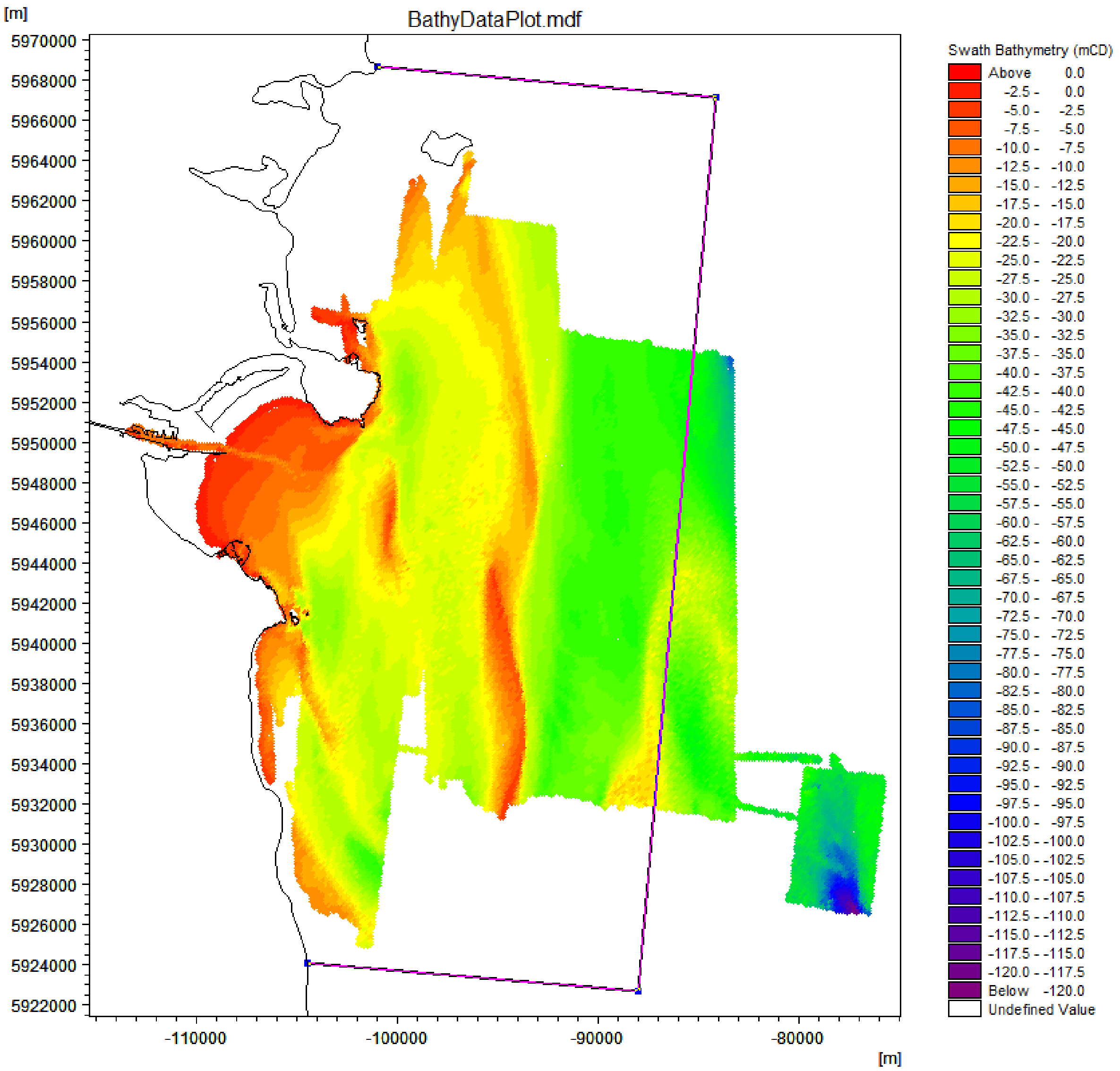


Figure 57. Extent of the INFOMAR Multibeam Swath Bathymetry Data Used

A.2 Tidal Model

The tidal model is used to:

- Provide a description of baseline tidal processes (water levels and currents) within the study area;
- Assess the potential impact of the Scheme on tidal processes; and
- Provide a suitable tidal flow field to inform plume dispersion studies.

This section details the tidal model design, configuration and the process of calibration and validation undertaken to first improve and then quantify the performance of the model for use in the present study.

A.2.1 Model Design

A.2.1.1 Model Mesh

The model mesh is described in Section A.1.

A.2.1.2 Open Boundary Conditions

Open boundary conditions within the tidal model are specified as spatially and temporally varying water levels, derived from tidal constituents. These are provided from the DTU10 (Technical University of Denmark, 2010) global ocean tide model. The model includes ten tidal constituents, (namely M2, S2, N2, K2, K1, O1, P1, Q1, M4, S1) and predictions of tidal water levels have been validated by the data providers against tidal gauge data from many locations in north-west Europe.

Slight adjustments were made to these data as part of the calibration process (see Section A.2.2.3).

A.2.1.3 Bed Roughness

A bed roughness value of Manning's 'M' of 32 $m^{1/3}/s$ was applied throughout most of the model domain. A rougher value of 20 $m^{1/3}/s$ was applied in a 3 km wide strip along the southern boundary to stabilise the model by reducing jetting that was otherwise occurring. This localised change in bed roughness does not measurably affect model performance in the central study area.

A.2.1.4 Structures

The effect of piles are included in the tidal model as 'pier structures'. Individual piles are represented with the appropriate diameter, from which an appropriate coefficient is calculated to impose a drag reduction to modelled flows within the cell that the structure is located.

The location of piles represented as part of the baseline and Scheme are shown in Figure 58.

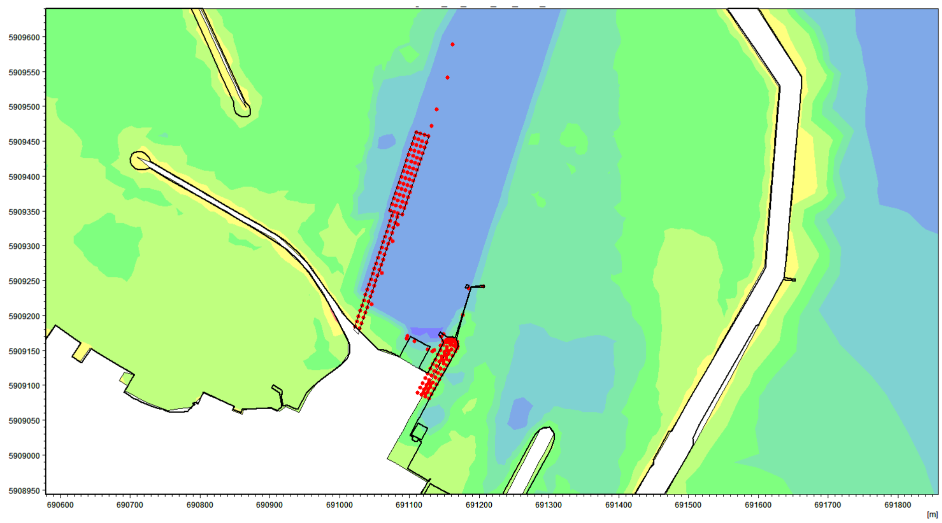


Figure 58. Locations of Existing and New Scheme Piles Simulated in the Tide and Wave Models

The representation of piled structures in the baseline is limited to Saint Michael's Pier and the RO-RO loading ramp and associated mooring dolphins extending northwards from the end of the pier.

The representation of the Scheme includes mooring dolphins and both the decked and access walkway sections of the jetty as piles.

Other features of the harbour such as pontoons or mooring grounds belonging to any of the local yacht clubs are not represented in the model.

A.2.1.5 Other Inputs

No fresh water inputs (e.g. from rivers) are included in the model as there are no significant sources of fresh water in DLH or at Burford Bank that would measurably affect marine processes at these locations.

For use of the tidal model in relation to further plume dispersion studies, it was also considered that the absence of a fresh water discharge through Dublin Port would represent a worst case scenario for assessing the risk of sediment in suspension being advected into the River Liffey/Dublin Port or onto the Dublin Bay SAC. During the testing phase of the particle tracking model, it was noted that releases of sediment in the vicinity of DLH did not result in a pathway into the River Liffey (without any discharge applied) or Dublin Port itself (Alexandra Basin).

Meteorological effects, including winds or changes in air pressure, were not normally included in the model. This is common practice for scheme assessment modelling as no particular weather event is being simulated. A small number of sensitivity tests to discrete uniform wind speed and direction scenarios over the model domain were undertaken (discussed in Section A.2.2.4) but are not explicitly calibrated or validated.

A.2.2 Calibration and Validation

Calibration and validation are undertaken to firstly optimise, and then demonstrate and quantify, the performance of a model in simulating environmental conditions for a particular application.

The calibration process aims to optimise the model performance through the adjustment of model parameters, to achieve the best overall model performance in comparison to measured data and other known local characteristics.

Validation of the model is carried out without any additional adjustments to model settings. The validation process aims to quantify the expected performance of the model when applied outside of the calibration period.

A.2.2.1 Calibration and Validation Datasets

A number of measured and synthetic datasets were collated to inform the calibration of the tidal model. In addition to the time series data, anecdotal evidence from previous studies in DLH and tidal stream atlas information are also used to validate model performance.

The datasets used to support the calibration and validation process are listed below. Figure 3 of the main report provides an overview of all named locations introduced below.

- Measured water level time series data for Dublin Port (North Wall), from the Irish National Tide Gauge Network. Data were obtained from March 2007 to August 2014 at 5 minute resolution;
- Measured water level time series data for Kish Bank Lighthouse, from the Irish National Tide Gauge Network. Data were obtained from January 2007 to August 2014 at 6 minute resolution;
- Measured water level time series data for DLH, provided by the client. Data were obtained for January to December 2013 at 1 minute resolution;
- Predicted tidal water level time series data for Dublin Port (North Wall) from the Admiralty Total Tide (TT) software. Data were obtained for February 2013 at 10 minute resolution;
- Tidal atlas style information for the western Irish Sea, (no detail within Dublin Bay), from the Reeds Nautical Almanac (Du Port & Buttress, 2010). Data are shown in hourly intervals for one tidal cycle; and
- Detailed studies of DLH, undertaken as part of previous supporting environmental statements, cite descriptions of observed processes acting within the harbour, along with typical flow speed patterns and magnitudes. These are detailed in EIS Ltd, 1997, and PH McCarthy & Partners, 1993.

The various measured data have been quality checked to some extent by the original data providers prior to publication. Further quality checks were undertaken for the present study by comparing coincident data from the measured and predicted time series'. The data were compared as time series' and as time independent scatter plots. The tests demonstrate a suitable level of agreement between the data sets from these relatively close locations in terms of the absolute range and the phase and rate of change in water levels. The data are therefore considered to provide a suitable representation of actual conditions at these locations against which to calibrate and validate the tidal model.

The tidal atlas information is of a relatively low temporal and spatial resolution. It does however provide a means of validating the general performance of the model in terms of offshore current speed and direction, in particular the times and direction of peak flood and ebb currents and the timing of flow reversal. Although not demonstrably validated in the source document, almanacs and tidal atlases are established and peer reviewed publications with an assumed reasonable level of accuracy and quality assurance.

Previous studies that report current information (either measured or modelled) are subject to various quality assurance procedures prior to publication. The basis and potential limitations of each data set has been reviewed and considered by ABPmer prior to use in the present study. More details regarding the development or collection of the data used in the present study may be found in the original referenced reports.

A.2.2.2 Calibration and Validation Guidelines, and Performance Metrics

The tidal model performance was assessed against a set of metrics defined in an internal guidance note (ABPmer, 2011). These metrics provide a comparative measure for the goodness-of-fit for both magnitude and phase between predicted water levels or currents and equivalent coincident observed data. Performance statistics quantify the variance between the two sets of information and are expressed as absolute magnitude difference, percentage difference and Root Mean Square (RMS) values which are subsequently considered together to determine an overall 'goodness-of-fit'.

An important consideration when improving or measuring the performance of a model is that differences between predicted and observed data may potentially be due to errors or noise in the observational record as well as inaccuracies or bias in any model prediction. Furthermore, a model cannot be demonstrably proven to an accuracy which is greater than that of the observed data.

The performance metrics and targets used to assess the tidal model performance for water levels according to ABPmer (2011) (consistent with other informal standards for tidal model calibration) are set out below:

- Mean absolute surface elevation difference (for high and low water levels). Calculated as the mean difference in high or low waters water levels (predicted minus observed peak value) in the period being tested. *The mean absolute water level difference should be within ±0.2 m;*
- Mean relative surface elevation difference (for high and low water levels). The mean absolute difference is also expressed as a percentage of the mean tidal range in the period being tested. *The relative water level difference should be within 15% of spring tidal ranges and 20% of neap tidal ranges;*
- Mean phase difference (at high and low water). Calculated as the mean time difference between high or low water peaks (predicted minus observed time), in the period being tested. *Water level phasing at high and low water should be to within ±20 minutes;*
- Time adjusted fit. This is the time correction required to minimise the RMS difference between the modelled and observed water levels at all timesteps in the period being tested; and
- RMS surface elevation difference. This value is calculated as the minimum RMS difference after the application of the time adjusted fit. *RMS surface elevation difference should be less than 0.2 m.*

Current speed and direction data against which to calibrate and validate the model are only available to the project in the form of text descriptions, diagrams and figures in previous reports. It is therefore not possible to provide detailed quantitative calibration targets or validation statistics. Qualitative and semi-quantitative comparisons are provided instead.

A.2.2.3 Calibration of Water Levels

During the process of quality checking the measured and predicted time series data, it was noted that:

- Observed water levels at Dublin Port and DLH (both tidal and non-tidal components) are almost identical;
- Tidal water levels at Dublin Port and Kish Bank Lighthouse are almost identical but the non-tidal signal tends to be greater at Kish; and
- Observed (total) and TT predicted (tidal) water levels at Dublin Port compare closely for most of the time (as expected) but occasionally deviate, coinciding with significant meteorological events, i.e. due to non-tidal surge.

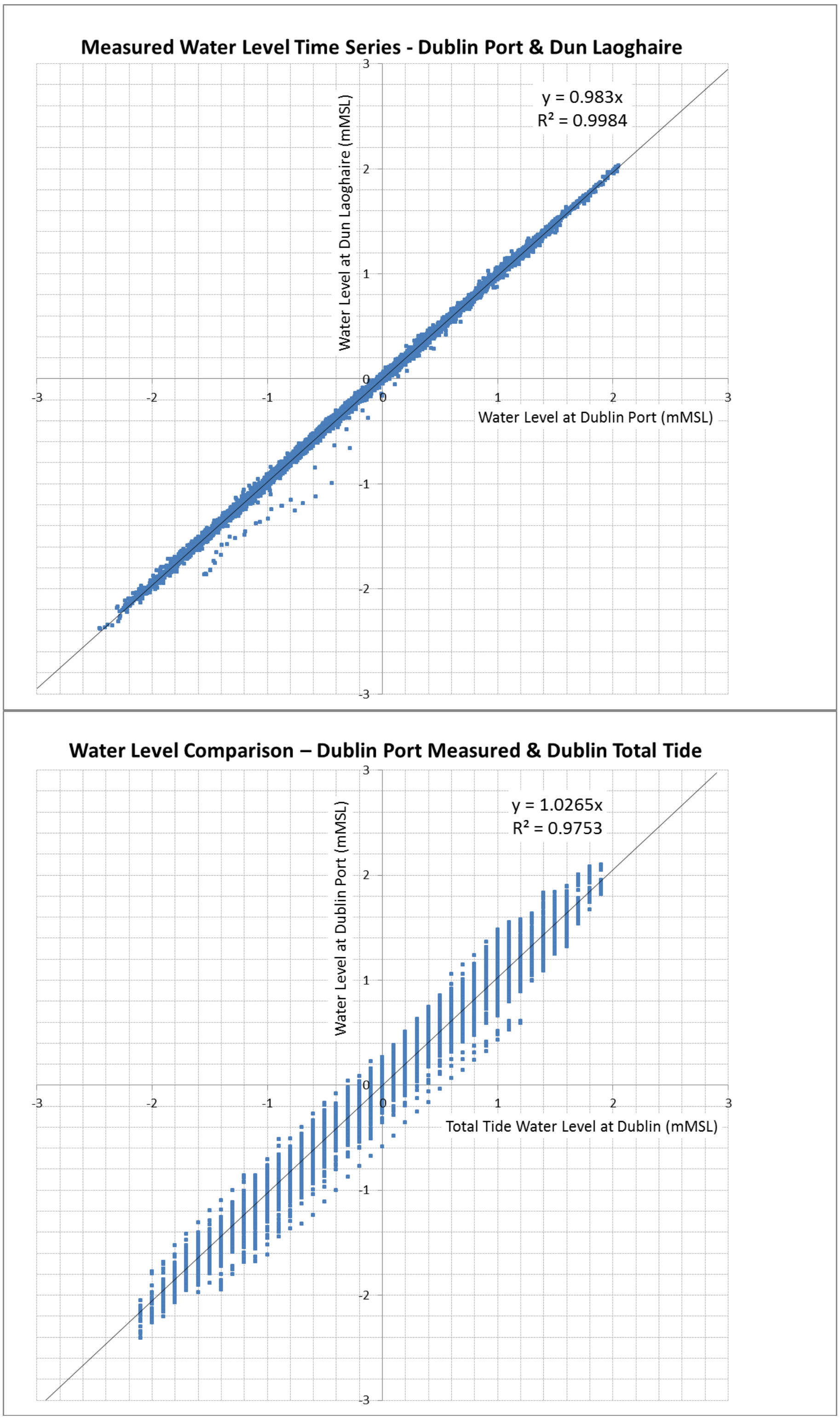


Figure 59. Coincident Observations of Total Water Levels at Dublin Port and Dun Laoghaire Harbour

Coincident measurements of total water levels at Dublin Port and Dun Laoghaire (including tidal and non-tidal components) are compared directly in Figure 59 and Table 5. The figure shows that the data closely follow a 1:1 slope and with a strong degree of correlation (R^2 = 0.9984). Therefore, because instantaneous water levels at these two locations are expected to be the same at any given time, tidal and non-tidal water level information for Dublin Port are equally valid for Dun Laoghaire. This is to be expected, considering the relatively short distance between the two locations.

Table 5. Comparison of Observed and TT Predicted (Tidal) Water Levels

Performance Metric	Measured Water Levels at Dublin Port and Dun Laoghaire Harbour	Measured Water Levels at Dublin Port and TT Predicted Tidal Water Levels at Dublin Port
Mean High Water WL Difference (Data2- Data1) [m]	0.01	-0.01
Mean Low Water WL Difference (Data2- Data1) [m]	-0.06	-0.10
Mean High Water Phase Difference (mins)	-2	11
Mean Low Water Phase Difference (mins)	-2	6
Mean High Water Level Difference as Percentage of Tidal Range [%]	0	0
Mean Low Water Level Difference as Percentage of Tidal Range [%]	-2	-3
RMS Difference	0.05	0.18
Phase Diff From Whole Timeseries (RMS) (mins)	-2	0

Tidal, non-tidal and total water levels at Dublin Port are compared directly in Figure 60 and Table 5 for the month of February 2013. The figure and table show that, in the example period, total high and low water levels frequently deviate by up to ~0.2 to 0.3 m from the tidal value (due to the non-tidal contribution). The magnitude of the non-tidal signal tends to be relatively larger at Kish Bank. Given the similarity in instantaneous water levels demonstrated between Dublin Port and DLH, a similar magnitude of non-tidal effects can be expected at these two stations.

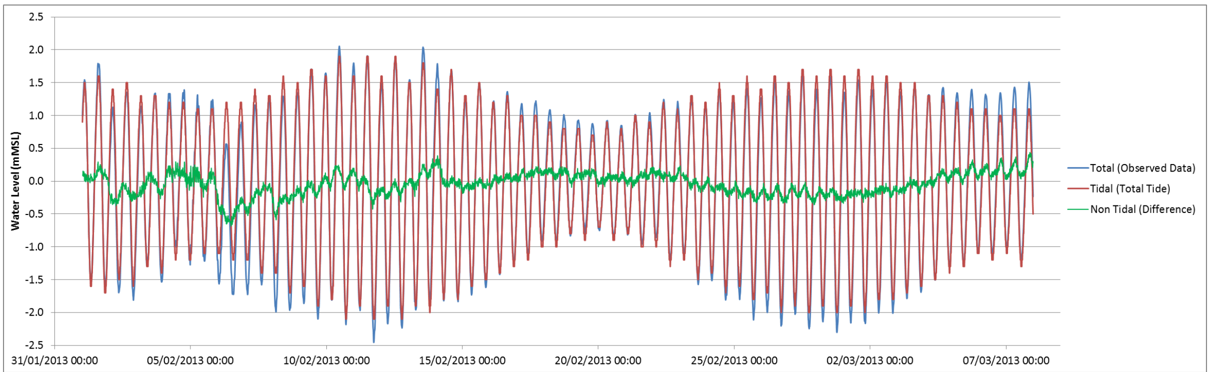


Figure 60. Comparison of Total, Tidal and Non-tidal Water Levels at Dublin Port

Based on a longer period of observed data from the nearby stations of Bangor, Northern Ireland, and Holyhead, Wales, (18 and 42 years, respectively), more extreme surge conditions (the top 1% of observed skew surges, as reported by the National Tide and Sea Level Facility, NTSLF, http://www.ntslf.org) can cause a high water to be up to 0.8 to 1 m higher than the expected tidal level.

The comparison between the measured total water level data at Dublin Port and the TT predicted tidal data again scores a high R^2 value (0.9753), despite the low resolution of the TT predicted dataset (to the nearest 0.1m). The statistics shown in Table 5 reflect (on average) the natural variability that might be expected in actual water level from that predicted due to the tide alone.

Due to the strong similarity demonstrated between the records for Dublin Port and DLH, tidal water levels from these locations in the model are calibrated with reference to the TT predicted tidal water levels for Dublin Port.

Similar analysis of measured data from Dublin Port and Kish Bank Lighthouse tide gauges shows that during known periods of low non-tidal influence at Dublin Port, water levels at the two locations compare closely. Differences are sometimes observed at low water due to an apparent drying of the Kish Bank Lighthouse gauge at approximately the level of low water springs. Non-tidal residuals at Kish Bank Lighthouse are typically larger than coincident values at Dublin Port or DLH, likely due to its more exposed location in deeper water. Therefore, tidal water level information for Dublin Port is considered to be likely equally valid for the location of Kish Bank Lighthouse and locations in-between including Dublin Bay and the BBSG. This is again to be expected, considering the relatively short distance between these locations.

The model was calibrated for a nine day period from 11th February to 20th February 2013 (shown in Figure 62). Tidal ranges in this period cover the transition from spring to neap tides, and are inclusive of individual tides that are approximately equal to the local mean spring and mean neap tidal ranges (3.3 and 1.9 m, respectively).

Tidal water levels predicted by the model for Dublin Port and DLH are compared with TT predicted tidal water levels for Dublin Port in Figure 61 and Table 6. The figure indicates that calibration of water levels at DLH is slightly better during spring tides than neap tides. To quantify the difference in performance, calibration statistics are provided separately in the table for two three-day sub-samples of the data, representative of spring and neap conditions respectively. Spring calibration statistics consider the period 11 to 14 February 2013; neap calibration statistics consider the period 17 to 20 February 2013.

The model is shown to perform well in reproducing tidal water levels at DLH and Dublin Port, and meets the required calibration metrics. Agreement is particularly good during larger (spring) tidal ranges. During smaller (neap) tidal ranges the model slightly under predicts high water levels whilst low water levels are more accurately reproduced (i.e. a smaller tidal range is produced in the model). The timing of high and low waters (i.e. the relative asymmetry of the tide) is suitably reproduced across all tidal ranges tested.

The difference between the modelled and predicted/observed tidal water levels in the model is small in absolute terms but is also shown to be similar to the frequently occurring natural variability in water level due to non-tidal effects (shown in Table 5). The relatively smaller neap tidal ranges reproduced by the model remain within the range of tidal ranges normally experienced at DLH and, therefore, are also representative of normal tidal conditions.

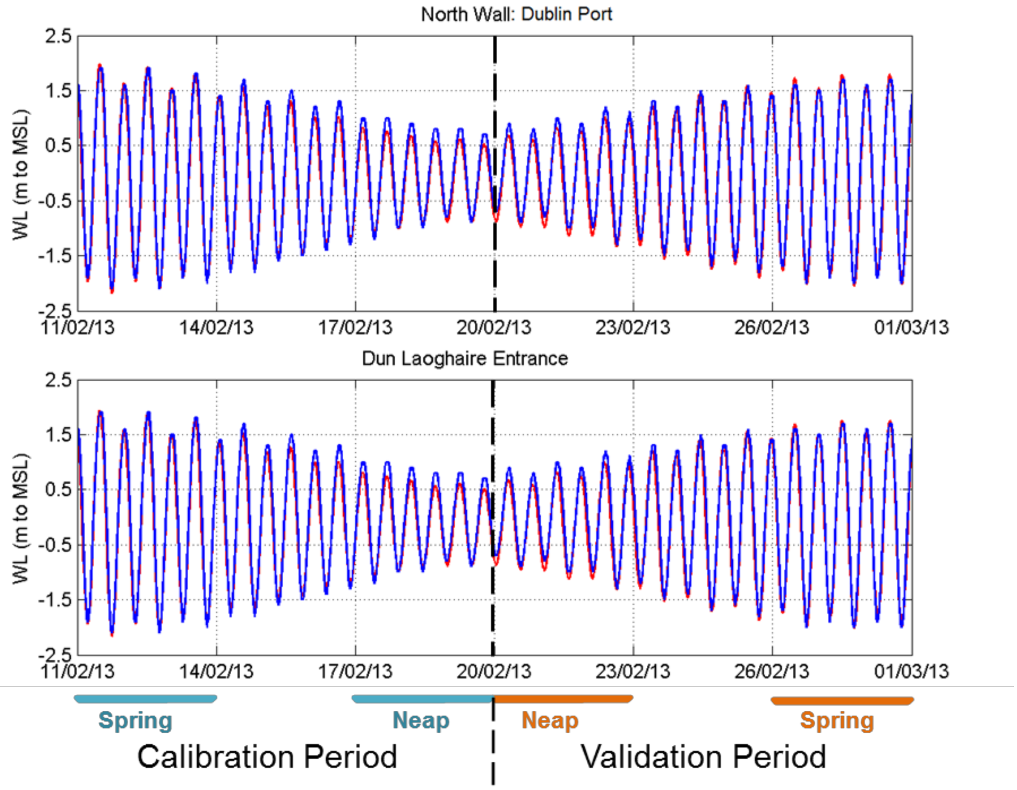


Figure 61. Comparison of Modelled Tidal Water Levels (Blue) with TT Predicted Tidal Water Levels for Dublin Port (Red)

Table 6. Tidal Model Water Level Calibration Statistics

	Spring Tide		Neap Tide	
	Dublin Port (North Wall)	Dun Laoghaire Entrance	Dublin Port (North Wall)	Dun Laoghaire Entrance
Mean High Water WL Difference (Modelled - Observed) [m]	0.01	-0.02	-0.22	-0.24
Mean Low Water WL Difference (Modelled - Observed) [m]	0.00	0.03	0.04	0.06
Mean High Water Phase Difference (mins)	-23	-23	-3	-3
Mean Low Water Phase Difference (mins)	0	0	11	12
Mean High Water Level Difference as Percentage of Tidal Range [%]	0	-1	-12	-13
Mean Low Water Level Difference as Percentage of Tidal Range [%]	0	1	2	3
RMS Diff	0.15	0.16	0.17	0.17
Phase Diff From Whole Timeseries (RMS) (mins)	-9	-10	-7	-7

A.2.2.4 Calibration of Current Speeds

The shape (land boundary and bathymetry) of DLH, and therefore its plan-area and volume are known to be replicated within the model to a relatively high level of accuracy. The model has also been demonstrated in previous sections to reproduce tidal water level variations at DLH to a high level of accuracy. Therefore, without reference to any other current data sources, the rate and total flux of water into and out of DLH during each tide, and the resulting current speeds, are likely to be relatively accurately represented in the model without further calibration.

Such small current speeds are not generally sensitive to bed roughness or other standard tuning parameters. Additional sensitivity tests (not explicitly reported) have been undertaken using the tidal model to quantify the effect of a range of typical and extreme wind speeds and directions on the reported patterns of tidal currents. The additional effect of winds may locally slightly enhance or weaken the strength of already relatively weak currents but does not alter the overall patterns of circulation. Winds at DLH are variable in nature and will, in practice, result in occasional variability about the underlying tidal condition. The tidal condition alone therefore provides a representative mean condition and is taken forward for use in the study.

A.2.2.5 Validation of Water Levels

The model was validated over the nine day period 20th February to 1st March 2013, following and not overlapping the calibration period (shown in Figure 62). This period is representative of a transition from neap to spring tides and again includes individual tides that are approximately equal to the local mean spring and mean neap tidal ranges (3.3 and 1.9 m, respectively).

Statistically there is no significant change to the standards of model performance (summarised in Table 7) in comparison to the calibration period. All sites meet the performance metric of 0.2 m for high and low water over the spring and neap validation periods. The times of high and low waters are within 20 minutes at all sites, with the exception of the phasing of the high water at Dun Laoghaire and Dublin Port, which has a slightly larger than ideal (-24 minutes) time difference at high water, as opposed to -3 minutes on the calibration period.

The overall performance of the model is however considered to be suitably calibrated and validated for its intended purpose in the present study.

Table 7. Tidal Model Water Level Validation Statistics

	Spring Tide		Neap Tide	
	Dublin Port (North Wall)	Dun Laoghaire Entrance	Dublin Port (North Wall)	Dun Laoghaire Entrance
Mean High Water WL Difference (Modelled - Observed) [m]	0.04	0.01	-0.19	-0.20
Mean Low Water WL Difference (Modelled - Observed) [m]	0.01	0.04	-0.10	-0.09
Mean High Water Phase Difference (mins)	-15	-14	-24	-24
Mean Low Water Phase Difference (mins)	7	6	-9	-9

	Spring Tide		Neap Tide	
	Dublin Port (North Wall)	Dun Laoghaire Entrance	Dublin Port (North Wall)	Dun Laoghaire Entrance
Mean High Water Level Difference as Percentage of Tidal Range [%]	1	0	-9	-10
Mean Low Water Level Difference as Percentage of Tidal Range [%]	0	1	-5	-4
RMS Diff	0.14	0.14	0.15	0.15
Phase Diff From Whole Timeseries (RMS) (mins)	-1	-3	-22	-22

A.2.2.6 Validation of Current Speeds

Validation of patterns of currents reported by the model is provided below in the form of qualitative and semi-quantitative comparison with the available data sources.

Offshore

Patterns of tidal currents predicted by the model in offshore areas during a mean spring tide are presented in a tidal atlas format in Figure 13 of the main report. Vectors in the figure indicate tidal current direction and the underlying colour map indicates tidal current speed; vectors are not shown where current speeds are less than the specified minimum value.

Qualitative comparisons have been made between patterns of currents (speed, direction and timing of peaks and reversals) in offshore areas of the model (shown in Figure 13 of the main report and the Reeds Nautical Almanac tidal atlas (Du Port and Buttress, 2010) for the south western Irish Sea). The published tidal atlas has a relatively low spatial resolution in comparison to the local detail of the model, and only approximate water surface current speeds are provided. However the tidal atlas is considered to provide a reasonably reliable indication of the broad scale behaviour of tidal currents offshore, which the model should reproduce. The Reeds Nautical Almanac tidal atlas cannot be reproduced directly here for copyright reasons. However, it is confirmed that peak spring current speeds (~1.1 to 1.2 m/s surface current speed, equivalent to ~1.0 to 1.1 m/s depth mean current speed) and the timing of peak flood and ebb currents and current reversal compare well between the two data sources.

The tidal model results in Figure 13 of the main report are also in general qualitative agreement with another chart of co-speed contours (BGS, 1990), which broadly suggests peak depth averaged current speed on a mean spring tide are ~0.8 to 1.0 m/s offshore of Dublin Bay.

Dublin Bay and Burford Bank Spoil Ground

Patterns of tidal currents predicted by the model in Dublin Bay and around Burford Bank Spoil Ground (BBSG) during a mean spring tide are presented in a tidal atlas format in Figure 13 of the main report.

Observed patterns of tidal currents in the vicinity of Burford Bank and the BBSG in outer Dublin Bay were reported in a previous study by Dublin City Council (2012), where static and mobile current meter surveys were undertaken in support of an application to extend an outfall by Dublin City Council. The period of survey (in 2010) captures two full spring-neap cycles, including individual tides with ranges equivalent to mean spring and mean neap conditions. The survey results cannot be reproduced directly here for copyright reasons. However, it is confirmed that peak spring and peak neap current speeds (including localised flood-ebb asymmetry at one location), and patterns of current direction measured by mobile current profiler surveys, qualitatively compare well with the tide model results in the present study.

Dun Laoghaire Harbour
Patterns of tidal currents predicted by the model in DLH during a mean spring tide are presented in a tidal atlas format in Figure 15 of the main report.

Observed patterns of tidal currents within DLH were reported in a previous study by PH McCarthy & Partners (1993), where a drogue tracking survey was undertaken in support of a consent application for the now-operational fast ferry terminal. A tide model, calibrated using these survey data, was also used to assess potential scheme impacts on currents. The survey was undertaken prior to the construction of the fast ferry terminal and the inner harbour breakwaters, so the detailed flow patterns observed in the survey are no longer valid in the present day baseline. Generally, the survey consistently showed only very weak flows to be present over most of the harbour (≤0.05 m/s). Local maximum current speeds (with some wind effects) were observed near to the harbour entrances of 0.3m/s and 0.1m/s for peak flood and peak ebb currents respectively. Peak flood currents were reportedly observed approximately four hours before high water. Large recirculation patterns were formed as a result of water entering (and to a lesser extent exiting) the harbour. In both the survey and the model results, the observed current speeds and patterns of recirculation were noted to be slightly sensitive to local wind speed and direction, although differences in absolute current speed were small.

A later study (EIS Ltd, 1997) was undertaken, following construction of the fast ferry terminal, in support of a consent application for the inner harbour breakwaters (later installed in 2000-2001). This study also undertook tidal modelling for scheme impact assessment where the baseline model performance was validated using the results of the previous drogue tracking study. The results of the scheme impact assessment modelling most closely resemble the present day baseline. The results from scheme tests most closely resembling the breakwater configuration actually built essentially concluded that the strength of recirculation patterns in the harbour would be reduced and that the current speed through the new inner harbour entrance would be enhanced locally (similar to that observed through the main harbour entrance).

It is confirmed that qualitatively similar patterns of current speeds are reproduced within the harbour by the tidal model created for the present study, including, flow speeds generally ≤0.05 m/s, flood tide dominance at the entrance and the general presence of recirculation patterns with a reasonable position and extent. As a semi-quantitative comparison, during a spring tide, the maximum model current speed through both the main and inner harbour entrances as a result of the actual breakwater design and present day bathymetry is predicted to be ~0.20 m/s.

A.3 Wave Model

The wave model is used to:

- Provide a description of baseline wave processes (local wave height, period and direction for a range of offshore return period conditions) within the study area; and
- Assess the potential impact of the Scheme on wave processes.

This section details the wave model design and configuration for use in the present study.

A.3.1 Model Design

A.3.1.1 Model Mesh

The model mesh is described in Section A.1.

A.3.1.2 Spectral and Temporal Formulation

The model is set up to utilise a directionally decoupled parametric spectral formulation in conjunction with a quasi-stationary time formulation. In this way, the model estimates the time-independent fully developed wave field resulting from the input boundary conditions at each timestep.

A.3.1.3 Open Boundary Conditions

As used, the wave model requires the following spectral and wind parameters as boundary conditions:

- Hs (Significant Wave Height);
- Tp (Peak Spectral Wave Period);
- mDir (Mean Wave Direction);
- DSD (Directional Standard Deviation);
- Wind Speed; and
- Wind Direction.

Wave conditions are applied at the offshore (open) boundary and wind conditions are applied over the whole surface of the model. In this way, when waves from offshore are not directed into the model, realistic waves are generated as a result of wind action over limited fetches within Dublin Bay and within Dun Laoghaire harbour.

A.3.1.4 Structures

The effect of piles are included in the wave model as 'point structures'. Individual piles are represented with the appropriate diameter, from which an appropriate coefficient is calculated to block or reflect wave energy within the cell that the structure is located.

The location of piles represented as part of the baseline and Scheme are shown in Figure 58.

The representation of piled structures in the baseline is limited to Saint Michael's Pier and the RO-RO loading ramp and associated mooring dolphins extending northwards from the end of the pier.

The representation of the Scheme includes mooring dolphins and both the decked and access walkway sections of the jetty as piles.

Other features of the harbour such as pontoons or mooring grounds belonging to any of the local yacht clubs are not represented in the model.

A.3.1.5 Reflective Boundaries

Smooth vertical quay walls within DLH have the potential to reflect some incident wave energy, affecting patterns of wave energy distribution within the harbour. Rubble mound breakwaters are less likely to reflect wave energy, rather acting to absorb energy via wave breaking.

Sections of coastline inside and outside of DLH (including the external faces of the main harbour breakwaters) were assigned a local value of reflectivity depending on the surface type, as identified in aerial images (courtesy of Google Earth).

The reflectivity coefficient (0 = full absorption, 1 = full reflection) is set as 0.4 for relatively rough surfaces, and 0.9 for relatively smooth surfaces. The distribution of rough and smooth sections is shown in Figure 62. Coastlines in other locations are assigned a 'land boundary' code, equivalent to a coefficient of 0 (full absorption).

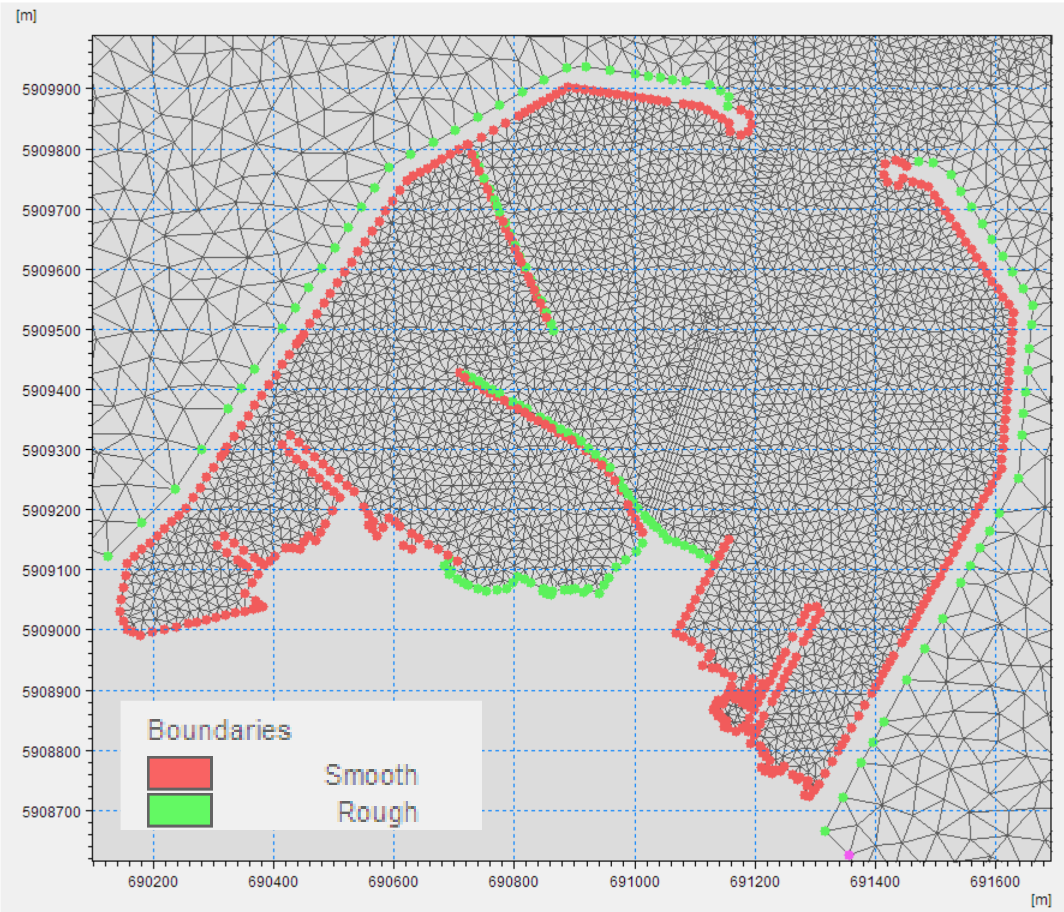


Figure 62. Distribution of Reflective Boundary Types in the Wave Model

A.3.1.6 Other Inputs

Constant water levels are set, depending on the chosen scenario. Mean high water spring and mean low water spring water levels were tested as part of the present study.

Currents are not included in the model as the magnitude of tidal current speeds in and around DLH was not considered sufficient to significantly control the propagation of waves into or within the harbour.

Otherwise, default parameters are used.

A.3.2 Calibration and Validation

The wave and wind boundary conditions were sourced from separately calibrated and validated data sets (see Appendix B). Wave conditions simulated by the model very near to the offshore boundaries are the same as the input boundary condition and so therefore meet the same level of validation at this location as the input data source from which they are derived.

The propagation of wave energy into Dublin Bay and within DLH reported by the model was reviewed by experienced ABPmer staff members who are familiar with both spectral wave modelling and the principles of coastal oceanography. The resulting patterns of waves were found to be reasonable and explained by the relevant factors (mainly the input wave conditions and the distribution of bathymetry within the study area).

The wave model is used in the present study to transform discrete wave conditions from an offshore location into Dublin Bay and DLH, in conjunction with the effect of wind. The ability of the model to simulate a particular time series of consecutive observed wave conditions is not a requirement of the present study and so calibration and validation of the wave model against time series data was not undertaken.

A.4 Sediment Plume Dispersion Model

The particle tracking model is used to assess the potential impact of sediment disturbance and resuspension during dredging and spoil disposal as part of the Scheme construction.

The results of the particle tracking model are dependant to a large extent upon the flow field provided by the validated tidal model and does not have the same requirements for a verification process models. Additionally, it is unlikely that suitable field evidence has or can be collected, against which to prove site specific particle tracking models.

The sediment types and corresponding characteristics (described in Table 3) are determined on the basis of suitable seabed sample data and standard relationships for associated quantities (e.g. settling velocity). These characteristics are not considered as calibration factors.

The schedule of the dredging operation and assumptions regarding rates of disturbance and overspill will affect the result of the modelling. Realistic worst case scenarios are described in Section 3.1 of the main report. Known operational parameters have been included where available. Other assumptions are stated and have been made on a suitably conservative basis for the purposes of EIA.

The sediment being released is represented as discrete particles of nominal mass. The individual mass and number of particles released are chosen such that the resolution of reported depth averaged SSC is accurate to within at least 1 mg/l, whilst also correctly accounting for the total mass and rate of sediment being released

The plume dispersion model is considered to provide a suitably realistic simulation of sedimentary processes in the context of the present study. No further calibration is deemed necessary.

A.5 References

ABPmer (2011). Numerical Model Calibration and Validation Guidance. ABP Marine Environmental Research Ltd, File Note R/1400/112.

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Environmental Impact Services Ltd, Mouchel McCullough and Murray O'Laoire Associates. (1997). Environmental Impact Statement for Proposed Marine and Recreational Development at Dun Laoghaire Harbour.

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Appendix B

Description of the Offshore Wave Climate

B. Description of the Offshore Wave Climate

B.1 Introduction

An objective of the main report is to characterise and assess the impact of the proposed Scheme on the wave climate within and around Dun Laoghaire Harbour. Wave climate is the statistical distribution of wave height and period by direction at a specific location over long time periods. The details of location specific wave climate will therefore vary spatially throughout the study area.

For the purposes of impact assessment in the present study, rather than simulating the entire wave climate (a long time-series), a range of representative wave condition scenarios are tested. The range is representative of the wave climate and includes more frequently occurring to more extreme sea states from the full range of possible coming directions.

This appendix describes the process used to quantify the wave climate at an offshore location in order to provide the boundary conditions for the wave model (described in Appendix A). The model is then used to translate conditions of known return period from offshore, into Dublin Bay and into Dun Laoghaire Harbour. In this way, the model is used to simulate waves throughout the study area with a broadly equivalent return period, for baseline and with-Scheme development scenarios.

The spectral wave model requires the following input parameters as boundary conditions:

- Hs (Significant Wave Height);
- Tp (Peak Spectral Wave Period);
- mDir (Mean Wave Direction);
- DSD (Directional Standard Deviation);
- Wind Speed, and;
- Wind Direction.

The following sections describe the method used to determine each of the above parameters.

Wave conditions are applied at the offshore (open) boundary and wind conditions are applied over the whole surface of the model. In this way, when waves from offshore are not directed into the model, realistic waves are generated as a result of wind action over limited fetches within Dublin Bay and within Dun Laoghaire harbour.

B.2 Sources of Data

Wind and wave hindcast data were extracted from the following data sources at the location [5.8546°W, 53.3499°N], which is geographically representative of the middle of the offshore edge of the project study area, and the eastern offshore boundary of the wave model (see Figure 3 of the main report).

B.2.1 Sources of Wind Data

A 31 year time-series of hourly wind conditions (wind speed and direction) from the NCEP 'Reanalysis II' hindcast data set (NCEP2) was used to inform the analysis.

The NCEP2 hindcast data set (Saha *et al.*, 2010) is jointly managed and administered by the subsidiaries of the US National Oceanic and Atmospheric Administration (NOAA); (a) the US National Centers for Environmental Prediction (NCEP); and (b) the National Center for Atmospheric Research (NCAR). These model hindcast data benefit from an assimilation of historical observed data (a method of optimising model predictions at each time step using the observed conditions at that time). Assimilation data typically include satellite, terrestrial weather stations and discrete observations from ships of opportunity. The hindcast data used here have a spatial resolution of approximately 0.31° (latitude and longitude) and are derived from a complete re-analysis at hourly intervals of the NCEP operational data for a 31 year period between January 1979 and December 2009. For the present study, a point time-series of the parameter 'wnd10m' (wind speed and direction at 10 m above Mean Sea Level, MSL) was extracted from the full data set for the required location, using linear (spatial) interpolation.

B.2.2 Sources of Wave Data

A 31 year time-series of hourly wave conditions (Hs, Tp and mDir) from ABPmer's SEASTATES wave hindcast database was used to inform the analysis.

The SEASTATES wave hindcast is informed in this time period by spatially and temporally varying winds from the NCEP2 wind hindcast, as described in B.2.1.

Wave height, period and direction parameters from the SEASTATES hindcast have been successfully validated against measured waves at 28 wave buoys around UK, including the Irish Marine Institute 'M2' buoy, ~50 km east north-east of Dublin Bay and ~25 km north-east of the location extracted for use in the present study.

Further details regarding SEASTATES hindcast data may be found at www.seastates.net.

B.3 Analysis of Wave Climate

Wave parameters for a range of coming directions and return periods were determined from the input wind and wave timeseries data as follows.

B.3.1 Mean Wave Direction, Wind Direction and Wave Directional Standard Deviation

The wave climate analysis provides wave parameters for all wave coming directions. The final result provides a directional resolution of 10°, i.e. 36 directional sectors (0°, 10°, 20°,…. 350°).

Wind direction in the domain is taken to be the same as the offshore wave coming direction.

A fixed representative value of directional standard deviation (directional spreading) of waves at the offshore location is used, DSD= 25°, representative of a mixed swell and wind sea.

B.3.2 Significant Wave Height

The Hs dataset was analysed to yield a subset of peak Hs values for individual storms above a threshold of Hs = 0.75 m. This returns approximately 10 storm peak Hs values per year for the data at this location.

Extreme value analysis was applied to these data, providing omni-directional significant wave heights for return periods of 10:1, 1:1, 1:10 and 1:50 years.

The full time-series of Hs values was filtered into 8 x 45° sectors. The 99th percentile Hs value was identified for each directional sector. The 99th percentile value for each directional sector is then divided by the largest 99th percentile value of all directional sectors in order to create a directional relative magnitude between 0 and 1 for each direction. The ratios were interpolated from 45° to 10° sectors. The omni-directional return period Hs values are then multiplied by these relative magnitudes in order to obtain directional estimates.

B.3.3 Corresponding Peak Wave Period

The time-series of peak Hs values in selected storms was filtered into 8 x 45° sectors. The gross steepness of waves was calculated for each event as Hs/L where L is the wave length estimated as [$L=gTp^2/(2\pi)$] (suitably assuming a deep water wave condition).

The average steepness of the top 10% of storm Hs values were taken as representative wave steepnesses for extreme wave conditions in each directional sector.

The representative steepness values were then used to estimate Tp for each extreme Hs value, for each directional sector.

B.3.4 Corresponding Wind Speed

The time-series of peak Hs values in selected storms was filtered into 8 x 45° sectors. The coincident wind speed at the time of each storm peak was plotted against the wave height. A series of linear fits were used to describe the relationship between wind speed and wave height during storms for each directional sector. The fits were then used to estimate the wind speed corresponding to specific return period wave heights for each directional sector.

B.4 Tables of Wave Climate

The offshore wave climate determined by the analysis described in Section B.3 is presented in the following tables.

The resulting wave conditions at the entrance to Dun Laoghaire Harbour (as predicted by the wave model described in Appendix A using a fixed water level of mean high water springs, MHWS) are also provided. It is however shown in the main report (Section 2.5.2) that there can be strong gradients in Hs (and other wave parameters) in the vicinity of the harbour entrance and so the exact values shown in the tables might vary depending on the exact location chosen.

Table 8. Wave Return Period Conditions Offshore and Corresponding Conditions at Dun Laoghaire Harbour (10:1 Year Return Period, MHWS)

Offshore				Entrance to Dun Laoghaire Harbour		
Wave and Wind Coming Direction (°N)	Significant Wave Height (m)	Peak Wave Period (s)	Wind Speed (m/s)	Significant Wave Height (m)	Peak Wave Period (s)	Wave Coming Direction (°N)
0	1.73	5.6	9.5	0.61	4.1	38
10	1.92	6.0	9.4	0.79	5.0	51
20	2.12	6.4	9.3	1.01	5.8	61
30	2.31	6.8	9.2	1.27	6.4	68
40	2.50	7.2	9.2	1.54	6.8	74
50	2.63	7.4	9.3	1.78	7.0	79
60	2.71	7.5	9.5	1.99	7.1	84
70	2.78	7.5	9.7	2.16	7.2	89
80	2.86	7.6	10.0	2.30	7.2	94
90	2.93	7.6	10.2	2.38	7.3	99
100	2.89	7.6	10.1	2.33	7.3	104
110	2.86	7.5	9.9	2.24	7.2	109
120	2.82	7.4	9.8	2.10	7.2	113
130	2.78	7.3	9.6	1.93	7.2	116
140	2.72	7.2	9.7	1.73	7.1	119
150	2.65	7.1	10.1	1.51	7.1	122
160	2.57	7.0	10.4	1.28	7.0	124
170	2.50	6.8	10.8	1.04	6.9	126
180	2.42	6.7	11.1	0.82	6.7	128
190	2.44	6.5	11.5	0.62	6.5	130
200	2.46	6.3	11.9	0.46	5.8	135
210	2.49	6.0	12.4	0.33	4.4	146
220	2.51	5.8	12.8	0.26	3.0	186
230	2.46	5.6	12.9	0.22	2.1	241
240	2.35	5.3	12.6	0.21	1.8	256
250	2.23	5.1	12.4	0.21	1.8	267
260	2.11	4.9	12.2	0.22	1.8	274
270	2.00	4.7	11.9	0.24	1.8	282
280	1.98	4.7	11.7	0.25	1.9	288
290	1.95	4.7	11.6	0.26	1.9	295
300	1.93	4.8	11.4	0.27	1.9	303
310	1.91	4.8	11.2	0.28	2.0	313
320	1.88	4.9	10.9	0.30	2.1	323
330	1.84	5.1	10.5	0.38	2.4	336
340	1.81	5.2	10.2	0.44	2.8	356
350	1.77	5.4	9.8	0.51	3.4	20

Table 9. Wave Return Period Conditions Offshore and Corresponding Conditions at Dun Laoghaire Harbour (1:1 Year Return Period, MHWS)

Offshore				Entrance to Dun Laoghaire Harbour		
Wave and Wind Coming Direction (°N)	Significant Wave Height (m)	Peak Wave Period (s)	Wind Speed (m/s)	Significant Wave Height (m)	Peak Wave Period (s)	Wave Coming Direction (°N)
0	2.46	6.6	12.1	0.84	4.7	43
10	2.73	7.1	12.0	1.10	5.7	57
20	3.00	7.6	12.0	1.41	6.5	66
30	3.27	8.1	11.9	1.76	7.1	72
40	3.54	8.6	11.9	2.12	7.5	78
50	3.73	8.9	12.0	2.44	7.8	82
60	3.84	8.9	12.3	2.68	7.8	86
70	3.94	9.0	12.6	2.87	7.9	90
80	4.05	9.0	12.9	3.01	7.9	95
90	4.16	9.1	13.2	3.09	8.0	99
100	4.10	9.0	13.1	3.03	7.9	104
110	4.05	8.9	13.0	2.92	7.9	108
120	4.00	8.8	12.9	2.76	7.9	112
130	3.94	8.7	12.8	2.55	7.8	115
140	3.86	8.6	13.0	2.31	7.8	118
150	3.76	8.5	13.4	2.05	7.7	120
160	3.65	8.3	13.9	1.77	7.7	122
170	3.54	8.1	14.3	1.48	7.6	124
180	3.43	8.0	14.7	1.21	7.5	125
190	3.46	7.7	15.2	0.96	7.4	127
200	3.49	7.4	15.7	0.75	6.8	129
210	3.53	7.2	16.2	0.58	5.6	135
220	3.56	6.9	16.8	0.45	4.3	152
230	3.49	6.6	16.8	0.37	3.1	203
240	3.33	6.4	16.4	0.31	2.3	246
250	3.16	6.1	16.0	0.29	2.1	264
260	3.00	5.8	15.6	0.26	1.9	271
270	2.84	5.6	15.2	0.25	1.8	279
280	2.80	5.6	15.0	0.26	1.9	287
290	2.77	5.6	14.7	0.27	1.9	294
300	2.74	5.7	14.4	0.29	1.9	303
310	2.71	5.7	14.1	0.32	2.0	313
320	2.67	5.8	13.8	0.37	2.2	326
330	2.61	6.0	13.4	0.49	2.7	342
340	2.56	6.2	12.9	0.61	3.2	2
350	2.51	6.4	12.5	0.71	3.9	26

Table 10. Wave Return Period Conditions Offshore and Corresponding Conditions at Dun Laoghaire Harbour (1:10 Year Return Period, MHWS)

Offshore				Entrance to Dun Laoghaire Harbour		
Wave and Wind Coming Direction (°N)	Significant Wave Height (m)	Peak Wave Period (s)	Wind Speed (m/s)	Significant Wave Height (m)	Peak Wave Period (s)	Wave Coming Direction (°N)
0	2.92	7.2	13.7	1.01	5.0	46
10	3.24	7.8	13.7	1.31	6.1	60
20	3.56	8.3	13.6	1.67	6.9	68
30	3.88	8.8	13.6	2.07	7.5	74
40	4.20	9.3	13.6	2.47	7.9	79
50	4.43	9.6	13.7	2.81	8.1	83
60	4.55	9.7	14.1	3.05	8.2	87
70	4.68	9.8	14.4	3.23	8.2	91
80	4.81	9.8	14.8	3.36	8.3	95
90	4.93	9.9	15.1	3.42	8.3	99
100	4.87	9.8	15.1	3.35	8.3	103
110	4.80	9.7	15.0	3.23	8.2	107
120	4.74	9.6	14.9	3.07	8.2	111
130	4.68	9.5	14.8	2.86	8.2	114
140	4.58	9.4	15.1	2.60	8.1	117
150	4.46	9.2	15.5	2.33	8.1	119
160	4.33	9.0	16.0	2.02	8.0	121
170	4.20	8.9	16.5	1.72	8.0	123
180	4.07	8.7	17.0	1.43	7.9	124
190	4.11	8.4	17.6	1.15	7.9	126
200	4.15	8.1	18.1	0.92	7.3	128
210	4.18	7.8	18.7	0.74	6.1	133
220	4.22	7.5	19.3	0.57	4.8	145
230	4.14	7.2	19.3	0.48	3.5	179
240	3.95	6.9	18.8	0.40	2.7	233
250	3.75	6.6	18.3	0.36	2.4	260
260	3.56	6.3	17.8	0.29	2.0	270
270	3.36	6.1	17.3	0.27	1.9	278
280	3.33	6.1	17.0	0.27	1.9	286
290	3.29	6.1	16.7	0.28	1.9	294
300	3.25	6.2	16.3	0.29	1.9	303
310	3.21	6.2	16.0	0.33	2.1	315
320	3.16	6.3	15.6	0.44	2.4	328
330	3.10	6.6	15.1	0.59	2.9	346
340	3.04	6.8	14.7	0.72	3.5	7
350	2.98	7.0	14.2	0.85	4.2	30

Table 11. Wave Return Period Conditions Offshore and Corresponding Conditions at Dun Laoghaire Harbour (1:50 Year Return Period, MHWS)

Offshore				Entrance to Dun Laoghaire Harbour		
Wave and Wind Coming Direction (°N)	Significant Wave Height (m)	Peak Wave Period (s)	Wind Speed (m/s)	Significant Wave Height (m)	Peak Wave Period (s)	Wave Coming Direction (°N)
0	3.13	7.5	14.5	1.09	5.2	48
10	3.48	8.0	14.5	1.41	6.2	61
20	3.82	8.6	14.4	1.80	7.0	69
30	4.17	9.1	14.4	2.21	7.6	75
40	4.51	9.7	14.4	2.62	8.0	79
50	4.75	10.0	14.5	2.97	8.2	83
60	4.89	10.1	14.9	3.20	8.3	87
70	5.03	10.1	15.3	3.38	8.4	91
80	5.16	10.2	15.6	3.49	8.4	95
90	5.30	10.3	16.0	3.54	8.4	99
100	5.23	10.2	16.0	3.47	8.4	103
110	5.16	10.1	15.9	3.36	8.4	107
120	5.09	10.0	15.9	3.19	8.3	111
130	5.02	9.8	15.8	2.98	8.3	114
140	4.92	9.7	16.0	2.72	8.3	117
150	4.78	9.5	16.5	2.44	8.2	119
160	4.65	9.4	17.1	2.13	8.2	121
170	4.51	9.2	17.6	1.82	8.1	122
180	4.37	9.0	18.1	1.52	8.0	124
190	4.41	8.7	18.7	1.23	8.1	125
200	4.45	8.4	19.3	1.00	7.4	127
210	4.49	8.1	19.9	0.81	6.2	132
220	4.53	7.8	20.4	0.63	5.0	143
230	4.45	7.5	20.5	0.53	3.7	173
240	4.24	7.2	19.9	0.44	2.9	227
250	4.03	6.9	19.4	0.39	2.5	258
260	3.82	6.6	18.8	0.31	2.0	269
270	3.61	6.3	18.3	0.28	1.9	277
280	3.57	6.3	17.9	0.27	1.9	285
290	3.53	6.4	17.6	0.28	1.9	294
300	3.49	6.4	17.2	0.30	1.9	304
310	3.45	6.4	16.9	0.34	2.1	316
320	3.40	6.6	16.5	0.47	2.5	330
330	3.33	6.8	16.0	0.63	3.0	348
340	3.26	7.0	15.5	0.78	3.6	9
350	3.20	7.3	15.0	0.92	4.3	32

B.5 Reference

Saha, S. *et al*., 2010. The NCEP Climate Forecast System Reanalysis. Bull. Amer. Meteor. Soc., 91(8), 1015-1057, doi:10. 1175/2010BAMS3001.1.

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