Environmental Impact Assessment Report

Volume 4

Appendix 6.4 Codling Wind Park Hydraulic Modelling Support

CODLING WIND PARK

Hydraulic Modelling Support

IBE2174
D02
15 Sept 2023

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
D01	Initial Review	SP	KC	MB	07/07/2023
D02	Draft Final	SP	KC	MB	15/09/2023

Approval for issue

M. Brian		15/09/2023

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1 INTRODUCTION

Codling Wind Park Limited (CWPL), a joint venture between Fred Olsen Renewables Ltd. (FORL) and Électricité de France (EDF) Renewables was established to develop Codling Wind Park. Both companies are leading developers, owners and operators of renewable energy assets, with many years of global experience in the renewable energy and offshore wind sector.

The Codling Wind Park (CWP) project comprises of the following main components:

- CWP Offshore Wind Farm (CWP OWF); and
- CWP Onshore transmission infrastructure (CWP OTI).

Whilst each component is comprised of multiple elements, this document considers the potential impact of developing a 220kV substation at Poolbeg on coastal processes within Dublin Port and wider Dublin Bay area. The substation at Poolbeg is required to facilitate the transmission of the 900 – 1,500 MW of electricity produced by the CWP OWF into the existing onshore transmission grid network. The layout of the Proposed Development is illustrated in Figure 1.1 overleaf.

A comprehensive description of the Proposed Development can be found in **Chapter 4 Project Description**.

The Proposed Development is located in close proximity to nationally important infrastructure and/or protected structure (Figure 1.1). It is therefore imperative to ensure that the Proposed Development does not result in either direct or in-direct impacts to existing infrastructure, the natural environment or protected structures.

To this end, RPS have been commissioned by CWP to undertake a detailed technical assessment of the hydraulic impact of the Proposed Development on the coastal processes, including the existing tide and wave regimes.

To inform this assessment, RPS have developed and undertook a numerical modelling programme to consider these potential impacts. The findings of this numerical modelling programme are presented in the following Sections of this technical report.

Figure 1.1: Looking out from Dublin Port with the north Bull wall and Great south wall shown in the distance.

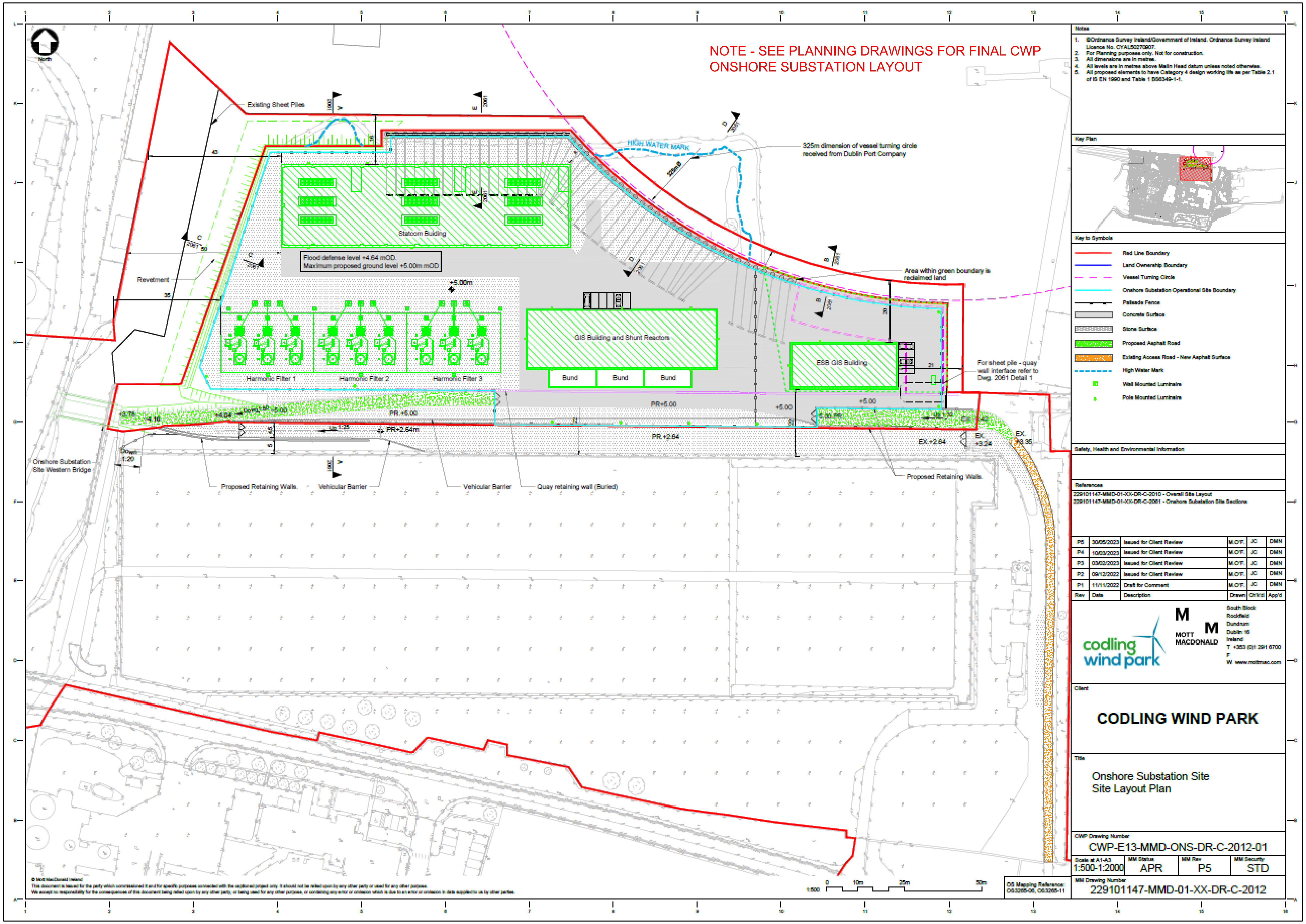


Figure 1.2: Codling Wind Park onshore sub-station site layout plan

2 MODELLING METHODOLOGY

RPS used the MIKE 21/3 hydrodynamic numerical modelling software package developed by DHI to address potential coastal processes issues. This was achieved by developing a range of two and three dimensional numerical models to represent:

- The pre-project scenario (in this case, post-MP2 Project); and
- The post-project scenario with the Codling Wind Park Project works in place.

These models were used to assess the operational impacts of the Proposed Development in the context of the following coastal processes:

- The tidal regime; and
- The inshore wave climate.

The impact of the Proposed Development on these coastal processes has been quantified by means of difference plots throughout this report, i.e., post-project minus pre-project conditions. As such, the extent and magnitude of potential impacts as a result of the Proposed Development can be clearly identified and compared against baseline conditions.

2.1 Coastal Process Modelling Software

A suite of coastal process models, based on the MIKE software developed by DHI, was used to assess the potential impact of the Proposed Development on the coastal processes within Dublin Port. The MIKE system is a state of the art, industry standard, modelling system, based on a flexible mesh approach. This software was developed for applications within oceanographic, coastal and estuarine environments. A brief synopsis of the MIKE system and modules used for this assessment is outlined below:

- **MIKE 21 & MIKE 3 Flow Model FM system** - Using these flexible mesh modelling systems, it is possible to simulate the mutual interaction between waves and currents by dynamically coupling the relevant modules in both two and three dimensions.
- **The Hydrodynamic module** –This module is capable of simulating water level variations and flows in response to a variety of forcing functions in lakes, estuaries, and coastal regions. The HD Module is the basic computational component of the MIKE 21 and MIKE 3 Flow Model systems providing the hydrodynamic basis for the Spectral Wave module.

  The Hydrodynamic module solves the two/three-dimensional incompressible Reynolds averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure. Thus, the module consists of continuity, momentum, temperature, salinity, and density equations. When being used in three dimensions, the free surface is taken into account using a sigma coordinate transformation approach whereby the vertical layer is divided equally into a discrete number of layers.
- **The Spectral Wave module** – This module simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas and accounts for key physical phenomena including wave growth by wave action, dissipation, refraction, shoaling and wave-current interaction.

2.1.1 Coastal Process Models and Data Sources

The models used to assess the impact of the Proposed Development on the coastal processes were developed from RPS' present-day Dublin Bay model.

RPS' present-day Dublin Bay Model was created using flexible mesh technology to provide detailed information on the coastal processes around Dublin Port and Dublin Bay. The model uses mesh sizes varying from 250,000 m^2 (equivalent to 500m x 500m squares) at the outer boundary of the model down to a very fine 225 m^2 (equivalent to 15m x 15m squares) along the approach channel and around the harbour channel (as presented in Figure 2.1). The bathymetry of this model was developed using data gathered from a hydrographic survey of the Dublin Port and Tolka estuary undertaken in 2017 and supplemented by data from the Irish National Seabed Survey, INFOMAR and other local surveys collated by RPS for the Irish Coastal

Wave and Water Level Modelling Study (ICWWS, 2018). These datasets were prioritised by date, with the most recent datasets being used first. Where overlaps between datasets existed, data were removed using a Geographical Information System (GIS) and then interpolated to the model domain to ensure a smooth transition between datasets. The position of the coastline in these models was defined by engineering drawings and GIS. The extent, mesh structure and bathymetry of this model is illustrated in Figure 2.1.

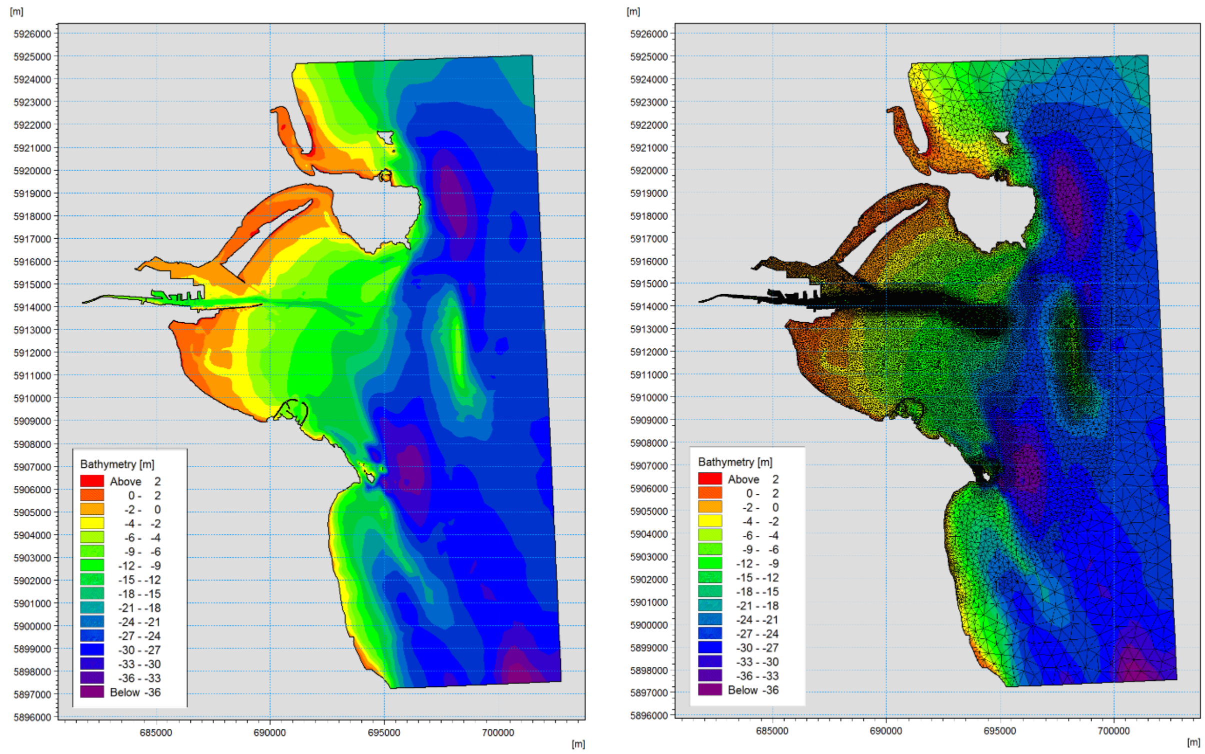


Figure 2.1 Extent and bathymetry of the Dublin Bay model (left) and the mesh structure of the Dublin Bay model (right)

The Dublin Bay model was then updated to produce a 2D version of the model that represented the baseline scenario (in this case, this represents the post-MP2 Project layout within Dublin Port). The Dublin Bay model was further updated to produce a second 2D version of the model which represented the Proposed Development in place. As such the post-project scenario model had updated bathymetry at Berth 47A and Pigeon House. These 2D models were used to appraise the impact of the Proposed Development on the inshore wave climate and produce tidal boundary condition data for the 3D models described below.

To account for density effects within Dublin Port caused by the freshwater inputs from the Liffey, Tolka and Dodder, it was necessary to undertake hydrodynamic modelling of the tidal regimes using 3D models. The extent of these 3D models which were developed using the same cell sizes and bathymetry is illustrated in Figure 2.5. The vertical domain of these models was defined using five equidistant sigma layers to represent the water column.

The bathymetry of the pre and post-project scenario models in the Dublin Port area is illustrated in Figure 2.2 and Figure 2.3 respectively. A Summary of the models that were developed for the assessment and their purpose is summarised in Table 2.1.

Table 2.1 Summary of the numerical models developed for the Proposed Development assessment and their purpose.

Numerical Model	2D Version	3D Version
Present day Dublin Bay	• Initial Calibration	• Initial Calibration
Pre-project scenario (Dublin Port with MP2 Project in place)	• Wave climate • Tidal regime	• Tidal regime
Post-project scenario (Dublin Port with Proposed Development in place)	• Wave climate • Tidal regime	• Tidal regime

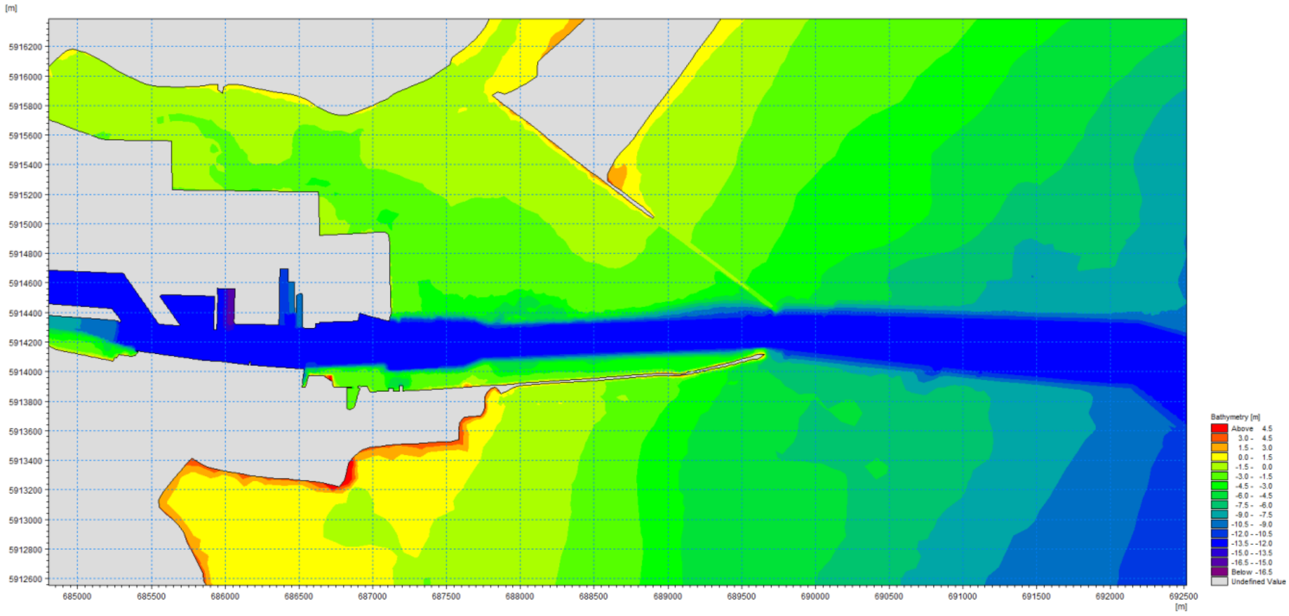


Figure 2.2: Bathymetry of the Dublin Port Baseline model (Post MP2 Project) – levels illustrated to Mean Sea Level

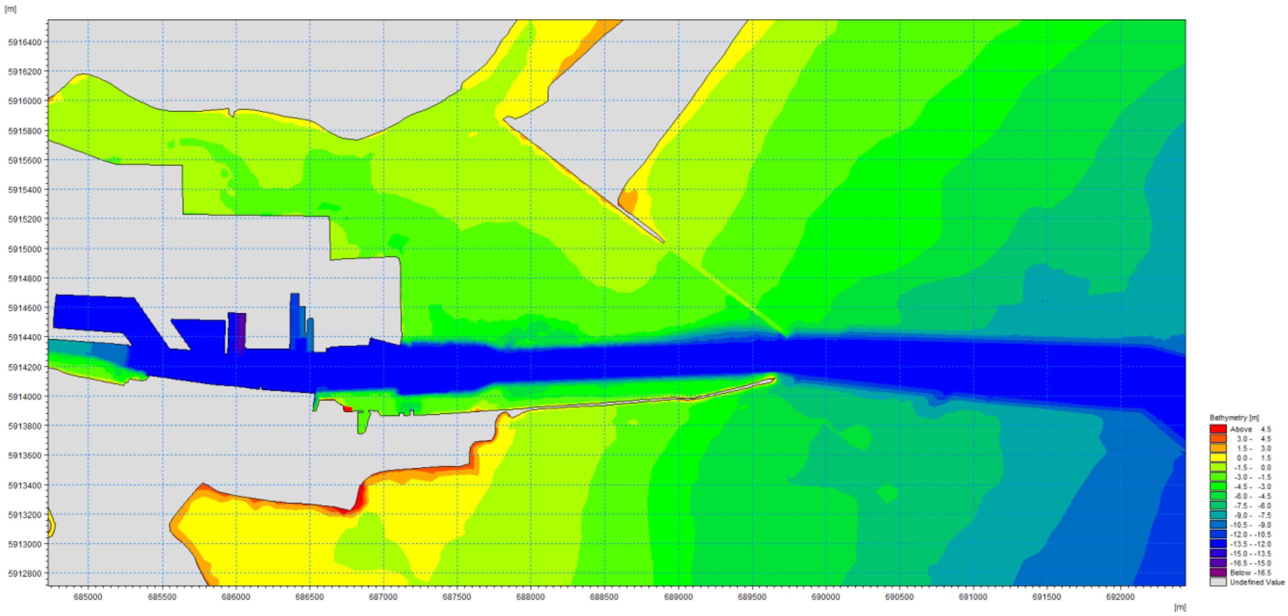


Figure 2.3: Bathymetry of the Dublin Port Operational model (Proposed Development and MP2 Project) – levels illustrated to Mean Sea Level

A survey in 2017 collected current data recorded by two Acoustic Doppler Current Profilers (ADCPs) which were deployed as part of the ABR Project. These devices accurately record current speed, current direction and water depth. One ADCP device was located in the harbour channel in close proximity to buoy 16 and the other device to the north of the approach channel.

The extent of the 2017 survey and location of the two ADCP devices that were deployed at part of the ABR Project is illustrated in Figure 2.4. Tidal current data recorded by these devices were used to calibrate and validate the present-day Dublin Bay model. Data recorded by the tide gauge located within Dublin Port was used to validate the simulated surface elevations. This calibration process is described in Appendix A.

The model verification process confirmed that the present Dublin Bay model provides a very good representation of the coastal processes in the Dublin Port and Dublin Bay areas.

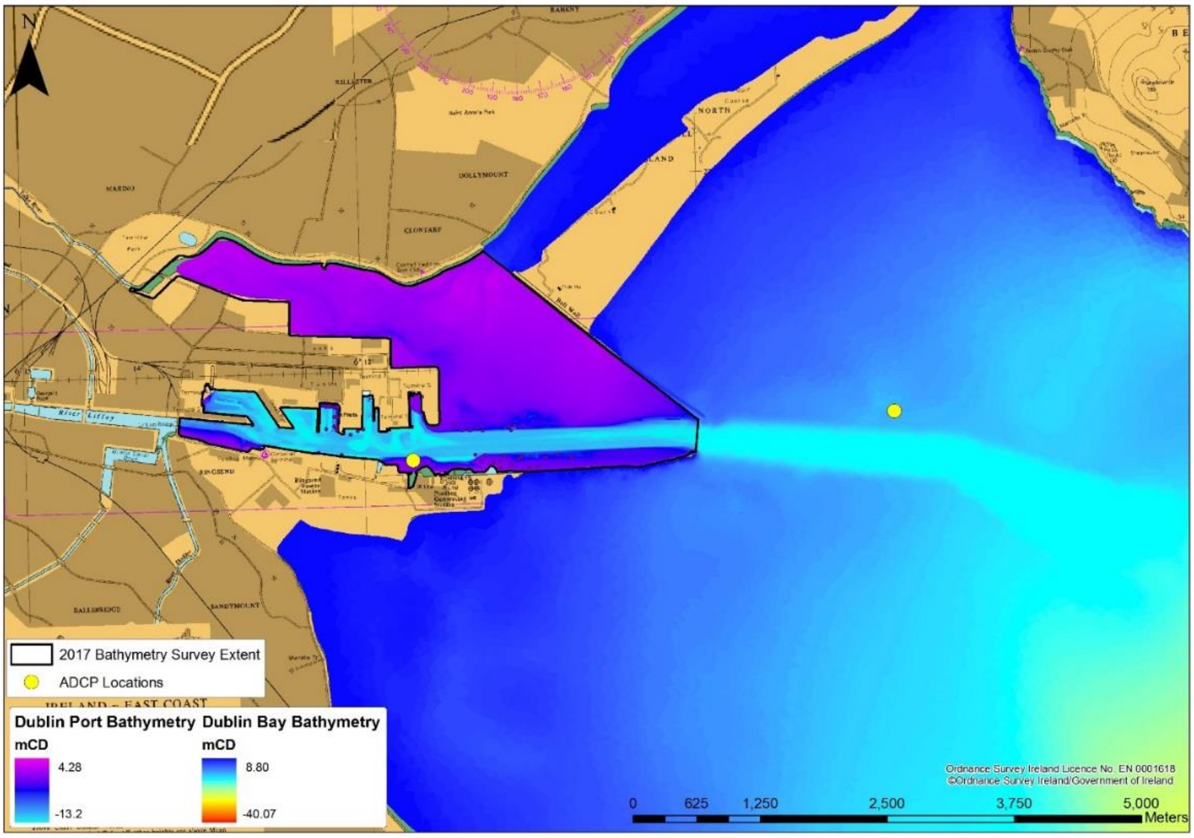


Figure 2.4: Location and coverage of the 2017 Bathymetric Survey

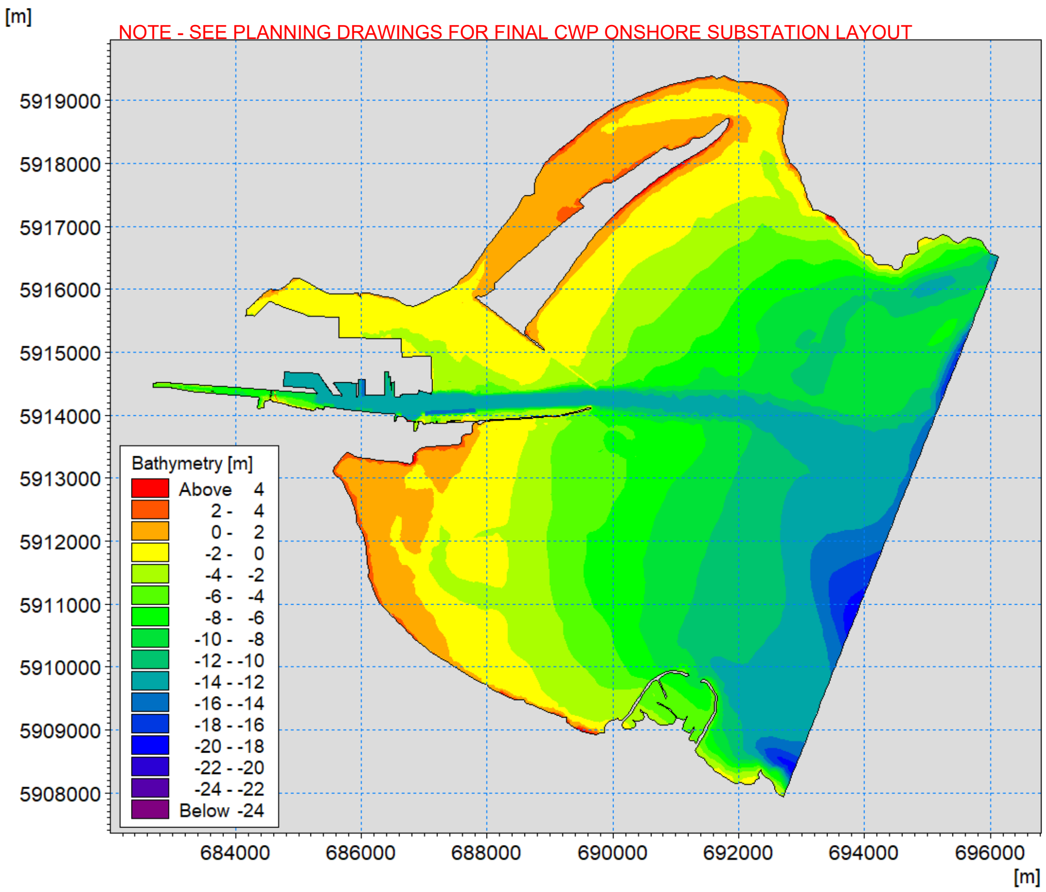


Figure 2.5: Bathymetry of the Dublin Port Baseline 3D model (Post MP2 Project) – levels illustrated to Mean Sea Level

2.1.1.1 Tidal Boundary Conditions

The tidal boundary conditions for the 2D pre-project and post-project scenario models were taken from RPS' Tide and Storm Surge Forecast (TSSF) model which is run on behalf of the Office of Public Works (OPW). This model was developed using flexible mesh technology with the mesh size (model resolution) varying from circa 24km along the offshore Atlantic boundary to circa 200m around the Irish coastline. The extent and bathymetry of the TSSF tidal surge model is presented in Figure 2.6.

RPS also utilised their ICPSS east coast wave model to gather wave boundary data for the Dublin Bay model to ensure that the hydrodynamic influence of the offshore Kish and Codling banks were accounted for in the model. The extent and bathymetry of the ICPSS east coast wave model is also presented in Figure 2.6.

All open sea boundaries were applied to the model as Flather boundaries whereby temporarily and spatially varying water level and current velocities are specified along the boundary. Flather boundaries are one of the most efficient boundary condition methods to downscale coarse model simulations to higher resolution areas as it avoids instabilities commonly associated with water level boundaries.

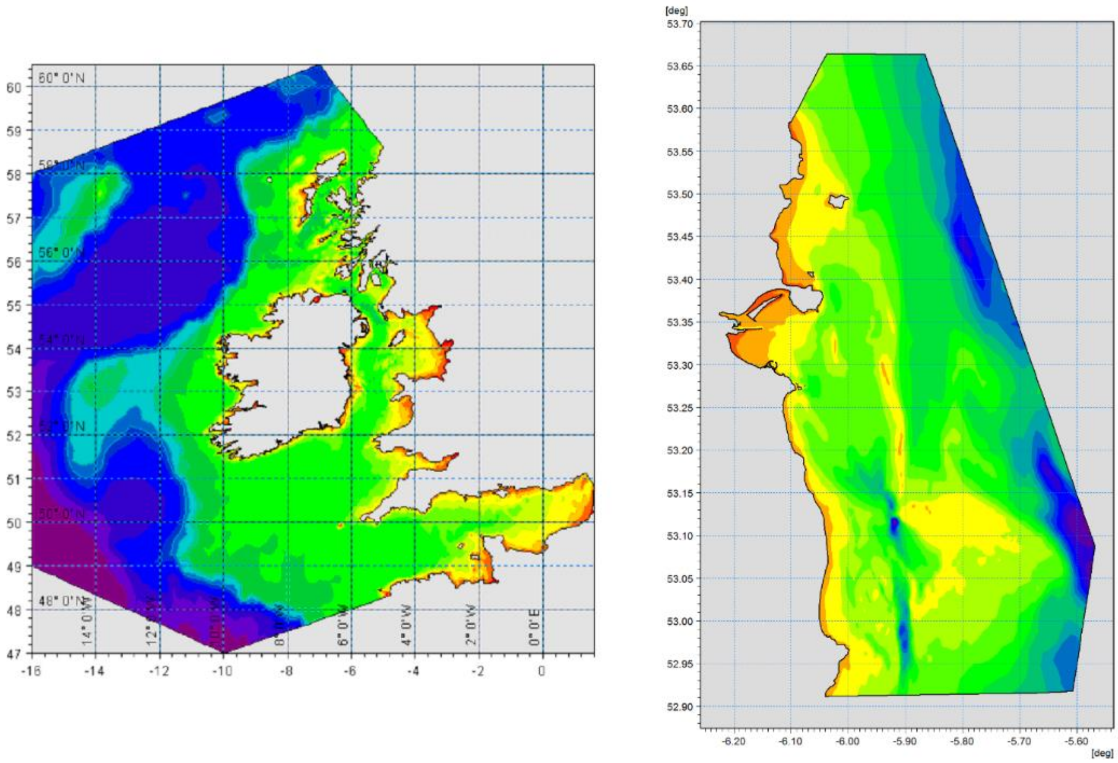


Figure 2.6 Extent and bathymetry of the Tide and Storm Surge Forecast (TSSF) model (left) and east coast wave model (right)

2.1.1.2 River Flows

The mean annual river flow values presented in Table 2.2 for the Liffey, Dodder and Tolka were used to calibrate the hydrodynamics of the baseline model (see Appendix A).

Upon successful calibration, RPS utilised the mean winter discharge rates to appraise the impact of the Proposed Development on the existing tidal regime as these conditions tended to produce marginally higher flow rates within the Port and therefore represented a worst-case scenario.

The flow rates presented in Table 2.2 were derived by reviewing available data from the Environment Protection Agency (EPA) HydroNet resource which provides historical data for hydrometric stations throughout Ireland. These data were verified through consultation with relevant stakeholders in Dublin Port who also record similar information for some water courses, including the River Liffey.

Table 2.2 Mean annual discharge rates from the Liffey, Dodder and Tolka used in the coastal process models.

Source	Mean annual discharge rate (m^3/s)	Mean winter discharge rate (m^3/s)
Liffey	15.6	25.0
Dodder	2.3	2.6
Tolka	1.4	1.6

2.1.1.3 Offshore wave information

Offshore wave data for points at 5.66ºW, 55.50ºN and 5.66ºW, 55.25ºN were taken from the UK Met Office European wave model and used as a source to select the largest event for each of the north-east, east and south-east directions. The three hourly data included wind wave and swell wave components in the form of the significant wave height, mean wave period, peak wave period and mean wave directions. The offshore wave climate data used in the wave transformation simulations are summarised in Table 2.3.

Table 2.3 Offshore wave climate data used to simulate the inshore wave climate.

Storm Event	Significant wave height (m)	Peak wave period (s)	Mean wave direction (ºN)
North Easterly	4.6	8.9	29
Easterly	5.5	8.2	98
South Easterly	5.4	10.4	148

2.1.1.4 Extreme Value Analyses of Wave Heights

In addition to examining inshore wave conditions during past storm events, RPS also considered the impact of the Proposed Development during 1 in 50 year return period climate conditions. The boundary conditions for these simulations were derived by undertaking an Extreme Value Analysis (EVA) of the data described in the previous section using the MIKE EVA 21 toolbox. This analysis was undertaken for 45 ºN directional sectors relevant to Dublin Port which were established by previous hydraulic studies to range between 22.5 – 157.5ºN.

Each EVA was performed by fitting a theoretical probability distribution to the 3-hourly wave data and hourly wind data. A partial duration series, also known as a peak over threshold model was used to select the largest events that occurred within the data set for each relevant directional sector. A Weibull probability distribution was then fitted to the datasets using a Monte Carlo re-sampling technique. This approach was used to derive a series of return period waves heights. The significant wave heights for various return period events are presented in Table 2.4 whilst the EVA output for each relevant directional sector is presented in Figure 2.7 to Figure 2.9.

Table 2.4: Output from the EVA of the offshore wave data (5.667ºW, 53.349ºN)

Return Period	Significant Wave Height [m] & Directional Sector [ºN]		
	22.50 – 67.50	67.5 – 112.5	112.5 – 157.5
2	3.03	2.69	3.84
5	3.80	3.44	4.44
10	4.30	3.93	4.83
20	4.77	4.41	5.19
50	5.37	5.02	5.66
100	5.82	5.48	6.01
200	6.26	5.94	6.36
500	6.83	6.54	6.82

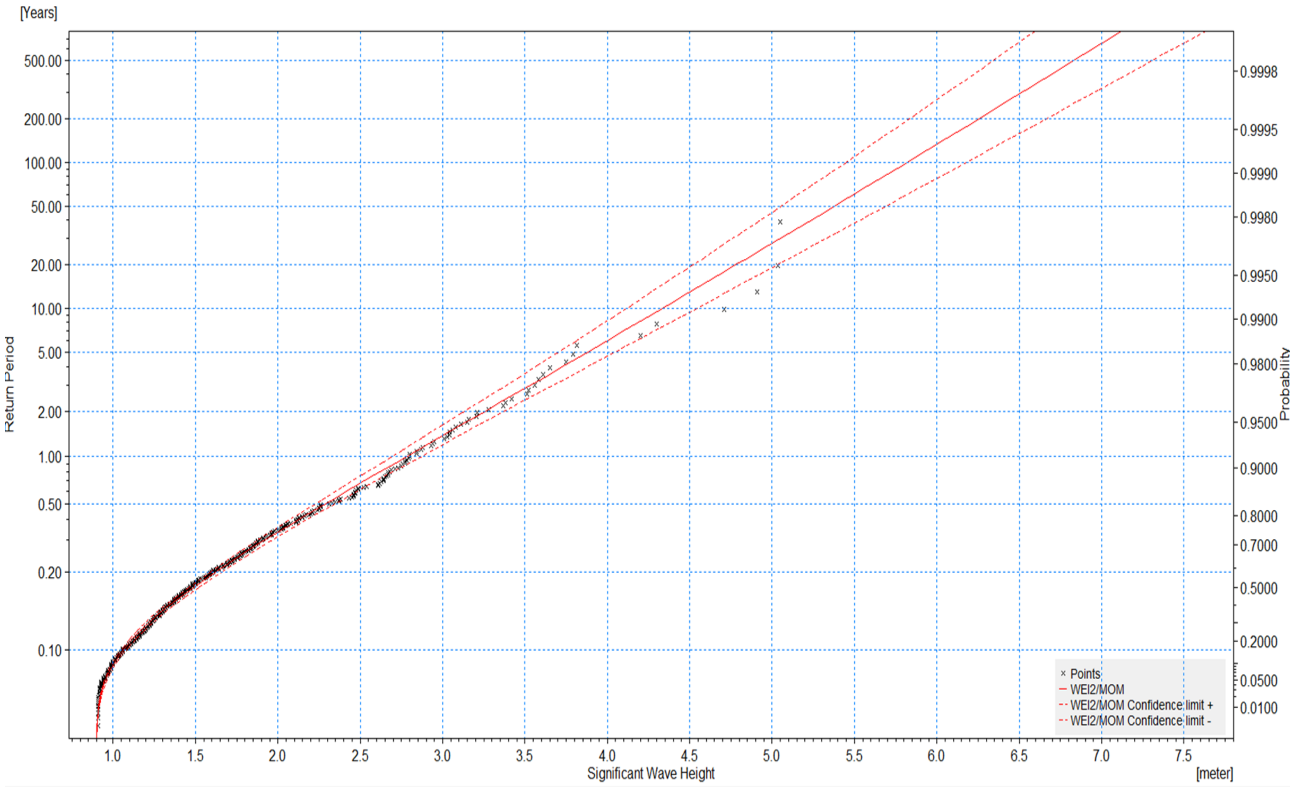


Figure 2.7: EVA of offshore waves from 22.50 – 67.50ºN between 1979-2019 at 53.349ºN -5.667ºW

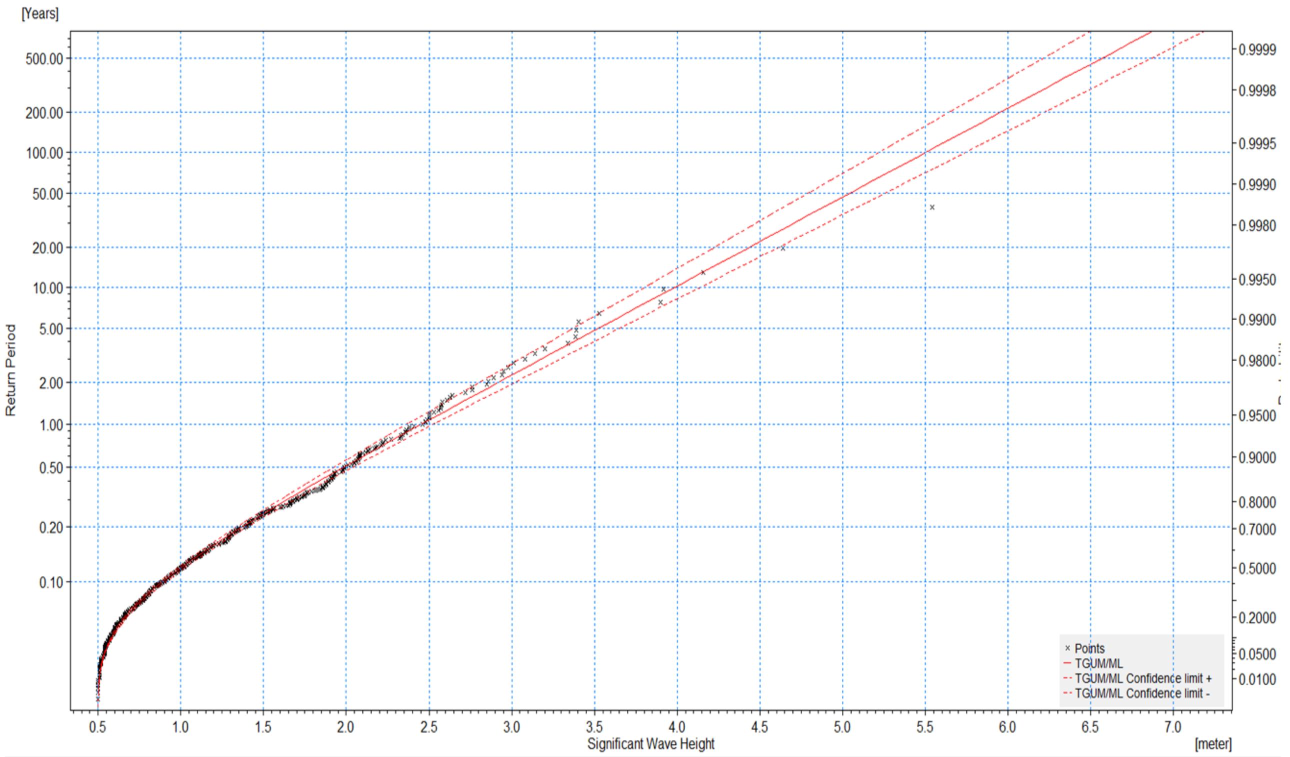


Figure 2.8: EVA of offshore waves from 67.50 – 112.50ºN between 1979-2019 at 53.349ºN -5.667ºW

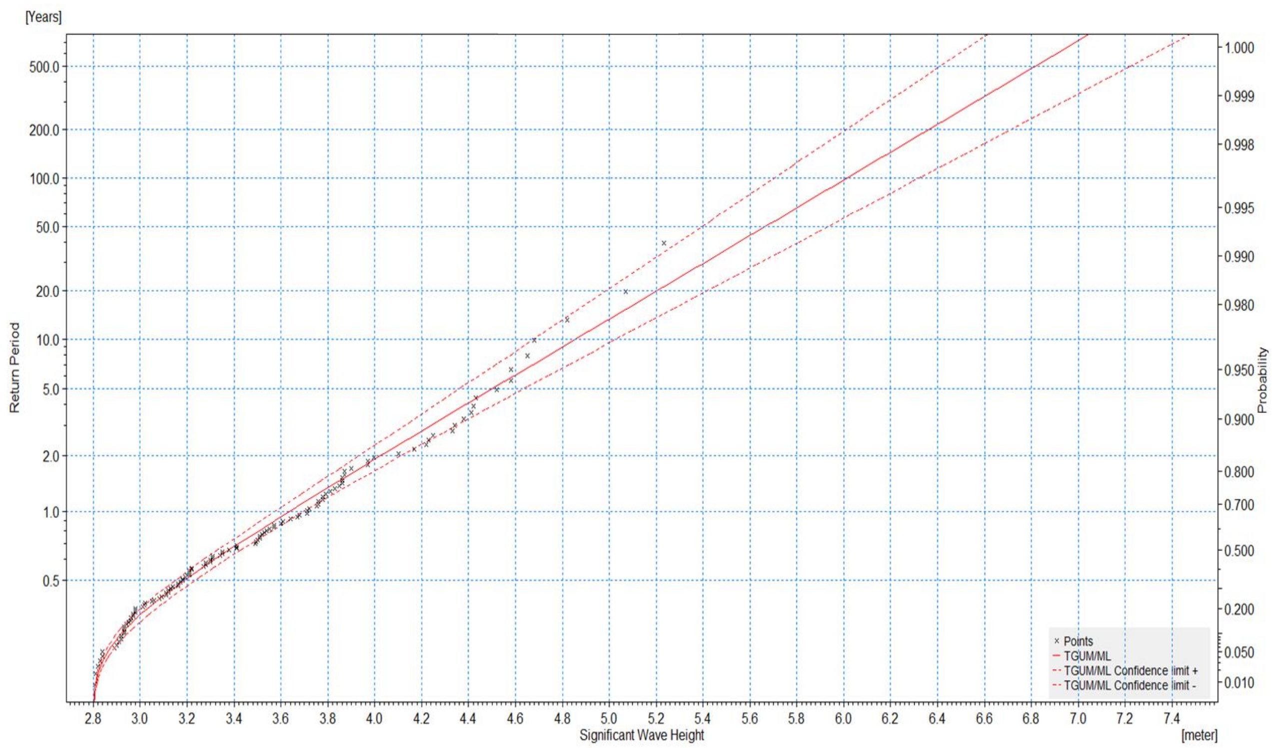


Figure 2.9: EVA of offshore waves from 112.50 – 157.50ºN between 1979-2019 at 53.349ºN -5.667ºW

2.1.1.5 Extreme Value Analyses of Wind Speeds

To derive corresponding wind speeds for the 1 in 50 year wave events, RPS analysed the offshore wind data simulated by NOAA's Climate Forecast System Re-Analysis (CFSR) model between 1979 and 2019 at the offshore point of 5.667 ºW, 53.349 ºN.

Following a similar approach used to assess extreme offshore waves, RPS also undertook an EVA of the offshore hourly wind data set for the 40 years from 1979 - 2019 using the MIKE EVA 21 toolbox. The extreme wind speeds for directional sectors relevant to Dublin Port are presented in Table 2.5 below.

Table 2.5: Output from the EVA of the offshore wind data (5.667ºW, 53.349ºN)

Return Period	Wind Speed [m/s] & Directional Sector [ºN]		
	22.50 – 67.50	67.5 – 112.5	112.5 – 157.5
2	16.23	15.49	17.07
5	18.39	18.19	19.71
10	19.71	19.89	21.36
20	20.91	21.49	22.88
50	22.40	23.49	24.79
100	23.48	24.96	26.18
200	24.52	26.40	27.54
500	25.86	28.26	29.29

2.2 Receiving Environment

In this section of the environmental appraisal, the baseline scenarios (Dublin Port with MP2 Project in place) in respect of tidal and wave patterns within Dublin Port and Bay are presented.

2.2.1 Tidal Regime within Dublin Port (Post-MP2 Project scenario)

The MIKE 3 Hydrodynamic module described in Section 2.1.1.1 was used in conjunction with the post-MP2 Project scenario 3D model to derive baseline tidal regime information within Dublin Port.

Typical tidal flow patterns for a spring ebb and spring flood tide are presented in Figure 2.10 and Figure 2.11. These tidal flow diagrams illustrate that the current speeds in the central navigation channel are marginally higher during mid-ebb conditions relative to mid-flood conditions owing to the contribution of flow from the Liffey, Dodder and Tolka.

It should be noted that the following plots represent conditions within the middle layer of the water column.

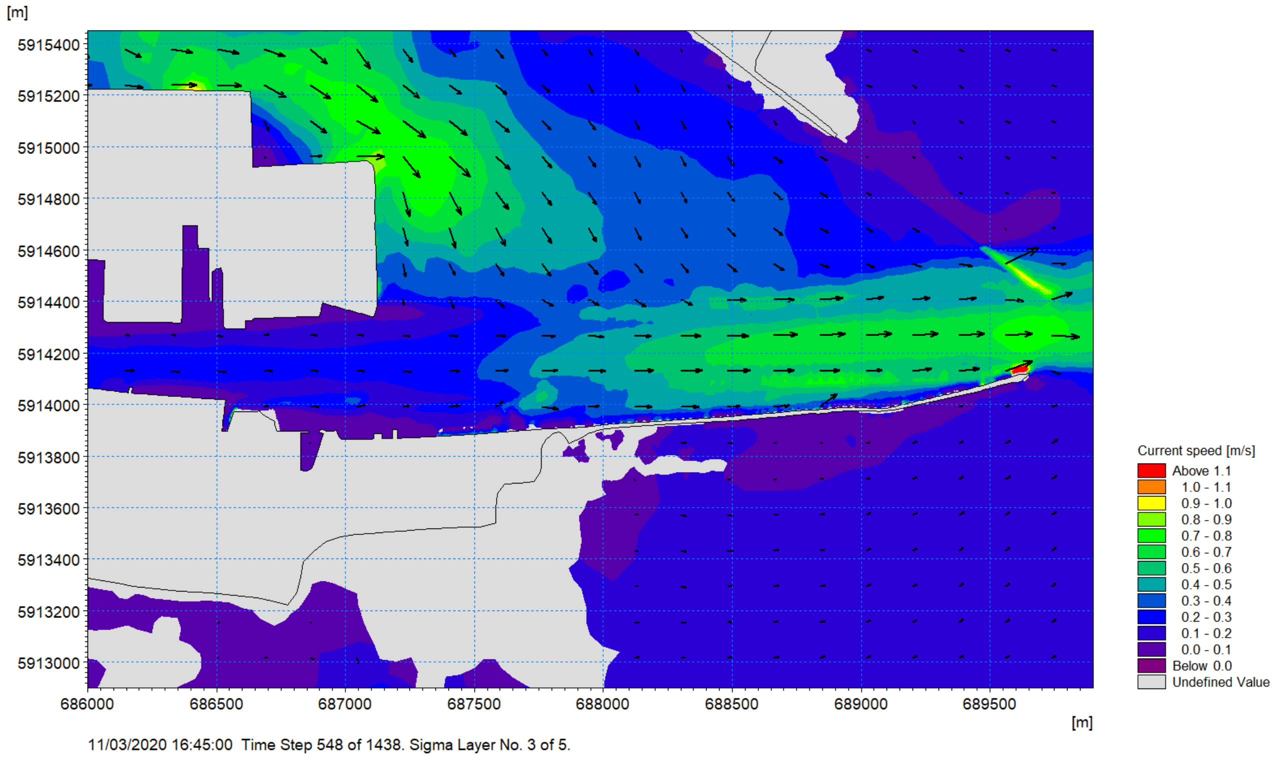


Figure 2.10 Typical spring mid ebb tidal flow patterns in vertical layer 3 of 5– Post-MP2 Project

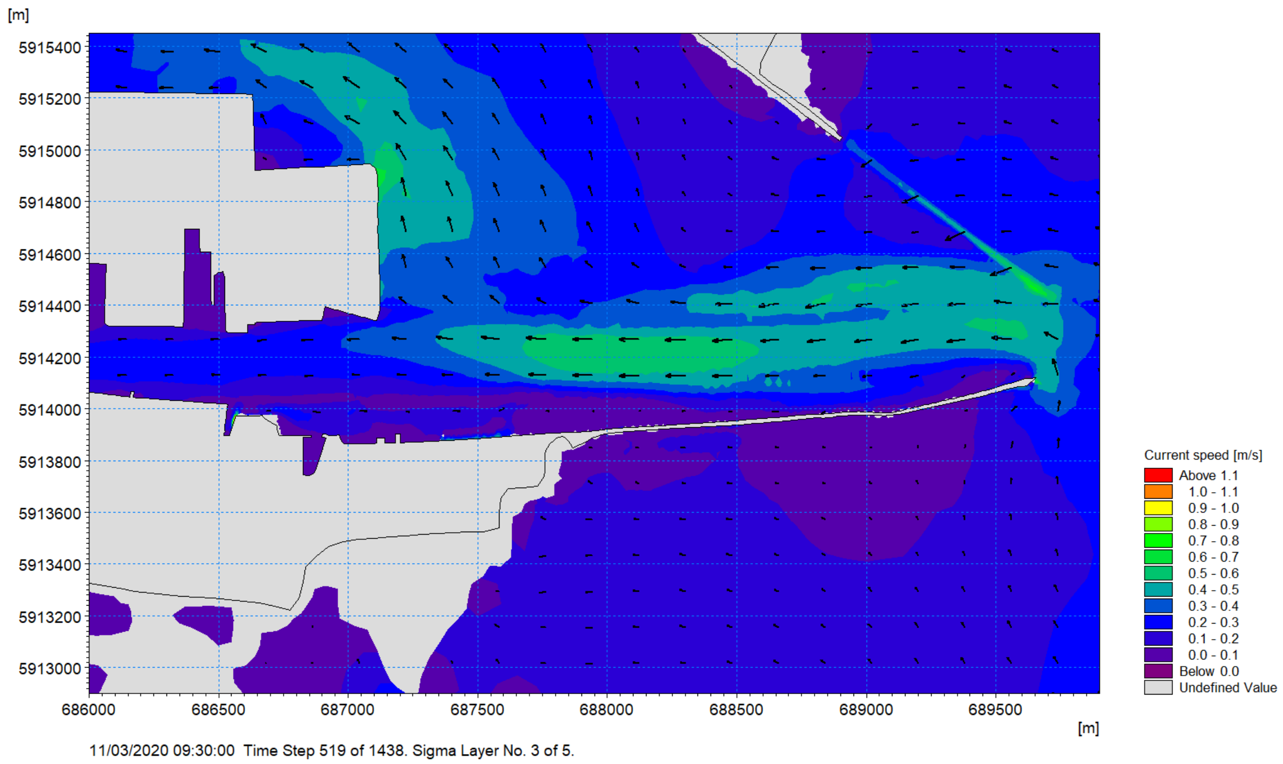


Figure 2.11: Typical spring mid flood tidal flow patterns in vertical layer 3 of 5 – Post-MP2 Project

2.2.2 Wave Climate within Dublin Port (Post-MP2 Project scenario)

The MIKE 21 Spectral Wave module described in Section 2.1.1 was used in conjunction with the post-MP2 Project scenario 2D model to transform the offshore wave conditions for the north easterly, easterly and south easterly storm events into the nearshore. These offshore wave conditions are summarised in Table 2.3. Corresponding wind speeds and directions as recorded by Met Éireann's M2 wave buoy were applied to the entire model domain.

It should be noted that the Spectral Wave module was considered the most appropriate method to assess the inshore wave climate as the alternative Boussinesq wave harbour disturbance model does not account for wind wave generation. This a particularly important factor for areas such as the Clontarf frontage where the wave climate is dominated by wind waves generated over short fetches.

Figure 2.12, Figure 2.13 and Figure 2.14 present the inshore wave heights in Dublin Bay at spring high tide during north easterly, easterly and south easterly storm events respectively. It will be seen from these figures that based on these simulations the largest waves that propagate into Dublin Port occur during easterly storm events at spring high water.

The extreme conditions described in Section 2.1.1 were then used to simulate 1 in 50 year return period storm events into Dublin Port. Figure 2.15, Figure 2.16 and Figure 2.17 shows the 1 in 50 year storm events from the north east, east and south east. The significant wave heights experienced at Pigeon House during these events did not generally exceed 0.75m.

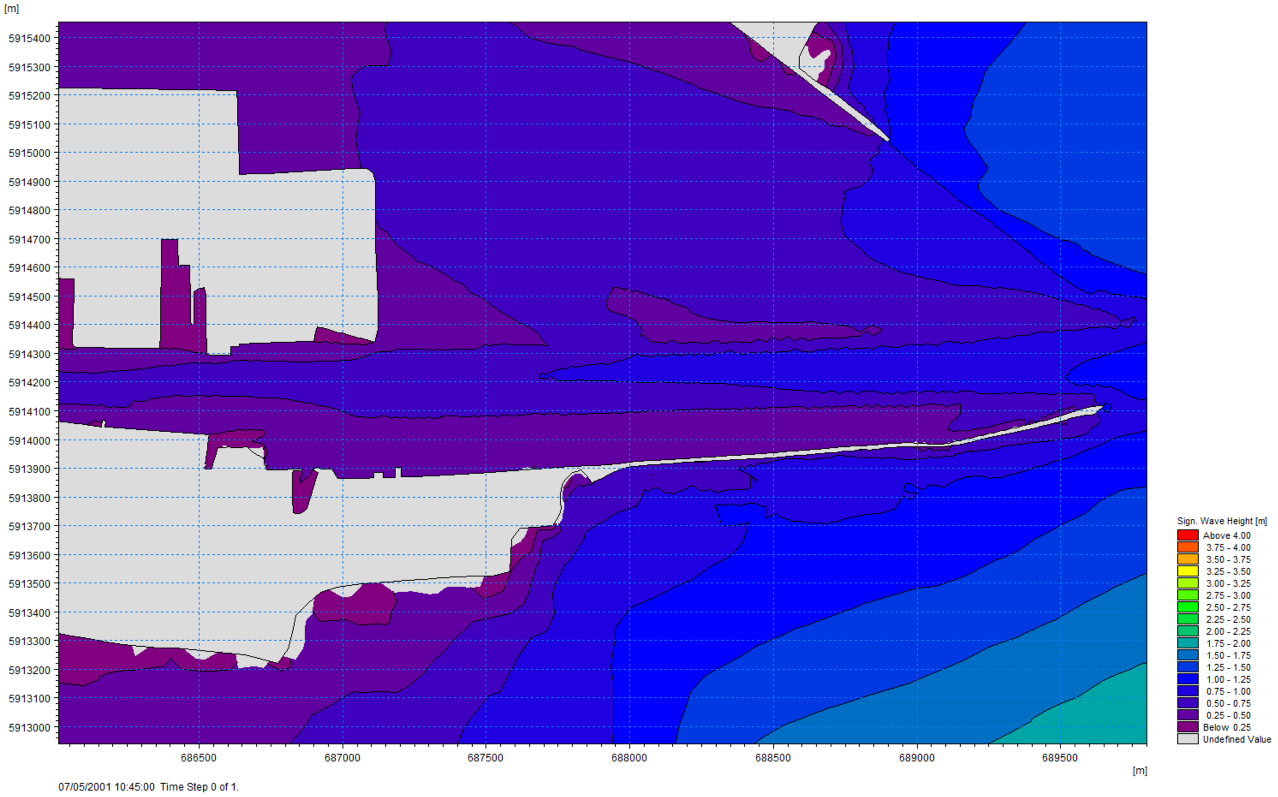


Figure 2.12: North Easterly storm wave heights at spring high water – Post-MP2 Project

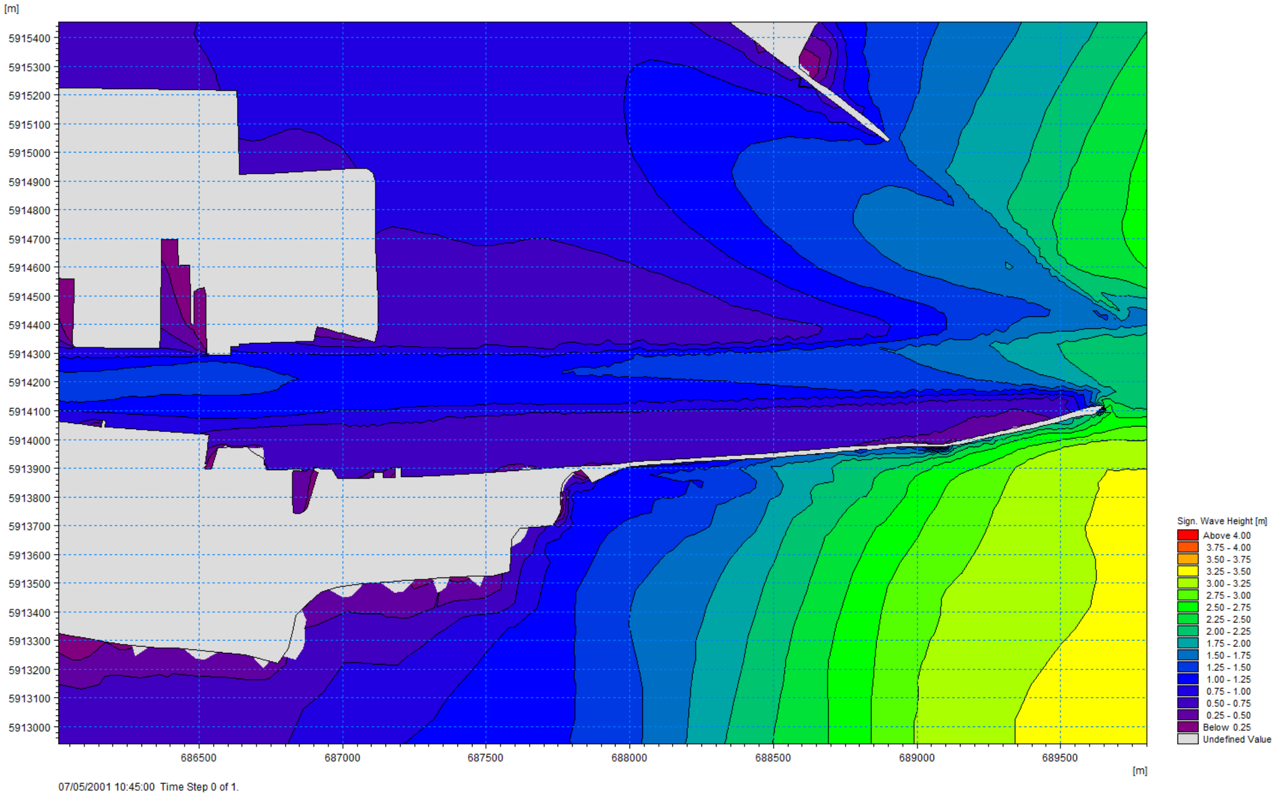


Figure 2.13**:** Easterly storm wave heights at spring high water – Post-MP2 Project

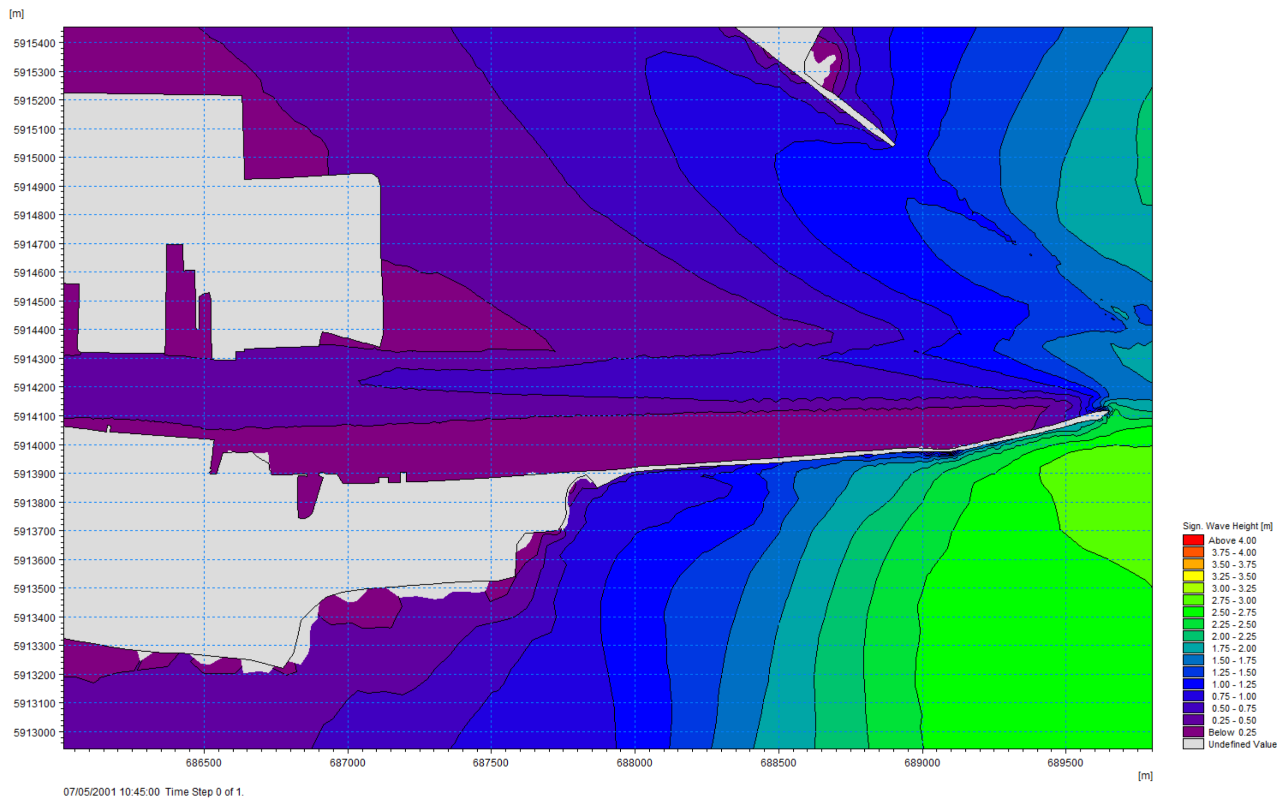


Figure 2.14: South Easterly storm wave heights at spring high water – Post-MP2 Project

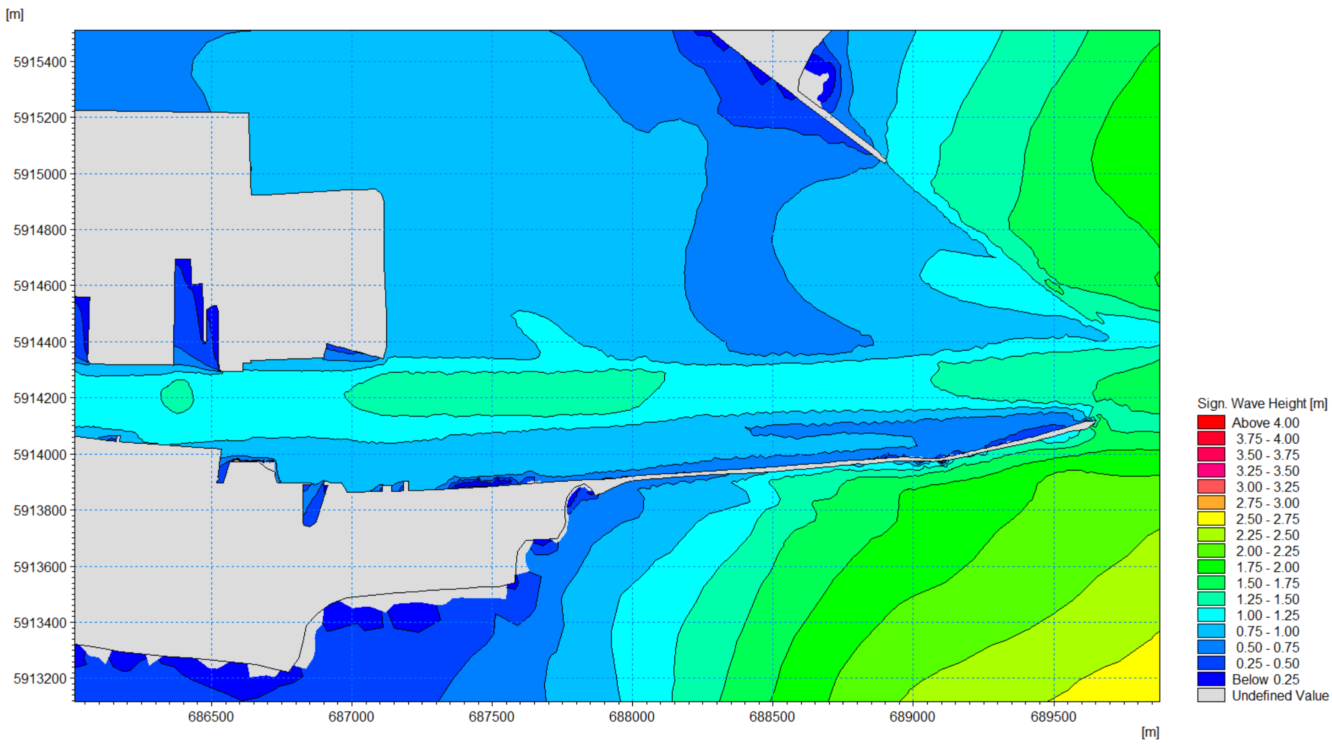


Figure 2.15: North Easterly 1 in 50 storm wave heights– Post-MP2 Project

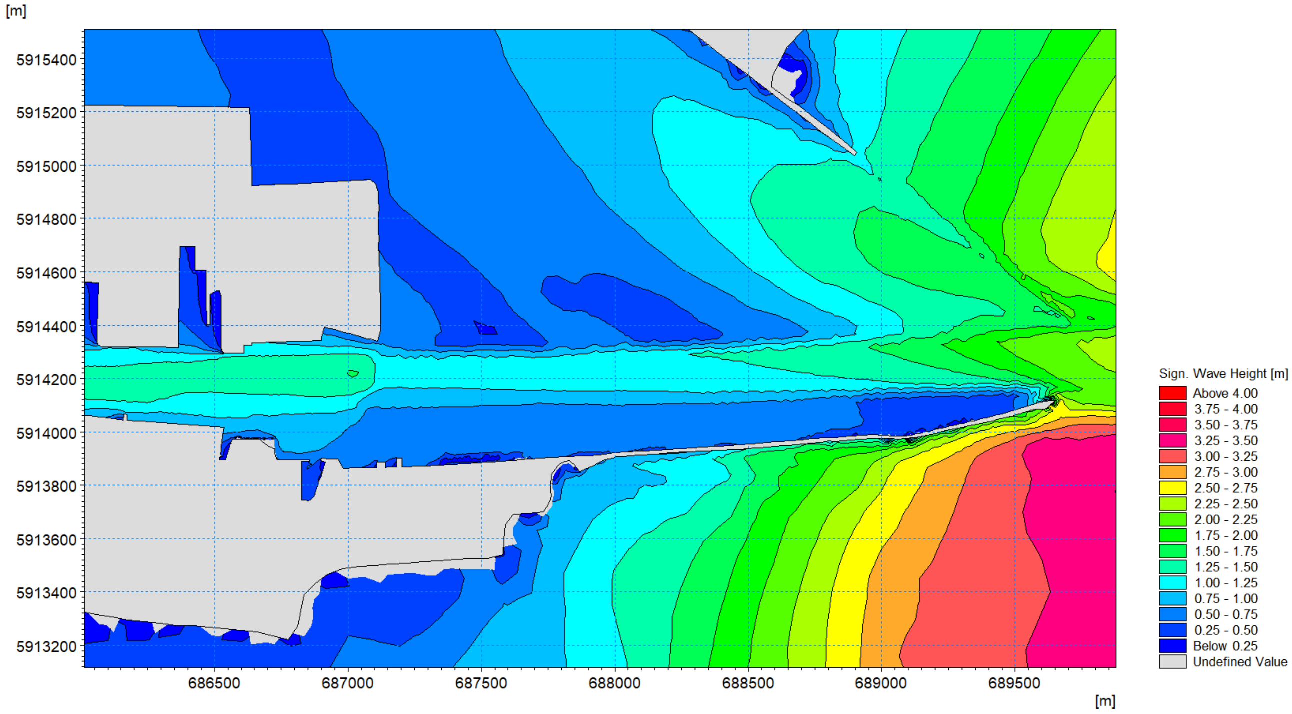


Figure 2.16: Easterly 1 in 50 storm wave heights – Post-MP2 Project

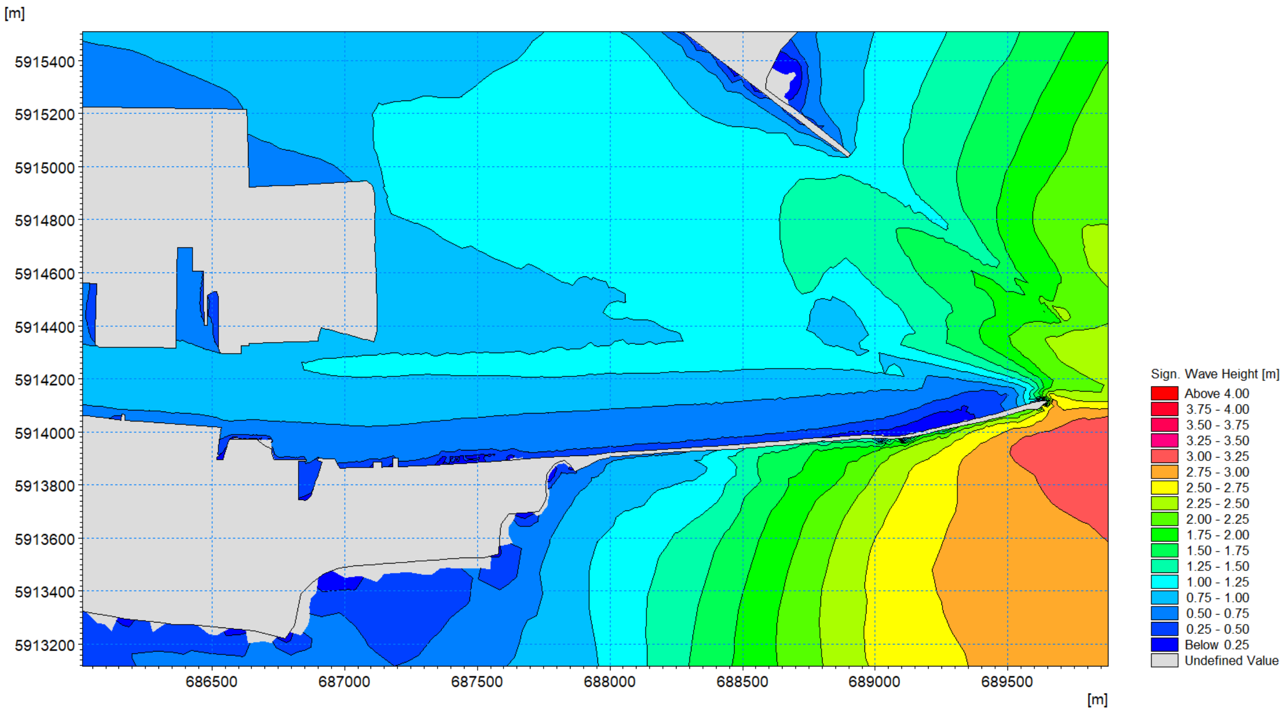


Figure 2.17: South Easterly 1 in 50 storm wave heights at spring high water – Post-MP2 Project

2.3 Description of Potential Impacts

2.3.1.1 Potential changes to the existing tidal regime

The potential for changes with the elements of the scheme in place was assessed to consider the potential for operational phase impact of the Proposed Development. The MIKE 3 Hydrodynamic module described in Section 2.1 was used in conjunction with the Proposed Development scenario 3D model to simulate the tidal regime in the Dublin Port following the implementation of the Proposed Development. Typical tidal flow patterns for a spring ebb and spring flood tide from the operational simulation are presented in Figure 2.18 and Figure 2.19. These figures represent conditions within the middle layer of the water column.

The difference in depth averaged modelled current velocities for the baseline and operational simulations have been computed for the mid spring ebb and the mid spring flood tides, and are presented in Figure 2.20, Figure 2.21. Spring tides are generally periods of greatest current velocities[1]. These figures demonstrate that current velocity remains substantially unchanged throughout most of the Port area. The maximum predicted change to the mid-ebb or flood current speeds is less than ±0.3m/s. The greatest changes are confined to within the footprint of the works at Berth 47A. Predicted changes in current speed reduce rapidly outside the works areas and changes to mid-ebb or mid-flood current speeds are less than ±0.01m/s outside the immediate area of the works. No notable changes to the tidal regime were detected outside of Dublin Port.

The net difference in the depth averaged mean current velocity over an entire spring tidal cycle (i.e., *c.*12.44hrs) is presented in Figure 2.22. This figure clearly shows that any predicted changes in current velocity resulting from the Proposed Development would be limited to relatively small areas within the vicinity of works. Net changes range between ±0.15m/s and are only predicted in very small areas within the footprint of the works. There are no predicted net changes to the mean current velocity over an entire spring tidal cycle outside of the footprint of the works.

Therefore, the tidal regime is predicted to remain substantially unchanged as a result of the Proposed Development. Given the localised nature and small absolute magnitude of any predicted changes in tidal current velocity it is unlikely that there will be any significant change in net scouring or deposition of sediments within the Liffey Estuary or Dublin Bay resulting from the Proposed Development.

The risk of impact is determined to be negligible, and no mitigation is required.

[1] Prevailing discharge rates from the Rivers Liffey, Dodder and Tolka Estuary will also influence current velocities within the Port and may occur independently of spring conditions. However, a comparative assessment found that increasing discharge flow rates in the River Liffey from 15.6 cumecs (mean annual flow rate) to 25.0 cumecs (mean winter flow rate) resulted in a negligible increase in tidal velocities of +0.03m/s at a point near Pigeon House.

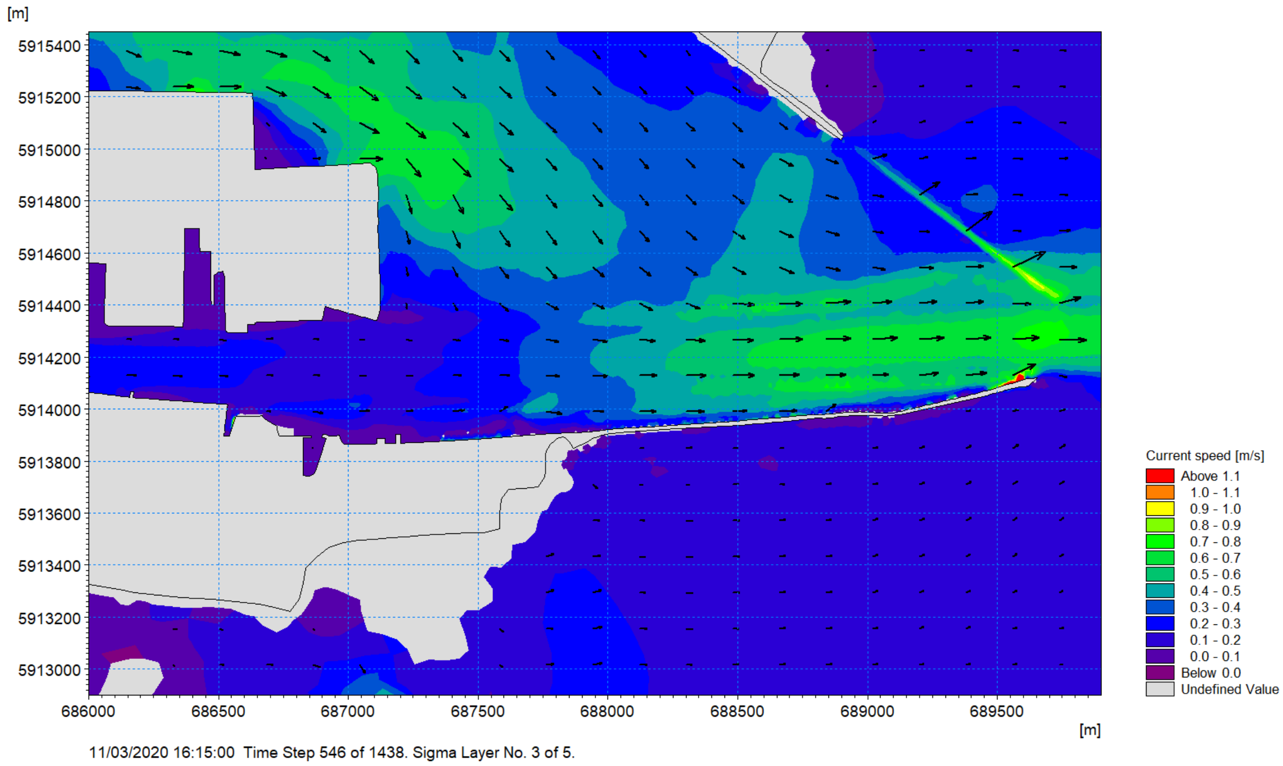


Figure 2.18: Typical spring mid ebb tidal flow patterns in vertical layer 3 of 5 – Operation Phase

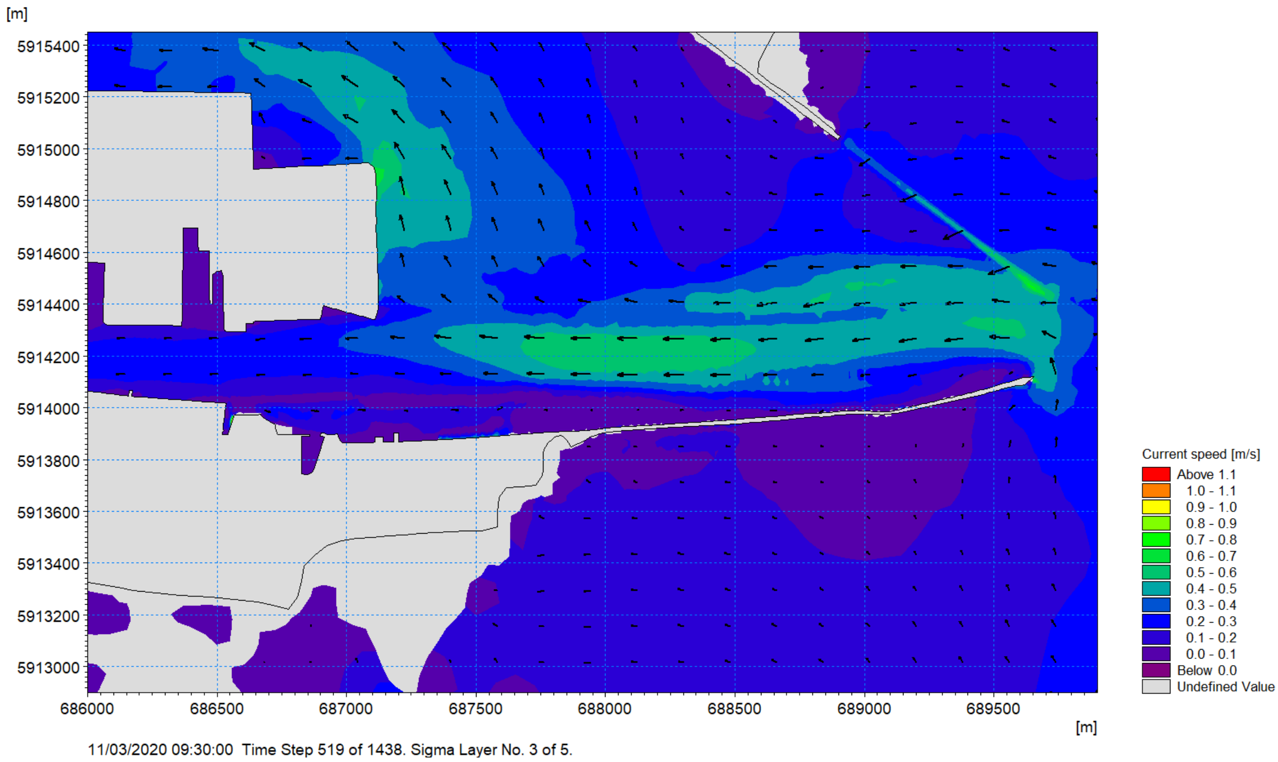


Figure 2.19: Typical spring mid flood tidal flow patterns in vertical layer 3 of 5 – Operation Phase

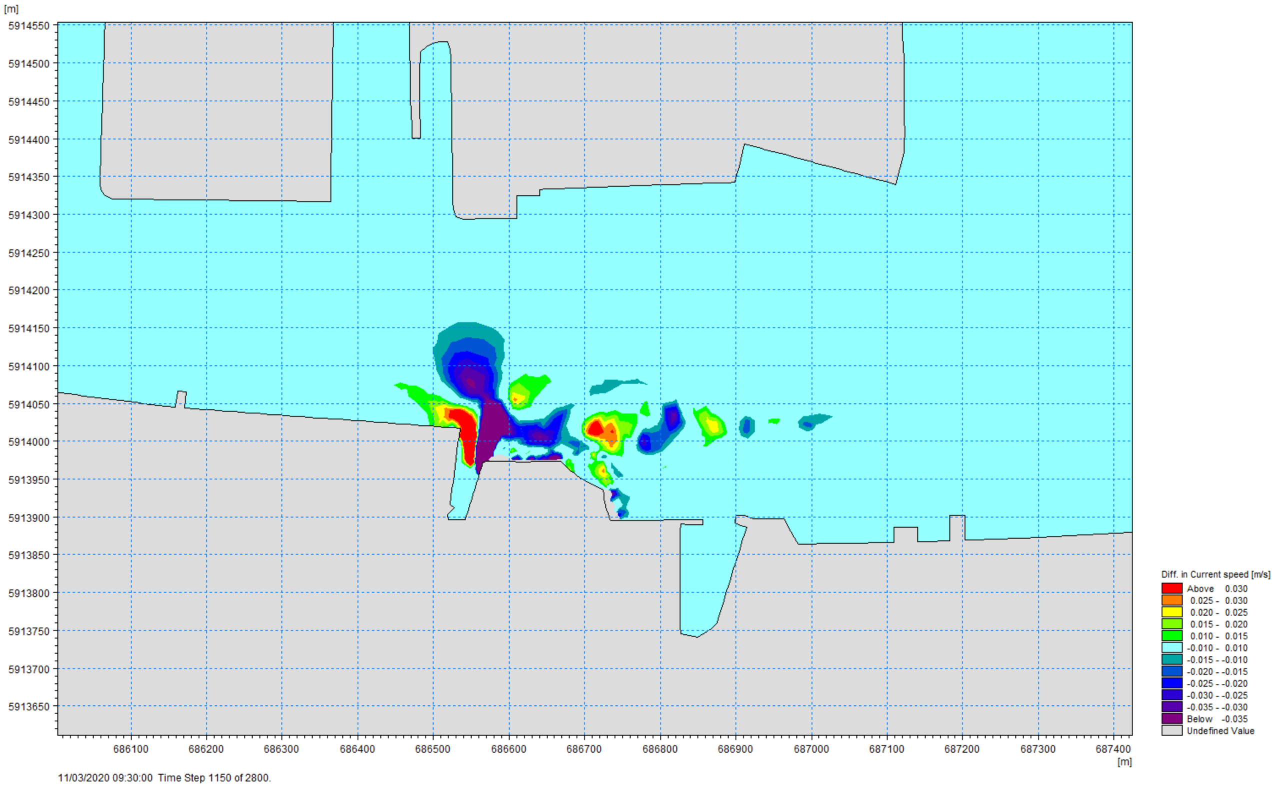


Figure 2.20: Difference in typical spring flood mid tidal flow patterns (depth averaged) as a result of the Proposed Development

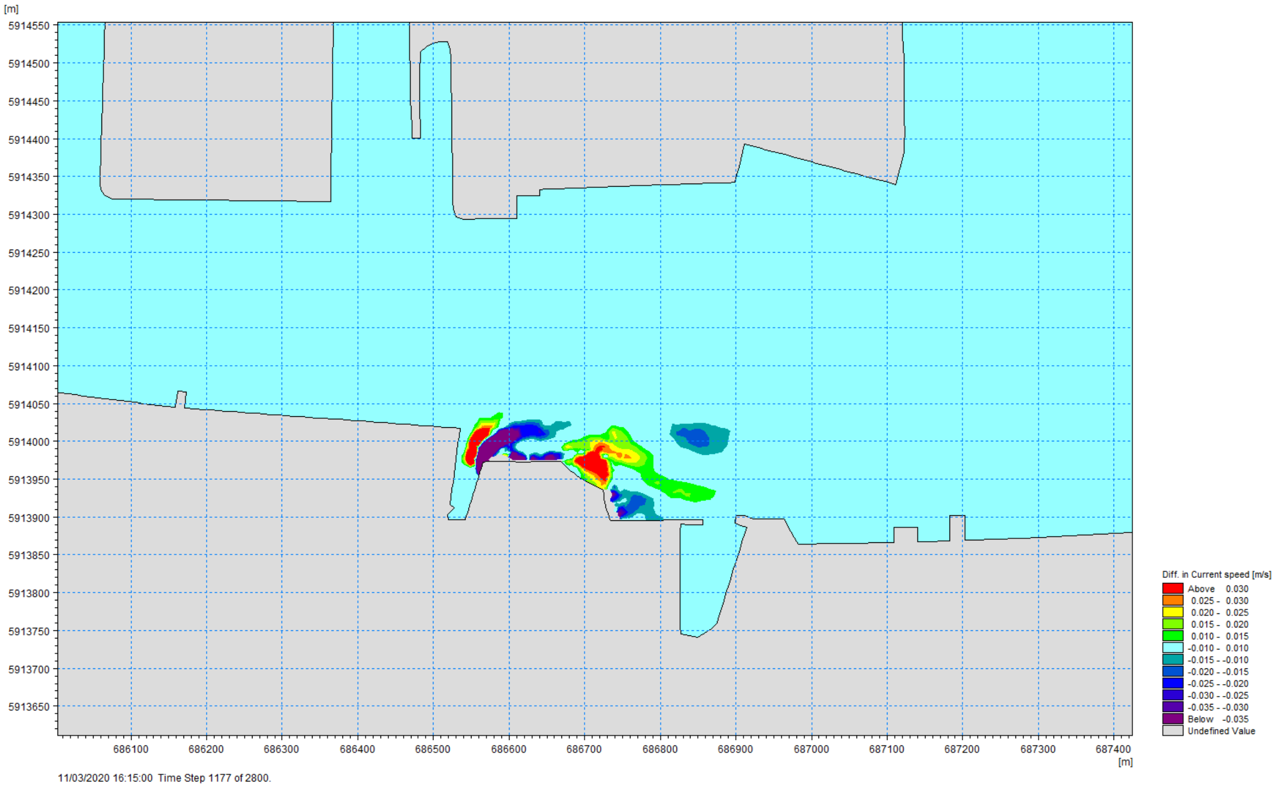


Figure 2.21: Difference in typical spring ebb tidal flow patterns (depth averaged) as a result of the Proposed Development

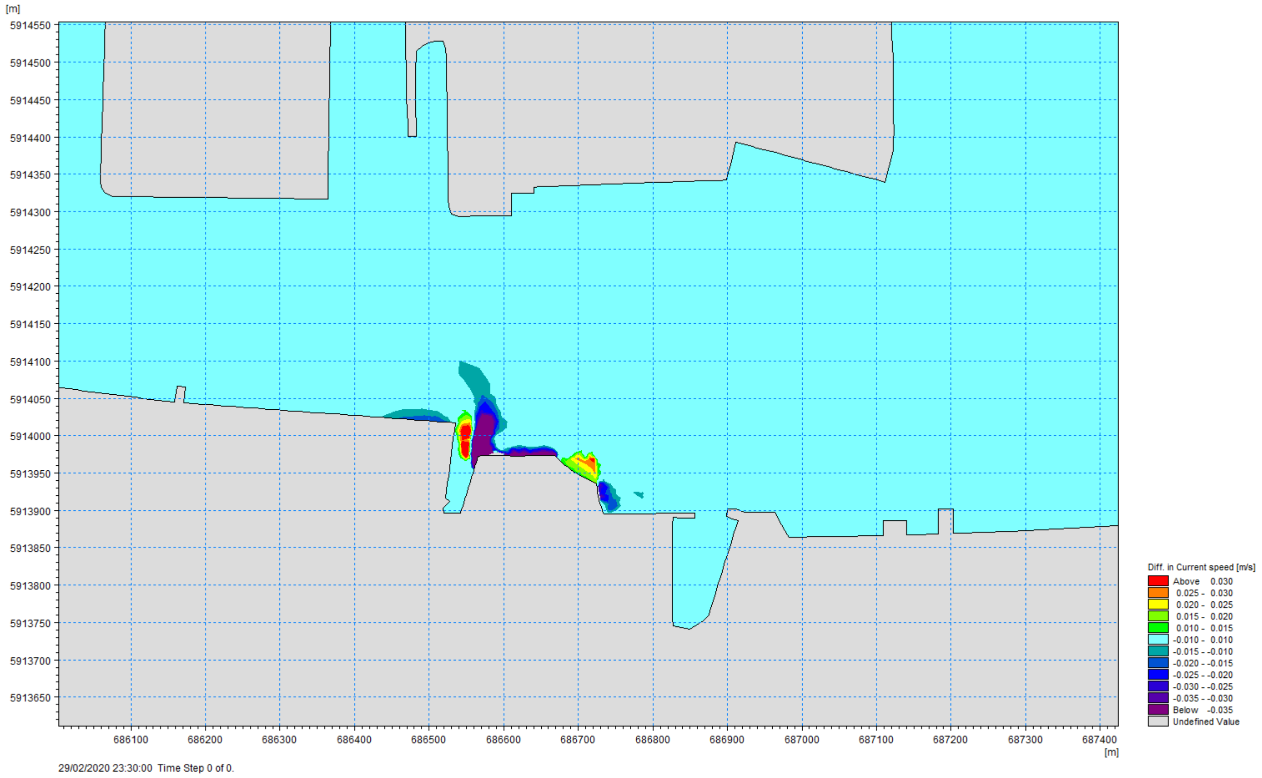


Figure 2.22 Difference in mean spring tidal flow patterns (depth averaged) across an entire tidal cycle as a result of the Proposed Development

2.3.1.2 Potential changes to the existing inshore wave climate

Operational phase impacts also included potential alteration to wave climate (and its associated possible impact on flood risk). The MIKE 21 Spectral Wave module described in Section 2.1 was used in conjunction with the Proposed Development scenario 2D model to re-run the offshore wave climate simulations in Dublin Bay based on the various wave conditions described in Section 2.2.2.

The simulated operational inshore wave climate in Dublin Port and the adjacent Dublin coastline is illustrated in Figure 2.23 to Figure 2.25 for north easterly, easterly and south easterly storm events at spring high tide respectively. Figure 2.26 to Figure 2.28 show the significant wave heights during 1 in 50 year storm events from the same range of directional sectors.

Wave height difference plots are presented for the storm events in Figure 2.29 to Figure 2.34 to highlight the changes to the inshore wave climate as a result of the Proposed Development. The results show that, during all storm events modelled, only small changes in the wave climate in Dublin Port are predicted and no discernible changes were detected along adjacent coastline areas. Changes in wave height are confined to the dredged and infilled areas during the operation phase.

During north easterly storm events, wave heights at Berth 47A are likely to increase by less than 0.30m but decrease by a similar magnitude at the infilled areas. During south easterly storm events, smaller changes of ±0.1m are predicted at Berth 47A due to the existing protection provided by the Great South Wall during this storm direction. During easterly storm events, predicted differences in the wave climate are confined to the dredged area where changes in wave height of less than 0.70m are predicted. Decreases of 0.7m are expected at the infilled area. These predicted changes are analogous in extent and magnitude to the change in wave conditions observed during 1 in 50 year return period storm conditions.

Changes in bathymetry due to dredging activities have the potential to alter the energy with which waves break and could conceivably result in wave overtopping of structures and flood defences. However, consideration of changes to the wave climate due to the Proposed Development presented above show no discernible change in relevant proximate outside the immediate areas of the works. Changes in wave height within the Port beyond the immediate footprint of the Proposed Development is predicted to be less than ±0.1m during typical storm conditions. These changes are not considered significant and will not impact operations within the Port. Therefore, the risk of potential coastal flooding due to the Proposed Development in these areas is determined to be negligible and no mitigation is required.

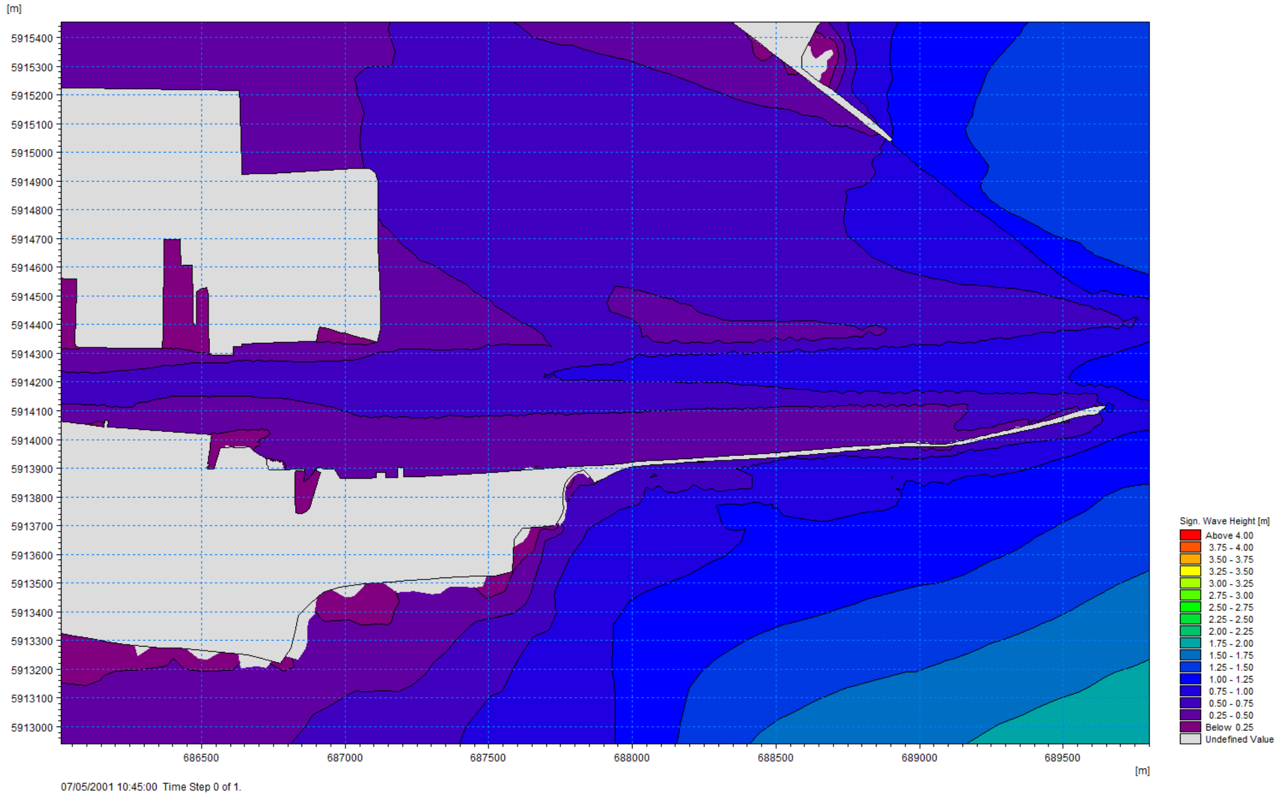


Figure 2.23: North Easterly storm wave heights at spring high water – Operation Phase

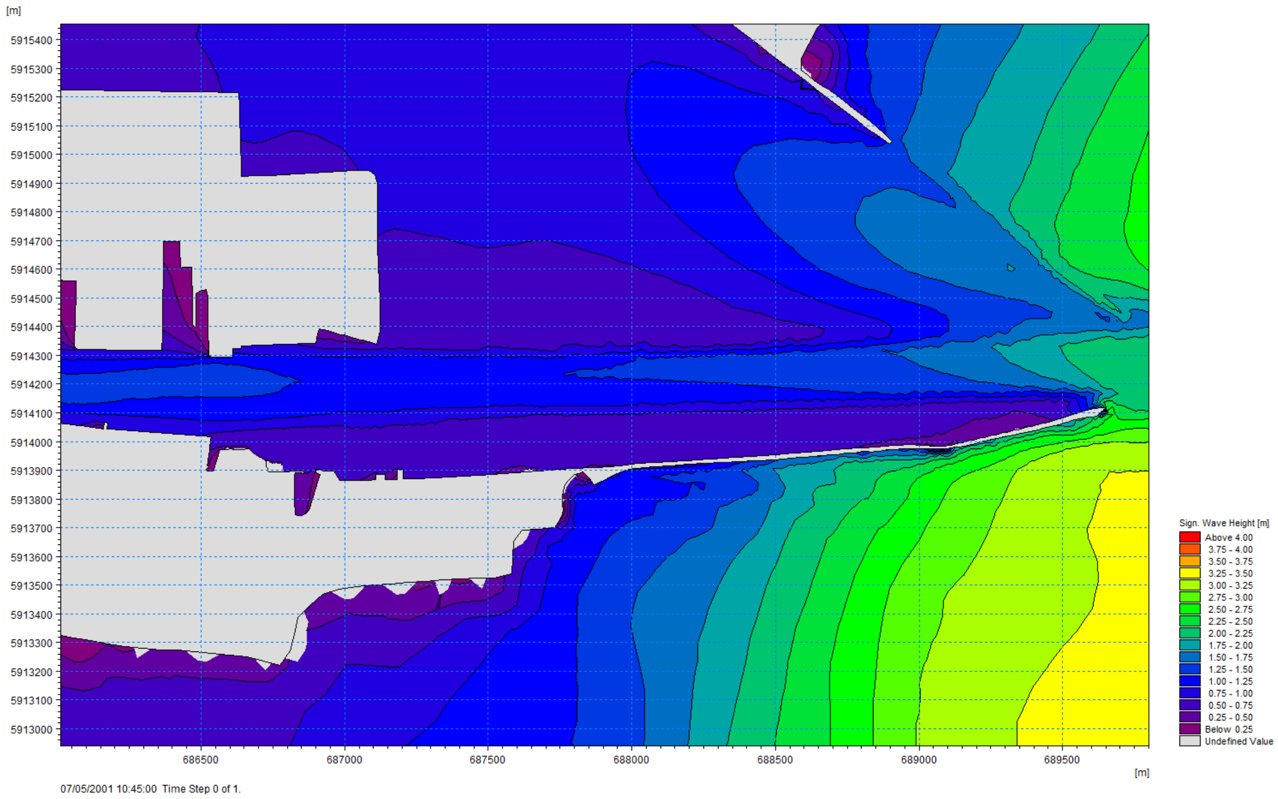


Figure 2.24: Easterly storm wave heights at spring high water – Operation Phase

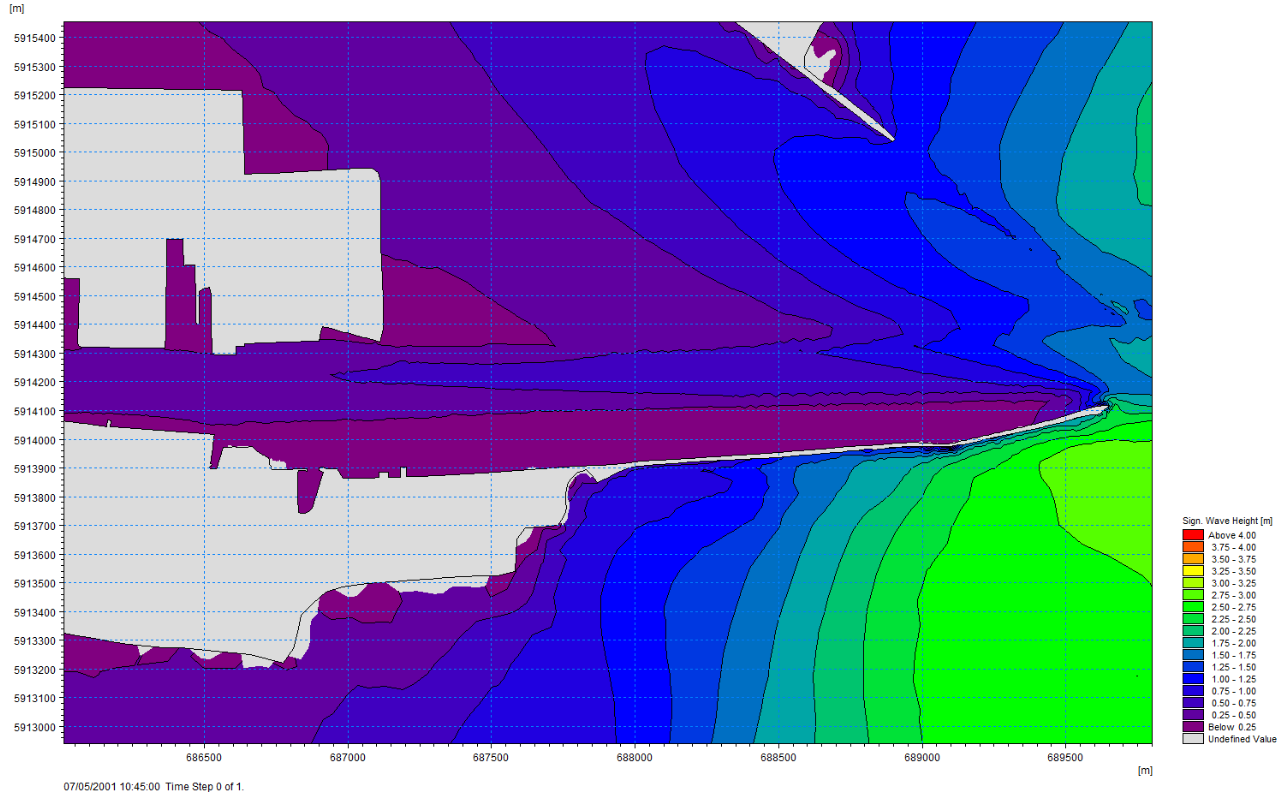


Figure 2.25: South Easterly storm wave heights at spring high water – Operation Phase

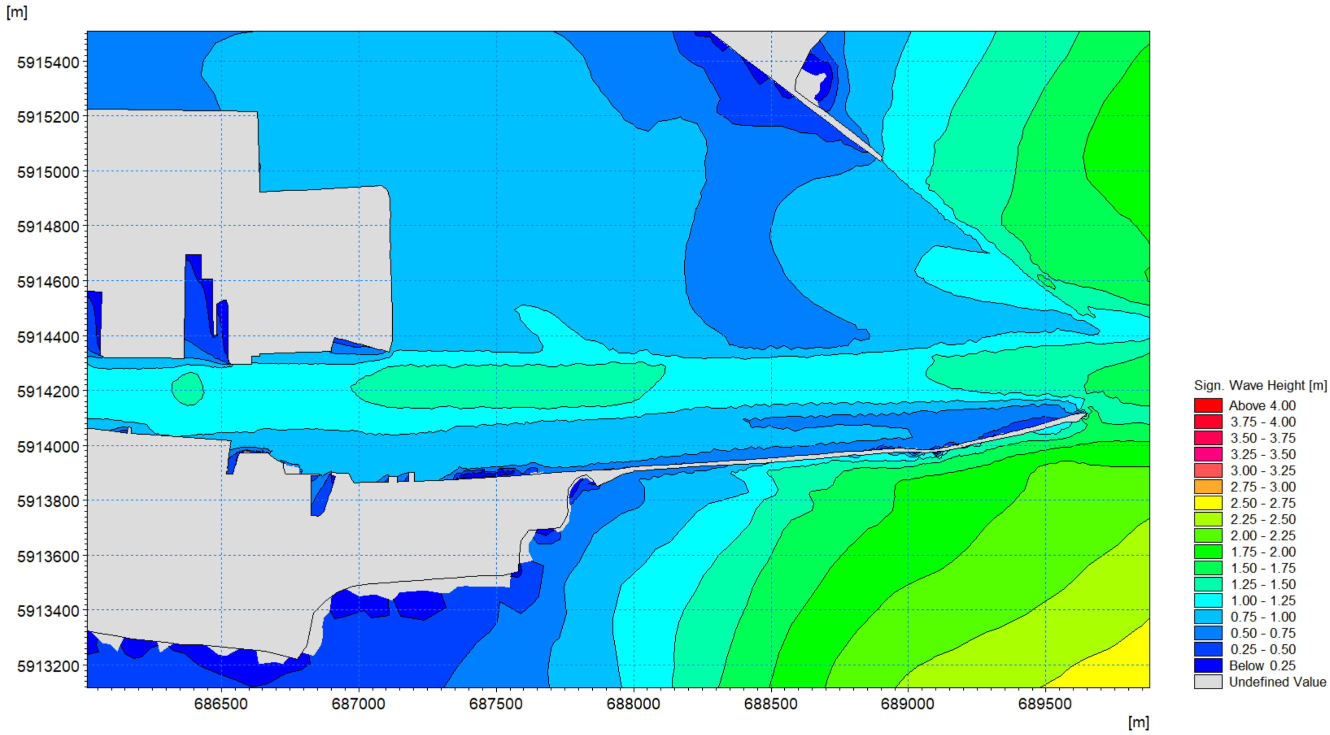


Figure 2.26: North Easterly 1 in 50 year storm event significant wave heights at spring high water – Operation Phase

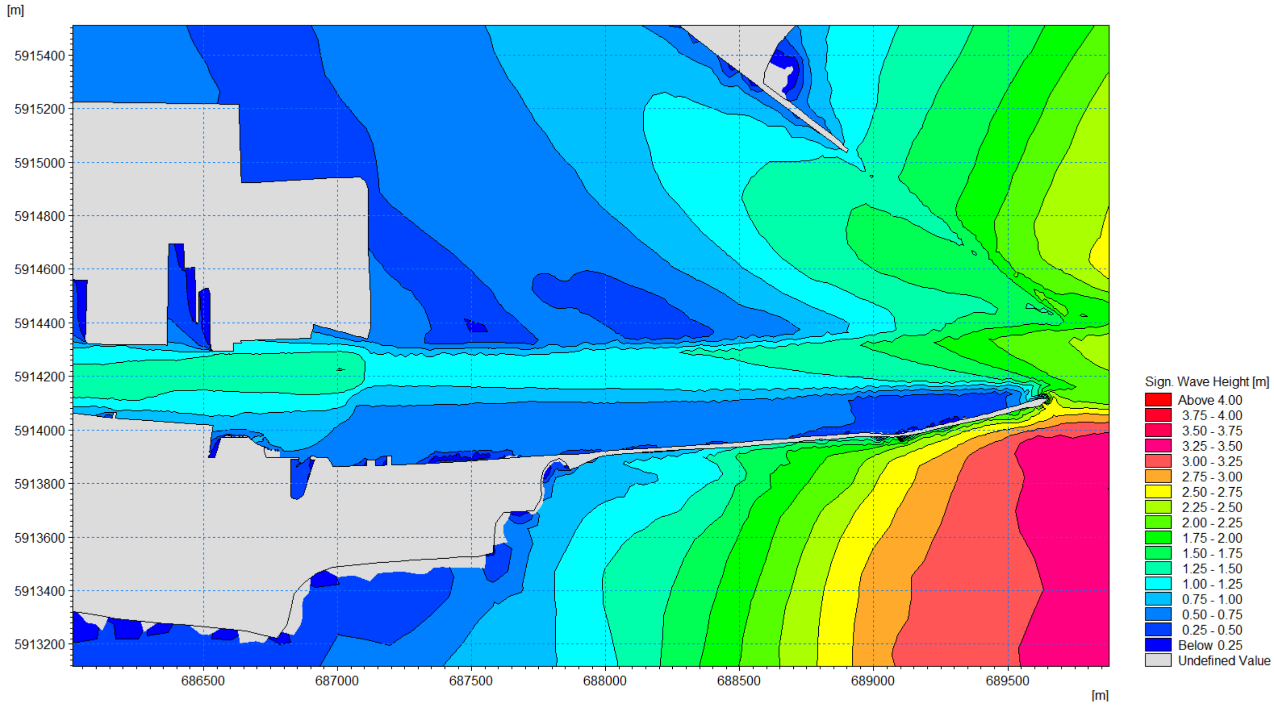


Figure 2.27: Easterly 1 in 50 year storm event significant wave heights at spring high water – Operation Phase

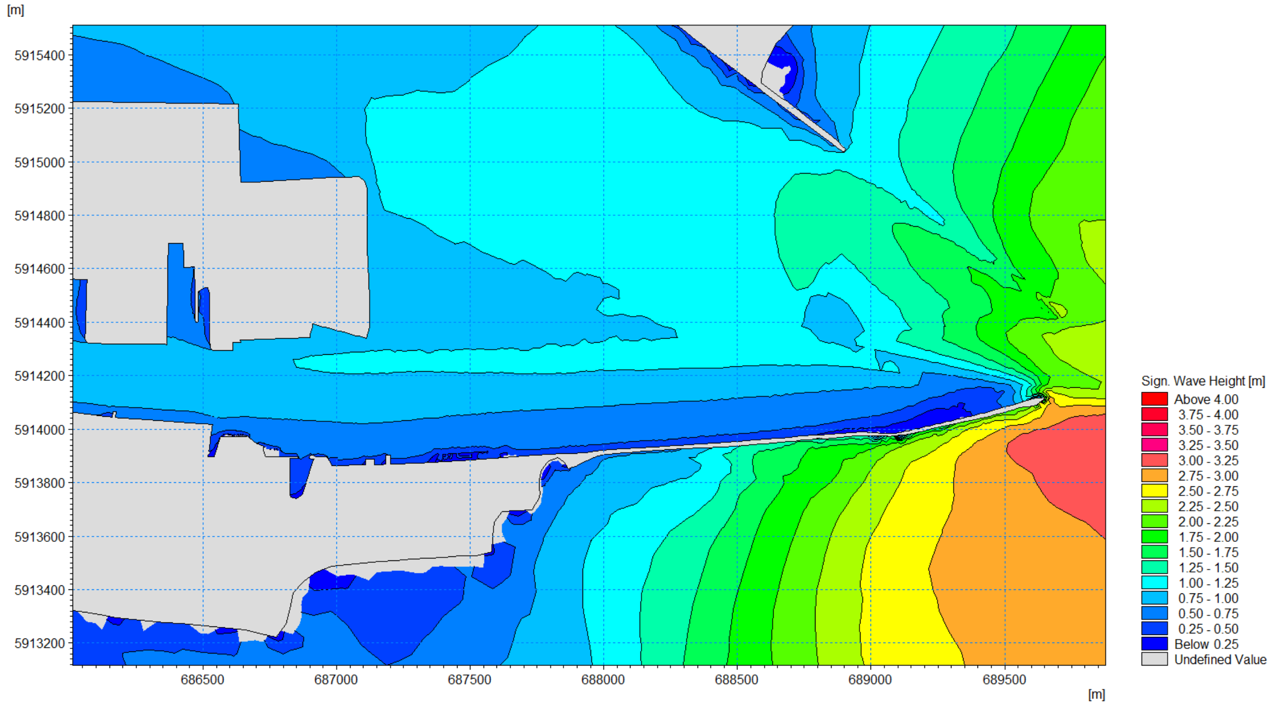


Figure 2.28: South Easterly 1 in 50 year storm event significant wave heights at spring high water – Operation Phase

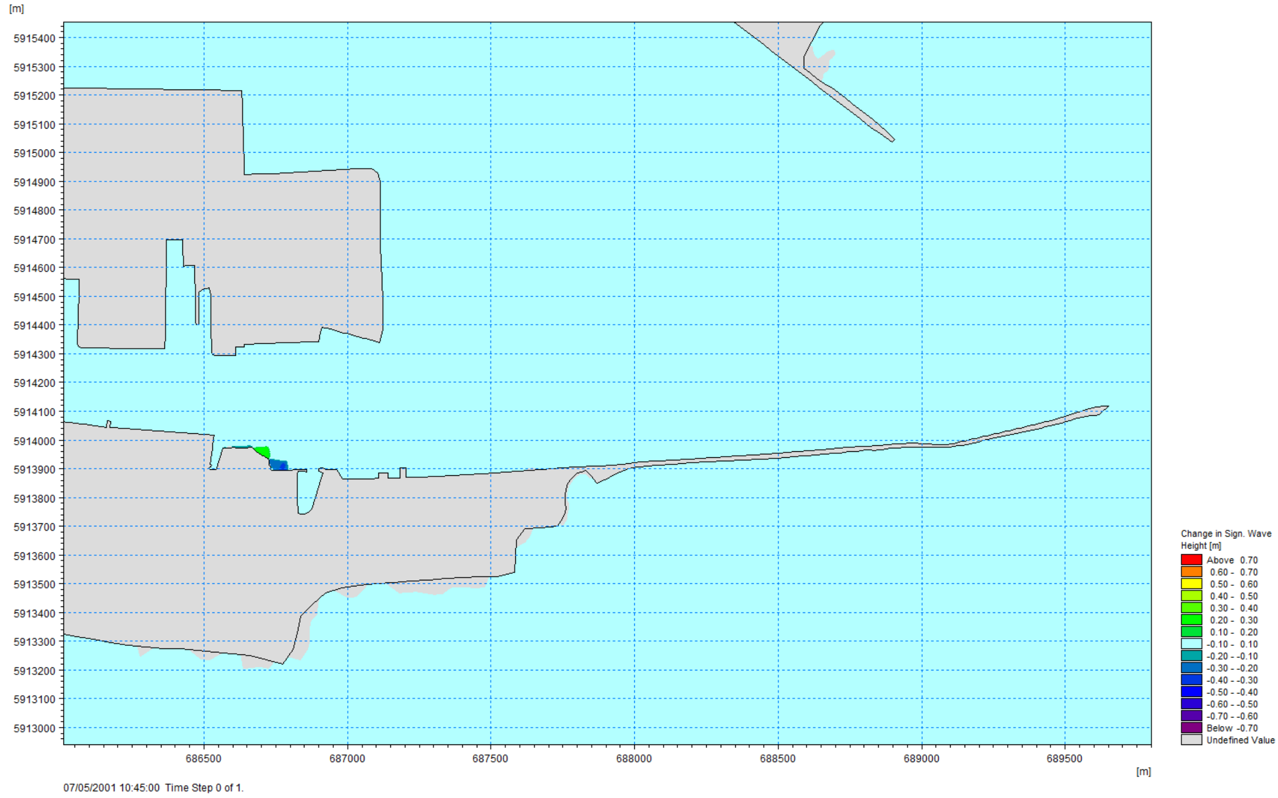


Figure 2.29: Difference in wave heights during a north easterly storm event as a result of the Proposed Development

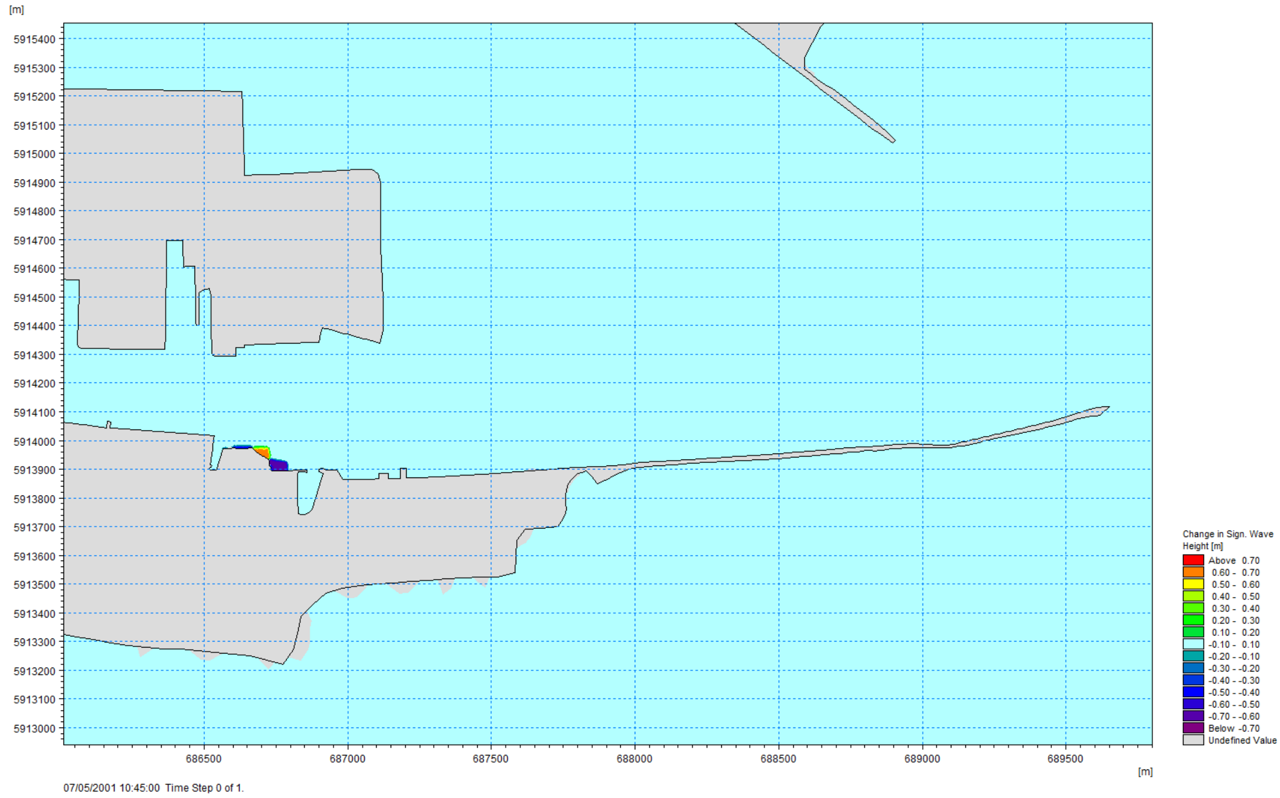


Figure 2.30: Difference in wave heights during an easterly storm event as a result of the Proposed Development

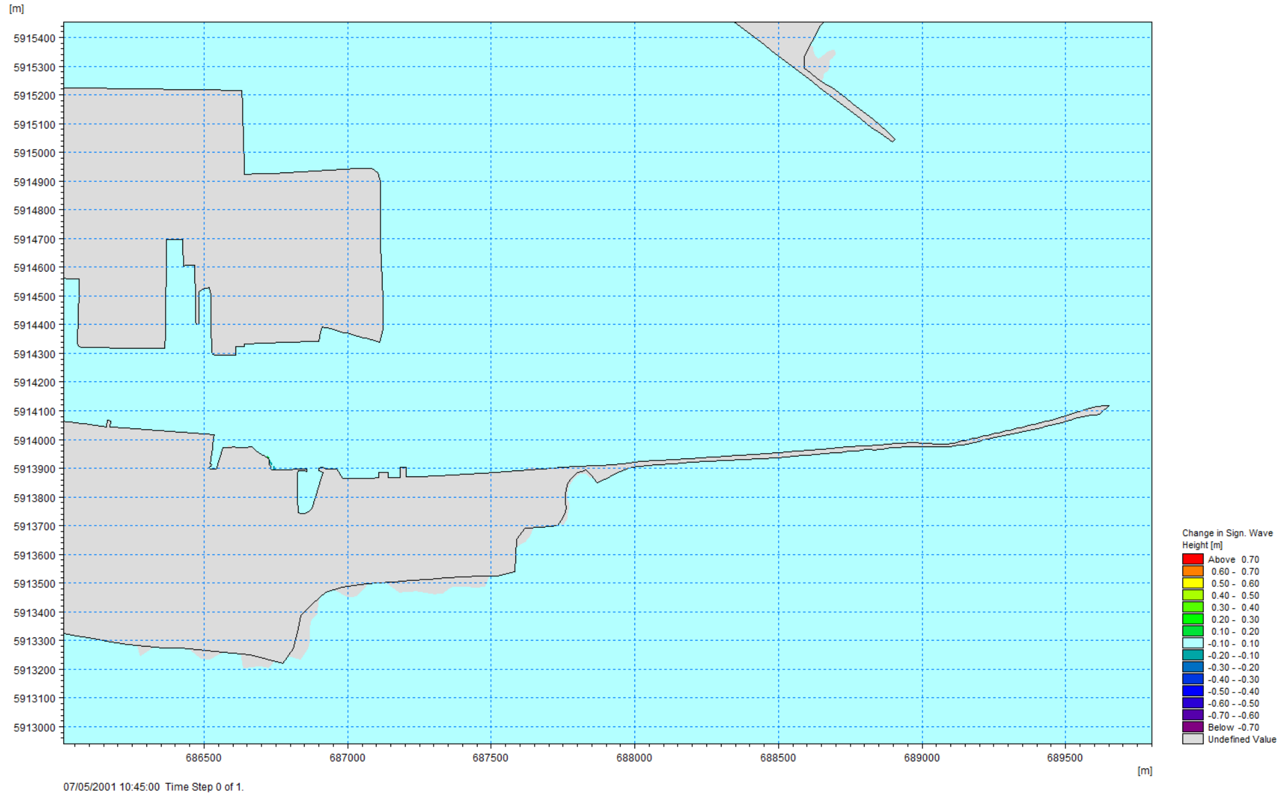


Figure 2.31: Difference in wave heights during a south easterly storm event as a result of the Proposed Development

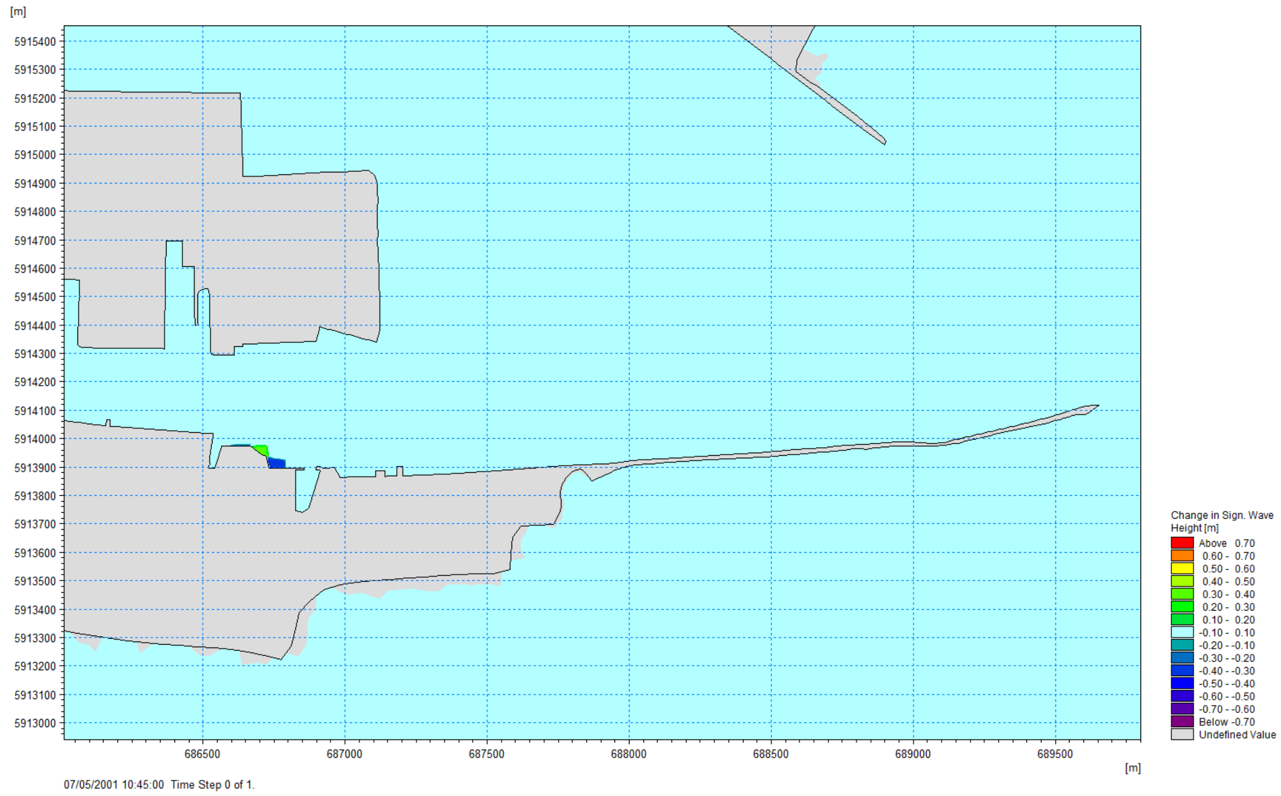


Figure 2.32: Difference in wave heights during a north easterly 1 in 50 year storm event as a result of the Proposed Development

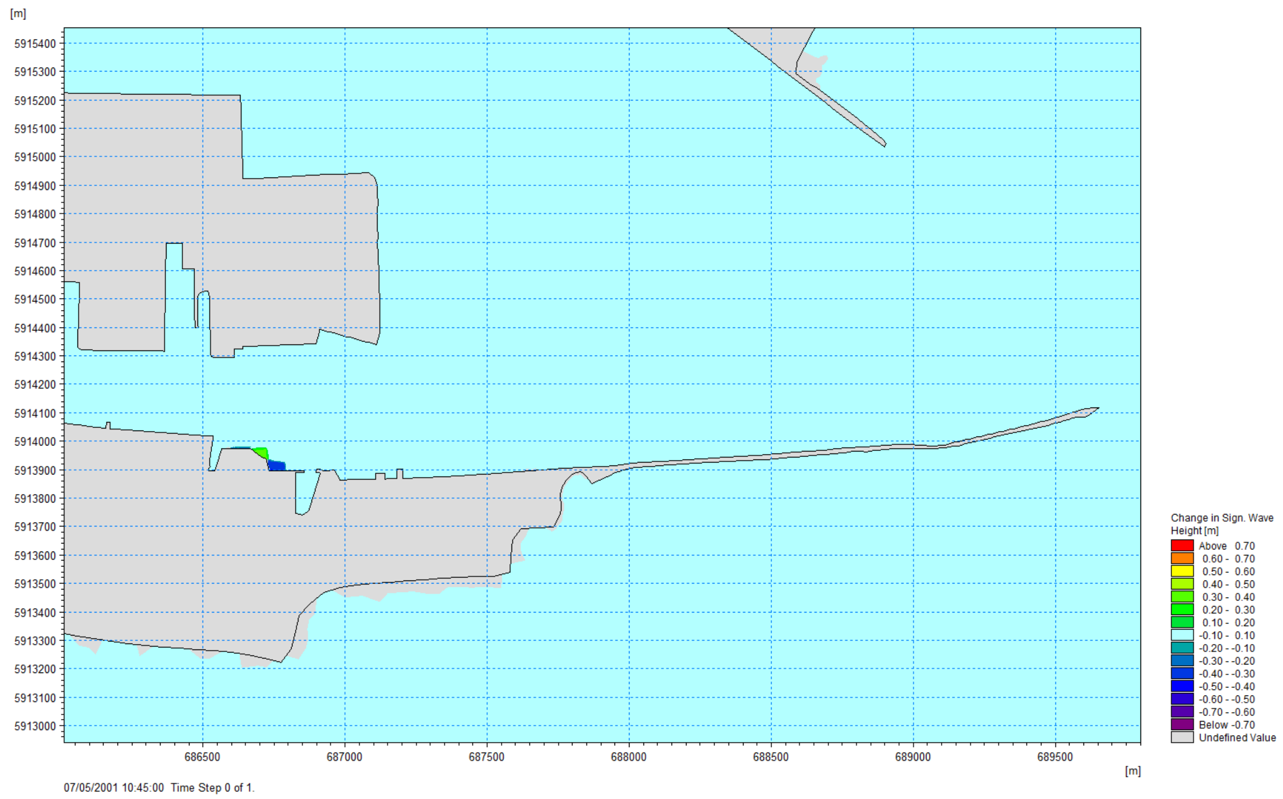


Figure 2.33: Difference in wave heights during an easterly 1 in 50 year storm event as a result of the Proposed Development

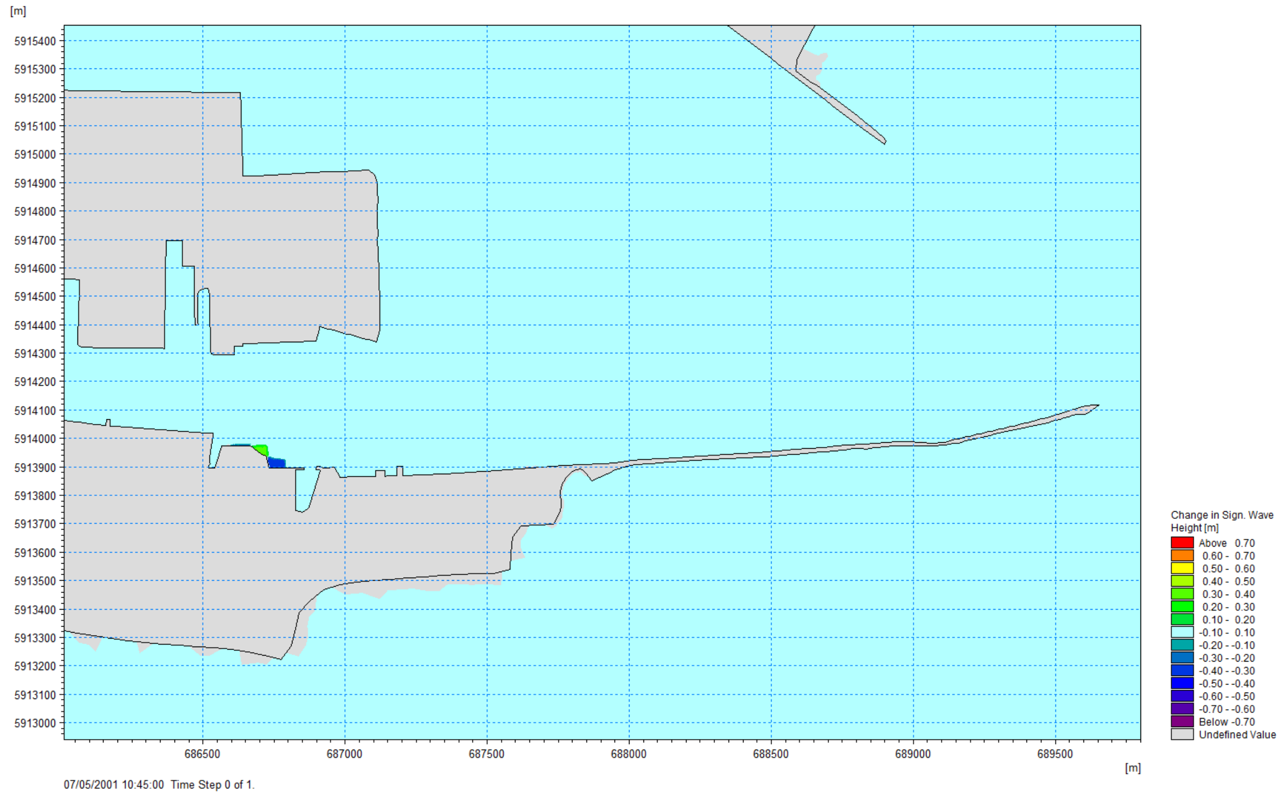


Figure 2.34: Difference in wave heights during a south easterly 1 in 50 year storm event as a result of the Proposed Development

3 CONCLUSION

This technical report investigated the potential impacts of the works proposed as part of the Poolbeg 220 kV sub-station development which is required to support the wider Codling Wind Park project in context of key coastal processes including the existing tidal regime and wave climate.

RPS used the MIKE 21/3 hydrodynamic numerical modelling software package developed by DHI, to address potential coastal processes issues. The model was calibrated using hydrographic data collected within Dublin Bay as part of the works in Dublin Port. The analysis of coastal processes was achieved by developing a range of two and three dimensional numerical models to represent:

- the pre-project scenario (in this case, post-MP2 Project); and
- the post-project scenario with the Codling Wind Park Project works in place.

Difference plots were produced which quantified the change in current velocities and significant wave height within the model domain. In terms of current velocities, changes were deemed insignificant (±0.15m/s) and were located around the working area. Minor changes of ±0.01m/s were observed elsewhere in the port.

Changes in the wave climate were associated with the areas of dredging and infilling only. As with the tidal regime, no changes in significant wave heights (±0.1m) were observed beyond the immediate vicinity of the Proposed Development area.

On the basis of this assessment, the impact of the Proposed Development on coastal processes will be deemed to be imperceptible.

Appendix A

Model Validation

For more than a decade, RPS have been providing Dublin Port Company with an extensive suite of engineering design, environmental assessment, planning and consent services needed to support Strategic Infrastructure Development (SID) projects, including the Alexandra Basin Redevelopment (ABR), Masterplan 2 (MP2) and most recently the third and final Masterplan project (3FM).

Through this work and using industry standard software, RPS have developed, calibrated and validated a range of hydraulic models to assess coastal processes within the Dublin Port area and wider vicinity. This Appendix presents the key findings from the validation exercise which is relevant to this study.

Model Validation Process

The Time Series Comparator tool provided within MIKE was used to undertake statistical analysis of modelled and measured datasets for both tidal and wave parameters.

The MIKE tool provides several performance measures and statistics including the Index of Agreement which is also known as d_2 or "*model skill*". Model performance may be assessed using two main types of metrics: those related to absolute values such as the mean absolute error (MAE) or the root-mean-square error (RMSE) and those which are normalised such as the model skill (d_2) or the Coefficient of determination (R^2).

The MIKE analysis provides three normalised parameters directly:

- Coefficient of determination R^2 being the square of the Pearson's product-moment correlation coefficient. It ranges from 0 to 1 with larger values indicating a better fit.
- Coefficient of efficiency or Nash-Sutcliffe coefficient E (Nash and Sutcliffe, 1970)[2]. It ranges from minus infinity to 1 with larger values indicating a better fit.
- Index of agreement d_2 (Willmott et al., 1985)[3]. It ranges from 0 to 1 with large values indicating a better fit.

Having developed a value relating to goodness-of-fit between measured and modelled data it is necessary to determine if the model is fit for the purpose of assessment. Classification is a useful tool in this respect. The simplest form of classification, shown in Table A.2, may be applied to those metrics whose values range from zero to unity.

Table A.2: Coefficient of Determination Interpretation

Coefficient of Determination (R^2)	Interpretation
0	The model does not predict the outcome
Between 0 and 1	The model partially predicts the outcome
1	The model perfectly predicts the outcome

On the other end of the scale more complex classifications have been developed, such as that proposed by Ladson for application of the coefficient of efficiency in stream flow modelling (Ladson, 2008)[4]. This is a dual system in which a reduced level of fit is accepted as satisfactory for the validation phase compared with that from the calibration phase parameters, Table A.3.

[2] Nash, J.E., Sutcliffe, J., (1970), River flow forecasting through conceptual models, Part I A discussions of principles, J. Hydrol., 10, 282-290.

[3] Willmott, C.J., Ackleson, S.G., Davis, R.E., Feddema, J.J, Klink, K.M., Legates, D.R., O'Donnell, J., Rowe, C.M., (1985), Statistics for the evaluation and comparison of models, J. Geophys. Res., 90, 8995-9005.

[4] Ladson, A. R. (2008) Hydrology: an Australian Introduction. Oxford University Press.

Table A.3: Coefficient of Efficiency Interpretation

Classification	Coefficient of Efficiency Calibration	Coefficient of Efficiency Validation	
Excellent	E ≥ 0.93	E ≥ 0.93	
Good	0.8 ≤ E < 0.93	0.8 ≤ E < 0.93	
Satisfactory	0.7 ≤ E < 0.8	0.6 ≤ E < 0.8	
Passable	0.6 ≤ E < 0.7	0.3 ≤ E < 0.6	
Poor	E < 0.6	E < 0.3	

For the purposes of this study the classification proposed by Sutherland is applied to the model output (Sutherland *et al* 2004)[5]. This classification is applied to metrics based around the normalising the Mean Absolute Error (MAE), where an allowance is made for the potential inaccuracy of the monitoring equipment, to derive an Average Relative Mean Absolute Error (ARMAE), as shown in Table 3.1. Model results from the study were analysed without accounting for potential device errors in the first instance (i.e. RMAE); therefore, the classification was applied on a conservative basis with a value of <0.7 providing a satisfactory level of model accuracy.

For each of the model parameters the MIKE timeseries comparator was used to derive statistics and performance measures.

Table 3.1: Average Relative Mean Absolute Error (ARMAE) Interpretation

Classification	Range of ARMAE	
Excellent	< 0.2	
Good	0.2 – 0.4	
Reasonable	0.4 – 0.7	
Poor	0.7 – 1.0	
Bad	> 1.0	

[5] J. Sutherland, D.J.R. Walstra, T.J. Chesher, L.C. van Rijn, H.N. Southgate. (2004), Evaluation of coastal area modelling systems at an estuary mouth. Coastal Engineering 51, 119– 142.

Tidal Regime Validation

The validation process of the baseline Dublin Port 3D hydrodynamic model was undertaken using data recorded by two Acoustic Doppler Current Profilers (ADCPs) that were moored in the Port and Dublin Bay as part of a previous monitoring programme. The location of these devices is illustrated in Figure A.1.

The validation process focused on establishing agreement between the model output and recorded observations and thus assessing overall model performance based on several key parameters including tidal range, current speed and direction.

Data from the tide gauge at Dublin Port was also used to verify simulated surface elevations.

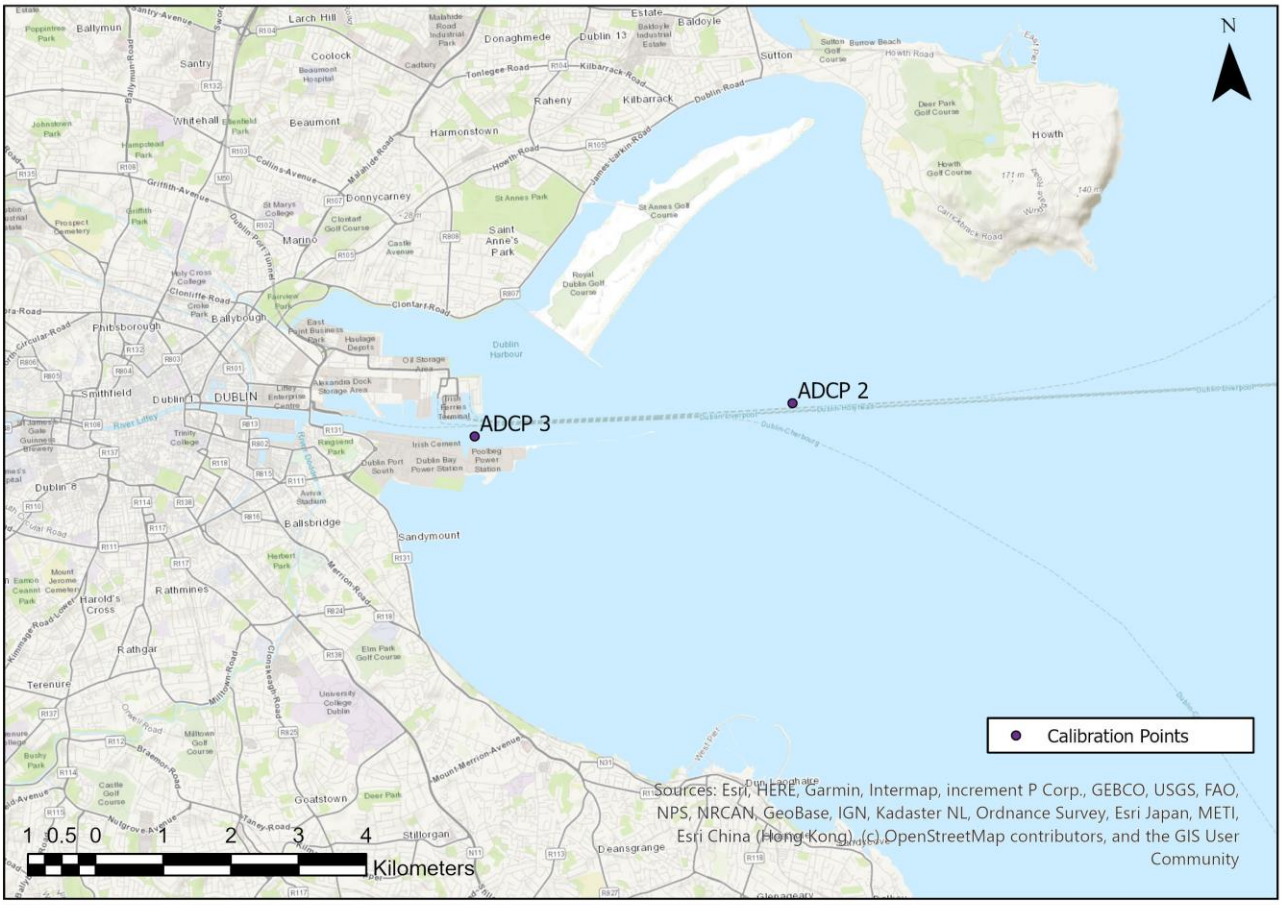


Figure A.1: Location of the ADCP devices in Dublin Bay that were used to validate the baseline 3D hydrodynamic model

The statistics and performance measures ascertained from the MIKE comparator software were supplemented to provide the Averaged Absolute Value (AAV) for the simulation to determine the Relative Mean Absolute Error (RMAE). Table A.1 presents a summary of the statistics and performance measures for the calibration period at each of the two ADCPs and Dublin Port tide gauge.

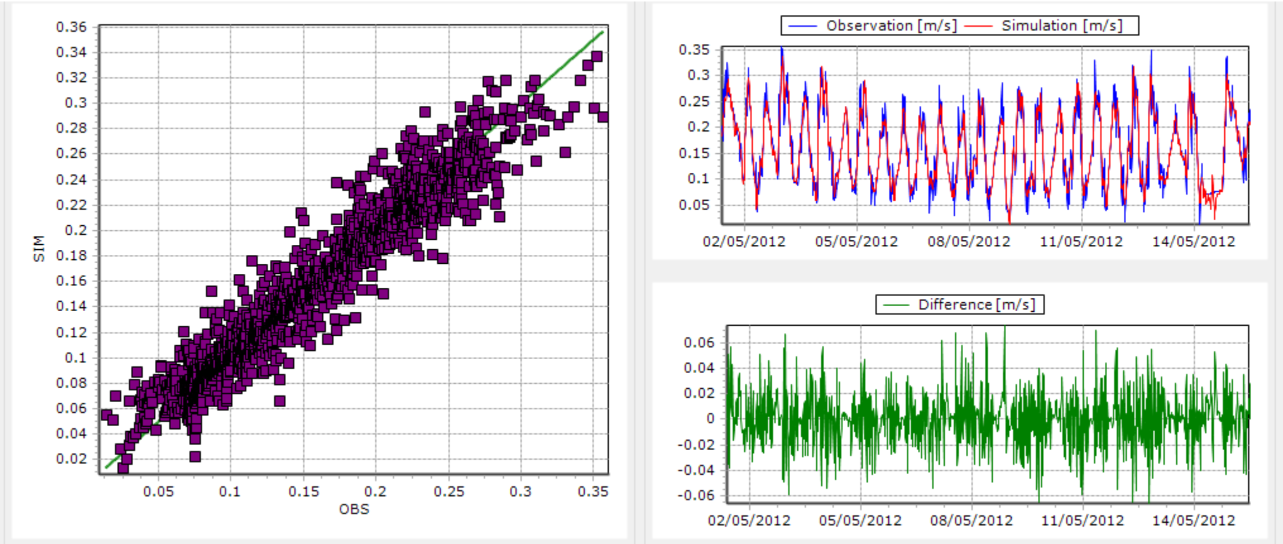
Based on this validation exercise, it was found that:

- Applying the Sutherland ARMAE classification, without any allowance for measuring device inaccuracies, shows that the goodness of fit for all parameters would be classed as either **'good' (green) or 'excellent' (blue)** at both locations.
- When the Ladson classification is applied on the coefficient of efficiency, all parameters are also rated **'satisfactory'** to **'excellent'**.

The hydrodynamic model described and used to inform the assessment presented in this document was therefore considered accurate and fit for purpose.

Table A.1: Model calibration performance metrics

Metric	Statistic			Performance Measure			
Parameter	**Average Absolute Value Observed AAV**	**Mean Absolute Error MAE**	**Root Mean Square Error RMSE**	**Coeff of Determination R^2**	**Coeff of Efficiency E**	**Index of Agreement d_2**	**Relative Mean Absolute Error ARMAE**
Dublin Port Tide Gauge							
Surface Elevation	0.1158	0.0461	0.0554	0.9973	0.9972	0.993	0.39
Inner ADCP – Current Velocity							
Surface layer	0.1835	0.0285	0.0387	0.8859	0.8652	0.9682	0.16
Middle layer	0.1313	0.0217	0.0324	0.8814	0.8619	0.6972	0.17
Bottom layer	0.0859	0.0178	0.0234	0.7839	0.7067	0.9344	0.21
Outer ADCP – Current Velocity							
Surface layer	0.1866	0.0210	0.0310	0.9494	0.9484	0.9870	0.11
Middle layer	0.1598	0.0148	0.0200	0.9195	0.9119	0.9786	0.09
Bottom layer	0.1392	0.0130	0.0175	0.8990	0.8857	0.9725	0.09
Inner ADCP – Current Direction [rad]							
Surface layer	0.6319	14.5418	19.8945	0.9171	0.9152	0.9784	0.04
Middle layer	0.2902	15.4551	20.8287	0.8872	0.8829	0.9702	0.18
Bottom layer	0.7607	13.9571	20.3591	0.9197	0.9101	0.9783	0.03
Outer ADCP – Current Direction [rad]							
Surface layer	4.4792	15.3744	27.7267	0.9461	0.9364	0.9848	0.29
Middle layer	4.0308	14.2014	23.2595	0.9481	0.9393	0.9855	0.28
Bottom layer	1.5296	15.7842	23.8407	0.9292	0.9222	0.9811	0.09



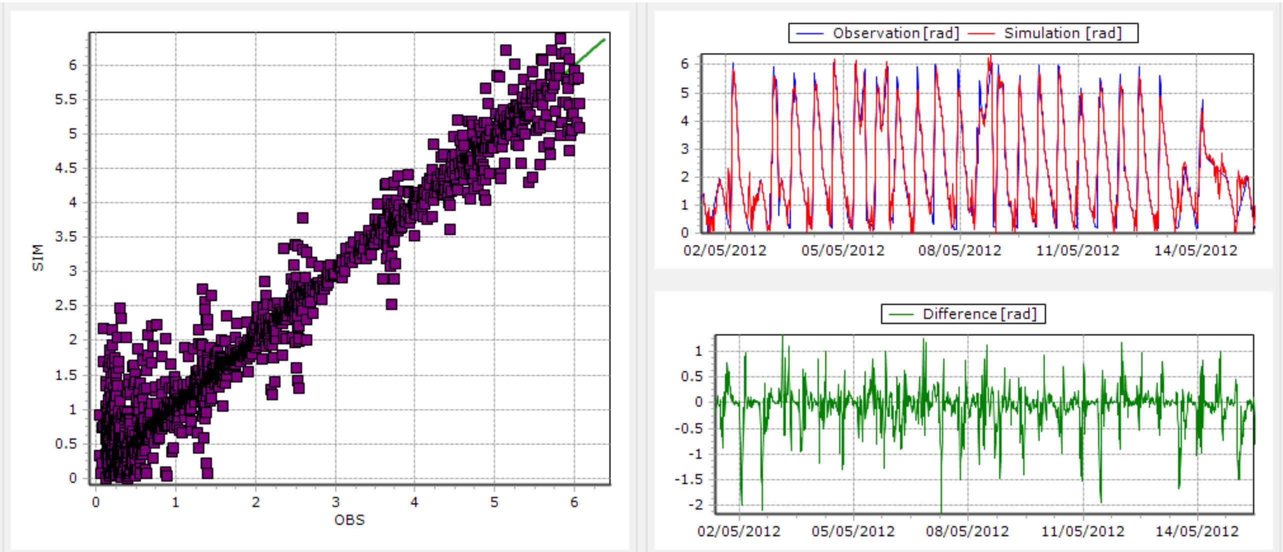
Performance Measures

Indice	Value	Unit
Mean Error	0.0002	[m/s]
Mean Absolute Error	0.0148	[m/s]
Root Mean Square Error	0.0200	[m/s]
Std. dev of Residuals	0.0200	[m/s]
Coefficient of Determination	0.9195	[-]
Coefficient of Efficiency	0.9119	[-]
Index of Agreement	0.9786	[-]

Statistics

	Observation	Simulation	Difference
Item Name	Middle Velocity	Lyr3: Current speed	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0144	0.0134	-0.0662
Maximum	0.3566	0.3363	0.0739
Average	0.1598	0.1596	0.0002
Std. deviation	0.0704	0.0673	0.0200

Figure A.2: Statistical comparison of middle current velocity from the Outer ADCP and the model



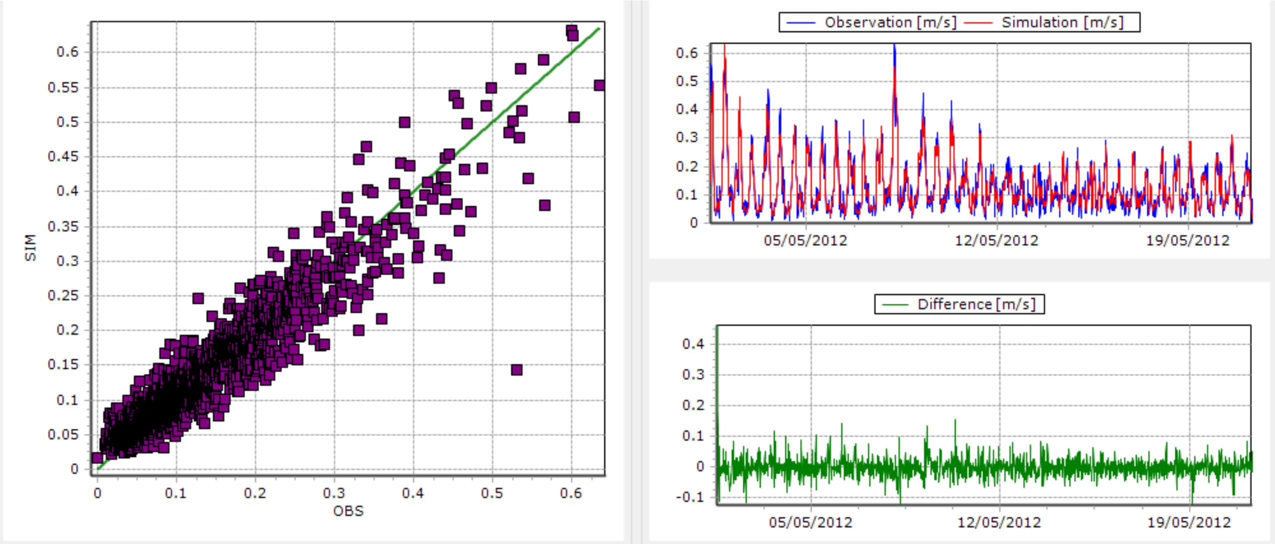
Performance Measures

Indice	Value	Unit
Mean Error	-0.0704	[rad]
Mean Absolute Error	0.2479	[rad]
Root Mean Square Error	0.4060	[rad]
Std. dev of Residuals	0.3998	[rad]
Coefficient of Determination	0.9481	[-]
Coefficient of Efficiency	0.9393	[-]
Index of Agreement	0.9855	[-]

Statistics

	Observation	Simulation	Difference
Item Name	Middle Direction	Lyr3: Current directi...	Difference
Item Unit	[rad]	[rad]	[rad]
Minimum	0.0432	-0.0038	-2.1710
Maximum	6.0706	6.3815	1.3248
Average	2.2816	2.3520	-0.0704
Std. deviation	1.7421	1.6472	0.3998

Figure A.3: Statistical comparison of middle current direction from the Outer ADCP and the model



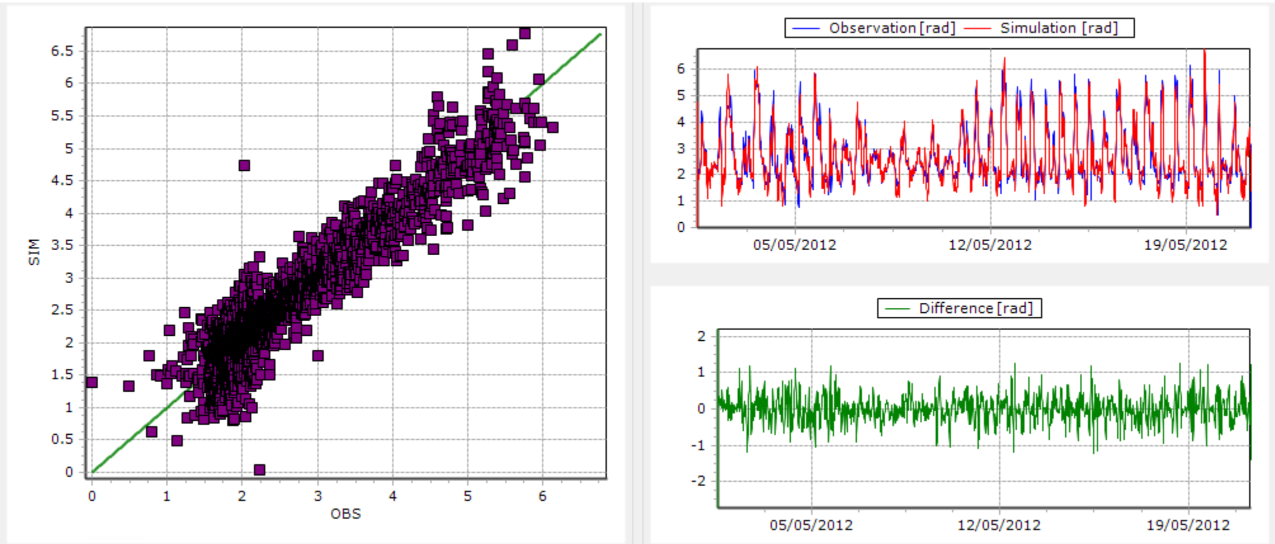
Performance Measures

	Indice	Value	Unit
▸	Mean Error	0.0001	[m/s]
	Mean Absolute Error	0.0217	[m/s]
	Root Mean Square Error	0.0324	[m/s]
	Std. dev of Residuals	0.0324	[m/s]
	Coefficient of Determination	0.8814	[-]
	Coefficient of Efficiency	0.8619	[-]
	Index of Agreement	0.9672	[-]

Statistics

		Observation	Simulation	Difference
▸	Item Name	Middle Velocity	Lyr3: Current speed	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0000	0.0000	-0.1238
	Maximum	0.6358	0.6313	0.4643
	Average	0.1313	0.1312	0.0001
	Std. deviation	0.0941	0.0873	0.0324

Figure A.4: Statistical comparison of middle current velocity from the Inner ADCP and the model



Performance Measures

	Indice	Value	Unit
▸	Mean Error	-0.0051	[rad]
	Mean Absolute Error	0.2694	[rad]
	Root Mean Square Error	0.3635	[rad]
	Std. dev of Residuals	0.3635	[rad]
	Coefficient of Determination	0.8872	[-]
	Coefficient of Efficiency	0.8829	[-]
	Index of Agreement	0.9702	[-]

Statistics

		Observation	Simulation	Difference
▸	Item Name	Middle Direction	Lyr3: Current directi...	Difference
	Item Unit	[rad]	[rad]	[rad]
	Minimum	0.0000	0.0393	-2.7215
	Maximum	6.1317	6.7727	2.1953
	Average	2.7122	2.7173	-0.0051
	Std. deviation	1.0699	1.0624	0.3635

Figure A.5: Statistical comparison of middle current direction from the Inner ADCP and the model

Wave Validation

The spectral wave model was verified using data collected by an Acoustic Wave and Current Profile (AWAC) device which was deployed in the centre of the licensed spoil site in Dublin Bay as part of a previous monitoring programme. The location of this device is illustrated in Figure A.6.

For the purposes of the validation exercise, wave simulations were run and compared for the following two periods when notable wave activity was recorded by the AWAC device:

- **Event 1:** 01/01/2018 to 09/03/2018
- **Event 2:** 29/01/2021 to 01/03/2021

The output for the significant wave height and wave periods at the site over the calibration period is presented in Figure A.7. An example of the MIKE timeseries comparator output for the wave components at the site is shown in Figure A.8.

Based on this validation exercise, it was found that:

- Applying the Sutherland classification, without any allowance for measuring device inaccuracies, shows that the goodness of fit for all parameters would be classed as either **‘good’ (green) or ‘excellent’ (blue)** during both events.
- When the Ladson classification is applied on the coefficient of efficiency, all parameters are also rated **‘excellent’ for both events**.

The spectral wave model described and used to inform the assessment presented in this document was therefore considered accurate and fit for purpose.

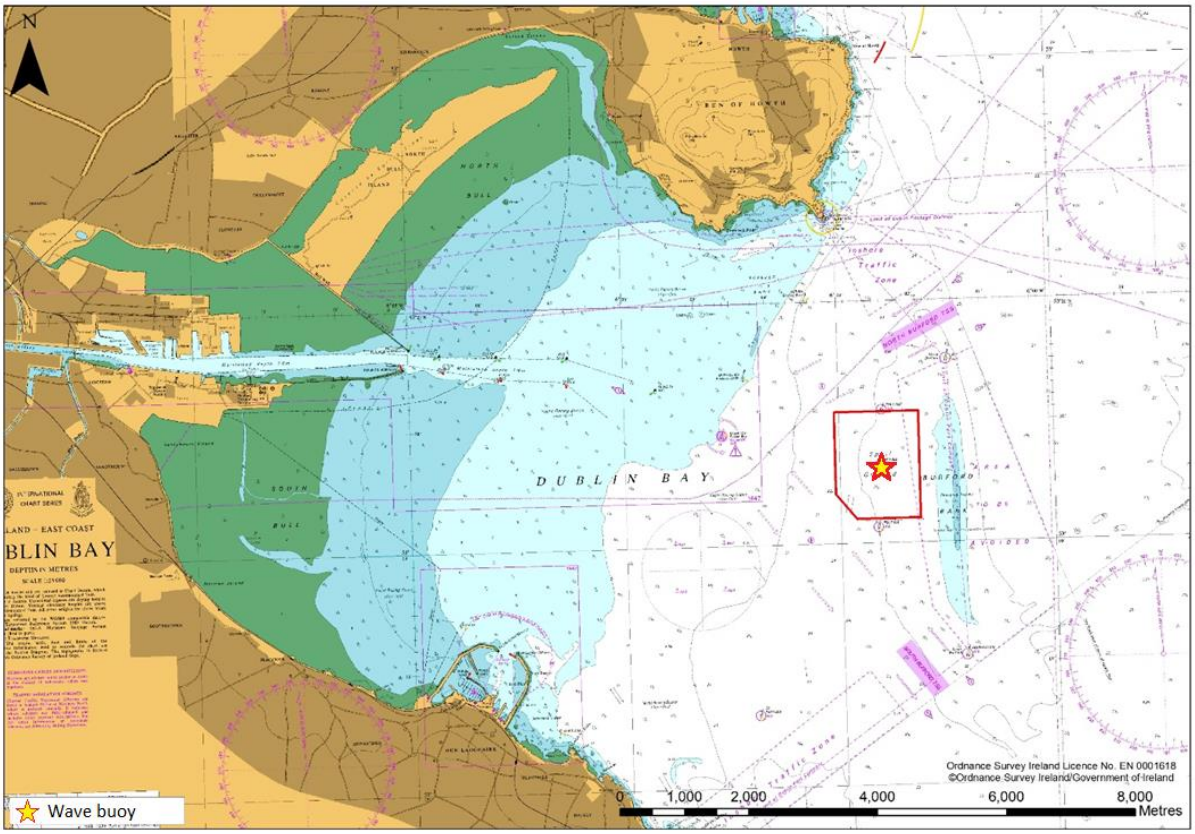
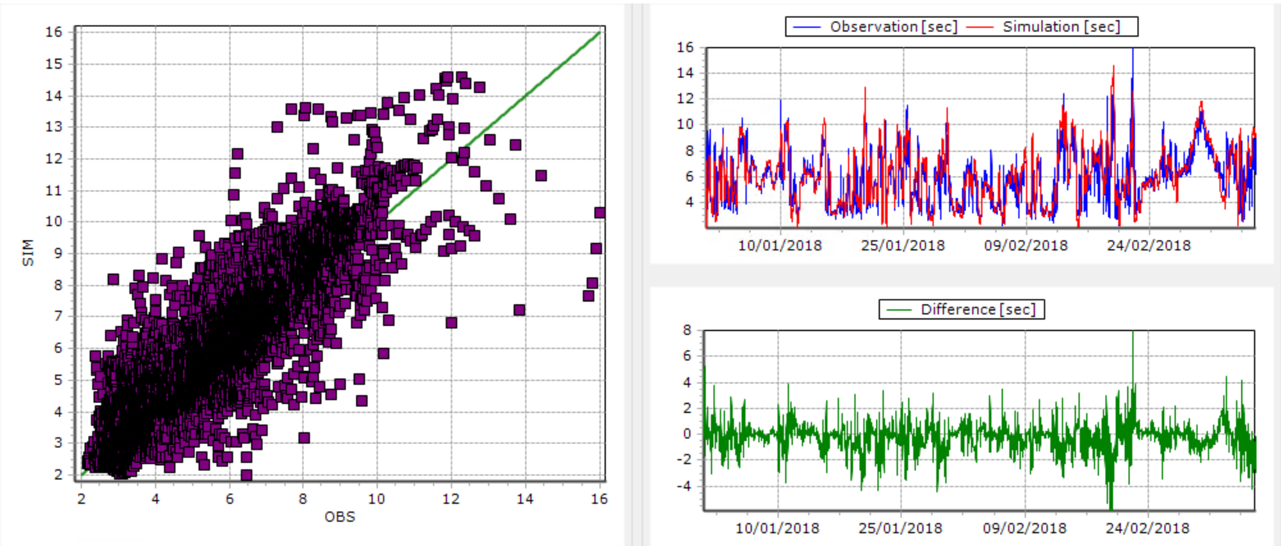


Figure A.6: Location of the licensed dredged spoil disposal site

Table 3.2: Validation statistics for significant wave height and period

Metric	Statistic			Performance Measure			
Parameter	**Average Absolute Value Observed AAV**	**Mean Absolute Error MAE**	**Root Mean Square Error RMSE**	**Coeff of Determination R^2**	**Coeff of Efficiency E**	**Index of Agreement d_2**	**Relative Mean Absolute Error* ARMAE**
Early Event							
Wave period	5.8192	0.7455	1.0763	0.7661	0.7511	0.9289	0.13
Sig. Wave Height	0.8516	0.0972	0.1341	0.9624	0.9531	0.9882	0.12
Later Event							
Wave period	7.4180	0.7157	1.0735	0.8299	0.7500	0.9443	0.10
Sig. Wave Height	1.0912	0.1041	0.1390	0.9591	0.9539	0.9874	0.10



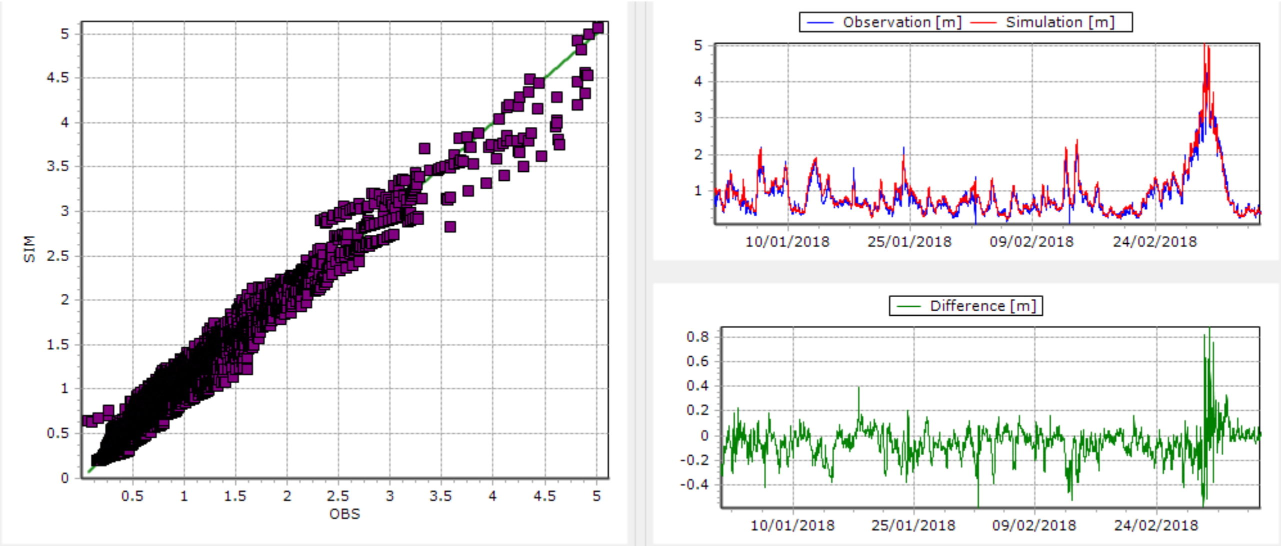
Performance Measures

Indice	Value	Unit
Mean Error	-0.2517	[sec]
Mean Absolute Error	0.7455	[sec]
Root Mean Square Error	1.0763	[sec]
Std. dev of Residuals	1.0464	[sec]
Coefficient of Determination	0.7661	[-]
Coefficient of Efficiency	0.7511	[-]
Index of Agreement	0.9289	[-]

Statistics

	Observation	Simulation	Difference
Item Name	Wave Period	Point 1: Peak Wav...	Difference
Item Unit	[sec]	[sec]	[sec]
Minimum	2.1700	2.0027	-5.9257
Maximum	16.0033	14.5892	8.0083
Average	5.8192	6.0708	-0.2517
Std. deviation	1.9684	2.1571	1.0464

Figure A.7: Statistical comparison of wave period between the modelled and observed for the 2018 storm event



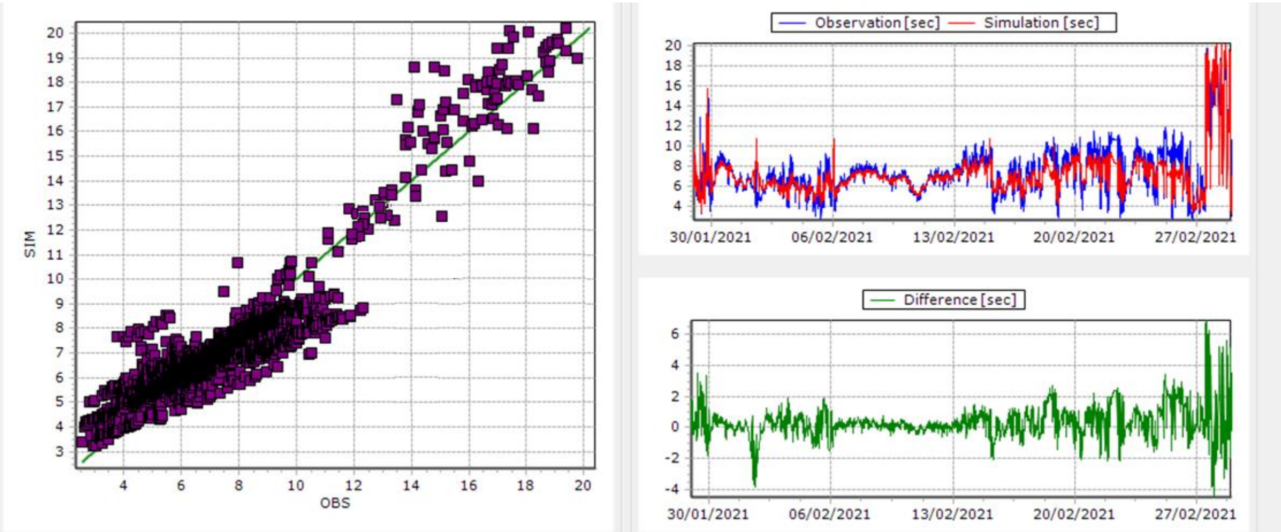
Performance Measures

Indice	Value	Unit
Mean Error	-0.0584	[m]
Mean Absolute Error	0.0972	[m]
Root Mean Square Error	0.1341	[m]
Std. dev of Residuals	0.1207	[m]
Coefficient of Determination	0.9624	[-]
Coefficient of Efficiency	0.9531	[-]
Index of Agreement	0.9882	[-]

Statistics

	Observation	Simulation	Difference
Item Name	Hs	Point 1: Sign. Wav...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.0678	0.1932	-0.5841
Maximum	5.0157	5.0671	0.8800
Average	0.8516	0.9101	-0.0584
Std. deviation	0.6202	0.6190	0.1207

Figure A.8: Statistical comparison of significant wave height between the modelled and observed for the 2018 storm event



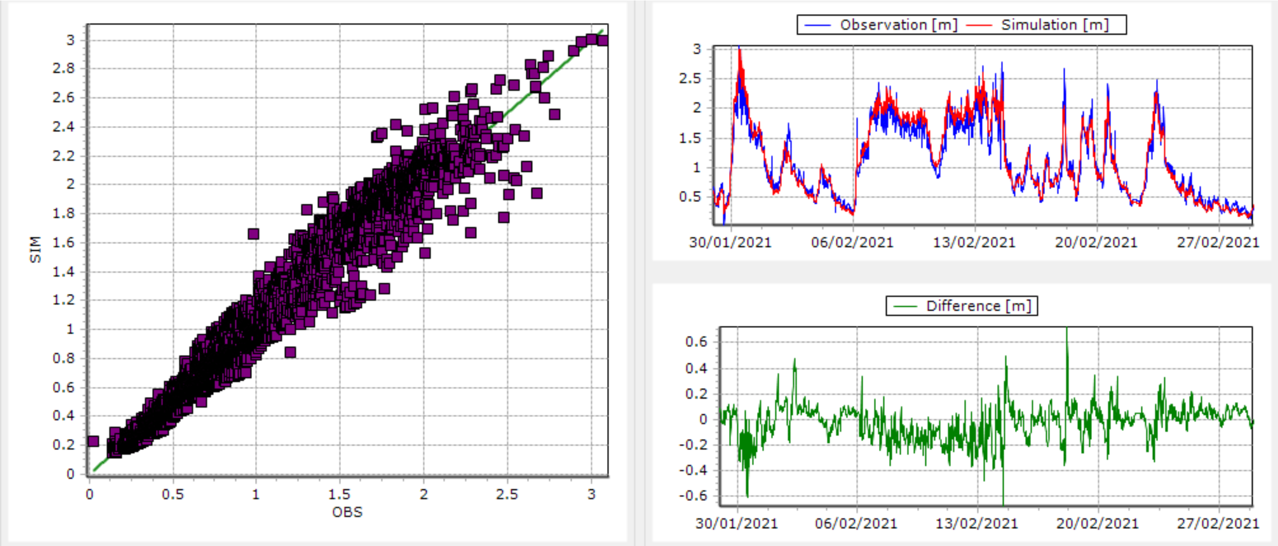
Performance Measures

Indice	Value	Unit
Mean Error	0.3091	[sec]
Mean Absolute Error	0.7157	[sec]
Root Mean Square Error	1.0735	[sec]
Std. dev of Residuals	1.0281	[sec]
Coefficient of Determination	0.8299	[-]
Coefficient of Efficiency	0.7500	[-]
Index of Agreement	0.9443	[-]

Statistics

	Observation	Simulation	Difference
Item Name	Wave Period	Point 1: Peak Wav...	Difference
Item Unit	[sec]	[sec]	[sec]
Minimum	2.5700	3.2109	-4.4773
Maximum	19.7625	20.2003	6.8736
Average	7.4180	7.1090	0.3091
Std. deviation	2.4782	2.1472	1.0281

Figure A.9: Statistical comparison of wave period between the modelled and observed for the 2021 storm event



Performance Measures

	Indice	Value	Unit
	Mean Error	-0.0314	[m]
	Mean Absolute Error	0.1041	[m]
	Root Mean Square Error	0.1390	[m]
	Std. dev of Residuals	0.1354	[m]
	Coefficient of Determination	0.9591	[-]
	Coefficient of Efficiency	0.9539	[-]
▶	Index of Agreement	0.9874	[-]

Statistics

		Observation	Simulation	Difference
▶	Item Name	Hs	Point 1: Sign. Wav...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.0258	0.1457	-0.6827
	Maximum	3.0675	3.0095	0.7245
	Average	1.0912	1.1226	-0.0314
	Std. deviation	0.5991	0.6472	0.1354

Figure A.10: Statistical comparison of significant wave height between the modelled and observed for the 2021 storm event