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# IRISH COASTAL WAVE AND WATER LEVEL MODELLING STUDY 2018

## Phase 3 - Dundalk



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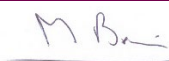
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## EXECUTIVE SUMMARY

This report presents the work undertaken and the findings of Phase 3 of the Irish Coastal Wave and Water Level Modelling Study (ICWWS) 2018 at Dundalk. The Phase 3 findings provide an improvement and update to the wave climate and water level combinations of known Annual Exceedance Probability (AEP) originally presented as output from the Irish Coastal Wave and Water Level Modelling Study (ICWWS) 2013 for specific flood risk locations considered vulnerable to wave overtopping.

Dundalk was identified by the OPW as a new coastal Flood Relief Scheme (FRS) location requiring a detailed assessment of wave climate and water level estimations to enable future wave overtopping analysis to be conducted, and it was thus included as a Phase 3 study area. Overtopping of existing defences and coastal structures (both manmade and natural) as a consequence of the interaction of waves and sea level conditions, including tide and surge, may contribute to coastal flooding in areas located behind these defences. The outputs of this study will inform the evaluation of the risk associated with wave overtopping, any resulting coastal flooding (both now and in the future) and the detailed design of measures to mitigate and manage any such identified coastal flood risk.

To derive overtopping volumes or rates, wave climate conditions for various water levels at the shoreline or defence line are required. For this study, a numerical model was used to transform offshore combined waves of known AEP to near the shoreline or defence line. The relevant offshore wave climate conditions were combined with present day water levels using a joint probability analysis. These combinations were then used to provide the input to the wave transformation model.

The Phase 3 study provides an improvement and update to the previous ICWWS 2013 study based on the inclusion of additional offshore wave data, bathymetry, and topographic data. A review and updated estimate of the extreme water levels around the coast of Ireland was also undertaken under ICWWS 2018, Phase 1, however as the updated water levels estimated at Dundalk were marginally lower than the levels previously published in the Irish Coastal Protection Strategy Study (ICPSS), a conservative approach was taken to adopt the marginally higher ICPSS levels in the current Phase 3 study. The wave modelling simulations in Phase 3 also made use of a more detailed 'fully spectral formulation' in comparison to a 'directional decoupled parametric formulation' used in the previous ICWWS 2013 study and also in Phase 2 of this study. Additional assessments were also made of the impact of wave set-up and beach drawdown and these were included in the resultant wave height and water level outputs, where relevant.

Combinations of present day wave climate (heights, periods and directions) and water levels for AEPs of 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% were derived for the Dundalk shoreline/defence line. A similar approach was undertaken to determine the corresponding wave climate and water levels for four future scenarios accounting for different projected sea level rise allowances. Spectral significant wave heights, peak spectral wave periods and mean wave directions for each AEP and water level at a series of shoreline/defence line locations comprise the key outputs of this study.



# 1 INTRODUCTION

Overtopping of existing defences and coastal structures (both manmade and natural) due to the interaction of waves and tidal conditions, including surge, may contribute to coastal flooding in areas behind these defences. Consequently, a number of locations around the coast of Ireland have been identified as requiring detailed assessments to provide wave climate and sea level estimations to enable future overtopping analysis to be conducted. The results of these assessments will subsequently inform the evaluation of the risk associated with wave overtopping, any resulting coastal flooding (both now and in the future) and the detailed design of measures to mitigate and manage any such identified coastal flood risk. The locations which the Office of Public Works (OPW) identified as requiring detailed assessment under Phase 3 of the ICWWS 2018 include;

- Tralee
- Shannon
- Bunratty
- Carlingford
- Dundalk

This report focuses on the detailed modelling undertaken for Dundalk and builds upon more limited wave modelling undertaken for the original Irish Coastal Wave and Water Level Modelling Study (ICWWS) (Reference 1), which provided a strategic indication of the variation in wave exposure around the coast of Ireland. The original study made use of UK Met Office offshore wave data from 1989 to 2004 for the Dundalk area, in conjunction with water levels derived as part of the Irish Coastal Protection Strategy Study (ICPSS) North East Coast in 2004. The models used for the original ICWWS lacked a detailed bathymetric survey of Dundalk Bay and made use of wave simulations based on a less detailed parametric formulation. Hence, the outputs were not considered sufficient to inform a detailed assessment of wave overtopping at Dundalk and a more detailed modelling approach was taken for this Phase 3 study.

The primary aim of the ICWWS 2018 Phase 3 was to generate a series of detailed wave climate conditions (heights, periods and directions) for various water levels at the shoreline or defence line, for a range of annual exceedance probability (AEP) events and to derive joint probability detailed wave climate and water level conditions for wave overtopping analysis/modelling, to inform scheme design standard and hydraulic performance of any proposed flood defence measures for Dundalk.

To ensure that the output of this study was as robust as possible, it was vital that model input data was up-to-date. Consequently, bathymetric survey data that had become available for the Dundalk Bay area since the original ICWWS were reviewed. In general, the offshore bathymetry for the model remained largely unchanged, however inshore survey data collected for the OPW Tidal, Storm Surge and Wave Forecasting System for the North East Coast of Ireland, at Dundalk Bay project in 2015 was incorporated in the models used for this study. Additional INFOMAR project data, from Geological Survey Ireland and the Marine Institute, and UK Hydrographic Office MEDIN data that had become available since the previous study was also incorporated.

The offshore wave climate in Dundalk Bay was established using extreme value analysis and joint probability analysis of present day water levels with both wave heights and wind speeds at offshore locations. Output from the extreme value analysis provided input conditions to the computational modelling which utilised the MIKE Spectral Wave (SW) Flexible Mesh module to transform the offshore combined waves into the nearshore area.

Combinations of present day wave conditions and water levels corresponding to AEPs of 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% were derived at Dundalk. A similar approach was undertaken in order to determine the corresponding wave climate conditions and water levels for four future scenarios accounting for different projected sea level rise allowances. Spectral significant wave heights, peak spectral wave periods and mean wave directions for each AEP and water level at a series of inshore locations comprise the key outputs of this study. For locations within Dundalk Bay not included as estimation locations in this study, combinations of water levels and wave conditions for various AEPs can be found in the ICWWS 2018, Phase 2 report, (Reference 2).

## 2 KEY INFORMATION ON STUDY OUTPUTS

The Phase 3 study outputs include combinations of wave climate and extreme sea level estimates for a series of shoreline/defence line locations in the study area. These outputs are based on analysis and modelling, including:

- Statistical extreme value analysis and joint probability analysis of offshore wave and wind data and inshore water levels at ICPSS / ICWWS 2018 coastal boundary estimation points.
- Numerical Modelling to transform offshore combined waves to the shoreline/defence line.

The following key information should be taken into consideration in conjunction with the study outputs/results.

- 1) Combinations of wave climate and water level estimates have been produced at each shoreline/defence line location. These combinations are joint probability occurrences, in which the two elements, wave climate and water level are likely to simultaneously occur for a given AEP. This represents the probability of a combined wave climate and water level event of this or greater, severity occurring in any given year. For example, a 0.5% AEP event has a 0.5% probability (or 1 in 200 chance) of occurring or being exceeded in any one year.
- 2) For each AEP from 50% to 0.1%, six combinations of waves and water levels were produced representing the complete joint probability range.
- 3) Wave climate and water level combinations were derived for present day sea levels, as well as the Mid-Range Future Scenario (MRFS), High End Future Scenario (HEFS), High+ End Future Scenario (H+EFS) and High++ End Future Scenario (H++EFS) which represent a 0.5m, 1.0m, 1.5m and 2.0m increase in sea level, respectively. These future scenario results do not account for any potential changes to the meteorological systems which may affect the offshore wave climate or wind speeds.
- 4) The wave climate and water level combinations output from the study are representative of a point situated at approximately half the shallow water wavelength seaward from the toe of the defence structure or shoreline.
- 5) Wave climate conditions are presented in terms of spectral significant wave height ( $H_{m0}$ ) in metres, spectral peak wave period ( $T_p$ ) in seconds, and mean wave direction (MWD) in degrees measured from North. The  $H_{m0}$  is representative of the mean of the highest third of the waves, whilst  $T_p$  is associated with the most energetic wave in the spectrum.
- 6) The extreme water levels refer to total water levels, which include the effects of astronomic tides and storm surge residual. Astronomic tides are the daily change in sea levels due to the rotation of the earth and the gravitational forces of the sun and moon along with the hydrodynamic response to the bathymetry, whilst storm surge residual refers to the change in sea level caused by the effect of atmospheric pressure variations and persistently strong winds.
- 7) The extreme water levels are also inclusive of local wind set-up or seiching, where abrupt changes in meteorological conditions, such as the passage of an intense depression, may cause oscillations in sea level (or seiches).
- 8) The extreme water levels are also inclusive of set-up likely to occur due to the effects of wave action (wave set-up effect).
- 9) The extreme water levels are produced to Mean Sea Level (MSL) and Ordnance Datum Malin (OD Malin) OSGM02 and OSGM15. Mean Sea Level refers to the average sea surface level of all tides over a period of time, whilst OD Malin is the vertical land levelling datum currently used in Ireland, based on the mean sea level recorded between January 1960 and December 1969 at Malin Head tide gauge. This is propagated across the country via the spatial surfaces of the transformation models



OSGM02 and OSGM15 produced by the Ordnance Survey of Great Britain (OS), Ordnance Survey Ireland (OSi) and Land & Property Services.

- 10) Although widely accepted methods have been used to derive the combinations of extreme wave climate and water levels, there are a number of limitations which should be considered when using this data for subsequent analysis. These include uncertainties in the derivation of the individual extreme values associated with topographic and other survey data uncertainties, inaccuracy in meteorological and offshore wave data, assumptions and / or approximations in the hydraulic / hydrodynamic models in representing physical reality, assumptions and / or approximations in the statistical analysis and uncertainties in datum conversions. Further uncertainty arises from the use of the FD2308 joint probability method in the absence of defined and agreed dependence values for waves and tidal levels around Ireland. Further detail on the uncertainties associated with the derivation of extreme tidal levels is given in Reference 3.

## 3 DATA SOURCES

### 3.1 Wave and Wind Data

RPS utilised hindcast data from the UK Met Office WAVEWATCH III wave model in order to determine appropriate wave and wind data for use in the detailed computational modelling for Dundalk. The available database contained 39 years, from 1980 to 2018 inclusive, of 3 hourly wind and wave data for the Irish Sea. For the Dundalk study, data was extracted from the dataset at two offshore locations; **53.748°N, 5.696°W** and **53.349°N, 5.667°W** as shown in Figure 3.1.

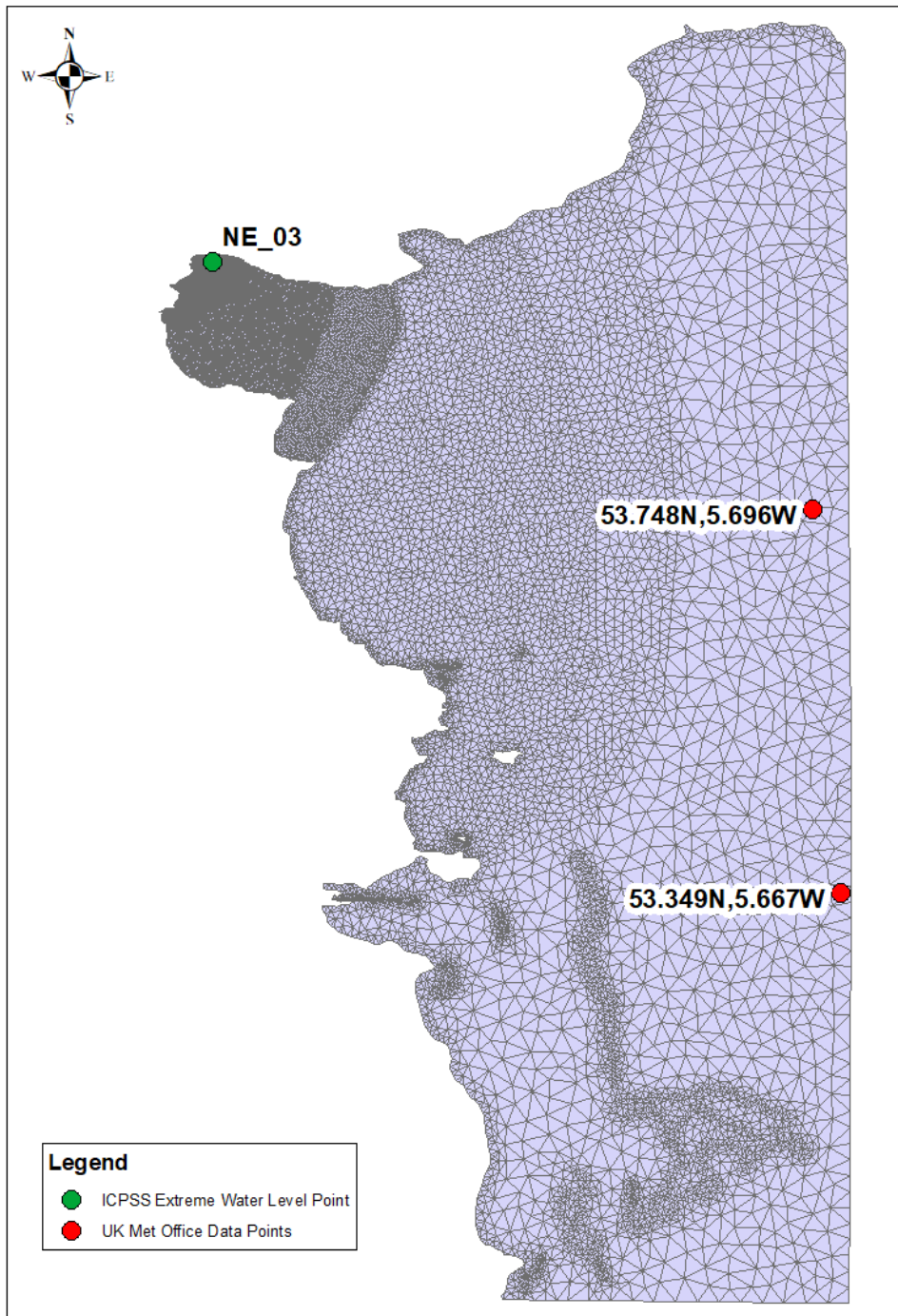


Figure 3.1: Location of UK Met Office Data Points and ICPSS Extreme Water Level Estimation Point

The UK Met Office data at the two offshore locations were directionally discretised and analysed to create profiles of the wave climate and wind speeds. These profiles were subsequently used to define boundary conditions for the Dundalk model.

Onshore wind data supplied by Met Éireann was also used to inform the establishment of the correlation between wind speeds and water levels around the coast of Ireland, including for Dundalk Bay.

## 3.2 Bathymetric Data

In order to facilitate the transformation of offshore wave data into inshore values relevant to the assessment of wave overtopping, detailed inshore bathymetric and topographic information was required to ensure that the transfer of wave energy from offshore to inshore was adequately represented in the Dundalk area. Sufficient data was also required to represent the various channels, drying zones and banks within the model domain.

Large areas of the offshore bathymetry information used in the model were obtained from INFOMAR survey data, a joint project between Geological Survey Ireland (GSI) and the Marine Institute. UK Hydrographic Office MEDIN data also provided coverage of a large area in the North East of the model domain, as shown in Figure 3.2.

OPW LiDAR data and more localised hydrographic surveys were used to provide specific information for inshore areas along with hydrographic survey data collected for the OPW Tidal, Storm Surge and Wave Forecasting System for the North East Coast of Ireland, at Dundalk Bay project from 2015, as shown in detail in Figure 3.3. The model was supplemented with Admiralty Chart data, as digitally supplied by C-Map of Norway, to ensure bathymetric coverage of the entire domain.

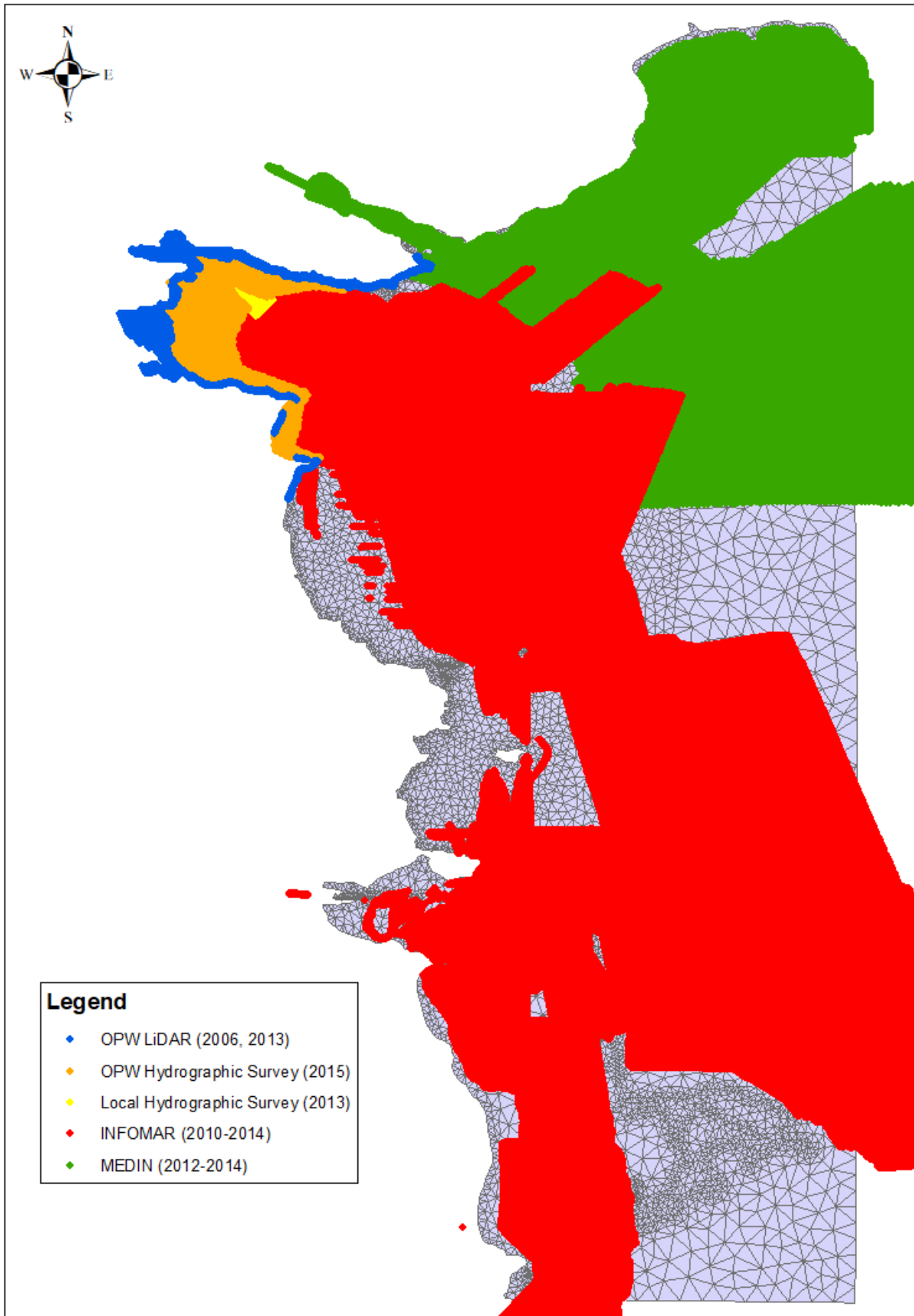


Figure 3.2: Survey Coverage of Dundalk Model Inshore Area

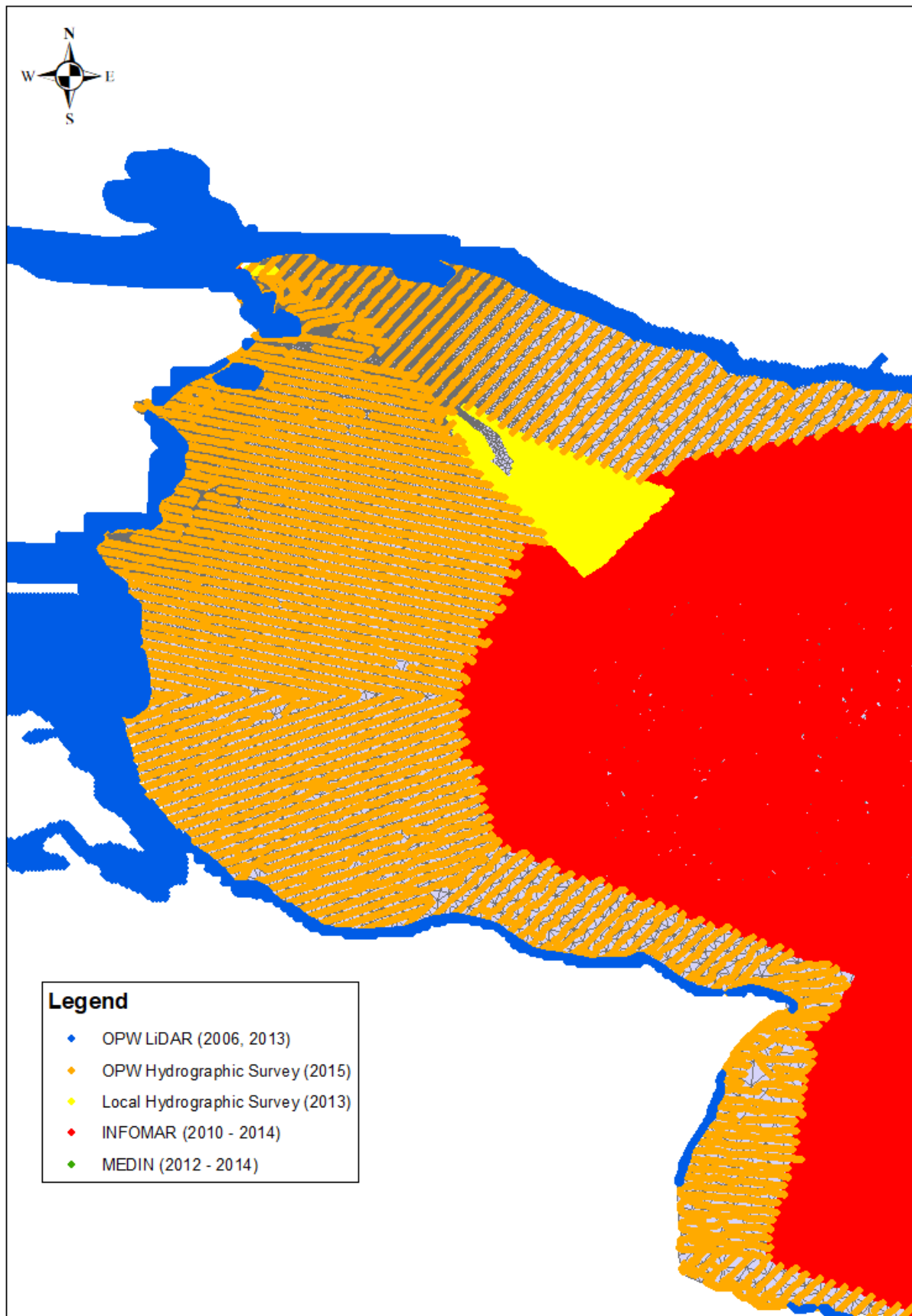


Figure 3.3: Survey Coverage of Dundalk Bay

RPS processed and quality checked all bathymetric data to ensure its suitability for use within the Dundalk modelling systems, consistently ensuring that any model interpolation processes produced valid meshes which were representative of the input data.

### 3.3 Water Level Data

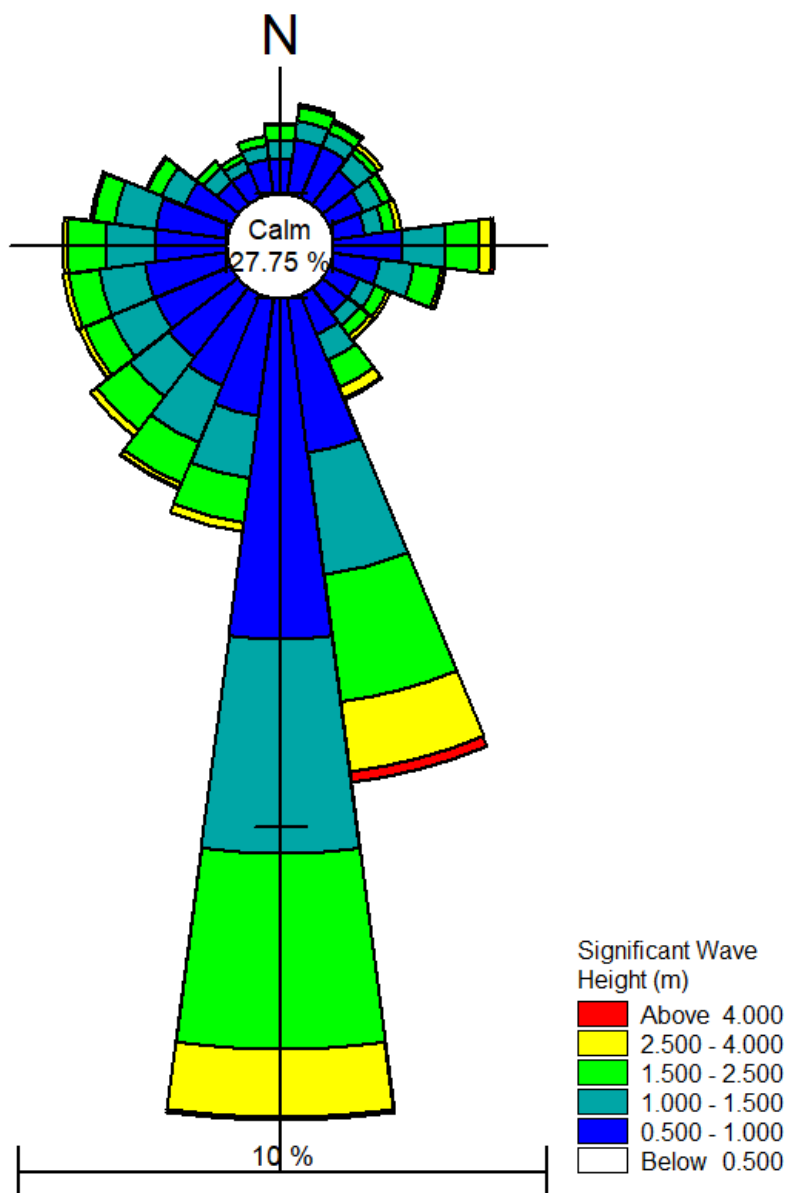
The extreme water levels used to inform the joint probability analysis and wave modelling were taken from the ICPSS / ICWWS 2018 Phase 1 estimation point NE3, close to Dundalk and covered the full range of required AEPs. The location of this point can be seen in Figure 3.1.

During Phase 1 of the ICWWS 2018, for the Dundalk area, new bathymetric information was input to the Irish Seas Tidal Surge Model, and the model revalidated to ensure the updated model was producing reasonable results, and a series of “extreme” events were then simulated. Once all these events were simulated, an extreme value analysis was undertaken by fitting various standard statistical distributions to the resulting water level datasets for each estimation point within Dundalk Bay. Refer to the Phase 1 Report for further detail on how these water levels were estimated (Reference 4). The extreme water levels derived during Phase 1 were marginally lower than the water levels previously estimated during the ICPSS, but were within the expected tolerance of the modelling and statistical analysis. As a conservative approach, the final water levels used for the Phase 3 modelling were therefore taken to be the higher of the two sets of results, which in this case was the previous ICPSS water levels.



## 4 STATISTICAL ANALYSIS

The offshore wave data from the UK Met Office WAVEWATCH III model was directionally discretised to identify the critical wave directions at the offshore locations relevant to Dundalk. The wave data was then used to provide boundary information for a series of computational wave models, used to transform this data from offshore to inshore in Dundalk Bay. Figure 4.1 shows the wave rose plot for the offshore point **53.748°N, 5.696°W**, which was the most relevant of the two offshore points (see Figure 3.1) used for transforming offshore waves into Dundalk Bay.



**Figure 4.1: Wave Rose for UK Met Office Point 53.748°N, 5.696°W (2011 – 2018)**

Extreme Value Analysis and Joint Probability Analysis of waves/wind speeds and water levels were performed on the offshore data for Dundalk prior to undertaking the wave transformation simulations.

## 4.1 Extreme Value Analysis

For the Extreme Value Analysis (EVA) a partial duration series, also known as peak over threshold model, was used to select the largest events which occurred within the UK Met Office dataset of wave heights and wind speeds. A theoretical probability distribution (Truncated Gumbel) was then fitted to the resultant extreme values and a Jackknife re-sampling technique used to derive a series of return period wave heights and wind speeds based on the omnidirectional dataset.

The latest UK Met Office methodology was employed to allocate return periods to wave heights and wind speeds from various directions. With this method the directional sector containing the largest wave height(s) was allocated the omnidirectional series of return period wave heights, while the remaining sectors had the omnidirectional return period wave height(s) proportioned according to their largest wave height(s) in comparison to the largest omnidirectional wave height(s). The same methodology was applied to wind speeds.

The UK Met Office suggest basing the analysis on the single maximum value for each directional sector, however RPS considered that this approach placed a lot of emphasis on individual values, and hence the analysis could easily be skewed by any outliers. As such, RPS have undertaken sensitivity testing, comparing the approaches of using single peak values only, or using the mean values of the largest three wave heights in the sector. Following this assessment, RPS deemed the latter approach to be more robust and appropriate for this length and type of dataset.

The results from the EVA are shown in Table 4-1 and Table 4-2 for points 53.349N, 5.667W and 53.748N, 5.696W respectively. Further details are provided in Appendix A.

Directional Sector		90°	120°	150°
Return Period (years)	0.5	3.38	2.88	3.61
	1	3.68	3.14	3.93
	2	3.97	3.39	4.24
	5	4.35	3.71	4.65
	10	4.64	3.96	4.96
	20	4.92	4.20	5.26
	50	5.30	4.52	5.66
	100	5.58	4.77	5.97
	200	5.87	5.01	6.27
	500	6.25	5.33	6.67
	1000	6.53	5.57	6.97

**Table 4-1: EVA Results for Wave Height (in metres) at 53.349N, 5.667W**

Directional Sector		90°	120°	150°
Return Period (years)	0.5	3.93	3.11	3.62
	1	4.31	3.41	3.97
	2	4.68	3.70	4.31
	5	5.17	4.09	4.76
	10	5.53	4.38	5.10
	20	5.90	4.67	5.44
	50	6.39	5.05	5.89
	100	6.75	5.34	6.22
	200	7.12	5.63	6.56
	500	7.60	6.01	7.01
	1000	7.97	6.30	7.35

**Table 4-2: EVA Results for Wave Height (in metres) at 53.748N, 5.696W**

## 4.2 Joint Probability Analysis

The Joint Probability Analysis of wave heights/wind speeds and water levels was undertaken using the spreadsheet and simplified methodology derived during the JOIN-SEA project, which is described in Section 5.7 of the DEFRA/Environment Agency RSD Guidance on Joint Probability Analysis, FD2308 (Reference 3). This methodology involves selecting a correlation coefficient between each pair of variables. This is normally based on established relationships (e.g. wave height and water level) for a particular area, however there are no pre-determined correlation coefficients available for the coast of Ireland. Therefore, RPS made use of the available wind, wave and tidal gauge data to derive joint event matrices between wave heights/wind speeds and water levels and subsequently determined appropriate correlation coefficients for Dundalk.

Once an appropriate correlation coefficient was selected, the relevant set of AEP water levels and wave heights/wind speeds were input to the JOIN-SEA spreadsheet for analysis. Extreme water levels were taken from the ICPSS results at Dundalk (Section 3.3), whilst the wave heights and wind speeds were derived during the EVA stage of this study (Section 4.1).

Combinations of wave heights/wind speeds and water levels for joint AEPs of 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% were derived for each sector relevant to Dundalk. For each joint AEP and direction, six water levels with corresponding wave heights/wind speeds were generated from the joint probability analysis to illustrate the complete joint probability range.

A sample plot of the offshore joint wave and water level exceedance curves at 53.748N, 5.696W for the 90° sector is shown in Figure 4.2, and full results from the joint probability analysis are included in Appendix B.

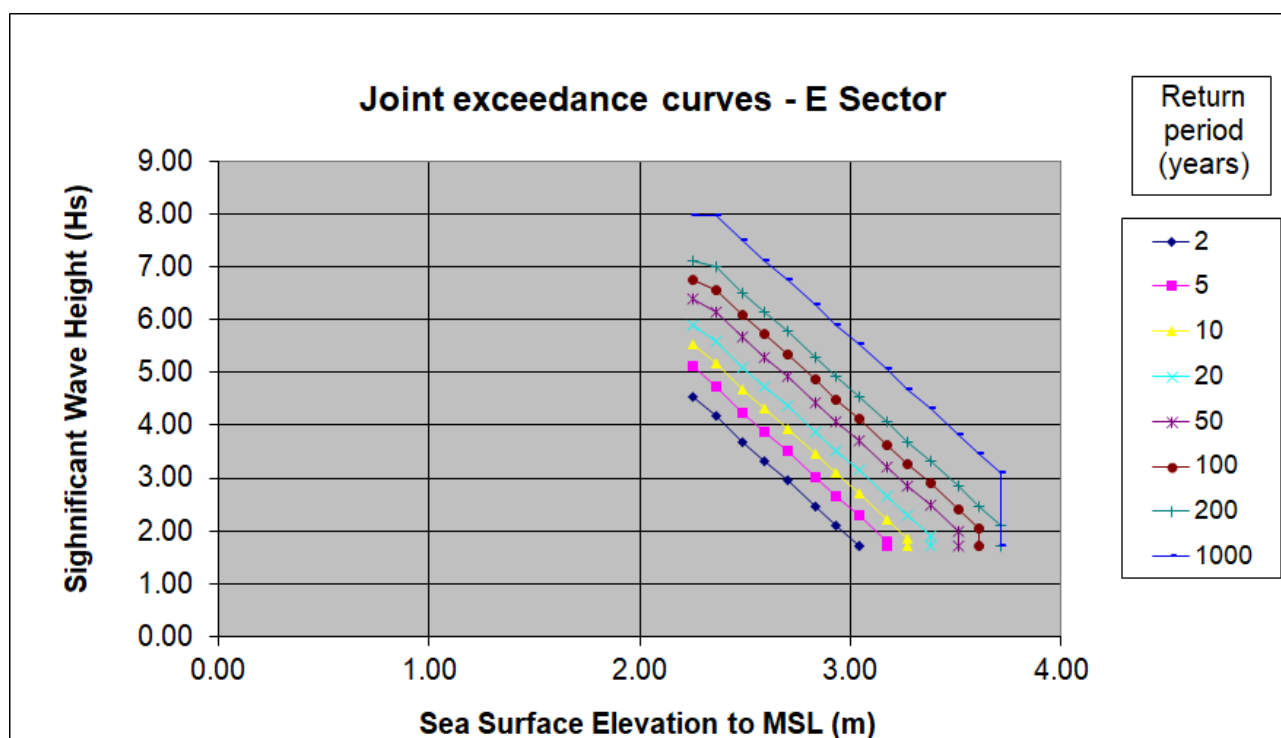


Figure 4.2: Offshore Joint Wave and Water Level Exceedance Curves at 53.748N, 5.696W (90deg sector)

### 4.2.1 Correlation Coefficients

The correlation between wave heights/wind speeds and water levels varies with storm direction around the coast of Ireland. The Joint Probability analysis was therefore undertaken for a range of storm direction sectors with the correlation coefficients derived for each sector shown in Table 4-3.

For the north east to south east coasts of Dundalk Bay, there was a strong correlation between the offshore wave heights and water levels for events from the south east and south, with less correlation from the east and the least correlation from the north east.

**Table 4-3: Derived Correlation Coefficients between Offshore Waves and Water Levels**

Direction (°)	Correlation Coefficient
0	
45	0.1
90	0.25
135	0.6
180	0.6
225	
270	
315	

## 5 MODEL DEVELOPMENT

### 5.1 Modelling System

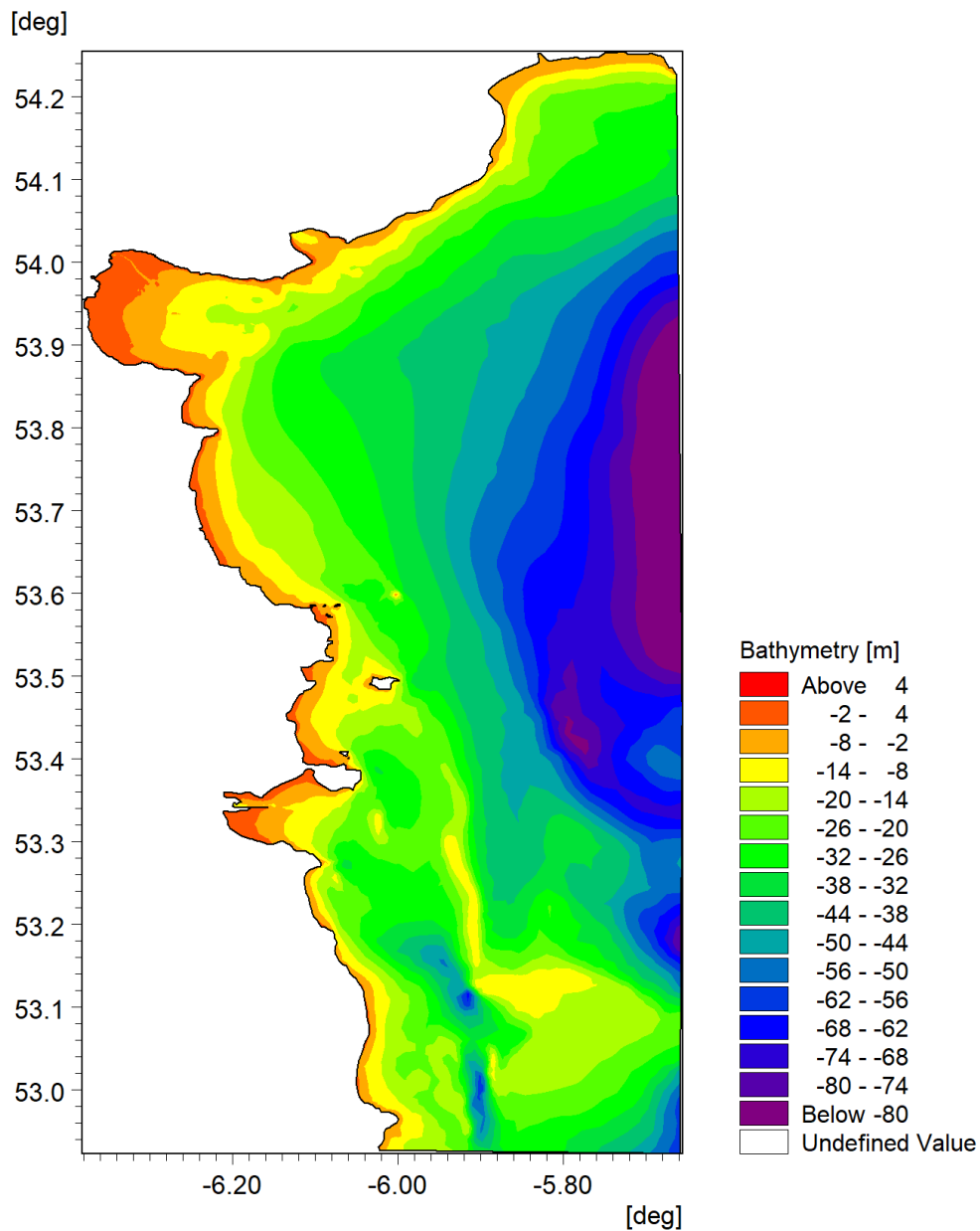
Following the statistical analysis, the offshore wave climate was transformed to inshore using the MIKE21 Spectral Wave (SW) Flexible Mesh model. The SW model is a third generation spectral wind-wave model with two modes of operation, using either the directional decoupled parametric or fully spectral formulations. As Phase 3 is intended to provide detailed information, the fully spectral formulation was used where possible. The SW module describes the propagation, growth and decay of waves in nearshore areas and can take into account the effects of refraction and shoaling due to varying depth, local wind generation and energy dissipation due to bottom friction, white capping and wave breaking. It may also include non-linear wave-wave interaction, wave-current interaction and the effect of time varying water depth and flooding and drying. The SW model has an optimal degree of flexibility in describing bathymetry and ambient flow conditions due to the use of a depth-adaptive and boundary-fitted unstructured mesh.

### 5.2 Model Bathymetry

A wave model was used to simulate transformation of combined swell and wind waves, from offshore into Dundalk Bay. The grid resolution of the model varied spatially depending on location and was selected to ensure that the variation and rate of change in the seabed topography due to banks, rocky shoals and particularly at the approaches to the shorelines/defence lines, were adequately resolved so that the changes in wave conditions due to shoaling, refraction and wave breaking were accurately modelled. This required fine grid resolution in places, down to circa 10m, particularly around banks and shoals and in the vicinity of areas of interest, with coarser grid resolution in deeper water and areas of more consistent bathymetry.

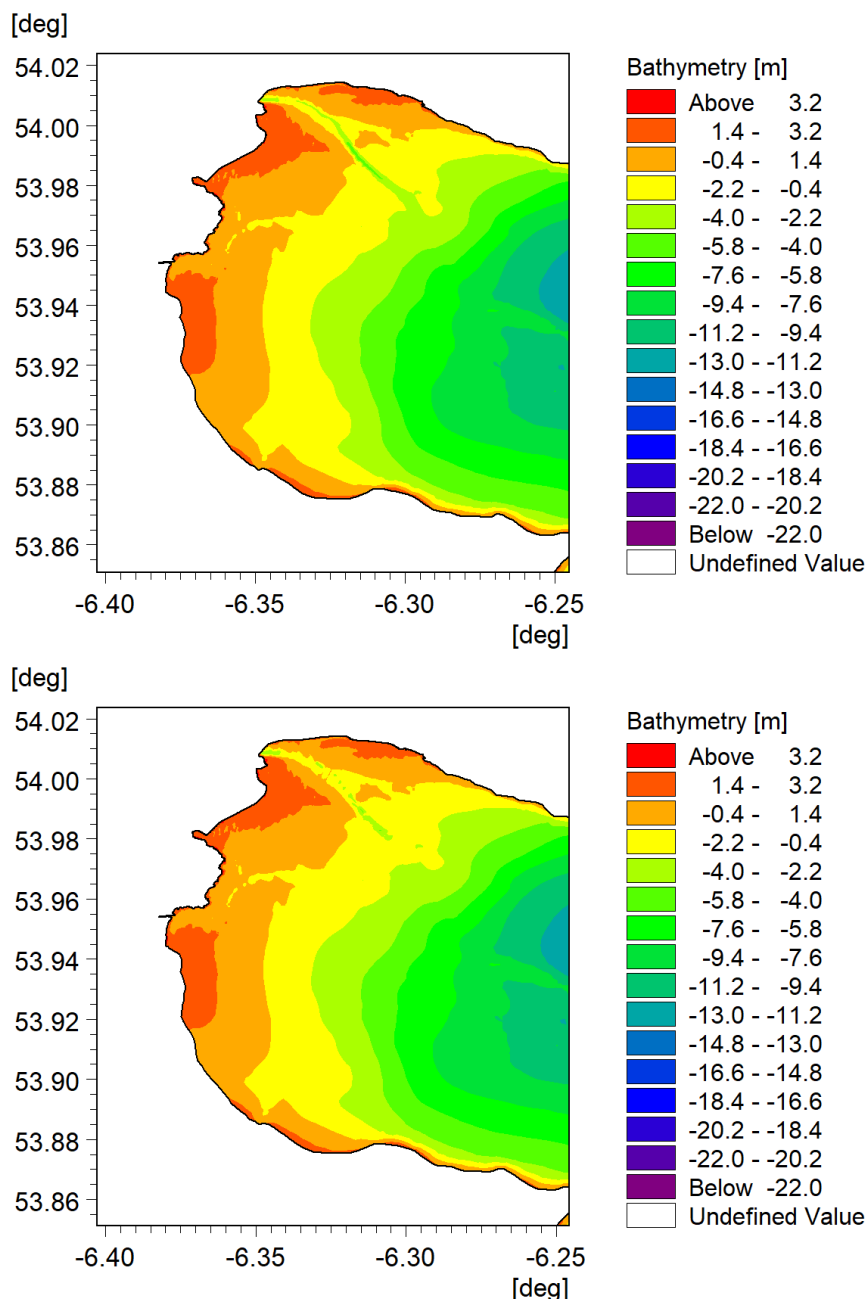
The wave model boundaries were positioned to accurately represent the wave climate of the UK Met Office data extraction points (Section 3.1). The resulting model extends from Ardglass in Northern Ireland to south of Wicklow in Ireland. This model was also used in Phase 2 of the ICWWS 2018 to simulate combined wave propagation for Ballynamony, Annagassan, Dunany, Cruisetown, Bettystown and Howth. The extent and bathymetry relative to Mean Sea Level (MSL) of the model for Dundalk can be seen in Figure 5.1.

Due to the complex bathymetry associated with the dredged entrance to Dundalk Harbour, achieving model convergence in the fully spectral model was difficult for two of the six locations within Dundalk (Locations B and C). Model convergence difficulties can arise when the mesh topography changes rapidly, and thus calculations from one cell to the next may not be resolved within the model tolerance, particularly when using the fully spectral formulation. To overcome this issue in Dundalk Bay, RPS modified the bathymetry of the dredged channel to smoothen the transition between the channel and surrounding cells, ultimately representing a shallower channel within the mesh, as shown in Figure 5.2. Due to the position of the channel, and the extreme water levels simulated, this minor amendment to the bathymetry had negligible effect on the inshore wave climate results. Some model convergence difficulties were still encountered, even after performing this adjustment, particularly for the more extreme events, and when this occurred RPS used the parametric formulation to transform the waves from offshore to inshore. To ensure consistency the parametric model results were compared to the fully spectral results to ensure that trends were consistent across the full range of results. This process demonstrated that the parametric formulation worked well in Dundalk Bay and correlation between fully spectral and parametric runs was easily achieved.



**Figure 5.1: North East Model Extent and Bathymetry (to MSL), used for Dundalk Simulations**





**Figure 5.2: Modifications to Bathymetry (to MSL) at the Entrance to Dundalk Harbour (top-before, bottom-after)**

### 5.3 Model Simulations

Dundalk is exposed to offshore storm wave conditions, from a range of directions, consequently multiple wave transformation model simulations were undertaken to assess the variability in inshore wave climate with incident wave direction. The direction which resulted in the most arduous conditions along each particular section of coastline was used to determine the inshore wave climate to be presented as the output from this study. It should be noted that for Dundalk, the critical storm direction changed frequently along the coast, resulting in the need to output data at a number of estimation locations.

The final critical storm directions simulated were 90, 120 and 150 degrees for a combined wave, which is a combination of both wind waves and swell waves. Simulations were undertaken for six combinations of wave heights and water levels for joint AEPs of 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% for each critical direction.

## 6 IMPACT OF SEA LEVEL RISE

Even without considering any increase in offshore wave heights due to the effect of climate change, the predicted increase in sea levels due to global warming has the potential to increase the wave climate at the shoreline/defence line due to greater water depths being available in the nearshore area. At present there is uncertainty about how global warming will actually affect the offshore wave climate or wind conditions in the future, thus the assessment of the effects of climate change in this study has considered four sea level rise scenarios.

For the purposes of flood risk assessment the current standard future scenario values adopted in Ireland for sea level rise are 0.5m for the Mid Range Future Scenario (MRFS) and 1.0m for the High End Future Scenario (HEFS), and thus these values were adopted for this study. Two additional climate change scenarios corresponding to sea level rise of 1.5m (H+EFS) and 2.0m (H++EFS) were also included.

Wave modelling scenarios undertaken for the present day were re-run for these four climate change scenarios. The simulations were undertaken for the wave directions established as the critical directions for Dundalk during the present day simulations but with the water level increased by the relevant amount.

## 7 MEAN SEA LEVEL TO OD MALIN CONVERSION

A review of the Mean Sea Level (MSL) to OD Malin datum relationship at Dundalk was undertaken as part of Phase 4 of the ICWWS 2018.

Although, there is a tide gauge situated at Dundalk itself, due to the local bathymetry, this gauge is subject to drying and thus the data is not suitable for harmonic assessment. However, the OPW Port Oriel tide gauge which has recently been levelled to OD Malin OSGM15 datum is situated nearby, and therefore an accurate estimate of the relationship between gauge datum and OD Malin datum could be made at this gauged site. Consequently, by undertaking an analysis of the Port Oriel gauge records the mean water level relative to OD Malin could be obtained directly.

The Port Oriel gauge data was analysed and covered the period April 2007 to April 2020. Using the MIKE 21 toolbox 'Tide Analysis of Heights', the data analysed, yielded a set of harmonics including a Z0 value which is equivalent to the mean sea level. Estimations of a Z0 value at the Port Oriel gauge were made for the latest year and latest three years of suitable data. RPS considered a three year period to be the optimum length of data required, with a minimum of one year of data for a reasonable estimate of Z0 due to seasonal variations. Analysis of a longer period of records carries more risk of a shift in the datum and is affected to a greater degree by sea level rise and other trends. A harmonic analysis on a rolling basis was also undertaken, where Z0 was taken as the average of a rolling analysis of periods of one year at intervals of one month, over a three year period.

Once the Z0 (mean sea level) value for Port Oriel was estimated, it was included in the creation of a surface grid representing the conversion between MSL and OD Malin OSGM15 around the coast of Ireland. This grid was used to transfer the MSL and OD Malin OSGM15 relationship from the gauged location of Port Oriel to the non-gauged location of the Dundalk frontage. Further details are included in the ICWWS 2018 Phase 4 report (Reference 5).

Using the Grid Inquest II software from Ordnance Survey Ireland (OSi), the relationship between OD Malin OSGM15 and OD Malin OSGM02 at Dundalk was also derived. The resulting updated datum conversions for Dundalk used to present the results of this study in terms of OD Malin OSGM02 and OSGM15 are presented in Table 7-1. The sign convention in Table 7-1 indicates OD Malin (OSGM02 and OSGM15) relative to MSL, with a positive value being above MSL and a negative value being below MSL. In order to convert from MSL to OD Malin, the correction stated is subtracted.

**Table 7-1: Estimated Conversion between MSL and OD Malin for Dundalk**

MSL to OD Malin	
MSL to Malin OSGM02	MSL to Malin OSGM15
+0.049m	+0.048m

## 8 ADDITIONAL CONSIDERATIONS

### 8.1 Beach Drawdown

Beach drawdown can be a significant issue on gradually sloping sandy beaches exposed to large ocean storm waves. Where this is the case the large storm waves, which form a series of breaking waves across the surf zone, can result in high undertow currents which in combination with the large breaking waves lifting the bed sediment can result in sand being stripped off the beach and carried to an offshore bar. This lowering or drawdown of the beach can result in larger reformed waves being able to directly attack shoreline structures at the back of the beach.

Areas such as Blackrock within Dundalk Bay are known to be subject to severe wave overtopping and are fronted by a 'soft' foreshore or beach. If wave conditions during storm events result in beach drawdown, this would potentially result in larger waves reaching Blackrock and thus increased overtopping. This section of the report therefore assesses and quantifies the risk of beach drawdown at the toe of the coastal defence structures at Blackrock and assesses the significance of this in terms of the incident wave climate.

To investigate the vulnerability of the seabed along the Blackrock frontage to beach drawdown, morphological modelling simulations were undertaken to determine the beach drawdown at the toe of the defence structure during a 1% AEP south easterly event.

In addition to considering the potential for beach drawdown today, RPS also investigated the effects of future climate change using the recommended sea level rise values described in Section 6, with 0.5m, 1.0m, 1.5m and 2.0m being used to represent the MRFS, HEFS, H+EFS and H++EFS respectively.

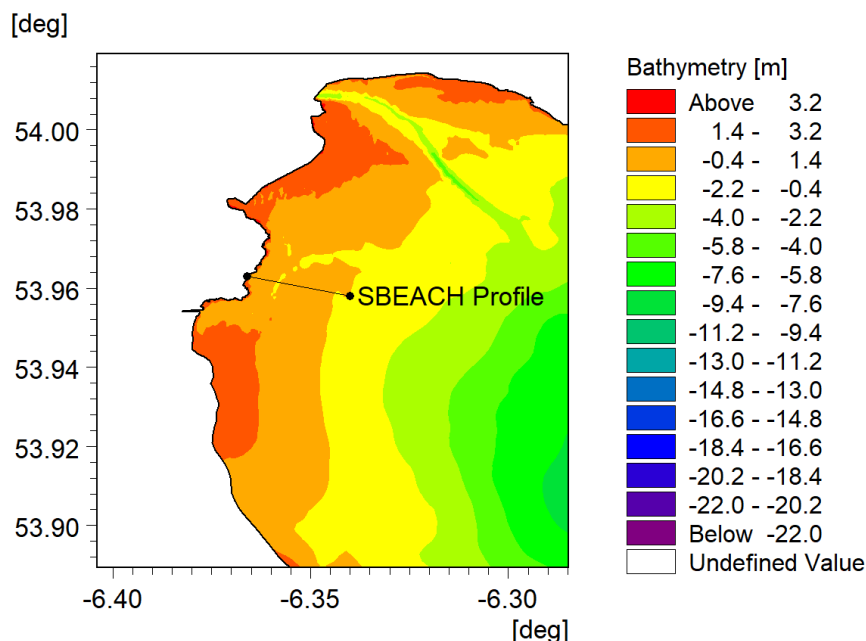
#### 8.1.1 SBEACH Morphological Model

The modelling of the morphological response of the seabed at the toe of the defence structure to storm events was undertaken using the US Army Corps of Engineers SBEACH model. SBEACH is an empirically based numerical model for simulating two-dimensional cross-shore beach change and was initially formulated using data from prototype-scale laboratory experiments and further developed and verified based on field measurements and sensitivity testing.

SBEACH calculates the mesoscale beach profile change with emphasis on beach and dune erosion and bar formation and movement. The model is extensively used in the US for predicting the response of beaches to storm attack particularly in the state of Florida where beaches are subject to severe wave attack during the hurricane season. SBEACH also allows for the inclusion of seawalls and revetments which may be used to protect the shoreline or dunes.

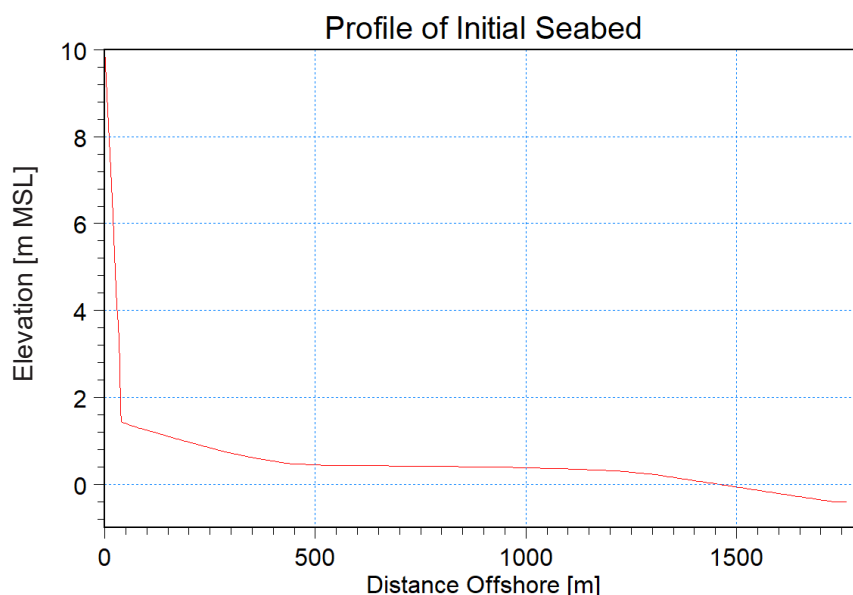
#### 8.1.2 Model Setup

The model was set up along a single representative profile to MSL as shown in Figure 8.1.



**Figure 8.1: SBEACH Profile Location**

The beach profile as input to the SBEACH model is shown in Figure 8.2. The grid resolution varied between 2m and 5m along the profile.

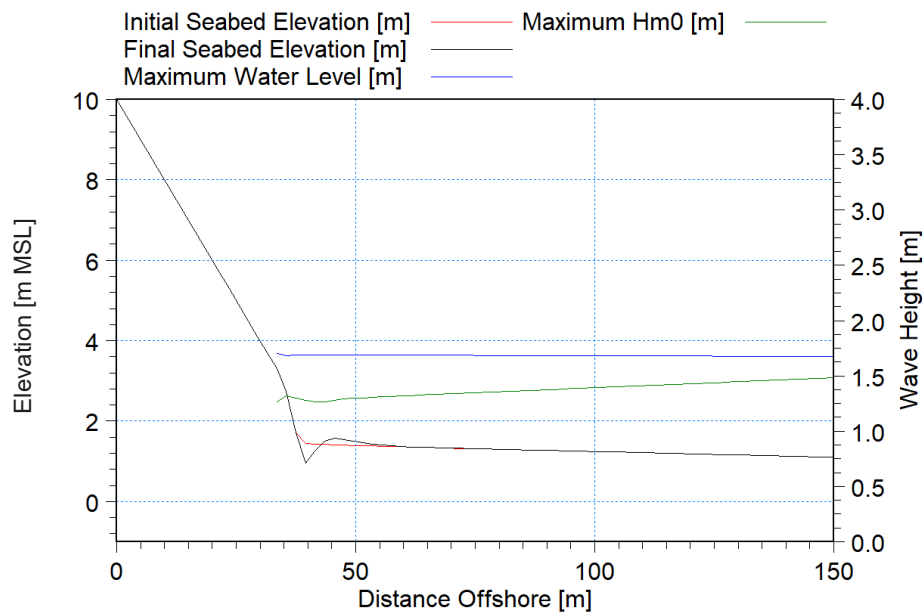


**Figure 8.2: SBEACH Profile for Blackrock Location**

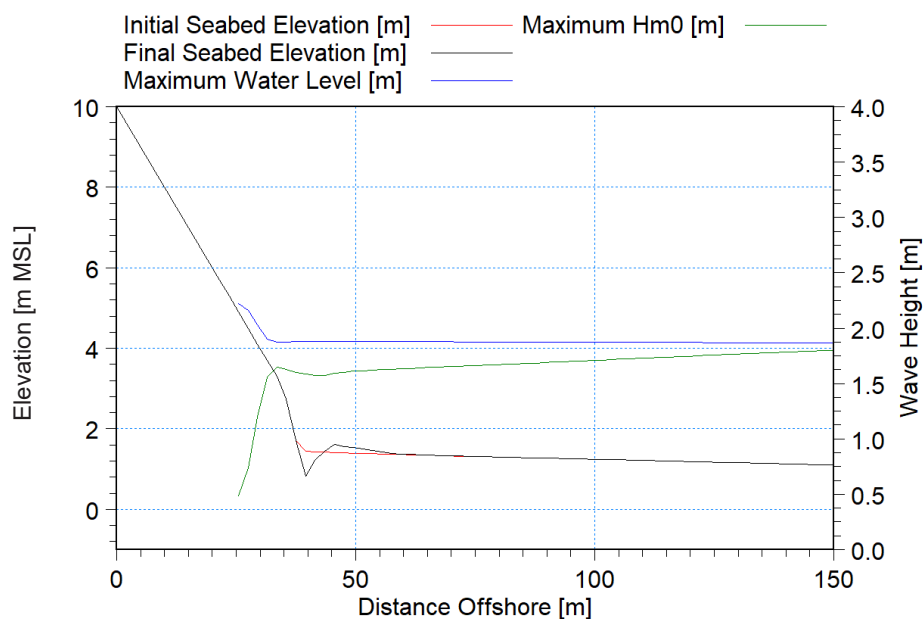
The 1% AEP south easterly wave climate was extracted from the wave transformation model simulations described in Section 5 and used in the SBEACH model to simulate the most onerous joint probability event. The same storm event was then re-run with increased water levels for the MRFS, HEFS, H+EFS and H++EFS scenarios. Due to drying at the toe of the structure at low tide, the storm event was only simulated for the period of time that the toe was submerged during the storm event. This varied for each water level, ranging from 7.25 hours for the present day sea level scenario to 10.5 hours for the H++EFS scenario.

### 8.1.3 Model Results

The results of the simulations for the present day, MRFS, HEFS, H+EFS and H++EFS sea levels are shown in Figure 8.3, Figure 8.4, Figure 8.5, Figure 8.6 and Figure 8.7 respectively.

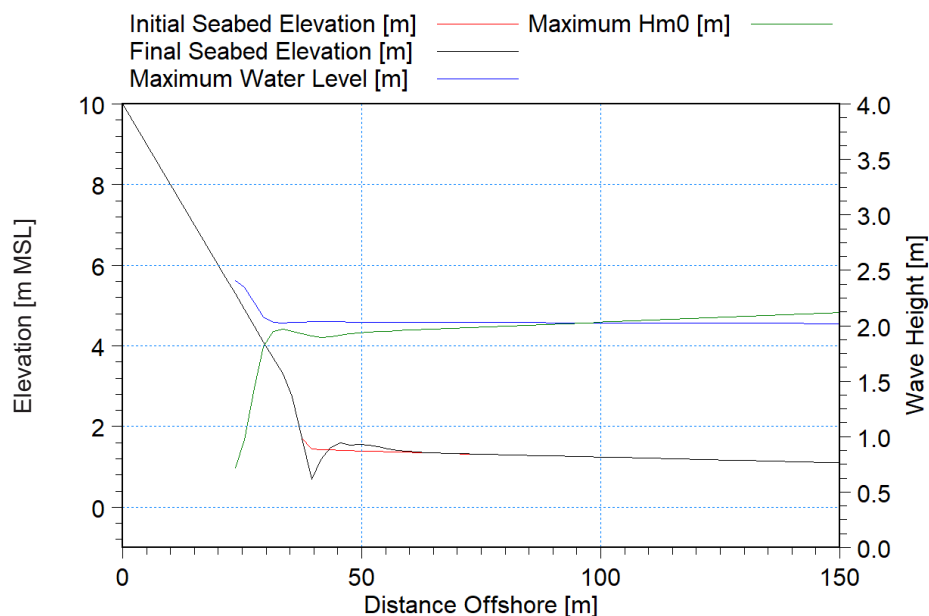


**Figure 8.3: Erosion along Profile at Blackrock under 1.0% AEP Storm Conditions at Present Day Sea Level**

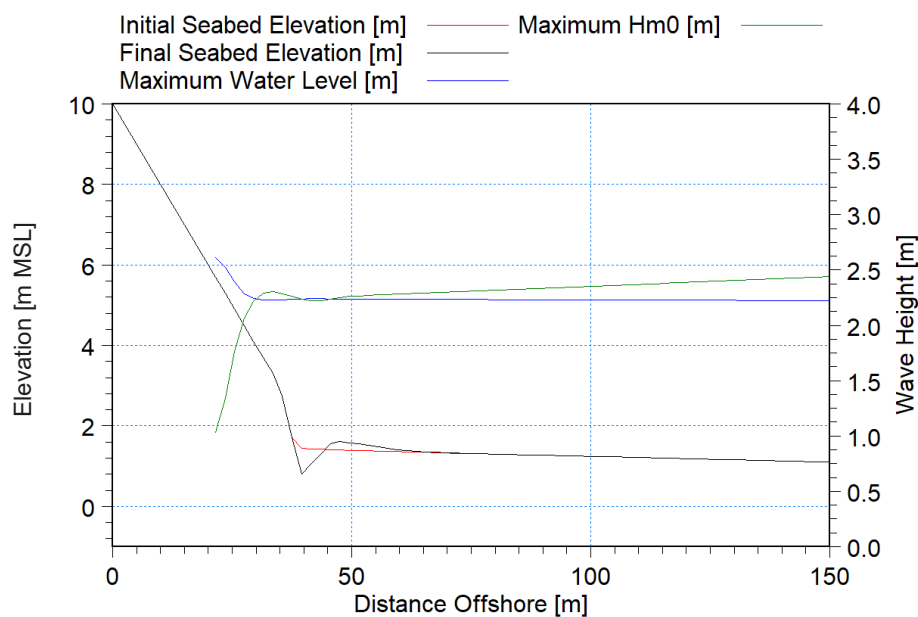


**Figure 8.4: Erosion along Profile at Blackrock under 1.0% AEP Storm Conditions at MRFS Sea Level**

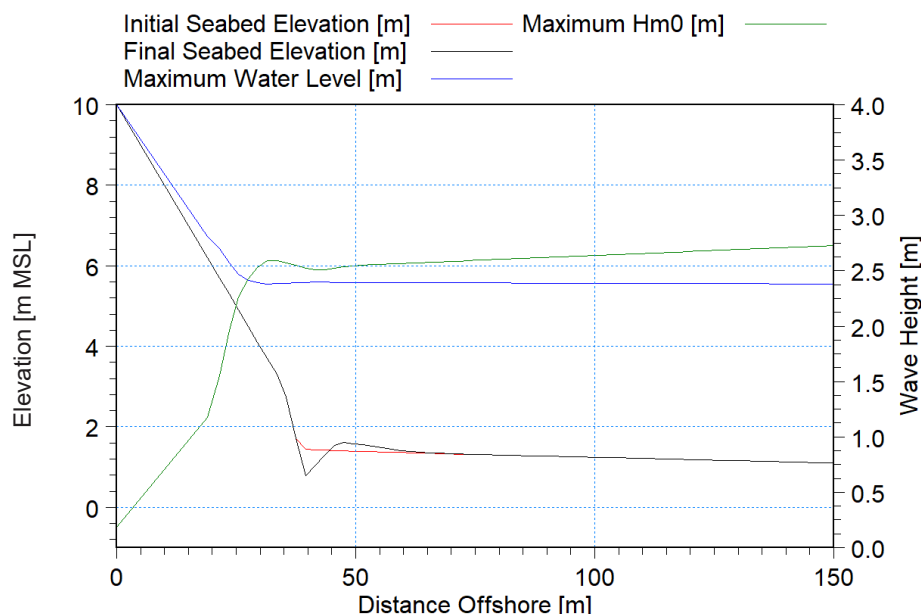




**Figure 8.5: Erosion along Profile at Blackrock under 1.0% AEP Storm Conditions at HEFS Sea Level**



**Figure 8.6: Erosion along Profile at Blackrock under 1.0% AEP Storm Conditions at H+EFS Sea Level**



**Figure 8.7: Erosion along Profile at Blackrock under 1.0% AEP Storm Conditions at H++EFS Sea Level**

It can be seen that beach drawdown at the toe of the coastal defence structure ranges from approximately 0.5m for present day sea levels to 0.7m for HEFS, H+EFS and H++EFS sea levels. A summary of the beach drawdown for all sea level scenarios considered is presented in Table 8-1.

**Table 8-1: Beach Drawdown at the toe of the Coastal Defence Structure**

Sea Level Scenario	Beach Drawdown (m)
Present Day	0.5m
MRFS	0.6m
HEFS	0.7m
H+EFS	0.7m
H++EFS	0.7m

Figure 8.3 to Figure 8.7 show a highly localised drawdown at the toe of the coastal defence structure followed by a slight increase in bed levels to seaward. The net result would be approximately zero change and the localised nature of the change is such that any impact on the incident wave climate would be insignificant. It is important to note that this analysis only considered the response of the beach to a single extreme event and that a succession of events could lead to greater drawdown in beach levels. However, no computational methods exist to accurately assess long term change in beach levels due to a succession of the storm events as none of the currently available packages simulate the beach recovery period between events.

It is clear from the results of the assessment for the various future sea level rise scenarios that the wave conditions along the Dundalk frontage are sensitive to water depth. Wave heights tend, for the same AEP, to increase in line with the increased water depth available under each increasingly severe sea level rise scenario. Consequently, anyone using the results of this study to inform the detailed design of defence measures should give consideration to potential long term change in beach levels within Dundalk Bay and how those might impact on the design wave climate and the stability of existing coastal slopes or any new structures proposed in the vicinity of the coast.

## 8.2 Wave Setup

On wide, relatively flat, beaches where large storm waves break and reform there is usually a significant gradient in the radiation stresses across the surf zone which results in a lowering of the mean sea level under the first line of breaking waves and a subsequent increase in the mean sea levels in towards the beach. This increase or setup of the mean water levels close to the beach means that reformed waves approaching a

coastal structure at the back of the beach may be slightly larger due to the locally increased water depth at the toe of the structure.

As the height of the waves that can approach Dundalk is strongly influenced by water depth in the area, the effect of wave setup could potentially have a significant impact on the inshore wave climate. To assess this, the combined extreme water levels and wave conditions for Dundalk were simulated using a MIKE coupled model. Wind setup was not included in this analysis as this was already included in the extreme water level analysis.

By modelling the same storm event through both a Coupled Model and an Uncoupled Model, it was possible to determine the impact (if any) the wave climate had on both the water level and subsequently the significant wave height. This impact is known as wave setup.

### 8.2.1 Coupled Model

The MIKE 21/3 Coupled FM Model was used for this part of the assessment. The Hydrodynamic Module and the Spectral Wave Module are the basic computational components of this model allowing the mutual interaction between water level variation and wave transformation to be modelled. Within this model the Hydrodynamic Module is dependent on information on the waves from the Spectral Wave Module, while simultaneously the Spectral Wave Module is reliant on water level conditions from the Hydrodynamic Module. Therefore, the two modules are dependent on each other making the wave conditions and water levels changeable throughout the simulation.

### 8.2.2 Uncoupled Model

The MIKE21 Spectral Wave FM Module was also used for this part of the assessment. It has been described in detail in Section 5.1.

Unlike the Coupled Model where the water level variation is changeable throughout the simulation, depending on the wave climate, in uncoupled mode the water level is specified prior to the Spectral Wave FM simulation. The water level therefore is completely independent of the wave climate. The specified water level variation remains unchanged throughout the simulation.

### 8.2.3 Results

A selection of AEP events from a south easterly direction were simulated for present day water levels in order to determine the significance of wave setup.

The resulting impact of wave setup for a selection of AEP events is presented in Table 8-2 and Table 8-3 in terms of water level and significant wave height respectively. These values were extracted at Dundalk Location D (refer to Figure 9.1) as it is the most central location within Dundalk Bay. It is noted that the indicated water level increase due to wave setup was greater for the 5% AEP than for the 1% or 0.1% AEP events. This is likely due to the radiation stresses created by wave action in the inshore being more pronounced at shallower water depths, however as the water levels increase with increasing return period the wave behaviour, including breaking changes and the influence of bed effects diminishes.

**Table 8-2: Water Level Increase associated with Wave Setup at Dundalk**

Percentage Annual Exceedance Probability (AEP)	Water Level (m)		Water level increase due to Wave Setup (m)
	Coupled Model	Uncoupled Model	
5	3.39	3.22	0.17
1	3.55	3.44	0.11
0.1	3.96	3.86	0.10

**Table 8-3: Wave Height Increase associated with Wave Setup at Dundalk**

Percentage Annual Exceedance Probability (AEP)	Significant Wave Height (m)		Significant Wave Height increase due to Wave Setup (m)
	Coupled Model	Uncoupled Model	
5	0.50	0.42	0.08
1	0.57	0.52	0.05
0.1	0.74	0.69	0.05

Wave setup adjustments of 0.10m and 0.05m were therefore applied to the water levels and significant wave heights (both increased) respectively presented in Section 9. These single values were used across all AEP events, incident wave directions and future water level scenarios.

## 9 RESULTS AND STUDY OUTPUTS

Dundalk Bay is exposed to waves approaching from the east to south east directions. Offshore wave conditions range from up to 7.2m significant height and 11.7s peak period for the 0.1% AEP event from an easterly direction to up to 7.3m significant height and 11.8s peak period for the 0.1% AEP event from a south easterly direction.

The Dundalk wave transformation model was used to simulate the full range of joint probability return period events up to 0.1% AEP, with six combinations of waves and water levels modelled for each event for the appropriate directional sectors. Following the transformation of the offshore wave conditions into the nearshore, the inshore results were extracted for six locations around Dundalk Bay.

For each AEP event from 50% to 0.1%, the output of the study near the shoreline/defence line along Dundalk Bay in areas which are potentially liable to flooding from wave overtopping is presented in terms of spectral significant wave height ( $H_{m0}$ ) in metres, spectral peak wave period ( $T_p$ ) in seconds and mean wave direction (MWD) in degrees measured from north, for each water level (WL).

Due to the effects of refraction, the storm wave directions at the shoreline/defence line were normally within  $\pm 30^\circ$  of the direction normal to the coastline. While the wave direction at the shoreline/defence line is therefore not critical for overtopping calculations, the mean wave direction has been provided for completeness. The output from this study is representative of a point situated at approximately half the shallow water wavelength seaward from the toe of the defence structure or shoreline. A note of the measured bed level at each estimation location and its source is also supplied.

Wave climate and water level combinations are provided for present day sea levels and for each of four future sea level rise scenarios (MRFS, HEFS, H+EFS, H++EFS).

Six estimation locations (A to F) were identified for Dundalk, as shown in Figure 9.1 and detailed in Table 9-1. The recommended wave and tidal levels for standard AEPs and each of the five epochs investigated for each point are presented in Table 9-2 to Table 9-7 respectively. It is notable that the estimated wave heights for each combined AEP event increase with water depth at Dundalk, which seems counterintuitive. However, this is a direct consequence of the extensive shallow depths of approach to the shoreline at Dundalk and hence the reduced bottom friction and energy loss experienced by the incoming waves as water depths over the beach increase.

For the present day sea level, Location E experienced the largest significant wave heights with a maximum of 0.91m to 1.31m for the 50% and 0.1% AEPs respectively. Corresponding peak wave periods were 7.36s and 8.96s. Location C experienced the smallest significant wave heights with a maximum of 0.30m to 0.56m for the 50% and 0.1% AEPs respectively, and corresponding peak wave periods of 7.33s and 7.74s.

An assessment of the impact of wave set-up on extreme water levels indicated that this could increase the still water levels by between 0.10m and 0.17m depending on the severity of the event. Consequently water levels considered for present day conditions ranged from 2.54m OD Malin (OSGM15) to 3.90m OD Malin (OSGM15) when the appropriate allowance for wave set-up identified in Section 8.2.3 was included. Bed levels at which the output data at Location C and Location E were extracted are shown as 1.97m OD Malin (OSGM15) and 1.20m OD Malin (OSGM15) respectively.

When using the results of this study to inform the detailed design of defence measures, consideration should be given to the potential long term change in beach levels within Dundalk Bay. Although the study showed only a localised drawdown at the toe of the coastal defence at Blackrock, this was the response of the beach during a single extreme event. A succession of extreme events may lead to greater drawdown in beach levels, so consideration must be given to how this may impact on the design wave climate and the stability of existing coastal slopes, or any new structures proposed in the vicinity of the coast.



**Figure 9.1: Estimation Locations for Dundalk**



Table 9-1: Co-ordinates for Estimation Locations for Dundalk

Location	Co-ordinates (WGS84)	
	Latitude (°N)	Longitude (°W)
A	54.0092	6.3000
B	54.0115	6.3444
C	54.0074	6.3464
D	53.9864	6.3595
E	53.9659	6.3622
F	53.9566	6.3700

Location	Co-ordinates (ITM)	
	Eastings [m]	Northings [m]
A	711429.125	808001.669
B	708513.127	808188.625
C	708392.708	807729.351
D	707588.222	805372.687
E	707463.913	803087.542
F	706975.972	802040.923

Table 9-2: Shoreline Wave Climate and Water Level Combinations – Location A

Irish Coastal Wave & Water Level Modelling Study (ICWWS) 2018 Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPO)						
Output: Shoreline Wave Climate and Water Level Combinations						
Location: Dundalk_Location A						
Bed Level (MSL): 1.665m						
Bed Level (OD Malin OSGM02): 1.616m						
Bed Level (OD Malin OSGM15): 1.617m						
Dated: September 2020						
Joint Probability Event (AEP): Varies from 50% to 0.1%						
Prepared By: RMcK			Checked By: AKB			
Table Reference: ICWWS_CAPO_NWNB_Dundalk						

Notes:						
1	Users of this information should refer to the ICWWS 2018 Phase 3 Dundalk Technical Report for a detailed description of the derivation of the data and it's applicability					
2	Bed Level taken at approximately half the shallow water wavelength from structure / shoreline					
3	Bed level source: OPW LIDAR data (2007)					
4	AEP denotes the combined wave and water level joint Annual Exceedance Probability					
5	Comb Wave Component describes the combination of wind waves and swell waves					
6	Hm0 denotes the spectral significant wave height in metres					
7	Tp denotes the spectral peak wave period in seconds					
8	MWD denotes the mean wave direction in degrees north					
9	Water level allows for wind/wave setup					

Present Day Scenario Water Level						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	2.59	2.54	2.54	0.42	9.06	162
	2.68	2.63	2.63	0.46	8.97	162
	2.81	2.76	2.76	0.52	8.64	162
	2.90	2.85	2.85	0.56	8.13	162
	3.00	2.95	2.95	0.60	7.97	162
	3.12	3.07	3.07	0.64	7.35	162
20%	2.59	2.54	2.54	0.42	9.67	162
	2.68	2.63	2.63	0.47	9.65	162
	2.81	2.76	2.76	0.53	9.06	162
	2.90	2.85	2.85	0.56	8.92	162
	3.00	2.95	2.95	0.61	8.59	162
	3.12	3.07	3.07	0.66	8.07	162
10%	2.59	2.54	2.54	0.43	9.95	162
	2.81	2.76	2.76	0.53	9.72	162
	2.90	2.85	2.85	0.57	9.16	162
	3.00	2.95	2.95	0.61	8.98	162
	3.12	3.07	3.07	0.66	8.67	162
	3.22	3.17	3.17	0.70	8.15	161
5%	2.59	2.54	2.54	0.43	10.08	162
	2.81	2.76	2.76	0.53	10.03	162
	2.90	2.85	2.85	0.57	9.87	162
	3.00	2.95	2.95	0.62	9.34	162
	3.12	3.07	3.07	0.67	9.00	161
	3.32	3.27	3.27	0.75	8.29	161
2%	2.59	2.54	2.54	0.43	10.38	162
	2.81	2.76	2.76	0.54	10.39	162
	3.00	2.95	2.95	0.62	10.02	162
	3.12	3.07	3.07	0.68	9.74	161
	3.22	3.17	3.17	0.72	9.18	161
	3.44	3.39	3.39	0.80	8.70	161
1%	2.59	2.54	2.54	0.43	10.93	162
	2.81	2.76	2.76	0.54	10.94	162
	3.00	2.95	2.95	0.63	10.24	161
	3.22	3.17	3.17	0.72	9.88	161
	3.44	3.39	3.39	0.81	9.01	161
	3.54	3.49	3.49	0.85	8.85	161
0.5%	2.59	2.54	2.54	0.44	11.14	162
	2.81	2.76	2.76	0.55	11.14	162
	3.00	2.95	2.95	0.63	10.95	161
	3.22	3.17	3.17	0.73	10.09	161
	3.44	3.39	3.39	0.82	9.46	161
	3.63	3.58	3.58	0.89	8.93	160
0.1%	2.59	2.54	2.54	0.44	11.46	162
	2.81	2.76	2.76	0.55	11.47	161
	3.00	2.95	2.95	0.64	11.48	161
	3.32	3.27	3.27	0.78	10.96	161
	3.63	3.58	3.58	0.91	9.97	160
	3.95	3.90	3.90	1.03	8.94	160

Mid-Range Future Scenario (MRFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.09	3.04	3.04	0.65	9.07	161
	3.18	3.13	3.13	0.69	8.98	161
	3.31	3.26	3.26	0.75	8.66	161
	3.40	3.35	3.35	0.78	8.14	161
	3.50	3.45	3.45	0.82	7.98	161
	3.62	3.57	3.57	0.86	7.35	161
20%	3.09	3.04	3.04	0.66	9.69	161
	3.18	3.13	3.13	0.70	9.67	161
	3.31	3.26	3.26	0.75	9.07	161
	3.40	3.35	3.35	0.79	8.93	161
	3.50	3.45	3.45	0.83	8.61	161
	3.62	3.57	3.57	0.88	8.07	161
10%	3.09	3.04	3.04	0.66	9.96	161
	3.31	3.26	3.26	0.76	9.73	161
	3.40	3.35	3.35	0.80	9.17	161
	3.50	3.45	3.45	0.84	8.99	161
	3.62	3.57	3.57	0.88	8.68	161
	3.72	3.67	3.67	0.92	8.15	161
5%	3.09	3.04	3.04	0.67	10.09	161
	3.31	3.26	3.26	0.77	10.03	161
	3.40	3.35	3.35	0.81	9.88	161
	3.50	3.45	3.45	0.84	9.36	161
	3.62	3.57	3.57	0.89	9.00	160
	3.82	3.77	3.77	0.96	8.31	160
2%	3.09	3.04	3.04	0.67	10.40	161
	3.31	3.26	3.26	0.77	10.40	161
	3.50	3.45	3.45	0.85	10.02	160
	3.62	3.57	3.57	0.90	9.75	160
	3.72	3.67	3.67	0.94	9.18	160
	3.94	3.89	3.89	1.02	8.70	160
1%	3.09	3.04	3.04	0.67	10.95	161
	3.31	3.26	3.26	0.78	10.95	161
	3.50	3.45	3.45	0.86	10.25	160
	3.72	3.67	3.67	0.95	9.89	160
	3.94	3.89	3.89	1.03	9.01	160
	4.04	3.99	3.99	1.06	8.86	160
0.5%	3.09	3.04	3.04	0.68	11.15	161
	3.31	3.26	3.26	0.78	11.15	161
	3.50	3.45	3.45	0.86	10.96	160
	3.72	3.67	3.67	0.95	10.09	160
	3.94	3.89	3.89	1.03	9.48	160
	4.13	4.08	4.08	1.10	8.94	160
0.1%	3.09	3.04	3.04	0.69	11.48	161
	3.31	3.26	3.26	0.79	11.49	161
	3.50	3.45	3.45	0.88	11.49	160
	3.82	3.77	3.77	1.00	10.97	160
	4.13	4.08	4.08	1.12	9.97	159
	4.45	4.40	4.40	1.23	8.94	159

High End Future Scenario (HEFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.59	3.54	3.54	0.88	9.08	160
	3.68	3.63	3.63	0.92	8.98	160
	3.81	3.76	3.76	0.96	8.67	160
	3.90	3.85	3.85	0.99	8.15	160
	4.00	3.95	3.95	1.02	7.98	160
	4.12	4.07	4.07	1.06	7.35	161
20%	3.59	3.54	3.54	0.88	9.70	160
	3.68	3.63	3.63	0.93	9.68	160
	3.81	3.76	3.76	0.97	9.07	160
	3.90	3.85	3.85	1.01	8.93	160
	4.00	3.95	3.95	1.04	8.62	160
	4.12	4.07	4.07	1.08	8.07	160
10%	3.59	3.54	3.54	0.89	9.97	160
	3.81	3.76	3.76	0.98	9.74	160
	3.90	3.85	3.85	1.01	9.17	160
	4.00	3.95	3.95	1.05	8.99	160
	4.12	4.07	4.07	1.09	8.69	160
	4.22	4.17	4.17	1.12	8.16	160
5%	3.59	3.54	3.54	0.89	10.09	160
	3.81	3.76	3.76	0.99	10.03	160
	3.90	3.85	3.85	1.02	9.88	160
	4.00	3.95	3.95	1.06	9.37	160
	4.12	4.07	4.07	1.10	9.01	159
	4.32	4.27	4.27	1.16	8.31	160
2%	3.59	3.54	3.54	0.90	10.41	160
	3.81	3.76	3.76	1.00	10.41	160
	4.00	3.95	3.95	1.07	10.02	159
	4.12	4.07	4.07	1.11	9.76	159
	4.22	4.17	4.17	1.15	9.19	159
	4.44	4.39	4.39	1.22	8.71	159
1%	3.59	3.54	3.54	0.90	10.96	160
	3.81	3.76	3.76	1.00	10.96	160
	4.00	3.95	3.95	1.08	10.26	159
	4.22	4.17	4.17	1.15	9.89	159
	4.44	4.39	4.39	1.23	9.01	159
	4.54	4.49	4.49	1.26	8.86	159
0.5%	3.59	3.54	3.54	0.90	11.15	158
	3.81	3.76	3.76	1.00	11.15	157
	4.00	3.95	3.95	1.08	11.15	157
	4.22	4.17	4.17	1.16	10.84	156
	4.44	4.39	4.39	1.24	10.05	156
	4.63	4.58	4.58	1.28	8.93	156
0.1%	3.59	3.54	3.54	0.92	11.50	160
	3.81	3.76	3.76	1.02	11.50	159
	4.00	3.95	3.95	1.10	11.50	159
	4.32	4.27	4.27	1.22	10.97	159
	4.63	4.58	4.58	1.32	9.97	158
	4.95	4.90	4.90	1.42	8.94	158

High+ End Future Scenario (H+EFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	4.09	4.04	4.04	1.09	9.08	159
	4.18	4.13	4.13	1.12	8.99	159
	4.31	4.26	4.26	1.16	8.68	159
	4.40	4.35	4.35	1.19	8.15	160
	4.50	4.45	4.45	1.21	7.98	160
	4.62	4.57	4.57	1.22	7.36	160
20%	4.09	4.04	4.04	1.10	9.71	159
	4.18	4.13	4.13	1.13	9.70	159
	4.31	4.26	4.26	1.18	9.07	159
	4.40	4.35	4.35	1.21	8.93	159
	4.50	4.45	4.45	1.24	8.63	159
	4.62	4.57	4.57	1.27	8.07	159
10%	4.09	4.04	4.04	1.10	9.97	159
	4.31	4.26	4.26	1.19	9.75	159
	4.40					

Table 9-3: Shoreline Wave Climate and Water Level Combinations – Location B

Irish Coastal Wave & Water Level Modelling Study (ICWWS) 2018 Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPO)						
Output: Shoreline Wave Climate and Water Level Combinations						
Location: Dundalk_Location B						
Bed Level (MSL): 1.455m						
Bed Level (OD Malin OSGM02): 1.406m						
Bed Level (OD Malin OSGM15): 1.407m						
Dated: September 2020						
Joint Probability Event (AEP): Varies from 50% to 0.1%						
Prepared By: RMcK			Checked By: AKB			
Table Reference: ICWWS_CAPO_NWNB_Dundalk						

Notes:						
1	Users of this information should refer to the ICWWS 2018 Phase 3 Dundalk Technical Report for a detailed description of the derivation of the data and it's applicability					
2	Bed Level taken at approximately half the shallow water wavelength from structure / shoreline					
3	Bed level source: OPW LiDAR data (2007)					
4	AEP denotes the combined wave and water level joint Annual Exceedance Probability					
5	Comb Wave Component describes the combination of wind waves and swell waves					
6	Hm0 denotes the spectral significant wave height in metres					
7	Tp denotes the spectral peak wave period in seconds					
8	MWD denotes the mean wave direction in degrees north					
9	Water level allows for wind/wave setup					

Present Day Scenario Water Level						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	2.59	2.54	2.54	0.35	9.05	157
	2.68	2.63	2.63	0.36	8.96	156
	2.81	2.76	2.76	0.38	8.62	154
	2.90	2.85	2.85	0.39	8.10	153
	3.00	2.95	2.95	0.40	7.97	152
	3.12	3.07	3.07	0.42	7.35	150
20%	2.59	2.54	2.54	0.36	9.63	157
	2.68	2.63	2.63	0.37	9.61	156
	2.81	2.76	2.76	0.39	9.06	154
	2.90	2.85	2.85	0.40	8.90	153
	3.00	2.95	2.95	0.41	7.38	151
	3.12	3.07	3.07	0.43	7.11	148
10%	2.59	2.54	2.54	0.36	9.94	157
	2.81	2.76	2.76	0.40	9.68	154
	2.90	2.85	2.85	0.41	9.13	153
	3.00	2.95	2.95	0.42	8.96	152
	3.12	3.07	3.07	0.44	8.61	151
	3.22	3.17	3.17	0.45	8.11	150
5%	2.59	2.54	2.54	0.45	3.00	153
	2.81	2.76	2.76	0.46	3.13	151
	2.90	2.85	2.85	0.45	3.68	153
	3.00	2.95	2.95	0.44	4.10	152
	3.12	3.07	3.07	0.44	4.44	151
	3.32	3.27	3.27	0.46	7.28	148
2%	2.59	2.54	2.54	0.46	2.97	153
	2.81	2.76	2.76	0.49	3.14	152
	3.00	2.95	2.95	0.47	3.94	153
	3.12	3.07	3.07	0.46	4.42	152
	3.22	3.17	3.17	0.46	4.62	150
	3.44	3.39	3.39	0.49	7.42	147
1%	2.59	2.54	2.54	0.48	2.94	154
	2.81	2.76	2.76	0.50	3.04	152
	3.00	2.95	2.95	0.50	3.76	153
	3.22	3.17	3.17	0.48	4.60	151
	3.44	3.39	3.39	0.49	7.81	148
	3.54	3.49	3.49	0.51	7.64	147
0.5%	2.59	2.54	2.54	0.49	2.92	154
	2.81	2.76	2.76	0.52	3.01	152
	3.00	2.95	2.95	0.52	3.57	152
	3.22	3.17	3.17	0.50	4.54	151
	3.44	3.39	3.39	0.50	5.05	149
	3.63	3.58	3.58	0.53	7.85	146
0.1%	2.59	2.54	2.54	0.51	2.88	154
	2.81	2.76	2.76	0.55	3.01	153
	3.00	2.95	2.95	0.57	3.29	152
	3.32	3.27	3.27	0.55	4.65	151
	3.63	3.58	3.58	0.55	5.39	148
	3.95	3.90	3.90	0.59	7.75	145

Mid-Range Future Scenario (MRFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.09	3.04	3.04	0.44	9.05	152
	3.18	3.13	3.13	0.45	8.98	151
	3.31	3.26	3.26	0.47	8.66	149
	3.40	3.35	3.35	0.48	8.14	148
	3.50	3.45	3.45	0.50	7.96	147
	3.62	3.57	3.57	0.52	7.33	146
20%	3.09	3.04	3.04	0.45	9.65	152
	3.18	3.13	3.13	0.46	9.65	151
	3.31	3.26	3.26	0.48	9.07	150
	3.40	3.35	3.35	0.50	8.92	149
	3.50	3.45	3.45	0.51	8.60	148
	3.62	3.57	3.57	0.53	8.06	147
10%	3.09	3.04	3.04	0.45	9.94	152
	3.31	3.26	3.26	0.49	9.74	150
	3.40	3.35	3.35	0.50	9.17	149
	3.50	3.45	3.45	0.52	8.98	148
	3.62	3.57	3.57	0.54	8.67	147
	3.72	3.67	3.67	0.55	8.14	146
5%	3.09	3.04	3.04	0.46	10.07	152
	3.31	3.26	3.26	0.50	10.03	150
	3.40	3.35	3.35	0.51	9.87	149
	3.50	3.45	3.45	0.53	9.36	148
	3.62	3.57	3.57	0.55	9.00	147
	3.82	3.77	3.77	0.57	8.28	146
2%	3.09	3.04	3.04	0.47	10.36	152
	3.31	3.26	3.26	0.52	10.37	150
	3.50	3.45	3.45	0.54	10.01	149
	3.62	3.57	3.57	0.56	9.74	148
	3.72	3.67	3.67	0.57	9.17	147
	3.94	3.89	3.89	0.61	8.65	145
1%	3.09	3.04	3.04	0.48	10.93	152
	3.31	3.26	3.26	0.53	10.93	150
	3.50	3.45	3.45	0.55	10.25	149
	3.72	3.67	3.67	0.58	9.88	147
	3.94	3.89	3.89	0.62	9.00	146
	4.04	3.99	3.99	0.63	8.84	145
0.5%	3.09	3.04	3.04	0.49	11.13	152
	3.31	3.26	3.26	0.54	11.14	150
	3.50	3.45	3.45	0.56	10.95	149
	3.72	3.67	3.67	0.60	10.08	147
	3.94	3.89	3.89	0.63	9.42	146
	4.13	4.08	4.08	0.66	8.92	145
0.1%	3.09	3.04	3.04	0.53	11.07	150
	3.31	3.26	3.26	0.56	11.07	151
	3.50	3.45	3.45	0.58	10.90	150
	3.82	3.77	3.77	0.62	9.50	147
	4.13	4.08	4.08	0.66	8.81	144
	4.45	4.40	4.40	0.70	7.75	142

High End Future Scenario (HEFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.59	3.54	3.54	0.55	9.05	148
	3.68	3.63	3.63	0.56	8.98	147
	3.81	3.76	3.76	0.58	8.64	146
	3.90	3.85	3.85	0.59	8.13	145
	4.00	3.95	3.95	0.60	7.96	145
	4.12	4.07	4.07	0.62	7.32	143
20%	3.59	3.54	3.54	0.55	9.64	148
	3.68	3.63	3.63	0.57	9.66	147
	3.81	3.76	3.76	0.59	9.06	146
	3.90	3.85	3.85	0.61	8.92	146
	4.00	3.95	3.95	0.62	8.59	145
	4.12	4.07	4.07	0.64	8.06	144
10%	3.59	3.54	3.54	0.56	9.94	148
	3.81	3.76	3.76	0.60	9.73	147
	3.90	3.85	3.85	0.61	9.16	146
	4.00	3.95	3.95	0.63	8.98	145
	4.12	4.07	4.07	0.65	8.66	145
	4.22	4.17	4.17	0.67	8.14	144
5%	3.59	3.54	3.54	0.57	10.07	148
	3.81	3.76	3.76	0.61	10.03	147
	3.90	3.85	3.85	0.62	9.87	146
	4.00	3.95	3.95	0.64	9.35	146
	4.12	4.07	4.07	0.66	9.00	145
	4.32	4.27	4.27	0.69	8.28	144
2%	3.59	3.54	3.54	0.58	10.37	148
	3.81	3.76	3.76	0.62	10.38	147
	4.00	3.95	3.95	0.66	10.02	146
	4.12	4.07	4.07	0.67	9.74	145
	4.22	4.17	4.17	0.69	9.17	145
	4.44	4.39	4.39	0.73	8.67	143
1%	3.59	3.54	3.54	0.59	10.93	148
	3.81	3.76	3.76	0.63	10.94	147
	4.00	3.95	3.95	0.66	10.25	146
	4.22	4.17	4.17	0.70	9.88	145
	4.44	4.39	4.39	0.74	9.00	144
	4.54	4.49	4.49	0.76	8.84	143
0.5%	3.59	3.54	3.54	0.60	11.14	148
	3.81	3.76	3.76	0.64	11.14	147
	4.00	3.95	3.95	0.69	11.14	146
	4.22	4.17	4.17	0.73	10.84	145
	4.44	4.39	4.39	0.77	10.05	144
	4.63	4.58	4.58	0.79	8.92	143
0.1%	3.59	3.54	3.54	0.63	11.47	148
	3.81	3.76	3.76	0.67	11.47	147
	4.00	3.95	3.95	0.72	11.48	146
	4.32	4.27	4.27	0.75	10.96	145
	4.63	4.58	4.58	0.81	9.96	143
	4.95	4.90	4.90	0.87	8.93	142

High+ End Future Scenario (H+EFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	4.09	4.04	4.04	0.66	9.05	145
	4.18	4.13	4.13	0.68	8.98	145
	4.31	4.26	4.26	0.69	8.64	144
	4.40	4.35	4.35	0.71	8.13	143
	4.50	4.45	4.45	0.72	7.96	143
	4.62	4.57	4.57	0.73	7.31	142
20%	4.09	4.04	4.04	0.67	9.66	145
	4.18	4.13	4.13	0.68	9.67	145
	4.31	4.26	4.26	0.71	9.06	144
	4.40	4.35	4.35	0.73	8.92	144
	4.50	4.45	4.45	0.74	8.59	143
	4.62	4.57	4.57	0.76	8.05	143
10%	4.09	4.04	4.04	0.68	9.95	145
	4.31	4.26	4.26	0.72	9.73	144
	4.40	4.35	4.35	0.73	9.16	144
	4.50	4.45	4.45	0.76	8.98	143
	4.62	4.57	4.57	0.77	8.65	143
	4.72	4.67	4.67	0.79	8.14	142
5%	4.09	4.04	4.04	0.69	10.08	145
	4.31	4.26	4.26	0.73	10.03	144
	4.40	4.35	4.35	0.75	9.8	



Table 9-4: Shoreline Wave Climate and Water Level Combinations – Location C

Irish Coastal Wave & Water Level Modelling Study (ICWWS) 2018 Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPO)						
Output: Shoreline Wave Climate and Water Level Combinations						
Location: Dundalk_Location C						
Bed Level (MSL): 2.015m						
Bed Level (OD Malin OSGM02): 1.966m						
Bed Level (OD Malin OSGM15): 1.967m						
Dated: September 2020						
Joint Probability Event (AEP): Varies from 50% to 0.1%						
Prepared By: RMcK			Checked By: AKB			
Table Reference: ICWWS_CAPO_NWNB_Dundalk						

Notes:						
1	Users of this information should refer to the ICWWS 2018 Phase 3 Dundalk Technical Report for a detailed description of the derivation of the data and it's applicability					
2	Bed Level taken at approximately half the shallow water wavelength from structure / shoreline					
3	Bed level source: OPW LiDAR data (2007)					
4	AEP denotes the combined wave and water level joint Annual Exceedance Probability					
5	Comb Wave Component describes the combination of wind waves and swell waves					
6	Hm0 denotes the spectral significant wave height in metres					
7	Tp denotes the spectral peak wave period in seconds					
8	MWD denotes the mean wave direction in degrees north					
9	Water level allows for wind/wave setup					

Present Day Scenario Water Level						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	2.59	2.54	2.54	0.22	9.05	47
	2.68	2.63	2.63	0.23	8.97	49
	2.81	2.76	2.76	0.25	8.61	53
	2.90	2.85	2.85	0.26	8.11	56
	3.00	2.95	2.95	0.28	7.97	59
	3.12	3.07	3.07	0.30	7.33	63
20%	2.59	2.54	2.54	0.22	9.65	47
	2.68	2.63	2.63	0.24	9.62	49
	2.81	2.76	2.76	0.25	9.06	53
	2.90	2.85	2.85	0.27	8.90	55
	3.00	2.95	2.95	0.28	7.40	59
	3.12	3.07	3.07	0.31	7.12	64
10%	2.59	2.54	2.54	0.23	9.95	47
	2.81	2.76	2.76	0.26	9.69	52
	2.90	2.85	2.85	0.27	9.14	55
	3.00	2.95	2.95	0.29	8.97	58
	3.12	3.07	3.07	0.31	7.51	63
	3.22	3.17	3.17	0.33	8.12	65
5%	2.59	2.54	2.54	0.23	9.45	47
	2.81	2.76	2.76	0.26	3.38	60
	2.90	2.85	2.85	0.27	8.83	55
	3.00	2.95	2.95	0.29	8.28	58
	3.12	3.07	3.07	0.31	8.02	62
	3.32	3.27	3.27	0.36	7.27	69
2%	2.59	2.54	2.54	0.23	3.03	54
	2.81	2.76	2.76	0.27	3.45	60
	3.00	2.95	2.95	0.29	8.96	58
	3.12	3.07	3.07	0.31	8.57	61
	3.22	3.17	3.17	0.34	8.13	64
	3.44	3.39	3.39	0.39	7.39	72
1%	2.59	2.54	2.54	0.24	3.01	54
	2.81	2.76	2.76	0.27	3.35	60
	3.00	2.95	2.95	0.30	4.03	63
	3.22	3.17	3.17	0.34	8.57	64
	3.44	3.39	3.39	0.39	7.80	70
	3.54	3.49	3.49	0.42	7.63	74
0.5%	2.59	2.54	2.54	0.24	3.00	54
	2.81	2.76	2.76	0.28	3.32	61
	3.00	2.95	2.95	0.31	3.93	63
	3.22	3.17	3.17	0.34	9.00	64
	3.44	3.39	3.39	0.40	8.21	70
	3.63	3.58	3.58	0.45	7.83	75
0.1%	2.59	2.54	2.54	0.25	2.97	55
	2.81	2.76	2.76	0.29	3.37	60
	3.00	2.95	2.95	0.33	3.76	64
	3.32	3.27	3.27	0.38	9.70	66
	3.63	3.58	3.58	0.47	8.80	74
	3.95	3.90	3.90	0.56	7.74	82

Mid-Range Future Scenario (MRFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.09	3.04	3.04	0.31	9.05	60
	3.18	3.13	3.13	0.33	8.98	63
	3.31	3.26	3.26	0.36	8.64	67
	3.40	3.35	3.35	0.38	8.13	70
	3.50	3.45	3.45	0.41	7.96	73
	3.62	3.57	3.57	0.44	7.31	77
20%	3.09	3.04	3.04	0.31	9.65	60
	3.18	3.13	3.13	0.33	9.65	63
	3.31	3.26	3.26	0.36	9.06	66
	3.40	3.35	3.35	0.39	8.92	69
	3.50	3.45	3.45	0.41	7.47	73
	3.62	3.57	3.57	0.45	8.05	76
10%	3.09	3.04	3.04	0.32	9.95	60
	3.31	3.26	3.26	0.37	9.72	66
	3.40	3.35	3.35	0.39	9.16	69
	3.50	3.45	3.45	0.42	8.98	71
	3.62	3.57	3.57	0.45	8.65	75
	3.72	3.67	3.67	0.48	8.13	77
5%	3.09	3.04	3.04	0.32	10.08	60
	3.31	3.26	3.26	0.38	10.02	66
	3.40	3.35	3.35	0.40	9.87	68
	3.50	3.45	3.45	0.42	9.34	71
	3.62	3.57	3.57	0.46	8.99	74
	3.82	3.77	3.77	0.52	8.27	79
2%	3.09	3.04	3.04	0.32	10.37	60
	3.31	3.26	3.26	0.38	10.38	66
	3.50	3.45	3.45	0.43	10.01	71
	3.62	3.57	3.57	0.47	9.73	74
	3.72	3.67	3.67	0.50	9.17	76
	3.94	3.89	3.89	0.57	8.65	81
1%	3.09	3.04	3.04	0.33	10.93	60
	3.31	3.26	3.26	0.39	10.94	66
	3.50	3.45	3.45	0.44	10.24	70
	3.72	3.67	3.67	0.50	9.87	76
	3.94	3.89	3.89	0.58	9.00	81
	4.04	3.99	3.99	0.61	8.84	83
0.5%	3.09	3.04	3.04	0.34	11.14	60
	3.31	3.26	3.26	0.40	11.14	66
	3.50	3.45	3.45	0.45	10.95	70
	3.72	3.67	3.67	0.51	10.08	75
	3.94	3.89	3.89	0.58	9.42	80
	4.13	4.08	4.08	0.64	8.92	84
0.1%	3.09	3.04	3.04	0.36	11.07	65
	3.31	3.26	3.26	0.40	11.07	65
	3.50	3.45	3.45	0.45	10.08	75
	3.82	3.77	3.77	0.54	9.69	77
	4.13	4.08	4.08	0.65	8.80	83
	4.45	4.40	4.40	0.74	7.75	90

High End Future Scenario (HEFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.59	3.54	3.54	0.45	9.05	73
	3.68	3.63	3.63	0.48	8.97	76
	3.81	3.76	3.76	0.52	8.63	79
	3.90	3.85	3.85	0.55	8.12	81
	4.00	3.95	3.95	0.57	7.95	84
	4.12	4.07	4.07	0.61	7.32	88
20%	3.59	3.54	3.54	0.46	9.65	73
	3.68	3.63	3.63	0.49	9.66	75
	3.81	3.76	3.76	0.53	9.06	78
	3.90	3.85	3.85	0.56	8.92	80
	4.00	3.95	3.95	0.58	8.57	82
	4.12	4.07	4.07	0.63	8.05	85
10%	3.59	3.54	3.54	0.46	9.95	73
	3.81	3.76	3.76	0.53	9.72	78
	3.90	3.85	3.85	0.56	9.16	80
	4.00	3.95	3.95	0.60	8.98	82
	4.12	4.07	4.07	0.63	8.65	84
	4.22	4.17	4.17	0.66	8.13	87
5%	3.59	3.54	3.54	0.47	10.08	73
	3.81	3.76	3.76	0.54	10.03	77
	3.90	3.85	3.85	0.57	9.87	79
	4.00	3.95	3.95	0.60	9.34	81
	4.12	4.07	4.07	0.65	8.99	84
	4.32	4.27	4.27	0.70	8.27	88
2%	3.59	3.54	3.54	0.47	10.38	72
	3.81	3.76	3.76	0.55	10.38	77
	4.00	3.95	3.95	0.61	10.02	81
	4.12	4.07	4.07	0.65	9.74	83
	4.22	4.17	4.17	0.68	9.17	85
	4.44	4.39	4.39	0.76	8.67	89
1%	3.59	3.54	3.54	0.48	10.94	72
	3.81	3.76	3.76	0.56	10.94	77
	4.00	3.95	3.95	0.62	10.24	80
	4.22	4.17	4.17	0.69	9.88	84
	4.44	4.39	4.39	0.77	9.00	88
	4.54	4.49	4.49	0.80	8.84	90
0.5%	3.59	3.54	3.54	0.49	11.14	72
	3.81	3.76	3.76	0.56	11.14	77
	4.00	3.95	3.95	0.64	11.15	80
	4.22	4.17	4.17	0.71	10.84	84
	4.44	4.39	4.39	0.79	10.05	87
	4.63	4.58	4.58	0.84	8.92	91
0.1%	3.59	3.54	3.54	0.50	11.47	72
	3.81	3.76	3.76	0.58	11.48	77
	4.00	3.95	3.95	0.66	11.48	80
	4.32	4.27	4.27	0.75	10.96	85
	4.63	4.58	4.58	0.87	9.96	90
	4.95	4.90	4.90	0.97	8.93	94

High+ End Future Scenario (H+EFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	4.09	4.04	4.04	0.64	9.05	83
	4.18	4.13	4.13	0.67	8.97	85
	4.31	4.26	4.26	0.70	8.64	87
	4.40	4.35	4.35	0.73	8.13	89
	4.50	4.45	4.45	0.76	7.96	91
	4.62	4.57	4.57	0.78	7.31	95
20%	4.09	4.04	4.04	0.64	9.66	83
	4.18	4.13	4.13	0.67	9.67	84
	4.31	4.26	4.26	0.72	9.06	86
	4.40	4.35	4.35	0.75	8.92	88
	4.50	4.45	4.45	0.78	8.58	90
	4.62	4.57	4.57	0.81	8.05	93
10%	4.09	4.04	4.04	0.65	9.95	82
	4.31	4.26	4.26	0.73	9.73	86
	4.40	4.35	4.35	0.75	9.16	87
	4.50	4.45	4.45	0.79	8.98	89
	4.62	4.57	4.57	0.82	8.65	91
	4.72	4.6				

Table 9-5: Shoreline Wave Climate and Water Level Combinations – Location D

Irish Coastal Wave & Water Level Modelling Study (ICWWS) 2018 Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPO)						
Output: Shoreline Wave Climate and Water Level Combinations						
Location: Dundalk_Location D						
Bed Level (MSL): 2.055m						
Bed Level (OD Malin OSGM02): 2.006m						
Bed Level (OD Malin OSGM15): 2.007m						
Dated: September 2020						
Joint Probability Event (AEP): Varies from 50% to 0.1%						
Prepared By: RMcK			Checked By: AKB			
Table Reference: ICWWS_CAPO_NWNB_Dundalk						

Notes:						
1	Users of this information should refer to the ICWWS 2018 Phase 3 Dundalk Technical Report for a detailed description of the derivation of the data and it's applicability					
2	Bed Level taken at approximately half the shallow water wavelength from structure / shoreline					
3	Bed level source: OPW LIDAR data (2007)					
4	AEP denotes the combined wave and water level joint Annual Exceedance Probability					
5	Comb Wave Component describes the combination of wind waves and swell waves					
6	Hm0 denotes the spectral significant wave height in metres					
7	Tp denotes the spectral peak wave period in seconds					
8	MWD denotes the mean wave direction in degrees north					
9	Water level allows for wind/wave setup					

Present Day Scenario Water Level						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	2.59	2.54	2.54	0.24	9.06	141
	2.68	2.63	2.63	0.27	8.97	144
	2.81	2.76	2.76	0.32	8.62	146
	2.90	2.85	2.85	0.36	8.13	147
	3.00	2.95	2.95	0.40	8.01	147
	3.12	3.07	3.07	0.45	7.41	147
20%	2.59	2.54	2.54	0.24	9.65	141
	2.68	2.63	2.63	0.28	9.64	144
	2.81	2.76	2.76	0.33	9.06	146
	2.90	2.85	2.85	0.37	8.92	147
	3.00	2.95	2.95	0.41	8.58	147
	3.12	3.07	3.07	0.46	8.09	147
10%	2.59	2.54	2.54	0.24	9.95	141
	2.81	2.76	2.76	0.34	9.71	146
	2.90	2.85	2.85	0.37	9.16	147
	3.00	2.95	2.95	0.42	8.99	147
	3.12	3.07	3.07	0.46	8.66	147
	3.22	3.17	3.17	0.50	8.15	147
5%	2.59	2.54	2.54	0.25	10.07	141
	2.81	2.76	2.76	0.34	10.02	146
	2.90	2.85	2.85	0.38	9.87	147
	3.00	2.95	2.95	0.42	9.35	147
	3.12	3.07	3.07	0.47	9.02	147
	3.32	3.27	3.27	0.55	8.29	147
2%	2.59	2.54	2.54	0.25	10.34	142
	2.81	2.76	2.76	0.35	10.37	146
	3.00	2.95	2.95	0.43	10.02	147
	3.12	3.07	3.07	0.48	9.75	147
	3.22	3.17	3.17	0.52	9.20	147
	3.44	3.39	3.39	0.60	8.73	146
1%	2.59	2.54	2.54	0.26	10.90	142
	2.81	2.76	2.76	0.36	10.93	146
	3.00	2.95	2.95	0.43	10.24	147
	3.22	3.17	3.17	0.52	9.89	147
	3.44	3.39	3.39	0.61	9.03	146
	3.54	3.49	3.49	0.65	8.88	146
0.5%	2.59	2.54	2.54	0.26	11.11	142
	2.81	2.76	2.76	0.36	11.13	146
	3.00	2.95	2.95	0.44	10.94	147
	3.22	3.17	3.17	0.53	10.09	147
	3.44	3.39	3.39	0.62	9.49	146
	3.63	3.58	3.58	0.69	8.94	145
0.1%	2.59	2.54	2.54	0.28	11.40	142
	2.81	2.76	2.76	0.37	11.44	146
	3.00	2.95	2.95	0.46	11.46	148
	3.32	3.27	3.27	0.59	10.97	147
	3.63	3.58	3.58	0.71	9.98	146
	3.95	3.90	3.90	0.83	8.95	144

Mid-Range Future Scenario (MRFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.09	3.04	3.04	0.46	9.08	147
	3.18	3.13	3.13	0.50	8.99	147
	3.31	3.26	3.26	0.55	8.65	147
	3.40	3.35	3.35	0.58	8.18	146
	3.50	3.45	3.45	0.62	8.00	146
	3.62	3.57	3.57	0.67	7.38	145
20%	3.09	3.04	3.04	0.46	9.70	147
	3.18	3.13	3.13	0.50	9.68	147
	3.31	3.26	3.26	0.55	9.07	147
	3.40	3.35	3.35	0.59	8.94	147
	3.50	3.45	3.45	0.63	8.60	146
	3.62	3.57	3.57	0.68	8.09	145
10%	3.09	3.04	3.04	0.47	9.97	147
	3.31	3.26	3.26	0.56	9.74	147
	3.40	3.35	3.35	0.60	9.18	147
	3.50	3.45	3.45	0.64	9.00	146
	3.62	3.57	3.57	0.69	8.72	145
	3.72	3.67	3.67	0.72	8.16	145
5%	3.09	3.04	3.04	0.47	10.09	147
	3.31	3.26	3.26	0.57	10.04	147
	3.40	3.35	3.35	0.61	9.89	147
	3.50	3.45	3.45	0.64	9.44	146
	3.62	3.57	3.57	0.69	9.03	145
	3.82	3.77	3.77	0.77	8.34	144
2%	3.09	3.04	3.04	0.48	10.40	147
	3.31	3.26	3.26	0.58	10.41	147
	3.50	3.45	3.45	0.65	10.03	146
	3.62	3.57	3.57	0.70	9.78	145
	3.72	3.67	3.67	0.74	9.20	145
	3.94	3.89	3.89	0.82	8.70	144
1%	3.09	3.04	3.04	0.48	10.95	147
	3.31	3.26	3.26	0.58	10.96	147
	3.50	3.45	3.45	0.66	10.26	146
	3.72	3.67	3.67	0.75	9.92	145
	3.94	3.89	3.89	0.83	9.03	144
	4.04	3.99	3.99	0.87	8.88	143
0.5%	3.09	3.04	3.04	0.49	11.15	148
	3.31	3.26	3.26	0.59	11.16	147
	3.50	3.45	3.45	0.67	10.97	146
	3.72	3.67	3.67	0.75	10.11	145
	3.94	3.89	3.89	0.84	9.56	144
	4.13	4.08	4.08	0.91	8.96	143
0.1%	3.09	3.04	3.04	0.50	11.47	148
	3.31	3.26	3.26	0.60	11.48	147
	3.50	3.45	3.45	0.68	11.49	147
	3.82	3.77	3.77	0.81	10.99	145
	4.13	4.08	4.08	0.93	10.00	143
	4.45	4.40	4.40	1.05	8.96	141

High End Future Scenario (HEFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.59	3.54	3.54	0.68	9.09	146
	3.68	3.63	3.63	0.72	9.01	145
	3.81	3.76	3.76	0.77	8.70	144
	3.90	3.85	3.85	0.80	8.17	144
	4.00	3.95	3.95	0.84	7.99	143
	4.12	4.07	4.07	0.88	7.36	143
20%	3.59	3.54	3.54	0.68	9.72	146
	3.68	3.63	3.63	0.73	9.70	145
	3.81	3.76	3.76	0.78	9.10	144
	3.90	3.85	3.85	0.81	8.95	144
	4.00	3.95	3.95	0.85	8.65	143
	4.12	4.07	4.07	0.89	8.09	143
10%	3.59	3.54	3.54	0.69	9.98	146
	3.81	3.76	3.76	0.78	9.78	145
	3.90	3.85	3.85	0.82	9.21	144
	4.00	3.95	3.95	0.86	9.01	143
	4.12	4.07	4.07	0.90	8.72	143
	4.22	4.17	4.17	0.94	8.18	142
5%	3.59	3.54	3.54	0.69	10.10	146
	3.81	3.76	3.76	0.79	10.05	145
	3.90	3.85	3.85	0.83	9.91	144
	4.00	3.95	3.95	0.87	9.43	143
	4.12	4.07	4.07	0.91	9.03	143
	4.32	4.27	4.27	0.98	8.34	142
2%	3.59	3.54	3.54	0.70	10.43	146
	3.81	3.76	3.76	0.80	10.44	145
	4.00	3.95	3.95	0.88	10.05	143
	4.12	4.07	4.07	0.92	9.80	143
	4.22	4.17	4.17	0.96	9.22	142
	4.44	4.39	4.39	1.04	8.73	141
1%	3.59	3.54	3.54	0.71	10.97	146
	3.81	3.76	3.76	0.81	10.98	145
	4.00	3.95	3.95	0.88	10.29	144
	4.22	4.17	4.17	0.97	9.92	142
	4.44	4.39	4.39	1.05	9.03	141
	4.54	4.49	4.49	1.09	8.87	141
0.5%	3.59	3.54	3.54	0.71	11.16	146
	3.81	3.76	3.76	0.81	11.17	145
	4.00	3.95	3.95	0.90	11.17	144
	4.22	4.17	4.17	0.99	10.90	143
	4.44	4.39	4.39	1.08	10.08	141
	4.63	4.58	4.58	1.13	8.95	141
0.1%	3.59	3.54	3.54	0.72	11.50	146
	3.81	3.76	3.76	0.82	11.51	145
	4.00	3.95	3.95	0.91	11.51	144
	4.32	4.27	4.27	1.03	11.01	142
	4.63	4.58	4.58	1.15	9.99	140
	4.95	4.90	4.90	1.27	8.96	139

High+ End Future Scenario (H+EFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	4.09	4.04	4.04	0.90	9.09	143
	4.18	4.13	4.13	0.94	9.01	142
	4.31	4.26	4.26	0.98	8.70	142
	4.40	4.35	4.35	1.02	8.17	141
	4.50	4.45	4.45	1.05	7.99	141
	4.62	4.57	4.57	1.08	7.35	140
20%	4.09	4.04	4.04	0.91	9.73	143
	4.18	4.13	4.13	0.95	9.73	143
	4.31	4.26	4.26	1.00	9.10	142
	4.40	4.35	4.35	1.03	8.95	141
	4.50	4.45	4.45	1.07	8.65	141
	4.62	4.57	4.57	1.11	8.08	140
10%	4.09	4.04	4.04	0.91	9.98	143
	4.31	4.26	4.26	1.01	9.79	14



Table 9-6: Shoreline Wave Climate and Water Level Combinations – Location E

Irish Coastal Wave & Water Level Modelling Study (ICWWS) 2018 Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPO)						
Output: Shoreline Wave Climate and Water Level Combinations						
Location: Dundalk_Location E						
Bed Level (MSL): 1.245m						
Bed Level (OD Malin OSGM02): 1.196m						
Bed Level (OD Malin OSGM15): 1.197m						
Dated: September 2020						
Joint Probability Event (AEP): Varies from 50% to 0.1%						
Prepared By: RMcK			Checked By: AKB			
Table Reference: ICWWS_CAPO_NWNB_Dundalk						

Notes:						
1	Users of this information should refer to the ICWWS 2018 Phase 3 Dundalk Technical Report for a detailed description of the derivation of the data and it's applicability					
2	Bed Level taken at approximately half the shallow water wavelength from structure / shoreline					
3	Bed level source: OPW LiDAR data (2007)					
4	AEP denotes the combined wave and water level joint Annual Exceedance Probability					
5	Comb Wave Component describes the combination of wind waves and swell waves					
6	Hm0 denotes the spectral significant wave height in metres					
7	Tp denotes the spectral peak wave period in seconds					
8	MWD denotes the mean wave direction in degrees north					
9	Water level allows for wind/wave setup					

Present Day Scenario Water Level						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	2.59	2.54	2.54	0.71	9.09	111
	2.68	2.63	2.63	0.75	9.00	111
	2.81	2.76	2.76	0.80	8.66	112
	2.90	2.85	2.85	0.84	8.15	112
	3.00	2.95	2.95	0.88	8.00	112
	3.12	3.07	3.07	0.91	7.36	113
20%	2.59	2.54	2.54	0.72	9.73	111
	2.68	2.63	2.63	0.76	9.71	111
	2.81	2.76	2.76	0.82	9.09	112
	2.90	2.85	2.85	0.85	8.94	112
	3.00	2.95	2.95	0.89	8.61	112
	3.12	3.07	3.07	0.93	8.09	112
10%	2.59	2.54	2.54	0.72	9.99	111
	2.81	2.76	2.76	0.82	9.77	111
	2.90	2.85	2.85	0.86	9.20	112
	3.00	2.95	2.95	0.90	9.00	112
	3.12	3.07	3.07	0.94	8.69	112
	3.22	3.17	3.17	0.98	8.16	112
5%	2.59	2.54	2.54	0.73	10.11	111
	2.81	2.76	2.76	0.83	10.06	111
	2.90	2.85	2.85	0.87	9.91	112
	3.00	2.95	2.95	0.91	9.40	112
	3.12	3.07	3.07	0.95	9.02	112
	3.32	3.27	3.27	1.03	8.31	113
2%	2.59	2.54	2.54	0.73	10.46	111
	2.81	2.76	2.76	0.84	10.46	111
	3.00	2.95	2.95	0.92	10.05	112
	3.12	3.07	3.07	0.96	9.79	112
	3.22	3.17	3.17	1.00	9.21	112
	3.44	3.39	3.39	1.08	8.72	113
1%	2.59	2.54	2.54	0.74	10.99	111
	2.81	2.76	2.76	0.84	11.00	111
	3.00	2.95	2.95	0.92	10.29	111
	3.22	3.17	3.17	1.01	9.92	112
	3.44	3.39	3.39	1.09	9.03	112
	3.54	3.49	3.49	1.13	8.88	113
0.5%	2.59	2.54	2.54	0.74	11.18	111
	2.81	2.76	2.76	0.84	11.18	111
	3.00	2.95	2.95	0.93	11.00	111
	3.22	3.17	3.17	1.02	10.12	112
	3.44	3.39	3.39	1.10	9.54	112
	3.63	3.58	3.58	1.17	8.95	113
0.1%	2.59	2.54	2.54	0.75	11.52	112
	2.81	2.76	2.76	0.85	11.53	112
	3.00	2.95	2.95	0.94	11.54	112
	3.32	3.27	3.27	1.08	11.01	112
	3.63	3.58	3.58	1.20	10.00	112
	3.95	3.90	3.90	1.31	8.96	113

Mid-Range Future Scenario (MRFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.09	3.04	3.04	0.94	9.10	112
	3.18	3.13	3.13	0.98	9.00	112
	3.31	3.26	3.26	1.02	8.67	112
	3.40	3.35	3.35	1.06	8.17	113
	3.50	3.45	3.45	1.09	7.99	113
	3.62	3.57	3.57	1.12	7.35	114
20%	3.09	3.04	3.04	0.95	9.74	112
	3.18	3.13	3.13	0.99	9.72	112
	3.31	3.26	3.26	1.04	9.09	112
	3.40	3.35	3.35	1.07	8.95	112
	3.50	3.45	3.45	1.11	8.62	113
	3.62	3.57	3.57	1.15	8.09	113
10%	3.09	3.04	3.04	0.95	9.99	112
	3.31	3.26	3.26	1.05	9.78	112
	3.40	3.35	3.35	1.08	9.20	112
	3.50	3.45	3.45	1.12	9.01	112
	3.62	3.57	3.57	1.16	8.71	113
	3.72	3.67	3.67	1.19	8.16	113
5%	3.09	3.04	3.04	0.96	10.12	112
	3.31	3.26	3.26	1.06	10.06	112
	3.40	3.35	3.35	1.09	9.91	112
	3.50	3.45	3.45	1.13	9.43	112
	3.62	3.57	3.57	1.18	9.03	113
	3.82	3.77	3.77	1.24	8.33	113
2%	3.09	3.04	3.04	0.96	10.47	112
	3.31	3.26	3.26	1.07	10.47	112
	3.50	3.45	3.45	1.14	10.05	112
	3.62	3.57	3.57	1.19	9.80	112
	3.72	3.67	3.67	1.22	9.22	113
	3.94	3.89	3.89	1.30	8.72	113
1%	3.09	3.04	3.04	0.97	11.00	112
	3.31	3.26	3.26	1.07	11.01	112
	3.50	3.45	3.45	1.15	10.30	112
	3.72	3.67	3.67	1.23	9.92	112
	3.94	3.89	3.89	1.31	9.03	113
	4.04	3.99	3.99	1.34	8.88	113
0.5%	3.09	3.04	3.04	0.97	11.18	112
	3.31	3.26	3.26	1.07	11.19	112
	3.50	3.45	3.45	1.16	11.01	112
	3.72	3.67	3.67	1.24	10.12	112
	3.94	3.89	3.89	1.33	9.57	113
	4.13	4.08	4.08	1.39	8.96	113
0.1%	3.09	3.04	3.04	0.98	11.54	112
	3.31	3.26	3.26	1.09	11.54	112
	3.50	3.45	3.45	1.17	11.55	112
	3.82	3.77	3.77	1.30	11.02	112
	4.13	4.08	4.08	1.42	10.00	113
	4.45	4.40	4.40	1.52	8.96	114

High End Future Scenario (HEFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.59	3.54	3.54	1.16	9.10	112
	3.68	3.63	3.63	1.20	9.01	113
	3.81	3.76	3.76	1.24	8.69	113
	3.90	3.85	3.85	1.27	8.16	113
	4.00	3.95	3.95	1.30	7.99	114
	4.12	4.07	4.07	1.32	7.35	115
20%	3.59	3.54	3.54	1.17	9.75	112
	3.68	3.63	3.63	1.21	9.73	112
	3.81	3.76	3.76	1.26	9.10	113
	3.90	3.85	3.85	1.29	8.95	113
	4.00	3.95	3.95	1.32	8.64	113
	4.12	4.07	4.07	1.36	8.09	114
10%	3.59	3.54	3.54	1.18	10.00	112
	3.81	3.76	3.76	1.27	9.79	113
	3.90	3.85	3.85	1.30	9.21	113
	4.00	3.95	3.95	1.34	9.01	113
	4.12	4.07	4.07	1.38	8.71	114
	4.22	4.17	4.17	1.40	8.17	114
5%	3.59	3.54	3.54	1.18	10.12	112
	3.81	3.76	3.76	1.28	10.06	112
	3.90	3.85	3.85	1.31	9.92	113
	4.00	3.95	3.95	1.35	9.44	113
	4.12	4.07	4.07	1.39	9.03	113
	4.32	4.27	4.27	1.45	8.33	114
2%	3.59	3.54	3.54	1.19	10.48	112
	3.81	3.76	3.76	1.29	10.48	112
	4.00	3.95	3.95	1.36	10.05	112
	4.12	4.07	4.07	1.41	9.80	113
	4.22	4.17	4.17	1.44	9.22	113
	4.44	4.39	4.39	1.51	8.73	114
1%	3.59	3.54	3.54	1.20	11.01	112
	3.81	3.76	3.76	1.30	11.01	112
	4.00	3.95	3.95	1.37	10.31	112
	4.22	4.17	4.17	1.45	9.93	113
	4.44	4.39	4.39	1.53	9.03	114
	4.54	4.49	4.49	1.55	8.88	114
0.5%	3.59	3.54	3.54	1.21	11.45	108
	3.81	3.76	3.76	1.30	11.19	112
	4.00	3.95	3.95	1.39	11.19	112
	4.22	4.17	4.17	1.48	10.92	112
	4.44	4.39	4.39	1.56	10.09	113
	4.63	4.58	4.58	1.60	8.96	114
0.1%	3.59	3.54	3.54	1.21	11.55	112
	3.81	3.76	3.76	1.32	11.55	112
	4.00	3.95	3.95	1.40	11.55	112
	4.32	4.27	4.27	1.52	11.03	112
	4.63	4.58	4.58	1.64	10.00	113
	4.95	4.90	4.90	1.73	8.96	114

High+ End Future Scenario (H+EFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	4.09	4.04	4.04	1.38	9.11	113
	4.18	4.13	4.13	1.41	9.01	113
	4.31	4.26	4.26	1.45	8.70	114
	4.40	4.35	4.35	1.48	8.16	114
	4.50	4.45	4.45	1.50	7.99	115
	4.62	4.57	4.57	1.49	7.35	116
20%	4.09	4.04	4.04	1.39	9.75	113
	4.18	4.13	4.13	1.43	9.75	113
	4.31	4.26	4.26	1.48	9.10	113
	4.40	4.35	4.35	1.50	8.95	114
	4.50	4.45	4.45	1.53	8.65	114
	4.62	4.57	4.57	1.56	8.08	115
10%	4.09	4.04	4.04	1.40	10.00	113
	4.31	4.26	4.26	1.49	9.79	

Table 9-7: Shoreline Wave Climate and Water Level Combinations – Location F

Irish Coastal Wave & Water Level Modelling Study (ICWWS) 2018	
Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPO)	
<b>Output:</b> Shoreline Wave Climate and Water Level Combinations	
<b>Location:</b> Dundalk_Location F	
<b>Bed Level (MSL):</b> 1.235m	
<b>Bed Level (OD Malin OSGM02):</b> 1.186m	
<b>Bed Level (OD Malin OSGM15):</b> 1.187m	
<b>Dated:</b> September 2020	
<b>Joint Probability Event (AEP):</b> Varies from 50% to 0.1%	
<b>Prepared By:</b> RMcK <b>Checked By:</b> AKB	
<b>Table Reference:</b> ICWWS_CAPO_NWNB_Dundalk	

Notes:	
1	Users of this information should refer to the ICWWS 2018 Phase 3 Dundalk Technical Report for a detailed description of the derivation of the data and it's applicability
2	Bed Level taken at approximately half the shallow water wavelength from structure / shoreline
3	Bed level source: OPW LiDAR data (2007)
4	AEP denotes the combined wave and water level joint Annual Exceedance Probability
5	Comb Wave Component describes the combination of wind waves and swell waves
6	Hm0 denotes the spectral significant wave height in metres
7	Tp denotes the spectral peak wave period in seconds
8	MWD denotes the mean wave direction in degrees north
9	Water level allows for wind/wave setup

Present Day Scenario Water Level						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	2.59	2.54	2.54	0.38	8.09	114
	2.68	2.63	2.63	0.40	7.88	113
	2.81	2.76	2.76	0.45	7.18	112
	2.90	2.85	2.85	0.47	6.65	112
	3.00	2.95	2.95	0.50	6.32	111
	3.12	3.07	3.07	0.54	7.36	115
20%	2.59	2.54	2.54	0.38	8.87	114
	2.68	2.63	2.63	0.41	9.73	115
	2.81	2.76	2.76	0.45	9.10	115
	2.90	2.85	2.85	0.48	8.95	115
	3.00	2.95	2.95	0.51	8.63	114
	3.12	3.07	3.07	0.55	8.09	114
10%	2.59	2.54	2.54	0.39	9.08	114
	2.81	2.76	2.76	0.46	9.79	115
	2.90	2.85	2.85	0.49	9.21	115
	3.00	2.95	2.95	0.52	9.01	114
	3.12	3.07	3.07	0.56	8.71	114
	3.22	3.17	3.17	0.59	8.17	114
5%	2.59	2.54	2.54	0.39	9.73	114
	2.81	2.76	2.76	0.46	10.07	115
	2.90	2.85	2.85	0.49	9.92	114
	3.00	2.95	2.95	0.52	9.43	114
	3.12	3.07	3.07	0.56	9.03	114
	3.32	3.27	3.27	0.63	8.33	114
2%	2.59	2.54	2.54	0.40	10.09	114
	2.81	2.76	2.76	0.47	10.49	115
	3.00	2.95	2.95	0.53	10.06	114
	3.12	3.07	3.07	0.57	9.80	114
	3.22	3.17	3.17	0.60	9.23	114
	3.44	3.39	3.39	0.67	8.73	114
1%	2.59	2.54	2.54	0.40	10.35	114
	2.81	2.76	2.76	0.48	11.01	115
	3.00	2.95	2.95	0.54	10.31	114
	3.22	3.17	3.17	0.61	9.93	114
	3.44	3.39	3.39	0.68	9.04	114
	3.54	3.49	3.49	0.71	8.88	114
0.5%	2.59	2.54	2.54	0.41	11.03	114
	2.81	2.76	2.76	0.48	11.19	115
	3.00	2.95	2.95	0.55	11.02	114
	3.22	3.17	3.17	0.62	10.13	114
	3.44	3.39	3.39	0.69	9.57	114
	3.63	3.58	3.58	0.75	8.96	114
0.1%	2.59	2.54	2.54	0.42	11.49	114
	2.81	2.76	2.76	0.49	11.12	113
	3.00	2.95	2.95	0.56	11.55	114
	3.32	3.27	3.27	0.67	11.03	114
	3.63	3.58	3.58	0.77	10.01	114
	3.95	3.90	3.90	0.87	8.97	114

Mid-Range Future Scenario (MRFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.09	3.04	3.04	0.56	8.10	112
	3.18	3.13	3.13	0.59	7.89	111
	3.31	3.26	3.26	0.63	7.18	111
	3.40	3.35	3.35	0.65	6.64	111
	3.50	3.45	3.45	0.68	7.99	114
	3.62	3.57	3.57	0.72	7.35	115
20%	3.09	3.04	3.04	0.56	8.87	112
	3.18	3.13	3.13	0.59	8.26	112
	3.31	3.26	3.26	0.64	7.95	111
	3.40	3.35	3.35	0.67	7.31	111
	3.50	3.45	3.45	0.69	8.64	114
	3.62	3.57	3.57	0.73	8.09	114
10%	3.09	3.04	3.04	0.57	9.08	112
	3.31	3.26	3.26	0.64	8.19	111
	3.40	3.35	3.35	0.67	9.22	114
	3.50	3.45	3.45	0.70	9.02	114
	3.62	3.57	3.57	0.74	8.72	114
	3.72	3.67	3.67	0.77	8.18	114
5%	3.09	3.04	3.04	0.57	9.73	112
	3.31	3.26	3.26	0.65	10.07	114
	3.40	3.35	3.35	0.68	9.92	114
	3.50	3.45	3.45	0.71	9.45	114
	3.62	3.57	3.57	0.75	9.04	114
	3.82	3.77	3.77	0.81	8.34	114
2%	3.09	3.04	3.04	0.58	10.09	112
	3.31	3.26	3.26	0.66	10.50	114
	3.50	3.45	3.45	0.72	10.06	114
	3.62	3.57	3.57	0.76	9.81	114
	3.72	3.67	3.67	0.79	9.23	114
	3.94	3.89	3.89	0.86	8.73	114
1%	3.09	3.04	3.04	0.59	10.36	112
	3.31	3.26	3.26	0.66	11.02	114
	3.50	3.45	3.45	0.73	10.31	114
	3.72	3.67	3.67	0.80	9.93	114
	3.94	3.89	3.89	0.87	9.04	114
	4.04	3.99	3.99	0.90	8.88	114
0.5%	3.09	3.04	3.04	0.59	11.04	112
	3.31	3.26	3.26	0.67	11.20	114
	3.50	3.45	3.45	0.74	11.02	114
	3.72	3.67	3.67	0.81	10.13	113
	3.94	3.89	3.89	0.88	9.58	114
	4.13	4.08	4.08	0.94	8.96	114
0.1%	3.09	3.04	3.04	0.61	11.50	112
	3.31	3.26	3.26	0.68	11.11	113
	3.50	3.45	3.45	0.75	11.56	114
	3.82	3.77	3.77	0.86	11.03	113
	4.13	4.08	4.08	0.96	10.01	113
	4.45	4.40	4.40	1.06	8.97	114

High End Future Scenario (HEFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	3.59	3.54	3.54	0.75	8.10	111
	3.68	3.63	3.63	0.78	7.89	110
	3.81	3.76	3.76	0.81	7.18	110
	3.90	3.85	3.85	0.84	8.17	114
	4.00	3.95	3.95	0.87	7.99	114
	4.12	4.07	4.07	0.90	7.35	115
20%	3.59	3.54	3.54	0.75	8.87	111
	3.68	3.63	3.63	0.79	8.27	111
	3.81	3.76	3.76	0.83	7.95	110
	3.90	3.85	3.85	0.85	8.96	114
	4.00	3.95	3.95	0.88	8.65	114
	4.12	4.07	4.07	0.92	8.09	114
10%	3.59	3.54	3.54	0.76	9.09	111
	3.81	3.76	3.76	0.83	8.19	110
	3.90	3.85	3.85	0.86	9.22	114
	4.00	3.95	3.95	0.89	9.02	114
	4.12	4.07	4.07	0.93	8.72	114
	4.22	4.17	4.17	0.96	8.18	114
5%	3.59	3.54	3.54	0.77	9.73	111
	3.81	3.76	3.76	0.84	8.87	110
	3.90	3.85	3.85	0.87	9.93	114
	4.00	3.95	3.95	0.90	9.45	114
	4.12	4.07	4.07	0.94	9.04	114
	4.32	4.27	4.27	1.00	8.34	114
2%	3.59	3.54	3.54	0.78	10.09	111
	3.81	3.76	3.76	0.85	10.51	113
	4.00	3.95	3.95	0.91	10.06	113
	4.12	4.07	4.07	0.96	9.82	114
	4.22	4.17	4.17	0.99	9.24	114
	4.44	4.39	4.39	1.05	8.74	114
1%	3.59	3.54	3.54	0.78	10.37	111
	3.81	3.76	3.76	0.86	11.03	113
	4.00	3.95	3.95	0.92	10.32	113
	4.22	4.17	4.17	1.00	9.93	113
	4.44	4.39	4.39	1.07	9.04	114
	4.54	4.49	4.49	1.09	8.88	114
0.5%	3.59	3.54	3.54	0.80	11.44	111
	3.81	3.76	3.76	0.88	11.20	110
	4.00	3.95	3.95	0.95	10.33	110
	4.22	4.17	4.17	1.02	9.85	110
	4.44	4.39	4.39	1.09	8.93	110
	4.63	4.58	4.58	1.14	8.96	114
0.1%	3.59	3.54	3.54	0.80	11.51	111
	3.81	3.76	3.76	0.88	11.11	112
	4.00	3.95	3.95	0.95	11.57	113
	4.32	4.27	4.27	1.06	11.04	113
	4.63	4.58	4.58	1.16	10.01	113
	4.95	4.90	4.90	1.26	8.97	114

High+ End Future Scenario (H+EFS)						
AEP	Water Level (m)			Comb Wave Component		
	MSL	OD Malin OSGM02	OD Malin OSGM15	Hm0 (m)	Tp (s)	MWD (°)
50%	4.09	4.04	4.04	0.94	8.09	110
	4.18	4.13	4.13	0.97	7.89	110
	4.31	4.26	4.26	1.00	8.71	114
	4.40	4.35	4.35	1.03	8.17	114
	4.50	4.45	4.45	1.05	7.99	115
	4.62	4.57	4.57	1.06	7.35	115
20%	4.09	4.04	4.04	0.95	8.87	110
	4.18	4.13	4.13	0.98	8.27	110
	4.31	4.26	4.26	1.02	9.11	114
	4.40	4.35	4.35	1.04	8.96	114
	4.50	4.45	4.45	1.07	8.66	114
	4.62	4.57	4.57	1.10	8.09	114
10%	4.09	4.04	4.04	0.96	9.08	110
	4.31	4.26	4.26	1.03	9.80	114
	4.40	4.35	4.35	1.06	9.23	114
	4.50	4.45	4.45	1.09	9.02	114
	4.62	4.57	4.57	1.12	8.72	114
	4.72	4.67	4.67	1.15	8.18	114
5%	4.09	4.04	4.04	0.97	9.73	110
	4.31	4.26	4.26	1.04	8.87	110
	4.40	4.35	4.35	1.07	9.93	113
	4.50	4.45	4.45	1.10	9.46	114
	4.62	4.57	4.57	1.13	9.04	114
	4.82	4.77	4.77	1.19	8.34	114
2%	4.09	4.04	4.04	0.98	10.09	110
	4.31	4.26	4.26	1.05	10.51	113
	4.50	4.45	4.45	1.11	10.06	113
	4.62	4.57	4.57	1.15	9.82	114
	4.72	4.67	4.67	1.18	9.24	114
	4.94	4.89	4.89	1.24	8.74	114
1%	4.09	4.04	4.04	0.98	10.37	110
	4.31	4.26	4.26	1.06	9.88	110
	4.50	4.45	4.45	1.12	10.32	113
	4.72	4.67	4.67	1.19	9.94	114
	4.94	4.89	4.89	1.26	9.04	114
	5.04	4.99	4.99	1.29	8.89	114
0.5%	4.09	4.04	4.04	0.99	11.04	110
	4.31	4.26	4.26	1.06	10.09	110
	4.50	4.45	4.45	1.13	11.03	113
	4.72	4.67	4.67	1.20	10.13	113
	4.94	4.89	4.89	1.27	9.59	114
	5.13	5.08	5.08	1.32	8.97	114
0.1%	4.09	4.04	4.04	1.01	11.51	110
	4.31	4.26	4.26	1.08	11.12	112
	4.50	4.45	4.45	1.15	11.57	113
	4.82	4.77	4.77	1.26	11.04	113
	5.13	5.08	5.08	1.35	10.01	114
	5.45	5.40	5.40	1.45	8.97	114

## 10 REFERENCES

**Reference 1:** RPS, November 2013 “Irish Coastal Wave and Water Level Modelling Study – Coastal Areas Potentially Vulnerable to Wave Overtopping”

**Reference 2:** RPS, December 2020, “Irish Coastal Wave and Water Level Modelling Study 2018 – Phase 2 – Coastal Areas Potentially Vulnerable to Wave Overtopping”

**Reference 3:** DEFRA / Environment Agency, March 2005, R&D Technical Report FD2308/TR2, “Use of Joint Probability Methods in Flood Management: A Guide to Best Practice”

**Reference 4:** RPS, October 2020, “Irish Coastal Wave and Water Level Modelling Study 2018 – Phase 1 – Extreme Water Levels”

**Reference 5:** RPS, November 2020, “Irish Coastal Wave and Water Level Modelling Study 2018 – Phase 4 – Review of Mean Sea Level and OD Malin Head Relationship at Irish Gauge Locations”





## Appendix A

### Extreme Value Analysis of Offshore Wave data

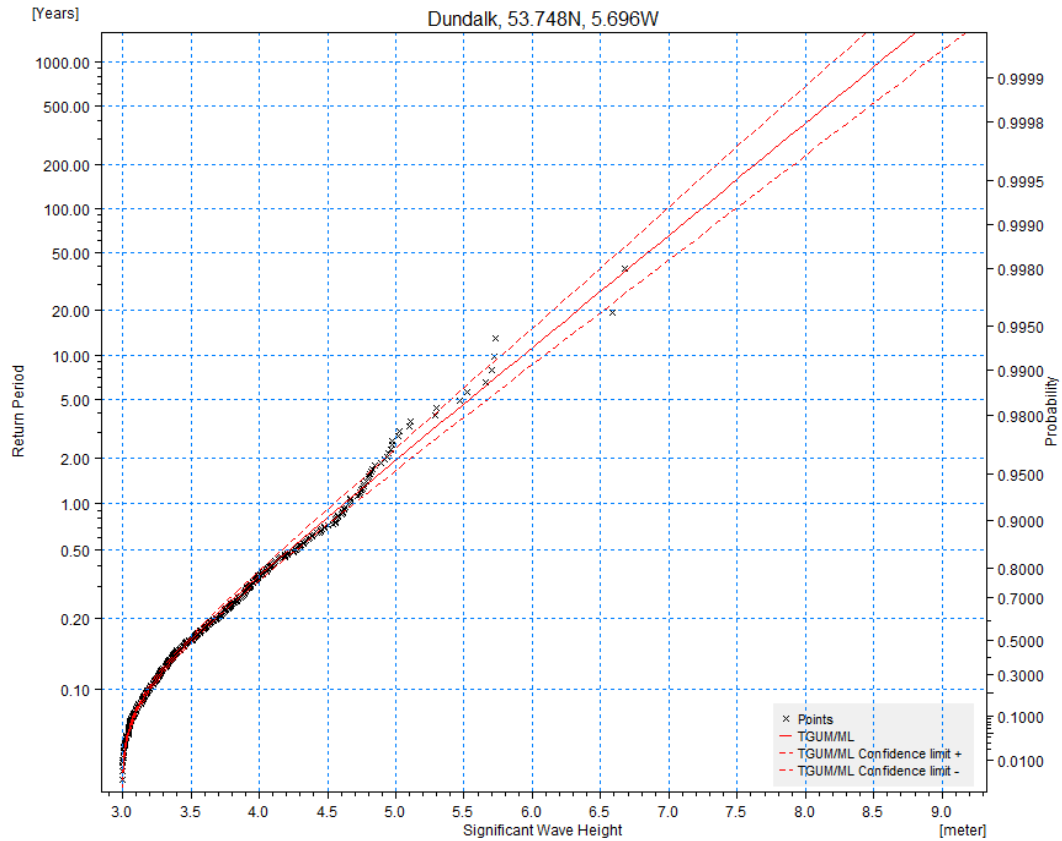


Figure A1: Omnidirectional EVA results for wave height at 53.748N, 5.696W

Table A1: Met Office Method Factorisation and Extreme Values for Relevant Directions 53.748N, 5.696W

53.748N, 5.696W								
Omnidirectional EVA			Dir Sector	Max Values			Av. Max	Factor
RP	Hm0 (m)		0	4.03	3.99	3.87	3.96	0.66
0.5	4.212		30	4.62	4.6	4.46	4.56	0.75
1	4.618		60	4.75	4.6	4.45	4.60	0.76
2	5.015		90	6.59	5.29	5.03	5.64	0.93
5	5.539		120	4.54	4.45	4.39	4.46	0.74
10	5.932		150	5.47	5.15	4.97	5.20	0.86
20	6.325		180	6.68	5.73	5.72	6.04	1.00
50	6.846		210	4.9	4.8	4.8	4.83	0.80
100	7.237		240	4.92	4.72	4.62	4.75	0.79
200	7.632		270	4.79	4.57	4.52	4.63	0.77
500	8.149		300	5.02	3.32	3.28	3.87	0.64
1000	8.542		330	3.04	2.96	2.95	2.98	0.49
							<b>max</b>	<b>6.04</b>
	<b>Factor</b>	0.93	0.74	0.86				
	<b>Direction</b>	<b>90</b>	<b>120</b>	<b>150</b>				
<b>Return Period</b>	0.5	3.93	3.11	3.62				
	1	4.31	3.41	3.97				
	2	4.68	3.70	4.31				
	5	5.17	4.09	4.76				
	10	5.53	4.38	5.10				
	20	5.90	4.67	5.44				
	50	6.39	5.05	5.89				
	100	6.75	5.34	6.22				
	200	7.12	5.63	6.56				
	500	7.60	6.01	7.01				
	1000	7.97	6.30	7.35				

Table A2: Met Office Method Factorisation and Extreme Values for Relevant Directions 53.349N, 5.667W

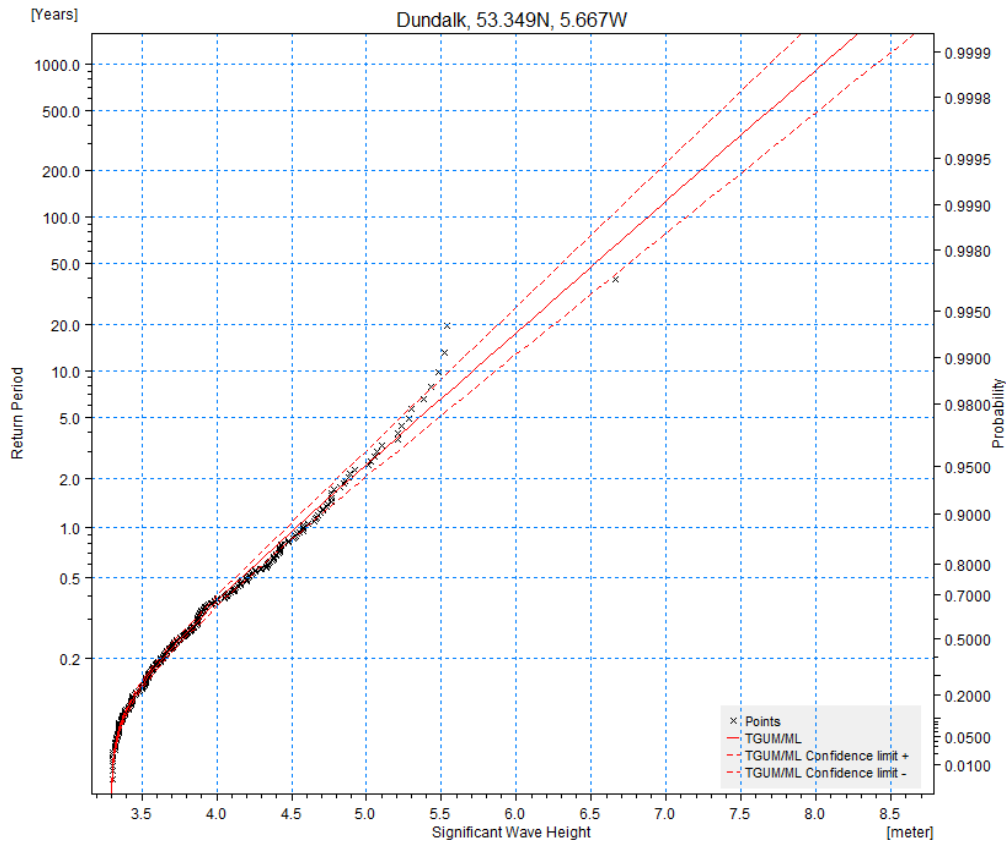


Figure A2: Omnidirectional EVA results for wave height at 53.349N, 5.667W

53.349N, 5.667W								
Omnidirectional EVA			Dir Sector	Max Values			Av. Max	Factor
RP	Hm0 (m)		0	4.86	4.78	4.54	4.73	0.80
0.5	4.162		30	5.38	5.23	4.77	5.13	0.87
1	4.531		60	5.05	4.96	4.91	4.97	0.84
2	4.890		90	5.54	4.64	4.16	4.78	0.81
5	5.358		120	4.17	4.11	3.96	4.08	0.69
10	5.712		150	5.43	5.07	4.82	5.11	0.87
20	6.061		180	6.66	5.52	5.48	5.89	1.00
50	6.525		210	5.10	4.71	4.43	4.75	0.81
100	6.877		240	5.21	4.92	4.62	4.92	0.84
200	7.226		270	5.21	4.48	4.26	4.65	0.79
500	7.691		300	4.90	3.90	3.51	4.10	0.70
1000	8.040		330	3.81	3.53	3.51	3.62	0.61
							<b>max</b>	<b>5.89</b>
	<b>Factor</b>	0.81	0.69	0.87				
	<b>Direction</b>	<b>90</b>	<b>120</b>	<b>150</b>				
<b>Return Period</b>	0.5	3.38	2.88	3.61				
	1	3.68	3.14	3.93				
	2	3.97	3.39	4.24				
	5	4.35	3.71	4.65				
	10	4.64	3.96	4.96				
	20	4.92	4.20	5.26				
	50	5.30	4.52	5.66				
	100	5.58	4.77	5.97				
	200	5.87	5.01	6.27				
	500	6.25	5.33	6.67				
	1000	6.53	5.57	6.97				



## Appendix B

### Joint Probability Analysis of Offshore Wave data and Inshore Water Level

**Table B1: Joint probability table showing probability of wave height with water level at 53.748N, 5.696W (90deg sector)**

		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
		Marginal return period (years) for				Significant Wave Height (m)			
Marginal return period (years) for	0.01	1.551	4.463	9.929	20.000	50.000	100.000	200.000	1000.000
	0.02	0.775	2.231	4.965	11.045	31.788	70.721	157.341	1000.000
	0.05	0.310	0.893	1.986	4.418	12.715	28.289	62.936	402.981
	0.1	0.155	0.446	0.993	2.209	6.358	14.144	31.468	201.491
	0.2	0.078	0.223	0.496	1.105	3.179	7.072	15.734	100.745
	0.5	0.031	0.089	0.199	0.442	1.272	2.829	6.294	40.298
	1	0.016	0.045	0.099	0.221	0.636	1.414	3.147	20.149
	2	0.008	0.022	0.050	0.110	0.318	0.707	1.573	10.075
	5	#N/A	0.009	0.020	0.044	0.127	0.283	0.629	4.030
	10	#N/A	#N/A	0.010	0.022	0.064	0.141	0.315	2.015
Extreme Sea Level (m)	20	#N/A	#N/A	#N/A	0.011	0.032	0.071	0.157	1.007
	50	#N/A	#N/A	#N/A	#N/A	0.013	0.028	0.063	0.403
	100	#N/A	#N/A	#N/A	#N/A	#N/A	0.014	0.031	0.201
	200	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.016	0.101
	1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.020

**Table B2: Joint probability table showing wave height and water level at 53.748N, 5.696W (90deg sector)**

Value of first variable:		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
Extreme Sea Level (m)	Value of second variable:	Significant Wave Height (m)							
2.49	4.54	5.11	5.53	5.90	6.39	6.75	7.12	7.97	
2.58	4.17	4.74	5.16	5.59	6.15	6.57	6.99	7.97	
2.71	3.68	4.25	4.67	5.10	5.66	6.08	6.51	7.49	
2.80	3.32	3.87	4.30	4.73	5.29	5.72	6.14	7.12	
2.90	2.95	3.51	3.92	4.36	4.92	5.35	5.77	6.75	
3.02	2.46	3.03	3.45	3.87	4.44	4.86	5.29	6.27	
3.12	2.09	2.66	3.08	3.51	4.06	4.49	4.92	5.90	
3.22	1.72	2.29	2.71	3.14	3.70	4.12	4.55	5.54	
3.34	#N/A	1.80	2.22	2.65	3.22	3.64	4.05	5.05	
3.44	#N/A	#N/A	1.85	2.28	2.85	3.27	3.69	4.68	
3.53	#N/A	#N/A	#N/A	1.91	2.48	2.90	3.33	4.31	
3.66	#N/A	#N/A	#N/A	#N/A	1.99	2.41	2.84	3.82	
3.75	#N/A	#N/A	#N/A	#N/A	#N/A	2.04	2.47	3.46	
3.85	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.10	3.09	
4.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.23	

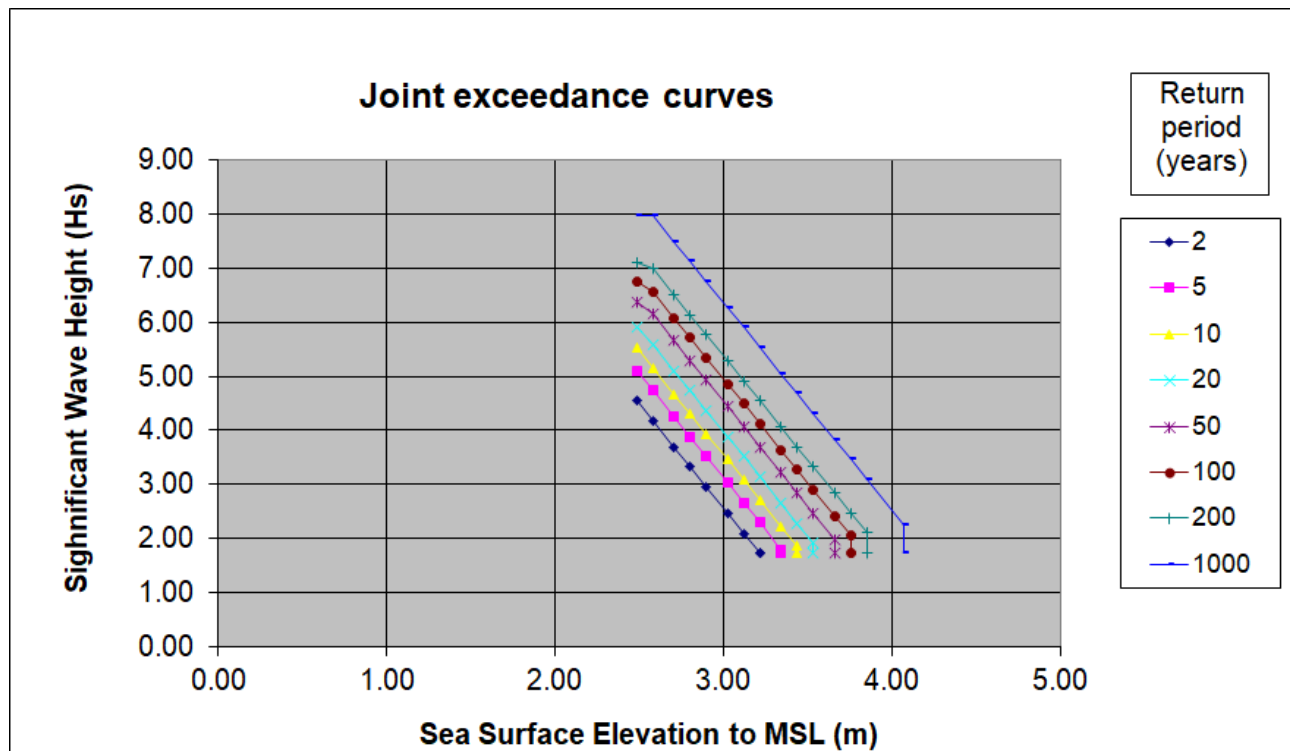


Figure B1: Offshore joint wave and water level exceedance curve at 53.748N, 5.696W (90deg sector)



**Table B3: Joint probability table showing probability of wave height with water level at 53.748N, 5.696W (120deg sector)**

		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
		Marginal return period (years) for				Significant Wave Height (m)			
Marginal return period (years) for	0.01	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.02	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.05	1.140	3.936	10.000	20.000	50.000	100.000	200.000	1000.000
	0.1	0.570	1.968	5.024	12.825	44.269	100.000	200.000	1000.000
	0.2	0.285	0.984	2.512	6.412	22.135	56.506	144.252	1000.000
	0.5	0.114	0.394	1.005	2.565	8.854	22.603	57.701	508.468
	1	0.057	0.197	0.502	1.282	4.427	11.301	28.850	254.234
	2	0.029	0.098	0.251	0.641	2.213	5.651	14.425	127.117
	5	#N/A	0.039	0.100	0.256	0.885	2.260	5.770	50.847
	10	#N/A	#N/A	0.050	0.128	0.443	1.130	2.885	25.423
Extreme Sea Level (m)	20	#N/A	#N/A	#N/A	0.064	0.221	0.565	1.443	12.712
	50	#N/A	#N/A	#N/A	#N/A	0.089	0.226	0.577	5.085
	100	#N/A	#N/A	#N/A	#N/A	#N/A	0.113	0.289	2.542
	200	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.144	1.271
	1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.254

**Table B4: Joint probability table showing wave height and water level at 53.748N, 5.696W (120deg sector)**

Value of first variable:		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
Extreme Sea Level (m)	Value of second variable:	Significant Wave Height (m)							
2.49	3.70	4.09	4.38	4.67	5.05	5.34	5.63	6.31	
2.58	3.70	4.09	4.38	4.67	5.05	5.34	5.63	6.31	
2.71	3.46	3.99	4.38	4.67	5.05	5.34	5.63	6.31	
2.80	3.17	3.69	4.09	4.48	5.00	5.34	5.63	6.31	
2.90	2.88	3.40	3.80	4.19	4.71	5.10	5.50	6.31	
3.02	2.50	3.01	3.41	3.81	4.33	4.72	5.11	6.02	
3.12	2.21	2.73	3.11	3.51	4.04	4.43	4.82	5.73	
3.22	1.91	2.44	2.83	3.22	3.74	4.14	4.53	5.44	
3.34	#N/A	2.05	2.45	2.84	3.36	3.75	4.15	5.06	
3.44	#N/A	#N/A	2.15	2.55	3.06	3.46	3.86	4.77	
3.53	#N/A	#N/A	#N/A	2.26	2.78	3.16	3.56	4.48	
3.66	#N/A	#N/A	#N/A	#N/A	2.39	2.79	3.17	4.09	
3.75	#N/A	#N/A	#N/A	#N/A	#N/A	2.50	2.89	3.80	
3.85	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.60	3.51	
4.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.83	

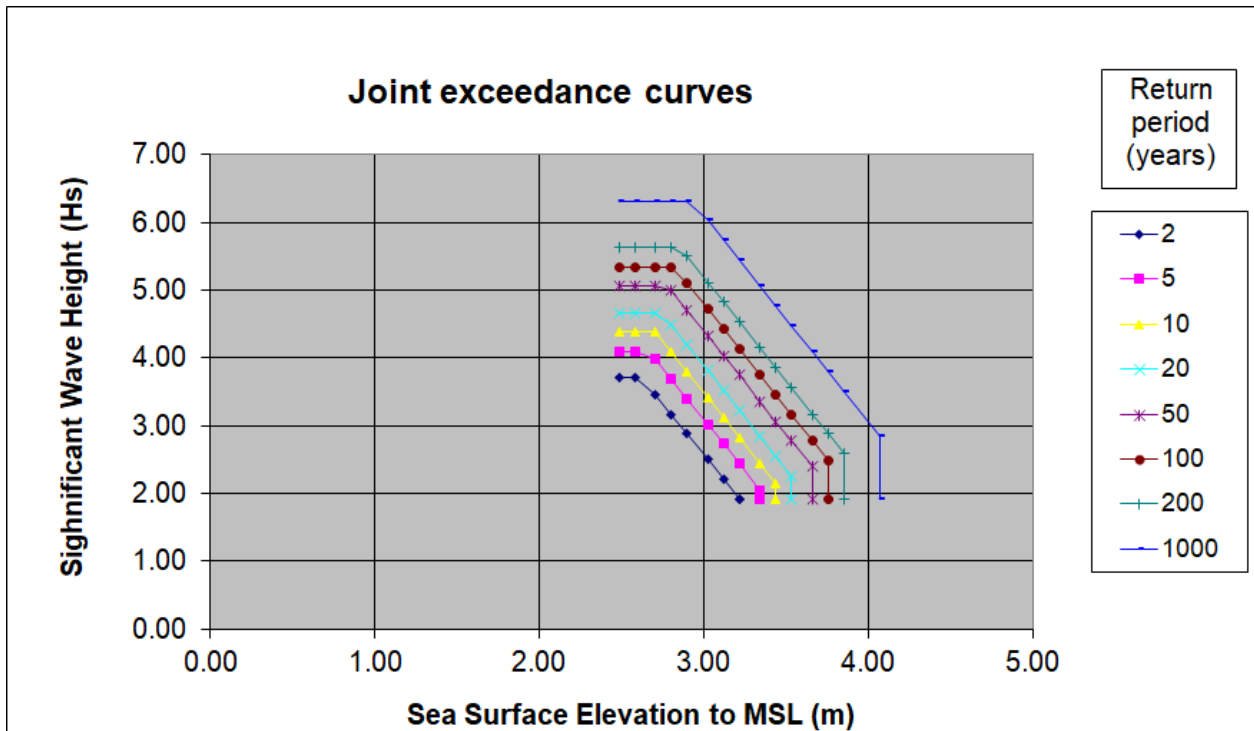


Figure B2: Offshore joint wave and water level exceedance curve at 53.748N, 5.696W (120deg sector)

**Table B5: Joint probability table showing probability of wave height with water level at 53.748N, 5.696W (150deg sector)**

		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
		Marginal return period (years) for				Significant Wave Height (m)			
Marginal return period (years) for	0.01	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.02	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.05	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.1	1.044	3.923	10.000	20.000	50.000	100.000	200.000	1000.000
	0.2	0.522	1.962	5.338	14.528	50.000	100.000	200.000	1000.000
	0.5	0.209	0.785	2.135	5.811	21.829	59.406	161.670	1000.000
	1	0.104	0.392	1.068	2.906	10.914	29.703	80.835	826.370
	2	0.052	0.196	0.534	1.453	5.457	14.851	40.418	413.185
	5	#N/A	0.078	0.214	0.581	2.183	5.941	16.167	165.274
	10	#N/A	#N/A	0.107	0.291	1.091	2.970	8.084	82.637
Extreme Sea Level (m)	20	#N/A	#N/A	#N/A	0.145	0.546	1.485	4.042	41.319
	50	#N/A	#N/A	#N/A	#N/A	0.218	0.594	1.617	16.527
	100	#N/A	#N/A	#N/A	#N/A	#N/A	0.297	0.808	8.264
	200	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.404	4.132
	1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.826

**Table B6: Joint probability table showing wave height and water level at 53.748N, 5.696W (150deg sector)**

Value of first variable:		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
Extreme Sea Level (m)	Value of second variable:	Significant Wave Height (m)							
2.49	4.31	4.76	5.10	5.44	5.89	6.22	6.56	7.35	
2.58	4.31	4.76	5.10	5.44	5.89	6.22	6.56	7.35	
2.71	4.31	4.76	5.10	5.44	5.89	6.22	6.56	7.35	
2.80	3.99	4.64	5.10	5.44	5.89	6.22	6.56	7.35	
2.90	3.64	4.30	4.79	5.28	5.89	6.22	6.56	7.35	
3.02	3.21	3.85	4.34	4.84	5.48	5.97	6.46	7.35	
3.12	2.87	3.51	4.00	4.50	5.14	5.63	6.12	7.26	
3.22	2.53	3.18	3.65	4.15	4.81	5.29	5.78	6.92	
3.34	#N/A	2.73	3.22	3.70	4.36	4.85	5.34	6.47	
3.44	#N/A	#N/A	2.88	3.37	4.01	4.51	5.00	6.13	
3.53	#N/A	#N/A	#N/A	3.03	3.67	4.17	4.66	5.79	
3.66	#N/A	#N/A	#N/A	#N/A	3.23	3.71	4.21	5.35	
3.75	#N/A	#N/A	#N/A	#N/A	#N/A	3.38	3.86	5.01	
3.85	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3.52	4.67	
4.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3.87	

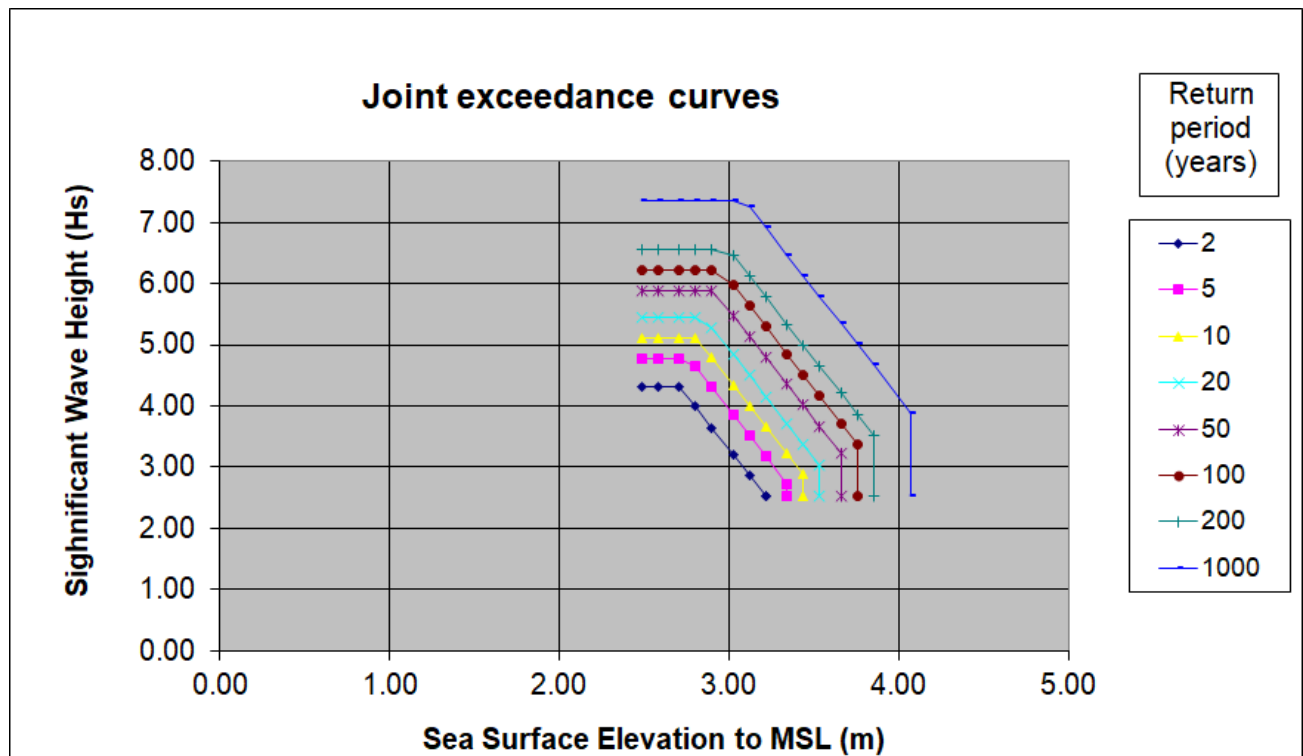


Figure B3: Offshore joint wave and water level exceedance curve at 53.748N, 5.696W (150deg sector)

**Table B7: Joint probability table showing probability of wave height with water level at 53.349N, 5.667W (90deg sector)**

		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
		Marginal return period (years) for				Significant Wave Height (m)			
Marginal return period (years) for	Extreme Sea Level (m)	0.01	1.551	4.463	9.929	20.000	50.000	100.000	200.000
		0.02	0.775	2.231	4.965	11.045	31.788	70.721	157.341
		0.05	0.310	0.893	1.986	4.418	12.715	28.289	62.936
		0.1	0.155	0.446	0.993	2.209	6.358	14.144	31.468
		0.2	0.078	0.223	0.496	1.105	3.179	7.072	15.734
		0.5	0.031	0.089	0.199	0.442	1.272	2.829	6.294
		1	0.016	0.045	0.099	0.221	0.636	1.414	3.147
		2	0.008	0.022	0.050	0.110	0.318	0.707	1.573
		5	#N/A	0.009	0.020	0.044	0.127	0.283	0.629
		10	#N/A	#N/A	0.010	0.022	0.064	0.141	0.315
		20	#N/A	#N/A	#N/A	0.011	0.032	0.071	0.157
		50	#N/A	#N/A	#N/A	#N/A	0.013	0.028	0.063
		100	#N/A	#N/A	#N/A	#N/A	#N/A	0.014	0.031
		200	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.016
		1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.020

**Table B8: Joint probability table showing wave height and water level at 53.349N, 5.667W (90deg sector)**

Value of first variable:		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
Extreme Sea Level (m)	Value of second variable:	Significant Wave Height (m)							
2.49	3.86	4.30	4.64	4.92	5.30	5.58	5.87	6.53	
2.58	3.57	4.02	4.35	4.68	5.11	5.44	5.77	6.53	
2.71	3.19	3.63	3.97	4.30	4.74	5.06	5.39	6.15	
2.80	2.92	3.34	3.68	4.01	4.45	4.78	5.11	5.87	
2.90	2.63	3.07	3.38	3.72	4.16	4.49	4.82	5.59	
3.02	2.24	2.69	3.02	3.33	3.78	4.11	4.45	5.21	
3.12	1.95	2.39	2.73	3.06	3.48	3.83	4.16	4.92	
3.22	1.66	2.10	2.44	2.78	3.20	3.53	3.87	4.64	
3.34	#N/A	1.72	2.05	2.39	2.83	3.16	3.48	4.26	
3.44	#N/A	#N/A	1.76	2.10	2.54	2.88	3.20	3.97	
3.53	#N/A	#N/A	#N/A	1.81	2.25	2.59	2.92	3.68	
3.66	#N/A	#N/A	#N/A	#N/A	1.87	2.20	2.54	3.30	
3.75	#N/A	#N/A	#N/A	#N/A	#N/A	1.91	2.25	3.03	
3.85	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.96	2.74	
4.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.06	

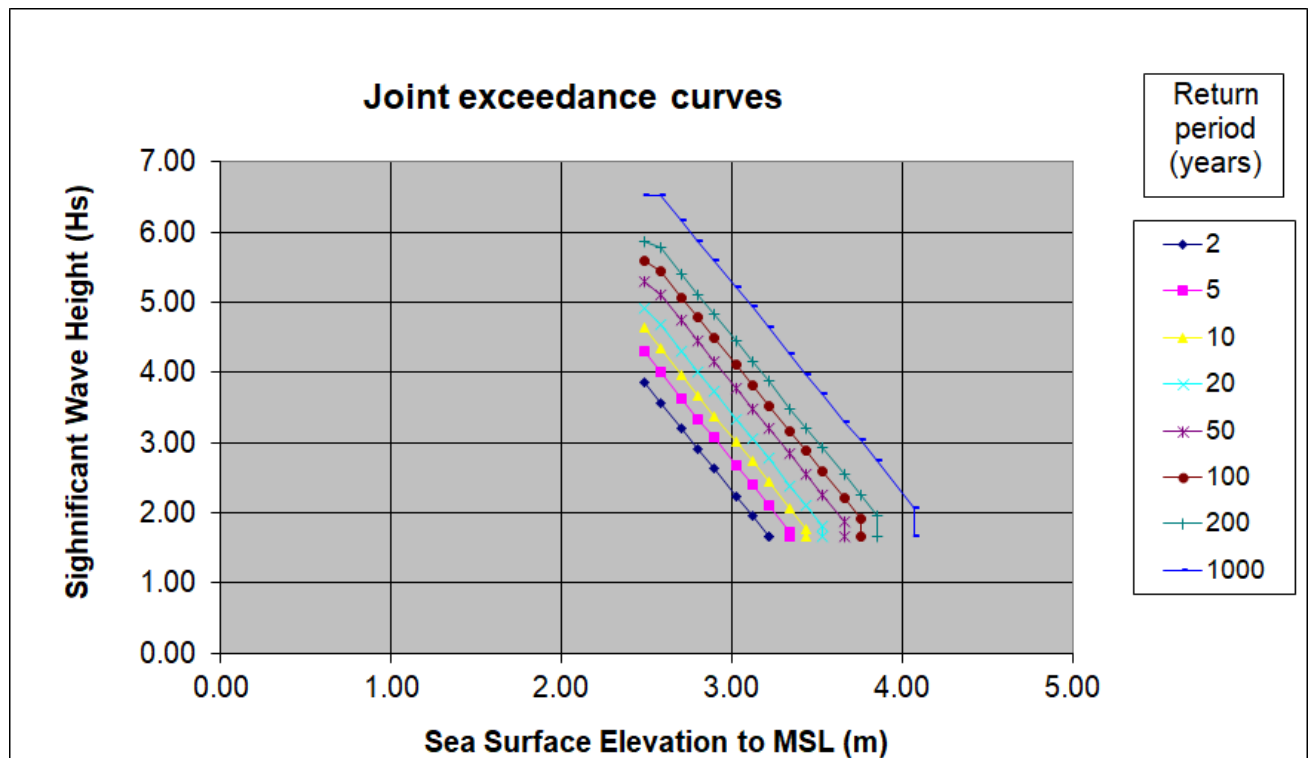


Figure B4: Offshore joint wave and water level exceedance curve at 53.349N, 5.667W (90deg sector)

**Table B9: Joint probability table showing probability of wave height with water level at 53.349N, 5.667W (120deg sector)**

		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
		Marginal return period (years) for				Significant Wave Height (m)			
Marginal return period (years) for	0.01	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.02	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.05	1.140	3.936	10.000	20.000	50.000	100.000	200.000	1000.000
	0.1	0.570	1.968	5.024	12.825	44.269	100.000	200.000	1000.000
	0.2	0.285	0.984	2.512	6.412	22.135	56.506	144.252	1000.000
	0.5	0.114	0.394	1.005	2.565	8.854	22.603	57.701	508.468
	1	0.057	0.197	0.502	1.282	4.427	11.301	28.850	254.234
	2	0.029	0.098	0.251	0.641	2.213	5.651	14.425	127.117
	5	#N/A	0.039	0.100	0.256	0.885	2.260	5.770	50.847
	10	#N/A	#N/A	0.050	0.128	0.443	1.130	2.885	25.423
Extreme Sea Level (m)	20	#N/A	#N/A	#N/A	0.064	0.221	0.565	1.443	12.712
	50	#N/A	#N/A	#N/A	#N/A	0.089	0.226	0.577	5.085
	100	#N/A	#N/A	#N/A	#N/A	#N/A	0.113	0.289	2.542
	200	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.144	1.271
	1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.254

**Table B10: Joint probability table showing wave height and water level at 53.349N, 5.667W (120deg sector)**

Value of first variable:		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
Extreme Sea Level (m)	Value of second variable:	Significant Wave Height (m)							
2.49	3.39	3.71	3.96	4.20	4.52	4.77	5.01	5.57	
2.58	3.39	3.71	3.96	4.20	4.52	4.77	5.01	5.57	
2.71	3.19	3.63	3.96	4.20	4.52	4.77	5.01	5.57	
2.80	2.93	3.38	3.72	4.05	4.48	4.77	5.01	5.57	
2.90	2.70	3.13	3.47	3.80	4.24	4.57	4.89	5.57	
3.02	2.38	2.81	3.14	3.48	3.92	4.24	4.57	5.33	
3.12	2.13	2.58	2.89	3.23	3.67	4.00	4.33	5.09	
3.22	1.88	2.33	2.66	2.98	3.43	3.76	4.09	4.85	
3.34	#N/A	2.00	2.33	2.66	3.10	3.43	3.76	4.53	
3.44	#N/A	#N/A	2.09	2.42	2.84	3.18	3.52	4.29	
3.53	#N/A	#N/A	#N/A	2.17	2.62	2.93	3.27	4.04	
3.66	#N/A	#N/A	#N/A	#N/A	2.29	2.62	2.94	3.72	
3.75	#N/A	#N/A	#N/A	#N/A	#N/A	2.38	2.70	3.47	
3.85	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.46	3.23	
4.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.66	

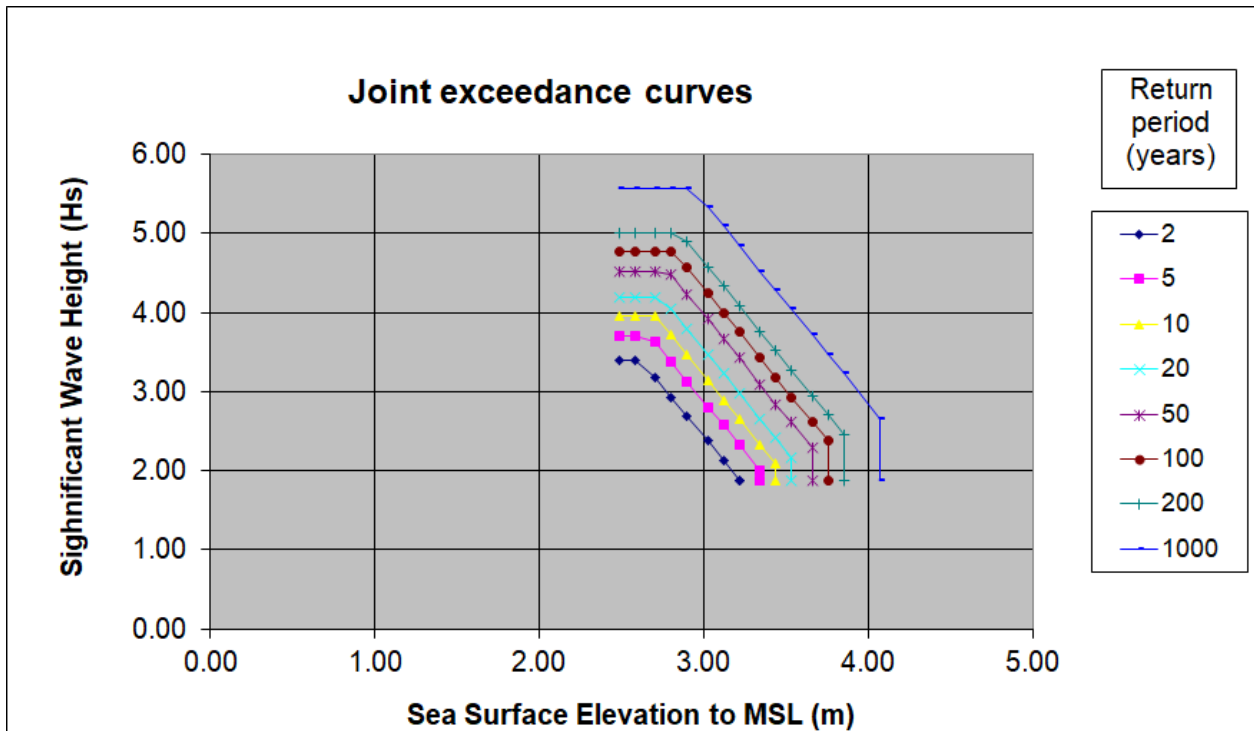


Figure B5: Offshore joint wave and water level exceedance curve at 53.349N, 5.667W (120deg sector)



**Table B11: Joint probability table showing probability of wave height with water level at 53.349N, 5.667W (150deg sector)**

		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
		Marginal return period (years) for				Significant Wave Height (m)			
Marginal return period (years) for	0.01	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.02	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.05	2.000	5.000	10.000	20.000	50.000	100.000	200.000	1000.000
	0.1	1.044	3.923	10.000	20.000	50.000	100.000	200.000	1000.000
	0.2	0.522	1.962	5.338	14.528	50.000	100.000	200.000	1000.000
	0.5	0.209	0.785	2.135	5.811	21.829	59.406	161.670	1000.000
	1	0.104	0.392	1.068	2.906	10.914	29.703	80.835	826.370
	2	0.052	0.196	0.534	1.453	5.457	14.851	40.418	413.185
	5	#N/A	0.078	0.214	0.581	2.183	5.941	16.167	165.274
	10	#N/A	#N/A	0.107	0.291	1.091	2.970	8.084	82.637
Extreme Sea Level (m)	20	#N/A	#N/A	#N/A	0.145	0.546	1.485	4.042	41.319
	50	#N/A	#N/A	#N/A	#N/A	0.218	0.594	1.617	16.527
	100	#N/A	#N/A	#N/A	#N/A	#N/A	0.297	0.808	8.264
	200	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.404	4.132
	1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.826

**Table B12: Joint probability table showing wave height and water level at 53.349N, 5.667W (150deg sector)**

Value of first variable:		Joint exceedance return period (years)							
		2	5	10	20	50	100	200	1000
Extreme Sea Level (m)	Value of second variable:	Significant Wave Height (m)							
2.49	4.24	4.65	4.96	5.26	5.66	5.97	6.27	6.97	
2.58	4.24	4.65	4.96	5.26	5.66	5.97	6.27	6.97	
2.71	4.24	4.65	4.96	5.26	5.66	5.97	6.27	6.97	
2.80	3.95	4.54	4.96	5.26	5.66	5.97	6.27	6.97	
2.90	3.63	4.23	4.68	5.12	5.66	5.97	6.27	6.97	
3.02	3.25	3.82	4.27	4.71	5.30	5.74	6.18	6.97	
3.12	2.94	3.51	3.96	4.41	4.99	5.43	5.87	6.89	
3.22	2.63	3.22	3.64	4.10	4.69	5.13	5.57	6.59	
3.34	#N/A	2.81	3.26	3.68	4.28	4.72	5.16	6.19	
3.44	#N/A	#N/A	2.95	3.39	3.97	4.42	4.86	5.88	
3.53	#N/A	#N/A	#N/A	3.09	3.65	4.11	4.55	5.58	
3.66	#N/A	#N/A	#N/A	#N/A	3.27	3.69	4.15	5.17	
3.75	#N/A	#N/A	#N/A	#N/A	#N/A	3.40	3.83	4.87	
3.85	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3.52	4.56	
4.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3.84	

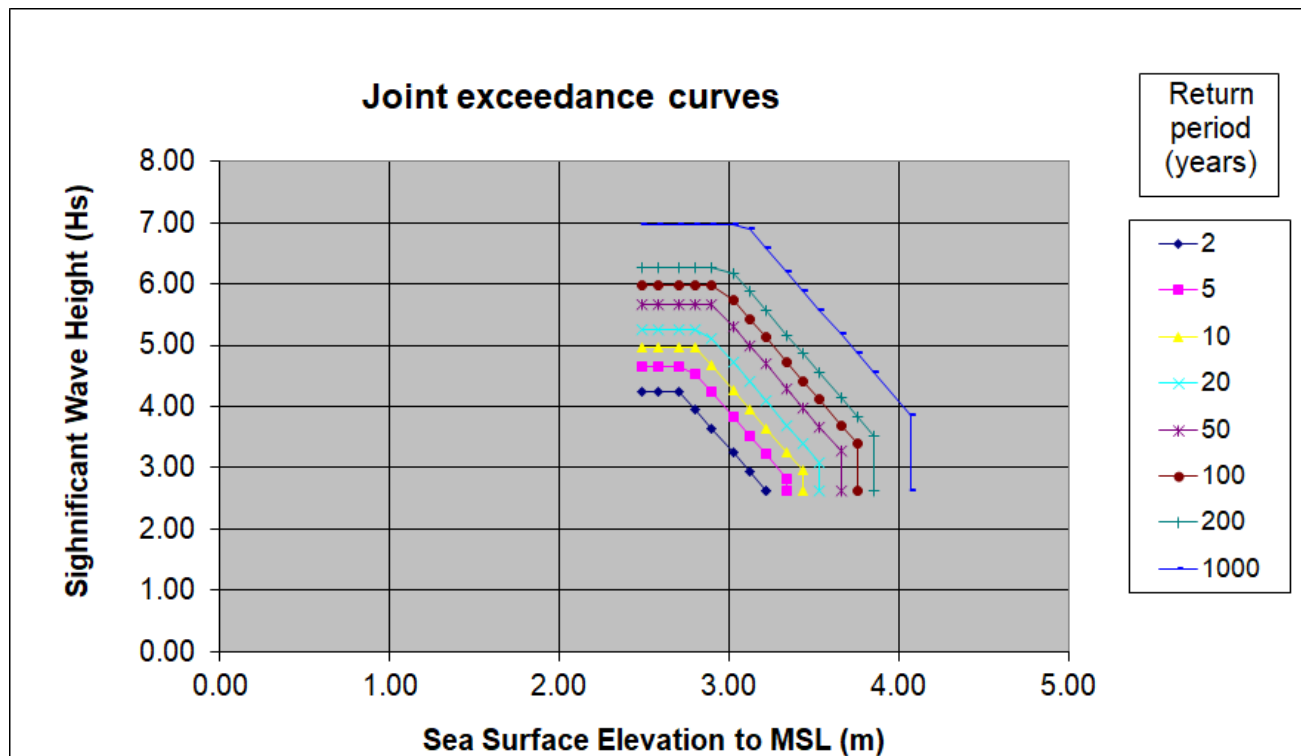


Figure B6: Offshore joint wave and water level exceedance curve at 53.349N, 5.667W (150deg sector)