Technical Note

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Maritime & Aviation

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Copy:	Keming Hu, Alec Sleigh
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Classification:	Project related

Subject: **Holyhead Waterfront Development – Wave Transformation Model**

1 Introduction

Royal HaskoningDHV was commissioned to undertake a series of numerical modelling exercises to inform the design of a proposed marina and shoreline revetments as part of the Holyhead Waterfront development project. The numerical modelling was required to inform the design on wave conditions near the proposed marina and reclamation areas as well as to study impacts on the hydrodynamics close to the study site. The wave conditions were assessed in two stages, first with transforming offshore waves to nearshore and then using the nearshore waves in wave penetration modelling to derive detailed wave conditions at the proposed development.

This technical note describes the methodology and results of the wave transformation modelling. A subsequent technical note (ref. PB8908-RHD-ZZ-ZZ-FN-C-0022) has been produced to detail the methodology and results of the wave penetration modelling. **Figure 1** shows the wider view of the study area.

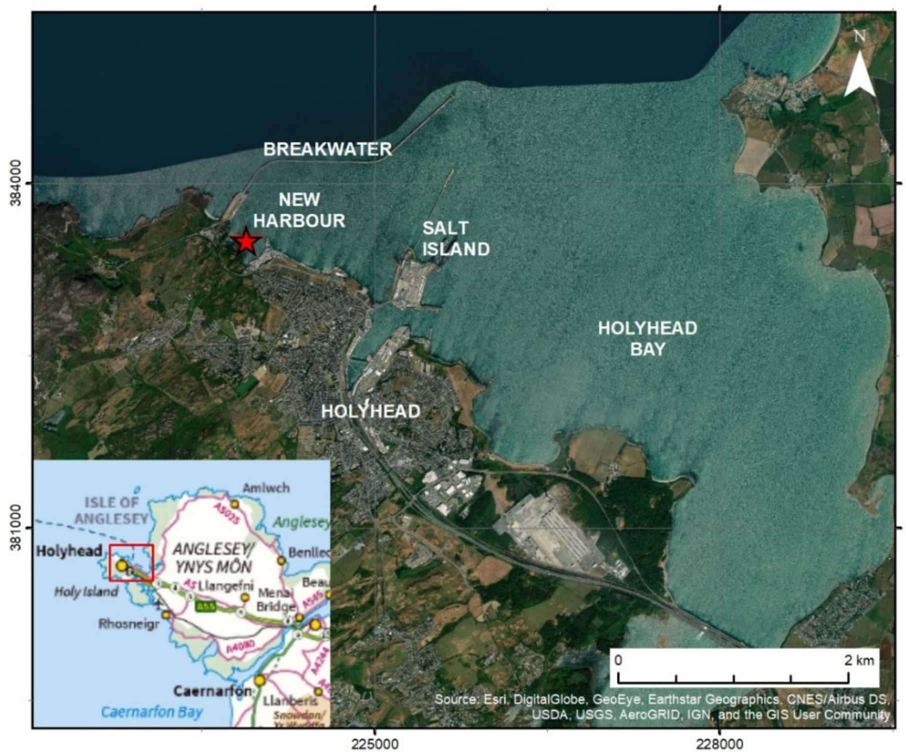

Figure 1: Overview of the study area (red star indicates the study site)

2 Methodology

The numerical modelling tool used for wave transformation modelling of the offshore to the nearshore wave climate was MIKE21-SW, a state of the art third generation spectral wind-wave model developed by DHI. The model simulates the growth, decay and transformation of wind generated waves and swells from the offshore and coastal areas. The model accounts for the following processes amongst others:

- Wave growth by action of wind;
- Non-linear wave-wave interaction;
- Dissipation due to white-capping;
- Dissipation due to depth-induced wave breaking;
- Refraction and shoaling due to depth variations;
- Diffraction; and
- Reflection.

For the purpose of this study an existing Mike-21-SW wave model was used that was previously developed by Royal HaskoningDHV for the Holyhead Breakwater PAR study (Holyhead Breakwater OBC, Appendix B: Technical Report No. M&APB6036R003F0.1). The model was developed for wave transformation analysis, with the appropriate refinement made to incorporate any additional bathymetric survey data available at the time and to better define the coastline in areas of interest using a locally refined mesh.

Inputs to the model were derived following data analysis considering latest available and most appropriate wave, wind and water level information. To inform design of the proposed development, assessment of sea waves and the long-period swell waves was carried out. Undertaken data analysis is presented in a separate technical note: Holyhead Waterfront Development – Extreme Wind/ / Wave Analysis (Doc Ref. PB8908-RHD-ZZ-ZZ-FN-C-0020-S2-P01 Extreme Wind-Wave Analysis TN), hereinafter referred to as Data Analysis Note. Summary of derived extreme wave and water level conditions adopted in the wave transformation modelling is provided in subsequent **Section 3**.

3 Boundary Conditions

For the purpose of this study, three types of wave conditions were assessed, i.e. Higher of Sea or Swell obtained from the Met Office; Swell waves from the Environment Agency's Coastal Flood Boundary Conditions dataset (CFB); and wind driven waves using wind data obtained from the Met Office for station RAF Valley. Joint probability assessment with extreme water levels (also obtained from the CFB dataset) for both the Higher of Sea or Swell and the EA Swell waves was carried out. Details of the obtained data and performed analysis are provided in Data Analysis Note.

To inform the design of the proposed development, four return period events were assessed, i.e. 1 in 1 year for operational conditions; and 1 in 100 year, 1 in 200 year and 1,000 year for survival conditions during extreme storm events. **Section 3.1** presents boundary conditions adopted in the MIKE21-SW model for the assessed scenarios for the Higher of Sea or Swell Waves simulations, whereas **Section 3.2** presents adopted boundary conditions for the swell waves simulations and **Section 3.3** for the locally wind generated waves. Boundary conditions for scenarios including climate change allowances are presented in **Section 3.4**.

3.1 Higher of Sea or Swell Waves

The offshore wave climate was acquired from the UK Met Office, as three-way frequency wave tables based on the 39 year “remap” wave hindcast data (WaveWatch III) for period between 1980 and 2019. Following an Extreme Value Analysis wave conditions for a range of return period events and key directional sectors were derived. To ensure that wind speed for generating a specific wave condition offshore was, a ‘matching’ wind speed was calculated.

To assess the worse-case scenario for the design specifications, a number of directional sectors and joint probability combinations were assessed. The scenario resulting in the worst nearshore wave conditions was then assessed in the wave penetration modelling. Following initial model runs for waves from 0deg and 330deg and three joint probability combinations, it was determined that joint probability combination with highest offshore conditions (JP1) resulted in highest nearshore waves and therefore it was used in the further runs for other directional sectors.

Adopted boundary conditions for the Higher of Sea or Swell waves for Present Day (Year 2020) scenarios and the three considered joint probability combinations are presented in **Table 1**, **Table 2** and **Table 3** respectively.

Table 1. Present Day Boundary conditions adopted for the Higher of Sea or Swell waves model simulations – Joint Probability combination JP1 (highest offshore waves with lowest water levels)

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)	‘Matching’ Wind Speed (m/s)
1 in 1 year JP1	0	5.98	4.62	6.71	15.51
	30	5.98	4.32	5.90	14.62
	60	5.98	4.05	5.71	13.81
	90	5.98	3.66	5.78	12.61
	240	5.98	5.25	7.15	17.32
	270	5.98	4.72	7.13	15.80
	300	5.98	4.95	6.94	16.47
	330	5.98	4.78	7.17	15.98
1 in 100 year JP1	0	6.17	8.48	9.09	25.45
	30	6.17	7.90	8.38	24.13
	60	6.25	7.01	7.51	21.99
	90	6.17	7.22	7.21	22.51
	240	6.17	10.32	10.45	29.22
	270	6.17	7.23	8.82	22.53
	300	6.17	7.82	8.34	23.94
	330	6.17	7.88	8.76	24.09
1 in 200 year	0	6.17	9.09	9.41	26.77

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)	'Matching' Wind Speed (m/s)
JP1	30	6.17	9.18	9.04	26.96
	60	6.33	7.01	7.51	21.99
	90	6.17	8.59	7.87	25.69
	240	6.17	12.20	11.36	32.42
	270	6.17	7.65	9.07	23.54
	300	6.17	8.31	8.60	25.07
	330	6.17	8.52	9.11	25.54
1 in 1,000 year JP1	0	6.25	10.51	10.12	29.57
	30	6.25	12.17	10.40	32.38
	60	6.59	7.01	7.51	21.99
	90	6.25	11.78	9.21	31.76
	240	6.25	16.56	13.24	37.35
	270	6.25	8.63	9.64	25.78
	300	6.25	9.46	9.17	27.53
	330	6.25	10.00	9.87	28.61

Table 2. Present Day Boundary conditions adopted for the Higher of Sea or Swell waves model simulations – Joint Probability combination JP2 (middle offshore waves and water levels)

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)	'Matching' Wind Speed (m/s)
1 in 1 year JP2	0	6.25	3.26	5.88	11.35
	330	6.25	3.59	5.72	12.39
1 in 100 year JP2	0	6.59	5.71	7.46	18.60
	330	6.59	5.70	7.45	18.57
1 in 200 year JP2	0	6.59	6.46	7.93	20.59
	330	6.69	5.70	7.45	18.57
1 in 1,000 year JP2	0	6.69	6.89	8.19	21.69
	330	6.76	6.65	8.05	21.08

Table 3. Present Day Boundary conditions adopted for the Higher of Sea or Swell waves model simulations – Joint Probability combination JP3 (highest water levels and lowest offshore waves)

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)	'Matching' Wind Speed (m/s)
1 in 1 year JP3	0	6.51	1.43	3.58	5.22
	330	6.51	2.00	4.39	7.20
1 in 100 year JP3	0	7.04	2.58	4.92	9.15
	330	7.04	3.00	5.63	10.52
1 in 200 year JP3	0	7.13	2.76	5.09	9.74
	330	7.13	3.16	5.78	11.04
1 in 1,000 year JP3	0	7.27	3.71	6.01	12.77
	330	7.27	3.99	6.03	13.63

3.2 Swell Waves

The Environment Agency's CFB study for point closest to Holyhead provides wave conditions for three directional sectors, i.e. South, South West and North West. For the purpose of this wave transformation modelling, wave directions of 210deg, 270deg and 330deg were adopted for the respective directional sectors. Following initial sensitivity test it was determined that 210deg swell wave direction resulted in the smallest nearshore wave conditions and therefore was not included in the further wave transformation modelling.

The CFB dataset includes confidence intervals for the provided wave conditions. However, the confidence intervals, especially for the North West direction, are relatively big. For that reason, initial sensitivity tests were carried out to determine impact of the two sets of swell wave conditions (with and without the confidence intervals) on model results. It was found that addition of the confidence intervals whilst having a big influence outside the Great Breakwater, it had very little influence on nearshore wave conditions at the project site. Therefore, it was judged overly conservative to apply the confidence intervals. Also, it was consistent with the assessment of Higher of Sea or Swell waves, where the Met Office data didn't include confidence intervals.

Similarly to the Higher of Sea or Swell waves, joint probability assessment was carried out for the Swell waves and three combinations were considered for the same return period events. Adopted boundary conditions for the Swell waves with confidence intervals for Present Day (Year 2020) scenarios and the three considered joint probability combinations are presented in **Table 4**, **Table 5** and **Table 3** respectively.

Table 4. Present Day Boundary conditions adopted for the Swell waves with confidence intervals – Joint Probability combination JP1 (highest offshore waves with lowest water levels)

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)
1 in 1 year	270	5.98	3.06	13.00

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)
JP1	330		1.75	9.10
1 in 100 year JP1	270	6.17	3.89	13.00
	330		4.93	13.00
1 in 200 year JP1	270	6.17	3.95	13.00
	330		5.54	13.00
1 in 1,000 year JP1	270	6.25	4.09	13.00
	330		6.96	13.00

Table 5. Present Day Boundary conditions adopted for the Swell waves with confidence intervals – Joint Probability combination JP2 (middle offshore waves and water levels)

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)
1 in 1 year JP2	270	6.25	2.61	11.70
	330		0.86	9.10
1 in 100 year JP2	270	6.59	3.45	13.00
	330		2.44	9.10
1 in 200 year JP2	270	6.69	3.45	13.00
	330		2.44	9.10
1 in 1,000 year JP2	270	6.76	3.71	13.00
	330		3.37	13.00

Table 6. Present Day Boundary conditions adopted for the Swell Waves with confidence intervals – Joint Probability combination JP3 (highest water levels with lowest offshore waves)

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)
1 in 1 year JP3	270	6.51	2.02	9.10
	330	6.33	0.55	9.10
1 in 100 year JP3	270	7.04	2.39	9.10
	330	6.76	1.61	9.10
1 in 200 year	270	7.13	2.45	9.10

Return Period	Wave Direction (deg)	Water Level (mCD)	Offshore Wave Height (m)	Peak wave Period Tp (sec)
JP3	330	6.84	1.73	9.10
1 in 1,000 year JP3	270	7.27	2.76	10.40
	330	7.00	2.14	10.40

3.3 Locally Wind Generated Waves

In addition to the sea and swell waves, locally wind generated waves from north-east and south-east directional sectors were considered with limited fetch over the Holyhead Bay up to 5km. Wind data was obtained from the Met Office for station RAF Valley (53º 15'N, 4º 32'E) for the available period from 2010 to 2019. The data was collected 10m above sea level. Data was provided as frequency tables of wind speed in knots for 12 directional sectors. Extreme value analysis and joint probability calculations were performed as discussed further in detail in the Data Analysis Note.

For the purpose of this study, locally wind generated waves from the easterly and south-easterly directions were assessed for the 1 in 100 year return period event to inform the design of the offshore breakwaters and the in 200 year return period event for design of the shoreline revetment. The adopted boundary conditions for the considered present day wind wave scenarios for the joint probability combination 1 (higher wind speed, lower water level) are presented in **Table 7**. Since the wind data was provided in 30deg directional sectors, the extreme value analysis was also calculated for these sectors. The wave modelling was carried out for 10deg sectors, adopting the closest wind conditions from the derived extreme value and joint probability analysis.

Table 7. Present Day Boundary conditions adopted for the Locally generated wind waves – Joint Probability combination JP1 (highest wind speed with lower water level)

Return Period	Wind Direction (deg)	Water Level (mCD)	Wind Speed (m/s)
1 in 100 year JP1	0	6.17	24.0
	10		24.0
	20		23.3
	30		23.3
	40		23.3
	50		27.3
	60		27.3
	70		27.3
	80		19.6
	90		19.6
	100		19.6

Return Period	Wind Direction (deg)	Water Level (mCD)	Wind Speed (m/s)
	110		20.0
	120		20.0
	130		20.0
	140		34.3
	150		34.3
	160		34.3
	170		37.4
	180		37.4
1 in 200 year JP1	0	6.17	25.4
	10		25.4
	20		24.5
	30		24.5
	40		24.5
	50		28.7
	60		28.7
	70		28.7
	80		20.7
	90		20.7
	100		20.7
	110		21.1
	120		21.1
	130		21.1
	140		36.2
	150		36.2
	160		36.2
	170		39.2
	180		39.2

3.4 Climate Change

The proposed development assumes 50 year design lifetime. Therefore, climate change allowances had to be considered when deriving wave conditions. In addition, 100 year timeframe was assessed to provide indication of potential change in wave conditions beyond the design lifetime. Assuming year 2020 as present day, the assessed timeframes are year 2070 and 2120 respectively.

Climate change allowances were considered for anticipated sea level rise and increase in wave height. Guidance on climate change from Natural Resources Wales (NRW)[1] provides sea level allowance for each epoch in millimetres (mm) per year and percentage of increase for offshore wind speed and wave height of 10% for epochs beyond 2055. However, the guidance acknowledges that climate change projections were being reviewed through the UK Climate Projections 2018 (UKCP18)[2] project and so it will be updated in the future accordingly. Since the UKCP18 results have been published and include yearly allowances for sea level rise around UK coast, these were used in this assessment instead of the NRW guidance. Wave climate was not assessed under UKCP18 and so the 10% increase allowance from NRW guidance was applied. Similarly, increase in wind speed was also applied as 10% uplift, in accordance with the NRW guidance.

From the UKCP18 dataset, a grid cell covering Holyhead was selected and allowances for sea level rise for the RCP8.5 (Representative Concentration Pathway, similar to previous high emissions scenario) for 95th percentile were selected for conservative approach. Cumulative sea level rise was calculated up to year 2070 and 2120. Based on that 0.5m and 1.32m was added to the present day extreme water levels derived in the Data Analysis exercise for the two timeframes respectively.

4 Model Set-up

The MIKE21-SW model has been set up, similar to the previous model for the PAR study, but updated with the latest available bathymetry data. The geographical model extent was defined to ensure the areas of interest and any changes to the wave climate were captured and appropriate offshore wave conditions were generated. Model domain and bathymetry is presented in **Figure 2**.

The MIKE21-SW model mesh was built using triangular mesh. The greater the detail of this triangular mesh the more precise the calculations, but the longer processing time needed for each simulation. It is common practise to use coarse mesh size in the offshore areas far from area of interest and to gradually decrease cell size closer towards the focus area of the model. Such approach was adopted for this study where area around the Holyhead Bay requiring the greatest precision was given the smallest mesh cell sizes, as illustrated in **Figure 3**. This also ensures that features of the shoreline that enhance shoaling and refraction effects are represented in the model.

[1] Natural Resources Wales - Adapting to Climate Change: Guidance for Flood and Coastal Erosion Risk Management Authorities in Wales, December 2017

[2] Mett Office UK Climate Projections - https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/

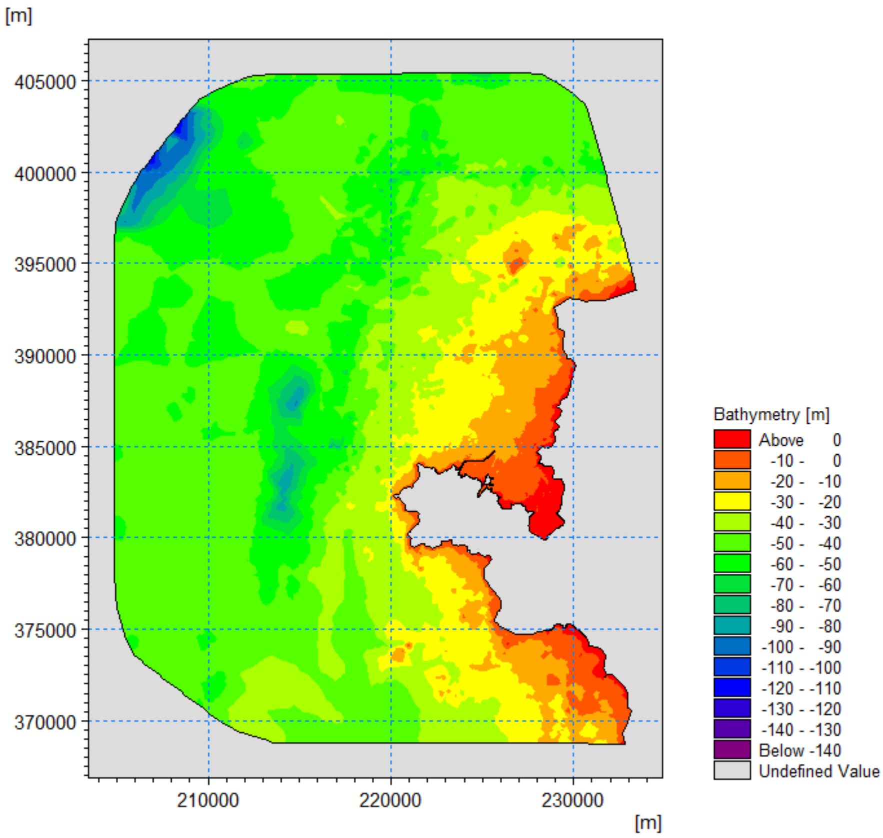

Figure 2. MIKE21-SW Model domain and bathymetry

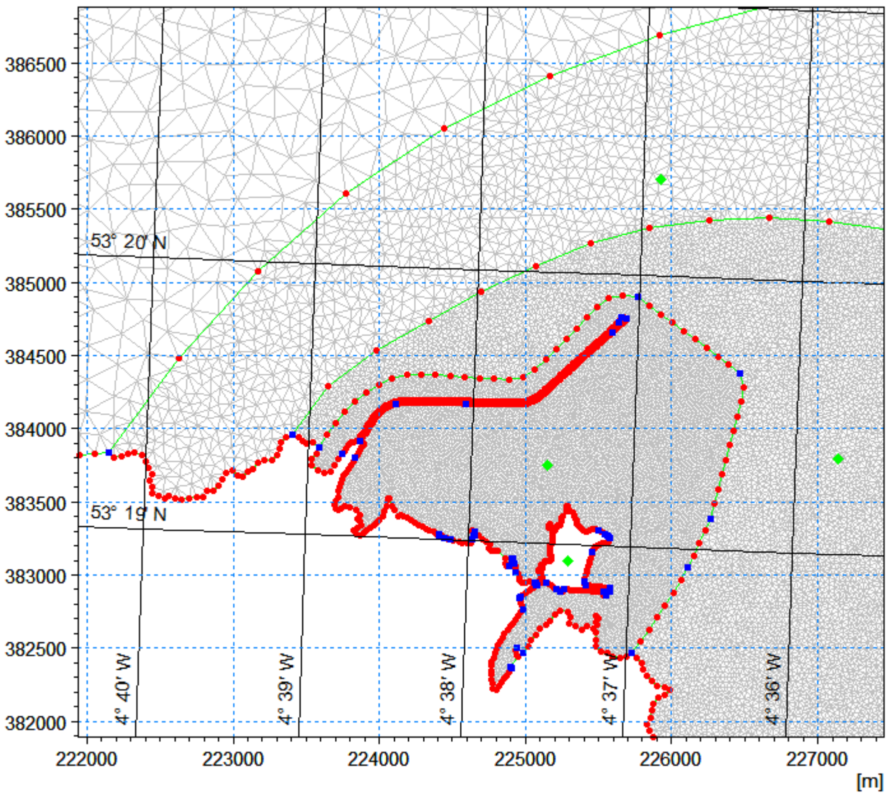

Figure 3. MIKE21-SW Model mesh near the proposed development

For the purpose of this analysis, the Directionally Decoupled Parametric Formulation was chosen together with SPM73 Wind Generation Formula which is an optimised setting from the previous project. practice and tests. Adopted model settings are listed in **Table 8** below.

Table 8. Adopted MIKE21-SW model settings

Description	Adopted Settings
Basic Equations	Spectral formulation: Directionally decoupled parametric formulation Time formulation: Quasi stationary formulation
Spectral Discretization	Discretization type: 360 degree rose Number of directions: 36
Wind Forcing	Wind generating formula: SPM73
Bottom Friction	Model: Nikuradse roughness, kn Constant value: 0.001m for the offshore areas; and 0.04 along the coastline for the shallow areas

5 Results

5.1 Output Points

A number of nearshore points (10) within the New Holyhead Harbours have been defined within the model domain as shown in **Figure 4** below. Nearshore wave conditions for each of the model runs undertaken have been extracted at these points and the full results, including contour plots of derived nearshore wave heights are presented in **Section 5.2** for Higher of Sea or Swell and in **Section 5.3** for the Swell waves.

Figure 4: Selected output points near the proposed development (red lines)

5.2 Higher of Sea or Swell Waves

Following initial model runs it was determined that the joint probability combination 1 (JP1, highest offshore wave with lowest water level) and 0°N directional sector resulted in the highest nearshore wave conditions. **Table 9** and **Table 10** present a summary of the results for three return period events for the Present Day and development lifetime (50 years) timeframes respectively for two points closest to the proposed development (point 8 and point 9, **Figure 4**). Results for all other joint probability combinations and offshore waves directions are provided in **Appendix A**.

Table 9. Results for Higher of Sea or Swell Waves for 0degN directional sector – JP1 – Year 2020

Return Period	Extreme Water Level (2020)	Offshore Wave height (m) (2020)	Offshore Wave period (s)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T1	5.98	4.62	6.71	0.29	0.51	2.60	4.59
T100	6.17	8.48	9.09	0.49	0.80	3.17	5.40
T200	6.17	9.09	9.41	0.52	0.84	3.23	5.47

Table 10. Results for Higher of Sea or Swell Waves for 0degN directional sector – JP1 – Year 2070

Return Period	Extreme Water Level (2070)	Offshore Wave height (m) (2070)	Offshore Wave period (s)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T1	6.48	5.08	6.71	0.31	0.53	2.57	4.51
T100	6.67	9.33	9.09	0.54	0.86	3.18	5.31
T200	6.48	5.08	6.71	0.56	0.90	3.24	5.38

Figure 5 to **Figure 10** present contour plots of the nearshore wave height for the Higher of Sea or Swell Waves for the three return period events and the two development timeframes respectively. All plots are results of offshore waves from north (0degN).

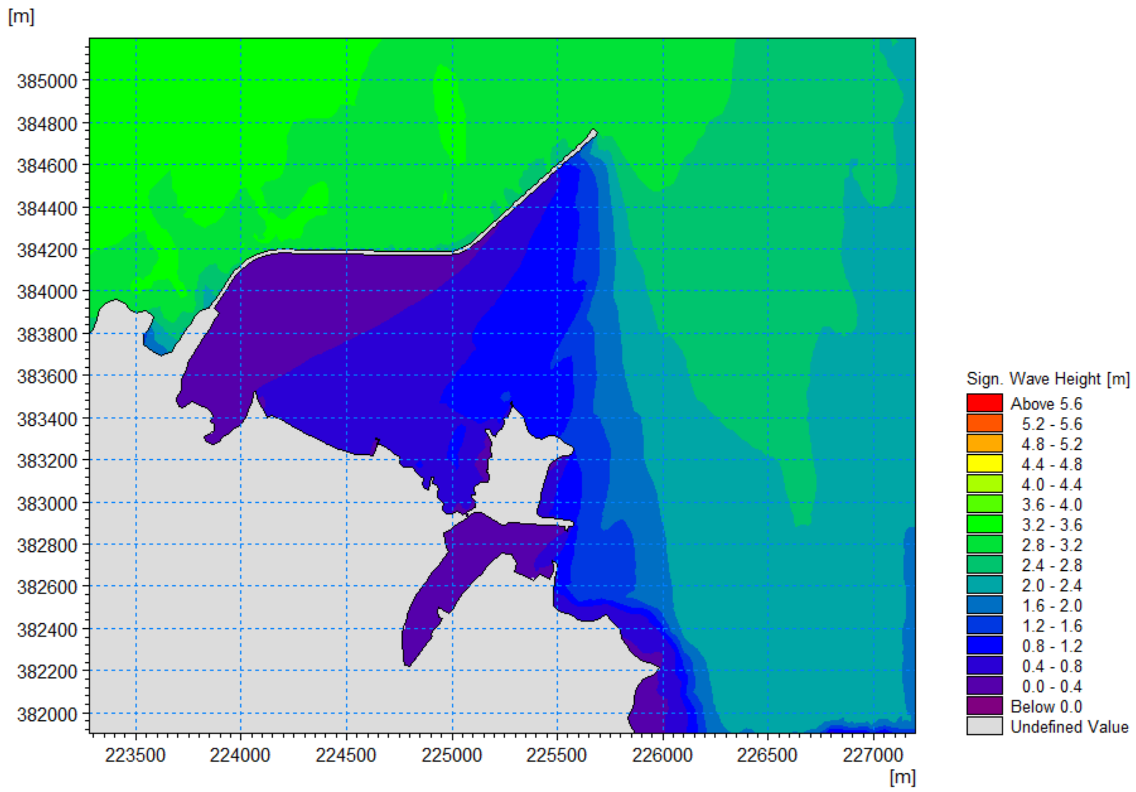

Figure 5. Higher of Sea or Swell Nearshore Wave Height for 1 in 1 year return period with Present Day (2020) climate – JP1 and 0degN directional sector

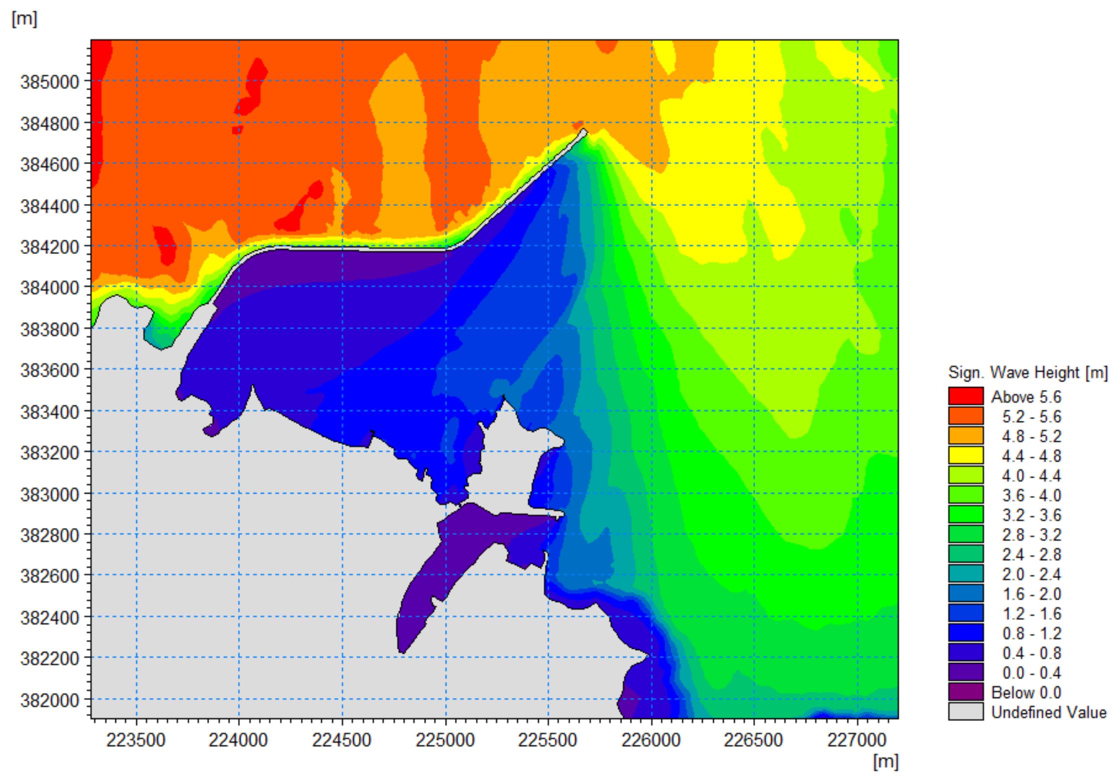

Figure 6. Higher of Sea or Swell Nearshore Wave Height for 1 in 100 year return period with Present Day (2020) climate – JP1 and 0degN directional sector

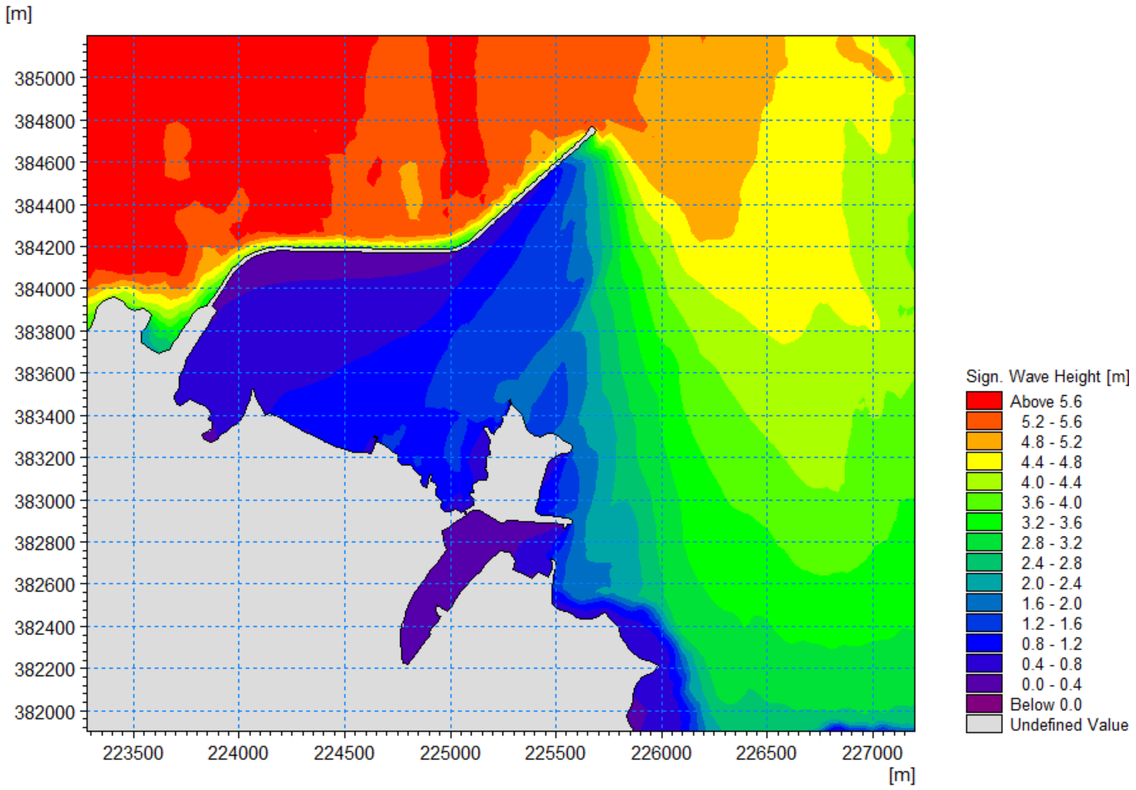

Figure 7. Higher of Sea or Swell Nearshore Wave Height for 1 in 200 year return period with Present Day (2020) climate – JP1 and 0degN directional sector

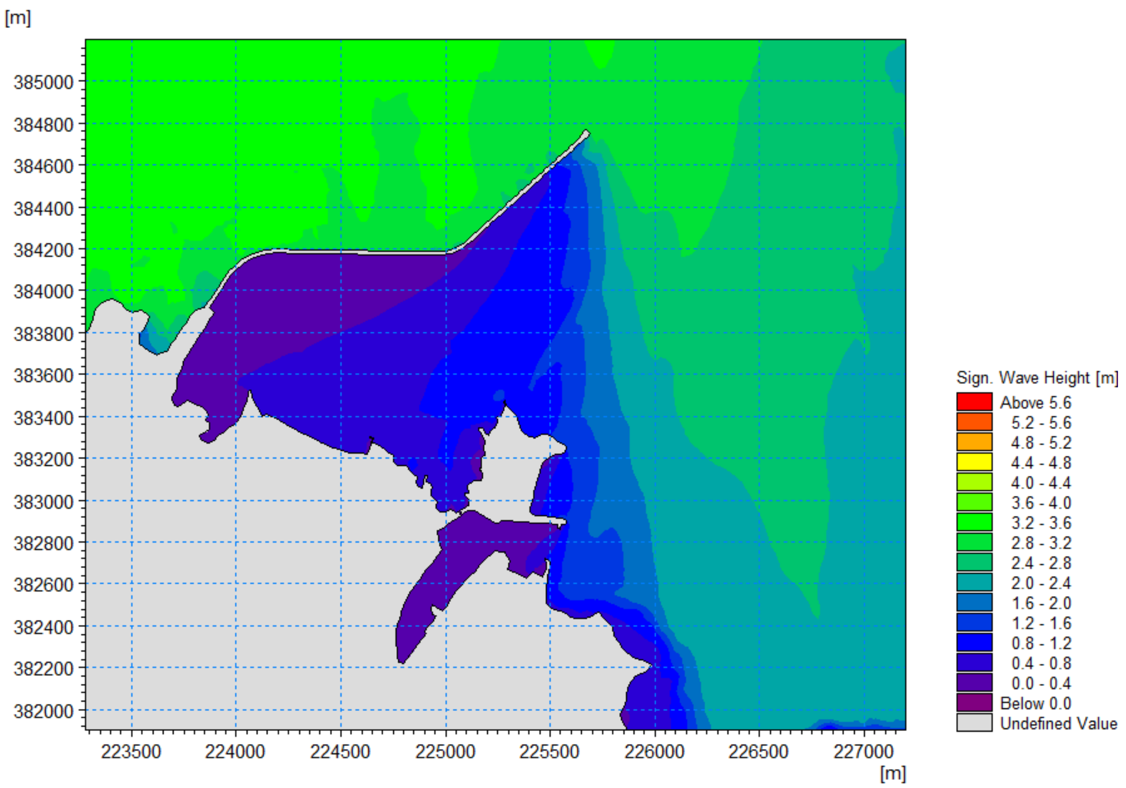

Figure 8. Higher of Sea or Swell Nearshore Wave Height for 1 in 1 year return period with climate change (Year 2070) event – JP1 and 0degN directional sector

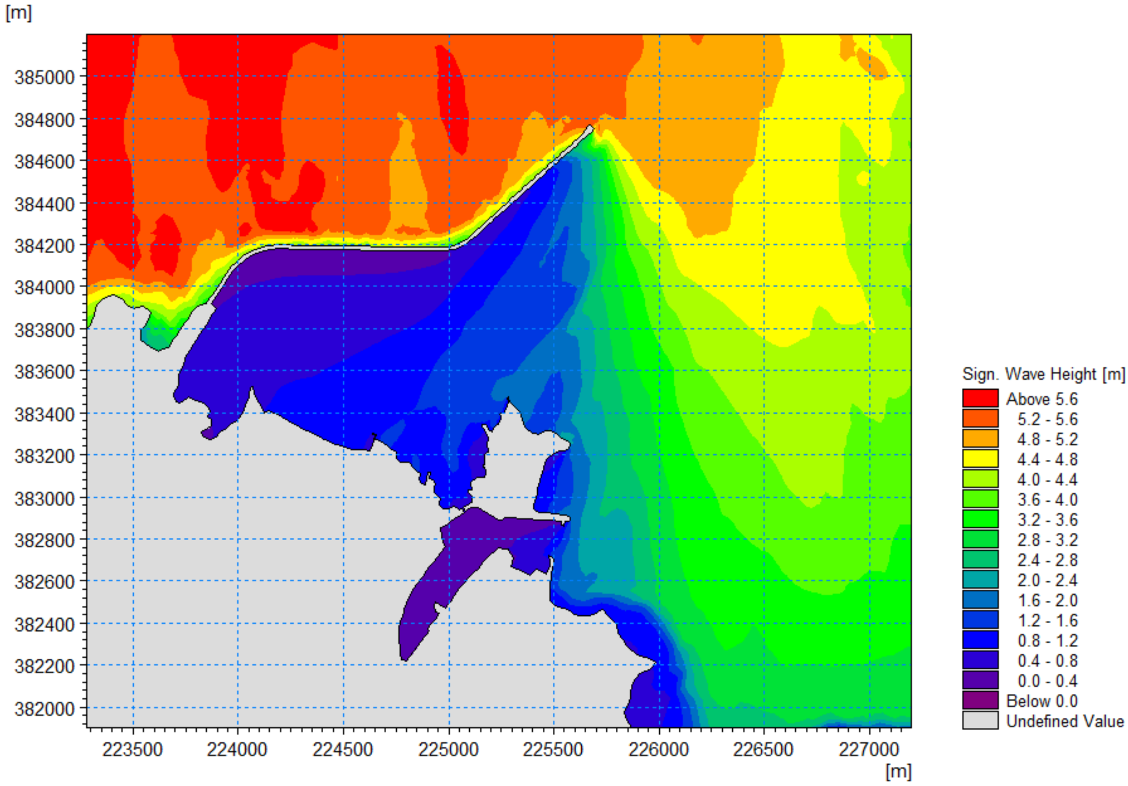

Figure 9. Higher of Sea or Swell Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 0degN directional sector

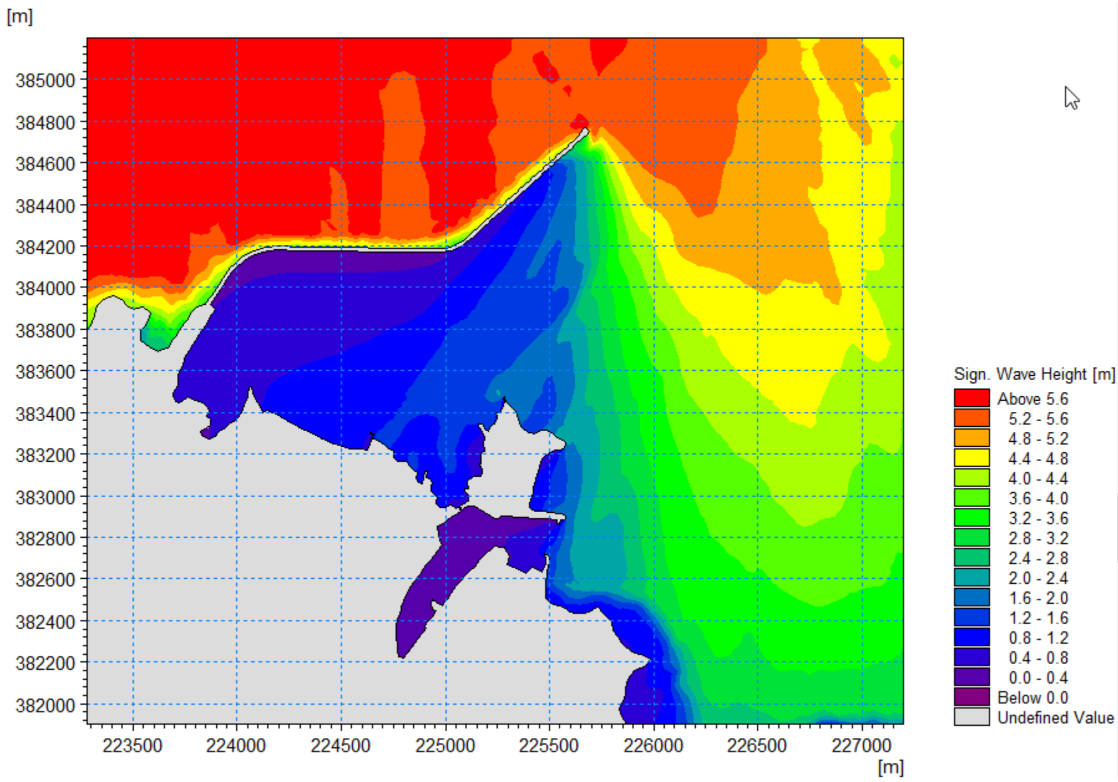

Figure 10. Higher of Sea or Swell Nearshore Wave Height for 200 in 1 year return period climate change (2070) event – JP1 and 0deg directional sector

5.3 Swell Waves

Similarly to the Higher of Sea or Swell, results for the Swell waves also showed that the Joint Probability combination 1 (highest offshore wave with lowest water level) resulted in the highest nearshore wave conditions but from a 330°N directional sector. **Table 11** and **Table 12** present a summary of the results for three return period events for the Present Day and development lifetime (50 years) timeframes respectively for two points closest to the proposed development (point 8 and point 9, **Figure 4**). Results for all other joint probability combinations and offshore waves directions are provided in **Appendix B**.

Table 11. Results for Swell Waves for 330degN directional sector – JP1 – Year 2020

Return Period	Extreme Water Level (2020)	Offshore Wave height (m) (2020)	Offshore Wave period (s)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T1	5.98	1.55	9.10	0.08	0.16	8.68	8.81
T100	6.17	3.43	13.00	0.17	0.38	12.10	12.26
T200	6.17	3.74	13.00	0.18	0.41	12.09	12.24

Table 12. Results for Swell Waves for 330degN directional sector – JP1 – Year 2070

Return Period	Extreme Water Level (2070)	Offshore Wave height (m) (2070)	Offshore Wave period (s)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T1	6.48	1.71	9.10	0.08	0.17	8.71	8.83
T100	6.67	3.77	13.00	0.18	0.40	12.13	12.28
T200	6.67	4.11	13.00	0.19	0.43	12.12	12.26

Figure 11 to **Figure 16** present contour plots of the nearshore wave height for the Swell Waves for the three return period events and the two development timeframes respectively. All plots are results of offshore waves from northwest (330degN).

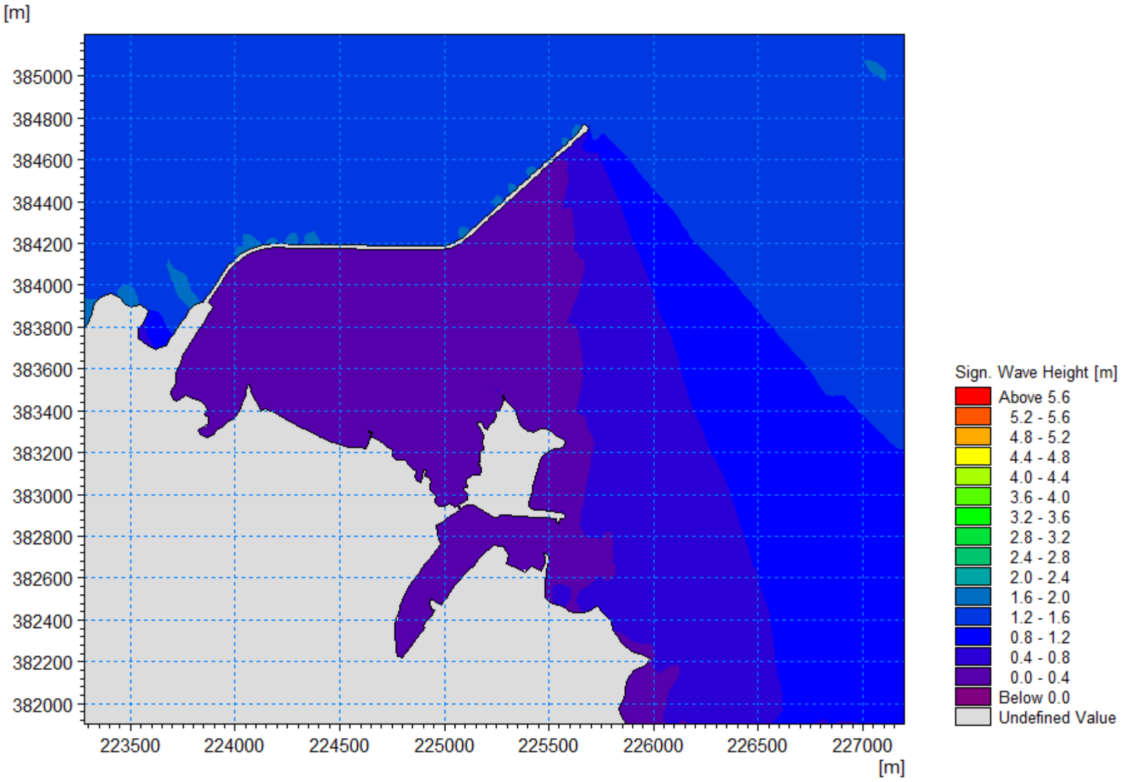

Figure 11. Swell Waves Nearshore Wave Height for 1 in 1 year return period with Present Day (Year 2020) climate – JP1 and 330degN directional sector

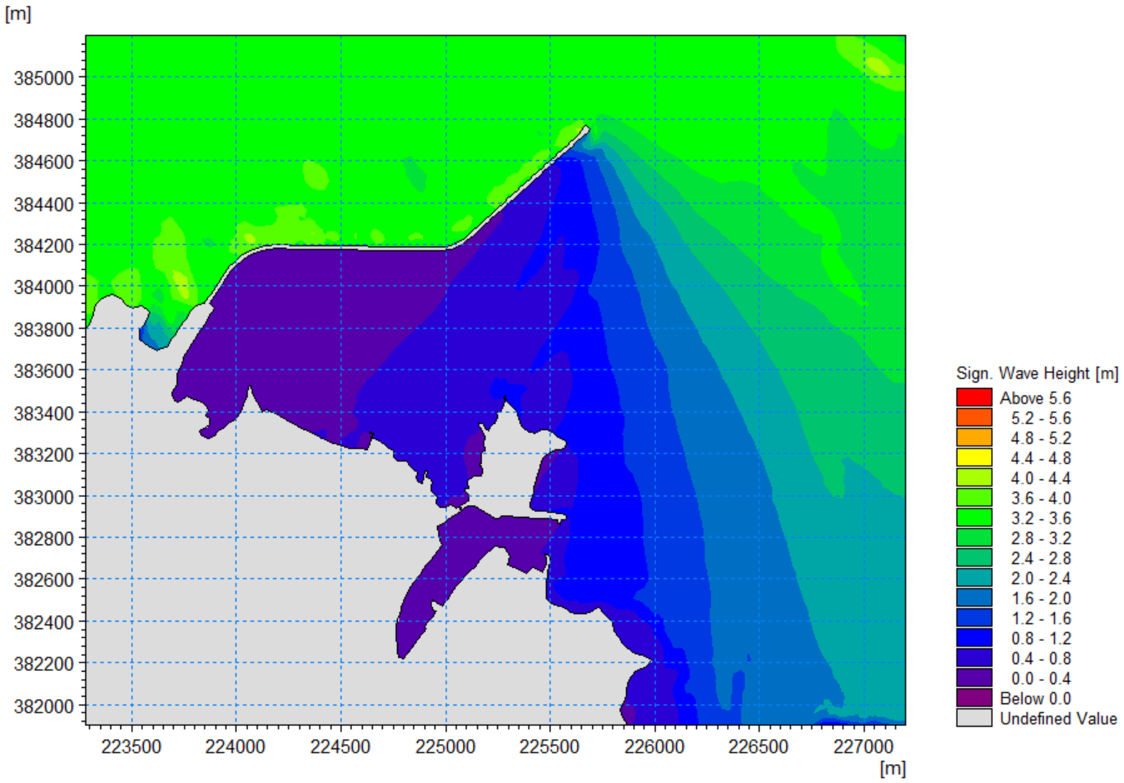

Figure 12. Swell Waves Nearshore Wave Height for 1 in 100 year return period with Present Day (Year 2020) climate – JP1 and 330degN directional sector

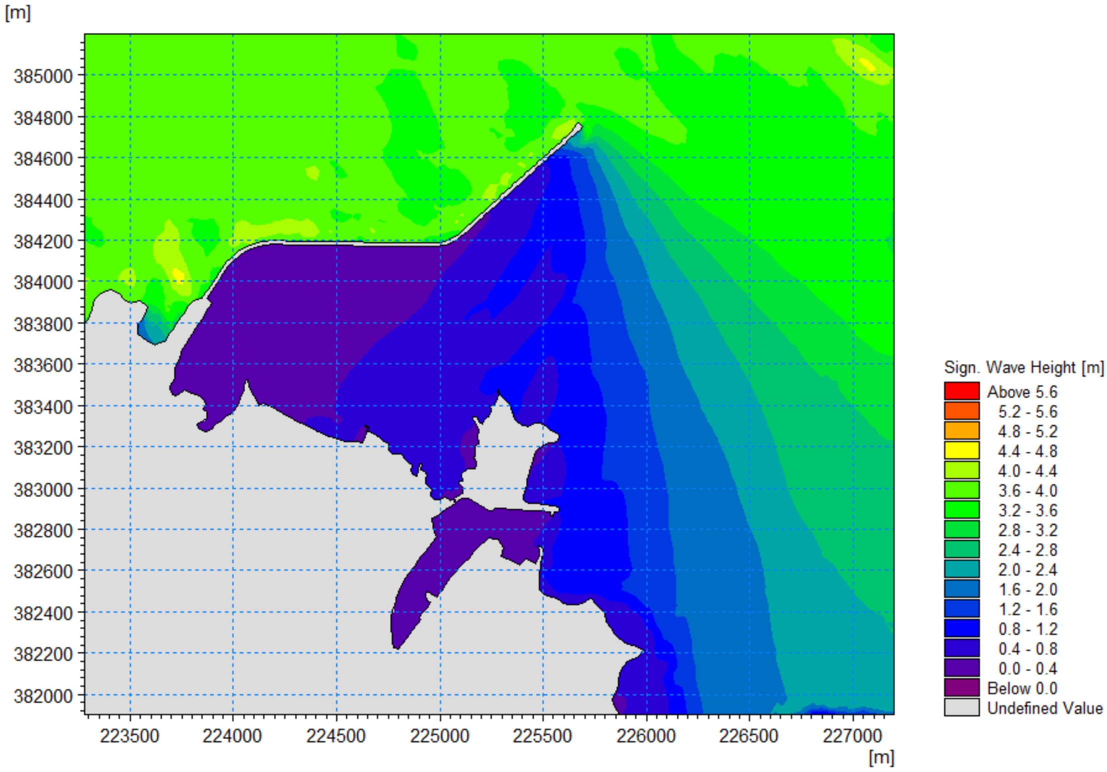

Figure 13. Swell Waves Nearshore Wave Height for 1 in 200 year return period with Present Day (Year 2020) climate – JP1 and 330degN directional sector

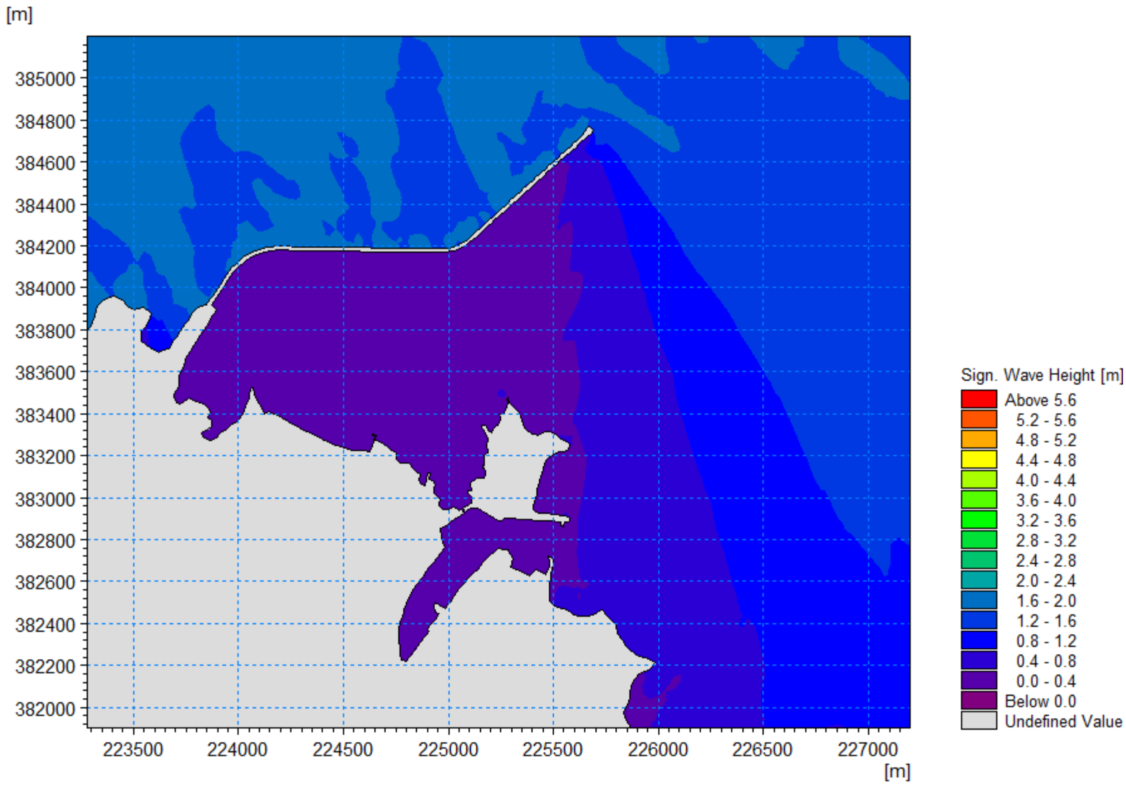

Figure 14. Swell Waves Nearshore Wave Height for 1 in 1 year return period with climate change (Year 2070) – JP1 and 330degN directional sector

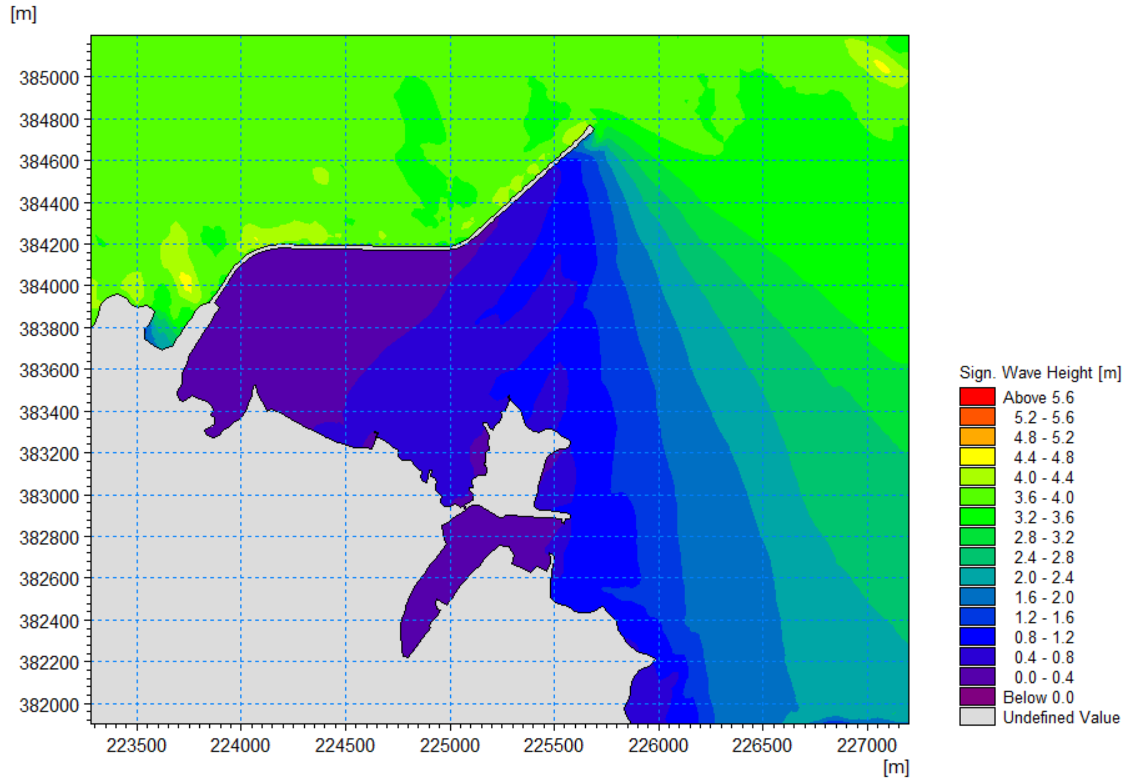

Figure 15. Swell Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 330degN directional sector

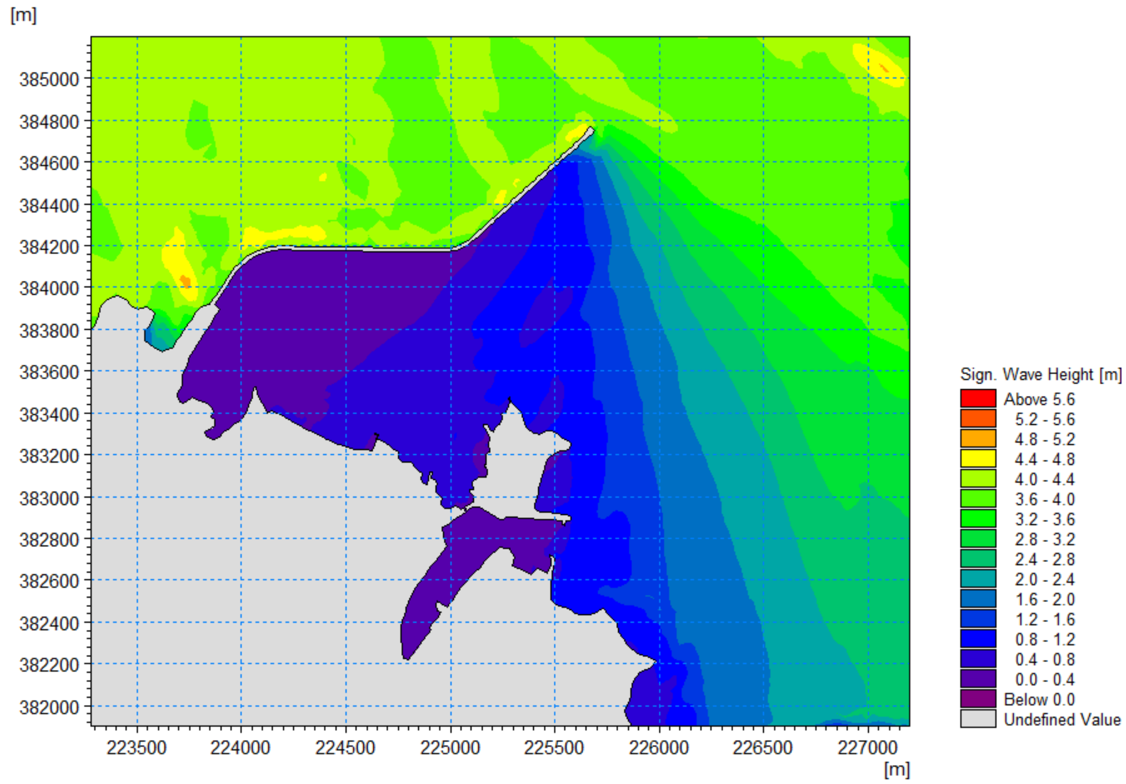

Figure 16. Swell Waves Nearshore Wave Height for 1 in 200 year return period with climate change (Year 2070) – JP1 and 330degN directional sector

5.4 Locally Wind Generated Waves

Table 13 and **Table 14** present a summary of the results for the 1 in 100 year return period event with wind from the south-easterly sectors for the Present Day and development lifetime (50 years) timeframes respectively for two points closest to the proposed development (point 8 and point 9, **Figure 4**).

Table 13. Results for Locally Wind Generated Waves – JP1 – Year 2020

Return Period	Extreme Water Level (2020)	Wind Speed (m/s) (2020)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T100	6.17	19.6	90	0.66	0.72	3.38	3.48
		19.6	100	0.66	0.69	3.36	3.42
		20.0	110	0.67	0.67	3.35	3.36
		20.0	120	0.64	0.62	3.28	3.25
		20.0	130	0.61	0.57	3.18	3.11
		34.3	140	1.05	0.96	4.01	3.87
		34.3	150	0.97	0.89	3.83	3.66
		34.3	160	0.90	0.82	3.63	3.47
		37.4	170	0.92	0.85	3.61	3.45
		37.4	180	0.87	0.81	3.45	3.33

Table 14. Results for Locally Wind Generated Waves – JP1 – Year 2070

Return Period	Extreme Water Level (2070)	Wind Speed (m/s) (2070)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T100	6.67	21.5	90	0.74	0.80	3.56	3.66
		21.5	100	0.74	0.77	3.54	3.59
		22.0	110	0.75	0.75	3.53	3.54
		22.0	120	0.72	0.70	3.46	3.42
		22.0	130	0.68	0.64	3.35	3.28
		37.8	140	1.17	1.08	4.22	4.08
		37.8	150	1.09	1.00	4.03	3.86
		37.8	160	1.01	0.92	3.83	3.65
		41.1	170	1.03	0.95	3.79	3.63
		41.1	180	0.97	0.91	3.63	3.50

Figure 17 to **Figure 26** present contour plots of the nearshore wave height for the Locally Wind Generated Waves for the 1 in 100 year return period event at the development lifetime epoch (2070) for all considered directions respectively.

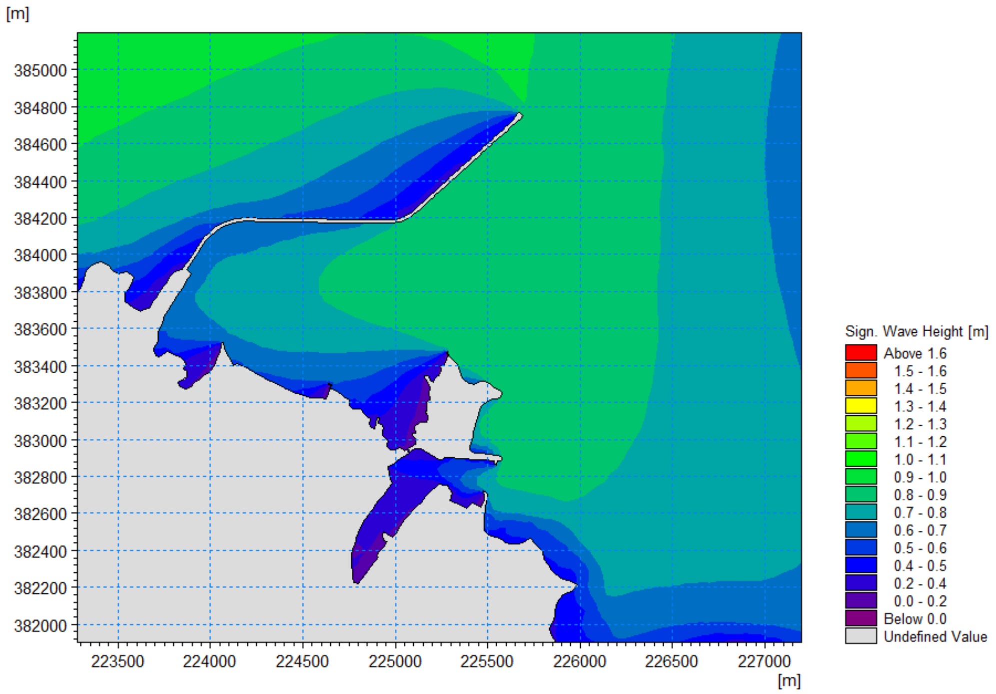

Figure 17. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 90degN directional sector

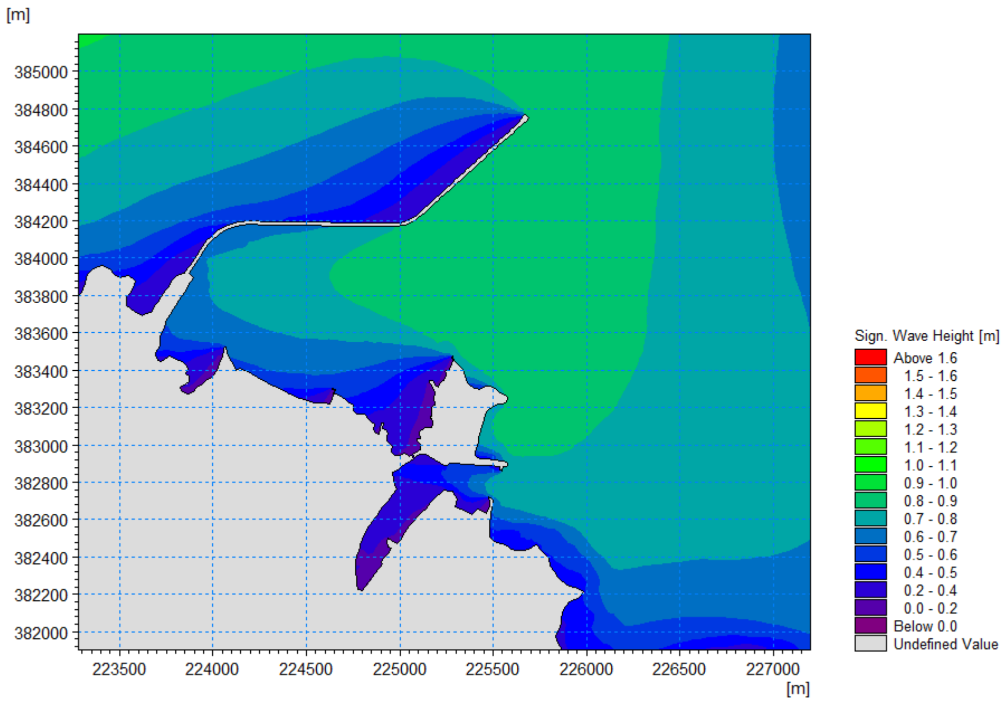

Figure 18. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 100degN directional sector

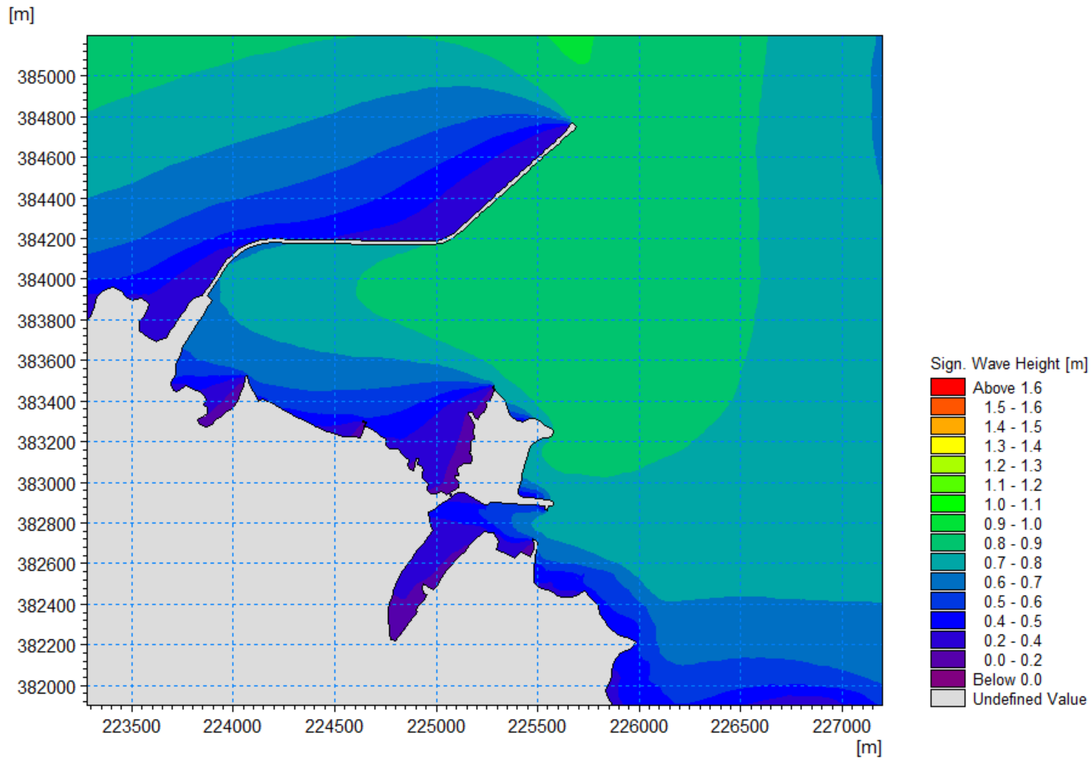

Figure 19. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 110degN directional sector

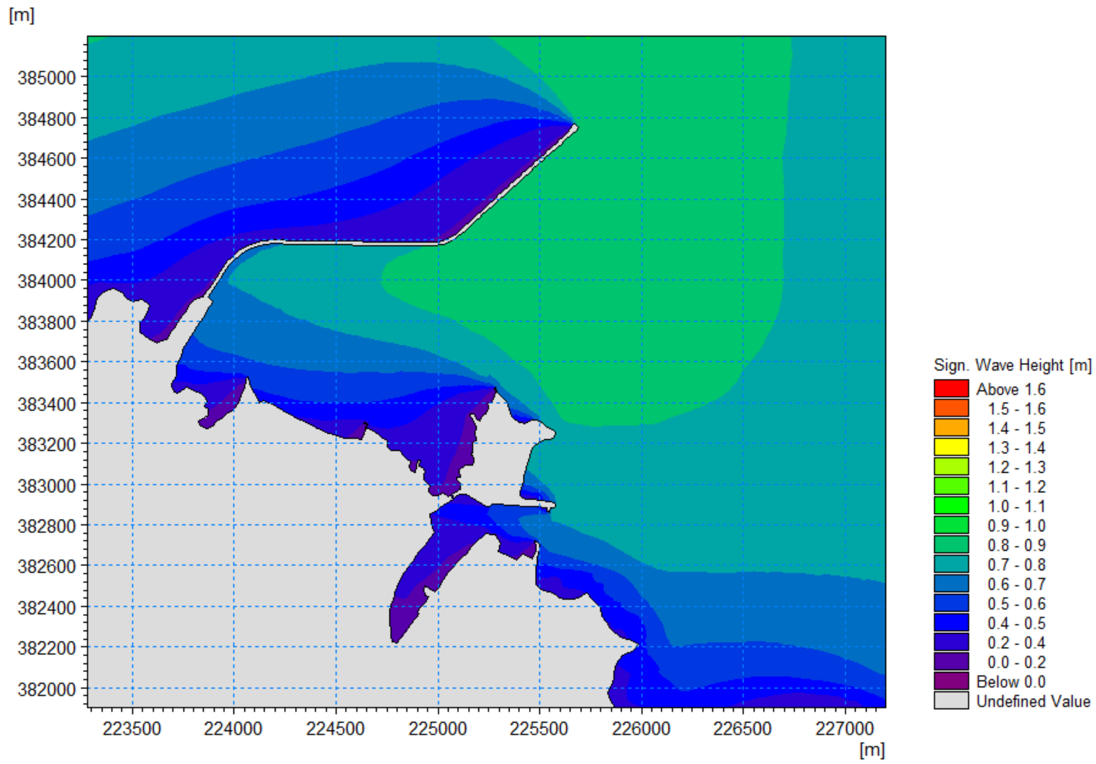

Figure 20. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 120degN directional sector

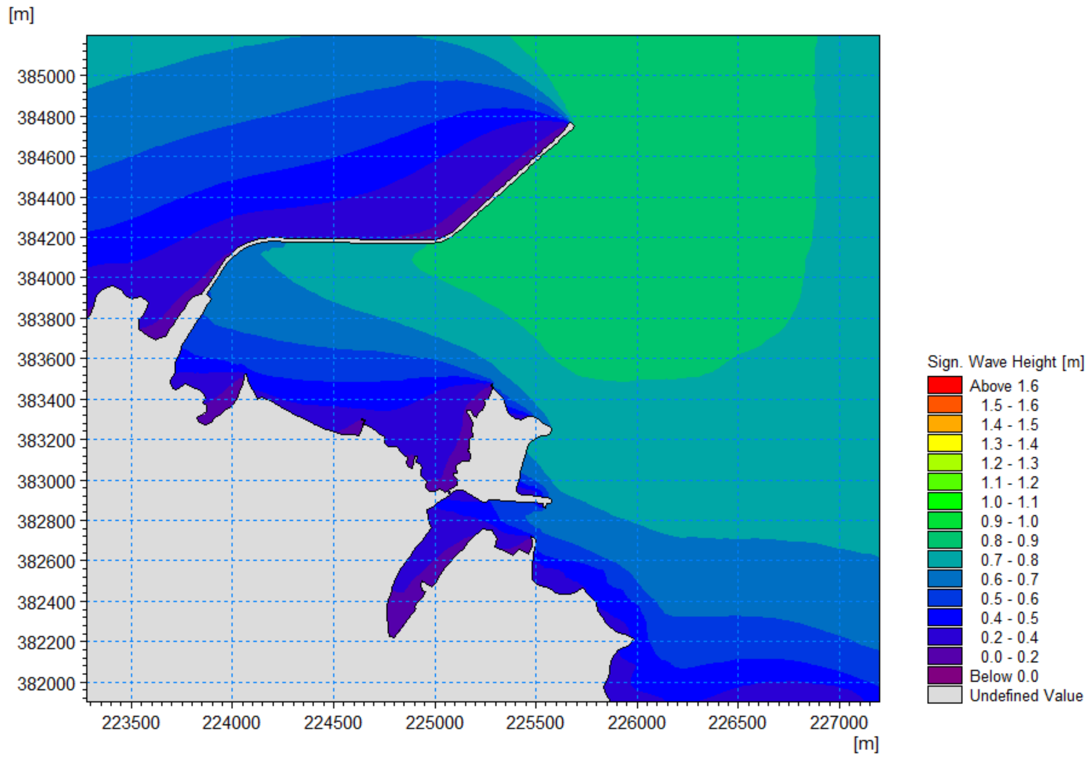

Figure 21. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 130degN directional sector

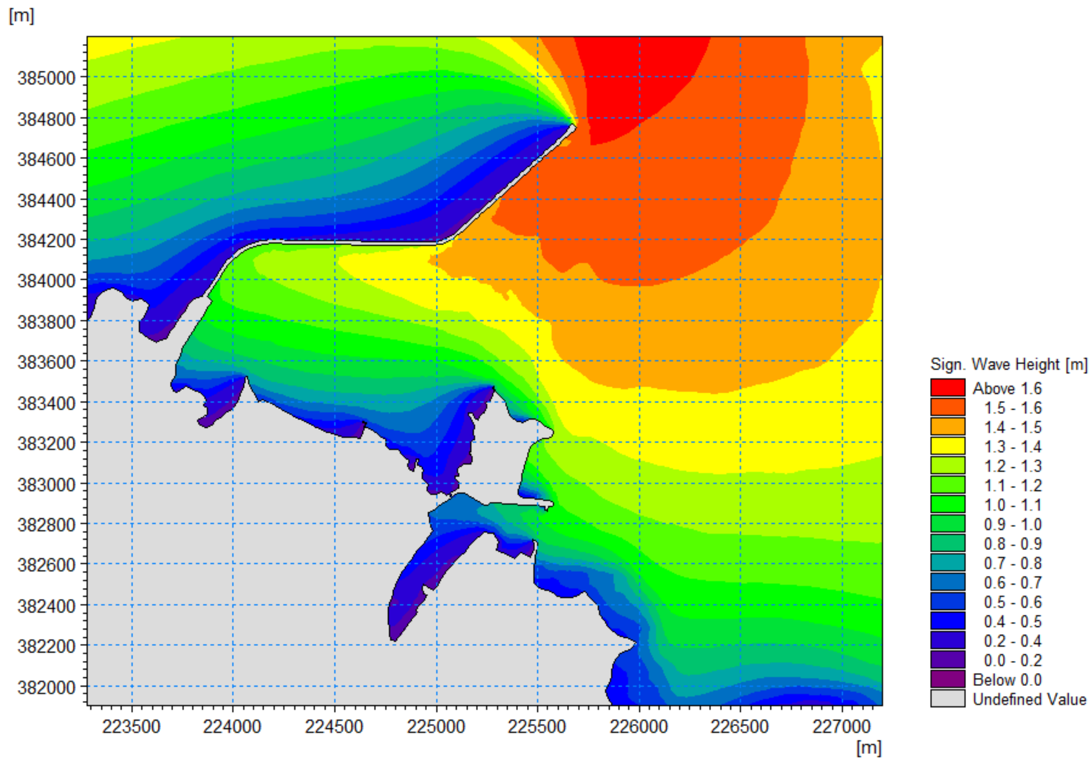

Figure 22. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 140degN directional sector

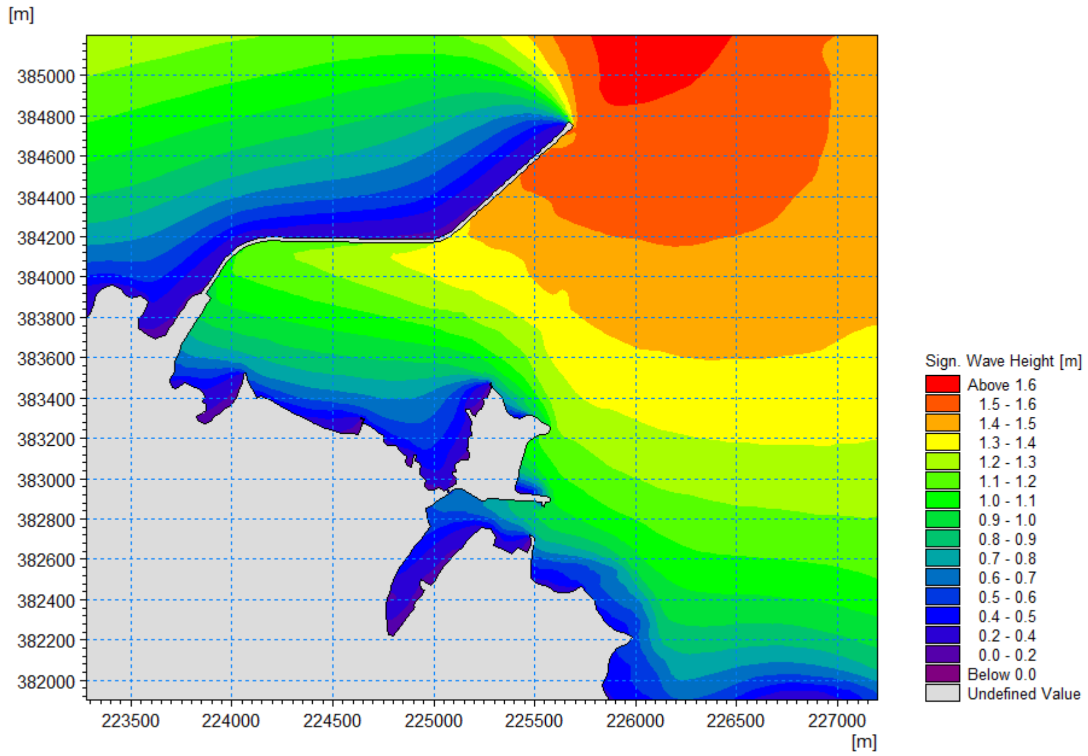

Figure 23. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 150degN directional sector

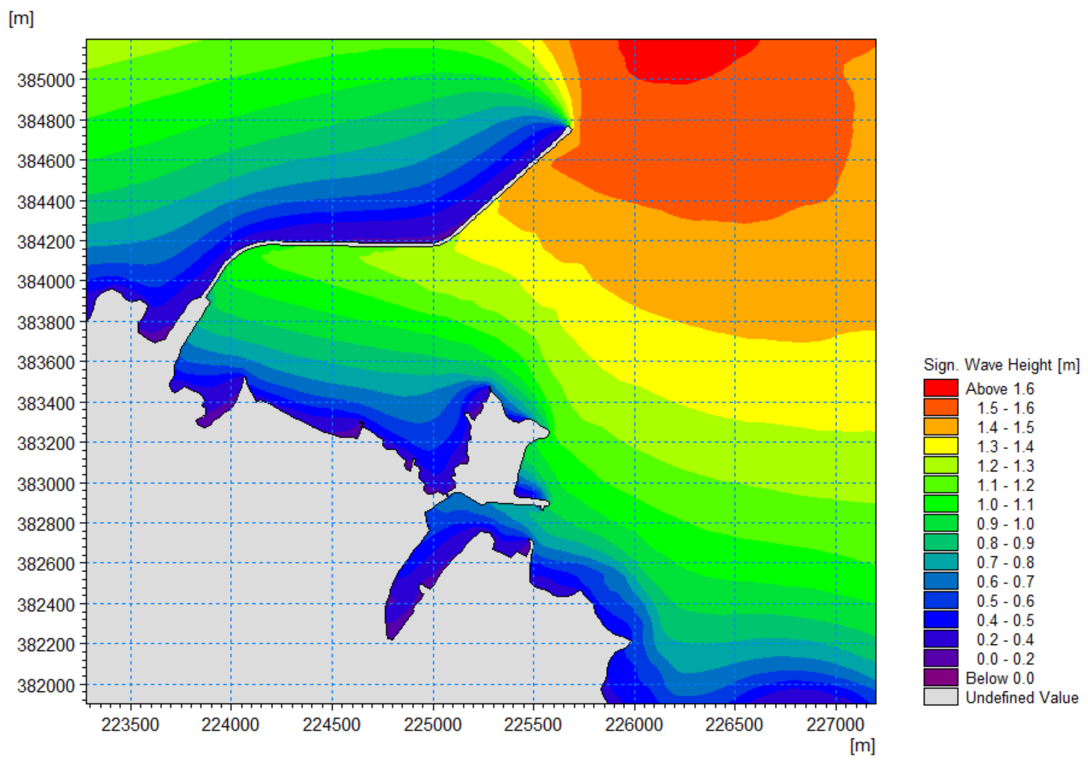

Figure 24. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 160degN directional sector

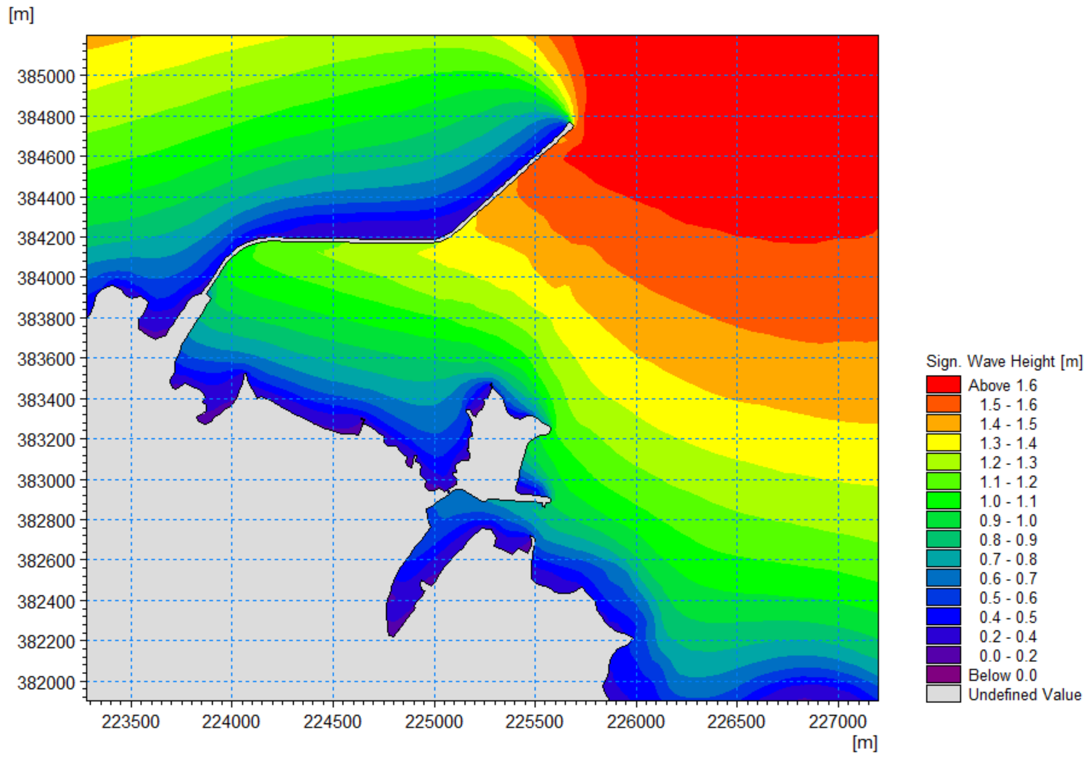

Figure 25. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 170degN directional sector

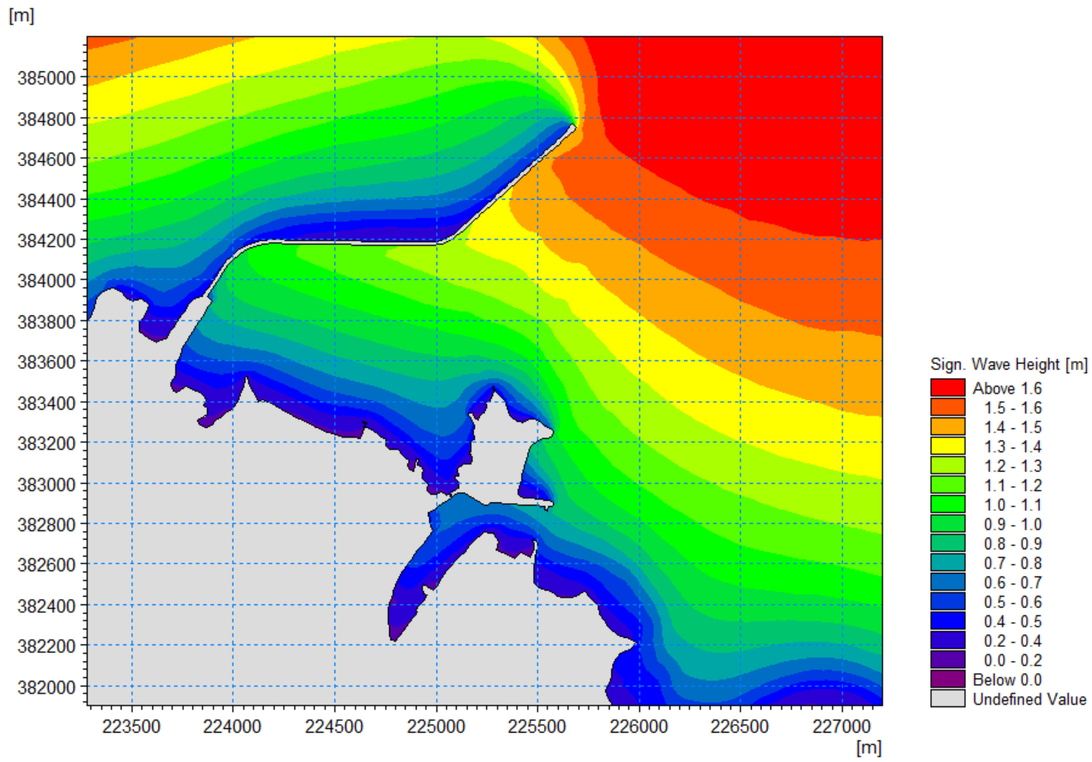

Figure 26. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2070) – JP1 and 180degN directional sector

Table 15 presents a summary of the results for the 1 in 100 year return period event for the maximum development lifetime (100 years) timeframe for the two points closest to the proposed development (point 8 and point 9 shown in **Figure 4**).

Table 15. Results for Locally Wind Generated Waves – 1 in 100 year return period JP1 – Year 2120

Return Period	Extreme Water Level (2120)	Wind Speed (m/s) (2120)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T100	7.49	26.4	0	0.44	0.67	2.53	3.38
		26.4	10	0.49	0.73	2.75	3.60
		25.6	20	0.53	0.78	2.97	3.73
		25.6	30	0.60	0.85	3.24	3.89
		25.6	40	0.67	0.91	3.48	4.00
		30.0	50	0.88	1.15	3.97	4.42
		30.0	60	0.96	1.19	4.11	4.46
		30.0	70	1.02	1.20	4.19	4.45
		21.5	80	0.73	0.82	3.56	3.71
		21.5	90	0.74	0.80	3.57	3.66
		21.5	100	0.74	0.77	3.55	3.60
		22.0	110	0.75	0.75	3.54	3.55
		22.0	120	0.72	0.70	3.46	3.43
		22.0	130	0.68	0.64	3.36	3.29
		37.8	140	1.18	1.09	4.25	4.11
		37.8	150	1.10	1.00	4.05	3.89
		37.8	160	1.01	0.93	3.84	3.68
		41.1	170	1.03	0.95	3.81	3.64
		41.1	180	0.97	0.91	3.64	3.51

Results in **Table 15** show that the highest inshore wave heights are for the scenarios wind from 140deg for Point 8 and from 70deg for Point 9, although the differences between 140deg and 70deg for both points are not significant. This is in line with results for the present day and 2070 scenarios presented in **Table 13** and **Table 14**, where the 140deg direction also results in the worst nearshore wave conditions.

Table 16 presents a summary of the results for the 1 in 200 year return period event for the maximum development lifetime (100 years) timeframe for the two points closest to the proposed development (point 8 and point 9 shown in **Figure 4**).

Table 16. Results for Locally Wind Generated Waves – 1 in 200 year return period JP1 – Year 2120

Return Period	Extreme Water Level (2120)	Wind Speed (m/s) (2120)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T200	7.49	27.9	0	0.47	0.71	2.60	3.49
		27.9	10	0.52	0.78	2.83	3.71
		27.0	20	0.56	0.83	3.06	3.84
		27.0	30	0.63	0.90	3.33	4.00
		27.0	40	0.71	0.97	3.58	4.11
		31.6	50	0.94	1.21	4.07	4.54
		31.6	60	1.01	1.25	4.21	4.58
		31.6	70	1.08	1.27	4.30	4.57
		22.8	80	0.78	0.88	3.67	3.83
		22.8	90	0.79	0.86	3.68	3.78
		22.8	100	0.79	0.83	3.66	3.71
		23.2	110	0.80	0.80	3.64	3.65
		23.2	120	0.77	0.74	3.56	3.53
		23.2	130	0.73	0.68	3.46	3.38
		39.8	140	1.25	1.15	4.36	4.21
		39.8	150	1.16	1.06	4.16	3.99
		39.8	160	1.08	0.98	3.95	3.77
		43.1	170	1.09	1.01	3.90	3.73
		43.1	180	1.02	0.96	3.73	3.59

Similarly to results for the 1 in 100 year return period event, results in for the 1 in 200 year event in **Table 16** show that the worst nearshore wave conditions are from the 140deg and 70deg directions for Point 8 and Point 9 respectively.

Figure 27 – **Figure 30** present contour plots of the nearshore wave height for the Locally Wind Generated Waves at the end of development lifetime (2120) with wind from the 70deg and 140deg directions for the 1 in 100 year and 1 in 200 year return period events respectively.

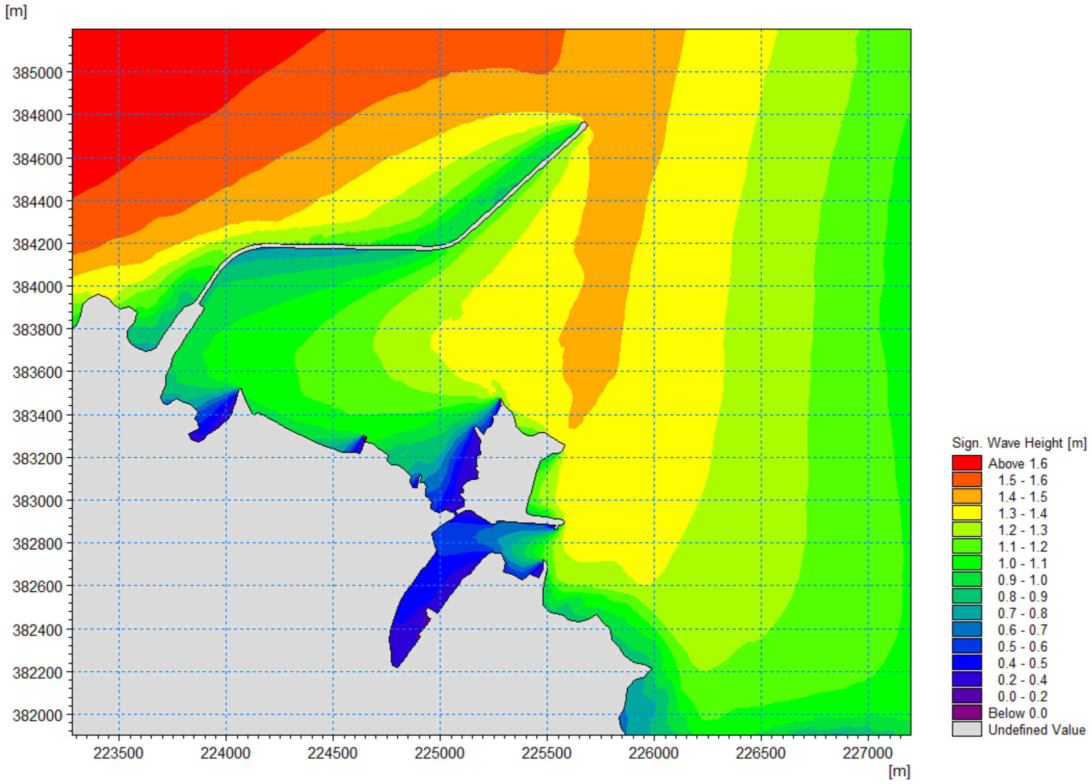

Figure 27. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2120) – JP1 and 70degN directional sector

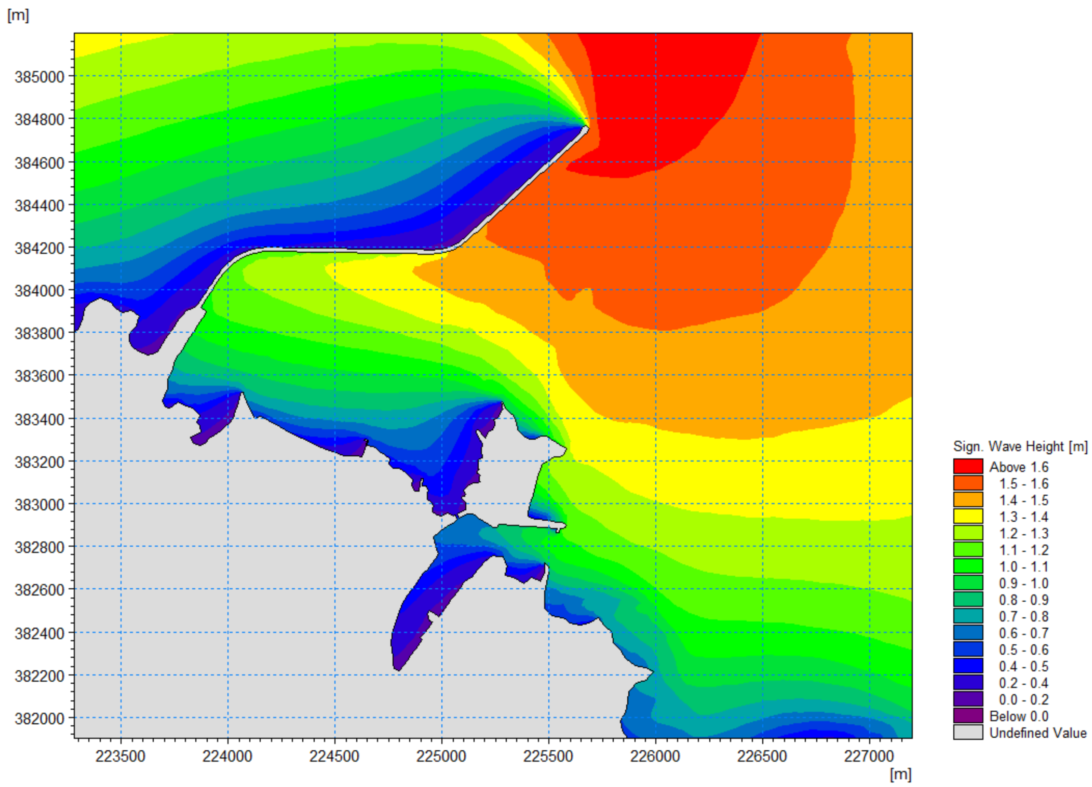

Figure 28. Locally Wind Generated Waves Nearshore Wave Height for 1 in 100 year return period with climate change (Year 2120) – JP1 and 140degN directional sector

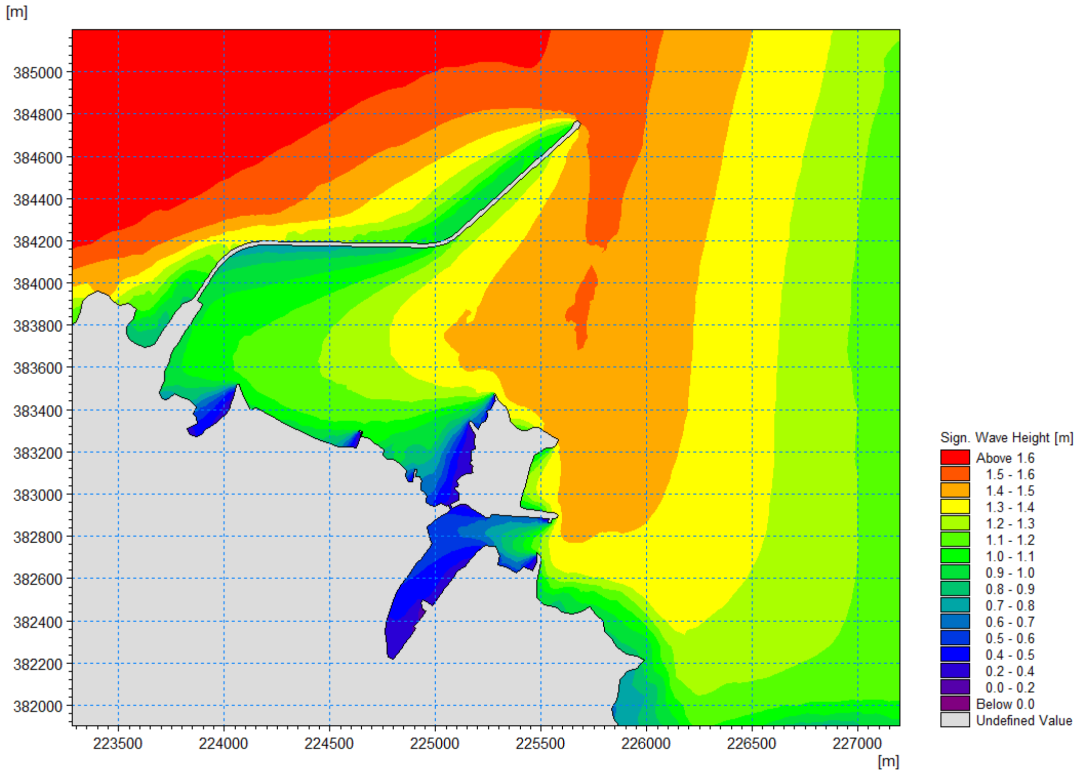

Figure 29. Locally Wind Generated Waves Nearshore Wave Height for 1 in 200 year return period with climate change (Year 2120) – JP1 and 70degN directional sector

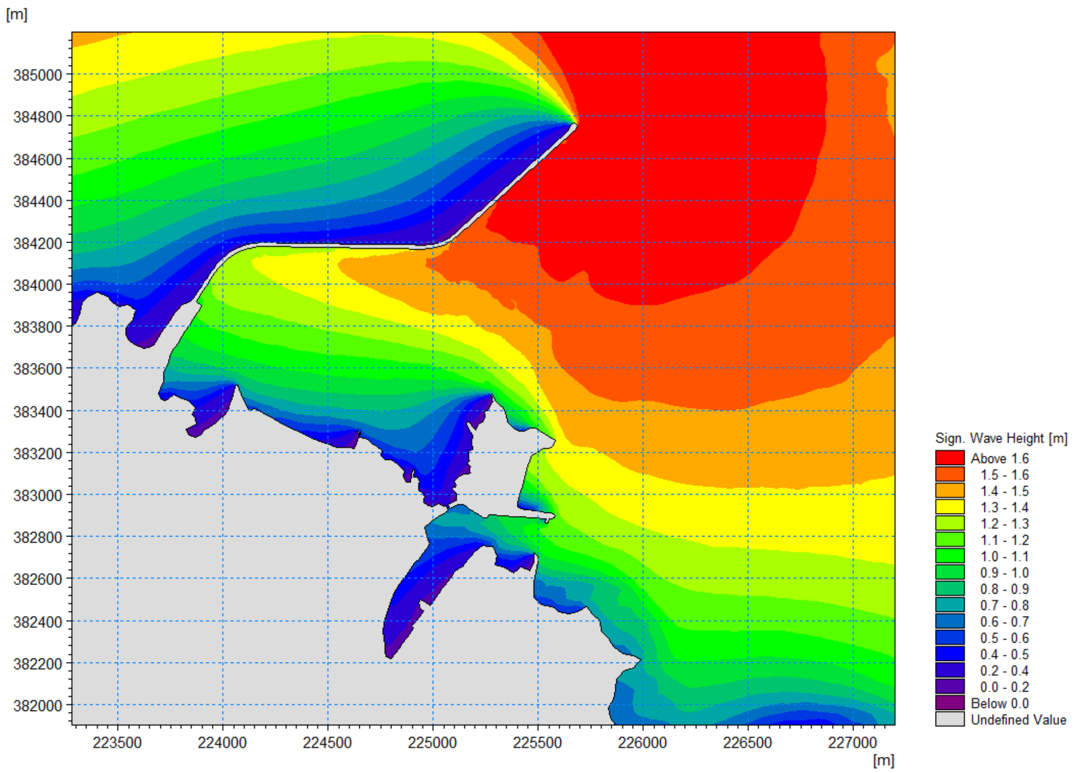

Figure 30. Locally Wind Generated Waves Nearshore Wave Height for 1 in 200 year return period with climate change (Year 2120) – JP1 and 140degN directional sector

To assess sensitivity of the resultant nearshore wave conditions to the extreme still water levels, sensitivity test was carried out for the 1 in 100 and 1 in 200 year return period events at 2120 with wind from 140deg direction, where allowance for storm surge of 0.96m was added to the still water level, giving a total level of 8.45mCD. Summary of the results for all assessed scenarios with wind from 140deg direction is presented in **Table 17**.

Table 17. Results for Locally Wind Generated Waves – comparison from 140deg sector

Return Period	Extreme Water Level	Wind Speed (m/s)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Period (s)	
				Point 8	Point 9	Point 8	Point 9
T100	6.17	34.3	140	0.99	1.05	4.01	3.87
T100	6.67	37.8		1.17	1.08	4.22	4.08
T100	7.49	37.8		1.18	1.09	4.25	4.11
T100	8.45	37.8		1.19	1.10	4.28	4.14
T200	7.49	39.8		1.25	1.15	4.36	4.21
T200	8.45	39.8		1.26	1.17	4.39	4.25

From **Table 17** it can be seen that even relatively big change in extreme still water levels (e.g. due to storm surge) would not result in a significant change in nearshore wave conditions (wave height) near the proposed development, where approximately 1m of change in water levels corresponds to increase in maximum wave height up to 0.02m.

Appendix A: Summary Results for Higher of Sea or Swell Waves

Table A1 and **Table A2** present results for four return period events with Present Day climate for two directional sectors (0degN and 330degN) and the three derived joint probability combinations for nearshore significant wave height and wave period respectively.

Table A3 and **Table A4** present results for four return period events with climate change (Year 2070) for two directional sectors (0degN and 330degN) and joint probability combination 1 for the nearshore significant wave height and wave period respectively.

Table A5 and **Table A6** present results for four return period events with Present Day climate for all considered directional sectors and joint probability combination 1 for the nearshore significant wave height and wave period respectively.

Table A1. Result for Higher of Sea or Swell Waves – Significant Wave Height (m) for four return period events, two directional sectors and three joint probability combinations (Present Day climate)

Higher of Sea and Swell Waves		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	0deg - JP1	2.76	2.67	2.41	1.80	0.65	0.90	1.07	0.29	0.51	0.82
	0deg - JP2	2.30	2.20	2.06	1.63	0.52	0.74	0.85	0.20	0.38	0.65
	0deg - JP3	0.94	0.93	0.90	0.78	0.10	0.19	0.28	0.05	0.08	0.14
	330deg - JP1	2.86	2.66	1.89	1.21	0.59	0.78	0.80	0.28	0.47	0.70
	330deg - JP2	2.02	1.86	1.23	0.76	0.34	0.48	0.48	0.20	0.30	0.44
	330deg - JP3	1.28	1.16	0.67	0.34	0.09	0.14	0.18	0.08	0.11	0.15
100 year	0deg - JP1	4.24	4.22	3.53	2.44	0.97	1.36	1.59	0.49	0.80	1.21
	0deg - JP2	3.24	3.18	2.79	2.05	0.77	1.08	1.25	0.35	0.60	0.97
	0deg - JP3	1.75	1.69	1.62	1.36	0.33	0.53	0.57	0.13	0.23	0.43

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Higher of Sea and Swell Waves		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
	330deg - JP1	4.04	3.77	2.78	1.81	0.85	1.16	1.24	0.44	0.71	1.04
	330deg - JP2	3.16	2.94	2.12	1.37	0.66	0.89	0.91	0.32	0.53	0.80
	330deg - JP3	1.95	1.79	1.13	0.66	0.26	0.39	0.39	0.16	0.24	0.35
200 year	0deg - JP1	4.43	4.41	3.66	2.52	1.00	1.41	1.65	0.52	0.84	1.26
	0deg - JP2	3.53	3.49	3.02	2.17	0.84	1.17	1.35	0.39	0.66	1.05
	0deg - JP3	1.86	1.80	1.72	1.43	0.37	0.58	0.63	0.15	0.26	0.48
	330deg - JP1	4.24	3.94	2.91	1.89	0.89	1.22	1.30	0.47	0.75	1.09
	330deg - JP2	3.17	2.94	2.12	1.37	0.66	0.89	0.91	0.32	0.53	0.80
	330deg - JP3	2.04	1.87	1.20	0.71	0.28	0.43	0.42	0.17	0.25	0.38
1000 year	0deg - JP1	4.82	4.79	3.92	2.67	1.08	1.52	1.77	0.58	0.91	1.35
	0deg - JP2	3.71	3.67	3.15	2.26	0.88	1.23	1.41	0.41	0.70	1.10
	0deg - JP3	2.44	2.33	2.18	1.73	0.54	0.79	0.89	0.22	0.39	0.69
	330deg - JP1	4.58	4.23	3.12	2.02	0.96	1.33	1.42	0.53	0.83	1.19
	330deg - JP2	3.61	3.36	2.45	1.60	0.76	1.04	1.08	0.37	0.62	0.92
	330deg - JP3	2.25	2.07	1.38	0.86	0.37	0.53	0.53	0.21	0.33	0.48

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Table A2. Result for Higher of Sea or Swell Waves – Peak Wave Period (sec) for four return period events, two directional sectors and three joint probability combinations (Present Day climate)

Higher of Sea and Swell Waves		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	0deg - JP1	7.67	7.67	7.66	7.56	6.26	6.81	7.21	2.60	4.59	6.56
	0deg - JP2	6.73	6.73	6.76	6.73	5.71	6.14	6.36	2.24	4.17	5.89
	0deg - JP3	4.15	4.18	4.21	4.22	2.61	3.37	3.63	2.04	2.18	2.83
	330deg - JP1	8.14	8.07	7.77	7.24	5.70	6.12	6.38	2.29	3.76	5.55
	330deg - JP2	6.75	6.70	6.29	5.63	4.05	4.59	4.43	1.85	2.73	3.99
	330deg - JP3	5.16	5.15	4.71	3.85	1.93	2.33	2.48	1.50	1.75	2.01
100 year	0deg - JP1	9.92	9.91	9.84	9.57	7.49	8.43	9.16	3.17	5.40	8.12
	0deg - JP2	8.43	8.43	8.40	8.25	6.77	7.42	7.86	2.77	4.90	7.13
	0deg - JP3	5.74	5.77	5.83	5.84	4.61	5.14	5.17	1.67	3.01	4.63
	330deg - JP1	9.82	9.70	9.37	8.68	6.46	7.12	7.68	2.74	4.33	6.48
	330deg - JP2	8.57	8.49	8.15	7.55	5.83	6.32	6.52	2.38	3.84	5.72
	330deg - JP3	6.50	6.47	6.07	5.43	3.54	4.24	4.02	1.65	2.36	3.56
200 year	0deg - JP1	10.19	10.18	10.10	9.81	7.61	8.60	9.38	3.23	5.47	8.28
	0deg - JP2	8.89	8.88	8.84	8.65	7.03	7.75	8.25	2.90	5.08	7.46
	0deg - JP3	5.94	5.97	6.02	6.03	4.83	5.35	5.39	1.74	3.18	4.87
	330deg - JP1	10.14	10.00	9.66	8.92	6.55	7.27	7.88	2.82	4.41	6.61
	330deg - JP2	8.57	8.49	8.15	7.54	5.83	6.32	6.50	2.37	3.83	5.71
	330deg - JP3	6.67	6.63	6.25	5.62	3.78	4.46	4.24	1.70	2.50	3.79
1000 year	0deg - JP1	10.77	10.75	10.65	10.32	7.86	8.97	9.84	3.34	5.61	8.62

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Higher of Sea and Swell Waves		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
	0deg - JP2	9.13	9.13	9.08	8.88	7.18	7.94	8.46	2.96	5.18	7.64
	0deg - JP3	6.94	6.95	6.98	6.94	5.76	6.27	6.45	2.15	4.05	5.93
	330deg - JP1	10.79	10.62	10.23	9.35	6.69	7.52	8.20	2.95	4.52	6.81
	330deg - JP2	9.17	9.07	8.73	8.12	6.21	6.78	7.08	2.54	4.11	6.15
	330deg - JP3	7.11	7.06	6.63	5.96	4.18	4.80	4.62	1.89	2.80	4.17

Table A3. Result for Higher of Sea or Swell Waves – Significant Wave Height (m) for four return period events with climate change (Year 2070), two directional sectors and joint probability combination 1 (highest offshore waves)

Higher of Sea and Swell Waves – JP1		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	0deg - 2120	2.90	2.80	2.54	1.93	0.69	0.97	1.11	0.30	0.53	0.87
	0deg - 2070	2.84	2.75	2.47	1.86	0.68	0.95	1.11	0.31	0.53	0.86
	330deg - 2120	3.00	2.78	1.97	1.27	0.60	0.81	0.82	0.30	0.48	0.73
100 year	0deg - 2120	4.48	4.44	3.73	2.64	1.06	1.50	1.68	0.53	0.86	1.34
	0deg - 2070	4.51	4.43	3.72	2.65	0.96	1.45	1.66	0.54	0.86	1.29
	330deg - 2120	4.27	3.94	2.92	1.93	0.91	1.26	1.30	0.47	0.76	1.13
200 year	0deg - 2120	4.69	4.65	3.88	2.73	1.10	1.56	1.75	0.56	0.91	1.39
	0deg - 2070	4.70	4.62	3.84	2.73	1.00	1.50	1.72	0.56	0.90	1.33
	330deg - 2120	4.49	4.15	3.07	2.03	0.96	1.33	1.38	0.51	0.81	1.19
1000 year	0deg - 2120	5.11	5.06	4.17	2.90	1.19	1.68	1.88	0.63	0.99	1.50
	330deg - 2120	4.89	4.48	3.31	2.19	1.04	1.46	1.51	0.57	0.90	1.31

Table A4. Result for Higher of Sea or Swell Waves – Peak Wave Period (sec) for four return period events with climate change (Year 2070), two directional sectors and joint probability combination 1 (highest offshore waves)

Higher of Sea and Swell Waves – JP1		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	0deg - 2120	7.80	7.81	7.81	7.70	6.27	6.89	7.17	2.48	4.46	6.56
	0deg - 2070	7.79	7.80	7.79	7.67	6.24	6.85	7.22	2.57	4.51	6.56
	330deg - 2120	8.30	8.22	7.87	7.22	5.53	6.04	6.04	2.25	3.60	5.43
100 year	0deg - 2120	10.10	10.10	10.02	9.73	7.63	8.57	9.10	3.16	5.40	8.18
	0deg - 2070	10.09	10.06	9.96	9.65	7.26	8.47	9.07	3.18	5.31	8.01
	330deg - 2120	10.01	9.88	9.49	8.72	6.47	7.18	7.41	2.75	4.30	6.49
200 year	0deg - 2120	10.38	10.37	10.28	9.97	7.76	8.75	9.32	3.23	5.48	8.35
	0deg - 2070	10.36	10.33	10.22	9.88	7.35	8.63	9.27	3.24	5.38	8.15
	330deg - 2120	10.33	10.18	9.78	8.97	6.59	7.36	7.62	2.83	4.40	6.64
1000 year	0deg - 2120	10.97	10.95	10.85	10.49	8.02	9.13	9.76	3.36	5.64	8.70
	330deg - 2120	11.00	10.81	10.36	9.41	6.77	7.64	7.95	2.98	4.55	6.88

Table A5. Result for Higher of Sea or Swell Waves – Significant Wave Height (m) for four return period events, all considered directional sectors and joint probability combination 1 (highest offshore waves) (Present Day climate)

Higher of Sea and Swell Waves - JP1		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	0deg	2.76	2.67	2.41	1.80	0.65	0.90	1.07	0.29	0.51	0.82
	30deg	1.38	1.27	1.19	1.12	0.50	0.66	0.78	0.29	0.43	0.60
	60deg	0.66	0.64	0.62	0.62	0.51	0.55	0.56	0.39	0.48	0.50
	90deg	0.48	0.47	0.46	0.46	0.48	0.48	0.47	0.39	0.43	0.38
	240deg	0.52	0.51	0.47	0.36	0.41	0.42	0.37	0.31	0.35	0.35
	270deg	1.03	0.67	0.53	0.41	0.36	0.41	0.41	0.27	0.34	0.37
	300deg	1.81	1.21	0.83	0.61	0.40	0.52	0.53	0.27	0.38	0.49
	330deg	2.86	2.66	1.89	1.21	0.59	0.78	0.80	0.28	0.47	0.70
100 year	0deg	4.24	4.22	3.53	2.44	0.97	1.36	1.59	0.49	0.80	1.21
	30deg	2.48	2.40	2.22	1.80	0.82	1.06	1.26	0.51	0.73	0.98
	60deg	1.31	1.24	1.21	1.14	0.85	0.94	0.97	0.66	0.80	0.84
	90deg	0.99	0.95	0.94	0.93	0.94	0.94	0.90	0.78	0.84	0.76
	240deg	1.36	1.12	0.97	0.72	0.80	0.83	0.73	0.58	0.66	0.69
	270deg	1.64	1.11	0.88	0.66	0.58	0.67	0.66	0.41	0.53	0.60
	300deg	2.64	1.95	1.39	0.98	0.66	0.85	0.85	0.42	0.61	0.78
	330deg	4.04	3.77	2.78	1.81	0.85	1.16	1.24	0.44	0.71	1.04
200 year	0deg	4.43	4.41	3.66	2.52	1.00	1.41	1.65	0.52	0.84	1.26
	30deg	2.81	2.76	2.51	1.98	0.91	1.18	1.41	0.57	0.81	1.08
	60deg	1.31	1.24	1.21	1.14	0.85	0.94	0.97	0.67	0.80	0.84

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Higher of Sea and Swell Waves - JP1		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
	90deg	1.19	1.14	1.12	1.10	1.08	1.10	1.05	0.90	0.97	0.88
	240deg	1.63	1.32	1.12	0.83	0.92	0.95	0.84	0.66	0.75	0.79
	270deg	1.74	1.18	0.93	0.70	0.62	0.71	0.69	0.43	0.56	0.64
	300deg	2.79	2.09	1.49	1.05	0.70	0.90	0.90	0.44	0.65	0.83
	330deg	4.24	3.94	2.91	1.89	0.89	1.22	1.30	0.47	0.75	1.09
1000 year	0deg	4.82	4.79	3.92	2.67	1.08	1.52	1.77	0.58	0.91	1.35
	30deg	3.56	3.54	3.10	2.33	1.09	1.41	1.68	0.69	0.97	1.28
	60deg	1.31	1.24	1.21	1.14	0.85	0.94	0.97	0.67	0.81	0.85
	90deg	1.60	1.54	1.48	1.42	1.36	1.37	1.32	1.13	1.21	1.08
	240deg	2.11	1.68	1.40	1.01	1.10	1.15	1.02	0.79	0.90	0.95
	270deg	1.96	1.36	1.06	0.79	0.69	0.81	0.78	0.48	0.63	0.72
	300deg	3.10	2.37	1.70	1.18	0.78	1.01	1.01	0.49	0.72	0.93
	330deg	4.58	4.23	3.12	2.02	0.96	1.33	1.42	0.53	0.83	1.19

Table A6. Result for Higher of Sea or Swell Waves – Peak Wave Period (Tp, sec) for four return period events, all considered directional sectors and joint probability combination 1 (highest offshore waves) (Present Day climate)

Higher of Sea and Swell Waves - JP1		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	0deg	7.67	7.67	7.66	7.56	6.26	6.81	7.21	2.60	4.59	6.56
	30deg	5.95	5.92	6.06	6.07	4.27	5.10	5.72	2.52	3.56	5.21
	60deg	3.73	3.62	3.57	3.56	3.12	3.26	3.33	2.71	2.98	3.21
	90deg	2.84	2.78	2.76	2.77	2.81	2.82	2.83	2.71	2.79	2.80
	240deg	3.62	2.94	2.75	2.44	2.51	2.50	2.42	2.12	2.25	2.27
	270deg	6.85	4.75	3.54	3.06	2.58	2.74	2.76	1.97	2.30	2.59
	300deg	7.85	6.94	5.53	4.58	3.46	3.81	3.79	2.01	2.66	3.46
	330deg	8.14	8.07	7.77	7.24	5.70	6.12	6.38	2.29	3.76	5.55
100 year	0deg	9.92	9.91	9.84	9.57	7.49	8.43	9.16	3.17	5.40	8.12
	30deg	8.54	8.70	8.66	8.33	6.41	7.51	8.03	3.49	5.39	7.58
	60deg	5.51	5.46	5.56	5.35	4.14	4.52	5.00	3.53	3.99	4.76
	90deg	4.03	3.94	3.91	3.88	3.88	3.89	3.92	3.66	3.78	3.79
	240deg	6.77	4.83	4.19	3.59	3.55	3.62	3.56	2.83	3.09	3.30
	270deg	8.53	6.14	4.73	3.96	3.41	3.65	3.64	2.41	2.89	3.40
	300deg	9.40	8.48	7.07	5.78	4.45	4.86	4.92	2.47	3.33	4.39
	330deg	9.82	9.70	9.37	8.68	6.46	7.12	7.68	2.74	4.33	6.48
200 year	0deg	10.19	10.18	10.10	9.81	7.61	8.60	9.38	3.23	5.47	8.28
	30deg	9.17	9.33	9.22	8.81	6.88	8.04	8.54	3.70	5.73	8.10
	60deg	5.51	5.45	5.55	5.34	4.13	4.51	4.99	3.53	3.98	4.73

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Higher of Sea and Swell Waves - JP1		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
	90deg	4.47	4.38	4.35	4.27	4.17	4.20	4.32	3.91	4.07	4.14
	240deg	7.52	5.35	4.58	3.88	3.82	3.92	3.86	3.00	3.30	3.56
	270deg	8.76	6.35	4.90	4.08	3.52	3.78	3.77	2.47	2.97	3.51
	300deg	9.68	8.76	7.37	6.01	4.60	5.03	5.12	2.54	3.43	4.54
	330deg	10.14	10.00	9.66	8.92	6.55	7.27	7.88	2.82	4.41	6.61
1000 year	0deg	10.77	10.75	10.65	10.32	7.86	8.97	9.84	3.34	5.61	8.62
	30deg	10.42	10.54	10.32	9.78	7.74	9.02	9.53	4.03	6.32	9.11
	60deg	5.50	5.41	5.50	5.31	4.13	4.48	4.95	3.54	3.95	4.67
	90deg	5.36	5.34	5.32	5.06	4.72	4.84	5.10	4.37	4.63	4.91
	240deg	8.84	6.32	5.28	4.41	4.23	4.40	4.36	3.26	3.62	4.01
	270deg	9.29	6.85	5.29	4.37	3.77	4.05	4.04	2.60	3.15	3.75
	300deg	10.21	9.29	7.86	6.38	4.85	5.32	5.43	2.67	3.61	4.79
	330deg	10.79	10.62	10.23	9.35	6.69	7.52	8.20	2.95	4.52	6.81

Appendix B: Summary Results for Swell Waves

Table B1 and **Table B2** present results for four return period events with Present Day climate for three directional sectors (210degN, 270degN and 330degN) and the three derived joint probability combinations for nearshore significant wave height and wave period respectively.

Table B3 and **Table B4** present results for four return period events with climate change (Year 2070) for two directional sectors (270degN and 330degN) and joint probability combination 1 for the nearshore significant wave height and wave period respectively.

Table B1. Result for Swell Waves – Significant Wave Height (m) for four return period events, three directional sectors and three joint probability combinations (Present Day climate)

Swell Waves - Joint Probability		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	210deg - JP1	0.17	0.11	0.08	0.06	0.04	0.05	0.05	0.01	0.03	0.04
	210deg - JP2	0.10	0.06	0.05	0.04	0.02	0.03	0.03	0.01	0.01	0.02
	210deg - JP3	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.01	0.01
	270deg - JP1	0.88	0.61	0.44	0.31	0.19	0.25	0.25	0.07	0.13	0.20
	270deg - JP2	0.74	0.51	0.37	0.27	0.16	0.21	0.21	0.06	0.12	0.17
	270deg - JP3	0.48	0.27	0.18	0.13	0.08	0.11	0.10	0.03	0.06	0.09
	330deg - JP1	1.10	1.02	0.74	0.49	0.22	0.30	0.32	0.08	0.16	0.26
	330deg - JP2	0.65	0.60	0.44	0.29	0.13	0.18	0.19	0.04	0.09	0.15
	330deg - JP3	0.47	0.43	0.31	0.21	0.09	0.13	0.13	0.03	0.07	0.11

Swell Waves - Joint Probability		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
100 year	210deg - JP1	0.27	0.18	0.14	0.10	0.06	0.08	0.08	0.02	0.05	0.07
	210deg - JP2	0.18	0.11	0.09	0.06	0.04	0.05	0.05	0.01	0.03	0.04
	210deg - JP3	0.09	0.05	0.04	0.03	0.02	0.02	0.02	0.00	0.01	0.02
	270deg - JP1	1.19	0.86	0.63	0.44	0.25	0.34	0.34	0.08	0.18	0.28
	270deg - JP2	1.06	0.76	0.56	0.39	0.22	0.30	0.30	0.08	0.16	0.25
	270deg - JP3	0.61	0.37	0.26	0.18	0.11	0.15	0.14	0.04	0.08	0.12
	330deg - JP1	2.37	2.18	1.66	1.12	0.52	0.73	0.79	0.17	0.38	0.61
	330deg - JP2	1.44	1.32	0.99	0.66	0.30	0.42	0.44	0.10	0.22	0.35
	330deg - JP3	1.05	0.96	0.69	0.45	0.20	0.28	0.29	0.07	0.14	0.24
200 year	210deg - JP1	0.27	0.18	0.14	0.11	0.06	0.08	0.09	0.02	0.05	0.07
	210deg - JP2	0.24	0.16	0.12	0.09	0.05	0.07	0.07	0.02	0.04	0.06
	210deg - JP3	0.09	0.05	0.04	0.03	0.02	0.02	0.02	0.00	0.01	0.02
	270deg - JP1	1.21	0.88	0.64	0.45	0.26	0.34	0.35	0.09	0.18	0.28
	270deg - JP2	1.11	0.80	0.58	0.41	0.23	0.31	0.32	0.08	0.17	0.26
	270deg - JP3	0.63	0.38	0.26	0.19	0.12	0.15	0.15	0.04	0.08	0.13
	330deg - JP1	2.58	2.36	1.80	1.21	0.56	0.79	0.85	0.18	0.41	0.65
	330deg - JP2	1.44	1.33	0.99	0.66	0.30	0.42	0.44	0.10	0.22	0.35
	330deg - JP3	1.10	1.01	0.73	0.48	0.21	0.29	0.31	0.07	0.15	0.25
1000 year	210deg - JP1	0.28	0.19	0.15	0.11	0.07	0.09	0.09	0.02	0.05	0.07

Swell Waves - Joint Probability	Significant Wave Height (Hs, m)									
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
210deg - JP2	0.24	0.16	0.12	0.09	0.05	0.07	0.07	0.02	0.04	0.06
210deg - JP3	0.10	0.06	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.02
270deg - JP1	1.25	0.91	0.66	0.46	0.26	0.35	0.36	0.09	0.19	0.29
270deg - JP2	1.13	0.81	0.59	0.41	0.23	0.32	0.32	0.08	0.17	0.26
270deg - JP3	0.77	0.51	0.37	0.26	0.15	0.20	0.20	0.05	0.11	0.17
330deg - JP1	3.05	2.79	2.11	1.42	0.64	0.92	0.98	0.20	0.46	0.76
330deg - JP2	1.83	1.68	1.27	0.86	0.39	0.55	0.58	0.13	0.28	0.46
330deg - JP3	1.32	1.21	0.87	0.57	0.25	0.35	0.36	0.08	0.18	0.29

Table B2. Result for Swell Waves – Peak Wave Period (Tp, sec) for four return period events, three directional sectors and three joint probability combinations (Present Day climate)

Swell Waves - Joint Probability		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	210deg - JP1	11.51	11.45	11.39	11.33	11.33	11.36	11.29	11.18	11.26	11.31
	210deg - JP2	10.28	10.24	10.20	10.16	10.18	10.19	10.15	-	10.13	10.17
	210deg - JP3	9.02	9.00	8.98	8.97	-	8.98	8.96	-	-	-
	270deg - JP1	11.51	11.44	11.34	11.23	11.23	11.28	11.17	10.90	11.11	11.21
	270deg - JP2	11.53	11.47	11.37	11.27	11.26	11.32	11.22	10.95	11.15	11.25
	270deg - JP3	9.05	9.02	8.97	8.91	8.90	8.94	8.88	8.68	8.83	8.90
	330deg - JP1	9.04	9.03	8.99	8.93	8.89	8.91	8.87	8.68	8.81	8.86
	330deg - JP2	9.06	9.05	9.02	8.98	8.94	8.96	8.93	8.79	8.89	8.92
	330deg - JP3	9.07	9.06	9.03	8.99	8.96	8.98	8.95	8.84	8.92	8.95
100 year	210deg - JP1	12.72	12.64	12.55	12.47	12.50	12.53	12.44	12.27	12.40	12.47
	210deg - JP2	11.52	11.47	11.41	11.35	11.37	11.39	11.33	11.23	11.31	11.35
	210deg - JP3	10.29	10.27	10.24	10.21	10.24	10.24	10.21	-	10.21	10.22
	270deg - JP1	12.71	12.62	12.50	12.38	12.42	12.46	12.32	12.09	12.29	12.37
	270deg - JP2	12.74	12.66	12.55	12.43	12.46	12.50	12.38	12.12	12.33	12.42
	270deg - JP3	10.31	10.27	10.21	10.15	10.15	10.18	10.11	9.90	10.06	10.13
	330deg - JP1	12.66	12.61	12.51	12.39	12.39	12.41	12.29	12.10	12.26	12.31
	330deg - JP2	10.29	10.27	10.21	10.14	10.11	10.14	10.08	9.88	10.03	10.08

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Swell Waves - Joint Probability		Peak Wave Period (Tp, sec)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
	330deg - JP3	9.05	9.04	9.01	8.96	8.93	8.95	8.91	8.76	8.87	8.91
200 year	210deg - JP1	12.71	12.63	12.55	12.47	12.49	12.53	12.43	12.27	12.40	12.47
	210deg - JP2	12.75	12.68	12.61	12.54	12.57	12.59	12.51	12.37	12.48	12.54
	210deg - JP3	10.29	10.27	10.24	10.21	10.24	10.24	10.21	-	10.21	10.22
	270deg - JP1	12.70	12.62	12.50	12.38	12.42	12.46	12.32	12.09	12.29	12.37
	270deg - JP2	12.73	12.65	12.54	12.42	12.45	12.49	12.37	12.12	12.32	12.41
	270deg - JP3	10.31	10.27	10.21	10.15	10.15	10.18	10.11	9.91	10.07	10.14
	330deg - JP1	12.65	12.59	12.48	12.36	12.37	12.38	12.27	12.09	12.24	12.28
	330deg - JP2	10.29	10.27	10.22	10.15	10.12	10.14	10.08	9.89	10.03	10.08
	330deg - JP3	9.05	9.04	9.01	8.96	8.93	8.95	8.91	8.75	8.87	8.91
1000 year	210deg - JP1	12.71	12.63	12.54	12.46	12.49	12.52	12.42	12.26	12.39	12.46
	210deg - JP2	12.75	12.69	12.61	12.55	12.58	12.60	12.52	12.39	12.50	12.55
	210deg - JP3	10.29	10.27	10.23	10.20	10.24	10.23	10.20	-	10.20	10.22
	270deg - JP1	12.70	12.61	12.50	12.38	12.43	12.46	12.32	12.10	12.29	12.37
	270deg - JP2	12.73	12.65	12.54	12.43	12.46	12.50	12.38	12.13	12.33	12.42
	270deg - JP3	11.55	11.50	11.42	11.34	11.35	11.39	11.30	11.07	11.25	11.33
	330deg - JP1	12.61	12.55	12.44	12.31	12.35	12.34	12.22	12.08	12.20	12.23
	330deg - JP2	11.51	11.47	11.40	11.31	11.29	11.32	11.24	11.03	11.19	11.24
	330deg - JP3	9.05	9.03	9.00	8.95	8.93	8.94	8.90	8.74	8.86	8.90

Table B3. Result for Swell Waves – Significant Wave Height (m) for four return period events with climate change (Year 2070), two directional sectors and joint probability combination 1 (highest offshore waves)

Swell Waves – JP1 - Climate Change		Significant Wave Height (Hs, m)									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	270deg - 2120	1.04	0.74	0.53	0.37	0.21	0.29	0.29	0.07	0.15	0.24
	330deg - 2070	1.22	1.13	0.82	0.54	0.24	0.33	0.35	0.08	0.17	0.28
	330deg - 2120	1.24	1.14	0.82	0.53	0.23	0.32	0.33	0.07	0.16	0.27
100 year	270deg - 2120	1.28	0.90	0.64	0.45	0.25	0.35	0.34	0.08	0.18	0.29
	330deg - 2070	2.60	2.39	1.82	1.23	0.56	0.80	0.84	0.18	0.40	0.66
	330deg - 2120	2.64	2.41	1.82	1.24	0.55	0.80	0.83	0.17	0.40	0.66
200 year	270deg - 2120	1.30	0.91	0.65	0.46	0.26	0.35	0.34	0.08	0.18	0.29
	330deg - 2070	2.83	2.59	1.97	1.33	0.60	0.86	0.91	0.19	0.43	0.71
	330deg - 2120	2.87	2.61	1.97	1.34	0.60	0.86	0.90	0.18	0.43	0.71
1000 year	270deg - 2120	1.35	0.94	0.67	0.47	0.26	0.36	0.35	0.08	0.18	0.30
	330deg - 2120	3.41	3.10	2.32	1.57	0.69	1.00	1.04	0.20	0.49	0.83

Table B4. Result for Swell Waves – Peak Wave Period (Tp, sec) for four return period events with climate change (Year 2070), two directional sectors and joint probability combination 1 (highest offshore waves)

Swell Waves – JP1 - Climate Change		**Peak Wave Period (Tp, sec)**									
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
1 year	270deg - 2120	12.76	12.69	12.59	12.49	12.51	12.55	12.44	12.19	12.39	12.48
	330deg - 2070	9.04	9.03	8.99	8.94	8.90	8.93	8.88	8.71	8.83	8.88
	330deg - 2120	9.05	9.04	9.01	8.96	8.94	8.96	8.92	8.77	8.88	8.92
100 year	270deg - 2120	12.73	12.66	12.55	12.45	12.51	12.53	12.41	12.19	12.38	12.45
	330deg - 2070	12.66	12.60	12.51	12.39	12.41	12.42	12.31	12.13	12.28	12.32
	330deg - 2120	12.69	12.64	12.54	12.44	12.46	12.47	12.37	12.18	12.33	12.38
200 year	270deg - 2120	12.73	12.65	12.55	12.45	12.50	12.53	12.41	12.19	12.38	12.45
	330deg - 2070	12.64	12.58	12.48	12.36	12.39	12.39	12.28	12.12	12.26	12.29
	330deg - 2120	12.67	12.62	12.52	12.41	12.44	12.44	12.34	12.17	12.31	12.35
1000 year	270deg - 2120	12.72	12.65	12.55	12.44	12.51	12.52	12.41	12.20	12.38	12.45
	330deg - 2120	12.63	12.57	12.47	12.36	12.41	12.40	12.29	12.16	12.28	12.31