TECHNICAL APPENDIX 4.2

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Significant Wave Height Desktop Study

Technical Report - Hatston Pier

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Significant Wave Height Desktop Study

Technical Report - Hatston Pier

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Rev 0	23/09/2022	Original release	LCO	KRM	RPD
Rev 1	25/11/2022	Additional wind data QC and model runs	LCO	KRM	RPD

SUMMARY

INTRODUCTION

Intertek Energy and Water Consultancy Services (Intertek) has been commissioned by Orkney Islands Council (OIC) Harbour Authority to provide a specialist wave consultancy service in relation to the potential developments at Scapa Deep Water Quay (SDWQ), Scapa Flow, and Hatston (Orkney Logistics Base), Kirkwall as these projects move towards Environmental Impact Assessment (EIA), detailed design and construction. As part of this work, Intertek has conducted a desktop study to determine significant wave heights (Hs) and peak wave periods (Tp) at these locations.

This report details the desktop study that Intertek carried out for the potential Orkney Logistics Base development, specifically investigating incident Hs/Tp at the development site for a selection of extreme wind scenarios, and potential changes to the wave regime resulting from the proposed development. A similar study for Scapa (Scapa Deep Water Quay harbour development) is presented in a separate report (Intertek, 2022).

PURPOSE OF STUDY

The aim of the assessment is to generate wave criteria to support the development phase of the project. As such the modelling aims to generate extreme wave conditions at pertinent locations for the Orkney Logistics Base development.

The modelling approach employed in this study – a Spectral Wave (SW) Model – generates estimates of wave conditions (such as Hs) as they approach the development site. It includes all pertinent processes that influence waves as they are generated by wind forcing and propagate across Wide Firth to the site – processes such as wind-wave generation, directional and frequency spreading, refraction, shoaling, bottom dissipation and wave breaking. The model also captures some effects of the development on these waves, such as energy losses as the waves propagate past piers. However, this model does not fully simulate interactions between the incident waves and the development itself – for example, wave diffraction around structures and run-up.

DEVELOPMENT OVERVIEW

The primary area of interest for this study is Bay of Kirkwall, north of the town of Kirkwall, and at the southern end of Wide Firth. At the time of writing, there is an existing quay at Hatston, comprising a rubble breakwater, and suspended deck structure installed over piles.

The proposed development at Hatston will be staggered in three phases but for this study, the SW model has been run to determine the wave field within the area of interest for two different development scenarios:

- Baseline – Present day piled structure with wave screen.
- Proposed Development (option 1) – Phase 1, Phase 2 and Phase 3 – New reclaimed quay structures and pier extension.

MODELLING APPROACH

A MIKE 21 SW model has been developed for Bay of Kirkwall, Wide Firth and surrounding waters. A linear interpolation technique was adopted to generate the Hatston SW model bathymetry. The model utilises an unstructured mesh of irregular triangular elements, allowing the model resolution to vary throughout the domain. This approach provides the greatest flexibility for addressing environmental conditions throughout the study area. The mesh resolution was optimised during the model development process so as to provide sufficient resolution in the area of the proposed Hatston development while avoiding onerous computational run times.

It is noted that the area of interest is fetch-limited (<50 km fetch in the longest directions) and so wind-wave growth is the primary driver. For this reason, the fully spectral, quasi-stationary formulation was deemed appropriate. The wind speeds were applied as constants in domain and time, and the uncoupled wind generation formulation was used.

In the absence of measured wave data within the model domain, the model was run mostly with default values as input parameters. However, some of these defaults were modified to use parameter values that Intertek has previously derived for calibrated SW models in similar (enclosed) offshore environments. The parameters of relevance were the bottom friction parameter (set to kn=0.02 m) and the white capping dissipation coefficients (set to cdis=4.5 and delta=0.5).

During development of the SW model, it was identified that there was a small possibility that the Hatston site could be impacted by waves from further afield propagating through the Orkney Islands and refracting round to impact Hatston. Sensitivity tests were therefore run for extreme waves propagating into the model domain from the east and from the north, in order to test the importance of such environmental conditions.

STUDY SUMMARY AND CONCLUSIONS

The potential wave conditions at Hatston before and after the proposed Orkney Logistics Base development have been predicted for a number of scenarios using a spectral wave model. The model results show that the predicted maximum Hs for both the pre- and post-development scenarios is approximately 2.0 m for the 1-in-50 year wind condition from a northerly direction. The maximum Tp is also predicted for the 1-in-50 year wind condition from a northerly direction. This is to be expected as it is the direction with the second longest fetch and with a strong extreme wind speed, allowing the waves to build up to the area of interest. The results presented represent a fully developed sea for a constant wind direction, and therefore include a degree of conservatism (as wind speed and direction will vary temporally and spatially on a local scale).

The tables and plots of predicted Hs for the post-development scenario show that there are areas around the development that are subject to wave energy losses through sheltering and/or interaction with piles. However, larger wave heights are predicted for locations along the northeast of the development. This section of the development is relatively more exposed and rarely subject to wave sheltering, and waves can therefore approach unobstructed. It also experiences the deepest water, so waves are less likely to be limited by shoaling or breaking.

Sensitivity tests have demonstrated that storm/swell waves propagating into the Orkney Islands from either the North Sea or North Atlantic do not reach Hatston with sufficient height or energy to be of any significant concern to the present study.

In the absence of suitable measured data the SW model predictions have been verified by comparison against estimates of wave height using several empirically-derived wave growth formulations. These comparisons confirm that the model is producing realistic predictions of wave conditions with perhaps a slight tendency towards conservatism.

RECOMMENDATIONS

The wave conditions presented in this report are considered suitable for purposes of planning and feasibility. We recommend, however, that they not be used for detailed engineering design without additional analysis and investigation.

CONTENTS

LIST OF TABLES AND FIGURES

Tables

Figures

GLOSSARY

DHI
Danish Hydraulic Institute

EIA
Environmental Impact Assessment

EVA
Extreme Value Analysis

Hs
Significant Wave Height

HSE
Health and Safety Executive

Intertek
Intertek Energy and Water Consultancy Services

JONSWAP
Joint North Sea Wave Project

MHWS
Mean High Water Springs

MSL
Mean Sea Level

OIC
Orkney Islands Council

OS
Ordnance Survey

SMB
Sverdrup-Munk-Bretschneider

SW
Spectral Wave

Tp
Peak Wave Period

UKHO
United Kingdom Hydrographic Office

1. INTRODUCTION

1.1 Overview

Intertek Energy and Water Consultancy Services (Intertek) has been commissioned by Orkney Islands Council (OIC) Harbour Authority to provide a specialist wave consultancy service in relation to the potential developments at Scapa Deep Water Quay, Scapa Flow, and Hatston (Orkney Logistics Base), Kirkwall as these projects move towards Environmental Impact Assessment (EIA), detailed design and construction. As part of this work, Intertek has conducted a desktop study to determine significant wave heights (Hs) and peak wave periods (Tp) at these locations.

This report details the desktop study that Intertek carried out for the potential Orkney Logistics Base development, specifically investigating incident Hs/Tp at the development site for a selection of extreme wind scenarios, and potential changes to the wave regime resulting from the proposed development. A similar study for Scapa (Scapa Deep Water Quay harbour development) is presented in a separate report (Intertek, 2022).

1.2 Background and Approach

OIC is looking to improve and expand Orkney's existing harbours and marine assets, to meet the needs of changing markets and position Orkney as a world leading maritime hub. Under the Orkney Harbours Masterplan (OICHA, 2022), the Orkney Logistics Base development has been proposed, which includes a new pier and quayside infrastructure, ship lift, fuel facility and land for harbour operations. The primary area of interest for this study is Bay of Kirkwall, north of the town of Kirkwall, and at the southern end of Wide Firth (see Figure 1-1 (Drawing number: P2570-LOC-003-A)). At the time of writing, there is an existing quay at Hatston, comprising a rubble breakwater, and suspended deck structure installed over piles.

Wide Firth is a largely enclosed body of water, within the Orkney Islands group, with a harbour area of 55 km^2. As it is enclosed it is for the most part not exposed to oceanic wave conditions (swell waves) from the North Atlantic or North Sea, and the predominant wave climate within this water body is fetch-limited wind-generated waves. To provide safe berthing and navigation around the pier it is important that the wave climate under extreme wind conditions is evaluated. The potential Hs at output locations around the proposed pier from wind-generated waves has been investigated through a numerical wave modelling study.

SIGNIFICANT WAVE HEIGHT DESK TOP STUDY - HATSTON

LOCATION OVERVIEW

Geographical Overview

Drawing No: P2570-LOC-003	A

Legend

★ Hatston Development

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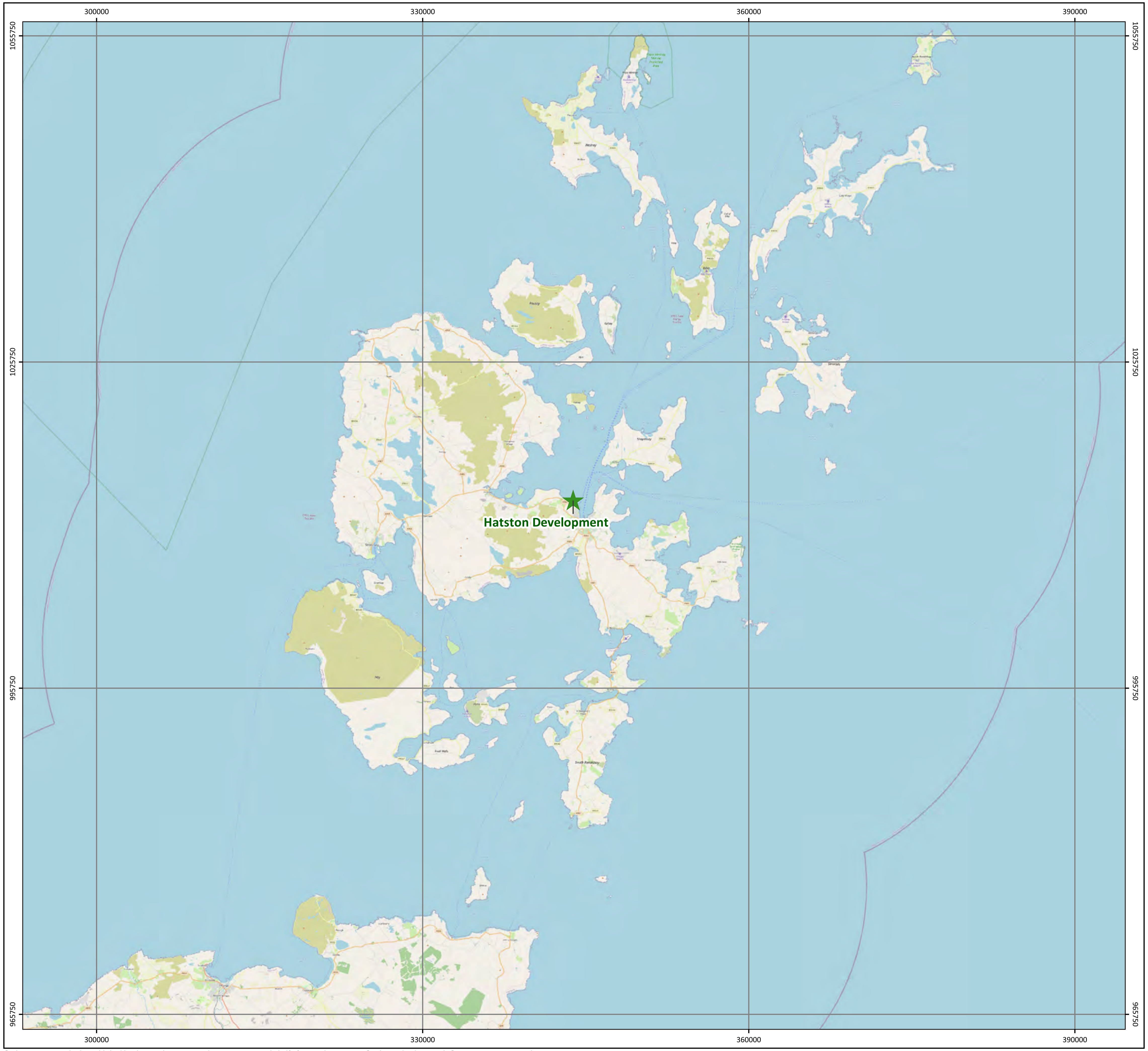

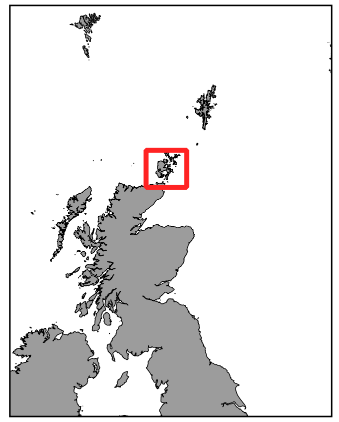

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Created By	Lewis Castle
Reviewed By	Emma Langley
Approved By	Emma Langley

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1.3 Purpose of Study

The aim of the assessment is to generate wave criteria to support the development phase of the project. As such the modelling aims to generate extreme wave conditions at pertinent locations for the Orkney Logistics Base development.

The modelling approach employed in this study – a Spectral Wave (SW) Model – generates estimates of wave conditions (such as Hs) as they approach the development site. It includes all pertinent processes that influence waves as they are generated by wind forcing and propagate across Wide Firth to the site – processes such as wind-wave generation, directional and frequency spreading, refraction, shoaling, bottom dissipation and wave breaking. The model also captures some effects of the development on these waves, such as energy losses as the waves propagate past piers. However, this model does not fully simulate interactions between the incident waves and the development itself – for example, wave diffraction around structures, wave reflection off hard surfaces (other than in a simplified fashion), and run-up. To capture such processes within the development area itself, a different model – the Boussinesq Wave Model – would be required. As such, the results of this study are considered suitable for use in project planning and feasibility studies, but are not directly suitable for detailed engineering design (e.g. to derive the forces exerted on structures).

1.4 Development Overview

The Hatston Orkney Logistics Base has been proposed as described in Section 1.2 and depicted in Figure 1-2 (Drawing number: P2570-LOC-004-A). The development will be staggered in three phases but for this study, the SW model has been run to determine the wave field within the area of interest for two different development scenarios:

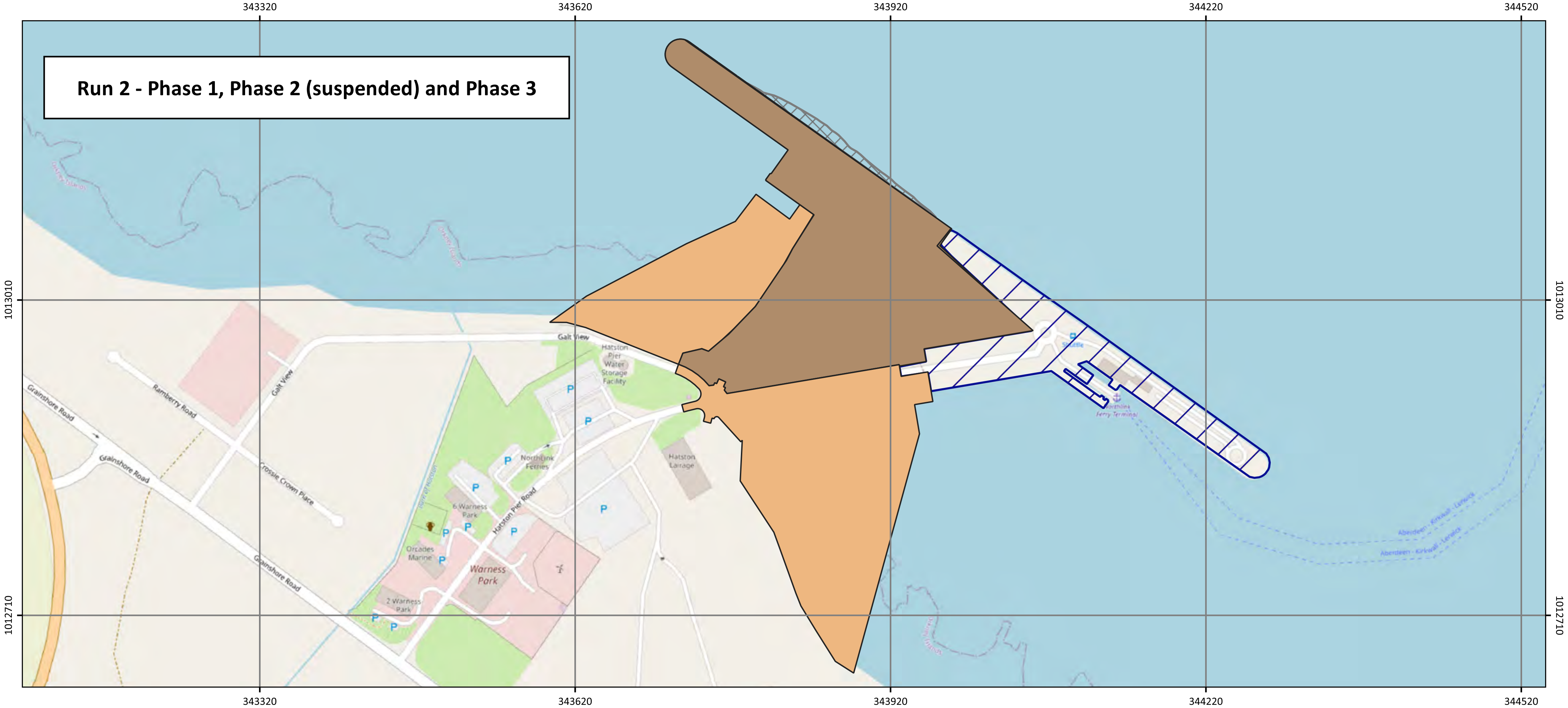
- Baseline – Present day piled structure with wave screen.
- Proposed Development (option 1) – Phase 1, Phase 2 and Phase 3 – New reclaimed quay structures and pier extension.

SIGNIFICANT WAVE HEIGHT DESK TOP STUDY - HATSTON

LOCATION OVERVIEW

Model Runs

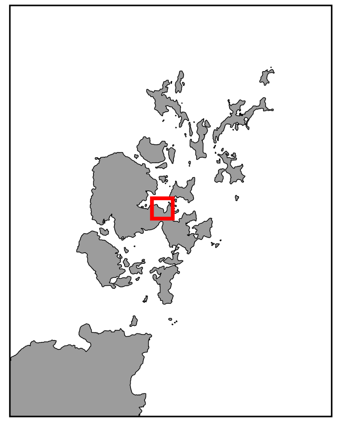
Drawing No: P2570-LOC-004	B



Legend

- Reclaimed Land
- Proposed Pier Extension
- Dredging Area
- Existing Pier (Suspended)

N



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Created By	Lewis Castle
Reviewed By	Emma Langley
Approved By	Emma Langley

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0 60 120 180 240 m

2. DATA

2.1 Coordinate System

The following horizontal and vertical coordinate system has been adopted throughout the desktop study:

- ***Horizontal Datum***: British National Grid (OSGB36/EPSG:27700).
- ***Vertical Datum***: Water depth is given as metres below Mean Sea Level (MSL) and as a negative value.

All data provided for Hatston Orkney Logistics Base and the SW model were converted to MSL at Kirkwall using tidal levels given in Admiralty Tide Tables (UKHO, 2016) (Table 2-1).

Table 2-1 Tidal levels and datums for Kirkwall

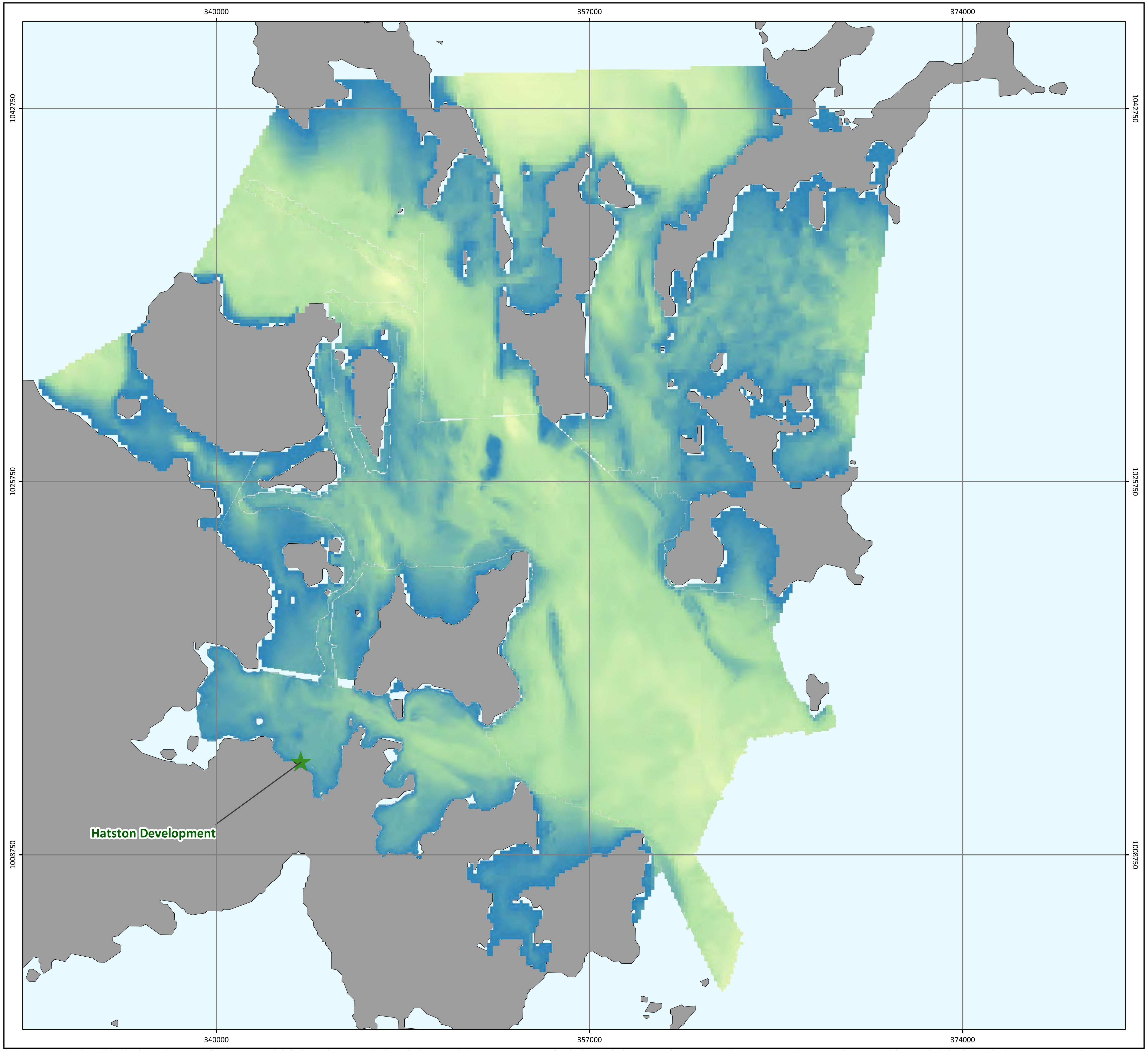
Name	Abbrev.	mMSL Kirkwall
Highest Astronomical Tide	HAT	1.7
Mean High Water Springs	MHWS	1.2
Mean High Water Neaps	MHWN	0.6
Mean Sea Level	MSL	0
Ordnance Datum Newlyn	ODN	-0.4
Mean Low Water Neaps	MLWN	-0.5
Mean Low Water Springs	MLWS	-1.2
Chart Datum	CD	-1.8
Lowest Astronomical Tide	LAT	-1.9

2.2 Bathymetry

Bathymetric data are required for the SW model. These data are used to create a representation of the topography of the sea floor. The data have been taken from a number of publicly available sources as detailed below. The primary datasets used to define the SW model for bathymetry were the UK Hydrographic Office (UKHO) bathymetry data set covering Bay of Kirkwall and the wider Orkney Islands, and bathymetry data provided by OIC local to the Hatston development site. Together these datasets provide a high level of detail at a consistent scale across the majority of the study area. This information was also supplemented by EMODnet bathymetry to enable 100% coverage of the SW model domain (EMODnet Bathymetry Consortium, 2018). The land boundary of the model was taken from the Ordnance Survey (OS) Mean High Water Springs (MHWS) polyline. The coverage and resolution of the available data is considered suitable for the purpose of building the Hatston SW model.

For the post-installation scenario, the SW model bathymetry was modified to include areas of proposed dredging and land reclamation as provided by OIC (see Figure 1-2).

All data sets were reduced to a common vertical datum of MSL, using data published by the UKHO (see Table 2-1). The coverage of the bathymetric data used for the SW model construction is shown in Figure 2-1 (Drawing number: P2570-BATH-002-A), together with the extents of the SW model domain.



SIGNIFICANT WAVE HEIGHT DESK TOP STUDY - HATSTON

BATHYMETRY

Model Bathymetry

Drawing No: P2570-BATH-002 | A

Legend

★ Hatston Development

Bathymetry (LAT)

0 m

-120 m

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Created By	Lewis Castle
Reviewed By	Emma Langley
Approved By	Liz Comer

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0 2 4 6 8 km

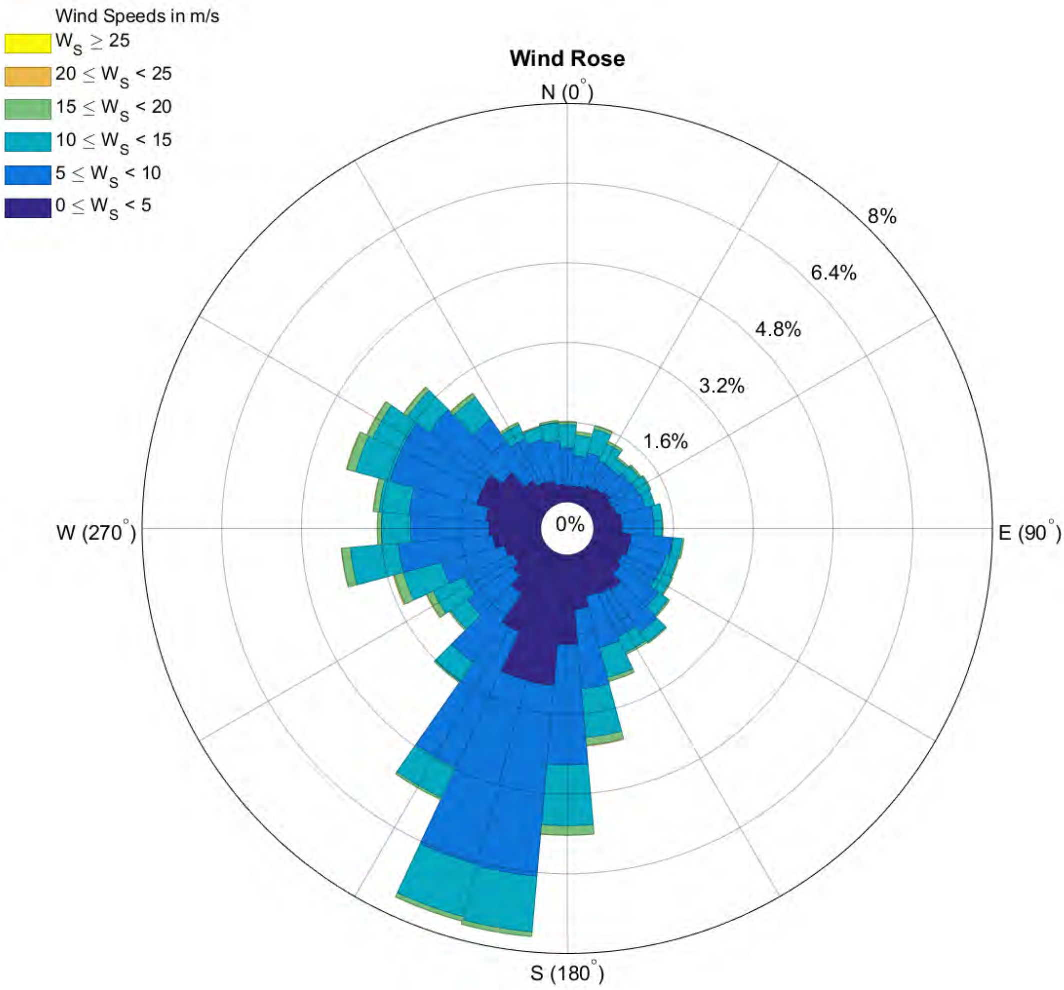
2.3 Wind

Wind data were required for the study since extreme wave conditions at the Hatston development site will be generated by wind fields blowing locally within Bay of Kirkwall and Wide Firth (rather than by waves propagating in from the North Atlantic or North Sea). As such, the SW model required estimates of extreme wind speeds that would be used to drive wave growth and propagation.

OIC provided ten years of wind speed data measured in 15-minute intervals at the Hatston site itself. These data were cleaned, removing outliers/spikes from the timeseries. The raw data set as provided was of poor quality with numerous high-speed spikes and associated anomalies. These were removed initially using automated procedures, with the remaining peak wind speeds checked by careful comparison with meteorological records for the days in question, in particular through use of wind and pressure readings recorded at the UK Met Office station at Kirkwall airport.

Figure 2-2 shows a wind rose of the cleaned ten-year dataset at Hatston. The data show a dominance in winds from a southerly to south-south-westerly direction with wind speeds up to 27.5 m/s. The proposed development at Hatston is on the north side of Orkney Mainland, providing some shelter from the prevailing wind.

Figure 2-2 Hatston wind rose



3. MODELLING APPROACH

3.1 Modelling Software

The modelling was conducted using the Danish Hydraulic Institute's (DHI) MIKE 21 suite of software. MIKE 21 is an industry standard software suite routinely used around the world for conducting studies in marine, estuarine and fluvial environments. Specifically, the MIKE 21 Spectral Wave (SW) model was used in this study.

MIKE 21 SW can simulate the growth, decay and transformation of wind-generated waves in coastal and offshore areas. Therefore, to assess the potential wave climate at the Hatston development site, extreme wind conditions were applied uniformly over the model domain for pertinent wind directions and return periods (see Section 4).

The SW model accounts for the following physical processes:

- refraction;
- shoaling;
- bottom dissipation;
- wave breaking;
- wind-wave generation;
- directional spreading;
- frequency spreading;
- wave-current interaction;
- simplified reflection and transmission coefficients at structures.

The SW model is suitable for defining wave conditions across a wide area such as Wide Firth, including in the shallower coastal waters as waves approach and enter the Hatston development site. However, the model is not capable of accounting for some wave processes relating to detailed interaction with objects or structures – processes such as wave diffraction, reflection (using a more detailed approach than the simplified approach adopted by the SW model), and run-up. These processes may be important for assessing wave conditions at a high spatial resolution within the area of the Hatston development. If this level of detail is required, it could be achieved through a follow-on study employing the Boussinesq Wave Model, which would couple with the SW model and allow all desired processes to be simulated.

3.2 Modelling Inputs and Assumptions

A linear interpolation technique was adopted to generate the Hatston SW model bathymetry. Figure 3-1 shows the interpolated bathymetry over the entire model domain whilst Figure 3-2 provides details of the model bathymetry in the vicinity of the study area.

The SW module includes two different formulations for simulating wave growth, propagation and transformation. It is noted that the area of interest is fetch-limited (<50 km fetch in the longest directions) and so wind-wave growth is the primary driver. For this reason, the fully spectral, quasi-stationary formulation was deemed appropriate. The wind speeds were applied as constants in domain and time, and the uncoupled wind generation formulation was used.

In the absence of measured wave data within the model domain, the model was run mostly with default values as input parameters. However, some of these defaults were modified to use parameter values that Intertek has previously derived for calibrated SW models in similar (enclosed) offshore environments. The parameters of relevance were the bottom friction parameter (set to kn=0.02 m) and the white capping dissipation coefficients (set to cdis=4.5 and delta=0.5).

During development of the SW model, it was identified that there was a small possibility that the Hatston site could be impacted by waves from further afield propagating through the Orkney Islands and refracting round to impact Hatston. One potential pathway identified was the possibility that storm waves from the North Sea could pass through Shapinsay Sound and The String before refracting into the Bay of Kirkwall. Pathways for waves approaching the islands from the north are even more tenuous. The possibility of such waves impacting the development site with any significant energy was considered remote due to the need for such waves to refract round the main islands and bypass smaller islets and areas of shallow water, all of which would cause significant energy losses from the wave field. Nevertheless, sensitivity tests were run for extreme waves propagating into the model domain from the east and from the north, in order to test the importance of such environmental conditions. The results of these tests are reported in Section 5.3.

Figure 3-1 Bathymetry in SW model domain – whole domain

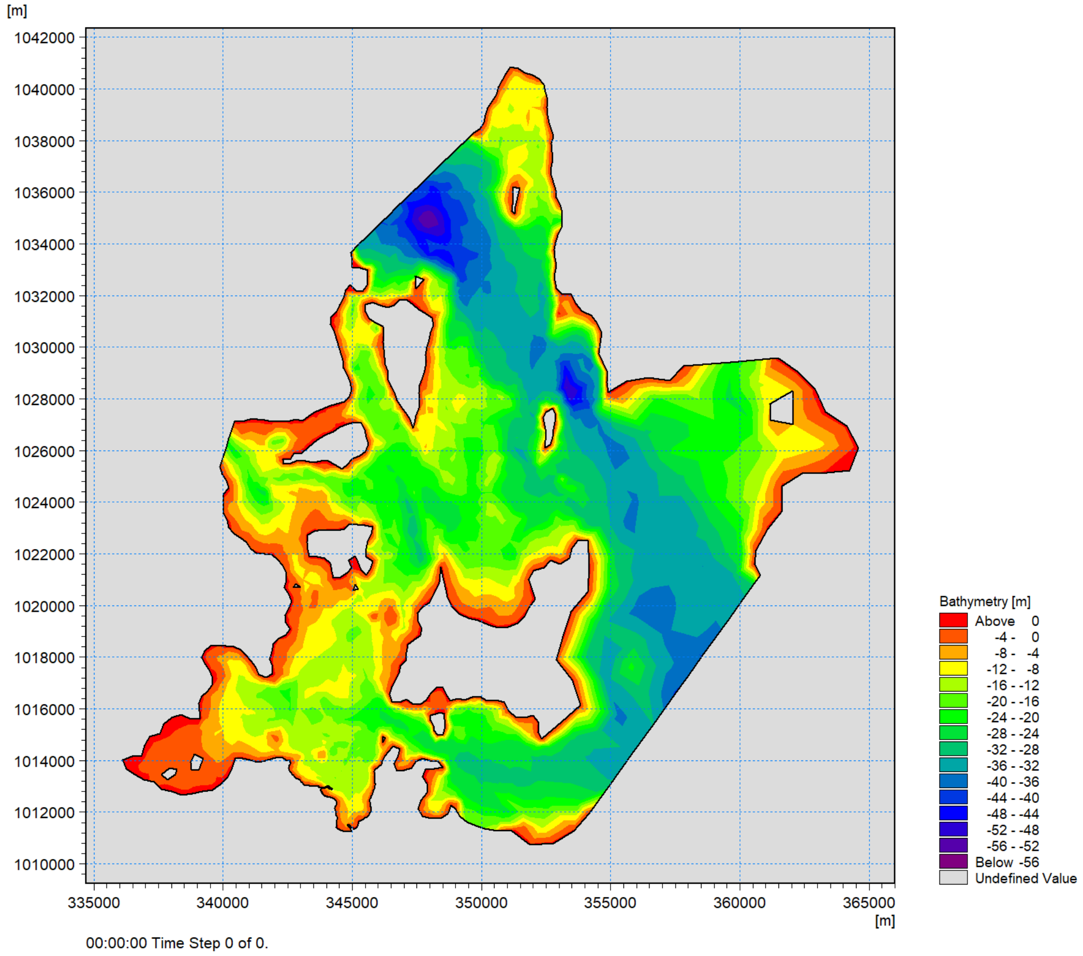
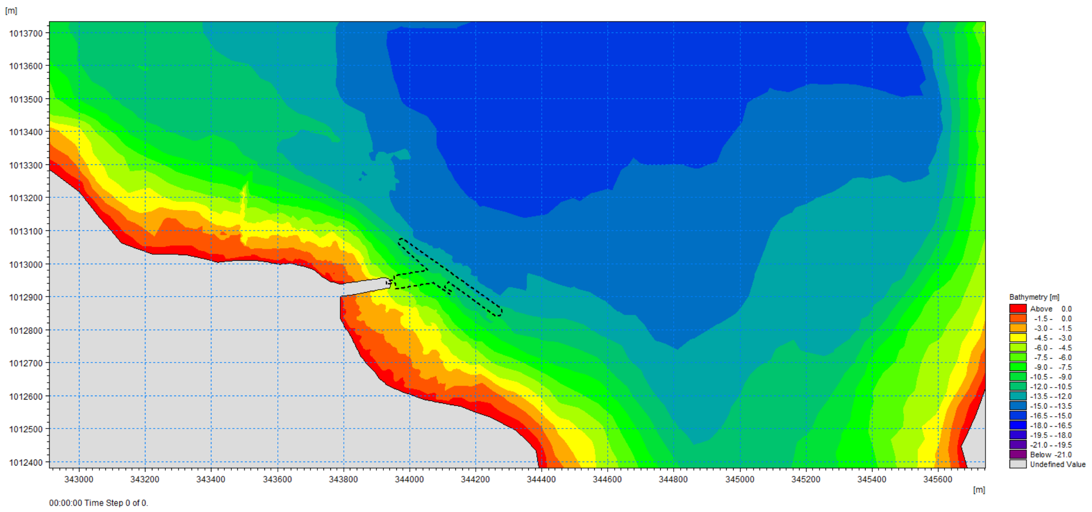


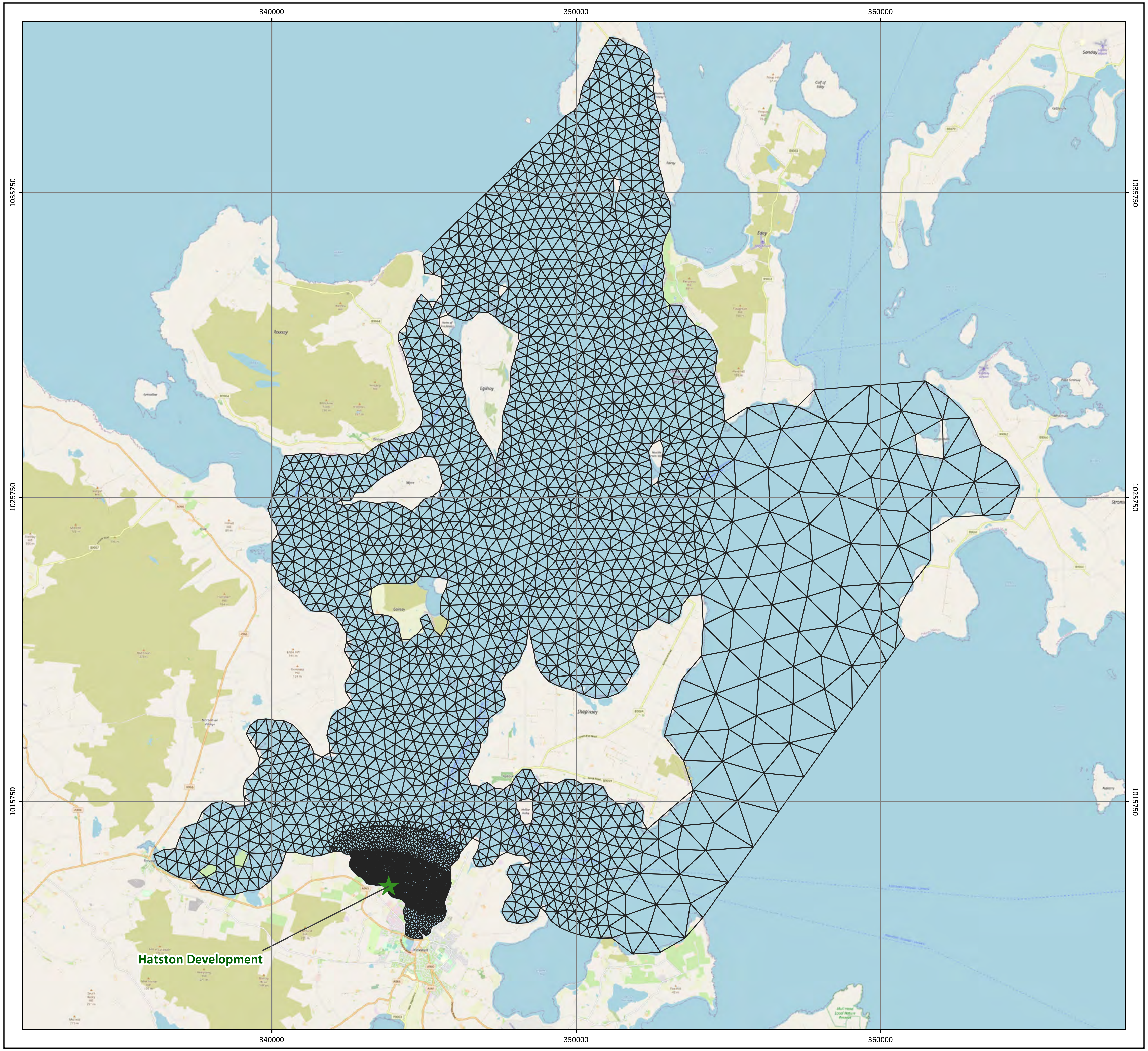
Figure 3-2 Bathymetry in SW model domain – area of interest



3.3 Model Configuration

MIKE 21 SW utilises an unstructured mesh of irregular triangular elements, allowing the model resolution to vary throughout the domain. This approach provides the greatest flexibility for addressing environmental conditions throughout the study area. The mesh resolution was optimised during the model development process so as to provide sufficient resolution in the area of the proposed Hatston development while avoiding onerous computational run times.

The final model resolution is considered appropriate and robust for undertaking the required study. The resolution near the offshore boundaries is coarser than the area of interest since high resolution is not required here and this approach reduces model run times and potential instabilities. The final Hatston SW model contains approximately 17,000 elements. The spatial resolution within and around the proposed development site is approximately 10 m. Figure 3-3 (Drawing number: P2570-LOC-005-A) shows the model mesh over the entire domain. Figure 3-4 (Drawing number: P2570-LOC-006-A) shows the model mesh near to the study area for both the pre- and post-development scenarios.



SIGNIFICANT WAVE HEIGHT DESK TOP STUDY - HATSTON

LOCATION OVERVIEW

Model Mesh

Drawing No: P2570-LOC-005	A

Legend

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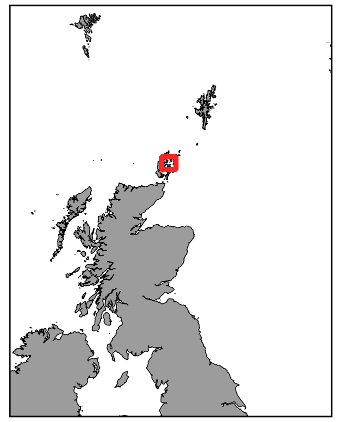
- Hatston Development
- Model Mesh



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Reviewed By	Emma Kilbane
Approved By	Emma Langley

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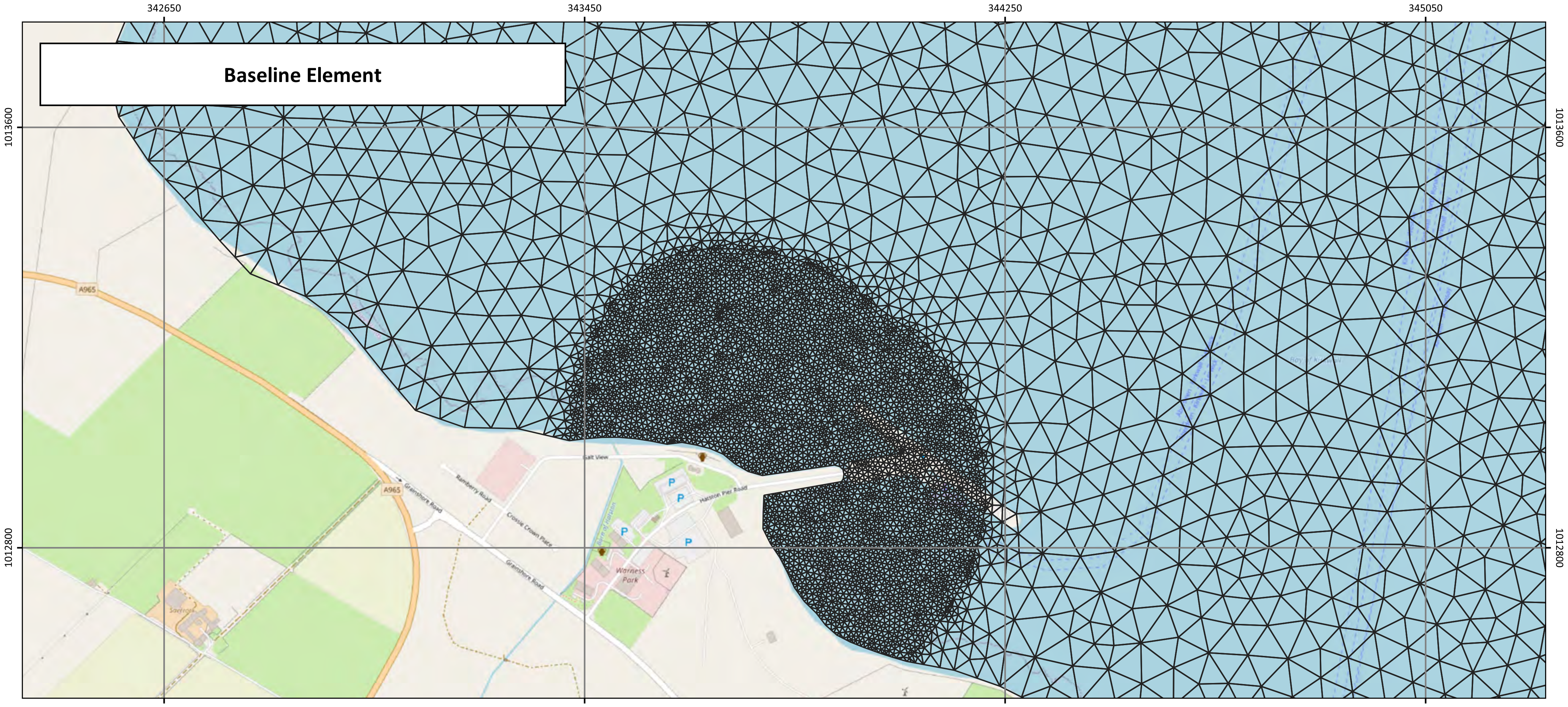

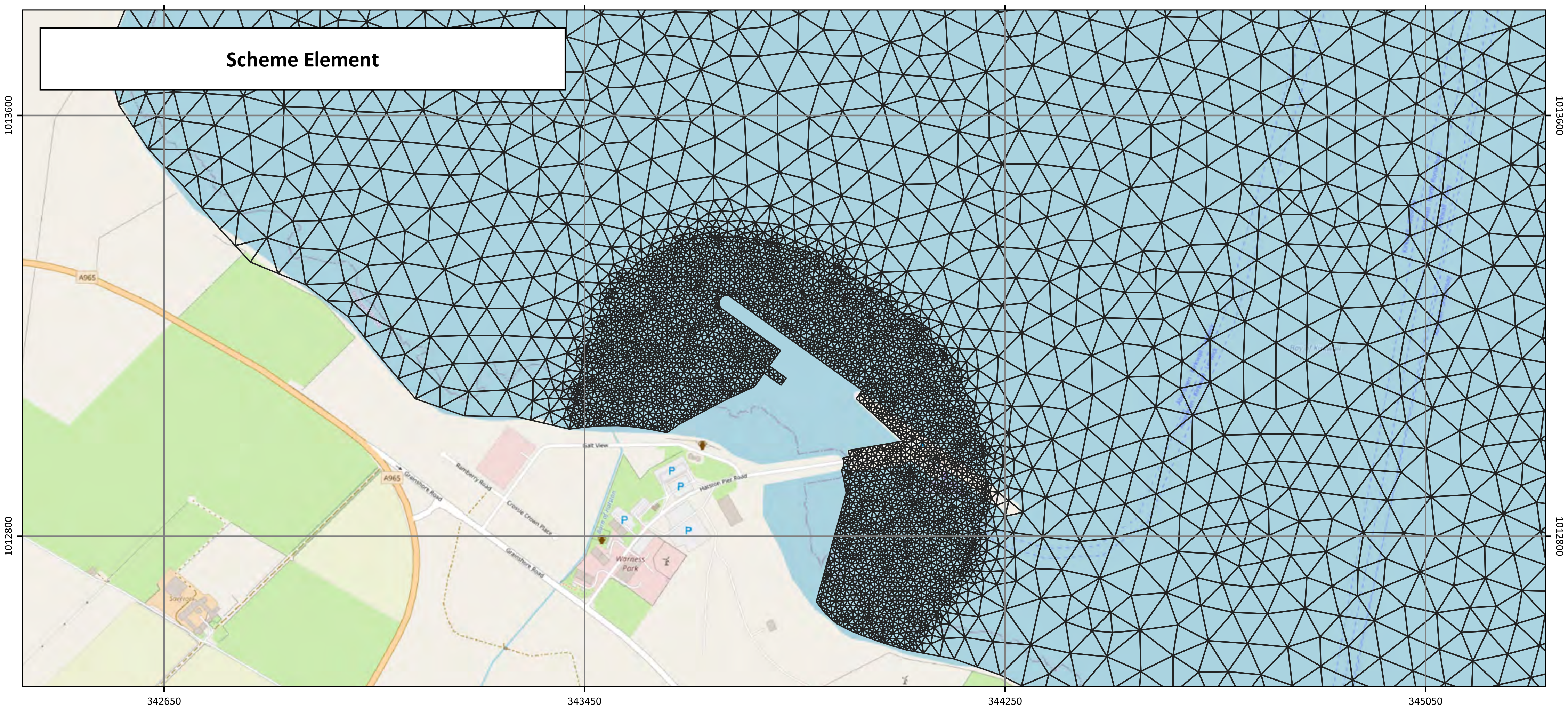

SIGNIFICANT WAVE HEIGHT DESK TOP STUDY - HATSTON

LOCATION OVERVIEW

Model Mesh at Development

Drawing No: P2570-LOC-006	A

Legend

Model Mesh

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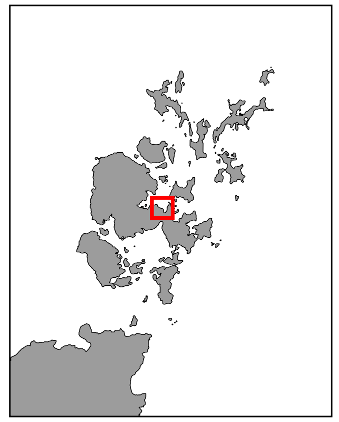

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Reviewed By	Emma Kilbane
Approved By	Emma Langley

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0 100 200 300 400 m

3.4 Model Validation

No suitable measured wave data have been identified within Wide Firth or the Bay of Kirkwall with which to validate the SW model outputs.

The SW model has been run using calibration parameters previously derived by Intertek for wave models in similar environments (see Section 3.2), but this does not inherently mean that these parameters are suitable for Hatston. Therefore, additional validation of the model outputs was undertaken using standard oceanographic techniques.

Specifically, Intertek estimated extreme waves using wave growth formulas derived from past empirical studies. A number of different approaches and formulations were considered, including the Joint North Sea Wave Project (JONSWAP) method, Sverdrup-Munk-Bretschneider (SMB) wave growth algorithms, and US Coastal Engineering Manual estimates for shallow water waves. These approaches all consider wave growth as a function of:

- wind speed (see Sections 3.5 and 4)
- available fetch (calculated from OS coastline data);
- limiting water depth (taken from the bathymetry data and SW model bathymetry).

In the past, Intertek has found that the JONSWAP approach may underestimate extreme waves but the SMB approach and US Coastal Engineering Manual shallow water estimates are dependable. As such, more weight has been placed on the predictions of these last two techniques.

The model validation results are somewhat complex to interpret and are therefore not presented in this report, although we would be happy to expand on this issue if required. In brief, however, the validation exercise has demonstrated that the SW model predictions are within the range of wave heights that would be expected based on empirically-derived growth formulations. If anything, the model predictions have a slight tendency to err on the conservative side (the predicted Hs is slightly higher than the growth formulations calculate). This gives confidence that the model results are appropriate for use in planning and feasibility studies for the proposed Hatston development.

3.5 Model Scenarios

The following scenarios have been modelled for both the baseline and development scenarios:

- Wind conditions: 1-in-1, 1-in-10 and 1-in-50 year return period, 15 knots (7.7 m/s) and 30 knots (15.4 m/s).
- Wind directional sectors (direction from): northwest, north, northeast and east.

This equates to 40 run scenarios (2 development scenarios x 5 wind conditions x 4 wind directions). The modelling was limited to the four selected wind directions as waves from other wind directions would propagate away from the primary area of interest. The selected wind scenarios represent a range of extreme conditions, and the waves generated by these winds will be of use in planning and feasibility studies for the proposed Hatston development.

All models are run assuming a water level of MHWS, as per the UKHO tidal levels for Kirkwall (see Table 2-1). This ensures the greatest wave heights at the development site since they will be least affected by interaction with the seabed (and resultant energy losses).

4. EXTREME VALUE ANALYSIS

4.1 Approach

Wind data are required in the SW model in order to provide the energy to generate, grow and propagate waves. Without forcing winds, modelled wave heights would steadily decrease through energy losses resulting in an under-prediction of wave heights in the area of interest.

Two of the required wind scenarios (15 knot and 30 knot speeds) were pre-defined by OIC. The other three scenarios required winds speeds with return periods of 1, 10 and 50 years to be derived. This was achieved through Extreme Value Analysis (EVA).

A cumulative frequency analysis was conducted on the directional wind data based on the occurrence of wind speed (ws) in bins of 0.2 m/s. A cumulative frequency table was produced, and percentage exceedance derived.

To derive wind speed for the 1-in-1, 1-in-10 and 1-in-50 year scenarios an EVA was conducted based on the cumulative frequency distribution. Intertek's in-house EVA software adopts a parametric frequency analysis approach by fitting a theoretical probability distribution to the dataset. A Weibull probability distribution (using the least squares method) was fitted to the data, with an R-squared value ranging from 0.98 to 0.99. This is a standard analytical technique that has been widely used for many decades to derive metocean criteria for the offshore industry.

See Appendix B for the summary directional EVA plots.

4.2 Output

Based on the approach described, Table 4-1 shows the results of the EVA for the ten-year Hatston data set. The highest return period wind speed is from a northerly direction. Each scenario was run within the Hatston SW model for both the baseline (pre-development) and post-installation scenarios. These speeds represent hourly-average wind speeds at a standard reference height of 10 m above surface.

Table 4-1 Extreme wind speeds (m/s) – hourly average at 10 m height

Directional sector	Return Period (years)		
	1-in-1	1-in-10	1-in-50
Northwest	22.15	26.23	28.82
North	20.57	23.54	25.38
Northeast	20.02	23.68	25.93
East	17.91	20.45	22.01

5. SPECTRAL WAVE MODEL PREDICTIONS

5.1 Significant Wave Height (Hs)

OIC provided a list of output locations around the area of interest (see Figure A-1 in **Error! Reference source not found.**). For these output locations, the predicted Hs for each wind speed condition for the four directional sectors are presented in Table 5-1 to Table 5-4.

Table 5-1 Predicted Hs (m), for a north-westerly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01	0.26	0.64	1.06	1.35	1.54	0.18	0.45	0.75	0.94	1.07
WV-H02	0.25	0.63	1.03	1.31	1.49	0.20	0.51	0.84	1.06	1.22
WV-H03	0.25	0.63	1.05	1.33	1.52	0.26	0.64	1.05	1.33	1.52
WV-H04	0.25	0.64	1.06	1.35	1.55	0.23	0.57	0.93	1.18	1.35
WV-H05	0.25	0.64	1.07	1.36	1.56	0.28	0.72	1.20	1.53	1.76
WV-H06	0.25	0.64	1.07	1.37	1.58	0.29	0.74	1.24	1.58	1.82
WV-H07	0.26	0.65	1.08	1.38	1.59	0.30	0.74	1.23	1.56	1.79
WV-H08	0.26	0.66	1.10	1.41	1.61	0.31	0.79	1.31	1.66	1.90
WV-H09	0.27	0.69	1.15	1.46	1.68	0.33	0.82	1.35	1.72	1.98
WV-H10	0.30	0.75	1.25	1.59	1.82	0.30	0.76	1.26	1.60	1.84
WV-H11	0.30	0.75	1.26	1.60	1.84	0.28	0.72	1.20	1.53	1.76
WV-H12	0.29	0.73	1.22	1.56	1.79	0.28	0.71	1.19	1.52	1.75
WV-H13	0.25	0.65	1.09	1.40	1.61	0.25	0.64	1.07	1.38	1.58
WV-H14	0.09	0.29	0.53	0.70	0.81	0.06	0.25	0.46	0.61	0.71
WV-H15	0.07	0.25	0.46	0.61	0.71	0.04	0.19	0.37	0.50	0.59
WV-H16	0.09	0.28	0.48	0.62	0.72	0.01	0.13	0.25	0.34	0.40
WV-H17	0.08	0.26	0.47	0.62	0.71	0.01	0.16	0.29	0.39	0.46
WV-H18	0.07	0.20	0.34	0.45	0.51	0.00	0.08	0.16	0.22	0.26
WV-H19	0.09	0.26	0.49	0.65	0.76	0.05	0.14	0.28	0.40	0.47
WV-H20	0.20	0.53	0.92	1.18	1.36	0.07	0.19	0.33	0.43	0.49

For wind from a north-westerly direction, the observation points on the outer harbour wall/edge (WV-H10 to WV-H12) are predicted to experience the highest waves with a maximum Hs of >1.8 m for a 1-in-50 year return period wind, for the pre-development scenario. The observation points behind the suspended decking (WV-H14 to WV-H20) are predicted to experience the lowest wave heights pre-development. Post-development, observation points WV-H05 to WV-H10 show an increase in predicted Hs, with a maximum Hs of c.2.0 m at WV-H09 for the 1-in-50 year wind. Observation points WV-H01 to WV-H04 and WV-H14 to WV-H20 show a decrease in predicted Hs post-development. The decrease in Hs at these locations likely represents wave energy losses due to interaction with the piles and other structures, but as noted previously, full wave interaction with structural elements is not included in the SW model and would require a Boussinesq wave modelling approach to simulate accurately.

Table 5-2 Predicted Hs (m), from a northerly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01	0.37	0.84	1.20	1.42	1.57	0.11	0.30	0.45	0.54	0.60
WV-H02	0.37	0.82	1.17	1.39	1.53	0.14	0.38	0.57	0.69	0.77
WV-H03	0.37	0.84	1.19	1.41	1.55	0.28	0.65	0.94	1.12	1.24
WV-H04	0.37	0.84	1.21	1.43	1.58	0.19	0.47	0.69	0.83	0.92
WV-H05	0.37	0.85	1.21	1.44	1.59	0.41	0.95	1.37	1.62	1.80
WV-H06	0.37	0.85	1.22	1.45	1.60	0.47	1.07	1.52	1.80	1.99
WV-H07	0.37	0.85	1.22	1.45	1.60	0.48	1.09	1.55	1.85	2.04
WV-H08	0.37	0.85	1.22	1.46	1.61	0.48	1.09	1.56	1.85	2.04
WV-H09	0.39	0.90	1.29	1.53	1.70	0.49	1.10	1.56	1.86	2.05
WV-H10	0.45	1.03	1.48	1.76	1.95	0.46	1.03	1.47	1.75	1.93
WV-H11	0.45	1.02	1.47	1.75	1.94	0.42	0.96	1.39	1.66	1.84
WV-H12	0.42	0.96	1.39	1.67	1.85	0.42	0.96	1.39	1.66	1.84
WV-H13	0.36	0.82	1.20	1.44	1.60	0.36	0.82	1.19	1.42	1.58
WV-H14	0.08	0.21	0.33	0.41	0.46	0.08	0.20	0.31	0.37	0.43
WV-H15	0.08	0.21	0.31	0.39	0.43	0.07	0.20	0.29	0.36	0.40
WV-H16	0.07	0.20	0.31	0.39	0.44	0.02	0.09	0.22	0.31	0.41
WV-H17	0.08	0.26	0.43	0.54	0.61	0.05	0.22	0.36	0.45	0.53
WV-H18	0.06	0.15	0.23	0.29	0.32	0.01	0.04	0.07	0.09	0.23
WV-H19	0.09	0.24	0.37	0.46	0.52	0.09	0.23	0.34	0.42	0.47
WV-H20	0.18	0.47	0.71	0.87	0.97	0.14	0.34	0.50	0.60	0.66

For wind from a northerly direction, the observation points on the outer harbour wall/edge (WV-H05 to WV-H13) are predicted to experience the highest waves with a maximum Hs of >1.9 m at WV-H10 and WV-H11 for a 1-in-50 year return period wind pre-development and Hs >2.0 m at WV-H07 to WV-H09 for a 1-in-50 year return period wind post-development. The observation points behind the suspended decking (WV-H14 to WV-H20) are predicted to experience the lowest wave heights pre-development. Observation points WV-H01 to WV-H04 and WV-H14 to WV-H20 show a decrease in predicted Hs post-development. The decrease in Hs at these locations likely represents wave energy losses due to interaction with the piles and other structures, but as noted previously, full wave interaction with structural elements is not included in the SW model and would require a Boussinesq wave modelling approach to simulate accurately.

Table 5-3 Predicted Hs (m), from a north-easterly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01	0.33	0.78	1.08	1.35	1.52	0.04	0.12	0.19	0.26	0.34
WV-H02	0.33	0.76	1.06	1.31	1.48	0.06	0.21	0.33	0.44	0.51
WV-H03	0.33	0.78	1.08	1.34	1.51	0.21	0.49	0.69	0.87	0.98
WV-H04	0.33	0.78	1.09	1.36	1.54	0.12	0.30	0.42	0.52	0.58
WV-H05	0.33	0.79	1.10	1.38	1.55	0.36	0.85	1.19	1.48	1.67
WV-H06	0.33	0.79	1.10	1.38	1.56	0.43	0.99	1.38	1.72	1.94
WV-H07	0.33	0.78	1.09	1.37	1.54	0.43	1.01	1.42	1.77	2.00
WV-H08	0.33	0.78	1.09	1.36	1.54	0.43	1.00	1.40	1.74	1.97
WV-H09	0.35	0.82	1.15	1.44	1.62	0.43	1.00	1.38	1.72	1.94
WV-H10	0.41	0.95	1.32	1.66	1.87	0.41	0.94	1.31	1.64	1.85
WV-H11	0.40	0.93	1.30	1.63	1.84	0.38	0.89	1.25	1.57	1.77
WV-H12	0.37	0.88	1.23	1.55	1.75	0.38	0.89	1.24	1.56	1.76
WV-H13	0.32	0.75	1.06	1.33	1.50	0.32	0.75	1.06	1.33	1.51
WV-H14	0.08	0.22	0.32	0.42	0.49	0.08	0.21	0.32	0.41	0.47
WV-H15	0.07	0.20	0.29	0.38	0.44	0.07	0.21	0.31	0.41	0.47
WV-H16	0.07	0.22	0.34	0.47	0.54	0.07	0.22	0.34	0.46	0.53
WV-H17	0.11	0.32	0.48	0.62	0.70	0.11	0.31	0.46	0.59	0.68
WV-H18	0.05	0.15	0.23	0.33	0.39	0.05	0.15	0.24	0.32	0.37
WV-H19	0.07	0.20	0.29	0.37	0.43	0.08	0.22	0.32	0.41	0.47
WV-H20	0.12	0.32	0.46	0.59	0.67	0.13	0.34	0.49	0.63	0.72

For wind from a north-easterly direction, the observation points on the outer harbour wall/edge (WV-H05 to WV-H13) are predicted to experience the highest waves with a maximum Hs of >1.8 m at WV-H10 and WV-H11 for a 1-in-50 year return period wind pre-development and Hs >1.9 m at WV-H06 to WV-H09 for a 1-in-50 year return period wind post-development. The observation points behind the suspended decking (WV-H14 to WV-H20) are predicted to experience the lowest wave heights pre-development. Observation points WV-H01 to WV-H04 and WV-H16 to WV-H18 show a small decrease in predicted Hs post-development. The decrease in Hs at these locations likely represents wave energy losses due to interaction with the piles and other structures, but as noted previously, full wave interaction with structural elements is not included in the SW model and would require a Boussinesq wave modelling approach to simulate accurately.

Table 5-4 Predicted Hs (m), from an easterly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01	0.20	0.50	0.63	0.76	0.85	0.01	0.11	0.15	0.18	0.21
WV-H02	0.19	0.49	0.61	0.74	0.82	0.01	0.13	0.17	0.22	0.24
WV-H03	0.20	0.51	0.64	0.77	0.86	0.08	0.24	0.30	0.37	0.41
WV-H04	0.21	0.53	0.65	0.80	0.89	0.05	0.18	0.22	0.28	0.31
WV-H05	0.21	0.53	0.66	0.81	0.90	0.18	0.47	0.57	0.70	0.77
WV-H06	0.21	0.53	0.66	0.80	0.89	0.25	0.64	0.80	0.97	1.08
WV-H07	0.20	0.52	0.64	0.78	0.87	0.26	0.67	0.83	1.01	1.12
WV-H08	0.20	0.51	0.63	0.77	0.86	0.25	0.64	0.79	0.96	1.08
WV-H09	0.20	0.53	0.66	0.80	0.90	0.23	0.59	0.73	0.90	1.00
WV-H10	0.22	0.58	0.72	0.88	0.99	0.22	0.57	0.71	0.87	0.97
WV-H11	0.22	0.56	0.70	0.85	0.95	0.21	0.56	0.70	0.85	0.96
WV-H12	0.21	0.54	0.68	0.83	0.93	0.21	0.55	0.68	0.84	0.94
WV-H13	0.18	0.47	0.59	0.72	0.81	0.18	0.48	0.60	0.73	0.82
WV-H14	0.10	0.28	0.36	0.45	0.50	0.10	0.28	0.36	0.44	0.50
WV-H15	0.10	0.28	0.35	0.44	0.49	0.11	0.29	0.37	0.45	0.51
WV-H16	0.11	0.31	0.39	0.48	0.54	0.12	0.32	0.41	0.50	0.56
WV-H17	0.13	0.35	0.43	0.53	0.59	0.13	0.35	0.44	0.54	0.60
WV-H18	0.09	0.27	0.34	0.43	0.48	0.09	0.26	0.33	0.41	0.46
WV-H19	0.08	0.22	0.28	0.35	0.39	0.08	0.23	0.29	0.37	0.41
WV-H20	0.06	0.19	0.24	0.30	0.34	0.10	0.27	0.35	0.44	0.49

For wind from an easterly direction, the observation points on the outer harbour wall/edge (WV-H05 to WV-H13) are predicted to experience the highest waves with a maximum Hs of >0.9 m at WV-H09 to WV-H12 for a 1-in-50 year return period wind pre-development and Hs >1.0 m at WV-H06 to WV-H09 for a 1-in-50 year return period wind post-development. The observation points behind the suspended decking (WV-H14 to WV-H20) are predicted to experience the lowest wave heights pre-development. Observation points WV-H01 to WV-H05 and WV-H18 show a decrease in predicted Hs post-development. The decrease in Hs at these locations likely represents wave energy losses due to interaction with the piles and other structures, but as noted previously, full wave interaction with structural elements is not included in the SW model and would require a Boussinesq wave modelling approach to simulate accurately.

Comparison of all wind directions modelled, in Table 5-1 to Table 5-4, indicates that wind from a northerly direction will generate the highest predicted wave heights, with the lowest from the easterly direction. There are only small predicted changes in wave height offshore the area of interest post-development, but greater changes are predicted post-development under and around the suspended decking and in the lee of the solid quay where wave energy is absorbed and sheltered respectively.

Figure D-1 to Figure D-40 show contours of the predicted significant wave height across the study area for each of the modelled baseline (Figure D-1 to Figure D-20) and post-development (Figure D-21 to Figure D-40) model runs.

5.2 Peak Wave Period (Tp)

Table D-1 to Table D-4 in Appendix D.3 show the peak wave periods predicted by the wave modelling. Notably, all peak wave periods are less than 5 s and waves from a northerly and north-westerly direction generally give the highest peak wave periods.

Depending on the wind direction, some of the observation points show occasionally anomalous predicted peak wave periods. For example, the predicted period may decrease as the wind speed and Hs increase. This occurs only for selected locations that are in the lee of structures for the given wind direction (or, more correctly, for the resulting direction of wave propagation). After review, Intertek believes that this reflects a limitation of the spectral wave model – in particular, its inability to model (or model with suitable accuracy) certain physical processes, as discussed further in Section 3.1.

The locations where SW model predictions may be anomalous are identified in Table D-1 to Table D-4. We recommend that these outputs are treated with caution. Since this issue is due to a fundamental limitation of the SW model, we recommend that additional investigation using the Boussinesq wave model would be required to derive robust wave periods for these locations.

5.3 Impacts from North Sea and North Atlantic Waves

As a sensitivity test, the SW model was run for selected scenarios to represent extreme waves propagating into the Orkney Islands from the North Sea and North Atlantic, to see if these waves could reach the Hatston site with sufficient height and energy to be of concern (e.g. in comparison to the locally wind-generated waves).

Extreme offshore wave conditions were taken from a Health and Safety Executive (HSE) assessment of wind and wave distributions around the UK and Ireland (HSE, 2001). Analysis was based on output from the NEXT wind and wave model, with data covering the full years 1977-1979 and 1989-1994 (nine years in total). For the Hatston sensitivity tests, output was taken from one model grid point east of Orkney, to represent waves propagating from the North Sea, and a second model grid point northwest of Orkney, to represent waves propagating from the North Atlantic. For the purpose of these tests it was not considered necessary to undertake a detailed EVA of the data; this could be done subsequently should the results indicate an important impact from these waves. Instead, a "representative extreme" wave condition was determined for each NEXT model grid point by picking out the approximate highest Hs and Tp from the available data set. It may be assumed that these conditions are not too dissimilar to the 1-in-10 year return waves.

The sensitivity tests thus comprised one extreme wave input at the eastern boundary of the SW model (Hs = 5.5 m, Tp = 18 s), and a second test with a northerly wave input at the north boundary of the SW model (Hs = 8 m, Tp = 17 s).

These tests were fairly conclusive that waves from outside the Orkney Islands cannot reach Hatston with any significant energy. The 5.5 m wave from the east had reduced to 0.35 m by arrival at Hatston. The 8 m wave from the north had reduced to no more than 0.2 m at Hatston. (We additionally note that even this wave height from the north is probably over-estimated, since the Hs = 8 m forcing condition was input directly along the north boundary of the SW model. This is unlikely in reality since this boundary is sheltered by the main body of Westray which is not included in the SW model domain.)

It may be thought that a 0.35 m wave is not trivial given the predicted maximum 1-in-50 year Hs at Hatston of c.2.1 m. However, two further considerations apply:

- The extreme local wind-wave and propagating swell wave will not necessarily be contemporary. For example, it would take a very specific set of meteorological circumstances for an extreme wind-wave from the north to reach Hatston at the same time as an extreme swell wave from the east.

- Even were the locally wind-generated waves and the more distant swell waves to impact Hatston at the same time, wave heights are not simply additive. For example, an Hs of 2.1 m (wind-sea component) combined with an Hs of 0.35 m (swell component) gives a resultant wave height of Hs = 2.129 m, thus adding a total of less than 3 cm to the combined wave height. This is considered negligible in the context of the present study and given other uncertainties in model parameterisation and input data.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Study Summary and Conclusions

The potential wave conditions at Hatston before and after the proposed Orkney Logistics Base development have been predicted for a number of scenarios using a spectral wave model. The model results show that the predicted maximum Hs for both the pre- and post-development scenarios is approximately 2.1 m for the 1-in-50 year wind condition from a northerly direction. The maximum Tp is also predicted for the 1-in-50 year wind condition from a northerly direction. This is to be expected as it is the direction with the second longest fetch and with a strong extreme wind speed, allowing the waves to build up to the area of interest. The results presented represent a fully developed sea for a constant wind direction, and therefore include a degree of conservatism (as wind speed and direction will vary temporally and spatially on a local scale).

The tables and plots of predicted Hs for the post-development scenario show that there are areas around the development that are subject to wave energy losses through sheltering and/or interaction with piles. However, larger wave heights are predicted for locations along the northeast of the development. This section of the development is relatively more exposed and rarely subject to wave sheltering, and waves can therefore approach unobstructed. It also experiences the deepest water, so waves are less likely to be limited by shoaling or breaking.

Sensitivity tests have demonstrated that storm/swell waves propagating into the Orkney Islands from either the North Sea or North Atlantic do not reach Hatston with sufficient height or energy to be of any significant concern to the present study.

In the absence of suitable measured data the SW model predictions have been verified by comparison against estimates of wave height using several empirically-derived wave growth formulations. These comparisons confirm that the model is producing realistic predictions of wave conditions with perhaps a slight tendency towards conservatism.

6.2 Study Recommendations

The wave conditions presented in this report are considered suitable for purposes of planning and feasibility. We recommend, however, that they not be used for detailed engineering design without additional analysis and investigation. Two issues are of particular note:

1. The SW model has not been validated against measured data. It has been run using calibration parameters successfully derived for other areas, and it has been verified against wave height independently calculated from empirically-derived wave growth formulations. Both of these factors give some confidence that the model predictions are reliable, but additional analysis – and ideally, comparison against measured wave data – would increase robustness in the calculated extreme wave conditions.
2. The SW model includes many important wave processes but does not simulate all processes that would affect waves in close proximity to a development, such as diffraction, reflection (other than in a simplified fashion) and run-up. OIC has highlighted the requirement for a more in-depth assessment of wave behaviour within the development, in particular with regard to the representation of wave reflection in the vicinity of development. This is not possible within the MIKE 21 SW model as it does not include a complex treatment of wave reflection and subsequent wave-wave interaction. To fully evaluate these processes, if required, Intertek would recommend

undertaking a Boussinesq wave model assessment to supplement the SW modelling. This would use the MIKE 21 Boussinesq wave model.

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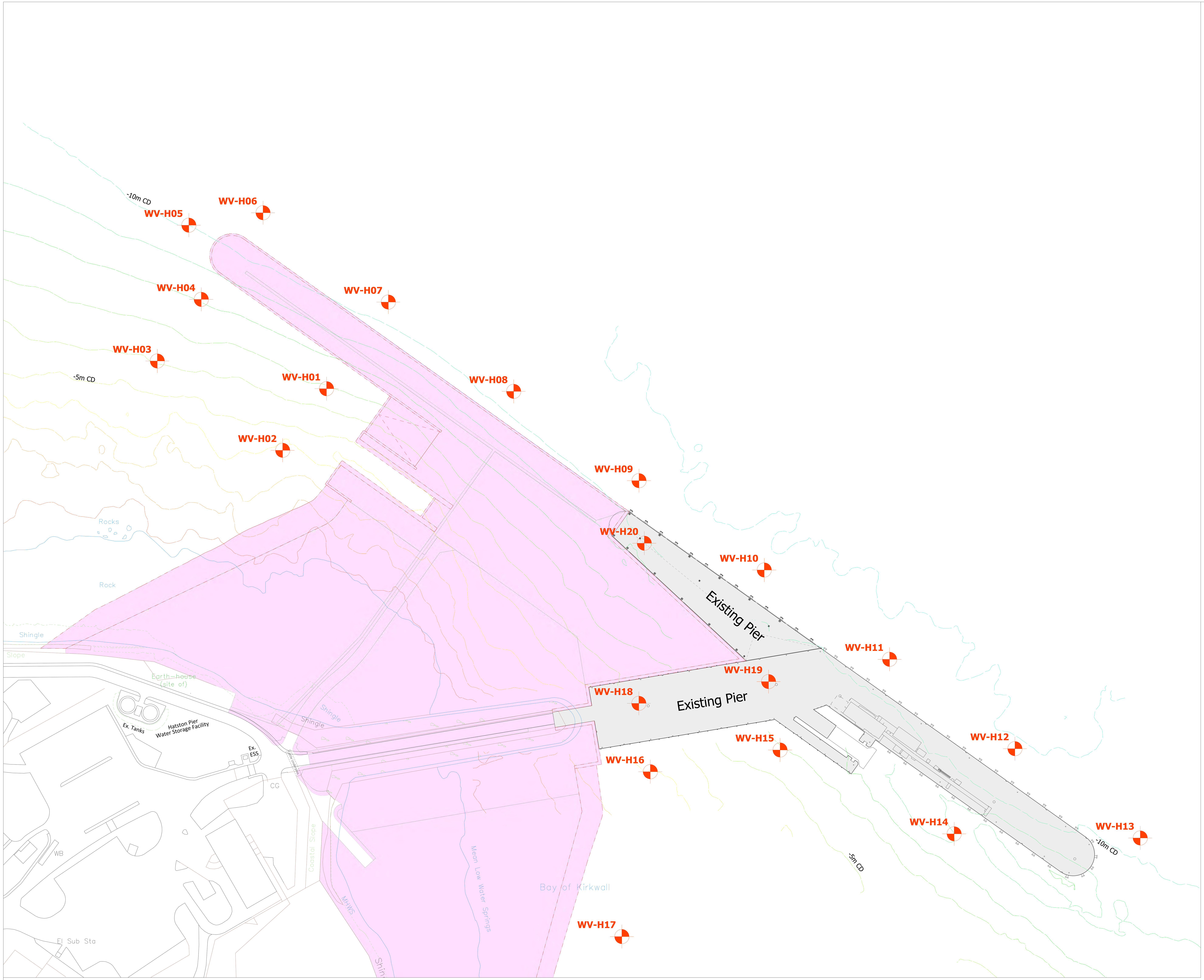
APPENDIX A

Output Locations



Data Location	Easting	Northing
WV-H01	343781.5	1013157.6
WV-H02	343753.0	1013117.5
WV-H03	343671.6	1013175.6
WV-H04	343700.1	1013215.6
WV-H05	343692.0	1013263.9
WV-H06	343740.3	1013272.0
WV-H07	343821.7	1013213.9
WV-H08	343903.1	1013155.9
WV-H09	343984.5	1013097.8
WV-H10	344066.0	1013039.7
WV-H11	344147.4	1012981.7
WV-H12	344228.8	1012923.6
WV-H13	344310.2	1012865.6
WV-H14	344189.3	1012868.3
WV-H15	344076.2	1012922.8
WV-H16	344991.9	1012908.7
WV-H17	343973.4	1012801.5
WV-H18	343984.4	1012953.1
WV-H19	344069.7	1012967.2
WV-H20	343988.0	1013057.2

REV	DATE	REVISION	DRN	CHK
-	31:08:2022	Issued for Info	PRN	

ORKNEY ISLANDS COUNCIL
Harbour Authority

Hatston Pier, Kirkwall - Proposed Extension

Wave Data Locations

Arch Henderson 1919

Civil Engineers
Structural Engineers
Architects
CDM Co-ordinators
Geotechnical services
Environmental services

Stewart Building, Lerwick, Shetland. ZE1 0LL.
Tel : 01595 695512
www.arch-henderson.co.uk - email : lerwick@arch-henderson.co.uk

Aberdeen; Dundee; Glasgow; Lerwick; Inverness; Thurso; Stromness; Southampton; Falkland Islands

DRAWN :	DATE :	CHECKED :	APPROVED :
PRN	Aug 2022	APS	APS

SCALE : (A1)	DRAWING STATUS :
As Shown	Preliminary

DRAWING No : 202043-SK310822 REV : -

ORKNEY ISLANDS COUNCIL
HATSTON PIER, KIRKWALL
WAVE DATA LOCATIONS

Scale 1: 1250

0 25 50 75 100 150 200 250m

SCALE 1:1250 at A1

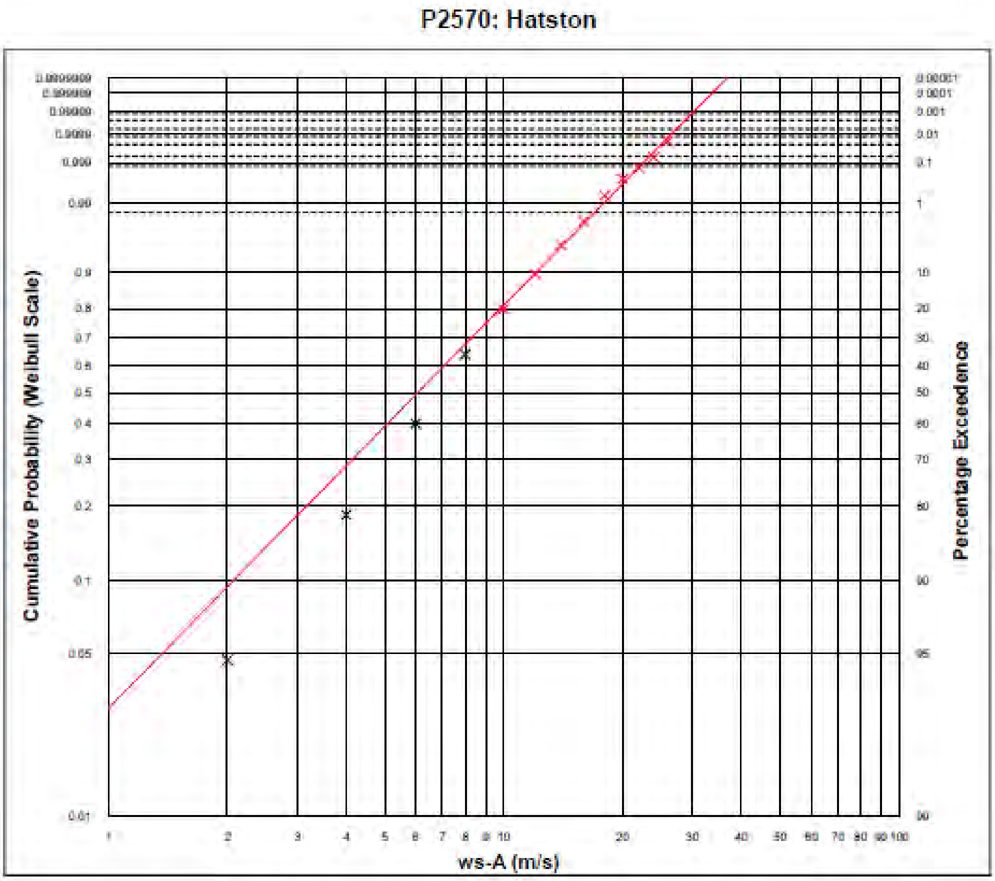
Chart Datum (Kirkwall)	Ordnance Datum (Newlyn)	Quay Heights and Tide Data Hatston Pier, Kirkwall
+6.40m	+5.00m	Quay Edge Level
+3.00m	+1.60m	Mean High Water Spring Tides
+1.40m	0.00m	Ordnance Datum (Newlyn)
+0.60m	-0.80m	Mean Low Water Spring Tides
0.00m	-1.40m	Chart Datum (Kirkwall)
-5.00m	-6.40m	
-7.50m	-8.90m	
-10.00m	-11.40m	

APPENDIX B

Extreme Value Analysis

B.1 EXTREME VALUE ANALYSIS RESULTS – WEIBULL PROBABILITY DISTRIBUTION

Figure B-1 Weibull probability distribution and results – north-westerly wind



Extrapolations:
(Wind speed, 60 min)

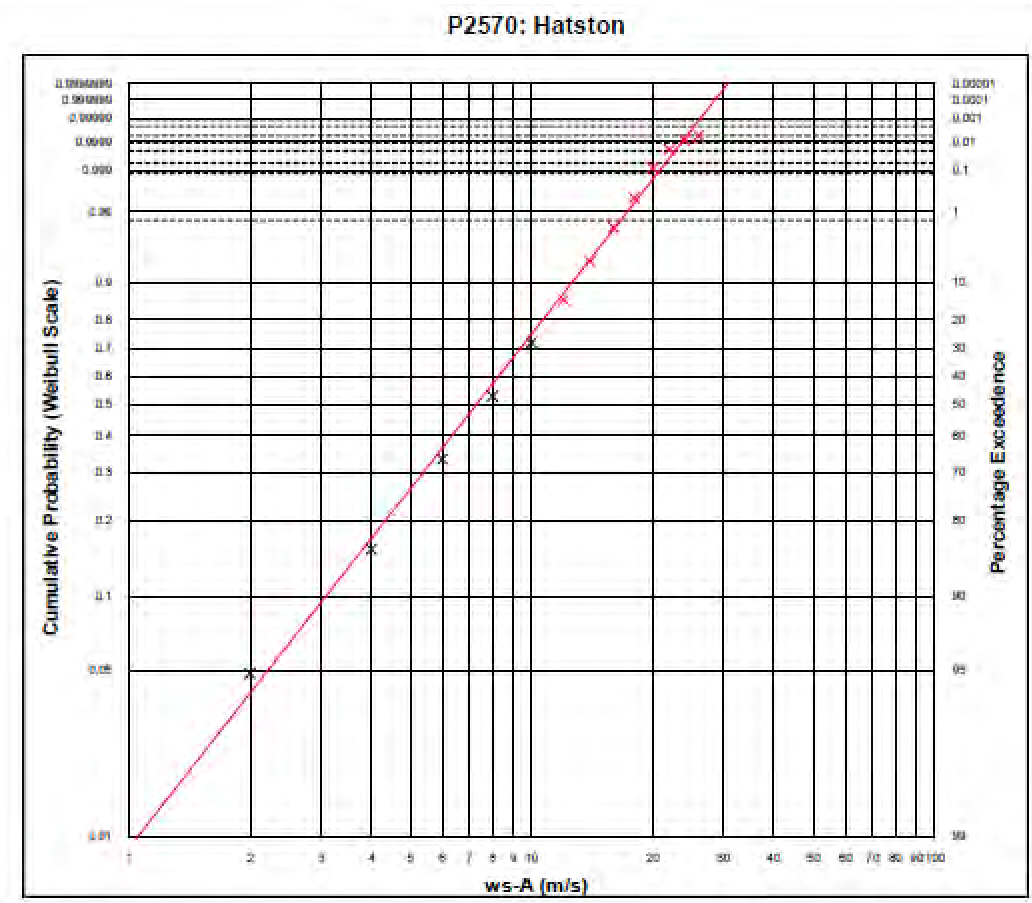
Return period	Cumulative Probability	Extreme value (m/s)
100 yr	0.99998756	29.88
50 yr	0.99997513	28.82
20 yr	0.99993782	27.37
10 yr	0.99987565	26.23
5 yr	0.99975129	25.05
2 yr	0.99937824	23.43
1 yr	0.99875647	22.15
0.0833 yr	0.98507764	16.98

Weibull parameters: A = 0.000 B = 7.472 C = 1.749
Regression line is fitted to the top 25% of the distribution. Fitting technique: least squares method
Data interval is 60.0 min

Notes:
1. Data source: Hatston OIC data
2. Location: 58° 59' N, 02° 58' W
3. Period: 1 January 2012 to 31 December 2021
4. 10 m above surface (?)
5. Wind speed (m/s)
6. Based on 15-minute data

Weibull Extreme Value Analysis for Hatston wind observations (Northwesterly)

Figure B-2 Weibull probability distribution and results – northerly wind



Extrapolations:
(Wind speed, 60 min)

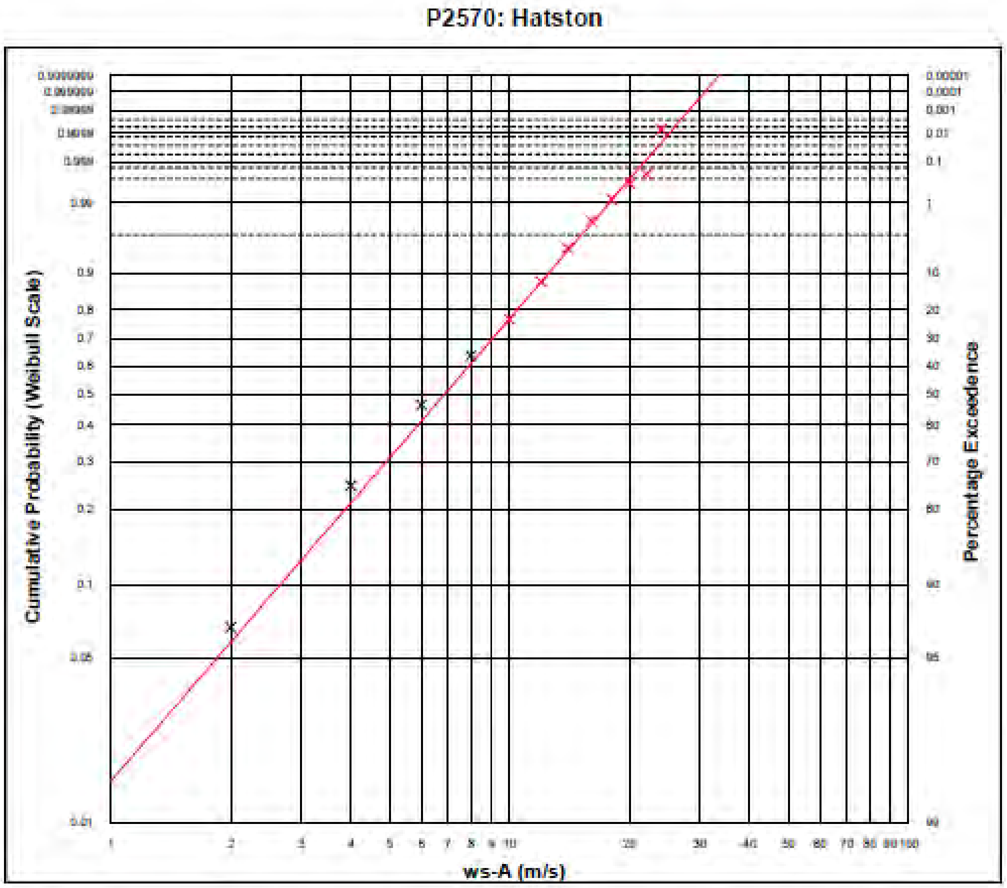
Return period	Cumulative Probability	Extreme value (m/s)
100 yr	0.99998787	26.12
50 yr	0.99997574	25.38
20 yr	0.99993936	24.35
10 yr	0.99987871	23.54
5 yr	0.99975743	22.70
2 yr	0.99939357	21.52
1 yr	0.99878714	20.57
0.0833 yr	0.98544573	16.65

Weibull parameters: A = 0.000 B = 8.614 C = 2.188
Regression line is fitted to the top 25% of the distribution. Fitting technique: least squares method
Data interval is 60.0 min

Notes:
1. Data source: Hatston OIC data
2. Location: 58° 59′ N, 02° 58′ W
3. Period: 1 January 2012 to 31 December 2021
4. 10 m above surface (?)
5. Wind speed (m/s)
6. Based on 15-minute data

Weibull Extreme Value Analysis for Hatston wind observations (Northerly)

Figure B-3 Weibull probability distribution and results – north-easterly wind



Extrapolations:
(Wind speed, 60 min)

Return period	Cumulative Probability	Extreme value (m/s)
100 yr	0.99997049	26.84
50 yr	0.99994098	25.93
20 yr	0.99985245	24.67
10 yr	0.99970490	23.68
5 yr	0.99940980	22.64
2 yr	0.99852450	21.19
1 yr	0.99704899	20.02
0.0833 yr	0.96458793	15.14

Weibull parameters: A = 0.000 B = 8.251 C = 1.988

Regression line is fitted to the top 25% of the distribution. Fitting technique: least squares method

Data interval is 60.0 min

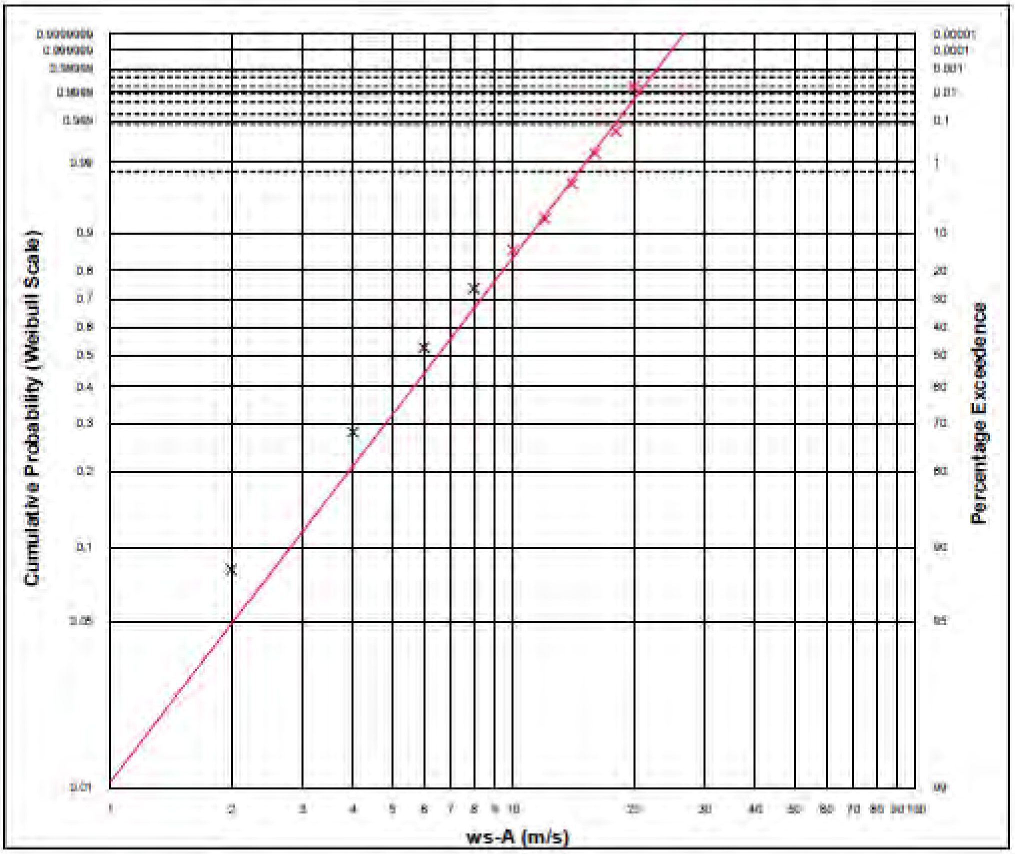
Notes:

1. Data source: Hatston OIC data
2. Location: 58° 59' N, 02° 58' W
3. Period: 1 January 2012 to 31 December 2021
4. 10 m above surface (?)
5. Wind speed (m/s)
6. Based on 15-minute data

Weibull Extreme Value Analysis for Hatston wind observations (Northeasterly)

Figure B-4 Weibull probability distribution and results – easterly wind

P2570: Hatston



Extrapolations:
(Wind speed, 60 min)

Return period	Cumulative Probability	Extreme value (m/s)
100 yr	0.99998750	22.65
50 yr	0.99997500	22.01
20 yr	0.99993749	21.14
10 yr	0.99987498	20.45
5 yr	0.99974996	19.73
2 yr	0.99937490	18.72
1 yr	0.99874979	17.91
0.0833 yr	0.98499749	14.55

Weibull parameters: A = 0.000 B = 7.651 C = 2.234

Regression line is fitted to the top 25% of the distribution. Fitting technique: least squares method

Data interval is 60.0 min

Notes:

1. Data source: Hatston OIC data
2. Location: 58° 59' N, 02° 58' W
3. Period: 1 January 2012 to 31 December 2021
4. 10 m above surface (?)
5. Wind speed (m/s)
6. Based on 15-minute data

Weibull Extreme Value Analysis for Hatston wind observations (Easterly)

APPENDIX C

Additional Results

C.1 SIGNIFICANT WAVE HEIGHT CONTOUR PLOTS – BASELINE

Figure C-1 Predicted Hs (m), 15 knots north-westerly wind direction

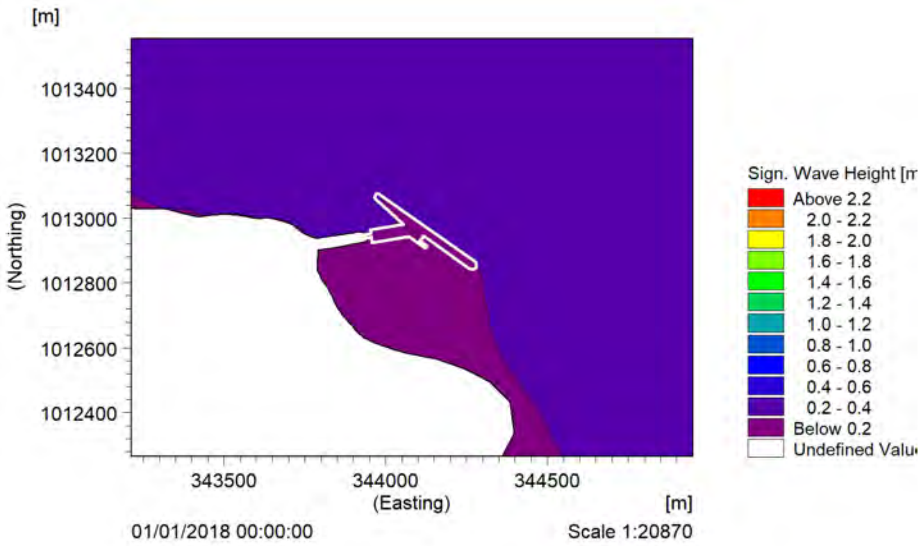


Figure C-2 Predicted Hs (m), 15 knots northerly wind direction

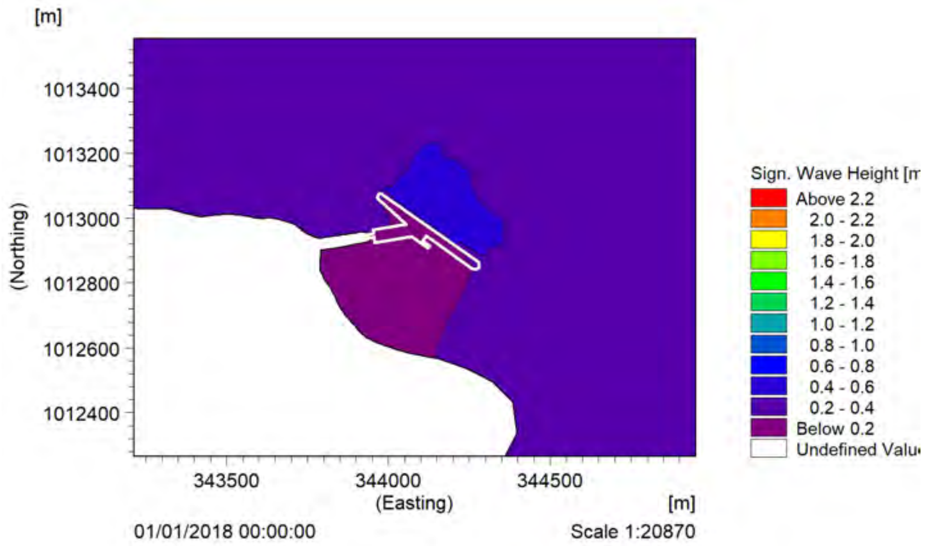


Figure C-3 Predicted Hs (m), 15 knots north-easterly wind direction

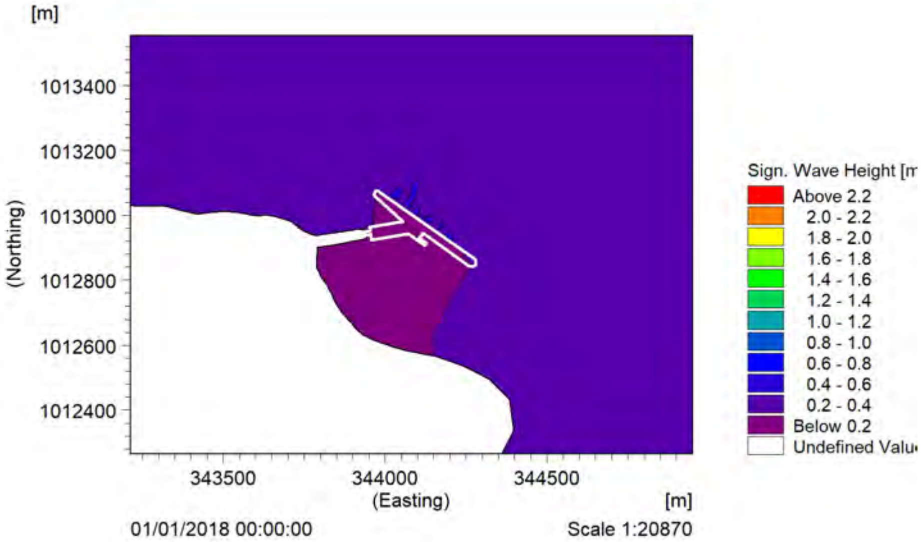


Figure C-4 Predicted Hs (m), 15 knots easterly wind direction

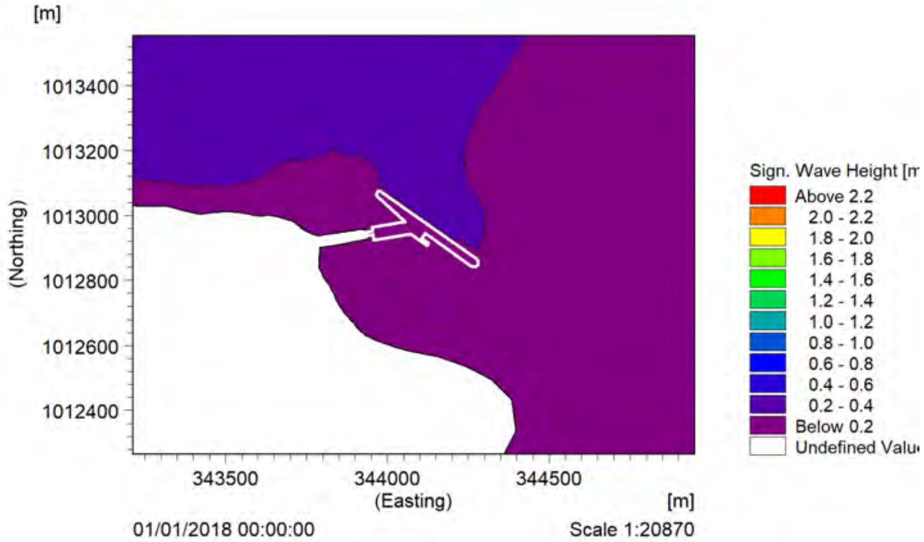


Figure C-5 Predicted Hs (m), 30 knots north-westerly wind direction

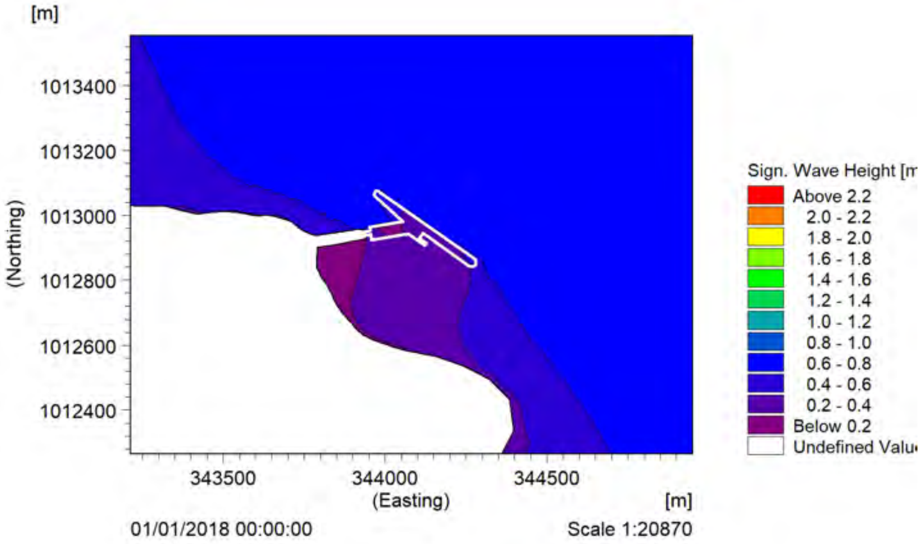


Figure C-6 Predicted Hs (m), 30 knots northerly wind direction

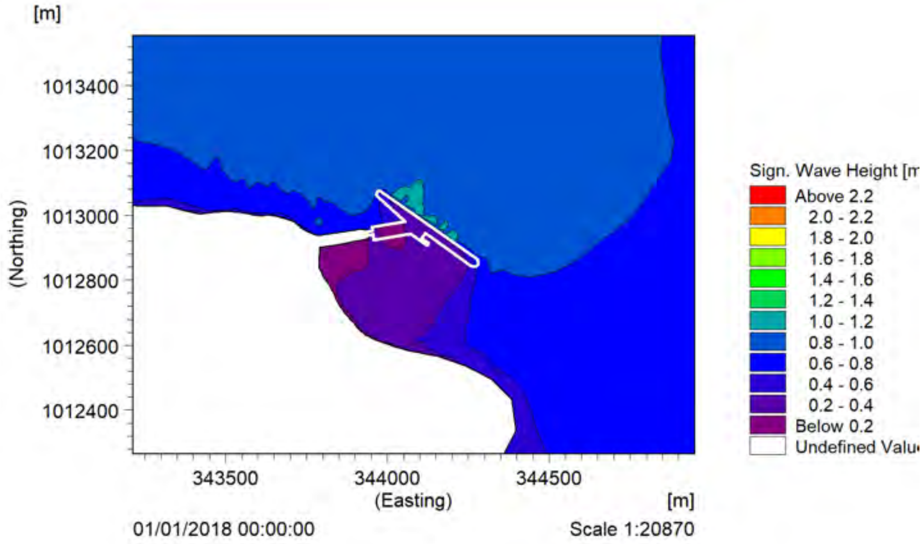


Figure C-7 Predicted Hs (m), 30 knots north-easterly wind direction

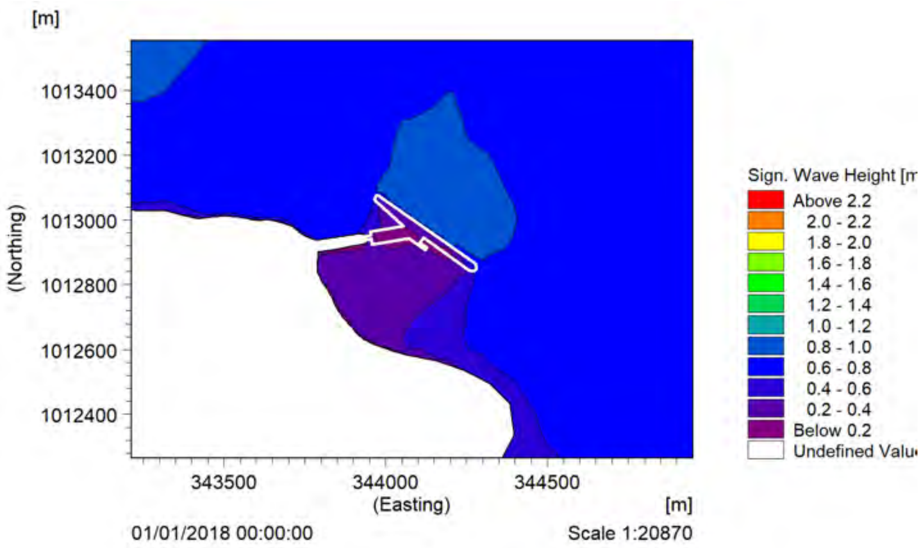


Figure C-8 Predicted Hs (m), 30 knots easterly wind direction

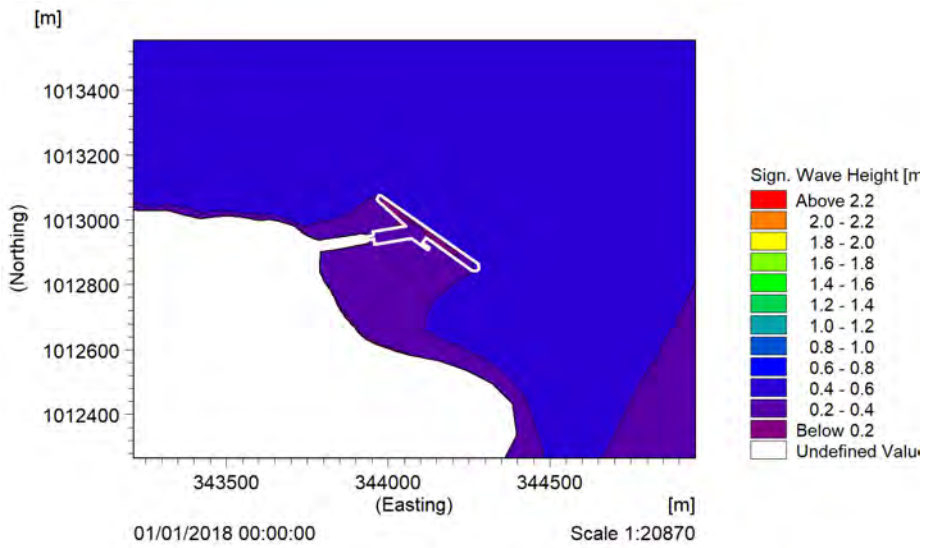


Figure C-9 Predicted Hs (m), 1-in-1 year north-westerly wind direction

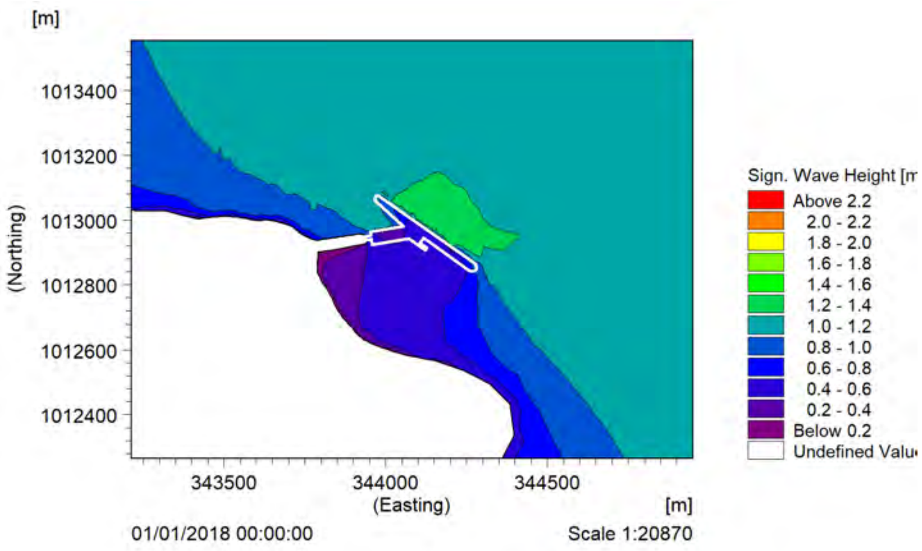


Figure C-10 Predicted Hs (m), 1-in-1 year northerly wind direction

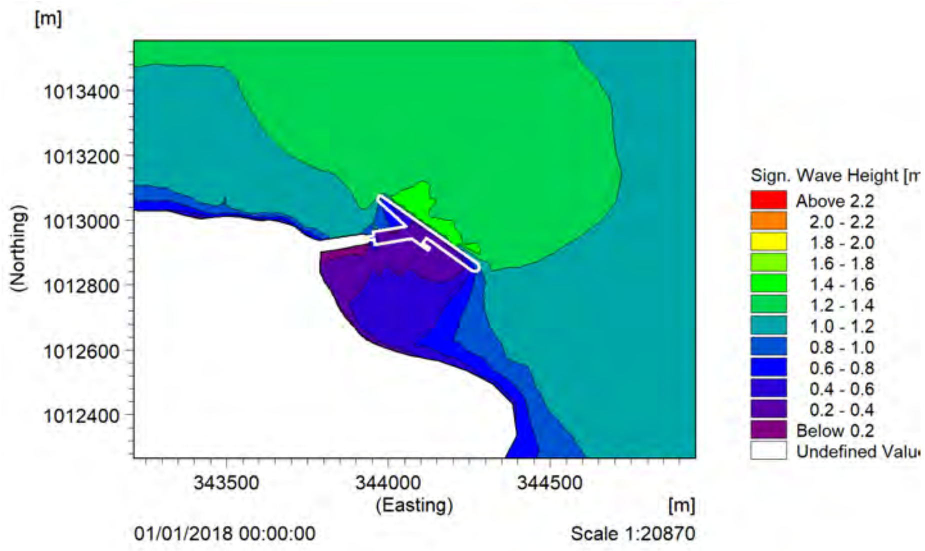


Figure C-11 Predicted Hs (m), 1-in-1 year north-easterly wind direction

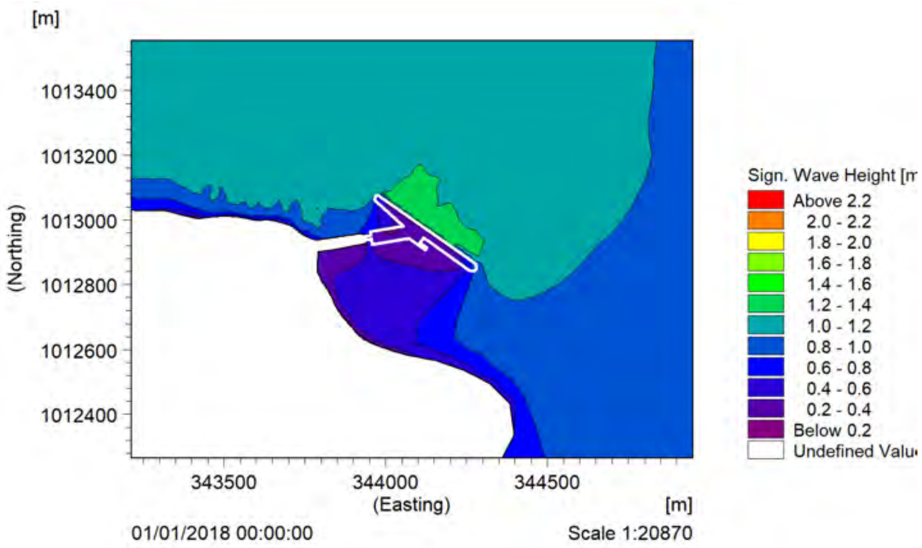


Figure C-12 Predicted Hs (m), 1-in-1 year easterly wind direction

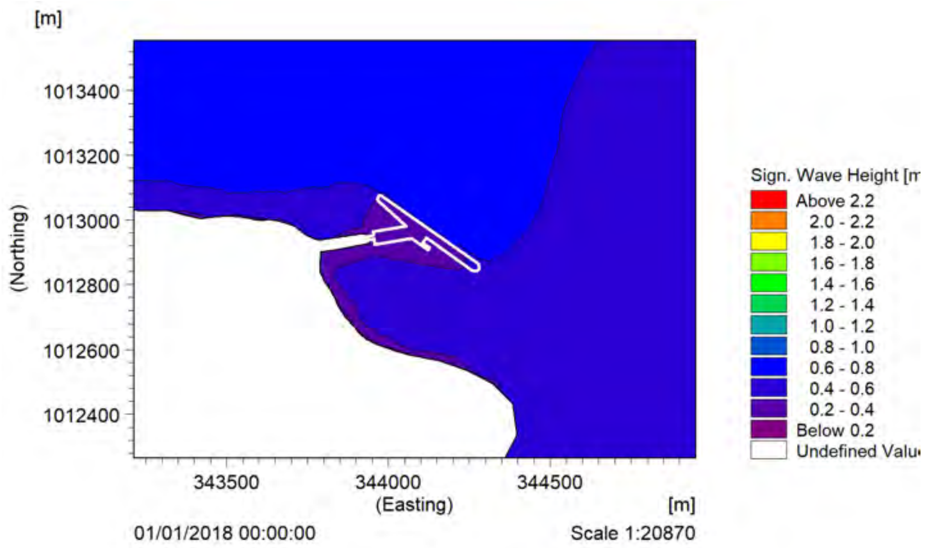


Figure C-13 Predicted Hs (m), 1-in-10 year north-westerly wind direction

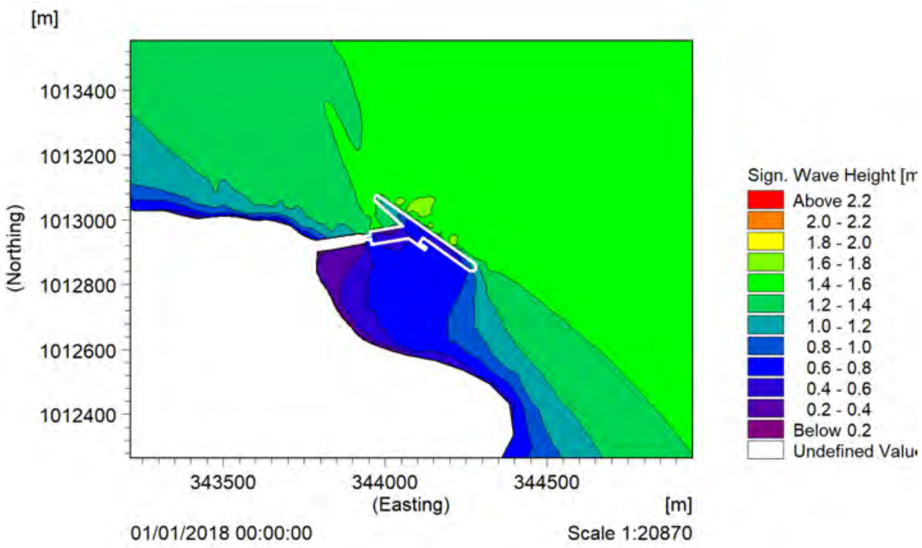


Figure C-14 Predicted Hs (m), 1-in-10 year northerly wind direction

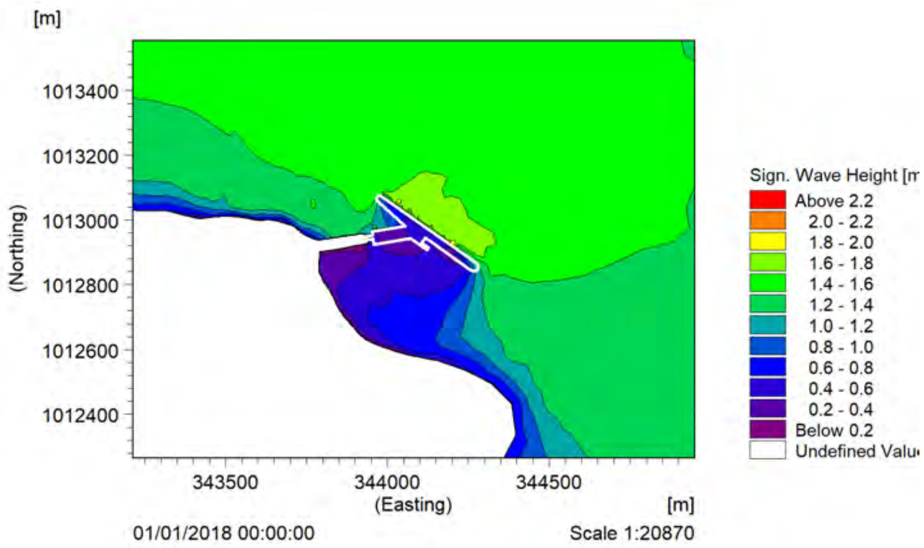


Figure C-15 Predicted Hs (m), 1-in-10 year north-easterly wind direction

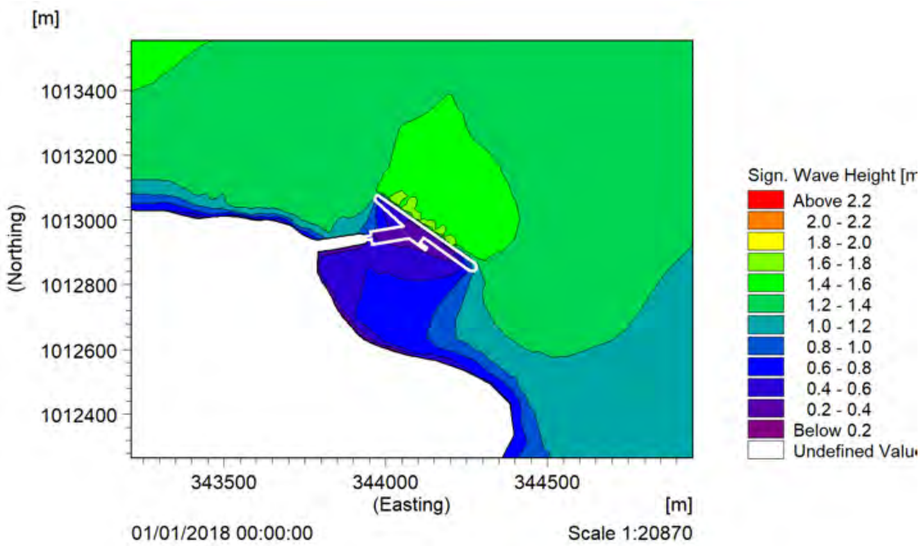


Figure C-16 Predicted Hs (m), 1-in-10 year easterly wind direction

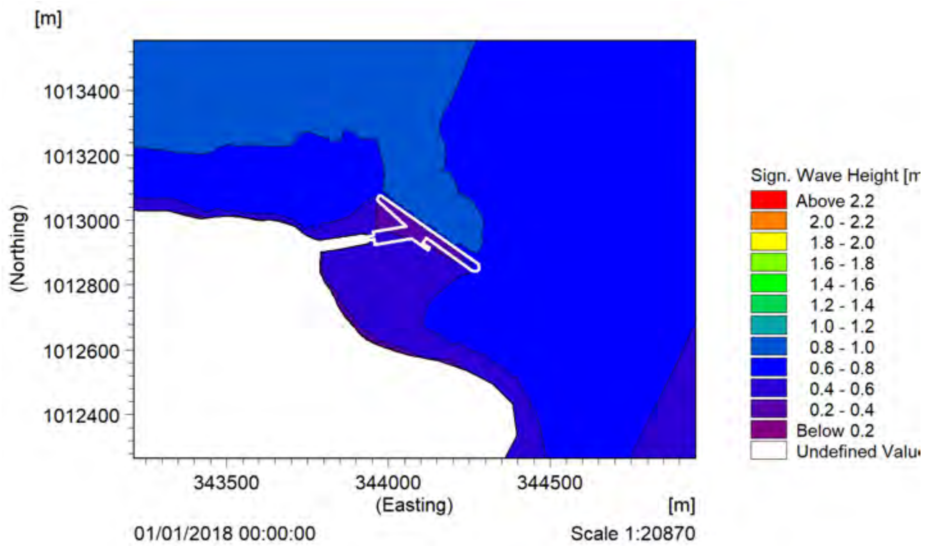


Figure C-17 Predicted Hs (m), 1-in-50 year north-westerly wind direction

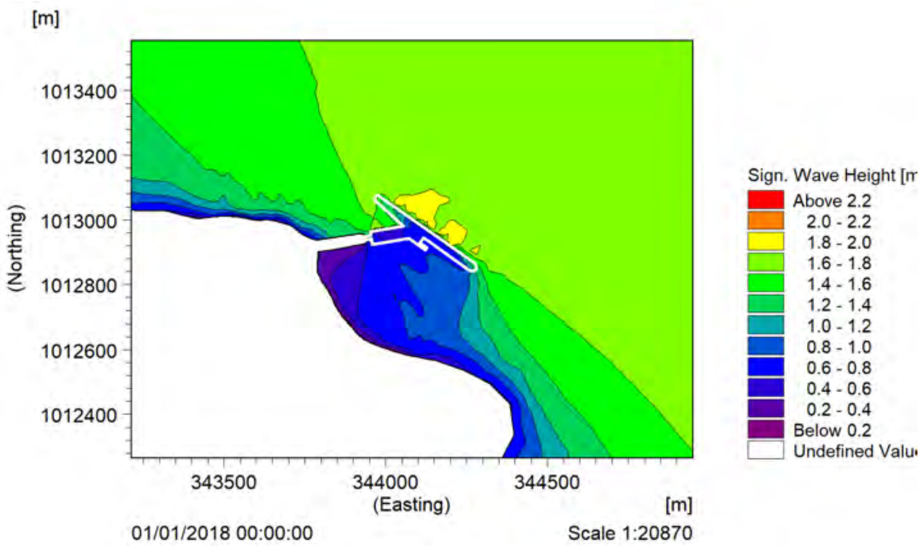


Figure C-18 Predicted Hs (m), 1-in-50 year northerly wind direction

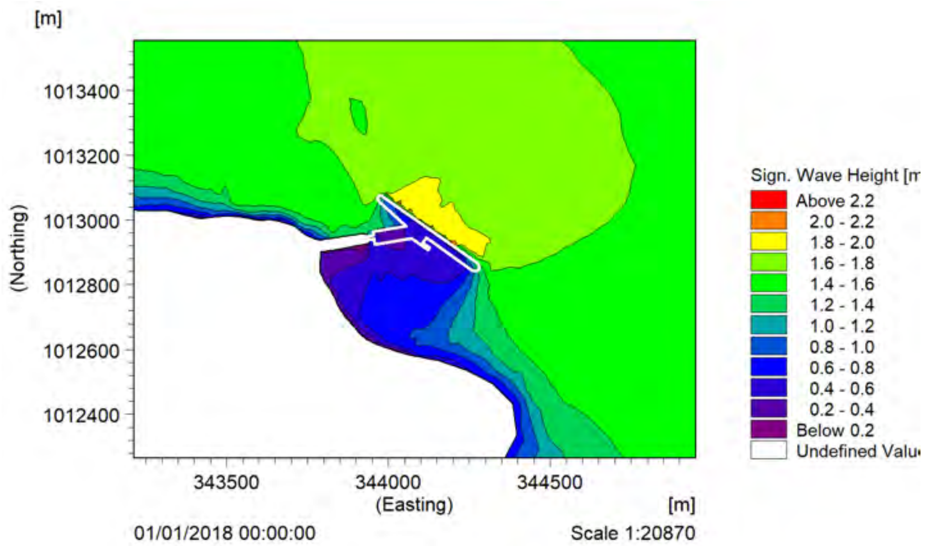


Figure C-19 Predicted Hs (m), 1-in-50 year north-easterly wind direction

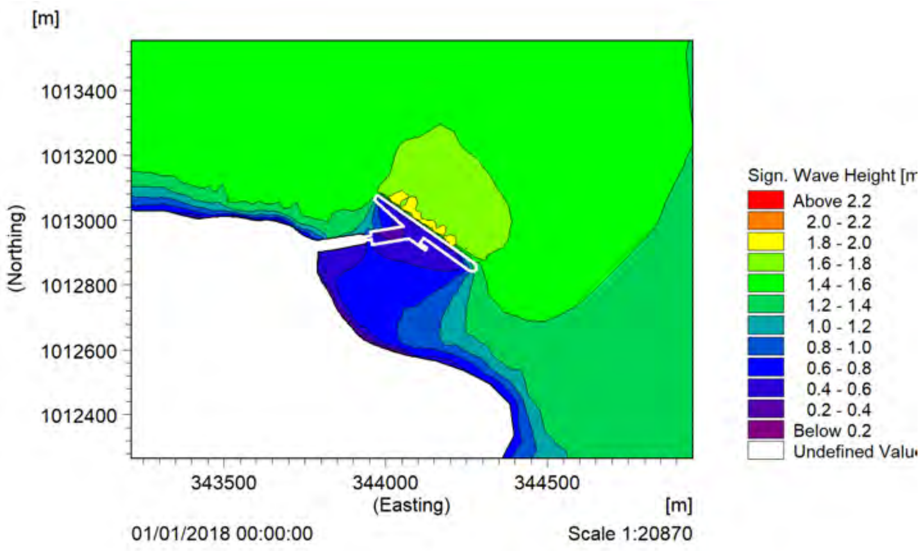
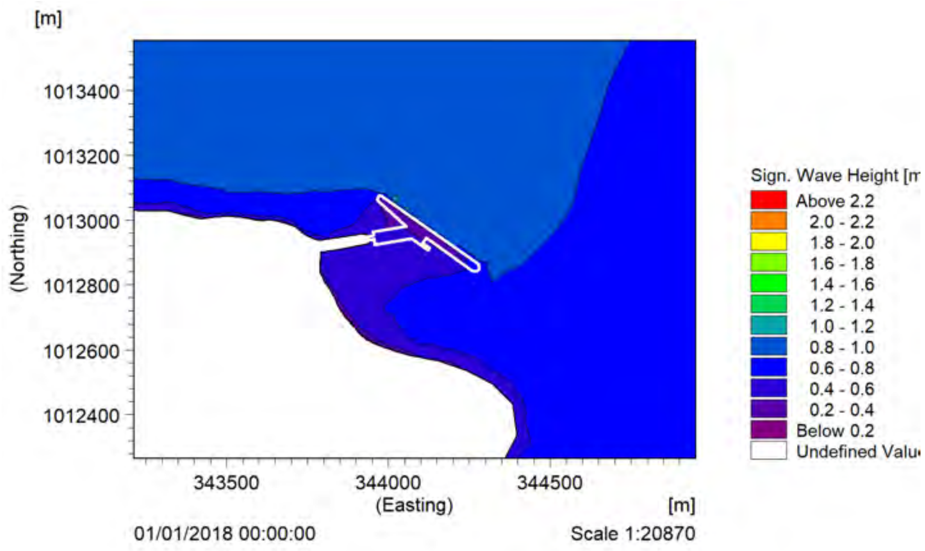


Figure C-20 Predicted Hs (m), 1-in-50 year easterly wind direction



C.2 SIGNIFICANT WAVE HEIGHT CONTOUR PLOTS – SCHEME

Figure C-21 Predicted Hs (m), 15 knots north-westerly wind direction

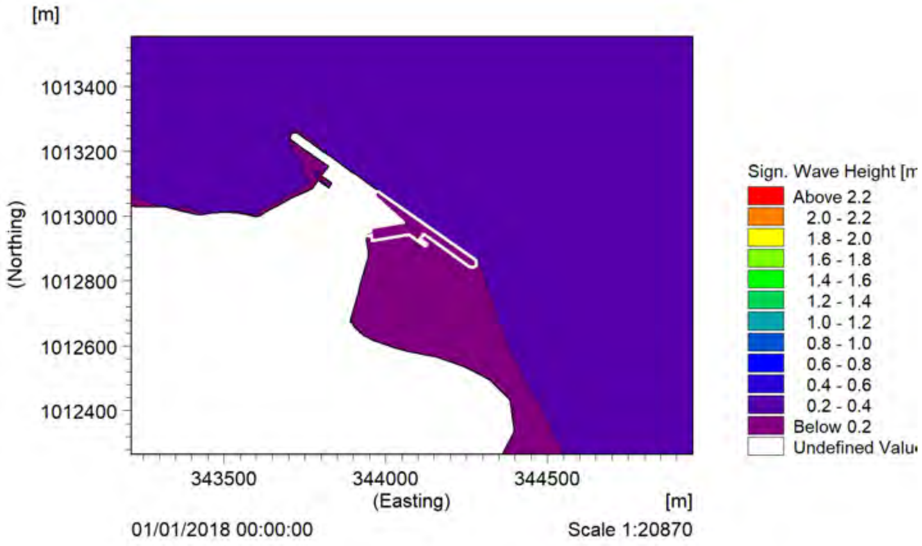


Figure C-22 Predicted Hs (m), 15 knots northerly wind direction

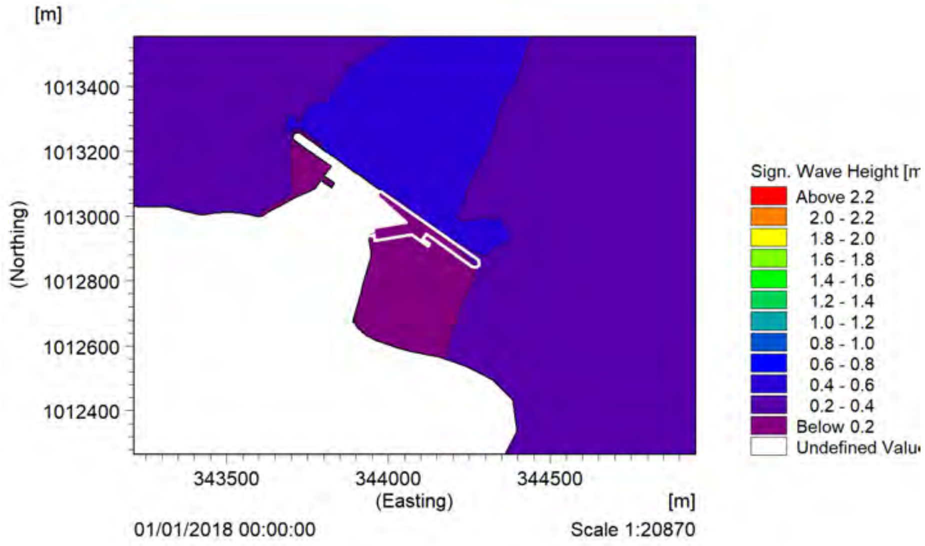


Figure C-23 Predicted Hs (m), 15 knots north-easterly wind direction

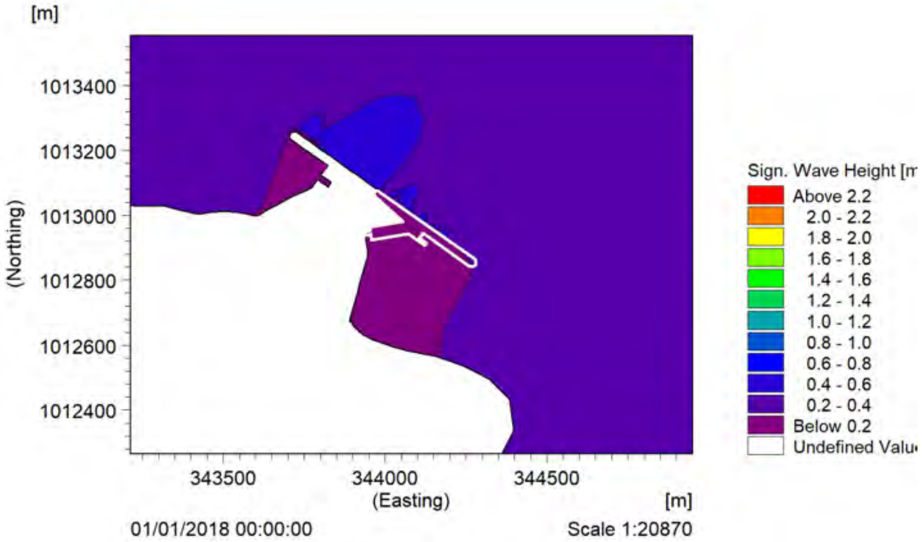


Figure C-24 Predicted Hs (m), 15 knots easterly wind direction

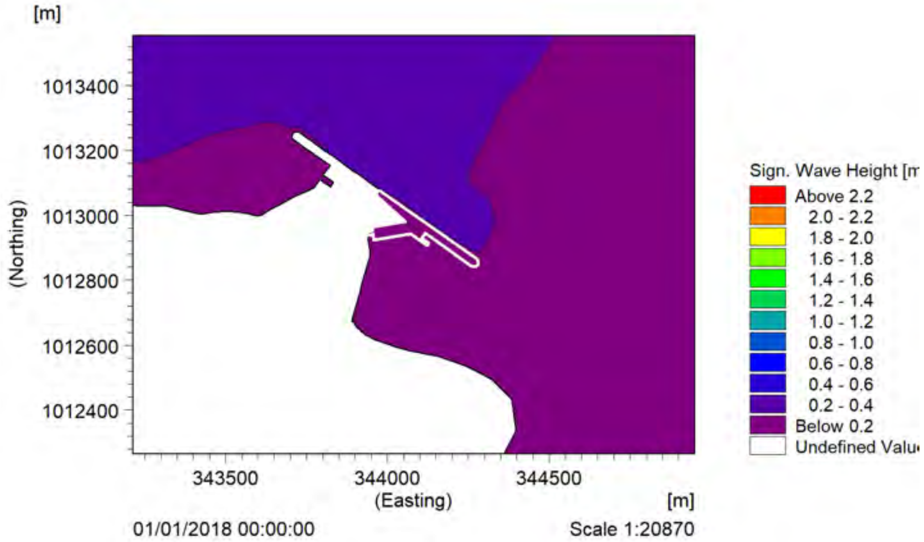


Figure C-25 Predicted Hs (m), 30 knots north-westerly wind direction

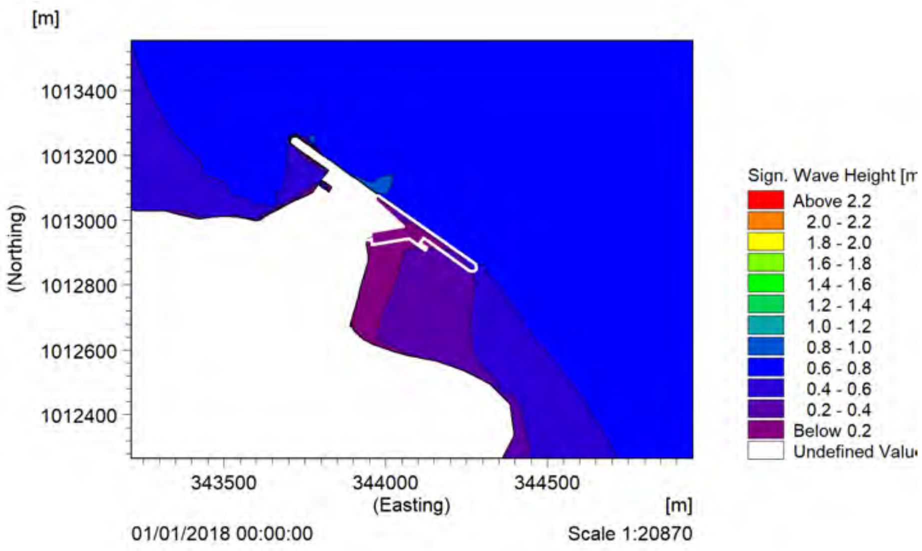


Figure C-26 Predicted Hs (m), 30 knots northerly wind direction

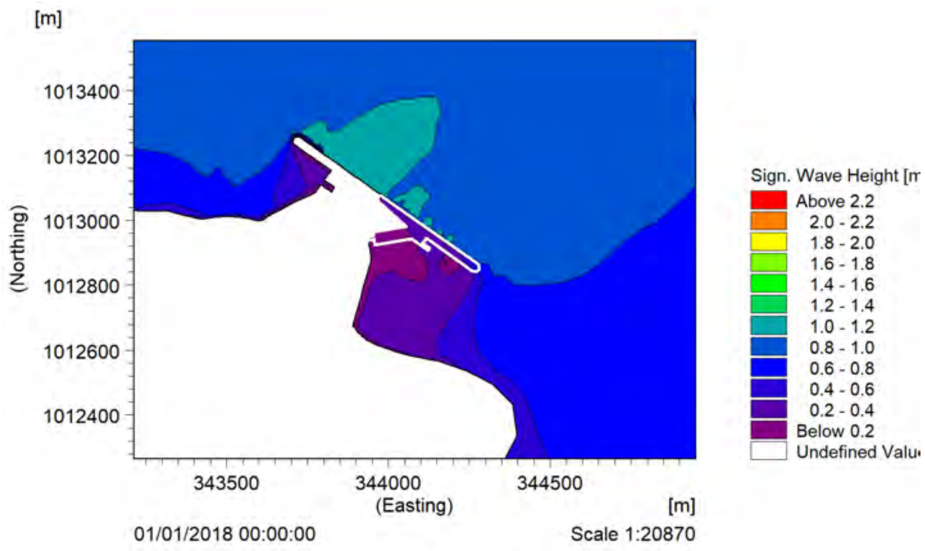


Figure C-27 Predicted Hs (m), 30 knots north-easterly wind direction

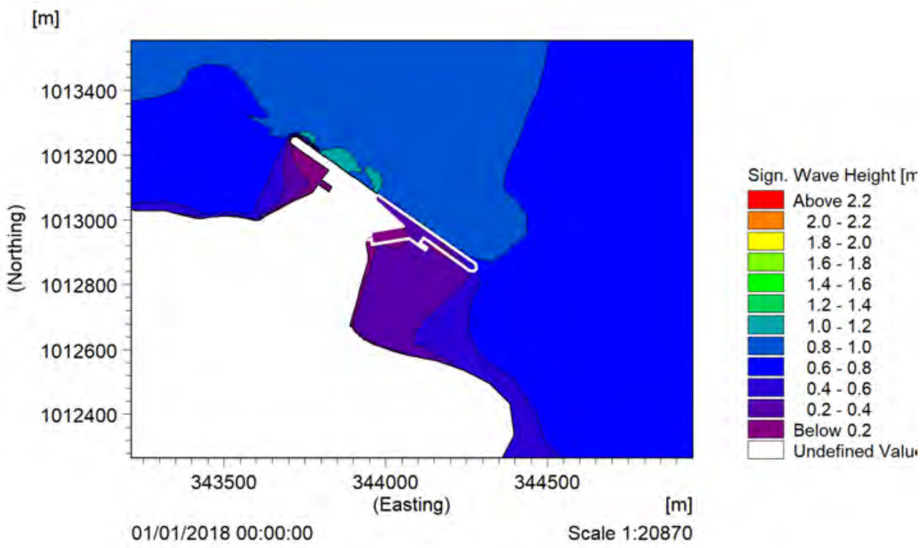


Figure C-28 Predicted Hs (m), 30 knots easterly wind direction

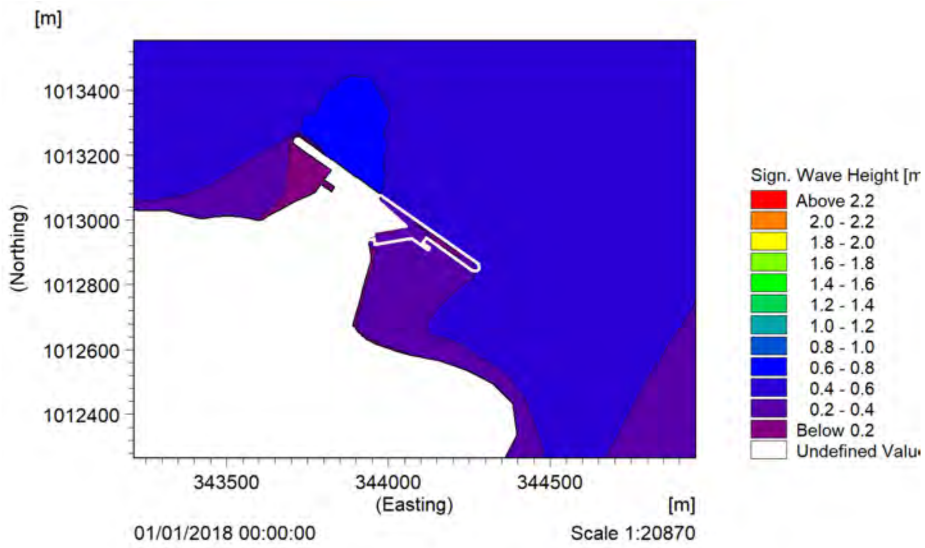


Figure C-29 Predicted Hs (m), 1-in-1 year north-westerly wind direction

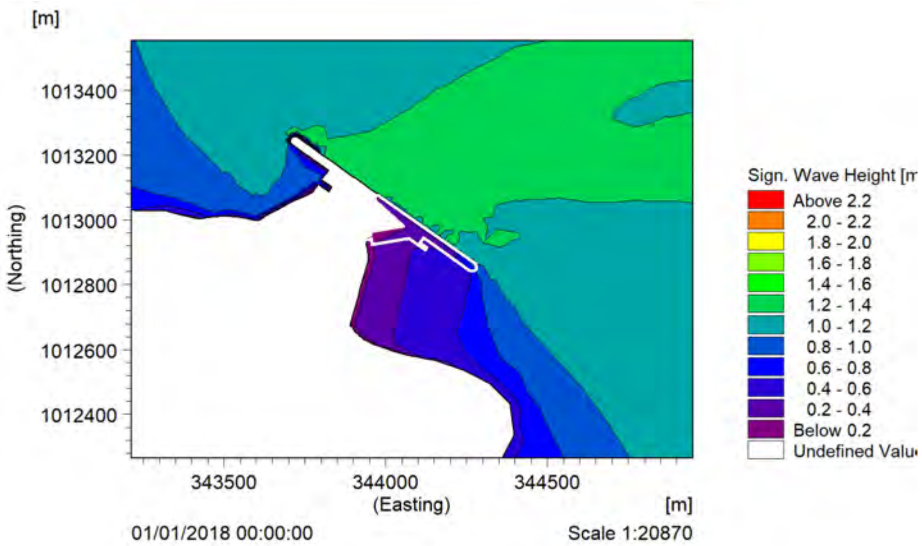


Figure C-30 Predicted Hs (m), 1-in-1 year northerly wind direction

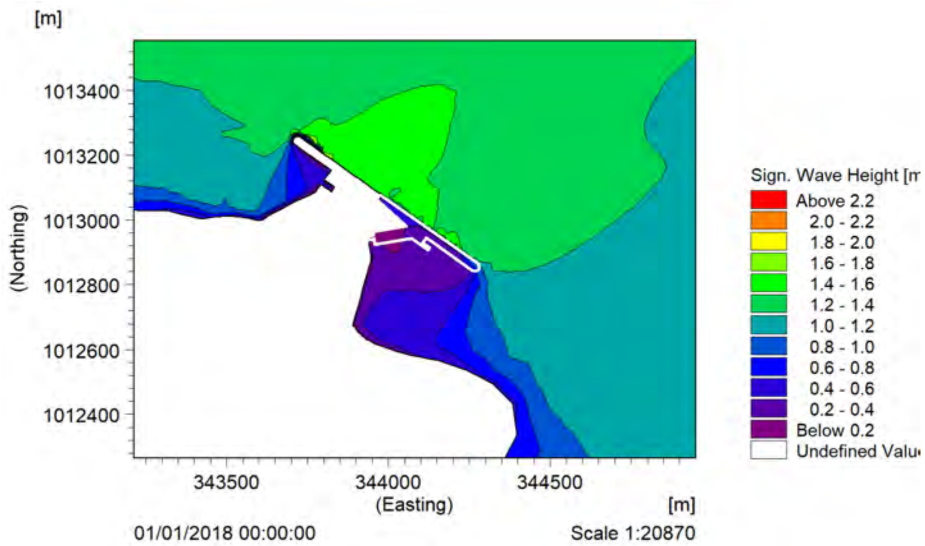


Figure C-31 Predicted Hs (m), 1-in-1 year north-easterly wind direction

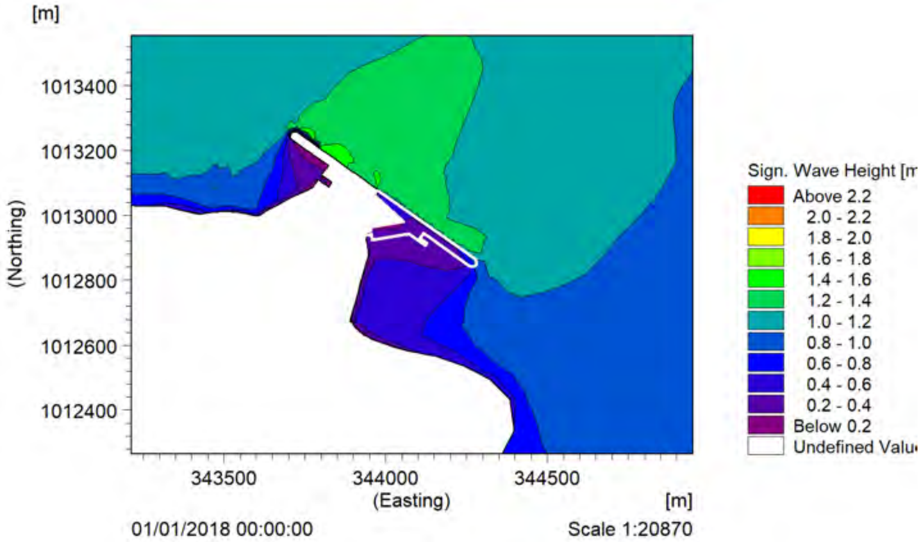


Figure C-32 Predicted Hs (m), 1-in-1 year easterly wind direction

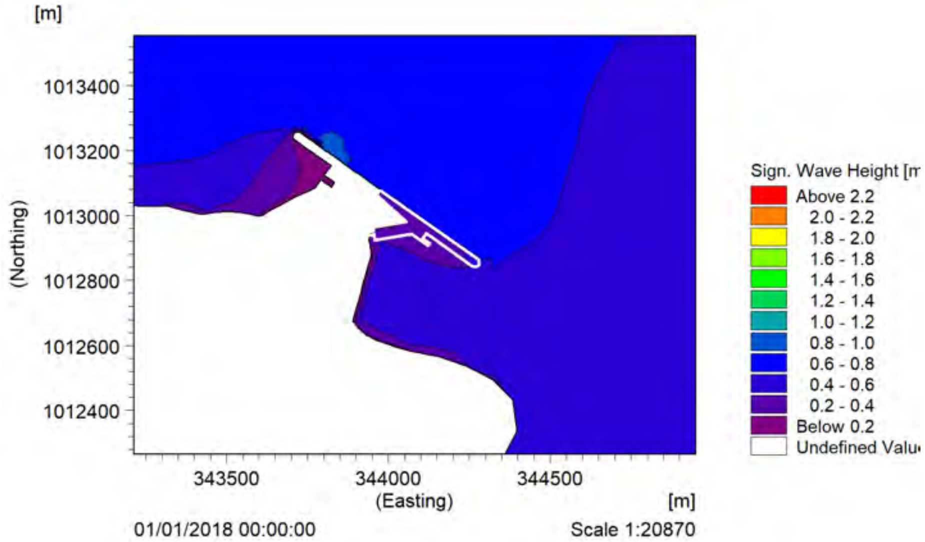


Figure C-33 Predicted Hs (m), 1-in-10 year north-westerly wind direction

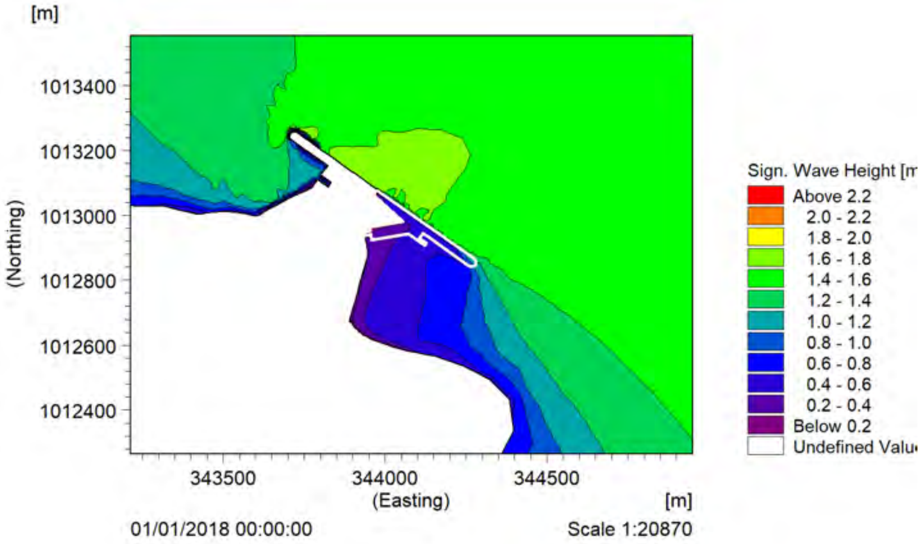


Figure C-34 Predicted Hs (m), 1-in-10 year northerly wind direction

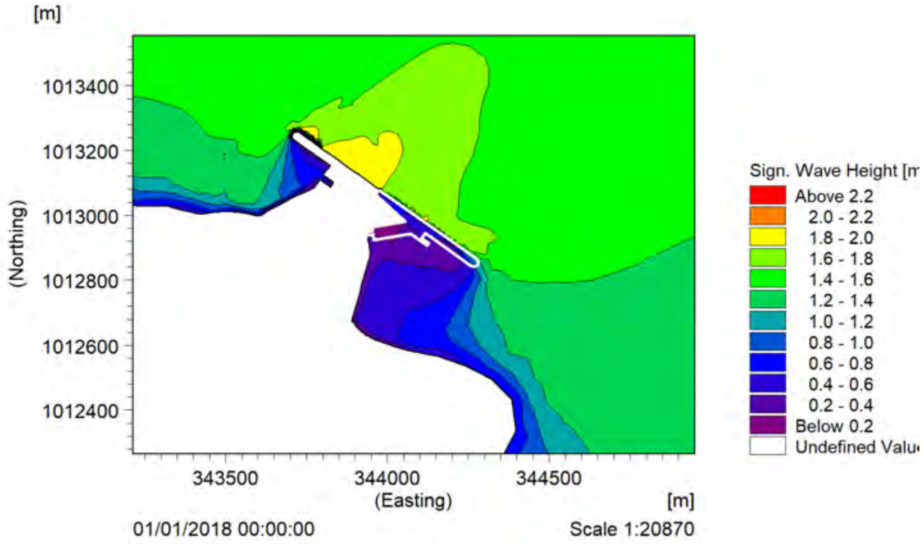


Figure C-35 Predicted Hs (m), 1-in-10 year north-easterly wind direction

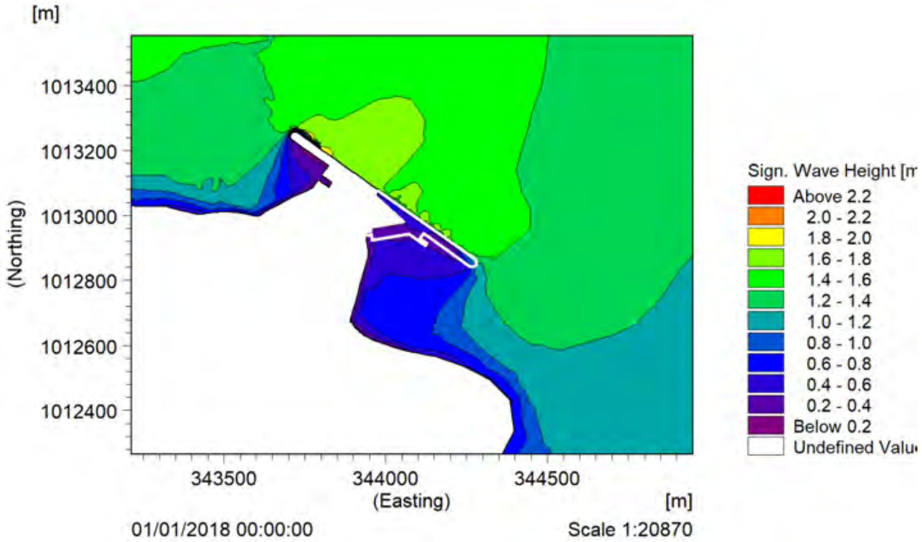


Figure C-36 Predicted Hs (m), 1-in-10 year easterly wind direction

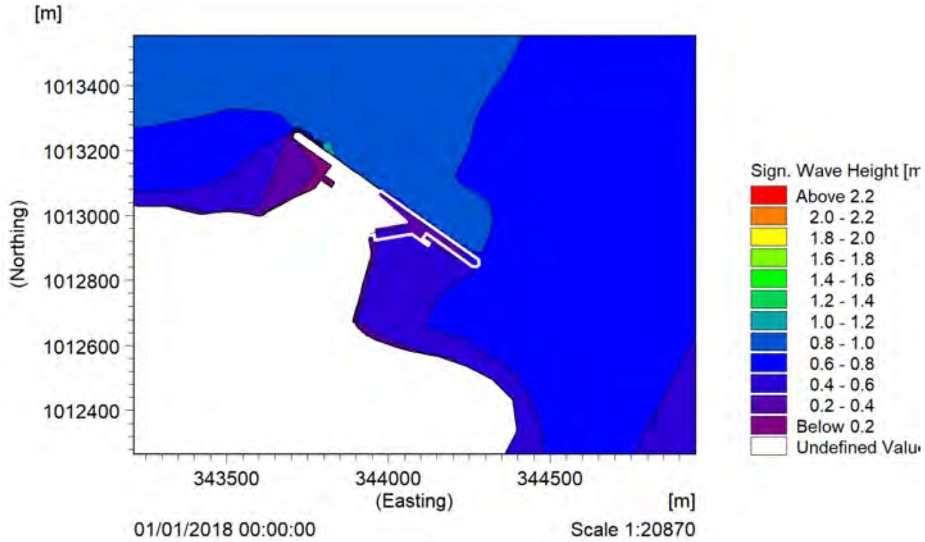


Figure C-37 Predicted Hs (m), 1-in-50 year north-westerly wind direction

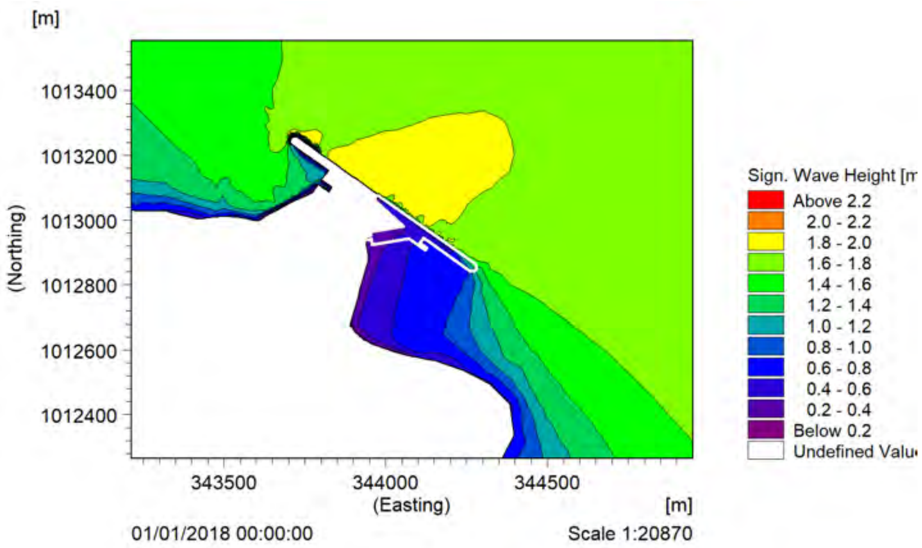


Figure C-38 Predicted Hs (m), 1-in-50 year northerly wind direction

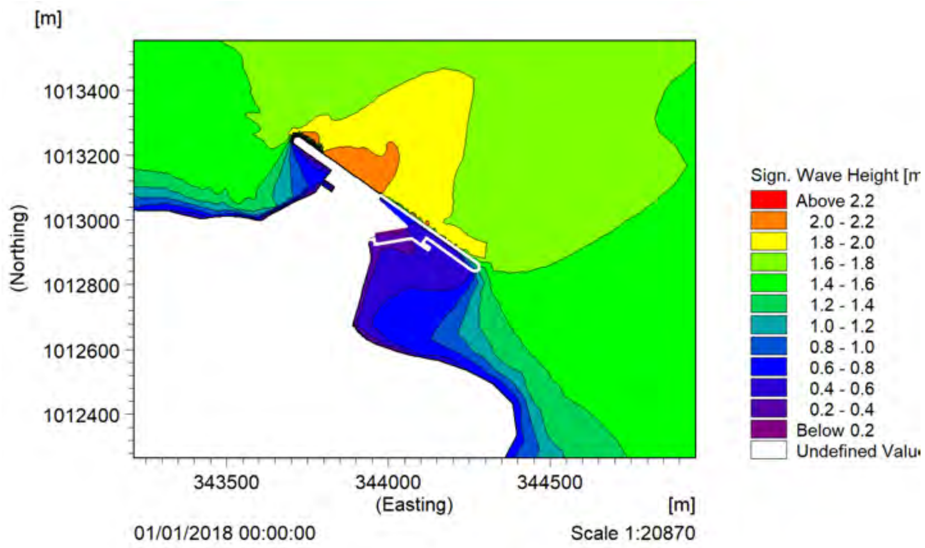


Figure C-39 Predicted Hs (m), 1-in-50 year north-easterly wind direction

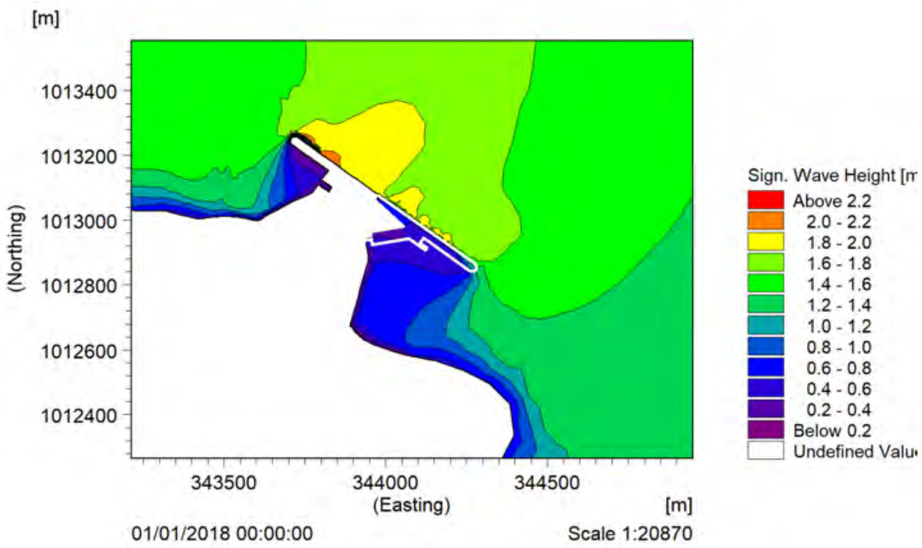
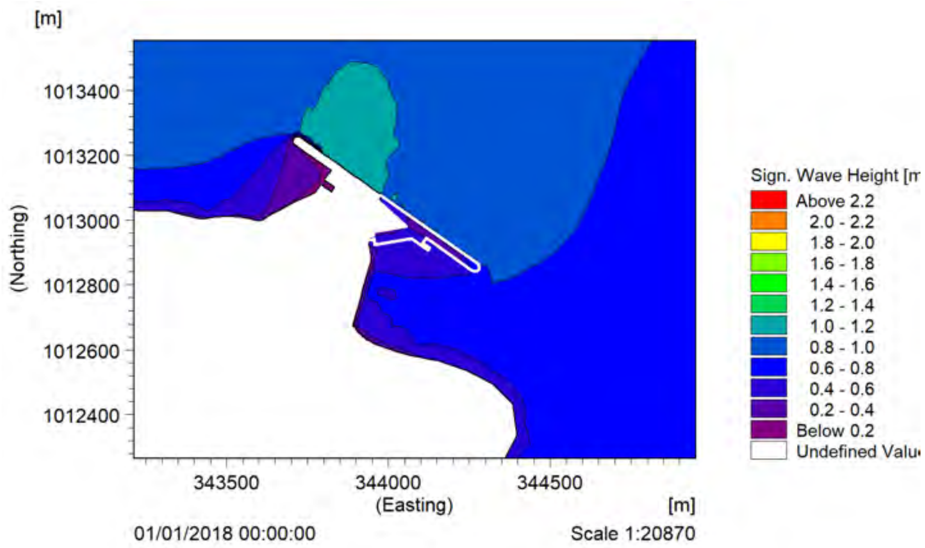


Figure C-40 Predicted Hs (m), 1-in-50 year easterly wind direction



C.3 PEAK WAVE PERIOD RESULTS TABLES

For the output locations depicted above, the resulting Tp for each wind speed condition at the four directional sectors are presented in Table D-1 to Table D-4.

Table C-1 Predicted Tp (s), for a north-westerly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01	2.10	3.00	3.62	3.96	4.10	2.00	2.79	3.33	3.40	3.87
WV-H02	2.10	2.99	3.61	3.96	4.10	2.01	2.85	3.45	3.73	3.93
WV-H03	2.09	2.99	3.61	3.95	4.09	2.07	2.97	3.58	3.92	4.04
WV-H04	2.09	2.99	3.62	3.96	4.09	2.04	2.92	3.53	3.85	3.98
WV-H05	2.09	2.99	3.62	3.96	4.09	2.10	3.00	3.63	3.97	4.12
WV-H06	2.09	2.99	3.62	3.97	4.10	2.13	3.02	3.64	3.99	4.16
WV-H07	2.10	3.00	3.63	3.97	4.13	2.15	3.04	3.66	4.01	4.25
WV-H08	2.11	3.01	3.64	3.98	4.18	2.16	3.04	3.67	4.01	4.27
WV-H09	2.13	3.02	3.65	3.99	4.22	2.16	3.04	3.67	4.02	4.29
WV-H10	2.17	3.05	3.67	4.02	4.29	2.18	3.05	3.68	4.03	4.31
WV-H11	2.19	3.06	3.69	4.04	4.33	2.18	3.06	3.69	4.04	4.34
WV-H12	2.19	3.06	3.70	4.05	4.35	2.20	3.08	3.71	4.06	4.36
WV-H13	2.22	3.10	3.72	4.07	4.36	2.22	3.11	3.63	3.96	4.26
WV-H14 *	2.16	3.04	3.63	3.97	4.14	2.28	3.28	2.22	1.88	2.18
WV-H15 *	2.08	3.00	3.61	3.95	4.08	2.36	3.37	3.92	2.90	3.21
WV-H16 *	2.03	2.91	3.51	3.83	3.96	0.00	0.93	1.22	1.37	1.46
WV-H17 *	2.22	2.63	2.88	2.87	1.91	2.64	1.08	1.38	1.54	1.66
WV-H18 *	2.04	2.95	3.56	3.90	4.01	0.00	0.84	0.94	1.07	1.14
WV-H19	2.05	2.97	3.58	3.92	4.02	2.30	3.30	3.81	4.13	4.42
WV-H20	2.06	2.97	3.59	3.93	4.05	2.34	3.31	3.92	4.30	4.51

* These locations are in the lee of structures for one or both model scenarios and the periods predicted by the SW model may be anomalous. These data should therefore be treated with caution. More accurate and robust periods will require use of a Boussinesq wave modelling approach.

Table C-2 Predicted Tp (s), from a northerly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01	2.63	3.57	4.05	4.31	4.43	1.86	2.70	3.20	3.43	3.54
WV-H02	2.63	3.56	4.05	4.32	4.45	1.91	2.75	3.25	3.51	3.63
WV-H03	2.63	3.57	4.05	4.31	4.44	2.54	3.45	3.93	4.19	4.32
WV-H04	2.63	3.57	4.05	4.31	4.44	2.36	3.19	3.63	3.87	4.03
WV-H05	2.63	3.58	4.06	4.32	4.44	2.64	3.58	4.07	4.33	4.45
WV-H06	2.63	3.58	4.07	4.32	4.45	2.64	3.59	4.08	4.33	4.46
WV-H07	2.63	3.57	4.05	4.31	4.43	2.64	3.59	4.09	4.34	4.48
WV-H08	2.62	3.56	4.03	4.30	4.42	2.64	3.58	4.06	4.33	4.45
WV-H09	2.63	3.56	4.03	4.30	4.42	2.63	3.57	4.04	4.31	4.43
WV-H10	2.63	3.56	4.04	4.31	4.43	2.63	3.56	4.03	4.31	4.43
WV-H11	2.62	3.55	4.02	4.31	4.42	2.63	3.56	4.03	4.31	4.42
WV-H12	2.62	3.55	4.02	4.30	4.42	2.62	3.55	4.02	4.31	4.42
WV-H13	2.61	3.54	4.01	4.30	4.41	2.61	3.55	4.01	4.30	4.42
WV-H14	2.63	3.58	4.04	4.32	4.43	2.62	3.58	4.05	4.33	4.45
WV-H15	2.63	3.57	4.03	4.31	4.43	2.64	3.59	4.07	4.35	4.48
WV-H16 *	2.29	2.89	3.44	4.04	4.25	2.72	3.68	3.03	2.60	1.43
WV-H17 *	2.54	3.50	3.97	4.25	4.38	2.66	2.68	1.50	1.65	1.80
WV-H18 *	2.49	3.42	3.88	4.17	4.31	0.00	3.14	3.65	3.87	1.92
WV-H19	2.63	3.57	4.02	4.30	4.41	2.63	3.60	4.08	4.35	4.48
WV-H20	2.51	3.44	3.86	4.11	4.26	2.64	3.61	4.13	4.38	4.53

* These locations are in the lee of structures for one or both model scenarios and the periods predicted by the SW model may be anomalous. These data should therefore be treated with caution. More accurate and robust periods will require use of a Boussinesq wave modelling approach.

Table C-3 Predicted Tp (s), from a north-easterly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01 *	2.58	3.52	3.94	4.27	4.45	3.12	3.75	4.14	4.03	2.13
WV-H02 *	2.58	3.52	3.94	4.28	4.48	3.12	2.89	1.62	1.59	1.55
WV-H03	2.59	3.53	3.94	4.27	4.46	2.60	3.55	4.02	4.35	4.59
WV-H04	2.59	3.53	3.94	4.27	4.46	2.67	3.61	4.06	4.37	4.60
WV-H05	2.59	3.53	3.94	4.27	4.46	2.59	3.54	3.97	4.30	4.53
WV-H06	2.59	3.53	3.95	4.28	4.47	2.59	3.53	3.95	4.27	4.47
WV-H07	2.58	3.52	3.94	4.27	4.45	2.59	3.53	3.95	4.29	4.49
WV-H08	2.58	3.52	3.93	4.26	4.44	2.58	3.53	3.95	4.28	4.48
WV-H09	2.57	3.51	3.92	4.25	4.41	2.58	3.52	3.94	4.27	4.45
WV-H10	2.54	3.51	3.91	4.24	4.40	2.55	3.51	3.92	4.25	4.41
WV-H11	2.52	3.50	3.90	4.23	4.39	2.52	3.50	3.90	4.23	4.38
WV-H12	2.50	3.49	3.89	4.22	4.38	2.50	3.49	3.89	4.21	4.37
WV-H13	2.49	3.48	3.88	4.20	4.36	2.47	3.46	3.86	4.18	4.34
WV-H14	2.46	3.52	3.92	4.25	4.41	2.47	3.53	3.92	4.25	4.42
WV-H15	2.48	3.52	3.91	4.25	4.42	2.49	3.53	3.92	4.25	4.43
WV-H16 *	2.63	3.54	3.95	4.28	3.49	0.94	1.14	1.36	1.56	1.68
WV-H17 *	2.34	1.88	2.16	2.22	2.28	1.27	1.84	2.14	2.20	2.27
WV-H18 *	2.64	3.57	4.00	4.33	4.56	0.85	1.46	1.78	2.00	2.12
WV-H19	2.48	3.53	3.94	4.28	4.47	2.49	3.54	3.94	4.27	4.45
WV-H20	2.57	3.58	4.03	4.36	4.59	2.48	3.52	3.91	4.24	4.39

* These locations are in the lee of structures for one or both model scenarios and the periods predicted by the SW model may be anomalous. These data should therefore be treated with caution. More accurate and robust periods will require use of a Boussinesq wave modelling approach.

Table C-4 Predicted Tp (s), from an easterly wind direction

Output Location	Baseline (Pre-development)					Scheme (Post-development)				
	15 kts	30 kts	1:1	1:10	1:50	15 kts	30 kts	1:1	1:10	1:50
WV-H01 *	1.81	2.56	2.77	3.00	3.15	0.00	0.84	0.95	1.04	1.10
WV-H02 *	1.81	2.56	2.78	3.00	3.15	0.00	0.95	1.06	1.16	1.23
WV-H03 *	1.84	2.63	2.84	3.05	3.21	2.25	1.94	2.11	2.18	2.27
WV-H04 *	1.83	2.61	2.83	3.03	3.20	1.14	1.77	1.45	1.58	1.65
WV-H05	1.84	2.63	2.85	3.05	3.21	1.89	2.72	2.98	3.22	3.33
WV-H06	1.83	2.61	2.83	3.03	3.20	1.85	2.64	2.87	3.08	3.23
WV-H07	1.81	2.55	2.76	2.98	3.14	1.81	2.56	2.78	3.00	3.16
WV-H08	1.75	2.48	2.70	2.93	3.04	1.78	2.52	2.74	2.97	3.10
WV-H09	1.70	2.44	2.66	2.88	3.00	1.76	2.50	2.73	2.96	3.08
WV-H10	1.70	2.45	2.68	2.90	3.02	1.71	2.45	2.67	2.89	3.01
WV-H11	1.68	2.41	2.63	2.84	2.97	1.67	2.41	2.63	2.84	2.97
WV-H12	1.61	2.34	2.55	2.76	2.89	1.64	2.37	2.58	2.79	2.92
WV-H13	1.59	2.31	2.52	2.72	2.85	1.59	2.32	2.53	2.73	2.86
WV-H14	1.36	2.03	2.22	2.43	2.51	1.36	2.02	2.21	2.41	2.49
WV-H15	1.34	2.00	2.19	2.37	2.46	1.34	2.00	2.18	2.36	2.45
WV-H16	1.36	2.01	2.20	2.40	2.47	1.36	2.01	2.20	2.40	2.46
WV-H17	1.41	2.09	2.27	2.46	2.61	1.41	2.08	2.26	2.46	2.60
WV-H18	1.34	1.99	2.18	2.37	2.45	1.18	1.76	1.93	2.10	2.17
WV-H19	1.31	2.10	2.30	2.49	2.56	1.33	2.11	2.32	2.55	2.68
WV-H20	1.72	2.47	2.69	2.92	3.05	1.70	2.47	2.70	2.94	3.05

* These locations are in the lee of structures for one or both model scenarios and the periods predicted by the SW model may be anomalous. These data should therefore be treated with caution. More accurate and robust periods will require use of a Boussinesq wave modelling approach.