Appendix Q Wave Modelling Report

PORT of TOWNSVILLE
Nexus North Queensland

Appendix Q
Wave Modelling Report

Townsville Marine Precinct Project
Environmental Impact Statement

GHD

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1. Background

GHD has been commissioned by the Port of Townsville Ltd (PoTL) to undertake the PoTL Marine Precinct Environmental Impact Statement (EIS). As part of the study, historical data analysis and wave modelling studies are to be undertaken to provide design data for assessment of construction and infrastructure components.

1.1 Scope of Works

The wave modelling component of this project is to be prepared as an integral part of the EIS for the Port of Townsville Marine Precinct. The aim of the wave modelling is to provide a detailed investigation to facilitate a breakwater option selection process prior to the project being granted appropriate approvals. The wave modelling will be used to assist in identifying breakwater options, which fulfil the required purposes of providing sheltered moorings and a sheltered swing basin for the Marine Precinct.

Based upon the ToR, under which the EIS is progressing, the wave modelling study shall:

- Provide information on the average nearshore wave climate adjacent to the project site;
- Provide information on average wave conditions which will be used in the set-up and application of the hydrodynamic model
- Assess performance of various breakwater options to identify a preferred option ; and
- Undertake detailed modelling to evaluate wave penetration into the berthing areas and the marina for the preferred option.

1.2 Site Location

Townsville is located in North Queensland, Australia, approximately 1,200 km north of Brisbane. The proposed development will be to the south of the existing Port of Townsville and at the mouth of Ross River, at the western end of Cleveland Bay. Magnetic Island, situated directly north of the site provides protection from northerly waves. Cape Cleveland to the east provides protection from the south-easterly trade winds such that only waves from the north east directly affect the site. Offshore waves from other directions can reach the site at reduced heights through refraction around Cape Cleveland and Magnetic Island.

The Townsville coastline is naturally protected from offshore wave conditions by the Great Barrier Reef, which sits approximately 70 km from the shoreline. It is therefore expected that wave climate in the area is mostly governed by local winds, acting on the area between the reef and the coastline and within Cleveland Bay.

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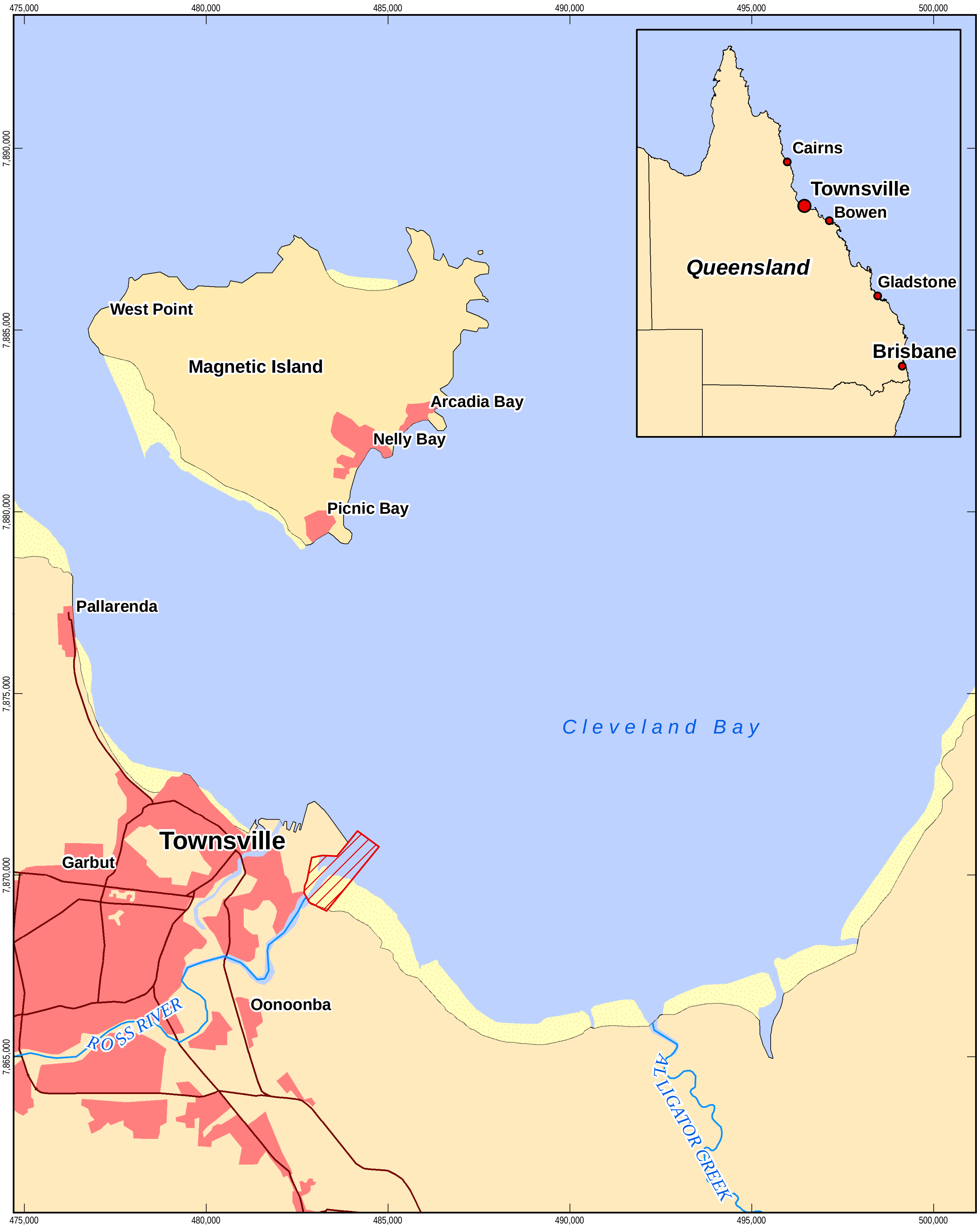

LEGEND

Project Area of Interest | Watercourse | Major Road | Builtup Area | Foreshore Flat

1:140,000 (at A4)

0 1 2 3 4 5

Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 55

N

Port of Townsville
Marine Precinct EIS

Job Number 42-15399
Revision A
Date 01 July 2009

Project Location

Figure 1

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Level 4 201 Charlotte Street Brisbane QLD 4000 Australia **T** +61 7 3316 4496 **F** +61 7 3316 333 **E** bnemail@ghd.com.au **W** www.ghd.com.au

Data source: Project AOI - GHD; Aerial (flown 2004) - ©The State of Queensland (Department of Environment and Resource Management); 250K Topo Data - ©Commonwealth of Australia (Geoscience Australia) 2007. Created by: TH

LEGEND

Breakwater Option B	Proposed Marine Precinct	Shed	Fuel Berth	Temporary Hardstand
Breakwater Option A	Stage 1	Maintenance (Open Hardstand)	Marine Infrastructure	Unloading Berth
Min and Max Option	Stage 2	Industrial Shed	Ramp	Trawler/Commercial Berth
	Stage 3	Barge Berth	Shed - Stage 3	Work Berths

1:10,000

0 50 100 150 200 250

Metres (at A4)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 55

N

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PORT of TOWNSVILLE

Port of Townsville
Marine Precinct EIS

Job Number 42-15399
Revision A
Date 06 Feb 2009

Proposed Site Layout and Breakwater Options

Figure 2

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2 / 100 Goondoon Street Gladstone QLD 4680 Australia T 61 7 4972 6377 F 61 7 4972 6236 E gltmail@ghd.com.au W www.ghd.com.au

Data source: Imagery (flown 2004) - NRW ©The State of Queensland (Department of Natural Resources and Water) November 2007. Proposed marine precinct, Breakwater options - GHD 2009.

1.3 Methodology

Review of the geography of the site confirms that the port is naturally protected from open ocean wave climate by the Great Barrier Reef. As a result, waves are generally limited to locally generated waves. The large distance between the reef and the coastline, on the other hand, suggests that relatively large waves could be generated during large storms.

The modelling study was undertaken through hindcasting of the wave climate employing the MIKE 21 SW model. Various sets of wind data are available around the site and a combined wind field was prepared as the model input.

The model was calibrated based on the wave buoy recordings available from Cleveland Bay and additional ADCP data. The calibrated model is then utilised to investigate performance of the study options.

Reviewing the available wind data, wind conditions representing average wind climate at the site were extracted and the SW model was employed to produce time series of wave data at the boundary of the nearshore hydrodynamic model.

Finally, after selection of the preferred breakwater arrangement, the breakwater alignment was optimised using MIKE 21 BW Boussinesq Wave model.

2. Physical Data

2.1 Bathymetric Data

Numerical wave models resolve the wave propagation equations based on site specific information including bathymetric data. As the model for Townsville Marine Precinct is driven by wind fields, a relatively large area needs to be included in the model to allow for wave forming and propagation.

The bathymetric data for large regions is generally referenced to Admiralty Charts. Australian Admiralty Charts provide detailed information on the bathymetry of regional seas. In addition to the published versions of the charts, a digital database of chart data is available as part of the MIKE modelling package. This database, called CMAP, provides detailed water depth and coastline information all around the world. The bathymetry of the site has therefore been based on the CMAP information and the four Australian Admiralty Charts as listed in Table 1.

Table 1 Admiralty Charts Townsville Region

Chart No.	Coverage
AUS 256	Cleveland Bay and Approaches
AUS 827	Cape Bowling Green to Palm Isles
AUS 828	Palm Isles to Brook Passage and Palm Passage
AUS 371	Whitsunday Passage to Palm Isles

2.2 Aerial Images

A set of aerial images from various years are available. The images cover the period between 1974 and 2003. The images have not been directly used in the modelling works, however have been used in the littoral transport assessment, reported separately.

2.3 Tide Data

Tide levels for the Port of Townsville are based on AUS 256 and as listed in Table 2. The water level variation of up to 4.0m has a considerable effect on the nearshore wave height and was included in the detailed modelling works by employing a varying water level based on indicative tidal ranges for the model simulations.

Table 2 Tide Levels for Townsville (LAT Datum)

Station	Lat (S)	Long (E)	HAT	MHWS	MWHN	MSL	MLWN	MLWS
Townsville	19°15’	146°50’	4.0	3.1	2.2	2.0	1.6	0.7

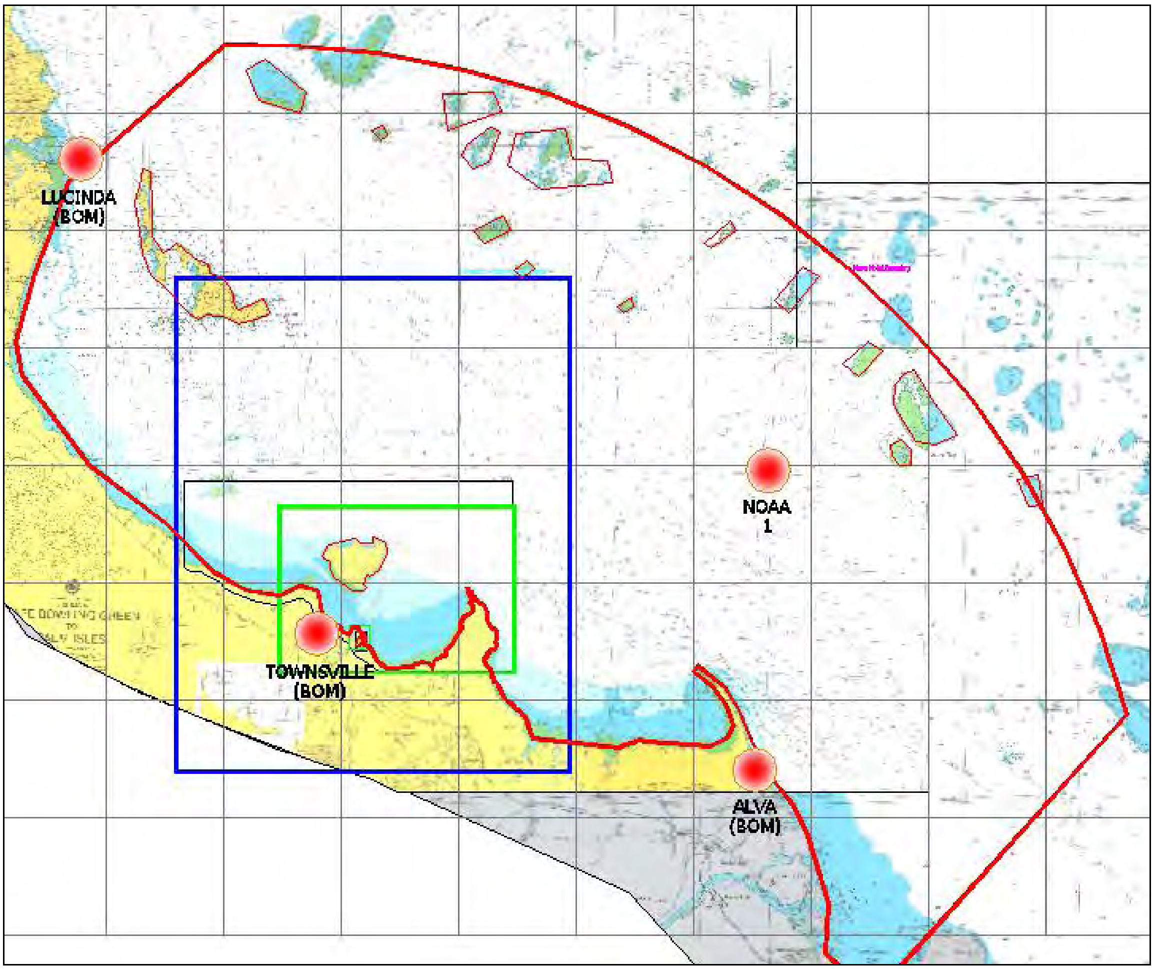
2.4 Wind Data

The locations of wind stations used in the modelling are shown in Figure 3, with the exception of NOAA2, further offshore, directly north of NOAA1. The sites of Townsville, Lucinda and Alva Beach are all maintained by the Bureau of Meteorology (BOM) and are real time measurements. The NOAA data is extracted from the WaveWatch III model, a global hindcast model that develops wave conditions based on wind data predicted by weather models. Data has been extracted at two nodes, NOAA1 and NOAA2, for this study.

The available data covers the period between 1997 and 2007. The data was processed and then interpolated over a matrix of 10*8 cells covering the modelled area. The produced wind field was then employed as the driving force for generation of waves. Wind roses were created for each station, samples of which can be seen in Figure 4.

Wind data was also processed to extract the ambient conditions. As it can be seen in Figure 5, wind speed at all stations around the site is generally between 5 and 10m/s, exceeding 10m/s for less than 15% of the time.

Figure 3 Locations of the Input Wind Data



**Reproduced from Admiralty Chart AUS827, copyright Commonwealth of Australia, user license number 2475SB*

Figure 4 Wind-Roses for NOAA1 and Townsville

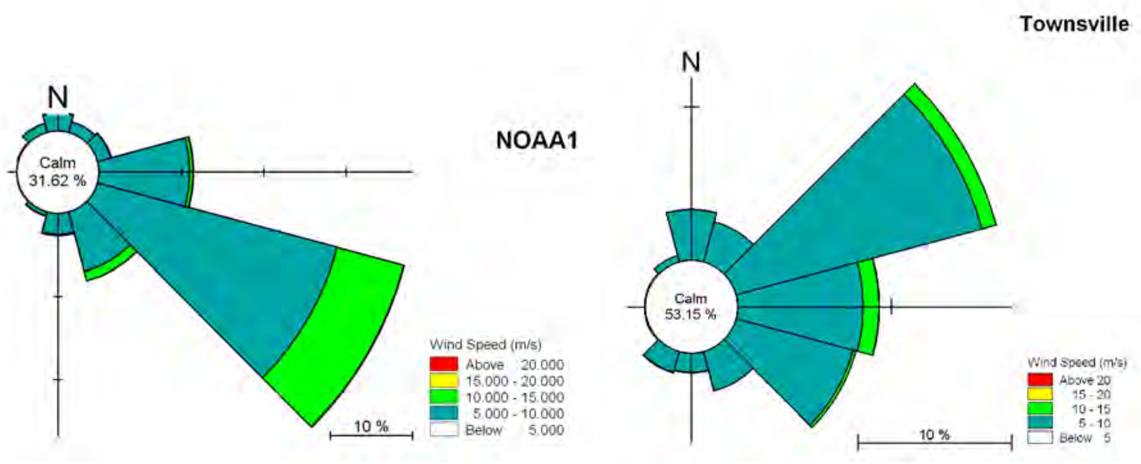
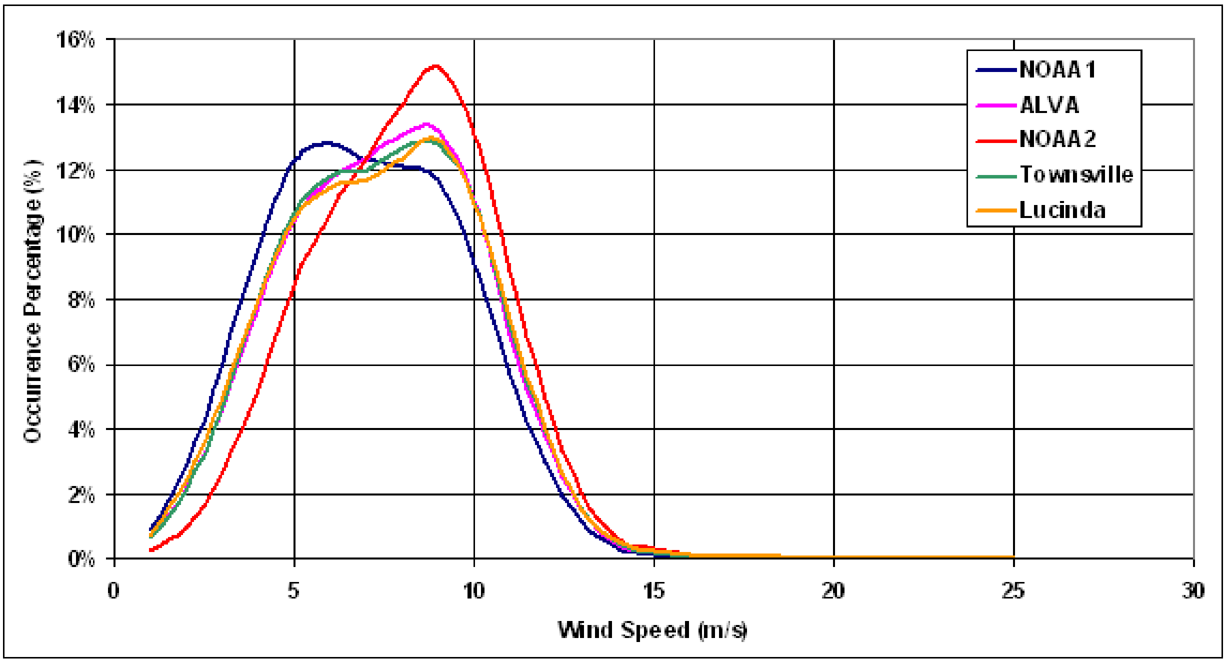


Figure 5 Distribution of wind speed at the studied stations



2.5 Nearshore Measurements

ADCP recorders have been deployed at two locations close to the site. The wave data from ADCP units is utilised in the calibration of the wave and hydrodynamic models. The coordinates of the deployment points are listed in Table 3 and shown in Figure 6.

Table 3 Location of ADCP Deployments

ADCP	Position		Deployment Period
1	Lat / Long:	$19^0$12.048' S, $146^0$54.519'E	Start: 15/08/08 13:00
	MGA Zone 55:	490397.011, 7876951.712	End: 22/09/08 08:00
2	Lat / Long:	$19^0$10.798'S, $146^0$58.736'E	Start: 15/08/08 11:00
	MGA Zone 55:	497785.130, 7879259.306	End: 22/09/08 08:00

The results of the ADCP calibration are reported in section 3.4.

LEGEND

ADCP Locations | Project Area of Interest | Proposed Marine Precinct | Proposed Breakwater

1:150,000(at A4)

0 1 2 3 4 5

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 55

Port of Townsville
Marine Precinct EIS

ADCP Deployment Locations

Job Number 42-15399
Revision A
Date 01 July 2009

Figure 6

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Data source: Marine Precinct ©The State of QLD (Port of Townsville LTD) 2009; ADCP locations - GHD; 250K Topo Data - ©Commonwealth of Australia (Geoscience Australia) 2009;. Created by: TH

3. Regional Wave Modelling Study

3.1 Numerical Model

The wave model study was undertaken utilising DHI's MIKE 21 SW Flexible Mesh model.

The SW model is a spectral wind-wave modelling program used in the assessment of wave climates in offshore and coastal areas, for both forecast and hindcast applications. It operates on a flexible mesh and can be dynamically coupled with the 2D/3D flow model, MIKE 21 HD.

The SW model can be utilised to evaluate various nearshore wave propagation effects including refraction, shoaling, breaking, wave growth, wave-wave and wave-current interaction as well as wave diffraction around headlands and islands.

GHD has successfully calibrated and applied SW models on a number of projects around the world and in Australia.

3.2 Modelling Domain

Initial evaluation of wave climate at Townsville reveals that waves are generally locally generated and propagate in the same direction as the wind. Within Cleveland Bay, waves generally propagate from Cape Cleveland towards Townsville. The presence of the southern patches of Great Barrier Reef with relatively few major deep channels offshore suggests that transmission of Pacific Ocean swells towards the nearshore areas is negligible.

Considering the nature of waves along the coastline, a closed boundary domain was employed to model the growth and propagation of waves. The model boundary to the northeast was established at the inner limits of Great Barrier Reef and from southeast and northwest was limited to provide a model area of approximately 150 km long. The model area then allows generation of wind generated waves over sufficiently long fetch lengths. The Digital Elevation Model (DEM) was created within the model domain. The DEM as employed in the modelling study can be seen in Figure 7. Five variations of the DEM focusing on the nearshore area were generated to investigate the alternative options envisaged during the project inception period. These options are shown in Figure 8.

Figure 7 Digital Elevation Model of Entire Area from Lucinda to Bowen

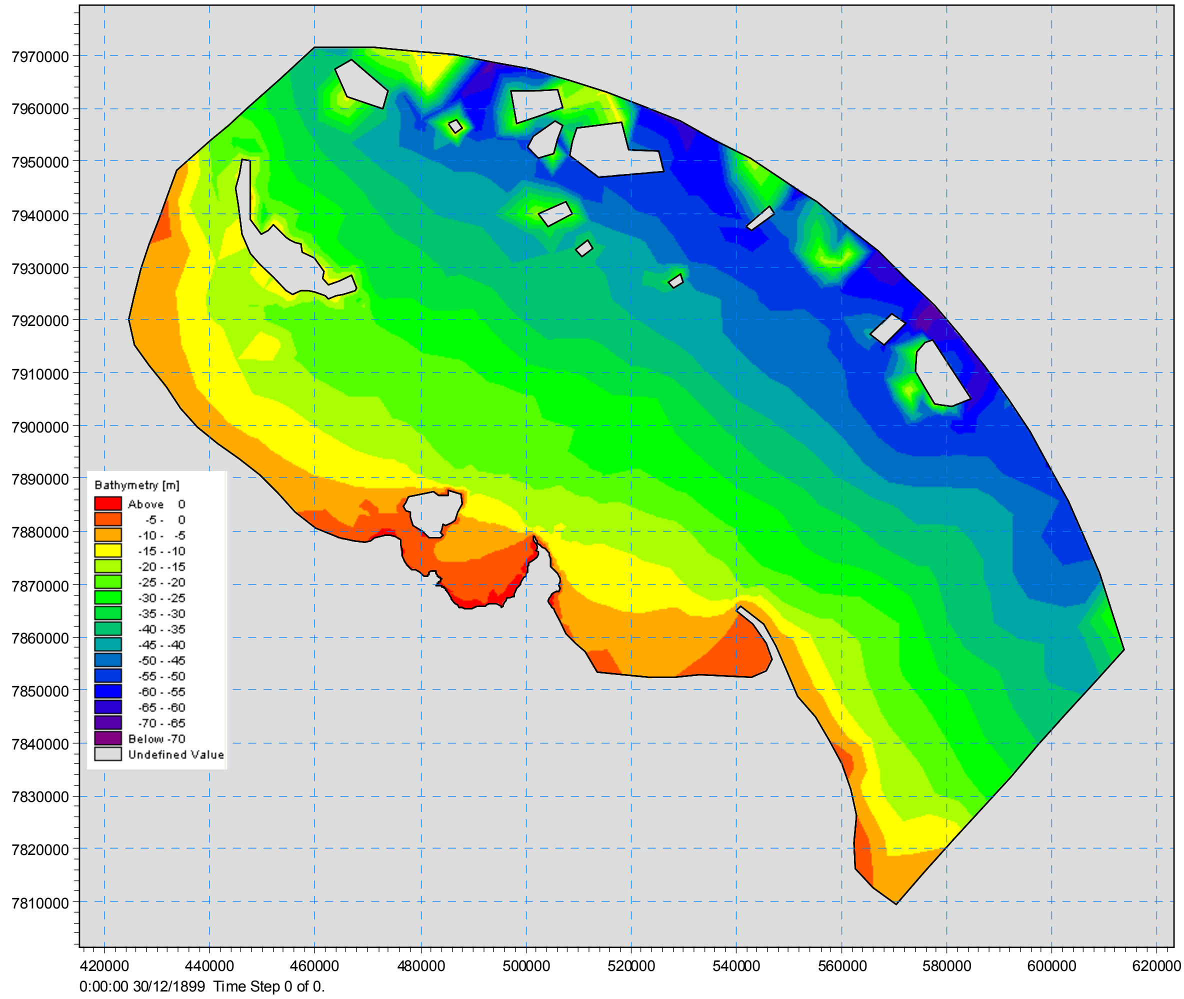
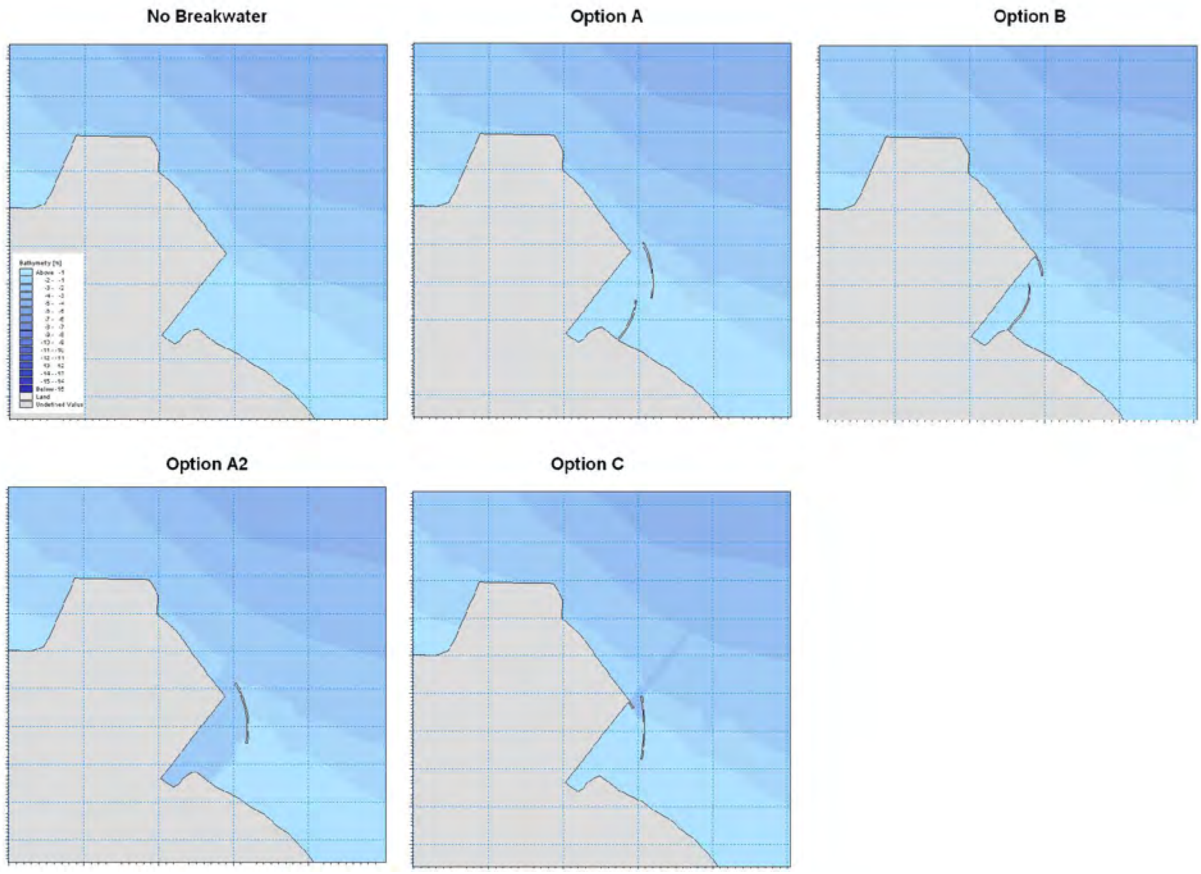


Figure 8 Nearshore Model Bathymetry – 5 Options Studied



3.3 Boundary and Climatic Data

As described earlier, the Townsville regional model has been setup as a closed boundary model, assuming that the amount of wave energy transferred from offshore of Great Barrier Reef to the near shore area is negligible. As a result, the model is run as a wave hindcast/transformation model. The input data for the hindcast model is the wind time series collated from various stations around the site.

In order to establish specific time windows of wind, describing various climatic conditions, a detailed statistical analysis of the available wind data was carried out. Based on the analysis, two month long time series representing the average and predominantly northerly conditions were selected. In addition to the actual historical data, two extreme wind conditions describing the 1 in 1 and 1 in 100 year return period storms were estimated based on Australian Standard 1170.

Additionally, a short window of time was selected as the basis for calibration during which a reasonably large storm had been recorded by the Cape Cleveland wave rider buoy. The resulting wind conditions for the model study are summarised in Table 4, below.

Table 4 Model scenarios and their respective wave condition

Scenario	Condition/Application	Actual Time	Source
Extreme I	1 in 1 year 19m/s (3s Gust) 11m/s (10 hour average)	N/A	AS/NZS1170
Extreme II	1 in 100 year 59m/s (3s Gust) 33m/s (10 hour average)	N/A	AS/NZS1170
Ambient I	Average Ambient Condition	1 Apr 2000 to 30 Apr 2000	BOM & NOAA
Ambient II	Northerly Winds	5 Jan 1998 to 15 Jan 1998	BOM & NOAA
Calibration I	Model Calibration	12 Jan 2004 to 31 Jan 2004	BOM & NOAA

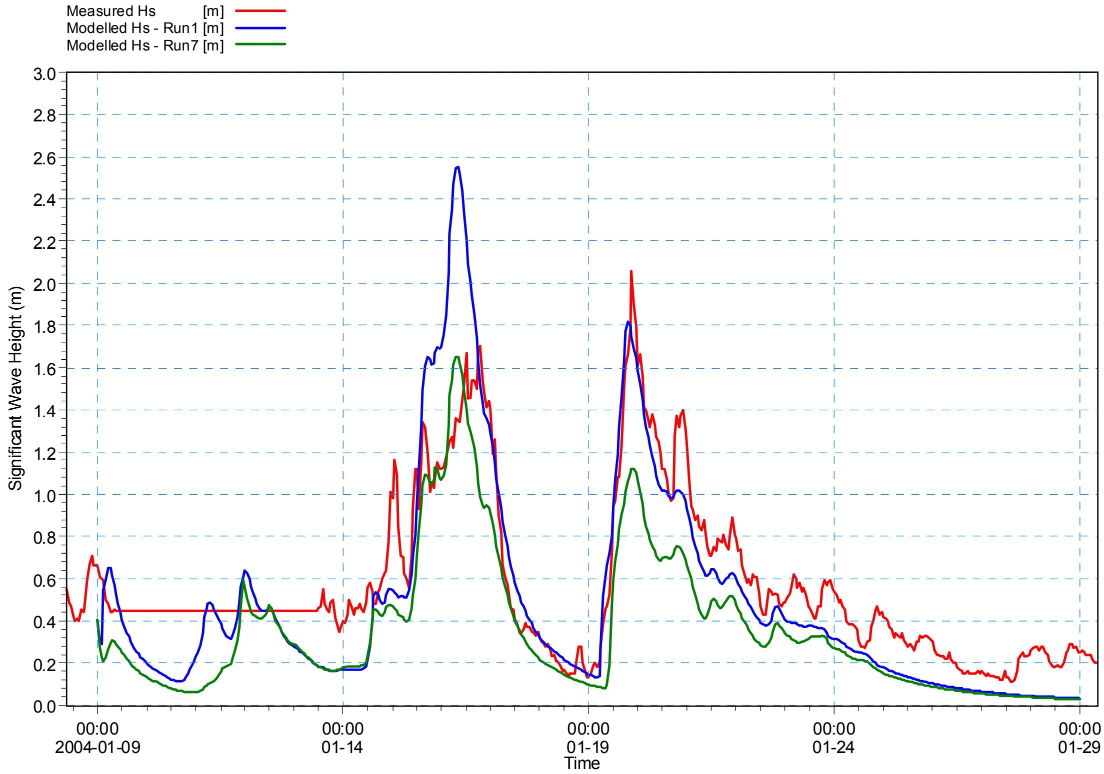
3.4 Model Calibration

Commercial models such as MIKE21 SW have been extensively tested in various modelling conditions. Nevertheless, due to variability of the physical conditions at different sites, it is necessary to calibrate the model against local recording and observations.

Model calibration and verification for this project was carried out in two stages. In the first stage, the reliability of wave generation was tested against the recorded buoy data from Cape Cleveland. As described in the previous section, the calibration scenario was based on approximately two weeks of recordings at Cape Cleveland. Various parameters including bed friction, white capping and wind generation settings were adjusted to calibrate the results.

A time series of the recorded data and model results is shown in Figure 9. The initial model results show that although the predictions are generally acceptable, the forecast time series do not consistently correlate to the recorded data. In particular, the first peak shows a greater difference than the second peak, which can be attributed in some respects to large scale wind field model that has been adopted. However, as the output from the first stage of the modelling is used only in a qualitative assessment of the wave conditions around the site, the results were deemed to be satisfactory. For the initial studies, calibration #7 as shown in Figure 9 was adopted.

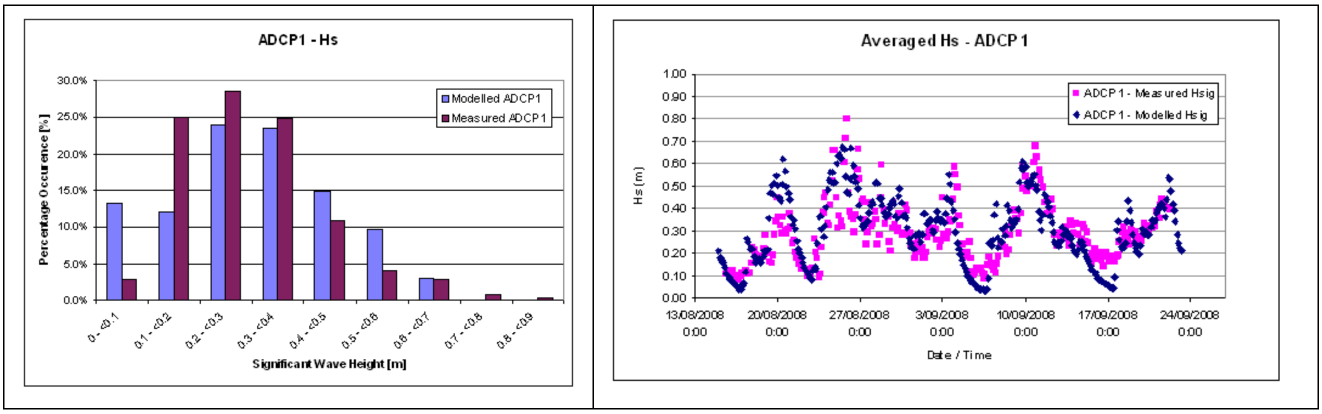
Figure 9 Hindcast and Measured Wave Height



The model was later calibrated to the ADCP data that was collected as part of the overall study. The locations and deployment periods are detailed in section 2.5. A comprehensive calibration was undertaken, with the main conclusions provided here.

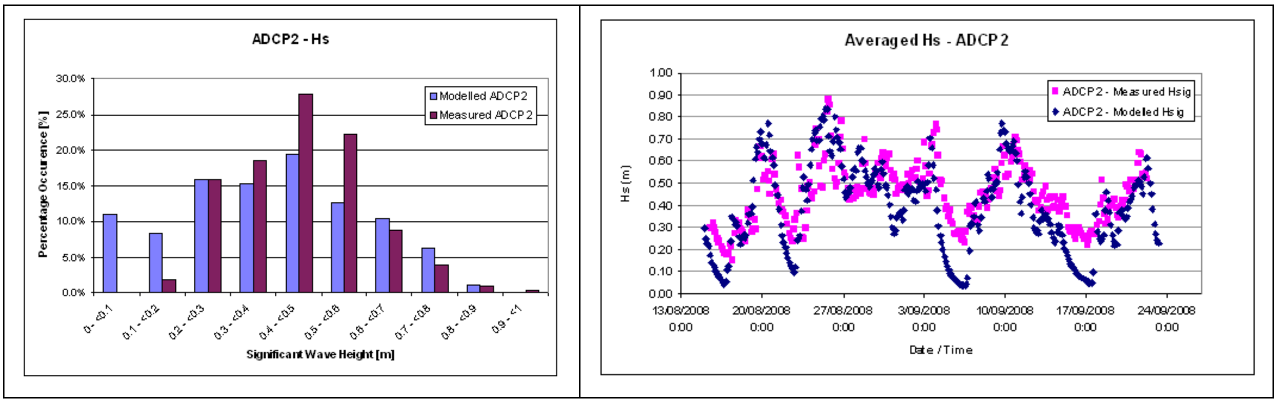
At the location of ADCP1, which is inside Cleveland Bay, the following is noted in terms of wave height. For the measured data, significant wave heights range as high as 0.9m, with 81% being less than 0.4m and 56% being less than 0.3m. The maximum record wave height in the modelled data was 0.7m, with 73% of the waves less than 0.4m and 50% less than 0.3m, which is comparable with the recorded distribution. Referring to Figure 10, the correlation between measured and modelled wave height is very good and provides confidence in the model.

Figure 10 ADCP1 Significant Wave Height Comparison



ADCP 2 is located further out in Cleveland Bay, near Cape Cleveland. Measured wave heights at the location were up to 1m, with 86% less than 0.6m and 36% less than 0.4m. Modelled wave heights corresponded well to the measured data, with heights up to 0.9m, 83% less than 0.6m and 50% less than 0.4m, refer Figure 11. There was however a higher prevalence of small wave heights (less than 0.2m) in the modelled data - 19% as compared to 2% for the measured data. These discrepancies appear to be localised and have been resolved by the time the waves reach ADCP1, further inshore, refer above.

Figure 11 ADCP2 Significant Wave Height Comparison



One concern that has arisen from the calibration analysis is the indication of long period swell wave penetration into Cleveland Bay which has not been considered in the modelling due to the offshore presence of the Great Barrier Reef.

However, the swell wave heights measured are less than 0.3m, as indicated by the ADCPs, which will not become a problem for the marine precinct. In addition, longer period waves are less likely to penetrate the breakwaters, so would be excluded from a harbour tranquillity assessment.

Regardless, the significant wave heights at both locations appear to be well calibrated and there is still a clear dominant wave direction of north-east (45 degrees) shown in all data sets at the location of the proposed breakwater and marina precinct.

Overall, analysis of the ADCP data in conjunction with the model gives confidence in the modelling process moving forward into detailed design.

3.5 Model Results

Following the calibration stage, the model was utilised to investigate wave conditions in the operational and extreme conditions listed earlier.

3.5.1 Extreme Wave Conditions

Nearshore wave heights for 1 in 1 year and 1 in 100 year return period conditions are expected to be around 1.0m and 2.8m respectively. The wave heights offshore of Cleveland Bay in these conditions are respectively about 1.6 and 6.1m. The nearshore wave parameters in extreme 1 in 1 year and 1 in 100 year conditions are shown in Figure 12 to Figure 21.

Wave parameters were also extracted for a set of selected points along the proposed quay wall and outside the prospective breakwater. The points are shown in Figure 22 and the wave parameters are listed in Table 5 and Table 6. It should be noted that due to the model limitations with respect to diffraction and reflection, the wave conditions inside the breakwaters should be considered indicative only, hence the range of wave parameters experienced at Point 4 and Point 5 has been shown (Table 6). Further modelling of the preferred option using MIKE21 BW will accurately establish the wave conditions behind the breakwaters and in the harbour.

Outside the breakwater, Point 1 and Point 2 are in close proximity and show similar wave parameters (Table 5). However Point 3, which is located slightly further into the bay, shows a reduction in wave height, due to continued refraction and shoaling of the wave. As Point 3 is closer to the breakwater, the effects of the structure are reflected in the wave parameters produced at this location.

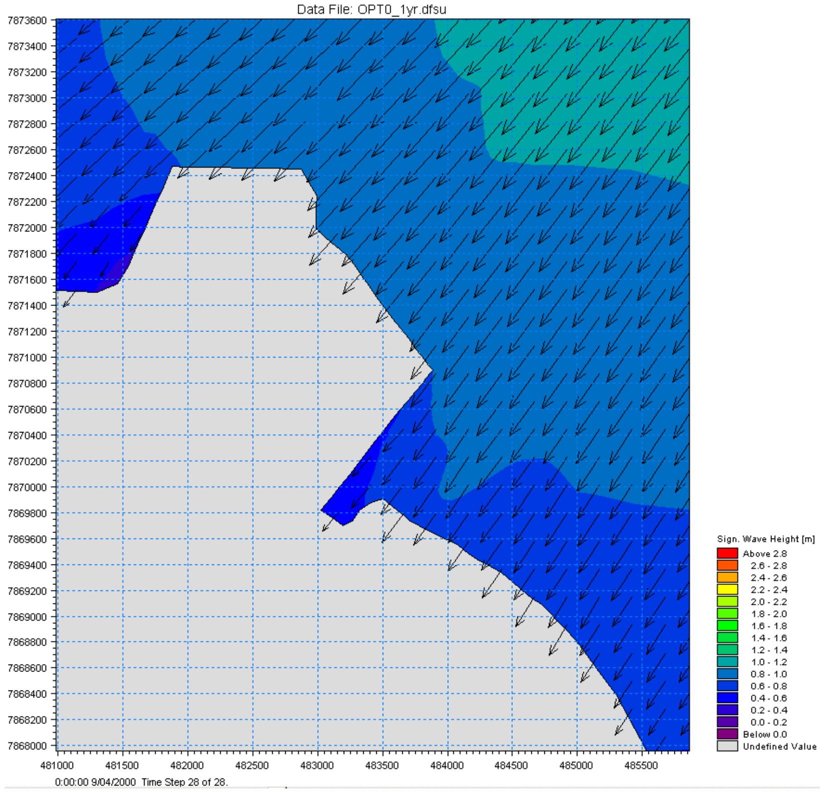


Figure 12 **No Breakwater Option**
1 in 1 year RP

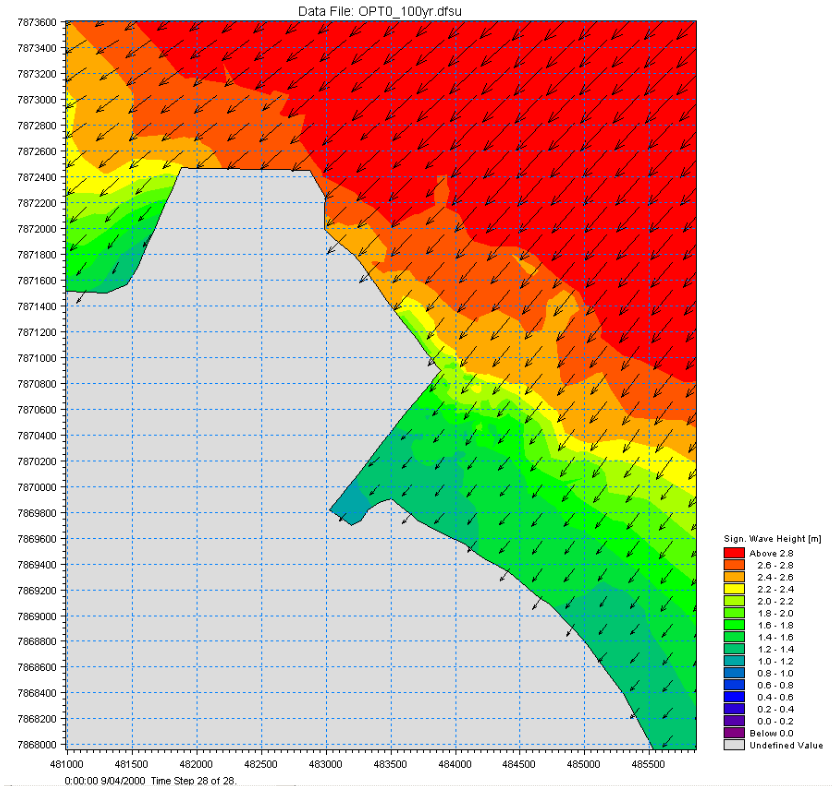


Figure 13 **No Breakwater Option**
1 in 100 year RP

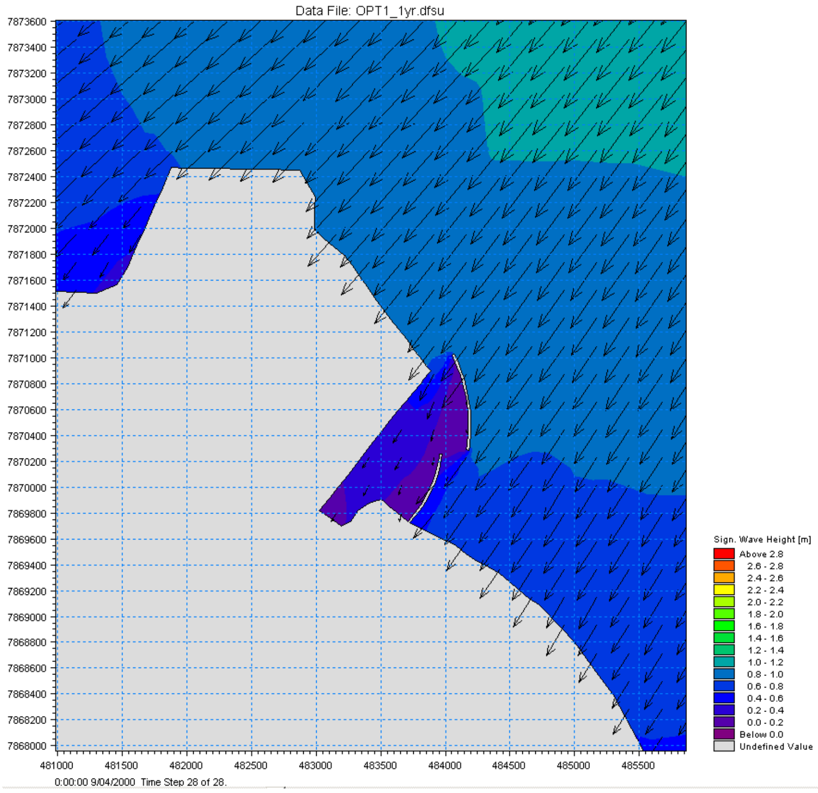


Figure 14 Option A
1 in 1 year RP

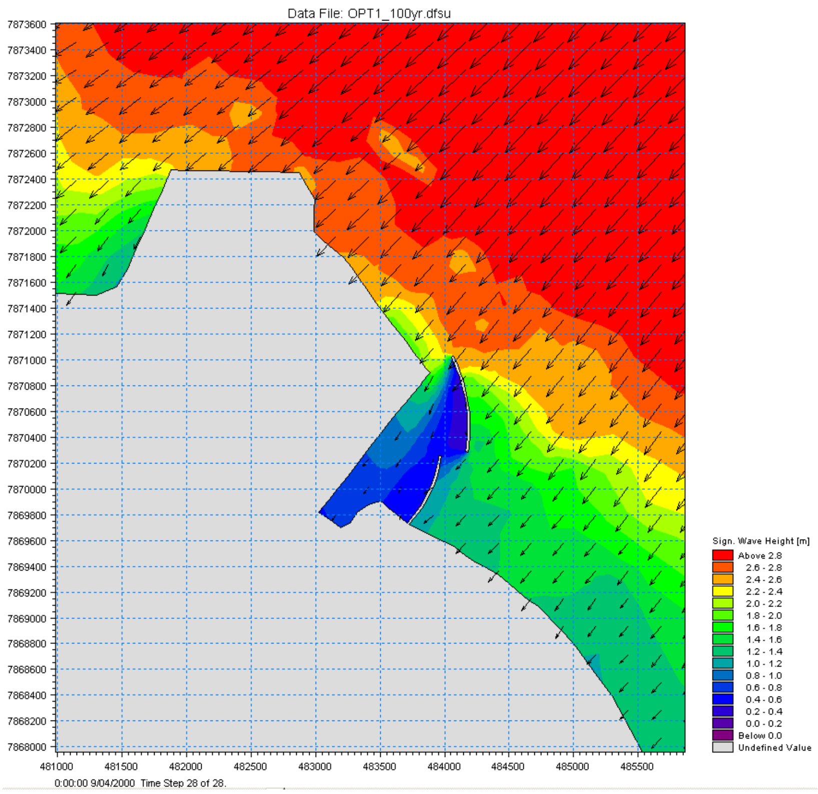


Figure 15 Option A
1 in 100 year RP

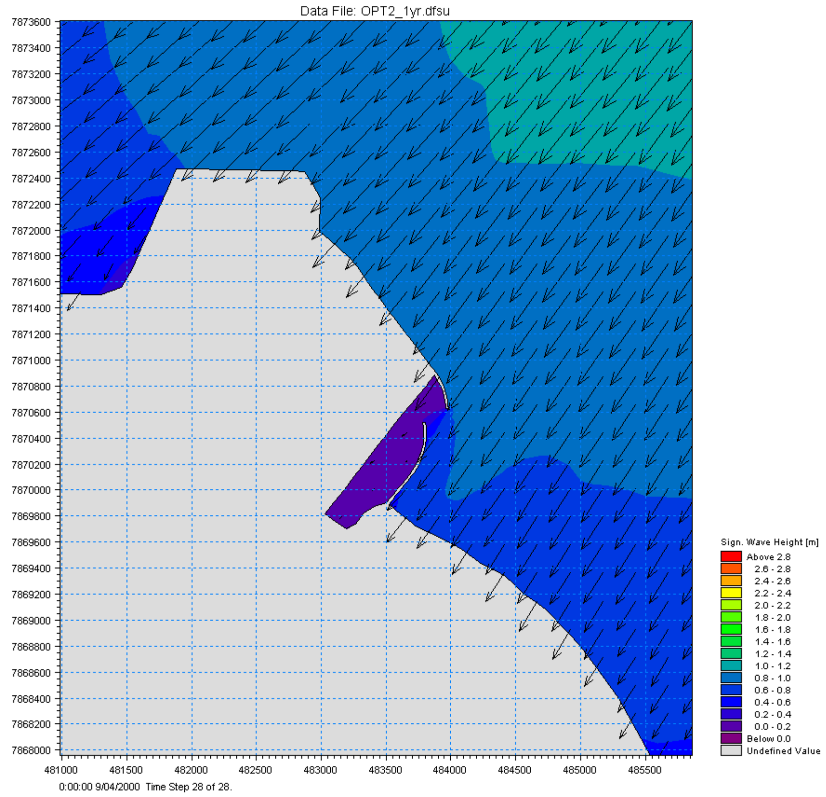


Figure 16 Option B
1 in 1 year RP

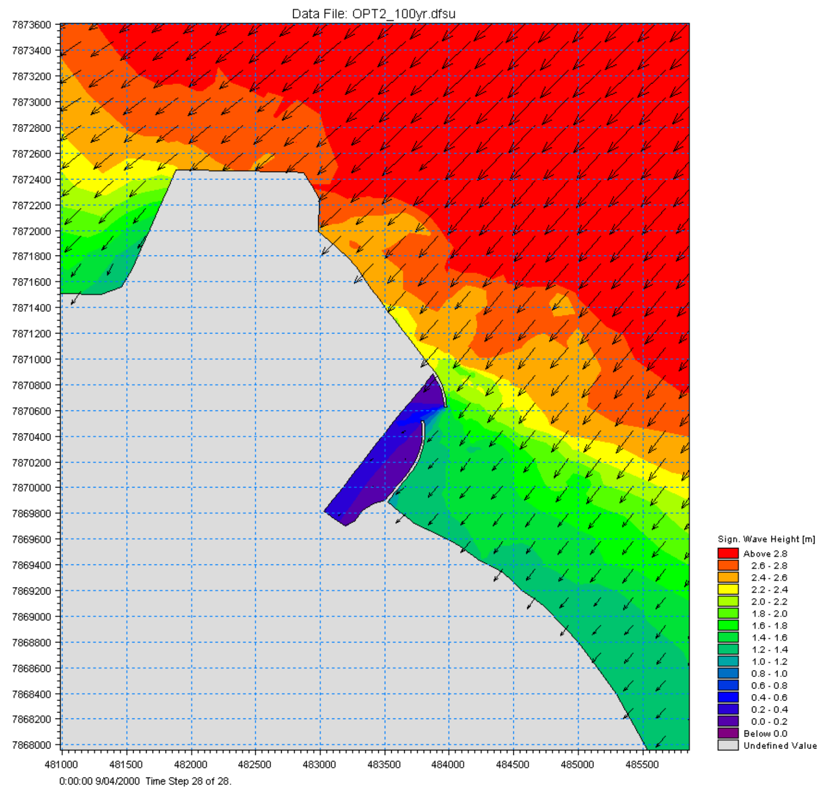


Figure 17 Option B
1 in 100 year RP

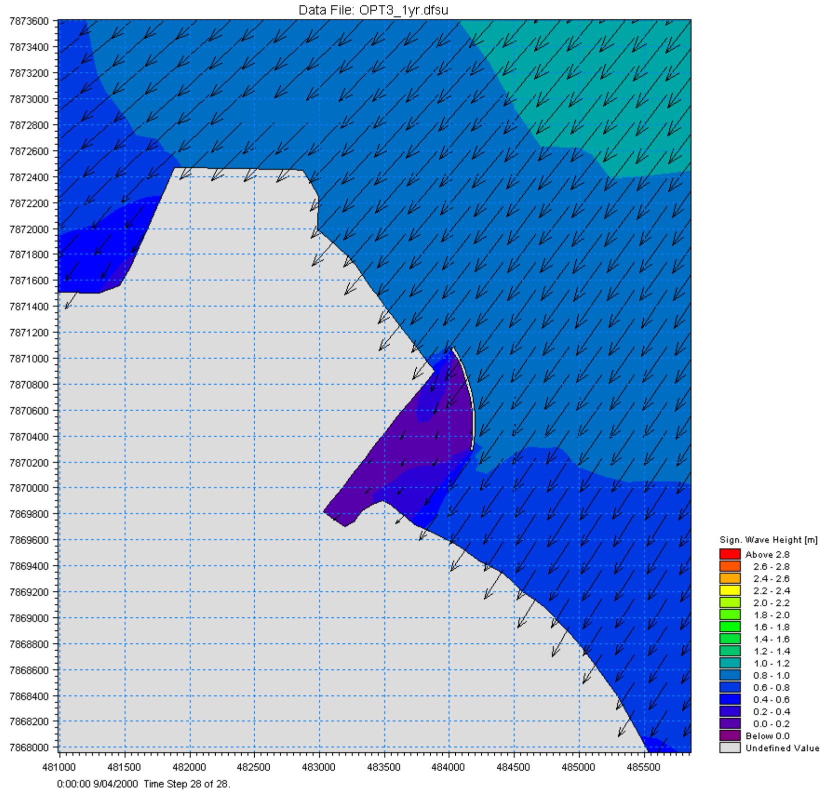


Figure 18 Option A2
1 in 1 year RP

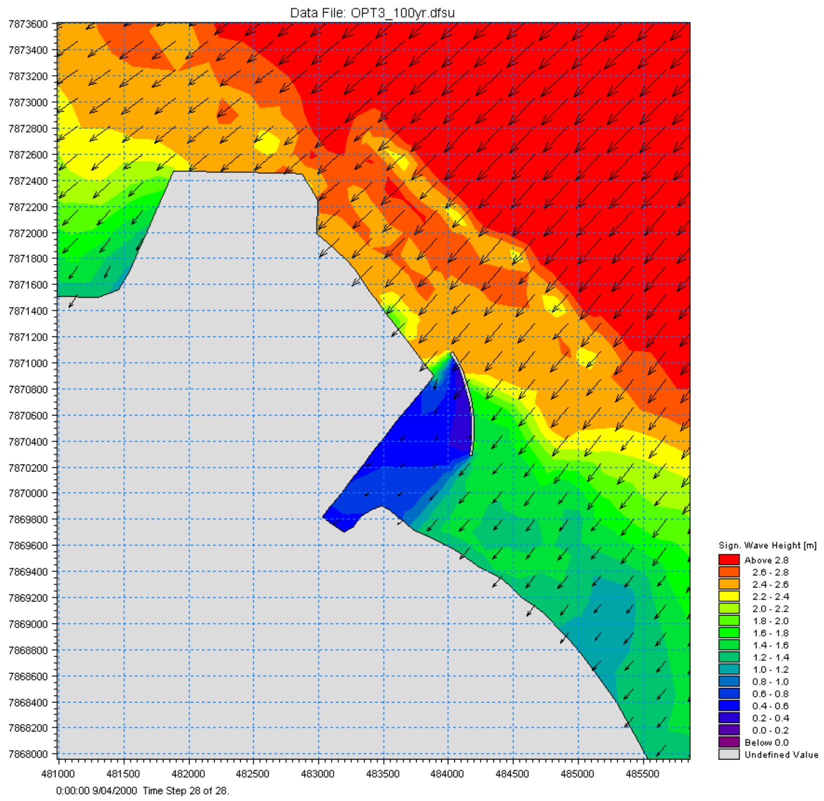


Figure 19 Option A2
1 in 100 year RP

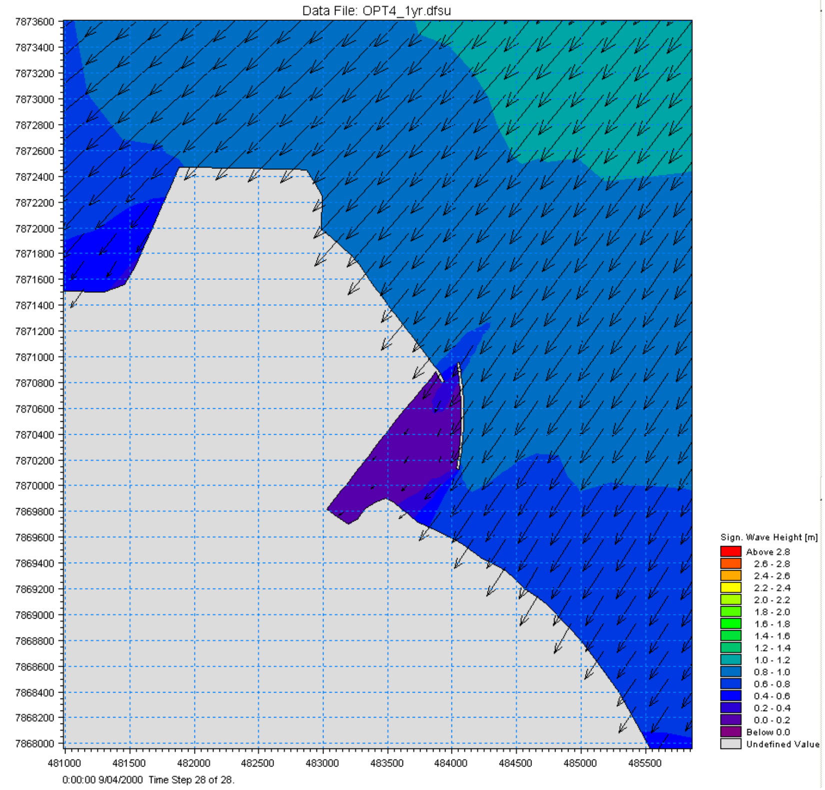


Figure 20 Option C
1 in 1 year RP

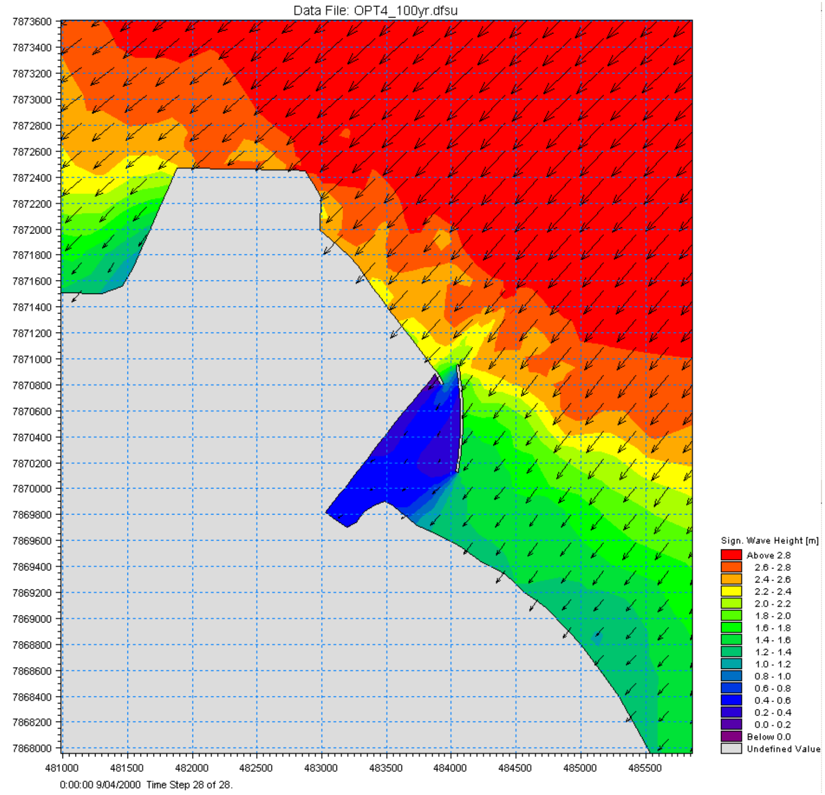
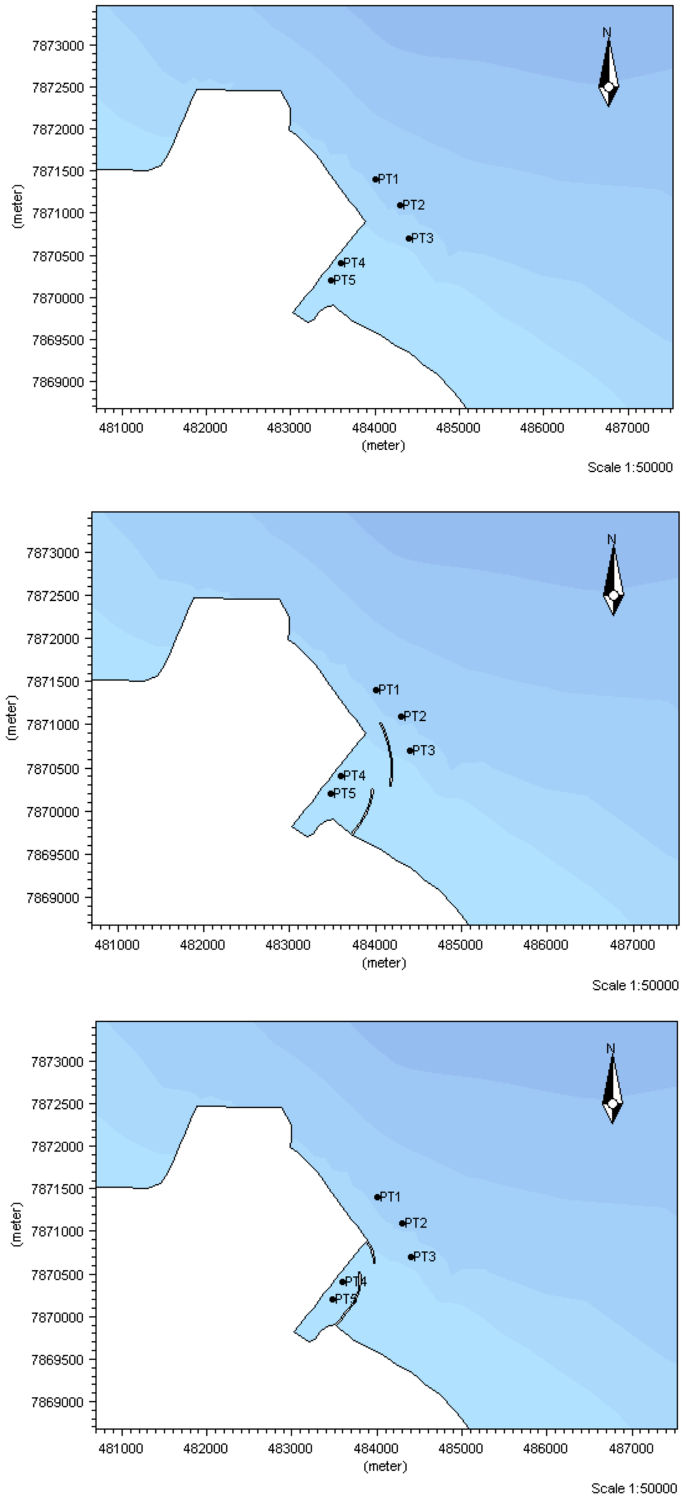


Figure 21 Option C
1 in 100 year RP

Figure 22 Selected points along the berth and outside prospective breakwaters




```
484000 7871400 0 PT1
484300 7871100 0 PT2
484400 7870700 0 PT3
483600 7870400 0 PT4
483480 7870200 0 PT5
```

**Table 5	Incident wave outside the breakwater**

Measurement points	Wave Parameters	No Breakwater RP: 1:100 years	 RP: 1:1 year
PT1	**Hs**	2.4 – 2.6	0.8 – 1.0
	Tp	9.0	6.0
	MWD	40	40
PT2	**Hs**	2.4 – 2.6	0.8 – 1.0
	Tp	9.0	6.0
	MWD	40	35
PT3	**Hs**	2.0 – 2.2	0.8 – 1.0
	Tp	9.0	6.0
	MWD	40	35

**Table 6	Wave parameters inside the harbour**

Option	RP (yr)	Hs	Tp PT4 / PT5	MWD
No Breakwater	**100**	1.2 – 1.4	9.0	45
	1	0.6 – 0.8	6.0	40
Option A	**100**	0.8 – 1.0	9.0	35
	1	0.2 – 0.4	6.0	30
Option B	**100**	0.2 – 0.4	9.0	55 – 60
	1	0.0 – 0.2	6.0	50 – 55
Option A2	**100**	0.4 – 0.6	9.0	40 – 60
	1	0.0 – 0.2	6.0	30 – 35
Option C	**100**	0.4 – 0.6	9.0	40 – 50
	1	0.0 – 0.2	6.0	35 – 40

Legend: *Hs = significant wave height (m*

Tp = peak wave period (sec)

MWD = mean wave direction (degrees N)

Ambient Conditions

As well as the extreme wave conditions, two operational conditions based on historic wind parameters were also simulated. The results from these cases can be used in the hydrodynamic model study or evaluation of wave agitation inside the precinct.

3.6 Conclusions and Recommendations

A wave model study was undertaken to evaluate performance of four (A, B, A2 and C) breakwater options and also to investigate the possibility of adopting a no breakwater option.

Initial model results reveal that the average wave heights at the location in yearly conditions can be as high as 1.0m. This suggests that, for the no breakwater scenario, smaller vessels will have difficulty in navigation and berthing will be also challenging even for larger size recreational vessels without protection from ambient wave conditions.

The extreme events will also expose vessels to large waves of 1.5m or greater.

The study results show that the breakwater arrangement in Option A can significantly reduce the wave agitation alongside the marina area. Based on the required level of protection, sensitivity analysis may be carried out on the length of the offshore breakwater. The present model results show that a small amount of wave penetration can be seen through the northern gap between the breakwater and the port. This can be reduced by extending the breakwater as it is shown in Option A2. In Option A2, the land connecting part of the breakwater was also removed to evaluate possible wave penetration from this side. Results revealed that penetration is negligible and wave heights are still within the acceptable limits. Some constraint to future port expansion may be incurred due to the navigation channel configuration for this option.

Option B provides effective protection against waves. The effect of this option on local sediment transport would require detailed assessment if adopted. Option C, which was created as a result of the optioneering workshop in Townsville on 14th October 2008, provides a high level of protection against waves while allowing for future expansion of the port.

This report forms part of the multi criteria assessment to select a preferred option based on environmental, cost and other criteria in addition to the operational criteria assessed in this report.

4. Marina Tranquillity Modelling Study

4.1 Introduction

Initial modelling studies based on MIKE 21 SW modelling resulted in selection of Option C as the preferred option. The SW model provided adequate information to perform a comparative study of wave agitation between the various studied options.

In order to evaluate tranquillity inside a harbour, it is necessary to investigate the effect of port structures on the wave field. Port structures, depending on their type and material, induce significant change in wave patterns. The change is generally in form of reflection and diffraction. These effects take place in relatively small spatial limits, typically smaller than a few wave lengths. As a result, spectral models can not be used to evaluate wave fields affected by the port structures and a phase resolving wave model, one that models the entire wave surface, should be used. In this project, the MIKE 21 BW model has been employed.

4.2 Numerical Model

A numerical wave modelling study was undertaken utilising DHI's MIKE 21 BW model.

MIKE 21 BW is a Boussinesq wave model, used for the assessment of wave dynamics in ports, harbours and coastal areas. This model is ideal for detailed design modelling as it is capable of reproducing the combined effects of all important wave phenomena in port/harbour areas, including refraction, diffraction, shoaling, wave breaking, reflection and transmission.

The BW model operates on a rectilinear grid mesh and utilises the results from the previous SW modelling as input wave conditions for assessment.

4.3 Tranquillity Criteria

Tranquilly criteria for a small harbour are based on the recommendations of Australian Standard 3962-2001 Guidelines for Design of Marinas. A summary of the recommendation for 'good' wave climate in small craft harbour is shown in Figure 23. Based on the same recommendations, for criteria for an 'excellent' wave climate multiply wave height by 0.75, and for a 'moderate' wave climate multiply wave height by 1.25. For vessels of less than 20 m in length, the most severe wave climate should satisfy moderate conditions. For vessels larger than 20 m in length, the wave climate may be more severe.

Based on the standard, a limit of 0.3m in 1 in 1 year would be considered acceptable and 0.25m excellent.

Figure 23   Criteria for a 'GOOD' wave climate inside a harbour

Direction and peak period of design harbour wave	Significant wave height (H_s)	
	Wave event exceeded once in 50 years	Wave event exceeded once a year
Head seas less than 2 s	Conditions not likely to occur during this event	Less than 0.3 m wave height
Head seas greater than 2 s	Less than 0.6 m wave height	Less than 0.3 m wave height
Oblique seas greater than 2s	Less than 0.4 m	Less than 0.3 m wave height
Beam seas less than 2 s	Conditions not likely to occur during this event	Less than 0.3 m wave height
Beams seas greater than 2 s	Less than 0.25 m wave height	Less than 0.15 m wave height

4.4 Model Setup

4.4.1 Modelling Domain

Based on the recommendations from the regional wave modelling study, the breakwater configuration of Option C was adopted for the harbour tranquillity modelling, refer Figure 24 below.

Figure 24   Harbour and Option C Breakwater Configuration

The setup of the model was based on the following parameters:

- Inner harbour basin dredged to -4.5m LAT;
- Stage 1 trawler basin dredged to -2.5m LAT;
- Channel dredged to -3m LAT; and

» Internal channel width of 50m.

4.4.2 Water Levels

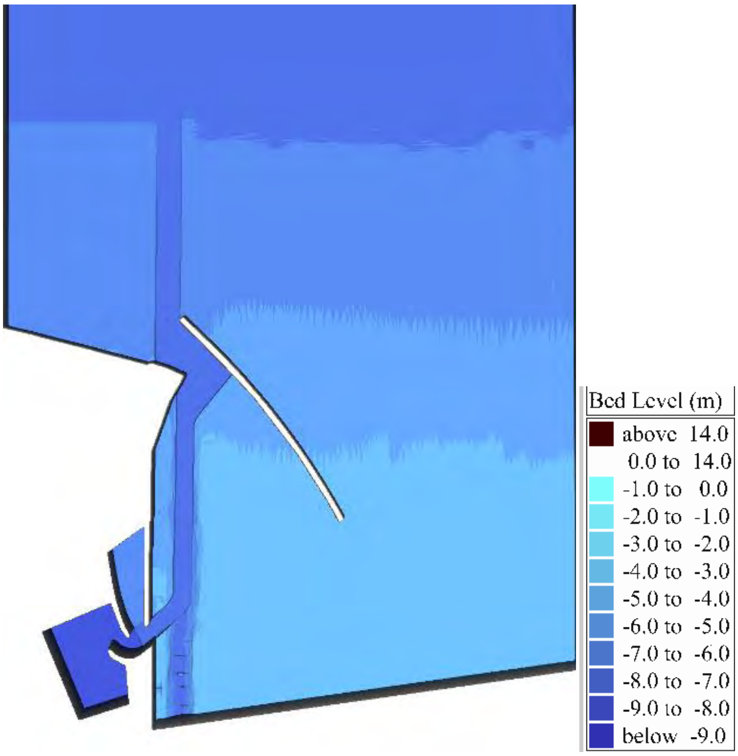
The models have been run using a water level of combined tide plus an allowance for storm surge for the 1 in 1 year and 1 in 100 year events. Higher water levels allow for potentially increased wave penetration behind the breakwater and modelling using a higher water level is therefore considered to be a conservative approach.

4.4.3 Digital Elevation Model

Similar to other numerical models, a Digital Elevation Model (DEM) describes the variation in bathymetry and location of the structures. As Boussinesq wave models resolve the wave surface through the wave length, grid spacing of the model is very small. This limits the size of the model area and increases the computational time required but at the same time provides the opportunity to include detailed variations in sea and harbour bed in the model. The DEM employed in this study covers an area of approximately 2 by 2 square kilometres, with a grid spacing of 2m each direction.

In order to make the computation most efficient, the model has been rotated by 39^0, so that it corresponds to the main wave direction. The model area is shown in Figure 25.

Figure 25 Digital Elevation Model employed in BW model study (LAT Datum)



4.4.4 Study Scenarios

Boundary conditions for the model were based on the previous 1 in 1 and 1 in 100 year scenarios studied with MIKE 21 SW model, for the Option C breakwater configuration. In order to evaluate wave heights inside the harbour, a directional random wave train was generated to simulate the estimated significant wave heights outside the harbour. The waves were extracted from the MIKE 21 SW model to correspond with the boundaries of the BW model. The modelled scenarios are listed in

Table 7. Sensitivity cases were carried out on wave direction. The time series length was chosen to allow waves to travel from the generation lines to areas within the harbour and appropriate reflection effects to take place (based on wave celerity).

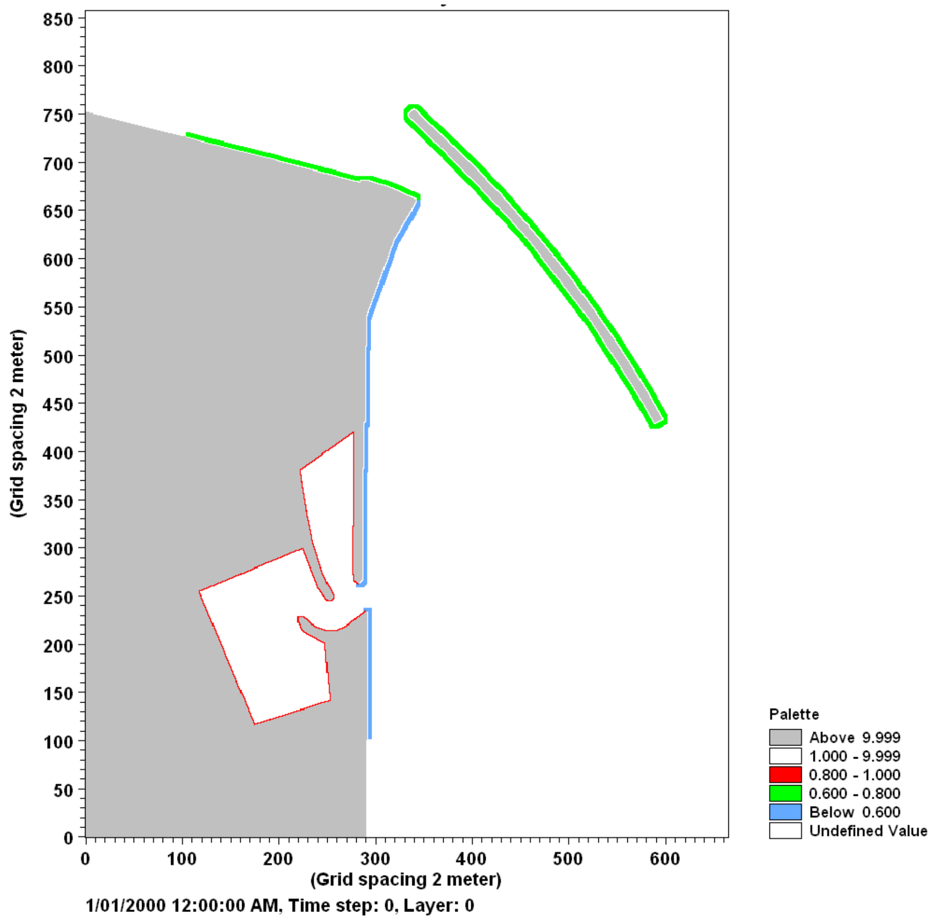
Table 7 Modelled Scenarios

Case	ARI (Years)	Hs (m)	Tp (s)	Direction (°N)	Type of Wave Spectra
1	1	1.0	6.0	40	Monochromatic Directional
2	1	1.0	6.0	35	Monochromatic Directional
3	1	1.0	6.0	40	Spectral Directional
4	1	1.0	6.0	35	Spectral Directional
5	1	1.0	6.0	40	Monochromatic Unidirectional
6	1	1.0	6.0	35	Monochromatic Unidirectional
7	100	2.8	9.0	40	Monochromatic Directional
8	100	2.8	9.0	50	Monochromatic Directional

4.4.5 Structure Reflection

Reflection and transmission of waves in MIKE 21 BW is modelled through definition of porosity maps. Porosity layers along various structures inside the model were estimated based on the wave parameters in each case and reflection (porosity) maps were created for each ARI condition. A sample reflection map for the 1 in 1 year condition is shown in Figure 26.

Figure 26 Porosity map for a 1 in 1 year case



4.5 Model Results

Wave heights inside the harbour were examined for all cases. Outputs of the model are in the form of wave surface profiles and significant wave heights measured through model runs. A plot of the surface elevation during 1 in 1 year conditions from 35 degrees is shown in Figure 27. Wave height plots for 1 in 1 year 35° directional and 40° uni-directional are shown in Figure 28 and Figure 29.The wave heights in all 1 in 1 year conditions were below 0.2m inside the basin and behind the breakwater in all conditions. For 1 in 100 year, the significant wave heights inside and around the marina are shown in Figure 30.

Figure 27 Wave Surface Patterns, 1 in 1 year

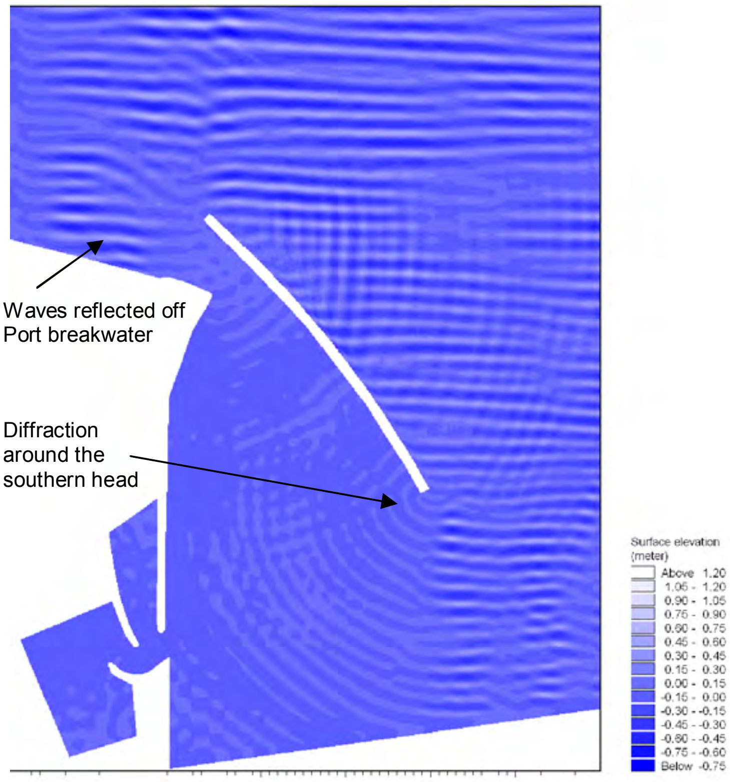


Figure 28 Significant Wave Heights, 1 in 1 year, 35°, Directional, Monochromatic

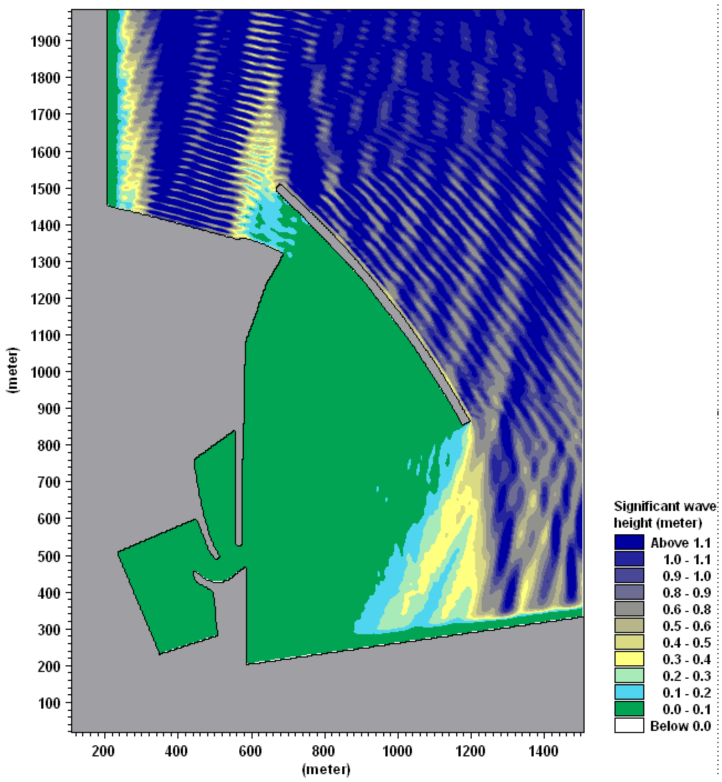


Figure 29 Significant Wave Heights, 1 in 1 year, 40°, Uni-Directional, Monochromatic

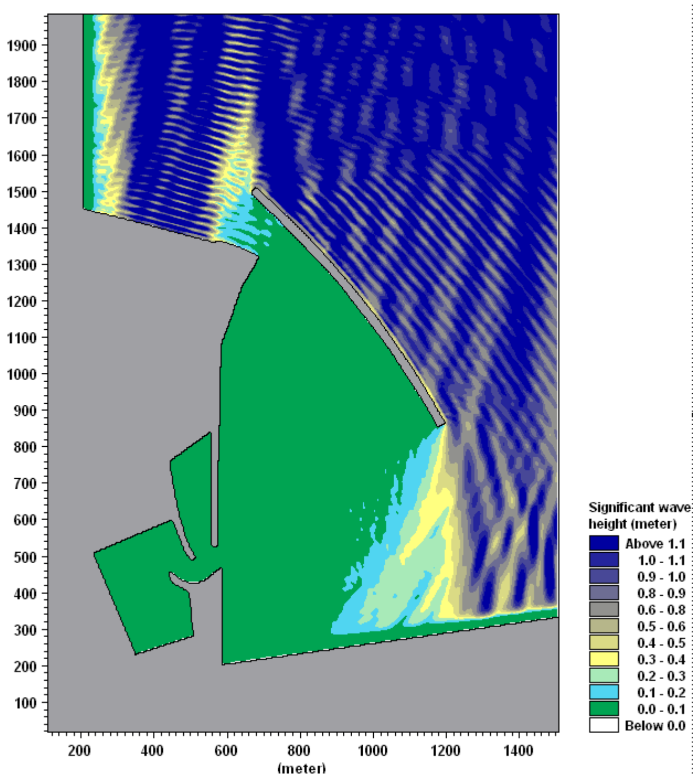
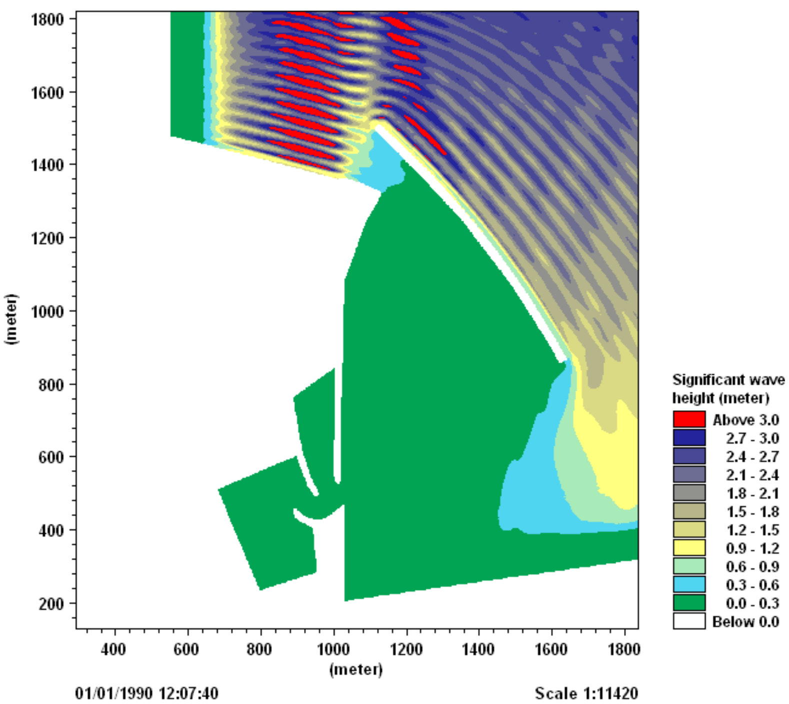


Figure 30 Significant Wave Heights, 1 in 100, year, 40°, Uni-Directional, Monochromatic



4.6 Conclusions

The MIKE 21 BW model has been utilised to evaluate tranquillity behind the main breakwater and inside the proposed harbour basin. The model results are presented for 1 in 1 year and 1 in 100 year return period cases. The modelling results reveal that in 1 in 1 year conditions, the significant wave height behind the breakwater and in the harbour is less than 0.2m in all cases.

It should be noted that the setup for BW model does not include the local effect of wind behind the breakwater and transmission through the main breakwater. Considering that these effects are very small, the wave climate within the boundaries of the protective breakwater will be acceptable.

During 1 in 1 year events, reflection from the port structures at the entrance of the main breakwater increases the wave heights to as high as 1.5m. This may cause some navigation issues for smaller vessels coming through the channel into the harbour under storm conditions.

Evaluation of wave heights inside the harbour for 1 in 100 years has also revealed that the breakwater structure provides acceptable level of protection during storms. Wave heights inside the breakwater are generally very small, less than 0.3m. Again, reflection from the breakwater has a similar effect to 1 in 1 year and can create large waves at the entrance, up to 3m in cases, potentially causing navigation difficulties.

The modelling results in general confirm that the layout of the breakwater is adequate to provide high level of protection against waves in all conditions to AS 3962 standards.

5. References

- AS 1170.2 (2002) *Australian Standard: Structural Design Wind Actions Part 2*
- AS 3962 (2001) *Australian Standard: Guidelines for Design of Marinas*

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