Cattle Bay Marina, Eden

Wave Modelling

59914148

Prepared for
Royal HaskoningDHV

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Executive Summary

Background

Cardno have undertaken wave climate and shoreline effect numerical wave and current modelling for a proposed marina layout at Cattle Bay in northern Twofold Bay, NSW. The main purpose was to investigate the potential effects of waves reflected from the proposed marina wave screen towards Cocora Beach, see **Figure 1.1**. Cardno have been engaged by Haskoning Australia (a company of Royal HaskoningDHV) on behalf of Eden Resort Hotel, to undertake that investigation.

Methodology

The overarching approach of the study was:

1. Conduct SWAN wave hindcast modelling of local sea and swell waves to establish the pre-wave-screen wave climate in the study region, specifically in terms of near shore wave height and weighted mean wave direction parameters.
2. Use this data to inform wave attenuator design. The aim of this being to establish a wave attenuator design that will satisfy two key criteria:
    a. Local sea and swell waves transmitted through the attenuator to the proposed marina moorings must satisfy the criteria for a "moderate" wave Climate in a Small Craft Harbour (see **Section 2.1**).
    b. The orientation and plan-form layout should minimise changes to the swell wave climate along Cocora Beach (thereby avoiding significant beach alignment change);
3. Conduct further SWAN wave hindcast modelling of local sea and swell waves incorporating the proposed wave attenuator. Establish the post-attenuator wave climate at various locations in the study area to determine whether or not the attenuator design satisfies the key criteria. This modelling was also to be conducted for two projected sea level rise scenarios.
4. Validate the SWAN modelling of the optimised attenuator design using the MIKE21 Boussinesq Wave Model to investigate the propagation of swell waves into Cattle Bay and Cocora Beach.
5. Conduct coupled hydrodynamic-wave modelling for a series of locally significant storms to assess the influence of tidal currents, and the implications that this may have on the aforementioned wave modelling.

The specifics of the modelling methodology and outcomes are provided in subsequent sections of this report.

Results

Important conclusions drawn from this investigation and implication for the design of the attenuator are as follow:

- Due to the design wave climate in the region of the proposed marina, a wave attenuation structure will be required to meet the "moderate" wave climate criteria set out in AS3962.
- Due to sheltering from swell waves provided by the Eden Headland and Snug Cove breakwater, the performance of the marina will be driven by local sea waves.
- The alignment of Cocora Beach is driven by swell, and hence the plan-form alignment of any wave attenuator would need to minimise changes to the swell wave climate along Cocora Beach that may result from wave reflections.
- The alignment of Cattle Bay Beach is driven by both swell and local sea waves. Hence, the implementation of a structure in Cattle Bay designed to alter the local sea or swell wave climate in Cattle Bay is likely to impact upon the long term beach alignment of Cattle Bay Beach, which is situated in the lee of said structure.

The proposed attenuator design was then modelled, and the following conclusions drawn:

- The wave attenuator achieves the design criteria in respect of Cocora Beach by reflecting swell wave energy to the south of Cocora Point, while the western component is well aligned with the incoming swell. Consequently, significant changes to the beach alignment of Cocora Beach are not expected as a result of the implementation of the wave attenuator.
- The presence of the attenuator is likely to result in some changes to the mean wave directions at Cattle Bay Beach, and hence may result in a clockwise beach plan-alignment rotation in the order to six to eight metres at the eastern and western ends, respectively.
- Design wave heights inside the proposed marina are reduced by the presence of the attenuator. However, the marina does not satisfy the “moderate” wave climate criteria set out in AS3962 with the current attenuator design at all locations. This could be achieved with a relatively minor extension of the attenuator at each end (along the current alignment).
- Projected sea level rise scenarios cause minimal changes to design wave heights in the study area.

MIKE21 Boussinesq Wave (BW) Model Validation

MIKE21 BW modelling was conducted in order to validate the SWAN swell modelling results. The MIKE21 BW model results supported the SWAN model results in that they showed swell waves reflected from the wave screen to the south of the Cocora Point. The results also indicated that the implementation of the wave screen would result in only minimal changes to swell wave spectra along Cocora Beach.

Coupled Wave-Hydrodynamic Modelling

In order to assess the influence of tidal currents, coupled hydrodynamic and wave modelling was undertaken for two recent major storms that affected the study area in June 2007 and May 2010 (Cardno, 2011). These results were compared to wave-only simulations run at a still water level (MSL).

The results of the modelling showed some divergence between the simulations modelled wave height during the peak of those events, indicating the importance of accounting for non-linear tidal influences on wave height. The results also showed that the influence of tidal currents on wave shoaling and refraction results in a slight semi-diurnal oscillation of wave direction - in the order to 2-4 degrees about shore normal, yet mean wave directions remained similar – indicating that the modelled long term mean weighted wave directions along Cocora Beach are unlikely to be significantly different for coupled wave and hydrodynamic, and wave only simulations.

Table of Contents

Tables

Glossary & Abbreviations

Term	Definition
AHD	Australian Height Datum - A common national plane of level corresponding approximately to mean sea level.
Amenity	Those features of an estuary/beach that foster its use for various purposes, for example, Clear water and sandy beaches make beach-side recreation attractive.
Anemometer	Device that measures wind speed.
ARI	Average Recurrence Interval; relates to the probability of occurrence of a design event.
Astronomical Tides	Tides which are only influenced by the gravitational effect of the moon and the sun. Does not include climate, geography or other factors.
Atmospheric Boundary Layer	The lower part of the atmosphere where the presence of the Earth’s surface is felt by (a modelled) wind, with its upper limit typically at altitude 150–500 m.
AWS	Automatic Weather Station.
Bathymetry	Depth profile of an area. Usually notated by amount of meters below mean sea level where negative signifies height above.
Batter Slope	Slope of for instance the side of a channel.
Beach Nourishment	The placement of large quantities of good quality sand on the beach to advance it seaward.
Bed Load	That portion of the total sediment load that flowing water moves along the bed by the rolling or saltating of sediment particles.
Berth	Locations where ships may be moored.
BOM	Bureau of Meteorology.
Calibration	The process by which the results of a computer model are brought to agreement with observed data.
CD	Chart Datum, common datum for navigation charts - 0.92m below AHD in the Sydney coastal region. Typically Lowest Astronomical Tide.
Computer Models	The mathematical representation of the physical processes, designed to simulate these processes in reality. These models are often run on computers due to the complexity of the mathematical relationships.
Cross-shore Transport	Sediment transport occurring normal (or perpendicular) to the beach face.
Diffraction	The curving of wave direction around an obstacle into the leeward side.
Discharge	The rate of flow of water measured in terms of volume per unit time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is flowing.
Dispersive Transport	The transport of dissolved matter through the estuary by vertical, lateral and longitudinal mixing associated with velocity shear.
Diurnal	A daily variation, as in day and night.
Domain Decomposition	A numerical method which arrives at the solution by splitting the problem into smaller subproblems then iterating until boundary values are equal.
DoP	NSW Department of Planning.
Ebb Tide	The outgoing tidal movement of water within an estuary.
ECL	East Coast Low (low pressure system).
Eddies	Large, approximately circular, swirling movements of water, often metres of tens of metres across. Eddies are caused by shear between the flow and a boundary or by flow separation from a boundary.
EIA	Environmental Impact Assessment.
EIS	Environmental Impact Statement.
ENSO	El Niño – Southern Oscillation.
Erosion	Short-term erosion, typically associated with a specific storm event. May be referred to as storm bite. The beach will typically recover after an erosion event.
Estuary	An enclosed or semi-enclosed body of water having an open or intermittently open connection to coastal waters and in which water levels

	vary in a periodic fashion in response to ocean tides.
Fetch	The length of the water over which wind has blown. Typically, the longer it is, the larger the wave.
Flood Tide	The incoming tidal movement of water within an estuary.
Foreshore	The area of shore between low and high tide marks and land adjacent thereto.
Fortnightly Tides	The variation in tide levels caused by the monthly variation of Spring and Neap Tides.
GA	Geoscience Australia.
GIS	Geographic Information Systems, computer-based spatial data management tools.
Groyne	A fixed structure which acts as a wall to sediment transport. Its effectiveness depends on the height, placement and length.
HAT	Highest Astronomical Tide - Highest water level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. This level will not be reached every year. HAT is not the extreme level which can be reached, as storm surges may cause considerably higher levels to occur.
H_b	Breaking wave height.
Hindcasting	Inputting previous known data into a design model to see how close the results are to the known results.
H_{m0}	Significant wave height (H_s) based on the zeroth moment of the wave energy spectrum (rather than the time domain H1/3 parameter).
H_{max}	Maximum wave height in a specified time period.
H_s (Significant Wave Height)	Hs may be defined as the average of the highest 1/3 of wave heights in a wave record ($H_{1/3}$), or from the zeroth spectral moment (Hmo), though there is a difference of about 5 to 8%.
Intertidal Zone	The area that is above water at low tide and under water at high tide.
IPCC	Intergovernmental Panel on Climate Change.
Jetty	A breakwater designed to protect the coastline or a mooring facility for ships.
LAT	Lowest Astronomical Tide - Lowest water level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. This level will not be reached every year. LAT is not the extreme level which can be reached, as storm surges may cause considerably lower levels to occur.
LGA	Local Government Area.
LiDAR	(Light Detection And Ranging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. Otherwise known as Aerial Laser Survey data.
Local Sea	A sea state consisting of waves generated by local wind (as opposed to swell).
Long Shore Current	A current that moves parallel to the coast.
Longshore Transport	The movement of sand along the coastline caused by waves and a wave-caused current running parallel to the beach.
Marine Sediments	Sediments in sea and estuarine areas that have a marine origin.
MHHW	Mean Higher High Water - The mean of the higher of the two daily high waters over a long period of time. When only one high water occurs on a day, this is taken as the higher high water.
MHL	Manly Hydraulics Laboratory.
MHLW	Mean Higher Low Water - The mean of the higher of the two daily low waters over a long period of time.
MHW	Mean High Water - The mean of all high waters observed over a sufficiently long period (preferably over the national tidal datum epoch).
MHWM	Mean High Water Mark.
MHWN	Mean High Water Neaps - The long-term mean of the heights of two successive high waters when the range of tide is the least at the time of first and last quarter of the moon.
MHWS	Mean High Water Springs - The long-term mean of the heights of two successive high waters during those periods of 24 hours (approximately

	once a fortnight) when the range of tide is greatest, during full and new moon.
MLHW	Mean Lower High Water - The mean of the lower of the two daily high waters over a long period of time.
MLLW	Mean Lower Low Water - The mean of the lower of the daily low waters over a long period of time. When only one low water occurs a day, this is taken as the lower low water.
MLW	Mean Low Water - The average of all low waters observed over a sufficiently long period (preferably over the national tidal datum epoch).
MLWN	Mean Low Water Neaps - The long-term mean of the heights of two successive low waters over the same periods as defined for MHWN.
MLWS	Mean Low Water Springs - The long-term mean of the heights of two successive low waters over the same periods as defined for MHWS.
Model Verification	Checking the assumptions and equations behind a model to make sure the model is an accurate representation.
MSL	Mean Sea Level - The mean level of the sea over a long period (preferably 18.6 years) or the mean level which would exist in the absence of tides.
Neap Tides	Tides with the smallest range in a monthly cycle. Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
NSW	New South Wales.
OEH	The NSW Office of Environment and Heritage.
Peak Wave Height	The highest wave height in a group of waves.
Phase Lag	Difference in time of the occurrence between high (or low water) and maximum flood (or ebb) velocity at some point in an estuary or sea area.
Refraction	Waves bending into a direction normal to the shore due to approaching shallower depths. The part of the wave which reaches the shallow depth first moves slower allowing the deeper part to catch up.
Seawall	Wall built parallel to the shoreline to limit shoreline recession.
Semi-diurnal	A twice-daily variation, for example, two high waters per day.
Shear Stress	The stress exerted on the bed of an estuary by flowing water. The faster the velocity of flow the greater the shear stress.
Shoaling	The variation of waves in their direction of propagation due to depth-induced changes of the group velocity in that direction. These changes in group velocity generally increase the wave amplitude as the waves propagate into shallower water.
Shoreline Recession	The long-term (decadal plus) net landward movement of the shoreline/mean water line. Occasionally referred to as long-term erosion.
SLR	Sea Level Rise.
Spring Tides	Tides with the greatest range in a monthly cycle, which occurs when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean).
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast.
Surf Beat	In the surf zone, the combination of wave-induced set-up and wave groupiness generates low frequency waves that radiate out to sea as infra-gravity waves.
Surf Zone	The section between the most seaward boundary of the breaker zone and waterline at the beach.
Swell	Regular, long-crested waves generated in a distant storm that have dispersed across the ocean.
Tidal Planes	A series of water levels that define standard tides, for example, 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.

Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth.
T_{m01}	Mean wave period as calculated from the first and zeroth spectral moments of the wave energy frequency spectrum. T_{m01} normally 8% higher (approx..) than T_{m02}.
T_p	Wave energy spectral peak period; that is, the wave period related to the highest ordinate in the wave energy spectrum.
T_s	The significant wave period.
T_z	Average zero crossing period based on upward zero crossings of the still water line. An alternative definition is based on the zeroth and second spectral moments.
Wave Climate	Long term characterization of waves at a location over a number of years with respect to significant wave height, period, direction, etc.
Wave Energy Spectrum	The relationship between the distribution of energy and the frequency in waves.
Wave Grouping	An uninterrupted sequence of waves with wave heights higher than an arbitrarily chosen, but usually high, threshold value.
Wave Length	The distance between two wave crests.
Wave Period	The time it takes for two successive wave crests to pass a given point.
Wave Run-up	The vertical distance between the maximum height that a wave runs up the beach (or a coastal structure) and the still water level, comprising tide and storm surge.
Wave Set-up	A rise in water level, particularly in the surf zone, to counteract the force exerted by a horizontal gradient in the radiation stress.
Wind Set-up	The change of mean water level due to the presence of wind. If wind is blowing onshore, it would cause a setup, whereas if it was blowing offshore it would cause a setdown.
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to pile up against downwind shores and generates secondary currents.
WRB	Waverider Buoy. Also DWRB which refers specifically to a Directional Waverider Buoy. This is the instrument used for the NSW deepwater wave measurement programme.

1 Introduction

Cardno responded to an invitation from Royal HaskoningDHV issued by email on 26 March 2014 to undertake wave climate and shoreline effect numerical wave and current modelling for the proposed marina layout at Cattle Bay in northern Twofold Bay, NSW. The main purpose was to investigate the potential effects of waves reflected from the proposed marina wave screen towards Cocora Beach, see **Figure 1.1**. Cardno have been engaged to undertake that investigation.

In the EIA prepared by Inspire Urban Design & Planning and Royal HaskoningDHV (RHDHV), 2013, a cranked (bent) attenuator was proposed to be used to reduce the effects of wave reflection from the attenuator onto nearby Cocora Beach, whilst providing berth protection from swell and Twofold Bay wind waves. RHDHV identified that the alignment of the attenuator may need to be refined based on further studies; which the consent authority has since requested be undertaken. The attenuator is described in the EIA as being constructed of concrete panels supported between vertical and raked piles.

Key matters to be addressed have been specified by Royal HaskoningDHV; they are:-

- confidence that the proposed wave models can appropriately simulate the complex wave transformation processes in Twofold Bay, including reflection and transmission;
- how the reflection process would be handled, for example, by an assumed reflection coefficient or explicitly based on the structure geometry;
- undertake a sufficient range of investigations to characterise future behaviour of Cocora Beach, noting that Cattle Bay Beach has been included also;
- discussion and justification on whether swell and wind waves are important, or only swell waves;
- consider the Royal HaskoningDHV concept design of the attenuator, and
- assess any effects of the attenuator on Cocora Beach using changes in weighted mean wave directions and an effective wave height.

Ultimately, the aim of the study has been to demonstrate that there would be no significant impacts on Cocora Beach, if possible; by designing the attenuator layout to remove or minimise the effects of wave reflections. Some changes on Cattle Bay Beach were expected also, being in the lee of the attenuator and marina berths which would transform the nearshore wave climate there.

The consent authority has requested that these issues be considered for present day conditions, and also considering mean sea level rise (SLR) scenarios of a 0.4m rise in mean sea level (MSL) by 2050, and 0.9m by 2100.

Cardno (2011) describes previous wave climate investigations for proposed marina development in this area. The model systems developed and calibrated in that work have been applied to this investigation. That report describes the data, study approach and outcomes of a wave climate investigation undertaken to develop local sea and swell wave climates in the Snug Cove area to assist the Land and Property Management Authority with a previous Cattle Bay marina project.

Normal directional conventions have been adopted, that is, winds and waves are coming from, relative to True North (^{o}TN).

Unless specified otherwise, depths are relative to Chart Datum, which is lowest astronomical tide (LAT) at Eden.

A detailed analysis of site wave and wind conditions is reported in Manly Hydraulics Laboratory (2007). That report describes the wave data recorded in the region and describes previous high wave events in Snug Cove. The report clearly demonstrates that open water wave conditions exceed those required for a “moderate” small craft harbour, as defined in the Australian Marina Code (2001). Typically, swell in Snug Cove is low and it is the local wind waves generated within Twofold Bay that cause unacceptable wave conditions for watercraft mooring at the berths.

2 The Study Area

Eden Harbour is located on the south coast of NSW about 500km south of Sydney, and is shown in **Figure 1.1**. This harbour facility, which is known also as Snug Cove, is one of the few natural deep water ports along the NSW coast. It is used by recreational and commercial vessels and provides facilities for a large commercial fishing fleet. There are two wharves about 200m long as well as two boat launching ramps. The effects of swell increase markedly west from Snug Cove to Cattle Bay Beach and Cocora Beach**,** (see Cardno, 2011).

The physiographic form of Snug Cove offers significant natural protection from Tasman Sea storm waves. Further protection is provided by a breakwater, first constructed in the 1960's and then extended between 1984 and 1987, on the eastern side of Snug Cove, see **Figure 1.1**.

The cove and the coast to the west to Cocora Point are also exposed to local sea that can be generated over the fetch within Twofold Bay by strong south to south-westerly sector winds. From time-to-time these winds cause waves in the harbour area to exceed the recommended criteria for the so-called "moderate" wave climate in small craft harbours.

Cardno has been advised by RHDHV that as Cattle Bay is classified as a "rough weather" location, it is necessary for the proposed marina to satisfy the "moderate" wave climate in small craft harbours set out in AS3962. These criteria are described in **Table 2-1**.

Table 2-1 Criteria for a "Moderate" Wave Climate in a Small Craft Harbour

Direction and Peak Period of Design Harbour Wave	Significant Wave Height (Hs)	
	Wave Event Exceeded Once in 50 Years	**Wave Event Exceeded Once Every Year**
Head seas less than 2s	Conditions not likely to occur during this event	Less than 0.38m wave height
Head seas greater than 2s	Less than 0.75m wave height	Less than 0.38m wave height
Oblique seas greater than 2s	Less than 0.5m	Less than 0.38m wave height
Beam seas less than 2s	Conditions not likely to occur during this event	Less than 0.38m wave height
Beam seas greater than 2s	Less than 0.31m wave height	Less than 0.19m wave height

Source: Adapted from MERCER, A.G., ISAACSON, M. and MULCHAHY, M.W. Design wave climate in small craft harbours. 18th Conference on Coastal Engineering. Capetown, 1982, as presented in Australian Standard AS3962.

As an example, MHL (2007) report that:-

'On 27 January 2007 gale force south-westerly winds resulted in severe wind wave activity in Twofold Bay and caused damage to vessels in Eden Harbour. One yacht, Gembrit, broke its mooring and was washed ashore on rocks between the mooring wharf and boat launching ramp. It is understood the Department of Lands is investigating options to upgrade facilities in Eden Harbour to accommodate larger commercial cruisers and/or develop a marina for recreational vessels. Given the damage to vessels in the harbour on 27 January 2007, the Department of Commerce's Manly Hydraulics Laboratory (MHL) was commissioned by the Department of Lands to undertake an investigation of wind and wave conditions that occurred on that day and to determine the frequency of such wave activity in the harbour', (MHL, 2007).

3 Physical Processes

The purpose of this section is to discuss the relevant physical and coastal processes for this investigation

3.1 Morphology

The alignments of the shorelines at Cocora Beach and Cattle Bay suggest that their forms are dominated by Tasman Sea waves propagating to the site as swell and that they are in general dynamic equilibrium with the present wave climate. However, there will be some effect of local sea also. Cardno's previous investigations for NSW Lands addressed both sea and swell wave conditions and showed significant spatial gradients in wave height. Those investigations were based on a wave modelling system that is based on the SWAN system. This model has been calibrated using MHL wave data.

The proposed fixed wave screen/panel attenuator will reflect most of the local sea and a significant proportion of the swell. The reflection/transmission effects depend upon the plan-form of the wall and its top and bottom levels, as well as water depth and wave period and possibly wave height. Both swell and sea wave conditions may have a range of directions, though the swell will be more focussed with a reduced directional spread. Wave transmission and reflection, both processes required modelling, are affected by tide level. The floating berth pontoons were also considered in the model layout, especially for local sea and Cattle Bay.

The quasi-equilibrium plan alignments of the two beaches are related to the weighted mean wave directions of the swell at the shoreline, as it varies along the shoreline – with some effect from local sea; given that these two beaches are basically enclosed by headlands and little longshore sediment transport beyond the two bays would be expected. There is potential for waves reflected from the attenuator, for example, to change the weighted mean wave directions and hence the plan alignment of the beaches. Hence Cardno investigated those changes in terms of those potential direction changes, both swell and sea. The outcomes of any changes can be determined by incorporating beach alignment changes and the existing sand volume into a new overall plan alignment. This procedure has been applied at sites such as Ettalong Beach and Botany Bay beaches. At those sites, as with these two beaches, the relative influence of sea and swell varies with location.

The purpose of this section is to describe the parameters and physical processes that are important to the overall wave climate and shoreline form in the Eden Harbour region. They are: -

- Waves
- Water Levels
- Winds

3.2 Waves

Waves that propagate to the study area in northern Twofold Bay may have energy in three distinct frequency bands. They are principally related to the generation and propagation of ocean swell and local sea, together with long waves in some circumstances. High ocean waves generated by a storm are generally categorised as sea because wind energy is still being transferred to the ocean. Long waves (wave periods greater than about 25 seconds) can be caused by a range of processes including wave grouping, and may be important for port development, structure design and boat berthing. However, they are not addressed in this report.

Waves are irregular in height (crest to trough distance) and period (time between successive crests passing a fixed point) and so it is necessary to describe wave conditions using a range of statistical parameters. In this study the following have been used:-

- H_s significant wave height - either H_{mo} or $H_{1/3}$, which is the average of the highest 1/3 of waves in a record
- H_{mo} significant wave height (H_s) based on $4\sqrt{mo}$ where mo is the zeroth moment of the wave energy spectrum (rather than the time domain $H_{1/3}$ parameter).

- H_{max} maximum wave height in a specified time period
- T_p wave energy spectral peak period, that is, the wave period associated with the highest ordinate in the wave energy spectrum
- T_z average zero-crossing period based on upward zero crossings of the still water line. An alternative definition is based on the zeroth and second spectral moments of the equivalent wave energy spectrum.

Wave heights defined by zero up-crossings of the still water line fulfil the Rayleigh Distribution in deep water and thereby provide a basis for estimating other wave height parameters from H_s. In shallow water, for example, near the berths, significant wave height defined from the wave spectrum, H_{mo}, is normally larger (typically 5% to 8%) than $H_{1/3}$ defined from a time-series analysis. H_{mo} is the output significant wave height from wave modelling. Generally, for local sea, which is likely to be the more important frequency band at this site, H_{mo} and $H_{1/3}$ will be similar.

3.2.1 Directional Spreading

Ocean waves also have a dominant direction of wave propagation and directional spread about that direction. The spreading can be defined by a Gaussian or generalised cosine ($\cos^n$) distribution (amongst others). There is also a wave grouping tendency. Directional spread is reduced by refraction as waves propagate into the shallow, nearshore regions and the wave crests become more parallel with each other and the seabed contours. Directional spreading causes the sea surface to have a more short-crested wave structure in deep water and was included in the SWAN wave modelling undertaken for this study.

3.2.2 Near Shore Processes

Waves propagating into shallow water may undergo changes caused by refraction, shoaling, bed friction, wave breaking and, to some extent, diffraction.

Wave refraction is caused by differential wave propagation speeds. That part of the shoreward propagating wave that is in the more shallow water has a lower speed than those parts in deeper water. When waves approach a coastline obliquely these differences cause the wave fronts to turn and become more coast parallel. Associated with this directional change there are changes in wave heights. On irregular seabeds wave refraction becomes a very complex process.

Waves propagating shoreward have reduced speeds in shallow water. In order to maintain constancy of wave energy flux (ignoring energy dissipation processes) their heights must increase. This phenomenon is termed shoaling and leads to a significant increase in wave height near the shoreline.

A turbulent boundary layer forms above the seabed with associated wave energy losses that are manifested as a continual reduction in wave height in the direction of wave propagation - leaving aside further wind input, refraction, shoaling and wave breaking. The rate of energy dissipation increases with greater wave heights and longer wave periods.

Wave breaking occurs in shallow water when the wave crest speed becomes greater than the wave phase speed. For irregular waves this breaking occurs in different depths so that there is a breaker zone rather than a breaker line. Seabed slope, wave period and water depth are important parameters affecting the wave breaking phenomenon. As a consequence of this energy dissipation, wave set-up (a rise in still water level caused by wave breaking), develops shoreward from the breaker zone in order to maintain conservation of momentum flux. This rise in water level increases non-linearly in the shoreward direction and allows larger waves to propagate shoreward before breaking. Field measurements have shown that the slope of the water surface is normally concave upward. Wave set-up at the shoreline can be in the order of 15% of the equivalent deep-water significant wave height. Smaller set-up occurs in estuarine entrances, but the momentum flux remains the same. Wave set-up is smaller where waves approach a beach obliquely, but then a longshore current can be developed. Wave grouping and the consequent surf beats also cause fluctuations in the still water level.

Wave diffraction, which causes wave propagation behind breakwaters, for example, was included in this study as part of the wave modelling, but was not important for the dominant south-westerly local sea that propagates to the site; except for the wave propagation around the ends of the wave attenuator.

3.2.3 Wave Spectrum

In a random wave field each wave may be considered to have a period different from its predecessors and successors and the distribution of wave energy is often described by a wave energy frequency spectrum. In fact, the whole wave train structure changes continuously and individual waves appear and disappear until quite shallow water is reached and dispersive processes are reduced as all phase speeds become more dependent on depth alone. In developed sea states, that is swell, the Bretschneider modified Pierson-Moskowitz spectral form has generally been found to provide a realistic wave energy description. For developing sea states the JONSWAP spectral form, which is generally more 'peaky', has been found to provide a better spectral description. The frequency and direction spectral forms may be combined to form frequency-direction spectra.

3.2.4 Maximum Wave Height

For structural design in the marine environment it is necessary to define the H_{max} parameter related to storms having average recurrence intervals (ARI) of R years. However, the expected H_{max}, relative to H_s in statistically stationary wave conditions, increases as storm/sea state duration increases. Based on the Rayleigh Distribution the usual relationship is: -

$$H_{\max} = H_s \sqrt{0.5 \ln N_z}$$

where N_z is the number of waves occurring during the time period being considered, where individual waves are defined by T_z.

$\ln$ is the natural logarithm

This relationship has been found to overestimate H_{max} by about 10% in severe ocean storms. In shallow water the relationship is not fulfilled. In very shallow water H_{max} is replaced by the breaking wave height, H_b. Nevertheless, recorded data from east coast Waverider buoy installations shows a wide range of values and although a factor for H_{max}/H_s of 1.85 is adopted often, it may be greater than 2.

3.2.5 Hydrodynamic Effects

Waves propagating through an area affected by a current field are caused to turn in the direction of the current. The extent of this direction change depends on wave celerity, current speed and relative directions. Wave height is also changed. Opposing currents cause wavelengths to shorten and wave heights to increase and may lead to wave breaking. Wave propagation is blocked when the current speed is greater than one quarter of the phase speed. Conversely, a following current reduces wave heights and extends wavelengths. Currents in Twofold bay are not likely to have a major effect on the northern Twofold Bay wave climate.

3.3 Winds

Winds cause both the ocean waves that propagate to the site as low swell and the local sea generated in Twofold Bay. It is an important physical parameter for these investigations.

Wind data obtained from the Bureau of Meteorology for this study is described in Cardno (2011).

3.4 Water Levels

Water level variations in northern Twofold Bay result from one or more of the following natural causes:-

- Eustatic and Tectonic Changes
- Tides
- Wind Set-up and the Inverse Barometer Effect
- Coastal Trapped Waves
- Wave Set-up
- Wave Run-up

- Greenhouse Effect (sea level rise)
- Global Changes in Meteorological Conditions

Eustatic sea level changes are long-term worldwide changes in sea level relative to the land mass and are generally caused by changes to the polar ice caps and mean water temperature of the ocean mass. No rapid changes are believed to be occurring at present and this aspect has not been addressed. Nevertheless, a global sea level rise of about 2.5mm per annum is now generally accepted. Tectonic changes are caused by movement of the Earth's crust; they may be vertical and/or horizontal.

Many scientists believe that global warming of the Earth's atmosphere will lead to an increasing rise in mean sea level. Predictions of global sea level rise due to the Greenhouse effect vary considerably. It is impossible to state conclusively by how much the sea may rise, and no policy yet exists regarding the appropriate provision that should be made in the design of new coastal developments. Based on a 50-years planning period and IPCC (2007), a projected mean sea level rise of 0.4m to 2050 would be an appropriate marina design parameter for this site.

Tides are caused by the relative motions of the Earth, Moon and Sun and their gravitational attractions. While the vertical tidal fluctuations are generated as a result of these forces, the distribution of land masses, bathymetric variation and the Coriolis force determine the local tidal characteristics.

Wind set-up and the inverse barometer effect are caused by regional meteorological conditions. When the wind blows over an open body of water, drag forces develop between the air and the water surface. These drag forces are proportional to the square of the wind speed. The result is that a wind drift current is generated. This current may transport water towards the coast upon which it piles up causing wind set-up. Wind set-up is inversely proportional to depth. Coast parallel, northward flowing currents can also cause a surge through refraction towards the coast and the Coriolis Effect.

In addition, the drop in atmospheric pressure, which accompanies severe meteorological events, causes water to flow from high pressure areas on the periphery of the meteorological formation to the low pressure area. This is called the 'inverse barometer effect' and results in water level increases up to 1cm for each hecta-Pascal (hPa) drop in central pressure below the average sea level atmospheric pressure in the area for the particular time of year, typically about 1010 hPa. The actual increase depends on the speed of the meteorological system and 1cm is only achieved if it is moving slowly. The phenomenon causes daily variations from predicted tide levels up to 0.05m. The combined result of wind set-up and the inverse barometer effect is called storm surge. Because wave conditions for attenuator functional design in northern Twofold Bay are likely to be caused by south-westerly winds, storm surge is not likely to be a design parameter for this attenuator layout study, but would occur during a very severe ocean storm and would need to be addressed in attenuator structural design. Nevertheless, wave conditions transferred from offshore to the marina have included estimated hourly tide levels.

Coastal trapped waves (CTW) are long period wave phenomena that propagate northward along the continental shelf (Freeland *et al*, 1986). Their origin is not fully understood, but they are believed to originate from the passage of successive high and low pressure meteorological systems across southern Australia. These systems have inter-arrival times varying from 3 to 7 days, typically, and these are the periods of the observed CTW. These waves are irregular and cause approximate coast parallel currents and variations in water levels. They are trapped on the continental shelf by refraction and the Coriolis force. CTW are known to occur on the continental shelf of NSW and will affect observed water levels in the Eden region.

Wave run-up is the vertical distance between the 'maximum' height a wave runs up the beach or a coastal structure and the still water level - comprising astronomical tide plus storm surge. Additionally, run-up level varies with surf-beat, which arises from wave grouping effects. Wave run-up implicitly includes wave set-up, but has not been addressed in this study. It is commonly estimated in terms of R_2 – only 2% of waves run-up higher than this.

Global meteorological and oceanographic changes, such as the El Nino Southern Oscillation phenomenon in the eastern southern Pacific Ocean, together with continental shelf waves, cause medium term variations in mean sea level. The former phenomenon may persist for a year or more. The causes are not properly understood, but analyses of long term data from Australian tide gauges indicate that annual mean sea level may vary up to 0.1m from the long term trend, whilst mean sea level may vary by more than 0.2m over the time scale of weeks.

3.5 Tsunami

Tsunami are caused by sudden crustal movements of the Earth and are commonly, but incorrectly, called 'tidal waves'. They are infrequent and unlikely to occur during a storm. They are known to occur on the east coast of Australia. Their incidence and effects in northern Twofold Bay are unknown, but historically have been very low along the NSW coast. They can affect marina facilities through unexpectedly high currents.

Cardno have recently completed an assessment of tsunami risk for selected NSW coastal sites for State Emergency Services and the Office of Environment and Heritage.

4 Utilised Data

The following data were used in this investigation.

4.1 Bathymetry

Two AUS Charts, 192 and 806, were digitised and applied to this study. The latest versions of these charts provide a good description of Twofold Bay and the Snug Cove seabed and shoreline area.

4.2 Water Levels

Water levels within Snug Cove will be dominated by the astronomical tide. Tidal planes at Eden, which is a Standard Point, are presented in Australian National Tide Tables (2009) and are re-presented in **Table 4-1**.

Table 4-1 Tidal Planes at Eden

Tidal Plane	Level (m LAT)
Highest Astronomical Tide (HAT)	2.1m
Mean Higher High Water (MHHW)	1.8m
Mean Lower High Water (MLHW)	1.2m
Mean Sea Level (MSL)	1.0m
Mean Higher Low Water (MHLW)	0.8m
Mean Lower Low Water (MLLW)	0.2m

These levels are to datum lowest astronomical tide (LAT). Tides at Eden are semi-diurnal, that is, it experiences two high tides and two low tides per day.

As described in **Section 3**, water levels within Twofold Bay are affected also by processes other than the astronomical tide. The following climate change projected sea level rise scenarios have also been considered by this study:

- 0.4 m MSLR by 2050; and
- 0.9 m MSLR by 2100;

4.3 Wind

In common with MHL (2007), wind data was obtained from two automatic weather stations operated by the Bureau of Meteorology, namely Green Cape and Merimbula Airport. Based on based on the results of model verification conducted by Cardno (2011), the wind data from the Green Cape anemometer (2000-2010) was utilised over the Merimbula Airport wind data for the SWAN hindcast modelling.

4.4 Wave

Offshore wave data from 1978 to December 2013 from the MHL offshore Eden Waverider buoy (WRB) was supplied by RHDHV for the study. However up until December 2011 this data was non-directional, see **Table 4-2** below. Consequently, additional offshore wave data was obtained from the global/regional NSW WaveWatch III that Cardno developed and calibrated (including at Eden), for OEH.

Table 4-2 Available Offshore Wave Data

Data Set	Availability
Eden WRB - Non-Directional	Feb 1978 to Dec 2011
Eden WRB - Directional	Dec 2011 to Dec 2013
NSW WaveWatch III - Directional	Jan 1979 to Jan 2009

Swell wave hindcast modelling for a region such as Twofold Bay requires a long time series of directional offshore wave data – longer than the two years available from the Eden WRB. Therefore, it was necessary to estimate the wave direction at the Eden WRB from 1978 to 2011.

Consequently, the Eden WRB data from 1979 to 2011 was directionalised by adopting the corresponding NSW WaveWatch III modelled wave direction at the time of each WRB temporal data point. A verification of the suitability of this method was conducted by assessing the directionality of the Eden data (2011-2013) and the NSW WaveWatch III modelled data (1979-2009).

A comparison of the general directionality of each data set shows reasonable agreement – see **Figure 4.2**. As the WW3 output location is located approximately 25km due east of the Eden WRB (further offshore), the main difference between the two datasets is that the WW3 data has a greater proportion of wave energy coming from the South to Southwest sectors, while the Eden WRB depicts slightly more easterly waves. That said, a comparison of the overall directionality shows that the WW3 dataset provides a good representation of what is physically realistic at Eden.

5 Model Systems

Cardno have applied their calibrated SWAN wave model system of the region (Cardno, 2011) for much of the modelling undertaken for this investigation, but also applied the MIKE-21 Boussinesq Wave (BW) system for verification. A brief description of these modelling systems is provided herein.

5.1 SWAN Model

SWAN was developed at the Delft Technical University and includes wind input, (local sea cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. It also includes a nested grid capability to facilitate computation by having fine grids at inshore locations where bathymetric and structure details vary significantly and coarser offshore grids where a larger model extent is required, but seabed bathymetric changes are generally smaller. This procedure allows efficient modelling to be undertaken without sacrificing resolution where it is needed.

Cardno have verified the SWAN model system for local sea conditions in Snug Cove, as well as Botany Bay and Port Jackson. Swell calibration has been undertaken in Botany Bay, Port Kembla and Port Hedland, for example. In no cases has the model required modification, other than bed friction, directional spread and wave breaking index. However, it does rely on realistic wind and offshore wave data.

5.2 MIKE-21 Boussinesq Wave Model

The MIKE21 Boussinesq Wave (BW) is a state of the art numerical wave model developed by DHI, and generally used for the modelling of wave disturbance in ports, harbours and coastal areas. MIKE21 BW is based on the numerical solution of the time domain formulations of Boussinesq type equations, Madsen et al (1991, 1992, 1997a,b), Sorensen and Sorensen (2001) and Sorensen et al (2004).

MIKE21 BW is capable of reproducing the combined effects of all important wave phenomena of interest in ports, harbours and coastal engineering, including, shoaling, refraction, diffraction, wave breaking, bottom dissipation, moving shoreline, partial reflection, wave transmission, non-linear wave-wave interactions, frequency spreading and directional spreading.

The two dimensional wave model solves the Boussinesq type equations using a flux-formulation with improved frequency dispersion characteristics. The enhanced Boussinesq type equations makes the models suitable for the simulation of the propagation of non-linear directional waves from deep to shallow water.

The MIKE21 BW model was used to conduct a more detailed investigation of swell wave propagation into Cattle Bay and Cocora Beaches and to validate the SWAN swell wave modelling.

5.3 Wiegel Spectral Wave Transmission Model

Cardno confirmed the 1D spectral transmission characteristics of the proposed wave attenuator structure using a spectral screen transmission calculation tool that is based on Wiegel (1960), confirmed with WRL published data (monochromatic physical wave testing), but addressing spectral incident waves.

This routine can be applied to stationary wave screens that allow transmission below the structure where there is a gap between the seabed and the base level of the wave screen. Wave transmission is wave period dependent and so a wave spectrum is divided into a range of frequency bands and each band and its energy level transformed individually to form a transmitted spectrum, from which a spectral wave height is calculated. Hence swell and local sea are affected differently.

Cardno used this routine to calculate swell and sea transmission coefficients at two tide levels, and for present sea level, 0.4m and 0.9m sea level rise cases, see **Section 4.2**. These transmission coefficients were confirmed to be acceptable to the project by Royal HaskoningDHV.

Wave reflection parameters were calculated on a total energy basis, assuming zero energy loss.

6 Study Approach

The overarching approach of the study was:

1. Conduct SWAN wave hindcast modelling of local sea and swell waves to establish the pre-attenuator wave climate in the study region, specifically in terms of the effective near shore wave height and weighted mean wave direction parameters.
2. Use this data to inform wave attenuator design. The aim of this was to establish a wave attenuator design that would satisfy two key criteria, namely:
    a. Local sea and swell waves transmitted through the attenuator to the proposed marina moorings must satisfy the criteria for a “Moderate” Wave Climate in a Small Craft Harbour (see **Section 2.1**);
    b. The orientation and plan-form layout should minimise changes to the wave climate along Cocora Beach (thereby avoiding significant beach alignment change).
3. Conduct further SWAN wave hindcast modelling of local sea and swell waves incorporating the proposed wave attenuator. Establish post-attenuator wave climate at various locations in the study area to determine whether or not the attenuator design satisfies the key criteria. This modelling was also to be conducted for two projected sea level rise scenarios, namely:
    a. 0.4m SLR by 2050; and
    b. 0.9 m SLR by 2100.
4. If the design does not satisfy the criteria, then repeat steps 2 and 3 until the criteria are satisfied.
5. Validate the SWAN modelling of the optimised attenuator design using the MIKE21 BW model to investigate the propagation of swell waves into Cattle Bay and Cocora Beach.
6. Conduct coupled hydrodynamic-wave modelling for a series of locally significant storms to assess the influence of tidal currents, and the implications that this may have on the aforementioned wave modelling.

The specifics of the modelling methodology and outcomes are provided in subsequent sections of this report.

7 Modelling Methodology

The adopted methodology for the SWAN modelling of local sea and swell waves at the study area is provided herein. The MIKE21 validation modelling is described in **Section 9**.

7.1 SWAN Model Setup

The model grid layout is shown on **Figure 7.1**. Details of grid sizes are shown on the figure. It was used to undertake a range of local sea and ocean wave investigations so that the attenuator layout could be optimised/confirmed. A grid size of 5m in the region of the study site ensured good resolution in the immediate study area, especially of the near shore seabed slopes.

Obstacles such as a wave attenuator can be included in the SWAN model in two ways, namely:-

- With set reflection and transmission coefficients that will have been pre-calculated using the spectral transmission routine to calculate transmission coefficients – separately for sea and swell. Reflection coefficient is then calculated on an energy summation allowing 5% (estimate) for energy dissipation at the attenuator. This method has been applied at another site where Cardno had two wave recorders installed to record incident waves alone and combined incident and reflected waves at a second recorder, and these field measurements verified the model results.
- Specifying structural details and using an internal SWAN routine to determine the transmission and reflection coefficients.

Cardno considered both methods and decided to adopt the first because the outcome is more certain. The SWAN model simulations extended over a long period, from 1979 for offshore waves.

A series of model output locations were established, and are shown in **Figure 7.2**. Output locations near the shoreline of Cattle Bay and Cocora Beach are located in a depth of ≈-1m at LAT and represent the extent of shoreline that might reasonably be expected to be potentially affected by waves reflected from the attenuator. Other output locations are situated in the lee of the wave attenuator, in order to assess its efficacy.

7.2 Swell Waves

The swell wave climate at the study area was determined by implementing the SWAN wave model to prepare wave transfer coefficients for a full suite of offshore wave heights, periods and directions, namely:

- Mean Wave Periods (Tz) ranging from 1 s to 3 s - at 1 s intervals;
- Wave Directions from North, clockwise through to south - at 22.5 degree intervals;
- Significant Wave Heights of up to 8 m; and
- Three different tidal levels - LAT, MSL and HAT.

The results of this SWAN wave modelling provided matrices of wave coefficients and near shore wave directions at the model output locations shown on **Figure 7.2** The resultant base cases provided a reliable basis for the transfer of offshore wave data from the Eden WRB (with modified directional inputs – see **Section 4.4**), to inshore swell time-series at the nominated output locations.

Once the inshore wave time-series were established at the nominated output locations, the resulting inshore significant wave heights, peak period and direction time-series were used to calculate mean energy-weighted wave directions for swell waves at the nominated output locations, utilising the following relationships:

$$\frac{\sum\left(U * H_S^2 * T_p\right)}{\sum\left(H_S^2 * T_p\right)} \quad \text{and} \quad \frac{\sum\left(V * H_S^2 * T_p\right)}{\sum\left(H_S^2 * T_p\right)}$$

Where Hs is significant wave height.
Tp is peak wave period.
U is the east-west component of the wave direction.
V is the north-south component of the wave direction.

7.3 Local Sea Waves

The swell wave climate at the study area was determined by implementing the SWAN wave model to prepare wave transfer coefficients for a full suite of local wind speed, direction and water level, namely:

- Wind speeds ranging from 0 m/s to 30 m/s - at 2.5 m/s intervals;
- Wind directions from north, clockwise through to south back to north (around the clock) - at 22.5 degree intervals;
- Three different tidal levels - LAT, MSL and HAT.

The results of this SWAN wave modelling provided matrices of wave coefficients and near shore wave directions at the model output locations shown on **Figure 7.2**. The resultant base cases provided a reliable basis for the transference of Green Cape wind data to inshore time-series of local sea waves at the nominated output locations.

Once the inshore wave time-series was established at the nominated output locations, the wave parameters were calculated using the equations in **Section 7.2**.

7.4 Combining Swell and Local Sea Waves

The weighted mean wave directions from the separate swell and sea simulations were then combined on an energy weighting basis. The mean energy-weighted wave direction for *combined* swell and local sea waves was calculated using the following equations:

$$\frac{\Sigma(U_{swell}*H_{s\_swell}^2*T_{p\_swell})+\Sigma(U_{sea}*H_{s\_sea}^2*T_{p\_sea})}{\Sigma(H_{s\_swell}^2*T_{p\_swell}H_s^2*T_p)+\Sigma(H_{s\_sea}^2*T_{p\_sea})} \quad \text{and} \quad \frac{\Sigma(V_{swell}*H_{s\_swell}^2*T_{p\_swell})+\Sigma(V_{sea}*H_{s\_sea}^2*T_{p\_sea})}{\Sigma(H_{s\_swell}^2*T_{p\_swell})+\Sigma(H_{s\_sea}^2*T_{p\_sea})}$$

Where Hs is significant wave height.
Tp is peak wave period.
U is the east-west component of the wave direction.
V is the north-south component of the wave direction.

8 Results

8.1 Existing (Pre-Attenuator) Condition Simulations

The results of the SWAN modelling in terms of the weighted mean wave directions for local sea, swell and combined are depicted for selected output locations in **Figures 8.1**, **8.2** and **8.3,** respectively.

These results show several key findings. The first of these is that the orientation of Cocora Beach is predominantly aligned with the incoming swell (see **Figure 8.1**). The resultant long term mean weighted wave directions for the swell waves along Cocora Beach were consistently shore normal, that is, perpendicular to the current beach alignment as depicted in aerial imagery and described by available bathymetric data. **Figure 8.2** shows that the local sea wave climate along Cocora Beach is generally dominated by more southerly waves, an expected result given that these waves are driven primarily by winds from the south-east to south-west sector. These results also show that Cattle Bay Beach is less influenced by swell wave energy that Cocora Beach. This can be attributed to the swell wave energy gradient that occurs across northern Twofold Bay, which is protected by the Eden headland and more recently the Snug Cove breakwater extension. **Figure 8.4** gives an example of this swell wave energy gradient, for a typical swell period occurrence of Tz = 9 s easterly waves. As a result local sea waves more heavily influence the alignment of Cattle Bay Beach than Cocora Beach.

This is further demonstrated by **Figure 8.3**, which depicts the mean weighted wave direction for the combined local sea and swell waves. This confirms that the overall wave climate along Cocora Beach is dominated by the incoming swell, whilst along Cattle Bay Beach the wave climate is strongly influenced by both swell and local sea waves.

Another key finding is that of the design wave climate throughout the study area. **Table 8-1** depicts the design wave climate for both local sea and swell waves at a number of locations throughout the study area. These output locations are depicted on **Figure 7.2**. It shows that at the southern end of Cocora Beach the design wave climate is dominated by the penetration of offshore swell from Tasman Sea storms. However, the Eden headland and Snug Cove breakwater extension provide sheltering from this offshore swell to Cattle Bay Beach and the proposed Cattle Bay marina. Consequently, the swell wave energy gradient in Twofold Bay results in the design wave climate in Cattle Bay being dominated by local sea waves.

Table 8-1 also shows that for the existing (pre-wave attenuator) condition, the 1-year Average Recurrence Interval (ARI) and 50-years ARI significant wave heights in the marina exceed the "moderate" wave climate criteria set out in AS3962, and presented in **Table 2-1**. This confirms that a wave attenuation structure will be required for the marina in order to meet the AS3962 criteria.

Important conclusions drawn from this investigation and implication for the design of the attenuator are as follows:

- Due to the design wave climate in the region of the proposed marina, a wave attenuation structure will be required to meet the wave climate criteria set out in AS3962.
- Due to sheltering from swell waves provided by the Eden Headland and Snug Cove breakwater, the performance of the marina will be driven by local sea waves.
- The alignment of Cocora Beach is driven by swell, and hence the plan-form alignment of any wave attenuator would need to minimise changes to the swell wave climate along Cocora Beach that may result from wave reflections.
- The alignment of Cattle Bay Beach is affected by both swell and local sea waves. Hence, the implementation of a structure in Cattle Bay designed to alter the local sea or swell wave climate in Cattle Bay is likely to affect the long term beach alignment on Cattle Bay Beach, which is situated in the lee of said structure.

Table 8-1 Design Wave Heights for Local Sea and Swell (Pre- Attenuator) – Locations shown on Figure 7.2

Significant Wave Height, Hs (m) / Output Location	PRE-ATTENUATOR			
	Local Sea Waves		Swell Waves	
	1 year ARI	50 years ARI	1 year ARI	50 years ARI
A	0.60	0.82	0.09	0.14
B	0.60	0.82	0.16	0.25
G	0.61	0.80	0.99	1.38
I	0.60	0.79	1.20	1.59
R	0.73	0.98	0.15	0.22
S	0.74	1.00	0.16	0.24
T	0.72	0.98	0.31	0.50
U	0.73	1.00	0.37	0.57
V	0.75	1.01	0.29	0.46
W	0.76	1.03	0.17	0.26

8.2 Wave Attenuator Design

8.2.1 Plan-form Alignment

Based on the outcomes of the sea wind and swell modelling results, Royal HaskoningDHV provided Cardno with a preliminary wave attenuator design, shown in **Figure 8.5** in plan view. The design is based on the notion that the alignment and behaviour of Cocora Beach is predominantly driven by swell waves and the performance of the marina mostly by local sea waves.

The design is intended to satisfy the two key criteria outlined in **Section 6**, namely:

- To provide a "moderate" Wave Climate for the watercraft moored in its lee; and
- To minimise the changes to the wave climate along Cocora Beach;

Consequently, the attenuator alignment is cranked (i.e. bent), the purpose of which is twofold; the eastern section of the attenuator is oriented to reflect swell wave energy south of Cocora Point, while the western section is essentially aligned with the predominant swell direction so that it does not affect swell propagation.

Based on this design, and the predominant local sea wave and swell directionality (**Figures 8.1** and **8.2**), the alignment of attenuator is likely to produce some minor adverse effects in the form of local sea waves reflected to Cocora Beach from the western section of the attenuator. The significance of this issue is discussed in **Section 8.3**.

8.2.2 Wave Transmission Performance

The function of the proposed wave attenuator is to interact with the incident wave energy in the upper part of the water column, leading to a reduction of wave heights on its leeward side. Wave attenuation caused by the proposed design would generally be achieved through wave reflection, though some attenuation may also be achieved through out-of-phase damping, interference with water particle motions and viscous damping.

Wave attenuator performance is generally assessed in terms of a transmission coefficient,

K_T, which is defined as;

$$K_T = \frac{H_T}{H_I}$$

Where;

H_I is the incident wave height; and

H_T is the transmitted wave height.

To this end, a wave transmission coefficient was calculated for swell waves and local sea waves separately (as their wave periods differ significantly) using a spectral screen transmission module based on Wiegel (1960) to calculate transmitted wave energy through a fixed wave screen.

These transmission coefficients were calculated based on top and bottom levels of +2 mAHD and -3.0 mAHD, respectively. As the depth below the attenuator is different from one end to the other due to bathymetric variations, for swell waves, the wave transmission coefficient was calculated as the average of four cases (shown in **Table 8-2)**.

For local sea waves, the wave transmission coefficient was calculated as the average of two cases at MSL, taking into account the bathymetric variation along the attenuator. The JONSWAP frequency spectrum for young sea states was used (see **Table 8-3**).

The Pierson-Moskowitz frequency spectrum for fully-developed sea states was used for swell cases (see **Table 8-2**).

Table 8-2 Wave Transmission Coefficient Calculation Input (Swell)

Swell Wave Transmission Coefficient	Case 1	Case 2	Case 3	Case 4	
	Loc K	**Loc P**	**Loc K**	**Loc P**	
WL (mAHD)	1.1 (HAT)	1.1 (HAT)	-1 (LAT)	-1 (LAT)	
Hs (m)	1	1	1	1	
Tz (s)	9	9	9	9	
Water Depth (m)	9	7.3	7	5.3	
Breakwater Draft (m)	4	4	2	2	
Transmission Coefficient (-)	0.70	0.64	0.82	0.77	**Mean = 0.73**

Table 8-3 Wave Transmission Coefficient Calculation Input (Local Sea)

Swell Wave Transmission Coefficient	Case 1	Case 2	
	Loc K	**Loc P**	
WL (mAHD)	0 (MSL)	0 (MSL)	
Hs (m)	1	1	
Tz (s)	2.5	2.5	
Water Depth (m)	8	6.3	
Breakwater Draft (m)	3	3	
Transmission Coefficient (-)	0.366	0.374	**Mean = 0.37**

8.3 Post-Attenuator Simulations

As described in **Section 6**, once the initial wave attenuator design was accepted, further SWAN wave hindcast modelling of local sea and swell waves was performed incorporating the proposed wave attenuator structure. This allowed for an investigation of the effects of the wave attenuator, not only on the proposed marina wave climate, but also of any potential effects on the wave climate on Cocora and Cattle Bay Beaches.

8.3.1 Impact on Energy-Weighted Mean Wave Direction

Figures 8.6, 8.7 and 8.8 present energy-weighted mean wave direction for swell waves, local sea waves and combined swell/local sea.

Cocora Beach

Figure 8.6 shows that there is minimal change to the energy-weighted mean wave direction of swell waves along Cocora Beach. This indicates that the eastern component of the attenuator achieves one of its design functions by reflecting swell wave energy to the south of Cocora Point, while the western component is well aligned with the incoming swell. **Figure 8.7** demonstrates that the attenuator design does result in local sea waves being reflected to Cocora Beach, in particular the southern end where weight mean wave direction of local sea waves has swung more easterly (direction coming from) by 10 to 15 degrees.

As mentioned in **Section 8.1**, the alignment of Cocora Beach is driven by swell and hence **Figure 8.8** shows that the energy-weighted mean wave direction for combined local sea and swell waves shows minimal change after the implementation of the proposed wave attenuator structure. Combined local sea/swell wave directions generally change by less than half a degree along Cocora Beach. These model results show that the implementation of the proposed wave attenuator design is unlikely to result in long term changes to the energy-weighted mean wave direction along Cocora Beach, and is thus unlikely to significantly affect its alignment/orientation in the long term.

Cattle Bay Beach

It can be seen that the presence of the attenuator is likely to result in some changes to the mean wave directions on Cattle Bay Beach. **Figure 8.7** shows that the energy-weighted mean wave direction of local sea waves shifts clockwise (westerly) approximately six degrees. This is could potentially result in a change in the beach alignment along Cattle Bay Beach.

This, however, is to be expected and is common in regions where the nearshore wave climate has been altered by the presence of the proposed wave attenuation structure. One of the consequences of altering the wave climate in the marina is that the wave climate near Cattle Bay Beach will also inevitably be altered, leading to a potential for beach alignment change. **Figure 8.8** shows that the overall combined local sea and swell energy-weighted mean wave directions shift clockwise in the order of four to six degrees – varying along the shore line.

In order to quantify the potential resulting beach alignment change on Cattle Bay Beach, an assessment was made into the potential future equilibrium beach alignment under altered (post-attenuator) wave climate conditions (assuming reasonably that Cattle Bay Beach would rotate to be normal to the altered wave climate).

Figure 8.9 shows that the beach alignment would rotate clockwise in accordance with the changes in mean energy-weighted wave direction for combined swell and local sea waves. Rotation at the western and eastern ends of the beach are estimated (based on the changed energy-weighted mean wave directions) to be six and four degrees, respectively. A point of rotation was approximately calculated based on the above angles and a beach length of 180m, assuming no change in sub-aerial beach volume – realistic for a closed embayment. This then approximately leads to 8.4m movement landward at the western end and 7m movement seaward at the eastern end of Cattle Bay Beach.

Some of this potential for beach alignment change may be ameliorated by the reduced energy of incoming waves at Cattle Bay Beach provided by the attenuator. This would merely act to lengthen the time taken for the beach rotation to occur.

8.3.2 Impact on Design Wave Climate

The effects of the wave attenuator on design wave criteria were assessed by estimating ARI wave heights from the inshore wave data, for the pre- and post-attenuator situation. This was achieved by fitting a Weibull distribution to independent peak storm wave heights exceeding the 98th percentile. **Table 8-4** shows the estimated 1-year ARI and 50-years ARI wave heights at the nominated output locations (see **Figure 7.2**). Design wave heights for output locations within the marina are indicated in red.

Table 8-4 Design Wave Heights for Local Sea and Swell (Pre- and Post-Attenuator) – Locations shown on Figure 7.2

Significant Wave Height, Hs (m)	Local Sea Waves				Swell Waves			
	Pre-Attenuator		Post - Attenuator		Pre-Attenuator		Post - Attenuator	
Output Location	1 year ARI	50 years ARI	1 year ARI	50 years ARI	1 year ARI	50 years ARI	1 years ARI	50 years ARI
A	0.60	0.82	0.52	0.69	0.09	0.14	0.08	0.11
B	0.60	0.82	0.53	0.71	0.16	0.25	0.12	0.19
G	0.61	0.80	0.63	0.85	0.99	1.38	0.99	1.38
I	0.60	0.79	0.61	0.80	1.20	1.59	1.20	1.59
R	0.73	0.98	0.57	0.80	0.15	0.22	0.15	0.22
S	0.74	1.00	0.39	0.52	0.16	0.24	0.12	0.17
T	0.72	0.98	0.52	0.66	0.31	0.50	0.23	0.36
U	0.73	1.00	0.36	0.46	0.37	0.57	0.25	0.39
V	0.75	1.01	0.34	0.45	0.29	0.46	0.20	0.33
W	0.76	1.03	0.34	0.46	0.17	0.26	0.13	0.20

Design local sea wave heights along Cattle Bay Beach (output locations A and B) are slightly lower post-attenuator. The effects of the attenuator are lessened here due to the exposure of Cattle Bay Beach to waves diffracted around the western end of the attenuator.

Critical design wave heights along Cocora Beach (output locations G and I) are generally those of swell waves, which are largely unaffected by the presence of the attenuator – further indicating that much of the swell reflected by the attenuator is reflected to the south of Cocora Point. It appears as though the presence of the attenuator has increased the local sea wave energy along Cocora Beach. The alteration of the local sea wave climate along Cocora Beach is also discussed in **Section 8.3.1**, wherein it is also mentioned that the wave climate along Cocora Beach is dominated by the incoming swell, and changes to the local sea wave climate along Cocora Beach are unlikely to cause changes to the overall combined local sea/swell wave climate.

As expected, design local sea wave heights in the proposed marina location (output locations R through to W) are reduced due to the presence of the attenuator. However, it should be noted that not all of the marina locations had 1-year ARI and 50-years ARI design wave heights within the “moderate” wave climate criteria set out in AS3962, particularly Points R and T, indicating that the eastern and western extents of the marina are affected by local sea waves that are diffracted around the ends of the wave attenuator.

Satisfaction of the “moderate” wave climate in these locations could be achieved through a number of means. Given the efficacy of the current attenuator alignment in satisfying the design criteria in respect to Cocora Beach, the most suitable method would be to block the diffracted local sea waves by extending the attenuator at each end. Due to the short period nature of the design local sea waves this extension need only be relatively minor.

8.3.3 Sea Level Rise Effects on Design Wave Criteria (Post-Attenuator)

In addition to the present day situation for the post-attenuator situation (**Section 8.3.2**), additional SWAN simulations were undertaken in order to assess the effects of mean se level rise on the design wave criteria. Model results for the 2050 (0.4m) and 2100 (0.9m) SLR scenarios (see **Table 8-5** and **Table 8-6**) show that the design wave heights inside Snug Cove are unlikely to change significantly under these sea level rise projections.

Table 8-5 Local Sea Waves Extremal Analysis – SLR Effects (Post-Attenuator)

Local Sea	1-Year ARI						50-Years ARI					
	Present Day		2050		2100		Present Day		2050		2100	
Location	H_s	T_p	H_s	T_p	H_s	T_p	H_s	T_p	H_s	T_p	H_s	T_p
A	0.52	2.6	0.54	2.7	0.56	2.7	0.69	3.0	0.70	3.0	0.73	3.0
B	0.53	2.7	0.55	2.7	0.56	2.7	0.71	3.0	0.73	3.1	0.75	3.1
G	0.63	3.1	0.65	3.1	0.66	3.1	0.85	3.6	0.87	3.7	0.89	3.7
I	0.61	3.3	0.63	3.3	0.65	3.4	0.80	3.9	0.84	4.0	0.86	4.1
R	0.57	2.9	0.58	2.9	0.58	2.9	0.80	3.4	0.80	3.4	0.81	3.5
S	0.39	2.3	0.39	2.3	0.39	2.3	0.52	2.6	0.52	2.6	0.52	2.6
T	0.52	2.6	0.53	2.7	0.54	2.7	0.66	3.0	0.67	3.0	0.68	3.0
U	0.36	2.4	0.36	2.4	0.37	2.5	0.46	2.7	0.47	2.8	0.47	2.8
V	0.34	2.3	0.34	2.3	0.34	2.3	0.45	2.7	0.45	2.7	0.45	2.7
W	0.34	2.6	0.34	2.6	0.35	2.6	0.46	3.0	0.46	3.0	0.46	3.0

Table 8-6 Swell Waves Extremal Analysis – SLR Effects (Post-Attenuator)

Swell	1-Year ARI						50-Years ARI					
	Present Day		2050		2100		Present Day		2050		2100	
Location	H_s	T_p	H_s	T_p	H_s	T_p	H_s	T_p	H_s	T_p	H_s	T_p
A	0.08	8.6-13.4	0.08	8.6-13.4	0.08	8.6-13.4	0.11	9.9-12.8	0.11	9.9-12.8	0.11	9.9-12.8
B	0.12	9.7-13.4	0.12	9.7-13.4	0.12	9.7-13.4	0.19	10.9-12.6	0.19	10.9-12.6	0.19	10.9-12.6
G	0.99	9.6-12.3	1.00	9.6-12.3	1.00	9.6-12.3	1.38	9.6-12.3	1.42	9.6-12.3	1.46	9.6-12.3
I	1.20	7.7-10.8	1.26	8.1-10.8	1.30	8.0-10.8	1.59	7.7-10.8	1.66	8.1-10.8	1.74	8.0-10.8
R	0.15	8.8-12.7	0.15	8.8-12.7	0.15	8.8-12.7	0.22	10.0-12.0	0.22	10.0-12.0	0.22	10.0-12.0
S	0.12	8.6-12.9	0.12	8.6-12.9	0.12	8.6-12.9	0.17	9.9-12.0	0.17	9.9-12.0	0.17	9.9-12.0
T	0.23	10.4-13.0	0.23	10.4-13.0	0.23	10.4-13.0	0.36	11.6-12.2	0.36	11.6-12.2	0.36	11.6-12.2
U	0.25	9.8-12.8	0.25	9.8-12.8	0.25	9.8-12.8	0.39	11.2-12.0	0.39	11.2-12.0	0.39	11.2-12.0
V	0.20	10.3-13.1	0.20	10.3-13.1	0.20	10.3-13.1	0.33	11.7-12.2	0.33	11.7-12.2	0.33	11.7-12.2
W	0.13	8.3-12.8	0.13	8.3-12.8	0.13	8.3-12.8	0.20	9.9-11.8	0.20	9.9-11.8	0.20	9.9-11.8

Peak wave periods corresponding to the design wave heights for local sea waves were obtained through a correlation analysis of the wave time-series in each of the nominated output locations. **Figures 8.10** and **8.11** show correlation graphs for the present day sea level rise scenario. As design wave heights are unlikely to be significantly influenced by sea level rise, the correlation relations for the present day scenarios are adopted for calculating the peak wave period in the 2050 and 2010 SLR scenarios.

Correlation graphs relating significant wave height and peak period of swell waves show more scatter (see **Figures 8.12** and **8.13** for the present day situation). Peak wave periods were calculated based on the design wave heights as presented in **Table 8-6**. These periods were based on the 95th percent confidence intervals of modelled swell wave Tp's corresponding to significant wave height bins of 0.1m.

In order to validate these results, simulations for two additional offshore wave cases were undertaken. These cases represent the 1-year ARI and 50-years ARI offshore wave events as used by Cardno (2011) and determined by MHL (2007). As these waves will be from the south-south-eastern sector in most cases, directions ranging from 90°TN to 180°TN (22.5 degree intervals) were considered.

The resulting peak periods, presented in **Figure 8.13**, seem to be in reasonable agreement with the confidence intervals shown in **Table 8-6**, and provide confidence in the adopted peak periods associated with the swell wave design criteria.

9 MIKE21 Boussinesq Wave Model Validation

In order to validate the SWAN swell wave modelling, a more detailed investigation of the swell wave propagation into Cattle Bay and Cocora Beaches following the installation of the attenuator and marine facilities was undertaken using the MIKE21 Boussinesq Wave (BW) model system developed by DHI – see **Section 5.2**. This is a phase resolving model and requires small grid sizes and time steps. It includes refraction, shoaling, diffraction, bed friction, wave breaking and frequency-direction spectral input. It can include partial and full wave reflectivity – rock breakwaters, attenuators and vertical walls.

The model extends from Cattle Bay Beach in the north to about 1500m south of that, and from the Eden headland in the east to west of Cocora Point in the west. **Figure 9.1** shows this model grid layout and selected model output locations along Cocora Beach – common to MIKE-21 BW and SWAN. Each MIKE-21 BW simulation was run for about 60 minutes of prototype time – to emulate Waverider buoy-type records; following a period of 15 minutes required to establish dynamic equilibrium.

Wave dissipation was adopted at the shoreline – that is, no shoreline reflection.

MIKE-21 BW modelling requires a constant bed level along the input wave boundary, a requirement that can lead to a highly schematised model set-up. No wind input is included. The wave attenuator was incorporated into the model as a porous structure, with the transmission and reflection coefficients of the wave attenuator included in the modelling using a numerical porous structure. The value of the porosity was determined using an MIKE-21 BW routine that depends on the water depth, grid size and wave parameters.

The model was set up to extend from just south-west of Cocora Point and inshore to the shoreline in Cattle Bay. Grid size was adopted to be 2m. Swell wave direction has little variation in this area.

Two typical cases were investigated with this model because of its heavy computational requirements; these were swell waves with a peak spectral period, Tp of 10s and 15s, both with and without the proposed wave screen.

Internal wave generation in the simulations was set up specifying a time-series of water level boundary fluctuations described by a JONSWAP spectrum with the following shape parameters:

- $\gamma = 3.3$
- $\sigma_a = 0.07$
- $\sigma_b = 0.09$

Figure 9.2 shows the model results for the Tp = 10s simulations for the existing (pre- wave screen - top frame), and post wave screen (bottom frame) scenarios. The results are presented in terms of significant wave height (H_s) and wave penetration coefficient, *k*, which represents the proportion of swell wave energy propagating into the study area from the Tasman Sea. Additionally, **Figure 9.3** shows the change in *k* resulting from the influence of the attenuator. This plot shows increased wave energy directly in front of the eastern section of the attenuator, resulting from the reflection of swell waves. Importantly, this figure also shows that the wave attenuator achieves its design objective of reflecting long period swell to the south of the Cocora Point.

Figures 9.4 and **9.5** show that a similar pattern is evident for the Tp = 15s simulations, indicating that the attenuator still achieves this objective for longer period swell.

As an additional validation to the SWAN modelling, the energy spectral density function was plotted at the Cocora Beach output locations G and I (see **Figures 9.6** and **9.7**) for both the Tp =10s and Tp = 15s MIKE21 BW simulations.

These figures show that there is minimal observed change to the energy spectral density at these locations along Cocora Beach.

These results are consistent with the results of the SWAN swell wave modelling, which indicated that the presence of the wave attenuator would cause minimal changes to weighted wave mean direction, or design wave heights of swell waves along Cocora Beach.

10 Coupled Wave and Hydrodynamics Investigation

In relatively open coast regions such as Twofold Bay, beach alignment is predominantly driven by swell wave activity (as demonstrated in **Section 8.1**). Hence, when assessing the impact that a wave attenuator may have on surrounding shorelines, tidal currents are usually considered, but not numerically modelled (on the basis that flood and ebb effects cancel each other out). However, in order to provide a more in depth assessment of the effects of the wave attenuator on the shoreline, coupled hydrodynamic and wave modelling was undertaken for the two recent major storms to have affected the study area in June 2007 and May 2010 (Cardno, 2011).

One of the advantages of the Delft3D hydrodynamic model system (FLOW) is its ability to be coupled with the SWAN wave model in what is known as a Flow-Wave-Flow model (hereafter referred to as FWF). This function works using cyclical results transferred between the two model systems. That is, the Delft3D FLOW model is set running, and at specified intervals (for this project the interval was one hour), the FLOW model stops and its results (e.g. for water level, tidal currents etc.) are transferred into the SWAN wave model, where these results are incorporated into the SWAN wave calculations. After these SWAN wave calculations have been performed, its results are then transferred back to the FLOW model (e.g. for radiation stresses, wave setup, wave induced currents etc.) where they are incorporated into the Delft3D flow calculations, and so forth. In this way the results between the two model systems transfer back and forth for the duration of the coupled simulation, with the information transfers taking place at appropriately specified intervals.

As a basis for comparison with uncoupled results, a series of SWAN (wave only – hereby in this section referred to as SWAN) non-stationary swell wave simulations were also conducted for the two storm events. These simulations were run excluding the effect of the dynamic astronomical tide, and were run at a still water level of 0m AHD. Results from these two types of simulations were compared at a number of output locations along Cocora Beach, Locations F to J (see **Figure 7.2**).

Figures 10.1 to 10.10 show simulation results in terms of time-series of wave height and direction throughout the storm duration. These results show a few key findings.

The first is that the SWAN and FWF simulations generally show good agreement in terms of the evolution of wave height and direction along Cocora Beach throughout the duration of each storm event. Generally speaking, divergence in nearshore wave height only occurs during the peak of each storm event, when the offshore Hs exceeds a 4m to 5m threshold. During the peak storm periods the modelled Hs differed by up to 25% at some Cocora Beach locations between the two simulation types

Another interesting finding is that the influence of tidal levels and currents on wave shoaling and refraction results in a slight semi-diurnal oscillation of wave direction - in the order to 2-4 degrees about shore normal. However, despite this semi-diurnal oscillation, the resulting time averaged mean wave direction of the FWF and SWAN simulations along Cocora Beach remain very similar. The results also show that differences in wave direction were generally at a maximum during peak offshore wave activity, generally in the range of 2 to 8 degrees.

It is likely that the divergence between the SWAN and FWF significant wave heights during these periods of high offshore wave energy is the result of a number of processes, namely:

- The influence of tide level (and thus near-shore water depths) on wave direction, wave breaking and wave energy dissipation;
- The enhanced ability of FWF simulations to describe wave setup (and thus to affect the above); and
- The influence of tidal currents on wave shoaling and refraction.

With regards to the modelling of significant wave height, the divergence of the FWF and SWAN modelled wave heights during the period of high offshore wave energy demonstrate the importance of conducting wave modelling at more than one tide level, in order to capture non-linear tidal influences on wave height. Furthermore it provides justification of the methodology described in **Section 7**, where swell and local sea wave hindcast modelling was conducted at three tide levels (LAT, MSL, and HAT) in order to properly capture some of these non-linear influences.

Given that the alignment of Cocora Beach is primarily driven by the action of ambient swell acting over long periods of time, it was important to investigate whether or not the long term, mean wave direction would differ when described by the FWF and SWAN simulations, respectively. Whilst the greatest sustained differences in the modelled wave directions between these two simulation types occurred during periods of peak offshore wave energy, this alone is unlikely to have ramifications for the assessment of long term changes to beach alignment at Cocora Beach. During ambient offshore wave conditions, the modelled FWF wave directions oscillated about a mean wave direction, which was well described by the SWAN (alone) modelling. These results indicate that the modelled long term mean weighted wave directions along Cocora Beach are unlikely to be significantly different from FWF and SWAN (alone) simulations.

Therefore, given the computationally intensive nature of coupled hydrodynamic – wave modelling (FWF), the adopted approach of determining the weighted mean wave direction along Cocora Beach through SWAN non-dynamic tidal simulations is justified, given its greater computational efficiency.

11 Concluding Remarks

Cardno have undertaken wave climate and shoreline effect numerical wave and current modelling for a proposed marina layout at Cattle Bay in northern Twofold Bay; the main purpose of which was to investigate the potential effects of waves reflected from the proposed marina wave screen towards Cocora Beach.

As part of the study Cardno have conducted SWAN wave hindcast modelling of local sea and swell waves to determine the influence of the proposed wave screen on the near shore wave climate of the study area in terms of near shore wave height and weighted mean wave direction.

The results of the study indicate that the alignment of Cocora Beach is controlled by swell, but the performance of the wave screen in terms of the marina will be driven by local sea waves.

Cardno have modelled a proposed wave screen structure and found that the structure achieves its design criteria in respect to Cocora Beach by reflecting swell wave energy to the south of Cocora Point. Consequently, significant changes to the beach alignment are not expected at Cocora Beach as a result of the implementation of the wave attenuator.

The presence of the attenuator is likely to result in some changes to the mean wave directions at Cattle Bay Beach, and hence may result in a clockwise beach plan-alignment rotation in the order to six to eight metres at the eastern and western ends, respectively.

Design wave heights inside the proposed marina are reduced by the presence of the attenuator. However, the marina does not satisfy the “moderate” wave climate criteria set out in AS3962 with the current attenuator design at all locations. This could be achieved by a relatively minor extension of the attenuator at each end (along the current alignment)

Projected sea level rise scenarios cause minimal changes to design wave heights in the study area.

Cardno have also conducted a validation of the SWAN swell wave modelling using the MIKE21 Boussinesq Wave (BW) Model. The results showed that swell waves reflected from the attenuator to the south of Cocora Point, and also indicated that the implementation of the attenuator would result in only minimal changes to swell wave spectra along Cocora Beach.

In order to assess the influence of tidal currents, coupled hydrodynamic and wave modelling was undertaken for two recent major storms that affected the study area in June 2007 and May 2010 (Cardno, 2011). The results show the importance of accounting for non-linear tidal influences on wave height and also indicate that the modelled long term weighted mean wave directions along Cocora Beach are unlikely to be significantly different for FWF and SWAN simulations.

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Wave Modelling

FIGURES

Cardno

Cattle Bay Marina – Wave modelling

Locality Plan
Cattle Bay

Figure 1.1

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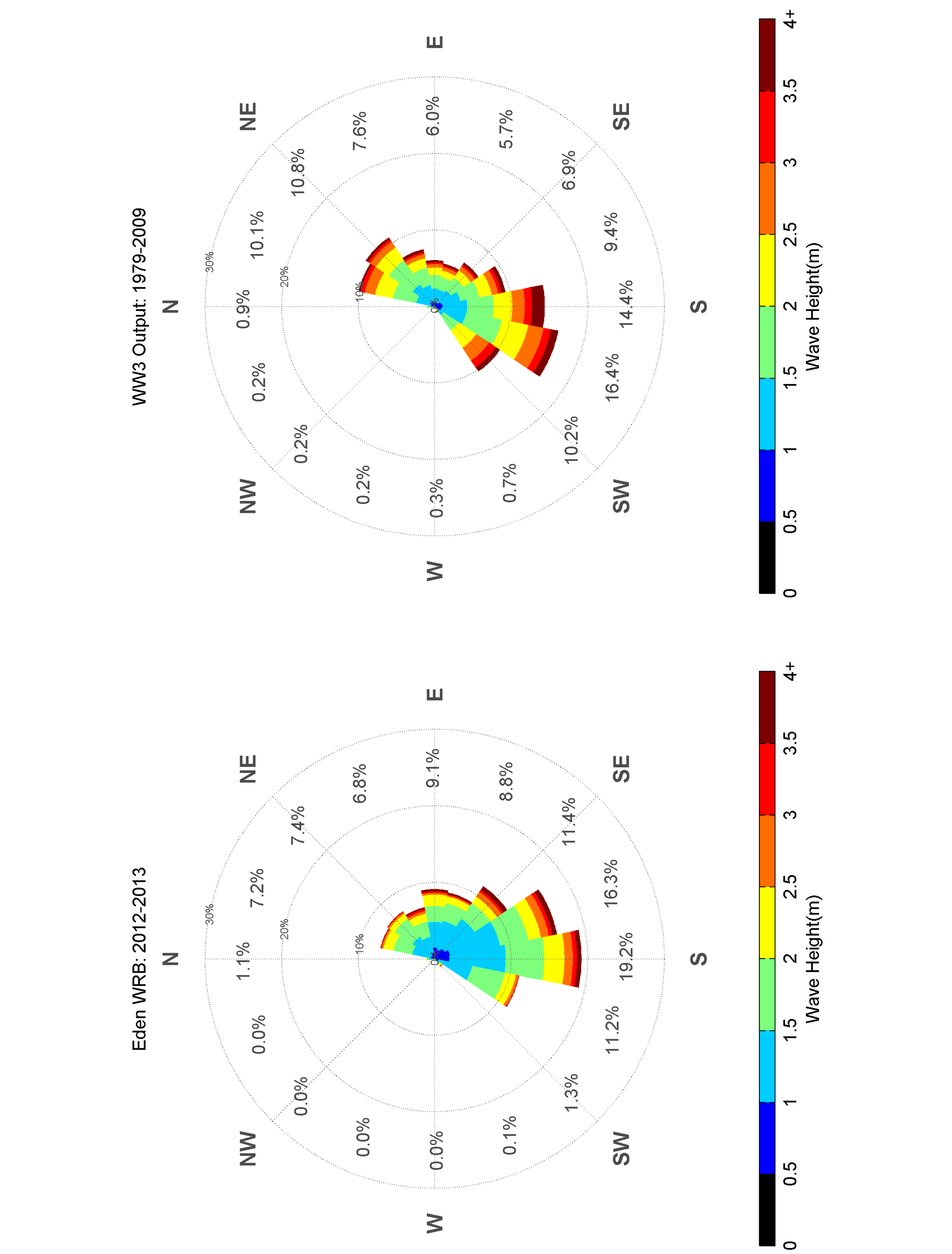

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Cattle Bay Marina – Wave modelling

Eden WRB and WW3 Wave Data Comparison of Directionality

Figure 4.1

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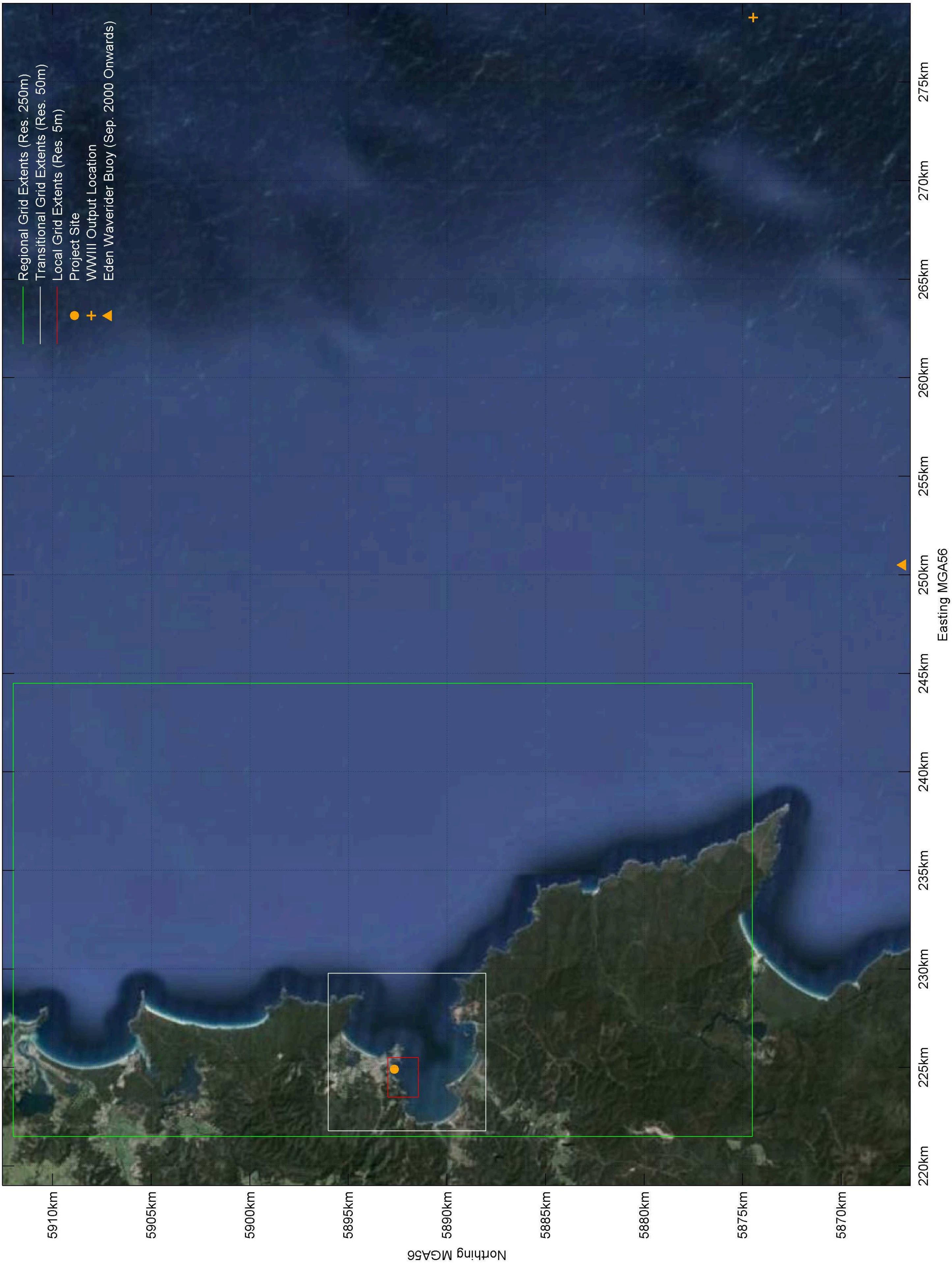

Cattle Bay Marina – Wave modelling

Grid Extents and Data Set Locations
Eden

Figure 7.1

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Cattle Bay Marina – Wave modelling

SWAN Model Output Locations

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Figure 7.2

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Cattle Bay Marina – Wave modelling

Mean Energy–Weighted Wave Direction
Swell Waves (Pre–Attenuator)

Figure 8.1

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Cattle Bay Marina – Wave modelling

Mean Energy–Weighted Wave Direction
Local Sea Waves (Pre–Attenuator)

Figure 8.2

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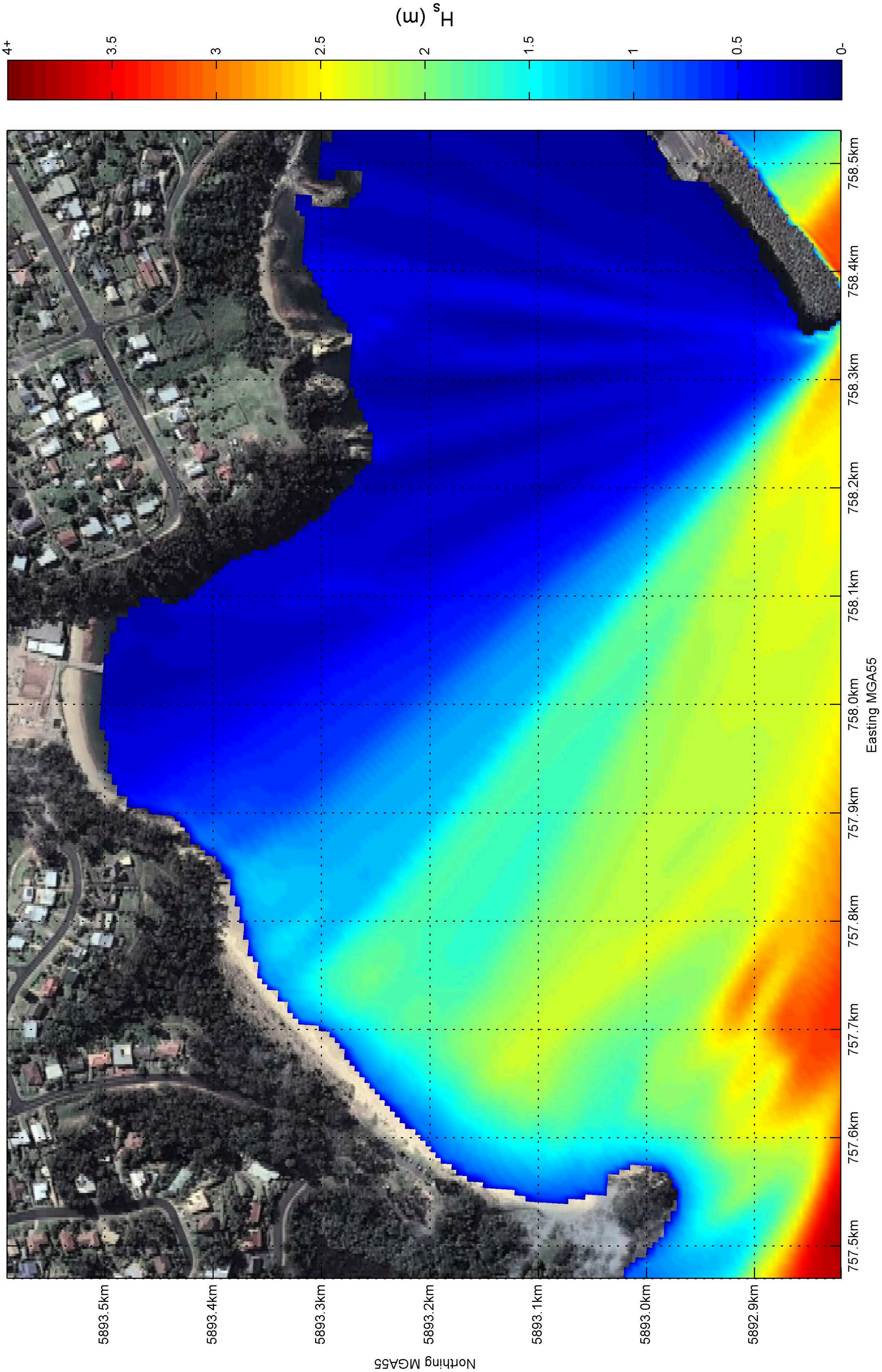
Cattle Bay Marina – Wave modelling

Mean Energy–Weighted Wave Direction
Combined Swell and Local Sea Waves (Pre–Attenuator)

Figure 8.3



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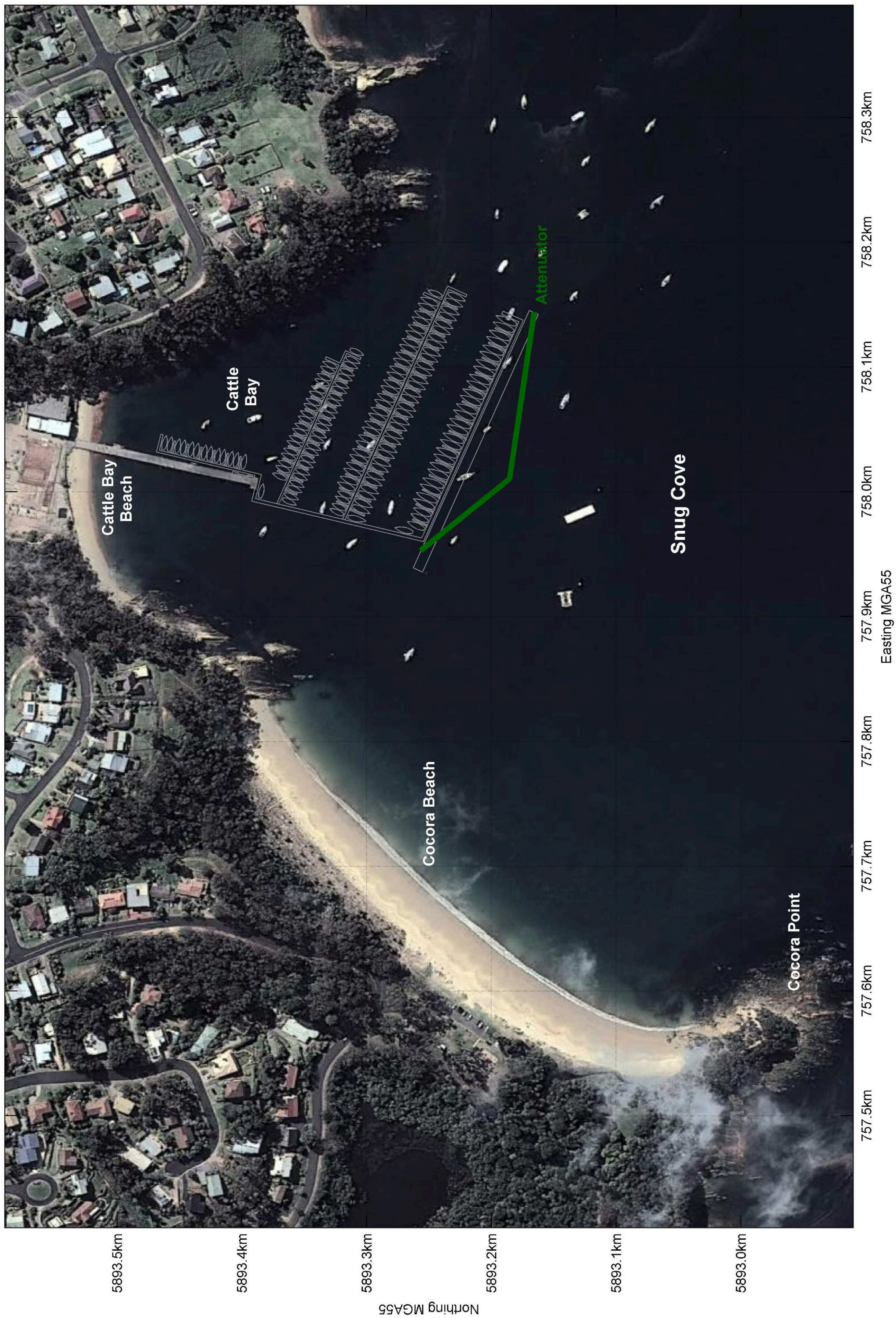
Cattle Bay Marina – Wave modelling

Observed Swell Wave Energy Gradient In Twofold Bay

Figure 8.4



Cattle Bay Marina – Wave modelling

Wave Attenuator Layout
Cattle Bay

Figure 8.5

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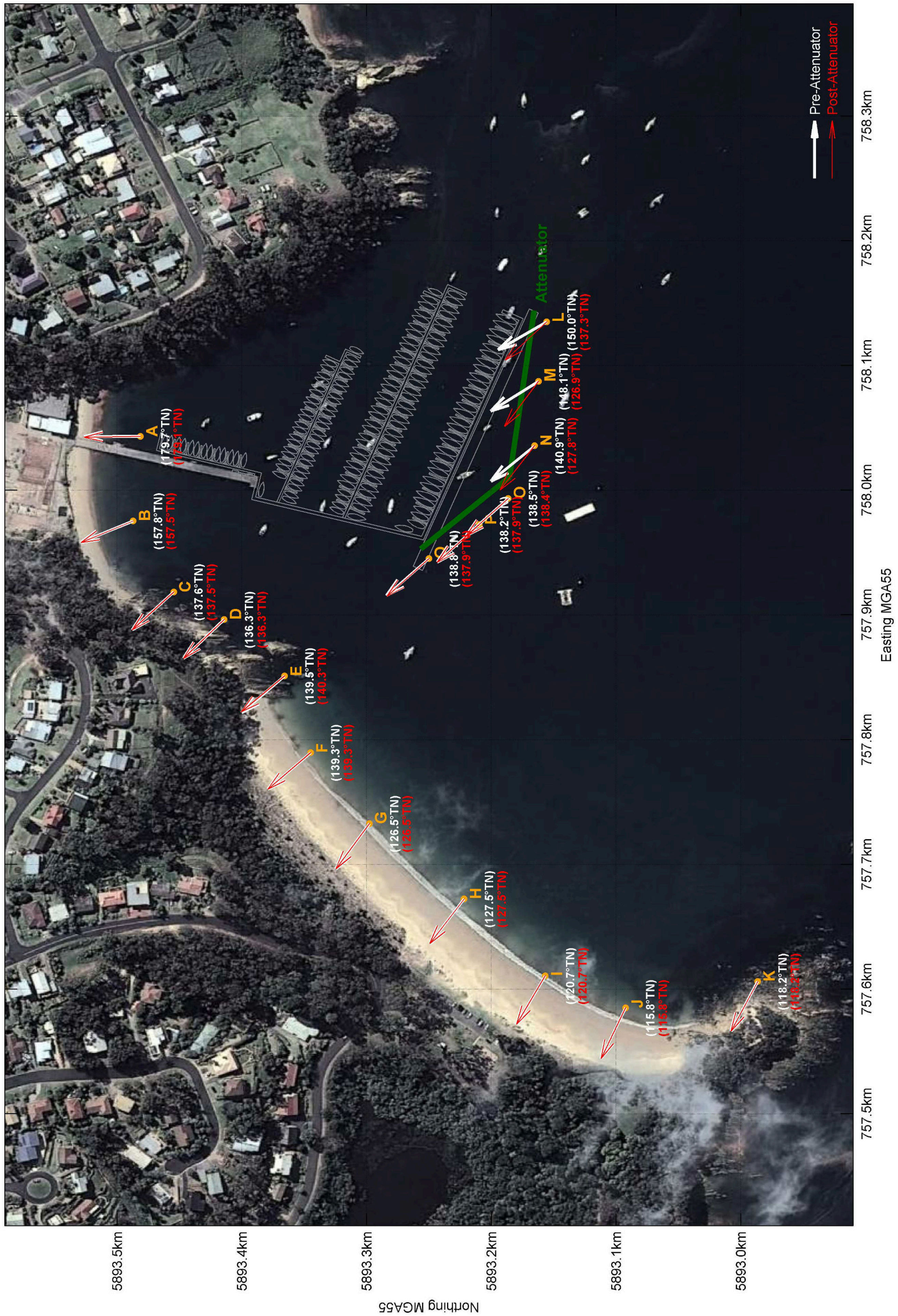

Cattle Bay Marina – Wave modelling

Mean Energy–Weighted Wave Direction
Swell Waves (Pre– and Post–Attenuator)

Figure 8.6

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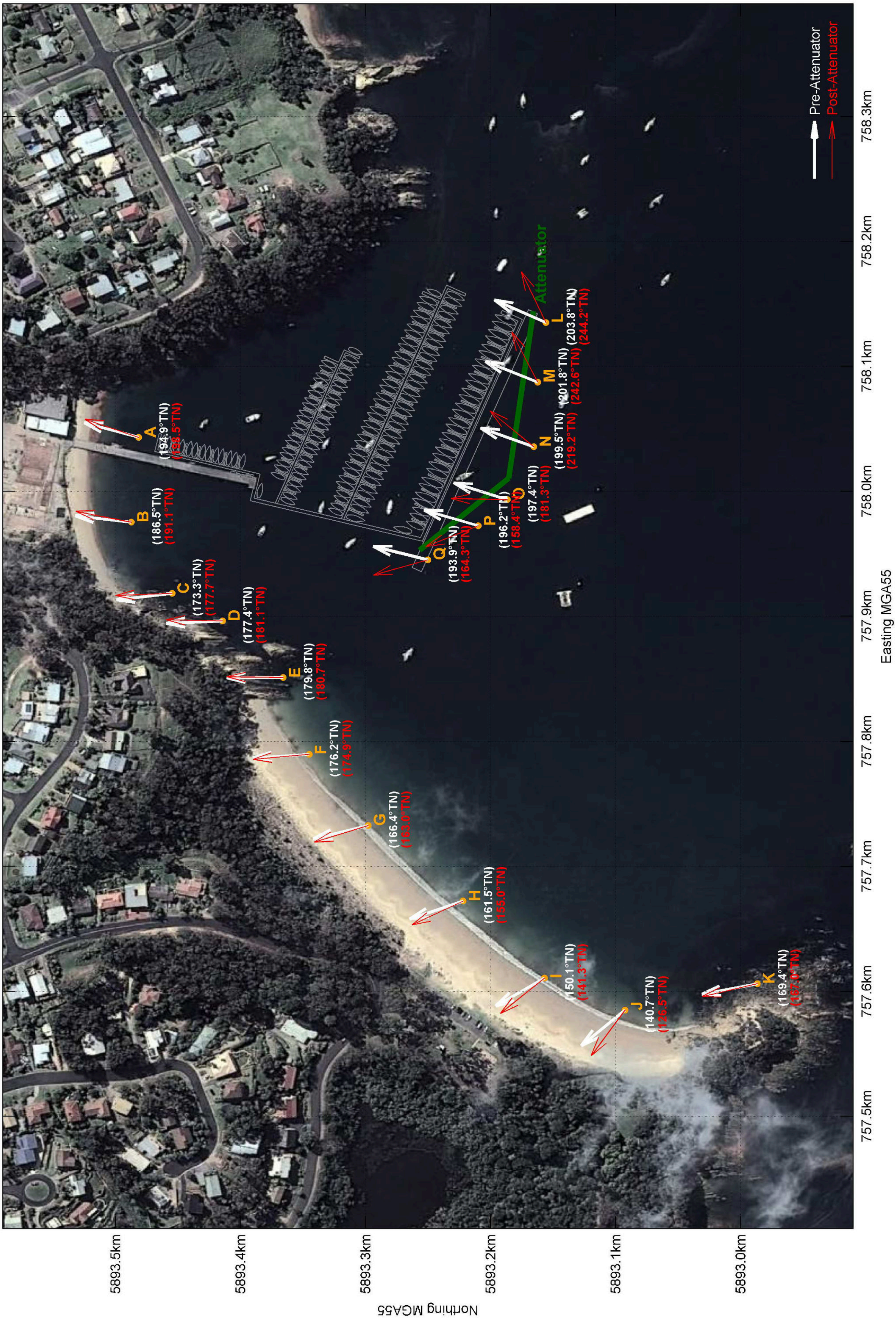

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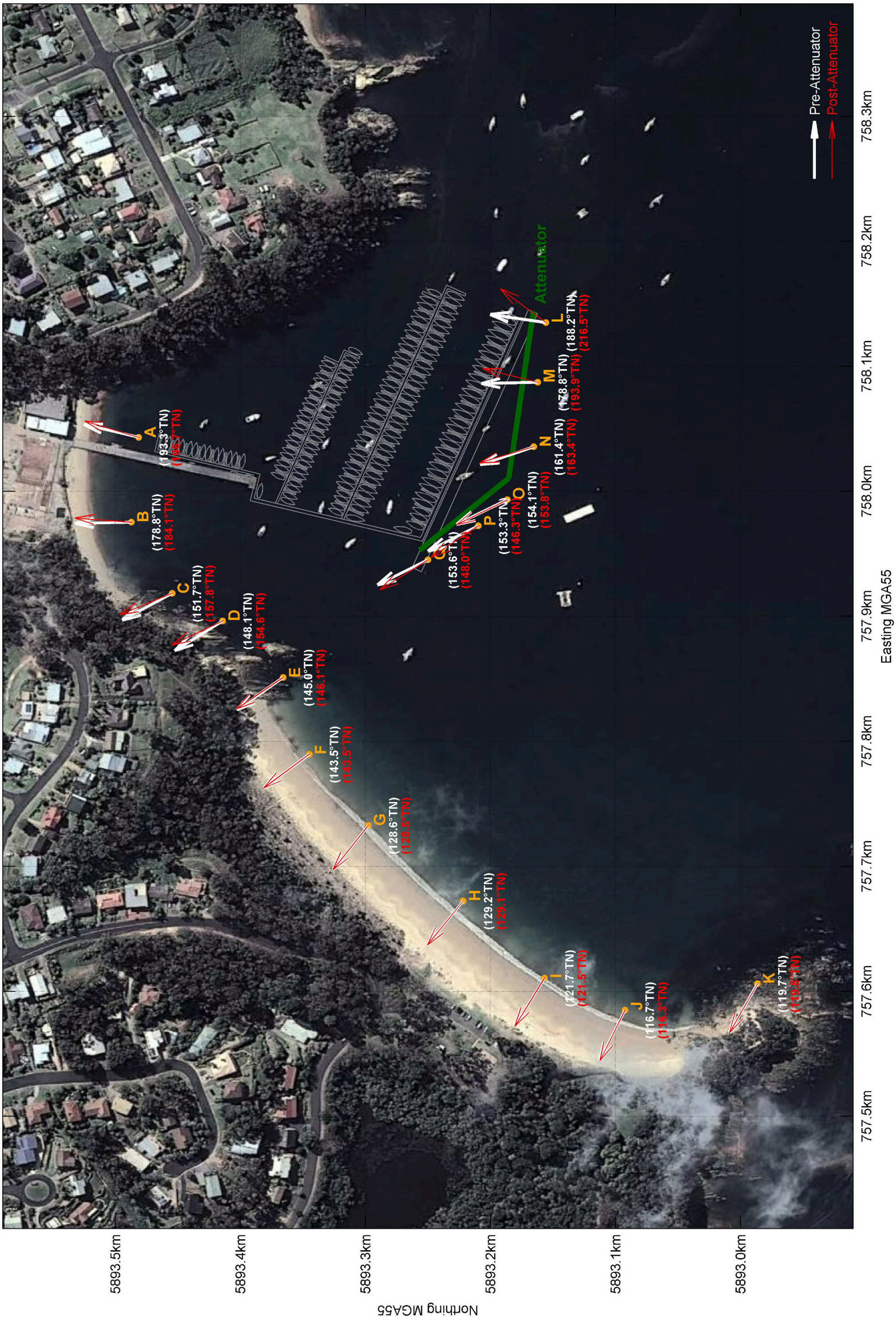
Cattle Bay Marina – Wave modelling

Mean Energy–Weighted Wave Direction
Local Sea Waves (Pre– and Post–Attenuator)

Figure 8.7



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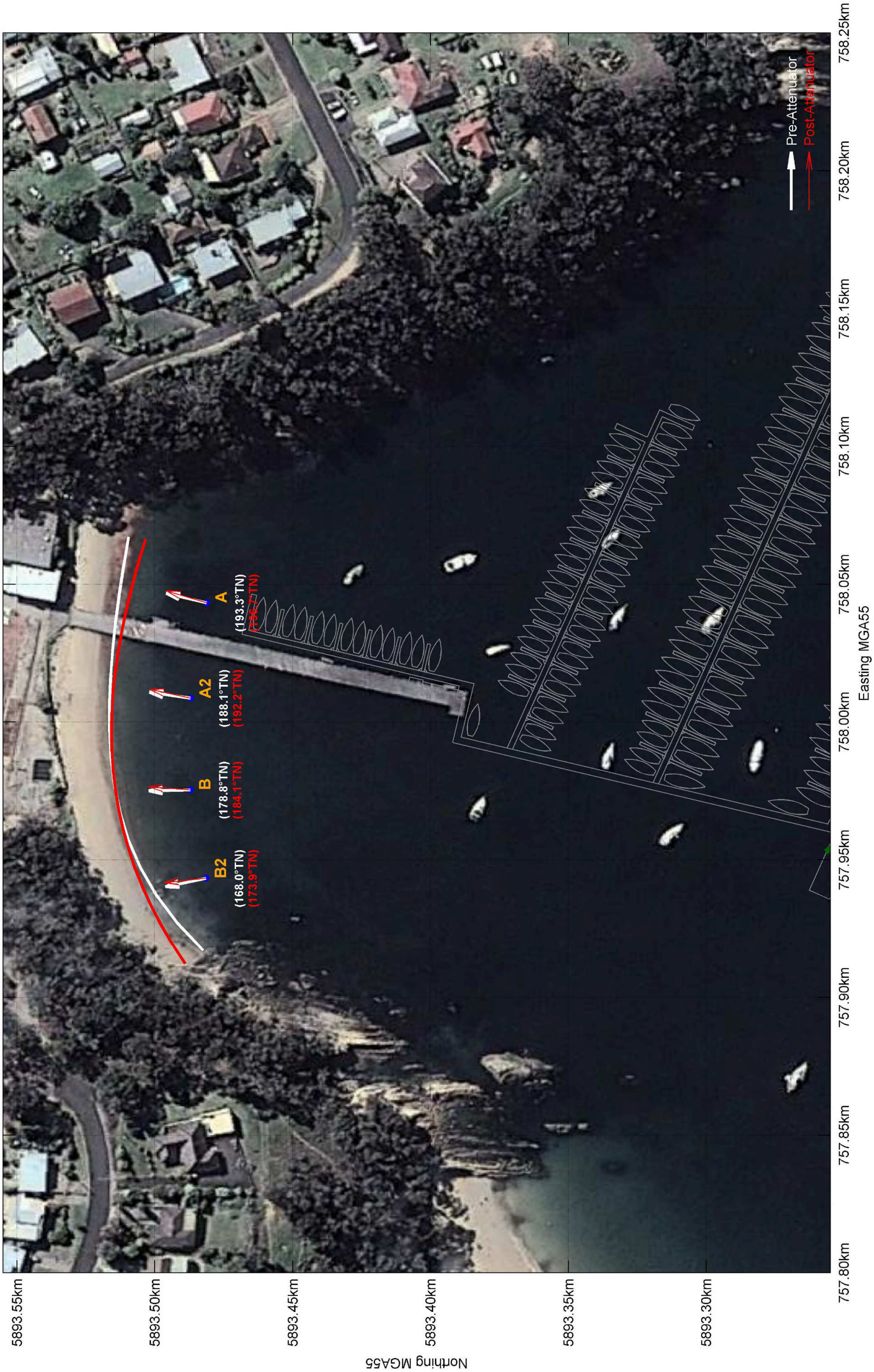
Cattle Bay Marina – Wave modelling

Mean Energy–Weighted Wave Direction
Combined Swell and Local Sea Waves (Pre– and Post–Attenuator)

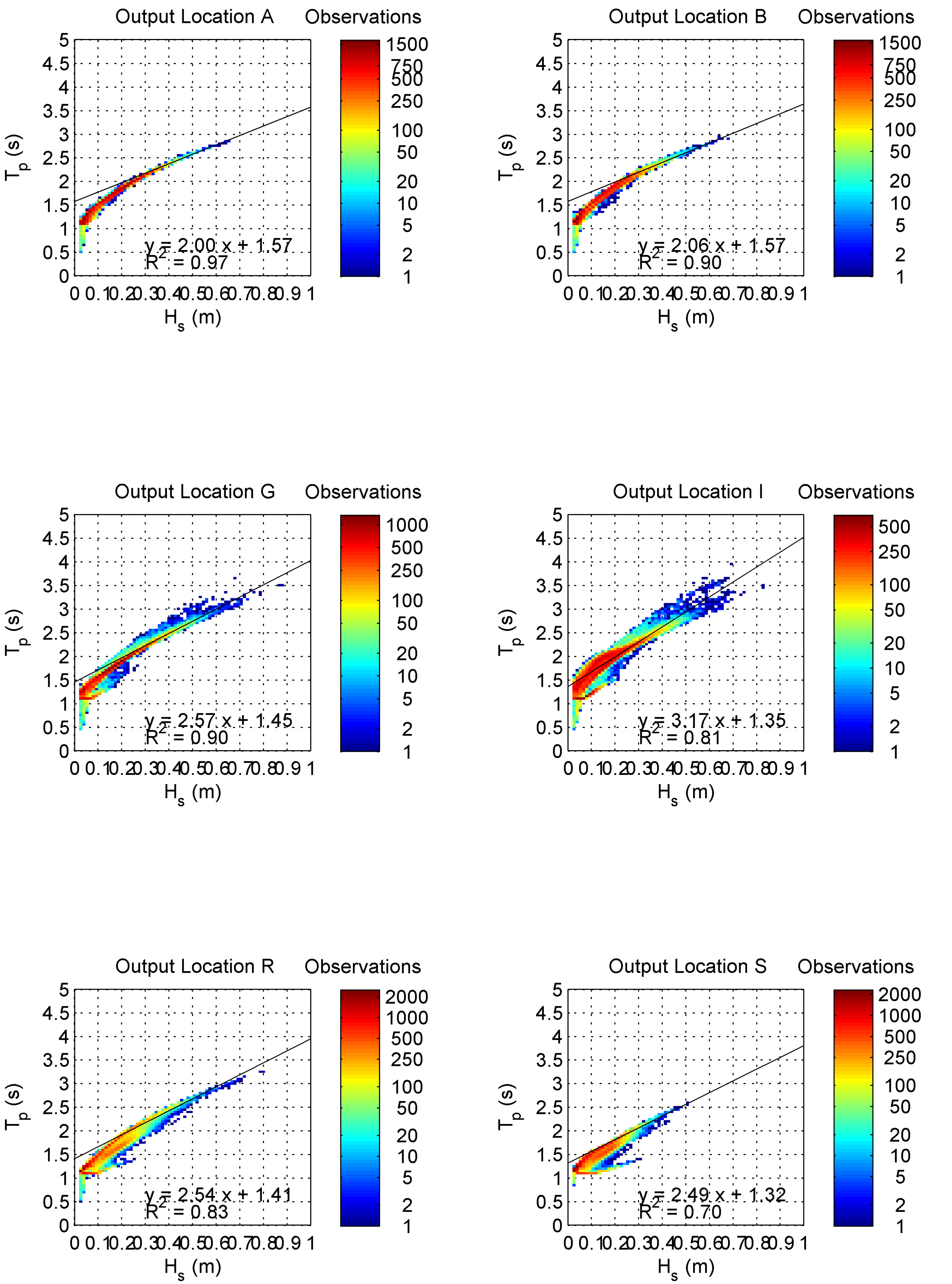
Figure 8.8



Cattle Bay Marina – Wave modelling

Beach Alignment Change
Catte Bay Beach

Figure 8.9



Cattle Bay Marina – Wave modelling

Correlation Significant Wave Height – Peak Wave Period
Local Sea Waves – Present Day (1/2)

Figure 8.10

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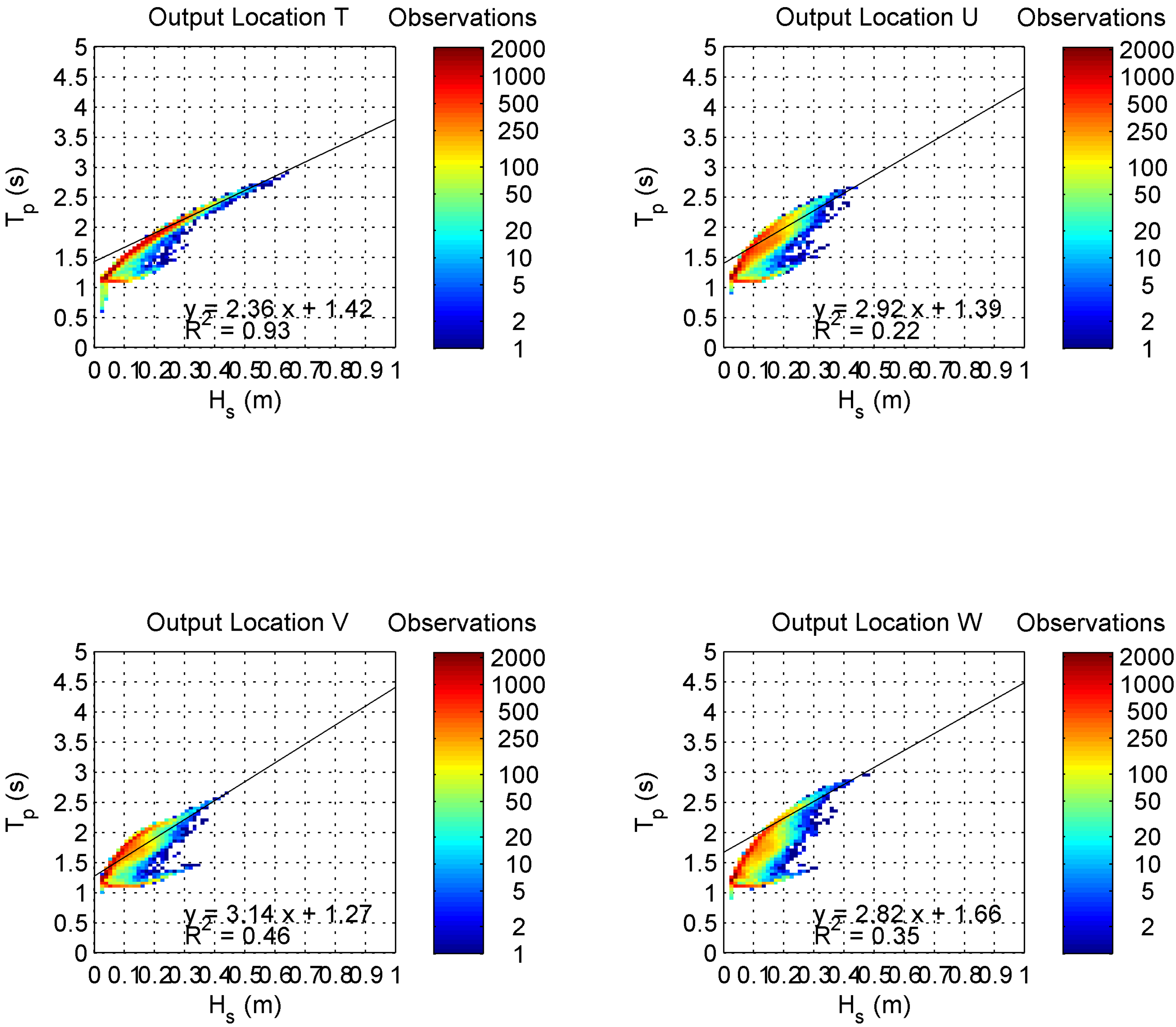
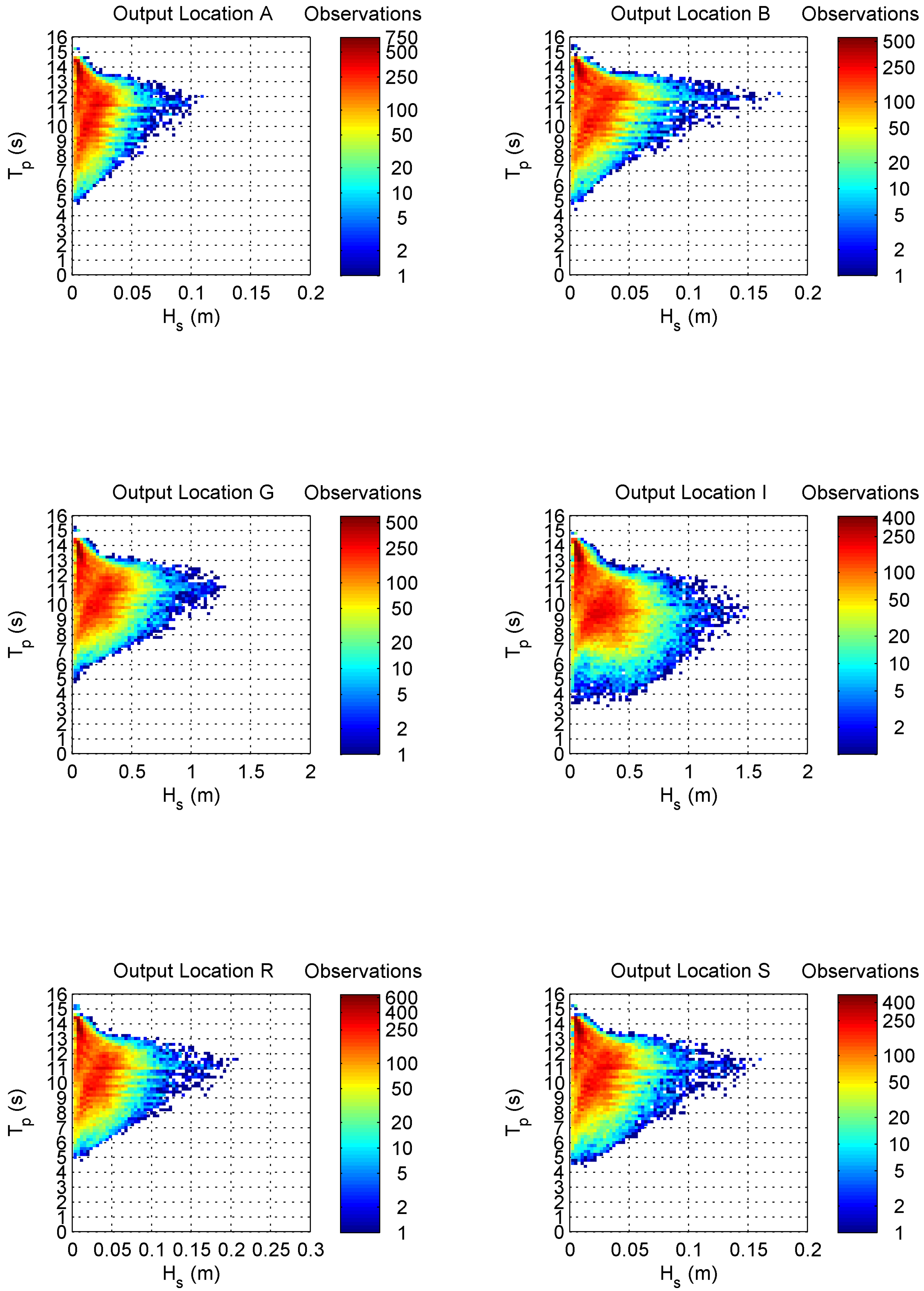


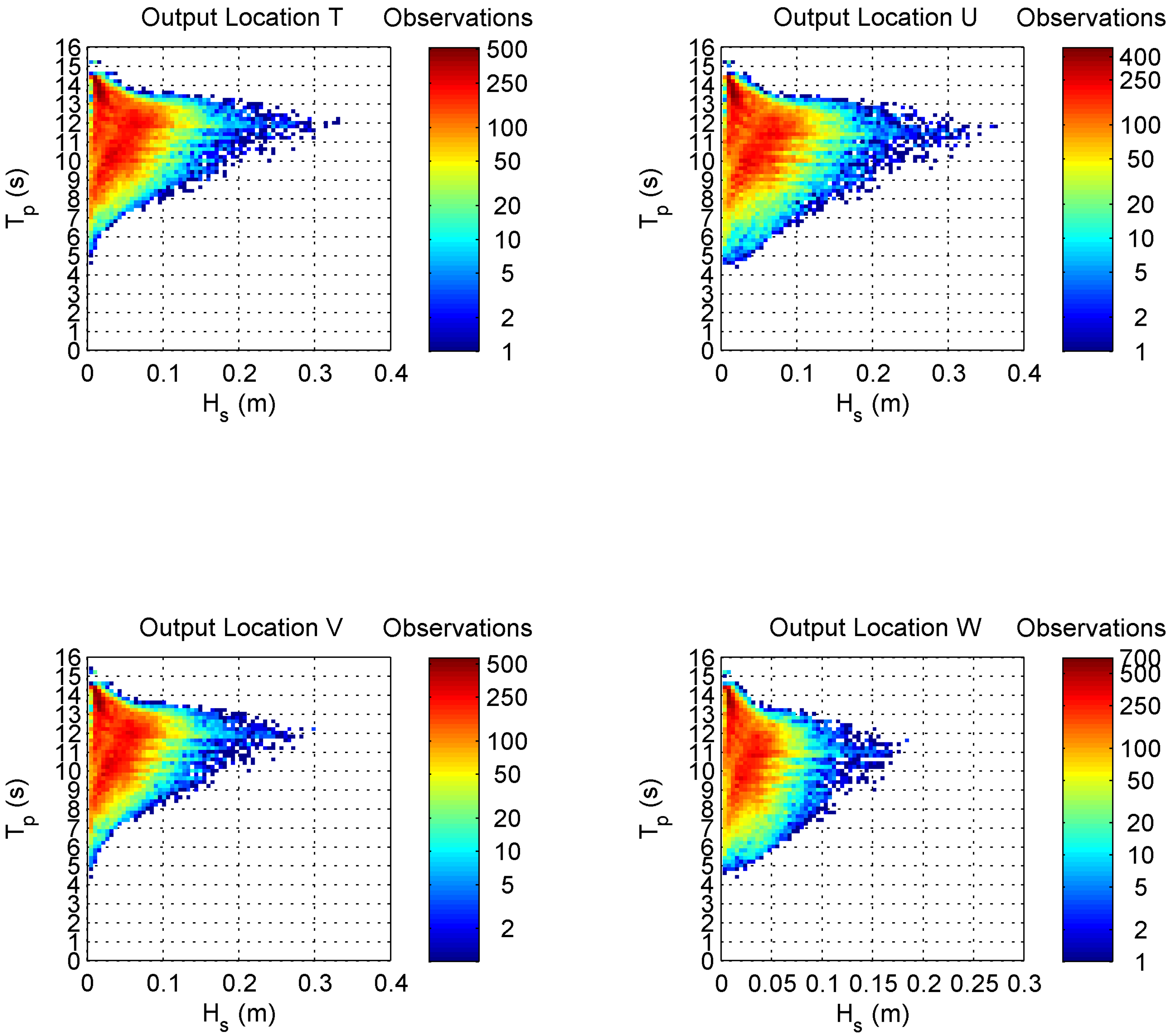
Cattle Bay Marina – Wave modelling

Correlation Significant Wave Height – Peak Wave Period
Local Sea Waves – Present Day (2/2)

Figure 8.11



Cattle Bay Marina – Wave modelling
Correlation Significant Wave Height – Peak Wave Period
Swell Waves – Present Day (1/2)
Figure 8.12



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Cattle Bay Marina – Wave modelling

Correlation Significant Wave Height – Peak Wave Period
Swell Waves – Present Day (2/2)

59914148 Jul 2014

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Figure 8.13

Present Day				A			B			G			I			R			S			T			U			V			W		
Offshore Wave Input			WL	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1	-1.0	0.0	1.1
Hs	Tp	Dir (°TN)																															
6.10	11.1	E	90	9.6	9.5	9.7	9.8	9.8	10.0	9.1	9.3	9.5	8.4	8.4	8.5	9.3	9.3	9.4	9.4	9.4	9.4	9.7	9.8	10.0	9.4	9.6	9.7	9.7	9.9	10.1	9.3	9.2	9.4
		ESE	112.5	9.2	9.0	9.1	9.3	9.3	9.4	8.6	8.7	8.8	7.7	7.6	7.5	8.8	8.7	8.8	8.9	8.7	8.7	9.2	9.3	9.5	8.9	8.9	9.1	9.2	9.4	9.5	8.8	8.5	8.6
		SE	135	9.5	9.3	9.4	9.6	9.6	9.6	8.8	8.9	9.0	8.0	7.7	7.6	9.2	9.0	9.0	9.2	9.0	9.0	9.4	9.5	9.6	9.2	9.2	9.3	9.4	9.5	9.7	9.1	8.9	8.9
		SSE	157.5	10.3	10.2	10.3	10.3	10.3	10.4	9.9	9.9	10.0	9.5	9.4	9.3	10.2	10.1	10.1	10.1	10.1	10.1	10.2	10.2	10.3	10.1	10.1	10.2	10.2	10.2	10.3	10.2	10.1	10.1
		S	180	11.3	11.2	11.2	11.2	11.2	11.3	11.1	11.1	11.1	11.1	11.0	11.0	11.2	11.2	11.2	11.1	11.1	11.2	11.1	11.1	11.2	11.1	11.1	11.2	11.1	11.1	11.2	11.2	11.2	11.2
7.80	12.6	E	90	10.9	10.8	10.9	11.0	11.1	11.2	10.4	10.5	10.6	9.7	9.7	9.7	10.6	10.5	10.6	10.7	10.7	10.7	10.8	11.0	11.2	10.7	10.8	10.9	10.9	11.0	11.2	10.7	10.5	10.7
		ESE	112.5	10.5	10.3	10.4	10.6	10.6	10.7	9.8	9.9	9.9	9.0	8.9	8.7	10.1	9.9	10.0	10.2	10.0	10.0	10.4	10.6	10.7	10.2	10.2	10.3	10.5	10.6	10.7	10.2	9.9	9.9
		SE	135	10.9	10.6	10.7	10.9	10.9	10.9	10.2	10.2	10.2	9.5	9.2	8.9	10.6	10.4	10.4	10.5	10.4	10.3	10.7	10.8	10.9	10.5	10.5	10.6	10.7	10.8	10.9	10.5	10.3	10.3
		SSE	157.5	11.8	11.6	11.6	11.8	11.8	11.8	11.4	11.4	11.4	11.1	11.0	10.9	11.7	11.5	11.5	11.6	11.5	11.5	11.6	11.6	11.7	11.5	11.5	11.5	11.6	11.6	11.7	11.6	11.5	11.5
		S	180	12.7	12.6	12.5	12.7	12.6	12.6	12.5	12.5	12.5	12.6	12.5	12.5	12.6	12.6	12.5	12.6	12.5	12.5	12.6	12.5	12.5	12.5	12.5	12.5	12.6	12.5	12.5	12.6	12.5	12.5

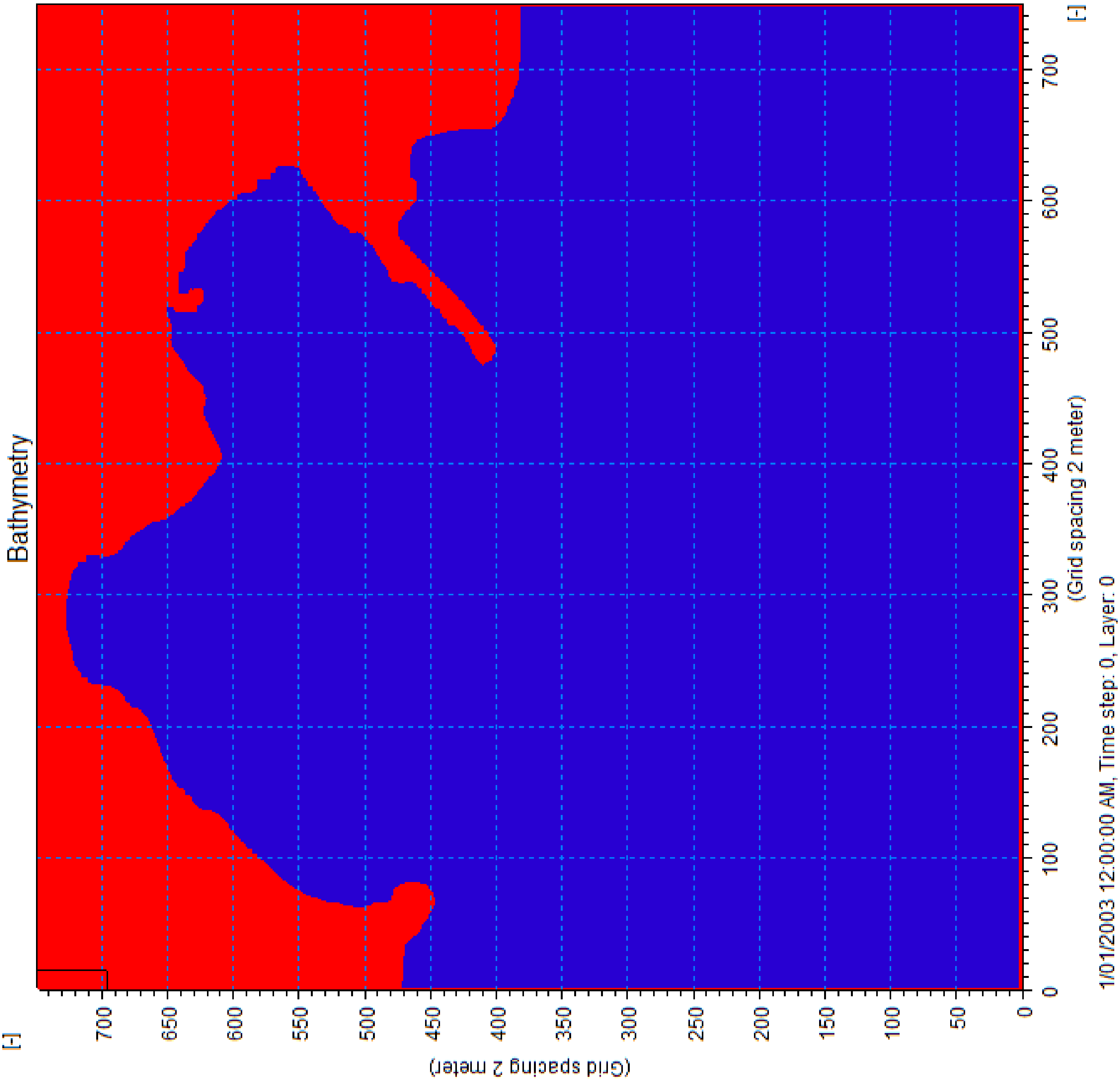
2050				A			B			G			I			R			S			T			U			V			W		
Offshore Wave Input			WL	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5	-0.6	0.4	1.5
Hs	Tp	Dir (°TN)																															
6.10	11.1	E	90	9.6	9.7	9.7	9.8	9.9	10.0	9.2	9.4	9.5	8.4	8.5	8.5	9.3	9.4	9.4	9.4	9.4	9.4	9.7	9.9	10.1	9.5	9.7	9.7	9.8	9.9	10.1	9.3	9.4	9.3
		ESE	112.5	9.1	9.1	9.1	9.3	9.4	9.4	8.6	8.7	8.8	7.7	7.5	7.4	8.7	8.7	8.8	8.8	8.7	8.6	9.3	9.4	9.6	8.9	9.0	9.1	9.3	9.4	9.6	8.7	8.6	8.5
		SE	135	9.4	9.4	9.3	9.6	9.6	9.6	8.8	8.9	9.0	7.9	7.6	7.6	9.1	9.0	9.0	9.1	9.0	8.9	9.4	9.6	9.7	9.2	9.2	9.3	9.5	9.6	9.7	9.0	9.0	8.8
		SSE	157.5	10.3	10.3	10.3	10.3	10.4	10.4	9.9	9.9	10.0	9.4	9.3	9.3	10.1	10.1	10.1	10.1	10.1	10.1	10.2	10.3	10.4	10.1	10.1	10.2	10.2	10.3	10.4	10.1	10.1	10.1
		S	180	11.2	11.2	11.3	11.2	11.2	11.3	11.1	11.1	11.1	11.1	11.0	11.0	11.2	11.2	11.2	11.1	11.1	11.2	11.1	11.2	11.2	11.1	11.1	11.2	11.1	11.2	11.2	11.2	11.2	11.2
7.80	12.6	E	90	10.9	10.9	10.9	11.0	11.1	11.2	10.4	10.5	10.7	9.7	9.7	9.7	10.6	10.6	10.6	10.7	10.7	10.7	10.9	11.1	11.3	10.7	10.9	11.0	10.9	11.1	11.3	10.6	10.7	10.6
		ESE	112.5	10.4	10.4	10.3	10.6	10.7	10.7	9.8	9.9	10.0	9.0	8.8	8.7	10.0	10.0	10.0	10.1	10.0	9.9	10.5	10.6	10.8	10.2	10.3	10.3	10.5	10.6	10.8	10.0	10.0	9.8
		SE	135	10.8	10.7	10.7	10.9	10.9	10.9	10.2	10.2	10.3	9.4	9.1	8.9	10.5	10.4	10.3	10.5	10.4	10.2	10.8	10.9	10.9	10.5	10.5	10.6	10.8	10.9	11.0	10.4	10.4	10.2
		SSE	157.5	11.7	11.7	11.6	11.8	11.8	11.8	11.4	11.3	11.4	11.0	10.9	10.8	11.6	11.6	11.5	11.5	11.5	11.4	11.6	11.6	11.7	11.5	11.5	11.5	11.6	11.6	11.7	11.6	11.5	11.5
		S	180	12.6	12.5	12.5	12.6	12.6	12.6	12.5	12.5	12.4	12.6	12.5	12.4	12.6	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.6	12.5	12.5

2100				A			B			G			I			R			S			T			U			V			W		
Offshore Wave Input			WL	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0	-0.1	0.9	2.0
Hs	Tp	Dir (°TN)																															
6.10	11.1	E	90	9.5	9.7	9.8	9.8	10.0	10.0	9.3	9.4	9.6	8.4	8.5	8.6	9.3	9.4	9.5	9.4	9.4	9.4	9.8	10.0	10.2	9.6	9.7	9.8	9.9	10.0	10.2	9.2	9.4	9.3
		ESE	112.5	9.0	9.1	9.2	9.3	9.4	9.4	8.6	8.8	8.9	7.6	7.5	7.4	8.7	8.8	8.8	8.7	8.7	8.6	9.3	9.5	9.6	8.9	9.1	9.1	9.3	9.5	9.6	8.5	8.7	8.5
		SE	135	9.3	9.4	9.4	9.6	9.6	9.6	8.9	9.0	9.1	7.8	7.6	7.5	9.0	9.0	9.0	9.0	9.0	8.8	9.5	9.6	9.7	9.2	9.3	9.3	9.5	9.6	9.8	8.9	9.0	8.7
		SSE	157.5	10.2	10.3	10.3	10.3	10.4	10.4	9.9	10.0	10.0	9.4	9.3	9.3	10.1	10.1	10.2	10.1	10.1	10.1	10.2	10.3	10.4	10.1	10.2	10.2	10.2	10.3	10.4	10.1	10.1	10.1
		S	180	11.2	11.2	11.3	11.2	11.3	11.3	11.1	11.1	11.1	11.0	11.0	11.0	11.2	11.2	11.3	11.1	11.2	11.2	11.1	11.2	11.3	11.1	11.2	11.2	11.1	11.2	11.3	11.2	11.2	11.2
7.80	12.6	E	90	10.8	10.9	11.0	11.1	11.2	11.3	10.5	10.6	10.7	9.7	9.7	9.7	10.5	10.6	10.7	10.7	10.7	10.7	11.0	11.2	11.3	10.8	10.9	11.0	11.0	11.2	11.4	10.6	10.7	10.7
		ESE	112.5	10.3	10.4	10.4	10.6	10.7	10.7	9.8	9.9	10.0	8.9	8.7	8.6	9.9	10.0	10.0	10.0	10.0	9.9	10.5	10.7	10.8	10.2	10.3	10.4	10.6	10.7	10.8	9.9	10.0	9.8
		SE	135	10.7	10.7	10.7	10.9	11.0	10.9	10.2	10.2	10.3	9.2	9.0	8.9	10.4	10.4	10.4	10.4	10.3	10.2	10.8	10.9	11.0	10.5	10.6	10.6	10.8	10.9	11.0	10.3	10.3	10.1
		SSE	157.5	11.7	11.6	11.7	11.8	11.8	11.8	11.4	11.4	11.4	11.0	10.9	10.8	11.6	11.5	11.5	11.5	11.5	11.4	11.6	11.7	11.7	11.5	11.5	11.5	11.6	11.7	11.7	11.5	11.5	11.4
		S	180	12.6	12.6	12.5	12.6	12.6	12.6	12.5	12.5	12.4	12.5	12.5	12.4	12.6	12.6	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Cattle Bay Marina – Wave modelling

Offshore Wave Cases
1 and 50–year ARI

Figure 8.14



Cattle Bay Marina – Wave modelling

MIKE21 BW Modelling
Model Grid Setup

Figure 9.1

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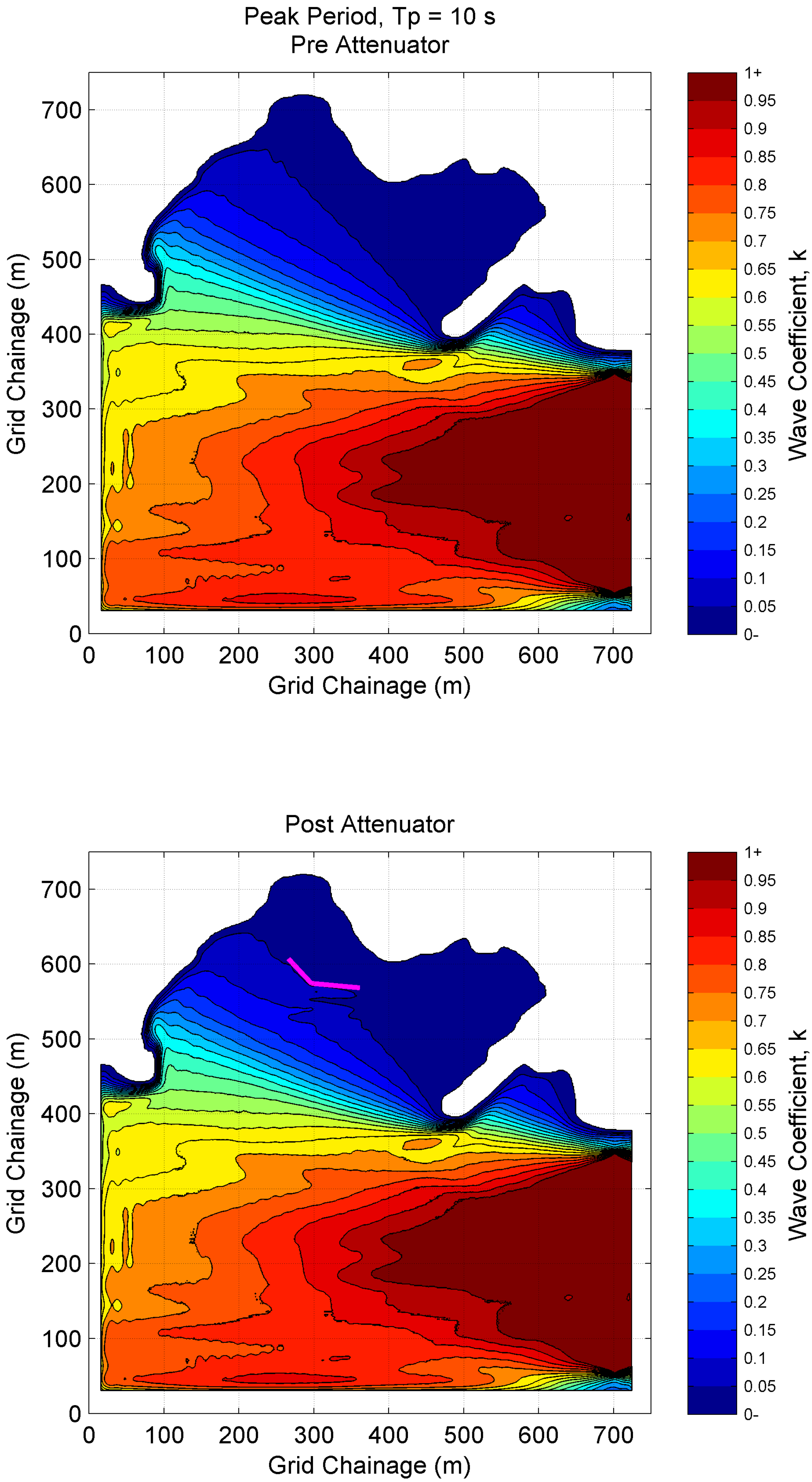

Cattle Bay Marina – Wave modelling

MIKE21 BW Modelling
Swell Wave Penetration – Tp = 10 s

Figure 9.2

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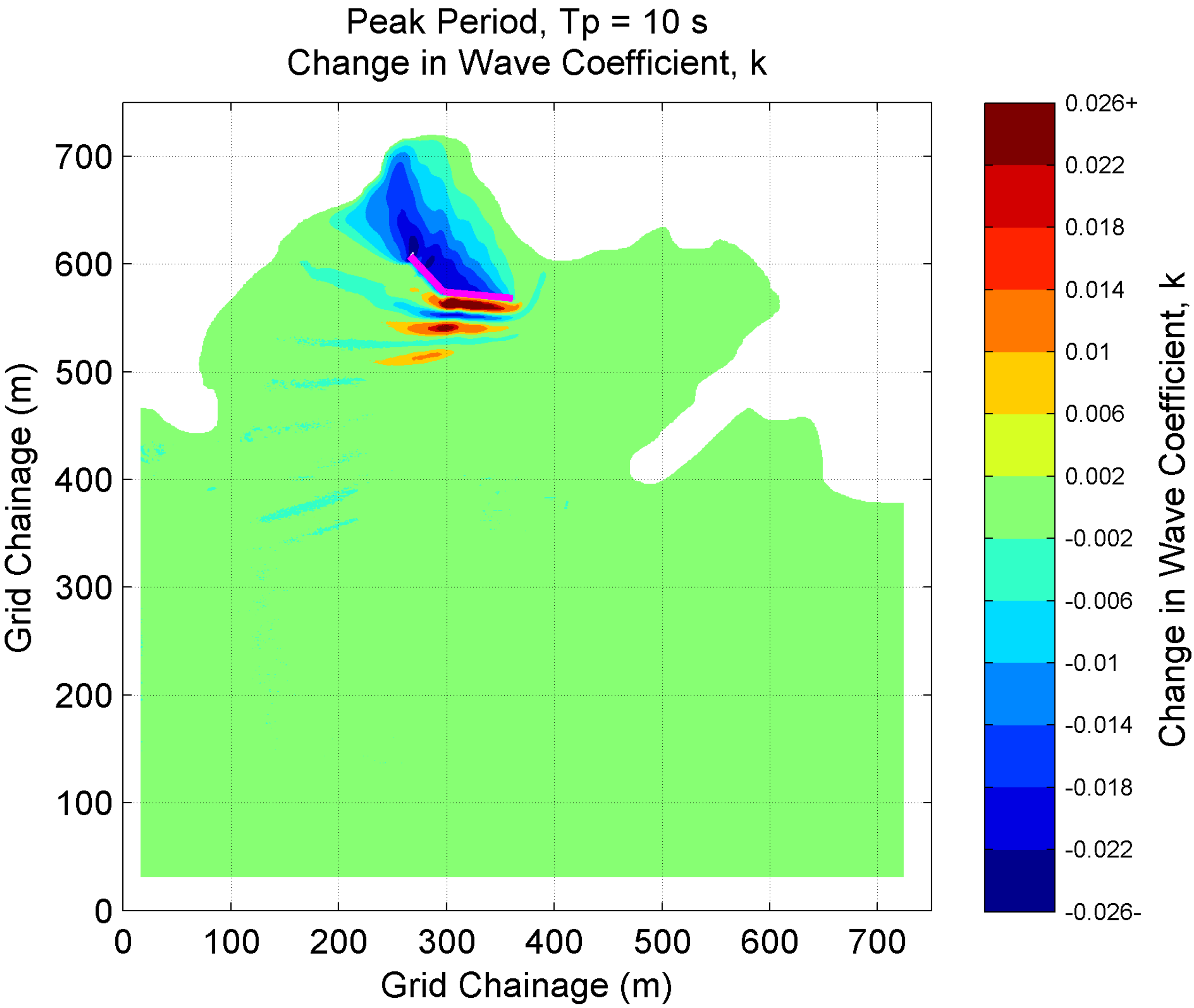

Cattle Bay Marina – Wave modelling

MIKE21 BW Modelling
Swell Wave Penetration – Tp = 10 s

Figure 9.3

Cardno

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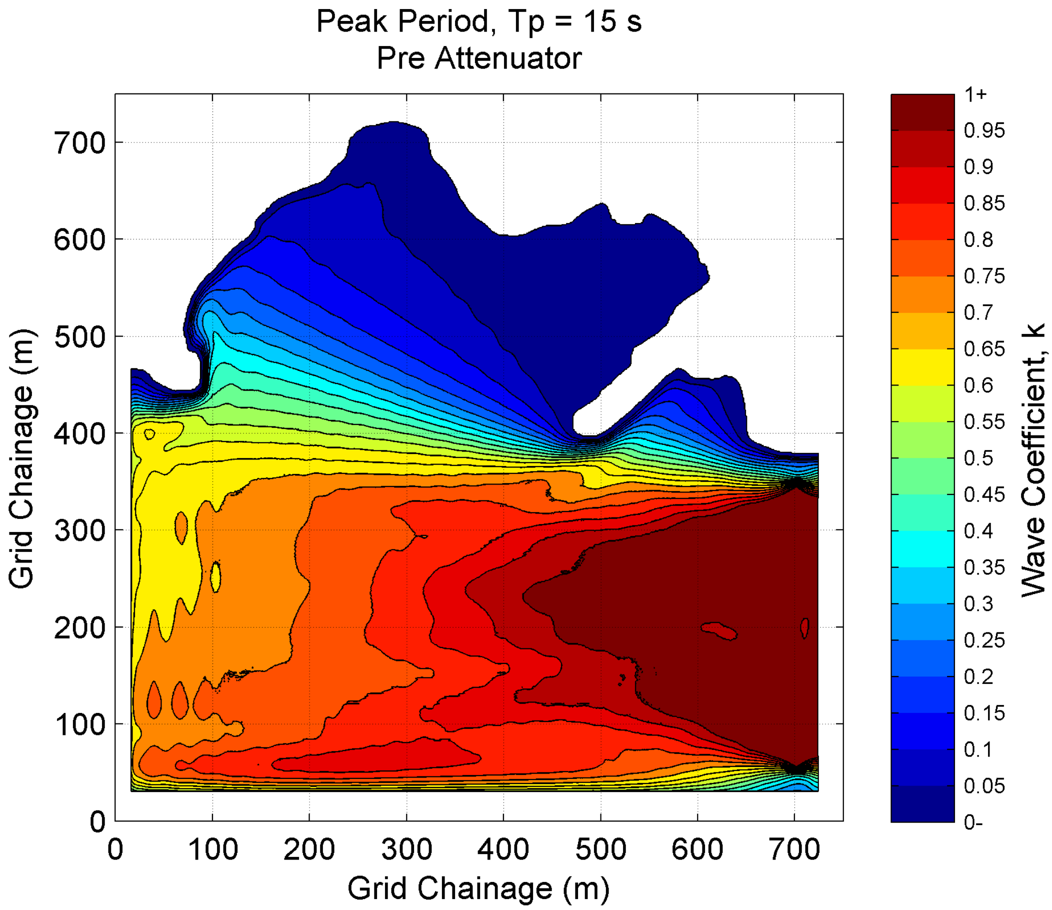

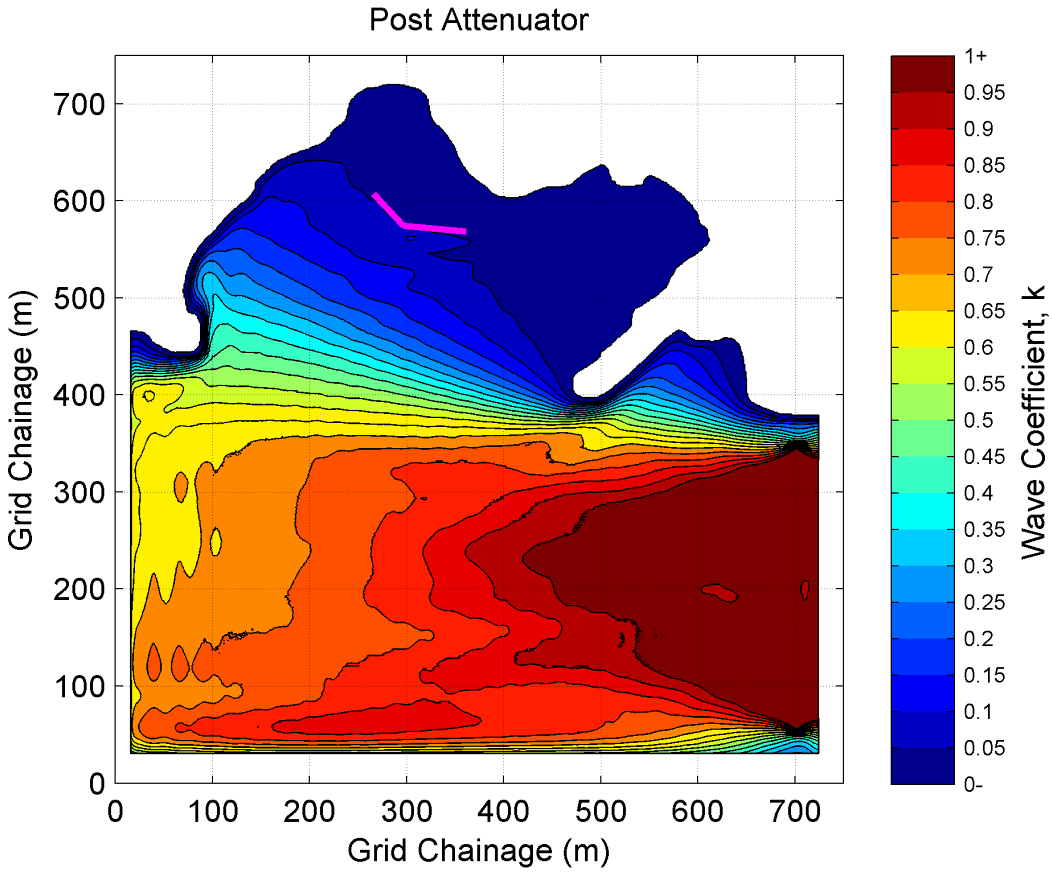

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Cattle Bay Marina – Wave modelling

MIKE21 BW Modelling
Swell Wave Penetration – Tp = 15 s

Figure 9.4

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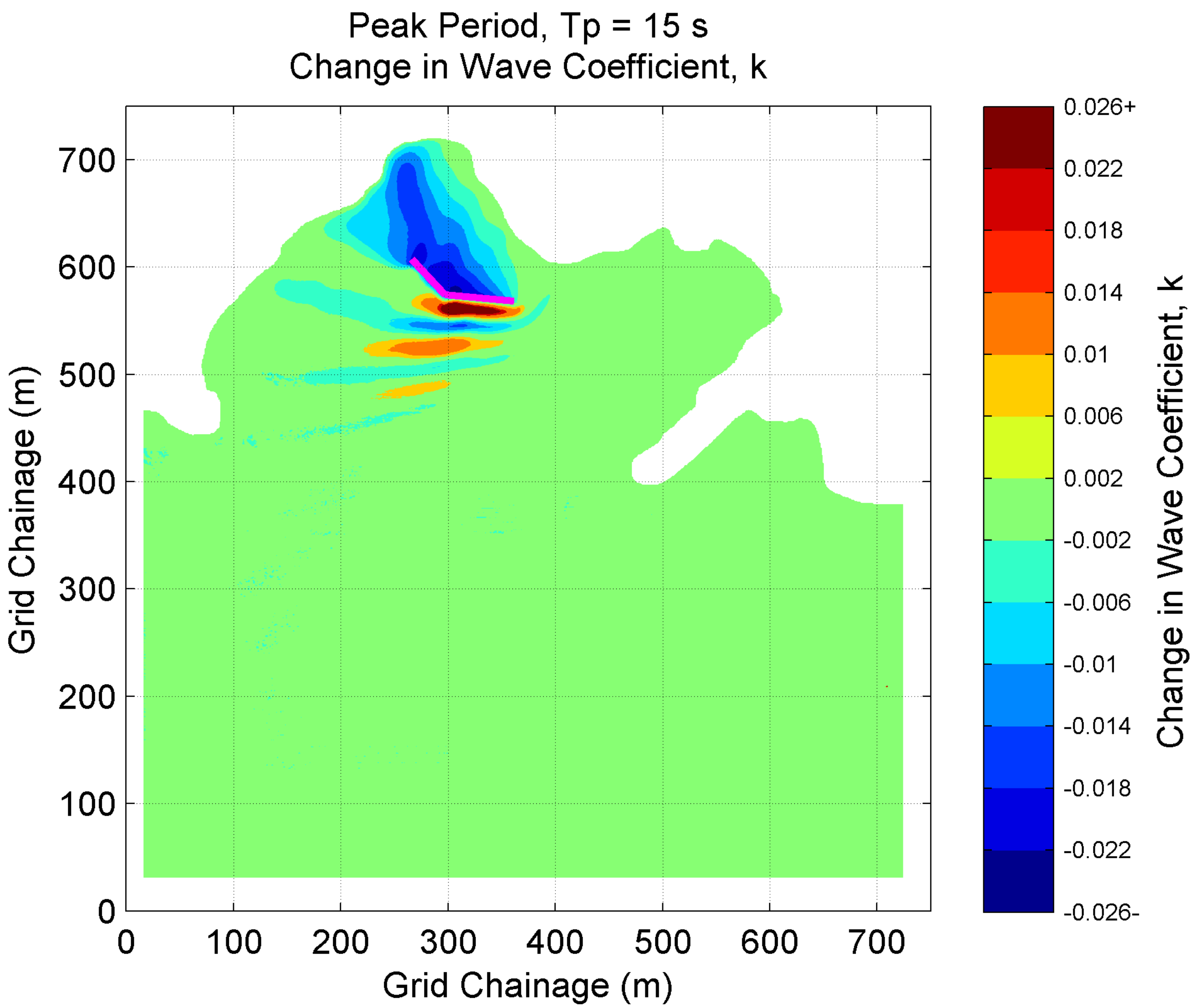

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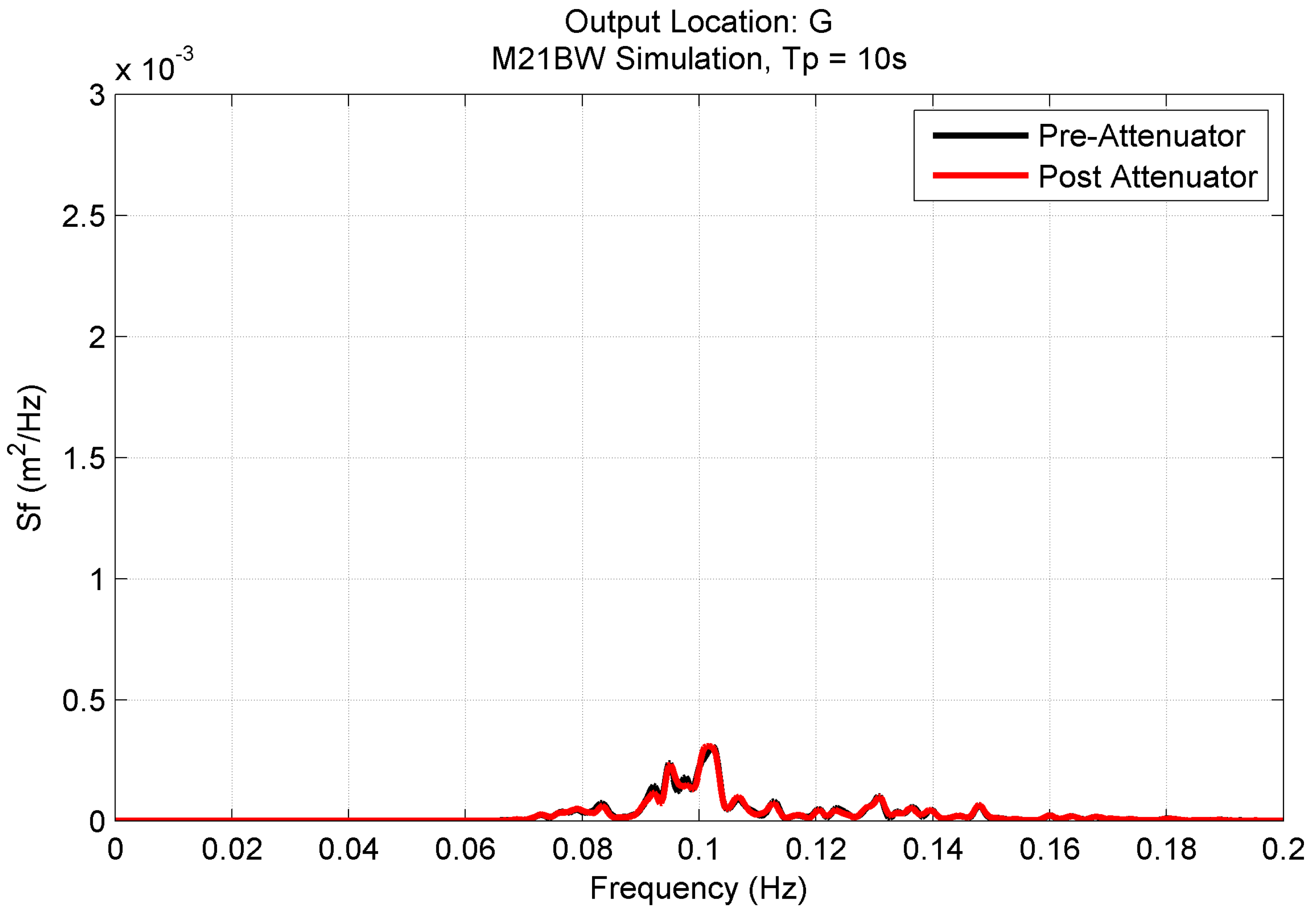
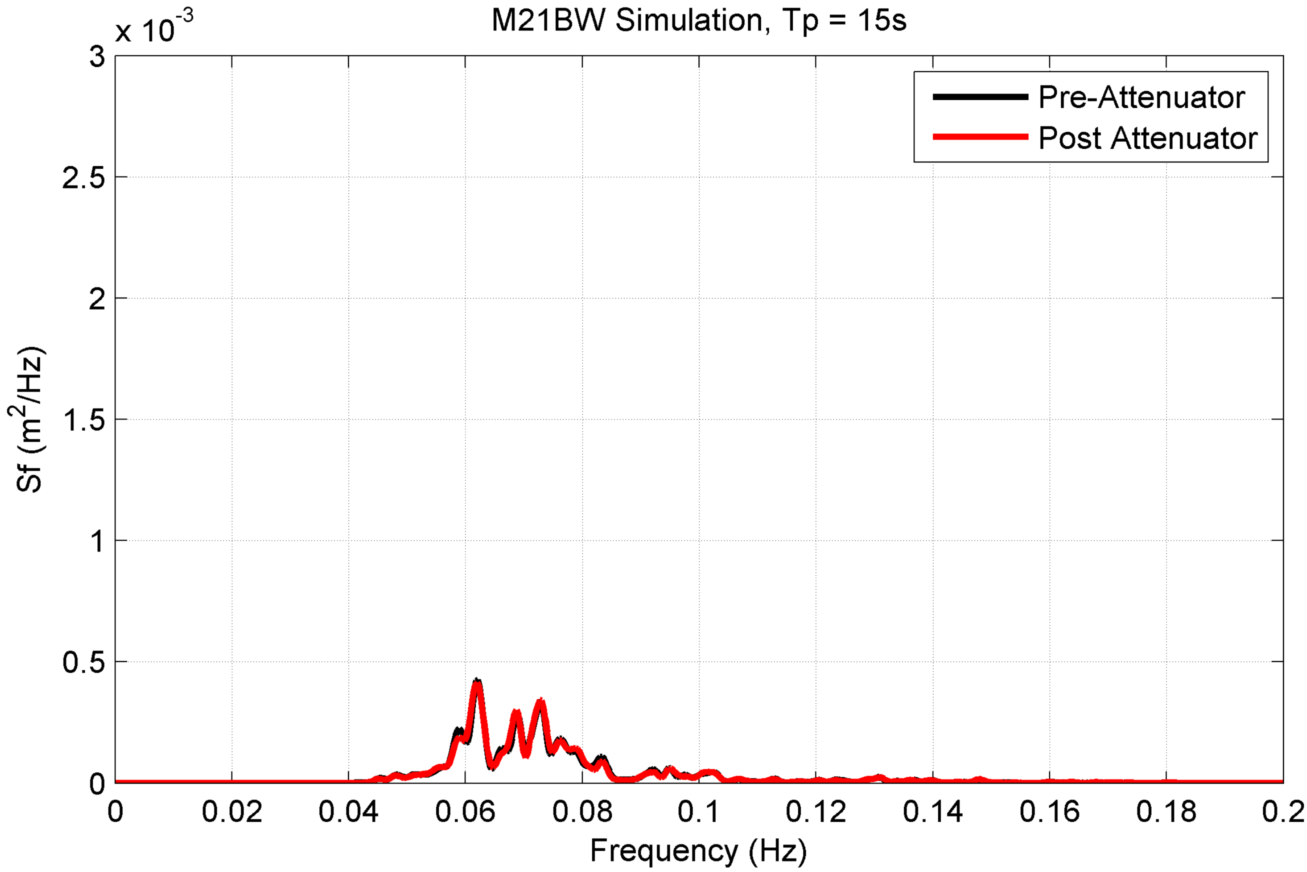
Cattle Bay Marina – Wave modelling
MIKE21 BW Modelling
Swell Wave Penetration – Tp = 15 s
Figure 9.5





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Cattle Bay Marina – Wave modelling

MIKE21 BW Modelling
Energy Spectral Density – Output Location G

Figure 9.6

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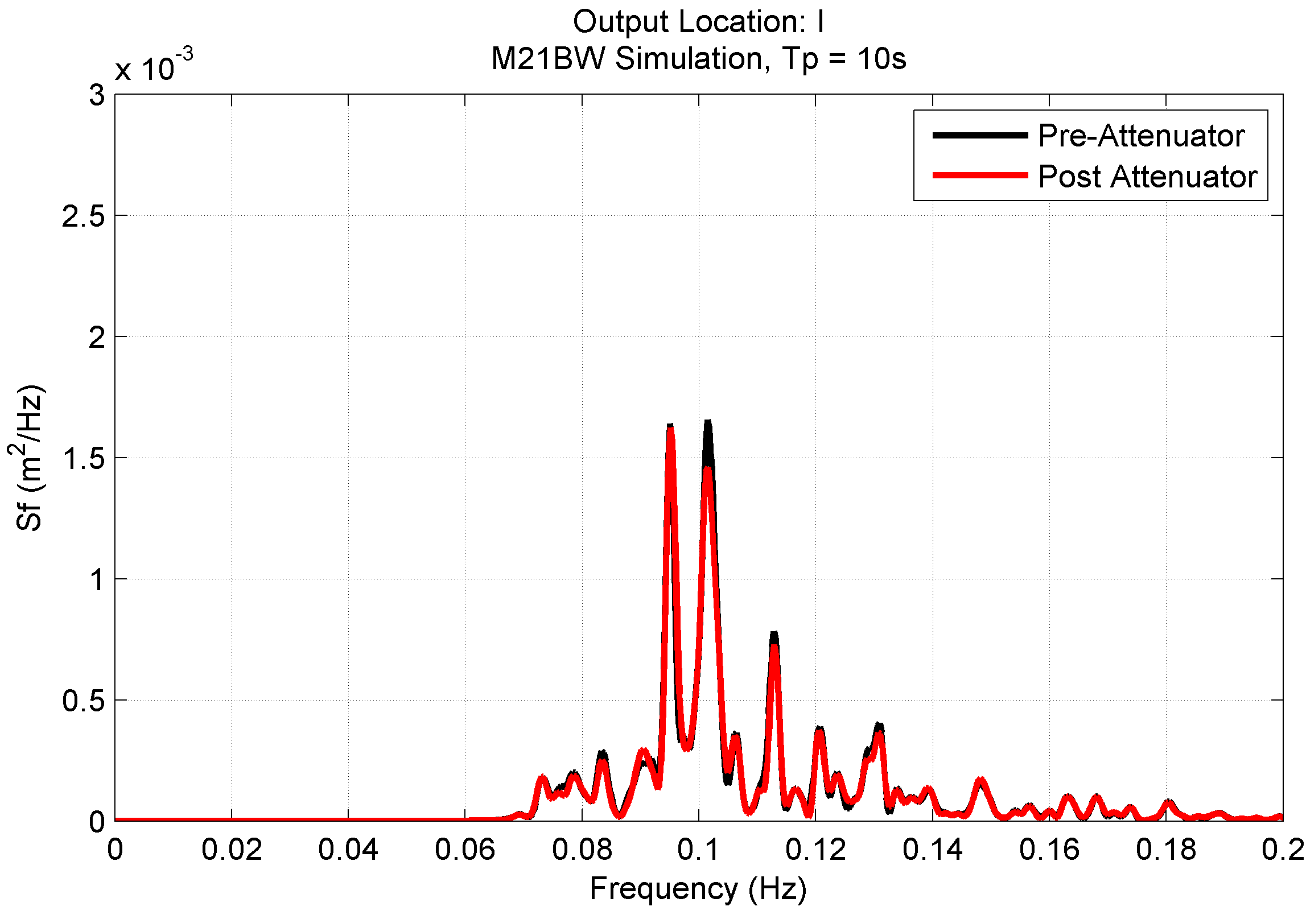
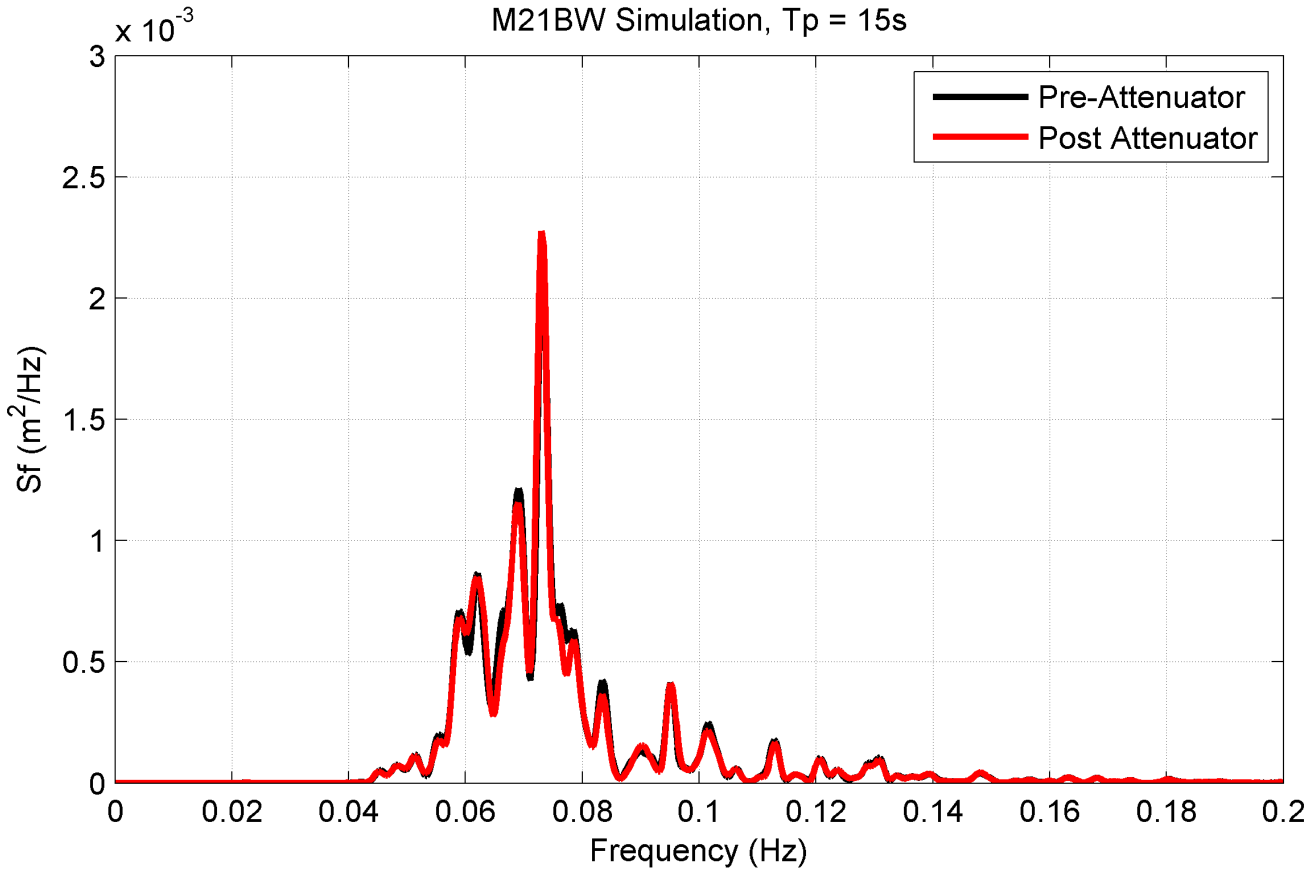
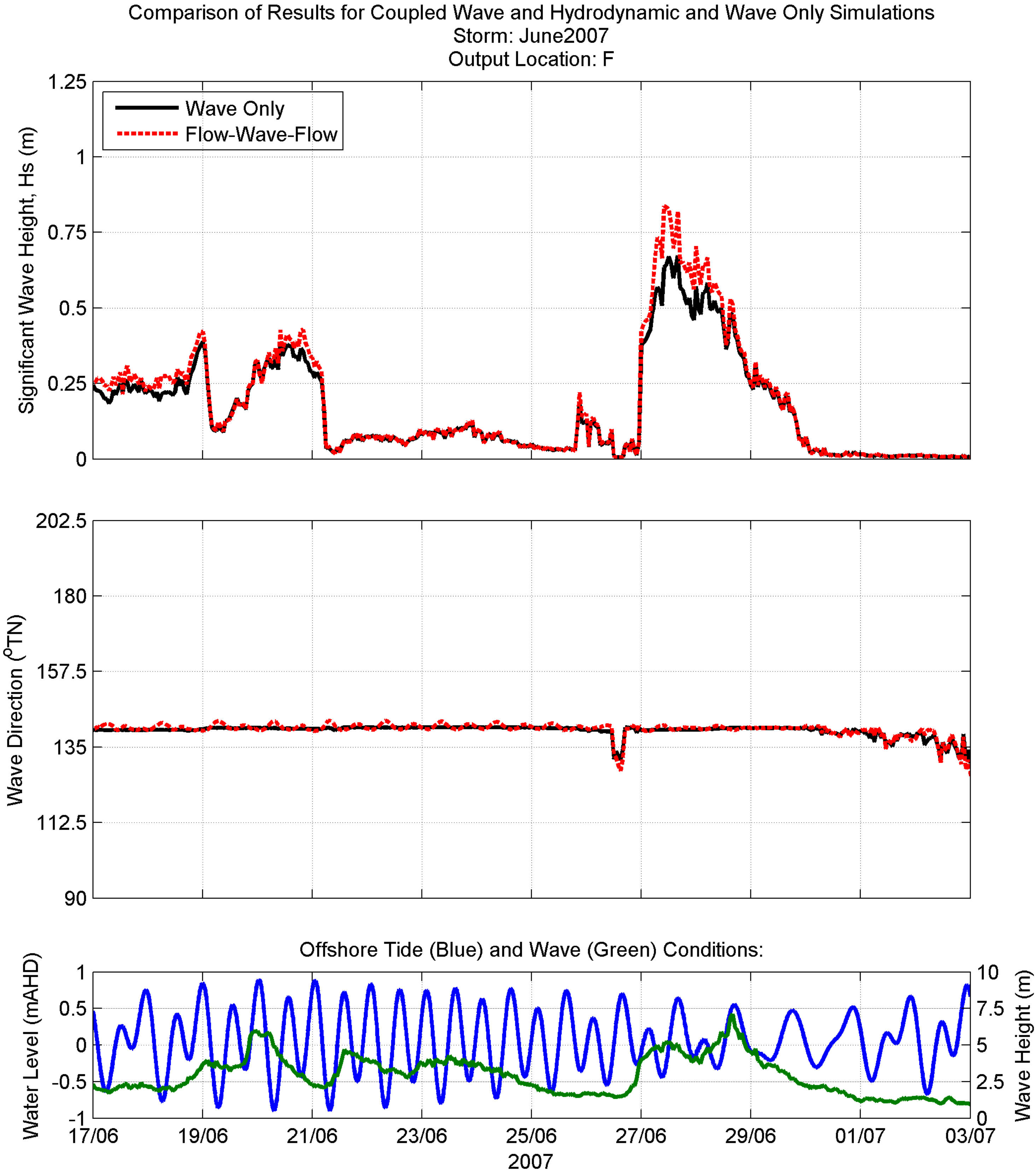




MIKE21 BW Modelling
Energy Spectral Density – Output Location I

Figure 9.7



Cattle Bay Marina – Wave modelling

FWF Model Results – June 2007 Storm
Output Location F

Figure 10.1

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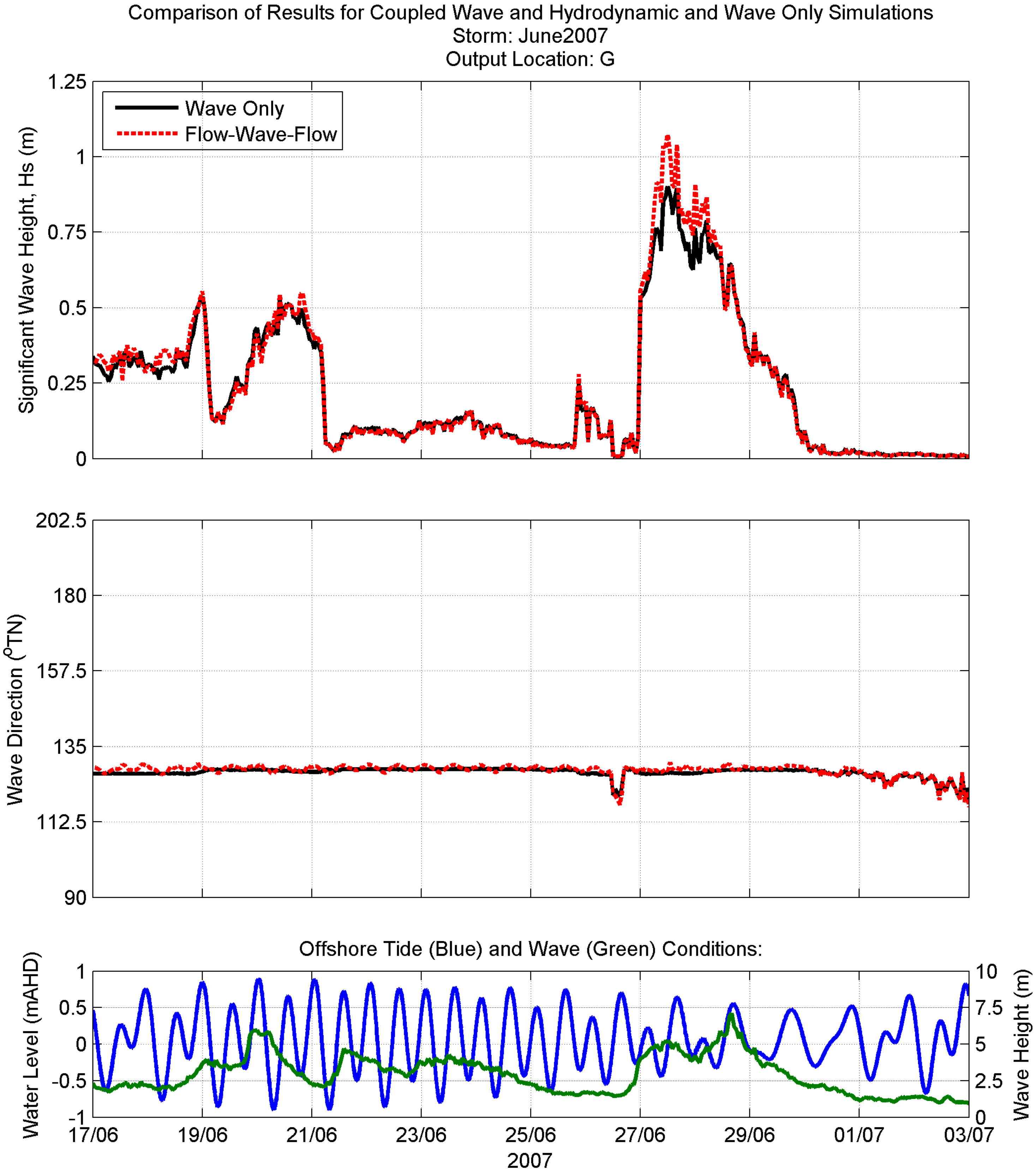

Cattle Bay Marina – Wave modelling

FWF Model Results – June 2007 Storm
Output Location G

Figure 10.2

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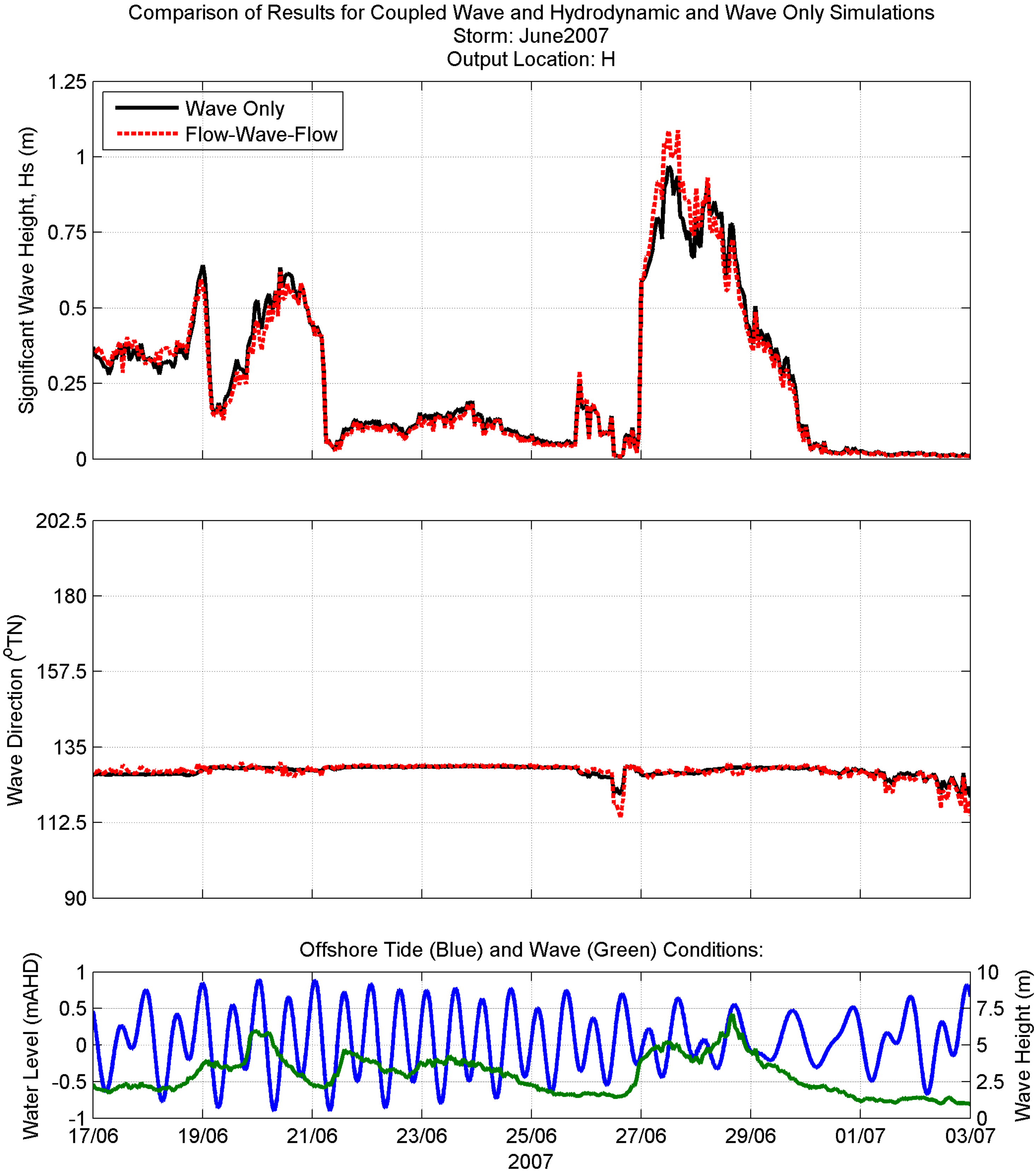

Cattle Bay Marina – Wave modelling

FWF Model Results – June 2007 Storm
Output Location H

Figure 10.3

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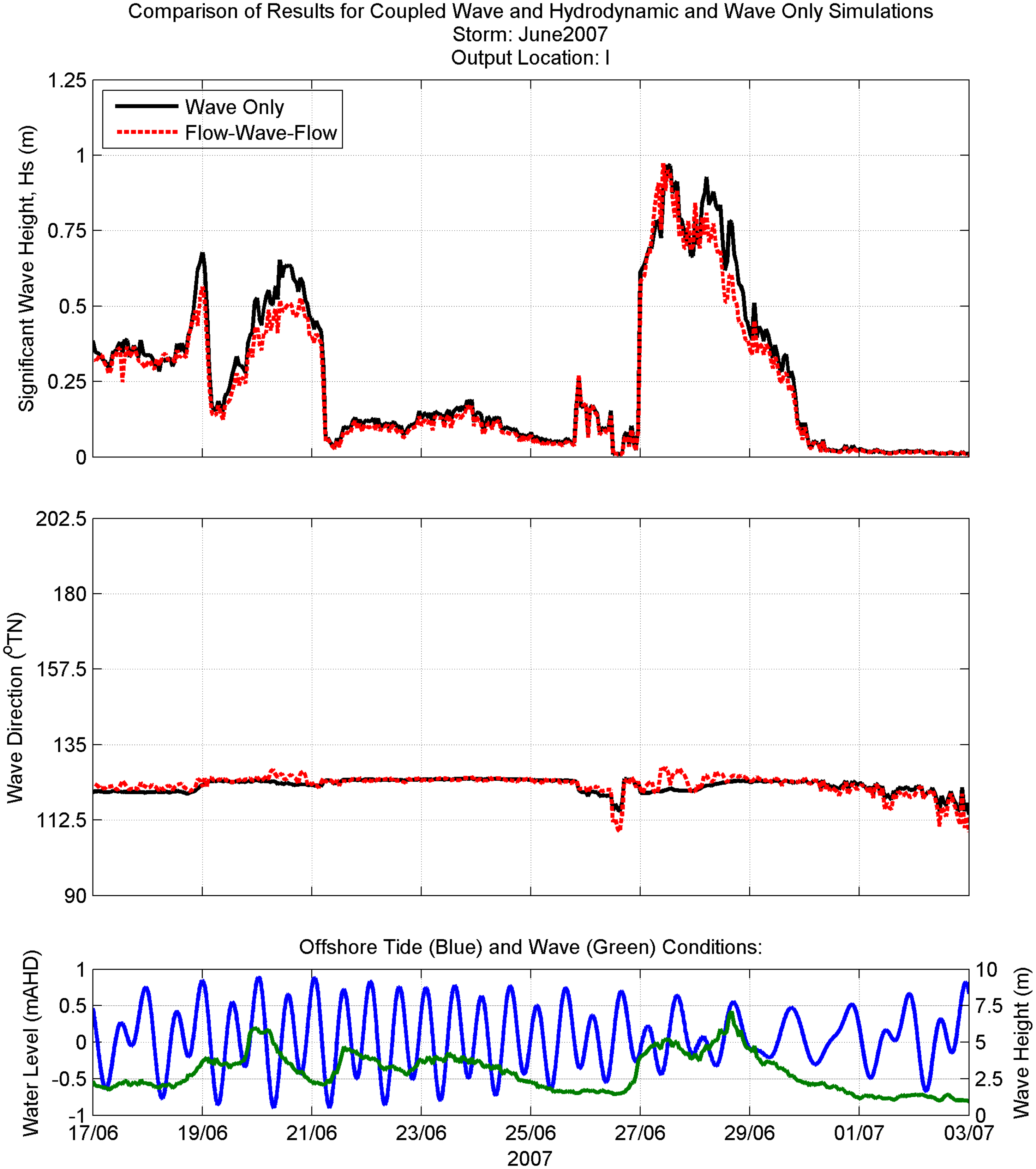
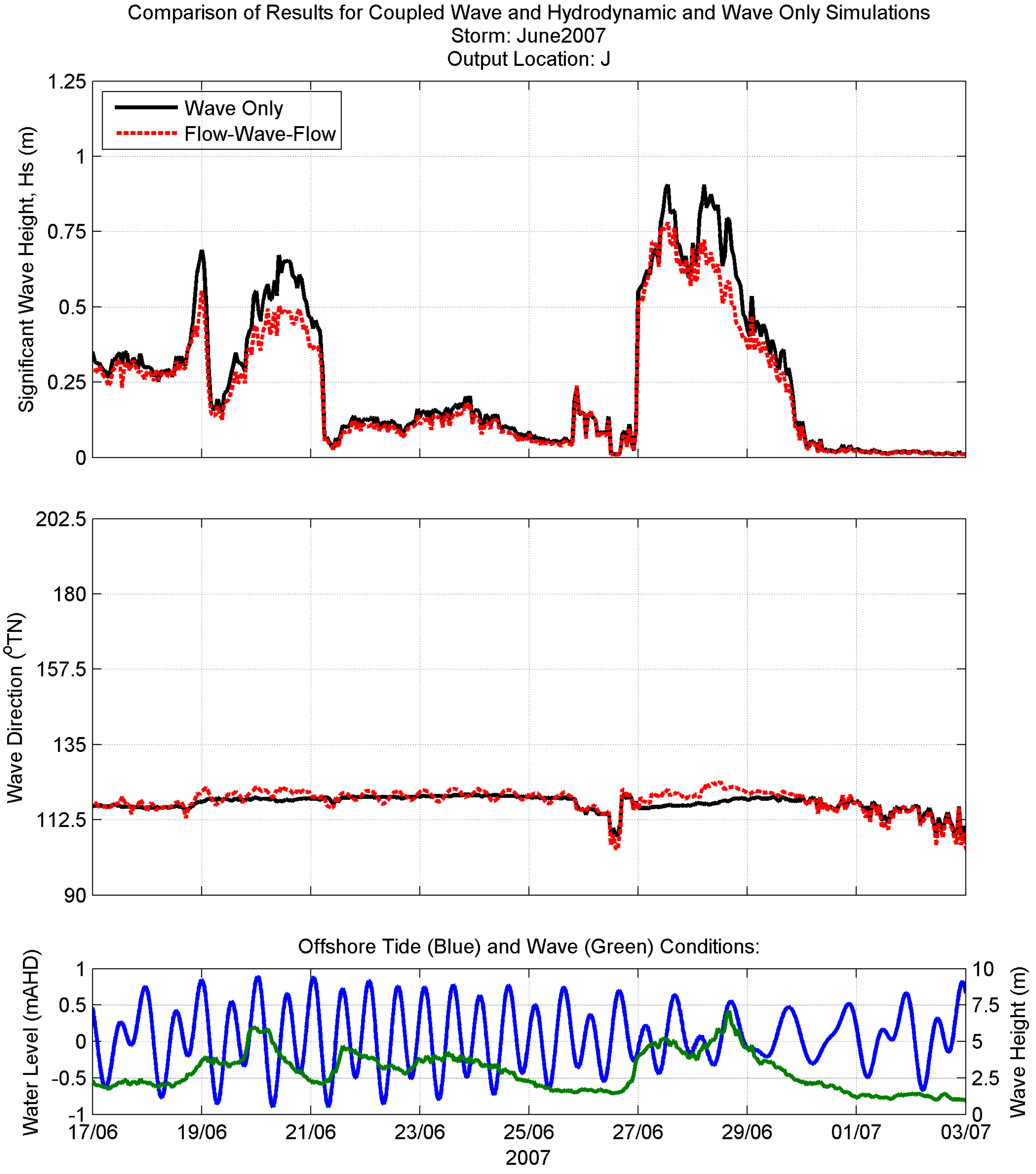


Cattle Bay Marina – Wave modelling

FWF Model Results – June 2007 Storm
Output Location I

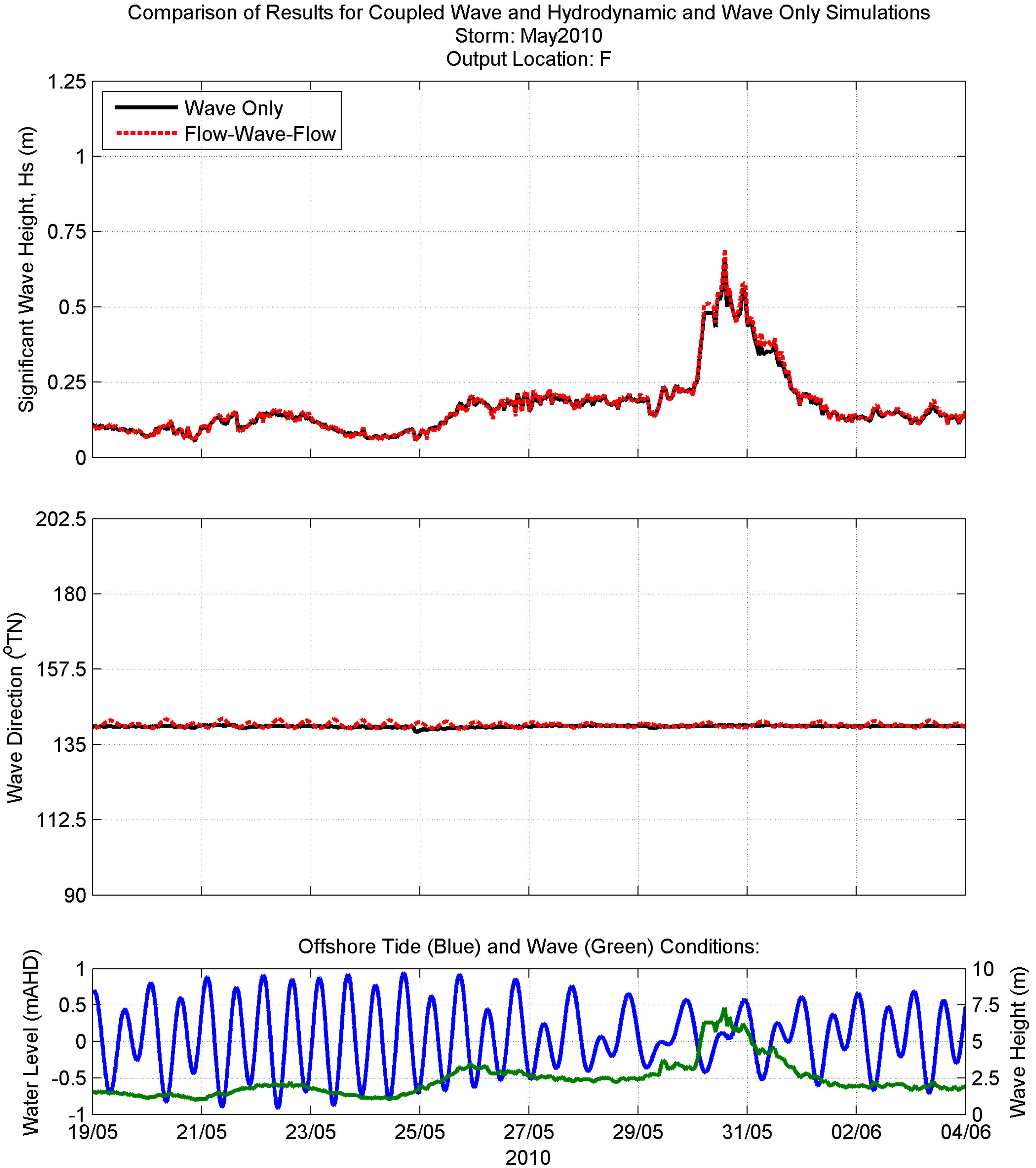
Figure 10.4



Cattle Bay Marina – Wave modelling

FWF Model Results – June 2007 Storm
Output Location J

Figure 10.5



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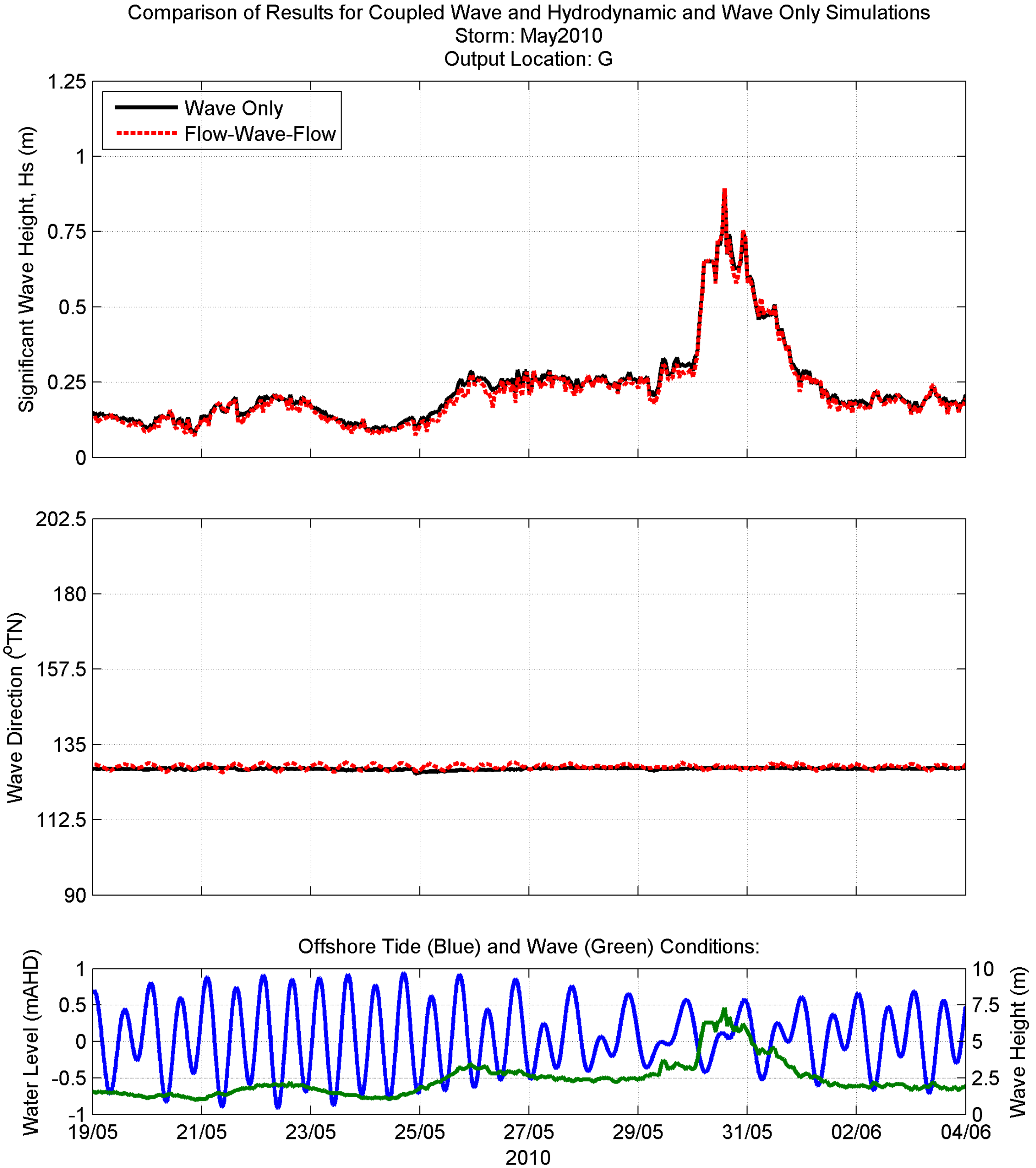
Cattle Bay Marina – Wave modelling

FWF Model Results – May 2010 Storm
Output Location F

Figure 10.6



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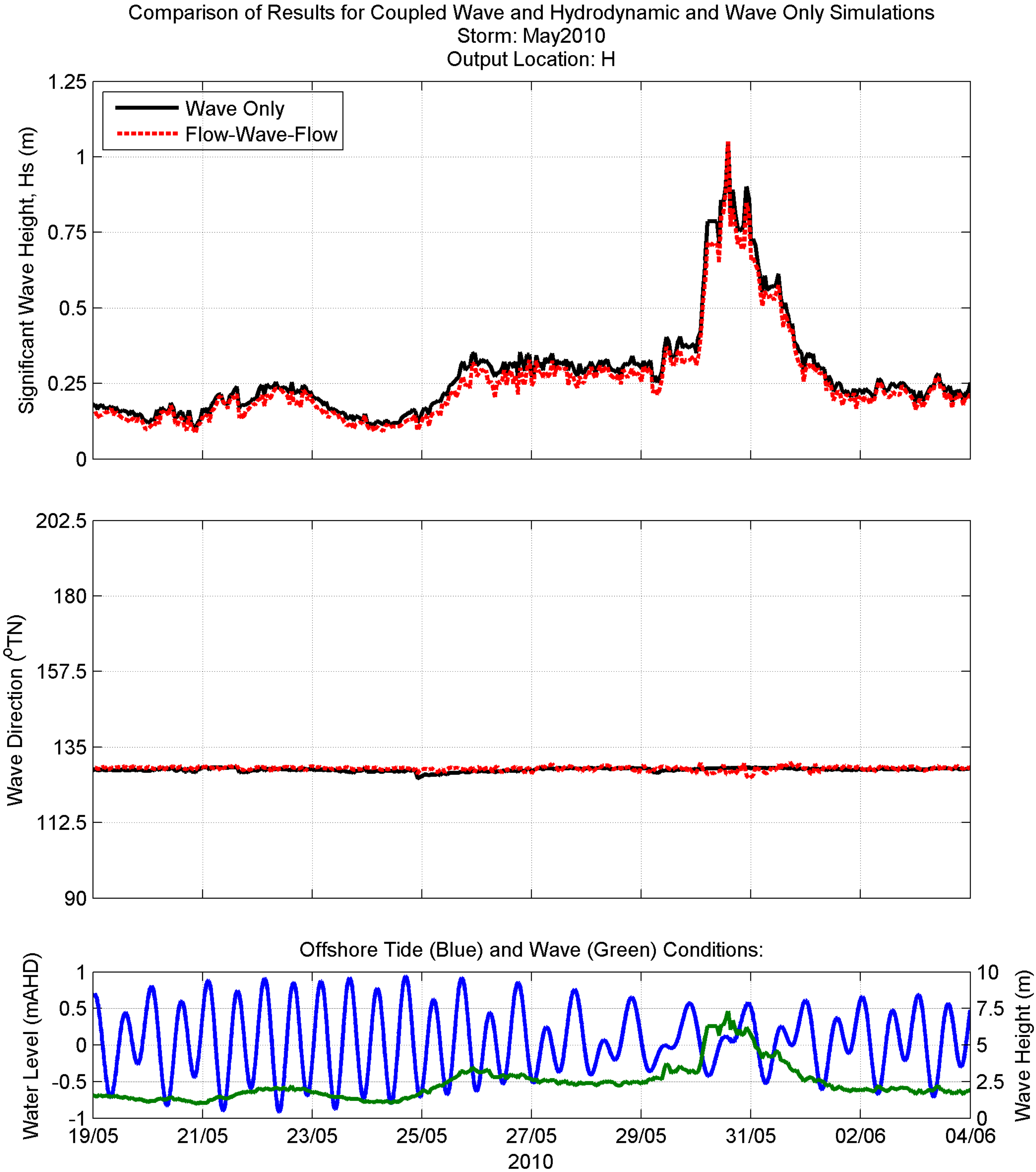
Cattle Bay Marina – Wave modelling

FWF Model Results – May 2010 Storm
Output Location G

Figure 10.7



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Cattle Bay Marina – Wave modelling

FWF Model Results – May 2010 Storm
Output Location H

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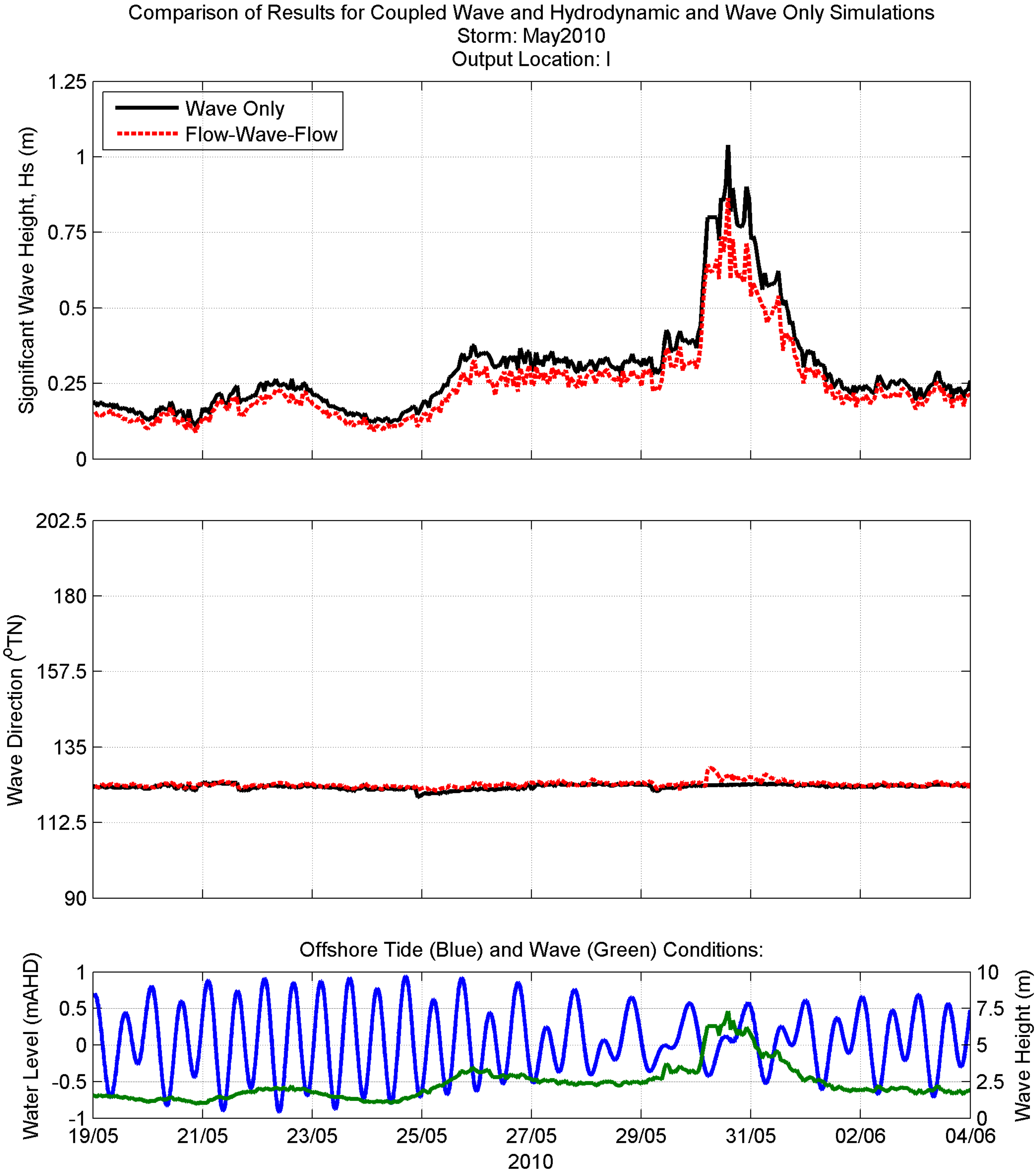
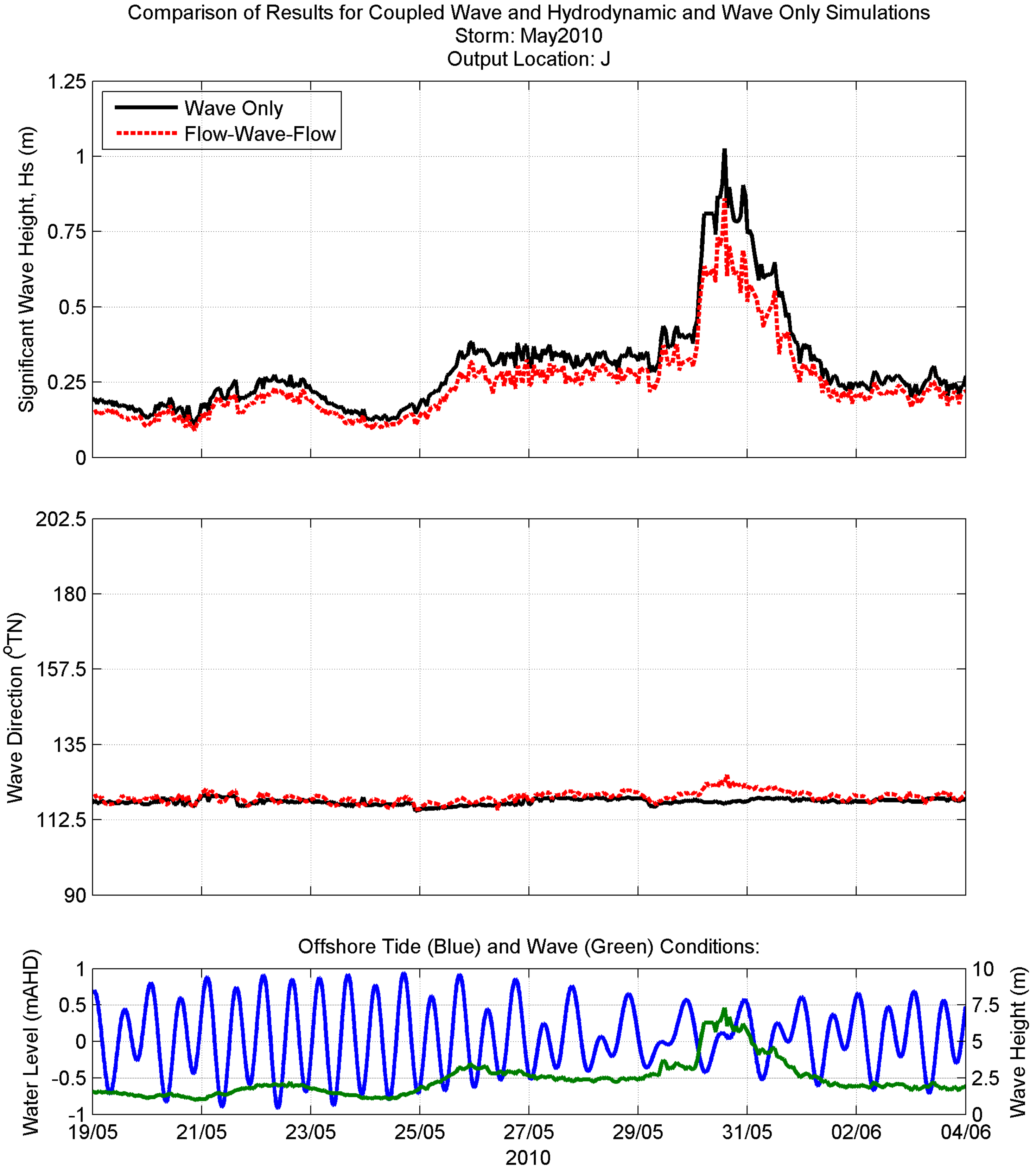
Figure 10.8



Comparison of Results for Coupled Wave and Hydrodynamic and Wave Only Simulations
Storm: May2010
Output Location: I
Significant Wave Height, Hs (m)
Wave Only
Flow-Wave-Flow
1.25
1
0.75
0.5
0.25
0
Wave Direction (°TN)
202.5
180
157.5
135
112.5
90
Offshore Tide (Blue) and Wave (Green) Conditions:
Water Level (mAHD)
Wave Height (m)
19/05
21/05
23/05
25/05
27/05
29/05
31/05
02/06
04/06
2010



Cattle Bay Marina – Wave modelling

FWF Model Results – May 2010 Storm
Output Location J

Figure 10.10