MID WEST PORTS

Coastal processes

MAINTENANCE DREDGING SIMULATIONS AT GERALDTON

Prepared by GEMMS Global Environmental Modelling and Monitoring Systems

Purpose

This report describes how a model of Champion Bay and the surrounding coastline was developed to predict the distribution of sediments within the study area as a result of transport by waves, wind, tides and currents.

Several different scenarios were programmed into the model and this report presents the outcomes of this work within a series of figures depicting sediment movement over a 2 year period post dredging

Importance

This report presents the likely fate of the plume and sediments created and moved as part of the dredging operations and nearshore placement of dredged material.

This information allowed MWPA to assess the potential environmental impacts of the project and to determine the correct management and mitigation measures to put in place to minimise and prevent significant environmental impact.

Report Links

This report informed the final nearshore placement area location decision and was a primary input to the project Environmental Impact Assessment.

Outcomes

This report confirms that the relocation of dredged material from the shipping channel to the nearshore placement area makes sediments available to the beaches north of the Geraldton Port. The model also demonstrates that no significant environmental impacts are predicted.

The outcomes of the modelling supports the beneficial use of dredged material to maintain the sediment supply within the local coastal systems, of Champion Bay and Geraldton’s northern beaches, by returning sediments into the bay where they can support the structure and function of the natural ecosystem.

Global Environmental Modelling and Monitoring Systems
www.gemms.com.au

MID-WEST PORT AUTHORITY MAINTENANCE DREDGING SIMULATIONS AT GERALDTON

FINAL REPORT

JULY 2021

ABOUT GEMMS

Global Environmental Modelling and Monitoring Systems (GEMMS) has expertise in marine meteorology and oceanography and provides scientific advice on a wide range of projects in riverine, coastal and oceanic settings.

GEMMS is a leading developer of numerical models, including one of the world's first and most successful 3D coastal ocean models (GCOM3D). The GEMMS system of well validated environmental models, and rigorous analytical procedures, provide critical advice on a variety of environmental, engineering and oceanographic problems.

GEMMS also undertakes ocean measurement programs with a primary focus on winds, waves, currents and tides in coastal and riverine environments. Marine data measured by GEMMS' instrumentation is used to provide further understanding of the marine environment and to validate the numerical prediction models.

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Rev 6	Final	15/07/2021	G Hubbert	

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Abbreviations and Definitions

BEACON 1	The location near the western end of the channel where winds, waves and currents are monitored.
DREDGE3D	GEMMS 3D Dredging Simulation Model
ECMWF	European Centre for Medium Range Weather Forecasts
ERA5	The latest version (version 5) of the Ecmwf ReAnalysed Global Atmospheric Model output
GCOM3D	GEMMS 3D Ocean Model
GEMMS	Global Environmental Modelling & Monitoring Systems
HYCOM	US Navy Hybrid Coordinate Global Ocean Model
MWPA	Mid-West Port Authority
SWAN	Simulating WAves Nearshore
TSHD	Trailer Suction Hopper Dredge
WA	Western Australia
ZOI	Zone Of Influence
ZOMI	Zone Of Moderate Impact
ZOTM	Zone Of Total Mortality

1 INTRODUCTION

This report details the work carried out by Global Environmental Modelling and Monitoring Systems (GEMMS) in support of environmental impact studies for the proposed maintenance dredging program at the Port of Geraldton in late 2021.

The Port of Geraldton (Figure 1.1) is managed by the Mid-West Ports Authority (MWPA) and includes a shipping channel, a seven-berth inner harbour with associated tug boat harbour, and a large fishing boat harbour.

Recent hydrographical surveys have indicated that sediments have been building up within and just outside the main harbour and channel reducing the draught available to ships entering and leaving the harbour (Figure 1.1). To resolve this problem the MWPA is seeking approval to carry out maintenance dredging works to ensure that the channels and berths are maintained at their designed dimensions.

MWPA plans to commission a trailer suction hopper dredge (TSHD) to undertake dredging works.

Sediments from the inner harbour basin and berth pockets are proposed to be relocated into the Berth 7 Reclamation Area where the dredged material will settle and be permanently encapsulated within the existing specially constructed reclamation area. Return wasters will be discharged into the harbour basin.

Sediments from the channel are proposed to be removed by the TSHD and deposited in a nearshore placement area north of the Port in Champion Bay (Figure 1.1). This has been identified as beneficial re-use site where clean sediments are expected overtime to return to the natural sediment transport system.

MWPA is seeking to undertake the dredging program during the 2021/22 financial year, with a preference for the spring/ summer seasons, depending on the availability of the dredging equipment.

GEMMS have undertaken dredging simulation modelling for this project to determine the likely fates of particles released into the water column during dredging and disposal activities.

The GEMMS dredging simulation model (DREDGE3D) was driven by current profiles (GCOM3D and HYCOM) and wave radiation forcing and orbital velocities (SWAN). Meteorological forcing was derived from the European Centre for Medium Range Weather Forecasts (ECMWF) ERA5 hourly reanalysis data (historical output from successive forecasts has been combined into an hourly global gridded dataset and upgraded by the incorporation of meteorological observations) .

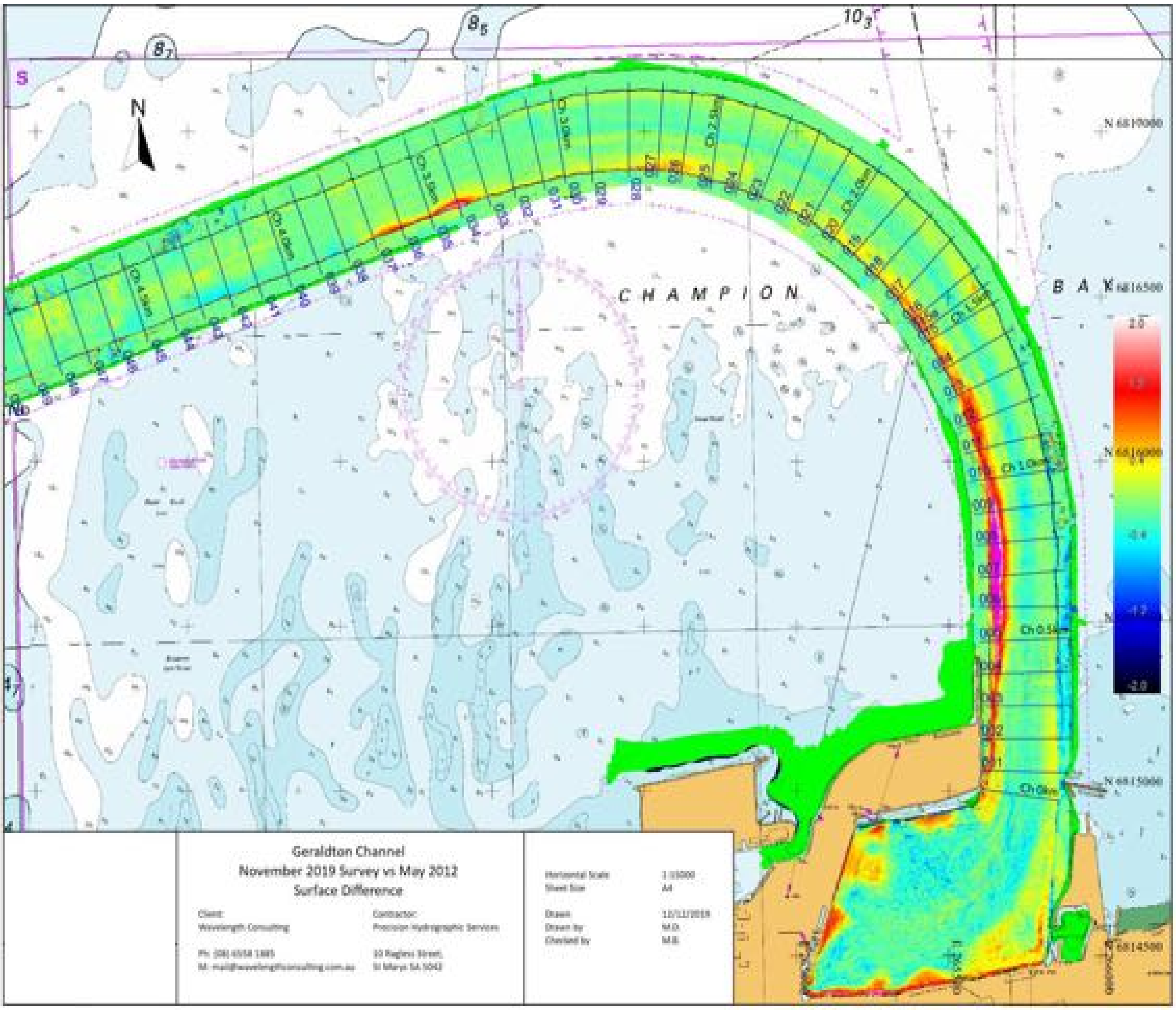


Figure 1.1 The Harbour Basin and Channel showing sediment accumulation (courtesy of MWPA)

2 THE ATMOSPHERIC AND OCEAN ENVIRONMENT

2.1 Meteorology

In the warm months a quasi-permanent heat trough develops over the Pilbara region of WA. This broad area of low pressure combines with high-pressure south-westwards over the Indian Ocean to drive persistent southerly winds along the west coast. Figure 2.1 shows a typical synoptic sequence in January with a heat trough extending southwards from the Pilbara.

In the winter months the heat trough disappears and the wind climate becomes more directionally variable. Figure 2.2 shows a typical winter synoptic sequence demonstrating this variability. A cold front pushing northwards from high latitudes initially combines with a high pressure system to the east to produce strengthening northerly quarter winds over the region. Following the frontal passage, winds initially become lighter and more variable and then turn south-westerly as high pressure builds to the southwest.

These features are exhibited by measurements from meteorological stations in the region of interest for this project, namely at Geraldton Airport, Geraldton Port Channel Beacon and at North Island in the Abrolhos Group.

North Island (Figure 2.3) is the most representative of the regional meteorology due to its offshore location away from local land-sea effects.

The southerly winds resulting from the dominant summer synoptic situation are a clear feature in the polar wind summer diagram for North Island (Figure 2.4) and the polar wind winter diagram (Figure 2.5) exhibits the synoptic variability.

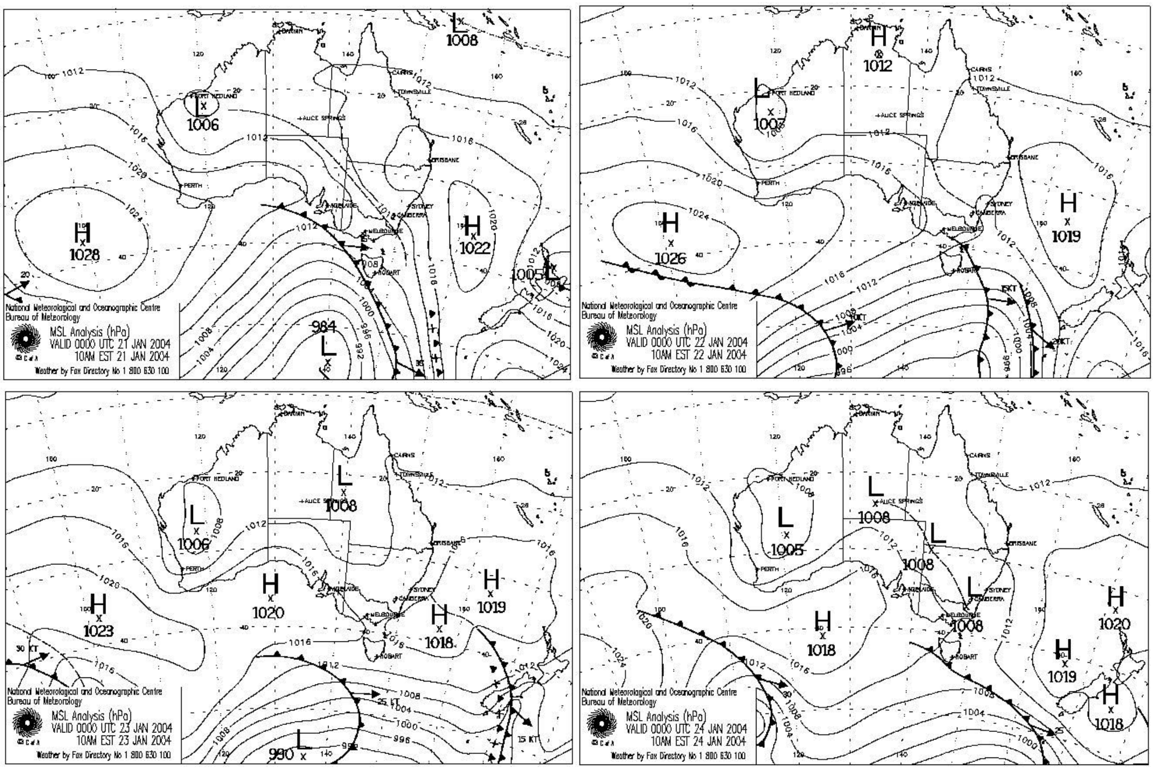


Figure 2.1: Typical warm month pattern showing persistence of low pressure through Pilbara and in this case developing southwards.

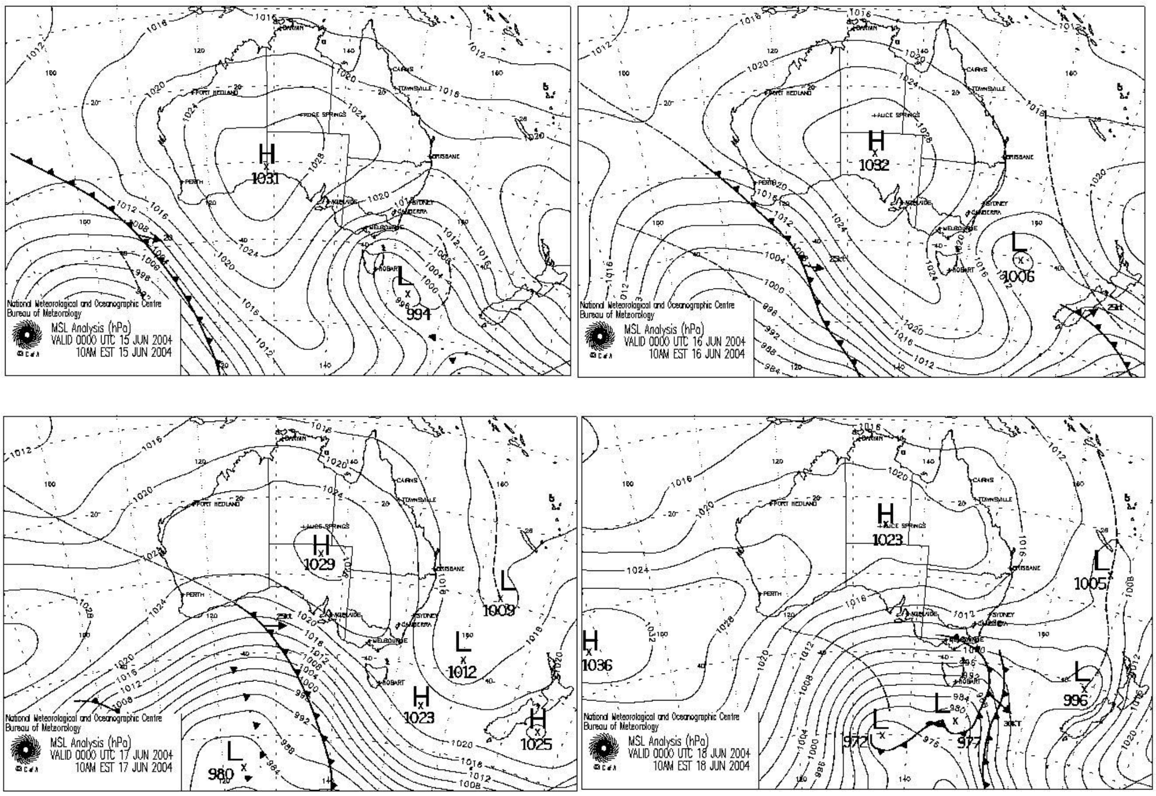


Figure 2.2: Typical winter pattern showing northerly winds preceding frontal passage.

Figure 2.3: **Meteorological data sites.**

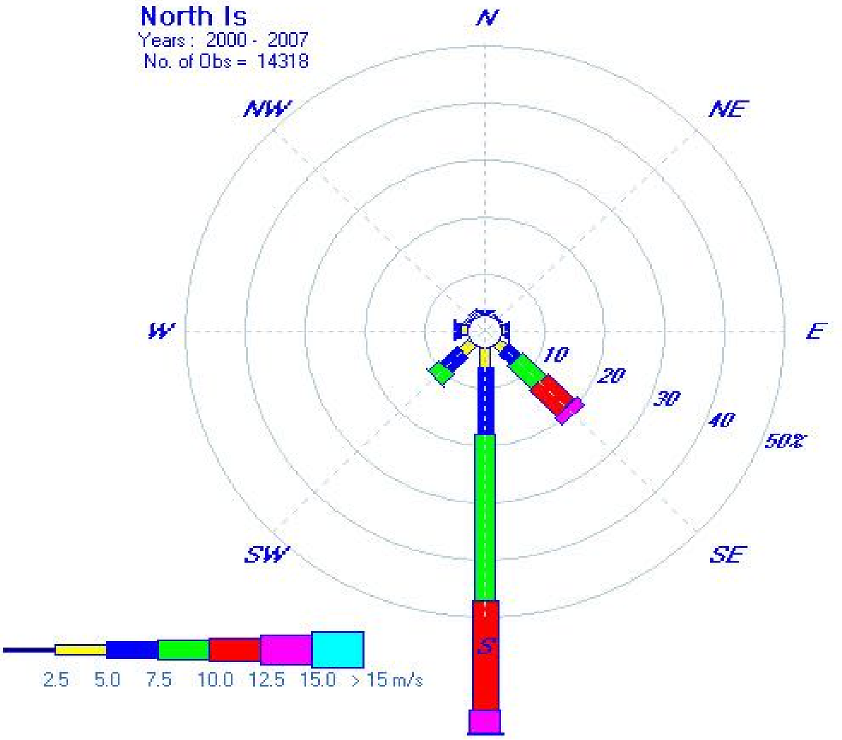


Figure 2.4: Summer wind rose at North Island (2000-2006).

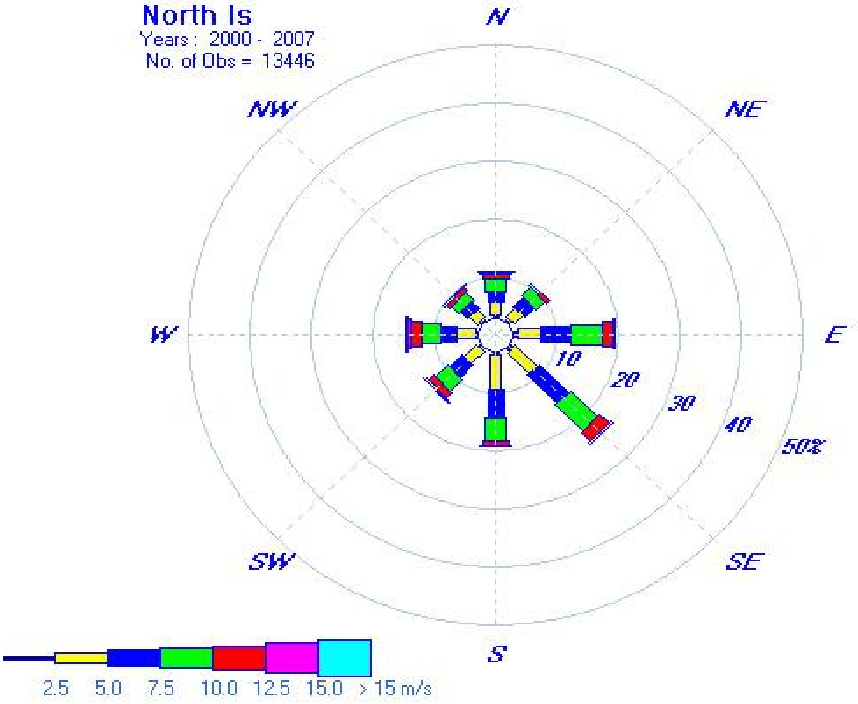


Figure 2.5: Winter wind rose at North Island (2000-2006).

2.2 Oceanography

Geraldton lies on the eastern shoreline of the Indian Ocean and the oceanography of the coastal region is subject to the influences of large-scale oceanic processes in the Indian Ocean and local effects of winds and tides.

The main features of Indian ocean circulation which affect the waters off Geraldton are the Leeuwin Current system that consists of a near-surface southward flow and the deeper northward flow of the Leeuwin Undercurrent, and transient coastal counter currents [*Cresswell and Golding*, 1980; *Pattiaratchi and Woo*, 2009]. In addition meanders and eddies spin up everywhere along the Western Australian coast all year long.

The Leeuwin Current forms off the Gascoyne shelf at latitudes south of 20°S and then consists of a relatively narrow, but intense, poleward warm current flowing in the upper 250m of the water column with its core usually located seaward of the shelf break.

The Leeuwin Current system intensifies during the autumn/winter period resulting in warmer waters flowing south and hence coastal waters off southern WA are generally warmer in winter than in summer when the southerly winds bring cooler waters from the south.

Closer to the coast, a system of equatorward coastal counter currents has been identified consisting of the Capes Current which extends along the south WA coast [*Pearce and Pattiaratchi*, 1999) and the Ningaloo Current which flows intermittently along the northwest coast [*Woo et al*., 2008].

Figure 2.6 shows a map from Rossi et al (2013) illustrating the main features of the ocean circulation off the southern coast of WA. The red arrows indicate typical behaviour of the Leeuwin Current and the blue indicate the coastal counter currents (Ningaloo Current and Capes Current).

These features are driven by a combination of thermodynamics and dynamics in the Indian Ocean and therefore cannot be represented by an ocean model which does not include temperature and salinity

This also means that it is not possible to accurately simulate the currents off Geraldton with an ocean model setup on a local grid just surrounding Geraldton driven by winds and tides.

It is necessary to incorporate Indian Ocean physics into the simulations by establishing a larger grid which, in turn, is deriving Indian Ocean currents, temperatures and salinities from a suitable global ocean model.

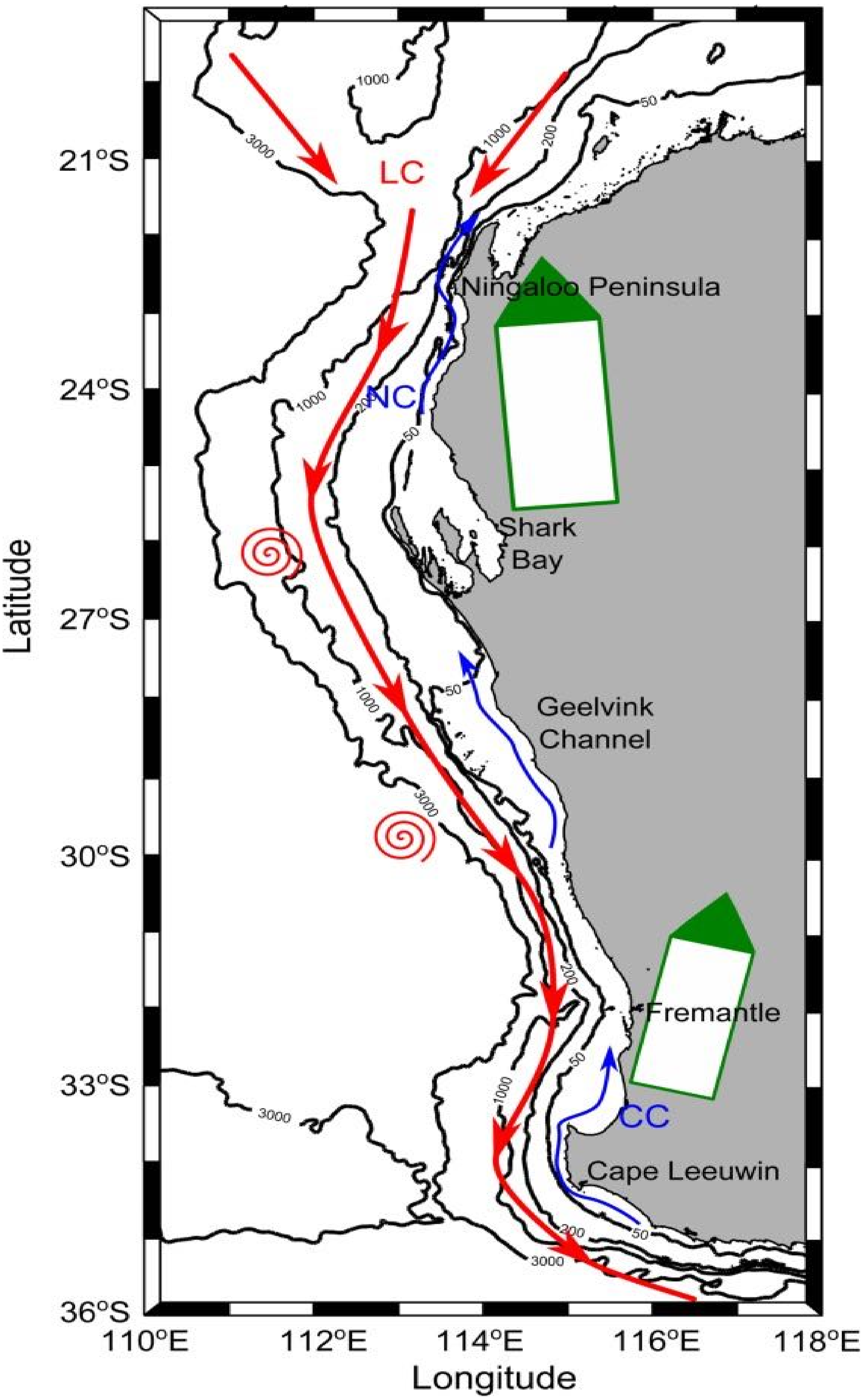


Figure 2.6: Illustration of the dominant current systems of southern Western Australia (red arrows indicate the Leeuwin Current; blue arrows indicate the Ningaloo Current and Capes Current).

3 SIMULATION METHODOLOGY

Dredging modelling simulates ocean hydrodynamics, the physics of dredged sediments released into the water column and the dredging and disposal mechanics. The characteristics of the released sediment, the timing and location of releases are determined by the project plan, site characteristics and the equipment used for dredging and spoil disposal. Consequently, dredge simulation modelling is only part of a wider process, as shown by Figure 3.1 which illustrates the typical dredging simulation and impact assessment process (the role of GEMMS is coloured green).

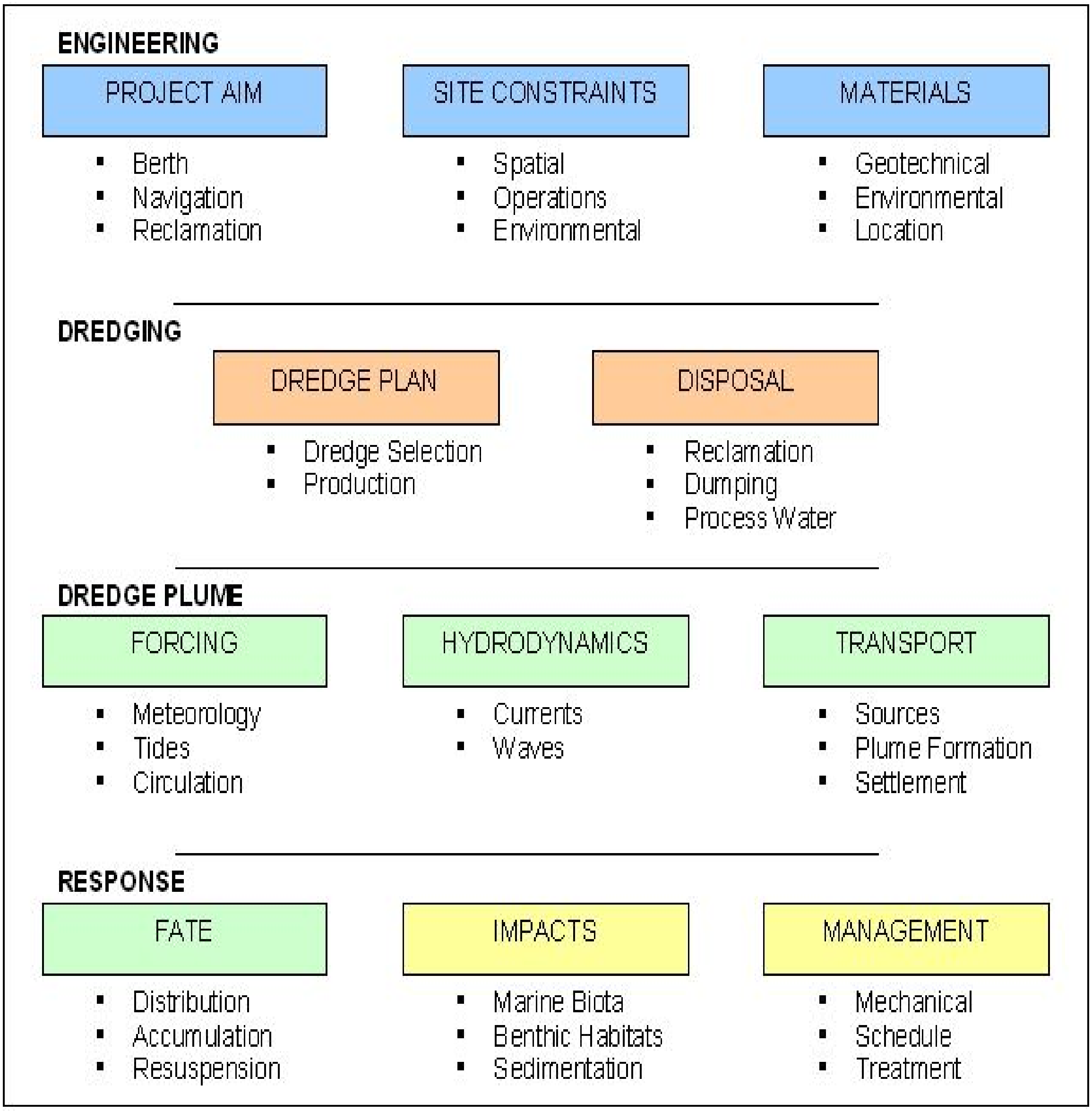


Figure 3.1: The Dredging Simulation Modelling and Impact Assessment Process

3.1 The Simulation Process

As illustrated in Figure 3.1, the dredging simulation modelling requires a range of key inputs, including engineering, geotechnical, meteorological and oceanographic components. These inputs feed into the simulation process which uses three sophisticated numerical computer models:

1) The GEMMS 3D Coastal Ocean Model (GCOM3D) to simulate the complex three-dimensional ocean currents in the region;
2) The SWAN wave model; and
3) The GEMMS 3D Dredge Simulation Model (DREDGE3D) to simulate the behaviour of the dredge(s) and determine the fate of particles released into the water column during the dredging operations.

These models derive critical input from global atmospheric and ocean models, namely:

1) The ECMWF reanalysed global atmospheric model forecasts (ERA5)
   - Winds and atmospheric pressures
2) The US Navy global ocean model (HYCOM)
   - Large scale ocean currents, temperatures and salinities

A summary of the modelling process involved in dredging simulations is shown in Figure 3.2.

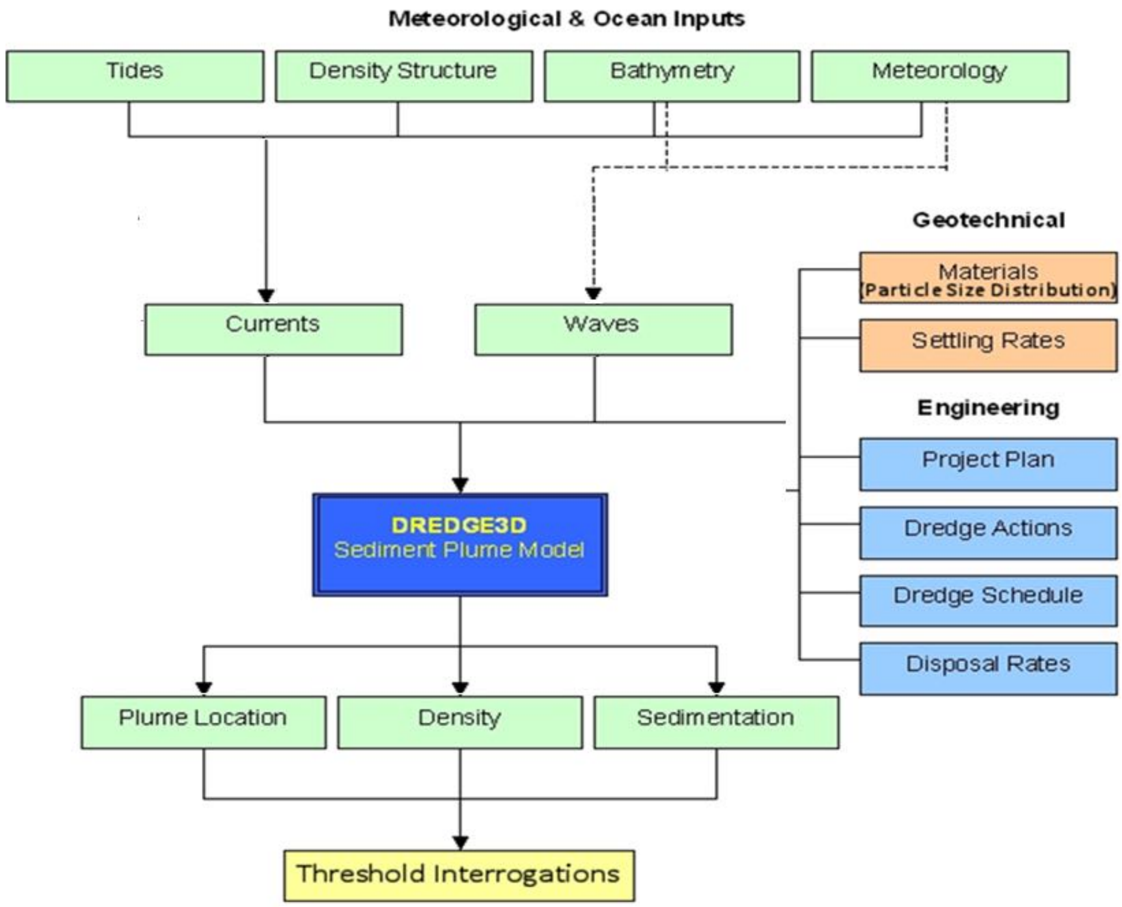


Figure 3.2: Key Components of Dredging Simulation Modelling.

4 ATMOSPHERIC MODEL DATA

4.1 Meteorology

4.1.1 Sourcing Meteorological Data for this Study

The meteorological analysis is critical to the outcomes of any coastal study of plume dispersion or sediment transport. The best plume model in the world will produce the wrong results if the waves, ocean currents and winds are not sufficiently accurate.

In past years (mainly 1990's and earlier) studies of the fate of oil spills and other discharge plumes often used meteorological station winds to drive ocean models. However, it has now been shown that when using coastal winds, or even winds measured on site, the errors are quite large due to the fact that:

- These winds are only accurate at the site;
- As a plume drifts under the influence of currents and waves it moves into areas influenced by winds, which are different to those at the release site;
- Even at the release site the waves and currents are not just driven by the local wind but are a result of waves and currents propagating into the area which are driven by different winds to those experienced at the release site.

In this study gridded wind fields from the reanalysed ECMWF global atmospheric forecast model are used (ERA5) to drive the three-dimensional baroclinic ocean model (GCOM3D) and the SWAN wave model. Local wind observations are still important however because they are essential for assessing the level of error in the model winds.

4.2 Verification of the Atmospheric Model Data

Hourly ERA5 wind and atmospheric pressure data was downloaded for the years 2017 and 2018 to enable up to 24 months of placement area fate investigations and several possible dredging program periods.

For reasons discussed earlier, separate comparisons were undertaken for summer and winter wind regimes. Figures 4.1 and 4.2 compare the summer wind rose from observations at Beacon 1 from 2008 to 2018 with the summer wind rose from ERA5 for the years 2017 and 2018.

The winter wind roses at beacon 1 are compared in Figures 4.3 and 4.4, whilst summer and winter comparisons at North Island are made in Figures 4.5 to 4.8.

Direct comparison of these wind roses is not appropriate, due to the fact that they represent different periods of time, however the qualitative agreement is very good at both sites.

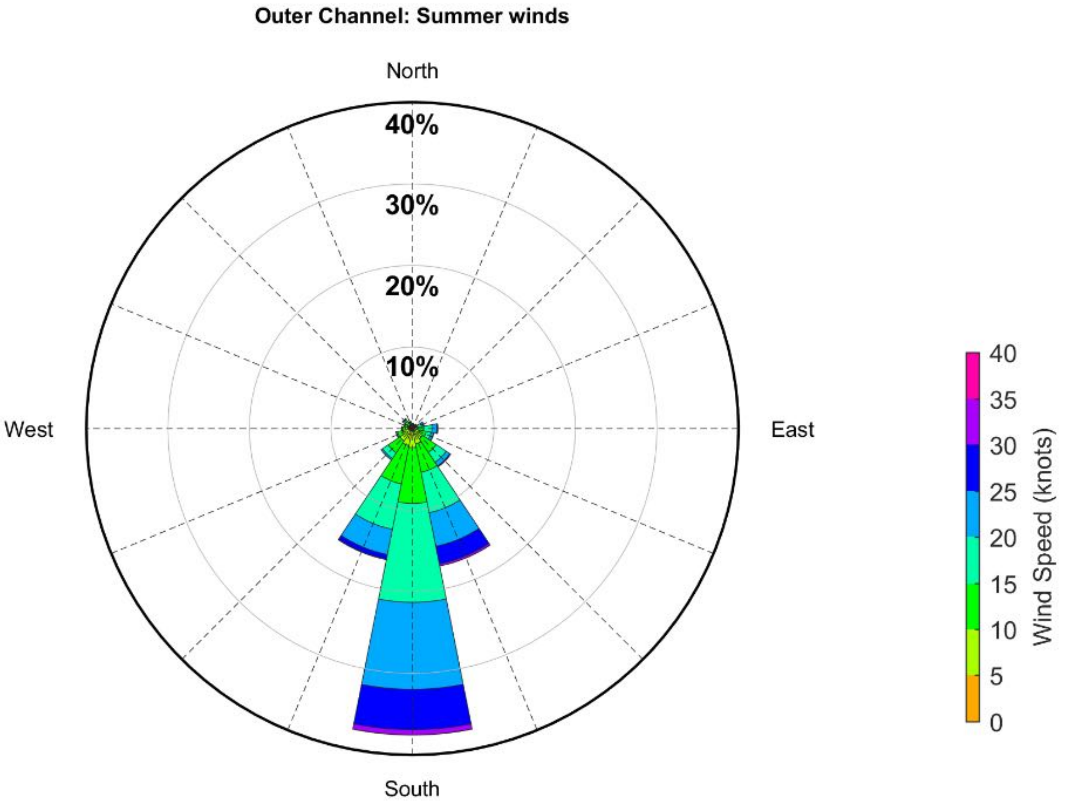


Figure 4.1 – Summer Wind Rose at Beacon 1 from the ERA5 reanalysed Atmospheric Model Forecasts for 2017 and 2018.

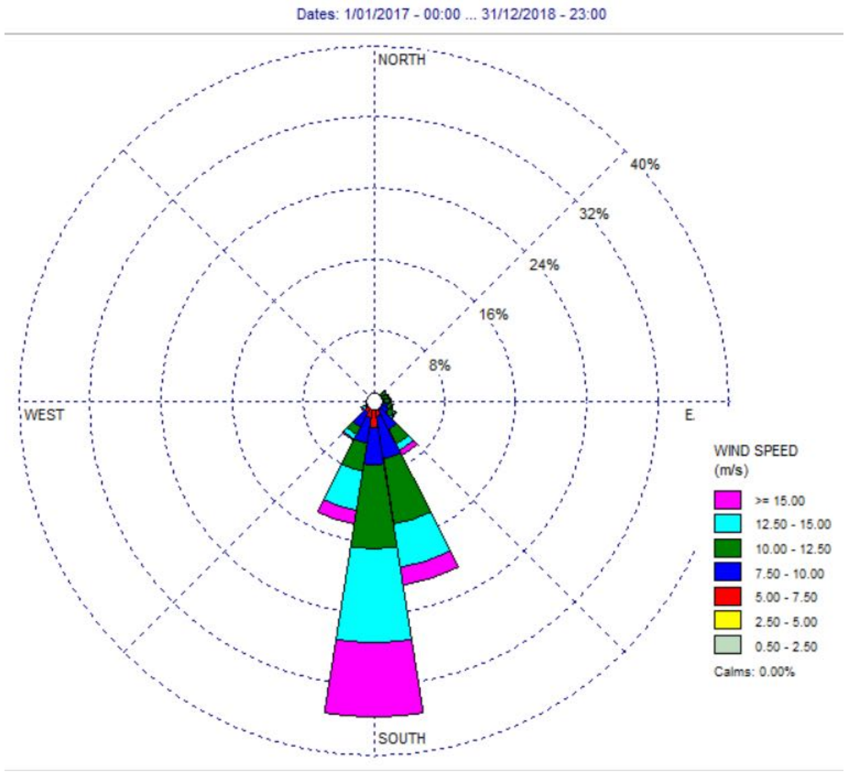


Figure 4.2:- Summer wind rose at Beacon 1 from data measured in 2017 and 2018.

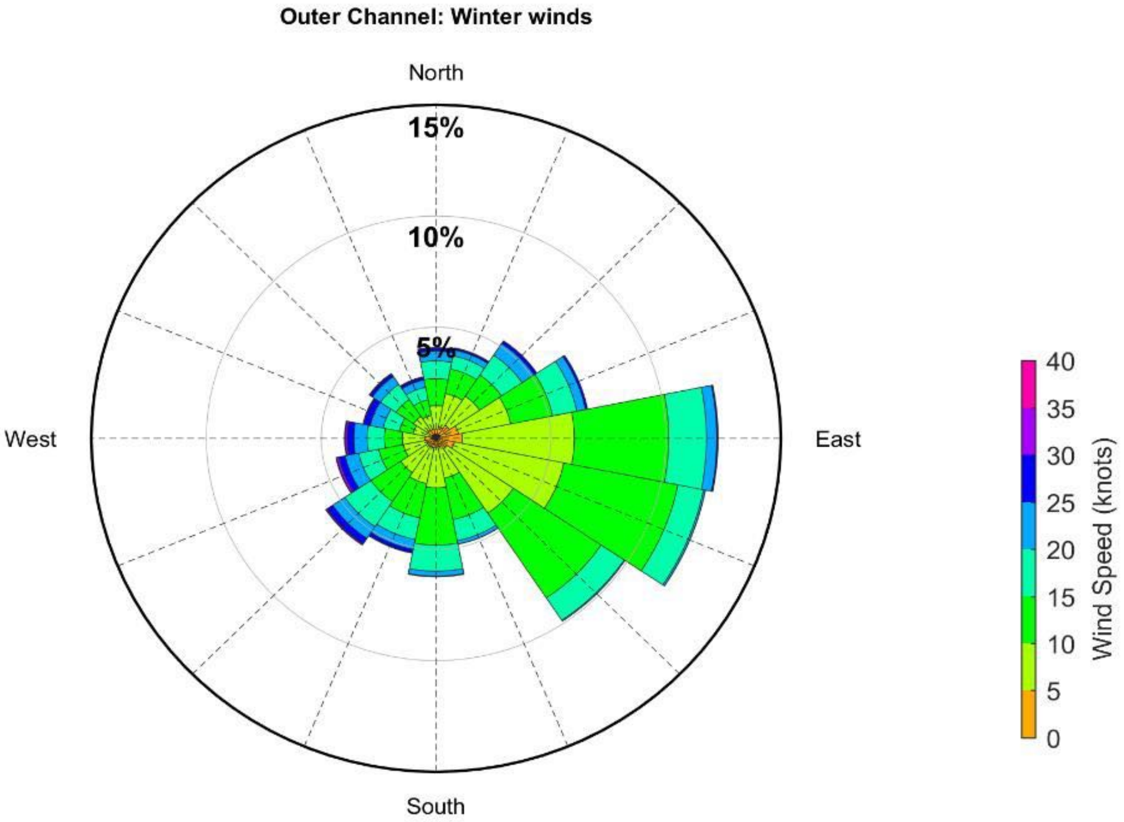


Figure 4.3 - Winter Wind Rose at Beacon 1 from the ERA5 reanalysed Atmospheric Model Forecasts for 2017 and 2018.

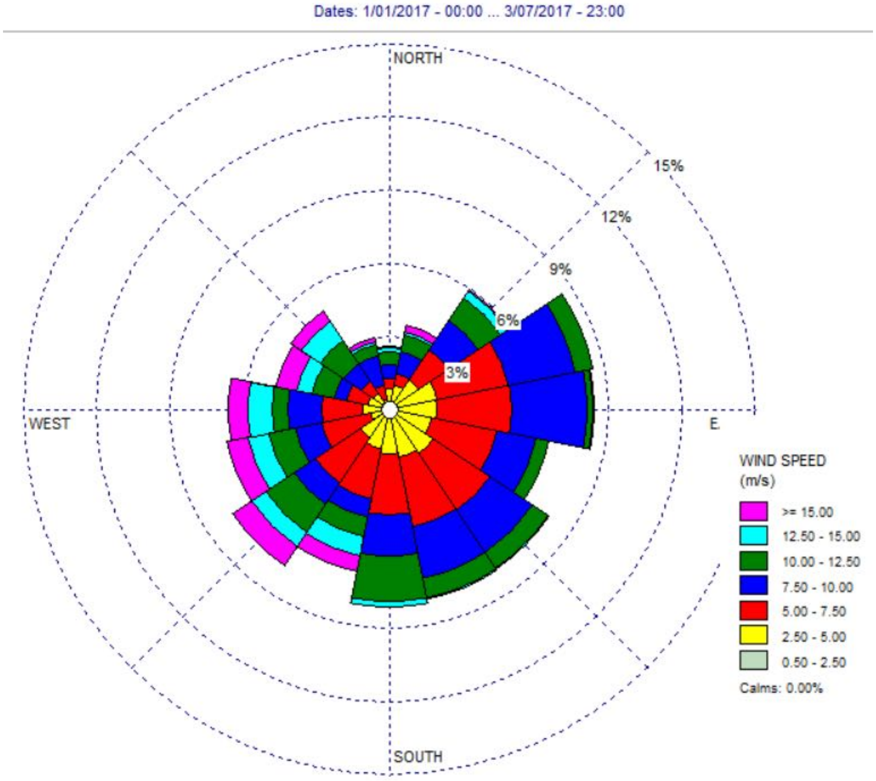


Figure 4.4 - Winter wind rose at Beacon 1 from data measured in 2017 and 2018.

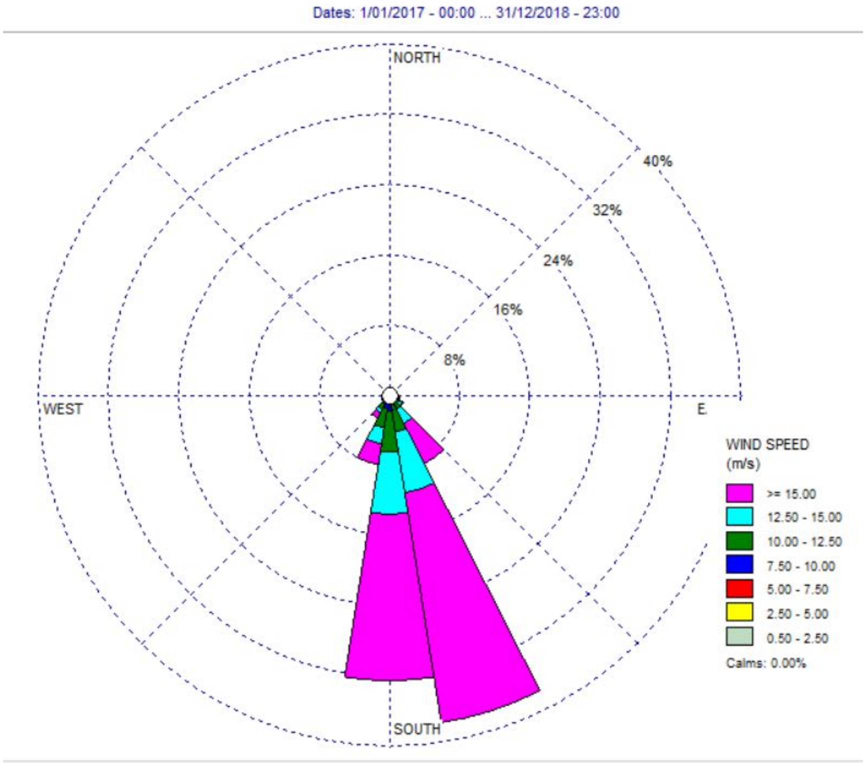


Figure 4.5 - Summer Wind Rose at North Island from the ERA5 reanalysed Atmospheric Model Forecasts for 2017 and 2018.

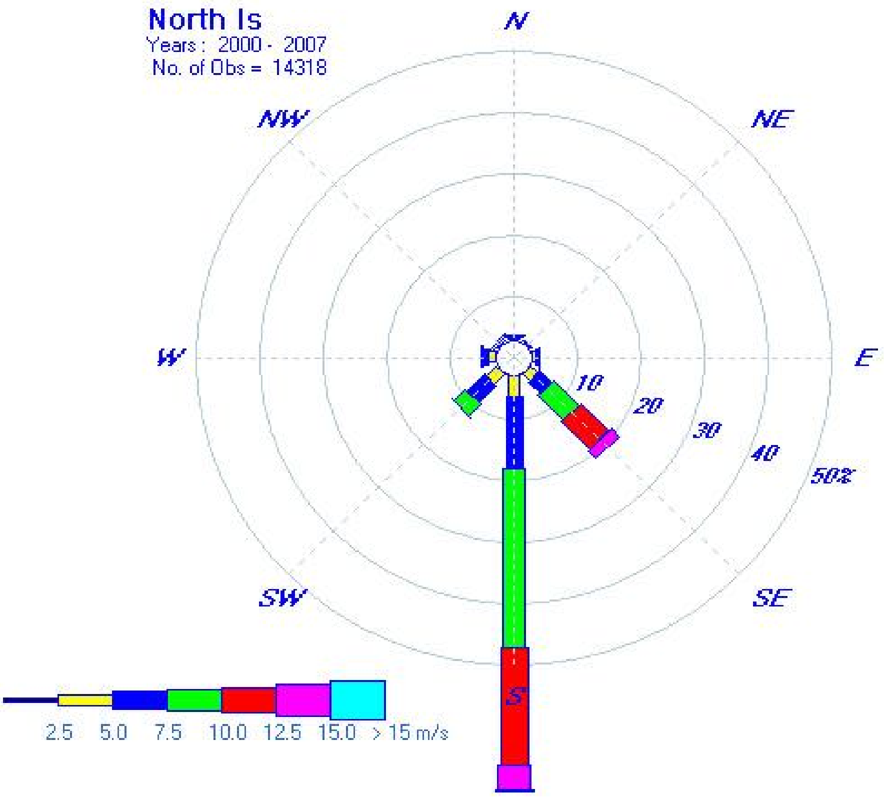


Figure 4.6 - Summer Wind Rose at North Island from data measured between 2000 and 20o6.

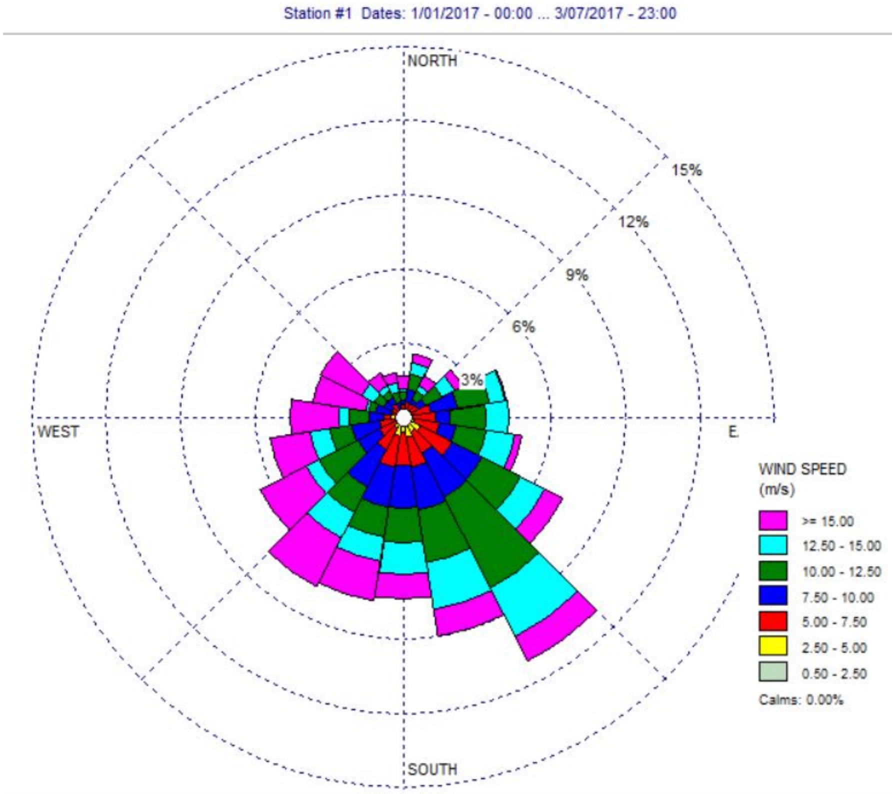


Figure 4.7 - Winter Wind Rose at North Island from the ERA5 reanalysed Atmospheric Model Forecasts for 2017 and 2018.

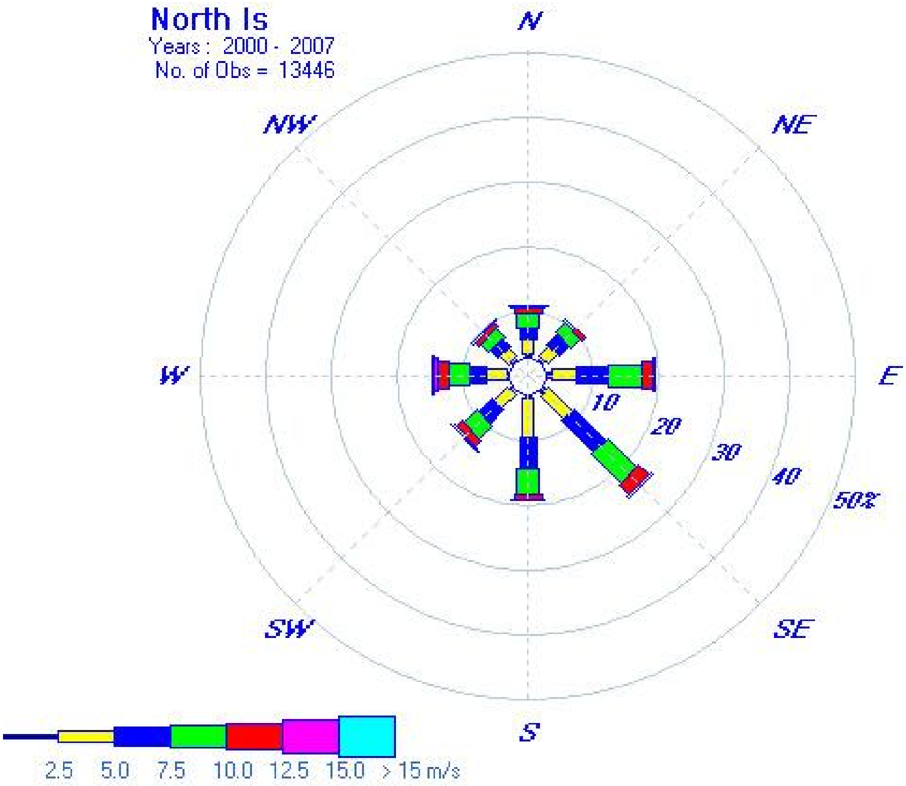


Figure 4.8 - Winter Wind Rose at North Island from data measured between 2000 and 20o6.

5 MODELLING THE OCEAN WAVES

5.1 SWAN

Wave simulations are carried out using the SWAN wave model. SWAN (Booij et al , 1999 and Ris et al, 1999) is a third-generation wave model, developed at Delft University of Technology that computes random, short-crested wind-generated waves in coastal regions and inland waters. The model simulates wave height, direction, period and energy to inform assessment of resuspension and coastal erosion processes.

SWAN includes a wide range of processes and includes the following physics:

- wave propagation in time and space, shoaling, refraction due to current and depth,
- frequency shifting due to currents and non-stationary depth;
- wave generation by wind;
- three- and four-wave interactions;
- white-capping, bottom friction, and depth-induced breaking;
- wave induced setup;
- propagation from laboratory up to global scales;
- transmission through and reflection from obstacles

Although primarily developed as a near-shore model, later versions of SWAN allow for basin-wide modelling obviating the need for nesting within other large-scale models such as WAM and Wavewatch.

5.2 Model Grids and Bathymetry

SWAN was run on three nested grids of increasing resolution. The largest grid (Figure 5.1) was setup with a 5km resolution to capture long period energy originating in the Indian Ocean.

The second grid (Figure 5.2 and inset in Figure 5.1) was setup with a resolution of 500m covering the offshore region in the vicinity of Geraldton and was nested in the larger Indian Ocean grid.

The third grid (Figure 5.3 and inset in Figure 5.2) was setup with a resolution of 50m covering Point Moore and Champion Bay and was nested in the second grid.

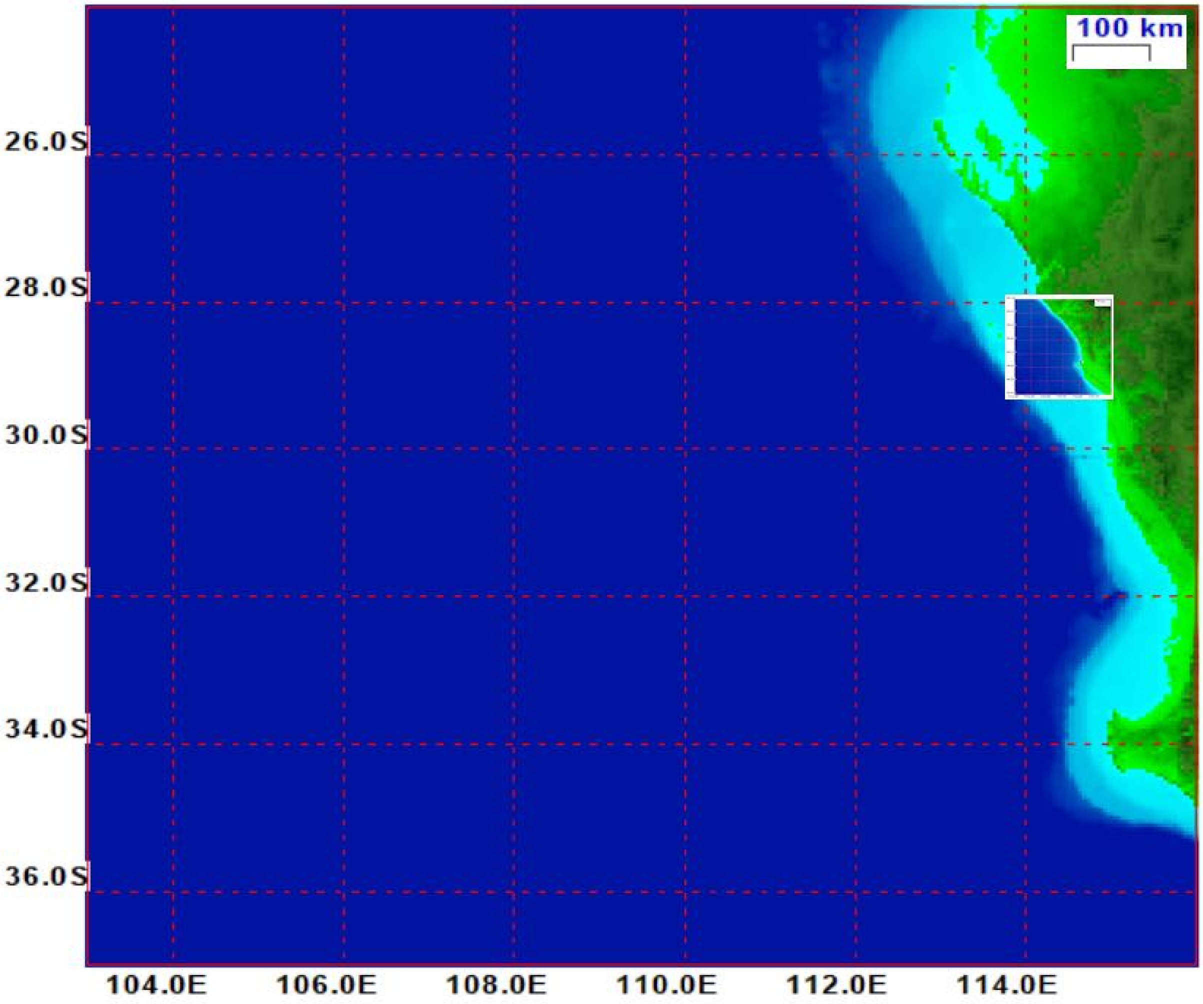


Figure 5.1 – Open ocean (5km resolution) and coastal (500m resolution) SWAN grids.

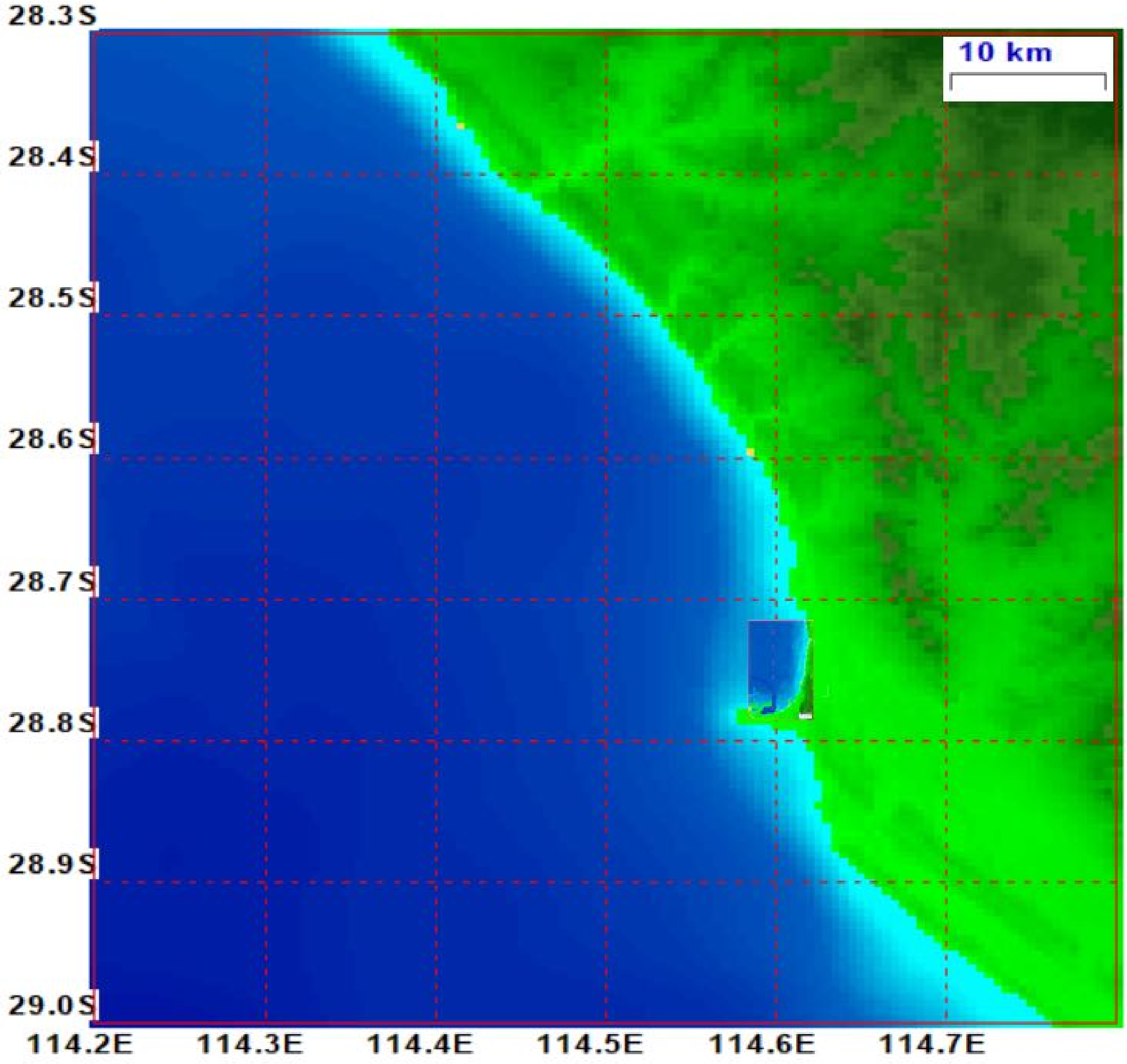


Figure 5.2 – Coastal (500m resolution) and Geraldton (50m resolution) SWAN grids.

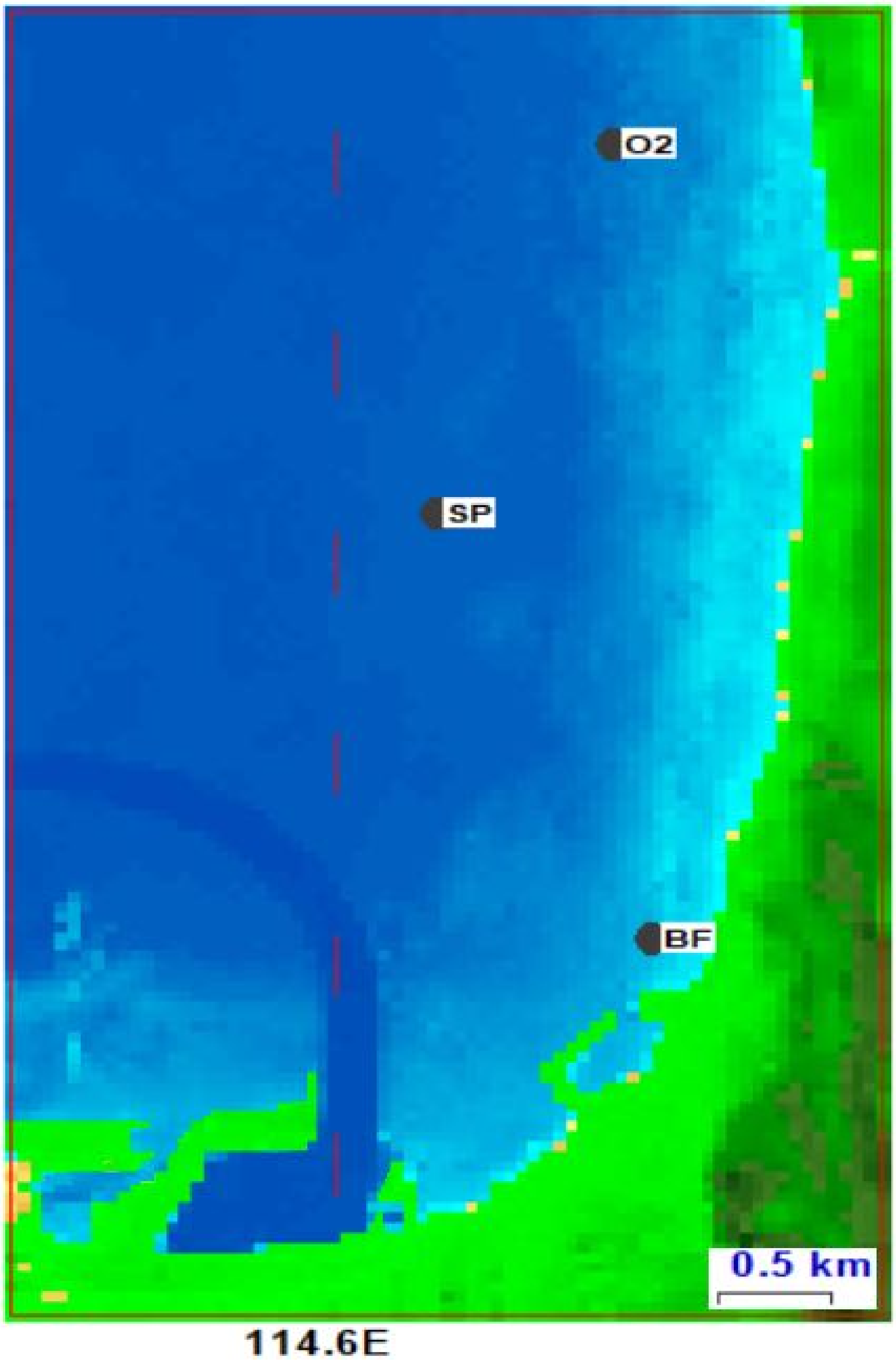


Figure 5.3 – Geraldton (50m resolution) SWAN grid.

5.3 Verification of Wave Modelling Results

Wave data was available for Beacon 1 from 2008 to 2018 but only from July 18 to September 3, 2014 at Beresford. In spite of the short period of available data It was decided to carry out comparisons of model predictions with data from 2014 to allow concurrent assessments at the offshore site (Beacon 1) and the nearshore site (Beresford).

5.3.1 Outer Channel Beacon 1

Significant wave heights, peak wave directions and peak periods predicted at Beacon 1 by SWAN in August and September 2014 are compared with observations in Figures 5.4 to 5.6.

Wave roses for the same period from SWAN predictions and the observations are compared in Figures 5.7 and 5.8

Due to the fact that small timing discrepancies between atmospheric model winds and observed winds can cause lags in time between the simulation and occurrence of an event, an alternative form of comparison was undertaken as summarised in Table 1.

Table 1 shows that SWAN predicts the occurrence of high and low wave events very well but tends to slightly underpredict the wave events in the 2m to 3m range.

SWAN predictions of wave directions and periods are however excellent.

Table 1: Comparison of statistics for SWAN predictions with observations at Beacon 1

Parameter	SWAN	Observations (AWAC)
Mean Significant Wave Height (m)	1.87	1.94
Mean Wave Direction (deg. from)	245	241
Mean Wave Period (secs)	14.3	14.4
% Time Wave Heights are less than 1 metre	5	5
% Time Wave Heights exceed 3 metres	4	6
% Time Wave Heights exceed 2 metres	33	41

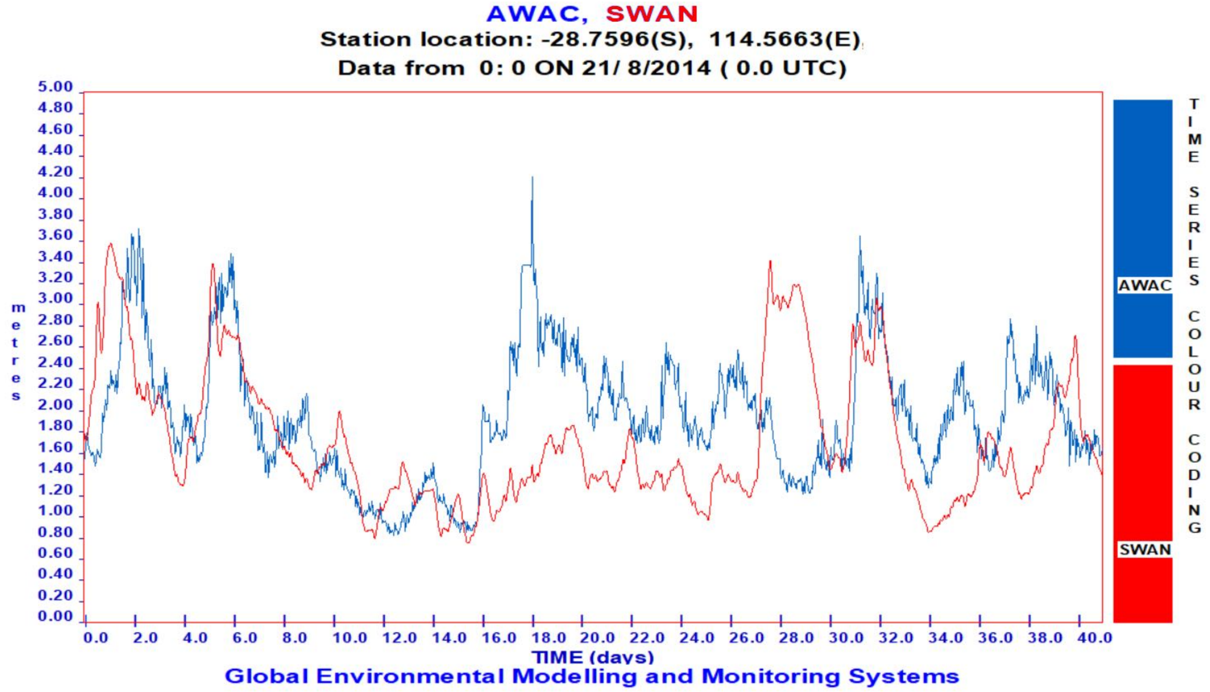


Figure 5.4 – Comparison of SWAN wave heights with observations at Beacon 1.

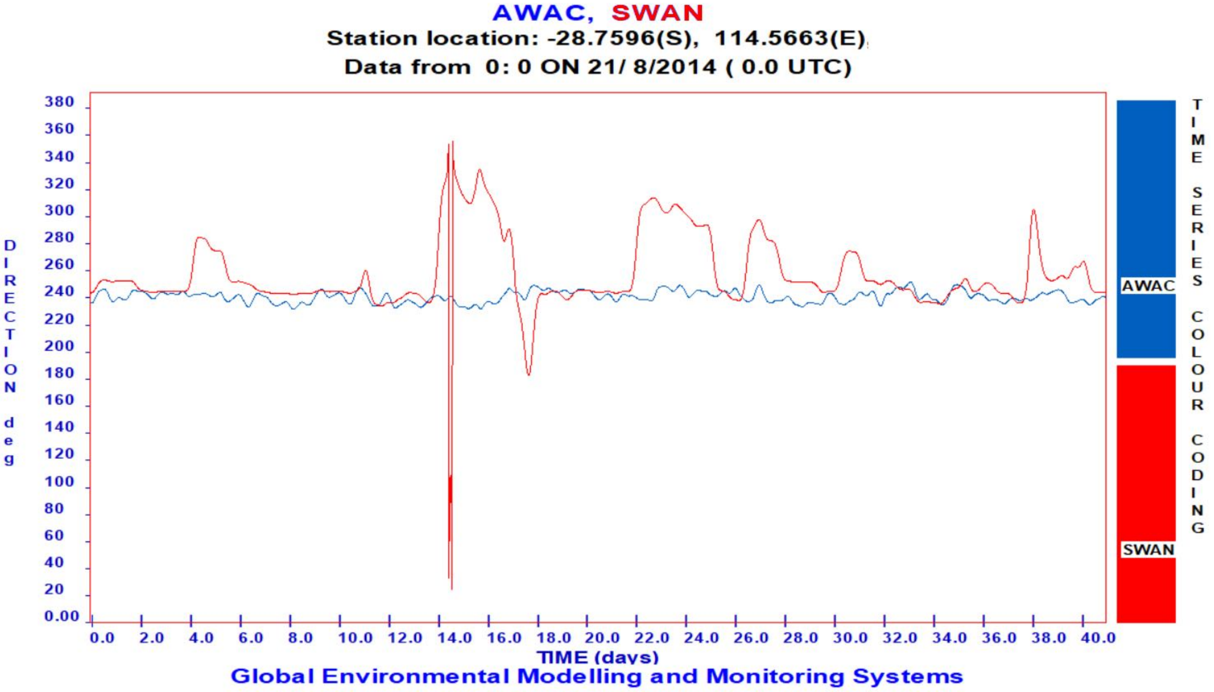


Figure 5.5 – Comparison of SWAN wave directions with observations at Beacon 1.

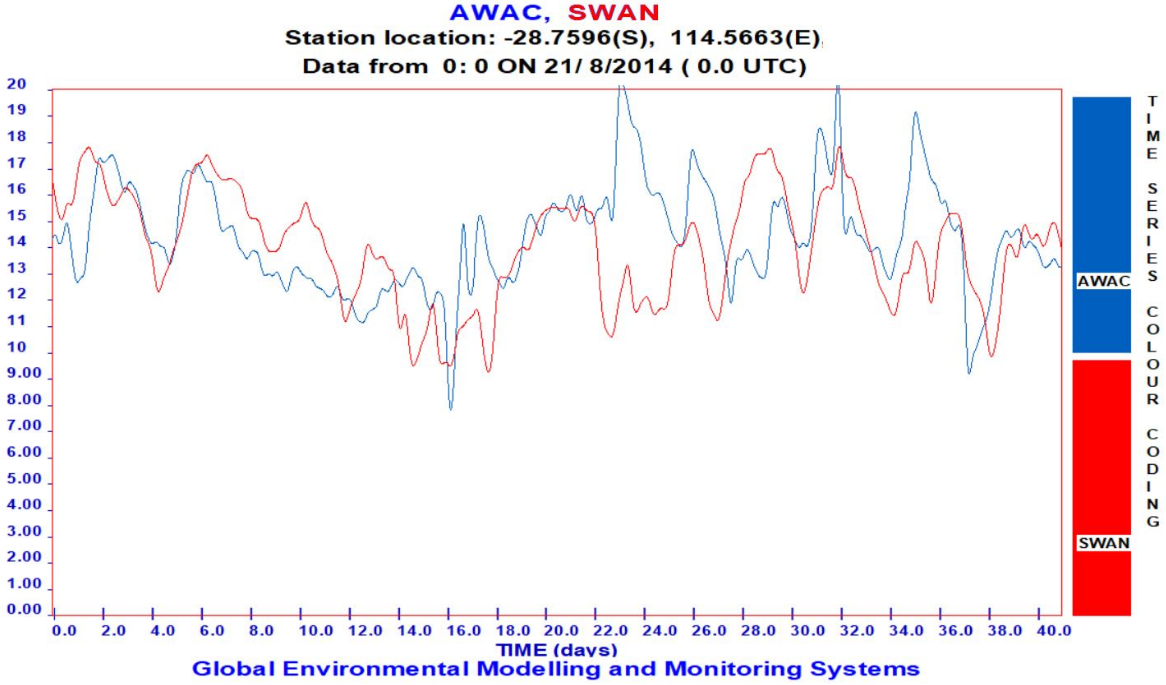


Figure 5.6 – Comparison of SWAN wave periods with observations at Beacon 1.

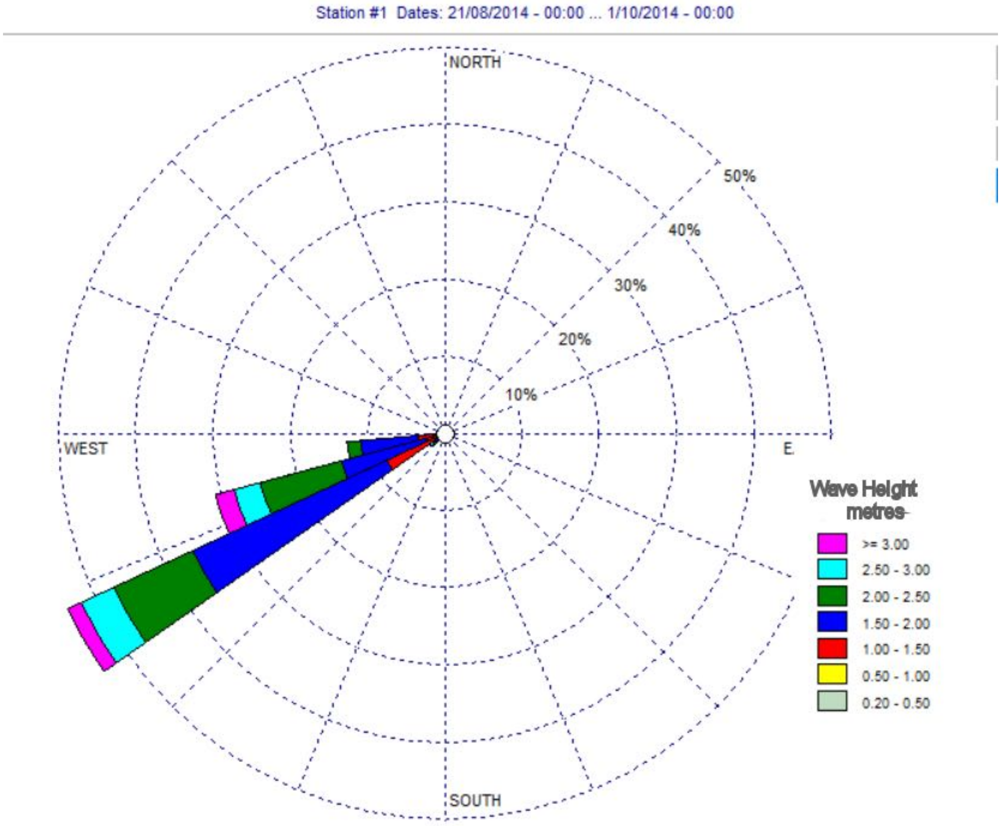


Figure 5.7 – Wave height rose from SWAN predictions at Beacon 1 (Aug-Sep, 2014).

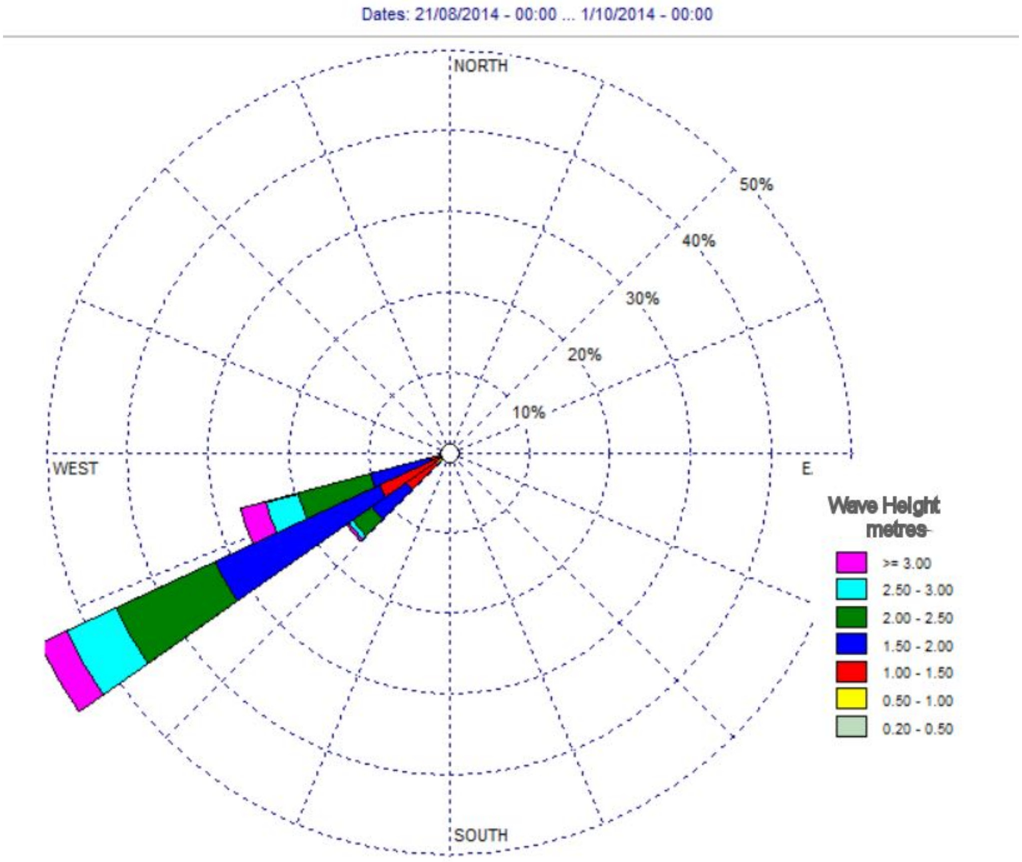


Figure 5.8 – Wave height rose from observations at Beacon 1 (Aug-Sep, 2014).

5.3.2 Beresford

Significant wave heights, peak wave directions and peak periods predicted at the nearshore site (Beresford) by SWAN in August and September 2014 are compared with observations in Figures 5.9 to 5.11.

Wave roses for the same period from SWAN predictions and the observations are compared in Figures 5.12 and 5.13

Table 2 summarises the mean values of the major wave parameters and indicates that SWAN predicts the mean wave heights and directions reaching the shoreline very well but that more of the long period swell energy has been transformed to shorter period waves than the measurements suggest.

In summary, it should be noted that wave propagation processes are complex and no model can absolutely replicate them all.

However, the validation has confirmed that the critical parameters affecting suspended sediment and bedload movement have been very well represented.

Table 2: Comparison of statistics for SWAN predictions with observations at Beresford

Parameter	**SWAN**	**Observations (AWAC)**
Mean Significant Wave Height (m)	0.87	0.87
Mean Wave Direction (deg. from)	277	276
Mean Wave Period (secs)	12.9	14.4

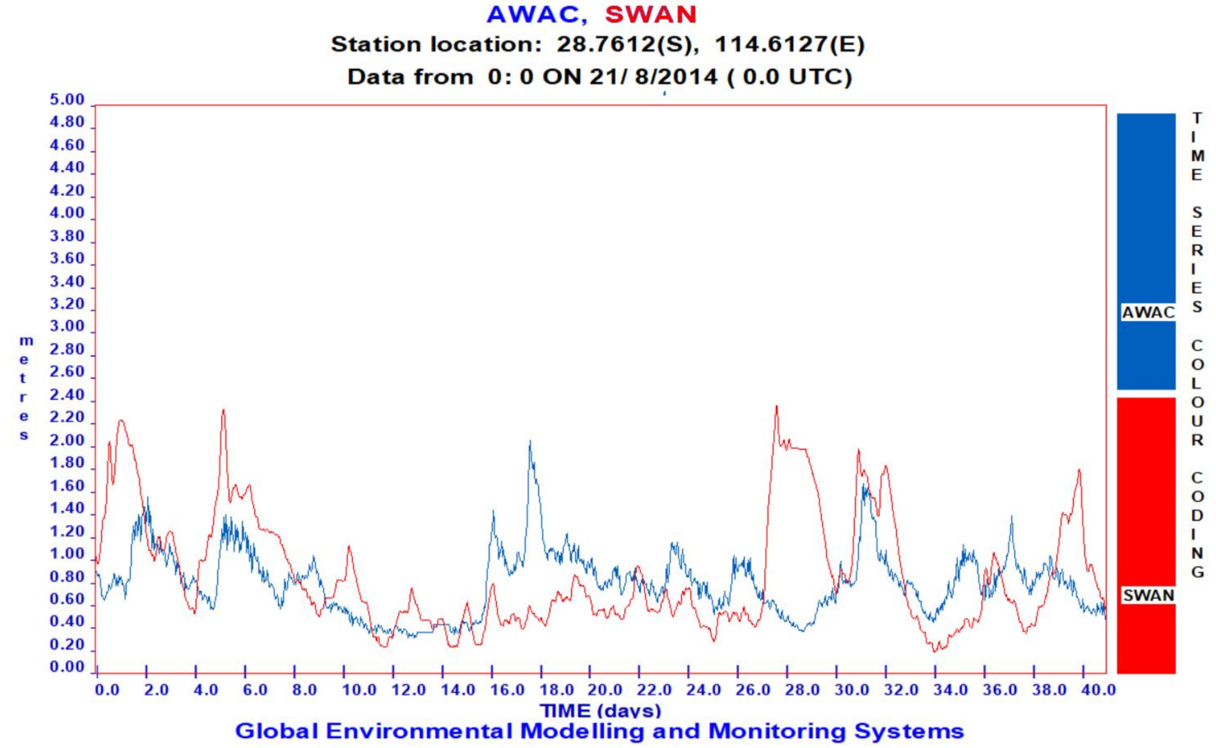


Figure 5.9 – Comparison of SWAN wave heights with observations at Beresford.

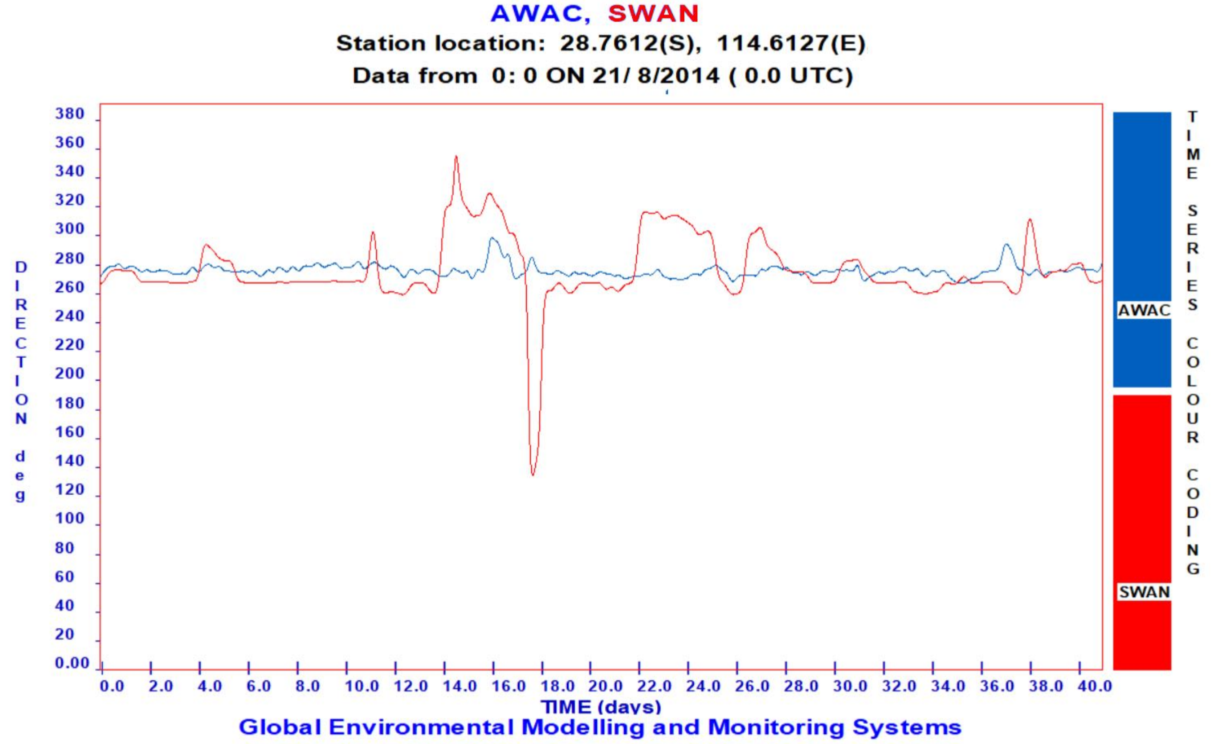


Figure 5.10 – Comparison of SWAN wave directions with observations at Beresford.

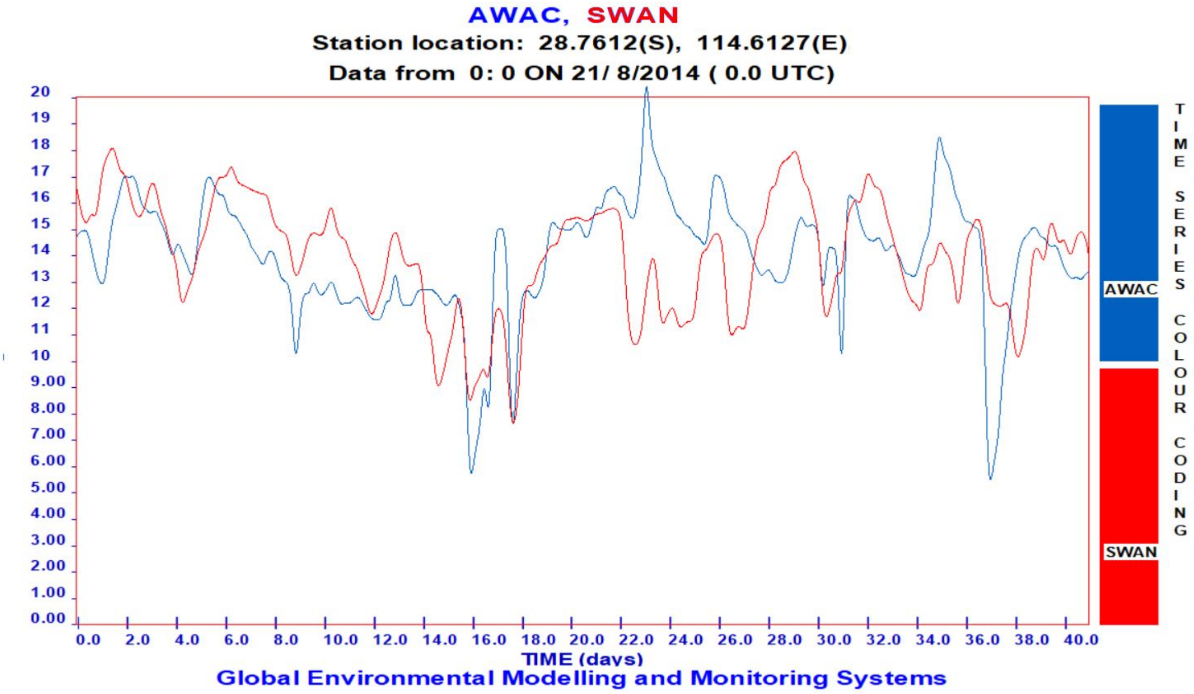


Figure 5.11 – Comparison of SWAN wave periods with observations at Beresford.

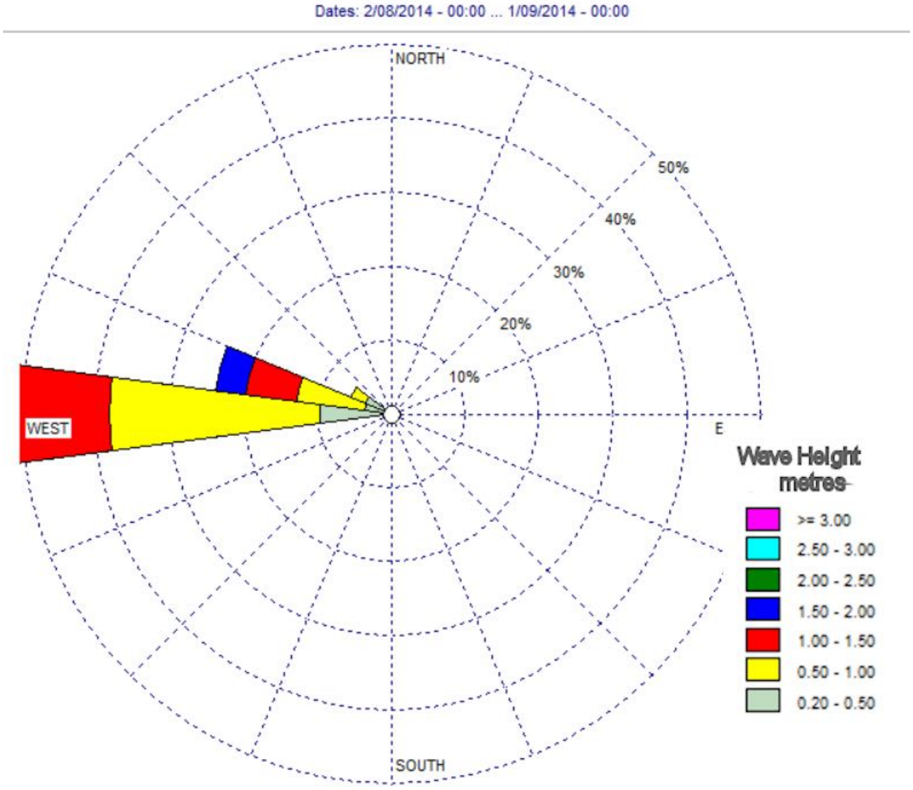


Figure 5.12 – Wave rose from SWAN predictions at Beresford (Aug-Sep, 2014).

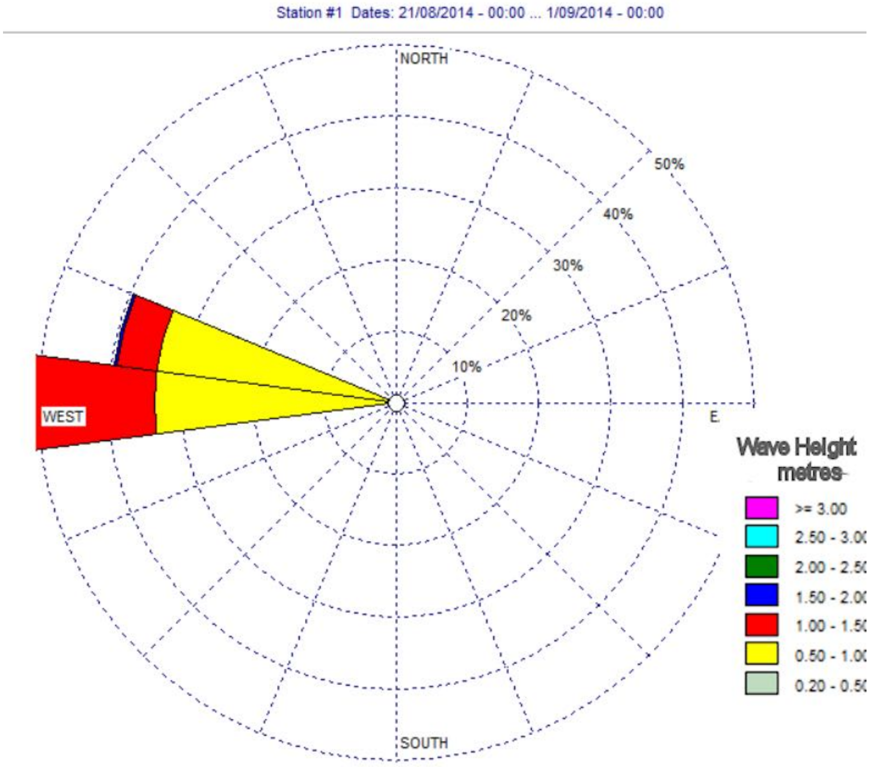


Figure 5.13 – Wave rose from observations at Beresford (Aug-Sep, 2014).

6 MODELLING THE OCEAN CURRENTS AND SEA LEVELS

The fate of ocean discharges is usually strongly affected by the complex currents and tides. It is therefore important to establish an ocean modelling system capable of accurately simulating the local oceanography to provide reliable predictions of water movements within the region of interest.

The ocean currents and sea levels were simulated by GCOM3D driven by large scale Indian Ocean currents, temperatures and salinities, tidal predictions, ECMWF meteorological data and the bathymetry of the project area. The dredging activities and the fate of the dredged material was modelled with DREDGE3D. An overview of the modelling approach is presented in Figure 6.1.

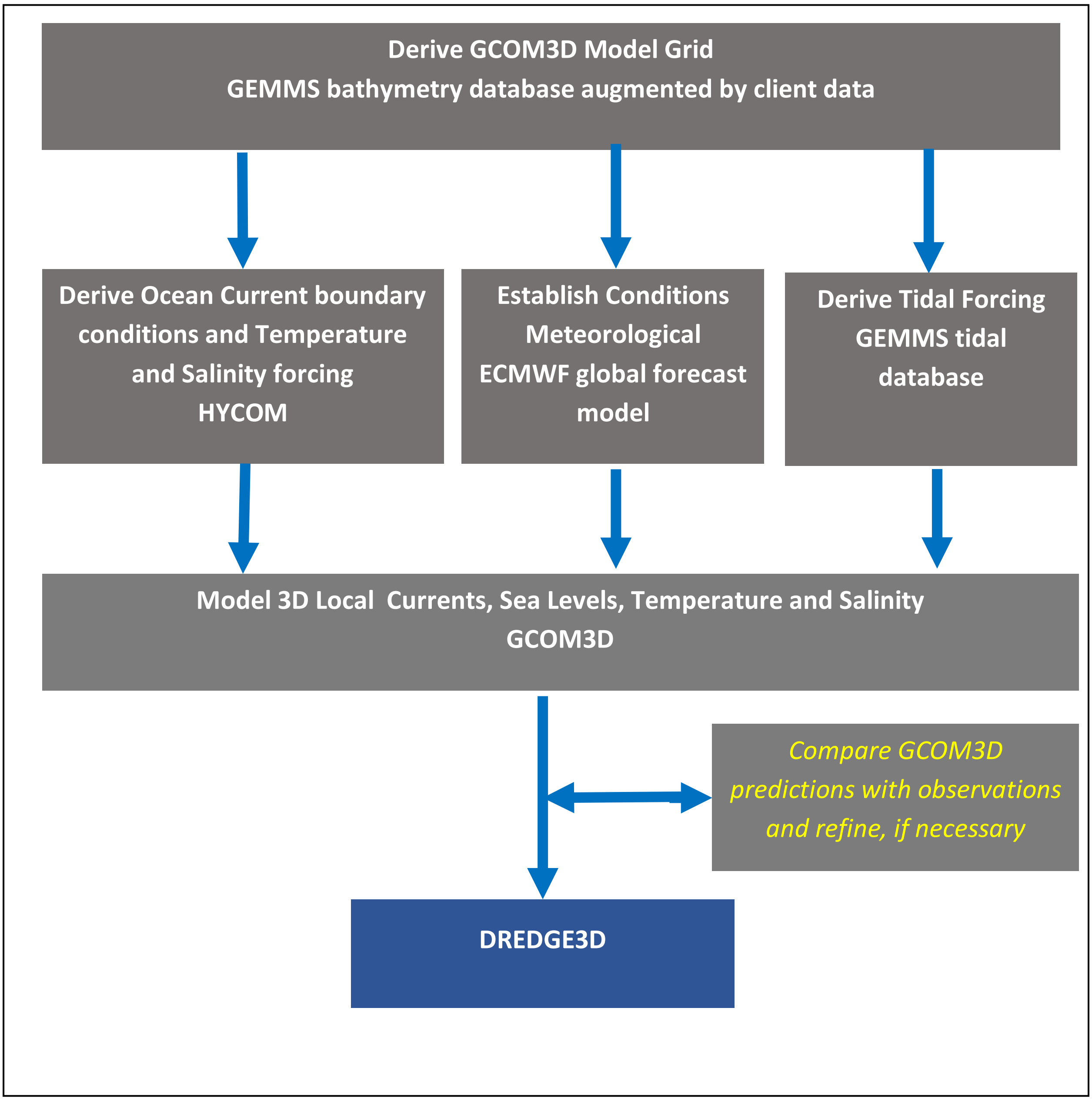


Figure 6.1 – Modelling Flow Chart

6.1 HYCOM

HYCOM is a hydrostatic, primitive equation general circulation model run globally by the United States Navy Research Laboratories. Flexible options for the vertical grid enable HYCOM to conserve water mass properties using isopycnal coordinates when there is strong vertical stratification and still provide adequate vertical resolution in regions with weak stratification, such as the surface mixed layer.

HYCOM includes several mixing scheme options but the NASA Goddard Institute for Space Studies level 2 turbulence closure [Canuto et al., 2001, 2002] scheme is the most sophisticated, being an extension of the original Yamada-Mellor turbulence closure scheme.

GCOM3D routinely uses HYCOM to provide boundary conditions for ocean currents and domain nudging of salinity and temperature fields. A sample of the HYCOM ocean currents used in this study off southern WA is shown in Figure 4.2.

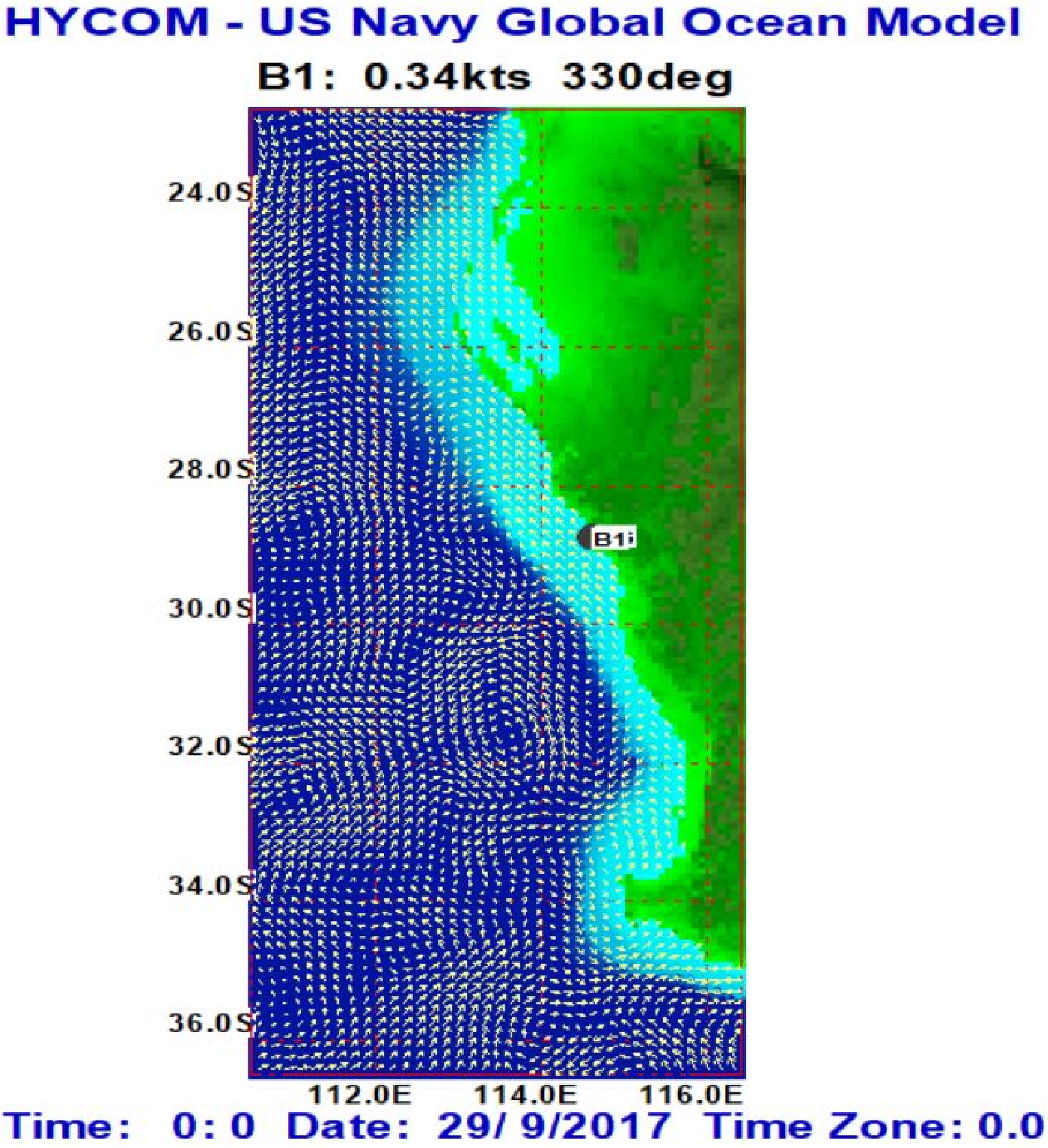


Figure 6.2 – Surface ocean Currents from HYCOM in September 2017

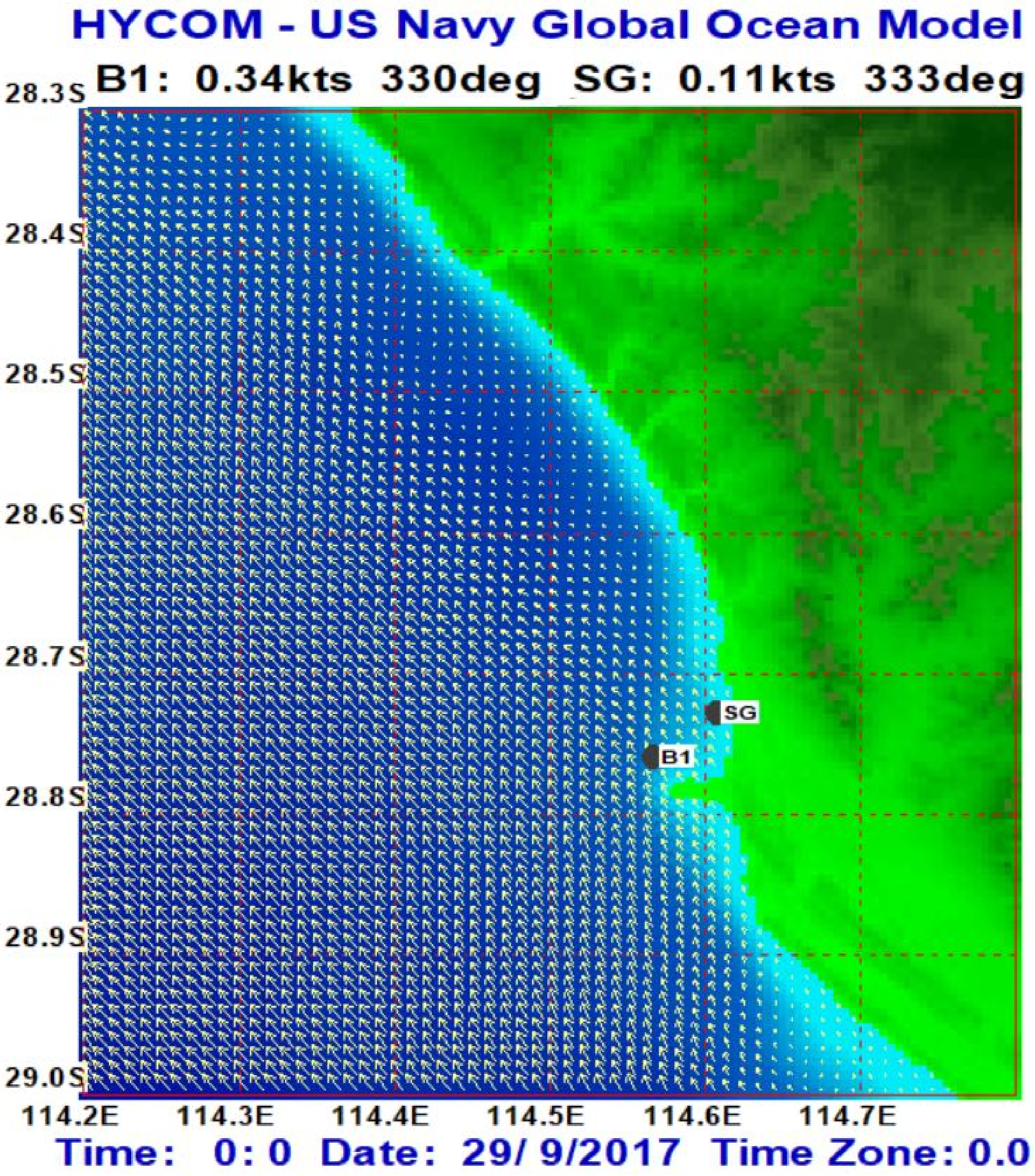


Figure 6.3 – HYCOM surface ocean currents zoomed in to the Geraldton region

6.2 Tides

The tides are simulated using data from the GEMMS Australian region tidal database which was originally developed from a very detailed coastal tidal modelling project undertaken for AMSA to provide data for the Search and Rescue system (which uses GCOM3D).

The tidal database has been continually augmented as more recent data becomes available and is constantly tested by AMSA.

Verification of the accuracy of the tidal levels predicted by GCOM3D is also carried out by comparison with sea level observations within the study region.

6.3 GCOM3D

The circulation off Geraldton needs to be modelled with a well-verified system. The GEMMS 3D Coastal Ocean Model (GCOM3D) has a proven record for modelling ocean currents in the region, having undergone extensive verification during the 2002/2003 capital dredging project at Geraldton. Further verification at nearby Oakajee has also been undertaken against ADCP (Acoustic Doppler Current Profiler) data collected by GEMMS.

GCOM3D (Hubbert 1993, 1999, Appendix A), originally developed in the early 1980s, was one of the world's first 3D ocean models and it calculates sea levels and water currents in both the horizontal and vertical planes. The model operates on a regular grid (in the x and y directions) and uses a z-coordinate vertical-layering scheme. That is, the depth structure is modelled using a varying number of layers, depending on the depth of water, and each layer has a constant thickness over the horizontal plane. This scheme is used to decouple surface wind stress and seabed friction and to avoid bias of current predictions for a particular layer caused by averaging of currents over varying depths, as used in sigma co-ordinate and "depth-averaged" model schemes. GCOM3D is also formulated as a freely scalable and re-locatable model so is easy to apply to differing bathymetric, meteorological and tidal regimes.

GCOM3D has been used in a wide range of ocean environmental studies including prediction of the fate of dredge spoil, oil spills, sediments, hydro-test chemicals, drill cuttings, produced formation water and cooling waters as well as in other coastal ocean modelling studies such as storm surges, search and rescue and America's Cup yacht races.

To model the 3D currents in Champion Bay, and along the adjacent coast, it is necessary to include large scale Indian Ocean influences by taking information from the BoM/CSIRO global ocean model, OceanMaps at the boundaries of GCOM3D and combining with tidal information to drive GCOM3D, together with winds and atmospheric pressures from the BoM.

GCOM3D was Australia's first operational 3D coastal ocean model when it was installed at the Australian Maritime Safety Authority (AMSA) for Marine Search and Rescue purposes in 1999. It remains the only operational coastal ocean model in Australia and runs routinely taking large scale oceanographic information (currents, sea levels, temperatures, salinity) from the BoM/CSIRO global ocean model; OceanMaps (similar to the use of output from HYCOM).

6.3.1 Inputs from the SWAN Model

GCOM3D and the SWAN wave model are run concurrently and the wave radiation stresses and orbital velocities generated by the wave model are input to GCOM3D to account for horizontal and vertical movement of the water body due to wave action.

6.3.2 GCOM3D Grids and Bathymetry

Bathymetry for work in the Australian Region is derived from the GEMMS high resolution database developed in conjunction with AMSA (for search and rescue purposes) from all available Government and private data. These data were augmented by 2016 LIDAR data and local soundings commissioned by the MWPA.

The circulation in the Geraldton region was simulated on three high resolution grids of increasing resolution (Figures 4.4 to 4.6) nested inside each other and deriving currents, temperatures, and salinities in the Indian Ocean from HYCOM.

The vertical levels in GCOM3D go to depths greater than 10,000 metres if required by the bathymetry. The levels in the top 220m of the ocean are variable but are typically set to: 0, 2, 4, 6, 9, 14, 20, 28, 38, 50, 65, 84, 108, 138, 175 and 220m below mean sea level.

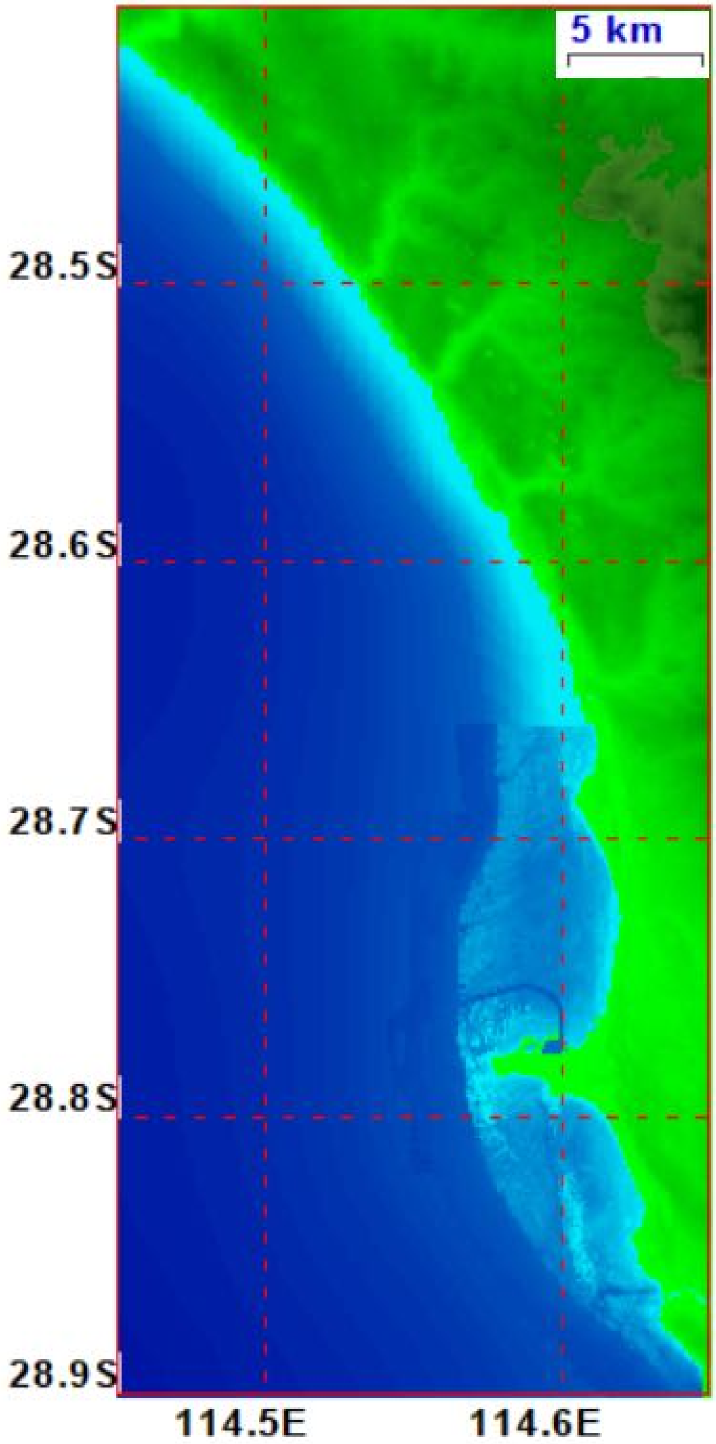


Figure 6.4 - 100m resolution grid for GCOM3D

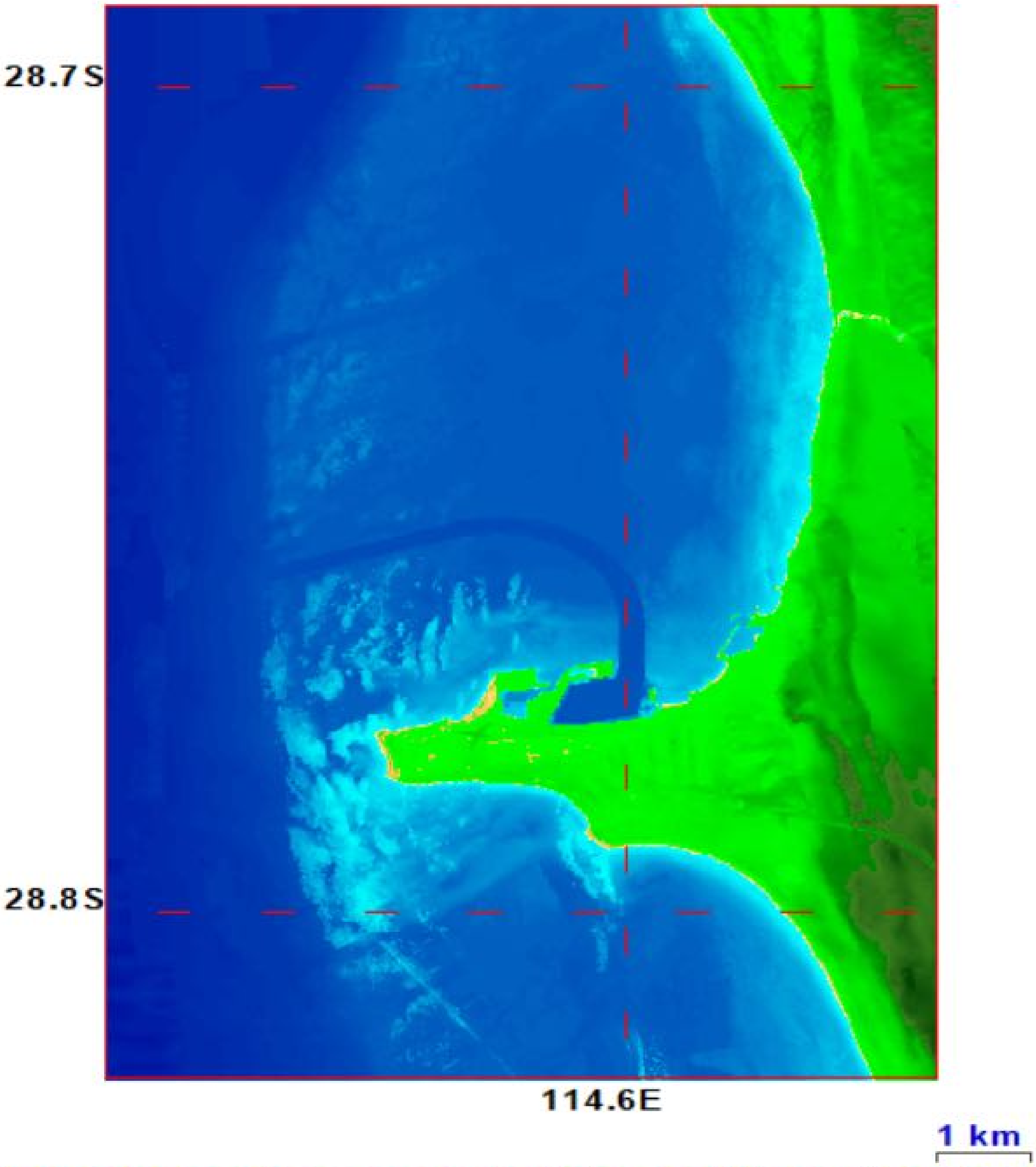


Figure 6.5 – 40m resolution grid of Geraldton and Champion Bay

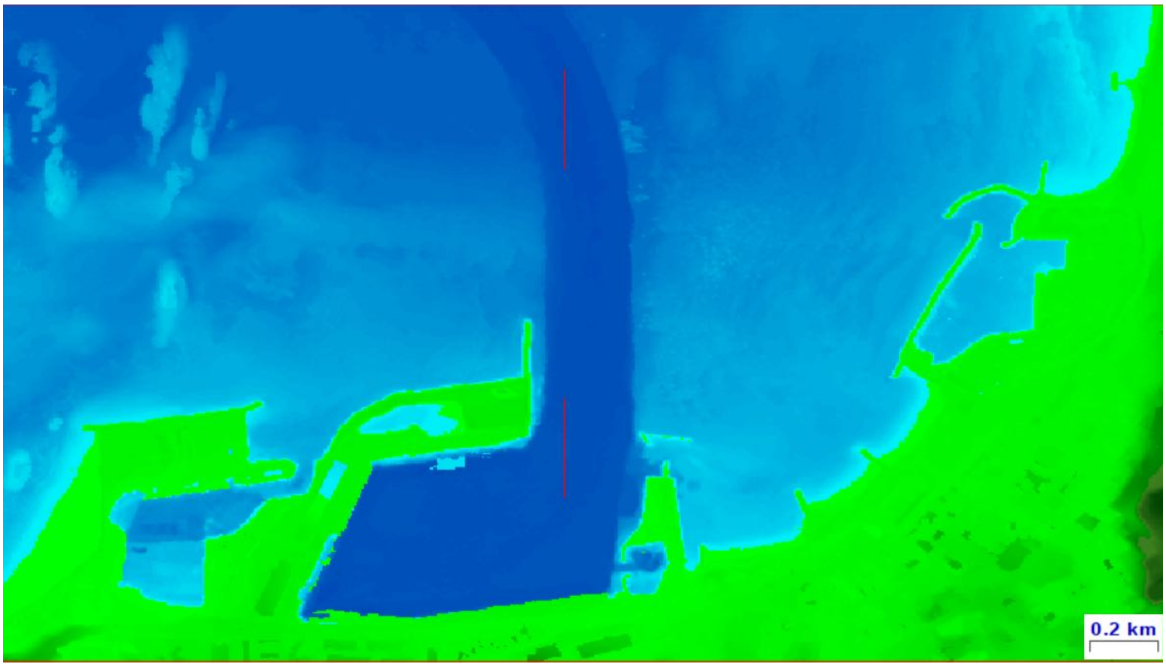


Figure 6.6 – 5m grid of Geraldton Port, boat harbour and beaches

6.4 Verification of GCOM3D

6.4.1 Sea Levels

Sea levels predicted by GCOM3D were compared with observations from the deployment of an AWAC at Beresford in 2014 (Figure 6.7). The results show very good agreement and indicate that GCOM3D is representing sea level variations accurately.

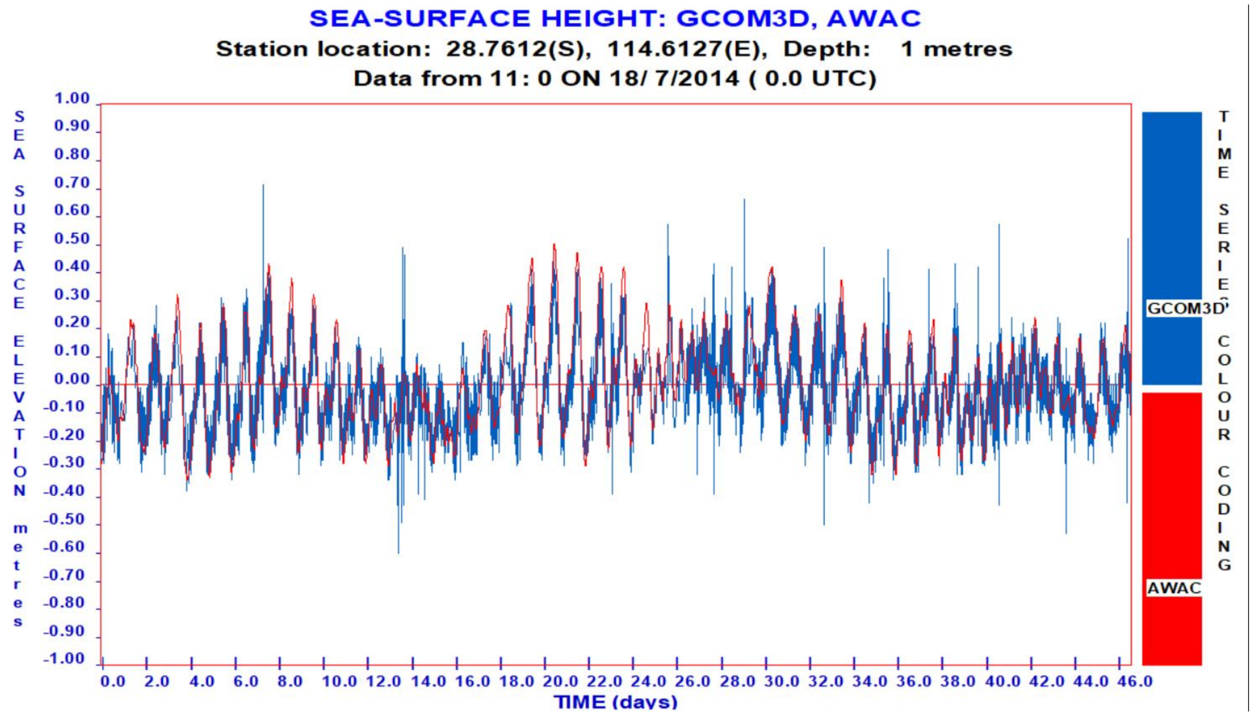


Figure 6.7 – GCOM3D sea level predictions (blue) compared with measurements at Beresford (red).

6.4.2 Currents at Beacon 1 in the Outer Channel

Surface current speeds, easterly and northerly current components predicted at Beacon 1 by GCOM3D in August and September 2014 are compared with observations in Figures 6.8 to 6.10.

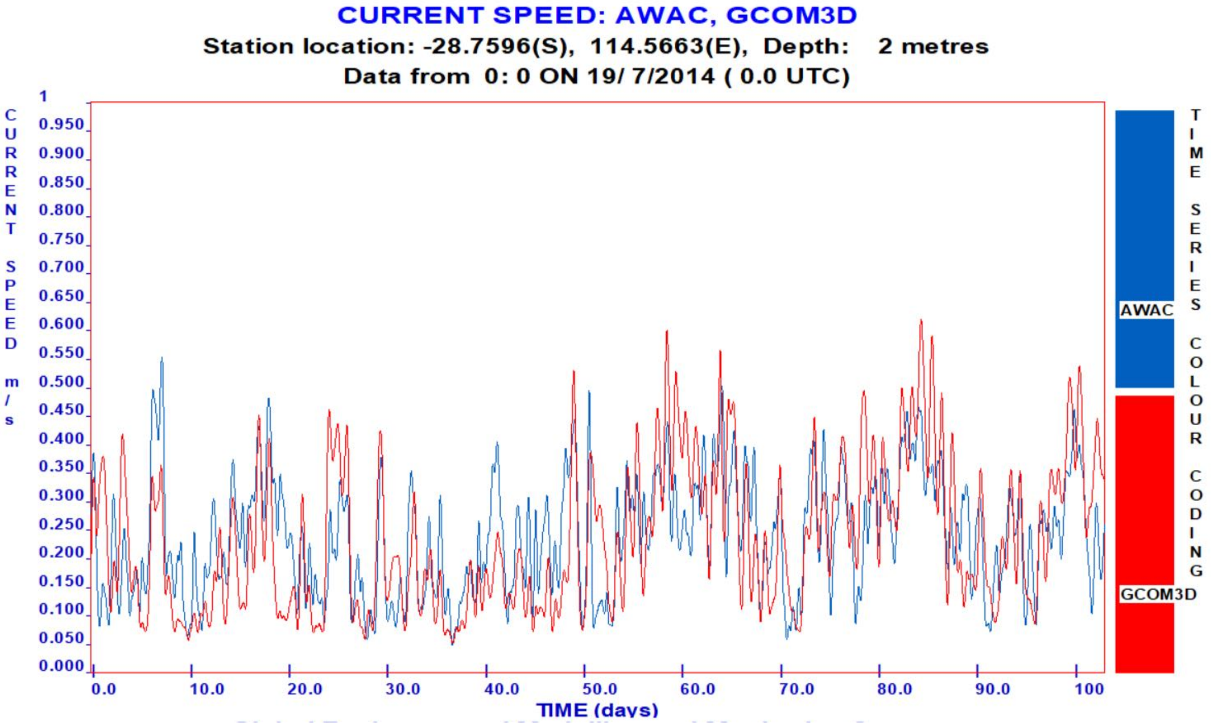


Figure 6.8 – Current speed predictions from GCOM3D (red) compared with observations from an AWAC at Beacon 1 in the outer channel (blue).

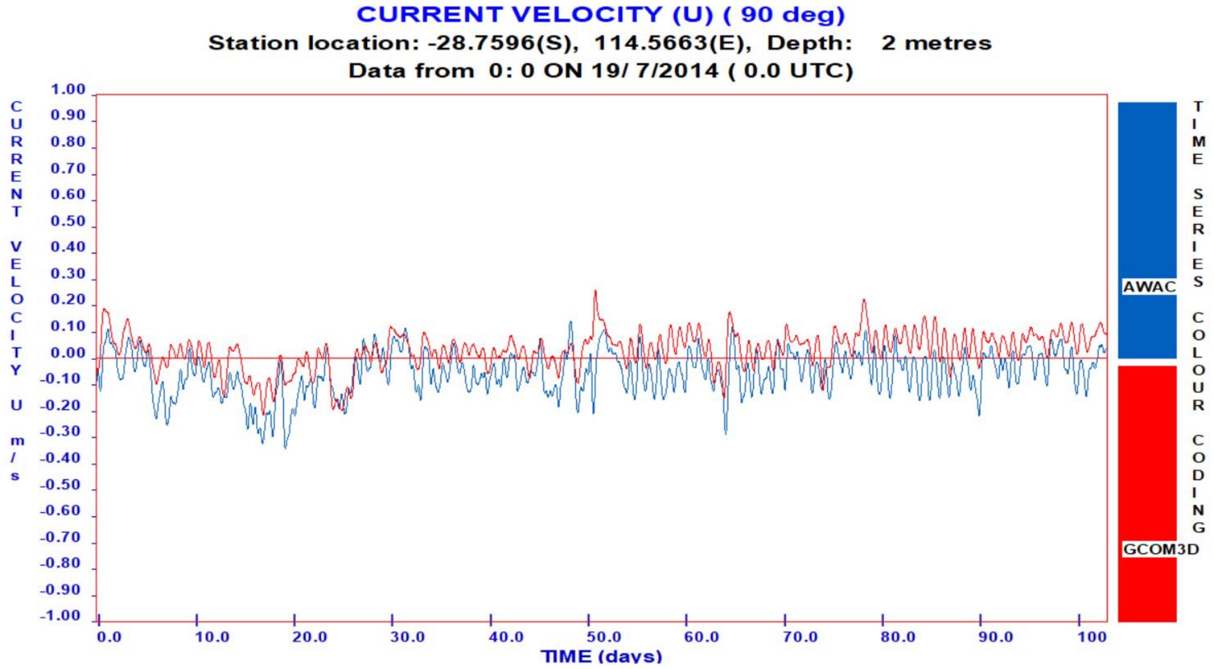


Figure 6.9 – Easterly current flow predictions from GCOM3D (red) compared with observations from an AWAC at Beacon 1 in the outer channel (blue).

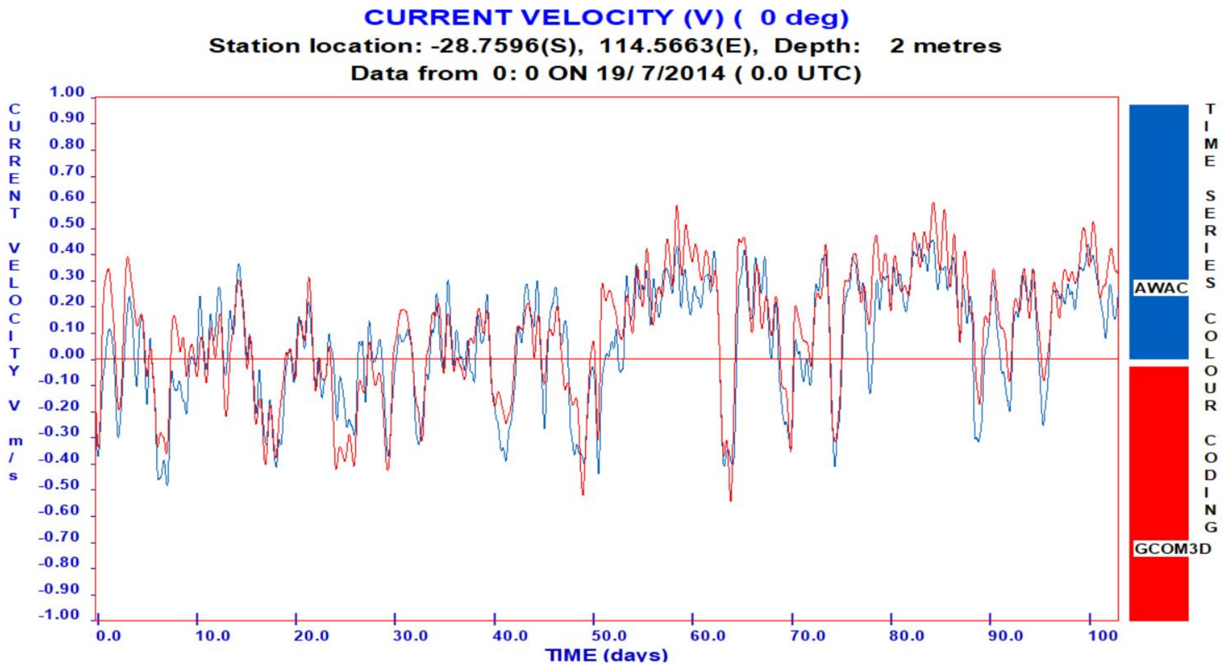


Figure 6.10 – Northerly current flow predictions from GCOM3D (red) compared with observations from an AWAC at Beacon 1 in the outer channel (blue).

6.4.3 Currents at Beresford

Surface current speeds, easterly and northerly current components predicted at Beresford by GCOM3D in August and September 2014 are compared with observations in Figures 6.11 to 6.13.

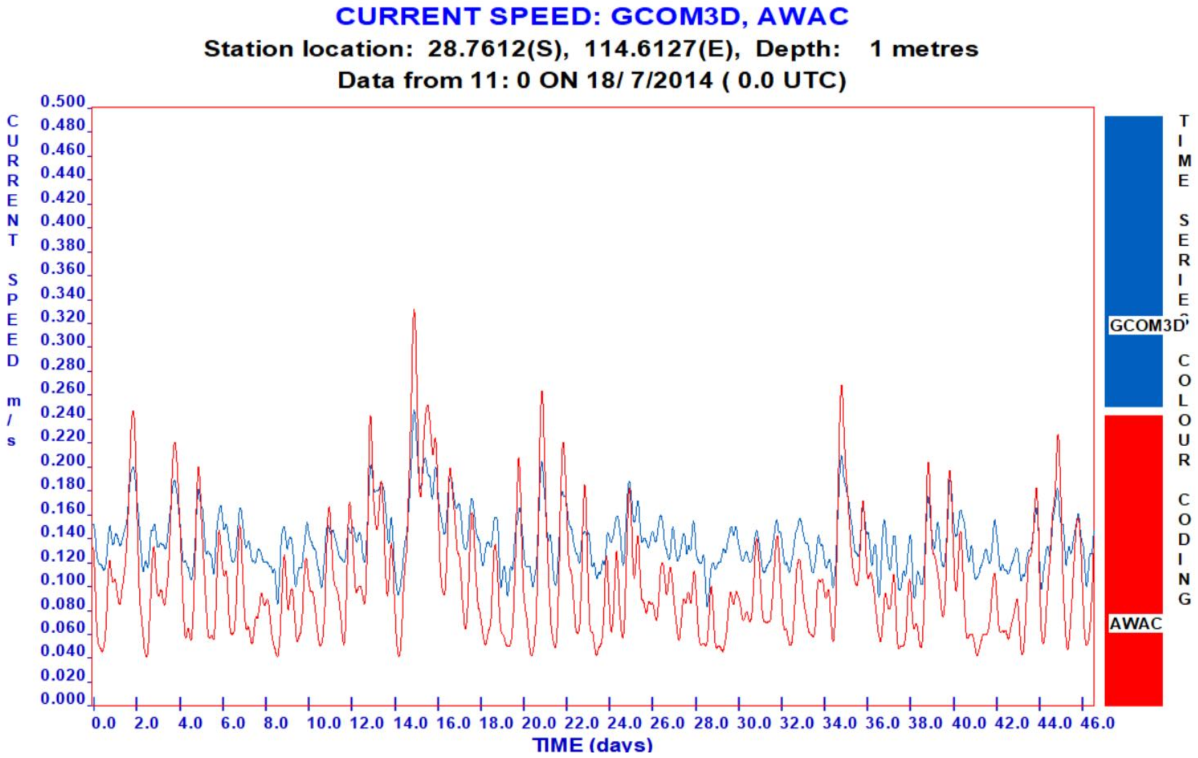


Figure 6.11 – Current speed predictions from GCOM3D (red) compared with observations from an AWAC at Beresford (blue).

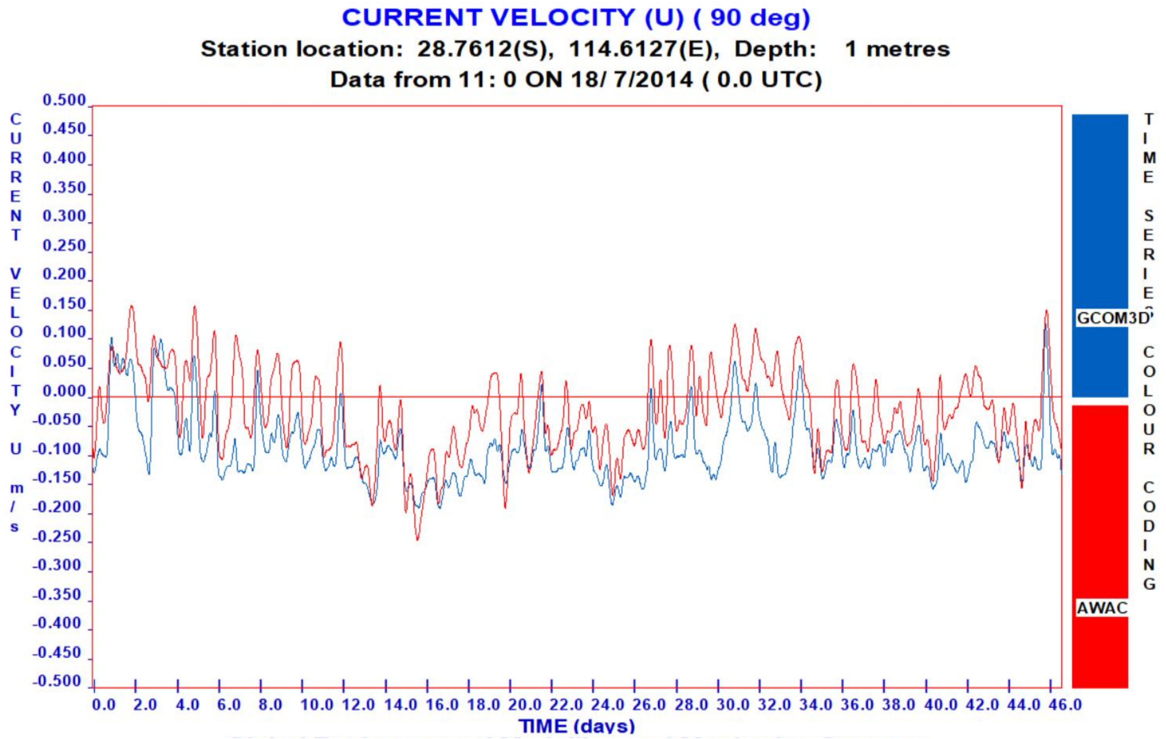


Figure 6.12 – Easterly current flow predictions from GCOM3D (red) compared with observations from an AWAC at Beresford (blue).

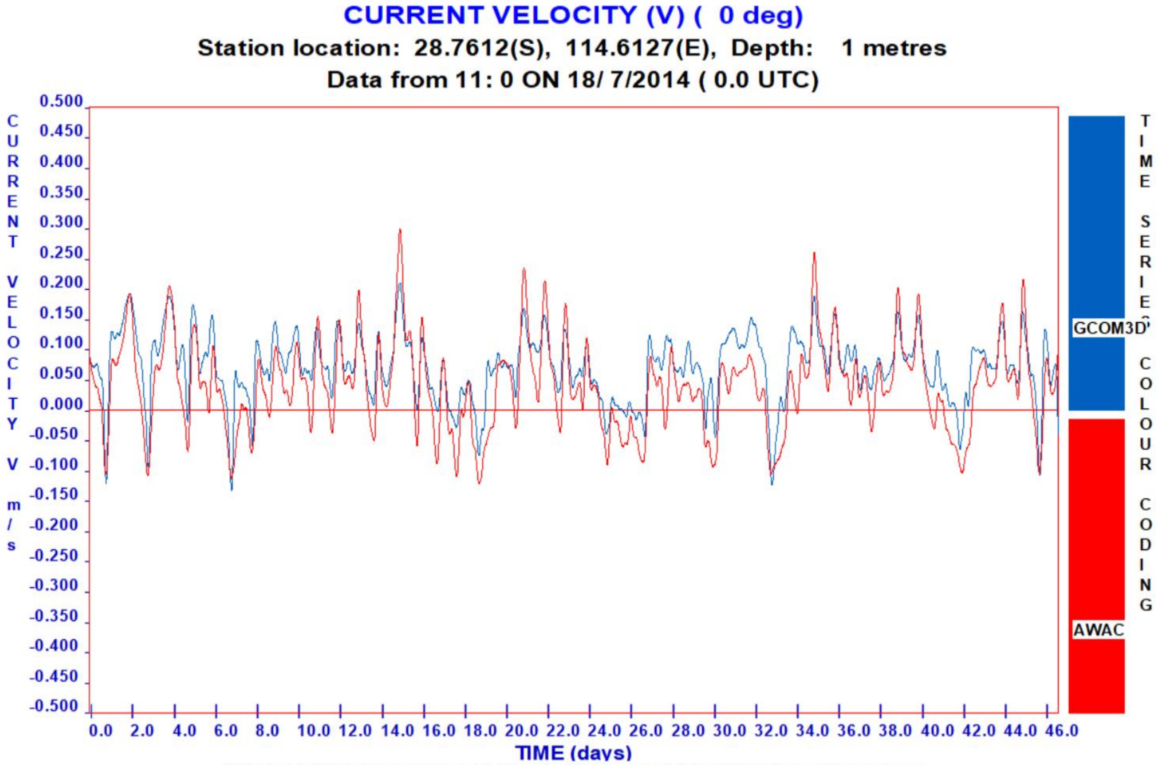


Figure 6.13 – Northerly current flow predictions from GCOM3D (red) compared with observations from an AWAC at Beresford (blue).

6.4.4 Summary

Statistical comparisons between GCOM3D predictions and observations are summarised in Table 3.

The comparisons at Beacon 1 in the outer channel are exceptionally good with both the mean current speed and the residual current speed and direction in very good agreement.

The agreement between predictions and observations for the mean current speed and the residual current direction at the inshore site at Beresford is also very good. The observed mean residual current speed is somewhat less than that predicted by GCOM3D but in that regard it is important to recognise that numerical models cannot simulate very slow currents accurately. If the actual current speed is near zero, the numerical model will always have a higher value which tends to increase the calculated mean value.

An important outcome of the model predictions and the observations is that there is a residual north-easterly current at both Beacon 1 and at Beresford. This result has significant implications for the residual movement of turbid plumes and seabed sands.

Table 3: Comparison of statistics for GCOM3D predictions with observations

Parameter	GCOM3D	Observations (AWAC)
Beacon 1		
Maximum Sea Level (m)	**1.16**	**n/a**
Minimum Sea Level (m)	**-1.16**	**n/a**
Mean Current Speed (m/s)	**0.24**	**0.24**
Mean Residual Current Speed (m/s)	**0.11**	**0.09**
Mean Residual Current Direction (deg to)	**26**	**28**
Beresford		
Maximum Sea Level (m)	**0.7**	**0.5**
Minimum Sea Level (m)	**-0.6**	**-0.4**
Mean Current Speed (m/s)	**0.13**	**0.11**
Mean Residual Current Speed (m/s)	**0.11**	**0.05**
Mean Residual Current Direction (deg to)	**53**	**56**

7 SIMULATION OF THE DREDGING

The dredge modelling is carried out in three steps:

1) Firstly, the 3D ocean circulation of the region is predicted for the full dredge program using GCOM3D,
2) Then hourly wave predictions with the SWAN wave model running on nested grids provides orbital velocities in shallow waters for resuspension calculations
3) Finally, the total dredge program is simulated using DREDGE3D, which simulates the behaviour of the dredge(s) at time steps of 3-5 minutes.

7.1 DREDGE3D

The GEMMS 3D Dredge Simulation Model (DREDGE3D) is the revolutionary dredging simulation model developed by GEMMS (for the Geraldton Port expansion project in 2003) in response to stringent demands by regulators for detailed simulations of the activities of dredges in order to provide more reliable predictions of environmental impacts.

DREDGE3D is a real-time, or hindcast, prediction system, not a scenario analysis model like most sediment transport models which are applied to dredging programs. The model aims to simulate the dredging processes and the consequent release of material into the water column as close to reality as is possible.

No other software system presently takes this detailed approach to simulating the actual activities of different types of dredges for the entire dredging program on a scale of minutes.

The model inputs the physical environmental data from GCOM3D, together with wave data from the SWAN wave model (or direct wave measurements with wave attenuation algorithms applied) to simulate the movement, deposition and resuspension of particles released into the water body across the study area.

At Geraldton in 2002/3 DREDGE3D produced turbidity predictions which compared favourably with in-situ data, aerial photographs and satellite images. Since then, DREDGE3D has been used in over 20 dredging projects in Australia and over 30 projects in other countries, mainly in the UAE.

7.1.1 Model Features

DREDGE3D is a Lagrangian particle model and does not run on a grid and consequently is independent of grid resolution.

DREDGE3D works off a "dredge log" which is put together in consultation with project engineers (and dredge contractors) to best represent the likely dredging program. The dredge log is constructed from information such as dredge types, dredging program, particle size distributions, stoppage times, time for trips to disposal sites, maintenance, refuelling, the release of fines by cutter wheels or drag heads, under keel clearance and propellor wash, and overflowing of barges and TSHDs.

DREDGE3D releases particles into the water column, as determined by the dredge log, representing the range of particle sizes (typically 50) and volume of each particle size fraction. Thereafter the particle transport is simulated and the x,y,z coordinates of each particle written out to a file each hour of the dredging program.

All sources of particles introduced to the water column can be simulated including releases from a CSD cutter head; a TSHD drag head; a Backacter bucket; barge and hopper overflow; placement area dumping; reclamation bund overflow and TSHD propeller wash.

Particles move through the water as a function of the assigned settling velocity, the ambient current speeds and a random walk dispersion algorithm

Particles which settle to the ocean bed can be resuspended if the shear stress resulting from the ambient bottom currents and orbital velocities generated by waves exceed defined thresholds which vary as a function of particle size and density.

Modelling predicts the hourly distribution of Total Suspended Solids (TSS) and seabed coverage to be developed over the total dredge program.

7.1.2 Establishment of the Dredge Log

The detailed specifications of the dredge(s), and their expected dredging program, is developed from the best understanding available at the time of the study.

The fine detail of all activities which result in the release of particles into the water column is required as input to the dredging simulations and is incorporated into a detailed "dredge log", which represents the best estimate of how the dredging program might be undertaken on a scale of minutes.

The information required to set up the simulated dredge log for the Trailer Suction Hopper (THSD) in this study included:

- Total volume of material to be dredged
- Region to be dredged
- Expected start time(s)
- Expected duration of dredging
- Particle size distributions and settling rates for all types of material to be dredged
- Full details on the equipment and method to be used which could contribute to release of particles into the ocean including Trailer Suction Hopper (TSHD), barges, overflowing of bunds, sea dumping etc.
- Draft (full and empty) of the TSHD
- Minimum under keel clearance (UKC) of the TSHD
- Daily operating schedules for the duration of the program
- Average hours per week of operation
- Maintenance schedule (repairs, refuelling etc.)
- Time of operation before overflow of THSD hopper
- Duration, depth and rate (m^3/sec) of overflow
- Whether under keel clearance is controlled or not
- No dredging periods
- Dredging rate (m3/sec)
- Hopper capacity (m^3) for overflow and no overflow conditions in terms of dry solids
- Speed of TSHD while dredging, travelling to, and returning from, the placement area
- Location and capacity of the placement area.

7.1.3 Particle Size Distributions and Settling Velocities

Because the formation of sediment plumes is largely associated with the finer fraction of material, it is necessary to understand the relative distribution of material, particularly smaller than 100 microns (1 micron = 10^{-6} m). Particle size distributions (PSD) for this study was provided by MWPA, from geotechnical coring samples taken inside the Port and along the channel at the locations shown in Figure 7.1.

DREDGE3D then selected the PSD for the sample site nearest to where the dredge was working.

Figure 7.1 – Sediment sampling locations.

Examples of the settling velocities derived for the PSDs are given in Table 1. Particle settling velocity values in Australia are often based on analyses of sediment cores by CSIRO Australia using a sedigraph. Sodium hexametaphosphate is used by CSIRO as the medium through which the measured particles fall. The data is later corrected to take into account the difference in the settling velocities in sea water.

Table 1: Settling rates of different sized particles (based on analyses by CSIRO Australia).

Size (µm)	Settling Rate (mm/sec)
5000.0	19734.4
2000.0	3157.5
1000.0	789.38
700.0	386.79
500.0	197.34
400.0	126.30
300.0	71.044
200.0	31.575
100.0	7.8938
90.0	6.3939
80.0	5.0520
70.0	3.8679
60.0	2.8418
50.0	1.9734
40.0	1.2630
30.0	0.71044
20.0	0.31575
10.0	0.07894
7.0	0.03868
5.0	0.01973
3.0	0.00710
1.0	0.00079
0.5	0.00020

7.1.4 DREDGE3D Methodology

To illustrate the detail required to carry out the dredging simulations, the procedure is typical for the simulation of dredging with the TSHD was:

1) Read the coordinates of the next location from the dredge log
2) Determine dredging action (dredging, overflowing or not, sailing to placement area, dumping or returning from the placement area)
3) If dredging
    - Read the cutting rate
    - Read the particle size distribution for this location
    - Calculate the volume to be dredged in the time step between now and the next location
    - Add this volume to the total volume count
    - Compare dredged volume with total volume to be dredged to maintain check of mass balances
    - Distribute the mass to the model particles to be released at this time step according to the particle size analysis curve for that location
    - Keep a count of the total mass distributed to each particle size
    - Determine the fate of each model particle (released at drag head, overflowed, retained in hopper)
    - Add overflow mass to total overflow mass
    - Add hopper mass to total hopper mass
4) If dumping at the placement area or pumping to the settlement pond
    - Release/pump all particles in the hopper to the designated area
    - Add dumped mass to total dumped mass
    - Check if placement area mass has exceeded placement area capacity.

All model particles released were tracked for the full duration of the dredging program (approx.. 45 days) and the XYZ coordinates written out to a binary output file every hour (eventually generating millions of model particles). At each output time step the total mass assigned to each model particle released so far was added up and compared with the total mass dredged. If they are not the same, the model stops and an error is flagged.

Note that another source of turbidity is the wash from the TSHD or barge propellers, particularly when the under keel clearance (UKC) reduces as the hopper fills. This process is simulated using empirical algorithms developed during the Dampier Port dredging program from measurements of turbidity in the vicinity of the TSHD propellers.

All these processes are reflected in the detail of the dredge log.

7.1.5 Analysis of Results

DREDGE3D stores the x,y,z coordinates of all simulated particles released into the water column, together with particle information such as volume and size, every hour for the duration of the program.

After completion of the simulation the turbidity levels are derived throughout the region of potential impact by scanning the water column from surface to bottom for the highest turbidity rather than averaging over the water column. The results therefore show the highest turbidity levels found across the region of influence.

The turbidity results are then analysed, based on exposure criteria provided by marine biologists, to produce durations of exposure to sedimentation or turbidity over all the important habitat regions. The exposure criteria are usually in the form of the time that a particular component of the marine habitat (e.g. coral or seagrass) be exposed to given levels of turbidity before stress or mortality begins to occur. The results of this analysis determine areas of potential total mortality or partial mortality and also areas which may experience turbid plumes but no mortality effects are expected (visible effects only).

Although a large amount of detail is included in the dredge simulations the results are still based on a wide range of assumptions and the proper use of the output should be to provide an indication of potential impacts from the dredging program.

A prime example of this uncertainty is the fate of fines deposited at the placement site. It cannot be assumed that all fines are instantly available for re-suspension because, in reality, some fines will be buried. Over the long term they may be stirred up by a major wave event or slowly redistribute in the spoil and so assumptions need to be made regarding this imprecise process.

8 DREDGING SIMULATIONS

8.1 Dredging Equipment and Methodology

Dredging will be completed by a trailing suction hopper dredge (TSHD), the dredge (Figure 8.1) will be equipped with a suction pipe which ends in a drag head (Figure 8.2). The drag head is lowered to the seabed and then slowly moved along the channel removing accumulated sediments by suction. The mixture of sediments and seawater will be pumped into the dredge's hopper, as the hopper starts to fill excess waters will be overflowed until the hopper reaches capacity. Once the hopper capacity is reached the dredge will sail to the designated Dredge Material Placement Area (DMPA).

The dredge size and specification is expected to be similar to the previous 2012 maintenance dredging, a small to medium sized TSHD with the following specification:

- Hopper capacity: 3,400m^3
- Length: 100m
- Breadth: 20m
- Draught loaded: 5m

Based on monitoring data collected during the 2012 maintenance dredging it is expected the hopper net capacity will be ~20% (~680m^3) prior to overflowing and ~70% (~2,380m^3) at full capacity following overflowing. Similarly, based on monitoring data collected during the 2012 maintenance dredging it is expected that an operational efficiency of 85% will be achieved, which allows for operational constrains such as weather and shipping. Based on similar conditions to 2012 an average production rate is expected to be ~170m^3/hr.

Figure 8.1 Example TSHD (image source https://products.damen.com)

Figure 8.2 Example TSHD drag head (image source https://products.damen.com

Sediments totalling ~45,000m3 will be removed within the Inner Harbour basin and berth shipping pockets. Dredged sediments from these locations will be transported to the Northern Reclamation DMPA and pumped from the dredge hopper to the DMPA via a pipeline.

As with inner harbour dredging, entrance channel sediments will be removed via trailing suction hopper dredge (TSHD). Sediments totalling ~185,000 m^3 will be removed from high spots occurring within the entrance channel as presented. Dredged sediments from the entrance channel will be transported to the Nearshore DMPA. Figure 8.3 illustrates the regions to be dredged.

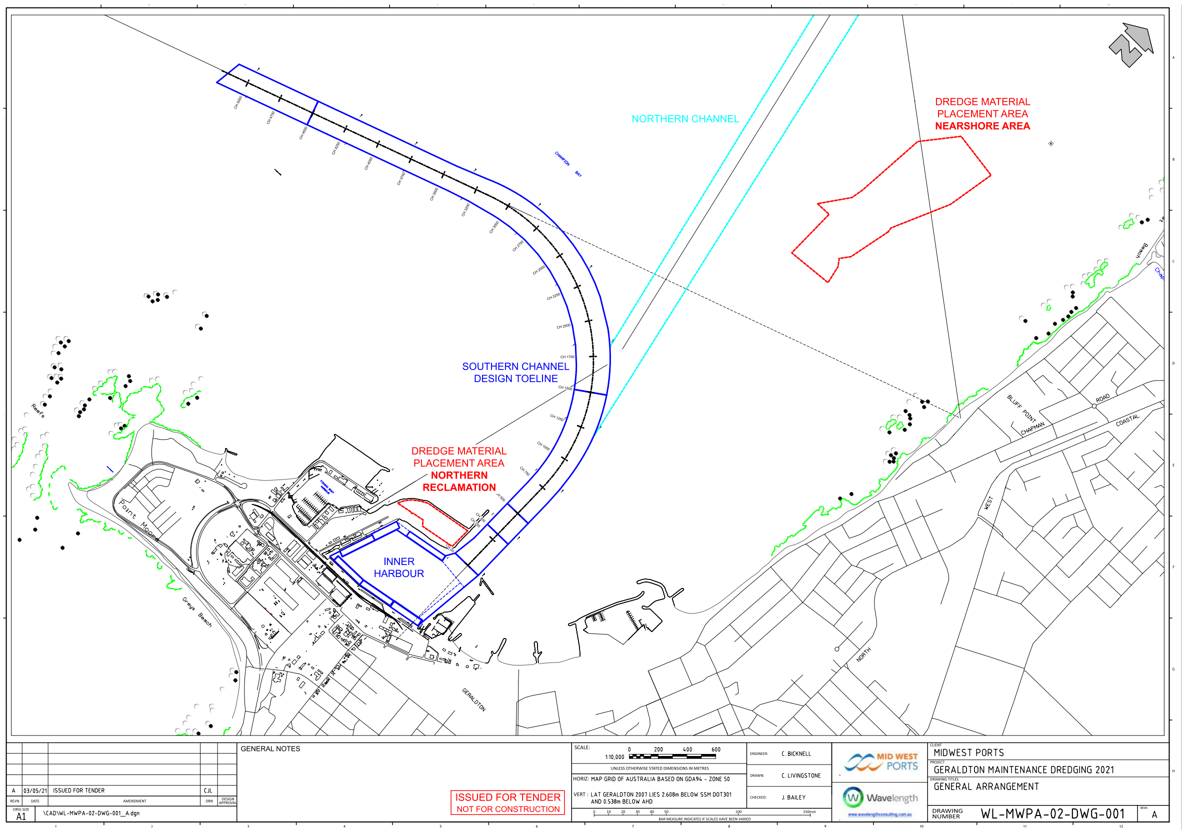


Figure 8.3 Example TSHD drag head (image source https://products.damen.com)

Inner harbour and channel dredging will be undertaken concurrently. It has been assumed that one of every four dredge runs will be undertaken within the Inner Harbour and pumped to the Northern Reclamation DMPA. This will equate to only one to two hopper loads from within the inner harbour in a 24hr period.

Similarly, it is assumed that three in every four dredge loads will be from the channel, while the inner harbour is being completed then all loads will be from the channel. This will equate to 3-4 loads and then 4-5loads in a 24 hour period.

The following cycle times have been assumed based on consultation with potential dredging contractors and review of monitoring data collected during the previous maintenance dredging in 2012:

- average sailing speed: 8knts
- average time to fill hopper (no overflow): 1hr
- average time to fill hopper (overflow): 5hr
- discharge time (using hopper doors): 0.5hr
- discharge time (using pipeline): 2hr
- operability: 85%

These assumptions indicate that the cycle time between successive discharges at the placement area will be approximately 6-7 hours, depending on the location being dredged.

8.2 Inputs to DREDGE3D

The entire dredging program was simulated by DREDGE3D using the proposed dredging equipment and methodology described above.

The key inputs to DREDGE3D were:

- The start time of the dredging, which was assumed to be 1 September 2017
- 3D currents and sea levels from the ocean modelling with HYCOM and GCOM3D
- Wave induced currents and orbital velocities from the SWAN wave model
- Volume distributions and particle size analyses provided in the port area and out along the channel
- Information embodied in the “dredge log” and outlined in section 7.1.2

8.3 Analysis of the Fate of Dredged Particles

Dredged particles released into the water column will settle as a function of their settling velocity and the forces on the particles from the waves and currents.

The lighter particles may persist in the water column for some time, contributing to Total Suspended Solids (TSS) plumes, whereas the heavy particles will tend to reach the seabed and, depending on their particle size and the environmental conditions, remain on the seabed or be resuspended and move on to another location.

The analysis method described in section 7.1.5 was applied to the hourly output files from DREDGE3D to derive TSS and sedimentation resulting from the dredging.

It is standard in dredging programs to identify regions where TSS plumes or sedimentation have any of the following outcomes:

1) Zone of total mortality (ZOTM) – self explanatory
2) Zone of moderate impact (ZOMI) – some, but not total mortality
3) Zone of Influence (ZOI) – negligible mortality but visible outcomes

The criteria for determining these zones were provided by marine biologists.

The dominant location for sedimentation results from the disposal of dredged material at the Placement Area (Figure 8.4) however particles may move on from the Placement Area over time due to wave and current events.

Due to the overflowing of the dredge hopper some sedimentation occurs at the dredging sites, but these are excluded from the analysis because it is assumed that any such particles will be extracted during subsequent dredging activities.

The analysis of TSS predominantly relates to the 45-day dredging period as it is unlikely that TSS plumes will persist at detectable levels for any significant period beyond the cessation of the dredging.

The analysis of the sedimentation resulting from the dredging activities however was carried out over a 2-year period to investigate the long-term fate of particles initially deposited on the Placement Area and then resuspended (e.g. during storm events) and transported to other locations.

Three specific tasks were defined regarding sedimentation:

1) What will be the fate of material dredged from the shipping channel after it is deposited in the Placement Area?
2) Will sedimentation produce any adverse effects on the marine environment?
3) What would have been the fate of the sediments that have built up in the shipping channel if the channel was not there?

To investigate questions (1) and (2) the movement of sediments from the Placement Area was simulated over a 24-month period with the sediment transport module of DREDGE3D driven by meteorological data from the ECMWF ERA5 reanalysed forecasts, the SWAN wave model and the GEMMS 3D baroclinic ocean model (GCOM3D)

To investigate question (3) the fate of sediments placed along the alignment of the shipping channel was simulated over a 24-month period using bathymetry from which the channel has been removed (also with DREDGE3D, SWAN, GCOM3D and ECMWF meteorology).

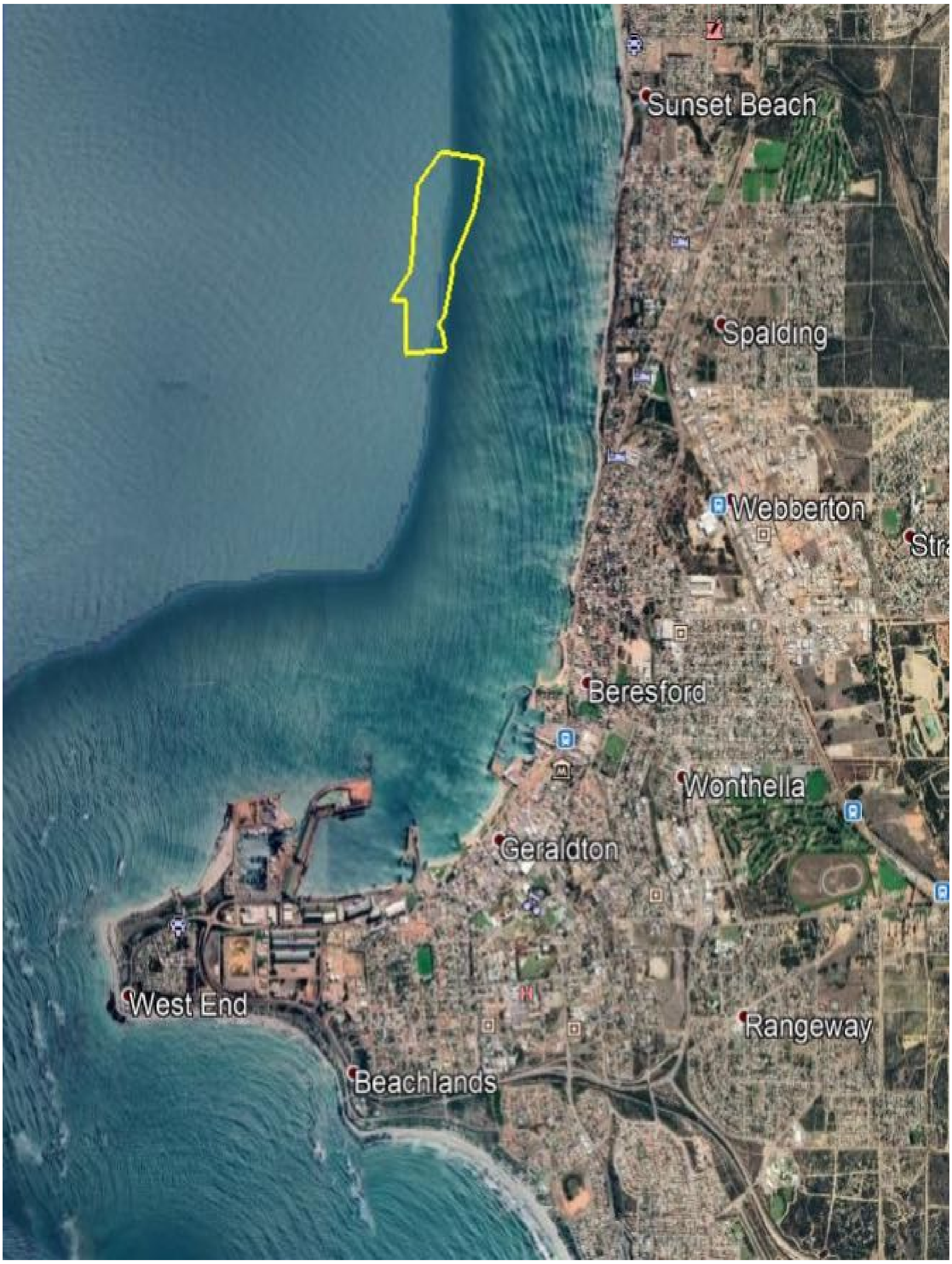


Figure 8.4 Proposed Nearshore Placement Area

8.3.1 TSS Derived from Dredging of the Harbour Region

An initial assessment of the TSS levels resulting from the dredging of the port area was undertaken to investigate whether the allowance for the dredge to overflow while filling the hopper was likely to cause impact concerns outside the harbour region and particularly along the shoreline.

Figure 8.5 indicates the maximum TSS levels occurring for at least one hour from material released into the water column by the dredging of the port area. Note that TSS levels significantly above 20 mg/litre occurred in the port region but these levels dissipated rapidly as turbid plumes moved out of the port region.

The results indicate that the regions outside the harbour are unlikely to experience significant TSS levels.

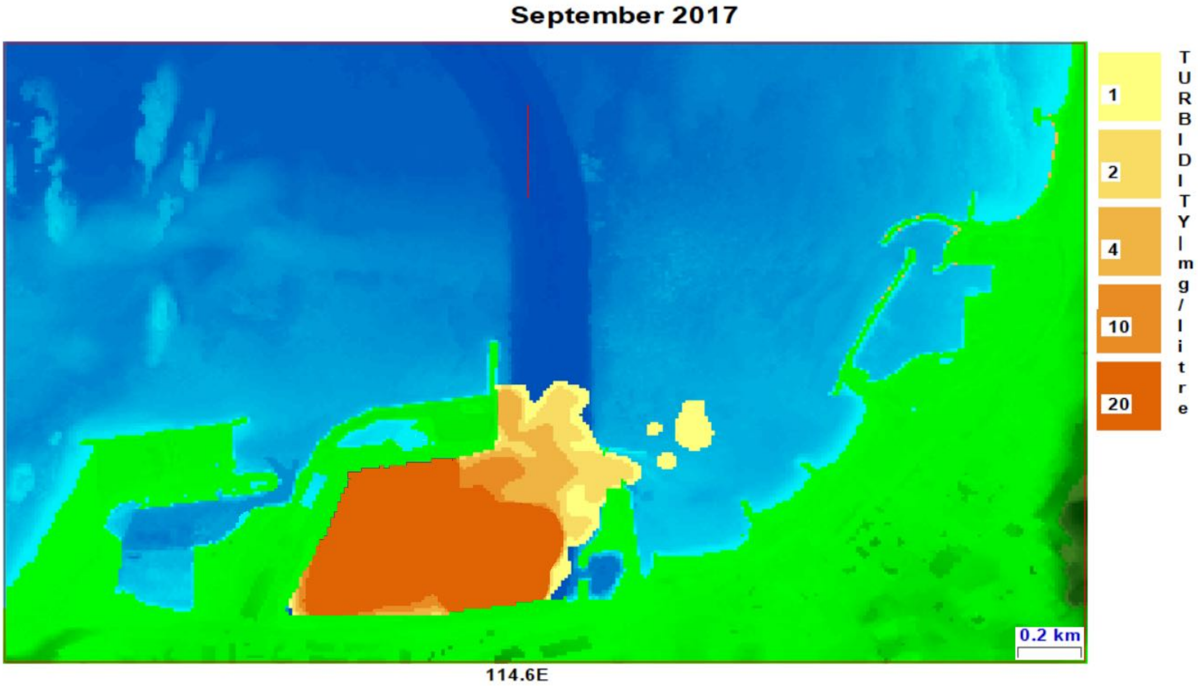


Figure 8.5 Maximum TSS values from Port Dredging Activities with Overflow

8.3.2 Light Attenuation Due to the Dredging Program

The main impact of TSS plumes from dredging is to attenuate the light reaching marine flora, expressed in terms of Photosynthetically Available Radiation (PAR – watts/m^2).

The advice provided for this study was to determine the number of hours that PAR levels of 45 were exceeded across Champion Bay during the 45-day dredging program. From these data, it is understood that marine biologists will be able to determine the ZOI, ZOMI and ZOTM regions.

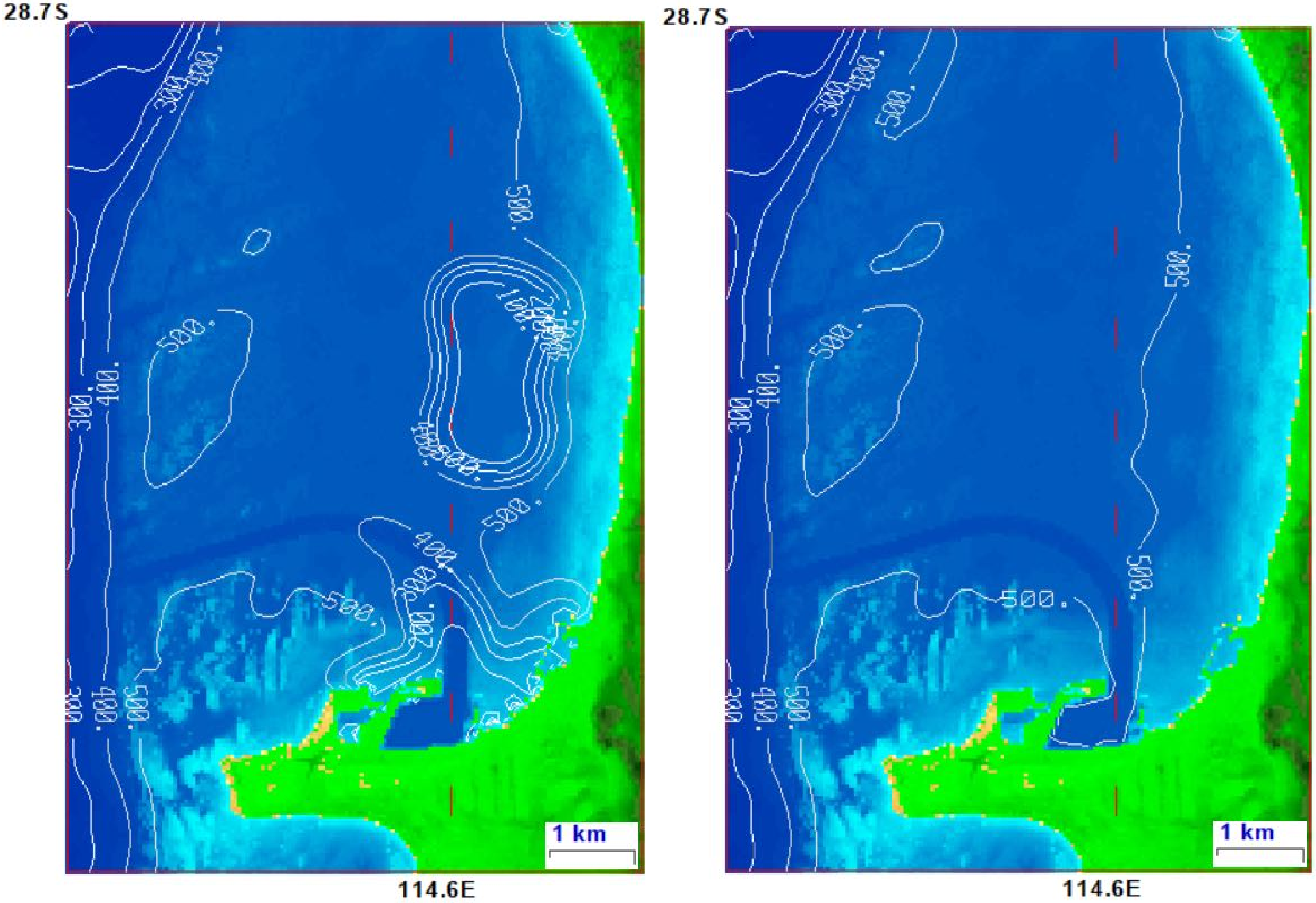
In order to produce these results special software was written to take into account the TSS levels, the water depth and light attenuation coefficients as a function of depth. Unfortunately, there is not a linear relationship between light attenuation and TSS because a given TSS level can consist of varying particle sizes and the larger the constituent particle sizes, the more light is able to penetrate.

A very conservative approach was selected to overcome this problem by adopting light attenuation coefficients, as a function of depth, determined from the Geraldton capital dredging program in 2002/3. This dredging program produced very fine suspended particles from the action of a cutter suction dredge's teeth on hard calcarenite. The suspended material produced from the proposed dredging program will be considerably coarser and hence light reaching the seabed will in fact be significantly greater than predicted.

The number of hours above a PAR level of 45 are plotted in Figure 8.6 (a). By comparison, Figure 8.6 (b) shows the number of hours above a PAR level of 45 in ambient conditions. The data underlying Figure 8.6 was provided to the marine biologists for further analysis.

When interpreting the results in Figure 8.6 it is important to note that:

- The plots show the number of hours that a PAR level of 45 was exceeded, indicating that sufficient light was reaching the sea bed for that number of hours.
- The total number of daylight hours during the 45 days of dredging was just over 500, hence the regions indicated as above the 500 hours contour are obtaining PAR levels above 45 for most of the available daylight hours
- The surface irradiance from the sun varies significantly from dawn to dusk due to the angle of the sun, Hence, in some areas, PAR levels may be below 45 near to dawn or dusk but above 45 for the remainder of the day.
- The regions with the least number of hours above a PAR level of 45, as a result of dredging, occur in the Port area and over the placement area
- There are no areas which do not experience any exposure to PAR levels above 45. This is due to the episodic nature of the exposure to plumes - plumes occur during dredging and overflowing and then dissipate whilst the TSHD sails to the placement area, deposits the spoil and then sails back. Plumes at the placement area are similarly episodic as they only occur when the dredge is depositing material (approximately every 7 hours).



(a) (b) (c)

igure 8.6 **Number of hours above PAR of 45 – (a) tss, (b) ambient**

8.3.3 Long Term Fate of Sediments Deposited in the Placement Area

The average depth of sediments over the placement area after completion of dredging can be calculated as follows:

- The approximate area of placement area = 530,000 m2
- The approximate amount of material disposed at placement area = 186,000 m3
- The approximate average thickness of spoil covering is therefore = 35cm

Of course, in reality, the spread of sediments at the Placement Area will not be even, however it is noted that the contract for dredging sets a limiting height of 1 metre of material deposited in the Placement Area.

Each model particle (of which there were several million) which ended up in the Placement Area carried with it an associated volume, particle size and settling rate. The simulation of the fate of these particles continued on, past the cessation of dredging, for another 2 years to investigate where material went and whether any significant deposits of sediments occurred.

The results are summarised in Figure 8.7 which shows locations where particles from the Placement Area generated sedimentation thicker than 0.5cm, 2cm and 5cm.

The image showing sedimentation thicker than 0.5cm gives an indication of the overall destinations of particles whereas the image showing sedimentation thicker than 5cm suggests that significant deposits did not move very far from the Placement Area and tended to be found along the coast from Sunset Beach to Glenfield.

8.3.4 Sediment Zones of Impact

The analysis criteria provided by the marine biologists for assessing the environmental outcomes of sedimentation were:

1) Zone of Influence: areas where the accumulation of sediment is >4cm for >6 consecutive weeks
2) Zone of Moderate Impact: areas where the accumulation of sediment >15cm for >8 consecutive weeks
3) Zone of Total Mortality: considered to be impossible outside the dredging footprint and the placement area

Figure 8.8 shows the regions identified as satisfying the ZOI and ZOMI criteria. In both cases the Placement Area is identified but of course it also satisfies the ZOTM criteria.

The other region identified by the ZOI and ZOMI criteria is the nearshore region along the coast from Sunset Beach to Glenfield. Given that DREDGE3D does not have beach processes in the code it is reasonable to assume that much of this material will interact with the shoreline over time.

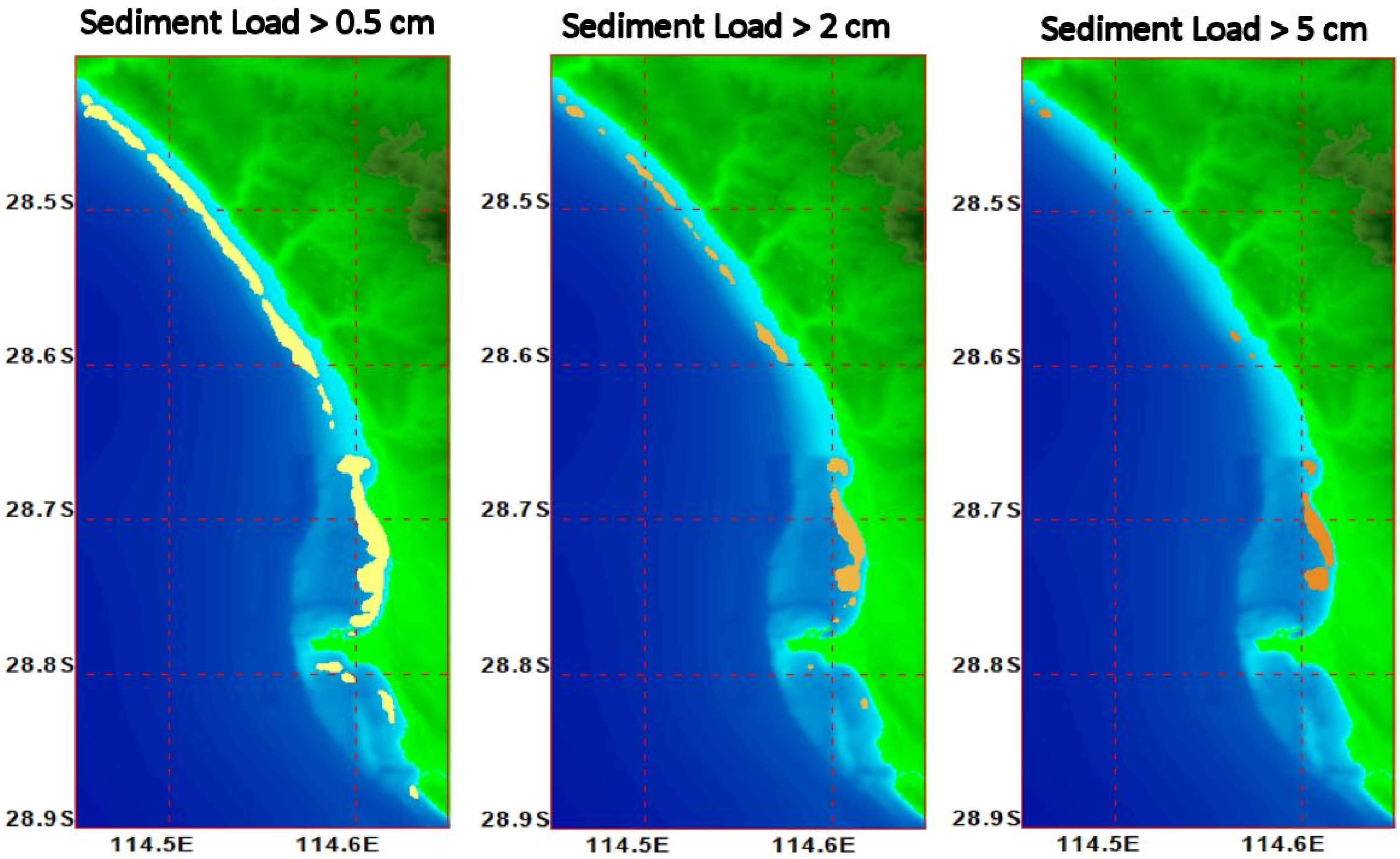


Figure 8.7 – Sediment distribution from Placement Area > 0.5 cm, 2cm and 5cm after 2 years

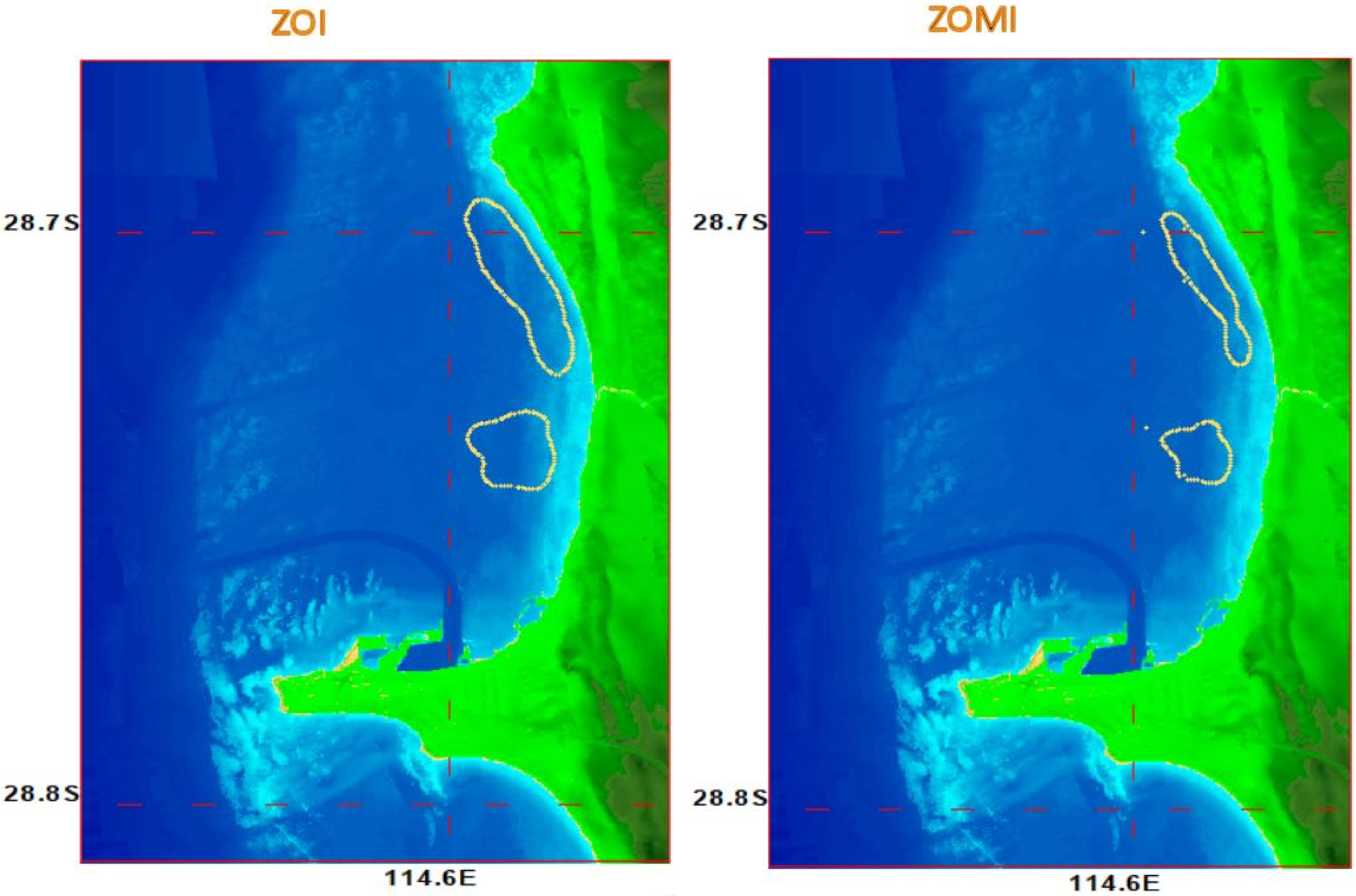


Figure 8.8 Zones of Influence (ZOI) and of Moderate Impact (ZOMI)

8.4 Fate of Sediments if the shipping channel was not present

The purpose of this investigation was to gain some understanding of the long-term impact of the existence of the shipping channel and whether it has resulted in less availability of sediments to the beaches north of Geraldton Port. For this study, the bathymetry was reconstructed to fill in the shipping channels as shown in Figure 8.9.

The methodology needs to be considered carefully if comparisons are to be made with the results of the dredging program for the following reasons:

- The dredging program will extract approximately 185,000 m^3 from the shipping channel over a period of 45 days and deposit the material at the Placement Area providing a nearshore source of sediments
- The channel was last dredged in 2012 and so it could be argued that the amount of material captured by the channel every year has been approximately 20,000m^3.
- To provide a comparative study the two scenarios would need to be simulated for nine years which was beyond the scope of this study
- The two scenarios were simulated for two years and the results analysed in terms of percentages, and not volumes, to provide comparability.

Figure 8.10 shows regions where seabed sediments > 1cm deep from the no-channel scenario were found at any time during the first 2 years (even if sediments were resuspended and moved on). The purpose of this image is purely to indicate pathways taken by mobile sediments coming around Point Moore or from deeper waters. Table 4 compares the fates of sediments in the two scenarios over the two-year period.

Table 4 - The Fate of Sediments from the Placement Area and the No-Channel Scenario

Elapsed Time (months)	% sediments outside domain from the Placement Area	% sediments outside domain for the no-channel scenario	% sediments found near the shoreline from the Placement Area	% sediments found near the shoreline from the no-channel scenario
3	4.0	5.0	6.7	2.8
6	4.6	6.5	8.7	5.5
12	7.1	8.8	7.0	5.0
24	9.8	9.5	6.2	4.5

The conclusion from these results is that, provided that material from maintenance dredging is deposited at a nearshore site, more of the material is available for beach nourishment than if the shipping channel was not in existence. However, it needs to be noted that we are comparing a continuous process with a process that only occurs every 9 or 10 years.

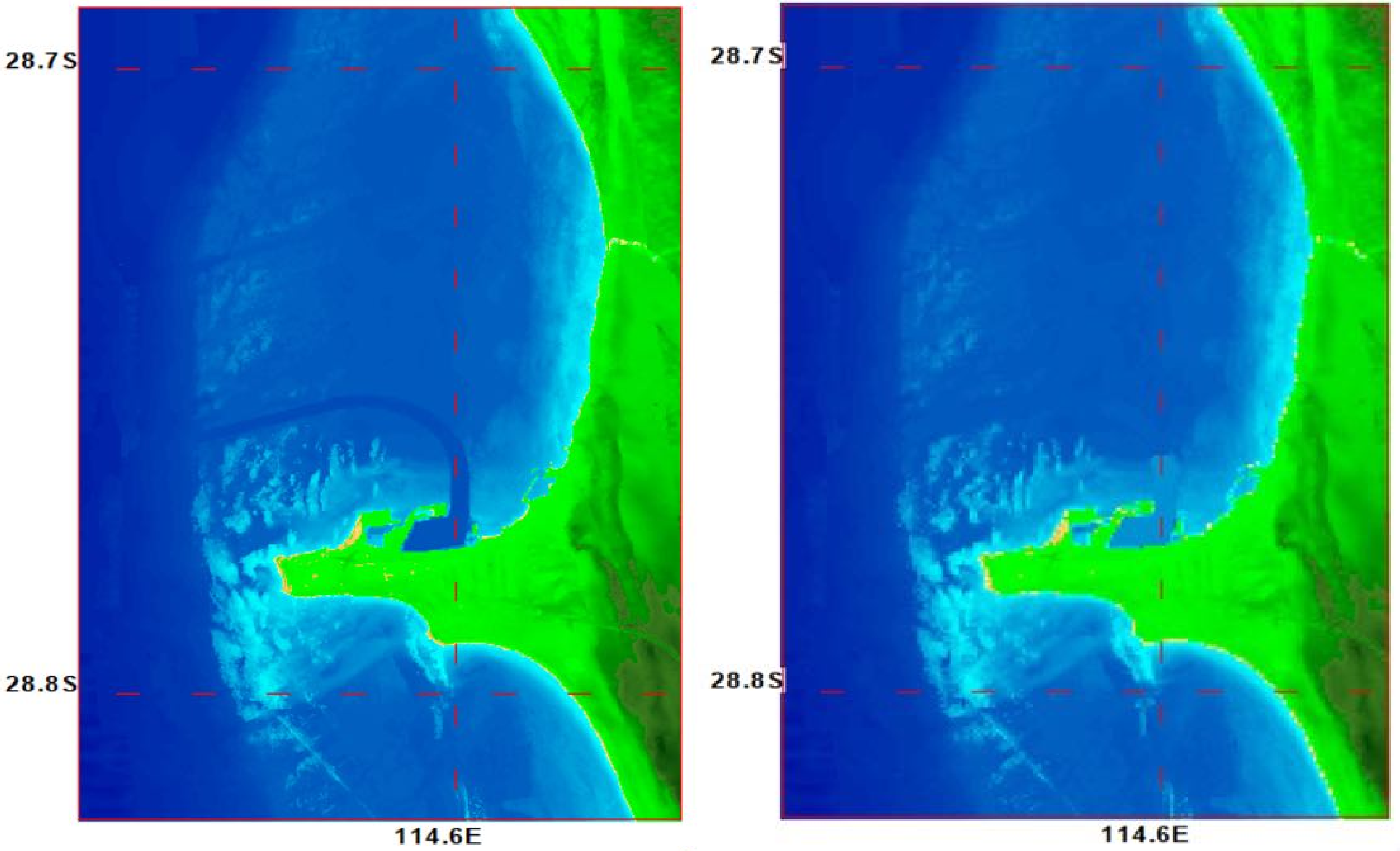


Figure 8.9 **Bathymetry with and without the Shipping Channel**

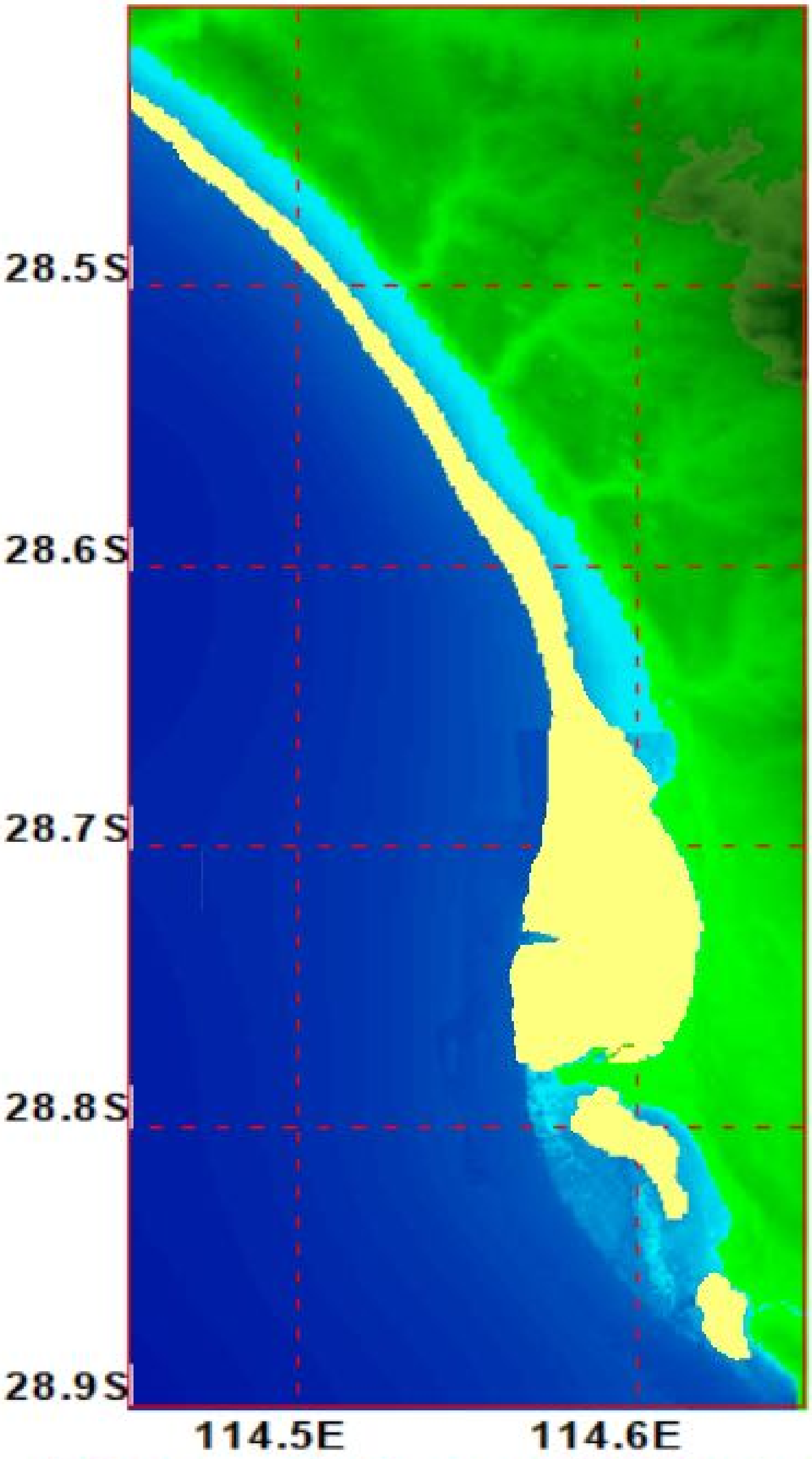


Figure 8.10 Sediment coverage > 1cm at ANY time during the first 2 years with no channel

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APPENDIX A: DESCRIPTION OF GCOM3D

For studies of hydrodynamic circulation and sea level variation under ambient and extreme weather conditions, GEMMS has developed the GEMMS 3-D Coastal Ocean Model (GCOM3D). GCOM3D is an advanced, fully three-dimensional, ocean-circulation model that determines horizontal and vertical hydrodynamic circulation due to wind stress, atmospheric pressure gradients, astronomical tides, quadratic bottom friction and ocean thermal structure. The system will run on Windows/NT or UNIX platforms. GCOM3D is fully functional anywhere in the world using tidal constituent and bathymetric data derived from global, regional and local databases.

GCOM3D has never been fully published. Some details appear in publications (Hubbert 1991, 1993, 1999). Further information is given below.

A.1 History and Physics

The history of development of GCOM3D began in 1982, initially stimulated by the 3D model development by Lendertsee (1973) who applied a “z” co-ordinate 3D barotropic model to a number of coastal engineering tasks in the 1970’s.

The publication of what was the predecessor to the Princeton Ocean Model in 1987 by Blumberg and Mellor (1987) raised the standard of 3D ocean modelling by incorporating the vertical mixing schemes then used in atmospheric modelling into an ocean model for the first time.

GCOM3D was the first “z” coordinate ocean model to incorporate the Mellor-Yamada (1974, 1982) vertical mixing scheme and was first used for consulting purposes in 1984 for the Geelong ocean outfall study near Barwon Heads in Victoria.

GCOM3D is a fully baroclinic ocean model but is most often run in barotropic (hydrodynamic) mode due to either the lack of data on ocean thermal structure or the dominance of winds and tides as the major forcing factors.

A.2 General Description

GCOM3D is a fully three-dimensional, ocean-circulation model that determines horizontal and vertical circulation due to wind stress, atmospheric pressure gradients, astronomical tides, quadratic bottom friction and ocean thermal structure.

The system will run on Windows or UNIX platforms

GCOM3D is formulated as a re-locatable model which can be applied anywhere in the world using tidal constituent and bathymetric data derived from global and local databases.

The three-dimensional structure of the model domain, tidal conditions at the open boundaries, thermodynamics and wind forcing are defined for each model application by extraction of data stored in gridded databases covering a wider geographical area of interest.

The model scale is freely adjustable, and nesting to any number of levels is supported in order to suit the oceanographic complexity of a study area.

As the model is fully three-dimensional, output can include current data at any or all levels in the water column.

A.3 Horizontal and Vertical Structure

The model operates on a regular grid (in the x and y directions) and uses a z-coordinate vertical-layering scheme. That is, the depth structure is modelled using a varying number of layers, depending on the depth of water, and each layer has a constant thickness over the horizontal plane.

The horizontal resolution and the vertical layer depths and thickness can be varied according to the situation to be modeled and the ocean physics which needs to be represented.

The vertical scheme decouples surface wind stress and seabed friction and avoids the bias of current predictions for a particular layer caused by averaging of currents over varying depths, as used in sigma co-ordinate and “depth-averaged” model schemes.

In the upper water column levels are typically a few metres apart, increasing to several hundred metres in deep waters.

A.4 Numerical Procedures

The basic equations are solved using a split-explicit finite-difference scheme on an Arakawa-C grid (Mesinger and Arakawa, 1976) as described in Hubbert et al. (1990). The continuity equation and the gravity wave and Coriolis terms in the momentum equations are solved on the shortest time step, (the adjustment step) using the forward-backward method.

The non-linear advective terms are solved on an intermediate advective time step using the two-time-level method of Miller and Pearce (1974). Finally, on the longest time step, the so-called physics step, the surface wind stress, bottom friction stress and atmospheric pressure terms are solved using a backward-implicit method. This approach is extremely efficient in oceanographic models with free surfaces because of the large disparity between advective speeds and gravity-wave phase speeds in deep water.

The numerical scheme used for the advective step is the two-time-level method of Miller and Pearce (1974). This scheme alternates the Euler and Euler-backward (Matsuno) schemes at odd and even advective time-steps and has the major advantage of an amplification factor of almost exactly unity for the Courant numbers that are found in ocean models (Hubbert et al. 1991).

The adjustment and advective integration cycle is carried out N times to produce an interim solution which is completed with the inclusion of the physics terms using a numerical technique similar to that described for the adjustment step.

A.5 Boundary Conditions

Boundary conditions can be applied in a range of ways depending on the type of process being modelled.

Meteorological forcing is applied via the wind stress and surface pressure gradient at all submerged model grid-points in the computational domain. The surface drag co-efficient used when calculating the wind stress is based on Smith and Banke (1975).

Tidal and meteorological forcing at lateral boundaries is achieved by specifying the incremental displacement of the water surface due to changes in tidal height and atmospheric pressure. These boundary conditions are applied using a 'one-way nesting' technique to the appropriate model variable with a logarithmic decreasing intensity from the boundary to some specified number of model grid-points (typically 10-15) into the domain.

At coastal boundaries and along river banks, the wetting and drying of grid cells is accomplished via the inundation algorithm published in Hubbert and McInnes (1999a and b).

On outflow, a radiation boundary condition, as described in Miller and Thorpe (1981) is applied to the velocity field to prevent the buildup of numerical energy, while on inflow boundaries, a zero-gradient condition is applied.

A.6 Tidal Data Assimilation

In order to improve the simulation of tidal forced dynamics the model includes the facility to "nudge" the solution with tidal height predictions at locations within the model domain.

The nudging method is based on deriving a new solution at grid points near each tidal station from a weighted combination of the model solution and the station sea level prediction.

A.7 Model Applications

GCOM3D has undergone exhaustive evaluation and verification in the 15 years it has served the coastal engineering industry in Australia and has a proven record of accurately predicting the wind and tidal driven ocean currents around the Australian continental shelf (and in many other parts of the world).

The Australian National Search and Rescue system is based on ocean currents from GCOM3D, which has been running in real-time at the Australian Maritime Safety Authority in Canberra for the past 4 years. It is the first real-time ocean prediction model in Australia.

The U.S. Navy also purchased GCOM3D for its coastal ocean forecasting system.

GCOM3D has also been used in a wide range of ocean environmental studies including prediction of the fate of oil spills, sediments, hydrotest chemicals, drill cuttings, produced formation water and cooling waters as well as in other coastal ocean modelling studies such as storm surges and search and rescue.

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APPENDIX B: SELECTED LIST OF DREDGING PROJECTS

Client	Location	Year
Geraldton Port Authority	Geraldton	2002-2004
Albany Port Authority	Albany	2005-2008, 2012
Fremantle Port Authority	Fremantle Inner Harbour	2007
Chevron (Gorgon)	Barrow Island	2005-2008
Dampier Port Authority	Onslow	2012
BHP	Port Hedland, Nelson Point (RGP6)	2008
BHP	Port Hedland, Harriet Point (RGP5)	2008
BHP	Port Hedland, Qantum	2009
Coastal Engineering Solutions	Corner Inlet (Victoria)	2010
RioTinto	Cape Lambert Port B	2008-2009
RioTinto	Cape Lambert CLU80 Port Expansion	2006 - 2007
Sino Iron	Cape Preston	2008
Abu Dhabi Gas Industries	Das Island (UAE)	2007
Woodside	Scott Reef	2007
ADOC	Hail Island (UAE)	2014-2017
GASCO	Ruwais (UAE) reclamation	2007
Woods Baggot	Jubail Island (UAE)	2017
Jazan Economic City	Jazan (Saudi Arabia)	2017
Abu Dhabi Ladies Club	Abu Dhabi (UAE)	2016
Abu Dhabi Emirate	Sir Baniyas Island (UAE)	2015
Takreer	Ruwais(UAE)	2009, 2013
DOME Oilfield Services	Ghurab Island (UAE)	2013
DOME Oilfield Services	Al Gurm (UAE)	2006
EXSYM	Abu Dhabi (UAE)	2007
DOPA, UAE	Al Yasat al Sufla Island (UAE)	2014
ADMA-OPCO	Sarb Artificial Islands (UAE)	2012
ZADCO	Zirku Island (UAE)	2010
City Pacific	Townsville Ocean Terminal (Qld)	2008
Port Hinchinbrook	Port Hinchinbrook Marina (Qld)	2008
Exxon	Caution Bay (PNG)	2008
Bunbury Port Authority	Bunbury	2009

APPENDIX C: VERIFICATION OF DREDGE3D

C.1 Field Measurements at Cape Lambert

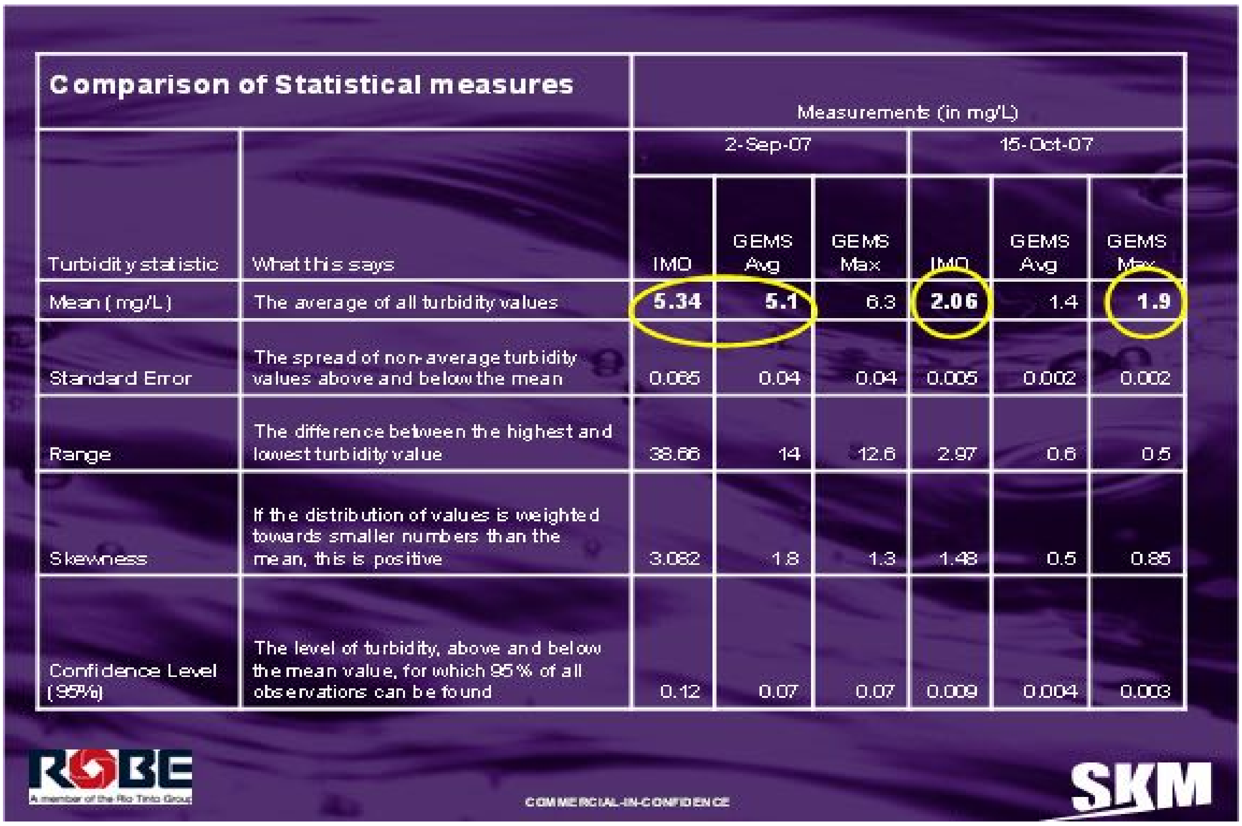
The best verification of DREDGE3D available so far was carried out during the dredging program at Cape Lambert (2007) in Australia. The verification study was run independently of GEMMS, by SKM who carried out the comparison with field measurements collected by Insitu Marine Optics. SKM compared TSS plume predictions produced by GEMMS from DREDGE3D (eery 10 minutes at a spatial resolution of 10 metres) with data collected on September 2, 2007 and October 15, 2007.

The full presentation which was presented to the EPA and the Dredge Management Committee by SKM is available from GEMMS on request. Tables 3 and 4 give statistical comparisons and correlations respectively, reproduced from the presentation to the EPA in Western Australia. The results of the study showed that the predicted plume was in the correct region and the correlation between predicted and observed TSS values was high (74% on September 2).

To date the Cape Lambert verification study is the most detailed, and most successful, assessment of the accuracy of dredging simulations in Australia.

Table C.1 Statistical comparison of predictions from DREDGE3D with observed TSS.

(reproduced with permission from RIO Tinto)



Comparison of Statistical measures

		Measurements (in mg/L)					
		2-Sep-07			15-Oct-07		
Turbidity statistic	What this says	IMO	GEMS Avg	GEMS Max	IMO	GEMS Avg	GEMS Max
Mean (mg/L)	The average of all turbidity values	**5.34**	**5.1**	6.3	**2.06**	1.4	**1.9**
Standard Error	The spread of non-average turbidity values above and below the mean	0.065	0.04	0.04	0.005	0.002	0.002
Range	The difference between the highest and lowest turbidity value	38.66	14	12.6	2.97	0.6	0.5
Skewness	If the distribution of values is weighted towards smaller numbers than the mean, this is positive	3.082	1.8	1.3	1.48	0.5	0.85
Confidence Level (95%)	The level of turbidity, above and below the mean value, for which 95% of all observations can be found	0.12	0.07	0.07	0.009	0.004	0.003

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C.2 Field Measurements at Geraldton in 2002

The results of DREDGE3D predictions for TSS in Champion Bay, averaged over 8 sites, are compared with observations taken by the Geraldton Port Authority on 7 days in late November and December 2002 in Table C.2

The observed values are an average of 21 measurements taken in Champion Bay on the particular day.

Table C.2 indicates that on December 5, 2002 the model exhibits a generally higher suspended sediment load in Champion Bay than recorded. On the other 6 days, however, the agreement is much closer. Given the potential errors in the input data (winds, dredge performance, particle distribution) the overall agreement must be considered to be very good.

Table C.2: Comparison of DREDGE3D Predicted TSS values with Measured TSS Values.

	TSS (mg/l)							
	Nov-28	**Nov-29**	**Dec-05**	**Dec-06**	**Dec-10**	**Dec-24**	**Dec-27**	**Average**
DREDGE3D Average	**4.1**	**3.2**	**7.3**	**4.3**	**3.1**	**2.7**	**2.7**	**3.9**
Observed Average	**5.2**	**3.5**	**3.9**	**3.9**	**3.5**	**2.3**	**2.9**	**3.6**

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MID-WEST PORT AUTHORITY MAINTENANCE DREDGING SIMULATIONS AT GERALDTON

AN ADDENDUM TO THE FINAL REPORT DETAILING PLACEMENT AREA WAVE IMPACT STUDIES

AUGUST 2021

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Abbreviations and Definitions

BEACON 1	The location near the western end of the channel where winds, waves and currents are monitored.
ECMWF	European Centre for Medium Range Weather Forecasts
ERA5	The latest version (version 5) of the Ecmwf ReAnalysed Global Atmospheric Model output
GEMMS	Global Environmental Modelling & Monitoring Systems
MWPA	Mid-West Port Authority
SWAN	Simulating WAves Nearshore

1 INTRODUCTION

This report details the work carried out by Global Environmental Modelling and Monitoring Systems (GEMMS) as a follow up to environmental impact studies undertaken for the proposed maintenance dredging program at the Port of Geraldton in late 2021, reported in GEMMS (2021) – the REPORT.

This report investigates whether the advent of the Placement Area (Figure 1.1) would have any impact on the waves approaching the shoreline which might lead to changes in beach erosion/accretion processes.

The average depth of sediments over the placement area after completion of dredging can be calculated as follows:

- The approximate area of placement area = 530,000 m^2
- The approximate amount of material disposed at placement area = 186,000 m^3
- The approximate average thickness of spoil covering is therefore = 35 cm

Given that, as detailed in the REPORT, the SWAN wave model produced reasonably good agreement with wave parameters measured at Beresford (location in Figure 1.1, results in Table 1) it was decided to carry out further high resolution wave studies to investigate this issue.

The following steps were taken:

1) Select the third nested wave model bathymetric grid used for the dredging studies
2) Manually establish a flat Placement Area raised 35cm above the natural seabed (Figure 2.1)
3) Manually establish an alternate bathymetry with an undulating distribution of material but limiting “mounds” to 1 metre above the natural seabed (Figure 2.2)
4) Extract wind speeds and directions from the ECMWF reanalysed global atmospheric model forecasts (ERA5) for a month which included at least one period of strong winds and waves
5) Run the SWAN wave model for 3 cases
    a) No Placement Area
    b) A flat Placement Area elevated 35cm above the natural seabed
    c) An undulating Placement Area with “mounds” limited to 1 metre above the natural seabed.
6) Analyse the wave directions and heights to discern any differences

Table 1: Comparison of statistics for SWAN predictions with observations at Beresford

Parameter	SWAN	Observations
Mean Significant Wave Height (m)	0.87	0.87
Mean Wave Direction (deg. from)	277	276
Mean Wave Period (secs)	12.9	14.4

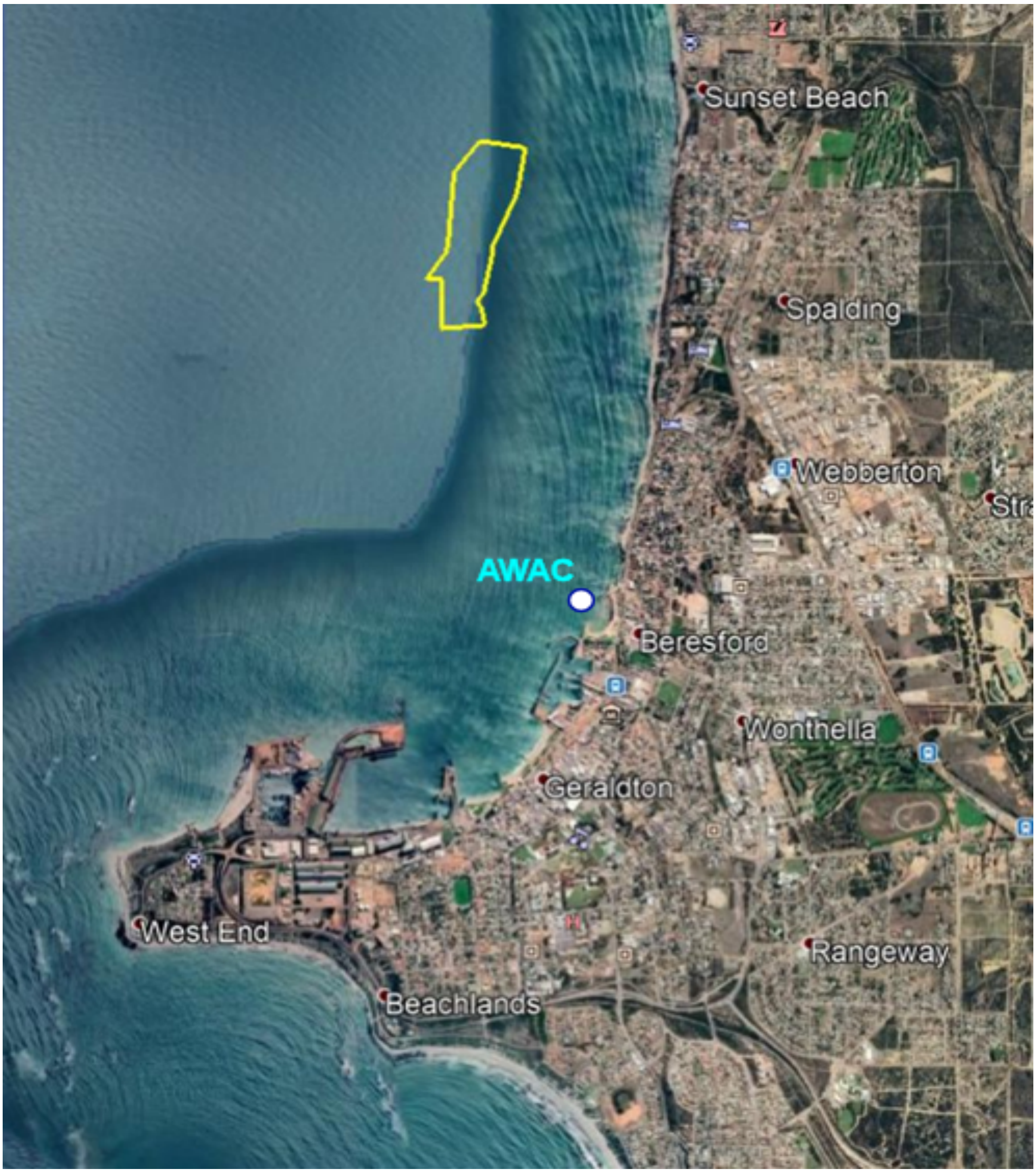

Figure 1.1 – The location of the proposed Placement Area for dredged material and the Beresford wave measurements (AWAC)

2 SWAN MODEL GRIDS AND BATHYMETRY

As detailed in the REPORT, SWAN was run on three nested grids of increasing resolution. The third, and highest resolution grid, was modified to produce alternate grids for these studies; the first of which included a flat Placement Area (Figure 2.1) and the second included an undulating Placement Area (Figure 2.2). Both figures show the ten output stations chosen to store wave data from the model runs.

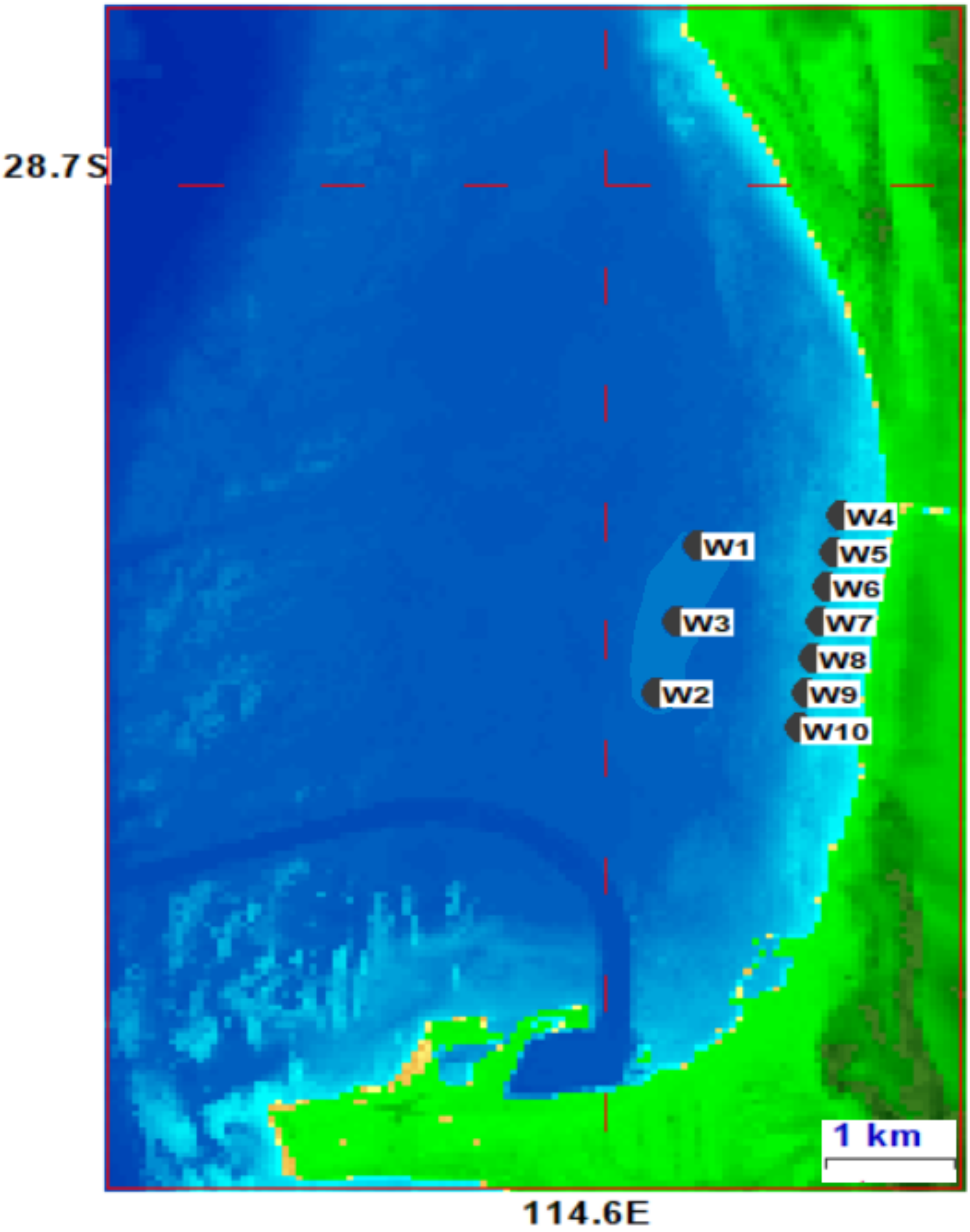

Figure 2.1 – The third nested grid with a flat Placement Area showing the output stations

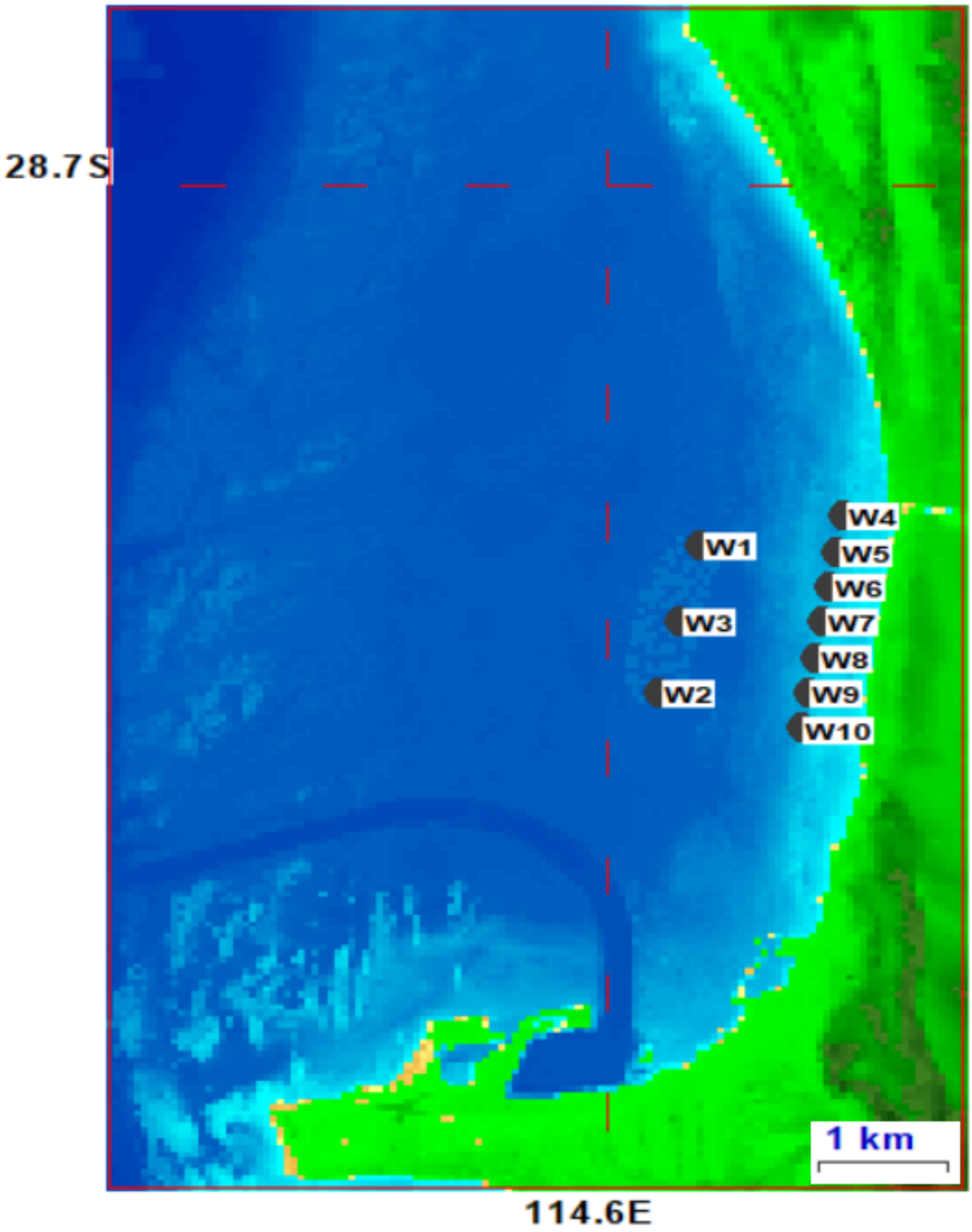

Figure 2.2 – The third nested grid with an undulating Placement Area showing the output stations

3 SIMULATIONS AND ANALYSIS

3.1 Event Selection

A search of the wind speeds and wave heights in the ECMWF ERA5 data described in the REPORT resulted in January 2018 being chosen as the period to simulate. The reasons for this choice were:

The wind speeds for that month (Figure 3.1) include weather systems ranging from moderate to storm like conditions; and

The mean significant wave height for the month of 1.46m compared well with the mean significant wave height for 2018 of 1.44m.

In order to allow appropriate build up to these January conditions the SWAN modelling was commenced on 26 December 2017.

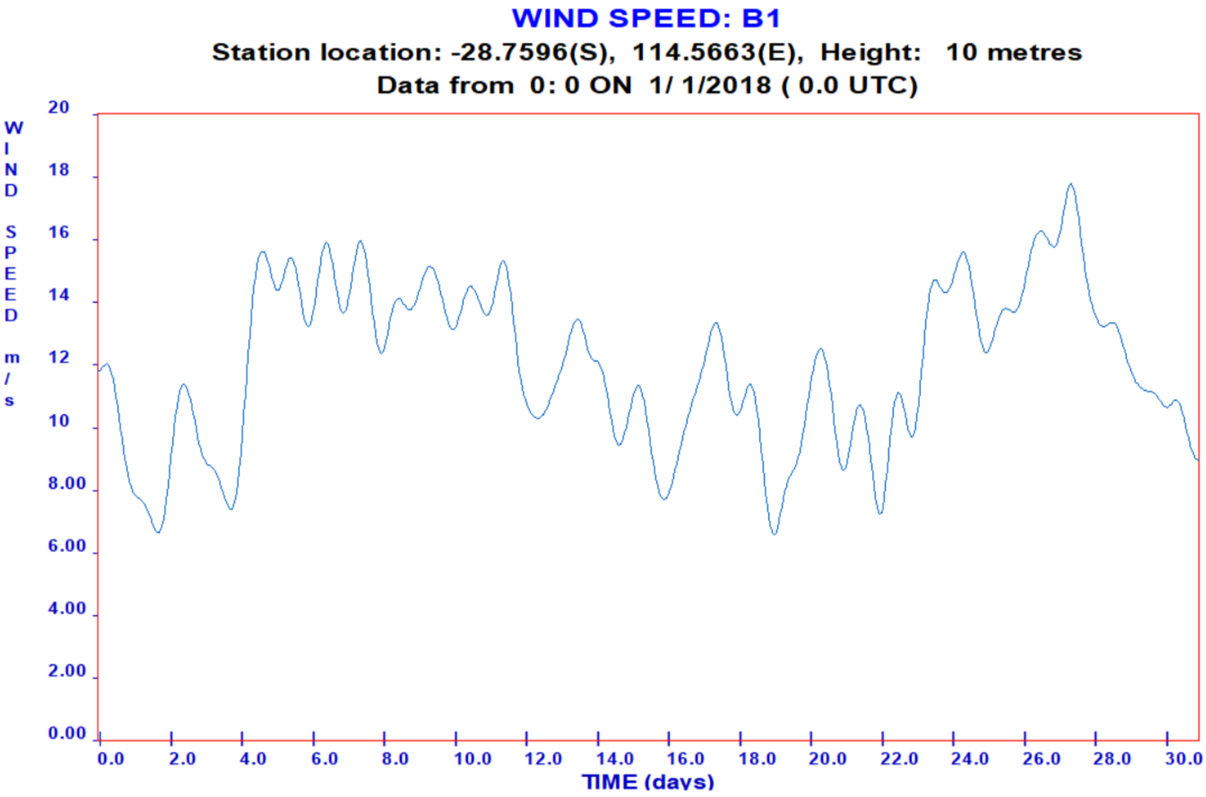

Figure 3.1 – Wind speeds at the Outer Channel Beacon during January 2018

Three separate SWAN simulations were carried out on the three versions (no PA, flat PA, undulating PA) on the highest resolution SWAN grid, nested in the outer SWAN grids.

Wave output data was stored at the locations W1 to W10 shown in Figure 2.2

For the purposes of this report however the analysis is concentrated on four of the output stations near the shoreline: W4, W6, W8 and W10

3.2 Analysis

In order to establish a point of comparison between the three sets of wave results the widely used formula for estimating total longshore sediment transport rate known as the "CERC" formula (*Shore Protection Manual*, 1984) was selected.

The formula is based on the assumption that the total longshore sediment transport rate is proportional to the longshore wave energy flux and is defined as:

$$Q = \frac{K}{16\sqrt{\gamma_b}} \rho g^{\frac{3}{2}} H_{sb}^{\frac{5}{2}} \sin(2\theta_b)$$

where Q is the submerged total longshore transport rate,

K is an empirical coefficient,

ρ is density of water,

g is acceleration due to gravity,

Hsb is significant wave height at breaking,

γ_b is the breaker index, and

θb is the wave angle to the shoreline at breaking.

For the purposes of this study values that are common to all three simulations can be ignored, leaving:

$$Q = H_{sb}^{\frac{5}{2}} \sin(2\theta_b)$$

i.e. the significant wave height at breaking, raised to the power 2.5, multiplied by the sine of twice the angle of the wave at breaking to the shoreline.

The shoreline adjacent to the Placement Area is aligned at approximately 6 degrees from true north however small differences in θb can have an important effect on the value of Q.

Accordingly, shoreline directions were derived for each of the wave output stations from examination of the Google Earth image in Figure 3.2.

The shoreline direction assignments chosen were:

W4: 355 deg
W6: 8 deg
W8: 6 deg
W10: 1 deg

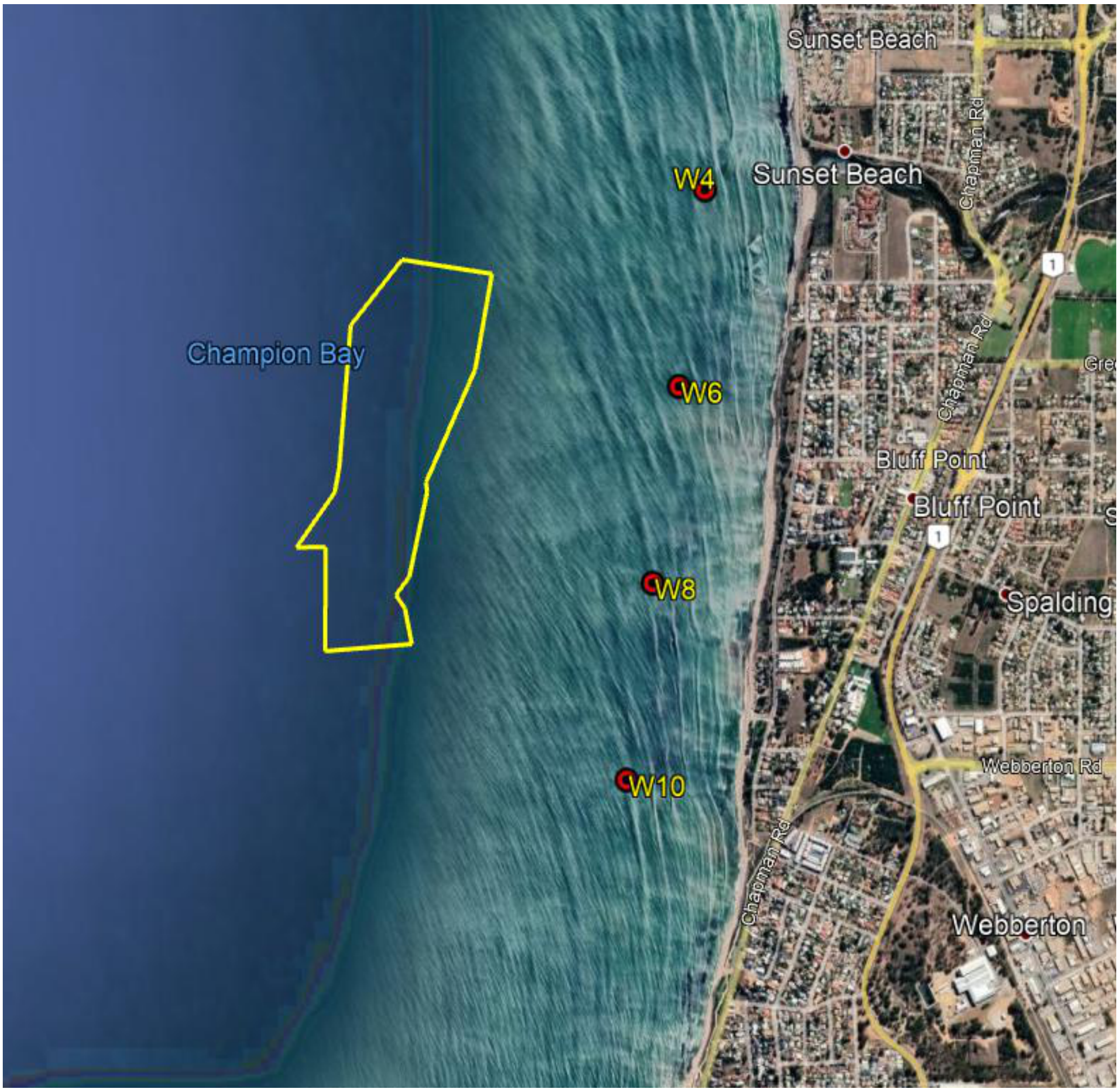

Figure 3.2 – Locations of the wave output stations included in this report

3.3 Results

After establishing the shoreline directions for each output station, the values for **Q**, ignoring the effect of the constants, were calculated hourly for the four analysis sites for the period of the simulations (approximately 1 month).

The results presented are:

a) The mean values of the significant wave height, peak wave direction (from) and **Q** for the three simulations (no PA, flat PA and undulating PA) at sites W4, W6, W8 and W10 (Table 2);

b) The complete spreadsheet comprising all the hourly values of these variables at W4, W6, W8 and W10 for each of the three placement area simulations (attached to this report);

c) The **Q** values for a month for each of the three placement area simulations at sites W4, W6 and W8 (Figures 3.3, 3.4 and 3.5 respectively); and

d) The significant wave height, peak wave direction and peak wave period (Figures 3.6, 3.7 and 3.8 respectively) for a month at site 6.

Table 2: Mean values at Sites 4, 6, 8 and 10 over the period of one month

Site 4			Site 6			Site 8			Site 10		
Zero PA	**Flat PA**	**Lumpy PA**	**Zero PA**	**Flat PA**	**Lumpy PA**	**Zero PA**	**Flat PA**	**Lumpy PA**	**Zero PA**	**Flat PA**	**Lumpy PA**
Significant Wave Height (cf Mean at Site 8 for 2018 of 1.44m)											
1.49	**1.47**	**1.47**	**1.55**	**1.54**	**1.54**	**1.46**	**1.45**	**1.45**	**1.48**	**1.47**	**1.47**
Peak Wave Direction (deg)											
238	**238**	**239**	**238**	**239**	**239**	**237**	**236**	**236**	**246**	**245**	**245**
Q											
1.834	**1.762**	**1.689**	**3.103**	**2.997**	**2.887**	**3.076**	**3.147**	**3.217**	**1.067**	**1.142**	**1.218**

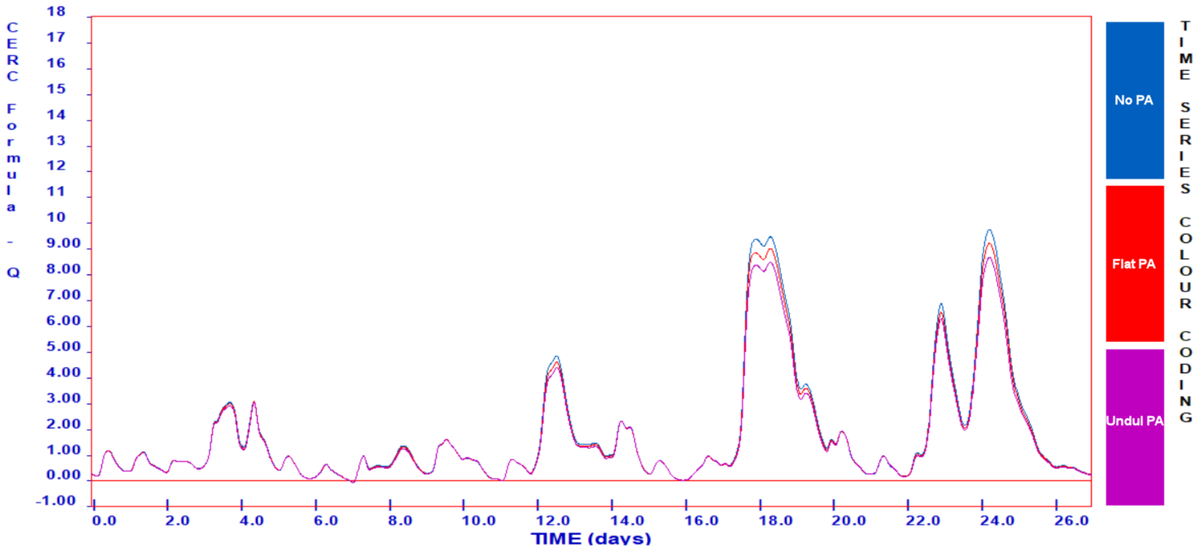

Figure 3.3 – Q values (minus constants) for the three placement area options at site 4

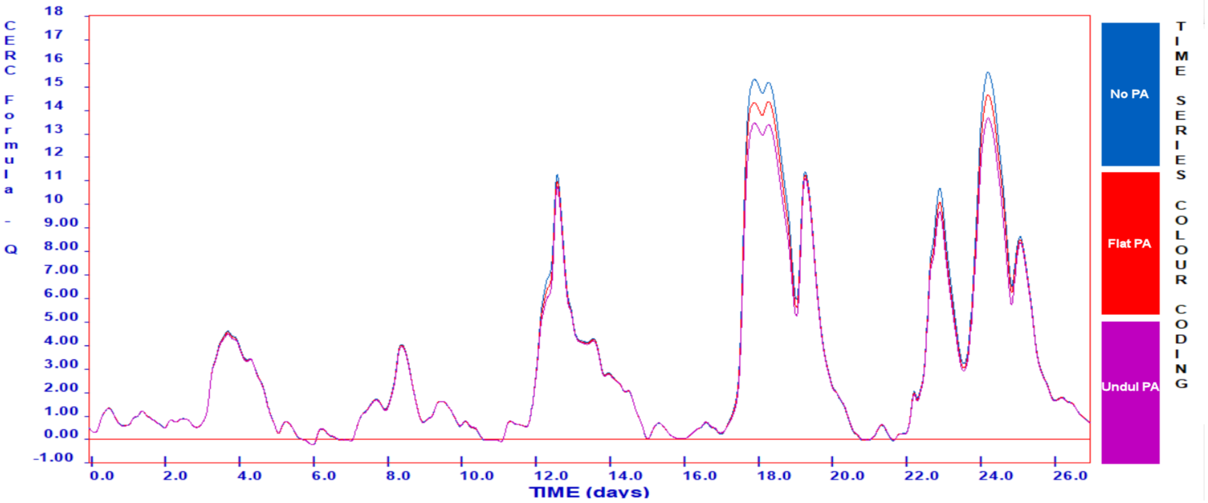

Figure 3.4 – Q values (minus constants) for the three placement area options at site 6

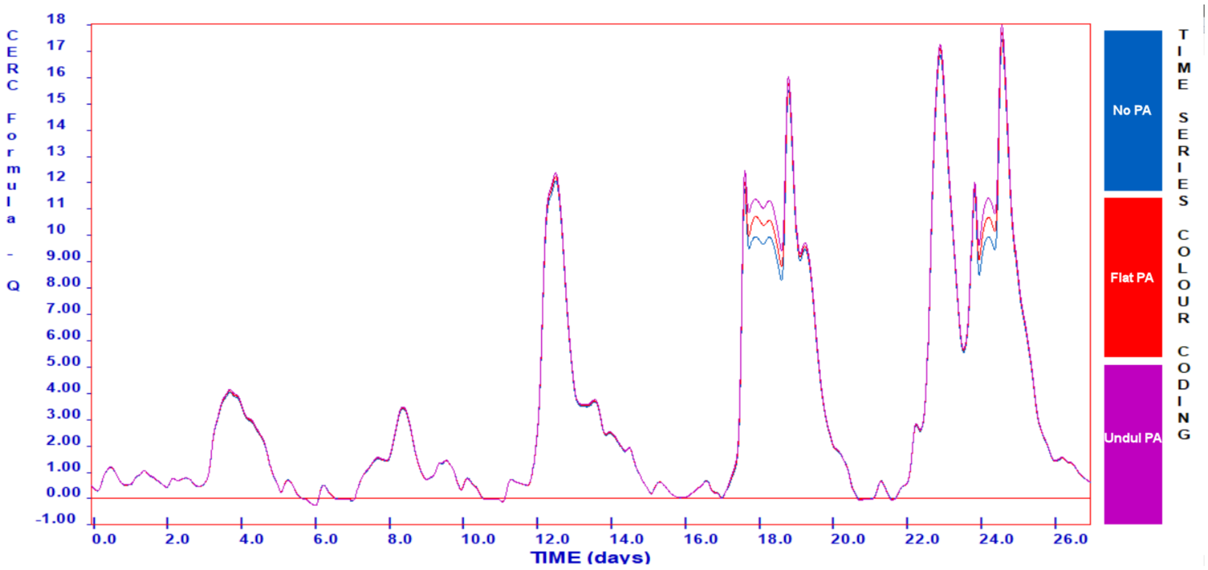

Figure 3.5 – Q values (minus constants) for the three placement area options at site 8

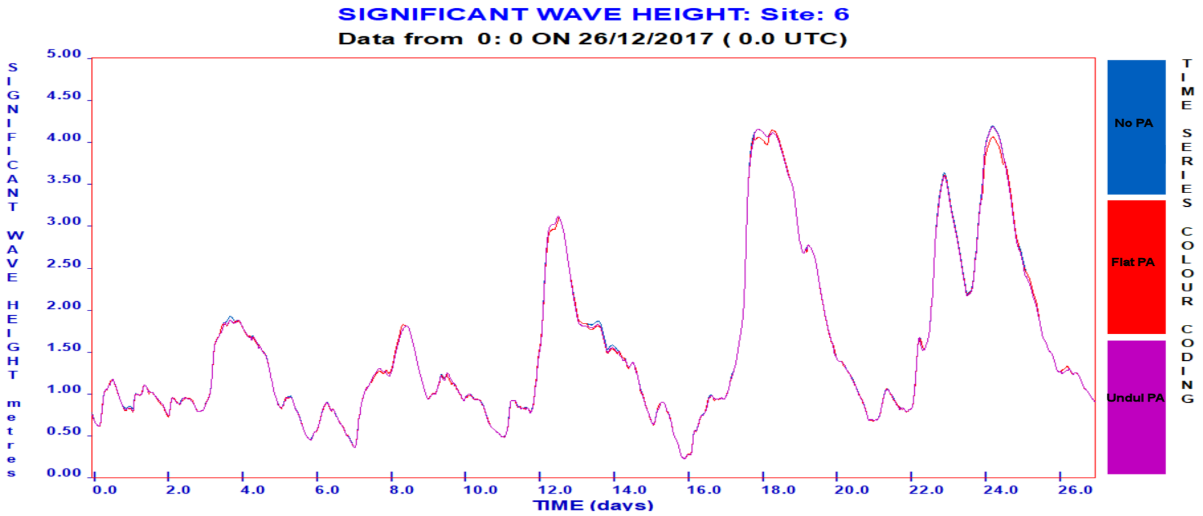

Figure 3.6 – Significant wave heights for the three placement area options at site 6

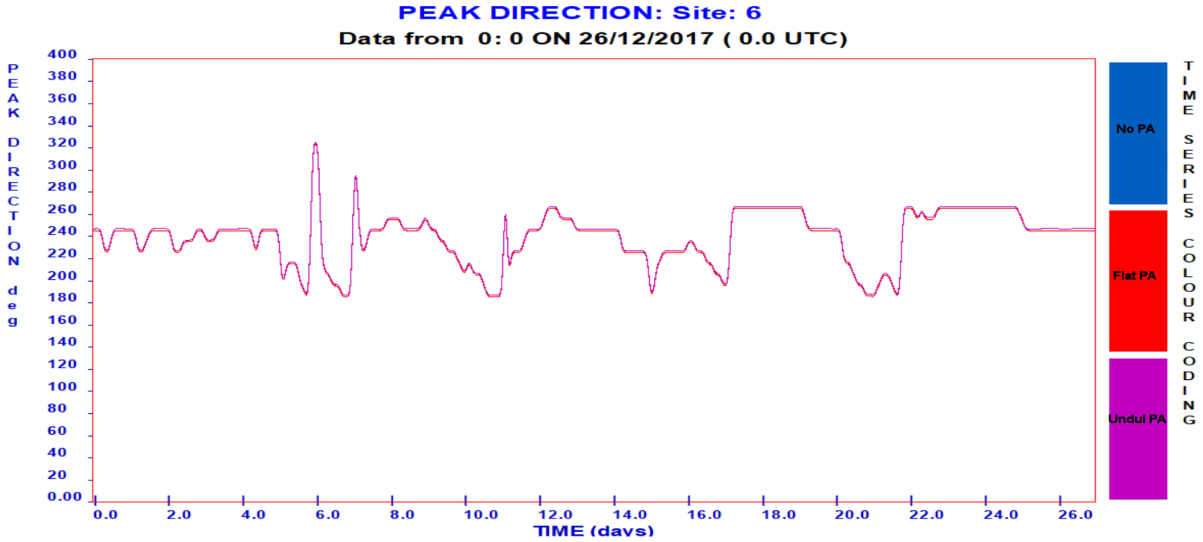

Figure 3.7 – Peak wave directions for the three placement area options at site 6

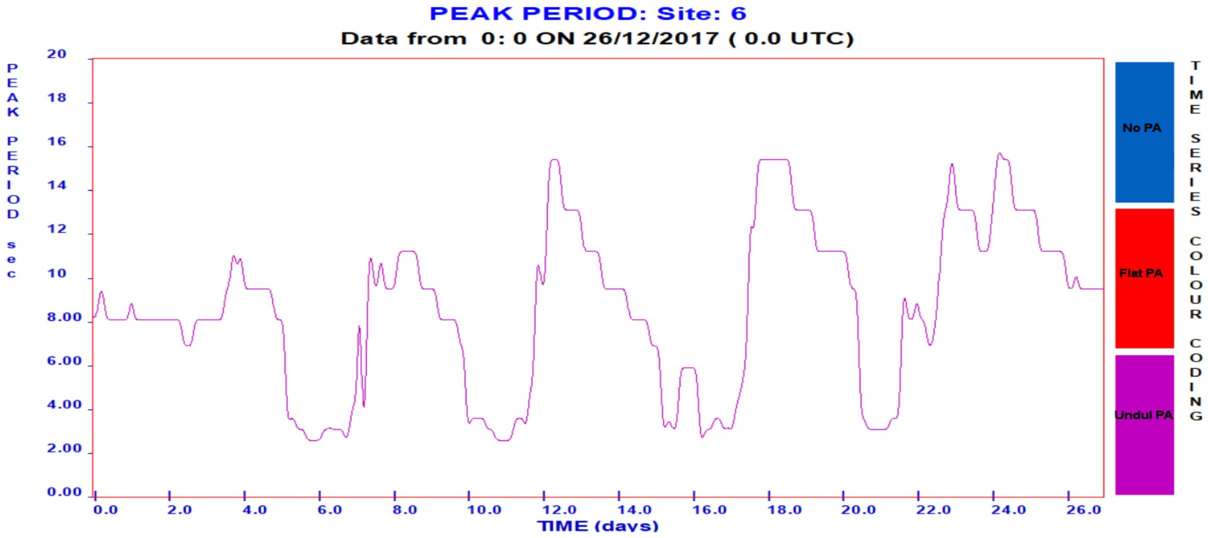

Figure 3.8 – Peak wave periods for the three placement area options at site 6

4 CONCLUSIONS

The following findings appear to be consistent with the results:

1) The chosen simulation period (26 December 2017 to 22 January 2018) is not an outlier in the long-term statistics as the mean wave height for 2018 derived from SWAN modelling at Site 8 was 1.44m and this compares well with the simulation period average of 1.46m at Site 8;

2) The **Q** values indicate small changes to the near shore waves resulting from the advent of the material on the Placement Area;

3) The most notable changes, albeit still small, are observed in the peak wave directions with changes up to 1 degree. The changes in the significant wave heights are less than 1%;

4) The small changes in peak wave directions suggest a slight refraction of waves in a clockwise direction around the north of the Placement Area and a slight refraction in an anti-clockwise direction around the south of the Placement Area;

5) The noticeable changes in peak wave direction, and hence **Q**, relate to storm events when the longer period swell waves penetrate to the shoreline. These storm events have the ameliorating impact of flattening the placement area as sediment is moved away towards the shoreline. This flattening would reduce the influence of the placement site on the waves and so any impacts are expected to be short-term over the first 1-2 years.

6) Any impacts on the shoreline are expected to be episodic associated with storm events. If there are changes in sediment transport the most likely impacts are a slight increase in longshore movement around site 8 and a slight decrease at site 6. The magnitude of any change is expected to be less than the natural variability observed over the previous 15 years of shoreline monitoring records.