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GLOBAL ENVIRONMENTAL MODELLING SYSTEMS

GLOBAL ENVIRONMENTAL MAPPING SYSTEMS

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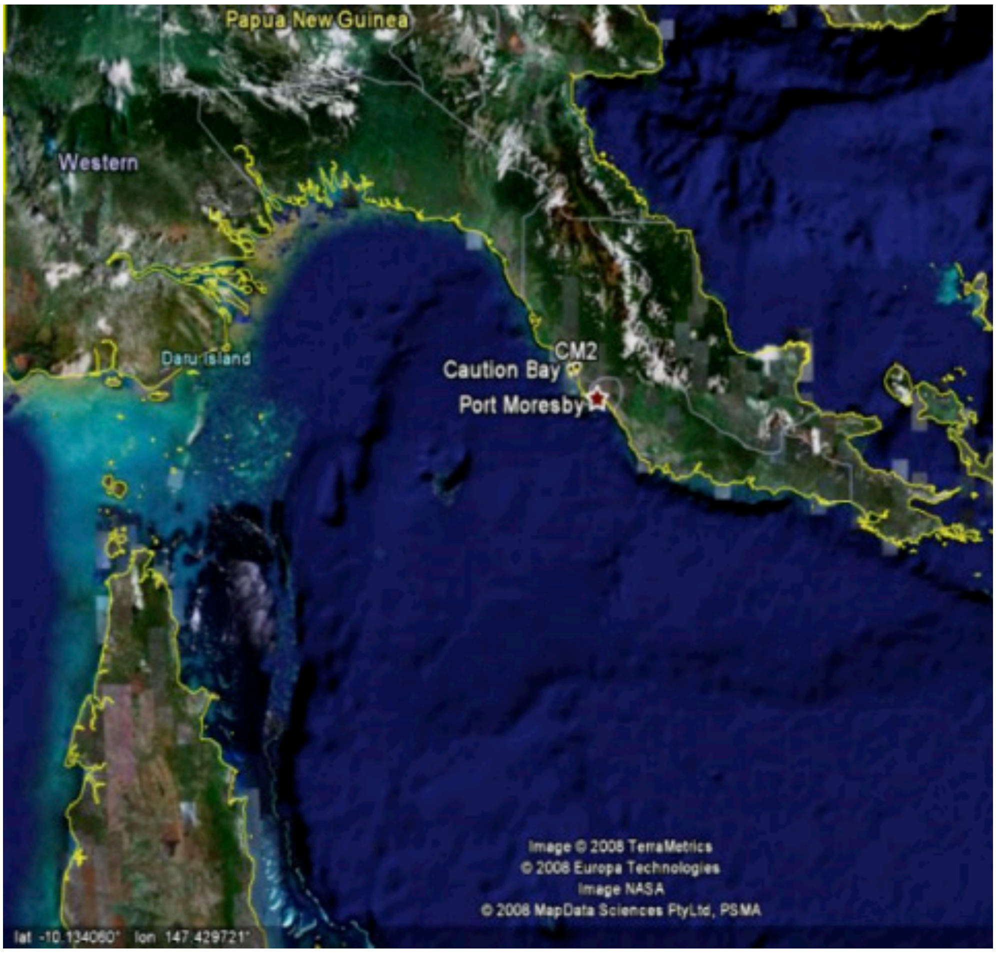
Caution Bay, Papua New Guinea

Oceanographic Studies

& Dredging Program Simulations

COFFEY NATURAL SYSTEMS



December ***2008***

ABOUT GEMS

Global Environmental Modelling Systems (GEMS), a wholly owned Australian company, has expertise in the development and application of high-resolution computer models to realistically predict atmospheric and oceanographic conditions for use in riverine, coastal and oceanic settings.

The GEMS team is made up of qualified and experienced physical oceanographers, meteorologists, numerical modellers and environmental scientists. GEMS is a leading developer of numerical models in Australia. It has developed a system of validated environmental models and rigorous analytical procedures that provide solutions to a variety of environmental, engineering and operational problems.

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1. INTRODUCTION

The Papua New Guinea Liquefied Natural Gas (PNG LNG) Project involves the development of a number of gas fields and facilities in a series of development phases to produce liquefied natural gas (LNG) for export. The development will also produce condensate. The development of the Hides, Angore, and Juha gas fields and blowdown of the gas caps at the existing Kutubu, Agogo and Gobe oil fields will supply the gas resources. An extensive onshore and offshore pipeline network will enable transportation of the gas to a new LNG Facilities site on the coast of the Gulf of Papua in Caution Bay near Port Moresby (Figure 1.1). Stabilised condensate will be transported to the existing oil processing, storage, and offloading facilities at the Kutubu Central Processing Facility and Kumul Marine Terminal respectively. Small amounts of condensate are also produced at the LNG Facilities site.

Esso Highlands Limited (Esso), a Papua New Guinea subsidiary of the Exxon Mobil Corporation (ExxonMobil), is the operator of the PNG LNG Project. The PNG LNG Project will be developed in five phases over a period of 10 years to ensure reliability and consistent quality of supply of LNG for over the 30 year life of the project.

A list of the proposed developments is provided below, and Figure 1.0 shows a schematic of facilities and pipelines:

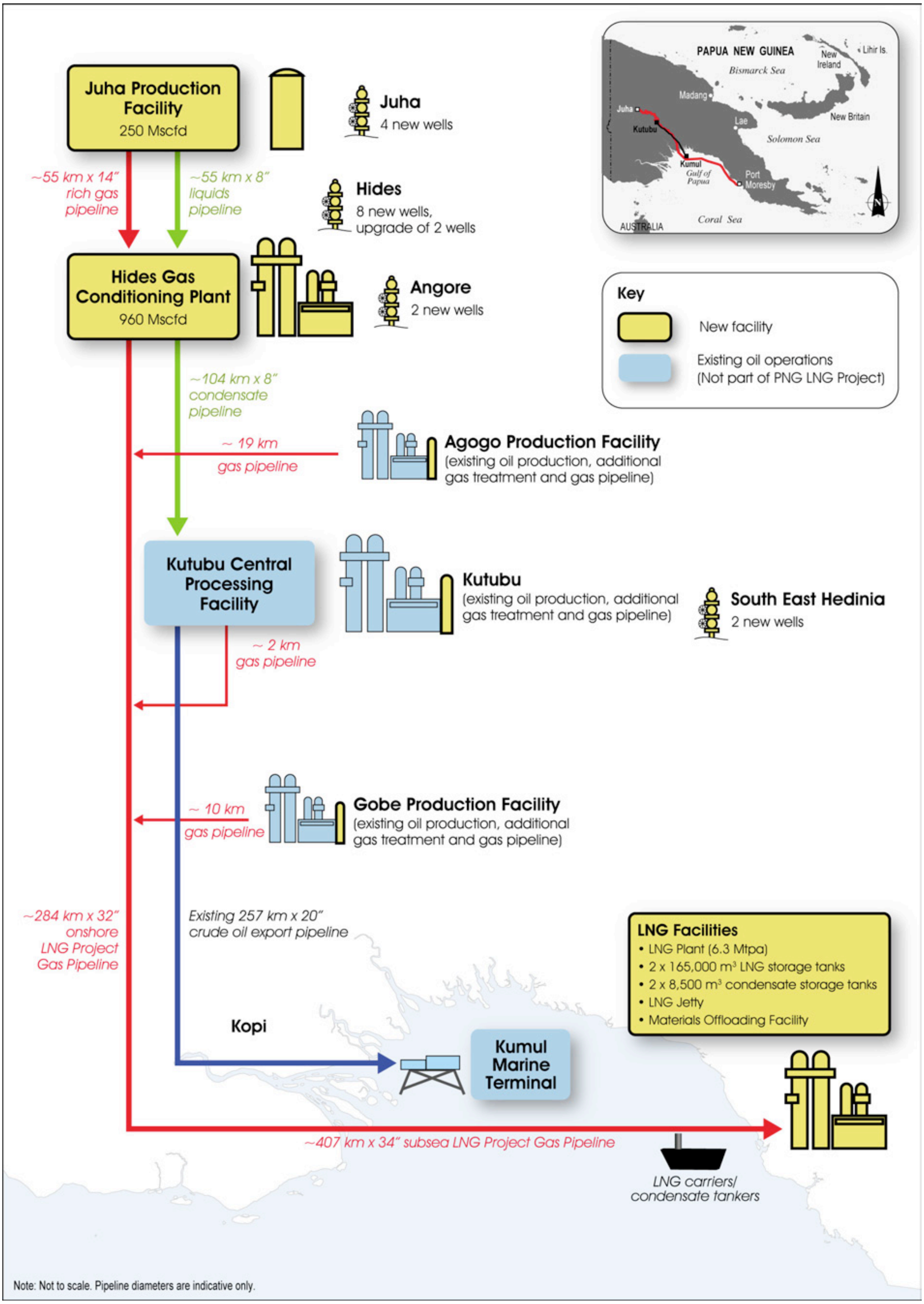

Figure 1.0 Schematic of PNG LNG Facilities & pipelines.

1.1 UPSTREAM DEVELOPMENT COMPONENTS:

- Hides gas field development:
  - Seven wellpads with a total of eight new wells and re-completion of two existing wells.
  - Hides gathering system including gas flowlines from new and re-completed Hides wells.
  - Hides spineline and mono-ethylene glycol (MEG) Pipeline in the same right of way (ROW).
  - Hides Gas Conditioning Plant.
  - Hides–Kutubu Condensate Pipeline in the same ROW as the LNG Project Gas Pipeline.

- Juha gas field development:
  - Three new wellpads with four new wells.
  - Juha gathering system including gas flowlines from new Juha wells.
  - Juha spinelines and MEG Pipeline in the same ROWs.
  - Juha Production Facility.
  - Juha–Hides pipelines right of way (ROW) containing three pipelines including Juha–Hides Rich Gas Pipeline, Juha–Hides Liquids Pipeline and Hides–Juha MEG Pipeline.

- Angore gas field development:
  - Two new wellpads with two new wells.
  - Angore gathering system including gas flowlines from new Angore wells.
  - Angore spineline and Angore MEG Pipeline to Hides Gas Conditioning Plant, both in the same ROW.

- Gas from existing fields:
  - Gas treatment at the Agogo Production Facility and a new Agogo Gas Pipeline from the Agogo Production Facility to LNG Project Gas Pipeline.
  - Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to LNG Project Gas Pipeline.
  - Gas treatment at the Kutubu Central Processing Facility and a new Kutubu Gas Pipeline from the Kutubu Central Processing Facility to the LNG Project Gas Pipeline.
  - South East Hedinia gas field development: one new wellpad and two new wells; new gathering system including gas flow lines from the South East Hedinia new wells to the Kutubu Central Processing Facility in the same ROW as the Kutubu Gas Pipeline.

- Kopi scraper station.

- LNG Project Gas Pipeline:
  - Onshore: from Hides Gas Conditioning Plant to Omati River Landfall.
  - Offshore: Omati River Landfall to Caution Bay Landfall.

1.2 LNG FACILITIES DEVELOPMENT COMPONENTS:

- Onshore LNG Plant including gas processing and liquefaction trains, storage tanks, flare system and utilities.
- Marine facilities including jetty, LNG and condensate export berths, materials offloading facility and tug moorage.

1.3 SUPPORTING FACILITIES AND INFRASTRUCTURE:

In addition to the principal gas production, processing and transport, and LNG production and export facilities, the project will involve the following permanent infrastructure and facilities:

- New roads and upgrade of existing roads.
- New bridges and upgrade of existing bridges.
- Upgrade of two existing airfields (upstream at Komo and Tari).
- New helipads (multiple).
- New wharf and an upgrade of the existing Kopi roll-on, roll-off facility.
- Water supply systems and pipelines, wastewater and waste management facilities.
- Operations Camps (at Hides, Juha and Tari).

A series of temporary works and access roads will also be required during the construction phase, including:

- Construction camps (multiple).
- Material/pipe laydown areas.

The proposed layout of the Materials Offload Facility (MOF) and berthing jetty for LNG transport vessels in Caution Bay, at the time of these studies, is shown in Figure 1.2. Note that this shows the causeway for the Materials Offloading Facility extending out to 1 km from the mangroves: the (now) proposed shorter causeway is shown as the outline in Figure 1.2.

1.4 OBJECTIVES:

Global Environmental Modelling Systems (GEMS) has been contracted by Coffey Natural Systems (CNS) to carry out oceanographic studies in Caution Bay, Papua New Guinea for this ESSO Highlands LNG development. The results of these oceanographic studies feed into studies of coastal processes being undertaken by Kellog, Brown and Root (KBR) and environmental impact assessments undertaken by CNS.

The work has involved analysis of oceanographic data collected by Cardno Lawson and Treloar (CLT), simulations of the hydrodynamics of Caution Bay, under ambient and extreme conditions, simulation of the impacts of the solid causeway on circulation in Caution Bay, and simulation of the small dredging program required for development of the MOF, jetty and berthing facilities.

The original objectives of this oceanographic study were to:

- Describe the physical oceanographic characteristics, current movements, sediment transport and coastal processes of the study area.

- Predict the nature and extent of any sediment plumes generated by the construction and operation of the proposed development using sediment data supplied by CNS.

- Describe the fate and behaviour of sediment during the construction and operation of all marine facilities including impacts from the nearshore marine pipeline and landfall, Materials Offloading

Facility (solid earthen structure), the marine terminal (trestle so water can flow under), any dredging required for the tanker approach (draft of 15 m required) and shipping traffic.

- Predict the nature and extent of any changes to tides and currents resulting from the construction and operation of the proposed development.
- Identify measures to reduce any impacts of the project on existing oceanographic processes.

In addition, GEMS has carried out a detailed analysis of the wind, wave, tide and current data collected by CLT to integrate the outcomes of the analysis with the results of the modelling studies.

The work has been undertaken using the output of the MetOcean analysis and the output of four sophisticated numerical computer models:

1. The Australian Bureau of Meteorology high resolution (10km) atmospheric forecast model (**MesoLAPS** – Mesoscale Limited Area Prediction System);

2. The GEMS 3D Coastal Ocean Model (**GCOM3D**) to simulate the complex three-dimensional ocean currents in Caution Bay;

3. The **SWAN** wave model to simulate the waves in the region; and

4. The GEMS 3D Dredge Simulation Model (**DREDGE3D**) to determine the fate of particles released into the water column during the dredging operations.

In addition a small field program, involving the release of surface drifters, was undertaken by GEMS and CNS to obtain further data for the understanding of the oceanography of the region and for the verification of the 3D ocean model.

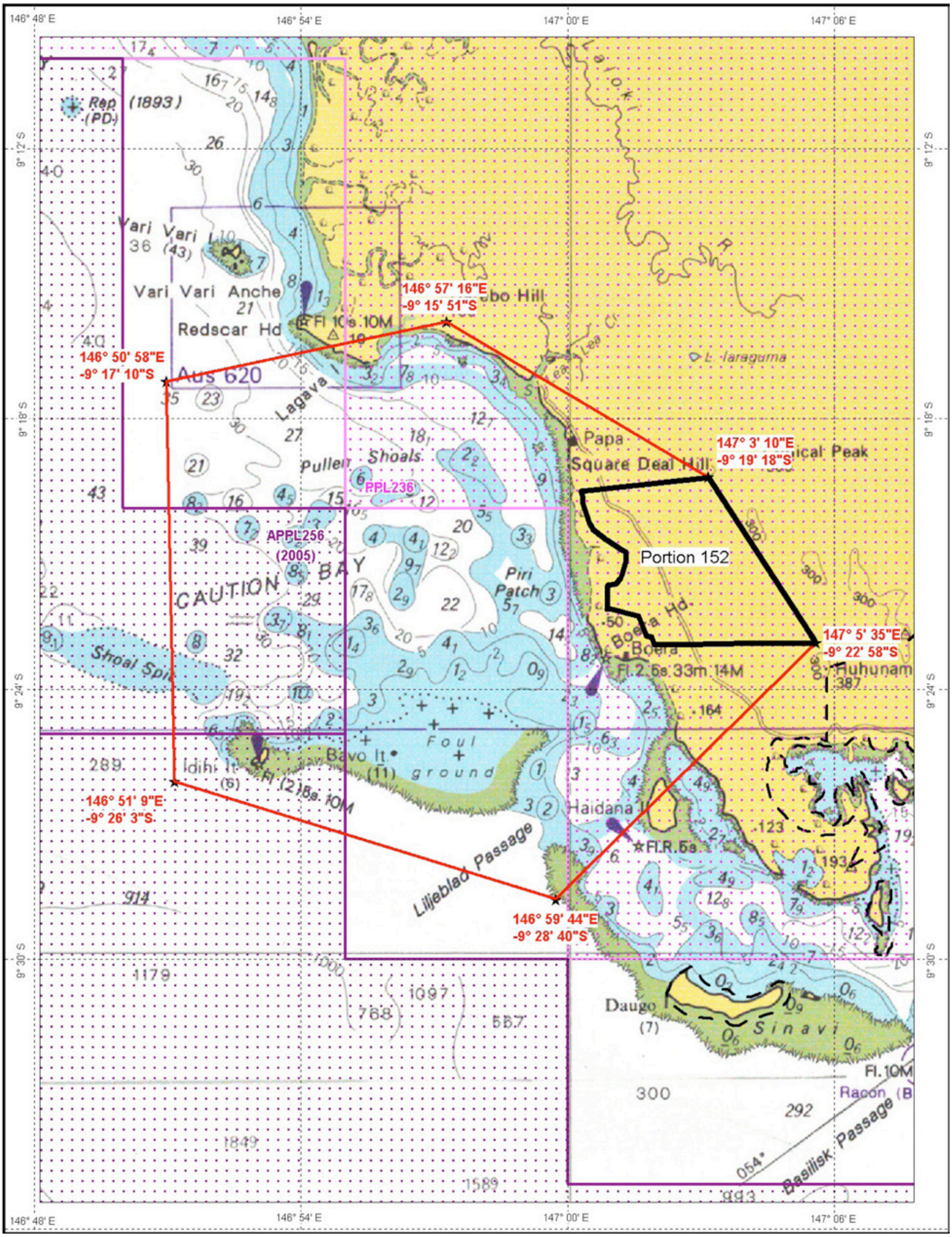

Figure 1.1: The location of the LNG processing plant at LNG Facilities Site on the shores of Caution Bay in the Gulf of Papua (courtesy of CNS).

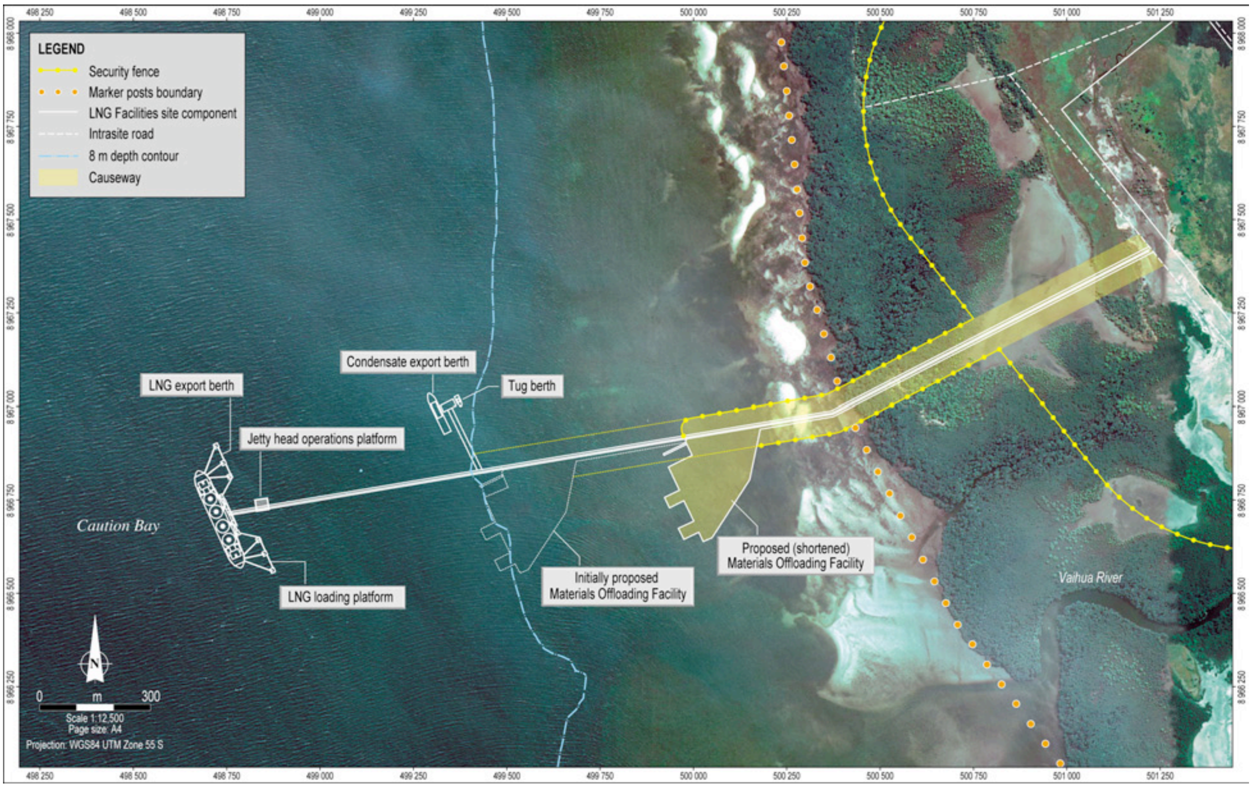

Figure 1.2: Proposed layout of the LNG loadout jetty and Materials Offload Facility in Caution Bay.

2. OCEAN MODELLING METHODOLOGY

2.1 BATHYMETRY

The bathymetry in Caution Bay is complex with the existence of coral reefs and channels. The southern and western perimeters of Caution Bay descend to open ocean depths of over a thousand metres.

The bathymetric data sets used in this study were derived from the GEMS database which has been developed from a range of sources including digital hydrographic chart data from Geosciences Australia. These data were updated with local bathymetry provided by ExxonMobil.

2.2 METEOROLOGICAL FORCING

Accurate modelling of the waves and currents in any region can only be achieved with a suitable representative meteorological data set. In the past, much of the atmospheric forcing applied to drive ocean models has been based on historic, single station (wind) data obtained from the nearest automatic or manual weather station to the site of interest.

In work carried out for Woodside Energy off Northwest Cape in Australia, the limitations of adopting measured winds were clearly demonstrated. In that study, using satellite tracked drifting buoys, it was shown that when using coastal winds or even winds measured on site, the errors were quite large due to the fact that:

a) Measured winds are only accurate at the release site;

b) As a dredging plume drifts on the currents it moves into areas influenced by winds which are different to those at the release site; and

c) Even at the dredge spoil release site the currents are not just driven by the local wind but are also a result of currents flowing into the area which are driven by different winds to those at the release site.

As a result GEMS has moved to applying spatial and time varying data from numerical weather prediction (NWP) models to force its oceanographic models.

2.3 HYDRODYNAMIC MODELLING

2.3.1 TIDAL FORCING

Tidal forcing for the modelling study was based on data from the GEMS Australian region gridded tidal data base, which has been developed with extensive modelling programmes (primarily for AMSA Search and Rescue in Canberra).

2.3.2 OCEAN MODEL SETUP

The ocean currents and sea levels were modelled on two "nested" grids with GCOM3D. A large scale grid (Figure 2.1) was used to generate boundary conditions for a higher resolution GCOM3D grid (Figure 2.2). The coarse grid was run at a resolution of 1 km, driven by tides and MesoLAPS winds and atmospheric pressures. The finer grid was nested in the larger grid at a resolution of 100 metres. It is necessary to run this nested system to fully capture the complex currents resulting from large scale flows in the Gulf of Papua and shallow reef structures in Caution Bay.

Examples of the tidal currents predicted by GCOM3D in the Caution Bay region are shown in Figure 2.3.

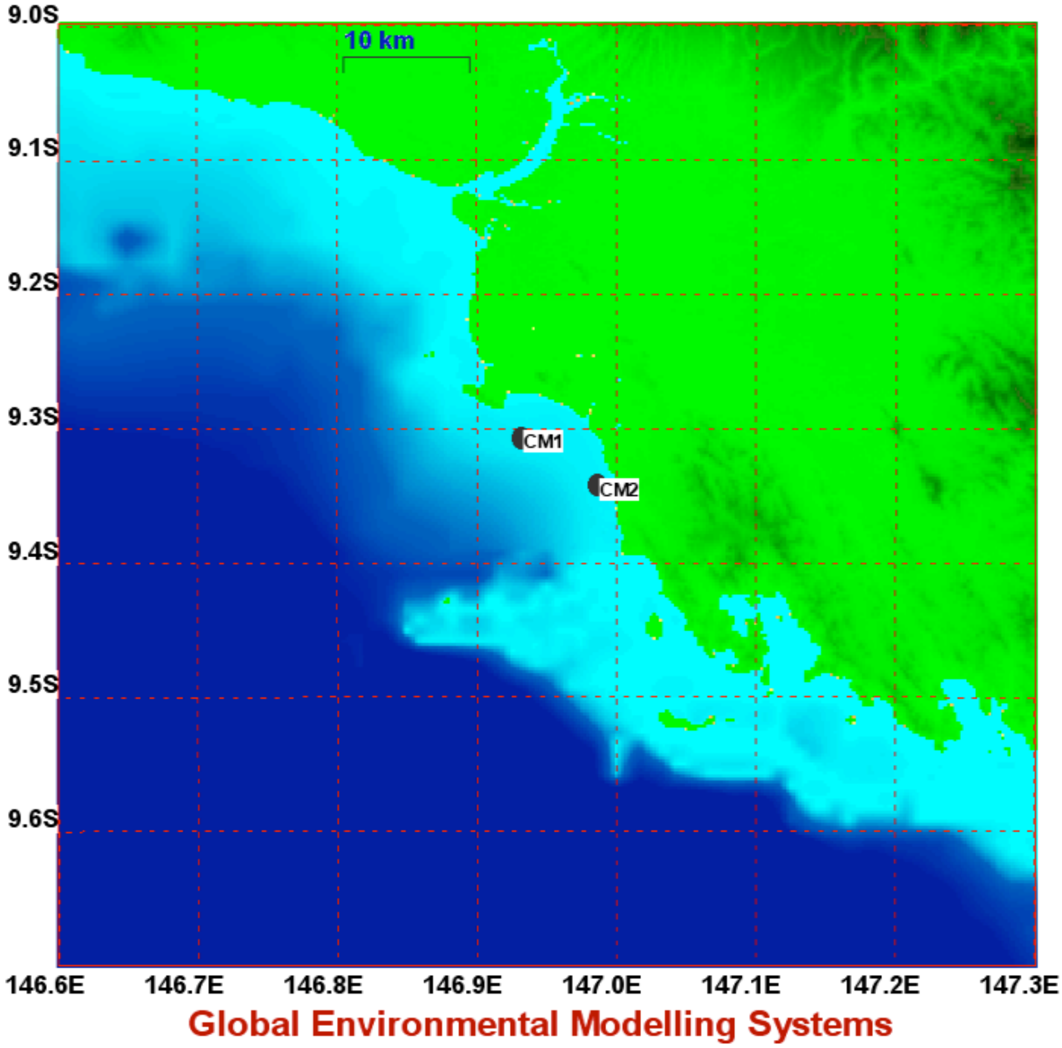

Figure 2.1: Large Scale Ocean Model grid. (CM1 and CM2 are the Acoustic Doppler Current Profiler [ADCP] current metering locations)

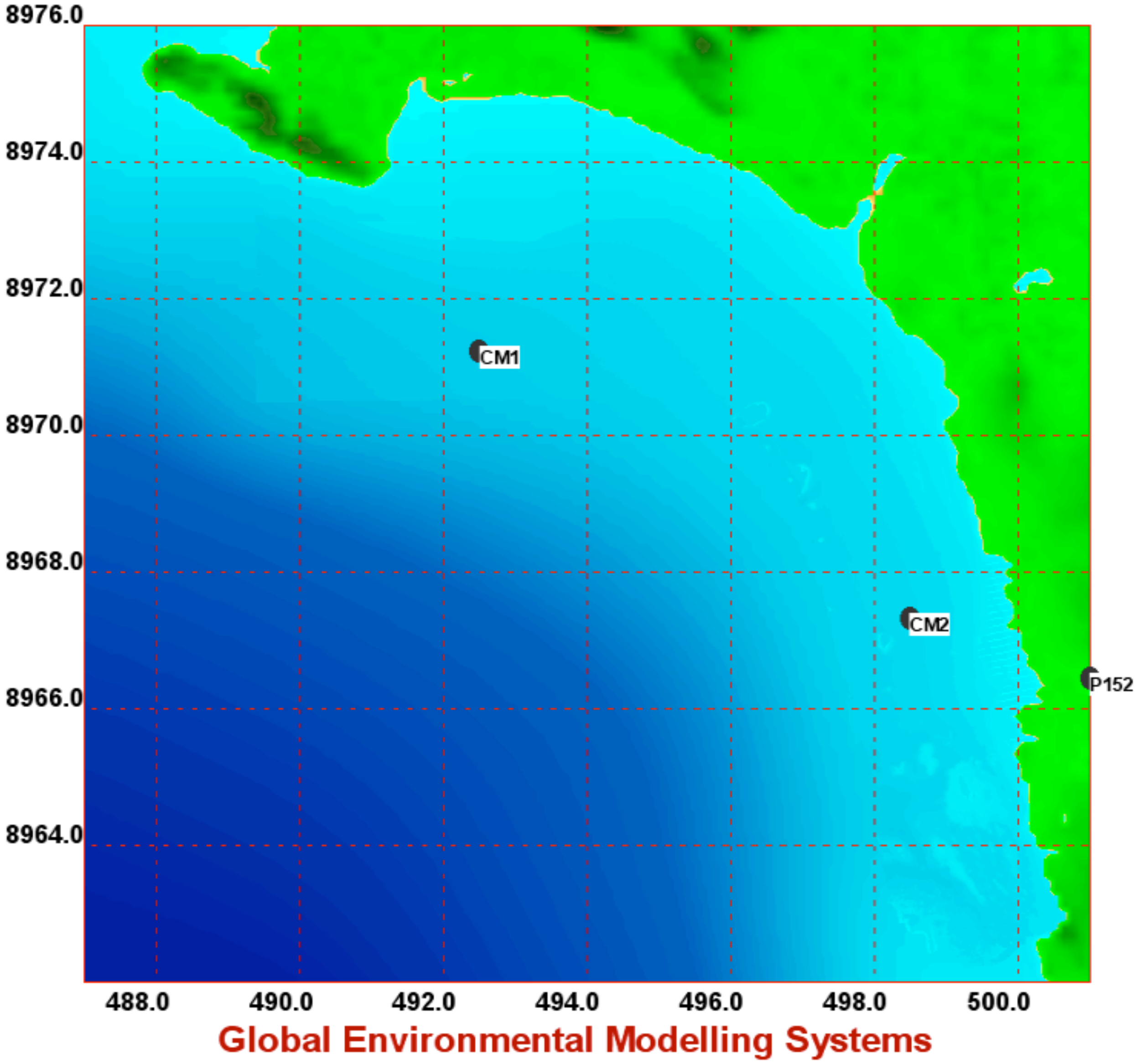

Figure 2.2 Caution Bay Ocean Model Grid (CM1 and CM2 are the ADCP current metering locations)

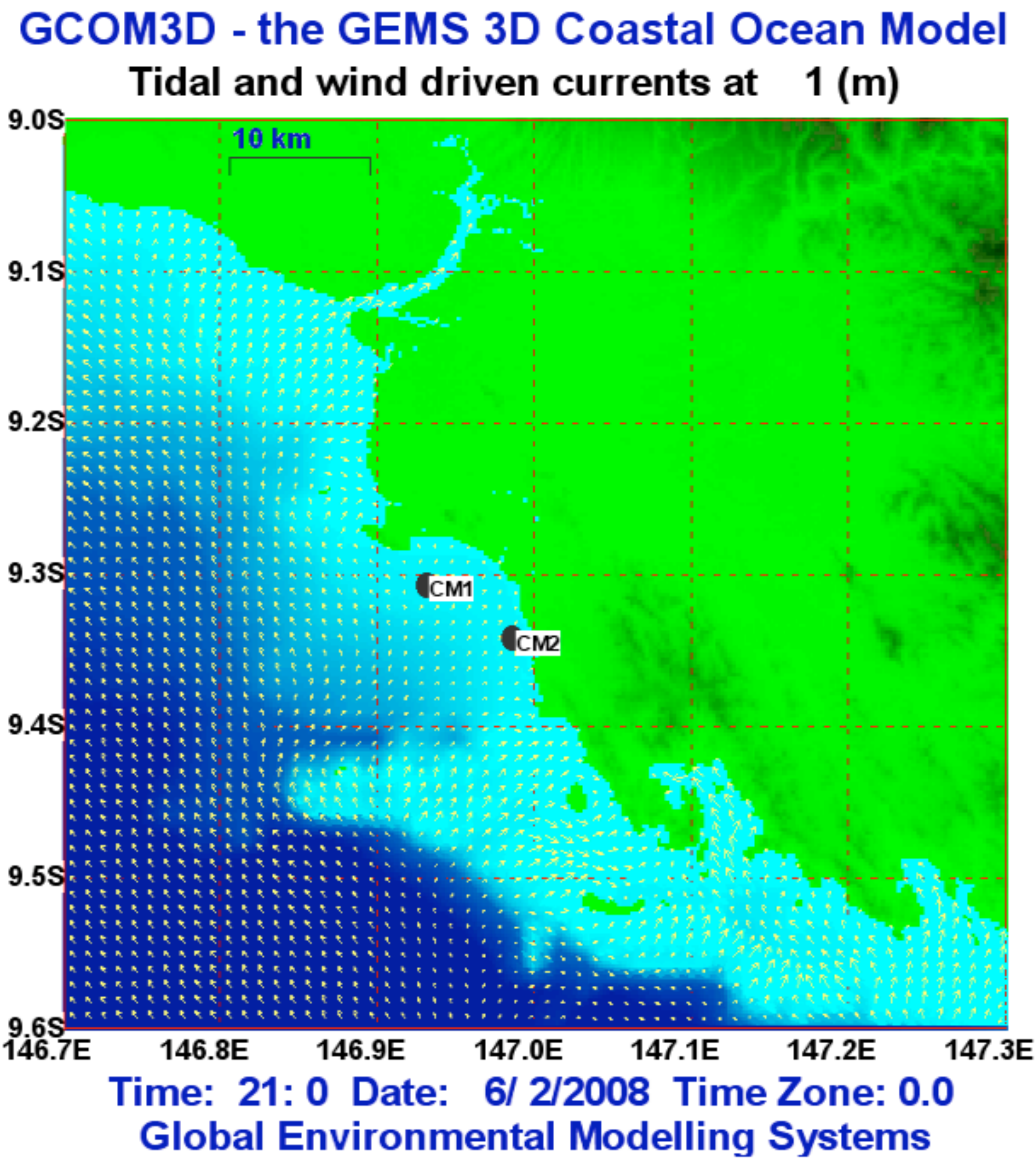

Figure 2.3: Example of the surface currents in the region of Caution Bay predicted by GCOM3D.

2.4 WAVES

The SWAN model (see Appendix A.2) was established on a series of nested grids covering the broader eastern Indian Ocean and the North West Shelf region in order to estimate the spatial and temporal variation of wave-induced (bottom) orbital velocities over the period of the modelling for incorporation into the re-suspension module of the dredge model.

Wave Grids and Winds

In order to capture broad scale wave generation processes affecting the region, a grid was established over the Gulf of Papua, extending south to Cairns and west to Torres Strait at a resolution of approximately 5km. An inner grid was then established at 250m resolution, in order to model the more detailed near-shore processes in Caution Bay. The grid domains are shown in Figures 2.4 and 2.5.

The model was initialized with archived winds from the Bureau of Meteorology's numerical weather prediction analysis fields. The nested model suite was run for verification against available wave data. The model was then run for a period of one year (July 2007 to July 2008) for analysis of ambient conditions.

SWAN Setup

SWAN allows for a range of parameter settings, some of which may be tuned to the particular application. The settings employed in the current study are set out in Table 1.

Table 1: SWAN set-up specifications.

Model Grid	Ocean Grid	Caution Bay Region
Minimum Latitude	-15.0	-9.85
Maximum Latitude	-7.0	-8.95
Minimum Longitude	142.5	146.4
Maximum Longitude	151.0	147.3
Grid Resolution (deg)	0.05	0.0025
Directional resolution (deg)	20	20
Frequency Range (Bins)	0.04 - 1(20)	0.04 - 1(20)
Friction Scheme	None	Collins*

* Collins Friction Factor: When creating hydrodynamic model, the Collins Friction Factor is used to represent the friction which exists between the seafloor (including features such as sand, coral and vegetation) and seawater passing over the seafloor.

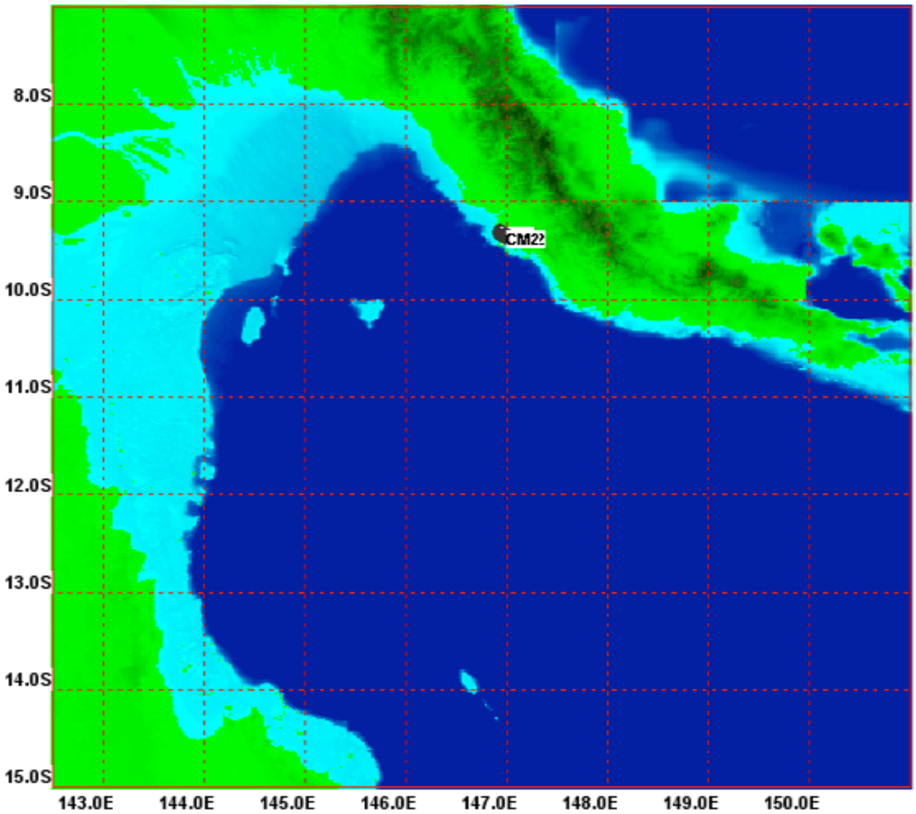

Figure 2.4 Large scale Wave model grid regions.

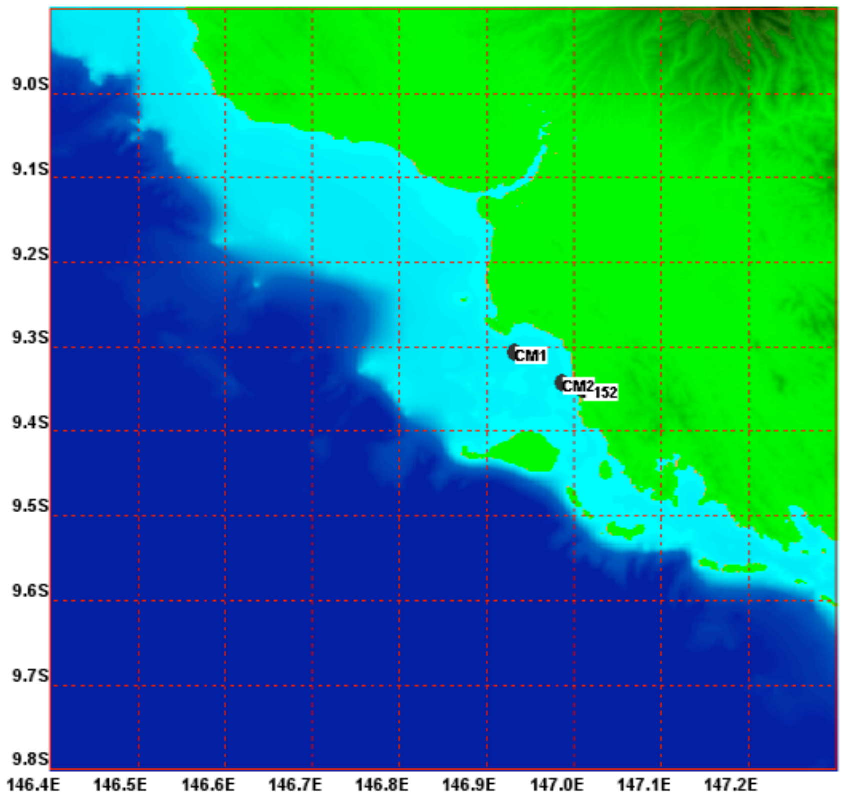

Figure 2.5 Caution Bay Wave Model Grid

3. ANALYSIS OF METEOROLOGICAL &OCEANOGRAPHIC DATA IN CAUTION BAY & VERIFICATION OF PREDICTIVE MODELS

It is important to understand the meteorology and oceanography of the region before any detailed modelling is commenced. This is necessary in order to ensure that the modelling is representing the full range of influences on ocean circulation. The process should proceed as follows:

1) Analysis of relevant meteorological and oceanographic data for the region;

2) Verification of all models to be used for prediction against the field observations; and

3) Prediction of oceanographic conditions with verified ocean models.

Unfortunately a full analysis of the MetOcean data collected in Caution Bay by Cardno Lawson and Treloar was not available at the time of this study and so GEMS has undertaken an independent analysis of the wind, wave, tide and current data.

An Automatic Weather Station (AWS) was sited on land and two Acoustic Doppler Current Profilers (ADCP) were deployed in the two locations (denoted CM1 and CM2) in Caution Bay shown in Figure 3.1. The ADCPs measure waves, sea levels and currents at a number of levels in the water column.

This section reports the results of data analysis and verification of model output against these data.

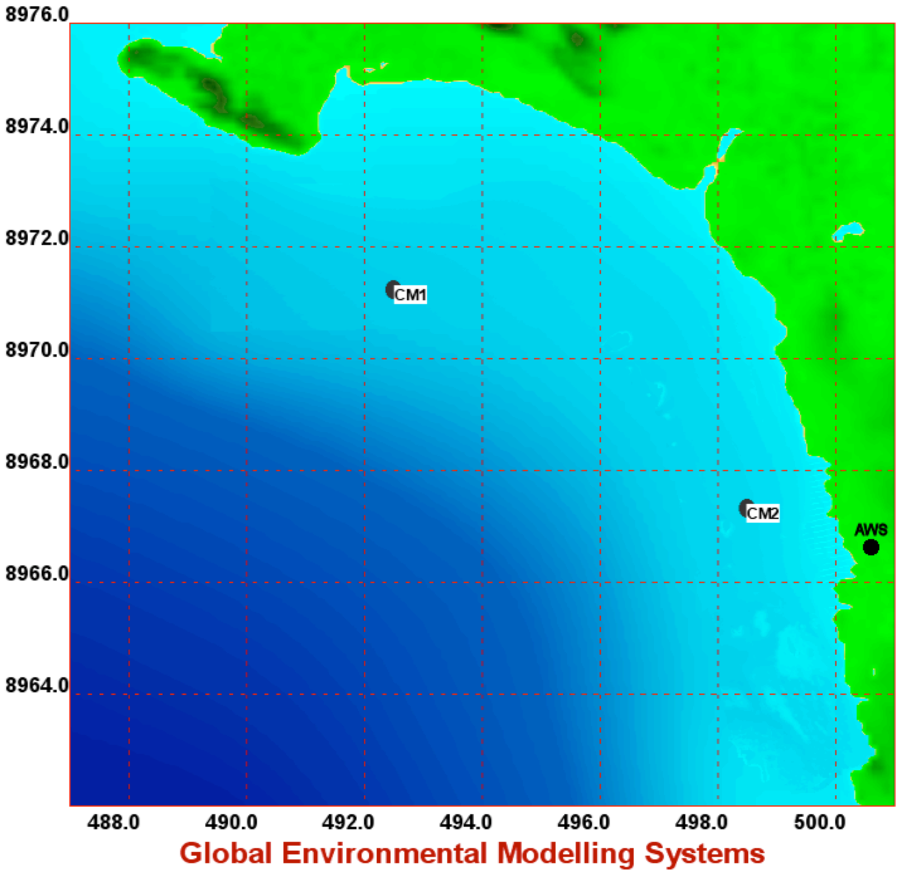

Figure 3.1: Location of the current meters (ADCPs) and the AWS.

3.1 GENERAL COMMENTS

The applicability of a given time period of data to understanding regional climatological influences or to verifying predictions of a model is directly related to the scale (time period) of the data and the location of the observations.

In simple terms, the data needs to capture the scale of the signal of the parameter to be analysed.

For climatological analyses where the focus is on determining the major influences on the region and the variation over seasons and years, the data must be of sufficient time period to capture these processes. The location of the observations needs to be within the region, but not necessarily at the precise site of planned operations.

For determining the behaviour of parameters with shorter times scales (e.g. sea breezes, tides), much shorter time periods are appropriate, but the data should be near to, or arguably representative of, the location of the planned operations.

For model verification, once the meteorology and oceanography is understood, the verification periods can be for relatively short (e.g., 1 month).

3.2 METEOROLOGICAL DATA

To drive ocean models to simulate realistic ocean currents, it is important to use an atmospheric forecast model that reliably represents spatial and temporal variations on daily (incl., sea-breezes), seasonal and inter-annual time scales. As a consequence, the atmospheric model data used must also be verified against observations.

3.2.1 METEOROLOGICAL DATA SOURCES

An AWS was deployed on land near the coast of Caution Bay. Unfortunately, the location on land (see Figure 3.2) is not ideal for oceanographic studies as the influence of land-sea affects can be significant, particularly in the vicinity of significant topography as in Papua New Guinea. As a result, the offshore winds can be expected to be quite different to the onshore winds measured by the AWS.

The data available from the AWS was for the period from February 8 to May 13, 2008 (i.e., a relatively short period), which is useful for verification of models but has limited use for climate studies.

To augment these data, GEMS obtained three years of data from the Australian Bureau of Meteorology (BoM) MesoLAPS atmospheric model.

The BoM routinely operates a suite of Numerical Weather Prediction (NWP) models at a range of spatial and temporal resolutions. These models are nested in space so that the model system captures a range of atmospheric scales ranging from global through regional (continental) to the local, or mesoscale.

The main Australian region forecast model run by the BoM is LAPS (Limited Area Prediction System) runs on a 35km grid from halfway across the Indian Ocean to east of New Zealand. This model runs twice daily nested in the BoM global atmospheric model – GASP (Global Assimilation and Prediction model) and produces forecasts out to ten days.

The BoM has also operated its meso-scale model (MesoLAPS) at a spatial resolution of about 10km for a period of more than eight years. The model is nested inside LAPS and runs twice daily producing an analysis and forecasts out to 48 hours.

Meteorological data from the analysis cycle (zero hour) and the first eleven hours of forecasts of this model are now routinely downloaded twice daily and archived by GEMS. This generates a database of hourly meteorological data with the longest forecast time step of eleven hours.

Validation of the accuracy of the meteorological data for each new study area needs to be undertaken. however, GEMS has compared a number of potential sources of spatially and temporally varying wind fields and concluded that MesoLAPS provides the best representation of coastal wind regimes in Australia and the Pacific.

Figure 3.2: Image of the physical environment of the Automatic Weather Station.

3.2.2 VERIFICATION OF MESOLAPS MODEL DATA

For this study, the MesoLAPS model data was compared with the data from the AWS on land to assess the reliability of the MesoLAPS data in the region and then a longer term analysis of offshore ambient conditions was undertaken using the three years of model data. The agreement between the MesoLAPS data and the data from the AWS is shown in Figure 3.3 and provides confidence in the longer term analyses.

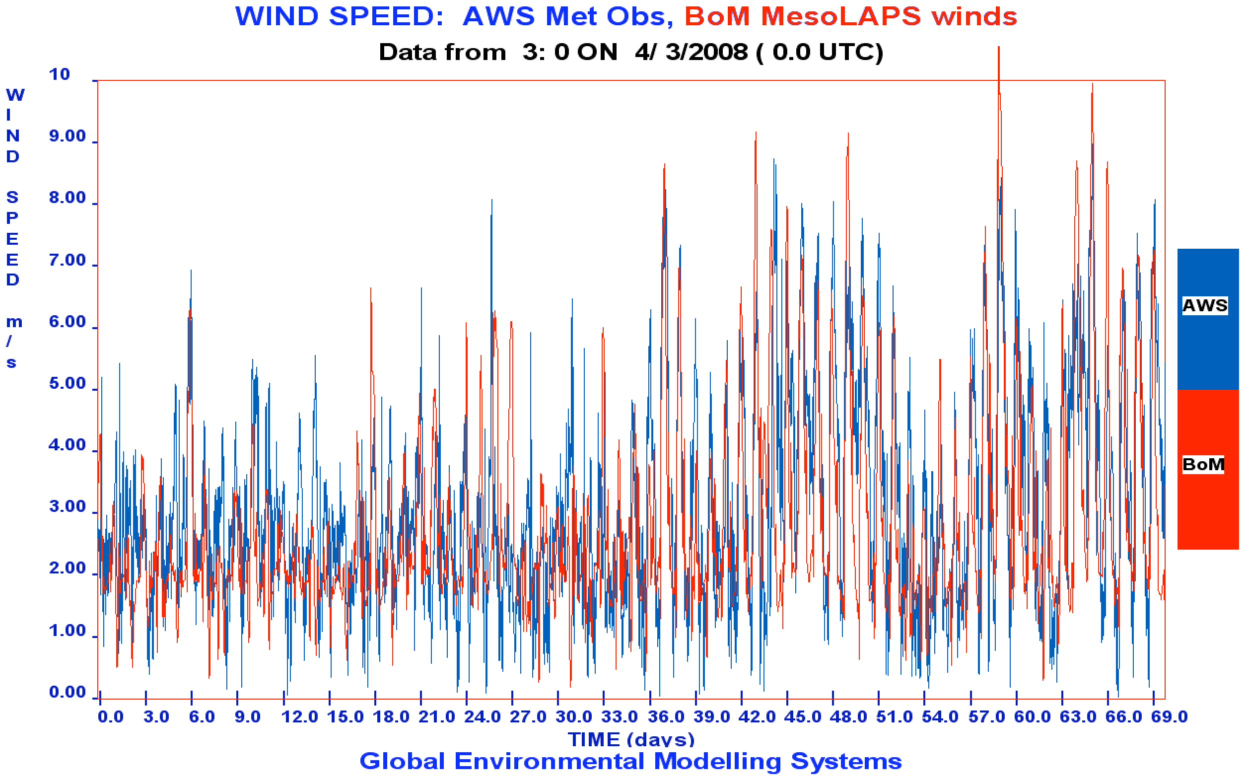

Figure 3.3: Comparison of MesoLAPS model wind speed data with data from the AWS at the site of the AWS.

3.3 SEA LEVEL DATA

3.3.1 DATA SOURCES

The data available for this study covered the period December 20, 2007 to May 8, 2008. To obtain a continuous data set for this period GEMS had to synthesize a single data set from the two sets of data obtained at sites CM1 and CM2 in Figure 3.1. A plot of these data is shown in Figure 3.4.

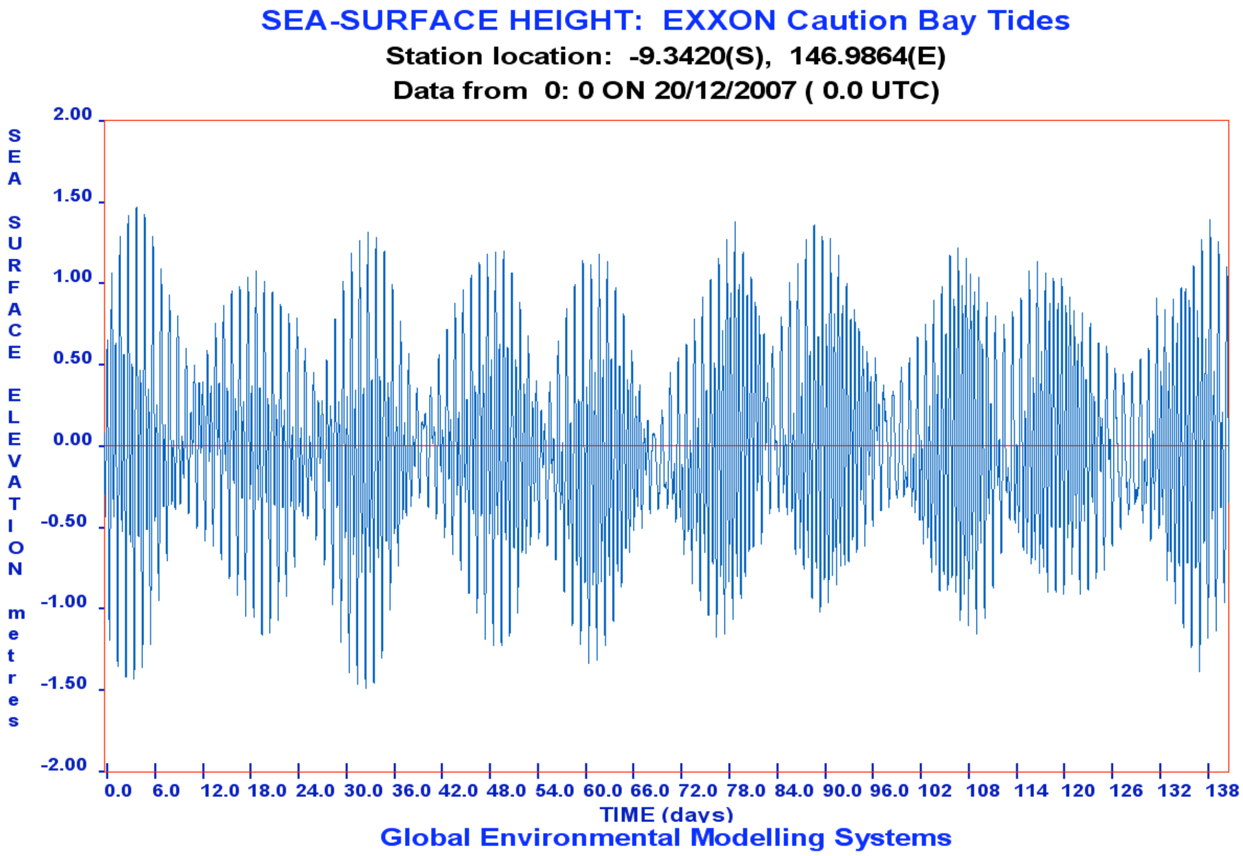

Figure 3.4: Sea levels in Caution Bay from December 20, 2007 to May 8, 2008.

3.3.2 VERIFICATION OF TIDAL PREDICTIONS BY THE 3D OCEAN MODEL

Tidal forcing at the open ocean boundaries of the 3D hydrodynamic model (GCOM3D) is based on data from the GEMS Australian region gridded (1km resolution) tidal data base, which has been developed with extensive modelling programmes (primarily for AMSA Search and Rescue in Canberra). This program covered the Gulf of Papua.

Figure 3.5 compares the sea levels predicted by GCOM3D with observations at site CM2, near the proposed LNG jetty. The similarity between the results provides confidence in long term predictions of sea level by GCOM3D.

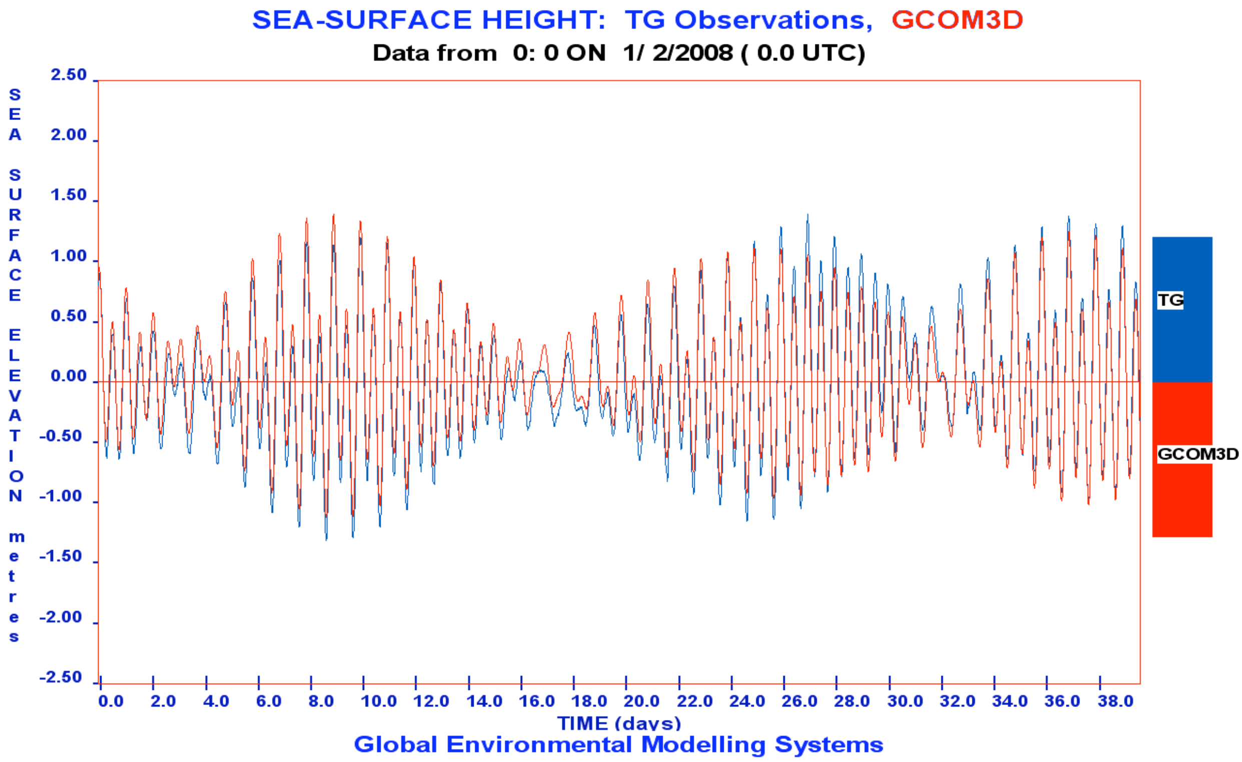

Figure 3.5: Comparison of sea levels predicted by GCOM3D with observations at CM2.

3.4 CURRENT DATA

3.4.1 DATA SOURCES

Due to the vastly different currents measured at the two ADCP sites, the observations cannot be synthesized into one dataset as for the sea level observations. Data on currents was obtained at site CM1 from February 10, 2008 to May 8, 2008 (Figures 3.6 and 3.7 show depth averaged speeds and directions respectively) whilst data was available from site CM2, near the proposed LNG jetty, from September 23, 2007 to February 9, 2008 (Figures 3.8 and 3.9) and from April 17, 2008 to May 8, 2008 . It is assumed that the data between February 10 and April 16, 2008 at CM2 was lost.

Short term surface drifter tracks are also available for two periods in 2008 (June and August).

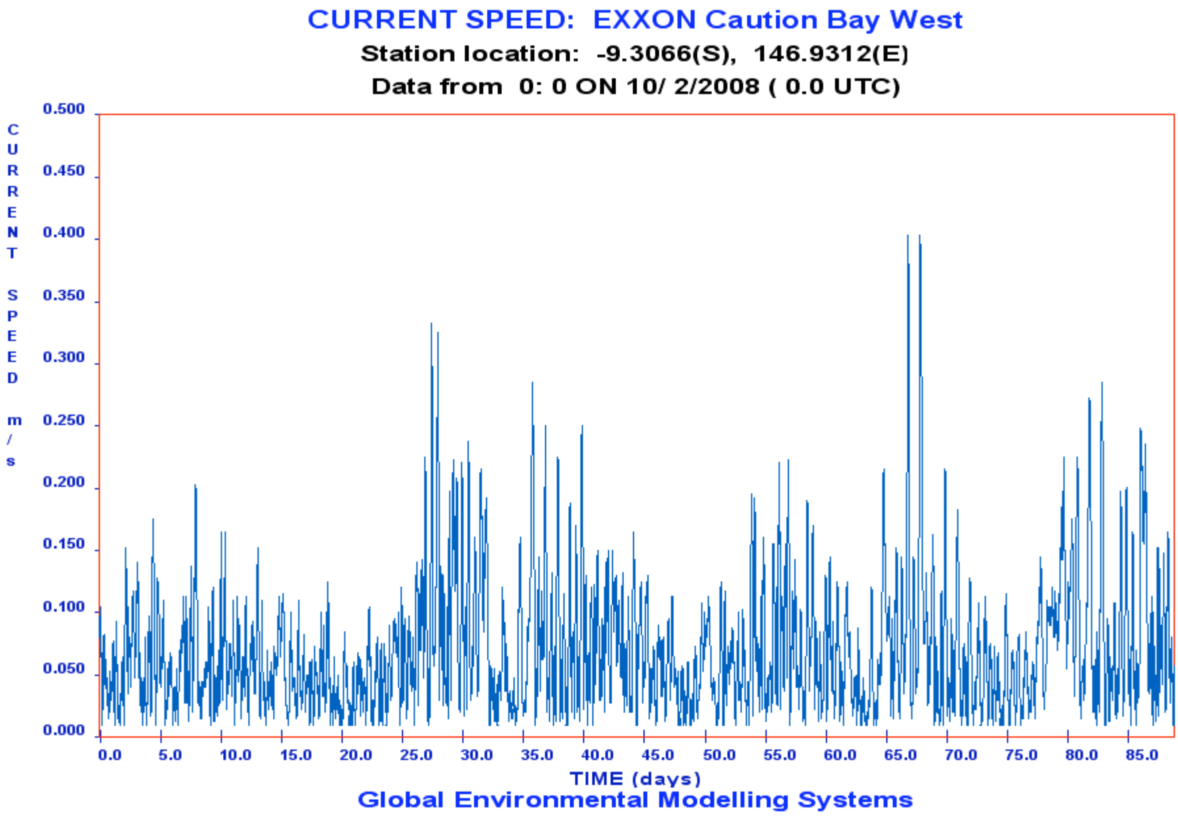

Figure 3.6: Depth averaged current speeds measured at site CM1 from February 10 to May 8, 2008.

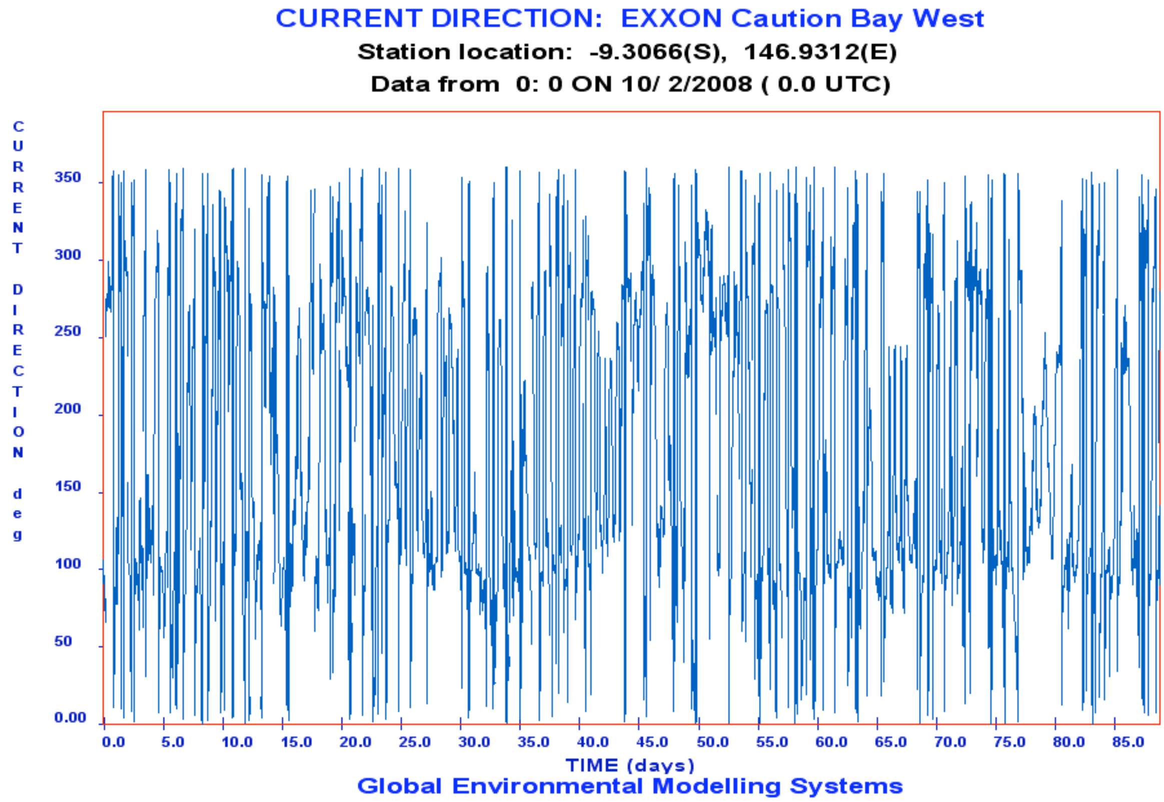

Figure 3.7: Depth averaged current directions measured at site CM1 from February 10 to May 8, 2008.

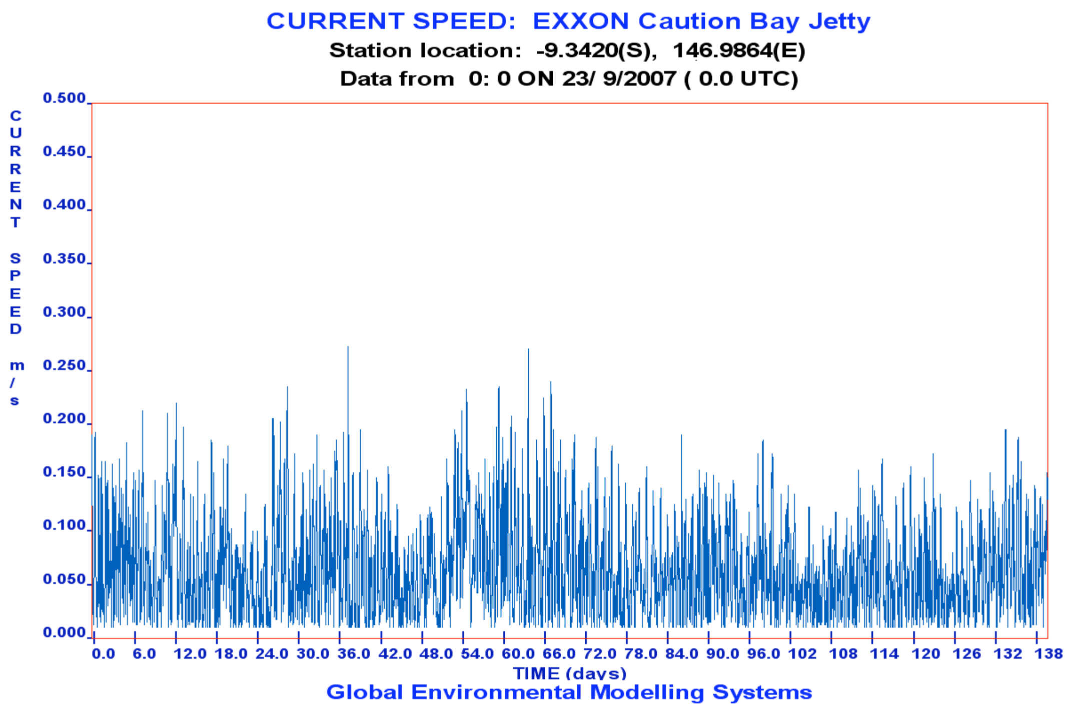

Figure 3.8: Depth averaged current speeds measured at site CM2 from September 23, 2007 to February 9, 2008.

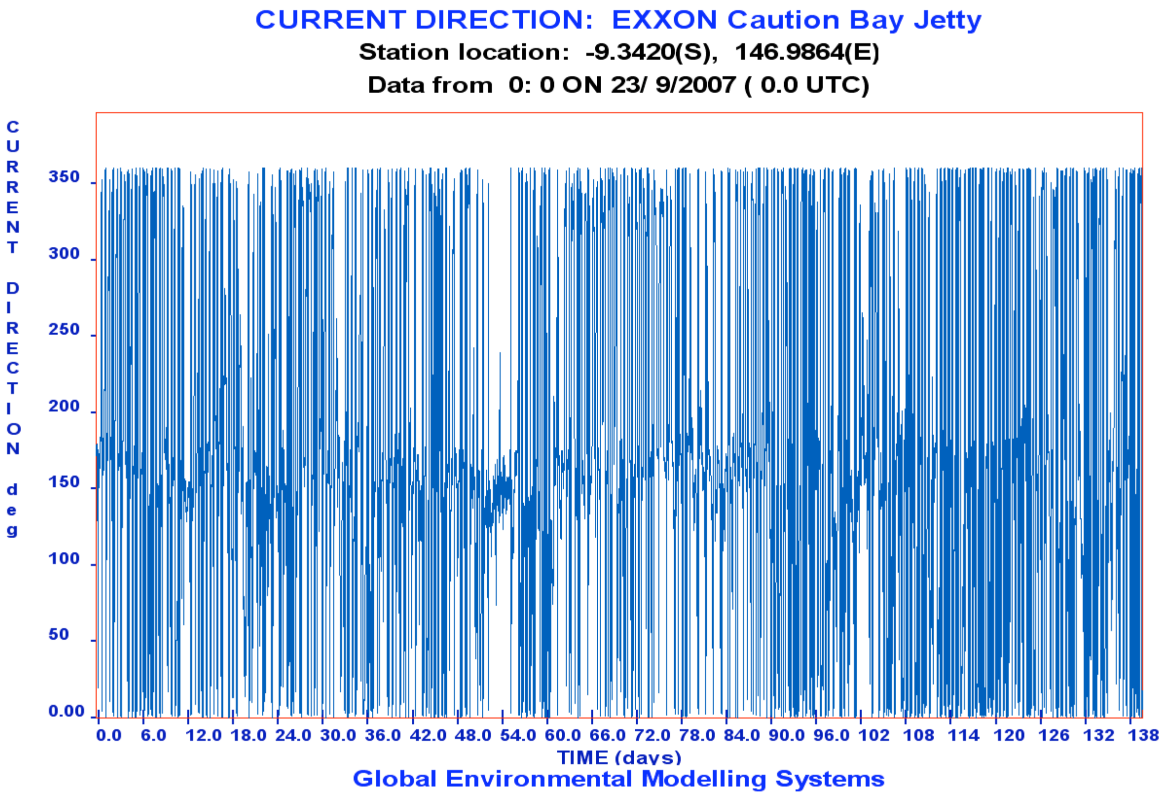

Figure 3.9: Depth averaged current directions measured at site CM2 from September 23, 2007 to February 9, 2008.

3.4.2 VERIFICATION OF GCOM3D

Ideally, the 3D hydrodynamic model should be verified in terms of its ability to represent the horizontal and vertical variations in currents over time. Unfortunately, for this study, the data provided from the ADCPs had been depth-averaged and so the verification of vertical variations in currents was not possible.

The comparison of GCOM3D predictions of current speeds and directions near the proposed LNG jetty (site CM2) with observations shown in Figures 3.10 and 3.11 respectively provides strong evidence that GCOM3D is reliably predicting the ocean circulation in the study region.

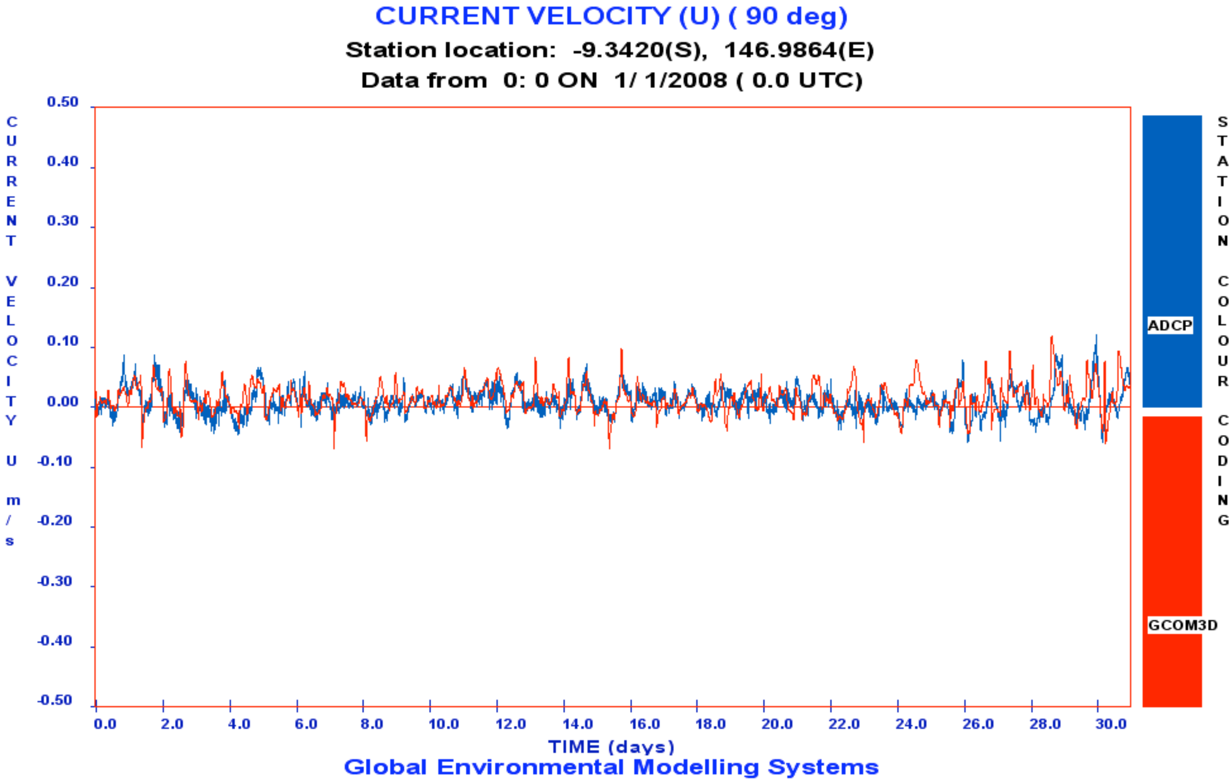

Figure 3.10: Comparison of GCOM3D predictions of the easterly current component with measurements at site CM2 from January 1 to February 1, 2008.

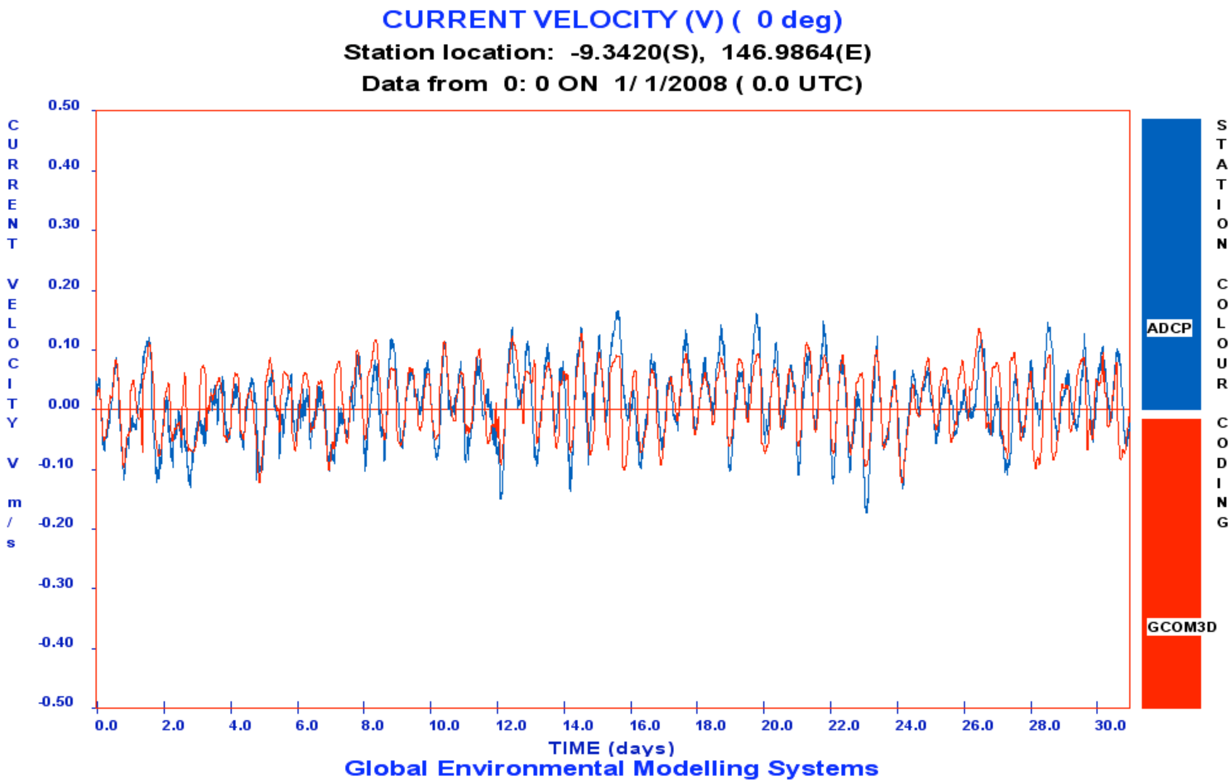

Figure 3.11: Comparison of GCOM3D predictions of the northerly current component with measurements at site CM2 from January 1 to February 1, 2008.

3.5 WAVE DATA

The wave climate is heavily dominated by the wind climate, therefore the analysis and verification of winds provides an important input to the assessment of the variation in wave forcing.

3.5.1 DATA SOURCES

Data on waves was obtained at site CM1 from February 10, 2008 to May 8, 2008.

Wave data was also available from site CM2, near the proposed LNG jetty, from September 23, 2007 to February 9, 2008 (Figures 3.12 to 3.15 show maximum wave heights, significant wave heights, peak wave energy directions and peak wave periods respectively) and from April 17, 2008 to May 8, 2008. As noted earlier, the data between February 10 and April 16, 2008 at CM2 was assumed lost.

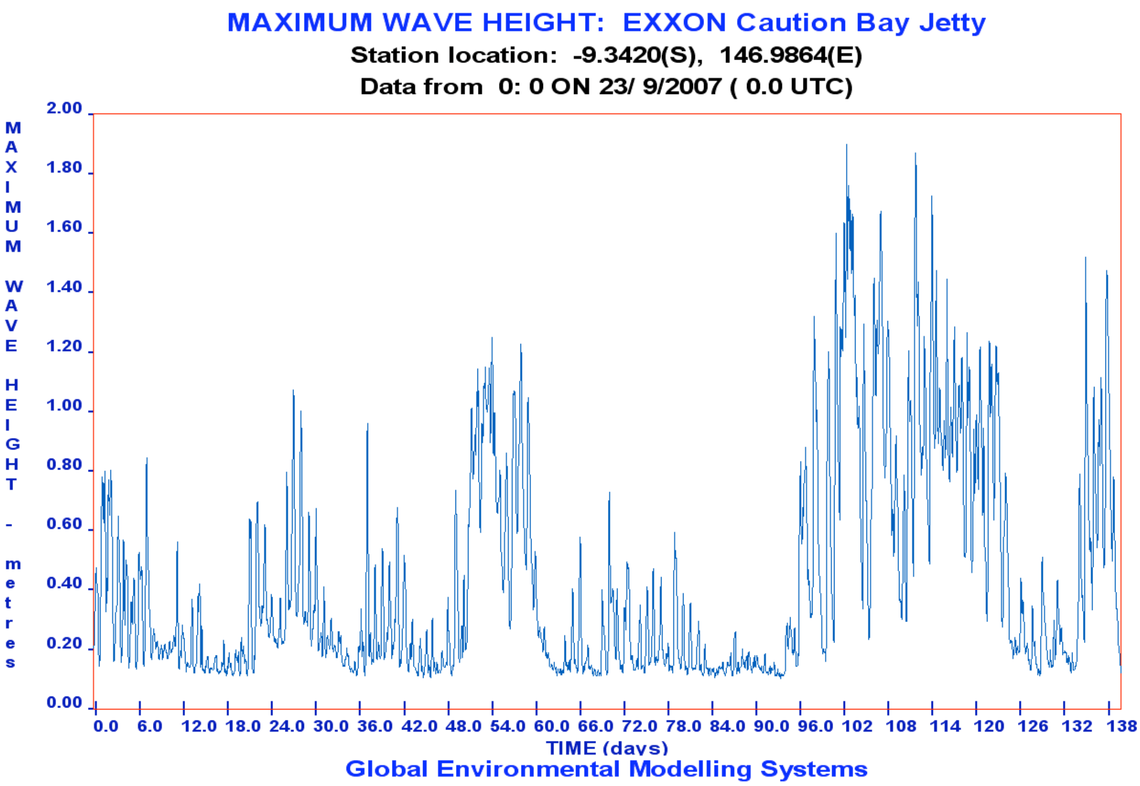

Figure 3.12: Maximum wave height at CM2 from September 13 2007 to February 9 2008.

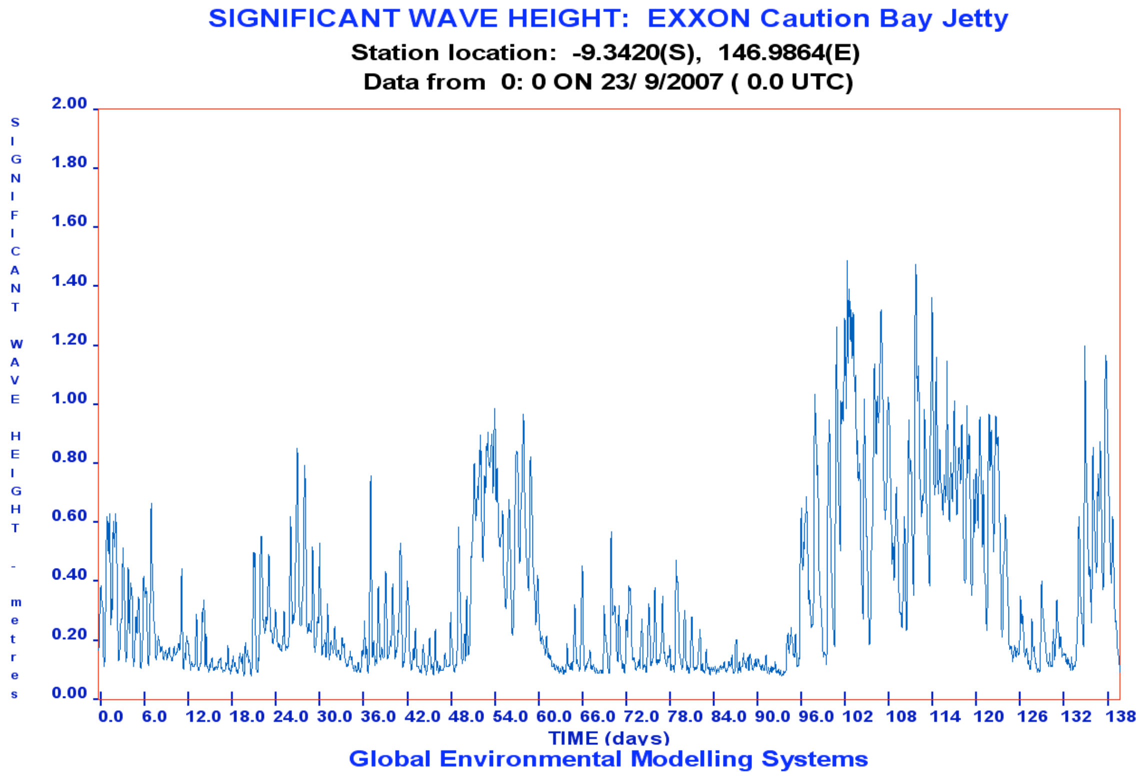

Figure 3.13: Significant wave height at CM2 from September 13 2007 to February 9 2008.

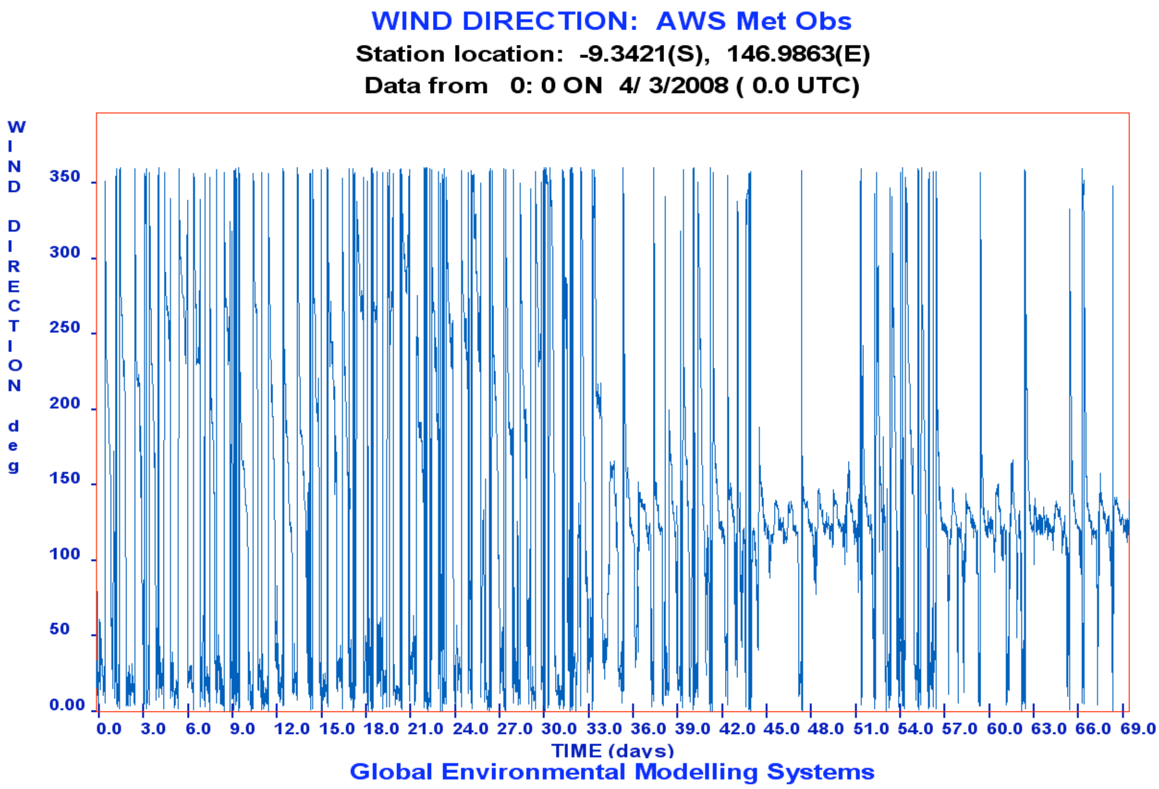

Figure 3.14: Wave direction at CM2 from September 13 2007 to February 9 2008.

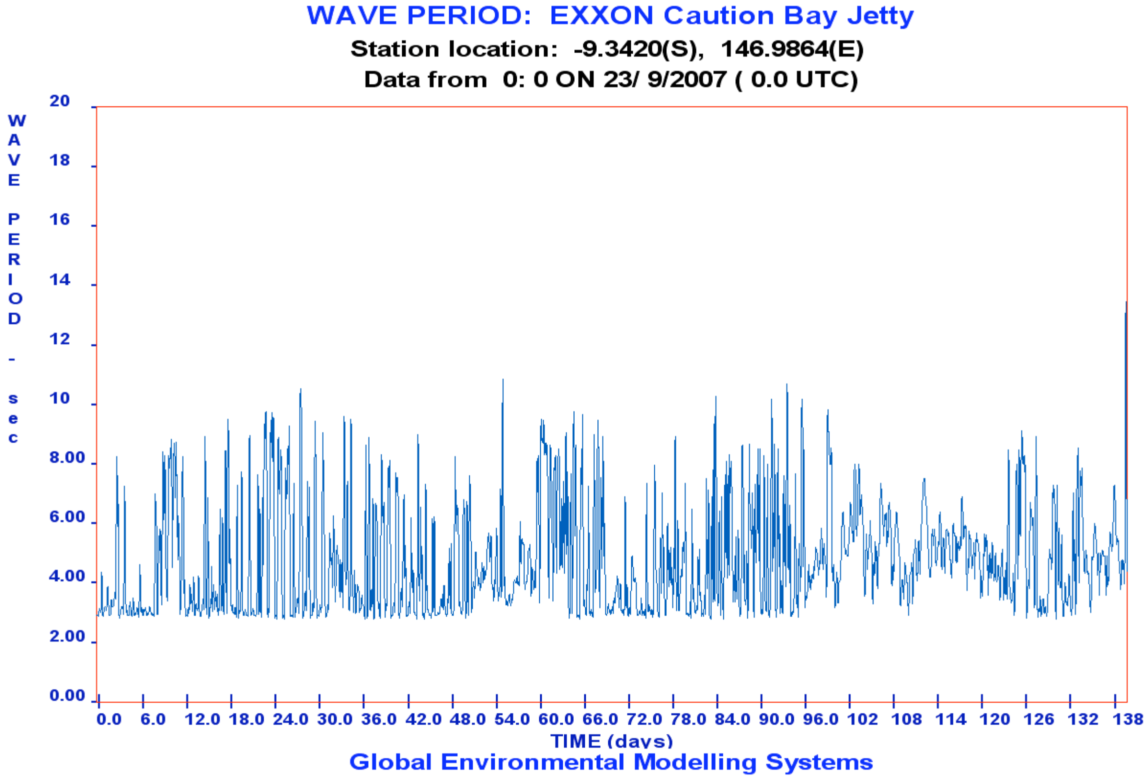

Figure 3.15: Wave periods at CM2 from September 13, 2007 to February 9, 2008.

3.5.2 MODEL VERIFICATION

GEMS uses the SWAN wave model driven by BoM model wind fields for ocean and coastal wave prediction. The comparison of SWAN predictions of significant wave heights, directions and periods near the proposed LNG jetty (site CM2) with observations during January 2008, shown in Figures 3.16 to 3.18 respectively, provides strong evidence that GCOM3D is reliably predicting the ocean circulation in the study region. The period of January 2008 was chosen for verification because it was the period where the strongest waves were observed, driven by the northwest monsoons.

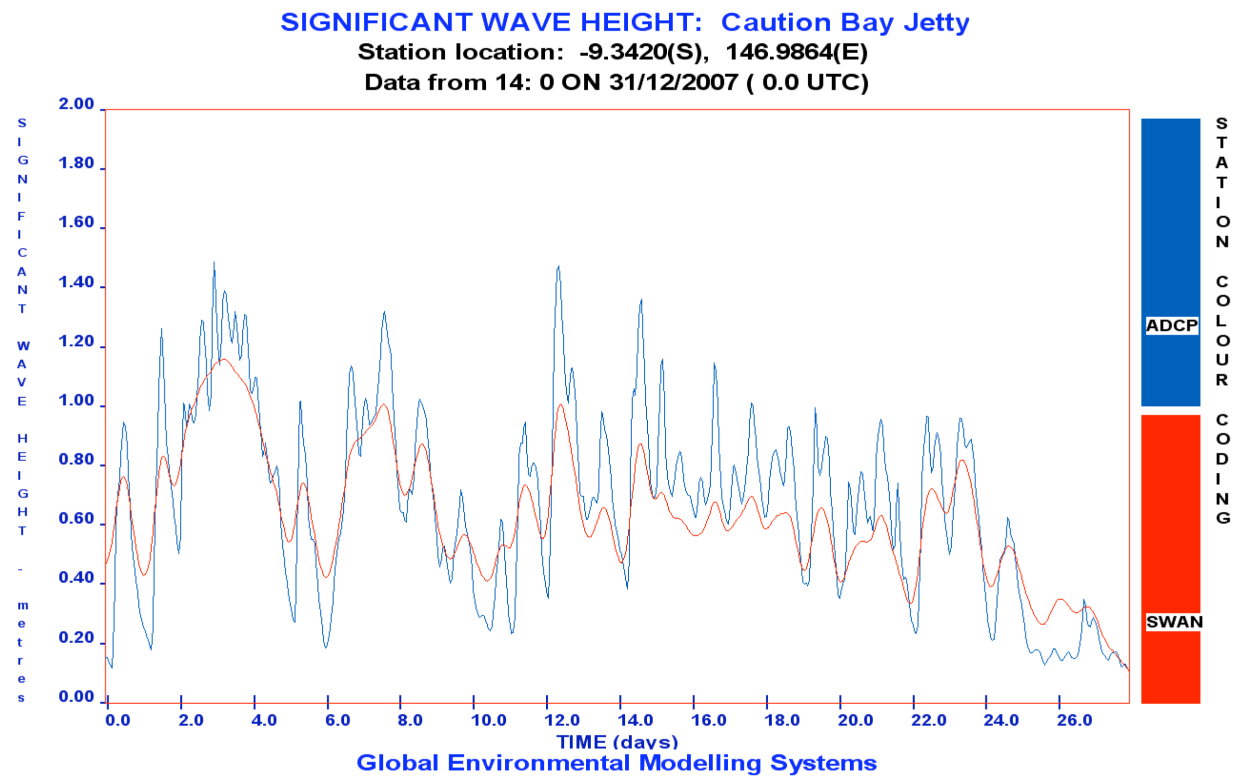

Figure 3.16: Comparison of SWAN predictions for significant wave heights with observations during January 2008.

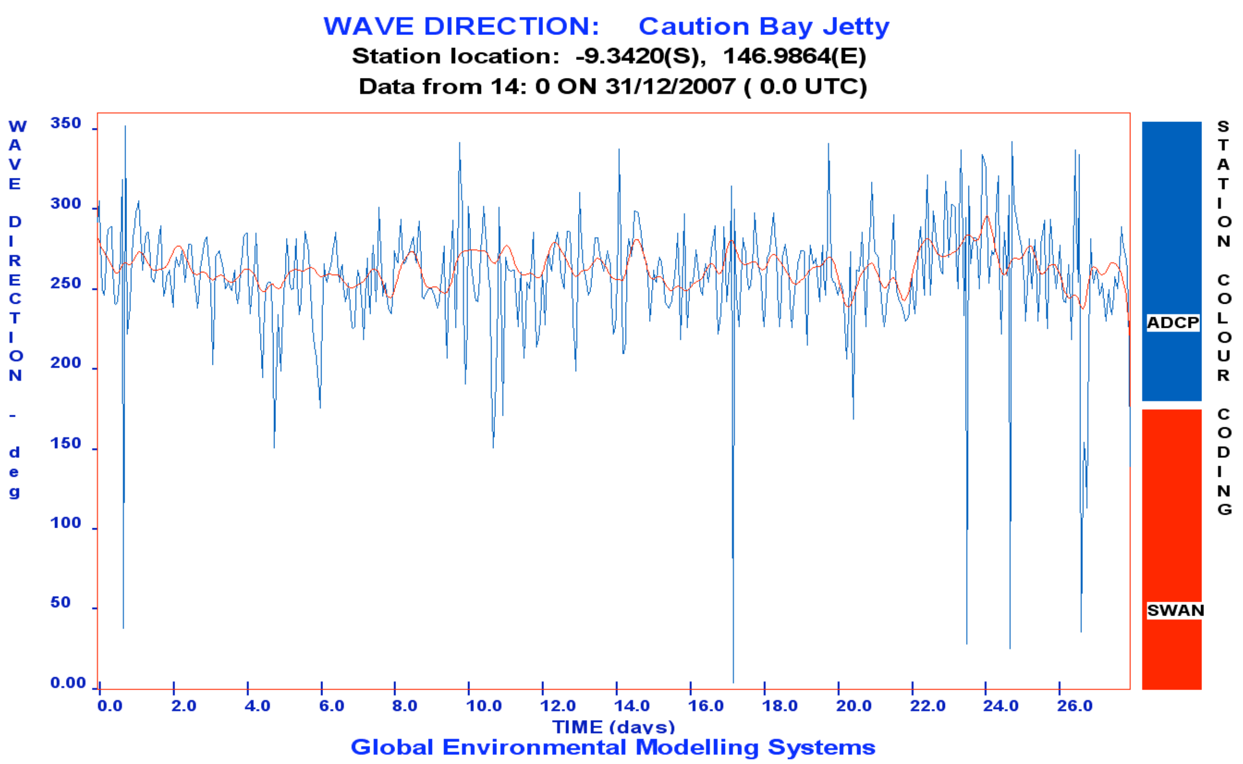

Figure 3.17: Comparison of SWAN predictions for wave directions with observations during January 2008.

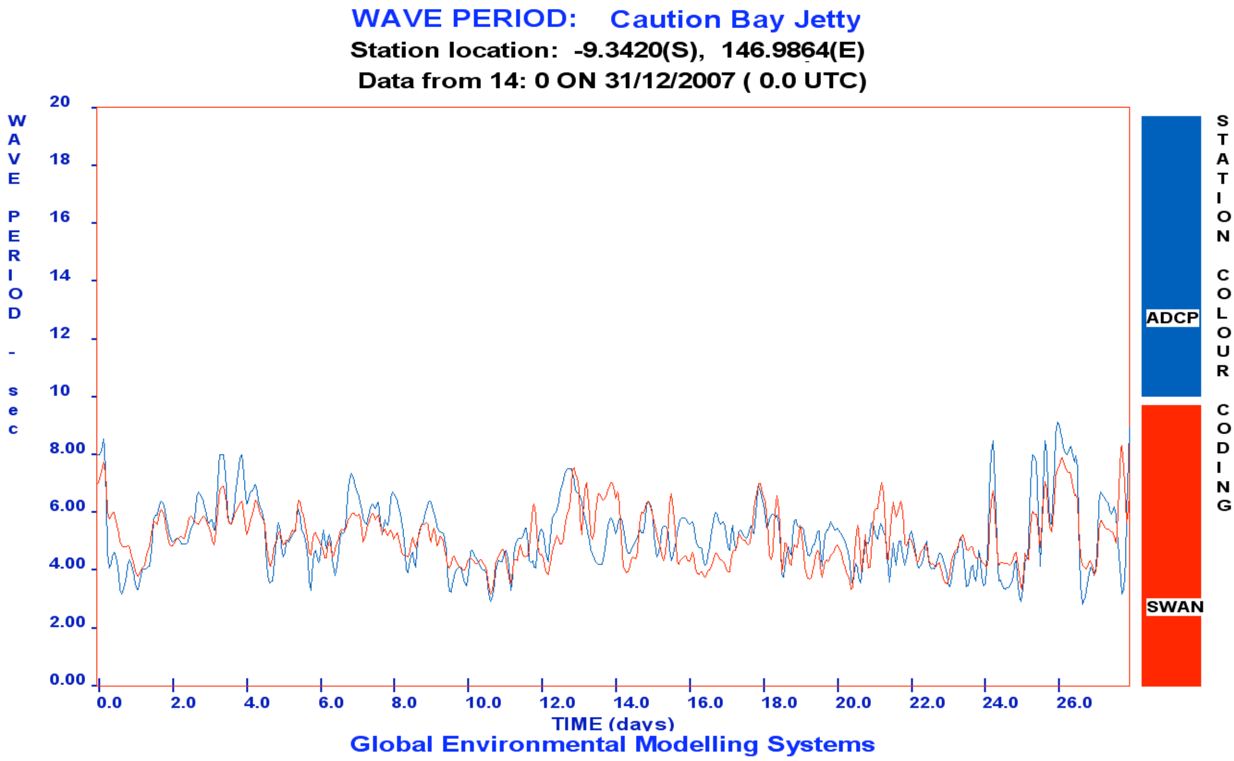

Figure 3.18: Comparison of SWAN predictions for significant wave periods with observations during January 2008.

4. AMBIENT CONDITIONS IN CAUTION BAY

The ambient conditions in Caution Bay were derived by analyzing the data obtained by CLT and the model output from the BoM MesoLAPS model (three years of data), the GEMS 3D ocean Model (12 months of predictions) and the SWAN wave model (12 months of predictions).

4.1 METEOROLOGY

The climate of the region is effectively dominated by two main seasons. The period from December to March is generally dominated by the Northwest monsoons, whereas from May to December the Southeast trade winds (or monsoons) generally prevail.

The wind rose derived from the **onshore** AWS data from February to May, 2008 is shown in Figure 4.1. The northwest monsoon winds during late summer are present in the data together with the onset of the southerly winds as winter in the Southern Hemisphere approaches.

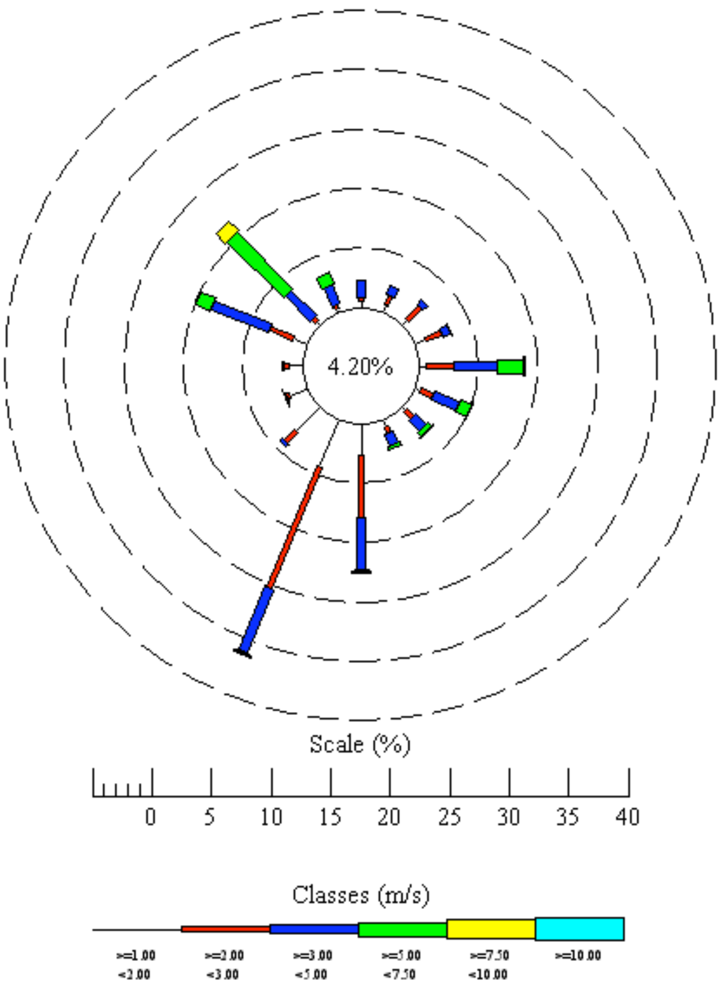

Figure 4.1: Wind rose based on the AWS data from February to May, 2008.

The analysis of three years of **offshore** MesoLAPS data showed the full range of seasonal variations changing from the summer monsoons to the winter trade winds. Figure 4.1 shows the wind rose derived from the three years of data. The analysis of the three years of data is summarised in Table 2. The results show three main features:

a) The dominance of the southeasterly trade winds offshore;

b) The existence of katabatic winds from the northeast off the coastal topography; and

c) The significant difference in the wind regime between onshore and offshore sites

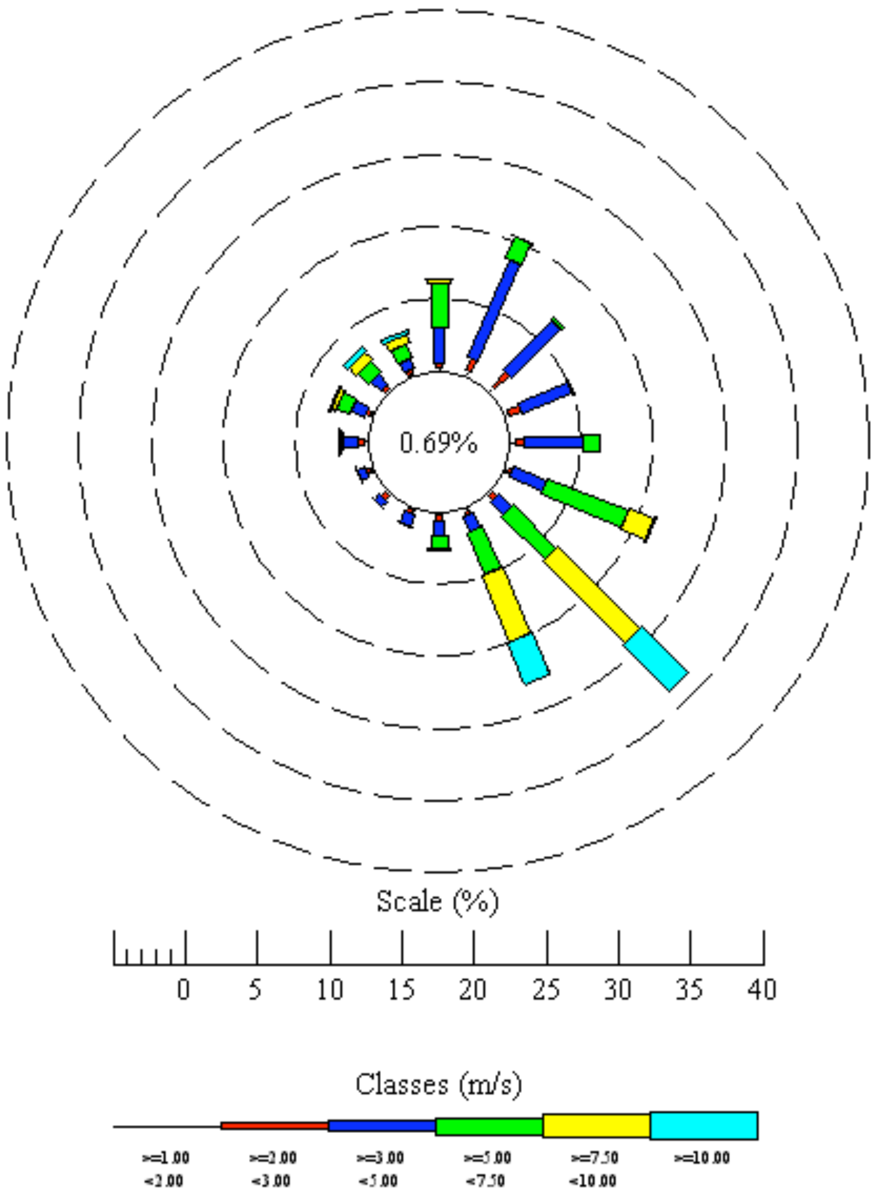

Figure 4.2: Wind rose based on the MesoLAPS model data from July 2005 to July 2008.

Table 2: Summary of the analysis of MesoLAPS data from July, 2005 to July, 2008

Parameter	**Three Years of MesoLAPS data (July, 2005 – July, 2008)**	**Three months of AWS data (February, 2008 – April, 2008)**
Mean Hourly Wind Speed	4.8 m/s	3.1 m/s
Mean Wind Direction	300 deg	85 deg
Average of Top 100 Wind Speeds	11.5 m/s	8.8 m/s
Average Direction of Top 100 Wind Speeds	314 deg	134 deg

4.2 OCEAN TIDES

The tidal harmonic constituents at a site are determined by analysing long term sea level measurements using Fourier analysis techniques. The method used by GEMS is based on the method applied by the Canadian Institute for Ocean Sciences. Analysis of the sea level data collected in Caution Bay produced the harmonic components listed in Table 3. Table 3 also summarises the long term tidal characteristics.

Table 3: Tidal harmonic parameters and tidal characteristics from the analysis of Caution Bay sea level data.

Data start date	20/12/2007		
Data duration	140 days		
Model start date	01/07/2007		
Model duration	365 days		
Maximum sea level	1.47 metres		
Minimum sea level	-1.49 metres		
Tidal harmonics*	Period	Amplitude (<0.1)	Phase (local)
O1	25.8193	0.143	152.1
K1	23.9345	0.272	194.5
N2	12.6583	0.165	259.7
M2	12.4206	0.528	277.7
S2	12.0000	0.337	254.2

* Tidal Harmonic Constants are developed for particular regions by Fourier analysis of existing tidal records. Once developed, they can be used in hydrodynamic modelling to predict future tides.

4.3 OCEAN CURRENTS

The analysis of 12 months of modelled data and the 5 month data set of currents at the two sites in Caution Bay is summarized in Table 4.

Table 4: Results of analysis of 12 months of modelled data and observed current data at two sites in Caution Bay

Parameter	CM1	CM2
Mean Hourly Current Speed	0.07 m/s	0.07 m/s
Residual Current Speed	0.01 m/s	0.02 m/s
Residual Current Direction	99 deg	122 deg
Major Axis Direction	330 deg	107 deg
Average of top 100 current speeds along major axis	0.22 m/s	0.32 m/s

4.4 OCEAN WAVES

The analysis of 12 months of modelled data and the 5-month data set of waves in Caution Bay at the jetty site (CM2) is summarized in Table 5.

Table 5: Results of analysis of 12 months of modelled data and observed wave data at the jetty site (CM2) in Caution Bay

Parameter	Value
Maximum Wave Height	1.90 m
Maximum Significant Wave Height	1.41 m
Mean Direction of top 100 Maximum Waves	276 deg
Mean Period of top 100 Maximum Waves	4.8 sec
Minimum wave height	0.10 m
Mean Wave Height	0.42 m
% Time Wave Heights Exceed 1 metre	10%

5. EXTREME CONDITIONS IN CAUTION BAY

The occurrence of tropical cyclones in the Gulf of Papua is very infrequent. There have been five named cyclones since 1993:

1. Adel (1993)
2. Upia (2002)
3. Epi (2003)
4. Pierre (May, 2007)
5. Guba (November, 2007)

Of these Guba is by far the most relevant as it entered the Gulf of Papua from the southeast as a Category one cyclone (see track in Figure 5.1) and caused flooding on the southeastern portions of Papua New Guinea. The CLT instruments were recording during this period and the peak significant wave heights at the Caution Bay jetty site were just over 1 metre, whilst there was only a small storm surge and peak currents reached 0.2 m/s.

A search of the tropical cyclone data base, back to before satellite observations were available (1950s), did not reveal any incident of cyclone genesis in the northern part of the Gulf of Papua. Cyclones either entered the Gulf of Papua from the southeast or from the west from the Gulf of Carpentaria. In all cases the cyclones were situated well to the south of Caution Bay and simulations so far have not produced greater impacts at Caution Bay than those experienced during Tropical Cyclone Guba.

The conclusion from this is that there is minimal chance of a tropical cyclone causing significant impacts at the jetty site.

To study the impacts of a tropical storm (not cyclone) in Caution Bay, a 990 hPa event was simulated, with the storm travelling from northwest to southeast past Caution Bay at a distance such that the strongest winds would impact near the coastline. The track of the storm is shown in Figure 5.2.

The wind and pressure fields were simulated with the GEMS severe storm model and these fields were then used to drive GCOM3D on the grid shown in Figure 5.2. Tidal forcing was excluded from the study in order to obtain an understanding of the true storm surge response in Caution Bay.

Figure 5.3 shows the peak wind speeds at the jetty site in Caution Bay during the passage of the storm, whilst Figures 5.4 and 5.5 show the storm surge and currents, respectively, generated at sites CM1 and CM2.

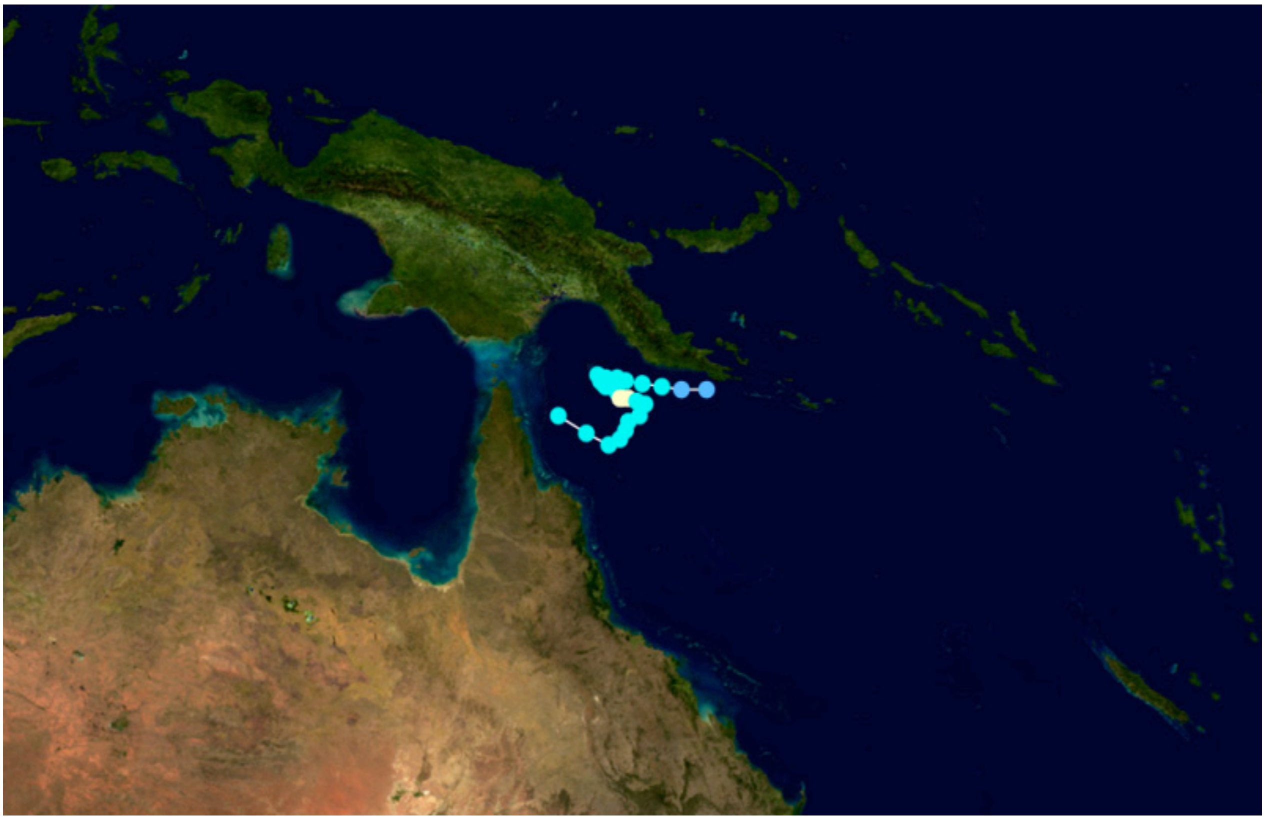

Figure 5.1: Track of tropical cyclone Guba which reached 980 hPa in the Gulf of Papua.

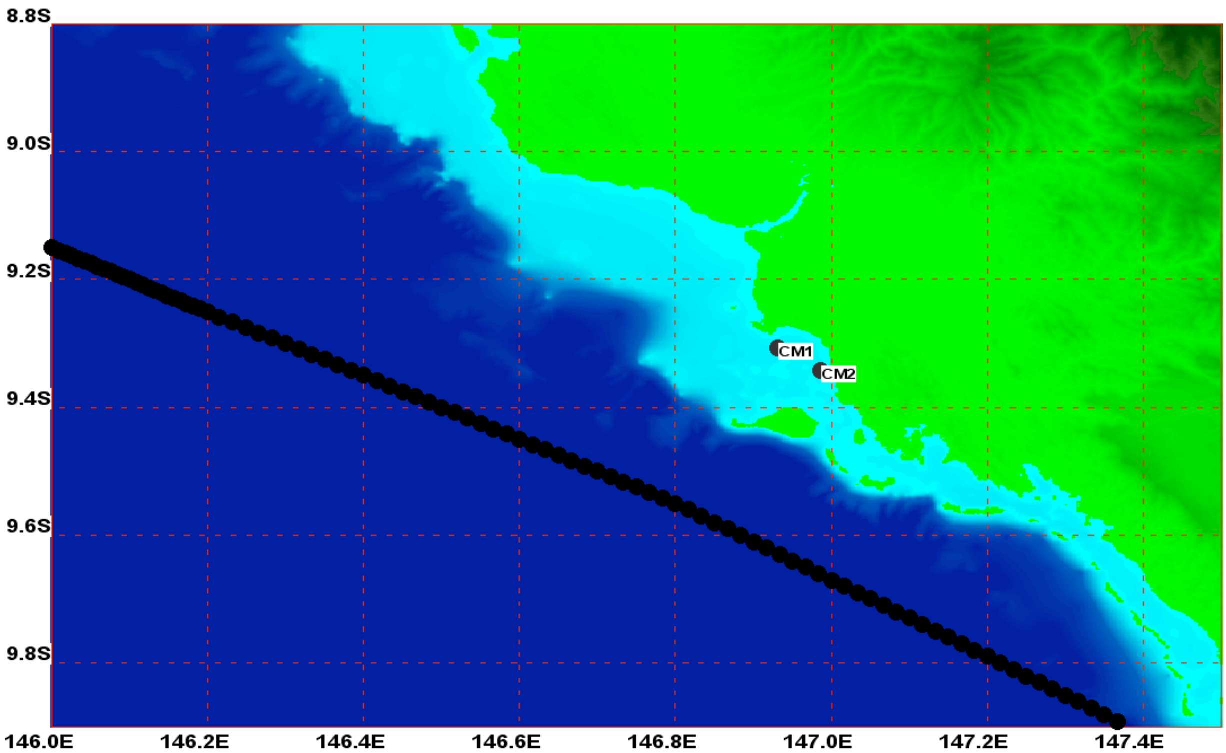

Figure 5.2: Track of a 990 hPa tropical storm travelling past Caution Bay.

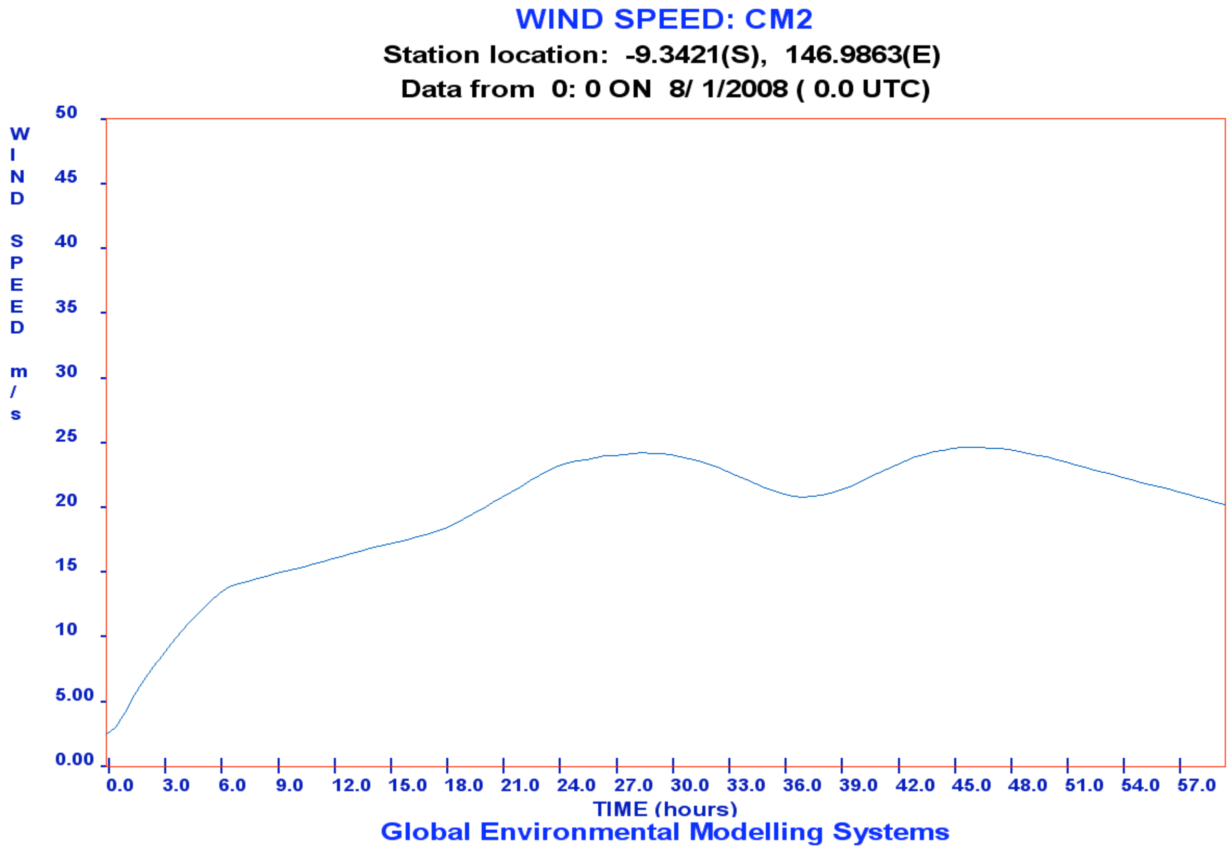

Figure 5.3 Wind speeds generated at the LNG Jetty by the passage of a 990 hPa cyclone.

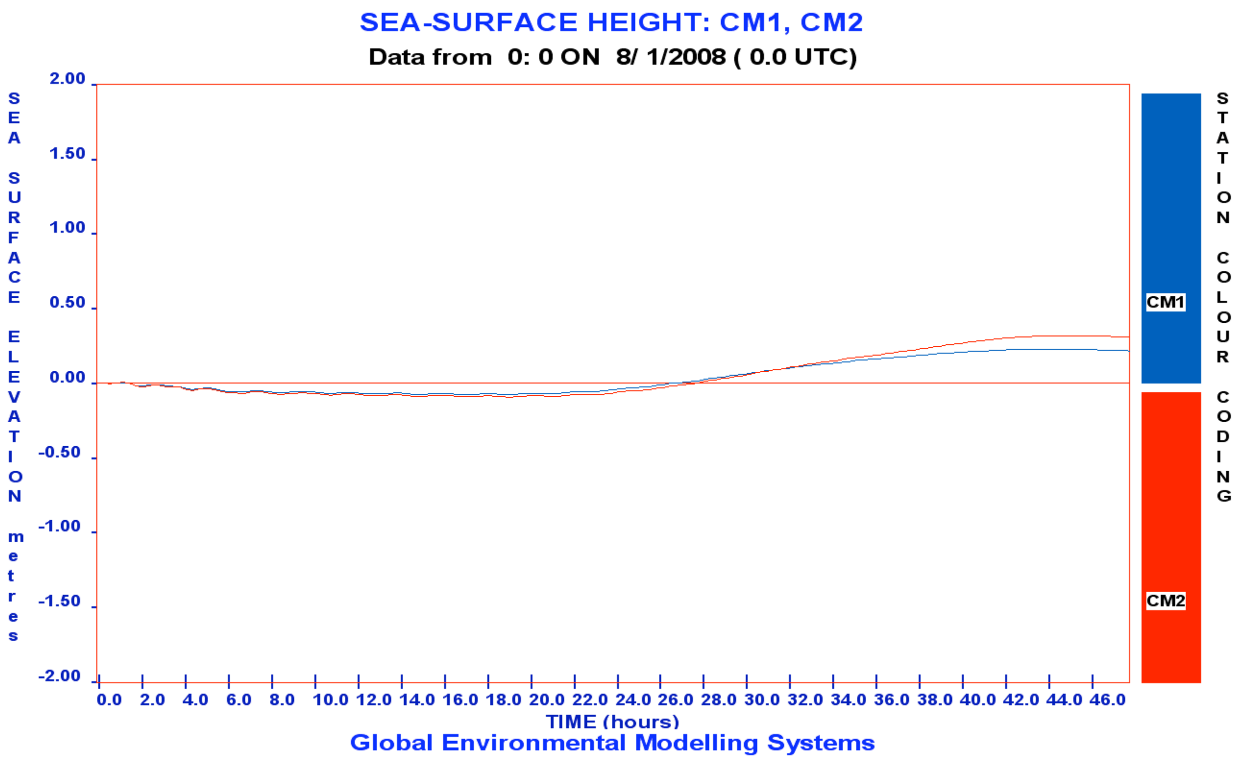

Figure 5.4: Storm surge in Caution Bay generated by the passage of a 990hPa storm.

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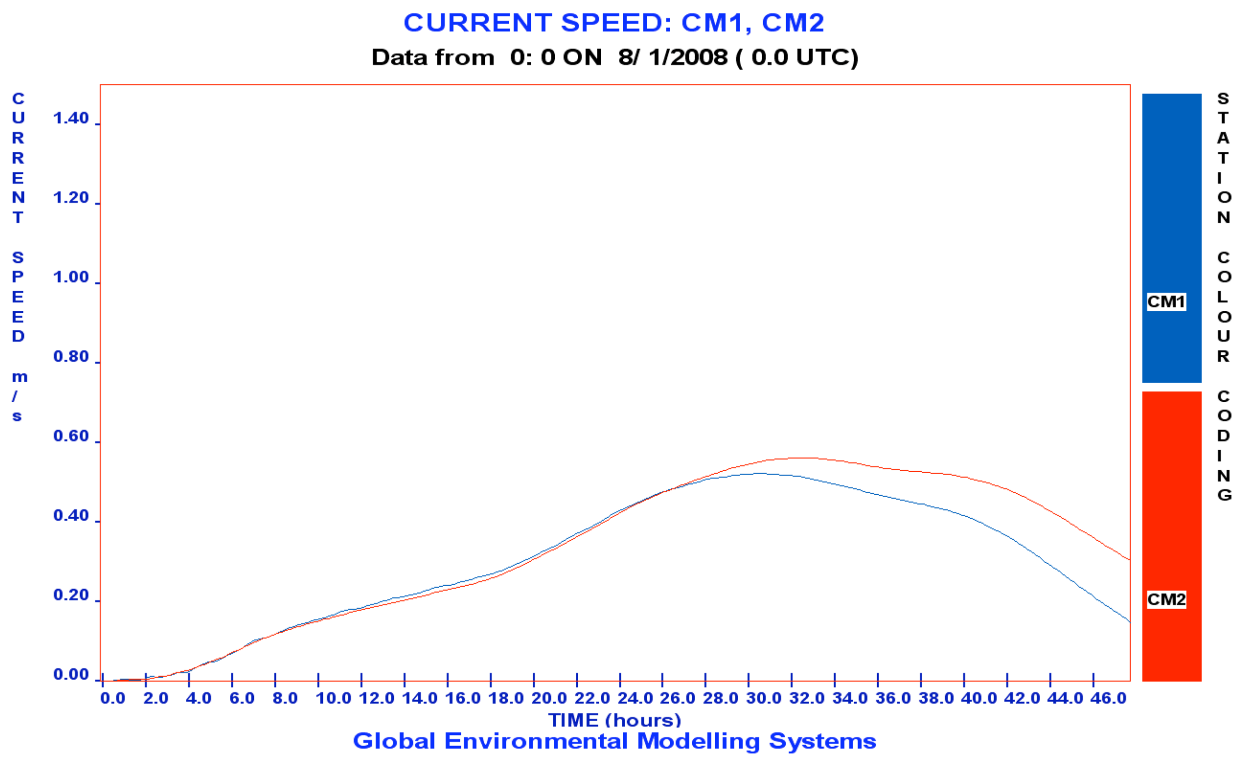

Figure 5.5: Currents generated at sites CM1 and CM2 in Caution Bay generated by the passage of a 990hPa storm.

Table 6 summarises the peak wind, wave, sea level and current conditions generated in Caution Bay by the passage of the 990 hPa storm. It should be noted, however, that this storm is purely theoretical and stronger than any event found in the meteorological database. The reason for the simulation is to put an extreme upper bound on sea conditions at the jetty site.

Table 6: Summary of the peak wind, wave, sea level and current conditions generated in Caution Bay by the passage of the 990 hPa storm.

Parameter	Theoretical Tropical Storm	Tropical Cyclone Guba
Maximum Wind Speed	25 m/s	12 m/s
Maximum Lea Level	0.25 m	0.1 m
Maximum Current Speed	0.40 m/s	0.21 m/s
Maximum Significant Wave Height	3.2 m	1.0 m

6. THE IMPACTS ON THE HYDRODYNAMICS OF CAUTION BAY OF THE SOLID CAUSEWAY

The construction of the MOF and jetty as set out in Figure 1.2 involves the building of a solid causeway to the MOF and then a piled jetty to the LNG tanker berthing facilities. The establishment of this solid causeway may have some effects on the local circulation. The task in this part of the study was to investigate the impacts of the causeway, if any, on the local waves and currents.

To undertake this study, a high resolution bathymetric grid was established with a grid resolution of 20 metres as shown in Figure 6.1. The grid was then modified to include the solid causeway as shown in Figure 6.2.

These two grids were then used to model the "before" and "after" ambient and storm driven current circulation in the region. To quantify the effects of the causeway several monitoring points (M1, M2, M3, CM1 and J in Figure 6.1) were set up to store sea levels and currents during the "before" and "after" simulations. The placing of these monitoring points was for the following reasons:

- M1 and M3 are approximately 100 metres north and south of the causeway respectively,
- M2 is approximately 100 metres west of the end of the causeway
- J is at the proposed LNG berthing jetty
- CM2 is at the site of the ADCP near the jetty location

6.1 AMBIENT CONDITIONS

Two model simulations with the 3D ocean model were carried out for 12 months from July 1, 2007 to July 1, 2008. The first simulation generated the circulation in Caution Bay without the solid causeway and the second simulation included the causeway. In both cases the high resolution ocean model was nested inside the results obtained for the larger domain, which have been reported earlier.

A zoomed sample comparison of the flow around the solid causeway is shown in Figure 6.3 whilst the original circulation for the same time is shown in Figure 6.4.

The results obtained at the monitoring points are summarised in Table 7.

6.2 STORM CONDITIONS

The "before" and "after" simulations of storm conditions were also carried out on the high resolution grids, nested in the larger domains described earlier. It has been noted that the strongest storm conditions are likely to come during the summer northwest monsoons or due to a tropical storm cell forming in the upper regions of the Gulf of Papua. To test the impact of the solid causeway the theoretical storm described in the previous section was used to drive the ocean model on the high resolution grids.

The results of these simulations are reported in Table 7 in terms of the change in conditions after the causeway is built.

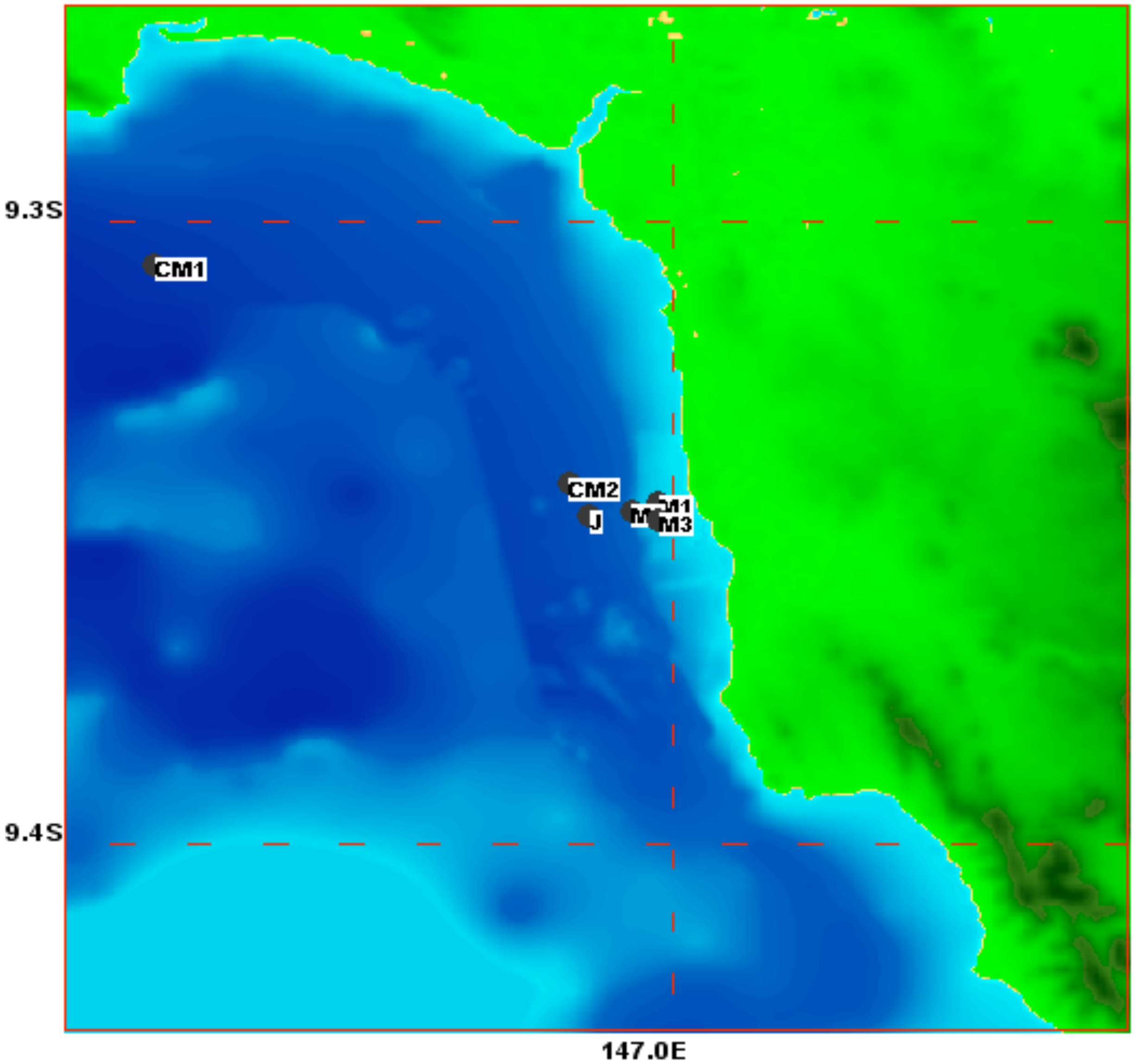

Figure 6.1: The bathymetric grid established to simulate circulation before the solid causeway is built showing the location of the model monitoring stations.

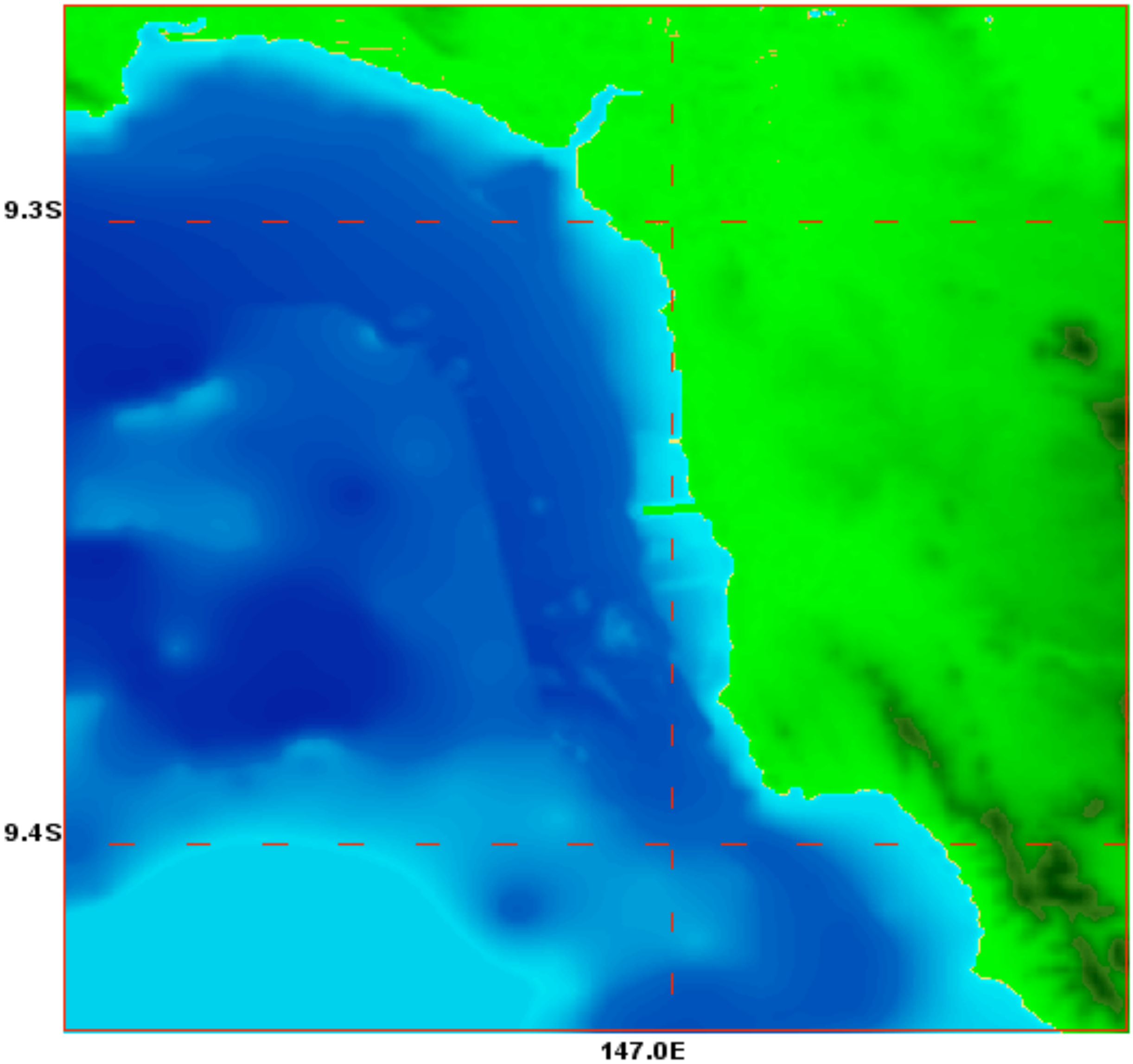

Figure 6.2: The bathymetric grid established to simulate circulation after the solid causeway is built.

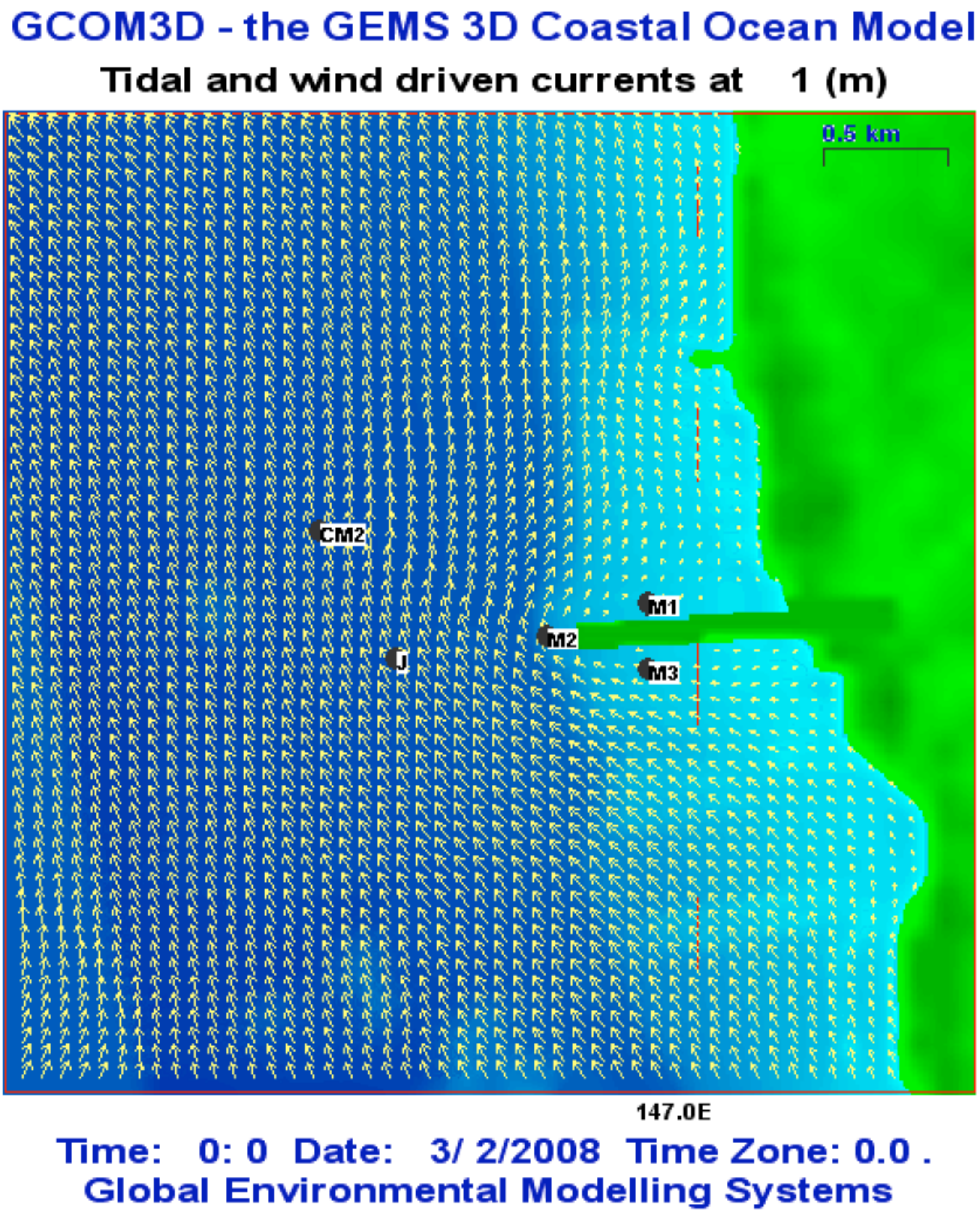

Figure 6.3: A "snapshot" of the flow around the solid causeway.

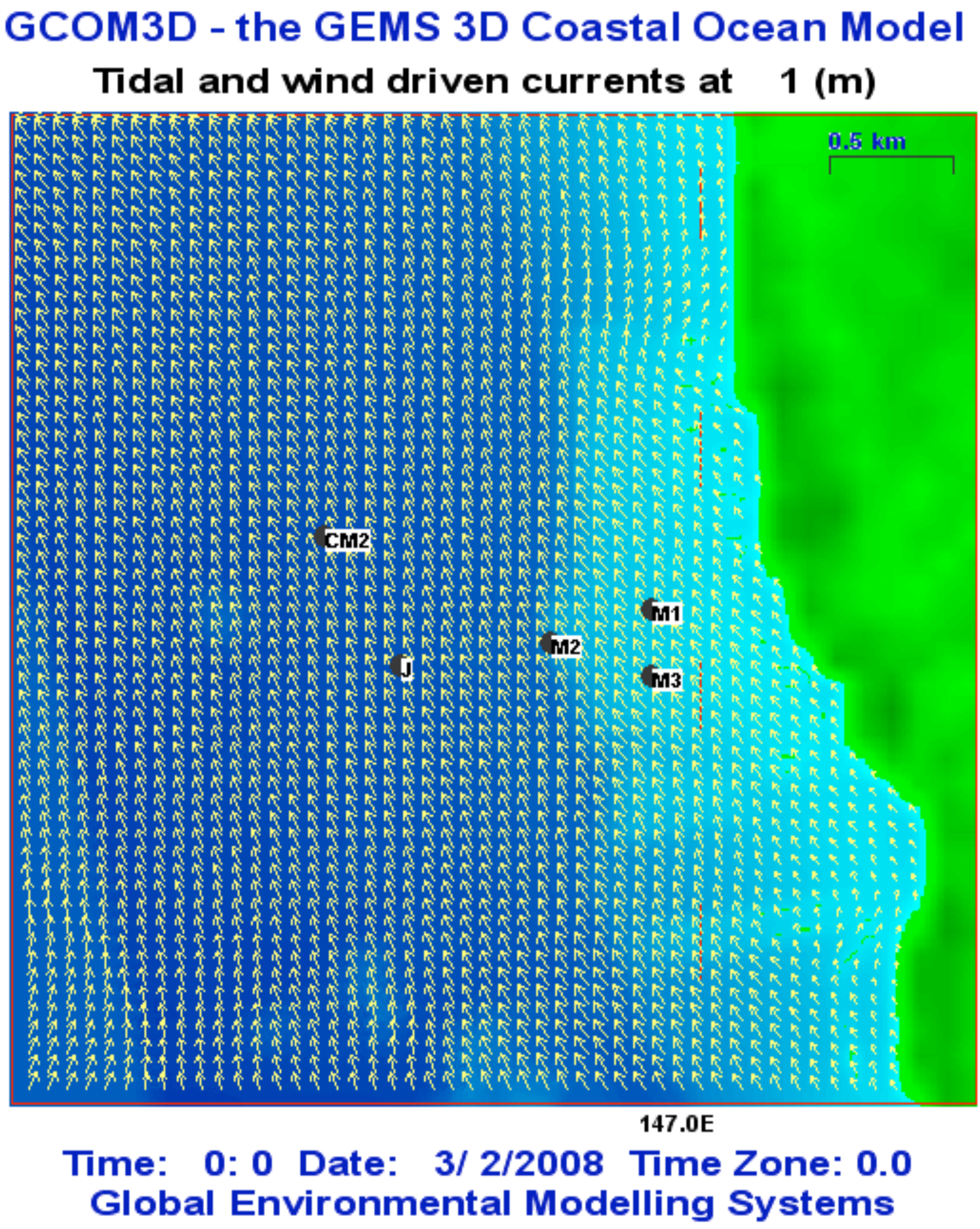

Figure 6.4: A "snapshot" at the same time as Figure 6.3 before the causeway was built.

Table 7: Summary of results obtained at the Monitoring locations before and after the solid causeway is built.

Parameter	Percentage or Absolute change to ambient conditions after the solid causeway is built	Percentage or Absolute change to storm conditions after the solid causeway is built
Sea level	0.0%	0.0%
Current Speed at M1 (100 metres north of the causeway)	-78%	-33%
Current Direction at M1 (100 metres north of the causeway)	83 degrees	80 degrees
Current Speed at M2 (100 metres west of the causeway)	+6%	+15%
Current Direction at M2 (100 metres west of the causeway)	6 degrees	5 degrees
Current Speed at M3 (100 metres south of the causeway)	-62%	-78%
Current Direction at M3 (100 metres south of the causeway)	68 degrees	60 degrees
Current Speed at J (Location of berthing jetty)	+2.0%	+4.0%
Current Direction at J (Location of berthing jetty)	0 degrees	0 degrees

6.3 DISCUSSION OF RESULTS

The overall results are generally as would be expected. The existence of the solid causeway interrupts the longshore flow and forces the flow around the end of the causeway. This produces slower regions of circulation on either side (north and south) of the causeway and slightly accelerated flow around the western end of the causeway. The flow directions north and south of the causeway are severely modified such that the predominant coast parallel flow is forced to flow offshore around the end of the causeway.

The solid causeway will also acts as a barrier to ocean waves from the northwest which occur mainly during the summer season. These waves represent the highest experienced at the site and therefore their attenuation will have an impact on beach processes in the vicinity of the Vaihua River mouth and the solid causeway.

The most important outcomes of this study are that:

1) During ambient conditions:
   a) The slowing of the alongshore flow north and south of the causeway (M1 and M2) may result in a buildup of sedimentation;
   b) The flow at the jetty site (J) is virtually unchanged (2% increase) and will not have any significant effect on ship movements;
   c) The wave climate near the mouth of the Vaihua River will change due to the “wave shadow” from the causeway;
   d) The wave climate at the jetty will not change; and
   e) There is no change in sea levels.

2) During extreme conditions:
   a) A storm situation is most likely to occur from the northwest and so will drive currents alongshore onto the northern side of the solid causeway whilst the southern side will, to an extent, be in the lee of the storm conditions.
   b) Currents (and waves) on the northern side of the causeway are reduced less than the currents (and waves) on the southern side.
   c) Currents at the end of the causeway are increased by approximately 15% in order to get the water mass travelling along the coast around the causeway.
   d) The direction of the currents is changed in a similar manner as for the ambient flows due to the alignment of the causeway.

e) The flow at the jetty site (J) is virtually unchanged (4% increase);

f) The wave heights near the mouth of the Vaihua River will be reduced due to the "wave shadow" from the causeway;

g) The wave climate at the jetty will not change; and

h) There is no change in sea levels.

6.3.1 IMPACTS OF THE SOLID CAUSEWAY

The solid causeway blocks the normal flow of the currents along the coast and forces the flow around the end of the causeway. This produces regions of weaker currents shorewards of the MOF on both sides of the causeway (compare Figures 6.3 and 6.4).

The causeway also reduces the wave action from the northwest (mainly during summer) on the south side of the causeway near the mouth of the Vaihua River (Figure 6.3). The data gathered so far indicates that the highest ambient waves at the jetty (approx. 2 metres) occur during the summer driven by northwest winds. During winter the waves generated by southerly winds are severely limited by the reef and the shallow bathymetry and tend to be not much higher than 1 metre.

The reduced wave action from the northwest will result in less suspension of sediments during summer and therefore less transport from the area near the river mouth.

During winter and the dominant southerly winds, suspended material will be blocked by the causeway and tend to deposit in the region of weak currents.

Both these processes will result in an accumulation of sediments between the river mouth and the solid causeway. The result will most likely be the creation of sandy cays and eventual blockage of the entrance to the river in 3 to 5 years.

The flux of waters from the ocean into the river mouth and the salt pan regions is probably delicately balanced at present. Blockage of the entrance will cause ecological problems but dredging to maintain the entrance to the Vaihua River will be required indefinitely with associated impacts of sedimentation.

For these reasons a simple maintenance dredging program is a good idea.

Options:

a) Introduce a piled section to the planned southern causeway

This option will improve the alongshore transport but will not overcome the wave shadow problem which is probably the major issue. As noted above, maintenance dredging near the river mouth is not the ideal mechanism of managing the connection between the river and the sea and may cause environmental problems, and will be required indefinitely unless the causeway is removed after its use.

b) Move the causeway further north and maintain its solid structure

This option will overcome the wave action problem near the river mouth (as long as the causeway is moved far enough) and the accumulation of sands will also occur further away from the river mouth. There are several disadvantages of this approach however, namely:

- Transport of sediments past the causeway will still be limited and (careful) maintenance dredging will be needed.
- The movement of the jetty northwards would require significant changes to the overall design of the LNG plant.

c) Shorten the solid causeway

This option was investigated further because if it can be made to work it does not involve interference with the design and siting of the remaining components of the facility.

Two further simulations were run to investigate the impacts of shortening the solid causeway to 75% and 50% of its present length.

The second scenario (50% reduction in length) produced the best results because it allowed wave action from the northwest to still reach the area around the river mouth. The first scenario (25% reduction in length) improved the situation considerably but there was still some affect on northwesterly waves near the river mouth.

The results are summarized in Table 8, which compares the impacts of the full length solid causeway with one 25% shorter and one 50% shorter.

In view of these results it is recommended that in order to limit the impacts of the solid causeway on the coastal processes in the vicinity of the Vaihua River mouth, the solid causeway length be reduced by an amount between 25% and 50%.

Table 8: Summary of impacts at the Monitoring locations for the three cases of no causeway; causeway length reduced by 25% and reduced by 50%.

Parameter	Percentage or Absolute change to ambient conditions after the solid causeway is built	Percentage or Absolute change to ambient conditions after the solid causeway is built 25% shorter	Percentage or Absolute change to ambient conditions after the solid causeway is built 50% shorter
Sea level	0.0%	0.0%	0.0%
Current Speed at M1 (100 metres north of the causeway)	-78%	-55%	-8%
Current Direction at M1 (100 metres north of the causeway)	83 degrees	63 degrees	10 degrees
Current Speed at M2 (100 metres west of the causeway)	+6%	+3%	0%
Current Direction at M2 (100 metres west of the causeway)	6 degrees	5 degrees	3 degrees
Current Speed at M3 (100 metres south of the causeway)	-62%	-45%	-5%
Current Direction at M3 (100 metres south of the causeway)	68 degrees	50 degrees	8 degrees
Current Speed at J (Location of berthing jetty)	+2.0%	+4.0%	+4.0%
Current Direction at J (Location of berthing jetty)	0 degrees	0 degrees	0 degrees

7 DREDGE MODELLING

It is expected that for the existing plan for the LNG jetty that the amount of material to be dredged will be approximately 200,000 m^3.

The simulation of the dredging has been undertaken using the output of four sophisticated numerical computer models:

1) The Australian Bureau of Meteorology (BoM) operational high resolution (10km) atmospheric forecast model, (MesoLAPS);

2) The GEMS 3D Coastal Ocean Model (GCOM3D) to simulate the complex three-dimensional ocean currents on the Northwest Shelf;

3) The SWAN wave model to simulate the waves during the dredging operations for calculations of sediment re-suspension; and

4) The GEMS 3D Dredge Simulation Model (DREDGE3D) to determine the fate of particles released into the water column during the dredging operations.

The dredging program is simulated with the GEMS 3D Dredge Simulation Model (DREDGE3D) which simulates the specific fate of particles discharged during the dredging program. This model is a Lagrangian particle model and therefore does not run on a grid and, as a result, is independent of grid resolution. The model inputs the physical environmental data from GCOM3D, together with wave data from SWAN and meteorological data from MesoLAPS, to simulate the movement and deposition of suspended particles in the water body resulting from a dredging activity defined by an estimated dredge log.

DREDGE3D was used initially, with great success, in the Geraldton Port Redevelopment Project in Australia, where it was compared with in-situ data, aerial photographs and satellite images. In the past three years since the dredging of Geraldton Port, DREDGE3D has been used in a number of Australian dredging projects including Mermaid Sound (for both the Dampier Port Authority and the Hamersley Iron port expansion projects), Chevron Gorgon dredging at Barrow Island, the Albany Port Authority Expansion Project, two projects in Queensland, several developments in the United Arab Emirates and in New Caledonia for the INCO nickel processing plant and port development.

The simulation of the dredge program in this study relied on the best available meteorology and bathymetric information and included assumptions and details from other recent dredging programs in Australia. Where there was uncertainty in model parameters, conservative values were chosen such that the model would tend to overestimate the impact.

7.1 METHODOLOGY

The basic steps undertaken are as follows:

7.1.1 DATA REVIEW AND MODEL SETUP

- Incorporate detailed bathymetry data and establish bathymetric grids of:
    a) The Coral Sea, the Gulf of Papua and Caution Bay for wave modelling;
    b) The Gulf of Papua and Caution Bay for 3D ocean current modelling; and
    c) Caution Bay for dredging simulations.
- Analyse the wave and current data to determine the important physical influences which need to be represented by the modelling
- Extract data from the high resolution (10km) Bureau of Meteorology forecast model (MesoLAPS).
- Analyse the AWS and MesoLAPS data to understand the meteorological processes in the region
- Setup tidal forcing for the region from the GEMS Australian region tidal database (originally developed for AMSA Search and Rescue in Canberra).

7.1.2 ESTABLISH ENVIRONMENTAL FORCING FOR THE DREDGE MODELLING

For the period chosen for dredging simulations:

- Extract data from the high resolution (10km) Bureau of Meteorology forecast model (MesoLAPS).
- Run GCOM3D on the nested grid system, producing half-hourly output of 3D ocean currents.
- Run the SWAN wave model on the nested grid system, producing hourly output of ocean waves and associated orbital velocities induced at the sea bed.

7.1.3 SET UP THE DREDGE MODEL INPUT INFORMATION

Dredge log(s) describing the best estimate of the dredging activities were established, including:

- Dredge(s) to be used and proposed hours of operation

- Dredge cutting rate(s), hopper sizes, associated barge sizes, barge speeds (going to spoil ground, returning from spoil ground) etc.
- All potential sources of turbidity together with rate and duration
- Proposed spoil ground(s)
- Material types and particle size distributions (PSD) encountered along the dredging path
- The expected maintenance schedules and associated down times.
- Downtimes for environmental reasons (e.g. coral spawning, whale migration)

7.1.4 SIMULATE THE DREDGING PROGRAM

The dredging simulation was undertaken as follows:

- Establish the required outcomes of dredge simulations (e.g. impact zone criteria, locations for deriving TSS levels and durations, bottom sedimentation thickness, etc.)
- Run DREDGE3D for the full representative dredging period driven by the simulated dredge log, currents from GCOM3D and orbital velocities from SWAN.
- Analyse output from the simulations to provide data for initial impact assessment studies.
- Derive impact zones, based on model output.

7.2 DEVELOPMENT OF THE DREDGE LOG

The detailed specifications of the dredge and the expected program was developed by GEMS based on experience with other dredging programs.

7.3 PARTICLE SIZES AND SETTLING RATES

Particle size distributions were supplied by CNS from grab samples taken during field trips. Full depth cores had been taken but were not analysed in time for this study. Particle settling velocity values were determined for a range of particle sizes by applying Stoke's equations. The PSDs are defined in Table 6, together with the settling velocities associated with each particle size.

Table 6: The particle size distribution percentages and settling velocities used in the dredge simulations.

Diameter (microns)	Settling Rate (mm/s)	Material Crushed by CSD
10000.0	17.0	79680.0
5024.0	7.0	20020.0
2000.0	7.0	3172.0
1000.0	6.0	796.00
632.5	6.0	317.20
399.1	3.0	126.30
317.0	3.0	79.600
158.9	8.0	20.020
126.2	2.0	12.630
100.0	2.0	7.9680
89.3	2.0	6.3300
79.6	2.0	5.0280
63.3	4.0	3.1720
50.2	4.0	2.0020
39.9	3.0	1.2630
31.7	3.0	0.7968
25.2	5.0	0.5028
20.0	2.0	0.3172
15.9	2.0	0.2002
10.0	2.0	0.0797
8.0	2.0	0.0503
5.0	1.0	0.0200
4.0	1.0	0.0126
2.8	1.0	0.0063
2.0	1.0	0.0032

7.5 DREDGING SIMULATIONS

The dredge modelling was carried out in three steps. The first two steps were carried out concurrently:

a) The 3D ocean circulation of the region was simulated on the nested grid system described earlier and half-hourly output of 3D currents on a 200 metre resolution grid were stored for the duration of the simulation;

b) The hourly wave parameters were predicted with the SWAN wave model for the same period on the nested grid system described earlier. Sea bed orbital velocities were also stored hourly for input to calculations of re-suspension of dredged particles from the sea bed.

The third step was to simulate the total dredge program (54 days) using DREDGE3D to predict the fate of particles released into the water column by the Cutter Suction Dredge (CSD), driven by 3D ocean currents from GCOM3D, waves from SWAN, the estimated dredge log and particle size distributions at every time step defined in the dredge log. Spatial coordinates (x, y and z) of all particles released in the dredge model were stored hourly for later analysis.

7.6 ANALYSIS OF THE DREDGING SIMULATION RESULTS

To investigate the turbidity exposure issues, the hourly output was analysed to derive the percentage of time regions were exposed to greater than 5, 10 and 20 mg/litre of Total Suspended Solids (TSS). The results of these analyses are shown in Figures 7.1 to 7.3 respectively.

7.7 DISPOSAL OF DREDGE SPOIL

The dredged material was assumed to be loaded into barges after being dredged by the cutter suction dredge. The barge(s) would then transport and dispose of the material to the deeper water outside the reef and Caution Bay shelf.

One concern with this process may have been the possibility of sediment dispersing back onto the reefs at the shelf edge. The disposal location (in 450 m water depth) is sufficiently far away from the reef edge (approximately 20 km from the nearest point of the reef at Idihi Island). Transport of sediment back to the reef is most unlikely as illustrated in Figure 7.4, which shows the maximum cumulative lateral extent of TSS plumes in the water column when the dredging is undertaken during winter and the turbid plume is driven north. It is unlikely the dredging would be undertaken during the summer at times of risk of tropical storms and the difficulty a cutter suction dredge has in operating when the waves exceed 1 metre.

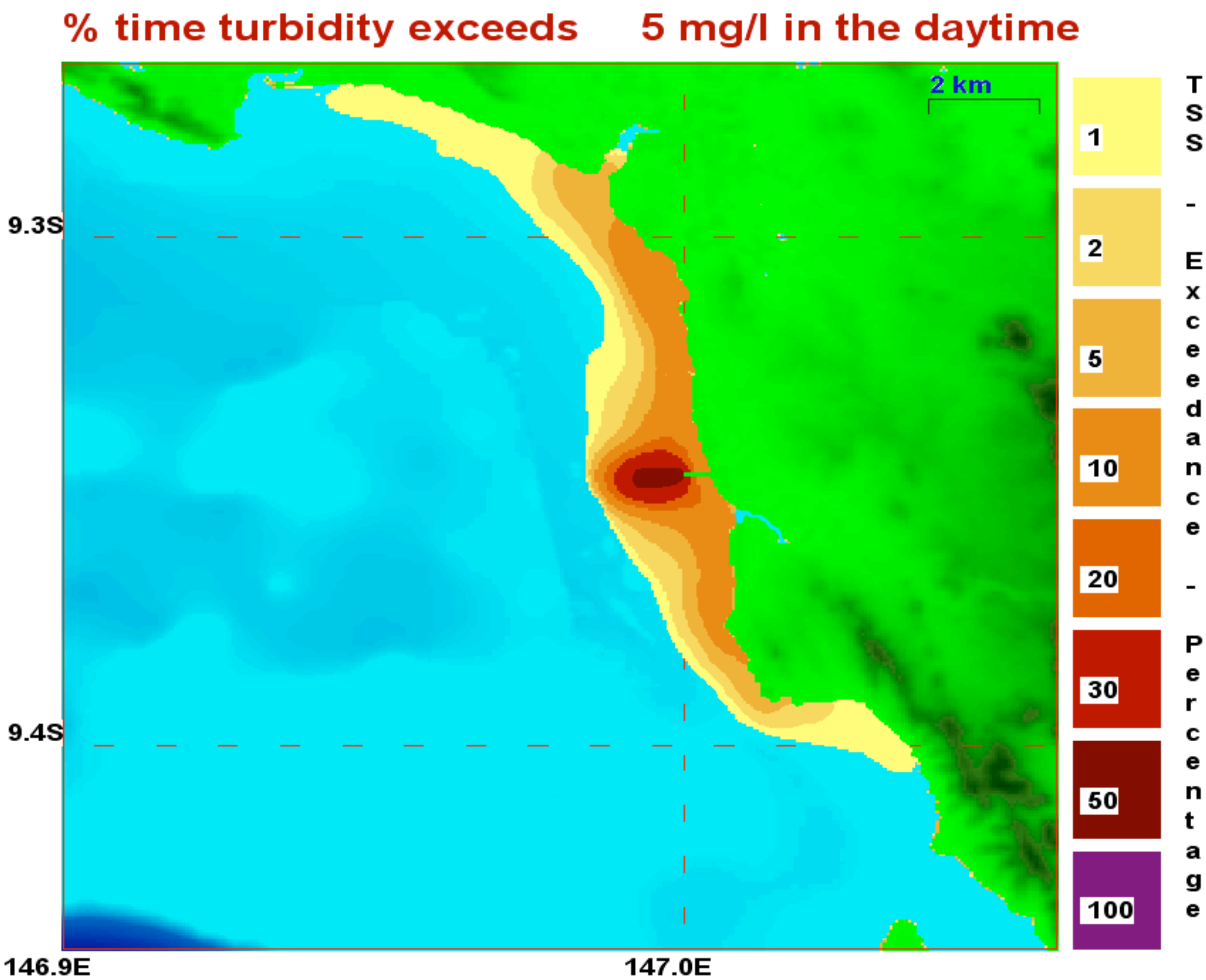

Figure 7.1: The percentage of time that a TSS value of 5 mg/l is exceeded during the dredging program.

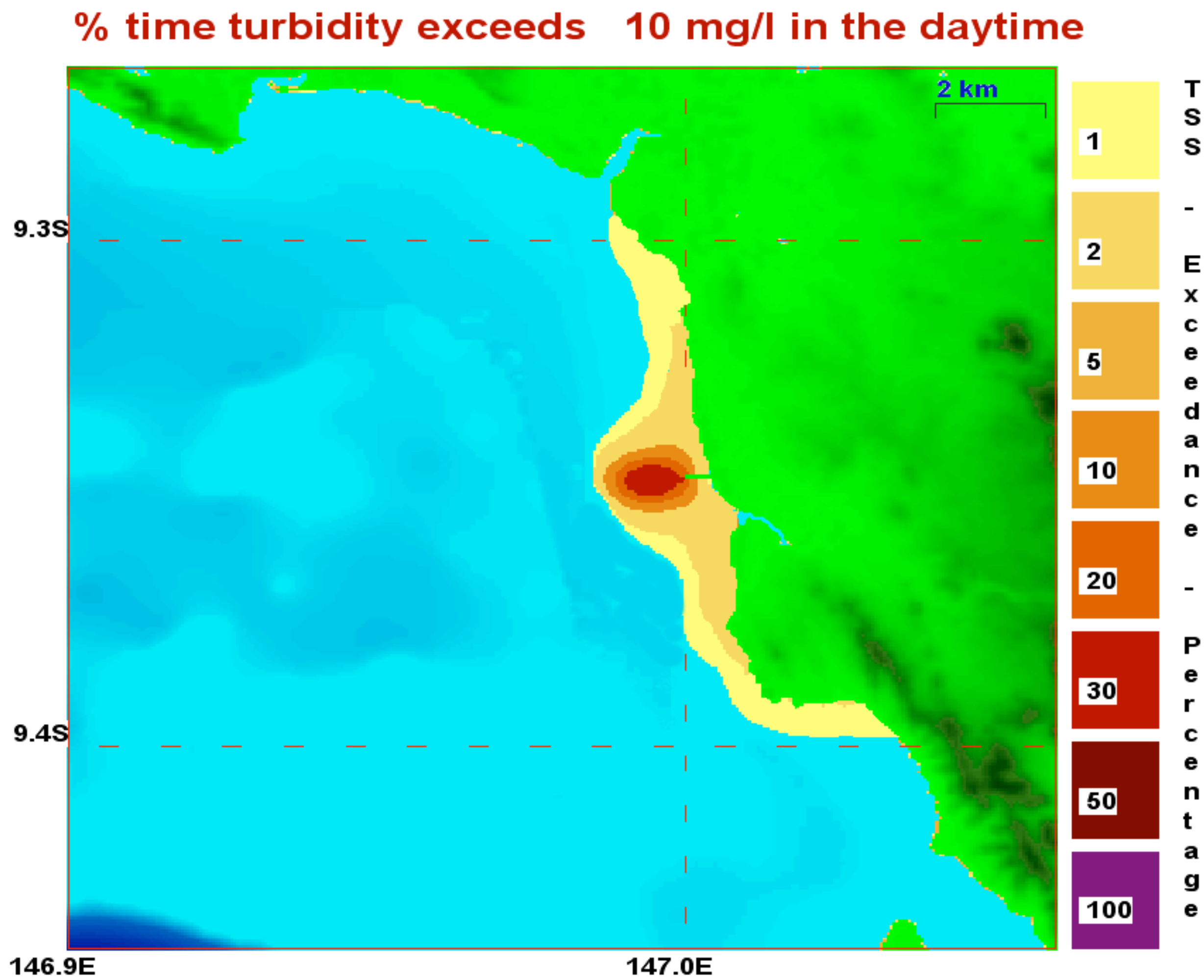

Figure 7.2: The percentage of time that a TSS value of 10 mg/l is exceeded during the dredging program.

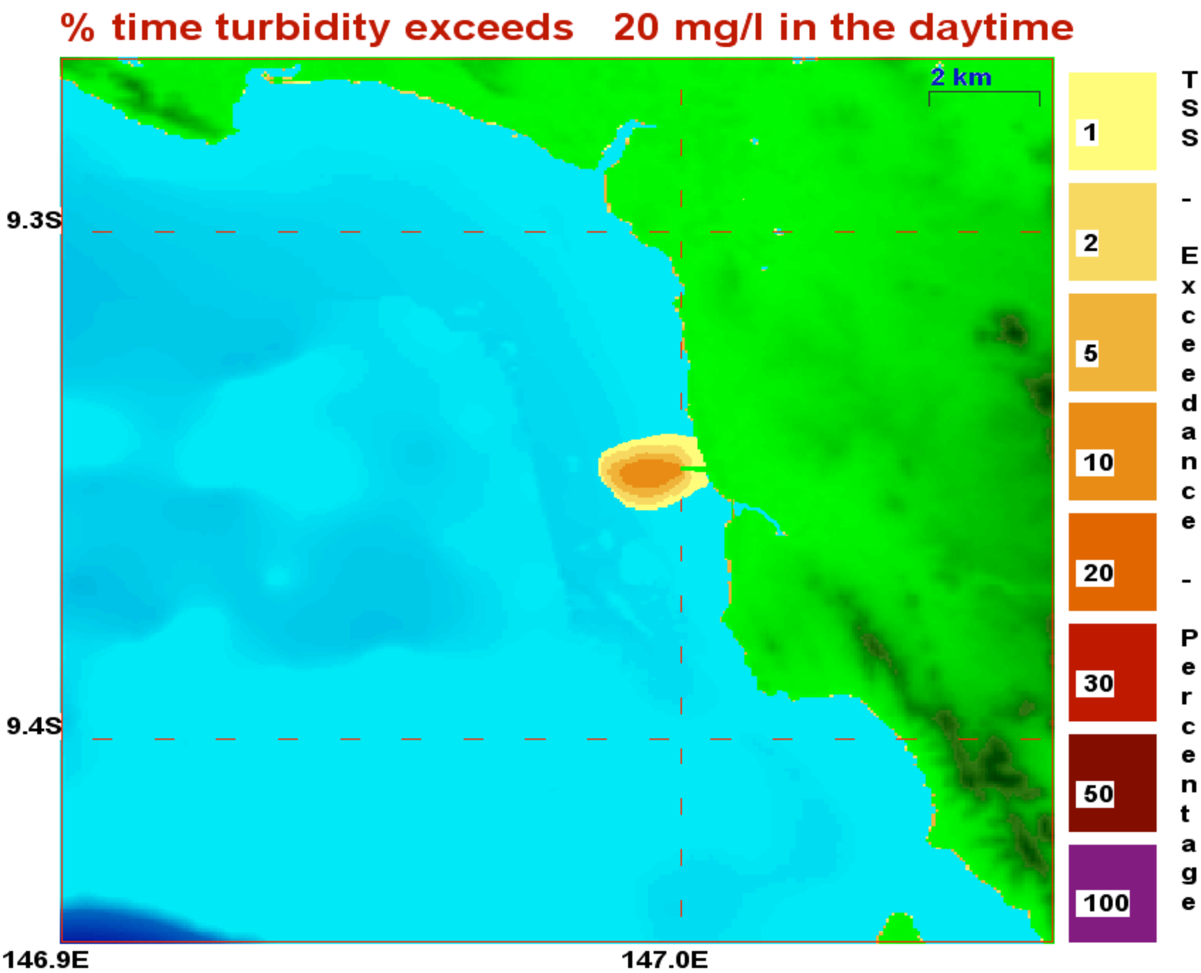

Figure 7.3: The percentage of time that a TSS value of 20 mg/l is exceeded during the dredging program.

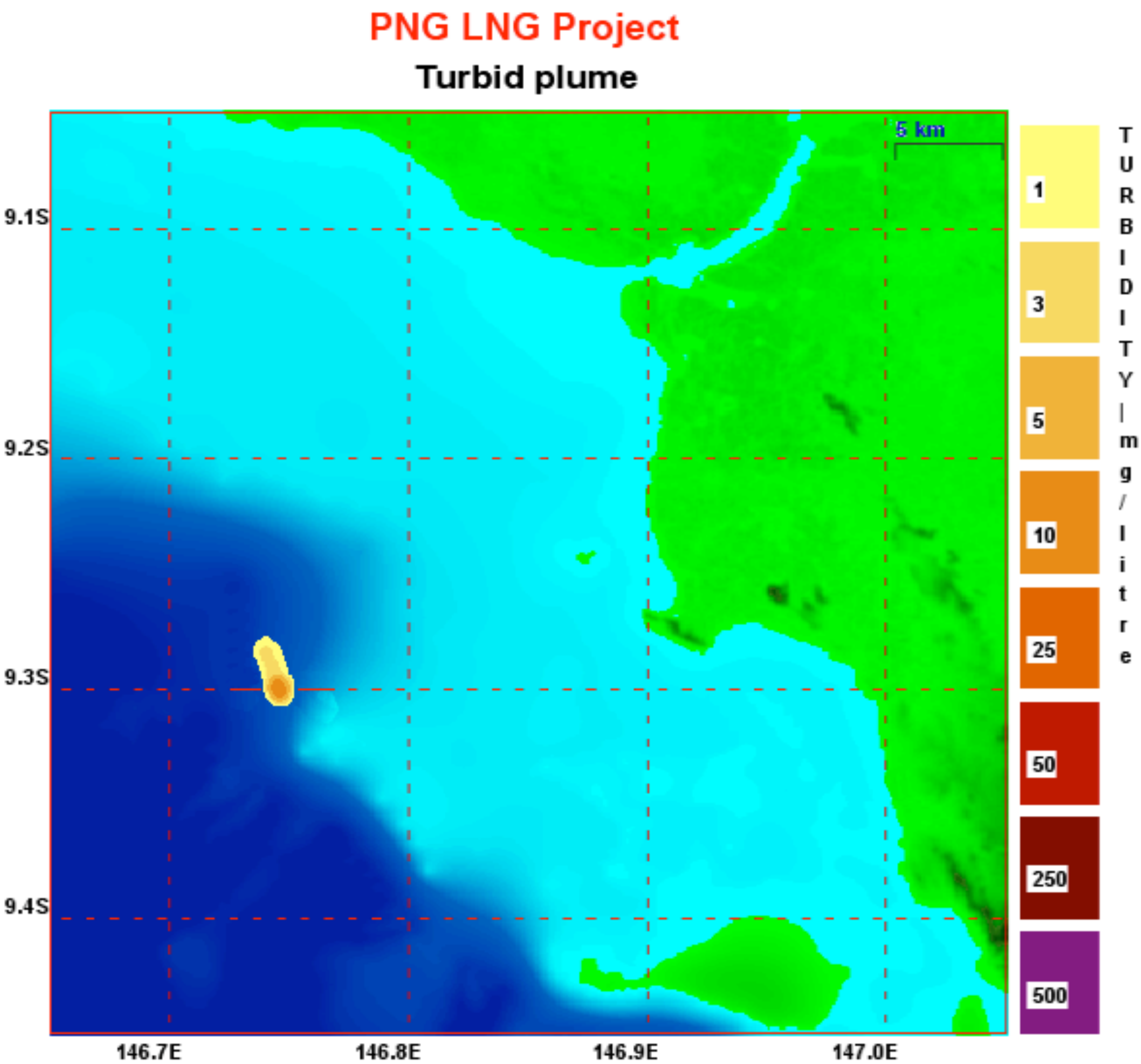

Figure 7.5: Turbid plume generated at the spoil disposal site.

8. BRINE DISCHARGE MODELLING

The Base case for a freshwater source for the Caution Bay facilities is seawater desalination. Desalination units will provide fresh water for construction and operation phases of the project. For the construction phase barge mounted desalination units will most probably be utilized. These units can be moored near the shore at a location close to the construction site.

For the operations phase of the LNG Plant, a separate desalination package unit will be used and will be located within the LNG Plant. This will provide for the various freshwater users within the LNG Plant. The Rotator Camp (permanent camp) facilities will have it's own desalination unit for providing potable water to the camp.

GEMS investigated the dilution of the saline reject waters discharged after the desalination process.

The basic assumptions regarding the desalination plant process were:

1. Reverse osmosis (RO) is proposed for seawater desalination.
2. The seawater reverse osmosis (SWRO) unit water recovery rate is assumed to be 50%, due to lower salinity of the seawater in Caution Bay (near the LNG site). Typical SWRO units have water recovery rates in the range of 40 to 60% depending on the seawater salinity; higher salinity will lead to lower recovery rates.
3. The SWRO waste streams are RO reject stream and backwash water from filtration units.
4. RO reject stream salt concentration (TDS) is approximately twice the RO feed salt concentration.
5. The backwash stream will have high suspended solids concentration containing biological, mineral and organic matter.
6. The waste streams from SWRO will have to be treated for suspended solids and pH control before discharge into the sea.
7. The discharge outfall should also be at located away from the seawater intake for the SWRO to avoid any recirculation of concentrate and the location should be such that it avoids calm and stagnant waters.
8. The SWRO reject will most likely outfall into sea through multi-port diffusers, however, a single port diffuser was modelled to obtain a worst-case scenario.
9. Other solutions for mitigating the effects of the SWRO effluent such as comingling with other wastewater discharges will be considered during subsequent stages of engineering.
10. There will be no thermal discharge from SWRO as the rise in water temp thru the RO process is very low (about 1ºC)

Construction Phase Water Requirement

The fresh water requirement for construction phase is estimated to be:

- Year 1: 640 Million litres over 12 months
- Year 2: 840 Million litres over 12 months
- Year 3: 900 Million litres over 12 months
- Year 4: 730 Million litres over 12 months
- Year 5: 210 Million litres over 4 months.

The above requirement also includes water for hydrotest operations. The peak construction phase fresh water requirement will be 2500 m3/day.

The SWRO reject (brine) stream will be routed to an outfall into the sea. During the early periods of construction (i.e., the first two years), the brine flow rate will be relatively low and it is proposed to be discharged into the sea approximately 200m from the shore to avoid any calm or stagnant waters and aid diffusion.

As the construction activity peaks in subsequent years freshwater requirements and hence the SWRO reject flow increases.

Meanwhile the jetty construction would have been completed and the SWRO discharge line can be relocated to run along the jetty to an outfall in deeper waters (approx. 2km from shore and around -12m depth below low tide level). The outfall will be relocated to deeper waters as the construction activity peaks.

Some of the fresh water consumed will generate wastewater which will have to be treated if required before discharge.

The sanitary sewage from the temporary construction camp and hydrotest water will undergo appropriate treatment before being discharged

Some of the fresh water generated will be lost to the environment due to activities such as fugitive dust control during construction and will not generate wastewater for treatment and disposal. It is assumed that about 50% of the freshwater gets converted to wastewater.

The dispersion modelling considered the discharge conditions below:

Outfall Flow, for modelling:	2,500 m3/day
Mixing Area Definitions:	The regions, outside which the salinity is no greater than 5% and 10% above ambient values.

8.2 BRINE DISPERSION RESULTS

The hydrodynamic model GCOM3D was run for a 12 month period to produce simulated hourly currents throughout the year.

The GEMS PLUME3D model was then used to simulate the brine reject water outfall discharging for the full 12 months.

As a reference to determine the nature of the impact analysis, conditions that have been applied by the Western Australian DEC for discharging from desalination plants were chosen. These regulations state that the proponent shall:

1) *ensure that salinity variation resulting from the discharge is no greater than 5% above the ambient level for more than one percent of the time within a Moderate Protection Mixing Zone (MPMZ). The size of the MPMZ varies depending on the sensitivity of the local habitat but typically is approximately 4 hectares surrounding the discharge location); and*
2) *ensure that toxicant concentrations do not exceed the 90% species protection levels at the end of the outfall pipe for more than 5% of the time, nor exceed the 99% species protection levels at the edge of the MPMZ.*

By contrast the World Health Organization (WHO) requires a brine discharge to be within 10% of ambient levels 100 metres from the discharge location, also therefore defining mixing zone of approximately 4 hectares (100 metres in all directions).

The WA DEC condition is therefore more strict than the WHO condition.

The WA salinity condition therefore requires a dilution of approximately 40 times to be achieved 99% of the time, except within an area of 4 hectares surrounding the outfall.

The WHO salinity condition however only requires a dilution of approximately 20 times to be achieved 99% of the time, except within an area of 4 hectares surrounding the outfall.

The results of the 12 month simulation were therefore analysed to determine the percentage of the time that 40 dilutions and 20 dilutions were achieved. Figure 8.1 presents the resultant model output under the most conservative conditions, showing the mixing zones required to achieve 40 dilutions for 100%, 99%, 95%, 90%, 75% and 50% of the time. Note that this modelling was undertaken with the causeway at its originally extended length, 500 m longer than that proposed.

Figure 8.2 presents the resultant model output showing the mixing zones required to achieve WHO guidelines of 20 dilutions for 100%, 99%, 95%, 90%, 75% and 50% of the time.

8.3 COMMENT

Figure 8.1 clearly shows areas of elevated salinity reflecting the reduced currents to the north and south of the originally proposed causeway, although at the most conservative (<5% above ambient) case. While salinity from brine discharge from the causeway at the original length was not modeled at the WHO less than 10% above ambient values, it is likely that some pockets of elevated salinity would also occur north and south of the long causeway, as originally considered.

Whilst the results of the dispersion studies do not seem to indicate any major problems with the currently proposed causeway length, (Figure 8.2) they do exceed the Western Australian DEC conditions, largely due to the effects on the local currents of the solid causeway. The results do however satisfy the WHO guidelines (in line with most other regulatory conditions around the world) and also satisfy the WA guidelines 95% of the time.

The impacts can be reduced further with the introduction of a multi-port diffuser at the end of the brine discharge pipe, or discharging further offshore once the LNG jetty is completed. The study assumed an open pipe discharge, and a diffuser will significantly increase initial dilution of the discharge.

The final design of the discharge configuration must also take into account the need for all the potential reject waters that will be discharged when the plant is operational to be considered. Co-disposal with other sources may be possible but only the brine has been modeled in this study.

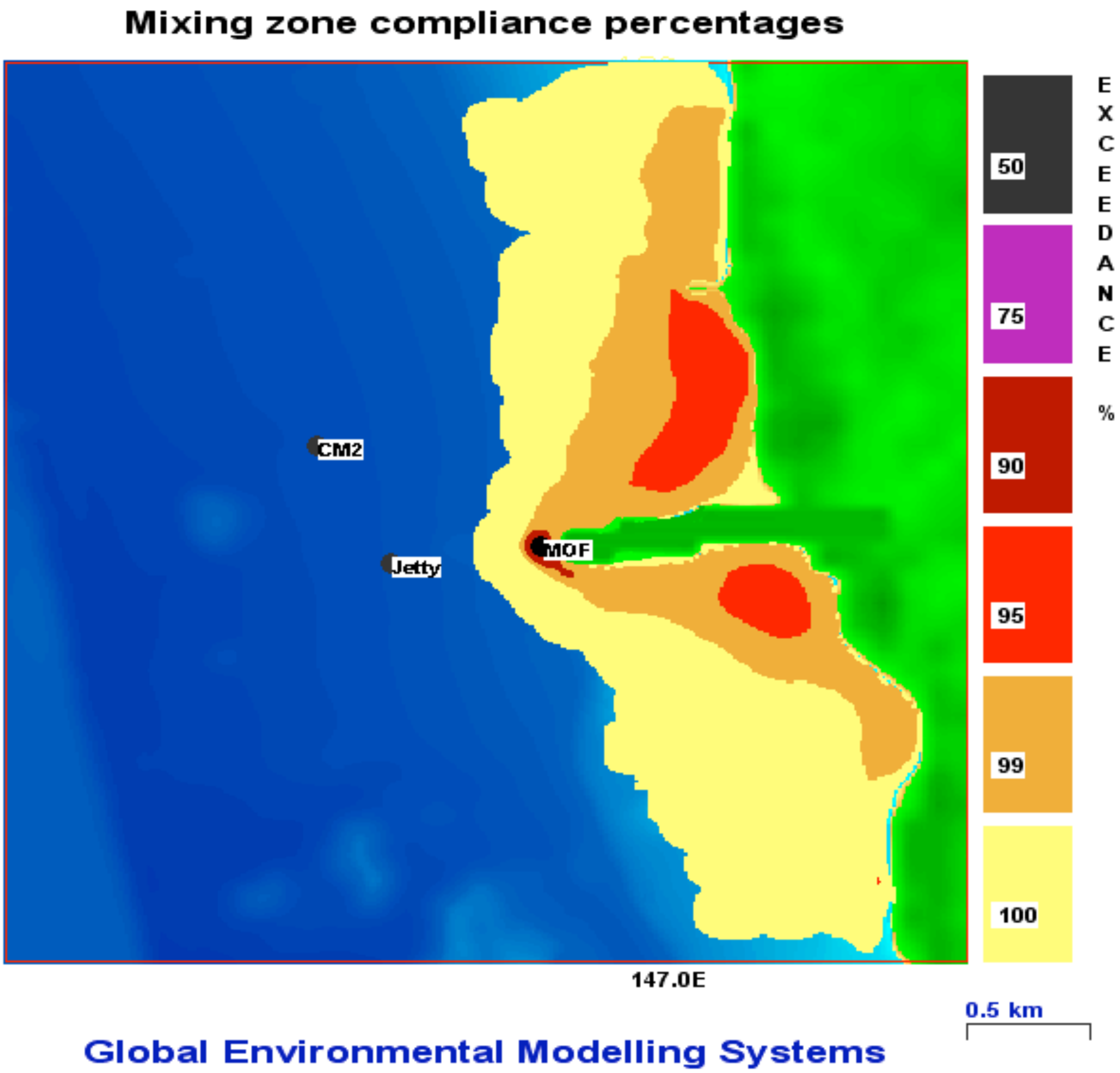

Figure 8.1: The percentage time that salinity levels are less than 5% above ambient values – original causeway.

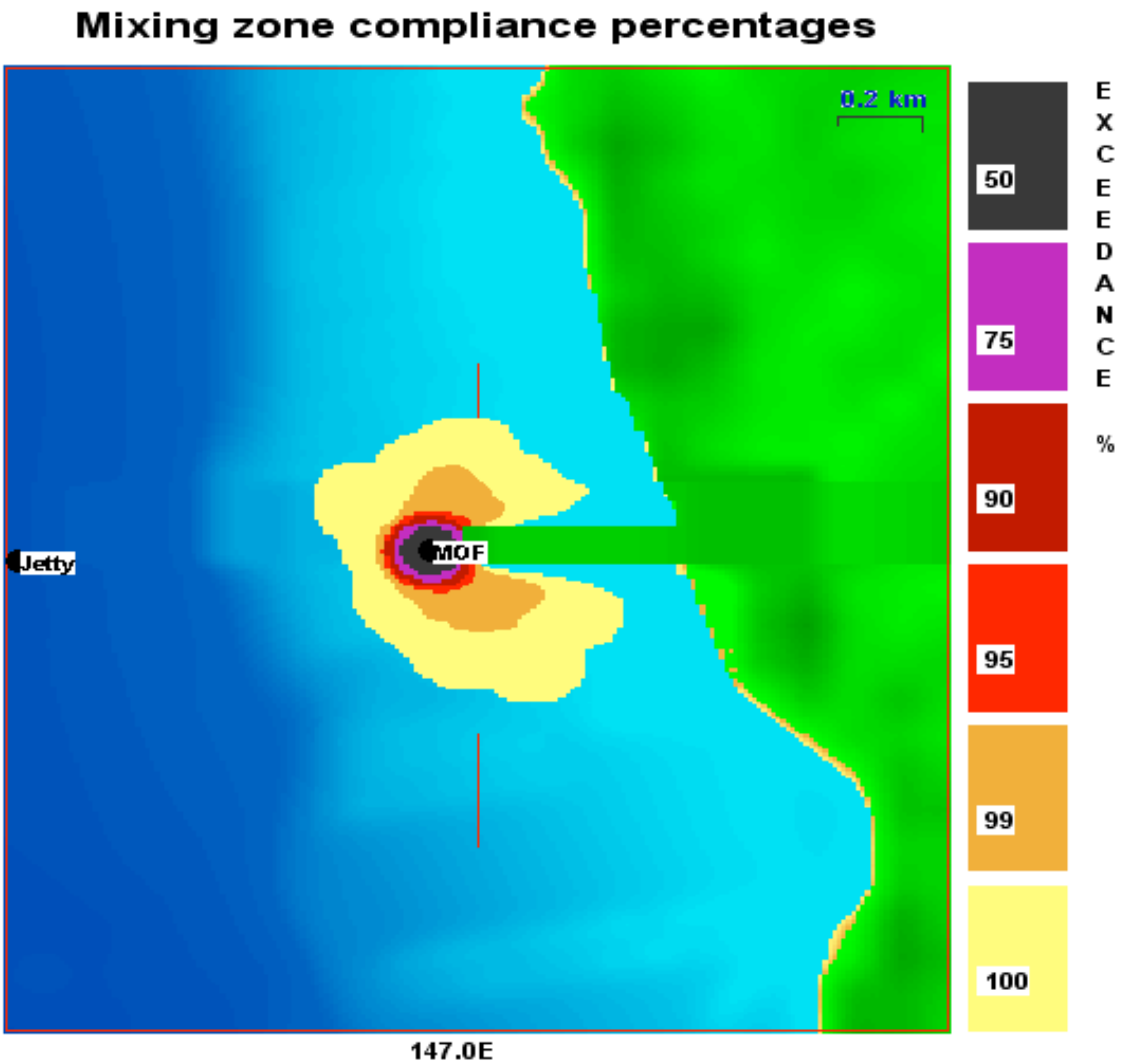

Figure 8.2: The percentage time that salinity levels are less than 10% above ambient values – shortened causeway (currently proposed)

9. REFERENCES

World Health Organisation. 2007. 'Desalination for Safe Water Supply: Guidelines for the Health and Environmental Aspects Applicable to Desalination.' Public Health and the Environment.

APPENDIX A: MODEL DESCRIPTIONS

A.1 GCOM3D

For studies of hydrodynamic circulation and sea level variation under ambient and extreme weather conditions, GEMS has developed the GEMS 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 (Hubbert 1993, 1999) calculates 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. The three-dimensional structure of the model domain, tidal conditions at the open boundaries, 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 hydrodynamic 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 two-dimensional version of the model that includes tidal and flood inundation is also available for use in river systems. 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 Oil Spill Response and Search and Rescue systems are based on ocean currents from GCOM3D, which has been running in real-time at the Australian Maritime Safety Authority in Canberra for the past 2 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.

A.2 SWAN

To obtain realistic estimates of random, short-crested wind-generated waves in such conditions for a given bottom topography, wind field, water level and current field, the numerical wave model SWAN can be used.

The SWAN model was developed at Delft University of Technology, Delft (the Netherlands). It is specified as the new standard for nearshore wave modelling and coastal protection studies. The SWAN model has been released into the public domain.

- SWAN simulates the following physical phenomena:
- 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.
- Nonlinear wave-wave interactions (both quadruplets and triads).
- Whitecapping, bottom friction, and depth-induced breaking.
- Blocking of waves by current

The SWAN model is a non-stationary third-generation wave model (see e.g. Holthuijsen et al., 1993; Ris, 1997) and is the successor of the stationary second-generation HISWA model (Holthuijsen et al., 1989).

The non-stationary SWAN model is based on the discrete spectral action balance equation and is fully spectral (over the total range of wave frequencies and over the entire 360°). This latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated. The wave propagation is based on linear wave theory (including the effect of currents). The processes of wind generation, dissipation and nonlinear wave-wave interactions are represented explicitly with state-of-the-art third-generation formulations. (It is noted that for reasons of economy, more simple first- and second-generation formulations are also optionally available.) The SWAN model can also be applied as a stationary model (stationary mode). This is considered acceptable for most coastal applications because the travel time of the waves from the seaward boundary to the coast is relatively small compared to the time scale of variations in incoming wave field, the wind or the tide.

To avoid excessive computing time and to achieve a robust model in practical applications, fully implicit propagation schemes (in time and space) have been implemented. The SWAN computations can be made on a regular and a curvilinear grid in a Cartesian co-ordinate system. Nested runs can be made with the regular grid option.

SWAN provides many output quantities including two-dimensional spectra, significant wave height and mean wave period, average wave direction and directional spreading, root-mean-square of the orbital near-bottom motion and wave-induced force (based on the radiation-stress gradient).

The SWAN model has successfully been validated and verified in several laboratory and (complex) field cases (see e.g. Ris, 1997).

A.3 DREDGE3D

The dredge modelling is carried out in two steps. Firstly the 3D ocean circulation of the region is predicted for the full dredge program using GCOM3D. Then the total dredge program is simulated using DREDGE3D, which simulates the behaviour of the dredge(s) based on an estimated dredge log (at time steps of 10-30 minutes).

DREDGE3D release particles into the water column, as determined by the dredge log, representing the range of particle sizes (say 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. On completion the hourly data files can be analysed to determine turbidity and sedimentation impacts across the region throughout (and after) the dredging program.

The information required to set up the simulated dredge log for Trailer Suction Hopper (TSHD) and Cutter Suction Dredges (CSD) includes:

- Total volume of material to be dredged
- Region to be dredged
- Expected duration of dredging
- Average hours per week of operation
- Maintenance schedule (repairs, refueling etc.)
- Time of operation before overflow (of THSD or CSD barges)
- Duration of overflow
- Depth of overflow
- Overflow rate m^3/sec
- Whether under keel clearance is controlled or not (THSD only)
- Particle size distributions for all types of material to be dredged

Modelling relies on the best available meteorology and bathymetric information and includes assumptions and details from other recent dredging programs. Where there is uncertainty in model parameters, conservative values are chosen such that the model will tend to overestimate the impact.

Modelling predicts the hourly distribution of Total Suspended Solids (TSS) and seabed coverage to be developed over the total dredge program. The hourly output is analysed to derive periods of continuous exposure to turbidity and/or sedimentation above defined thresholds.

When interpreting the results the following issues should be noted:

- All plots show turbidity levels due to dredging alone (no contribution from background levels),
- All potential sources of turbidity are included in the simulations

The turbidity levels are derived at each model grid point by scanning the water column from surface to bottom for the grid cell with the highest turbidity rather than averaging over the water column. The results therefore show the highest turbidity levels found across the grid.

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.

The simulation of several dredging periods experiencing differences in the Meteorology, together with the detailed dredge log method, provides a rich source of information from which potential impacts can be derived. In the actual dredging program however, regions that show potential impacts may not occur due to variations in meteorology and/or dredge behaviour.