Global Environmental Modelling Systems
Incorporating
Global Environmental Monitoring Systems
and
Global Environmental Mapping Systems
Australian Oceanographers and Ocean Software Developers

TOWNSVILLE OCEAN TERMINAL

Oceanographic Studies

and

Investigation of the Flushing

of the Canal Estate and Marina

August 2007

Report 516-07

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About GEMS

Global Environmental Modelling Systems (GEMS), a wholly owned Australian company, has expertise in oceanography, meteorology and coastal engineering. GEMS is a leading developer of high-resolution computer models to realistically predict atmospheric and oceanographic conditions for use in riverine, coastal and oceanic studies.

To aid the understanding of the meteorology and/or oceanography for a particular study, GEMS also designs and implements ocean observation programs with sophisticated instrumentation. These data are analysed to determine the key meteorological and oceanographic processes to be simulated and are also used to verify the model applications. The results of modelling studies are integrated into GIS systems for ease of interpretation and synthesis with other environmental data.

Disclaimer

Contents

Summary of Findings 5

Summary of Findings 5

1 Introduction 9

2 Meteorology 11

2.1 Wind Climatology at Townsville 11

2.1.1 Cool Months 11

2.1.2 Warm Months 11

2.1.3 Analysis of Wind Records 11

2.2 Meteorological Forcing for the Ocean Modelling 15

2.2.1 Meso-LAPS 15

3 Oceanography 17

3.1 Tides 17

3.2 Currents 17

3.3 Sediment Processes 18

3.4 Surface Drift Track Measurements 18

4 Hydrodynamic Model Setup and Verification 22

4.1 Model Setup 22

4.1.1 Meteorological Forcing 22

4.1.2 Cleveland Bay Bathymetric Grid (Grid A) 22

4.1.3 Townsville Ocean Terminal Bathymetric Grids (Grids B and C) 22

4.1.3 Tides 23

4.2 Verification of GCOM3D 27

4.2.1 Tides 27

4.2.2 Currents 27

5 Impacts of the Development on Water Level and Currents 31

6 Modelling the Flushing of the Marina Waters 32

7 Maintenance of the External Access Channel 35

7.1 Turbidity and Sedimentation in Cleveland Bay 36

7.2 Sedimentation Modelling Studies for the TOT Access Channel 37

7.3 Sedimentation Modelling Studies for the TOT Berthing Area 38

8 References 39

Appendix A: Selected Ocean Modelling Publications 40

Appendix B: Model Descriptions 42

B.1 GCOM3D 42

B.2 Discharge Plume Modelling with PLUME3D 43

Table of Figures

Figure 1.1: The proposed Townsville Ocean Terminal development in front of the Townsville Casino. 10
Figure 2.1. Example of synoptic evolution during July. 12
Figure 2.2. Example of synoptic evolution during January. 13
Figure 2.3. Polar wind diagram for Cape Cleveland for 'cool' months. 14
Figure 2.4. Polar wind diagram for Cape Cleveland for 'warm' months. 14
Figure 3.1: A wireless GPS Davis Drifter prior to deployment. 19
Figure 3.2: A wireless GPS Davis Drifter after deployment. 19
Figure 3.3: The concurrent tracks of five GPS drifters released (black mark) at 0800 hours on November 14, 2006. 20
Figure 3.4: The concurrent tracks of five GPS drifters released (black mark) at 0800 hours on November 15, 2006. 20
Figure 3.5: The five concurrent 23 hour tracks of two GPS drifters released (black cross) at 0800 hours on November 16, 2006. 21
Figure 4.1: The region covered by the Cleveland Bay bathymetric grid (Grid A) 24
Figure 4.2: Townsville Ocean Terminal bathymetric grid (Grid B) including the dredged access channel and showing the locations (M1 – M10) where flushing characteristics were studied. 25
Figure 4.3: Townsville Ocean Terminal bathymetric grid (Grid C) with an opening at the southern end of the Strand Breakwater. 26
Figure 4.4: Sample of the flood tide in Cleveland Bay predicted by GCOM3D. 28
Figure 4.5: Sample of the ebb tide in Cleveland Bay predicted by GCOM3D. 28
Figure 4.6: Comparison of GCOM3D predictions for tidal levels at Townsville Port with values from the Tide Tables for November, 2006. 29
Figure 4.7: Comparison of GCOM3D drift track predictions with the observed track on November 14, 2006. 29
Figure 4.8: Comparison of GCOM3D drift track predictions with the observed track on November 15, 2006. 30
Figure 4.9: Comparison of GCOM3D drift track predictions with two observed tracks on November 16, 2006. 30
Figure 7.1: Access channel plan prior to the decision to deepen it by 0.6 metre 35
Figure 7.2: Sample of the total suspended solids measured in the outer harbour by GHD in June, 2001. 36

Summary of Findings

The proposed Townsville Ocean Terminal (TOT) will be developed opposite the existing Port of Townsville and adjacent to the existing Townsville Hotel and Casino Complex and the Townsville Entertainment Centre. The Project consists of two key components:

- The cruise ship terminal, berthing pocket and associated facilities; and
- The integrated residential waterfront development and associated facilities.

Global Environmental Modelling Systems (GEMS) was contracted to supply environmental modelling services to Hyder Weathered Howe for environmental impact studies relating to the development of the TOT and associated canal estate and marine facilities.

The development site is to be reclaimed with material mainly extracted from the site and some from land based sources. As a result the only dredging which is required is to develop the external access channel for boat access to the site and for flushing of the marina waters plus the creation of the large boat berth pocket and linkage to the existing Port swing basin.

Impact on Hydrodynamic Processes

From the information available prior to the study, the precise behaviour of the flooding and ebbing tide in Cleveland Bay was not clear. The main uncertainty was the effect of Magnetic Island and whether the tide ebbs between the island and the coast or is forced to go around the eastern side of the island due to the shallow bathymetry between the island and the coast.

To study this process in particular, and the flooding and ebbing tides in general, GEMS deployed five wireless GPS ocean surface drifters (Davis drifters) in Cleveland Bay to map surface current movements. **The results provided a very good verification of the ocean model simulations and confirmed that a significant component of the ebb tide does pass east of Magnetic Island.**

For the development impact assessment studies the Gems 3D Coastal Ocean Model (GCOM3D) was run for one month (two spring-neap cycles) driven by tides and winds. This simulation was carried out twice using the pre- and post-development bathymetric grids to compare currents and water levels outside the development.

The average differences in the sea levels and current speeds before and after the development were negligible.

Flushing Studies

Flushing studies are a 3D problem because surface waters will generally flush faster than bottom waters. The variation of flushing rates through the water column depends on the degree of vertical mixing. Strong tidal flows can create turbulence and mixing and so the variation of flushing through the water column will vary as the tides pass from spring to neap cycles. Bottom waters will flush less during neap tides and low wind conditions.

Since the bottom waters will generally flush slower than surface waters it is essential that the flushing path (in this case the external access channel) be maintained at a depth at least as deep as the deepest part of the marina. It is important to note that this requirement will not be captured by simulating flushing with 2D ocean models (such as Mike21 or Delft3D in 2D mode) because these models will necessarily not differentiate bottom waters from surface waters and therefore spuriously flush the entire water column.

It is therefore important to study flushing with a reliable 3D ocean model in order to capture the variation of flushing through the water column and simulate the vertical mixing processes. In this study the flushing of the waters within the development was modelled with the GEMS 3D marine plume discharge model, PLUME3D.

The key features of the TOT canal estate and marina design which effect flushing were:

- an external access channel to the north to a depth of 4.9m AHD; the same as the deepest part of the development (this depth is essential to flush the marina waters)
- the south end of the western seawall was opened up with a 100 metre piled structure;
- the internal "arms" of the development were connected from the eastern side of the development via "bridges" which allowed circulation around the "arms".

After viewing the initial flushing results a further grid was set up to investigate the improvements to the flushing achieved by incorporating the following changes:

- the northwest entrance to the development was opened from 75 metres to 100 metres;
- the southern gap in the western seawall was reduced to 75 metres;
- the external entrance channel and the internal channel along the western seawall were deepened to 5.5 metres; and
- the large southern basin was "sloped" into the western channel from a depth of 4.5 metres on the eastern side (this change was specifically focussed on achieving flushing of bottom waters).

The two different design options were explored to determine the optimum design for flushing.

The results showed that the changes incorporated in Grid C produce better flushing than the original grid (Grid B). **Grid C achieves 90% flushing of all areas of the TOT within a spring-neap tidal cycle.**

Sedimentation of the Access Channel to the Development

The major cause of re-suspension of material from the ocean floor is wave action, which makes material available to be relocated by the prevailing ocean currents. Strong bottom currents can also release material into the water column but these generally are only strong enough during storms.

Previous studies (GHD, 2003) have shown that Cleveland Bay transports significant amounts of suspended sediments (example shown in Figure 7.2) and that the rate of nett deposition in the Townsville Port Outer Harbour is of the order of 10cm/month.

The TOT access channel is much shallower and more exposed than the port outer harbour and so a somewhat lower nett sedimentation rate might be expected in the channel than in the outer harbour due to the higher energy environment in the channel.

To assess the long-term behaviour of bottom sediments in Cleveland Bay and the expected rate of deposition in the access channel after completion of the project, a long term modelling study was undertaken with the GEMS 3D sediment transport model (SEDTRAK3D).

For this study SEDTRAK3D was run for the 365 days of 2001, driven by currents from GCOM3D, waves in Cleveland Bay provided by Coastal Engineering Solutions (CES) and winds from the Bureau of Meteorology MesoLAPS atmospheric model.
The results after 1 year were analysed along the TOT access channel to derive the annual nett deposition of material in the access channel.

The results showed a build up in the access channel of 2- 3 cm per month, significantly less than derived by GHD for the Port outer harbour. This result is expected due to the much higher energy environment of the shallower and more exposed TOT access channel resulting in significantly more resuspension and movement of fine sediments.

These results suggest an annual accumulation in the range of 25 to 35 cm in the access channel which equates to approximately 7,000 m^2 per annum (about 2% of the annual maintenance dredging load of the Townsville Port Authority).

An important corollary of this result is that, since the access channel is the main flushing route from the development, it must be maintained near to the planned depth of 5.5 metres AHD to ensure adequate flushing. The channel will therefore have to be dredged at least every two years.

It is important to note, when interpreting these results, that this study focused on the suspension and relocation of material due to waves and currents in a 12 month period and not on the loss of sand from beaches/shallow areas during severe storms and cyclones.

Sedimentation of the TOT Large Vessel Berthing Area

The TOT large vessel berthing area is on the eastern side of the existing Port western breakwater. Due to the size of the ships expected to utilise the berth it will have to be maintained to a similar depth to the surrounding Port facilities. The nett sedimentation rate is therefore expected to be similar to the Port inner harbour.

To investigate this further, the data from the 365 days simulation with SEDTRAK3D was analysed to derive:

1. The nett sedimentation at the TOT large ship berthing area; and
2. The nett sedimentation in the outer harbour

The latter result was derived in order to compare with the results obtained by GHD.

The results showed an average build up in the TOT berthing area of 8- 9 cm per month, or up to 1 metre per year. The average nett sedimentation in the outer harbour region was 11 cm per month, which compares favourably with other studies.

These results however did not include ship movements as a source of resuspension and therefore the real annual sediment budget could be expected to be lower than predicted.

Logic suggests that the TOT berthing area should be dredged every time the Port inner harbour is dredged because the increase in total volume to be dredged will be small due to the relatively small area occupied by the TOT berthing area.

1 Introduction

The proposed Townsville Ocean Terminal (TOT) will be developed opposite the existing Port of Townsville and adjacent to the existing Townsville Hotel and Casino Complex and the Townsville Entertainment Centre (Figure 1.1). The Project consists of two key components:

- The cruise ship terminal, berthing pocket and associated facilities; and
- The integrated residential waterfront development and associated facilities.

The TOT will be constructed within the Western Breakwater of the Port of Townsville and the residential waterfront development will be constructed on reclaimed land to the west of the TOT, providing waterfront residential properties including attached and detached dwellings and apartment buildings.

Global Environmental Modelling Systems (GEMS) was contracted to supply environmental modelling services to Hyder Weathered Howe for environmental impact studies relating to the development of the TOT and associated canal estate and marine facilities.

The development site is to be reclaimed with material mainly extracted from the site and some from land based sources. As a result the only dredging which is required is to develop the external access channel for boat access to the site and for flushing of the marina waters plus the creation of the large boat berth pocket and linkage to the existing Port swing basin.

The major requirements of the study were:

- Establish the GEMS 3D Coastal Ocean Model (GCOM3D) at a suitable grid resolution covering an adequate region to accurately model the oceanography of Cleveland Bay;
- Gather and collate tidal and current flow information to verify GCOM3D;
- Run GCOM3D to assess the current hydrodynamic conditions and the effect of the project on the area;
- Run GCOM3D on a high resolution grid surrounding the development to determine the flushing characteristics of various design options;
- Incorporate wave model data supplied by CES into the hydrodynamic model to provide the basis for sedimentation/resuspension studies;
- Run a sediment transport model, driven by ocean currents and waves, to assess changes to ambient sedimentation patterns as a function of the development;
- Provide a report detailing the modelling carried out and the effect of the project on the hydrodynamic conditions present around the extraction and project sites;
- Provide technical input to assist with the production of an EIS.

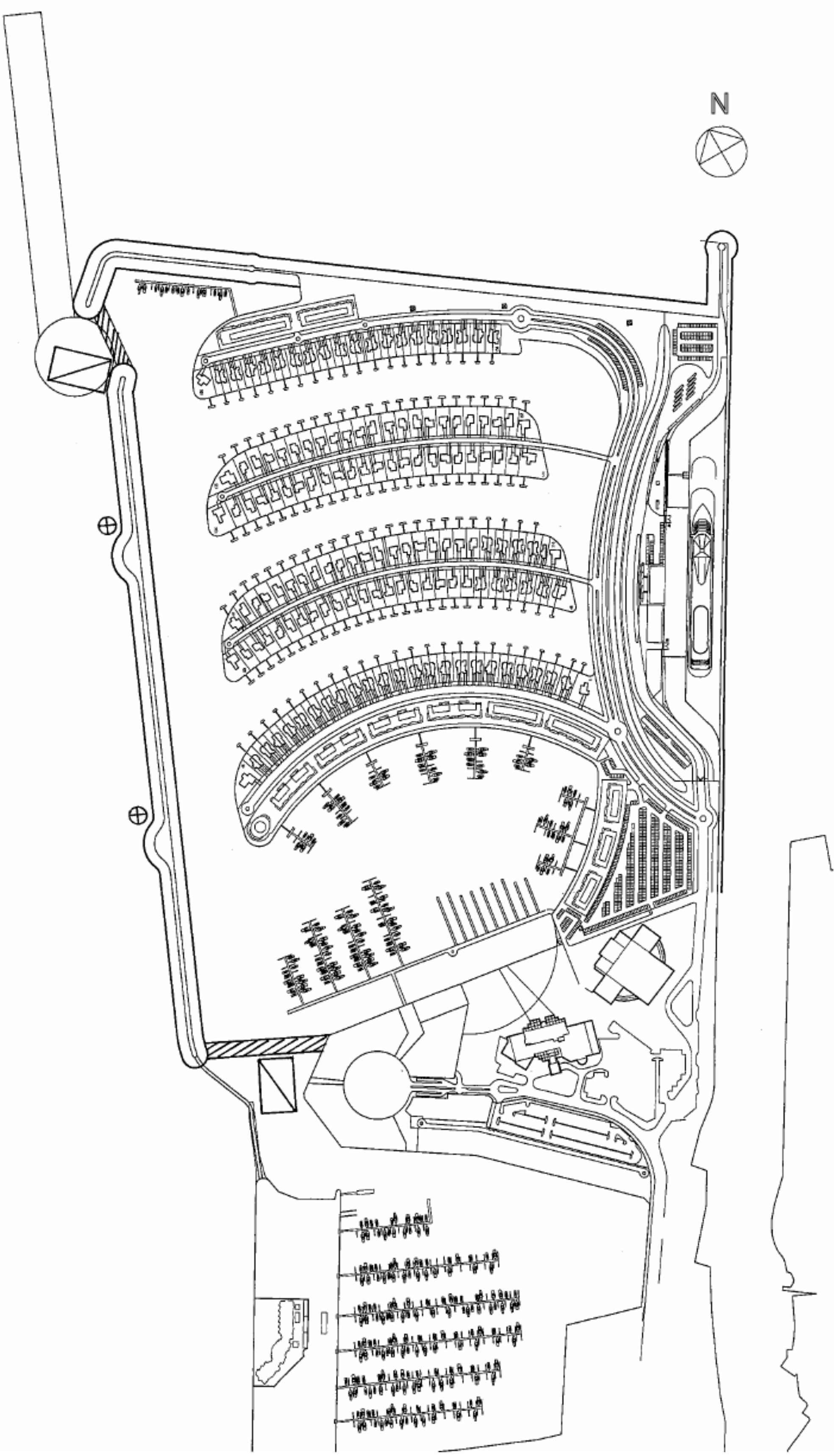

Figure 1.1: The proposed Townsville Ocean Terminal development in front of the Townsville Casino.

2 Meteorology

2.1 Wind Climatology at Townsville

The wind regime at Townsville can be broken into two main seasons.

2.1.1 Cool Months

During the cooler months of the year the controlling synoptic feature is the sub-tropical ridge that drives south-easterly winds across the Coral Sea. During this period the ridge is periodically weakened by transitory cold fronts at mid-latitude; however, high pressure (and the south-easterlies) usually re-establishes rapidly after the passage of such systems. This results in persistent south-easterly wind across the tropical Queensland coast.

Figure 2.1 shows the evolution of the synoptic pattern typical of this period in which the strength of the south-easterlies over northern Queensland is controlled by the relative strength of high pressure to the south.

2.1.2 Warm Months

During the warmer months of the year a region of low pressure develops across the north of the continent and the sub-tropical ridge weakens and migrates further southwards. This results in generally weaker pressure gradients and the development of coastal sea-breezes.

Figure 2.2 shows the evolution of the typical synoptic pattern for the warmer months of the year; the example shows transitory tropical low pressure systems that can produce locally stronger winds in association with upper atmospheric disturbances. In extreme cases, such low-pressure systems may develop into tropical cyclones.

2.1.3 Analysis of Wind Records

Wind records are available from the Bureau of Meteorology Automatic Weather Station at Townsville, but this site is not considered to provide good representation of the marine wind regime in the area. Accordingly, GEMS has used winds from the Bureau's meso-LAPS numerical weather prediction model. These winds are stored at an interval of one hour and at spatial resolution of approximately 10 km.

Winds from this database were extracted over a spatial grid to drive the ocean models used in the project. Figure 2.3 and Figure 2.4 show polar wind diagrams for Cape Cleveland, for the 'cool' and 'warm' months respectively, constructed from the meso-LAPS data.

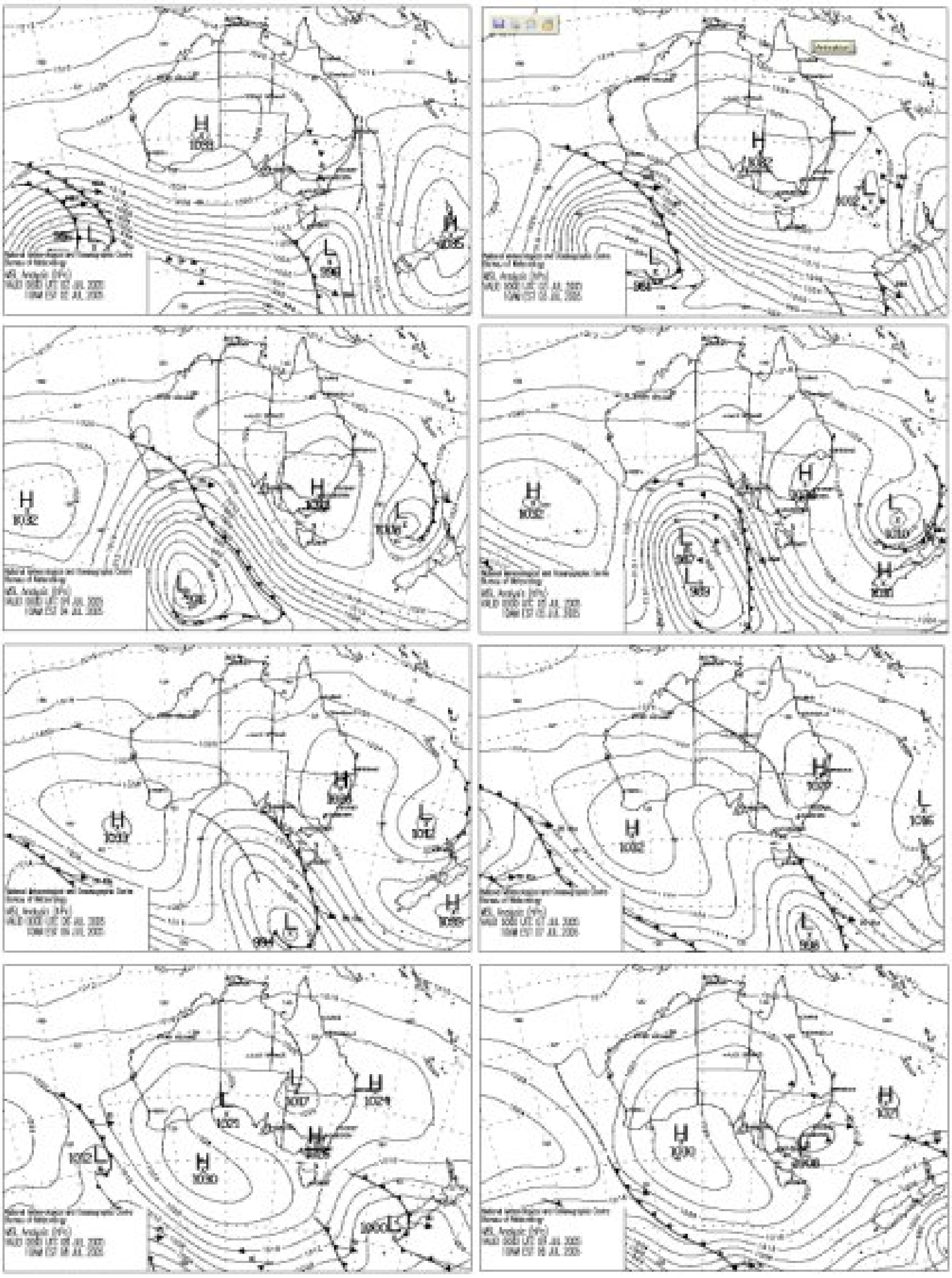

Figure 2.1. Example of synoptic evolution during July.

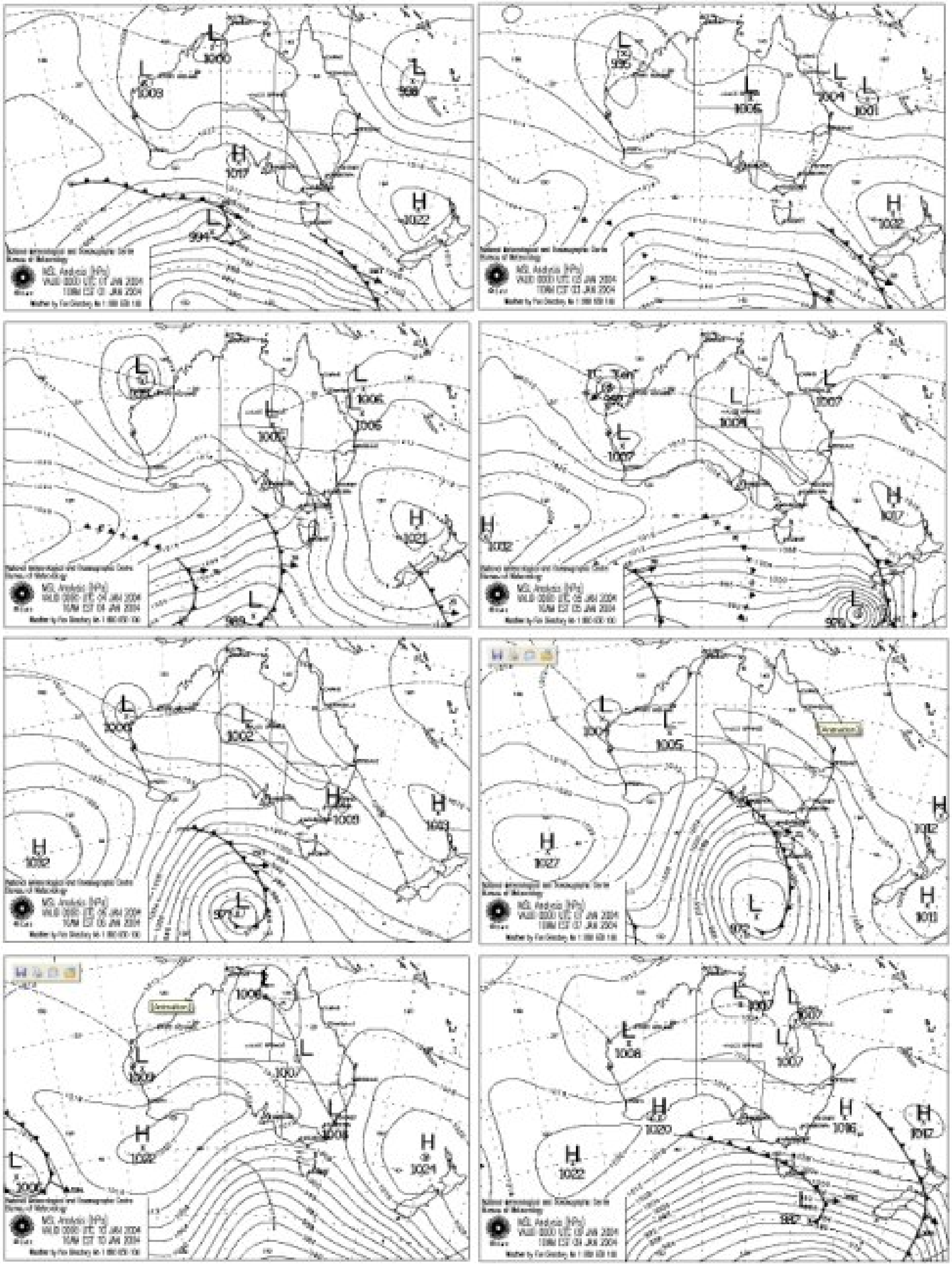

Figure 2.2. Example of synoptic evolution during January.

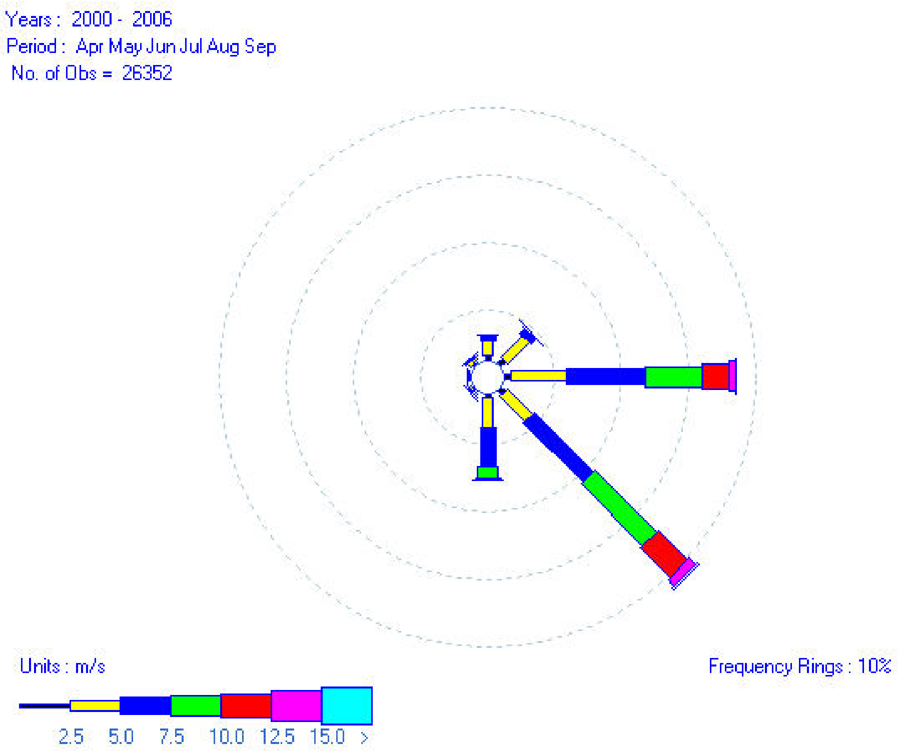

Figure 2.3. Polar wind diagram for Cape Cleveland for 'cool' months.

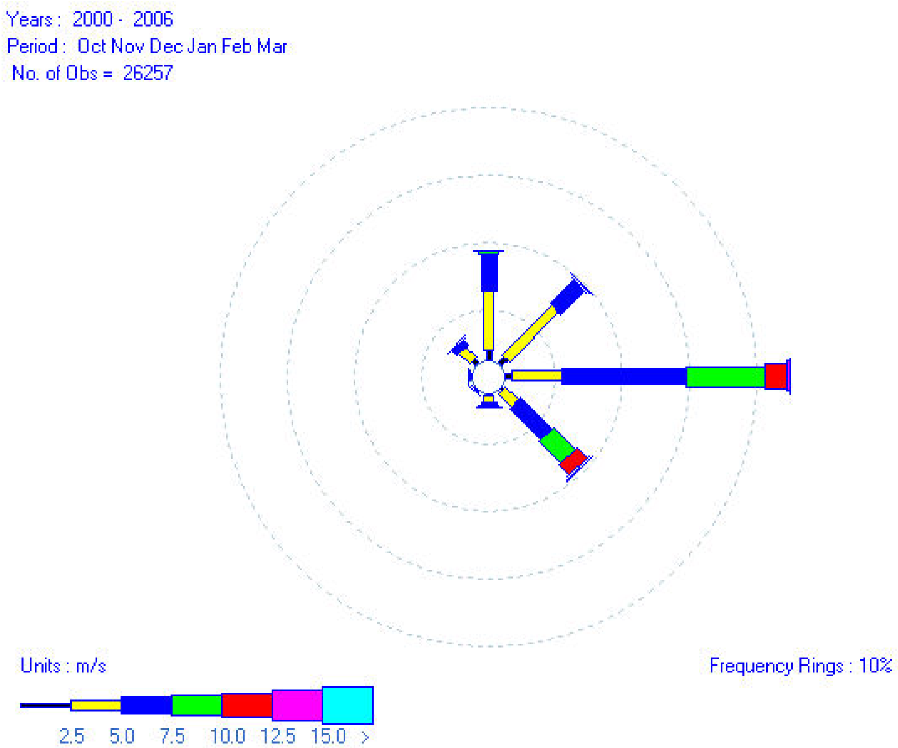

Figure 2.4. Polar wind diagram for Cape Cleveland for 'warm' months.

2.2 Meteorological Forcing for the Ocean Modelling

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 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 release site the currents are not just driven by the local wind but are also a results 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.

2.2.1 Meso-LAPS

The Bureau of Meteorology (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), which 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 – Mesoscale Limited Area Prediction System) at a spatial resolution of about 10km for a period of more than six years (since the Sydney 2000 Olympics). This model is nested inside LAPS and runs twice daily producing 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.

3 Oceanography

Townsville Port is situated in Cleveland Bay, bounded on the east by Cape Cleveland and on the west by Cape Pallarenda. Cleveland Bay faces due north with Magnetic Island in its entrance. The majority of the bay is less than 10 metres deep and approximately 50% is less than 5 metres deep.

The shallowness of Cleveland Bay, together with its location on the continental shelf results in a significant tidal range (approximately 3.8m) and a susceptibility to large storm surges from tropical cyclone events. Conversely the shallowness and aspect of Cleveland Bay and the existence of the Great Barrier Reef mitigate against large wave conditions. The dominant winds come from the southeast and again due to its aspect Cleveland Bay is protected from this direction by Cape Cleveland.

3.1 Tides

The tidal range (Lat to HAT) in Cleveland Bay is about 3.8 m. The flood tide is generally propagating northward off Townsville and its movement onto the coast is in the same general direction as the major source of the forcing (the Moon). The ebb tide however is moving against the Moon's forcing as the waters recede at the coastline and therefore the peak ebb tidal currents are often slightly slower than the peak flood tidal currents. Since the nett mass transport over time into and out of Cleveland Bay, due to the tide alone, is zero the above considerations will result in sharper peaks in the flood tide currents than the ebb tide currents.

3.2 Currents

The currents in Cleveland Bay are predominantly driven by the tides (discussed earlier) and the winds. The wind driven currents are generally flowing northward along the coast driven by the predominant south-easterly winds.

Surprisingly there have been very few current measurement programs in Cleveland Bay but the data reported by Mason et al (1991) suggests neap tidal current speeds are generally less than 5 cm/s whilst spring tidal current speeds reach 30 cm/s. A modelling study, supported by ADCP transects, by GHD in 2001 (GHD, 2003) reports agreement with these current speed ranges.

3.3 Sediment Processes

The existence of wind-driven currents from the south, combined with flood tidal flows from a similar direction, can produce a dominant longshore flow, which can transport suspended sediments from the south into Cleveland Bay. This process can be especially important during flooding events in the Burdekin River, to the south of Cape Cleveland.

During the flood tide, the waters in Cleveland Bay can be over 3m deeper than during the ebb tide and so larger wave action can occur which will contribute to resuspension of sediments, which can be transported on the flood tide. The slightly weaker ebb currents, together with less wave action will most likely result in a nett accumulation of sediments in Cleveland Bay.

3.4 Surface Drift Track Measurements

From the information available prior to the study, the precise behaviour of the flooding and ebbing tide in Cleveland Bay was not clear. The main point of interest is the affect of Magnetic Island and whether the tide ebbs between Magnetic Island and the coast or is forced to go around the eastern side of Magnetic Island due to the shallow bathymetry between Magnetic Island and the coast.

To study this process in particular and the flooding and ebbing tides in general, GEMS deployed five wireless GPS ocean surface drifters (Davis drifters) in Cleveland Bay to map surface current movements; and

Figures 3.1 and 3.2 show a GPS wireless Davis Drifter (originally developed by Scripps Institute of Oceanography for deep ocean satellite tracking) before and after deployment. The underwater “sails” act to lock the drifter into the upper water column and ensure the drifter moves with the near surface currents.

The drifters were deployed at various locations between the Townsville Port and Magnetic Island during daylight hours between November 14 and 16, 2006 (see Figures 3.3 to 3.5).

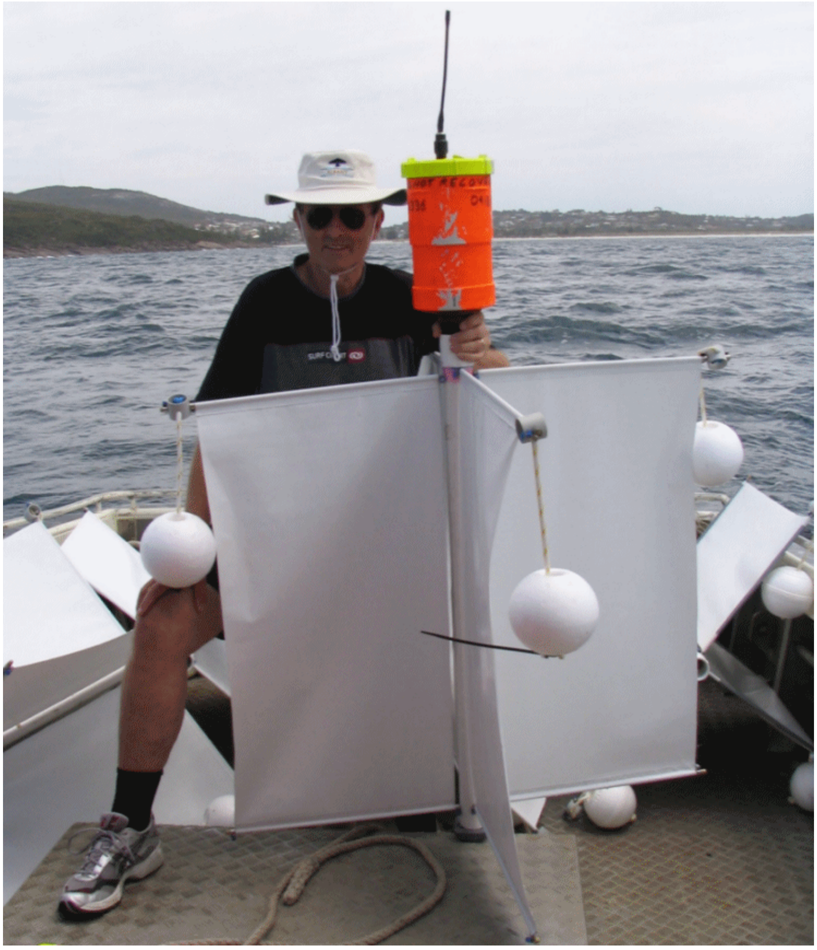

Figure 3.1: A wireless GPS Davis Drifter prior to deployment.

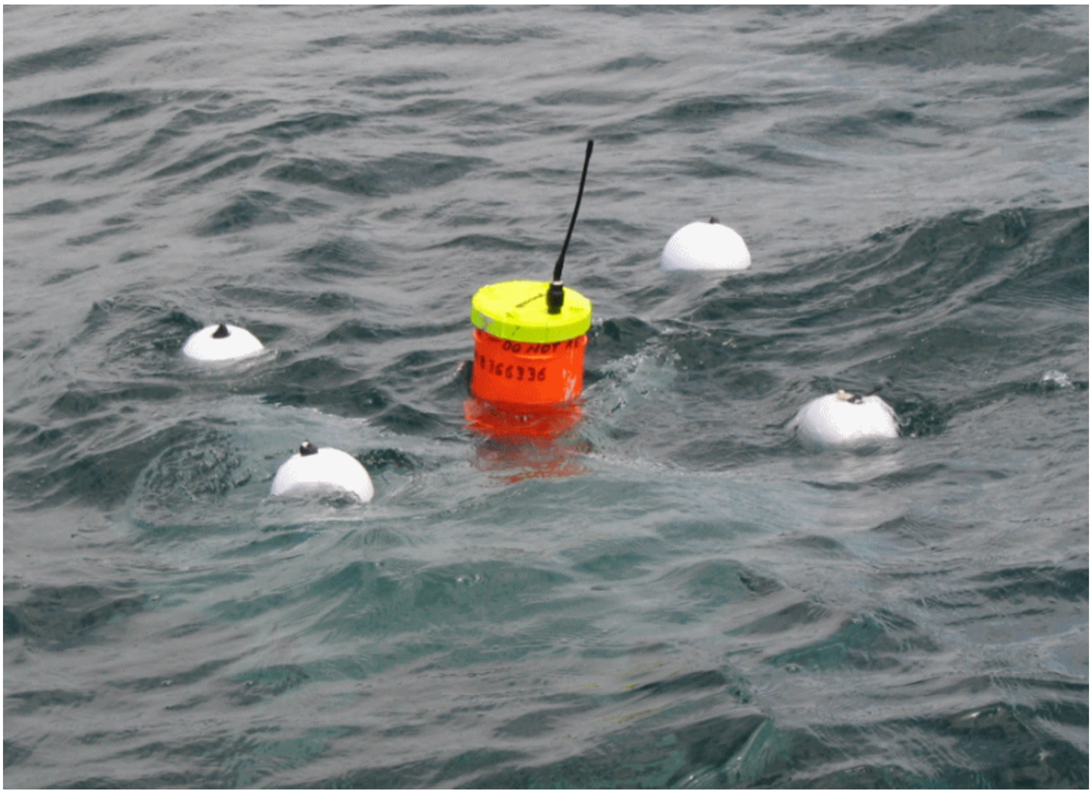

Figure 3.2: A wireless GPS Davis Drifter after deployment.

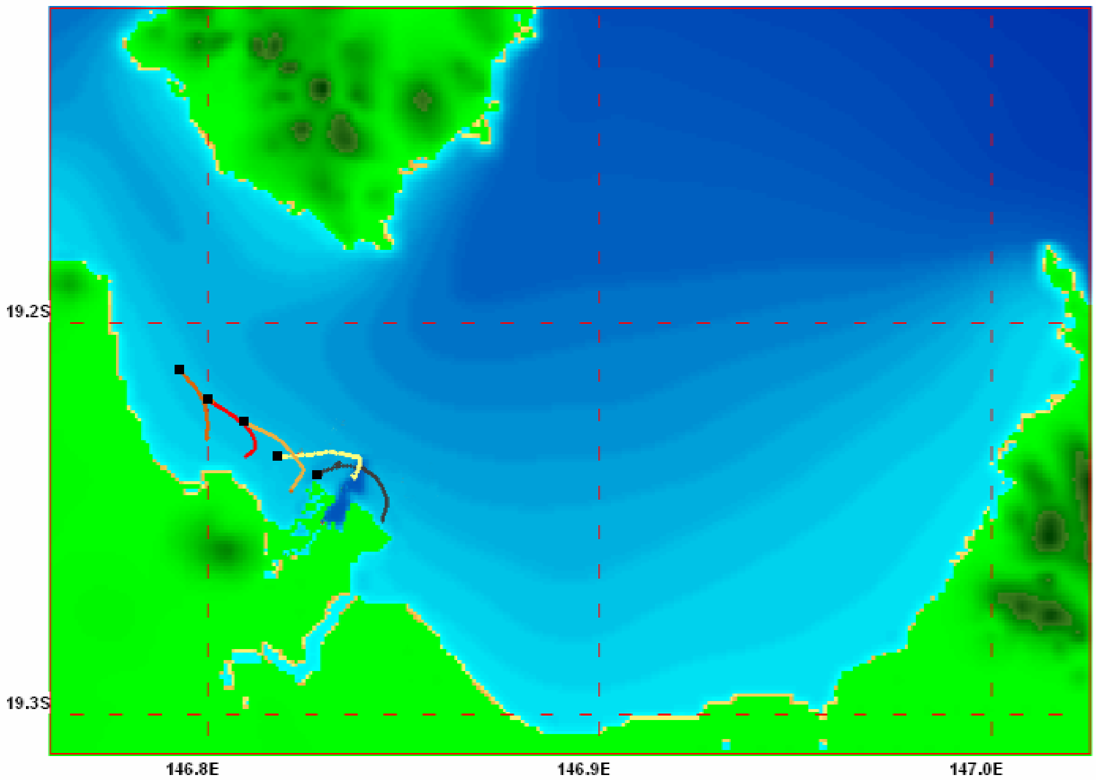

Figure 3.3: The concurrent tracks of five GPS drifters released (black mark) at 0800 hours on November 14, 2006.

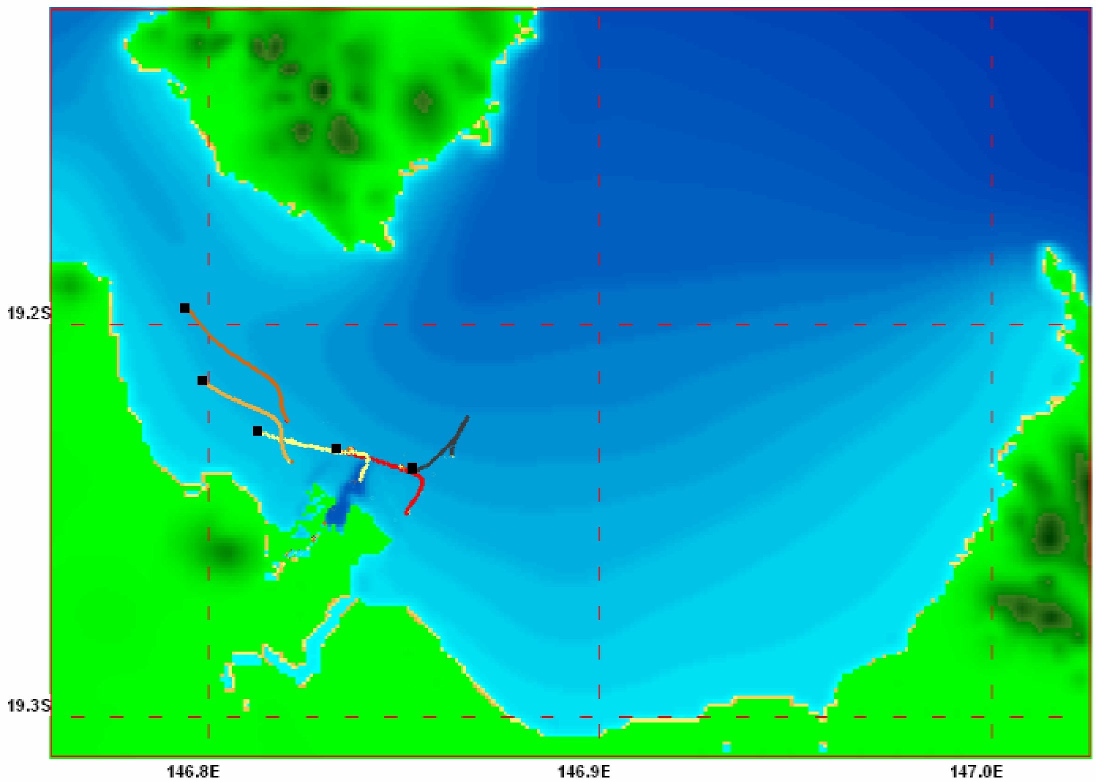

Figure 3.4: The concurrent tracks of five GPS drifters released (black mark) at 0800 hours on November 15, 2006.

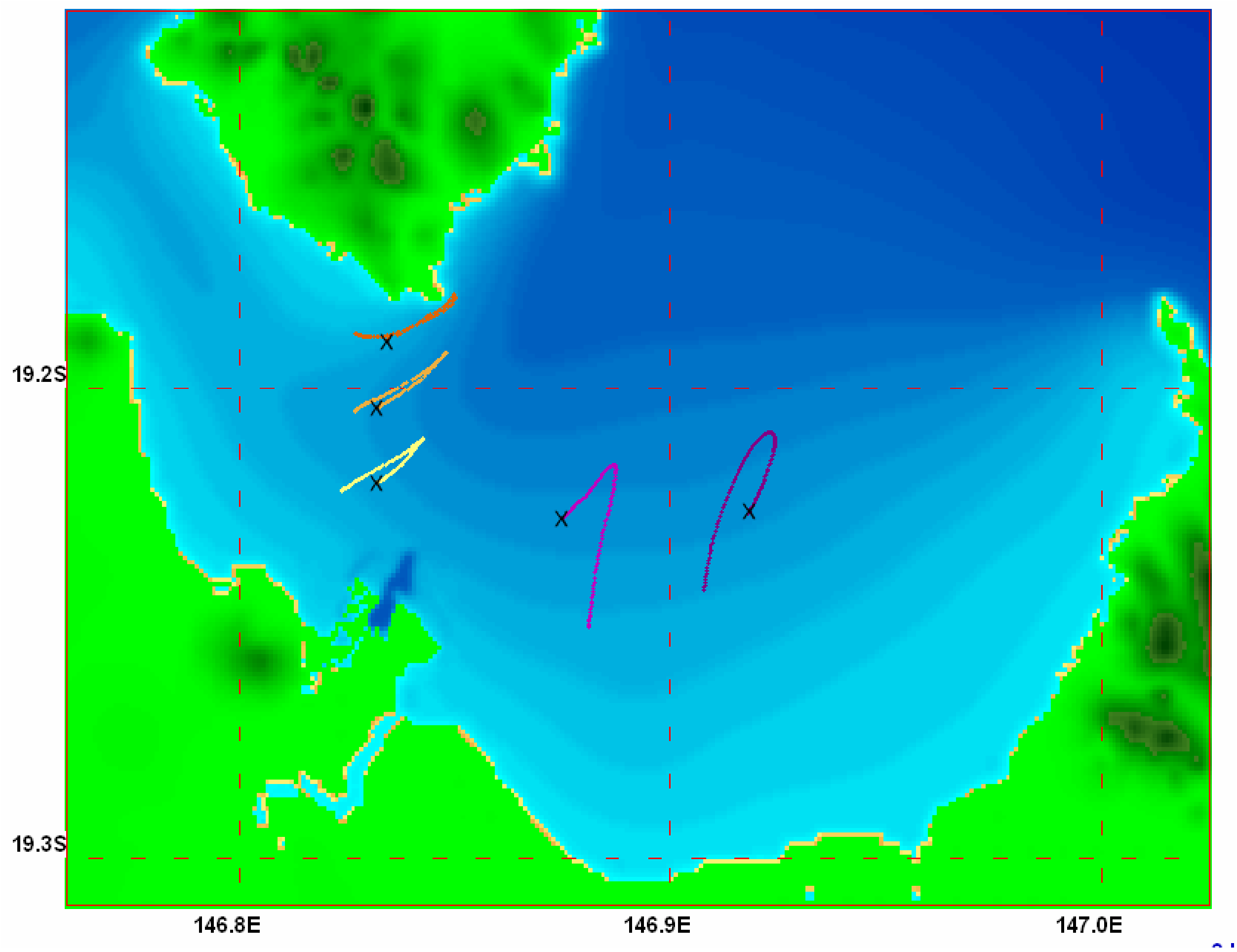

Figure 3.5: The five concurrent 23 hour tracks of two GPS drifters released (black cross) at 0800 hours on November 16, 2006.

4 Hydrodynamic Model Setup and Verification

The results of these studies are all dependent on an accurate simulation of the 3D currents in and around the development. The first task was therefore to setup the GEMS 3D Coastal Ocean Model (GCOM3D) and verify that the model reliably simulates the existing circulation, in Cleveland Bay and around Magnetic Island by comparing predictions with observations. If problems are found during this process then the cause must be identified and corrected (e.g. incorrect bathymetry, tides, winds or some issue within the physics of the model).

4.1 Model Setup

4.1.1 Meteorological Forcing

As explained earlier GEMS uses the BoM high resolution MesoLAPS model data for marine winds around Australia.

4.1.2 Cleveland Bay Bathymetric Grid (Grid A)

To model the tides and currents in the region of the development the oceanography of a much large region must first be modelled to establish the correct process for the flooding and ebbing tide in Cleveland Bay.

Bathymetry for simulations in Cleveland Bay was derived from the GEMS 250 metre resolution database of the region and augmented by digitisation of the marine chart. The Cleveland Bay grid is shown in Figure 4.1.

4.1.3 Townsville Ocean Terminal Bathymetric Grids (Grids B and C)

The client provided plans for the proposed development (Figure 1.1) which were digitised and combined with further high resolution bathymetric and coastline digitisation of the marine chart.

Some of the key features of Grid B (Figure 4.2) which affect flushing in this design were:

- an external access channel to the north to a depth of 4.9m chart datum; the same as the deepest part of the development (maintenance of this depth is essential to flush the marina waters as there must be a flushing route as least as deep as the deepest part of the marina)
- the western seawall was opened up with a 100 metre long piled structure at the southern end

- the internal “arms” of the development were connected from the eastern side of the development via “bridges” which allowed circulation around the “arms”.

After viewing the initial flushing results a further grid (Grid C) was set up to investigate potential improvements to the flushing.

The changes made to Grid C (Figure 4.3) were:

- the northwest entrance to the development was opened from 75 metres to 100 metres;
- the southern gap in the western seawall was reduced to 75 metres;
- the external entrance channel and the internal channel along the western seawall were deepened to 5.5 metres; and
- the large southern basin was “sloped” into the western channel from a depth of 4.5 metres on the eastern side (this change was specifically focussed on achieving flushing of bottom waters).

4.1.3 Tides

Tidal conditions on the open boundaries of the large domain were defined from the Australian region gridded tidal base held by GEMS and originally developed for the Australian Maritime Safety Authority Search and Rescue operations in Australian waters. Higher resolution modelling is then nested inside the larger model.

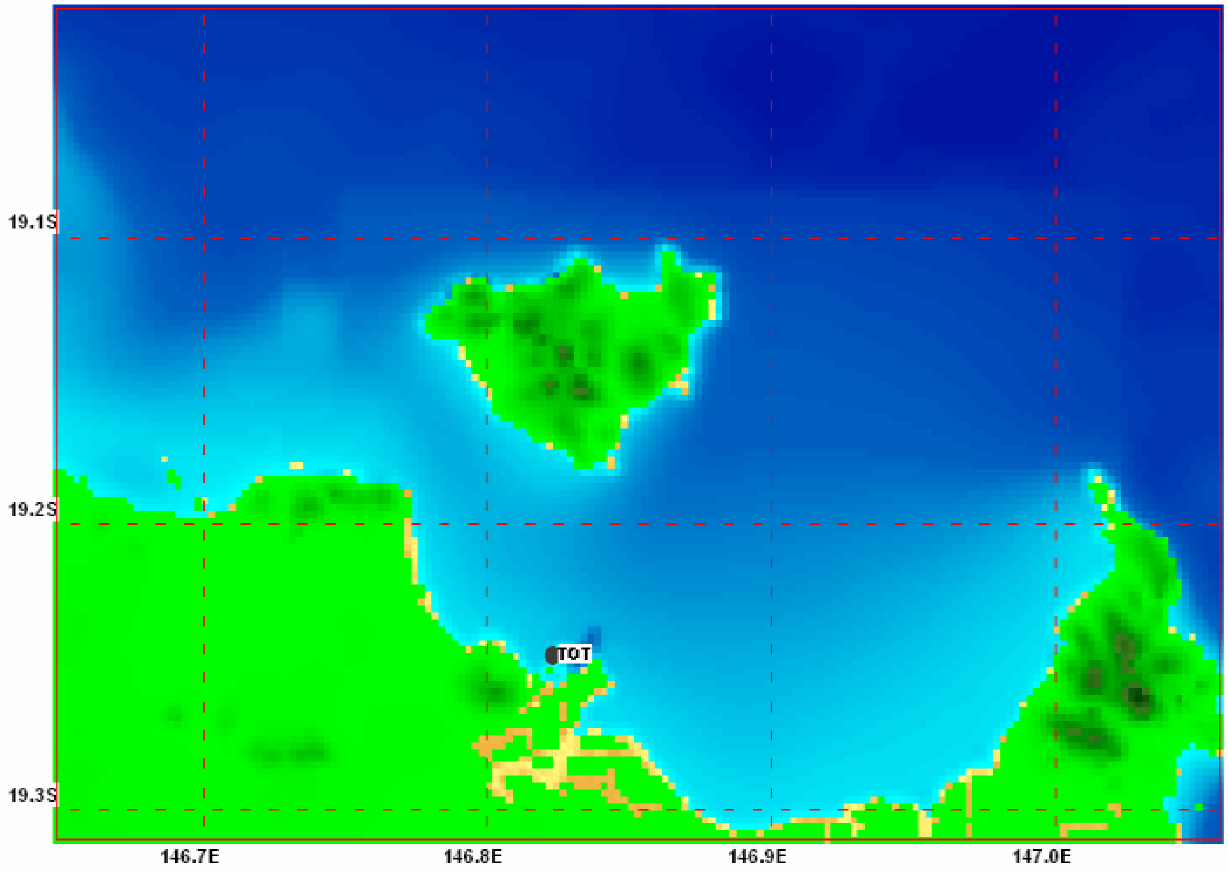

Figure 4.1: The region covered by the Cleveland Bay bathymetric grid (Grid A)

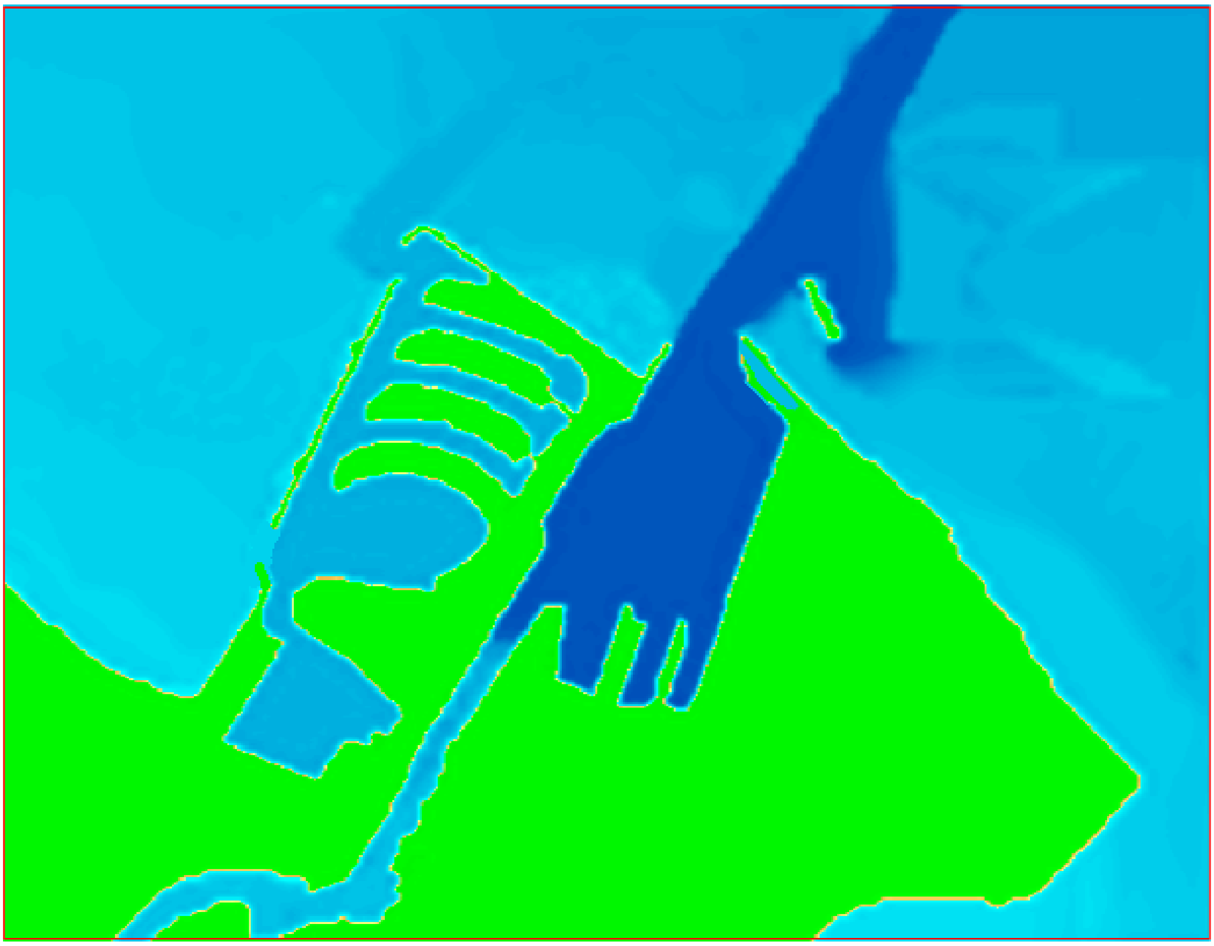

Figure 4.2: Townsville Ocean Terminal bathymetric grid (Grid B) including the dredged access channel and showing the locations (M1 – M10) where flushing characteristics were studied.

Figure 4.3: Townsville Ocean Terminal bathymetric grid (Grid C) with an opening at the southern end of the Strand Breakwater.

4.2 Verification of GCOM3D

Current meter data in Cleveland Bay was not available to the study and so the verification of GCOM3D is based upon comparisons with tide gauge data at Townsville Port and the results of the surface current mapping with GPS drifters by GEMS in November 2006.

To undertake the verification, GCOM3D was run for the full month of November, 2006 on the nested grid system (Grid A and then Grid B) driven by tides and MESOLAPS winds to cover the duration of the drifter tracking and to obtain a lunar cycle of sea level predictions.

4.2.1 Tides

Figures 4.4 and 4.5 show samples of the flood and ebb tide throughout Cleveland Bay under existing conditions. The predictions for sea levels are compared with tidal predictions for Townsville Port in Figure 4.6.

4.2.2 Currents

Comparison of drift tracks predicted by GCOM3D with one of the observed tracks on each of the three days (November 14 to 16, 2006) are shown in Figures 4.7 to 4.9.

The results show very good agreement between the predictions of GCOM3D and the measurements. This result indicates that GCOM3D is simulating the propagation of tides and currents into, and out of, Cleveland Bay, including the flow around Magnetic Island with a high degree of accuracy.

A major point to note regarding the currents in Cleveland Bay is that the shallow bathymetric cross-section between Magnetic Island and the mainland does not allow sufficient mass flux during the ebb tide and therefore it is forced to also flow back around the eastern side of Magnetic Island (see Figure 4.4). This pattern of the ebbing tide is important for the flushing of turbidity created during dredging.

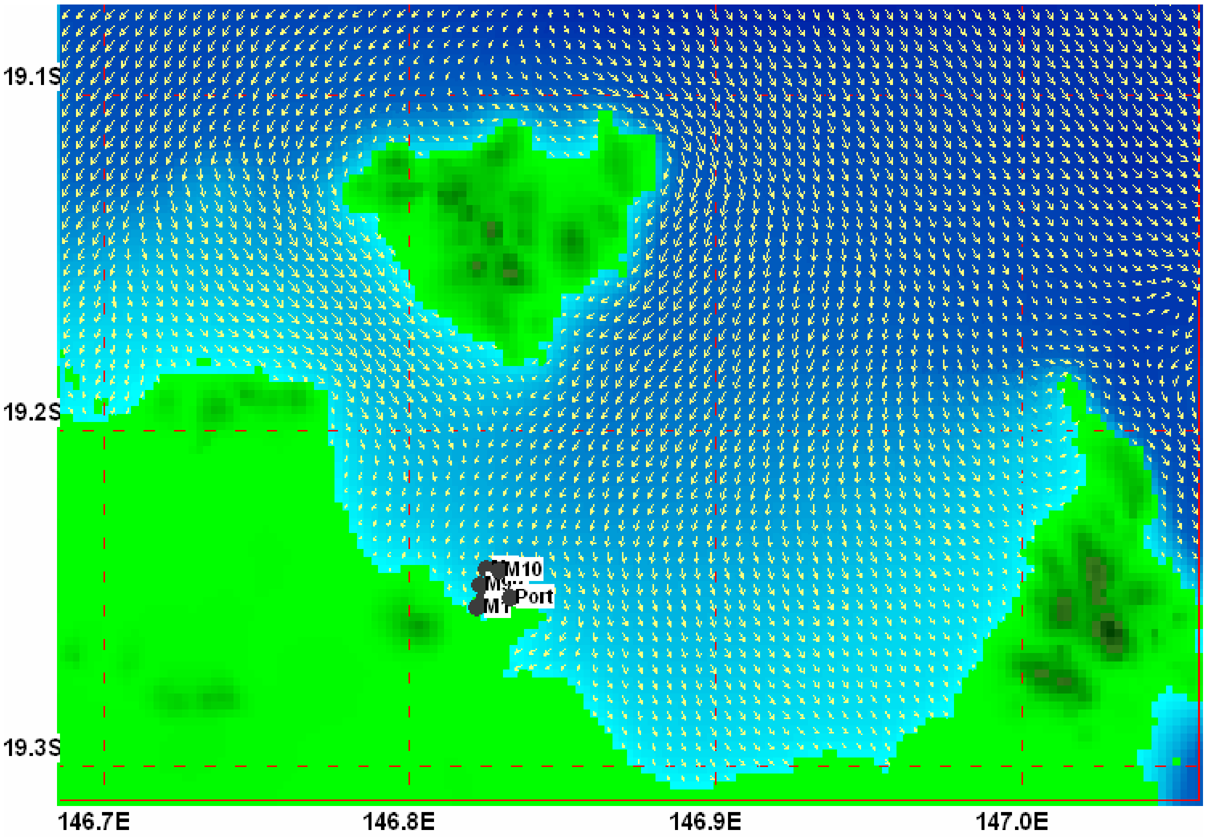

Figure 4.4: Sample of the flood tide in Cleveland Bay predicted by GCOM3D.

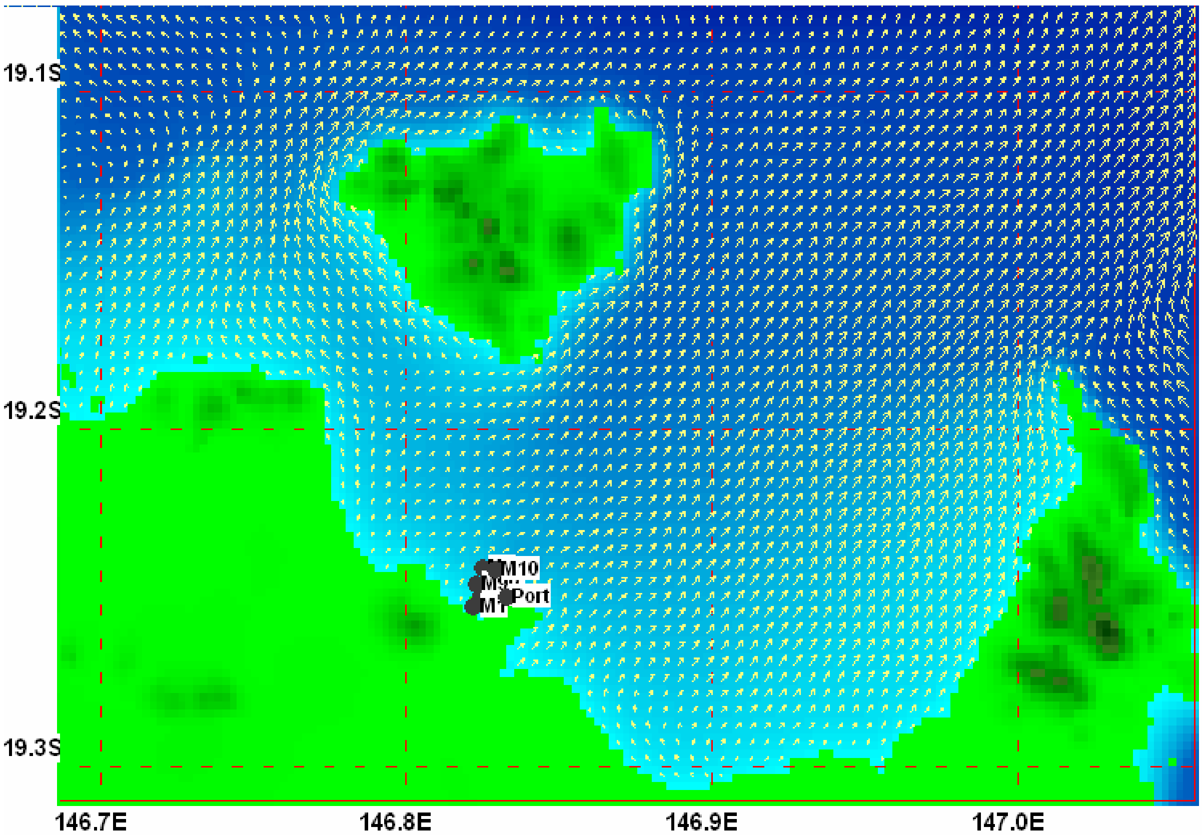

Figure 4.5: Sample of the ebb tide in Cleveland Bay predicted by GCOM3D.

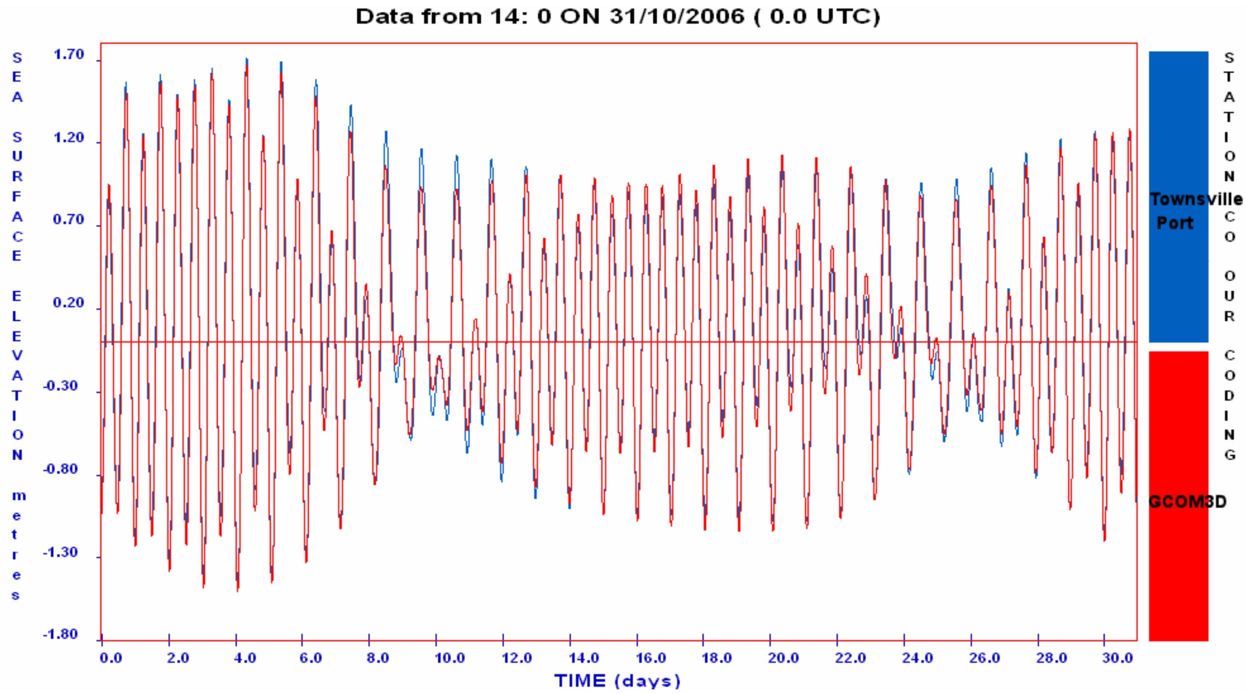

Figure 4.6: Comparison of GCOM3D predictions for tidal levels at Townsville Port with values from the Tide Tables for November, 2006.

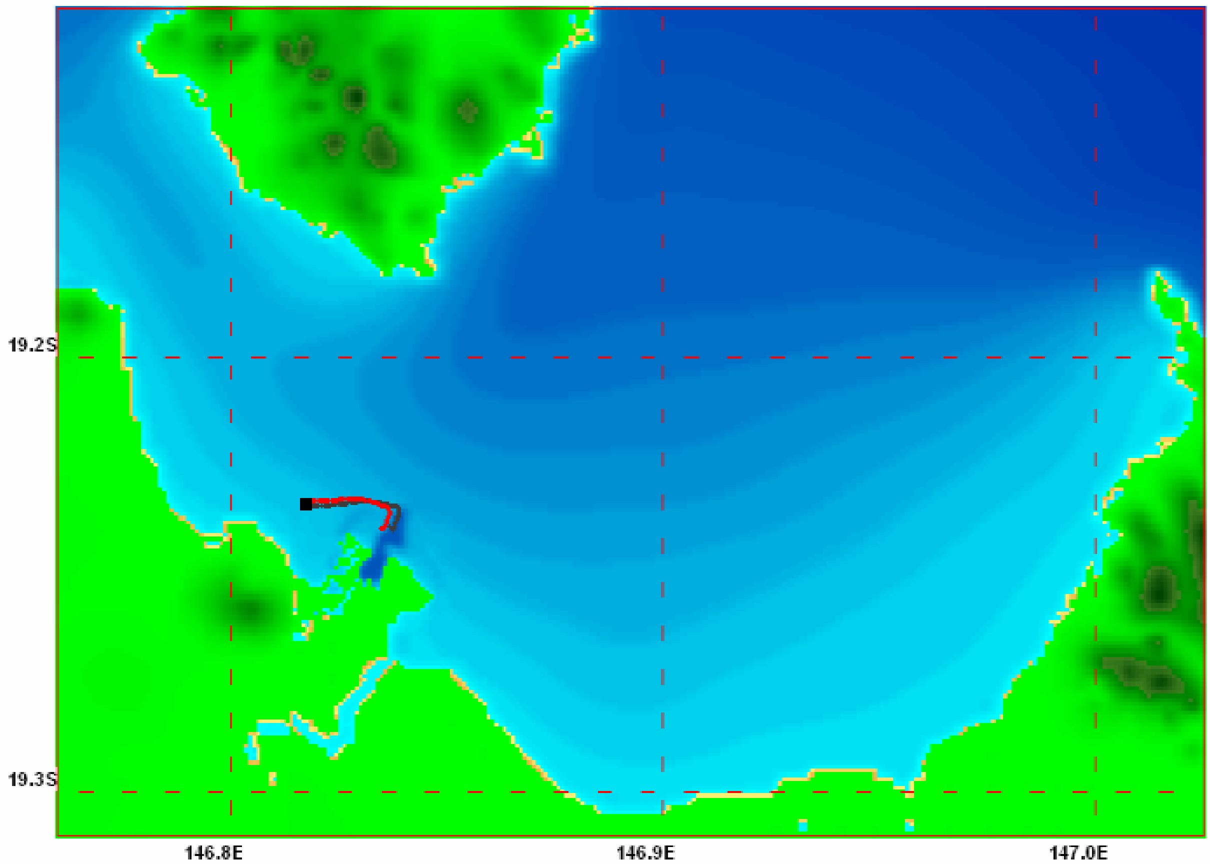

Figure 4.7: Comparison of GCOM3D drift track predictions with the observed track on November 14, 2006.

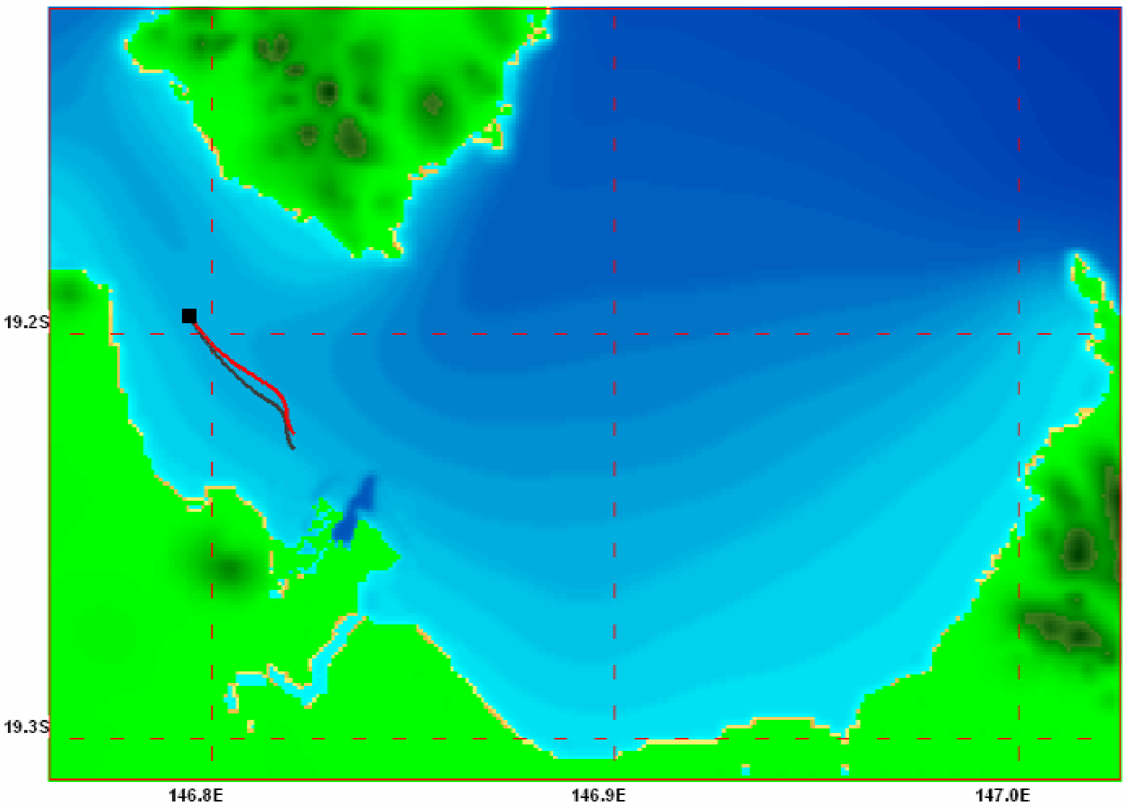

Figure 4.8: Comparison of GCOM3D drift track predictions with the observed track on November 15, 2006.

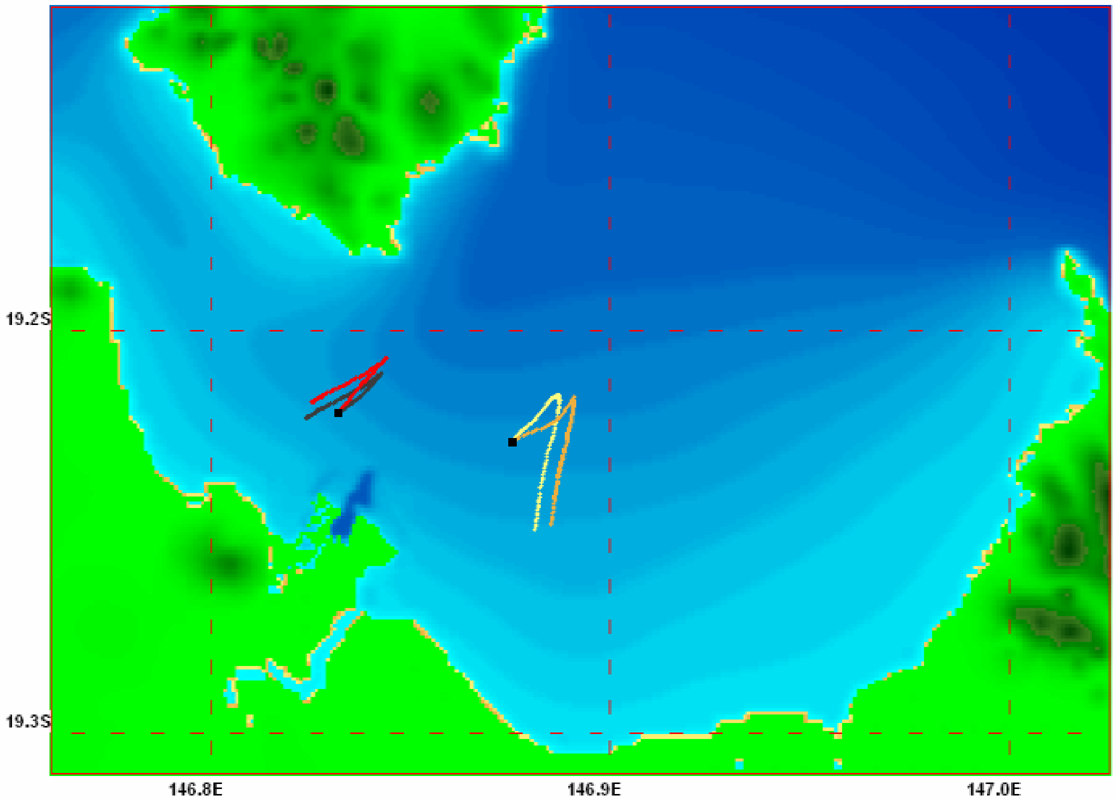

Figure 4.9: Comparison of GCOM3D drift track predictions with two observed tracks on November 16, 2006.

5 Impacts of the Development on Water Level and Currents

For the development impact assessment studies GCOM3D was run for one month (two spring-neap cycles) driven by tides and winds. This simulation was carried out twice using the pre- and post-development bathymetric grids to compare currents and water levels outside the development.

Table 1 gives the average differences in the sea levels and current speeds before and after the development at a location in the open waters of Cleveland Bay northward of the new seawall (M10 in Figure 4.3).

Table 1: Mean changes in sea level and current speeds as a result of the Townsville Ocean Terminal development.

Sea Level	Current Speed
0.00004 metres	0.007 m/sec

The results in Table 1 show negligible difference in the sea levels and small changes in the current speeds. These variations, particularly the sea level, are too small to argue that the model is accurately discerning a difference.

Note that the current directions at M10 are effected by the creation of the new seawall on the northern perimeter of the development.

6 Modelling the Flushing of the Marina Waters

The flushing of the waters within the development was modelled with the GEMS 3D marine plume discharge model, PLUME3D. This model can track selected volumes of water in a number of locations throughout the marina waters to determine the flushing rates and identify any regions of very poor flushing.

In past studies of this kind "scenario" modelling has often been used which investigates dispersion under varying meteorological and tidal conditions such as:

- Spring tides and south-easterly (constant) winds
- Neap tides and weak winds.

In the Townsville region, these two scenarios are often chosen because the first represents the most frequent wind regime experienced and the second represents the conditions of least dispersion of any discharges.

With the advance in computer speed it is now possible to carry out long term hindcast simulations using real winds and real tides to study the flushing over a long period. In this study the flushing rates around the marina waterways were studied at a number of locations (see the locations marked in Figure 4.3) for a period of 3 months.

An important point to note is that flushing studies are a three-dimensional problem because surface waters will generally flush faster than bottom waters. The variation of flushing rates through the water column will depend on the existence of mechanisms to drive vertical mixing. The strong tidal flows can create turbulence and mixing and so the variation of flushing through the water column will vary as the tides pass through the spring to neap cycles. Bottom waters will flush less during neap tides and low wind conditions.

Since the bottom waters will generally flush slower than surface waters it is essential that the flushing path (in this case the external access channel) be maintained at a depth at least as deep as the deepest part of the marina. It is important to note that this requirement will not be captured by simulating flushing with 2D ocean models (such as Mike21 or Delft3D in 2D mode) because these models will necessarily not differentiate bottom waters from surface waters and therefore spuriously flush the entire water column.

It is therefore important to study flushing with a reliable 3D ocean model in order to capture the variation of flushing through the water column and simulate the vertical mixing processes.

As discussed earlier, two different design options were explored to determine the optimum design for flushing. The bathymetric grids for these options are shown in Figures 4.2 and 4.3.

Tables 2 and 3 summarise the variation in time of the average percentage (from the top to the bottom) of the water column flushed at the locations M1 to M9 for the two separate design options (figures 4.2 and 4.3) respectively.

The results show that the changes incorporated in Grid C produce better flushing than the original study grid (Grid B). Gird C achieves 90% flushing of all areas of the TOT within a spring-neap tidal cycle.

Table 2: Comparison of the variation with time of the average percentage of the water column flushed within the marina waterways for the bathymetry in Figure 4.2 (Grid B)

Elapsed Time	M1	M2	M3	M4	M5	M6
1 day	94	75	73	76	62	60
2 days	82	59	38	59	43	36
3 days	70	50	15	49	31	29
4 days	61	45	8	36	23	26
5 days	55	40	6	22	18	24
7 days	46	35	5	16	13	22
10 days	40	25	3	12	9	17
14 days	30	15	3	5	4	10
21 days	15	10	-	2	2	3
28 days	5	3	-	-	-	-

Table 3: Comparison of the variation with time of the average percentage of the water column flushed within the marina waterways for the bathymetry in Figure 4.3 (Grid C) with sloping bottom and wider entrance

Elapsed Time	M1	M2	M3	M4	M5	M6
1 day	87	75	69	73	61	60
2 days	73	61	47	57	43	39
3 days	64	52	35	47	30	31
4 days	57	44	23	34	22	25
5 days	51	37	17	21	17	20
7 days	44	28	13	15	13	16
10 days	39	18	10	11	9	11
14 days	28	10	5	5	4	5
21 days	13	5	2	2	2	3
28 days	4	2	-	-	-	-

7 Maintenance of the External Access Channel

The original plan was to dredge the external access channel to a width of 50 m and a depth of 4.9m AHD (Figure 7.1). To aid the flushing of internal waterways the access channel is now to be dredged to a depth of 5.5m AHD. The channel will now extend approximately 350 metres into Cleveland Bay and approximately 35,000 m3 will be removed during the initial construction.

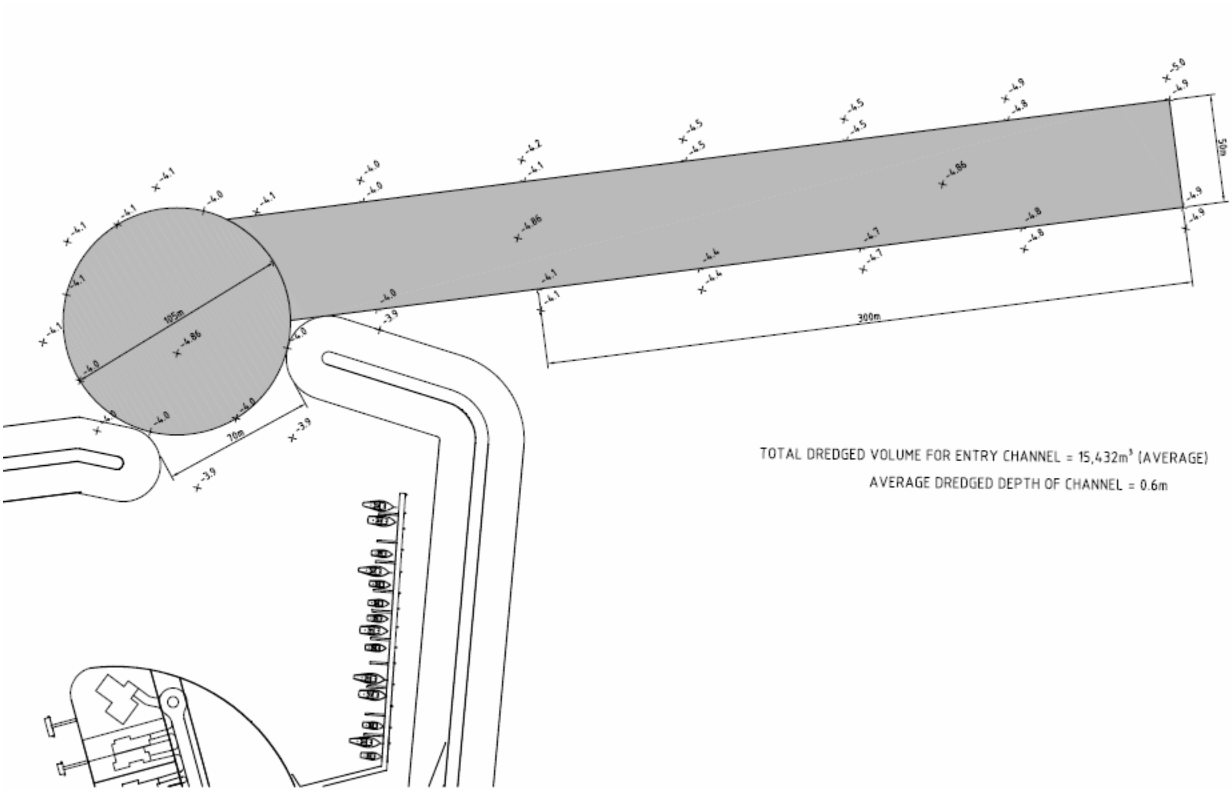

Figure 7.1: Access channel plan prior to the decision to deepen it by 0.6 metre

7.1 Turbidity and Sedimentation in Cleveland Bay

The major cause of resuspension of material from the ocean floor is wave action, which makes material available to be relocated by the prevailing ocean currents. Strong bottom currents can also release material into the water column but these generally are only strong enough during storms.

Previous studies (GHD, 2003) have shown that Cleveland Bay transports significant amounts of suspended sediments (example shown in Figure 7.2) and that the rate of nett deposition in the Townsville Port Outer Harbour is of the order of 10cm/month.

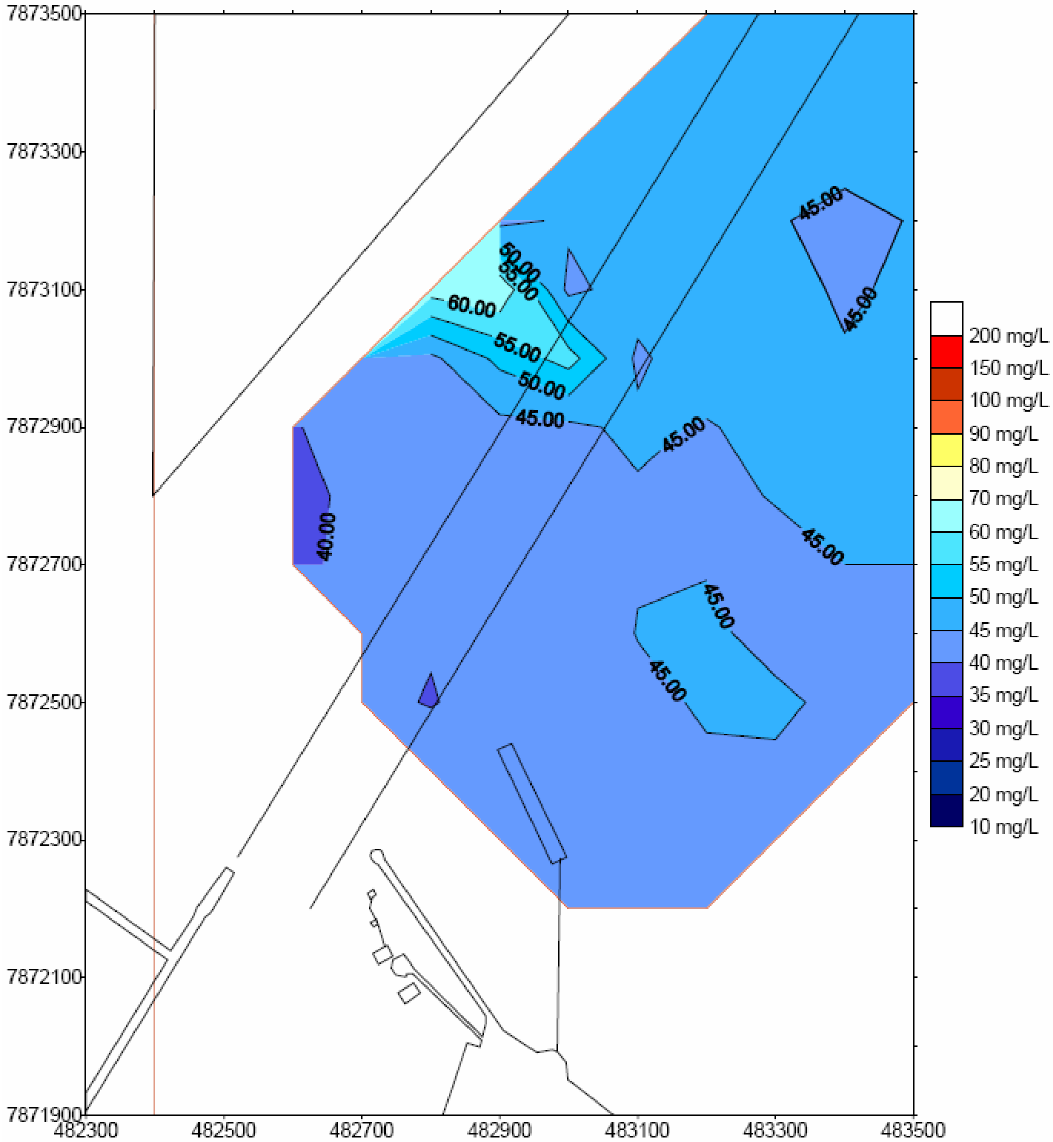

Figure 7.2: Sample of the total suspended solids measured in the outer harbour by GHD in June, 2001.

7.2 Sedimentation Modelling Studies for the TOT Access Channel

The TOT access channel is much shallower and more exposed than the Port outer harbour and so a somewhat lower nett sedimentation rate is expected in the channel than in the outer harbour due to the higher energy environment in the channel.

To assess the long-term behaviour of bottom sediments in Cleveland Bay and the expected rate of deposition in the access channel after completion of the project, a long term modelling study was undertaken with the GEMS 3D sediment transport model (SEDTRAK3D).

SEDTRAK3D 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 (either from observations or from the SWAN wave model) and meteorological data from the Bureau of Meteorology, to simulate the movement, deposition and resuspension of suspended particles in the water body.

SEDTRAK3D is able to differentially trace the fate of each group of particle sizes through the water column. Post-processing at selected time steps allows computation of sedimentation or total suspended sediment, TSS, (mg/l) either at particular levels, as an average or maximum through the water column.

For this study SEDTRAK3D was run for the 365 days of 2001, driven by currents from GCOM3D, waves in Cleveland Bay provided by Coastal Engineering Solutions (CES) and winds from the Bureau of Meteorology MesoLAPS atmospheric model.

The simulation of "typical" meteorological conditions with the 2001 meteorological data should account for most sources of sediment transport. However it should be noted that the 2001 meteorological data contained "normal" storms with return periods of less than 1 year but major storms, or cyclones, with return periods greater than 1 year were not represented.

A further potential source of sediment transport, is propeller wash but this mechanism was not considered to be a major source of sediment movement for two reasons:

a) Under keel clearances, and speed limitations on boats, would generally ensure that propellor wash was only a minor source of turbidity.

b) Along the channel, propeller wash would generally act to move sediments along the channel but not into or out of the channel

The particle sizes used for the study were derived from the information in the GHD report (GHD, 2003) with one major difference. The GHD study only used two particle sizes (20 microns and 80 microns which represented the peaks in the distribution curve) whereas for this study 50 particle sizes were used to better represent the distribution of particle sizes.

The results after 1 year were analysed along the TOT access channel to derive the annual nett deposition of material in the access channel.

The results showed a build up in the access channel of 2- 3 cm per month, significantly less than derived by GHD for the Port outer harbour. This result would be expected due to the much higher energy environment of the shallower and more exposed TOT access channel resulting in significantly more resuspension and movement of fine sediments.

These results suggest an annual accumulation in the range of 25 to 35 cm in the access channel which equates to approximately 7,000 m^2 per annum (about 2% of the annual maintenance dredging load of the Townsville Port Authority).

An important corollary of this result is that, since the access channel is the main flushing route from the development, it must be maintained near to the planned depth of 5.5 metres AHD to ensure adequate flushing. The channel will therefore have to be dredged at least every two years.

It is important to note, when interpreting these results, that this study focused on the suspension and relocation of material due to waves and currents in a 12 month period and not on the loss of sand from beaches/shallow areas during severe storms and cyclones.

7.3 Sedimentation Modelling Studies for the TOT Berthing Area

The TOT large boat berthing area is on the eastern side of the existing Port western breakwater. Due to the size of the ships expected to utilise the berth it will have to be maintained to a similar depth to the surrounding Port facilities. The nett sedimentation rate is therefore expected to be similar to the Port inner harbour.

To investigate this further, the data from the 365 days simulation with SEDTRAK3D was analysed to derive:

3. The nett sedimentation at the TOT large ship berthing area; and
4. The nett sedimentation in the outer harbour

The latter result was derived in order to compare with the results obtained by GHD.

The results showed an average build up in the TOT berthing area of 8- 9 cm per month, or up to 1 metre per year.

These results however did not include ship movements as a source of resuspension and therefore the real annual sediment budget could be expected to be lower than predicted.

Logic suggests that the TOT berthing area should be dredged every time the Port inner harbour is dredged because the increase in total volume to be dredged will be small due to the relatively small area occupied by the TOT berthing area.

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Appendix A: Selected Ocean Modelling Publications

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Hubbert, G.D. and McInnes, K.L. (1996). Climate Change and the Coastal Zone. Part II: Inundation Modelling in Port Phillip Bay. *Journal of Climate Change*

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Appendix B: Model Descriptions

B.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 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 with 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 relocatable 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. A two-dimensional version of the model that includes tidal and flood inundation is used in river systems.

GCOM3D has undergone exhaustive evaluation and verification in the 13 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 Search and Rescue system predicts ocean currents with GCOM3D, which has been running in real-time at the Australian Maritime Safety Authority in Canberra for the past 3 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.

B.2 Discharge Plume Modelling with PLUME3D

PLUME3D is a high resolution version of GCOM3D which nests inside GCOM3D (i.e. obtains boundary conditions from) and includes 3D plume dispersion algorithms for modelling the behaviour of a wide variety of discharge materials including sediments, sewerage, thermal discharges, oils and chemicals, accounting for processes such as dispersion and dissolution, under defined release conditions (quantity, rate etc). This model was the first 3D plume model to be used in Australia for the Geelong Ocean Outfall Study in 1984. The oil spill prediction model, OILTRAK3D, is a sub-model of PLUME3D.

PLUME3D uses predictions from GCOM3D, run on a larger grid, to provide the ocean conditions into which the cooling water is discharged. The three-dimensional structure of the model allows the discharge plume to be simulated throughout the water column taking into account the effects of natural processes such as surface waves, horizontal diffusion and dispersion. The plume model can be used stochastically to simulate a large number of random events over time or can be used for specific case studies in a deterministic mode.

PLUME3D can model the behaviour of a variety of constituents within a single release volume given information on the density and other physical and chemical parameters. The model reports mass and concentration levels on the water surface, on shorelines, in the sediments or through the water column. Where multiple constituents are involved, the model can report the distribution of each constituent individually. Horizontal and vertical cross-sections are also available to better illustrate the three dimensional distributions.

GCOM3D and PLUME3D also produce Windows and Arc-GIS compatible graphic output that can be readily incorporated into Word documents or GIS systems (for integration with other spatial information for emergency spill response planning).