BHP BILLITON IRON ORE

RGP6 Port Development

Sediment Plume and Hydrodynamic Modelling

Report

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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

Global Environmental Modelling Systems (GEMS) was contracted by the FAST team (a joint venture between FLUOR Australia Pty Ltd and Sinclair Knight Mertz Pty Ltd) to carry out simulations of the dredging impacts for the BHP Billiton Iron Ore (BHPBIO) Rapid Growth Project 6 (RGP6), development of the Port Hedland Harbour. The project is one of a series of works intended to increase the iron ore delivery through Port Hedland Harbour.

1.1 PROJECT BACKGROUND

1.1.1 OVERVIEW

The proposed dredging at Nelson Point is to allow for the construction of two new shipping berths along with associated berth pockets, departure channel and swing basin (Figure 1). When completed, the berths will be able to accommodate vessels of approximately 250,000 DWT with a breadth of 55 m and a length of approximately 350 m.

The dredging program is comprised of the following:

- Dredging of two new berth pockets to a design depth of -19.2 m CD;
- Extending and deepening the existing departure channel adjacent to the berths to a design depth of -14.8 m CD to allow for safe departure of loaded vessels;
- Extending and deepening the swing basin at Harriet Point to a design depth of -9.3 m CD in order for arriving vessels to gain access to the new berths; and
- Associated over-dredging of approximately 0.7m due to dredging tolerances;

In order to effectively manage the dredged material, one offshore and one onshore site have been identified as DMMA. The offshore DMMA (Spoil Ground ‘One’) is located approximately 20km north of Port Hedland (Figure 2) and the onshore DMMA (H) is located to the south of Lumsden Point (Figure 1). Figure 2 also shows the location of the offshore disposal site used by the RGP5 and LOF dredging programs (Spoil Ground “I”).

1.1.2 CAPITAL DREDGING WORKS

The Nelson Point dredging works will require approximately 6.0 Mm3 of material to be dredged, including over-dredging. This total volume is based on a conservative allowance for material that was to be dredged by Fortescue Metals Group (FMG) but is now included in RGP6 due to the early termination of FMG third berth dredging. The footprint to be disturbed by this dredging, including
batters, is approximately 60ha. A breakdown of the estimated dredging volume and footprint is provided in Table 1.

Table 1: Volume of Material to be Dredged.

<table>
<thead>
<tr>
<th>Location</th>
<th>Design Depth of Dredging (m CD)</th>
<th>Approximate Dredge Volume (Mm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New berth pockets</td>
<td>-19.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Departure Areas</td>
<td>-14.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Maneuvering area</td>
<td>-9.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Total footprint</td>
<td></td>
<td>6.0</td>
</tr>
</tbody>
</table>

The estimates in Table 1 include a conservative allowance for incomplete FMG dredging, including material around the Leonardo Da Vinci cyclone moorings. These volumes will be refined following receipt of a clearance survey of the area. The management of this material will be split between offshore disposal to DMMA ‘One’ and onshore disposal to DMMA’H’.

It is expected that offshore disposal will be completed by a large backacter type dredge supported by split hull hopper barges, and that onshore disposal will be completed by the Cutter Suction Dredge (CSD) Leonardo Da Vinci cutting and pumping dredged material through a combination of floating, sinker, and onshore dredge pipelines.

The split between offshore and onshore disposal is dependent on the availability and capability of key dredging plant but it appears likely that the split between offshore and onshore disposal will be based on:

- The offshore disposal of overlying sediments (including PASS) to -4.0mCD using a large backacter
- The onshore disposal of all remaining material using the CSD.

The key characteristics of this scenario are provided in Table 2.
Table 2  Key Characteristics for RGP6 Dredging Simulations

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td>Total volume to be dredged</td>
<td>6.0 Mm³, including over-dredging</td>
</tr>
<tr>
<td>Offshore disposal of dredged material - DMMA Spoil Ground “One”</td>
<td>Up to 2.7 Million m3</td>
</tr>
<tr>
<td>Onshore disposal of dredged material - DMMA H:</td>
<td>Up to 4.0 Million m3 (Up to 6.0 M m³ with bulking factor)</td>
</tr>
<tr>
<td>Duration of dredging</td>
<td>Offshore disposal: approximately 68 weeks</td>
</tr>
<tr>
<td></td>
<td>Onshore disposal: approximately 46 weeks</td>
</tr>
<tr>
<td>Area of marine disturbance for dredging</td>
<td>60 ha at Nelson Point</td>
</tr>
<tr>
<td>Area expected to contain PASS</td>
<td>21 ha at Nelson Point</td>
</tr>
<tr>
<td>Characteristics of DMMA H</td>
<td>Construction footprint: ~200 ha</td>
</tr>
<tr>
<td></td>
<td>Reclamation footprint: 140 ha</td>
</tr>
<tr>
<td></td>
<td>Perimeter bund height: +9.0 m AHD</td>
</tr>
</tbody>
</table>

**Note:** The exact split between offshore and onshore disposal however depends on a number of variables, including:

- The differing production rates of the backacter and CSD affecting the execution schedule
- Maintaining continuity of work for key plant across RGP5 and RGP6 to avoid standby costs.
- Environmental fieldwork requirements and the corresponding effects on the approvals schedule
- Environmental impacts
- Costs

In view of these issues the numbers in Table 2 were derived as “highly conservative” values so that the results of the modelling, which will be included in the approvals submission, will represent the worst case for both onshore and offshore disposal.
Figure 1. RGP6 Dredge footprint and reclamation Area “H”.
Figure 2. Port Hedland Marine Chart showing offshore disposal sites “One and “I”.”
1.2 CUMULATIVE EFFECTS OF DREDGING IN PORT HEDLAND HARBOUR

The dredging program envisaged for RGP6 is not the only dredging program planned for Port Hedland Harbour and so FAST considered that it was important to examine the cumulative impacts of these dredging programs.

The other works which may be carried out concurrently or just prior to RGP6 are RGP5 at Harriet Point and dredging for the Load out Facilities (LOF) for the full range of BHPBIO expansion projects.

The impacts of these other two projects have been studied individually (GEMS, 2008a and b) but the potential cumulative impacts of RGP5, RGP6 and the LOF dredging have not been considered.

Accordingly this study examines the results for RGP6 in isolation from RGP5 and LOF dredging and in sequence with RGP5 and LOF to search for any cumulative impacts.

As a result of this approach there was a need to undertake four dredging simulations:

- a) the dumping at Spoil Ground “One” arising from the backacter dredging for RGP6;
- b) the release of fines into Port Hedland harbor arising from the RGP6 backacter dredging and the bulk excavation CSD dredging and associated discharging to reclaim area “H”;
- c) the dumping at Spoil Ground “I” arising from the combined backacter dredging for RGP5 and the LOF together with the dumping at Spoil Ground “One” arising from the backacter dredging for RGP6; and
- d) the release of fines into Port Hedland harbor arising from the backacter dredging and the bulk excavation CSD dredging for RGP5, RGP6 and the LOF and associated discharging to reclaim area “H”.

Note that the material dredged by the CSD for the RGPS program is to be pumped to reclamation area “A” which is outside the road and rail causeway and cannot drain back into the harbor.

In addition to the cumulative impacts of the release of particles into the water column during dredging, the effects on hydrodynamics within the harbour as a result of the changed bathymetry were also investigated by running a “before” and “after” simulation with the 3D hydrodynamic model.
1.3 SCOPE OF WORK

The scope of work provided by FAST required the following tasks to be completed:

- Simulation of the baseline oceanography inside Port Hedland Harbour and in the adjacent open ocean beyond the proposed spoil ground;

- Simulation of the potential sediment plumes, sedimentation and sediment re-suspension originating from material excavated by the proposed RGP6 dredging program.

- Investigation of potential cumulative effects on turbidity or sedimentation of the three proposed BHPBIO dredging programs in Port Hedland Harbour (RGP5, RGP6 and the LOF)

- Assessment of the hydrodynamic impacts of the changes to the inner harbor and spoil ground region resulting from the dredging and spoil disposal works proposed during RGP5, RGP6 and the LOF developments (by comparison with the baseline hydrodynamics).

Specific scope items included:

- Attending scoping meetings with project staff to define model data inputs, modelling scenarios inclusive of commencement dates, duration, dredge methodology, dredge footprints etc;

- Establishing meteorological, oceanographic and water quality input conditions for the hydrodynamic and dredge plume modelling;

- Setting up and undertaking verification and validation of appropriate models, inclusive of validating any assumptions;

- Modelling the hydrodynamics within the inner harbour to assess the accretion and scouring due to modifications from dredging the berth pockets.

- Producing plots and numerical output and analyses for the two phases of the dredging (Backacter Dredge and Cutter Suction Dredge) and associated disposal to report levels of exposure to sedimentation and TSS levels at sensitive receptor sites.

- Predict sediment re-suspension from dredging activities and for disposal of material at the nominated spoil ground(s);

- Submitting draft and final technical reports summarising all methods, models used, key modelling input parameters, assumptions, limitations, findings and GIS compatible drawings, evaluation/discussion; conclusions and recommendations.
1.4 STUDY OBJECTIVES

The objective of the RGP6 sediment plume modelling was to establish a reliable prediction of where Total Suspended Solids (TSS) levels and sedimentation rates may be increased and by what levels as a result of the dredging activities and dredged material management operations associated with the RGP6 project.

As a part of this modelling effort, hydrodynamic modelling was required to assess changes in erosion and sedimentation rates within the inner harbour as a result of the dredging works. The modelling also considered the cumulative impacts of the RGP5 and LOF dredging operations.

1.5 PROJECT PROCESS

The RGP6 design process, with particular focus upon the dredge plume modelling, is illustrated by Figure 3. The GEMS role within the plume modelling process is coloured green in Figure 3.

1.6 DREDGE PLUME MODELLING

Dredge plume modelling estimates seawater hydrodynamics and the physics of dredged sediments released into the water column. The characteristics of the released sediment, the timing and location of releases are determined by the project plan, site characteristics and the equipment used for dredging and spoil disposal. Consequently, dredge plume modelling is only part of a wider process, as suggested by Figure 3. A more detailed summary of the dredge plume modelling process is shown in Figure 4.

As indicated by Figure 4, the dredge plume modelling requires a range of key inputs, including engineering, geotechnical, meteorological and oceanographic components. Summaries of the inputs used within the modelling process are included in later sections. Analysis of these inputs uses three sophisticated numerical computer models:

- The GEMS 3D Coastal Ocean Model (GCOM3D) to simulate the complex three-dimensional ocean currents in the region;

- The SWAN wave model to simulate the waves outside the inner harbour during the offshore spoil disposal operations, and for calculations of subsequent sediment re-suspension; and

- The GEMS 3D Dredge Simulation Model (DREDGE3D) to determine the fate of particles released into the water column during the dredging operations.
Figure 3. RGP6 Dredge Plume Modelling Project Process
Figure 4. Dredge Plume Modelling Key Inputs and Models
2. METEOROLOGICAL AND OCEAN INPUTS

2.1 CLIMATOLOGY

Port Hedland is located on the fringe of the wet-dry tropics of northern Australia, experiencing two distinct seasons – a ‘wet’ season from November to March and a ‘dry’ season from May to September, with transition months that may have the characteristics of either period. Throughout the year, diurnal variations in land temperature cause local land-sea breeze cycles close to the coast, with a shift in speed and direction. The effect of these local winds biases the observations at coastal wind stations, such that they cannot be used to accurately describe offshore winds – that are responsible for generating waves and wind-induced currents.

During the ‘dry’ season from May to September a belt of high pressure known as the sub-tropical ridge forms over the continent and results in semi-persistent easterly flow across the Pilbara. This flow may weaken and strengthen as individual high pressure centres evolve to the south in response to cold frontal activity. The easterly flow is characterised by low moisture content and stable weather conditions.

Figure 5 shows a synoptic sequence in which a high is initially directing easterly winds across north-west Australia. A cold front pushing northwards from high latitudes then weakens the high but a new high pressure system begins to develop in the wake of the frontal system. The formation of such a new high is often accompanied by a period of stronger easterlies across the Pilbara and Kimberly regions.

Southwards movement of the solar equator following the winter solstice results in warming of the continent and a gradual southward migration of the subtropical ridge. This has a two-fold effect by which the general strength of the easterlies weaken and a persistent ‘heat’ trough (area of low pressure) forms along the Pilbara coast.

This broad area of low pressure combines with high-pressure south-westwards over the Indian Ocean to drive persistent southerly winds along the west coast. Figure 6 shows a typical synoptic sequence in January with a heat trough extending southwards from the Pilbara.

Generally cyclogenesis occurs well to the north where sea temperatures are warmer; storms may then intensify as they track southwards. The direction of movement of the storms is generally controlled by upper atmospheric ‘steering’ – some storms track to the west under the influence of strong upper easterlies, but others can re-curve towards the Pilbara coast. This situation can be conducive to rapid intensification and acceleration of the cyclones toward the Pilbara coast.

It has been assumed that dredging activities will cease under cyclonic conditions.
Figure 5. Typical cool-month pattern easterlies across northern Australia, weakening under the influence of front (Panel 3), then beginning to re-establish (Panel 4).

Figure 6. Typical warm-month pattern showing persistence of low pressure through the Pilbara.
2.2 METEOROLOGICAL DATA SETS

2.2.1 OBSERVED WINDS

Two main meteorological observation data sets are available for the region. These are longer term data from the Bureau of Meteorology (BOM) site at Port Hedland aerodrome and a seven year data set for the Port Authority instrument at Beacon 15.

The BOM site data may be useful for determining long-term climate variability, but the Beacon 15 data will be clearly much more representative of the offshore maritime environment. However, we note that single point winds will generally not adequately represent the spatial variability over the region.

2.2.2 MODEL WINDS

Coastal wind observations create a biased representation of the offshore wind patterns due to the formation of local land-sea breeze circulation. In order to adequately describe spatial variation of wind stresses, it is necessary to interpolate the wind field between observation sites. Various numerical wind field products are available, generated from networks of anemometers at a range of spatial scales.

The Australian 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 regional wind field used by GEMS for dredge plume modelling is MesoLAPS, a meso-scale model at a spatial resolution of about 10km operated since 2000 by the Bureau of Meteorology (BoM). The model is nested inside a larger Australia-wide wind field model (LAPS) and runs twice daily producing forecasts out to 48 hours. Wind fields 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. In effect, this generates 12-hourly interpolated wind fields and a database of hourly meteorological modeled wind fields with the longest forecast time step of eleven hours.

Validation of the accuracy of the wind fields for each new study area needs to be undertaken by comparison against observations within the study region (see section 4). However, previous studies by GEMS have shown that the MesoLAPS wind fields provide a very good representation of coastal wind regimes (e.g. GEMS, 2007 and GEMS, 2008).
2.3 SEASONAL WIND VARIABILITY

The wind data from Port Hedland airport and from Beacon 15 have been used in an analysis that demonstrates the distinct seasonality of the Port Hedland wind climate. Figures 7 and 8 show a bar chart of the percentage occurrence of wind directions in the periods January to March and June to October respectively. These figures clearly illustrate the change from dominant westerlies in summer to easterlies in winter.

However the data at Port Hedland airport is most likely influenced by its location on land and so a detailed analysis of the data at Beacon 15 has been undertaken.

Figure 9 shows wind rose diagrams at Beacon 15 created for each month based on the aggregated 2001-2007 data. Figure 10 shows the same data aggregated for the cool months (May-August) and the warm months (October-March), respectively.

These diagrams again show the persistence of southwest to westerly winds though the warmer months compared with sustained periods of easterly quadrant winds that occur in the cool months. This seasonality in the wind climate is likely to be reflected in both the wave and regional currents. The impact on the latter may have a significant effect on the relative behavior of dredge plumes through the year.

Figure 7. Wind speed bar chart at Port Hedland Airport (Jan-Mar)
2.4 INTER-ANNUAL VARIABILITY

The inter-annual variability of winds is an important consideration because one ‘representative’ year must be selected for the plume modeling. This variability can be quantified in different ways. However, because the winds in any one year control the residual currents, the focus is on the relative frequency of easterlies and westerlies.

Figure 11 shows the relative percentage of easterly and westerly winds in each year from 2001 to 2007 based on the mesoLAPS data for the Beacon 15 site. This has been constructed by considering the wind direction for all observations where the wind speed is at least 5 m/s. Periods where the wind is less than 5 m/s are excluded because these correspond to periods where there will be less significant wind forcing.

Figure 11 shows that 2004 had a relatively strong easterly bias (compared to average) where as 2003 was biased to westerlies. The year 2007 shows the relative easterly and westerly winds close to their average values for the period.
Figure 9. Winds roses by month based on Beacon 15 data from 2001 to 2007 inclusive.
Figure 10. Aggregation of data by ‘cool’ and ‘warm” seasons.

Figure 11. Inter-annual variation of east-west component winds from 2001 to 2007; dotted lines show averages over the seven years.
2.5 OCEANOGRAPHY

The coastal oceanography of the Port Hedland region is dominated by the large tidal regime, which is active throughout the year. Wind conditions are generally moderate, mainly influencing surface currents only. There is a relatively calm wave regime, typically less than one metre background swell. However, under cyclonic conditions, which may occur from November to April, extreme winds, waves and storm surges may occur, drastically altering the tide-driven circulation.

Dredging is expected to cease during cyclonic conditions. Hence no cyclone events have been included within the modelling, although it is recognised that any cyclone event is likely to dramatically alter any existing plume. Due to the unique nature of any tropical cyclone, there is no characteristic impact — although strong currents, increased wave action, high levels of suspended sediment and alongshore sediment transport are common.

Other phenomena that may affect the coastal circulation include tsunamis and river flooding. Tsunami, generated from the Sunda Arc, have impacted on a yearly basis for the last five years (2004-2008), affecting shelf circulation for several days after arrival. River flooding from the De Grey or Turner rivers may discharge large volumes of freshwater, generating significant sediment plumes affecting the Port Hedland region. However, the rivers are sufficiently distant from the Port that the discharge is considered unlikely to affect local circulation. The sediment plumes are considered to be part of the background variability of suspended sediment and have not been considered as part of the dredge plume modelling.

2.5.1 NON-CYCLONIC CONDITIONS

The dominant influence on the ambient circulation in Port Hedland Harbour is the large tides experienced in the region. The tidal range is 7.6 metres and, particularly during spring tides, generates very strong current flows in and out of the harbour entrance. These flows are important for this study as they will tend to move sediment plumes rapidly around the harbour, keeping finer sediments suspended until the slack water at the change of tide when material may settle on the harbour bed. The strong currents during spring tides are capable however of re-suspending some of the lighter fractions of the sediments and creating turbidity in the water column which may flush from the harbour on the ebb tide.

Ambient, non-cyclonic, waves are generally less than 2 metres and are not considered to contribute significantly to the coastal processes which tend to be dominated by the annual occurrence of cyclone events.
2.5.2 CYCLONIC CONDITIONS

On average, Port Hedland experiences the influence of at least one tropical cyclone each year, with up to 10 cyclones passing across the Northwest Shelf region in any cyclone season, from November to April. A coastal crossing west of Port Hedland can generate large waves and storm surges and inundate a significant proportion of the town and environs. The 1 in 100 year sea level event (including storm surge, tides and wave setup) is approximately 6 metres above mean sea level (GEMS, 2000).

Even the passage of an intense cyclone several hundred kilometres offshore from Port Hedland can generate significant wave action on the coast. Severe tropical cyclone Vance (1999) passed approximately 200 km offshore from Port Hedland but generated large waves on top of a spring tide which severely eroded the foreshore and the combined spring tide and wave setup inundated the yacht club and the coastal road.

These events are not included in the dredging simulations because dredging would cease if a tropical cyclone warning was issued. The relevance however is that the wave action and coastal currents generated annually by tropical cyclones off Port Hedland are the major contributor to coastal movement of sediments and therefore the major cause of re-mobilisation of material at the offshore spoil grounds.

2.6 BATHYMETRY

The bathymetric data sets held by GEMS were updated with further detailed bathymetry and topography provided by SKM. The GEMS database has been developed from a range of sources including data from Geoscience Australia (formerly AUSLIG) and previous studies at Port Hedland.

Given the possibility of dredge plumes entering Port Hedland Harbour, the scales required for the modeling varied from the need to simulate the large scale propagation of tides along the Northwest Shelf to resolving current flows through the harbour entrance.

Accordingly three grid scales were used. Figure 12 shows the large scale Northwest Shelf region used to simulate the tidal and large scale wind-driven dynamics. Figure 13 shows the intermediate scale grid used to define the coastal region near Port Hedland. Figure 14 shows the fine scale 25 metre resolution grid used to define the inner harbour and the nearshore area.

Bathymetry was converted to two grids for the hydrodynamic and dredge plume modelling.
Figure 12. Large scale Northwest shelf GCOM3D grid (NW Cape to Broome).

Figure 13. Intermediate scale GCOM3D grid.
Figure 14. High resolution GCOM3D inner grid.
2.7 TIDES

Port Hedland experiences a semi-diurnal macrotidal regime, with a lowest to highest astronomical tidal range of 7.6m (Defence 2006). The tidal planes defined from analysis of Port Hedland tide gauge are summarised in Table 3.

The 28-day lunar spring-neap cycle is pronounced, with an average neap tide range of 1.4m and average spring tide range of 5.8m. This cycle is mildly influenced by the position of the solar equator, with the largest daily tide range experienced in March and September, near the vernal and autumnal equinoxes (Figure 16).

<table>
<thead>
<tr>
<th>Tidal Plane</th>
<th>Abbreviation</th>
<th>Level (to LAT)</th>
<th>Level (to MSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest Astronomic Tide</td>
<td>HAT</td>
<td>7.6m</td>
<td>+3.7m</td>
</tr>
<tr>
<td>Mean High Water Springs</td>
<td>MHWS</td>
<td>6.7m</td>
<td>+2.8m</td>
</tr>
<tr>
<td>Mean High Water Neaps</td>
<td>MHWN</td>
<td>4.6m</td>
<td>+0.7m</td>
</tr>
<tr>
<td>Mean Sea Level</td>
<td>MSL</td>
<td>3.9m</td>
<td>0.0m</td>
</tr>
<tr>
<td>Mean Low Water Neaps</td>
<td>MLWN</td>
<td>3.2m</td>
<td>-0.7m</td>
</tr>
<tr>
<td>Mean Low Water Springs</td>
<td>MLWS</td>
<td>0.9m</td>
<td>-3.0m</td>
</tr>
<tr>
<td>Lowest Astronomic Tide</td>
<td>LAT</td>
<td>0.0m</td>
<td>-3.9m</td>
</tr>
</tbody>
</table>
Tidal forcing for the hydrodynamic modelling in this study was based on tidal constituents from the GEMS Australian region gridded tidal database, which has been developed with extensive modelling programmes (primarily for AMSA Search and Rescue in Canberra). This database was verified using tide station data (see section 5).

Non-tidal water level phenomena, including surges and inter-annual mean sea level variations have not been included in the model.

2.8 DENSITY STRUCTURE

The focus of the RGP6 project occurs within Port Hedland Harbour, which experiences strong flows due to the macrotidal regime. It is believed that strong mixing results, that reduces the potential for vertical density gradients to occur.

The effects of freshwater runoff have been neglected from the model. Although rainfall in the region may be high, particularly associated with wet season events including tropical cyclones, the catchment area is relatively small and the contribution of freshwater runoff to the density gradient is considered to be minor relative to the effect of tidal mixing.
3. ENGINEERING & GEOTECHNICAL INPUTS

3.1 MATERIALS

Because the formation of sediment plumes is largely associated with the finer fraction of material, it is necessary to understand the relative distribution of material, particularly that smaller than 100 microns ($10^6$ m). Comparison of the sediment characteristics from borehole logs provided by Coffey Geosciences demonstrated a high level of variability of sediment distributions. As a result it was decided to characterize the material to be dredged in terms of three material types which are dominant at different depths.

For each material type, a single sample was selected to be representative, based on visual comparison of the distributions. The classification of material identified as types “A”, “B” and “C” are summarized in Table 4.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Material Type</th>
<th>Approx. Depth (CD)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Muds and Silts</td>
<td>+3m to 0m</td>
<td>Fine grained material, with low cohesion</td>
</tr>
<tr>
<td>Type B</td>
<td>Sandstone</td>
<td>0m to 14m</td>
<td>Weak calcareous rock</td>
</tr>
<tr>
<td>Type C</td>
<td>Conglomerate</td>
<td>14m to dredge depth</td>
<td>Moderate strength sedimentary rock, with igneous conglomerate</td>
</tr>
</tbody>
</table>

Particle size distributions for this study were defined from CSIRO analyses of borehole samples provided Coffey Geosciences. The particle size distributions for material types A, B and C are given in Table 5 together with the settling velocities assumed for each particle size.

From Table 5 it can be seen that:

- Material type A has 39% of the material smaller than 100 microns, with 21% less than 10 microns.
- Material type B has 21% of the material smaller than 100 microns, with 11% less than 10 microns.
- Material type C has 16% of the material smaller than 100 microns, with 5% less than 10 microns.
Table 5: Particle size distributions and Settling Rates for Material Types A, B and C. (based on analyses by CSIRO)

Note that CSIRO does not carry these experiments out in seawater of a given salinity. Instead they are measured in a chemical solution which inhibits flocculation. As a result the CSIRO measurements are adjusted to the density of seawater at the dredging location.

<table>
<thead>
<tr>
<th>Size (µm)</th>
<th>Settling Rate</th>
<th>A(%)</th>
<th>B(%)</th>
<th>C(%)</th>
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<tr>
<td>5000.0</td>
<td>19734.4</td>
<td>3.0</td>
<td>34.0</td>
<td>11.0</td>
</tr>
<tr>
<td>2000.0</td>
<td>3157.5</td>
<td>7.0</td>
<td>15.0</td>
<td>11.0</td>
</tr>
<tr>
<td>1000.0</td>
<td>789.38</td>
<td>13.0</td>
<td>10.0</td>
<td>6.0</td>
</tr>
<tr>
<td>700.0</td>
<td>386.79</td>
<td>12.0</td>
<td>10.0</td>
<td>6.0</td>
</tr>
<tr>
<td>500.0</td>
<td>197.34</td>
<td>5.0</td>
<td>2.0</td>
<td>6.0</td>
</tr>
<tr>
<td>400.0</td>
<td>126.30</td>
<td>5.0</td>
<td>2.0</td>
<td>10.0</td>
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<tr>
<td>300.0</td>
<td>71.044</td>
<td>5.0</td>
<td>3.0</td>
<td>15.0</td>
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<td>1.0</td>
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<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>50.0</td>
<td>1.9734</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
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<td>1.2630</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
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<td>2.0</td>
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<tr>
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<td>3.0</td>
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<td>5.0</td>
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<td>1.0</td>
<td>0.00079</td>
<td>5.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>0.5</td>
<td>0.00020</td>
<td>3.0</td>
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<tr>
<td><strong>Total %</strong></td>
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<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
<td></td>
</tr>
</tbody>
</table>
3.2 DREDGING PLANT

3.2.1 BACKACTER

It is expected that a large Backacter and supporting barges will be used to dredge the material to be disposed offshore. The Backacter is essentially a large excavator on a pontoon, specifically designed for dredging. It will mechanically excavate the material to be dredged and load it into a split hull hopper barge moored alongside. Due to the combination of sailing distance to DMMA ‘One’, sailing speed, and dredging rates it is estimated that two split hull hopper barges will be used with a holding capacity of 4,000m³ each.

3.2.2 CUTTER SUCTION DREDGE (CSD)

The CSD is expected to work from the north east to the south east across the dredging footprint, prioritising the completion of berth pockets. An alternative sequence of works may be adopted to minimise standby due to shipping, and to minimise the duration of works.

Dredged material will be pumped to DMMA “H” via a combination of floating, submerged, and onshore pipeline.

The CSD will be subject to standby due to the interface with shipping as the continued operation of the port and safe navigation of vessels is given the priority over dredging works at all times. This interface will require all dredging plant, including floating pipeline, anchors, and the vessel itself, to be removed from existing navigation areas on instruction by the Port Hedland Port Authority (PHPA) Harbour Master. The standby rate on this project has been estimated as 40%.

3.3 EXCESS WATER DISCHARGE

Excess water will be discharged from DMMA H on an as needs basis which may be up to 24 hours per day with average volumes ranging from 2,500 m³ to 5,500 m³ per hour for the duration of the project. Discharge will be via a non return water outlet to South East Creek, at the following approximate coordinates:

E_MGA94_50: 666400 metres

N_MGA94_50: 7748650 metres

Settlement times for this project will typically be 48 hours, to allow fines to settle to such an extent that the presence of sediments within the water discharge will be less than 150mg/L.
However, this may be adjusted based on monitoring of discharge water. DMMA H will be divided into two main areas, with coarser material retained in the northern half of the area and fines settled out and retained in the southern half of the area.

For modeling purposes the TSS of the overflow from the reclamation area “H” was defined by FAST to be 150 mg/litre. The release rate is directly related to the CSD pumping rate once the reclaim area commences to overflow. The composition (PSD) of the overflow will be different to that of the source material as the particle size distribution of the overflow will be skewed towards the finer end as a result of heavier particles settling out. The dredge model assumed that the distribution of particles in the overflow was similar to that defined for the finest material (Type A) in Table 5.

3.4 DREDGE LOGS

The detailed execution of the dredging program was established by FAST based on information provided by the dredging contractor and the Engineering team. The results were provided to GEMS in the form of spreadsheets from which GEMS established the dredge logs which drive DREDGE3D.
4. VERIFICATION OF THE METEOROLOGICAL FORCING OF THE OCEAN MODELS

Numerical models operated by national weather services, such as the Meso-Laps model, are regularly and extensively verified. The BoM has carried out such verification exercises in support of its marine forecasting program (Kent et al). This report gives confidence that the model is able to represent the near-shore maritime wind climate very well. However, further local verification has been carried out for the model winds from within the study area. This verification has been undertaken by comparing mesoLAPS model output for the against the Beacon 15 data set.

The data have been subjected to a formal quantitative correlation analysis, the results of which are reported here. However, it is noted (Pielke, 2002) that in point-to-point comparisons the spatial and temporal displacement of the predicted from the observed fields can yield an apparent poor verification even though the shape and magnitude of the overall pattern may be exact. Pielke therefore emphasises the importance of qualitative assessment of the data through inspection. Accordingly, this report includes time series plots of the data to allow direct inspection, rather than relying solely on correlation statistics.

Time Series

Inspection of the full seven year time series data set is problematic; accordingly, representative periods showing model-observation wind speed and wind direction comparisons for cool and warm month periods are presented respectively through Figures 16 to 19. Plots of the full data sets are also available in digital form.

These figures show that the meso-LAPS model reflects the trends of both wind speed and direction. There is a small but consistent bias to underestimation in the warm months which most likely reflects the fact that the model somewhat underestimates the amplitude of the sea-breeze cycle during this period. There is less bias in the wind speed in the cooler months, but the model does fully capture the amplitude of the diurnal cycle.

Correlation Analysis

A correlation analysis was carried out by breaking each wind observation into u (east-west) and v (north-south) components. This analysis was undertaken separately for the cool months and warm months respectively.

Variance and correlation coefficients based on least squares fitting as well mean and Root Mean Square (RMS) errors were computed for the data sets.

The results of this analysis are shown schematically through Figures 20 through 23. Computed correlation statistics, mean and Root Mean Square errors are presented in Table 6.

Overall, the results confirm that the model winds are providing very good representation of the overall regional wind climate. It is noted that when winds are light and wind error greatest, the meteorological forcing is much less significant compared to tidal forcing.
Figure 16. Sample time series from warm months in 2002 comparing model versus observed wind speed from Beacon 15.

Figure 17. Sample time series from warm months in 2002 comparing model versus observed wind direction from Beacon 15.
Figure 18. Sample time series from cool months in 2002 comparing model versus observed wind speed from Beacon 15.

Figure 19. Sample time series from cool months in 2002 comparing model versus observed wind direction from Beacon 15.
Figure 20. Correlation plots of observed versus model u-component of wind at Beacon 15 for warm months from 2000 to 2007.

Figure 21. Correlation plots of observed versus model v-component of wind at Beacon 15 for warm months from 2000 to 2007.
Figure 22. Correlation plots of observed versus model u-component of wind at Beacon 15 for cool months from 2000 to 2007.

Figure 23. Correlation plots of observed versus model v-component of wind at Beacon 15 for cool months from 2000 to 2007.
<table>
<thead>
<tr>
<th>Statistic</th>
<th>All Months</th>
<th>May- August</th>
<th>October - March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>u</td>
<td>v</td>
<td>u</td>
</tr>
<tr>
<td>Variance $R^2$</td>
<td>0.7117</td>
<td>0.4804</td>
<td>0.6522</td>
</tr>
<tr>
<td>Correlation Coefficient $R$</td>
<td>0.8436</td>
<td>0.6931</td>
<td>0.8076</td>
</tr>
<tr>
<td>RMS Error</td>
<td>2.7847</td>
<td>2.5387</td>
<td>2.5869</td>
</tr>
<tr>
<td>Mean Error</td>
<td>2.0367</td>
<td>1.8053</td>
<td>1.9196</td>
</tr>
</tbody>
</table>
5. SIMULATION OF OCEAN CURRENTS – GCOM3D

The ocean currents and sea levels were modelled on three “nested” grids with the hydrodynamic model GCOM3D. A description of the hydrodynamic model is contained within Appendix A. Two large scale grids (Figures 12 and 13) were used to generate boundary conditions for a higher resolution GCOM3D grid (Figure 14).

All three grids were driven by tides and MesoLAPS winds and atmospheric pressures (described earlier). The finer grid was nested in the intermediate grid at a resolution of 25 metres. It is necessary to run this nested system to fully capture the interaction between the flows in Port Hedland harbour and the open ocean.

The vertical levels in the model go to depths greater than 10,000 metres if required by the bathymetry. The levels in the top 220 metres for the Port Hedland simulations were:
- 0, 2, 4, 6, 9, 14, 20, 28, 38, 50, 65, 84, 108, 138, 175 and 220 metres below mean sea level.

GCOM3D was run for 12 months on the nested grid system to generate half-hourly currents inside and outside Port Hedland Harbour, starting on January 1, 2007. To maintain the atmospheric forcing as “typical”, the next time step after December 31, 2007 was wound back to January 1, 2007 and this cycle was repeated for the duration of the dredging.

An example of the ebb tide currents in the Port Hedland offshore region predicted by GCOM3D is shown in Figure 24. These currents are the main mechanism for flushing turbid plumes from the region as the flood tide drives plumes towards the coast.

An example of flood tide currents in Port Hedland Harbour predicted by GCOM3D is shown in Figure 25. This Figure illustrates the difficulty for dredge plumes to escape the harbour during the flood tide and hence the periods of ebb tide are critical for the flushing of turbidity from the harbour.
Figure 24. Example of spring tide ebb currents predicted by GCOM3D.

Figure 25. Example of flood tide currents predicted by GCOM3D in Port Hedland harbour.
5.1 VERIFICATION OF THE HYDRODYNAMIC MODEL (GCOM3D)

To verify how well GCOM3D simulated the oceanography in Port Hedland harbour, and in waters off the coast of Port Hedland, comparisons with the data obtained by BHPBIO (outside the harbour) and by the Port Hedland Port Authority (in the harbour) were carried out.

Figure 26 shows the location of the two AWAC current measuring devices off Port Hedland harbour. The instruments have been recording oceanographic data since December 2007 which allows comparisons of model predictions with observations during different climatic conditions.

Figure 27 shows the location of a single point current meter in Port Hedland harbour which recorded data for the Port Hedland Port Authority from October 10 to November 26, 2007.

As highlighted earlier, there are two basic climatic regimes in the region, the period dominated by westerly-south-westerly winds, which generally occurs in summer, and the period dominated by easterly winds which occurs in the winter months. As a result two verification periods were chosen from the available offshore data record namely, December 2007 and June 2008.

Comparisons with the data in the harbour were limited to the time period of the observations.

5.1.1 VERIFICATION AGAINST OFFSHORE WINTER DATA

To illustrate the different influence on the ocean currents of the two dominant meteorological periods, Figures 28 and 29 present progressive vector diagrams derived from the near-surface currents observed at the offshore AWAC during June, 2008 and December, 2007 respectively.

The results indicate that a persistent residual current to the northeast is operating during the period of south-southwesterly winds but when these winds drop and are replaced by easterlies there is virtually no residual current or the possibility of flow in a westerly direction.

Figures 30 and 31 shows the comparison between observed near-surface currents at the two AWAC sites in June and July, 2008. The major point to note is that the offshore currents are significantly stronger, peaking around 0.70 m/s compared with the maximum inshore currents of approximately 0.50 m/s.

Comparisons of GCOM3D predictions with observations during the easterly wind regime in June, 2008 are presented in the following Figures:

Figure 32: Comparison of GCOM3D predictions for sea levels in June, 2008 with observations by the inshore AWAC.

Figure 33: Comparison of GCOM3D predictions for the west to east component of near-surface currents in June, 2008 with observations by the inshore AWAC.
Figure 34: Comparison of GCOM3D predictions for the west to east component of near-bottom currents in June, 2008 with observations by the inshore AWAC.

Figure 35: Comparison of GCOM3D predictions for the south to north component of near-surface currents in June, 2008 with observations by the inshore AWAC.

Figure 36: Comparison of GCOM3D predictions for the south to north component of near-bottom currents in June, 2008 with observations by the inshore AWAC.

Figure 37: Comparison of GCOM3D predictions for the west to east component of near-surface currents in June, 2008 with observations by the offshore AWAC.

Figure 38: Comparison of GCOM3D predictions for the west to east component of near-bottom currents in June, 2008 with observations by the offshore AWAC.

Figure 39: Comparison of GCOM3D predictions for the south to north component of near-surface currents in June, 2008 with observations by the offshore AWAC.

Figure 40: Comparison of GCOM3D predictions for the south to north component of near-bottom currents in June, 2008 with observations by the offshore AWAC.

5.1.2 VERIFICATION AGAINST OFFSHORE SUMMER DATA

To investigate the model predictions during the period dominated by west-south-westerly winds the first 40 days of the instrument deployment (from Dec 16, 2007) was studied.

Comparisons of GCOM3D predictions with observations during December, 2007 are presented in the following Figures:

Figure 41: Comparison of GCOM3D predictions for sea levels in December, 2007 with observations by the inshore AWAC.

Figure 42: Comparison of GCOM3D predictions for the west to east component of near-surface currents in December, 2007 with observations by the inshore AWAC.

Figure 43: Comparison of GCOM3D predictions for the south to north component of near-surface currents in December, 2007 with observations by the inshore AWAC.

Figure 44: Comparison of GCOM3D predictions for the west to east component of near-surface currents in December, 2007 with observations by the offshore AWAC.

Figure 45: Comparison of GCOM3D predictions for the south to north component of near-surface currents in December, 2007 with observations by the offshore AWAC.

Note: Plots of the near-bottom current comparisons are not presented as they do not add to the winter results.
5.1.3 VERIFICATION AGAINST OBSERVATIONS IN PORT HEDLAND HARBOUR

Due to the physically constrained nature of Port Hedland Harbour, the currents within the harbour are believed to be mainly tidal in nature, which has been supported by previous measurements within the Port (Paul & Lustig 1978). However only limited data was available to verify the hydrodynamic model in Port Hedland Harbour. Cardno Lawson & Treloar Pty Ltd (CLT) obtained data on behalf of the Port Hedland Port Authority from a fixed current meter in Port Hedland Harbour in the period October 11 to November 25, 2007 and, with the approval of the Port Authority, made the data available to GEMS for model validation studies.

Due to the brevity of the observations seasonal variations in the harbour could not be investigated but the data record was long enough to verify how accurately the tidal responses in the harbour were being predicted. Comparisons of surface and seabed currents were also not possible since the data came from a single point current meter measuring currents 5 metres below the surface of the water (at Mean Sea Level).

For this part of the verification study GCOM3D was run for the period October 1, 2007 to January 31, 2008, driven by MesoLAPS winds and atmospheric pressures and by tides and predictions of current speeds and directions were stored at the current meter site.

The data provided by CLT did not contain sea level measurements and so a comparison of sea level predictions by GCOM3D inside Port Hedland harbour with observations from the Port Hedland Port Authority tide gauge in the harbour is presented in Figure 46.

Figures 47 and 48 compare GCOM3D predictions for current speeds and directions (respectively) in Port Hedland harbour with observations by the single point current meter from October 11 to November 25, 2007.

In both cases the agreement is very good and establishes the capability of GCOM3D to simulate the hydrodynamics of Port Hedland Harbour.

5.1.4 SUMMARY OF VERIFICATION RESULTS

Statistics for all near-surface and near-bottom comparisons of GCOM3D predictions with offshore observations are presented in Tables 7 and 8. Table 9 presents statistics for the comparisons in Port Hedland harbour.

Inspection of the results presented in Figures 32 to 48 and in Tables 7, 8 and 9 show that GCOM3D is representing the tidal variations, the residual currents and the near-surface and near-bottom currents inside and outside Port Hedland harbour with a high degree of accuracy. This result gives confidence that the major driving force for the dredge plumes is well represented.
Table 7: Summary of statistics from analysis of the AWAC data and GCOM3D predictions from June 10 – July 31, 2008.

<table>
<thead>
<tr>
<th></th>
<th>Inshore AWAC</th>
<th>Inshore GCOM3D</th>
<th>Offshore AWAC</th>
<th>Offshore GCOM3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level Range</td>
<td>5.55 m</td>
<td>5.59 m</td>
<td>5.32 m</td>
<td>5.37 m</td>
</tr>
<tr>
<td>Major axis for surface currents</td>
<td>254 deg</td>
<td>251 deg</td>
<td>298 deg</td>
<td>294 deg</td>
</tr>
<tr>
<td>Major axis for bottom currents</td>
<td>237 deg</td>
<td>233 deg</td>
<td>298 deg</td>
<td>294 deg</td>
</tr>
<tr>
<td>Mean surface current speed</td>
<td>0.22 m/s</td>
<td>0.22 m/s</td>
<td>0.29 m/s</td>
<td>0.28 m/s</td>
</tr>
<tr>
<td>Mean bottom current speed</td>
<td>0.18 m/s</td>
<td>0.18 m/s</td>
<td>0.22 m/s</td>
<td>0.21 m/s</td>
</tr>
<tr>
<td>Residual surface current speed and direction</td>
<td>0.01 m/s 315 deg</td>
<td>0.02 m/s 235 deg</td>
<td>0.01 m/s 196 deg</td>
<td>0.02 m/s 236 deg</td>
</tr>
<tr>
<td>Residual bottom current speed and direction</td>
<td>0.06 m/s 285 deg</td>
<td>0.07 m/s 235 deg</td>
<td>0.08 m/s 280 deg</td>
<td>0.03 m/s 254 deg</td>
</tr>
<tr>
<td>Sea level correlation</td>
<td></td>
<td>96%</td>
<td></td>
<td>96%</td>
</tr>
<tr>
<td>West-east surface current component correlation</td>
<td></td>
<td>90%</td>
<td></td>
<td>93%</td>
</tr>
<tr>
<td>South-north surface current component correlation</td>
<td></td>
<td>87%</td>
<td></td>
<td>93%</td>
</tr>
</tbody>
</table>
Table 8: Summary of statistics from analysis of the AWAC data and GCOM3D predictions from December 15, 2007 to February 1, 2008.

<table>
<thead>
<tr>
<th></th>
<th>Inshore AWAC</th>
<th>Inshore GCOM3D</th>
<th>Offshore AWAC</th>
<th>Offshore GCOM3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level Range</td>
<td>5.83 m</td>
<td>5.75m</td>
<td>5.49m</td>
<td>5.53m</td>
</tr>
<tr>
<td>Major axis for surface currents</td>
<td>91 deg</td>
<td>87 deg</td>
<td>72 deg</td>
<td>67 deg</td>
</tr>
<tr>
<td>Major axis for bottom currents</td>
<td>90 deg</td>
<td>85 deg</td>
<td>123 deg</td>
<td>115 deg</td>
</tr>
<tr>
<td>Mean surface current speed</td>
<td>0.26 m/s</td>
<td>0.25 m/s</td>
<td>0.31 m/s</td>
<td>0.30 m/s</td>
</tr>
<tr>
<td>Mean bottom current speed</td>
<td>0.21 m/s</td>
<td>0.20 m/s</td>
<td>0.25 m/s</td>
<td>0.24 m/s</td>
</tr>
<tr>
<td>Residual surface current speed</td>
<td>0.06 m/s</td>
<td>0.07 m/s</td>
<td>0.06 m/s</td>
<td>0.07 m/s</td>
</tr>
<tr>
<td>and direction</td>
<td>93 deg</td>
<td>85 deg</td>
<td>77 deg</td>
<td>73 deg</td>
</tr>
<tr>
<td>Residual bottom current speed</td>
<td>0.05 m/s</td>
<td>0.09 m/s</td>
<td>0.03 m/s</td>
<td>0.02 m/s</td>
</tr>
<tr>
<td>and direction</td>
<td>98 deg</td>
<td>122 deg</td>
<td>57 deg</td>
<td>85 deg</td>
</tr>
<tr>
<td>Sea level correlation</td>
<td>-</td>
<td>92%</td>
<td>-</td>
<td>92%</td>
</tr>
<tr>
<td>West-east surface current</td>
<td>-</td>
<td>89%</td>
<td>-</td>
<td>85%</td>
</tr>
<tr>
<td>component correlation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South-north surface current</td>
<td>-</td>
<td>84%</td>
<td>-</td>
<td>82%</td>
</tr>
<tr>
<td>component correlation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Summary of statistics from analysis of the data in Port Hedland harbour and GCOM3D predictions from October 11 to November 25, 2007.

<table>
<thead>
<tr>
<th></th>
<th>Current Meter</th>
<th>GCOM3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Current Axis</td>
<td>140 deg</td>
<td>141 deg</td>
</tr>
<tr>
<td>Mean Current Speed</td>
<td>0.093 m/s</td>
<td>0.091 m/s</td>
</tr>
<tr>
<td>Current correlation along major axis</td>
<td>-</td>
<td>87%</td>
</tr>
</tbody>
</table>
Figure 26. Location of the two AWAC current, tide and wave measuring instruments.

Figure 27. Location of the short term current meter mooring in Port Hedland harbour.
Figure 28. Progressive Vector Diagram from the offshore AWAC for 3 weeks in June, 2008.
Figure 29. Progressive Vector Diagram from the offshore AWAC for 18 days in December, 2007.
Figure 30. Comparison of near-surface current speeds observed at the two AWAC current meter sites in June and July 2008.
Figure 31. Comparison of near-surface current directions observed at the two AWAC current meter sites in June and July 2008.
Figure 32. Comparison of GCOM3D predictions for sea levels in June, 2008 with observations by the inshore AWAC.
Figure 33. Comparison of GCOM3D predictions for the west to east component of near-surface currents in June, 2008 with observations by the inshore AWAC.
Figure 34. Comparison of GCOM3D predictions for the west to east component of near-bottom currents in June, 2008 with observations by the inshore AWAC.
Figure 35. Comparison of GCOM3D predictions for the south to north component of near-surface currents in June, 2008 with observations by the inshore AWAC.
Figure 36. Comparison of GCOM3D predictions for the south to north component of near-bottom currents in June, 2008 with observations by the inshore AWAC.
Figure 37. Comparison of GCOM3D predictions for the east to west component of near-surface currents in June, 2008 with observations by the offshore AWAC.
Figure 38. Comparison of GCOM3D predictions for the east to west component of near-bottom currents in June, 2008 with observations by the offshore AWAC.
Figure 39. Comparison of GCOM3D predictions for the south to north component of near-surface currents in June, 2008 with observations by the offshore AWAC.
Figure 40. Comparison of GCOM3D predictions for the south to north component of near-bottom currents in June, 2008 with observations by the offshore AWAC.
Figure 41. Comparison of the sea levels predicted by GCOM3D with observations at the nearshore AWAC in December 2007.
Figure 42. Comparison of the near-surface current speeds in the west-east direction predicted by GCOM3D with observations at the nearshore AWAC in December 2007.
Figure 43. Comparison of the near-surface current speeds in the south-north direction predicted by GCOM3D with observations at the nearshore AWAC in December 2007.
Figure 44. Comparison of the near-surface current speeds in the west-east direction predicted by GCOM3D with observations at the offshore AWAC in December 2007.
Figure 45. Comparison of the near-surface current speeds in the south-north direction predicted by GCOM3D with observations at the offshore AWAC in December 2007.
Figure 46. Comparison of the sea levels predicted by GCOM3D with tide table data for Port Hedland Harbour.
Figure 47. Comparison of the west-east current speeds predicted by GCOM3D from October 11 to November 25, 2007 with the current meter observations in Port Hedland Harbour.
Figure 48. Comparison of the south-north current speeds predicted by GCOM3D from October 11 to November 25, 2007 with the current meter observations in Port Hedland Harbour.
6. SIMULATION OF OCEAN WAVES – SWAN

The primary aim of wave modelling undertaken for the study was to quantify spatial and time varying wave-induced (bottom) orbital velocities for incorporation into the re-suspension module of DREDGE3D.

This was particularly important for the studies of re-suspension of material dumped at the offshore spoil ground(s) to investigate long term stability in the absence of cyclones.

The SWAN model produces time varying output of the bottom orbital velocity maxima at each output time step. The bottom maxima are a function of the wave height, wave period and the depth – the larger waves in shallower water will result in higher orbital velocities (and therefore greater contribution to re-suspension of sediments).

6.1 OVERVIEW OF THE SWAN MODEL

SWAN (see Appendix B) is a well validated third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. The model predicts a 2D wave field on pre-specified grid points.

SWAN accounts for the following physics:

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

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

In order to capture broad scale wave generation processes affecting the region, a grid was established over the southern ocean at a resolution of 0.5 degrees with inner grids at 0.1 degrees (~10k), 0.005 degrees (~500m) and 0.002 degrees (~200m).

The 500m grid allowed for potential activity at outer spoil grounds and outer channel dredging but with most activity covered by the more detailed inner grid. The overall model setup and grid structure is shown schematically in Figure 49 and summarized in Table 10.

For the current project wind forcing for the model was obtained from the Bureau of Meteorology NWP archive as previously described. For the outer Indian Ocean grid, winds from the global model GASP (spatial resolution approximately 70 km) were employed. Meso-LAPS model winds (spatial resolution approximately 12 km) were used for all inner grids.

6.3 MODEL VERIFICATION

The model, as established, has been verified against field data collected from within the study area.

Wave data were available from four sites as summarized in Table 11. The site locations are shown in Figure 50. Model output was extracted AT THE LOCATIONS SHOWN IN Table 12 throughout the duration of the runs.

For the purposes of this report, the model was verified against the longer data sets from Beacons 15 and 16.

Wave verification data are provided in three ways in this report:

- Time series plots of measured and observed wave parameters:
- Frequency exceedance plots, and
- Directional frequency plots.
Figure 49. Broad scale model grid structure.
<table>
<thead>
<tr>
<th>MODEL GRID</th>
<th>INDIAN OCEAN</th>
<th>NW AUSTRALIA</th>
<th>NW SHELF</th>
<th>PH 500m</th>
<th>PH 200m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Latitude</td>
<td>0</td>
<td>-15</td>
<td>-17.2</td>
<td>-19.84</td>
<td>-19.82</td>
</tr>
<tr>
<td>Minimum Longitude</td>
<td>70</td>
<td>110</td>
<td>115.2</td>
<td>118.1</td>
<td>118.24</td>
</tr>
<tr>
<td>Maximum Longitude</td>
<td>135</td>
<td>125</td>
<td>116.6</td>
<td>118.98</td>
<td>118.54</td>
</tr>
<tr>
<td>Grid Resolution</td>
<td>0.5</td>
<td>0.2</td>
<td>0.02</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td>Directional</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>0.04 – 1 (35)</td>
<td>0.04 – 1 (35)</td>
<td>0.04 – 1 (35)</td>
<td>0.04 – 1 (35)</td>
<td>0.04 – 1 (35)</td>
</tr>
<tr>
<td>Physics</td>
<td>Alves Banner</td>
<td>Alves Banner</td>
<td>Alves Banner</td>
<td>Alves Banner</td>
<td>Alves Banner</td>
</tr>
<tr>
<td>Friction Scheme</td>
<td>None</td>
<td>Collins</td>
<td>Collins</td>
<td>Collins</td>
<td>Collins</td>
</tr>
</tbody>
</table>
Figure 50. Inner wave model grids (200m within box) and model output points.

Table 11: Summary of observed wave data.

<table>
<thead>
<tr>
<th>LOCATION NAME</th>
<th>ID</th>
<th>LONGITUDE</th>
<th>LATITUDE</th>
<th>INSTRUMENT</th>
<th>PERIOD OF AVAILABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beacon 15</td>
<td>B15</td>
<td>118.5081</td>
<td>-20.1733</td>
<td>Wave Rider</td>
<td>November 2006 to October 2007</td>
</tr>
<tr>
<td>Beacon 16</td>
<td>B16</td>
<td>118.5104</td>
<td>-20.1721</td>
<td>AWAC</td>
<td>July 2004 to July 2007</td>
</tr>
<tr>
<td>Offshore Instruments</td>
<td>AW1</td>
<td>118.3982</td>
<td>-20.13128</td>
<td>ADCP/PUV</td>
<td>15 December 2007 to 3 March 2008</td>
</tr>
<tr>
<td>Inshore Instruments</td>
<td>AW2</td>
<td>118.51055</td>
<td>-20.22660</td>
<td>ADCP/PUV</td>
<td>15 December 2007 to 3 March 2008</td>
</tr>
</tbody>
</table>
Table 12: Summary of model output locations.

<table>
<thead>
<tr>
<th>NO.</th>
<th>LONGITUDE</th>
<th>LATITUDE</th>
<th>ID</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>118.3982</td>
<td>-20.1313</td>
<td>AW1</td>
<td>Offshore AWAC</td>
</tr>
<tr>
<td>2</td>
<td>118.5106</td>
<td>-20.2266</td>
<td>AW2</td>
<td>Inshore AWAC</td>
</tr>
<tr>
<td>3</td>
<td>118.5081</td>
<td>-20.1733</td>
<td>B15</td>
<td>Wave Obs Beacon</td>
</tr>
<tr>
<td>4</td>
<td>118.5104</td>
<td>-20.1721</td>
<td>B16</td>
<td>Wave Obs Beacon</td>
</tr>
</tbody>
</table>

6.3.1 WAVE HEIGHT

Wave heights were examined qualitatively by inspection of the time series plots of modelled and observed wave heights (for both total significant wave height and swell significant wave height, Tp>9s) shown in Figures 51 to 54. These plots were augmented by construction of wave height exceedance plots shown in Figures 55.

Periodic higher wave heights (> 1.5m) are generated by tropical cyclone activity. The model is not expected to be as accurate for these events as the wind model generally does not adequately capture the cyclonic wind field.

Exceedance plots for Hs have been constructed for three data sets for both Beacon 15 and Beacon 16 (Figure 55) – these allow comparison of curves for the observed data, the modelled data for the observation period and for the modelled data over the extended modeling period.

These plots quantify the degree to which the model is underestimating wave heights – typically about 0.1 - 0.15 m across the range of data. It is also noted that inspection of the time series data suggest that the underestimation is greater in the warmer months (northwest waves dominant) than the cooler months (easterly waves dominant).
6.3.2 WAVE DIRECTION (SWELL)

Verification of wave direction focused on swell. Time series plots for the two sites are shown in Figures 56 and 57.

The time series plots generally show the model swell direction to be lying near the centre of the directional range exhibited by the instruments. We note that the model is not expected to be able to produce the overall directional variability exhibited by the instruments. This variability is greater for data from the ADCP compared at B16 than for the wave rider at B15.

6.3.3 WAVE PERIOD

Time series plots comparing model and observed sea and swell periods at Beacon 16 are shown in Figure 58.

Inspection of the time series data shows that the model periods do a good job at predicting general phase shifts. In the absence of tuning model Tp is typically lower than observed Tp (by an average of 1-1.5 seconds for swell Tp).

6.3.4 SUMMARY

For the data presented here, the model is doing an excellent job in capturing general wave variability although, as described above, it is slightly underestimating wave heights and periods. Sensitivity tests suggest that wave height correlations would be improved further by applying a higher resolution grid and tuning of friction settings. However, relative to potential contribution of the wave climate on re-suspension, the verification results suggest that the model is doing a good job of representing the wave climate over the region impacted by dredge plumes.

6.4 BOTTOM (ORBITAL) VELOCITIES

The SWAN model produces time varying output of the bottom orbital velocity maxima at each output time step. The bottom maxima are a function of the wave height, wave period and the depth – the larger waves in shallower water will result in higher orbital velocities (and therefore greater contribution to re-suspension of sediments).
Figure 51. Time series comparison of observed (Wave Rider) and modelled significant wave height at Beacon 15 location.

Figure 52. Time series comparison of observed (AWAC) and modelled significant wave height at Beacon 16 location.
Figure 53. Comparison of observed and model swell (period > 9 seconds) at Beacon 15.

Figure 54. Comparison of observed and model swell (period > 9 seconds) at Beacon 16.
Figure 55. Model wave height exceedance compared with Beacon 15 and 16 observations (model for both the observation period and the extended period from 2001 to 2007 inclusive).
Figure 56. Comparison of observed versus model swell direction at Beacon 15.

Figure 57. Comparison of observed versus model swell direction at Beacon 16.
Figure 58. Comparisons of observed and model sea and swell period for Beacon 16 site.
7. DREDGE MODELLING – DREDGE3D

7.1 METHOD

Once the physical oceanography has been simulated it is possible to study the movement of discharges into the water column (e.g. sediments, chemicals etc.) or components of the water body itself (flushing rates of harbours, bays etc.).

The GEMS 3D Dredge Simulation Model (DREDGE3D) is used for simulating the specific fate of particles discharged during a dredging program. This model inputs the physical environmental data from GCOM3D, together with wave data from SWAN and meteorological data, to simulate the movement and deposition, of suspended particles in the water body across the study area.

DREDGE3D is a lagrangian particle model and therefore is independent of grids and grid resolutions. More details on the processes and methodology simulated in DREDGE3D is given in Appendix C.

DREDGE3D was used with great success in the Geraldton Port Redevelopment Project where it was compared with in-situ data, aerial photographs and satellite images.

In the past 6 years, since the dredging of Geraldton Port, DREDGE3D has been used in 13 dredging projects in Western Australia, four projects in Queensland, several developments in the United Arab Emirates and in New Caledonia for the INCO nickel processing plant and port development.

7.2 VERIFICATION

The best verification of DREDGE3D available so far was carried out during the recent dredging program at Cape Lambert (2007). The verification study was run independently of GEMS, by SKM who carried out the comparison with field measurements collected by Insitu Marine Optics (IMO).

SKM compared TSS plume predictions produced by GEMS from DREDGE3D (at a temporal resolution of 15 minutes and a spatial resolution of 10 metres) with data collected on September 2, 2007 and October 15, 2007. **GEMS was not provided with the field measurements.**

The full presentation which was presented to the EPA Service Unit and the Dredge Management Committee by SKM is reproduced, with appropriate permissions, as Appendix D of this document.

Tables 13 and 14 give statistical comparisons and correlations respectively, reproduced from the SKM presentation.

The results of the study showed that the predicted plume was in the correct region and the correlation between predicted and observed TSS values was very high (74% on September 2).
Table 13: Statistical comparison of TSS predictions from DREDGE3D with observed TSS.

<table>
<thead>
<tr>
<th>Turbidity statistic</th>
<th>What this says</th>
<th>2-Sep-07</th>
<th></th>
<th>15-Oct-07</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Mean (mg/L)</td>
<td>The average of all turbidity values</td>
<td>5.34</td>
<td>5.1</td>
<td>6.3</td>
<td></td>
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<tr>
<td>Standard Error</td>
<td>The spread of non-average turbidity values above and below the mean</td>
<td>0.065</td>
<td>0.04</td>
<td>0.04</td>
<td>0.005</td>
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<td>Range</td>
<td>The difference between the highest and lowest turbidity value</td>
<td>38.66</td>
<td>14</td>
<td>12.6</td>
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<tr>
<td>Skewness</td>
<td>If the distribution of values is weighted towards smaller numbers than the mean, this is positive</td>
<td>3.082</td>
<td>1.8</td>
<td>1.3</td>
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<tr>
<td>Confidence Level (95%)</td>
<td>The level of turbidity, above and below the mean value, for which 95% of all observations can be found</td>
<td>0.12</td>
<td>0.07</td>
<td>0.07</td>
<td>0.009</td>
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Table 14: Correlations between TSS predictions from DREDGE3D and observed TSS.

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<th>Measures of model fit</th>
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<th>15-Oct-07</th>
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<td>IMO v GEMS Avg</td>
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<td>0.29</td>
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<td>IMO v GEMS Max</td>
<td>0.42</td>
<td>0.25</td>
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<tr>
<td>Slope</td>
<td>0.74</td>
<td>0.54</td>
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<td>R² (Coefficient of determination)</td>
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<td>0.62</td>
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To date the Cape Lambert verification study is the most detailed, and most successful, assessment of the accuracy of dredging simulations in Australia. (See Appendix D).

It is hoped that detailed data on TSS will be obtained throughout this dredging program to enable further verification and testing of the processes simulated in DREDGE3D.
### 7.3 SIMULATION METHOD FOR THE CHOSEN DREDGING PERIOD

The basic steps to be undertaken to simulate a dredging program with the best estimate of the dredge simulation parameters are:

- Setup and verify GCOM3D and SWAN;
- Setup the dredge log which provides the fine detail of the dredging program to DREDGE3D;
- Define particle size distributions for the range of materials represented in the dredge log;
- Run GCOM3D for the representative dredging period driven by winds and tides;
- Run the SWAN wave model for the representative dredging periods driven by winds;
- Run DREDGE3D for the full representative dredging period driven by the simulated dredge log, currents from GCOM3D and orbital velocities from SWAN;
- Store the x,y,z coordinates of all simulated particles each hour for the duration of the dredging program;
- Analyse the hourly output from the simulation to provide data for initial impact assessment studies.
- Derive impact zones, based on model output and exposure criteria, defining regions of impact from TSS or sedimentation.

### 7.4 DEVELOPMENT OF THE DREDGE LOG

The detailed specifications of the dredges and their expected program for RGP6 was developed by SKM and underwrites the dredging program simulations. The fine detail of all activities which result in the release of particles into the water column is required as input to the dredging simulations and is provided in a detailed “dredge log”, which represents the best estimate of how the dredging program might be undertaken on a scale of minutes.

To illustrate the detail required to carry out the dredging simulations, the following procedure is typical for a CSD:

- Read the coordinates of the next location from the dredge log
- Determine dredging action (dredging or not, overflowing barges, pumping to reclamation areas)
- If dredging
Read the cutting rate
Read the particle size distribution for this location
Calculate the volume to be dredged in the time step between now and the next location
Add this volume to the total volume count
Compare dredged volume with total volume to be dredged to maintain check of mass balances
Distribute the mass to the model particles to be released at this time step according to the particle size analysis curve for that location
Keep a count of the total mass distributed to each particle size
Determine the fate of each model particle (released at cutter head, overflowed from barge, pumped to reclamation area, overflowed from reclamation area)
Add overflow mass to total overflow mass
Add pumped mass to total hopper mass

- If pumping to reclamation area
  - Add pumped mass to total reclamation area total mass
  - Check if reclamation area mass has exceeded capacity.
- All model particles released are tracked for the full duration of the dredging program (whether it be 2 months or 5 years) and the XYZ coordinates are written out to a binary output file every hour (eventually generating millions of model particles).
- At each output time step the total mass assigned to each model particle released so far is added up and compared with the total mass dredged. If they are not the same, the model stops and an error is flagged.

All these processes need to be reflected in the detail of the dredge log. The first 12 hours of the RGP6 CSD dredge log is shown in Table 15.

7.5 DREDGING SIMULATIONS

The dredge modelling is carried out in three steps. Firstly the 3-dimensional ocean circulation in the Port Hedland region is simulated for the 12 months of 2007 using the nested grids shown in Figures 12, 13 and 14. If dredging takes longer than 12 months then the time on January 1, 2008 is rest to January 1, 2007 to maintain the influence of the meteorological period which has been chosen as “average”.
Next the SWAN wave model is run for the same period to predict hourly wave induced orbital velocities to feed in to predictions of sediment re-suspension during the disposal of material at the offshore spoil ground(s).

Finally the total dredge program is simulated by DREDGE3D to predict the behaviour of particles released into the water column, driven by 3D ocean currents from GCOM3D, waves from SWAN, the dredge log and particle size distributions at each time step.

The dredge modelling results presented in this report, are for the following simulations:

a) the dumping at Spoil Ground “One” arising from the backacter dredging for RGP6;

b) the release of fines into Port Hedland harbor arising from the RGP6 backacter dredging and the bulk excavation CSD dredging and associated discharging to reclaim area “H”;

c) the dumping at Spoil Ground “I” arising from the combined backacter dredging for RGP5 and the LOF together with the dumping at Spoil Ground “One” arising from the backacter dredging for RGP6; and

d) the release of fines into Port Hedland harbor arising from the backacter dredging and the bulk excavation CSD dredging for RGP5, RGP6 and the LOF and associated discharging to reclaim area “H”.

Note that the material dredged by the CSD for the RGP5 program is to be pumped to reclamation area “A” which is outside the road and rail causeway and cannot drain back into the harbor.

The dredge modelling in each of these scenarios predicted the the X-Y-Z coordinates of all particles throughout the full dredging program and the results were stored hourly. These results were then analysed to determine the distribution of Total Suspended Solids (TSS) and seabed coverage to be developed over the total dredge program.
Table 15: Extract of the first 12 hours from the dredge log used for simulating the CSD dredging at Nelson Point.

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7.6 SIMULATION OF RGP6 BACKACTER DREDGING AND DISCHARGING TO SPOIL GROUND “ONE”

The basic parameters for the excavation and disposal to Spoil Ground “One” were as follows:

- Excavation plant: large backacter dredge
- 2,700,000m³ of material to be dumped, including some PASS
- Average production: 40,000m³ per week over 50 weeks
- Supporting barges: two large split hull (i.e. bottom dumping) hopper barges with a holding capacity of 3,700m³ each.
- Dumping site: PHPA spoil site “One”I (Figure 2)
- Working hours: 24 hours per day with stoppages for maintenance and ship movements
- Cycle time between each dump at sea: 10.8 hours
- Expected date of commencement – October, 2009

The removal of material with the large backacter dredge was simulated for 68 weeks starting in October. The material was taken to Spoil Ground “One” by barges and released every 11 hours.

Turbidity in the harbour

There is very little data on the percentage of fines which spill during backacter dredging. Undoubtedly it is considerably less than for a CSD since there is no grinding action from a rotating cutter head. After discussions with the project team it was decided that the assumption that 5% of the fines are released into the water column by the backacter dredge would represent a very conservative approach. Hence this was the assumption adopted for inclusion in the backacter dredge logs.

Due to the slow dredging rate of the backacter this assumption does not represent a large amount of material compared with other dredges. Based on the above assumptions, the backacter dredging rate is approximately 240m³ per hour resulting in 12m³ of fines being released into the water column each hour.

In isolation from other activities in the harbor this rate of release of material will be relatively easily flushed and not result in significant turbidity levels over time. This assertion is supported by Figure 59 which shows the TSS value exceeded 95% of the time, indicating only a very localised increase in TSS values even with very conservative assumptions.
Turbidity at the Spoil Ground

The turbidity arising from the spoil ground dumping process was in all cases episodic with a plume of fine material spreading out during the release, but by the time the next barge arrived 11 hours later the turbidity from the previous dumping had been predominantly dispersed.

The episodic nature of the activity at Spoil Ground “One” was further affected by frequent stopping of the back hoe dredge and barge movements for commercial shipping movements in the harbor.

Due to the episodic nature of the dumping at Spoil Ground “One” in a highly tidal area, average turbidity plots show nothing of value as averaging over time and over the water column reduce the results to practically zero. To illustrate this, a snapshot of turbidity during dumping at the southwest corner of the spoil ground is shown in Figure 60.

Figure 60 also shows a purple line encompassing the region which experiences TSS of greater than 1 mg/litre any time during the spoil dumping period. This region is plotted to give a better idea of the possible extent of any visible plumes during the spoil dumping period (although a plume of 1mg/litre might be hard to see with the human eye).

Sedimentation at the Spoil Ground

The results for sedimentation are easier to present due to the accumulation at the spoil ground over time. Figure 61 shows contours of the accumulated sediments resulting from the deposition of the material from the barges 1 month after the completion of the dredging.

Important to note is that there is no prediction of significant accumulation of sediments other than in the vicinity of Spoil Ground “One”.
Figure 59. The TSS value exceeded 95% of the time during the backacter dredging for RGP6 in Port Hedland harbor.
Figure 60. TSS snapshot at Spoil Ground “One” resulting from dumping near the southwest corner during the removal of material with a backacter dredge from Nelson Point.

Figure 61. Contours of accumulated sediments at Spoil Ground “One” resulting from the dumping of 2,700,000m³ of material.
The dredging of the bulk of the material at Nelson Point (4,000,000m³) is to be carried out by the CSD pumping to Reclaim Area “H”.

The dredging simulation of this activity took 325 days and was driven by 3D currents from GCOM3D and the detailed sequence of events parameterized in the dredge log provided by the FAST team and illustrated in Table 15.

The dredge log allowed for frequent stoppages due to commercial shipping movements in the harbor which acted to prolong the program but provided more periods without dredging to aid the flushing of dredge plumes.

The results of the bulk excavation dredging with the CSD are presented in terms of the accumulated sediments and contour plots of the TSS values which are exceeded 95% of the time as a result of material released into the water column from the dredging and reclamation overflow.

The major flushing mechanism for the material released into the water column in Port Hedland Harbour is the ebb tide, particularly the very strong ebb spring tides. A random example of the turbidity plume on an ebb tide from the dredging at Nelson Point is shown in Figure 62.

Figure 63 presents the accumulated sedimentation resulting from dredging with the CSD at Nelson Point and discharging into reclamation area “H”.

Figure 64 shows the TSS value exceeded 95% of the time during the 325 day dredging program.

These results are similar in concentration but different in behavior to the previous study for the RGP5 program at Harriet Point in Port Hedland harbour.

Keeping in mind that the flushing mechanism for Port Hedland harbour is the ebb tide, particularly during spring tides, the differences are mainly due to the location further up the harbour than Harriet Point away from the full length of the deep channel and the harbour entrance.

On the flood tide turbidity is driven up the harbour into the shallow areas and small tributaries/creeks and has little chance of flushing. Hence the relatively high turbidities up harbour from the dredging site.

On the ebb tide turbidity is driven towards the harbour entrance but it has further to go than from Harriet Point and so remains in the harbour longer.

The overflow from Reclaim Area “H” contributes to this analysis by providing a constant flow of turbid waters, initially at 150 mg/litre, from a source further from the harbour entrance than the dredging activity.
Figure 62. Turbidity snapshot on the ebb tide resulting from CSD dredging at Nelson Point.
Figure 63. Contours of accumulated sediments resulting from the bulk excavation CSD dredging at Nelson Point and pumping to reclamation Area “H”.
Average Turbidity in Water Column exceeded 95% of time

Figure 64. Contours of the TSS value exceeded 95% of the time resulting from the bulk excavation CSD dredging at Nelson Point and pumping to reclamation Area “H”.
7.8 SIMULATION OF RGP6 BACKACTER DREDGING DISCHARGING TO SPOIL GROUND “ONE” IN ASSOCIATION WITH DREDGING ACTIVITIES FROM RGPS AND THE LOF AND ASSOCIATED DISPOSAL AT SPOIL GROUND “I”

All three dredging programs will be dumping material at the spoil grounds as follows:

RGP5 – 500,000m³ at Spoil Ground “I”

LOF – 80,000 m³ at Spoil Ground “I”

RGP6 – 2,700,000m³ at Spoil Ground “One”

Therefore just over 3.2 million m³ of material will be disposed of at the two spoil grounds with the majority of the material being disposed of at Spoil Ground “One” by RGP6. The total volume represents an increase of approximately 20% over the RGP6 program.

Accordingly a dredge log was developed which combined the latest methodology for dredging PASS during the RGP5 and LOF programs and the RGP6 methodology described earlier.

The revised details provided by SKM for RGP5 are as follows:

1) Large backacter dredge as in RGP6
   - 350,000m³ of PASS to be dumped at PHPA spoil ground “I” (Figure 2)
   - Average production: 40,000m³ per week over 9 weeks
   - Supporting barges: two large split hull (i.e. bottom dumping) hopper barges with a holding capacity of 3,700m³ each.
   - Working hours: 24 hours per day with stoppages for maintenance and ship movements
   - Cycle time between each dump at sea: 7.5 hours
   - Expected date of commencement – March, 2009

2) Small grab dredge
   - 150,000m³ of PASS to be dumped at PHPA spoil site I (Figure 2)
   - Average production: 8,800m³ per week over 17 weeks
   - Supporting barges: three small split hull (i.e. bottom dumping) hopper barges with a holding capacity of 1,000m³ each.
   - Dumping site: PHPA spoil ground “I” (Figure 2)
   - Working hours: 24 hours per day with stoppages for maintenance and ship movements
   - Cycle time between each dump at sea: 4 hours
• Expected date of commencement – March, 2009

The dredging plan for the LOF is as follows:

• Excavation plant: large backacter dredge
• 80,000m³ to be dumped at PHPA spoil site I (Figure 2)
• Average production: 40,000m³ per week over 9 weeks
• Supporting barges: two large split hull (i.e. bottom dumping) hopper barges with a holding capacity of 3,700m³ each.
• Working hours: 24 hours per day with stoppages for maintenance and ship movements
• Cycle time between each dump at sea: 7.5 hours
• Expected date of commencement – May, 2009

The combined program therefore started in March, 2009 and lasted until completion of the disposal of RGP6 material in January, 2011.

It was assumed that on completion of RGP5 duties the large backacter dredge moved directly to carry out the LOF dredging. This meant the large backacter started dredging the LOF in May, 2009 and was finished by early July. This left a period of almost three months of after completion of disposal of material at Spoil Ground “I” before work commenced on RGP6 and disposal at Spoil Ground “One” (adjacent to Spoil Ground “I”) commenced.

As outlined above, the dredge log describing the disposal of material at the spoil grounds by the RGP5, LOF and RGP6 dredging programs spanned 21 months from May, 2009 to January 2011. For modelling purposes these activities were simulated during the year 2007 which has been shown to represent average meteorological conditions.

The longer duration of the disposal program has no effect on the turbidity outcomes. As before the turbidity arising from the dumping process was in all cases episodic with a plume of fine material spreading out during the release, but by the time the next barge arrived 4-11 hours later the turbidity from the previous dumping had been predominantly dispersed. The fact that this process continued for 21 months does not create denser plumes.

The major potential effect of the longer disposal program is due to the increased amount of material disposed of in the vicinity of Spoil Ground “One” (as opposed to the fines which are flushed from the area).

Figure 65 shows contours of the accumulated sediments resulting from the deposition of the material from the barges 1 month after the completion of the combined RGP5, LOF and RGP6 spoil disposal program.

Comparison with the standalone RGP6 results shown in Figure 61 show an increased volume of material but no other impacts on the surrounding region.
Figure 65. Contours of accumulated sediments at Spoil Grounds “One” and “I” resulting from the dumping of 3,280,000m$^3$ of material.
7.9 THE RELEASE OF FINES INTO PORT HEDLAND HARBOUR DURING RGP5, LOF AND RGP6 DREDGING PROGRAMS

The major source of material being released into the harbour will be from the CSD dredging with fines released both at the cutter head and at the overflow from the reclamation area. It is proposed that the CSD will commence work on RGP5 in April, 2009 and continue until December, 2009. The CSD will then be inactive for 7 weeks whilst undergoing maintenance and then commence RGP6 dredging in February, 2010.

During RGP5 dredging the only source of material released into the harbour by the CSD will be from the cutterhead as the material is to be pumped to Reclamation Area “A” which overflows to the waterways west of the Finucane Island rail and road causeway which do not drain into the harbour.

The 7 weeks gap between the CSD finishing dredging of RGP5 and commencing dredging RGP6 will ensure no cumulative turbidity effects occur as any turbidity remaining after RGP5 will be flushed from the harbour before RGP6 commences.

The only potential cumulative result across the different programs is then from the overlapping of CSD dredging activities with backacter dredging in the harbour. This occurs during the dredging for RGP6 as both the backacter and the CSD will be operating on the RGP6 program together for a period of time. This is accounted for in the basic simulations of RGP6.

All backacter work for RGPS and the LOF will be completed before the CSD commences RGP6 and so the only overlap across the programs is for the period from October to December, 2009 when the RGP6 backacter is working near Nelson Point whilst the CSD is dredging near Harriett Point.

To examine whether these activities produce any cumulative outcomes, a dredge log was developed to simulate the RGP5 CSD dredging from April to December, 2009 with the addition of the RGP6 backacter dredging commencing in October, 2009.

During this period the only sources of material released into the harbour were from the cutting action of each dredge as the RGP6 reclaim overflow was not operating and the RGP5 reclaim was overflowing outside the harbour precinct.

The dredging simulation of this activity took 265 days and was driven by 3D currents from GCOM3D and the detailed sequence of events parameterized in the dredge log.

The results are presented in Figure 66 in terms of contour plots of the TSS values which are exceeded 95% of the time as a result of material released into the water column, during the 265 day dredging program, from the two dredging activities.

Figure 67 reproduces the standalone results derived for RGP5 and it can be seen that there is very little difference with the main impact being slightly elevated turbidity in the vicinity of Nelson Point.
Figure 66. Contours of the TSS value exceeded 95% of the time resulting from the CSD dredging at Harriett Point and the backacter dredging at Nelson Point.
Figure 67. Contours of the TSS value exceeded 95% of the time resulting from the CSD dredging at Harriett Point (reproduced from the GEMS RGP5 study report).
8. HYDRODYNAMIC IMPACTS OF PROPOSED DREDGING PROGRAMS IN PORT HEDLAND HARBOUR

The cumulative effects of the proposed RGP5, RGP6 and LOF dredging have been investigated in this study in terms of the fate of particles released into the water column during dredging. The other cumulative issue which needs to be investigated is the impact, if any, of the changes in the bathymetry of Port Hedland harbour on the tides and currents in the harbour.

To study these changes, the sea levels and currents in Port Hedland harbour were simulated with GCOM3D using two different bathymetric data sets. The first bathymetry (Figure 68) represented the harbour depths before the dredging (including FMG dredging) whilst the second bathymetry (Figure 69) was constructed from data supplied by SKM to represent the harbour depths after completion of RGP5, RGP6 (including FMG) and LOF dredging.

To study any differences eight output stations (P1 to P7 and O in Figure 68) were established to store model output from both simulations.

GCOM3D was run for the “before” and “after” dredging cases from January 1, 2009 for a month and sea levels and current speeds and directions were stored at the eight output stations.

Table 16 summarises the mean current speeds and dominant current axes for the “before and “after” cases. Figure 70 shows the comparison of “before” and “after” sea levels at station P3 in the harbour and Figures 71 and 72 show the current speed comparisons at the two sites where differences can be discerned visually (P1 and P7).

The results show no impact on sea levels in Port Hedland harbour and no changes in currents just outside the harbour but there are some changes in localized currents within the Harbour.

The main changes in the harbor occur at sites P1 and P7 where the currents are slightly greater and slightly weaker respectively. At all other locations the changes in current speeds and directions are very small.

The reason the currents are slightly greater at P1 is probably due to the fact that, after dredging, the total mass of water in the harbor is greater and so there is likely to be a small increase in the mass flux moving through the harbor entrance on the ebb and flood tides. Since sea levels have not changed, the currents need to move slightly faster to move the extra mass.

The reason the currents are slightly weaker at P7 is probably due to its location, after dredging, being closer to deeper waters where the currents are slower.
Table 16: Comparison of results before and after the proposed dredging in Port Hedland harbour.

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean Current Speed (m/S)</th>
<th>Major Current Axis (Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GCOM3D before dredging</td>
<td>GCOM3D after dredging</td>
</tr>
<tr>
<td>P1</td>
<td>0.127</td>
<td>0.146</td>
</tr>
<tr>
<td>P2</td>
<td>0.150</td>
<td>0.148</td>
</tr>
<tr>
<td>P3</td>
<td>0.161</td>
<td>0.163</td>
</tr>
<tr>
<td>P4</td>
<td>0.072</td>
<td>0.072</td>
</tr>
<tr>
<td>P5</td>
<td>0.052</td>
<td>0.054</td>
</tr>
<tr>
<td>P6</td>
<td>0.141</td>
<td>0.143</td>
</tr>
<tr>
<td>P7</td>
<td>0.118</td>
<td>0.106</td>
</tr>
<tr>
<td>O</td>
<td>0.132</td>
<td>0.129</td>
</tr>
</tbody>
</table>
Figure 68. Bathymetry before proposed dredging of Port Hedland harbour showing the output stations for comparison of currents and sea levels (P1 to P7 and O).

Figure 69. Bathymetry in Port Hedland harbour resulting from the proposed RGP5, RGP6 and LOF dredging programs.
Figure 70. Comparison of sea levels in Port Hedland harbour before (blue) and after (red) dredging.
Figure 71. Comparison of current speeds at P1 before (blue) and after (red) dredging.
Figure 72. Comparison of current speeds at P2 before (blue) and after (red) dredging.
9. SUMMARY AND INTERPRETATION OF RESULTS

The major interpretation of the model results needs to be undertaken by marine biologists against a background of a detailed habitat survey and an understanding of the impacts of sedimentation and turbidity (hence light attenuation) on the known habitat.

The purpose of these studies is to provide input into that assessment process and to identify and understand the key meteorological, oceanographic and plume behavior processes which may help with future dredge management plans.

From an oceanographic point of view however the main points arising are discussed below.

9.1 BACKACTER DREDGING AT NELSON POINT COMMENCING IN OCTOBER

The key points to note arising from the results of the simulation of the Backacter dredging and disposal of the 2,700,000 m³ of material to Spoil Ground “One” include:

- Due to the dredging technique (with the backacter) there is minimal release of material at the removal site.
- The disposal process releases more material into the water column but only appears to have a local affect at the spoil ground.
- When the material is dumped at Spoil Ground “One” it produces a short term turbid plume which dissipates before the next dumping occurs 11 hours later.
- The heavier fractions of the spoil material settle to the sea bed and accumulate over time. The finer fractions disperse and there is no evidence of significant amounts resettling within the area.
- The episodic nature of the activity at Spoil Ground “One” was further affected by frequent stopping of the back hoe dredge and barge movements for commercial shipping movements in the harbor.
- Due to the episodic nature of the dumping at Spoil Ground “One” in a highly tidal area, average turbidity plots show nothing of value as averaging over time and over the water column reduce the results to practically zero.
9.2 CSD DREDGING AT NELSON POINT COMMENCING IN FEBRUARY

The key points to note arising from the results of the simulation of the CSD dredging, with disposal of dredge material in slurry pumped to Reclaim Area “H”, at Nelson Point include:

**Dredging Activity**

- As for all dredging programs in Port Hedland harbour, the flushing mechanism is the ebb tide, particularly during spring tides;
- The results are similar in concentration but different in behavior to the previous study for the RGP5 program at Harriet Point in Port Hedland harbour;
- The differences are mainly due to the location of Nelson Point further up the harbour than Harriet Point away from the full length of the deep channel and the harbour entrance;
- The location of the reclaim area overflow is also a significant difference as the RGP5 reclaim areas either overflowed near the harbour entrance or outside the harbour precinct;
- On the flood tide turbidity is driven up the harbour into the shallow areas and small tributaries/creeks and has little chance of flushing. Hence the relatively high turbidities up harbour from the dredging site;
- On the ebb tide turbidity is driven towards the harbour entrance but it has further to go than from Harriet Point and so remains in the harbour longer;
- The turbidity produced in Port Hedland Harbour flushes actively on the ebb tide to the extent that the 95 percentile TSS is indistinguishable from background values before the end of the spit is reached outside the harbour.

**Overflow from Reclaim Area “H”**

- The overflow from Reclaim Area “H” contributes to the TSS levels at the upper end of the harbour by providing a constant flow of turbid waters, initially at 150 mg/litre, from a source further from the harbour entrance than the dredging activity.
- The overflow consists mainly of very fine particles (the model assumes most are below 250 microns) and so there is very little long term sedimentation in the creek bed near Reclaim Area “H”. Particles may settle at low tide but are most likely to be re-suspended on the next flood tide and flushed towards the harbour when that tide begins to ebb (the water levels are high at the beginning of the ebb tide but not at the end).
- As a result the main outcome from the overflow is turbidity which will eventually flush from the harbour but will contribute to elevated TSS levels, particularly in the upper reaches of the harbour.
9.3 CUMULATIVE IMPACTS OF THE RGP5, LOF AND RGP6 DREDGING PROGRAMS

1) The studies of the cumulative dredging impacts indicated the following outcomes:

- The 20% increase in material disposed of in the vicinity of Spoil Ground “One” (at Spoil Ground “I”) resulting from the RGP5 and LOF dredging programs has no discernible impact on turbidity and the only detectable sedimentation impact is the increase in volume across the two spoil grounds;

- The only potential cumulative result across the different programs is from the overlapping of CSD dredging activities with backacter dredging in the harbour. This occurs during the dredging for RGP6 as both the backacter and the CSD will be operating on the RGP6 program together for a period of time. This is accounted for in the basic simulations of RGP6.

- All backacter work for RGP5 and the LOF will be completed before the CSD commences RGP6 and so the only overlap across the programs is for the period from October to December, 2009 when the RGP6 backacter is working near Nelson Point whilst the CSD is dredging near Harriett Point.

- Comparison of the contours for the TSS value exceeded 95% of the time during this period with the standalone results derived for RGP5 show that there is very little difference with the main impact being slightly elevated turbidity in the vicinity of Nelson Point.

2) The studies of hydrodynamic impacts within Port Hedland harbour as a result of the changed bathymetry indicated that:

- There will be no impact on sea levels in Port Hedland harbour and no changes in currents just outside the harbour but there are some changes in localized currents within the Harbour.

- The main changes in the harbor occur near the entrance to the harbour where the currents are slightly greater and near the newly dredged areas where the currents are slightly weaker. At all other locations the changes in current speeds and directions are very small.

- The reason the currents are slightly greater at the harbour entrance is probably due to the fact that, after dredging, the total volume of water in the harbor is greater and so there is likely to be a small increase in the mass flux moving through the harbor entrance on the ebb and flood tides. Since sea levels have not changed, the currents need to move slightly faster to move the extra mass.

- The reason the currents are slightly weaker near the newly dredged areas is probably due to the increased proximity to deeper waters where the currents are slower.
10. REFERENCES


APPENDIX A: DESCRIPTION OF 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.


A.1 HISTORY AND PHYSICS

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

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

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

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

A.2 GENERAL DESCRIPTION

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

The system will run on Windows or UNIX platforms.

GCOM3D is formulated as a re-locatable model which can be applied anywhere in the world using tidal constituent and bathymetric data derived from global and local databases.
The three-dimensional structure of the model domain, tidal conditions at the open boundaries, thermodynamics and wind forcing are defined for each model application by extraction of data stored in gridded databases covering a wider geographical area of interest.

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

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

### A.3 HORIZONTAL AND VERTICAL STRUCTURE

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

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

In the upper water column levels are typically a few metres apart, increasing to several hundred metres in deep waters.
A.4 NUMERICAL PROCEDURES

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

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

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

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

A.5 BOUNDARY CONDITIONS

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

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

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

At coastal boundaries and along river banks, the wetting and drying of grid cells is accomplished via the inundation algorithm published in Hubbert and McInnes (1999a and b).
On outflow, a radiation boundary condition, as described in Miller and Thorpe (1981) is applied to the velocity field to prevent the buildup of numerical energy, while on inflow boundaries, a zero-gradient condition is applied.

A.6 TIDAL DATA ASSIMILATION

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

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

A.7 MODEL APPLICATIONS

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

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

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

GCOM3D has also been used in a wide range of ocean environmental studies including prediction of the fate of oil spills, sediments, hydrotect 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.8 GCOM3D REFERENCES


APPENDIX B: DESCRIPTION OF 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 (Booij et al 1996), 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 and is the successor of the stationary second-generation HISWA model.

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 et al, 1994).

B.1: SWAN REFERENCES


Ris, R.C., L.H. Holthuijsen and N. Booij, 1994: A spectral model for waves in the near shore zone, Proc. 24th Int. Conf. Coastal Engng, Kobe, Japan, pp. 68-78
APPENDIX C: DESCRIPTION OF DREDGE3D

The dredge modelling is carried out in two steps. Firstly the 3-dimensional 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 10-15 minutes).

C.1 MODEL FEATURES

DREDGE3D is used for simulating the specific fate of particles discharged during a dredging program. The model is a Lagrangian particle model and does not run on a grid and consequently is independent of grid resolution.

The model inputs the ocean currents (and temperature, salinity if important) 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 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.

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

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

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

Modelling predicts the hourly distribution of Total Suspended Solids (TSS) and seabed coverage to be developed over the total dredge program. The hourly output is analysed to derive periods of continuous exposure to turbidity and/or sedimentation above defined thresholds.
C.2 ESTABLISHMENT OF THE DREDGE LOG

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

- Total volume of material to be dredged
- Region to be dredged
- Expected start time(s)
- Expected duration of dredging
- Particle size distributions and settling rates for all types of material to be dredged
- Number and type of dredges
- Draft (full and empty) of dredge(s)
- Average hours per week of operation
- Maintenance schedule (repairs, refuelling 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
- No dredging periods (such as coral spawning)
- Cutting rate
- Hopper capacity (m$^3$) for overflow and no overflow conditions in terms of dry solids
- Speed of dredge(s) while dredging, travelling to, and returning from, the dump site
- Number, location and capacity of disposal sites.
C.3 DREDGE3D METHODOLOGY

The basic steps undertaken by DREDGE3D (for a TSHD) are:

- Read from the dredge log the next location
- Determine dredging action (dredging, overflowing or not, sailing to spoil ground, dumping or returning from spoil ground)
- If dredging, read the cutting rate
- Calculate the volume to be dredged in the time step between now and the next location
- Add this volume to the total volume count
- Compare dredged volume with total volume to be dredged to determine when to cease dredging
- Distribute the mass to the model particles to be released at this time step according to the particle size analysis curve for that location
- Keep a count of the total mass distributed
- Determine the fate of each model particle (overflowed, retained in hopper)
- Add overflow mass to total overflow mass
- Add hopper mass to total hopper mass
- If dumping at spoil ground
- Release all particles in the hopper at the designated spoil ground
- Add dumped mass to total spoil ground mass
- Check if spoil ground mass has exceeded spoil ground capacity.

All model particles released are tracked for the full duration of the dredging program (whether it be 2 months or 2 years) and the XYZ coordinates are written out to a binary output file every hour (eventually several million particles).

At each output time step the total mass assigned to each model particle released so far is added up and compared with the total mass dredged. If they are not the same, the model stops and an error is flagged.
Note that for a TSHD another source of turbidity is the wash from the propellers, particularly when the under keel clearance (UKC) reduces as the hopper fills. This process is simulated using empirical algorithms developed during the recent Dampier Port dredging program from measurements of turbidity in the vicinity of the TSHD propellers.

C.4 ANALYSIS OF RESULTS

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.
APPENDIX D - CAPE LAMBERT VERIFICATION

(see accompanying document “Dredging Verification Studies at Cape Lambert.docx”)