Technical Appendix B5

Proposed Gorgon Dredging Simulation Studies

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CHEVRON

Gorgon Development

Dredging Program Simulation Studies

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1 Introduction

Global Environmental Modelling Systems (GEMS) has been contracted to carry out simulations of the dredging of the Materials Offload Facility (MOF) and the LNG shipping access channel for the Chevron Gorgon Development at Barrow Island.

The work is being undertaken using two sophisticated numerical computer models:

a) The GEMS 3D Coastal Ocean Model (GCOM3D) to simulate the complex three-dimensional ocean currents surrounding Barrow Island; and
b) The GEMS 3D Dredge Simulation Model (DREDGETRAK) to determine the fate of particles released into the water column during the dredging operations.

1.1 Scope of Work

The Scope of Work for this study has been undertaken in several stages as follows:

Stage 1: Simulations for a "Typical" 15 month Period

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a) Incorporate the latest bathymetry data and establish bathymetric grids (covering all potential regions of impact) for the hydrodynamic and dredge simulation modelling.

b) Analyse annual meteorology data for the region to choose a "typical" 15 month period.

c) Run GCOM3D for a selected period and compare with ocean currents and tides measured by MetOcean in 2003.

d) Show results of hydrodynamic model verification and discuss methodology with the EPASU.

e) Meet with URS and Baggermans to establish the best estimate of the dredge simulation parameters including:
   - Particle distribution curve
   - Dredge(s) to be used and proposed hours of operation
   - Dredge cutting rate(s)
   - All potential sources of turbidity together with rate and duration
   - Proposed spoil ground(s)
   - Establish the expected maintenance schedules and associated down times.

f) Meet with RPSBBG to establish the required outcomes of dredge simulations (e.g. TSS levels and durations, bottom sedimentation thickness, impact zone criteria)

g) Run GCOM3D for the “typical” 15 month period driven by winds, tides and satellite sensed large scale currents.

h) Run the full dredge scenario for the MOF and the LNG access channel for the “typical” 15 month period.

i) Analyse output from the simulation to provide data for initial impact assessment studies.

j) Derive impact zones, based on model output and RPSBBG exposure criteria, defining regions of full mortality, partial mortality and exposure without mortality.

Stage 2: Sensitivity Studies

a) Analyse annual meteorology data for the region to choose two “atypical” 15 month periods with more or less easterly wind events than the “typical” year.

b) Run GCOM3D for the two “atypical” 15 month periods driven by winds, tides and satellite sensed large scale currents.

c) Run full dredge simulations for three extra dredging scenarios:

  - An “atypical” meteorological period containing more easterly wind events.
  - An “atypical” meteorological period containing more westerly wind events.
  - A “typical” meteorological period with the underkeel clearance (UKC) of the THSD limited to 4 metres to reduce propeller wash.

d) Analyse output from the simulations to determine differences between the “typical” and “atypical” years and the effects of limiting UKC.

e) Derive impact zones based on model output and RPSBBG exposure criteria for the three sensitivity scenarios.

2 GEMS Background Information

GEMS 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 that provide solutions to a variety of environmental, engineering and operational problems. Services provided to the oil and gas exploration industry include:

- Oil Spill Prediction and Risk Modelling under fully representative climatic and oceanographic conditions;
- Real-time, on-call Oil Spill Modelling
- Dredge sediment fate modelling
- Production Formation Water and Pipeline Hydro-test discharge modelling and related risk analysis;
- Wave/Current design criteria modelling for pipelines and off-shore and on-shore facilities;
- Comprehensive tropical cyclone modelling, including winds, waves, currents and storm surge;
- Provision of accurate tidal prediction based on extensive 2D and 3D hydrodynamic ocean modelling.

Through it links with Australia's premier research institution, the Commonwealth Scientific and Industrial Research Organization (CSIRO), GEMS now includes satellite derived ocean elevation and large-scale ocean current data into its modelling suite. This state-of-the-art approach allows more accurate representation of ocean currents to be included in all ocean discharge applications. The methodology was applied successfully as part of a comprehensive Environmental Impact Assessment for the Woodside Enfield Project (and more recently for the BHP Stybarrow and Pyrenees studies) near the Ningaloo Marine Park.

The Australian Maritime Safety Authority (AMSA) has now fully implemented the GEMS atmospheric and oceanographic modelling suite into its Search and Rescue and Oil Spill Response systems. GEMS models provide the basis for on-going, round-the-clock spill response services for Chevron, Woodside, Apache and BHP-Billiton.

GEMS involvement with the oil industry in Australia dates back to its introduction of 3D modelling for oil spill trajectory modelling to the oil industry in the early 1990's. GEMS first undertook a series of tracking-verification exercises for WAPET in 1991. These verification studies demonstrated the need to model the ocean in three dimensions and to model at sufficiently high resolution to explain the flow in complex regions such as Barrow Island.

GEMS pioneered the stochastic approach to risk modelling, whereby the effects of inter-annual variability are treated intrinsically within the modelling program by running a large number of simulations commencing at randomly chosen times over several years.

3 Climate and Meteorology

The climate of the region is effectively dominated by two main seasons.

During the ‘dry’ season from May to October 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.

Warming of the continent following the winter solstice results in 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. Over the greater Gorgon area, the general flow then trends to be more southwesterly. Closer to the coast diurnal variations in terrestrial temperatures cause local sea-breeze impacts to become important.

This general trend toward more westerly flow results in monsoonal flow across the tropical north. Episodic bursts in monsoonal activity results in increased tropical convection (thunderstorms) and convective clusters can form into discrete low pressure systems and, if conditions are conducive, these can eventually intensify to tropical cyclones.

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 recurve towards the Pilbara coast. This situation can be conducive to rapid intensification and acceleration of the cyclones toward the Pilbara coast. More recent developments in numerical weather prediction and other forecasting techniques has allowed for more accurate forecasting of such events with longer advisory lead times.

In the past, much of the atmospheric forcing applied in the region has been based on the application of historic, single station (wind) data obtained from the nearest automatic or manual weather station to the site of interest.

This approach is often unsatisfactory since the single station data does not adequately represent the spatial variability of the governing climate conditions. GEMS has already moved to applying spatial and time varying data from numerical weather prediction (NWP) models to force its oceanographic models. The improvement in results based on this approach was verified in satellite tracked drifting buoy exercises carried out for the Woodside Enfield project between Northwest Cape and Barrow Island.

Data from the Bureau of Meteorology’s operational weather forecast model (LAPS - Limited Area Prediction System) is used for this purpose.

Meteorological measurements have been recorded at Barrow Island for many years and provide the ability to examine the behaviour of the local winds. The annual wind rose for Barrow Island, derived from 6 years of data (1999 - 2005), is given in Figure 3.1. These data are disaggregated into quarterly wind roses in Figures 3.2 to 3.5.

Figure 3.6 shows the results of an analysis of the occurrence of easterly or westerly wind events compared with the average during the years 1999 to 2005.

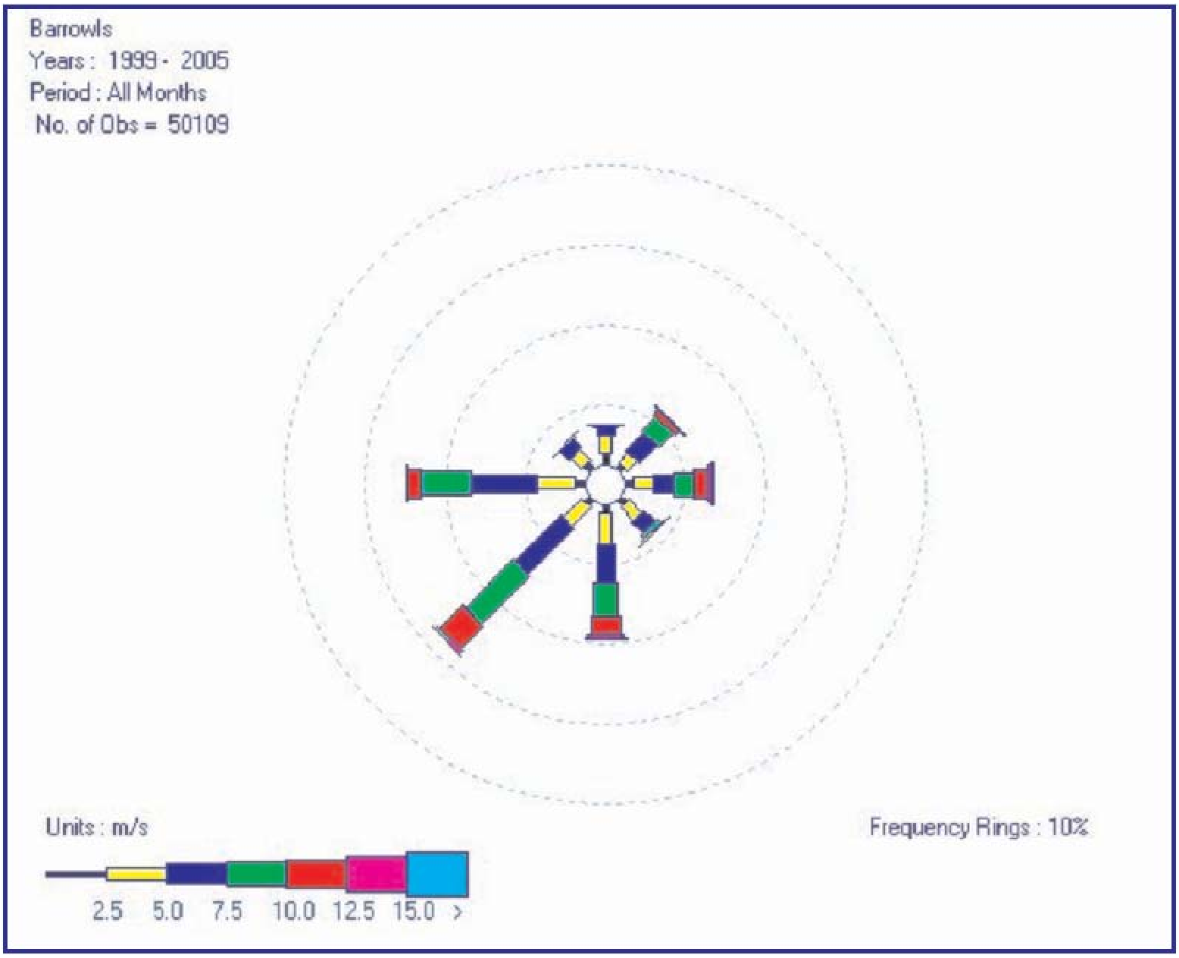

Figure 3.1: Annual wind rose for Barrow Island derived from the years 1999 to 2005.

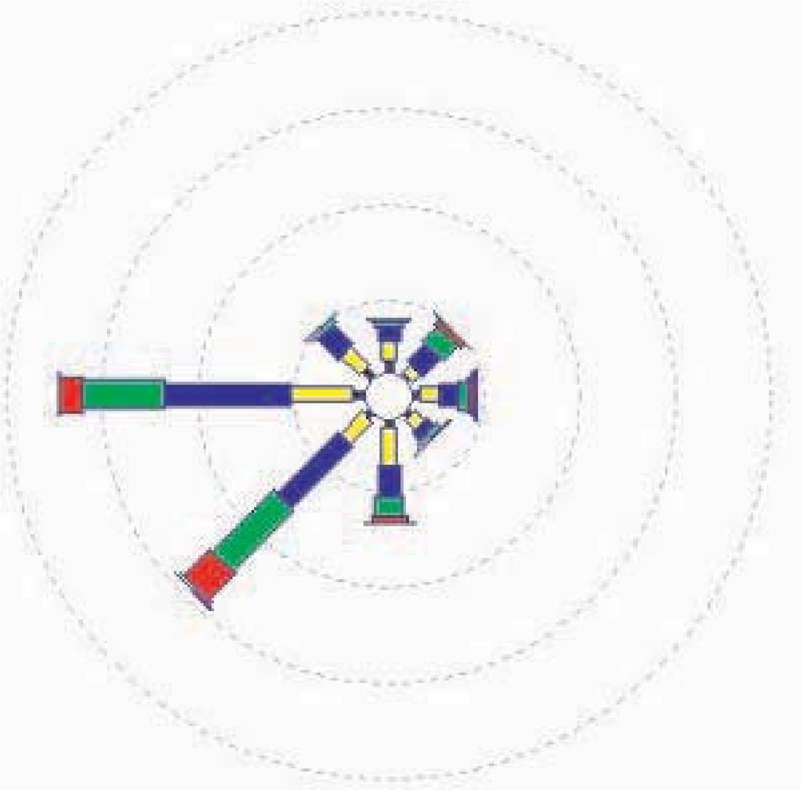

Figure 3.2: Wind rose for Barrow Island for January to March from 1999 to 2005.

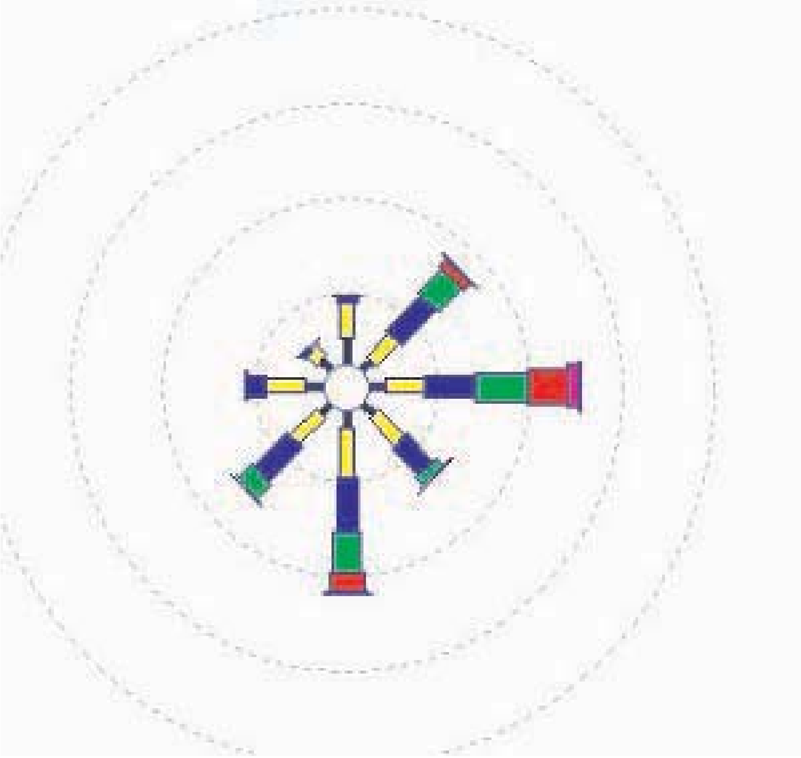

Figure 3.3: Wind rose for Barrow Island for April to June from 1999 to 2005.

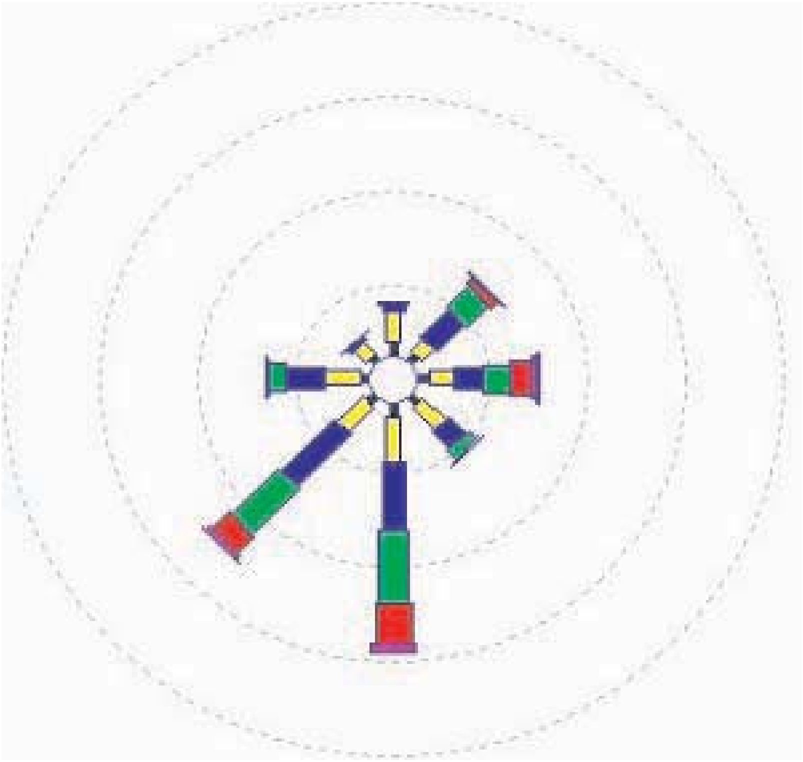

Figure 3.4: Wind rose for Barrow Island for July to August from 1999 to 2005.

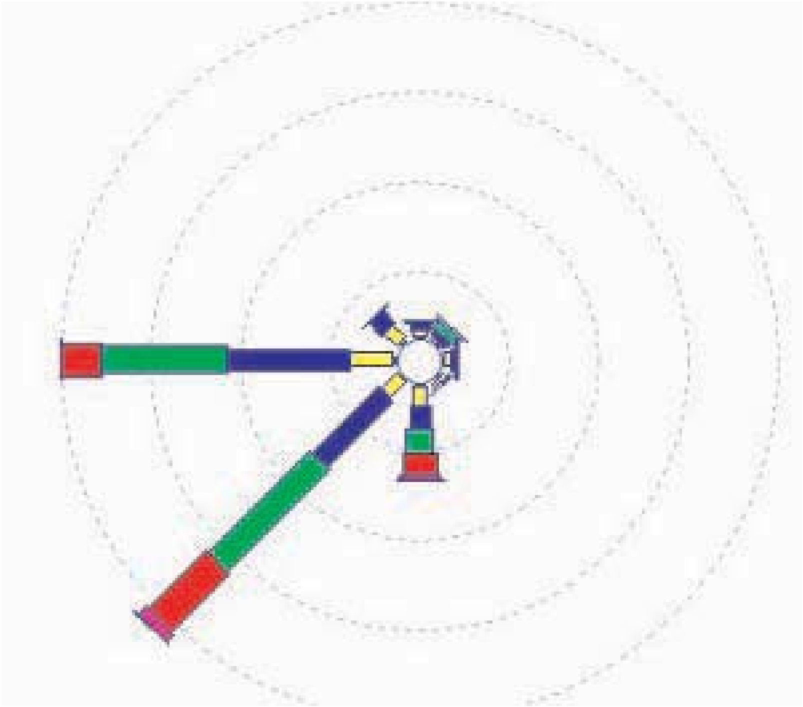

Figure 3.5: Wind rose for Barrow Island for September to December from 1999 to 2005.

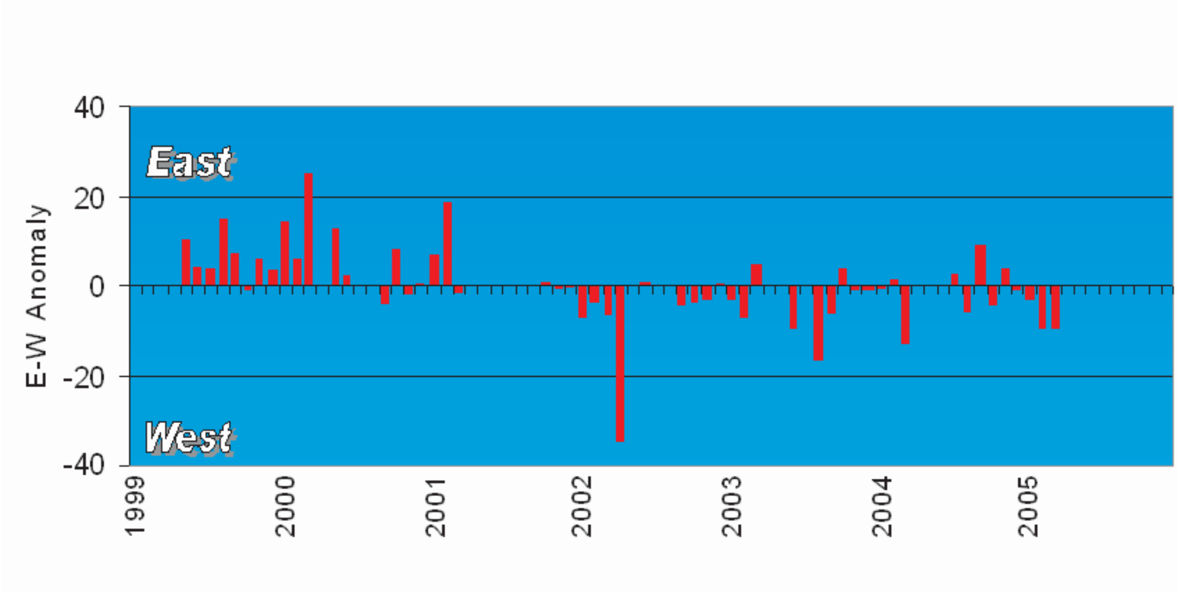

Figure 3.6: Analysis of the occurrence of easterly or westerly wind events compared with the average during the years 1999 to 2005.

4 GCOM3D and DREDGETRAK

4.1 Modelling the Physical Oceanography

The dominant influences on the circulation in the waters surrounding Barrow Island are the local wind and tides. This circulation can be simulated to a high level of accuracy using the GEMS three-dimensional ocean model (GCOM3D).

GCOM3D is a state-of-the-art 3D primitive equation ocean model, which has been developed by GEMS to study and predict ocean currents on or near the continental shelf and in harbours and estuaries anywhere on the globe. GCOM3D includes the non-linear advection terms and is driven by wind stress, atmospheric pressure gradients, astronomical tides, depth and terrain dependent bottom friction and ocean thermal structure (where relevant). For high-resolution studies over small regions GCOM3D can be nested in larger domains and still runs relatively fast on any modern computer (PC or UNIX).

For search and rescue applications and the tracking of buoyant discharges the surface ocean currents from GCOM3D are used. For oil spill modelling, water quality, sediment transport and other marine discharge studies, which often require an understanding of the vertical variation of the currents, the full three-dimensional current field is used.

GCOM3D is the longest serving three-dimensional ocean model in Australia. It was the first 3D ocean model to be used on a consulting job (Geelong Ocean Outfall, 1984) and has since been continuously developed in the research world and since the formation of GEMS in 1993.

GCOM3D has been used by the Australian Maritime Safety Authority in Canberra, as the national ocean forecast model for search and rescue (and oil spill prediction) for the past three years. During this time the model has been used at many locations around the Australian coastline and verified against SAR buoys (surface drifters) with only three cases in three years producing incorrect results. These cases have since been shown to be due to the influence of the East Australian Current, which has now been incorporated.

4.2 Dredge Modelling

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 (DREDGETRAK) is used either for simulating the ambient behaviour of coastal sediments under the influences of waves and currents or the specific fate of particles discharged during a dredging program. This model inputs the physical environmental data from GCOM3D, together with wave data and meteorological data, to simulate the movement and deposition, of suspended particles in the water body across the study area.

DREDGETRAK was used with great success in the Geraldton Port Redevelopment Project where it was extensively verified against in situ data, aerial photographs and satellite images.

In Western Australia it has since been used in Mermaid Sound for both the Dampier Port Authority and the Hammersley Iron port expansion projects and in New Caledonia for the INCO nickel processing plant and port development.

4.3 Model Forcing

Model forcing includes both wind and tides concurrently.

4.3.1 Meteorology

GCOM3D can be driven with gridded atmospheric model output or single station data. For this study wind observations at Barrow Island were used to represent the meteorology of the region. Data was obtained for a 6 year period from 1999 to 2005 and analysed.

Meteorological data for 2001 was chosen for the “typical” year as the wind rose for this year closely represented the long-term wind rose (Figure 3.1). The reason for this choice of time period can be more clearly seen in Figure 3.6 which shows the analysis of east-west anomalies in the six year wind record. This figure also underlines the selection of 2000 to represent the period containing more easterly events and 2002 to represent the period containing more westerly events.

4.3.2 Bathymetry

The bathymetric data sets held by GEMS were updated with bathymetry acquired by Chevron. The GEMS database has been developed from a range of sources including data from Geoscience Australia (formerly AUSLIG) and oil company surveys. Of particular relevance to this project is that the original 3D bathymetric survey of the Gorgon field is included together with the Apache Energy 3D bathymetric survey from south of Barrow Island to the Montebello Islands.

4.3.3 Tides

Tidal forcing was based on data from the GEMS Australian region gridded tidal data base which has been developed with extensive modelling programmes.

The tidal data for this project was enhanced with data from a high resolution tidal modelling project carried out by GEMS for Apache Energy in 1998.

5 Verification OF GCOM3D

Current measurements during August 2003 were available on the eastern side of Barrow Island and were used to compare with GCOM3D current predictions.

To verify GCOM3D a bathymetric grid covering the region in Figure 5.1 was set up at 100 metre resolution. Tidal data for the model boundaries was extracted from the GEMS database and winds from the Bureau of Meteorology were used to force the model.

GCOM3D was run for the month of August, 2003 producing hourly currents at between 5 and 15 levels in the water column (depending on the depth).

Figures 5.1 and 5.2 show examples of the flood and ebb tidal flow in the region respectively. Figures 5.3 and 5.4 show the good agreement obtained between GCOM3D predictions of current speed and direction and the observed data for the full month of August, 2003.

To augment this verification further measurements (including the release of drifters as recommended by the EPASU) are planned for later this year.

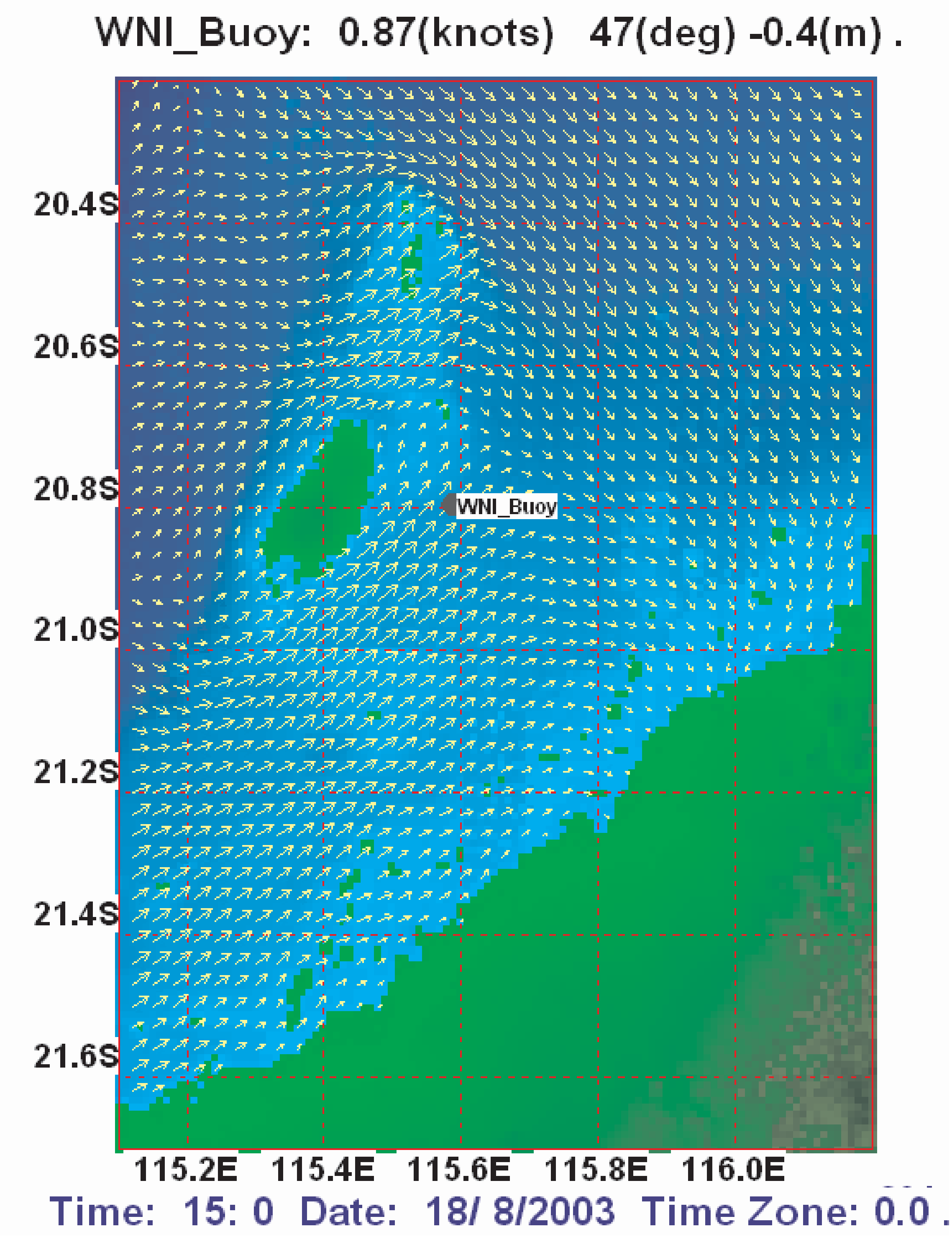

Figure 5.1: Example of the flood tide near Barrow Island predicted by GCOM3D.

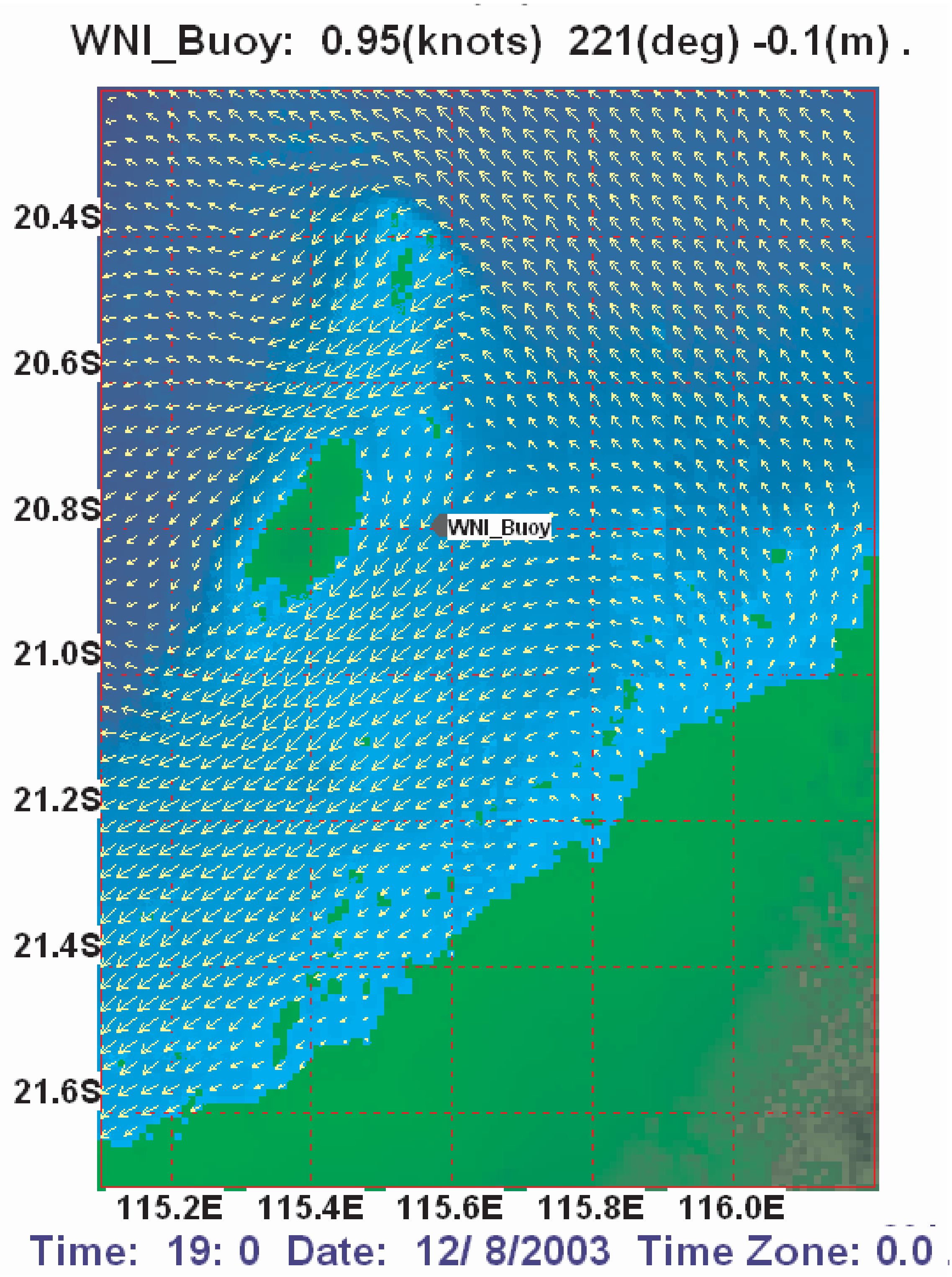

Figure 5.2: Example of the ebb tide near Barrow Island predicted by GCOM3D.

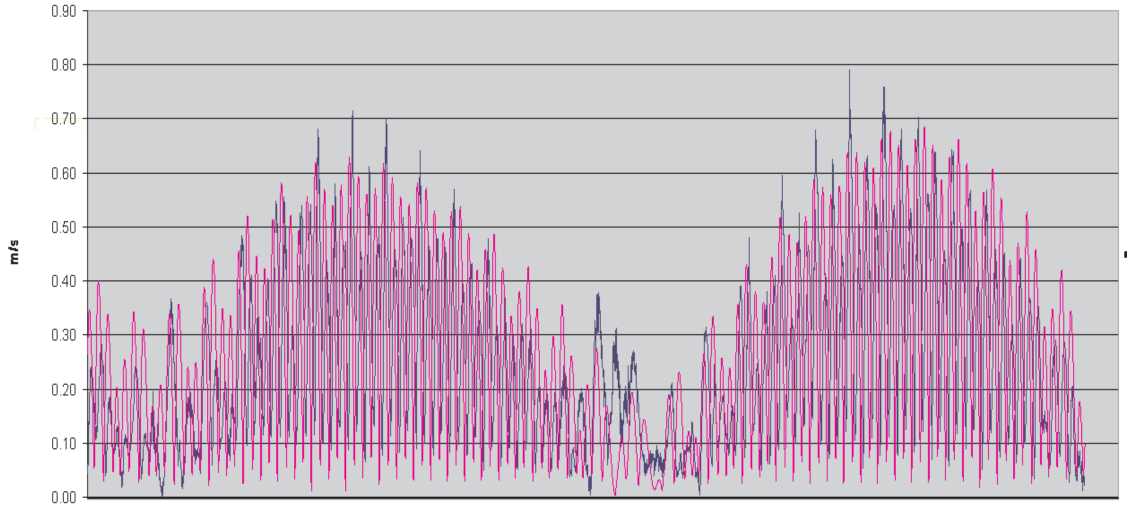

Figure 5.3: Comparison of current speeds measured with the WNI buoy (blue) and GCOM3D predictions (purple).

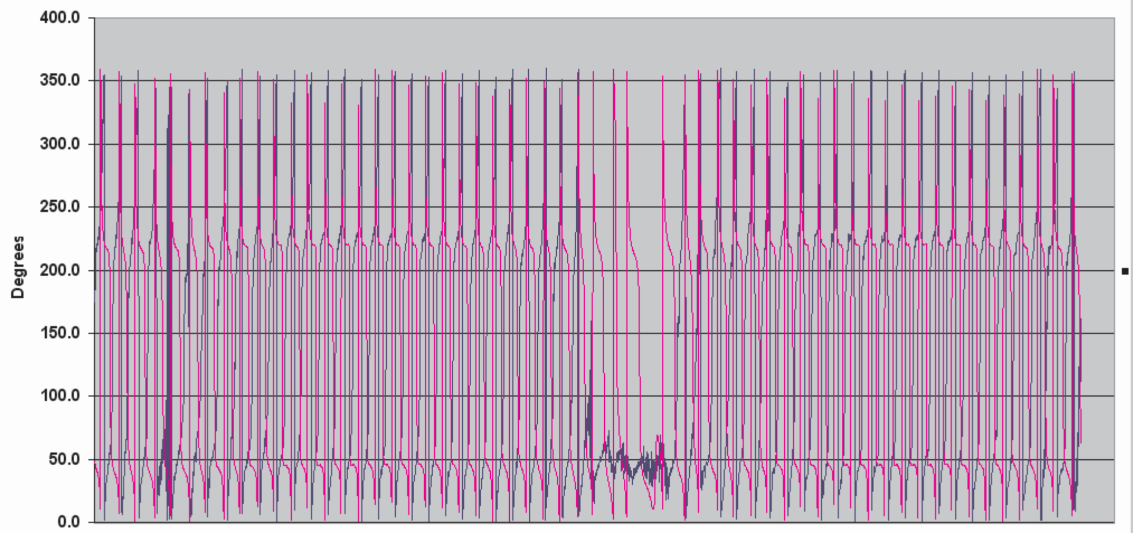

Figure 5.4: Comparison of current directions measured with the WNI buoy (blue) and GCOM3D predictions (purple).

6 Verification of Dredgetrak

The best verification of Dredgetrak available so far was carried out during the Geraldton Port dredging program. The results are described in this section.

6.1 Method

To establish predictions for the verification of the GEMS sediment plume model, a hindcast of the actual dredging program was carried out using the real-time wind, wave and dredge location/performance data. The hindcast was carried out from the commencement of dredging in October, 2002 until December 31, 2002 to generate fine particle loads in Champion Bay for comparison with TSS data collected in late November and December 2002 by the GPA.

The detailed tasks required to achieve these aims were as follows:

- Setup new model domain/bathymetry over a larger area than in previous studies
- Setup the sediment plume model with the new input data
- Process wind, wave and dredge location data from the commencement of dredging to December 31, 2002
- Hindcast ocean currents with the GEMS 3D Ocean Model (GCOM3D) driven by tides and winds from Geraldton Port for the period October 2002 to December 31 2002
- Hindcast turbid plume behaviour with the sediment plume model, driven by currents from GCOM3D, for the period October 2002 to December 31 2002
- Compare model predictions with satellite and aerial photos at four specific times in the prediction period.
- Analyse hindcast data to compare predicted TSS values with measured data in November and December 2002.

6.2 Results

Figure 6.1 shows the model region and the sites chosen for sampling TSS levels in Champion Bay. Figures 6.2 and 6.3 show sample surface currents from GCOM3D during the three month simulation under the influence of southerly and north-easterly winds respectively.

6.2.1 Comparison of Predictions with TSS Measurements

The results of the plume model predictions for TSS are compared with observations taken by the GPA on 7 days in late November and December in Table 1. The observed values shown in Table 1 are an average of all measurements taken in Champion Bay on the particular day. Since TSS measurements can vary significantly with small spatial or temporal changes it was considered to be more valid to compare regional averages rather than try and compare site-specific predictions and measurements.

Table 1 indicates that on December 5 the model exhibits a generally higher suspended sediment load in Champion Bay than recorded. On the other 6 days, however, the agreement is much closer. Given the potential errors in the input data (winds, dredge performance, particle distribution) the overall agreement must be considered to be very good.

6.2.2 Comparison of Model Predictions with Satellite and Aerial Photos

Comparison of model predictions with aerial or satellite photos can be misleading as it is impossible to determine what TSS values are contributing to the turbid plume in the images. Nevertheless a qualitative comparison can be made and such things as the basic path of the plume, denser areas etc. can be compared.

The GPA provided satellite images for November 26 and December 17, 2002 and aerial photos for October 30, December 5 and December 18, 2002. Comparisons are shown for these dates in the following figures:

a) Figures 6.4 and 6.5 compare the satellite image with model predictions on October 30, 2002.

b) Figures 6.6 and 6.7 compare an aerial photo with model predictions on November 26, 2002.

c) Figures 6.8, 6.9 and 6.10 compare aerial and satellite photos with model predictions on December 18, 2002

On the other three days of comparison with satellite and aerial photos the plume is predominantly moving northward and the predictions show similar paths and density patterns to the photos.

6.2.3 Outcomes

The qualitative comparisons with satellite and aerial photographs show similar features and density patterns although, as expected, agreement is by no means exact.

These qualitative results and the good agreement between predicted and measured TSS values on six out of the seven days suggests that the sediment plume model is simulating the sediment loads in Champion Bay very well and can reliably be used to predict the fate of turbidity from the dredging programme.

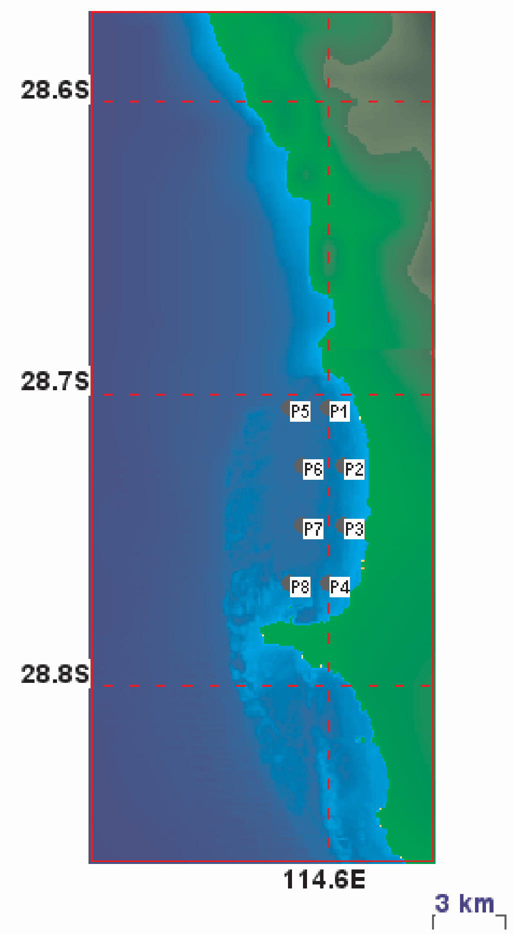

Figure 6.1: Model region showing TSS sites chosen for output in Champion Bay.

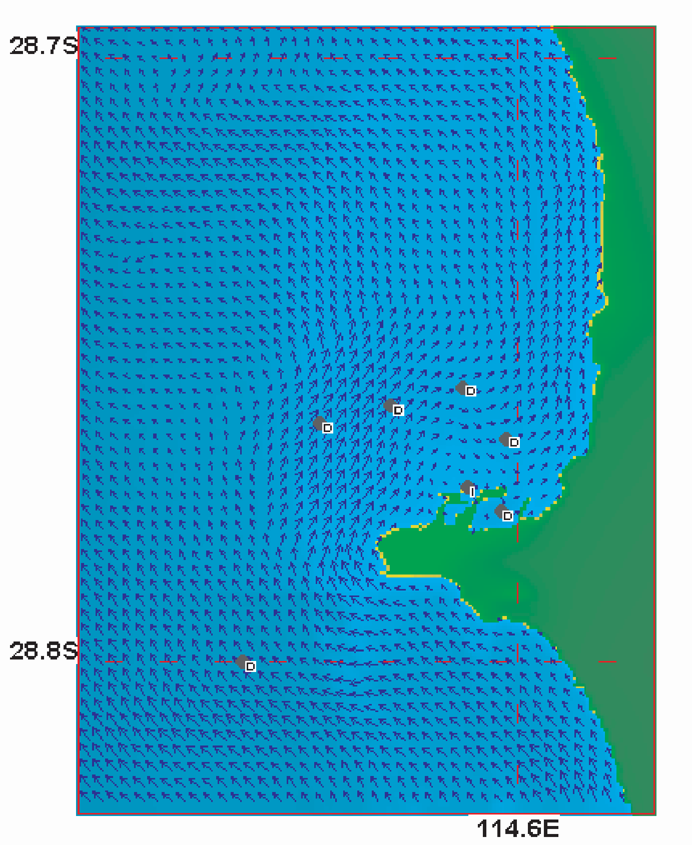

Figure 6.2: Sample surface currents from GCOM3D during southerly winds.

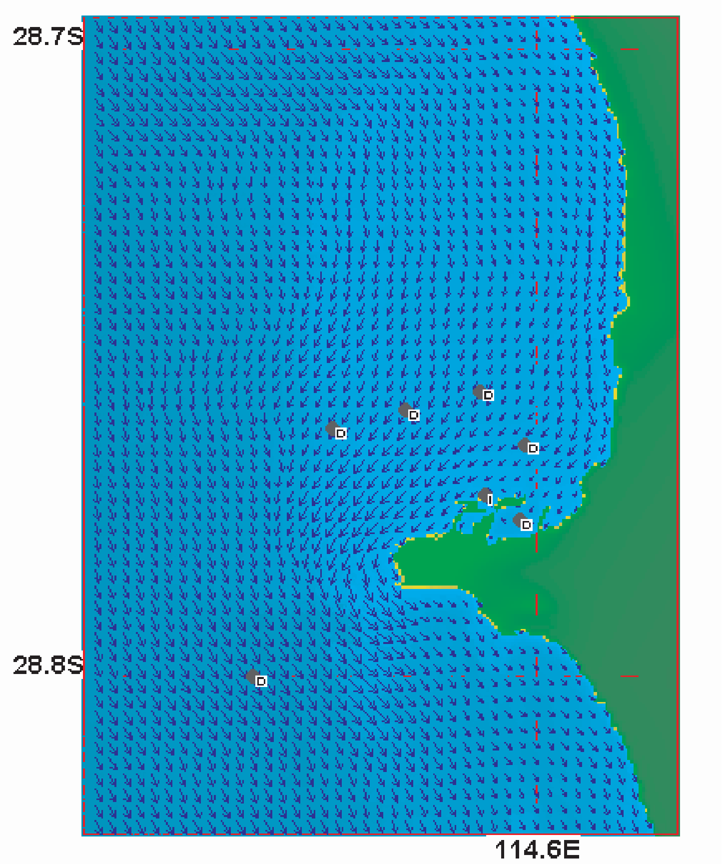

Figure 6.3: Sample surface currents from GCOM3D during north-easterly winds.

Table 1: Comparison of Predicted TSS values (P1-8) with measured values (TL1-21).

Site	**TSS (mg/l)**							
	Nov-28	**Nov-29**	**Dec-05**	**Dec-06**	**Dec-10**	**Dec-24**	**Dec-27**	**Average**
P1	5.4	7.3	9.7	6.1	4.9	3.4	1.3	
P2	5.2	3.0	8.8	2.6	3.9	3.5	1.1	
P3	4.9	2.5	6.0	4.6	2.0	3.5	1.0	
P4	4.2	2.2	5.6	3.5	3.0	1.8	0.4	
P5	4.2	5.4	8.7	6.3	4.5	3.3	5.4	
P6	3.6	2.3	8.7	3.4	2.9	2.7	5.0	
P7	2.9	1.6	5.6	4.2	1.7	2.5	5.4	
P8	2.7	1.0	5.5	3.3	1.9	1.0	2.3	
Average	**4.1**	**3.2**	**7.3**	**4.3**	**3.1**	**2.7**	**2.7**	**3.9**
TL1	5.8	1.2	2.6	1.7	4.7	1.2	2.9	
TL2	3.9	2.2	4.0	2.7	4.3	1.3	2.1	
TL3	3.4	3.3	2.9	3.0	1.8	0.9	2.4	
TL4	3.8	14.2	3.6	4.2	4.2	2.0	4.8	
TL5	3.1	1.9	6.0	2.7	2.6	1.6	1.9	
TL6	2.4	2.8	5.2	5.9	3.4	2.2	3.2	
TL7	9.3	2.7	4.5	2.0	2.5	1.4	3.1	
TL8	11.9	2.6	5.1	2.8	2.9	1.1	3.7	
TL9	6.7	2.2	5.0	3.3	1.8	5.1	5.6	
TL10	4.7	-	3.6	3.6	2.6	1.4	1.5	
TL11	-	2.9	3.1	4.4	2.7	1.6	2.1	
TL12	-	2.0	3.0	4.7	4.3	2.0	2.2	
TL13	3.4	2.7	5.4	5.3	2.8	1.2	1.6	
TL14	-	3.7	2.4	4.8	4.2	2.2	2.0	
TL15	-	2.7	2.6	4.5	4.0	4.1	1.8	
TL16	5.0	2.6	3.1	4.4	4.2	1.8	3.9	
TL17	-	2.7	2.8	4.4	3.4	1.3	2.9	
TL18	-	4.2	3.4	3.5	5.2	3.8	3.6	
TL19	-	3.6	2.9	4.1	3.3	2.8	2.3	
TL20	-	5.6	2.7	5.1	5.9	3.1	3.4	
TL21	4.2	4.6	7.2	4.6	3.7	6.1	3.5	
Average	**5.2**	**3.5**	**3.9**	**3.9**	**3.5**	**2.3**	**2.9**	**3.6**

Figure 6.4: Satellite photo of the turbid plume on October 30, 2002

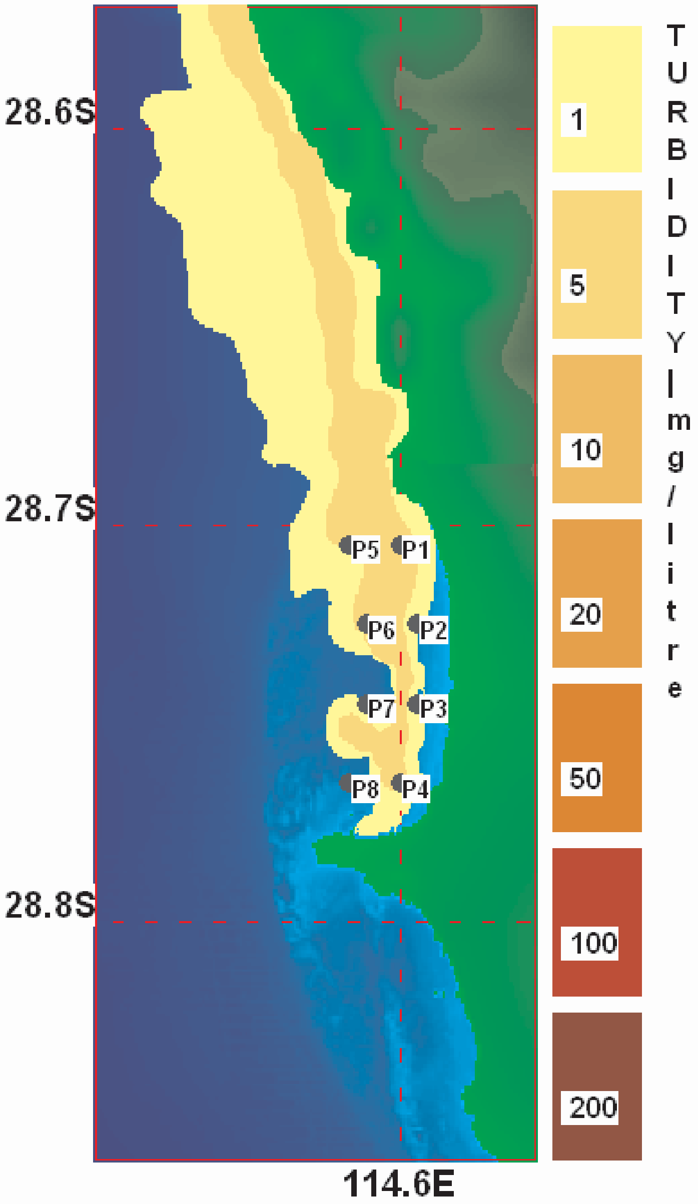

Figure 6.5: Model prediction for the turbid plume on October 30, 2002

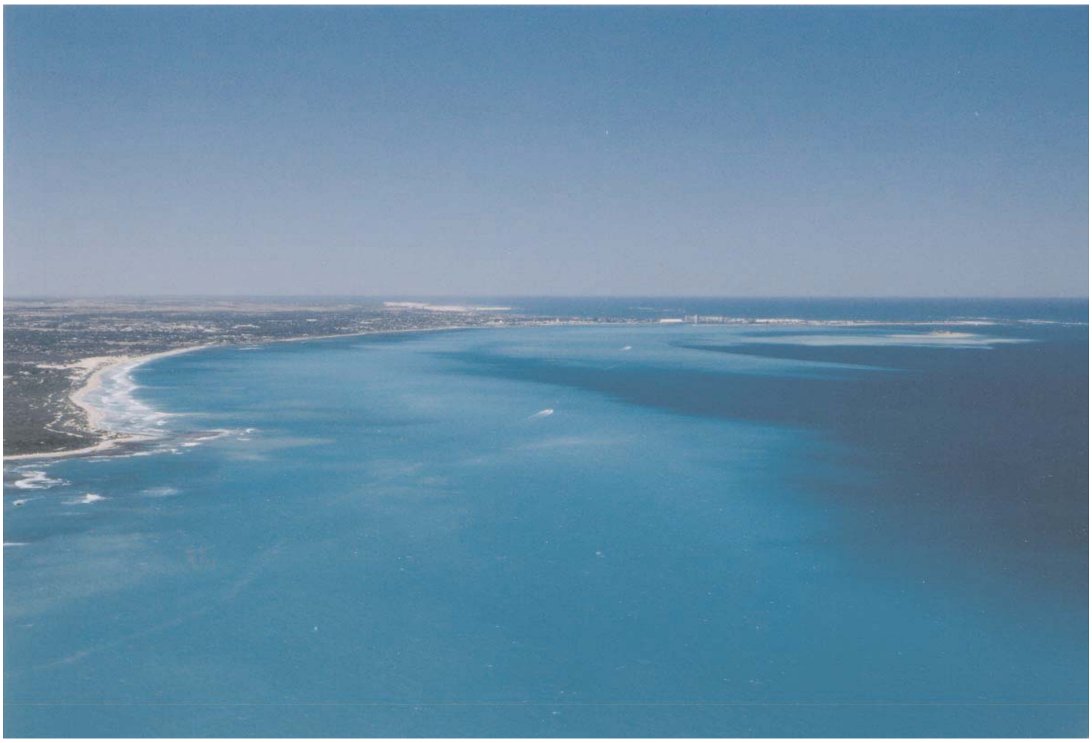

Figure 6.6: Aerial photo of the turbid plume on November 26, 2002

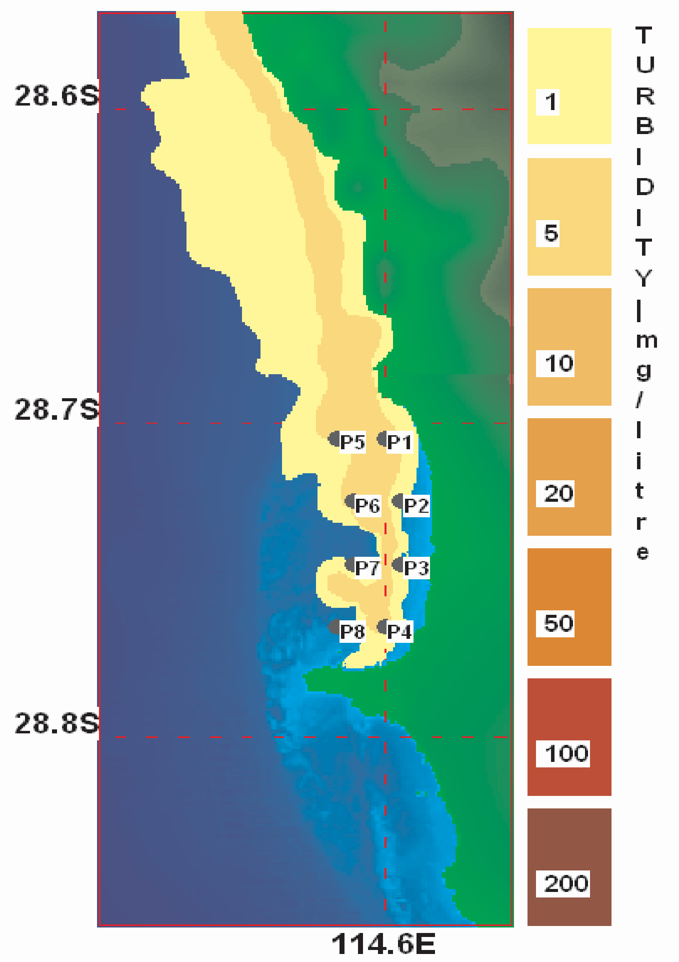

Figure 6.7: Model prediction for the turbid plume on November 26, 2002.

Figure 6.8: Aerial photo of the turbid plume on December 18, 2002

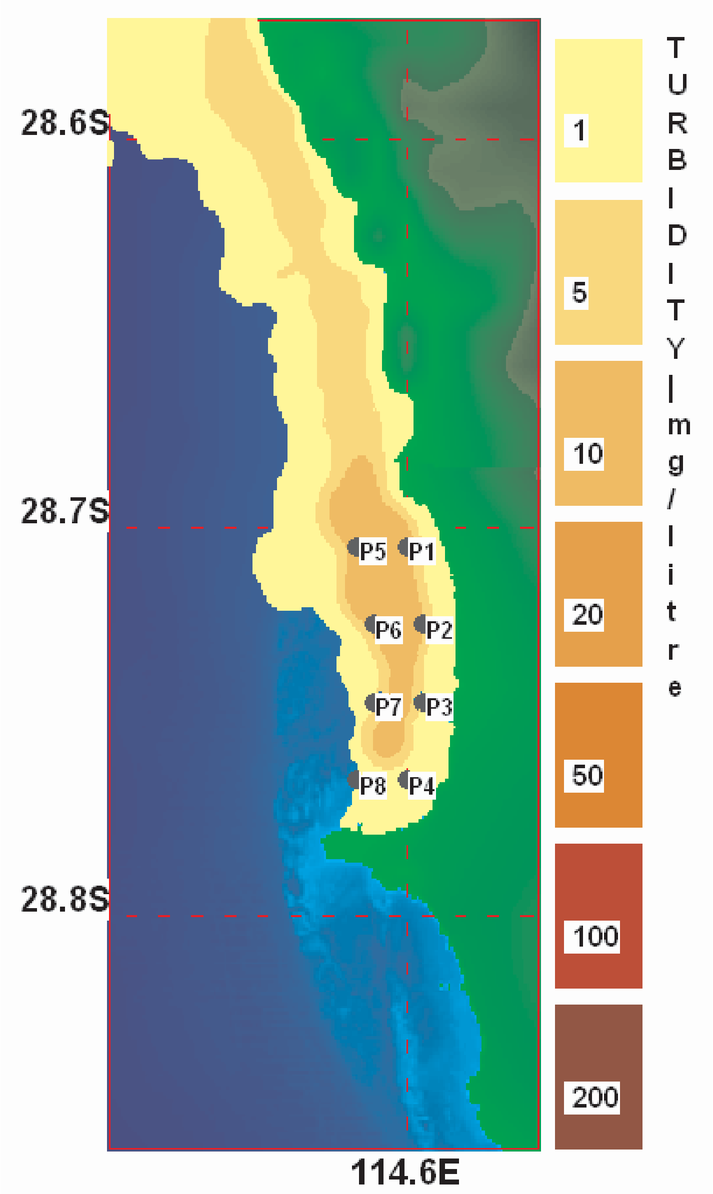

Figure 6.9: Model prediction for the turbid plume on December 18, 2002.

Figure 6.10: Satellite photo of the turbid plume on December 17, 2002.

7 Dredge Program Simulations with DREDGETRAK

The dredge modelling was carried out in two steps. Firstly the 3-dimensional ocean circulation of the region from south of Barrow Island to north of the Montebello Islands was predicted for 15 months using GCOM3D. Then the total dredge program was simulated over 464 days using DREDGETRAK which simulates the daily behaviour of the dredge(s) based on an estimated dredge log

Modelling relied on the best available meteorology and bathymetric information and included assumptions and details from other recent dredging programs in WA. Where there was uncertainty in model parameters, conservative values were chosen such that the model would tend to overestimate the impact. The modelling started in October (from the proposed dredging schedule) with pauses during coral spawning.

Modelling predicted the hourly distribution of Total Suspended Solids (TSS) and seabed coverage to be developed over the total dredge program (approximately 464 days). The daily output was analysed to derive periods of continuous exposure to turbidity and/or sedimentation above defined thresholds. The result of this analysis is summarised in maps of exposure zones showing regions affected by turbidity or sedimentation that result in high impact, moderate impact or a visible plume or a very small level of sedimentation.

7.1 Dredge Assumptions

For the model simulation of the dredging for the Material Offload Facility (MOF) the following assumptions were made (Box 7.1):

Box 7-1: Summary of Assumptions for MOF Dredging - Cutter Suction Dredge (CSD) Pumping to Bund

- A bund wall in the MOF outline will be filled with dredge spoil pumped directly from the CSD.
- The volume of cut and fill is estimated to be 800,000 m^3.
- According to the geotechnical data available, the material to be dredged is crystalline limestone with a capping of calcarenite.
- The rock is believed to be harder on average than that encountered at Geraldton.
- The characteristics of the spoil are anticipated to be similar to that generated at Geraldton (i.e. a high proportion of fines/flour and coarse limestone rubble).
- The duration of the dredging/reclamation program is estimated to be 18 weeks plus 2 (or more) weeks weather downtime.
- A mean dredge work rate of 96 hours of dredging per week. (actual rate will vary depending on hardness of rock).
- Lost time is due to dredge stopping and changing teeth every few hours (more frequently in harder rock) and for maintenance or refuelling activities.

- The dredge will start at outer end of the access channel and gradually work towards the shore creating a 6.5m deep channel (LAT).
- Maintenance will occur as needed. However when dredging rock there will be shut downs each 7 to 14 days in harder material and longer in softer materials. Refuelling will be undertaken each four to six weeks for 2 days.
- It is assumed that 5% of total material cut will be below 75 microns and that the distribution of these particle sizes will be similar to Geraldton.
- It is assumed that 50% of these fines will be released at the cutter head and 50% from the tailwater discharge.

For the simulation of the dredging of the LNG access channel and turning basin on the eastern side of Barrow Island the following assumptions were made (Box 7-2):

Box 7-2: Summary of Assumptions for the LNG Access Channel and Turning Basin

- The total volume to be dredged is estimated to be 7 million m^3.
- Roughly 40% of the total volume in the LNG Access Channel and turning basin is sediment which can initially be removed by TSHD.
- The TSHD dredging and disposal cycle period will be approximately 2.5 hrs (based on 90 minutes of dredging, 1 hour of travel to and from spoil ground including 10 minutes for dumping at the spoil ground).
- TSHDs are less weather dependent than CSDs and will be able to deliver about 134 hours production per week which equates to 53 loads per week on average.
- Assuming an average load of 6,000 m^3, giving a rate of approx. 300,000 m^3 per week, the sands can be removed in 11 - 12 weeks.
- In general maintenance will be undertaken travelling to and from the spoil grounds but the TSHD will cease operations for two days every 4 to 6 weeks to refuel and undertake major maintenance.
- Overflow will operate for the last 60 minutes of dredging and will be released under the keel of the TSD (-6 m depth).
- Overflow discharge will be approximately 8 m^3/sec (2 x 4 m^3 /sec dragheads).
- Fines within the sediments may be released.
- When dredging, without any controls on underkeel clearance, the principal source of fines is anticipated to be from propeller action. Overflow of fines from the hopper are added to this from beneath the keel.
- The sands are coarser than the “rock flour” and the particle size distribution used in this part of the simulation is based on laboratory analyses of field samples taken from Development area.
- The harder material will be removed by a large CSD pumping directly into one of two self propelled hopper barges that will transport the material to the spoil ground.
- CSD dredge behaviour and production rates are anticipated to be similar to the MOF dredging rates described above (effective production of 96 hours/week).
- The duration of CSD dredging is anticipated to be 48 weeks.

- Fines/flour will be generated at the CSD cutter head and at the hopper barge overflow which will be beneath the keel of the barge.

7.2 Simulation 1: The "Base" Case

For the "base" case DREDGETRAK was used to simulate the behaviour of particles released into the water column by the dredges using the dredging program assumptions outlined in the previous section. The dredging was started on October 1, 2000 and finished on January 8, 2002 to cover the period of most average conditions. Turbidity and sedimentation data were stored hourly for each 1 m layer of the water column of the gridded study area.

Sample plots showing predicted TSS plumes during the dredging program are shown in Figures 7.1 and 7.2. These plots provide an insight to the variations that are likely to occur as a result of changes to dredge location, tidal phase and wind strength and direction during the dredging program.

When interpreting the results in Figures 7.1 and 7.2 the following issues should be noted:

- all plots show turbidity levels due to dredging alone, and the colour codes were chosen to distinguish the different concentration ranges. The latter should not be taken as any indication of water coloration or clarity.

- The turbidity levels were 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.

The modelling predicts a build up of deposited sediments in the immediate vicinity of the dredging area and spoil disposal site from the settlement of the larger sediments (>75 μm). Finer sediment fractions remain suspended for longer periods and lead to increased turbidity which varies significantly in space and time. These variations are due to the active ocean circulation around Barrow Island driven by strong tides and marine winds.

The impact criteria provided by RPSBBG are given in Table 2. These criteria were used to analyse the 464 days of model output to produce exposure zones showing regions affected by turbidity or sedimentation that result in high impact, moderate impact or influence (but no impact) (Figures 7.3 and 7.4).

Closer examination of the results showed that:

a) The dredging of the MOF contributed very little to the impact zones. In other words, although there was turbidity generated during the dredging, the major effects were very localised in the region surrounding the dredging and the bund overflow. Likewise the sedimentation occurred within a small distance from the dredging and did not occur in sufficient quantities elsewhere to violate the impact criteria, or even register as a zone of influence.

b) The region of moderate impact due to sedimentation, extending northward to the Lowendal shelf, is entirely due to material released into the water column by the propeller wash of the THSD. This material is then subject to strong tidal currents and southerly winds for several hours at a time allowing it to move, deposit, resuspend etc. during several tidal cycles to reach the Lowendal Shelf. A further point to note is that the algorithms for generating suspended sediments due to propeller wash in the model are not well proven and may be over-estimating the outcomes.

7.3 Simulation 2: The "Base" Case with UKC Controlled

A second simulation of 464 days of dredging was carried out with the same assumptions/parameters as in Simulation 1 but with UKC controlled to 4 metres.

As before, the coral impact criteria were used to analyse the 464 days of model output to produce exposure zones showing regions affected by turbidity or sedimentation that result high impact, moderate impact or influence (but no impact) (Figures 7.5 and 7.6).

These results showed a significant reduction in the moderate impact zone, particularly in the region extending north towards the Lowendal Shelf.

Note that the sedimentation threshold was different for the base (2mg/cm^2) and UKC controlled (1mg/cm^2) cases. This explains the differences in the area of influence in Figures 7.3 and 7.5 and gives an insight into the effect of a change in the lower threshold.

7.4 Simulation 3: The "Base" Case with more Easterly Winds

A third simulation of 464 days of dredging was carried out with the same assumptions/parameters as in Simulation 1 but the dredging was started on October 1, 1999 and finished on January 8, 2001 to cover the period containing higher than average easterly wind events.

The overall results from this simulation were similar to the "base" case but with slightly increased flushing during the winter months when the easterlies added to the westward flushing action of the ebb tide around Barrow Island.

7.5 Simulation 4: The "Base" Case with more Westerly Winds

A fourth simulation of 464 days of dredging was carried out with the same assumptions/parameters as in Simulation 1 but the dredging was started on October 1, 2001 and finished on January 8, 2003 to cover the period containing higher than average westerly wind events.

The impact of the greater incidence of westerly winds (reduced level of easterly winds) was evident in slightly higher occurrences of turbidity across the Lowendal Shelf and past Varanus Island. However minimal change in the impact zones resulted.

Table 2: The Coral Impact Zone Criteria Supplied by RPSBBG

Note:

a) Exposure for at least six hours during daylight hours was regarded as satisfying the exposure criteria

b) The minimum TSS level adopted for the zone of influence (zone 3) was 2mg/litre

c) The minimum sedimentation adopted for the zone of influence (zone 3) was 1mg/cm^2

Zone 1: High Impact

Variable	Timeframe	Concentration	Time (consecutive days)
TSS	Short	≥25 mg l^{-1}	5
	Medium	≥10 mg l^{-1}	20
	Long	≥5 mg l^{-1}	80
Sedimentation	Short	≥25 mg cm^{-2} d^{-1}	5
	Medium	≥10 mg cm^{-2} d^{-1}	20
	Long	≥5 mg cm^{-2} d^{-1}	40

Zone 2: Moderate Impact

Variable	Timeframe	Concentration	Time (consecutive days)
TSS	Short	≥25 mg l^{-1}	2
	Medium	≥10 mg l^{-1}	7
	Long	≥5 mg l^{-1}	20
Sedimentation	Short	≥25 mg cm^{-2} d^{-1}	2
	Medium	≥10 mg cm^{-2} d^{-1}	7
	Long	≥5 mg cm^{-2} d^{-1}	20

Zone 3: Visible Plume and Extent of Sedimentation

Variable	Timeframe	**Concentration** (Anything above background, but less than the moderate impact zone)	Time (consecutive days)
TSS	Short	>0 mg l^{-1} <25 mg l^{-1}	2
	Medium	>0 mg l^{-1} <10 mg l^{-1}	7
	Long	>0 mg l^{-1} <5 mg l^{-1}	20
Sedimentation	Short	>0 mg cm^{-2} d^{-1} <25 mg cm^{-2} d^{-1}	2
	Medium	>0 mg cm^{-2} d^{-1} <10 mg cm^{-2} d^{-1}	7
	Long	>0 mg cm^{-2} d^{-1} <5 mg cm^{-2} d^{-1}	20

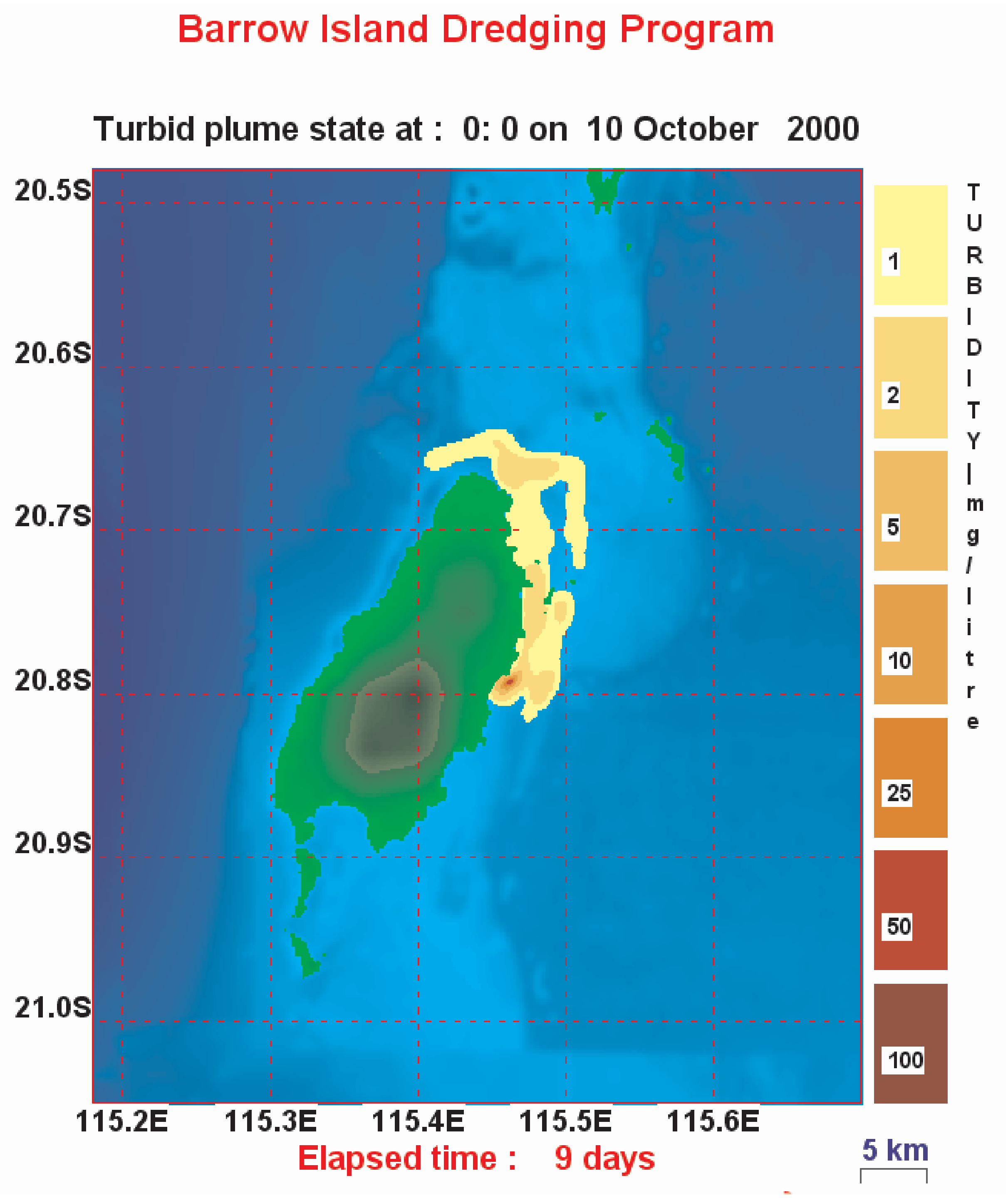

Figure 7.1: Sample TSS plot during dredging of the MOF by the CSD showing the flushing of turbidity around the northern end of Barrow Island.

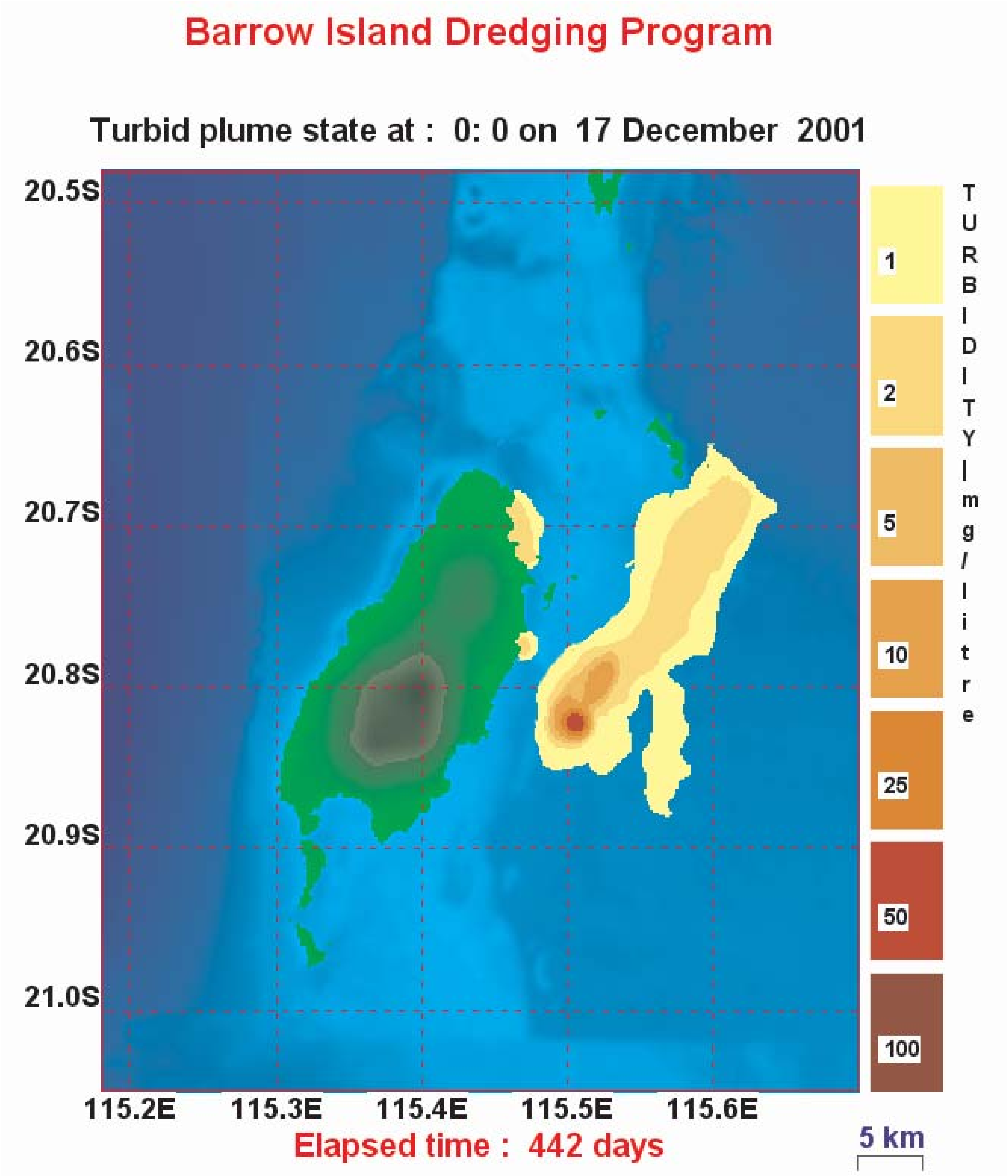

Figure 7.2: Sample TSS plot during dredging of the LNG access channel by the CSD in summer showing the effect of southwesterly winds.

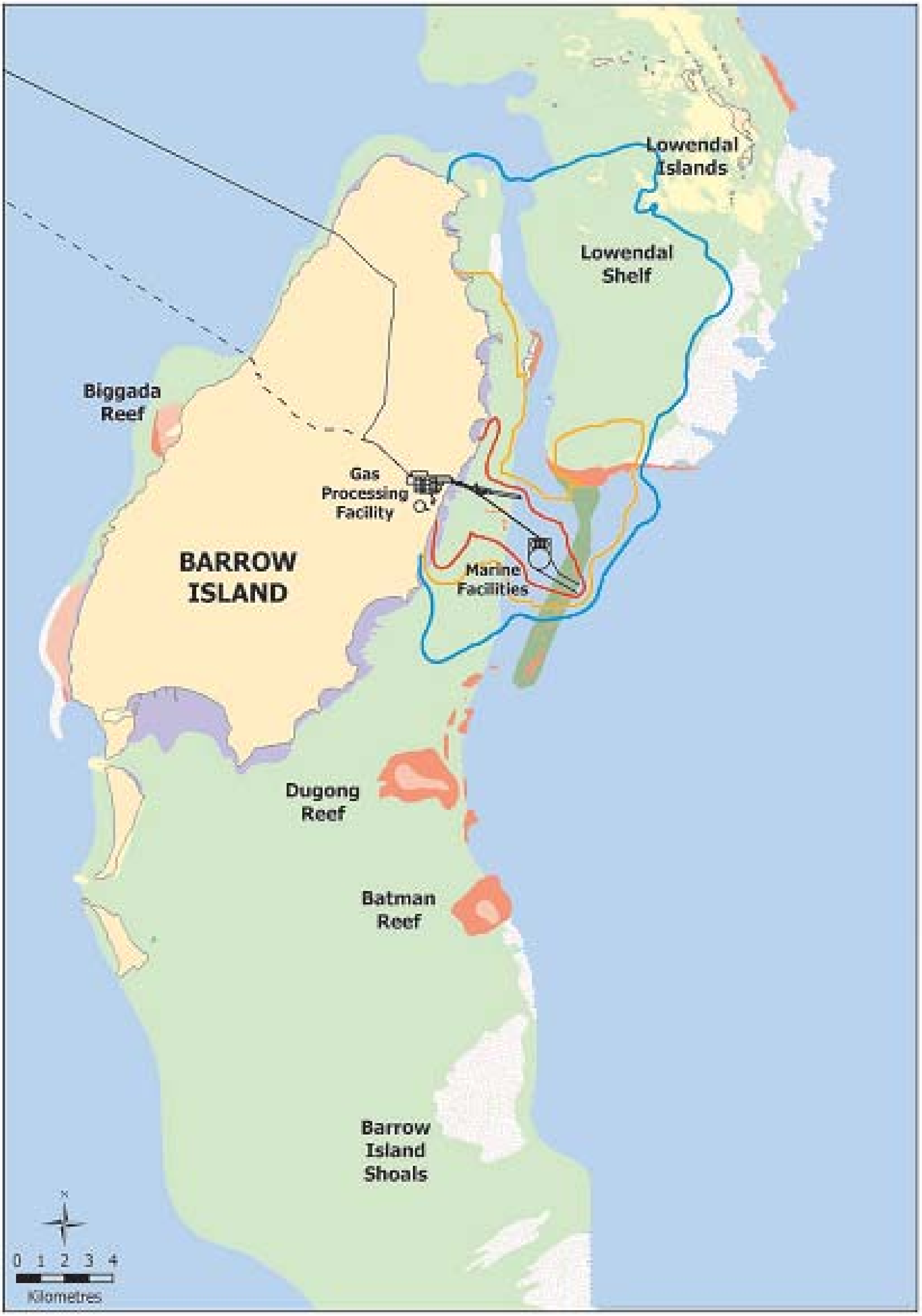

Figure 7.3 Mortality zones derived from sedimentation data for the “Base” case.
Level 1(red) = high impact,
Level 2 (orange) = moderate impact,
Level 3 (blue) = extent of sedimentation (2 mg/cm^2).

Figure 7.4: Mortality zones derived from TSS data for the “Base” case.
Level 1 (red) = high impact,
Level 2 (orange) = moderate impact,
Level 3 (blue) = visible plume (exposure above 2mg/litre).

Figure 7.5 Mortality zones derived from sedimentation data for the “Base” case with the UKC of the THSD controlled to 4 metres.
Level 1(red) = high impact,
Level 2 (orange) = moderate impact,
Level 3 (blue) = extent of sedimentation (1 mg/cm^2).

Figure 7.6 Mortality zones derived from TSS data for the “Base” case with the UKC of the THSD controlled to 4 metres.
Level 1 (red) = high impact,
Level 2 (orange) = moderate impact,
Level 3 (blue) = visible plume (exposure above 2mg/litre)..

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