SINCLAIR KNIGHT MERZ
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Pluto LNG Development

ADDENDUM TO PUBLIC ENVIRONMENT REPORT/ PUBLIC ENVIRONMENTAL REVIEW SUPPLEMENT AND RESPONSE TO SUBMISSIONS

- Rev 02
- 1 June 2007

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1. Introduction

1.1 Background

This document presents responses to comments made by the EPASU in relation to the Public Environment Report/ Public Environmental Review Supplement and Responses to Submissions (the Supplement) (March 2007) and the Revised Pluto LNG Development Dredging Simulation and Impact Assessment Report (May 2007). The comments are the outcomes of meetings held between the proponent and the EPASU and DEC on 1st and 8th May 2007. Subsequent to these meetings, a mutually agreed Scope of Work was drafted and commented on by the EPASU and DEC, prior to finalisation.

1.2 Document Structure

The remainder of this document is structured as follows:

- *Section 2* provides further assessment of dredging impacts with particular reference to predicted coral loss.
- *Section 3* responds to further queries on dredging.
- *Section 4* responds to queries on waste water discharges.
- *Section 5* addresses general comments.
- *Section 6* provides a reference list.

The document is supported by the following appendices:

- *Appendix A*: Baseline Water Quality Assessment Report April 2007 (MScience 2007a).
- *Appendix B*: Review of Recent Dredging Projects in Dampier Harbour (MScience 2007b).
- *Appendix C*: Benthic Habitats at West Lewis Island (MScience 2007c).
- *Appendix D*: Methods for Revised Dredge Modelling with the Inclusion of Sediment Resuspension (APASA 2007).

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2. Further Assessment of Dredging Impacts with Particular Reference to Predicted Coral Loss

2.1 Task 1: Further analysis of model outputs to determine effect of varying impact thresholds (intensity and duration) on the predicted area of impact.

Agreed Scope

- *A new level of sedimentation load will be established using baseline data from Tidepole Island where estimates of levels of sedimentation withstood by corals near dredging have been collected (data from the Angel Island site could potentially be used in the same way). Thresholds? If so, is tide pole analogous to the reefs around Angel Island and other impact sites? Please consider chronic and acute levels of sedimentation.*
- *A range of estimates of intensity-duration (frequency is also an important consideration) for sedimentation (mg/cm2/d) and suspended sediment concentrations (SSC; mg/L) will be established for inner and outer harbour areas using MacArthur et al 2002 type derivation.*
- *Investigate zone of influence using 80%ile intensity-duration (frequency) assessment for summer and winter and at different levels for inner and outer harbour areas.*
- *The output from Task 1 will be a series of impact zones: i.e. zone of potential loss, zone of potential impact, and zone of influence based on various combinations of intensity and duration of sedimentation and SSC.*

Notes:

- *Outputs will provide comparison of currently predicted impacts, based on previously established thresholds, with revised thresholds.*
- *Baseline field data for sediment measurements and coral measurements, which are yet to be fully analysed and interpreted, will be analysed and reviewed to provide inputs from model interrogation. Analysis of data to April 2007 will be available.*
- *The array of levels, durations and frequencies to be investigated will be determined by reference to the field data, McArthur et al 2002 methodology, literature and current and past data available for Mermaid Sound.*
- *Setting of the likely significance of each zone of influence, in terms of coral health, will be defined using a considered review of the methodology of McArthur 2002 and the wider literature and an analysis of previous dredging impact studies in Mermaid Sound (Task 3).*

Proponents Response

New Interrogations

The new interrogations were requested by the EPASU and primarily require the setting of new thresholds for SSC and sedimentation based upon data collected during the pre-dredging environmental baseline studies that commenced in August 2006. The new thresholds to be developed were also required to include relevant duration-frequency parameters that would allow the mapping of a zone of potential impact (based on SSC data) and a zone of potential loss (based on sedimentation data).

The expectation was that developing intensity-duration-frequency thresholds based on the baseline data could produce different estimates for the area of coral habitat that may be potentially impacted or lost.

The Baseline Data

The baseline data used to develop the new set of thresholds comprises information recently collected from a series of stations in Mermaid Sound. The Baseline Water Quality Assessment was undertaken by MScience (2007a) to provide some useful background information that could be used to help set relevant thresholds for the DSDMP. The full report prepared by MScience is provided in **Appendix A**. **Table 1** lists the stations sampled by MScience during the programme. Data recording commenced in August 2006 and was planned for completion in mid-May 2007.

- **Table 1 Period of Data Analysed and Station Zone (Reproduced from MScience 2007a)**

Station	Zone	SSC Data	ASSD Data	Depth (m) +
ANGI	Outer	15-Apr	Sep-Oct 06	5
HGPT	Mid	6-Mar	Oct 06	2.8
CHC4	Inner	19-Feb	Oct-Dec 06	1.9
MIDR	Outer	6-Mar	-	3.1
WINI	Inner	31-Mar	Dec -06-Feb 07	0.3
TDPL	Inner	5-Apr	Nov 06- Jan 07	-0.8
KGBY	Inner	4-Apr	-	0.3
HSHL	Outer	19 Sep -06	-	2.0

* recordings start in August 2006 for all stations except TDPL and KGBY which start in November 2006.

The locations of the stations are shown in **Figure 1** which also presents the position of three zones developed by MScience (2005) as a classification system for the coral communities in Mermaid Sound based upon observed differences in community types (inner/mid/outer).

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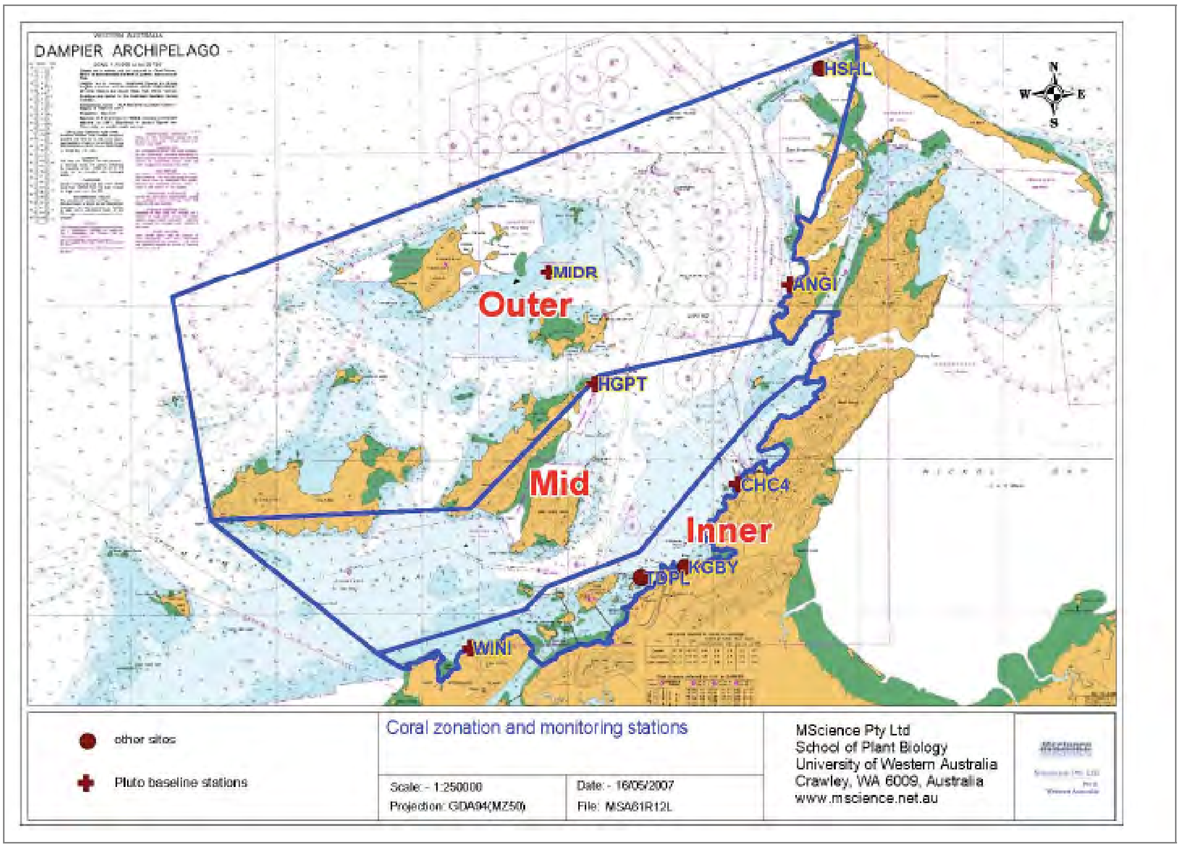
The zones have been included here as the baseline data shows some variability across Mermaid Sound with inner shore areas reporting higher levels of both SSC and sedimentation when compared to the mid and outer areas of the Sound. By implication these differences in SSC and sedimentation may have a considerable influence on the distribution of coral communities and appear to be strongly correlated with the current distribution of coral community types and therefore the zones have an ecological basis. The aim is to use the baseline data to construct a set of thresholds. Separating the stations into the 3 zones provides an opportunity to develop a set of thresholds relevant for each zone with each set possibly reflecting differences in sensitivity of the coral communities present.



- **Figure 1 Location of Sediment Stations and Coral Sensitivity Zones (MScience 2007a)**

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SSC Baseline Data

The summary statistics for the SSC baseline data are presented in **Table 2**.

- **Table 2 Suspended Sediment Concentrations (mg/L) by Station and Zone (MScience 2007a)**

Site	Mean	Median	80%ile	95%ile	99%ile	Max
ANGI	4.21	2.22	4.3	12.4	51.0	143
HGPT	3.94	2.49	4.9	11.2	29.0	233
CHC4	10.75	7.39	15.6	28.1	58.0	276
MIDR	1.66	1.46	2.2	3.9	7.6	29
WINI	7.52	2.92	9.2	33.1	65.0	160
TDPL	8.43	4.03	10.3	33.8	73.7	273
KGBY	9.28	2.48	8.6	43.1	89.4	252
HSHL	4.81	3.64	5.5	14.5	39.7	145
Inner	9.0	4.2	10.9	34.5	71.5	240
Inner (-TDPL)	9.1	5.2	12.4	30.6	61.5	218
Mid	3.9	2.5	4.9	11.2	29.0	233
Outer	3.6	2.4	4.0	10.3	32.8	106

The TDPL station (Tidepole) was located near the recent Hamersley Iron Dampier Port Upgrade dredging programme, which took place between December 2006 –April 2007 and therefore may have experienced elevated values of SSC at this time, however the removal of TDPL data from the calculation of an average for the inner zone does not reduce the 95 and 99%iles very much.

The SSC averages for the mid- and outer zones are very similar over the life of the baseline monitoring period which, although relatively short (i.e. less than a year), has been long enough to capture some large SSC elevations, with the 95 and 99%iles for each zone markedly higher than the mean and median. This is an important observation because coral health has been monitored during the baseline data collection period and no discernible impacts on corals health were observed during these peaks in SSC. The implication is that events of this size and duration have not had a measurable impact on corals health.

The SSC data was also analysed for intensity-duration-frequency statistics and these are presented in **Table 3** for just one of the stations away from dredging (ANGI) to demonstrate that the majority of elevated SSC events were of short duration. The entire analysis for all stations is presented in **Appendix A**.

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- **Table 3 Intensity-Duration-Frequency Data for Hours of SSC at ANGI (Modified from MScience 2007a)**

mg/L	Hours					
	1	6	12	24	72	Max
10	30	5	2	1	1	128
20	15	2	2	2	0	50
30	9	4	1	1	0	30
50	8	2	0	0	0	7
100	0	0	0	0	0	1
Monthly Frequency-Durations for Multipliers of the 80%ile Concentration						
X1	136	12	4	3	1	180
X2	38	8	4	1	1	128
X5	16	2	2	2	0	46
X10	10	2	1	0	0	19
Monthly Frequency-Durations for Multipliers of the 95%ile Concentration						
X1	14	5	3	1	1	101

Sedimentation – Baseline Data

The pre-dredging environmental baseline studies provide information on background sedimentation. Some loggers experienced technical problems that affected the recovery of some data in the relatively high energy conditions at some sampling sites. Very low net sedimentation was recorded at a number of sites while other sites recorded elevated sedimentation in response to identified disturbances (dredging and the passage of a cyclone) (**Table 4**).

- **Table 4 Sedimentation Baseline Data ($mg/cm^2/d$) (MScience 2007a)**

Station	Sedimentation					
	Mean	Median	80%ile	95%ile	99%ile	Max
ANGI	1.4	0.0	2.6	5.8	6.3	6.3
HGPT	0.1	0	0	1.0	2.8	4.4
CHC4	5.0	3.7	8.3	13.5	18.2	23.1
MIDR	No data					
WINI	3.7	1.2	5.2	13.0	32.9	38.0
TDPL	4.7	1.8	7.5	20.8	25.1	25.1
KGBY	No data					
HSHL	No data					
Inner	4.5	2.3	7.0	15.8	25.4	28.7
Inner (-TDPL)	4.4	2.5	6.8	13.3	25.5	30.5
Mid	0.1	0	0	1.0	2.8	4.4
Outer	1.4	0.0	2.6	5.8	6.3	6.3

The levels of sedimentation for mid- and outer zones are quite similar for the period that baseline data was collected and are quite low when compared with the inner zone. The maximum levels of sedimentation recorded range from 4.4 mg/cm^2/d for the mid zone to 30.5 mg/cm^2/d in the inner zone (Tidepole Station data). Note however, that removing the Tidepole data does not greatly alter the summary statistics.

There does not appear to be a strong relationship between high SSC and high sedimentation in the baseline data. Observed SSC increased during the passage of strong weather conditions due to resuspension of fine sediments. Net sedimentation tended to decrease at these times.

Methodology for Developing Intensity-Duration-Frequency Thresholds

The analysis of the baseline data was a necessary first step in the development of a series of thresholds for both SSC and sedimentation based upon an intensity-duration-frequency analysis.

In the agreed scope of works, the proponent stated that the use of 80%ile baseline data would be investigated for the definition of thresholds, but an examination of the data in **Table 4** reveal that the 80%iles for both SSC and sedimentation for all three zones are very low. The use of these 80%iles as a component of the thresholds analysis would, in the proponents opinion, lead to the setting of thresholds that are too low to be a useful guide to the potential impact of the dredging on the marine environment as there is a reasonable probability they will be exceeded whenever natural conditions promote resuspension of fine sediments within the Sound. A number of these natural events can be anticipated during the time frame of the proposed dredging programme.

The calculations of the 80%iles for SSC in the inner, mid- and outer zones are presented in **Table** 2**.** The 80%ile for SSC for the mid-zone stations was calculated to be 4.9 mg/L and for the outer zone was 4.0 mg/L. These are low values and are exceeded by short term pulses of elevated SSC ranging up to 233 mg/L for the mid-zone and 106 mg/L for the outer zone as a consequence of natural events. These events have produced short term elevations which have been recorded during the period of baseline data collection and importantly have had no detectable impact upon the corals which were monitored over the same time period.

As the published information for background SSC on reefs suggests that 10 mg/L is quite common for SSC values in seawater over coral reefs not impacted by human activities (Rogers 1990) it would appear the selection of an 80%ile level for the mid- and outer zones as a threshold in Mermaid Sound which is less than half that value has no basis in terms of signalling a tangible risk of an impact (i.e. effects).

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The 80%ile for the inner zone is higher at 10.9 mg/L (**Table 2**) reflecting the generally more turbid waters closer to the western shore of the peninsula and the SSC data collected from this zone has ranged up to 240 mg/L without any detectable impacts upon corals.

The water quality and corals monitoring programmes for previous dredging programmes in Mermaid Sound (MScience 2007b, **Appendix B**) provide no evidence that would support the use of the 80%iles of the baseline data collected since August 2006 as meaningful thresholds for any of the three zones. The coral monitoring data summarised in **Appendix B** also shows that despite substantial and prolonged elevations in SSC at several sites during dredging, there were no detectable impacts upon corals at these sites. Therefore, the proponent considers that use of the 80%iles calculated from the baseline data does not provide any useful information in terms of defining zones of potential impact or potential loss.

In the Draft PER, reference was made to the suitability of the methodology of McArthur et al 2002 as a template for the development of an intensity-duration-frequency thresholds analysis.

Setting Thresholds

The objective in setting thresholds is to set a level of SSC (and for sedimentation) which can act as a signal that potential impacts may occur and exceeding that threshold then triggers a series of pre-determined management responses. The underlying basis for the threshold is that a tangible risk of impact is evident once the threshold has been exceeded.

SSC Thresholds

The proponent notes that:

- Acute mortality (mortality events occurring within a period of less than a month) are most likely to be caused by smothering of corals by excessive sediment loading rather than low light or from irritation of coral membranes by suspended sediments; and
- Coral communities at which the baseline water quality data have been recorded have not shown significant levels of coral mortality over the monitoring period.

The proponent therefore concludes that the development of a series of thresholds for SSC based upon an intensity-duration-frequency analysis will produce potential zones of impact where corals may suffer sub-lethal effects, but not mortality. McArthur et al (2002) state:

"*The principal goal for deriving ecologically sound suspended sediment guidelines for ocean disposal should be to prevent significantly greater exposure beyond that to which the coral community is presently adapted. Any suspended sediments resulting from disposal activities should* *fall within the natural limits for that environment and thus cause no added stress to individual corals or the coral community."*

McArthur et al (2002) provide the following rationale for development of an intensity-duration-frequency approach to the setting of thresholds.

"Three factors were determined to be important aspects of coral and coral community effects of exposure to suspended sediments; 1) intensity, 2) duration, and 3) frequency.

***Intensit**y: High suspended sediment concentrations place stress on corals, therefore suspended sediment values near the high end of the normal range of concentrations to which South Florida coral communities are exposed are most likely to have adverse effects on community structure. Suspended sediment concentrations due to natural conditions plus dredged sediment disposal should not exceed the highest values to which South Florida coral communities are normally exposed. The highest allowable values have been selected as the 99th percentile observed concentration. A lower value, the 95th percentile observed concentration, has been selected as a threshold concentration. This threshold concentration can be exceeded only for specified durations and frequencies as discussed below. Concentrations below this threshold value are not considered to significantly affect coral communities because of their naturally higher frequency of occurrence.*

***Duration**: The average suspended sediment concentrations that persist in the environment throughout the year can be considered "background" levels of continuous or near continuous duration. These typical concentrations are not expected to adversely affect coral communities. High sediment concentrations may cause an adverse impact if the corals are exposed to these concentrations for sufficient time periods. Any significant increase in the time of exposure or duration of high sediment concentrations may result in excess stress in individual coral species and changes in community structure. Coral exposures to suspended sediment concentrations (dredged sediments plus native sediments) above the threshold value should not exceed the naturally occurring 95th percentile duration event.*

***Frequency**: Suspended sediment concentrations that coral communities are most frequently exposed throughout the year are those to which corals are principally adapted and, therefore, are not expected to have an adverse impact. Higher values are those caused by storm events and other anomalies, which occur less frequently. Corals are able to tolerate occasional heavy sediment concentrations provided there is sufficient time for recovery between high sediment events. Any significant increase in the frequency of high sediment concentrations may cause a change in community structure due to the disappearance of those species with lower sediment tolerance. Suspended sediment concentrations above the threshold value due to dredged sediment disposal, for a specific duration, should not occur at a frequency such that the combined frequency of the dredging and natural events are significantly greater than would normally occur. The level of significance or frequency guideline has been selected as the upper 95th percent confidence interval."*

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The MScience (2007) statistical analysis of the baseline SSC data reports a 95%ile for the inner zone of 34 mg/L, and 11.2 mg/L for the mid-zone and 10.3 mg/L for the outer zone respectively (**Table 2**). The values of the 95%iles for the mid and outer zones are close to the mean value of 10 mg/L reported by Rogers (1990) as the typical value for seawater over corals reefs with no human impacts.

MScience (2007a, **Appendix A**) demonstrate that the use of the 99%ile of the baseline SSC data to set the boundaries of a potential zone of impact would mean that all sites would be located within the impact zone even in the absence of dredging because the 99%ile data were observed during the baseline data gathering programmes.

The 99%ile absolute criterion should not be used to designate a zone of impact – although it could be used as a water quality target in managing dredging works. Instead, the second criterion of intensity-duration-frequency (McArthur et al 2002) could be used to establish zones of potential impact. Analysis of the baseline SSC data to produce the intensity-duration-frequency distributions is presented in **Table 5**. It is noteworthy that the majority of elevated SSC events are of short duration.

- **Table 5 Frequency of Exceedances of the 95%ile SSC for Various Durations**

Location	Hours					Mg/L
	1	**2**	**3**	**4**	**5**	**95%ile**
CHC4	35	8	0	0	0	28.1
KGBY	28	5	1	0	0	43.1
TDPL	35	15	10	5	3	33.8
WINI	67	35	21	10	4	33.1
Inner*	**16**	**8**	**5**	**2**	**1**	**35**
HGPT	43	8	3	1	0	11.2
MID*	**10**	**2**	**1**	**0**	**0**	**10**
HSHL	2	1	1	1	1	14.5
MIDR	17	3	1	0	0	3.9
ANGI	14	9	9	7	6	12.4
Outer*	**4**	**2**	**2**	**1**	**1**	**10**

From the data in **Table 5** it is possible to construct a series of intensity-duration-frequency (i-d-f) thresholds for each of the three zones (MScience 2007a, **Appendix A**) and these are displayed in **Table 6**. This set of intensity-duration-frequency thresholds was used to interrogate the model outputs.

- **Table 6 Suggested Allowable Frequency of Intensity-Duration Events Per Month**

	Inner	Mid	Outer
SSC threshold level (mg/L)	**35**	**10**	**10**
1 hour	16	10	4
2 hours	8	2	2
3 hours	5	1	2
4 hours	2	1	1
5 hours	1	1	1
6 hours	0	0	0

Setting Background SSC Values

Model predictions were originally produced in terms of SSC generated by dredging and disposal, or subsequent resuspension of this material and are additional to background. SSC concentrations in background data show a correlation with prevailing wave and current conditions, as well as tidal levels, reflecting a positive, non-linear, influence of bottom stress. Predictions for bottom stress were generated by APASA (2007) to simulate resuspension, hence data for bottom stress were available to apply variations in background SSC over time and space to correct initial model output to total SSC. MScience (2007a) describes the weighting that applied to relate bottom stress to background SSC within each zone based on the range of observed SSC and the range of predicted bottom stress.

Sedimentation Thresholds

The EPASU and DEC has indicated that the threshold levels of sedimentation as proposed in the Draft PER were possibly set too high and should be set by reference to the baseline sedimentation data.

The proponent has given an undertaking to produce a revised series of thresholds based upon the baseline sedimentation data but does not consider there is any evidence to suggest that this approach would produce a set of thresholds that are more meaningful indicators of potential corals mortality. On the contrary, the review of the literature provided in the Draft PER, and the review of other corals monitoring programmes during dredging in Mermaid Sound (MScience 2007b, **Appendix B**) support the proponents view that the original thresholds proposed for acute, medium and chronic thresholds should offer a reasonable prediction of coral loss based on a conservative approach that has been taken in the evaluation of potential coral losses.

As MScience (2007) notes, there is considerable uncertainty involved in extrapolating from data collected under conditions where corals did not die to make predictions about the levels at which

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coral death will occur. Figures for daily sediment loading were used in the Draft PER to indicate potential mortality and that is based upon information available for the causes of observed corals mortality in Mermaid Sound and the literature.

Acute Thresholds

The information presented in **Table 4** demonstrates that coral communities in the zones of sensitivity have survived the following maxima:

- Inner – 30 mg/cm^2/d
- Mid-Outer – 6 mg/cm^2/d.

A threshold for potential mortality should therefore be set above these respective values for the inner zone and the Mid-Outer zones. While it is possible to conclude the thresholds values should lie above the levels observed it is not possible to determine from the data how high above these maxima the sedimentation rates would have to be in order to cause mortality.

MScience (2007a, **Appendix A**) have suggested that in the absence of good data on the levels of sedimentation that will cause coral mortality in Mermaid Sound the best approach is to develop worst case – best case estimates. Worst case mortality for the interrogation exercise has been selected as maxima plus 10%. Alternative best case scenarios, provide a sensitivity analysis based upon multiples of the maxima observed within each zone was developed. The resultant worst to best case scenarios are presented in **Table 7** and were used to interrogate the model output data.

- **Table 7 Estimates of Worst Case to Best Sediment Loading that may Trigger Coral Mortality (MScience 2007a)**

Case*	Inner (mg/cm^2/d)	Outer-Mid (mg/cm^2/d)
Worst (1.1)	33	7
Best 1 (1.5)	45	9
Best 2 (2)	60	12
Best 3 (5)	150	30

* figures in parentheses represent multiples of the maximum deposition rate.

Medium-Term and Chronic Thresholds

The EPASU requested that some medium and chronic thresholds be presented for ‘vulnerable species’ which are taken to be the species found primarily in the mid- and outer zones, and are assumed to be largely excluded from the inner zone because they are vulnerable to increased sedimentation. Consequently, the following thresholds (**Table 8**) have been used to interrogate the model output for potential medium-term and chronic effects.

- **Table 8 Medium-Term and Chronic Thresholds for Model Re-interrogation**

Effect	Inner Zone	Mid-Outer Zone
Medium-term (5 days in 15 days)	60 mg/cm^2/d	12 mg/cm^2/d
Chronic (15 days in 30 days)	36 mg/cm^2/d	9 mg/cm^2/d

Threshold sedimentation rates chosen for the Mid-Outer zones, where coral species considered to be relatively ‘vulnerable are living, are the acute best case 1 and acute best case 2 listed in **Table 7**.

Setting Background Sedimentation Rates

The baseline data indicated that sites in the inner zone had relatively net sedimentation rates less that 2.5 mg/cm^2/d during periods excluding dredging operations and the period following a cyclone. The median value for the entire record (inclusive of those events) was 2.3 mg/cm^2/d. Moreover, there was no obvious correlation over time between sedimentation rates and measures of wave and current energy. Hence, model predictions for above background sedimentation were corrected by adding the median concentration (2.3 mg/cm^2/d) as a constant.

Baseline measurements of sedimentation in the outer zone had a median value of 0 and 95%ile value of 1.0. The latter was added to the model data to make estimates for total sedimentation rates.

Results

The results of the new modelling interrogations, using estimates for total SSC and sedimentation are provided in **Figure 2-5**. The figures should be interpreted with care because different threshold levels apply within each of the three zones for the SSC data and between inner and mid-outer zones for the sedimentation data. Bite also that the flagged locations are those where the thresholds were exceeded once during the simulation period. For SSC thresholds, locations are flagged where the intensity-duration threshold was exceeded for either the 6 hour, 5 hour, 4 hour, 3 hour, 2 hour or 1 hour frequency limit.

In keeping with the request from EPASU to produce zones of potential loss (mortality), impact and influence based upon the baseline data set the data outputs have been interpreted accordingly. However the revised zones of potential loss, impact and influence produced by this exercise are not considered to be a better estimate of the location and size of those zones than the estimates provided in the Draft PER and the Supplement and Responses to Submissions, where the proponent provided an interpretation based upon interrogations of the model outputs derived from the literature and first hand evidence of previous dredging programmes in Mermaid Sound (MScience 2007b, **Appendix B**).

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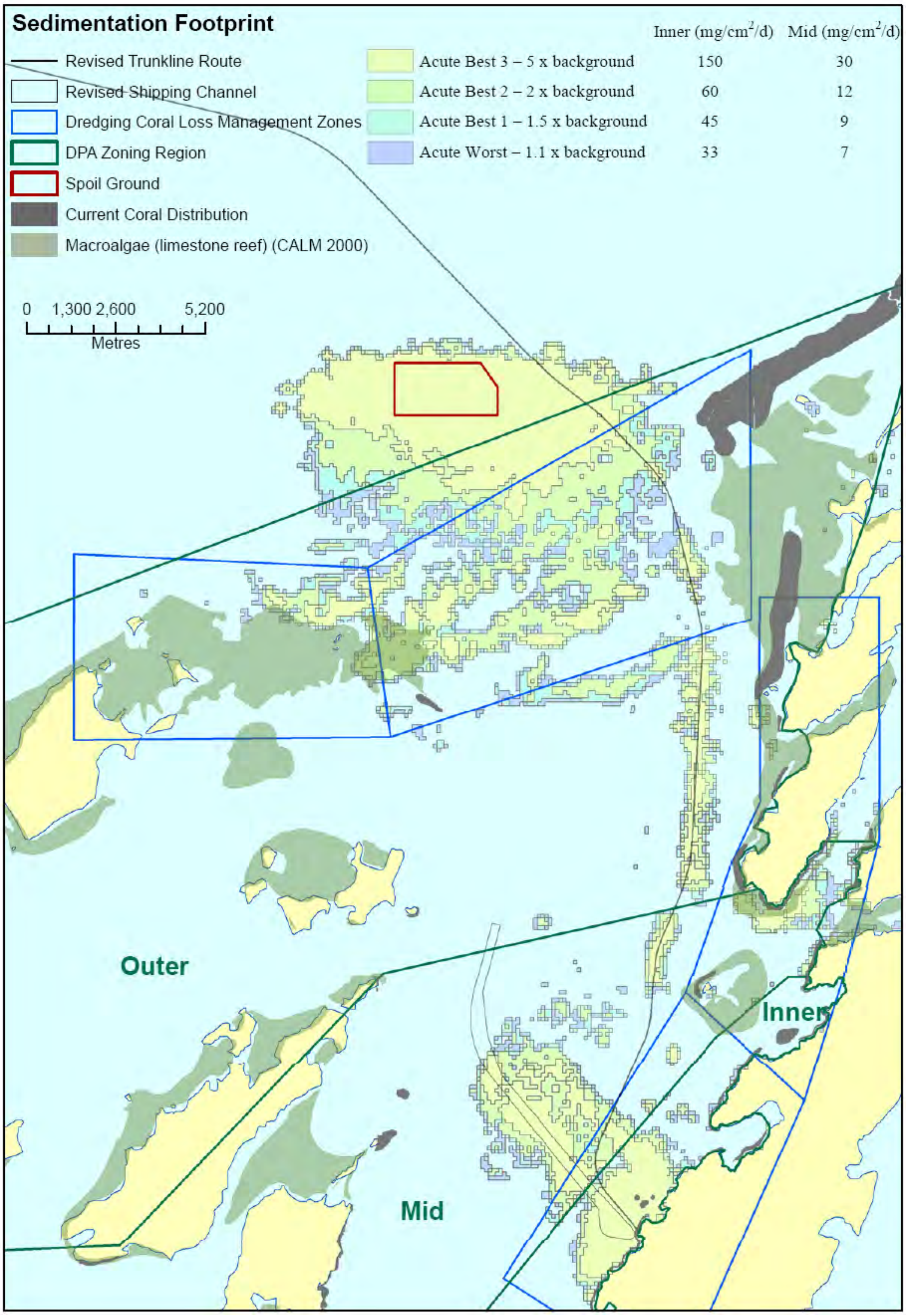
Zone of Potential Loss (Mortality)

Acute Sediment Thresholds

In **Figure 2** the worst case-best case scenarios are presented and it is important to note that while the footprints for the various cases are continuous in the figure, the thresholds upon which they are based vary considerably between the inner zone and the other two zones. It is noted that different thresholds apply within each of the marked zones in **Figure 2,** as defined in the key. Note also that the plot is constructed by compiling the outcomes predicted for three different general operations.

The acute best case 3 for example, is based upon a threshold set at five times the maxima observed during the baseline data collection period. For the inner zone, the footprint represents areas where daily sediment rates in excess of 150 mg/cm^2/day are predicted to occur while for the mid-outer zones the five times the maxima represents a daily sediment rate in excess of 30 mg/cm^2/d, which is considerably less than that which applies in the inner zone.



- **Figure 2 Predicted Footprint for Exceedance of Sedimentation Thresholds, based on derived worst and best case estimates for Acute Sedimentation.**

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Inner Zone: Within the inner zone the footprint of the area receiving the different threshold sediment loads does not vary greatly, in relation to the area and position of the footprint generated from each sedimentation threshold. As pointed out in the Draft PER and the Supplement the modelling interrogations performed to date have consistently shown that most of the sediment mobilised into the water column as a consequence of the dredging would not move far before settling out. Inclusion of resuspension has not resulted in a marked change to this conclusion, because resuspension mostly affects the transport of fines. Fines that are transported away are predicted to disperse and undergo continuous resuspension – hence sub-threshold sedimentation rates are expected at most locations beyond 3 km of the operation.

Consequently, the footprints for lower levels of sedimentation rates within the inner zone are not substantially bigger than that predicted for the highest level of sedimentation rate which is almost 5 times larger than the worst case scenario threshold which is set at 33 mg/cm^2/d.

The footprint has expanded slightly within the inner zone compared with the footprints provided in the Draft PER and Supplement and therefore also within the management zone 1 that was identified in the Draft PER for the purpose of estimating potential coral loss. The potential impact of this expansion is discussed in some detail in the section on Predicted Coral Impacts (see below).

Mid-Zone: Within the mid zone the areas where acute worst –best case scenario thresholds will be exceeded are very similar to those predicted from the earlier modelling interrogations for this zone. The exception is the area at the mouth of Flying Foam Passage where the reefs lining either side of the passage are predicted to experience sediment loadings in excess of those selected as thresholds using the baseline data.

The corals on these fringing limestone reefs would experience exceedances of the nominated thresholds from both the turning circle dredging programme and also the trunkline dredging. The predictions of exceedances of thresholds at the mouth of the passage are due to the process of resuspension reworking material northwards from the turning circle area and eastwards from the trunkline path.

It is important to recognise that this location is classified as part of the Mid-zone, hence the lowest thresholds were applied here (7 mg/cm^2/d to 30mg/cm^2/d), much lower than those applied to adjacent locations that were in the designated Inner zone.

The figure shows that there is considerable variation in the predicted rate of sedimentation across and into the entrance of Flying Foam passage with the highest values (30 mg/cm^2/d) occurring on and around the southern tip of Angel Island and lower values (7 mg/cm^2/d) extending into the Passage.

There is coral habitat in this area and the area is located within Management Zone 2 as identified in the Draft PER. Using worst-best case extrapolation from field data, the potential area where mortality of corals is predicted is slightly increased in this area over that predicted in the Draft PER. The potential extra losses as a consequence of setting these new thresholds are examined below in the section on Predicted Coral Losses. The area also contains some areas of macro algae and the potential impacts of sedimentation on macro algae are addressed in **Sections 3.2** and **3.10.**

Outer Zone: There are predicted exceedances of the worst-best case thresholds for acute sedimentation within the outer zone associated with the trunkline dredging and the dumping of spoil into spoil ground 2B. The majority of the sediment exceedances predicted as a consequence of dumping into spoil ground 2B are related to the effects of resuspension of fines. There is considerable difference in the size of the effect zone depending upon the threshold applied to simulation of dumping into spoil ground 2B.

Examination of **Figure 2** shows that there are no areas of coral which currently lie within the predicted footprints of the various worst-best case scenarios. Therefore, there are no predicted losses of corals within the outer zone. The western side of the footprint will extend over an area which is reported to contain macro algae beds and the issue of potential impacts on macro algae is discussed in **Sections 3.2** and **3.10**.

Medium-term and Chronic Thresholds

Figure 3 presents the footprints generated by the new model interrogations using the medium term and chronic thresholds set for inner and mid-outer zones as per **Table 6**. It is noted that different thresholds apply within each of the marked zones in **Figure 3,** as defined in the key. Note also that the plot is constructed by compiling the outcomes predicted for three different general operations.

The most striking feature of the footprints is that they are virtually indistinguishable from the footprints generated for the acute sedimentation rates. This means that while these medium term and chronic events will be present over the same areas which are subject to a series of acute events, there are no increases in the areas of potential loss of corals when the results of the medium-term and chronic threshold predictions are included.

As previously noted, locations around the entrance of Flying Foam Passage were judged against the markedly lower thresholds set for the Mid-Outer zones (9 mg/cm^2/d and 12 mg/cm^2/d) and coral loss may not necessarily follow from these thresholds (see discussion on Predicted coral losses below).

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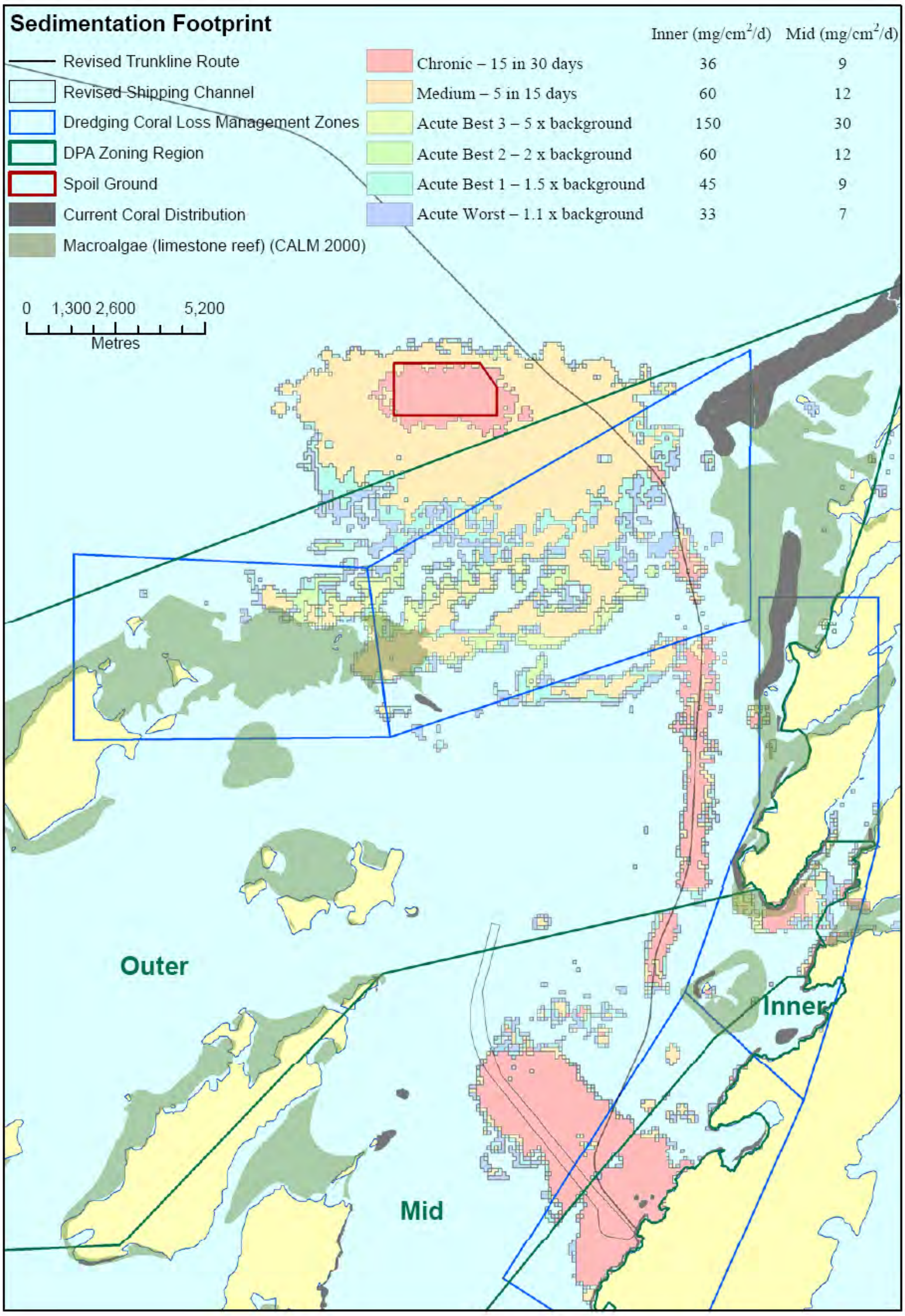

- **Figure 3 Predicted Footprint for Acute, Chronic and Medium Sedimentation Thresholds, based on derived worst and best case estimates for Acute, Chronic and Medium Term Sedimentation Thresholds.**

Zone of Potential Impact

Using the series of intensity-duration-frequency estimates developed from the baseline data for SSC produced the series of footprints displayed in **Figure 4**. It is noted that different thresholds apply within each of the marked zones in **Figure 4,** as defined in the key. Note also that the plot is constructed by compiling the outcomes predicted for three different general operations.

The threshold levels for each of the incremental events (stepwise by hours) are presented in **Table** 6 and reproduced in **Figure 4**. It is important to reiterate that the threshold values vary between the inner, mid- and outer zones and so even though the figure shows contiguous footprints for each set of events they are composites based on different threshold levels.

The footprint set generated for the six thresholds has been divided into two zones, based on the length of time of each group of events. Exceedence of thresholds for 4-6 hour events has been designated as the zone of potential impact primarily on the basis of the group representing one-third to half of the available daylight time and assuming the levels of SSC set for the thresholds would have some impact on light levels. This is an admittedly arbitrary approach but can be justified with reference to the durations and frequencies of events for the footprints now assigned to the zone of influence.

Thus, 1 hour events in which the SSC rises above 10 mg/L in the mid and outer zones are included in the footprint if they occur with a frequency greater than 10 events in month for the mid-zone and four events in a month for the outer zone. Intuitively it is likely that one or two events of 1-3 hours duration in exceedence of these frequencies will not significantly impact upon coral health, whilst an event with a duration of 4–6 hours elevated SSC could be construed as having a substantive (but sub-lethal) effect on corals (if it is accepted that the thresholds are meaningful in a biological context).

Within the zone of potential impact, based on the conservative thresholds, the footprint extends over a considerable area including some corals in all three zones.

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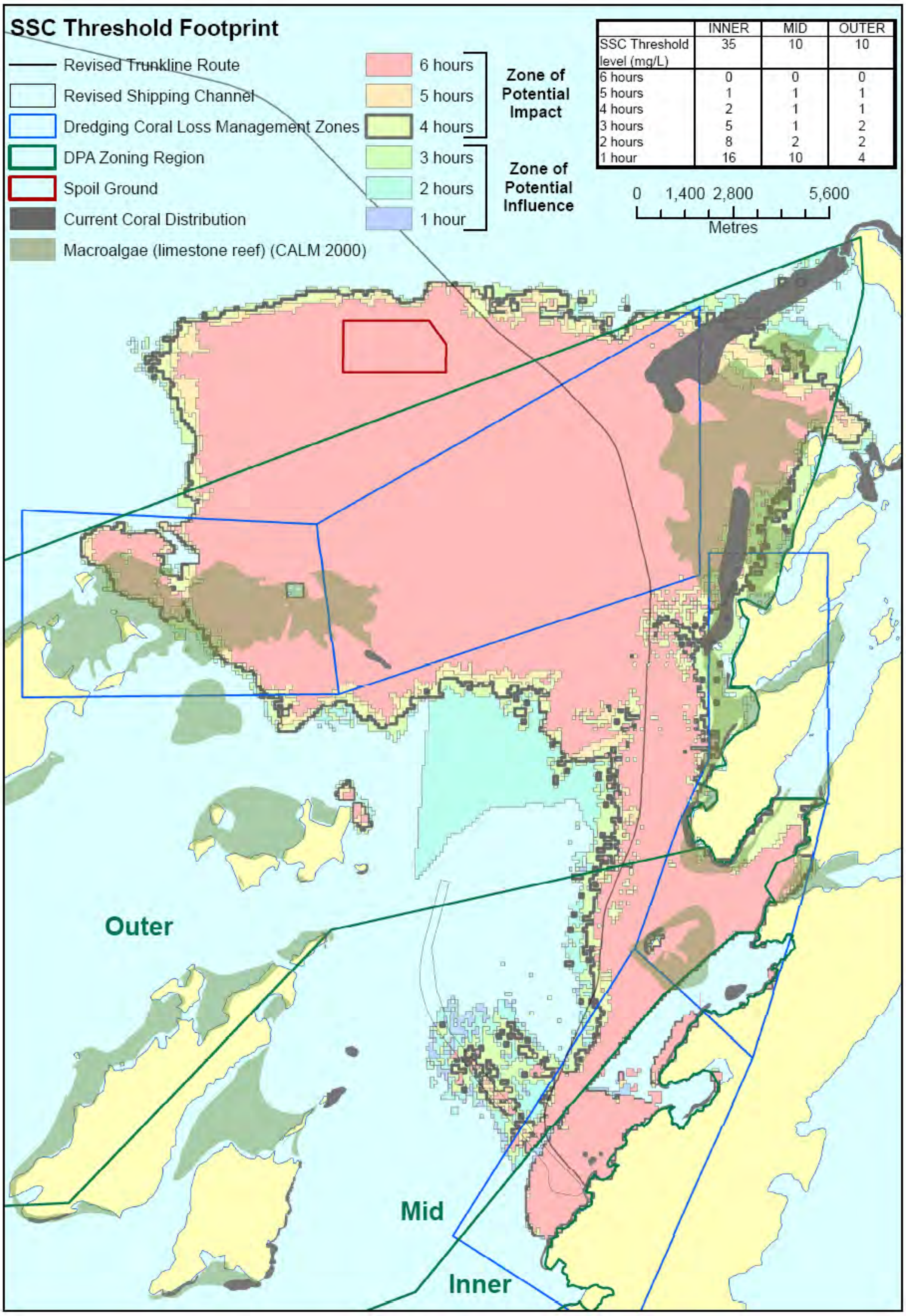

	INNER	MID	OUTER
SSC Threshold level (mg/L)	35	10	10
6 hours	0	0	0
5 hours	1	1	1
4 hours	2	1	1
3 hours	5	1	2
2 hours	8	2	2
1 hour	16	10	4

- **Figure 4 Predicted Footprints for SSC Thresholds based on the Intensity-Duration-Frequency Thresholds.**

Inner Zone: The threshold level for intensity within the inner zone was set at 35 mg/L and the footprint for zone of potential impact within the inner zone (**Figure 4** extends across corals that are also predicted to be impacted by sedimentation and it is possible that the stress from the elevated SSC events could add to the stresses on the corals in this area. It is not possible to determine whether these stresses are likely to be significant as there is no reliable data to show that the inshore corals will suffer sub-lethal effects at the threshold levels which have been set for the SSC intensity-duration-frequency analyses within the inner zone.

Mid Zone: In the mid-zone the zone of potential impact extends over a considerable area and the footprint includes the macro algae and corals around Conzinc Island and also extends up into Flying Foam Passage where it will cover the corals and macro algae on the fringing reefs at the mouth of that passage (**Figure 4**.

The threshold level for intensity in the mid-zone is 10 mg/L SSC and it is unlikely there would be any detectable impact at all upon corals in these areas. (macro algae are discussed in **Sections 3.2** and **3.10**) given that 10 mg/L is the mean value for background levels of SSC over coral reefs without human impact (Rogers 1990) and is well within the range of values that has been measured in the baseline data set without any evidence of impacts on corals. It is also important to note that MScience (2007) has estimated a general level of SSC for complete light extinction at 50 mg/L, which suggest that while 10 mg/L SSC will reduce light (and see section 1.2) it is not likely to be a significant impact on coral health over the time frames of hours rather than days.

As noted by Gilmour et al (2006), around inshore reefs of the Dampier Archipelago, background levels of suspended sediments varied among sites and months, but were consistently higher near the bottom where they were generally less than 10 mg L-1 and 4 NTU (MScience 2005). However, the levels of SSC did exceed 10mg/L and at those times there was no evidence of impact.

Gilmour et al (2006) also note the natural variability in levels of turbidity within the Pilbara complicates any attempt to determine threshold values for anthropogenic increases.

The use of background data to develop intensity-duration-frequency thresholds is supported by Gilmour et al (2006) but they point out that it must be based upon long-term variation in background levels of turbidity within the Pilbara and quantified at different sites over short and long time scales, and linked to impacts on the coral communities.

The recently completed baseline study (MScience 2007a, **Appendix A**) is considered as a useful starting point for the development of suitable baseline based thresholds, recognising, however, the limitations in making interpretation of sub lethal effects on corals in the absence of longterm data sets.

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Outer Zone: The footprint of the area of potential impact within the outer zone is large and is based upon an intensity threshold of 10 mg/L. As already discussed, this value is the mean recorded over coral reefs free from human impact.

Within the zone lies a large area of corals around Legrende Island and there are also several large areas of macro algae habitat (discussed in **Sections 3.2** and **3.10**). The corals of this outer zone are among the best developed in the Sound (MScience 2005) and also experience the best water quality in terms of background SSC levels. Using the methodology of McArthur et al (2002) therefore implies there may be an impact in this area but the question remains as to whether a threshold of 10mg/L persisting over hours rather than days is likely to cause serious stress.

Gilmour et al (2006) note that increased turbidity and light attenuation primarily stresses corals by reducing the rates of photosynthesis of their zooxanthellae. For individual corals over periods of days to months, the physiological consequences of decreased light availability range from mild to severe stress. Note that the timescales quoted are days to months, whereas the timescales of the thresholds used here are for hours.

Zone of Influence

The EPASU requested the production of a zone of influence for the dredging and during the development of the necessary response the proponent examined the suitability of using the 80%ile of baseline SSC (varied across the three zones) to set the boundaries of the zone of influence. The rationale for not completing the mapping of an 80%ile for SSC has already been addressed in an earlier section.

However, the thresholds for durations of 1-3 hour events of elevated SSC have been mapped and it is proposed that these form the requested zone of influence. That zone is presented on **Figure 4** where it can be seen that it does not extend much further on the eastern side of the Sound than the zone of potential impact but does extend over a much larger area in the middle of the Sound. Throughout this zone, the frequency of short term elevations of SSC may be increased as a consequence of the dredging programme but these short term events are not anticipated to impact on corals (or macro algae).

Predicted Impacts on Corals

The potential impacts on corals are a major consideration of the outcomes of the reinterrogation of the modelling output. As expected, the production of thresholds based upon baseline data for SSC and sedimentation and using the methodology of McArthur et al (2002) for intensity-duration-frequency thresholds for SSC has produced larger footprints of the zone of potential impact and the zone of potential loss.

However, while the resulting footprints are larger they are not significantly larger, reflecting the models predictions that most sediments that are mobilised from the dredging programme will settle fairly rapidly. Observations that have been supported by the results of previous dredge monitoring programmes (MScience 2007b, **Appendix B**).

The footprints of the sedimentation threshold exceedances are shown in **Figure 5** with the total areas of coral habitat within each management zone that will covered by the sediment from the dredging programmes at the turning circle and the trunkline.

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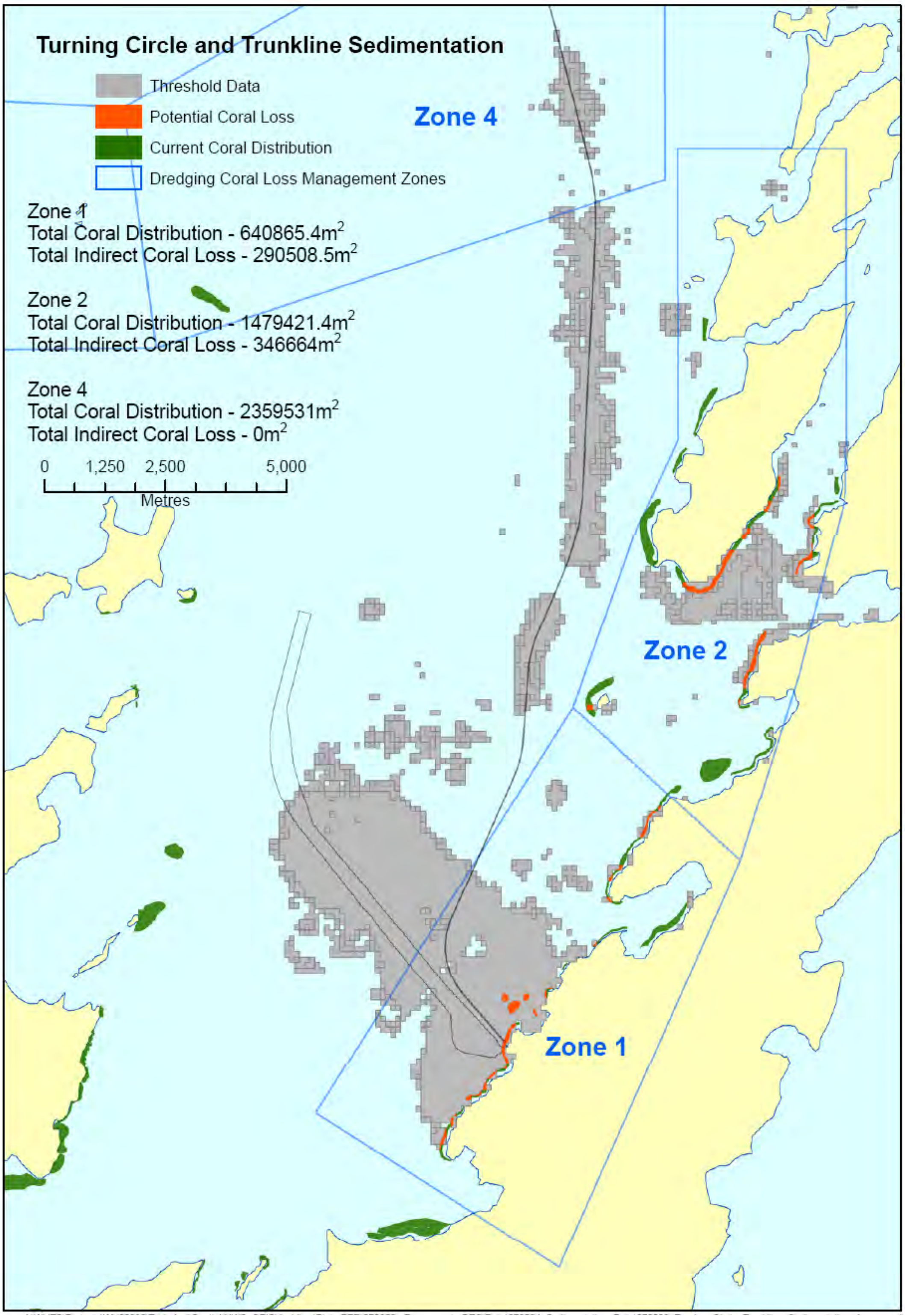

- **Figure 5 Predicted Footprints for Sedimentation from Turning Circle and Trunkline Dredging with Estimates for Potential Coral Loss**

In **Table 9,** the proponents previous estimation of potential corals losses is presented for comparative purposes**.** The Table contains the categories indirect loss and direct loss because that is the terminology used in the Draft PER and is included to avoid confusion, although no such distinction has been made in the figures showing areas of potential loss which have been presented here.

The estimate of direct loss has changed since the production of the Draft PER because of a slimmer footprint for the jetty construction at Holden Point and so the estimated total direct loss is now 1.64%. The rows in **Table 9** showing revised (threshold 100%) and revised (50%) refer to the supplementary interrogations that were completed and submitted in May 2007 showing a slight increase in the total area of potential cumulative loss as a consequence of a slightly increased footprint due to the incorporation of a resuspension component into the analysis. Note that the current area of corals present in both zones 1 and 2 has changed as a consequence of new distributional data supplied by MScience. The larger area of corals in zone 1 is due to the discovery of a patch of coral communities in Withnell Bay.

Attention is drawn to the column on the far right of Table 9 which presents the total for the potential cumulative losses in both zones 1 and 2 and in the Draft PER these were 42.4% and 5.5% respectively.

In the May 2007 results of revised modelling interrogations the 100% threshold prediction for loss was virtually the same as that made in the Draft PER, and is because of a revised (slightly lower) estimate of historical loss.

The May 2007 revision where a 50% of the original threshold was used produces an estimate in which the potential cumulative loss increases from 42.5% to 45.1% a change of 2.6%.

The proponent was requested to provide a set of new estimates of potential cumulative coral losses based upon thresholds set from the baseline data from sedimentation.

That data is provided in Table 10 and shows that there is an increase of potential cumulative losses in zone 1 if it is accepted that the thresholds based on baseline data are meaningful in that exceedances of these thresholds will lead to corals mortality. Thus the new percentage for potential cumulative loss of corals in zone 1 is 54.7%.

In both Tables 9 and 10 the proponent has combined the three components that comprised zone 2 in Table 7-35 of the Draft PER. The total area of corals BPPH in zone 2 has also increased slightly due to a reinterpretation of the data set.

Due to the predicted impacts of sedimentation on the corals at Flying Foam Passage the estimates of potential corals losses in zone 2 has risen, but again only if it is accepted that the sedimentation thresholds based on the baseline data are more likely to reflect the level of sedimentation at which mortality of corals would be observed.

All of the revised estimates are based upon the revised dumping plan where there is no dumping into spoil ground A/B.

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- **Table 9 Estimated Area of Direct Loss and Indirect Loss for Corals in the Draft PER and the Revised Data Submitted in May 2007 with the Original Thresholds (1005) and the Thresholds Halved (50%) (all values are m^2)**

Management Zone 1	Historical Area of BPPH	Current Area of BPPH	Current Historical Loss	Predicted Direct Loss	Predicted Indirect Loss	Predicted Cumulative Loss (Historical + Loss)	Potential Cumulative Loss
Draft PER	737 200	600 400	136 800 (18.6%)	20 000 (2.7%)	156 800 (21.1%)	157 000 (21.3%)	312 600 (42.4%)
Revised (100% threshold)	737 200	640 865.1	128 864.8 (17.48%)	12 100 (1.64%)	172 283.2 (23.4%)	140 964.8 (19.1%)	313 248 (42.5%)
Revised (50% threshold)	737 200	640 865.1	128 864.8 (17.48%)	12 100 (1.64%)	191 917 (26%)	140 964.8 (19.1%)	332 881.8 (45.1%)
Management Zone 2							
Draft PER Combined	4 244 500	4 244 500	0	0	232 900 (5.5%)	0	232 900 (5.5%)
Revised 100% threshold)	4 245 813.1	4 245 813.1	0	0	232 900 (5.48%)	0	232 900 (5.48%)
Revised 50%	4 245 813.1	4 245 813.1	0	0	232 900 (5.48%)	0	232 900 (5.48%)

- **Table 10 The Predicted Coral Losses with the Thresholds for Sedimentation set from Baseline Data (all values are m^2)**

Management Zone 1	Historical Area of BPPH	Current Area of BPPH	Current Historical Loss	Predicted Direct Loss	Predicted Indirect Loss	Predicted Cumulative Loss (Historical + Loss)	Potential Cumulative Loss
Baseline Data Thresholds	737 200	640 865.1	128 864.8 (17.48%)	12 100 (1.64%)	262 063 (35.5%)	140 964.8 (19.1%)	403 027.8 (54.7%)
Management Zone 2							
Baseline Data Thresholds	4 245 813.1	4 245 813.1	0	0	336 114.6	0	336 114.6 (7.9%)

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The proponent does not consider the new thresholds derived from the baseline data to be a reliable indicator of potential corals mortality. The review of the information from previous dredging programmes in Mermaid Sound (MScience 2007b, **Appendix B**) concludes that:

- Dredging has a bigger impact on water quality or coral health compared to spoil disposal;
- Substantial water quality impacts occur only at sites within 1 – 1.5 km of activity;
- Mortality of corals has only occurred at sites closer than 250m to dredging operations.

If those observations are applied to **Figure 5** which shows the zone of potential loss based on the new thresholds derived from baseline data it appears the new thresholds represent a gross exaggeration of the zone of potential loss. On the basis of water quality impacts within a distance of 1-1.5 km and mortality within 250 m of dredging the size of the zones of potential loss and of impact would be negligible.

While from a theoretical viewpoint the setting of thresholds based on baseline data is sound as it encompasses the range of environmental variability in sediment and SSC that corals normally experience it obviously requires a long term data set to more accurately define the limits to the coral communities tolerances. And it also requires some evidence of the reactions of coral communities under periods of duress when SSC and sedimentation are elevated well above the median. Such periods have occurred over short time intervals during the baseline study but in the absence of any evidence to the contrary it can only be concluded that over that entire range of sedimentation and SSC values recorded the corals have experienced little or no stress that could conceivably have been detected, and certainly no mortality.

Although it represents a good start the current baseline monitoring programme is short, relative to the lifespan of the organisms it is targeting. A data set spanning 20 years might provide a much more useful guide to the meaningful threshold levels for sedimentation and SSC that might be set for the corals in Mermaid Sound.

In the meantime the data from past dredging programmes is the only evidence available from Mermaid Sound upon which to base expectations of corals loss.

The results of monitoring corals during dredging programmes in the Sound suggest very strongly the coral communities are robust enough to survive the proposed dredging programme for the Pluto LNG Development and that the estimates of potential coral loss proposed in the Draft PER are in fact quite conservative.

The estimates provided in the Draft PER were compiled after a comprehensive review of the literature which included species specific data for as many of the species found in the Sound as information existed. The review of past dredging programmes supports the threshold levels originally proposed in the Draft PER as being more likely to be thresholds at which significant sub-lethal effects and partial mortality could be expected to occur.

2.2 Task 2: Evaluation of Potential Light Attenuation Impact

Agreed Scope

There was discussion at the 8 May 2007 meeting on the issue of whether it is possible (or meaningful) to develop a suitable parameter for light attenuation that can be investigated over varying durations and frequencies of exposure with the aim of determining potential impact. No consensus of opinion was reached at the meeting on what methodology could be used; all recognised the difficulties associated with any attempt to convert SSC into a measure of light attenuation in this particular environment.

As part of this task, investigation will be undertaken to evaluate whether it is possible to convert SSC to light (more specifically PAR) using relationships from the field data in a way that would give some confidence that the resulting parameter has some useful predictive capacity.

Preliminary examination of the baseline data set indicates there are some sites where there is evidence of some relationship between SSC and light, but at other baseline sites conditions of light and turbidity do not vary sufficiently over the life of the baseline programme to establish such relationships.

The following will be considered in the above assessment:

- *Relationship between SSC and light.*
- *Level of SSC at which midday light is extinguished.*

The baseline data should also be used to see what is the natural influences on the light and sediment climate and if the model is accurate in this regard. Given the baseline data indicates that light is largely tidally influence (depth) yet discussion on Tuesday indicated some wind wave influences (may be sight specific issues).

Additionally, light extinction caused by sediment resuspension (natural) during the day would probably be at the 95-99%. Impacts from light reduction will be chronic. Impact predictions must consider this.

Proponents Response

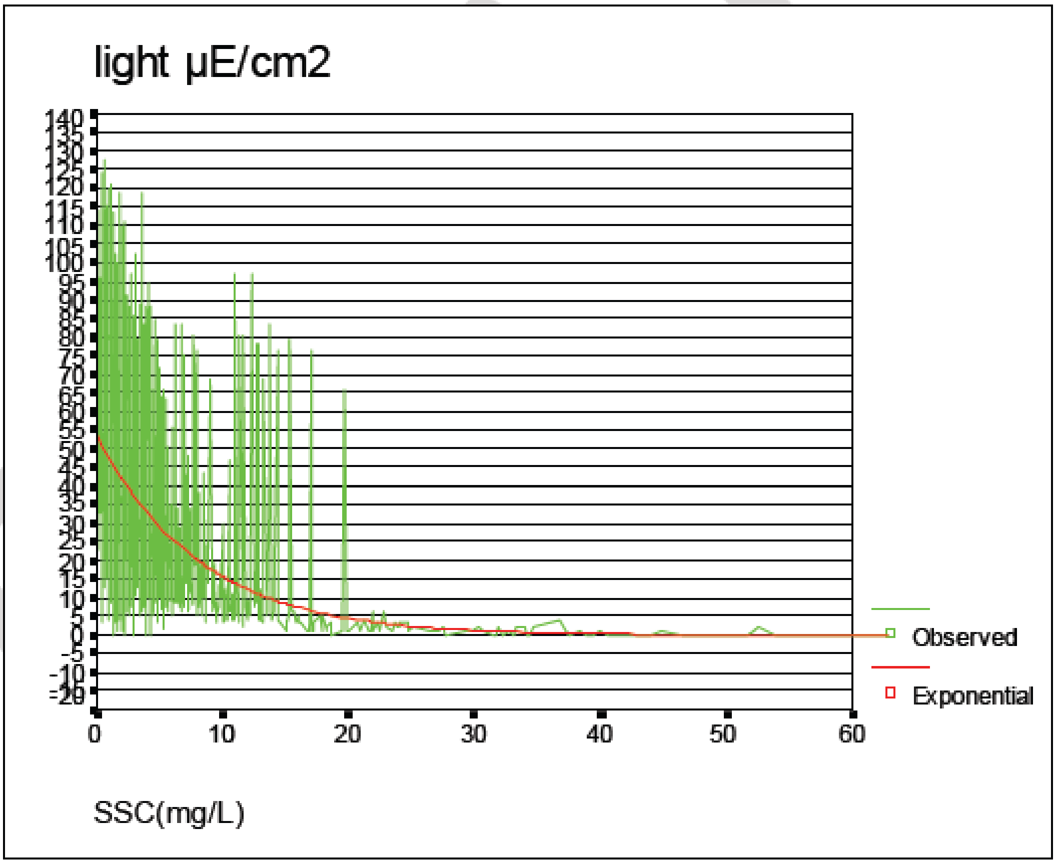
Relationship Between Light and SSC –Baseline Data (MScience 2007a)

MScience (2007a, **Appendix A**) investigated the relationship between light and SSC at the baseline data stations to determine whether a relationship could be developed that would allow the potential mapping of light attenuation as a threshold. All meters at the baseline stations logged light (PAR) in addition to estimating SSC over the same period. Depth of water over a meter has a significant direct effect on light reduction, but SSC can play a larger role when concentrations are high.

To examine the relationship between light extinction and SSC, light levels between 1000 hrs and 1400 hrs were correlated with SSC. The relationship was examined using the general model **Light = A*e$^{(B*SSC)}$** where A and B are derived from the empirical data. A typical data set is shown in **Figure 6** for the ANGI station where A=53 and B=-0.122.

Data were 'noisy' and most relationships had R^2 values of less than 0.2 (i.e. the relationship with SSC alone explains less than 20% of the variation). In addition to other influences such as tidal variation, it must be remembered that the SSC values from the meters only relate to water at the depth of the meter. Stratification of SSC is common in these waters with levels increasing towards the lower profile (Stoddart and Anstee 2005).

The proponent queries the rationale behind seeking to develop this relationship for the purpose of mapping thresholds of light attenuation as it is not commonly undertaken as an exercise precisely because the relationship is as typically noisy as demonstrated here. The most common approach to mapping potential zones of influence is to use SSC values and that is the approach which has been adopted in the preparation of the Draft PER.



- **Figure 6 Light Versus SSC at ANGI**

Light Extinction Estimates

MScience (2007a) has also examined the baseline data and compiled an estimate of the SSC at which light is expected to be extinguished at each station. These estimates are provided in **Table** 11 and the methodology of estimation is explained in **Appendix A**.

- **Table 11 Light Extinction Levels of SSC by Station (MScience 2007a)**

Site	SSC Level (mg/L)
ANGI	40
HGPT	n/a*
CHC4	100
MIDR	n/a*
WINI	70
TDPL	50

Site	SSC Level (mg/L)
KGBY	50
HSHL	n/a*
Inner	50
Mid	0
Outer	40

n/a* - at these sites, SSC values did not rise sufficiently high as to cause sufficient reduction in light levels as to allow estimation of extinction levels.

2.3 Task 3: Comparison of Pluto Impact Predictions with Past Dredging Programmes in Mermaid Sound

Agreed Scope

For this comparison, MScience will investigate relevant information from the following dredging programmes in Mermaid Sound:

- *2004 DPA dredging programme*
- *2004 Hamersley Iron dredging programme*
- *2005-6 Woodside dredging programme*
- *2006-7 Hamersley iron dredging programme.*

This will include information on dredging/disposal characteristics, measured water quality parameters and monitored impacts on nearby corals.

This task will include an assessment of threshold levels set by other dredging programmes in established zones of impact and influence and the basis of those thresholds. The analysis will compare the results of past monitoring programmes to determine whether or not thresholds were reached, or exceeded, and whether or not predicted impact (mortality of corals) occurred.

This assessment will provide contextual information for determining which of the threshold intensity-duration sets (and corresponding footprints) derived from Task 1 are the more realistic to use in defining zones of potential influence and impact.

This is a sound approach – however, most of these programmes did not collect real time WQ data so this will need to be taken into consideration.

Proponents Response

MScience (2007b) has undertaken a review of previous dredging operations within Mermaid Sound. This is provided in full in **Appendix B** and summarised below. It is also referred to in several responses within this document. The review concludes that:

- Dredging has a bigger impact on water quality or coral health compared to spoil disposal;
- Substantial water quality impacts occur only at sites within 1 – 1.5 km of activity;
- Mortality of corals has only occurred at sites closer than 250 m to dredging operations.

3. Further Queries on Dredging

3.1 Re-Use of Dredge Spoil Disposed in the Spoil Grounds

Discussion and response to 5.6 and 5.7 suggests that Woodside is considering re-use of dredge spoil disposed in the spoil grounds. This has not been discussed previously and would need to be incorporated into the proposal. The potential disturbance of previously dumped (and capped) contaminated sediment and modelling of the additional sediment plumes would also need to be assessed.

Proponents Response

At the time of the Draft PER submission, the proponent proposed to re-use some of the coarser material disposed of into spoil ground A/B (located within Mermaid Sound) for trunkline stabilisation. This would substantially minimise the amount of rock (approx. 165,000 m^3) that would need to be sourced from onshore quarries for this purpose and the associated environmental and safety issues related to quarrying, transporting, storing and handling large quantities of rock.

Following a preliminary review of cost and schedule implications, the proponent has committed to dispose all dredge spoil to the offshore spoil ground 2B to avoid potential impacts to the proposed marine reserve (approx 5 Mm3 of spoil was earmarked for disposal into spoil ground A/B adjacent to the proposed marine reserve area). However, the proponent would like to retain the ability to dispose of spoil from the NWSV channel crossing (<250,000 m^3) to spoil ground A/B. Dredging and trunkline installation across the NWSV channel will have significant time and access constraints for Woodside due to vessel traffic movements along the existing NWSV channel. Consequently, the proponent anticipates only having access to the channel 1 day/week over a short period of time for this aspect of the trunkline construction work. It will be very difficult to dispose of spoil from the channel to the offshore site due to the nature of some the equipment being used, which would be unsuitable for the more exposed conditions offshore, as well as the significant additional travelling time to and from the offshore site within the already short working window for undertaking this work. The offshore spoil ground 2B is 16 km further offshore than spoil ground A/B. The proponent is prepared to send the remaining approximately 5 Mm^3 that was previously allocated to spoil ground A/B to the offshore disposal site.

This change to the proposed dredging program obviously negates the need to further assess potential impacts from re-use of spoil recovered from spoil ground A/B. However, given the constraints associated with sourcing rock for trunkline stabilisation onshore the proponent would like to maintain the option of reusing some spoil from the offshore spoil ground.

Trunkline stabilisation works are not scheduled to commence until after pipelay activities during 2009. Therefore there will be opportunity to model and assess impacts from spoil reuse prior to this work occurring and suggest that this be included as a condition of approval prior to any stabilisation work commencing.

3.2 Benthic Habitat Map

A comprehensive benthic habitat map has not been provided. The habitat map provided only covers coral communities with >10% cover in any detail, but has not included existing coral communities along the NE coast of West Lewis Island. Mapping should include the soft bottom, platform reef and rocky reef substrates and their associated communities.

The additional data provided in Figure 7-31 of the Response to Submissions indicates that the extent of the algal community in the vicinity of the areas to be dredged, and the spoil dump sites, may be significant, particularly on platform reefs and other harder substrates. The date of the dredging expedition should be provided.

Proponents Response

Corals Along the NE Coast of West Lewis Island

The corals on the NE of West Lewis Island were not mapped because it was considered they were outside the potential zone of influence. It is correct that the original modelling interrogations produced several figures indicating these habitats would be within the zone of influence fo dredging (B-21, B-24, B-27, B-29, B-31, B-33) which are provided in the Technical Appendix to the Draft PER. However, the modelling interrogation that produced these results was based on the assumption that all sediment recovered by the dredging would be disposed into the existing spoil ground A/B and/or a trailer-suction hopper dredger would progress very slowly along the channel, and would therefore discharge from a location adjacent to West Lewis Island for many weeks. Simulations used winter conditions for these modelling exercises, hence the dredging location was upstream of prevailing winds. These dredging and disposal practices have since been amended to remove disposal significant disposal into A/B and to have the trailer suction hopper dredge working over a wider area, less intensely, on each case. Consequently, the potential zone of impact is not expected to reach this area at any time.

However, in response to the request for the coral communities on the NE coastline of West Lewis Island to be mapped, they have recently been surveyed by MScience and the resulting distribution map is presented in **Figure 7**. A description of the habitats at this location is provided in MScience 2007c (**Appendix C**).

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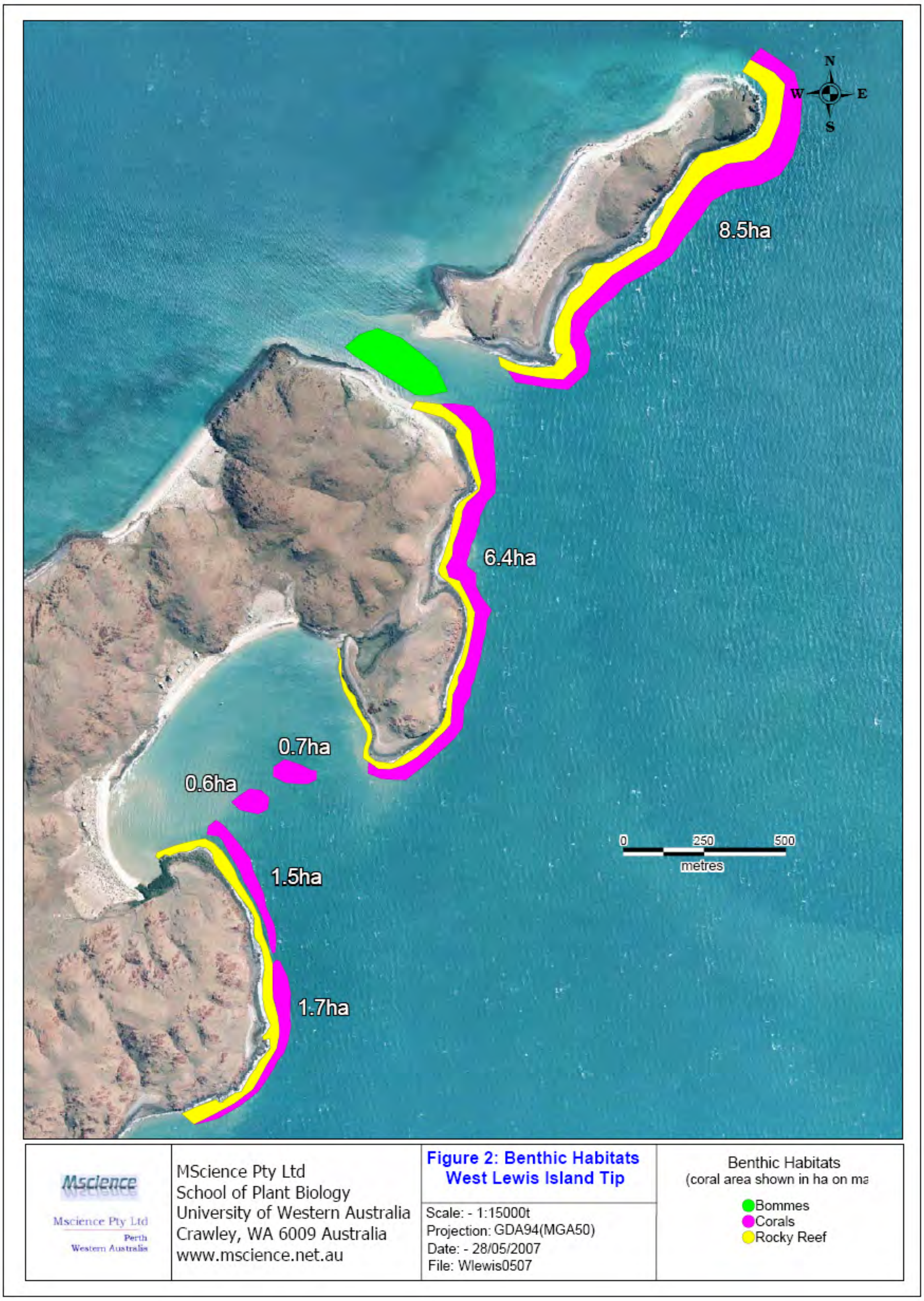

- **Figure 7 Benthic Habitats at West Lewis Island Tip (MScience 2007c)**

Macro Algae and Seagrass BPPH

The additional data provided in Figure 7-31 of the Supplement and Response to Submissions is misleading as an indicator of the presence or absence of Benthic Primary Producer Habitat because it presents the individual samples as ‘transects’. The additional data was collected from a scientific dredging programme undertaken by scientists from the WA Museum in July 1999 and was designed to obtain samples of fauna that could be identified to species (Hutchins et al 2004). A rake box dredge with a mouth area of 1200 mm x 330 mm and mesh size of 10 mm was towed at 2-3 knots for 10 minutes at each of 97 stations. Therefore each strip, or ‘transect’ of the bottom sampled by the dredge was 1.2 m wide and ranged in length from 600-900 m.

The dredge is not a quantitative sampling device but can be used to make semi-quantitative comparisons between the same dredge type over similar time periods, tow speeds, depths and on similar substrates with at least two replicates at each station. There was no replication in this survey so no semi-quantitative comparisons are possible.

The dredge has limitations as a sampling device, in that anything less than 1 cm in diameter will pass out through the mesh, including some soft, fleshy organisms that disintegrate. Once full, the dredge will not collect anymore of the macrobenthos, simply pushing material out of the way. It may also ride over the top of some benthos without catching any of it (the rake acts to avoid this problem on the type of dredge used in the survey). In areas of seabed overlain with very fine ooze, the dredge may disappear into it and run several metres below the surface, avoiding any live organisms that may be rafting on the surface.

What ends up in the dredge at the end of a single haul cannot be taken to be a quantitative sample of what was on the seabed that the dredge moved over. It is merely a quick and easy sampling device that is designed to provide specimens for taxonomic study.

Each of the dredge samples that form the basis of the ‘transect’ information presented in Figure 7-31 are described in the report on the dredging programme (Hutchins et al 2004). The report also contains a brief description of ‘habitat’ information which is presented in **Table 12.**

▪ **Table 12 Description of 'Habitat' for Selected Dredge Stations in Mermaid Sound (After Hutchins et al 2004). All Samples Collected with the Rake Box Except 2a.**

Station	Depth (m)	'Habitat' Description	Date
1	10	Rock, coarse sand; little material –frondose red algae and *Halophila*	14.07.99
2	18	Rock, grey muddy sand; very little material –sponges, soft corals and hydroids	14.07.99
2a	18	Grey muddy sand; very little material –drift sponges (scoop box dredge)	14.07.99
3	32-35	Muddy sand; coralline red algae and *Halophila*, free-living solitary corals	14.07.99
4	42-43	Muddy shelly sand, rubble and limestone rocks; sponges and gorgonians	14.07.99
22	37-38	Sand, few rocks, hydroids	17.07.99
23	37	Rock, sand; frondose red algae	17.09.99
26	34	Rock, muddy sand; frondose red algae, hydroids	17.09.99
27	33.5-34	Rock, muddy sand; very small catch –hydroids, soft corals	17.09.99
28	30.0-30.5	Rock, muddy fine sand; frondose red algae, hydroids	17.09.99
29	27-28	Rock, muddy sand, frondose red and brown algae, gorgonians	17.09.99
30	29-30	Rock, muddy sand; frondose red algae, hydroids	17.07.99
32	15-16	Rock, coarse sand, rubble; frondose red and brown algae, many sponges, hydroids, gorgonians	18.07.99
33	18-21	Coarse sand, rubble and shell; rhodoliths and frondose green and red algae, corals, soft corals and gorgonians	18.07.99
60	16-17	Mud, rock; frondose algae, sponges, hydroids, gorgonians	22.07.99
61	11	Mud, rock; red algae, few echinoids and holothurians	22.07.99
62	7-9	Fine shell, rocks, rhodoliths, frondose algae, sponges, gorgonians	22.07.99
63	11.5-12	Mud, gravel and shell (dredge spoil); very few sponges	22.07.99
64	12-14	Mud and rubble; sparse crustaceans and dead shells	23.07.99

The data presented in **Table 12** are the samples that were collected from stations at or near locations where the dredging programme will produce a plume (i.e. in or near the potential zone of influence). Figure 7-31 from the Supplement is reproduced here with the station numbers from **Table 12** added.

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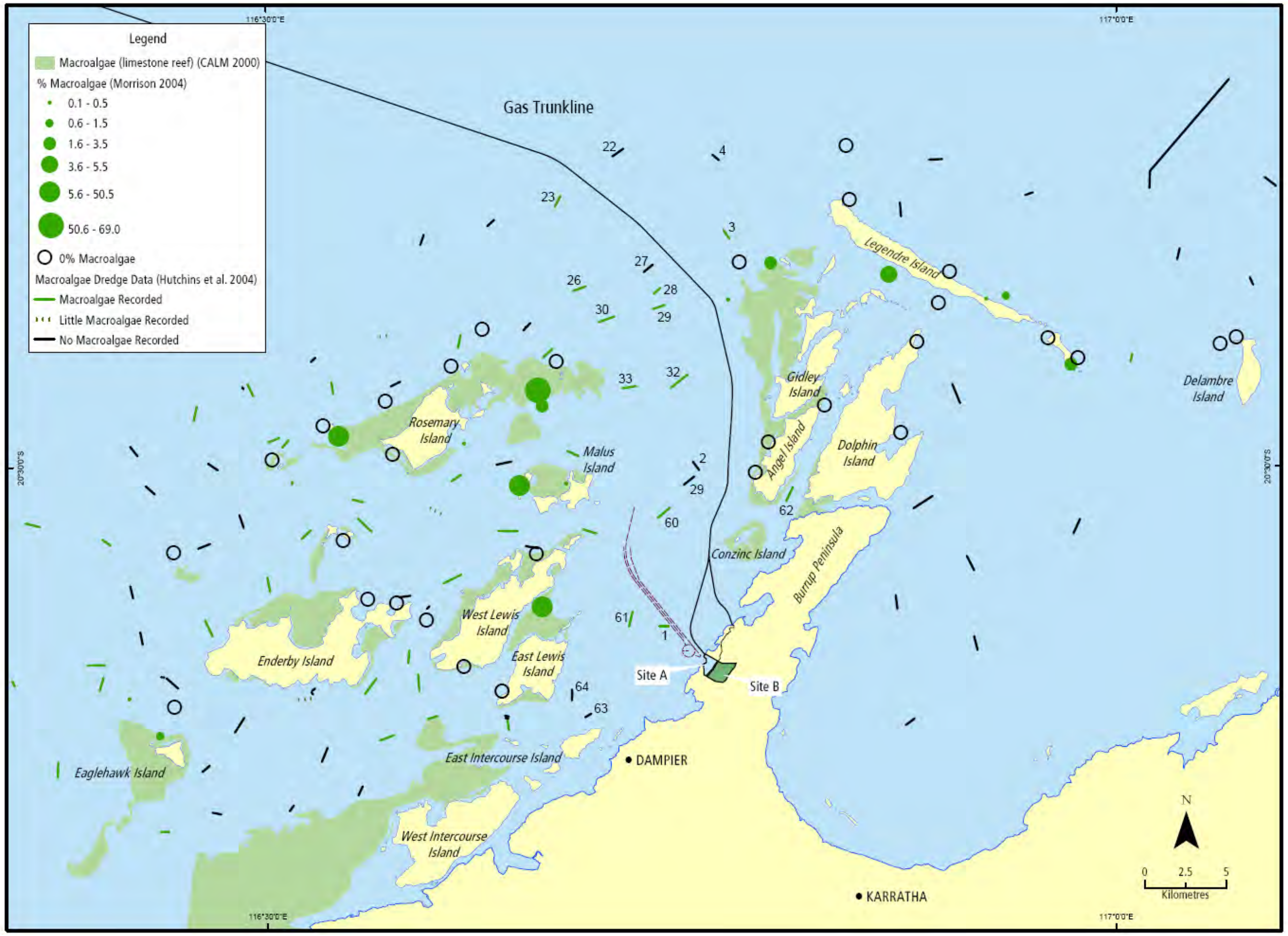

■ **Figure 8 Revised Macro Algae Distribution in Mermaid Sound (Figure 7-31 of Supplement and Responses to Submissions Document)**

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A number of the stations listed in **Table 12** record the presence of Benthic Primary Producers (BPP), including red algae (stations 1,3,23,26,28,29,30,32,33,60,61 and 62), brown algae (stations 29, 32, and 33) and green algae (station 33), the seagrass *Halophila* spp (stations 1 and 3) and also corals (station 33). However, none of the descriptions of 'Habitat' suggest that these BPP form a major component of benthos in terms of percent cover at any of these stations and it is not possible to draw that conclusion from the dredge data. The data records only presence or absence and there is no estimate of the relative proportions of any taxa inside each dredge haul so individual taxa of macrobenthos may be represented by a single record.

The presence/absence records of Hutchins et al (2004) were compared with the checklist of species and station records of the published taxonomic account of the species of macro algae collected by the dredge survey in the Sound (Huisman 2004). Only three of the stations listed in **Table 12** are mentioned (29, 30 and 32) in Huisman (2004) and only a single species of macro algae is recorded for each of these stations (station 29 –*Coelarthrum opuntia*, station 30 *Coelarthrum cliftoni* and station 32 *Echinophycus minutus*). This implies that very little macro algae material was collected by the dredge at those stations.

If the dredge was hauled up full, then the most that could be said about the potential coverage of habitat types is that the contents of the dredge in volume (about 0.36 m^3) are spread over an area of between 720-1080 m^2. This is a low density of coverage on this area of seabed and would fit with the findings of the CALM mapping exercise in Mermaid Sound (CALM 2000) and the surveys undertaken for the preparation of the Draft PER. It is possible that the dredge might have filled almost immediately after the start of the tow, and in these cases the material collected by the dredge is an underestimate as some material in the path of the dredge was not collected.

If the dredge is not full it is much more indicative of a sparse distribution of macrobenthos, although it is possible the dredge is still not catching everything in front of the mouth. For example, at station 1 (**Figure 8**) the description records very little material and implies the substrate over which the dredge passed was sparsely populated by macrobenthos. It is also interesting to note the presence of *Halophila* spp. at this station could be an artefact as there is no mention of how much seagrass was collected and whether it had been attached to the bottom when collected by the dredge (i.e. roots were attached). This species is quite common in drifts and might have been taken by the dredge from the water column.

The recent surveys (Draft PER Section6.3.1) undertaken for the areas to be dredged and to receive dredge spoil, produced results that were consistent with previous descriptions of the character of the seabed in these areas (CALM 2000; Jones 2004) and can be summarised as:

"*The nearshore marine survey of the proposed shipping channel into Site A recorded soft sediments only, with isolated and very sparse sponges, soft corals and macroalgae. The survey also identified* *seapens, macroalgae and seawhips in isolated areas of spoil ground 2B, albeit in very limited quantities"* (Draft PER p109).

There is nothing in the Hutchins (et al 2004) dredge survey data that is inconsistent with the findings of the recent marine surveys undertaken for the Draft PER.

The area around Conzinc Island was reported to have some macro algae beds in the CALM 2000 map of major marine habitats and there are also extensive areas of macro algae beds along the western sides of both Angel and Gidley Islands (**Figure 8**). The accuracy of the data for which the mapping exercise is based upon is uncertain. Spot dives (Morrison 2004) do not provide any clarification other than to record a coverage of 5.5% or less at the sites where the dives took place, but it is not obvious this can be extrapolated to the nearby areas.

Comparison of New Model Interrogation Outputs with Macro Algae Distribution

The new interrogations of the model outputs presented in this document has provided a series of revised footprints based upon a new set of thresholds for SSC and sedimentation derived from the baseline data collected by MScience, and including an intensity-duration-frequency sensitivity analysis (Refer to **Section 2.1**and **2.2**). For SSC thresholds the suggested frequencies and durations of elevated SSC events is provided in **Table 13**.

- **Table 13 Suggested Frequencies and Durations of Elevated SSC Events (MScience 2007a)**

SSC threshold Level (mg/L)	Inner	Mid	Outer
1 hr	35	10	10
2 hr	16	10	4
3 hr	8	2	2
4 hr	5	1	2
5 hr	1	1	1
6 hr	0	0	0

Inner Zone**: **Figure 4 presents the revised thresholds for SSC for varying intensity-duration-frequency shows the areas where the frequencies of the different duration events are predicted to be exceeded. Within the inner zone there are no areas of seabed where macrolagae has been recorded in densities that would classify the area as supporting macro algae BPPH in significant quantities.

Mid-Zone: There is an area around Conzinc Island where the 1-6 hour threshold frequencies are predicted to be exceeded during the dredging of the turning circle and also the trunkline. The area around Conzinc Island was reported to have some macro algae beds in the CALM 2000 map of major marine habitats and this is shown in **Figure 8**.

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The large area of macro algae beds along the west side of Angel and Gidley Islands is also predicted to be subjected to events of elevated SSC that exceed the recommended frequencies for 1-6 hour duration events.

Outer Zone: **Figure 4** also presents the thresholds for SSC for the scenario where material deposited into spoil ground 2B is resuspended and transported and shows the areas where the frequencies of the different duration events are predicted to be exceeded. The area identified as macro algae beds in (CALM 2000) along the western sides of Angle and Gidley Islands is expected to experience times when the 1-6 hour threshold frequencies will be exceeded during the spoil ground 2B dumping phase of the programme, but while the shorter duration events will be experienced over a large area (the zone of influence), the 4-6 hour events (the zone of potential impact) are restricted to the northern area of the macro algae beds.

Interpretation of **Figure 4** for SSC thresholds requires care as the baseline conditions used to develop the thresholds vary and incorporation of these different baseline levels into the thresholds means the threshold level is dependent on the zone (**Table 2**). For instance, the inner zone has a much higher threshold (35 mg/L) than the mid and outer zones (10 mg/L).

It is the proponents view that the only areas where the ‘macro algae’ beds mapped by CALM may contain macro algae with a percent coverage greater than 5% is in the region around Conzinc Island, and also along the western side of Angel and Gidley Islands (**Figure 8**). In these areas the background threshold level is set at 10 mg/L which is relatively low. The combinations of duration and frequency events have been selected as triggers using the methodology of McArthur (2002) and refined by MScience (2007). The footprints generated by predictions of where these thresholds will be exceeded have been identified as zones of influence and potential impact , but that assumes a very low tolerance of elevations of SSC for the macro algae in Mermaid Sound.

An SSC of about 40 mg/L is reported to be the critical level for light extinction in the outer zone (MScience 2007) and that coupled with the relatively short duration of the elevated SSC events, strongly suggests that there will be minimal (or no) impact on macro algae from light attenuation associated with elevated SSC events from the dredging programme.

The new interrogations of the model outputs also developed a series of thresholds for sedimentation levels based upon the background (baseline data) collected by MScience (2007). Three different thresholds are presented (acute, medium-term, chronic) and the thresholds for each are derived from analysis of the background information available on sedimentation rates. A detailed explanation of how these thresholds have been derived is presented in **Sections 2.1** and **2.2** and those sections also contain a detailed discussion of the potential impact on corals of sedimentation exceeding these thresholds.

Potential Impacts on Macro algae

Figure 5 presents the footprint for sedimentation thresholds and shows that the majority of the area which will be subjected to increased levels of sedimentation has no significant macro algae habitat. Note that the Figure shows the area of influence for two different sets of thresholds, with higher levels of sedimentation thresholds set for the inner zone compared to the mid- and outer zones. As explained in **Section 2.1** and **2.2**, the sediment threshold levels set for the mid- and outer zones are the same because the background data showed no discernable difference in the intensity-duration-frequency of sedimentation events for these two zones.

The inner zone has higher sedimentation threshold levels reflecting the presence of higher levels of sedimentation events in the background data (MScience 2007a).

Figure 5 shows that the majority of the northern area which will be subjected to increased levels of sedimentation is located well offshore from the area alongside Angel and Gidley Island where the CALM (2000) map of major marine habitat suggested the presence of macro algae beds. There is an area off the south-eastern end of Angel Island where there is predicted to be elevated levels of sedimentation for part of the trunkline dredging programme and in this area, the CALM (2000) map suggested macro algae beds on limestone reefs, but there is no corroborative evidence. The survey undertaken by Hutchins et al (2004) reported frondose algae from one dredge haul in this area, but Huisman (2004) records a single species (*Asparagopsis taxiformis*) from this station.

There are no macro algae beds within the area which the interrogations predict will be subjected to elevated levels of sedimentation as a consequence of dumping at spoil ground 2B.

Sedimentation and Macro algae

In a review of the literature documenting the impacts of sedimentation on the flora and fauna of rocky coasts, Airoldi (2003) concludes that the impacts of sedimentation on macro algae, coralline algae and turf algae are not well understood and there is considerable debate in the literature about whether some types of algae benefit from an increase in sedimentation, or are negatively impacted, or are not affected at all. Airoldi (2003) concludes that site specific characteristics of habitats, sedimentation, co-acting factors, and the adaptive capacity of individual species may explain the lack of coherence in results and observations published in the literature.

Airoldi (2003) also points out that many of the studies that report an impact on macro algae from sedimentation do not provide a quantitative estimate of the amount of sediment, the type of sediment involved and the potential impact of other factors such as turbidity and often fail to identify the mechanisms whereby sedimentation has had a negative or positive effect on individual species. In short much of the published information is qualitative (see Figure 4 in Airoldi 2003).

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The available information shows that macro algae and seagrasses are not significant components of the BPP Habitats present, and in the absence of well defined thresholds for the species of algae that might be present in the area but in very low densities, the development of any thresholds for macro algae in Mermaid Sound is problematic. The evidence for potential impacts of sedimentation on macro algae is discussed in greater detail in **Section 3.10**. The thresholds used in these interrogations are relatively low (**Table 8**) and are not expected to represent any potential impact to macro algae.

Therefore, corals were identified as the sensitive benthic primary producers which are known to be present in significant amounts and are known to be sensitive to increases in sediment and turbidity, although the pertinent thresholds for Mermaid Sound coral communities are subject to debate. The distribution of corals was accurately mapped, and suitable monitoring and impact sites were selected for monitoring before, during and after the dredge programme.

3.3 Environmental Quality Objectives

Modelling outputs should be mapped to show the areas where each of the Environmental Quality Objectives identified in the Pilbara Coastal Water Quality Consultation Outcomes report will not be met.

Proponents Response

In response to the Pilbara EQMF (from the Pilbara Coastal Water Quality Consultation Outcomes report) the proponent identified which values were likely to be impacted by dredging and which indicators (Water Quality parameters) were relevant (Table 5 of the Supplement and Responses to Submissions document).

The Pilbara EQMF does not set any numbers or thresholds. It recommends three zones: Maximum, High and Moderate and the objectives for each in terms of water quality are provided in **Table 14**.

- **Table 14 Environmental Quality Conditions for Pilbara Coastal Waters (Reproduced from Department of Environment 2006)**

Level of Ecological Protection	Environmental Quality Condition (Limit of Acceptable Change)	
	Contaminant Concentration Indicators	Biological Indicators
Maximum	No contaminants – pristine	No detectable change from natural variation
High	Very low levels of contaminants	No detectable change from natural variation
Moderate	Elevated levels of contaminants	Moderate changes from natural variation
Low	High levels of contaminants	Large changes from natural variation

The locations of the areas within Mermaid Sound where the different levels of ecological protection apply are provided in Map 9 of the Pilbara Coastal Water Quality Consultation Outcomes (Department of Environment 2006) and that figure is reproduced here (**Figure 9**).

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- **Figure 9 Pilbara Coastal Water Quality Consultation Outcomes**

The potential zone of influence from the proposed dredging programme will be mainly confined to the areas designated as either high or moderate ecological protection and there is some intrusion into areas rated as maximum ecological protection.

The Pilbara Coastal Water Quality Consultation Outcomes (Department of Environment 2006) list the limits of acceptable change for each of the three categories of maximum, high and moderate levels of ecological protection (**Table 14**).

With respect to the potential impact on water quality from the proposed dredging programme the proponent considers that the water quality parameters pH and dissolved oxygen are not expected to vary outside of the 80%ile and 20%ile of background levels and therefore have not been investigated as part of the modelling exercise.

Important water quality parameters that will be altered by the proposed dredging programme are turbidity and sedimentation and discussions with representatives of the EPASU indicated that the potential impact of fluctuations of these water quality parameters on ecosystem health and aesthetic values needed to be investigated. It was suggested that to assess the impact on Ecosystem Health Values the area where turbidity levels would exceed the 80%ile of background levels should be indicated on a map, and the area where sedimentation exceeds the 80%ile of background sedimentation should also be shown.

The proponent has undertaken a modelling reinterrogation exercise where both turbidity (as SSC) and sedimentation are examined in terms of intensity-duration-frequency for a range of background values of SSC and sedimentation derived from the recently collected MScience (2007a) baseline data (Refer to **Sections 2.1**and **2.2**).

The thresholds for the zones of potential impact and potential loss are based upon the 95%ile of the data recorded in the baseline study (MScience 2007a). The rationale for using the 95%ile is based on the application of the methodology of McArthur (2002) and is explained in detail in **Section 2.1**. As the outcomes are based on the water quality parameters of turbidity (SSC) and sedimentation and have been mapped, the response in **Section 2.1** is considered to be an adequate response to this comment on Environmental Quality Objectives.

It should be noted that the Pilbara Water Quality Consultation Guidelines list the levels of acceptable change, but there is no indication as to whether acceptable change is restricted to long term deviations from the background conditions or whether short term deviations form the background in water quality are also included.

Short term fluctuations in water quality already occur as a consequence of natural events like cyclones and the setting of water quality objectives presumably relates to the long term.

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The second request was to assess the impact on the aesthetic value of water quality wherever increased turbidity produced water conditions with lower than natural (i.e. background) water clarity. The proponent consequently undertook (Table 5 of the Supplement and Responses to Submissions document) to show where the natural visual clarity will be reduced by more than 20 %.

The proponent understands the 'natural visual clarity' to be a function of the effect of suspended material on the ability of water to transmit light and the impact on aesthetic value to be increasingly cloudy water producing a negative response in terms of visual amenity as suspended sediment loadings increases.

The investigation of the baseline data recently completed by MScience (2007a) includes a plot of light versus SSC data collected from one of the baseline data stations (ANGI) which is indicative of the data collected from all stations. **Figure 6** shows that at station ANGI the data are noisy with the correlation exhibiting R^2 of less than 0.2 which means the relationship with SSC alone explains less than 20% of the variation. MScience (2007a) also point out that the SSC values only relate to the 'quality' of the water at the depth of the meter and the SSC values will vary above and below this depth.

Consequently, given the high level of noise in the data set the proponent considers any attempt to plot a zone showing the area where a reduction of "natural visual clarity" by an amount of more than 20% cannot be undertaken with any degree of confidence.

3.4 Re-suspension and Light Attenuation

Re-suspension is likely to increase TSS and sedimentation over coral areas and reduce light attenuation. It is also likely to cause sediment to accumulate in low energy areas, perhaps even at distance from the dredge/dumping activity. Because this is a 2 yr programme the effects are likely to be very significant.

Proponents Response

The proponent has significantly reduced the proposed programme in terms of sediment mass to be relocated and the time to complete, from the earlier advised estimates, with the benefit of reduced input of fines and a shorter duration of influence (refer also to **Section 3.11**).

Modelling with resuspension (refer to **Appendix D**) has indicated that resuspension of fine sediments would occur in Mermaid Sound, due to the seabed stress set up by waves and currents and the nature of the existing sediments. Resuspension was predicted to increase SSC on a fairly localised basis. i.e. the wave modelling indicated that seabed stress will vary spatially and temporally due to variations in exposure to prevailing conditions, and variations in intensity of wave forces. This would lead to the patchy and variable background SSC observed in the field data, in the absence of dredging. Because the seabed of Mermaid Sound consists of fine sediments, wave resuspension of existing sediments is expected to be the major contributor to the existing patchy and variable levels of SSC (and associated light attenuation) that are observed.

Dredging would vary the existing situation if the proportion of fines on the surface was increased either locally or generally. Modelling indicates that dredge-sourced fines should initially sediment within the areas influenced by the initial settlement plume (rather than universally) but disperse further over time. Modelling also indicate a tendency for fines to disperse (to make up a lower proportion of local fines) and to migrate from the system over time via the multiple channelways. The relevance of the contribution of dredge-sourced fines relative to background sourced fines would therefore depend on local magnitudes of increase and the tolerance of BPP components to the total (dredge + background) SSC experienced. Multiple dredging and disposal operations have been carried out in Mermaid Sound and the existing field data gives some indication of the existing baseline SSC patterns, with those influences included, as well as the tolerance of local BPP components to these patterns. The threshold analysis has taken the baseline values and responses into account.

The field (MScience 2007a) and model data both indicate that sedimentation does not increase concurrently with SSC, because the energy that creates resuspension tends to cause erosion instead of accretion. However, elevated sedimentation can occur after the passage of higher energy events. As for SSC, sedimentation appears to vary spatially, with wave-sheltered locations tending to trap sediments to some degree. This is consistent with the field observations where some sheltered sites are particularly “dirty”. Thus, the outcomes of sediment discharge would vary with the location in Mermaid Sound. Most locations in the mid-outer sound showed high resuspension rates (hence low net sedimentation) in the model outcomes, hence fines introduced to these areas would be less likely to accumulate. Areas of relatively higher trapping in the mid-outer sound appear to be limited to locations sheltered from the western sector, and this sheltering varies with the passage of storms. In contrast, the wave modelling indicated that the inner margin of the Sound should have higher rates of trapping, for sediments that are discharged in this zone, or migrate into this zone. Elevated sedimentation was not predicted in these areas from dredging off Holden Point because a net northward migration was indicated for the time of year that dredging is proposed. The low wave-energy predicted for the southern end of Mermaid Sound, together with a local input of fines (such as the overflow of a previous dewatering operation to the immediate south) may explain the DEC observation of a water-clay layer build up at a site in the south end of Mermaid Sound.

The analysis of model outcomes takes account of the local bottom-stress variation and position of sensitive receptors along the predicted sediment migration routes to quantify the SSC and sedimentation rates that are expected from the specific case of dredge discharge off Holden Point under summer conditions.

Disposal of sediments to the offshore discharge site is one management step that has been taken to reduce the introduction of fines directly into Mermaid Sound. Simulation of a high fine content sediment mixture into this area under winter conditions indicates that fine sediments (clay –silt) are likely to be resuspended by levels of seabed stress predicted for the site. Under winter waves and currents, the modelling indicated a net southward migration with fines tending to migrate and disperse from the dump site into Mermaid Sound. The threshold analysis for SSC and sedimentation provides a guide to the significance of the SSC and sedimentation expected. Note that currents tend to parallel the shelf during summer conditions, hence the result shown here will be the seasonal worst-case

3.5 Vulnerable Coral Species

Medium and chronic thresholds for vulnerable coral species therefore also need to be included into the modelling outputs along with light reduction thresholds (this is a 2 year programme). Potential effects of turbidity induced light reduction have not been taken into account.

Proponents Response

Part of the re-interrogation of the model output in the present scope of work has included the setting of acute, medium and chronic thresholds for the corals species located in the mid and outer zones of the harbour. The classification into inner, mid- and outer zones was developed by MScience (2005) as a response to evidence which demonstrated the species composition and dominants of the corals communities of Mermaid Sound could be differentiated on the basis of their position in the Sound. The classification was supported by recorded differences in turbidity regimes which suggest the inner zone of corals is dominated by species that are more tolerant of higher turbidity.

The baseline data gathering exercise (MScience 2007a) has included 8 stations at which SSC have been measured since August 2006. These data are presented in **Table 13** (see **Section 2.1**) and included in the Table are calculations of SSC values by zone where the stations have been lumped to conform to the zonation pattern developed by MScience (2005). When the inner zone SSC mean, median and 95%ile values are compared to the mid and outer zones it is clear they are higher, suggesting that the coral communities occupying the inner zone have been subjected to higher levels of SSC than the coral communities of the mid- and outer zones. The mid-and outer zone results however show very little difference between these two zones in terms of recorded SSC.

Consequently, the use of background data to develop thresholds for the more ‘sensitive’ or ‘vulnerable coral communities that are believed to comprise those found in the mid and outer zones has assumed that the same level of 95%ile SSC will suffice for both mid- and outer zones.

3.6 BPPH Losses

BPPH losses need to be evaluated within a context of a map and statistics showing the area of permanent (or long-term) loss, the footprint area of short-term reversible loss and the area within which there is likely to be physiological or morphological impacts but not loss. The area beyond this last boundary should be the area of no impact. Given the lack of data on BPPH tolerances changes to background environmental conditions can be used to estimate the boundary, In the case of sedimentation or light attenuation the 80th percentile of natural background variability would be used as the criterion for modelling the boundary for no effects on BPPH. Where there is significant uncertainty around these thresholds then a best/worst and most likely scenario may be considered.

Proponents Response

The information provided in **Section 2.1** provides the response to this comment. The proponent has used the pre-dredging baseline studies data compiled by MScience (2007a) to develop a series of thresholds based upon the methodology of McArthur et al 2002.

The methodology adopted includes a worst case-best case scenario with respect to sedimentation.

3.7 Output from the Sedimentation Modelling

T*he output from the sedimentation modelling can only be taken as a guide. An estimate of worst case BPPH loss can be determined by drawing a generalised line around groupings of the polygons that represent sedimentation threshold exceedances.*

Response

The proponent interprets the request to include all groupings of the polygons that represent threshold exceedances within a single generalised line to mean that a line should be drawn to capture some outlying polygons that are disjunct from the larger areas of polygons generated from the modelling interrogations.

The rationale for this approach is that it represents a worst case scenario for BPPH loss. However, the current modelling outputs which have produced some outlier groupings of polygons is a product of a high resolution with a high degree of sensitivity. Consequently the production of any generalised line around the various groupings of polygons reduces the value of the model outputs, because it will include within the zones of potential impact and potential loss, areas of BPPH loss and impact which the model output has not predicted.

The output from the modelling is only a guide, but it represents a high degree of sophistication with respect to the input data, and how that data has been treated. The decision to resort to a model to provide predictions is based on the recognition that the movement of the plume is influenced by a

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complex suite of factors that require a high degree of integration and it is a backward step to begin drawing generalised lines on maps. The validation studies which have been undertaken demonstrate a strong correlation between predicted and observed outcomes and therefore provide a strong rationale for adopting the model outputs 'as is' for the basis for meaningful management strategies.

The predictive power of the model is one of the elements that will be tested during the proposed dredging programme. The information input could certainly be improved, for example there is currently no data on the SSC profiles through the water column during dredging programmes in Mermaid Sound, and that would be a useful piece of information, but until such time as that data is available, the modelling outputs produced here are best estimates.

It is worth noting that the modelling output is already considered by the proponent to present a worst case scenario, given that it was based on earlier dredging programme designs which included larger volumes, longer periods and the use of dredge spoil ground A/B. The more recent modifications include significant reductions in the volume of material, the duration of dredging, and locations of dump sites.

The model also used a very conservative over-estimate of the amount of material that would re-enter the entire water column through resuspension and therefore the predicted lateral transport of that material is considered to also be a gross overestimate (i.e. a worst case scenario).

3.8 Exceedence of the Threshold Criterion

Where losses of BPPH exceed the threshold criterion (Area 1 and 2) then the EPA expects the proponent to provide a substantial justification for the proposal supported by technically sound information demonstrating an understanding of the ecological role/function and value of the BPPH within the local context to help determine the significance of the potential impacts. There is also a need for an offsets package ***WEL.*** *See BPPH Guidance Statement.*

Proponents Response

The proponent provides the following assessment of the ecological role/function and value of the BPPH with the local context.

The threshold criterion for areas 1 and 2 (i.e. management zones 1 and 2) have been set by reference to the BPPH guidelines and are currently set at 0% for area 1, and 1% for area 2. As a starting point it is worth examining what these figures of 0% and 1% are meant to represent in terms of ecological role/function.

The BPPH guidelines aim to protect and maintain ecosystem integrity by setting limits to the amount of primary producer habitats that might be lost as a consequence of development projects in the marine environment. The 0% setting for area 1 is based on the information that historical losses within the management unit already exceed 10% and therefore no further losses are permitted.

The proponent argues that while there is evidence of a historical loss of some 17% of the area of BPPH (specifically corals habitat) that does not necessarily equate to a loss of 17% of the ecological role/function of that habitat. The current interpretation of the ecological role/function value as presented in the 10% rule is that 1 square metre of coral habitat anywhere within the designated management unit is the equal of any other square metre of coral habitat in terms of contribution to ecological role/function within the management unit.

Therefore the implication is that within areas 1 and 2 the predicted potential loss of 55% and 23 % of corals habitat respectively represents a loss of 55% and 23 % of ecological role/function and that amount of loss within these areas would then significantly impair ecosystem function. It is important to note that these losses are based upon the new threshold values used for model interrogation and the proponent considers these revised estimates to be gross over estimates of the likely corals losses, a view which is supported by the available data on previous dredging programmes (refer to MScience 2007b, **Appendix B**).

The question is whether it is fair to assume that all square metres of coral habitat are equal. It is highly likely that coral communities vary considerably in their individual contribution to ecosystem integrity, even over relatively small areas here in Mermaid Sound as elsewhere in the world (Hatcher 1990).

That is certainly the case with other BPPH such as mangroves where primary productivity can vary widely within a location and incidentally is very often obviously expressed in low percentage of coverage and reduced stature of the trees.

Coral communities in Mermaid Sound vary widely in the percent coverage of the substrate exhibited with the general trend for coral coverage to be low in the inner zone 10-20% and rising to coverage of 40% or more on some of the offshore reefs.

Given that the distribution and percent coverage of corals in the Sound appears to be largely determined by physical factors it could be assumed that not only are the corals of the outer areas of the Sound likely to be more diverse, and cover a larger surface area, with a potentially more complex three-dimensional structure, but are also likely to be far more productive (i.e. to produce more carbon per unit of area of coral) than the corals occupying the more turbid waters inshore.

Within the nominated management unit the amount of coral cover varies considerably ranging from under 10% to more than 20% and therefore if it is assumed the effect of physical factors is influencing the percentage of cover exhibited by the individual communities then it also is likely

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that individual communities may vary considerably in respect of primary productivity as a response to those same physical factors. And it is primary productivity which is the ecological role/function driving the ecosystem integrity the BPPH Guidelines presumably seek to protect and maintain.

Consequently, the proponent makes the point that what is important is not the percentage of coral BPPH area that may be lost, but the percentage of ecological role/function that is provided by the coral communities inside the management unit and how much of that may be lost or impaired by the development proposal.

Presumably the selection of an area of 50km^2 size as the nominal area for management units was in part based on a belief that area of this size encapsulated many of the ecological roles/functions contained within the unit. That may be true for some areas of the Australian coastline, but is certainly not true for many others.

The management units are currently set at about 50km^2 for areas 1 and 2 because this is the guidance received from the EPA in respect of the preferred size of management units but it has little to do with any perceived natural boundaries of ecological role/function. The proponent is not arguing here for a change in the current management unit boundaries, at this late stage of the approvals process, but rather arguing that in interpretation of the potential losses from within a management unit, the relevant scale should only be confined to the management unit if it can be shown that the unit is a logical encapsulation of localised ecological roles/functions, and that impairment of those ecological roles/functions can be shown to impair ecosystem integrity, which by definition must operate at the scale of ecosystem, whatever that relevant scale may be.

Elsewhere in this report the rationale is provided for the classification of the Sound into three broad zones on the basis of observed differences in the corals communities found within each zone, and the implication is drawn that physical factors are responsible for this differentiation (MScience 2005). Therefore, in an examination of ecological role/function it could have been more useful to develop management units which are defined by these zones. They will be much bigger than 50 km^2 but make more sense in terms of defining the perceived differences in ecological role/function which then define the contribution to ecosystem integrity.

Given that the zonation which has been observed by MScience (2005) could also be interpreted as a gradient of changing dominance, coverage and complexity from the inshore zone to the outer reefs of the Archipelago then there is also some value in viewing the entire Archipelago and certainly Mermaid Sound as a single ecosystem unit with a series of habitat types based upon geomorphology such as that proposed by Semeniuk et al 1982.

The other factor which suggests that Mermaid Sound may be best treated as a single ecosystem is that it is macro tidal and in other parts of the macro tidal tropical Australian coast, ecosystem units are by nature, typically large, e.g. King Sound and Darwin Harbour.

(AMSA 1997) noted that Australia's coastal and offshore marine habitats would best be managed as a system of Large Marine Ecosystems (LMEs) but also noted the boundaries of management units should be defined on a scientific basis although they are usually determined on the basis of historical or political grounds.

If the corals of the areas within area 1 and 2 are then considered from an ecological role/function in terms of contribution to the ecosystem integrity of Mermaid Sound then the potential loss of corals habitat does not appear quite as dramatic.

In **Figure 10** all the areas of potential coral loss are mapped and also shown are the areas of coral that is not expected to be impacted. The percentage of total coral losses from the proposed dredging is 1,220,554 m^2 compared to a total area of coral habitat of 12,286,400 m^2 or 9.9% of the total area of coral in the Mermaid Sound 'ecosystem'.

In addition most of the corals identified as lying within the potential loss zone exhibit sparse coverage, an average of about 15% and this means that of the total area of habitat, only 15% is actually coral and so applying that to the calculated area of potential loss suggests the loss of actual coral is 183,083m^2 –the area of the seabed actually covered by coral. The total coral estimate on the other hand includes substantial areas of corals in the outer zone which have coverages approaching 35-40% of the substrate and so the actual coral total is probably somewhere between 25-40% of the total substrate area, or 3,071,600-4,914,560m^2.

If the comparisons where then made as a per unit area of actual coral (BPP) then the potential loss for the Sound would between 3.7-5.9% of the total of ecological role/function - if it can be assumed that corals have uniform productivity throughout the Sound. The proponent suggests it is not valid to assume the productivity of the inner zone corals is equivalent to those in the outer zone. The literature suggests a general range in corals primary productivity of 5-40g/m^2/d (Hatcher 1990; Hoegh-Guldberg 1999).

Although there is no data available on the primary productivity data for the corals communities in Mermaid Sound it is likely that the inner zone corals tend toward the lower end of this range, while the outer corals tend toward the upper end.

Therefore if the assessment of the impact on ecological role/function were to be based on the primary productivity per unit area, then the outcome would likely be to reduce further the potential loss of ecological role/function from the potential loss of the area sparsely populated by corals.

Another factor which should be taken into account when determining the impact of a potential loss of these corals areas on ecosystem integrity is the relative contribution of other BPP in the Sound.

There are other BPP present and although they are mostly sparsely distributed throughout the Sound there are areas where macro algae, and sea grasses are present in greater densities. None of these sea grass areas lies within the footprints of sedimentation or SSC and only a small part of the macro algae patches with higher densities and none of that is expected to be impacted.

While a higher value of ecological role/function may be ascribed to a corals habitat when compared to a macro algae habitat it can realistically only be done if the ecological role/function includes components such as ‘biodiversity’ and ‘habitat structure’ but even then it would be debateable whether the ecological role/function of a square metre of corals was worth more in terms of maintaining ecosystem integrity than a square metre of macro algae. It probably is the case that corals habitat in the Sound supports a higher diversity of fish as Hutchins (2004) reports a coral reef fish fauna of 465 species, relative to 106 species over soft sediments, 116 mangrove associates and 67 pelagic species. However, these figures could reflect bias in sampling effort.

It may seem odd to be considering the various habitat areas of seabed in this way, but in effect that is what the current BPPH Guidelines require in order to determine the relative value of potential losses.

Direct comparisons of benthic micro algae and macro algae primary production suggest that corals are not as productive, per unit of area, (Hatcher 1990) and given that corals comprise a relatively small area of the total habitats area within the Sound (and within the nominal management zones) it is likely that the overall contribution to primary productivity (as fixed carbon/m^2/d) within the Sound is also correspondingly small.

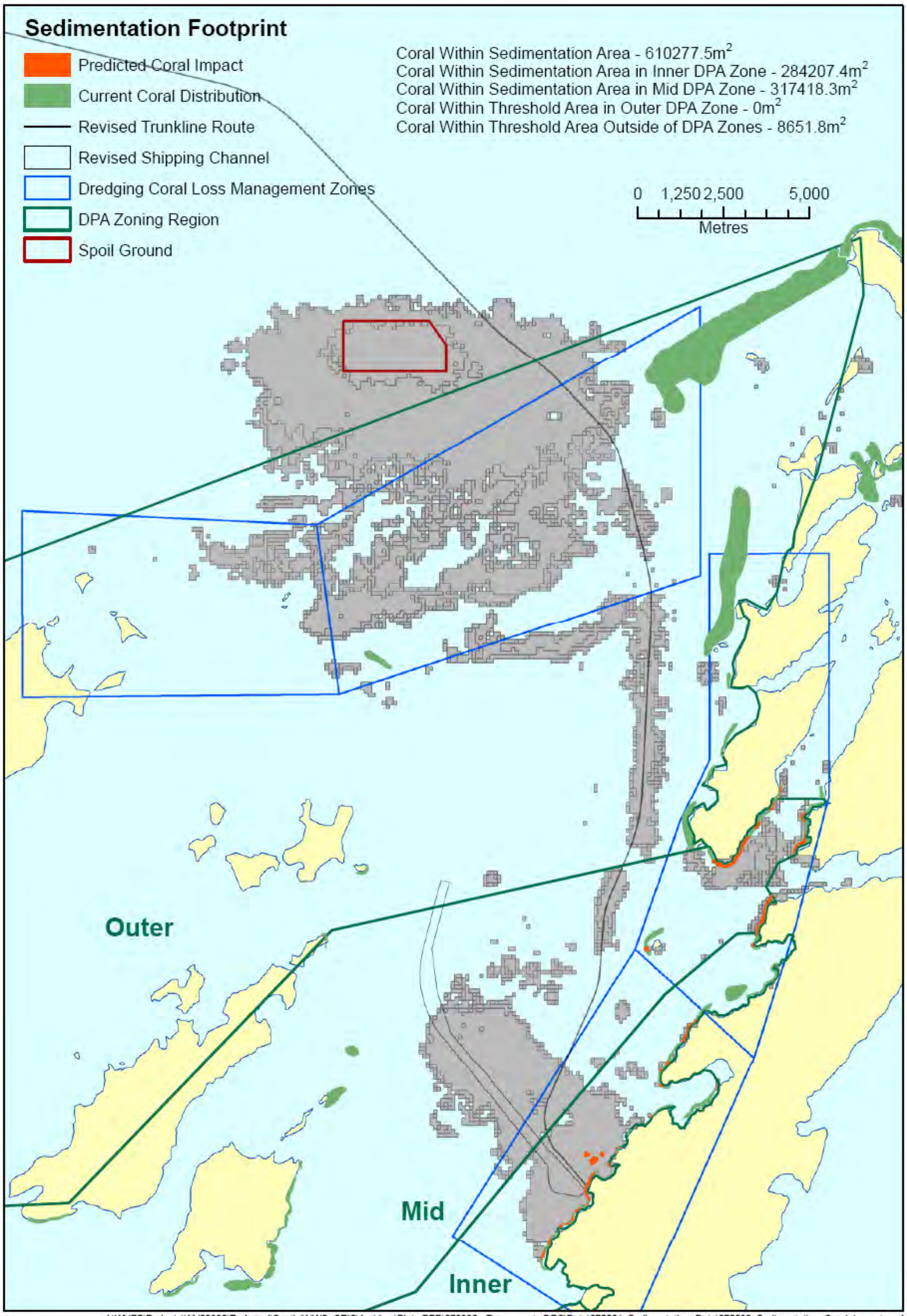
There are several observations to be made in respect of this assessment:

- Management units are best defined by ecological role/function and can be expected to differ widely in size and shape. The Guidelines acknowledge this but in the absence of better information the 50km^2 has become the default.
- Mermaid Sound is a logical base unit for determinations of ecosystem function.
- The total area of seabed covered by corals is relatively small and therefore the relative contribution to primary productivity in the sound may also be relatively small.

It is also important to consider that the great majority of areas that are estimated to be lost will likely be recolonised by corals at some point in the near future as the deposition of sediment upon the inshore reefs is expected to be a temporary phenomenon. That the losses are likely to be temporary should also be a mitigating factor in determination of the relative impact of the loss on ecological role /function and the contribution to ecosystem integrity.

Offsets

Woodside is currently in discussions with the Department of Environment and Conservation regarding commitments for environmental offsets to address predicted significant residual impacts from the Development. A formal environmental offsets proposal will be submitted to the Department next week. Woodside is proposing to offset potential impacts to benthic primary producer habitat (corals) through support of marine research in the Dampier Archipelago. The Indicative Management Plan for the Proposed Dampier Archipelago Marine Park (DEC 2005) outlines a range of management strategies for coral reef communities in the Archipelago including monitoring and research priorities. It is proposed that research supported via the Pluto offset package should be consistent with these priorities. Research associated with the implementation of Management Plans for Ningaloo Marine Park and Jurien Bay Marine Park is being coordinated through the Western Australian Marine Science Institution (WAMSI). Research in Mermaid Sound and the Dampier Archipelago Marine Park could be coordinated under a similar framework with funding for research provided to WAMSI by Woodside.



- **Figure 10 Sedimentation Footprint Showing Areas Where Corals Would be Potentially Impacted, Compared to Total Area of Corals in Mermaid Sound Ecosystem.**

3.9 Impacts to Corals on the West Side of Mermaid Sound

The proponent's response to 'comment 9.25' suggests that there will be no impacts to corals on the west side of Mermaid Sound and refers to TSS modelling results in Figure 8. However the sedimentation modelling results in ***Figure A21*** *(spoil disposal alone)* ***[should this be a ref to A11 and A12, there is no A21]*** *indicate that the acute sedimentation thresholds for sensitive species may be exceeded along the shoreline of NE West Lewis Island where corals are known to occur, but are not mapped. Incorporation of resuspension into the model is likely to exacerbate this effect.*

Proponents Response

Figure B21 (not A21) shows cumulative sedimentation without resuspension from intensive dredging for a full month in one location. The revised practice is to cast more widely and randomly on each pass, to reduce intensity of input. It is noted that the revised dredging programme assumes that a limited volume of dredged material will be disposed of into Spoil Ground A/B within Mermaid Sound with the bulk of material being disposed at offshore spoil ground 2b (refer to **Section 3.11**). Subsequently, the potential for impacts along the shoreline of NE West Lewis Island is considered unlikely.

A habitat map for the shoreline of NE West Lewis Island is provided in **Figure 7** (MScience 2007b)**.**

3.10 Macro-algal Communities and Seagrass

The BPPH assessment does not address potential impacts on macroalgal communities (what impact will sedimentation and turbidity have on this BPP and will the platform reefs be smothered by sedimentation?). Similarly, impacts on seagrass BPPH have not been properly addressed (will altered sediment particle size distribution in the vicinity of dredged areas and dump sites affect potential seagrass colonisation?).

Refer to response to Task 2 in Section 1 of this document also.

Proponents Response

The response provided to the comment in section 2.2 provides the details of why potential impacts from sedimentation and turbidity on macro algae and seagrasses have not formed a major part of the investigations undertaken by Woodside for this project. Briefly, the survey work undertaken to date has not revealed any significant BPPH of any type, other than corals, within the area identified as a potential impact zone. In the absence of any significant habitat of these two BPP types the

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proponent has focussed on addressing the issues surrounding the potential impacts of sedimentation and turbidity on the BPP (coral) which is present in significant quantities.

As outlined in **Section 3.2**, the available information on the impacts of sediment on macro algae has been recently reviewed by Aroldi (2003) who provides the following summary of the published information:

"Not all species and assemblages are equally affected by sedimentation and responses vary over space and time, depending on the characteristics of the depositional environment, life histories of species and the stage of development of individuals and assemblages, and in relation to variable physical factors, including hydrodynamics, light intensity and bottom topography."

For these reasons, the proponent concludes it is not currently possible to define a suitable set of thresholds for either sedimentation or turbidity that could be adopted for macro algae in Mermaid Sound. For example, the brown macro algae *Sargassum* spp. have been documented as a common component of the benthic macro algae in the Dampier Archipelago region and 3 species have been recorded, *S.decurrens*, *S. oligocystum* and *S.linerifolium* (Huisman and Borowitzka 2004). *Sargassum oligocystum* is the most widely distributed of the three species and is found throughout the tropical Indo-West Pacific (Huisman and Borowitzka 2004).

Literature searches for this species and the other two species produced few records that mentioned sedimentation, turbidity and dredging and in these references no indicators were found in respect of what range of turbidity and sedimentation the species typically encounter and what levels of sedimentation and turbidity might therefore serve as useful thresholds for the species in Mermaid Sound. For example, Mayakun and Prathep (2005) record *S.oligocystum* as one of a suite of species of macrolagae examined over wet and dry seasons at Samui, Thailand and conclude that the macro algae were highly seasonal in distribution and abundance with more species present during the dry season when waters were less turbid. However, no background turbidity data are provided, and the potential compounding impact of reduced salinity during the wet season months is not discussed.

Sargassum spp are reported to be seasonal in Mermaid Sound with peak biomass occurring in the summer and then the algae die out in winter. It is not known whether this observation applies to all three of the species so far reported from the Sound.

Typically where there is no data available for the suite of species present at a potential impact site, other species in the same genus or higher taxonomic classification are used to infer the likely impact. For example, in any examination of potential impacts of turbidity and sedimentation on *Sargassum* spp. information on the known responses of several species of *Sargassum* to increased sedimentation and turbidity can be useful.

Umar et al. (1998) reported that very high levels of sediment accumulation (up to 20 mm thick) on reefs affected recruitment, growth, survival and seasonal regeneration of *Sargassum microphyllum* but populations of the species were never completely extinguished and in some areas there was a positive correlation between *Sargassum* settlement and sedimentation. Umar et al (1998) also suggested an increase of twice the background level of long-term sediment deposition would reduce abundance but not lead to local extinction.

Catterall et al (1992) report that within two years of the cessation of dredging activities at Heron Island Reef (QLD), tall erect algae including some species of *Sargassum* (species not recorded) increased in overall abundance. In an assessment of the colonisation potential of a number of marine organisms Shanks et al (2003) report dispersal rates of *Sargassum mictum* of up to 193 km/yr. Ang (1985) examined the colonisation potential of two species of *Sargassum* (*S. siliquosum* and *S.paniculatum)* in the Philippines and reported recolonisation of bare substrate in 3-4 months. A similar study reported that new recruits of Sargassum spp. appeared in quadrats three months after the quadrats had been cleared during the reproductive season (Vuki and Price 1994).

Experimental studies of the colonization of *Sargassum* *plagiophyllum* on artificial substratum recorded a time lag of 9-10 months was needed for the recolonisation of a fresh substratum (Raju and Venugopal, 1971), suggesting that the rates of colonisation between various species of *Sargassum* may differ, and is likely to be influenced by a considerable number of environmental factors.

In the absence of any relevant data specific to the species actually present in Mermaid Sound the reference to what is known about cogeners is entirely justifiable, but may not always be relevant to all the species in a genus (Airoldi 2003).

In the present case the published literature on other species of *Sargassum* as quoted above, suggests that these species are more tolerant of increases in sediment and turbidity than coral species and are faster recolonisers of areas where short term changes in conditions have reduced or extinguished populations.

The lack of information on the ecological requirements and tolerances of the three species of *Sargassum* recorded from Mermaid Sound also applies to the large array of other macro algae species that have been recorded from Mermaid Sound (Huisman and Borowitzka 2004). Many of the other species of macro algae which inhabit similar areas to those colonised by *Sargassum* spp. may have similar, or widely different, tolerances to sedimentation and turbidity.

The decision to concentrate on corals as the BPPH communities to be assessed and monitored was therefore motivated by:

- survey data indicating there are no significant macro algae habitats within the potential zone of impact
- the lack of information about what would constitute meaningful thresholds of SSC and sedimentation for macro algae species recorded in the Sound
- Evidence that macro algae populations in Mermaid Sound are highly seasonal in abundance and distribution
- Evidence that some macro algae species are tolerant of sedimentation and turbidity impacts.

The available information on habitat preferences and seasonal fluctuations in distribution and abundance for some macro algae suggests it is likely that if there are impacts on macro algae from sedimentation and turbidity, these will be small scale and that the algae will quickly recover from the disturbance (Airoldi 2003).

The impacts of the proposed programme of dredging upon seagrasses has not been examined in detail because the survey data collected for the Draft PER are consistent with previous survey results which do not record any significant seagrass habitat within the area that can be defined as the potential zone of impact (see Figure 7-32 in Supplement and Responses to Submissions).

The presence of the seagrass in the dredge at station 1 of the 1999 dredge survey (Hutchins et al 2004) has been discussed in **Section 3.2**.

Section 3.10 refers to altered sediment particle size distribution in the vicinity of dredged areas and dump sites affecting potential sea grass colonisation. Areas which currently have no sea grass habitat, and have not had any sea grass habitat according to the few surveys which have taken place in Mermaid Sound since 1999, appear to possess a low potential for sea grass colonisation.

If some of these areas bare of sea grasses have the right sediment grain size proportions for colonisation by sea grasses then it appears there are other factors which are limiting sea grass colonisation at those sites. The limiting factor/s may be depth, scour, exposure, turbidity, nutrients, DO, salinity or any combination of these and probably varies between sites. In these areas the addition of a film of different sediment grain sizes from dredging activities and spoil disposal may render the substrate temporarily unfit for sea grass colonisation, but unless the other factors that appear to prevent those areas being colonised by sea grasses now are removed or modified then the addition of different sediments is not likely to constitute a limiting factor.

The assumption is made that it is the addition of fines which is considered likely to render the substrate sediment grain sizes unsuitable for colonisation, and it should be noted that the model outputs demonstrate that considerable volumes of the fine material currently present in the Sound (and which would be added by the dredging programme) are resuspended and ultimately transported to depositional areas where conditions allow the accumulation of fines.

The areas with high potential for sea grass colonisation presumably already have sea grass now, or there are some records of sea grass present in these areas at some time in the recent past (Figure 7-32 of the Supplement and Responses to Submissions).

All of the areas where sea grasses are known to be present in significant densities are located outside the zone of potential impact and so are not expected to suffer any deleterious impacts as a consequence of the dredging programme.

3.11 Modelling for Two Year Programme

The proponent should incorporate sediment resuspension, medium and chronic sedimentation thresholds for vulnerable corals, thresholds for other BPP and any other DEC requirements into the model, ***then re-run the model for the entire two year dredging period.*** *The model should include effects from the three dredges, all spoil dumping activities, trunkline construction and propeller wash simultaneously so that cumulative impacts can be adequately assessed. If the proponent is considering reuse of the spoil dumped in the spoil grounds as an option, then this activity would also need to be incorporated into the model.*

Proponents Response

Modelling undertaken to date has focused on what are considered to be the most intensive aspects of dredging operations, and has included consideration of the footprint associated with spoil disposal plans. A high level outline of the sequence of dredging works as currently defined is provided below.

Sensitivity thresholds have been constructed and applied for medium and chronic sedimentation thresholds for vulnerable corals. The modelling has been applied to quantify the influence of resuspension for key operations, using worst-case seasonal conditions (refer to **Appendix D**).

The power of the model in this context has been in testing the influence of different variables to design a programme that will reduce the impact of the dredging programme. Conservative allowances have been included at various steps. Hence, extrapolations from this data are expected to be conservative.

Dredging works for the Pluto LNG Development were indicated in the Draft PER to span up to two years. It is important to note that the work programme does not involve two years of continuous dredging but will proceed with dredging activities occurring over shorter intervals at different times. The overall two year programme encompasses both dredging and post-dredging activities.

Every effort is being made to seek to reduce the duration of dredging and footprint associated with dredging and dredge spoil disposal activities.

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The outcome of recent considerations include a commitment to revise spoil disposal plans so that the bulk of dredged material to be generated from the overall dredging programmes will be removed to offshore spoil ground 2B. This will significantly reduce volumes that would otherwise be disposed to the existing inner spoil ground A/B and should provide substantial environmental benefits in terms of the footprint.

Coarse spoil material to be deposited in the offshore spoil ground has been identified as likely to be suitable for backfill and stabilisation of the Trunkline. This option will be further evaluated in relation to its potential impacts during development of the Dredging and Spoil Disposal Management Plan.

For operational, logistical and safety reasons, there is a need to retain limited access to spoil ground A/B for aspects of dredging for the NWSV channel and shore crossing. There is a limited work window for safely undertaking the NWSV channel crossing work, which will require access to spoil grounds in reasonable proximity to the site to allow the work to be completed within the available work window. Moreover, the nature of the work will involve relatively small vessels that are not suited to offshore conditions.

Key aspects to highlight in relation to the likely sequence of dredging and post-dredging works, based on information currently available, is as follows (**Figure 11**):

- Dredging activities are not continuous over two years but rather are a series of discrete activities.
- The overall duration of dredging for completing the Berth Pocket, Turning Basin and Navigation Channel is expected to be about 12-13 months.
- Concurrent dredging activities on the Navigation Channel and Trunkline are likely to be of limited duration; this will include a short period (about 2-4 weeks) near the beginning of the dredging programme, when the early investment work on the Trunkline channel crossing will be undertaken, coinciding with the dredging works for the Turning Basin at Holden Point.
- The most intensive period of dredging activity will occur over the first 4-5 months, during the inshore works to create the Berth Pocket and Turning Basin at Holden Point. The work on the Berth Pocket is required to be started early to accommodate access for construction work for the nearby jetty.
- The bulk of dredging of the Navigation Channel is expected to span some 7-8 months; timing at this stage is indicated to be from about February 2008 through October 2008, although this may be subject to change should this work be progressed in stages.
- Pre-lay dredging associated with Trunkline works is likely to commence after the bulk of the Navigation Channel work is completed; pre-lay work along the Trunkline route is indicated to span about 4 months, starting from about November 2008.

- The bulk of dredging activities is likely to be complete by the completion of Trunkline pre-lay dredging work, when the programme then moves into Trunkline pipelay activities, extending for about 7 months.

Backfill and stabilisation work on the Trunkline will extend over about 4 months, from September 2009 to December 2009. This includes placement of quarry rock on sections of the route, backfill operations with sand / coarse calcareous material and installation of Gravity Anchors in the deeper offshore sections, beyond port limits.

This indicative timing may be subject to change as a result of ongoing work planning in relation to the proposed field operations.

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Activity	Approx. Duration	Likely Equipment	Months
			N D J F M A M J J A S O N D J F M A M J J A S O N D J
JEZ and Turning Basin dredging	4 mths	TSHD (2) and CSD (1)	
Navigation channel dredging**	8-9 mths	TSHD (1 or 2), CSD (1)	
Trunkline channel crossing dredging	2 weeks in 1 month	TSHD (1) CSD (1)	
Trunkline dredging KP1-6	2-4 weeks	TSHD	
Trunkline dredging KP11-85	10-12 weeks	TSHD	
Trunkline pipelay	~7 months	2 pipelay vessels	
Trunkline quarry rock placement	~4 months	Side dumper	
Trunkline backfill to KP50	~10-12 weeks	TSHD	
Trunkline Gravity Anchors > KP50	~4 months		
Berth Pocket, Turning Basin, Navigation Channel			
JEZ completions over 1 month in Feb 08 and by 1 March 08			
TSHD removes overburden -2 months; CSD working from JEZ at berth entry to cut and crush for final removal by TSHD			
Depending on presence of hard material (igneous rock) - possibility of drill and blast required inshore			
Priority and most intensive work to clear JEZ inshore area to accommodate jetty			
Continue rest of turning basin with CSD and follow up removal with TSHD working behind CSD.			
Options still being explored around most suitable method for dredging in JEZ / berth pocket			
Trunkline			
Trunkline channel crossing KP3.5-KP4.5 pre-investment work by 1 April 08			
Trunkline shore crossing blasting (30-40m) and BHD work ~ 3 mths in 2008 - timing to be advised and depending on equipment availability			
Trunkline pipelay over ~ 7 months from Feb 09 through Aug 09 - two vessels to work the inside and outside MS sectors; one vessel a DP			
Trunkline backfill/stabilisation to KP50 over 10-12 weeks from Sep 09 through Nov 09			
Gravity anchors stabilisation for >KP50 work over 4 months Sept 09 through Dec 09			
Quarry rock placement over ~4 months from Sept 09 through Dec 09			

- **Figure 11 Latest Proposed Dredging Programme**

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4. Waste Water Discharge

4.1 Hydrotest Water Additives

The hydrotest water additives for onshore tanks need to be determined and assessed through the EIA process. Because the discharge is into shallow inshore waters, the environmental risks are significantly greater than for offshore discharges. If this is not possible then worst case chemical additives can be considered to demonstrate that nearshore discharge of this hydrostat water can be managed within the constraints of the environmental quality management framework (Pilbara Coastal Water Quality Consultation Outcomes report).

Proponents Response

As stated in the Supplement, the proponent intends to test the onshore LNG and other storage tanks using seawater. In doing so, the residence time of the seawater in each tank will be minimised as far as reasonably practicable to reduce the risk of internal corrosion. Furthermore, consideration is also being given to using an active or passive cathodic protection system on selected elements of the tanks to aid in reducing corrosion. Using seawater has both environmental and economic benefits, as it reduces demand on the local potable water system and when discharged into the marine environment it represents negligible risk of impact to the receiving waters and ecology. It will also enable faster completion of the hydrotest activities.

Following the completion of hydrotesting activities the seawater will be routed to Mermaid Sound, via a discharge line and discharged from the export jetty. As the seawater used is intended to be untreated (that is, no chemicals added), ecological effects from this operation are likely to be negligible. A diffuser or energy dissipation device will be added to the end of the discharge line to minimise any potential physical impacts associated with the discharge activity (such as resuspending seabed sediments).

In the event that the planned hydrotest methodology for the onshore storage tanks is modified and treatment to hydrotest water (potable or seawater) is required, a risk assessment will be undertaken at the time to determine the significance of environmental and social effects associated with discharging into the nearshore marine environment. Based on the outcomes of the risk assessment, additional mitigation measures may be developed and implemented to reduce the residual risk to as low as reasonably practicable. These measures include selection of low toxicity chemicals as a pre-requisite for any treatment additives. Criteria to be used in the risk assessment will include the environmental quality management framework (Pilbara Coastal Water Quality Consultation Outcomes report, 2006).

At this stage, the proponent considers it unlikely that a hydrotest methodology requiring treatment of hydrotest water will be required. In the event that chemicals are added, discharge will require careful control to ensure adequate dilution (matched to the concentration, biodegradability and toxicity of chemicals selected) is achieved within a small area of influence around the jetty structure.

4.2 Performance Specifications of the Treatment Plant

The performance specifications of the treatment plant for removing the contaminants anticipated in the discharge is required since the table of predicted concentrations is not justified. If this is not possible then the performance characteristics of similar technology being used elsewhere could be provided to estimate likely waste water discharge quality. (It is also noted that the predicted metal concentrations will exactly meet the guidelines for high protection at the edge of a notional mixing zone. The proponent should endeavour to ensure that levels of contaminants in the discharge are such that concentrations are significantly below guidelines for high protection at the edge of the mixing zone to provide a safety margin.).

Proponents Response

Table 4 of the Supplement provides expected treated effluent quality parameters for the Pluto waste water treatment plant, following biological treatment via a membrane bioreactor. It should be noted these are 'typical' levels and values stated represent an assessment of what should be achievable based upon the use of best available technology and reported values from other comparable industrial facilities. Detailed design is yet to be finalised and levels are also subject to confirmation from waste water treatment vendors.

While predicted maximum metal concentrations will exactly meet the guidelines for high protection at the edge of the notional mixing zone 100% of the time (for 0.5% waste water), concentration of the metals will be less than half this for 95% of the time (for 0.21% waste water; refer to **Figure 13**). This is equivalent to the statistical requirement that the 95th percentile toxicant concentrations at an impact site must not exceed the guideline for that toxicant. It should also be noted that these predictions are based on worse case conditions for dilution (transitional season and neap tide) and that greater dilution are expected outside of these wind and tide combinations. Other conservatisms that need to be considered include:

- no weathering or reaction processes included in model (although this is not expected to be relevant for initial dilution outcomes)
- the modelling has been based on a maximum flow rate which is unlikely to be maintained for extended periods of time and furthermore, is not likely to be attained until several years after the as-built characteristics of the treatment package are tested and understood and WET results on the treated waste water discharge are available.

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4.3 MEG and aMDEA

Toxicity information is required for MEG and aMDEA (the toxicity classification from Hinwood et al (1994) is not sufficient. What data was this based on? and does it relate to humans, mammals, insects, fish, aquatic plants, etc?

Proponents Response

The process chemical aMDEA is commonly used in gas processing and is the activated form of methyldiethanolamine (MDEA) (CAS# 105-59-9). It is 100% miscible in water (at 20 ^{o}C) and is classed as readily biodegradable. Toxicity studies indicate that MDEA and aMDEA biodegrade relatively rapidly in water (refer to **Table 15** and **Table 16**). This chemical is discharged at the existing Karratha Gas Plant at an average concentration of <15 mg/L and an annual load of <1064 kg/year in 2005/06.

Monoethlylene glycol (MEG) is used to prevent hydrate formation in pipelines. Studies have previously been conducted to assess the biodegradation of MEG in the existing environment. Price *et al*. (1974) assessed the biodegradation of ethylene glycol in salt water over a 20-day incubation period. Concentrations of up to 10 mg/l of ethylene glycol were used resulting in 20% degradation after 5 days and 77% after 20 days (Price *et al* 1974). Similar to aMDEA, MEG is also 100% miscible in water (at 20 ^{o}C) and is classed as readily biodegradable.

Toxicty information for aMDEA and MEG are provided in **Table 17** to **Table 19**. No ecological or social impacts are expected based on the available toxicity information for the concentrations of aMDEA (<1 mg/L) and MEG ((<1 mg/L) expected in the discharge.

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- **Table 15 Biodegradability of MDEA/aMDEA (all data from European Chemicals Bureau (2000)**

Method*	Test Substance	Type of Test	Inoculum	Degradation
OECD Guideline 301 A	MDEA	Aerobic – Ready biodegradability	Activated sludge	96% after 18 days
OECD Guideline 301 C	MDEA	Aerobic – Ready biodegradability	Activated sludge	79% after 28 days
OECD Guideline 302 A	aMDEA	Aerobic – Inherent biodegradability	Activated sludge, adapted	94% after 7 days
OECD Guideline 302 B	aMDEA	Aerobic – Inherent biodegradability	Activated sludge, adapted	96% after 14 days
OECD Guideline 302 B	MDEA	Aerobic – Inherent biodegradability	Washed activated sludge from sewage works	92% after 11 days

*OECD guidelines refer to the Organisation for Economic Co-operation and Development Guidelines for the Testing of Chemicals and are a collection of the most relevant internationally agreed testing methods used by government, industry and independent laboratories to assess the safety of chemical products (refer to http://www.oecd.org/dataoecd/38/2/5598432.pdf for further information).

- **Table 16 Harmonised Offshore Chemical Notification Format (HOCNF) Biodegradation Classifications**

HOCNF Classification	Biodegradation in 28 days
Readily biodegradable	>60%
Inherently biodegradable	>=20% & <=60%
Not biodegradable	<20%

- **Table 17 Summary of Ecotoxicity Results for aMDEA**

Common Name	Scientific Name	Exposure Period	EC, LC or NOEC (mg/L)	Test Substance	Method/Remarks
Fish					
Rainbow Trout	*Oncorhynchus mykiss*	96 hr	LC0 320; LC50 762	MDEA	semistatic
Ide (freshwater)	Leuciscus idus	96 hr	NOEC 460; LC50 >1000	MDEA	static
Fathead minnow (freshwater)	*Pimephales promelas*	96 hr	LC50 >1000 NOEC 500-600*	aMDEA	
Crustaceans					
Daphnia	*Daphnia magna*	24 hrs 48 hrs	EC0 250; EC50 400; EC100 >500 EC0 125; EC50 230; EC100 500	aMDEA	
Algae					
N/A	*Scenedesmus subspicatus*	72 hrs 96 hrs	EC50 37; EC20 11; EC90 >100 EC50 20; EC20 7.4; EC90 90	aMDEA	Alga test in accordance with UBA
Bacteria					
Activated sludge, industrial	N/A	30 mins	EC10 >1000 – No inhibition of respiration of the adapted activated sludge up to 1000 mg/L.	aMDEA	ISO 8192 “Test for inhibition of oxygen consumption by activated sludge”
N/A	*Pseudomonas putida*	17 hrs 16 hrs	EC10 270; EC50 410; EC90 820 TGK (Toxicity Threshold Concentration) = 11800	aMDEA aMDEA	Bacterial growth inhibition test – DIN 38412/8 design Cell multiplication inhibition test

All data from European Chemicals Bureau (2000) except * taken from Alpha (2003)

- **Table 18 Summary of Ecotoxicity results for Mono-ethylene Glycol**

Common Name	Scientific Name	Exposure period	LC0, LC50, LC100 or NOEC (mg/L)
Crustaceans			
Common shrimp, sand shrimp	*Crangon crangon*	48 hrs 96 hrs	LC50 100,000 LC50 50,000
Crayfish	*Procambarus*	96 hrs	LC50 91,430
Fairy shrimp	*Streptocephalus proboscideus*	24 hrs	LC50 54,497
Fish			
Goldfish	*Carassius auratus*	24 hrs	LC50 >5,000
Bluegill	*Lepomis macrochirus*	96 hrs	LC50 >10,000
Carp	*Leuciscus idus melanotus*	24 hrs 48 hrs	LC0, LC50 & LC100 >10,000 LC0, LC50 & LC100 >10,000
Rainbow trout	*Oncorhynchus mykiss*	96 hrs	LC50 41,000
Medaka, high-eyes	*Oryzias latipes*	24 hrs 48 hrs	LC50 >1,000 LC50 >1,000
Fathead minnow	*Pimephales promelas*	24 hrs 96 hrs 7 days (growth) 7 days (mortality)	LC50 >10,000 LC50 72,860 NOEC 15,380 NOEC 32,000
	Poecilia reticulata	96 hrs 7 days	LC50 16,000 LC50 49,300
Zooplankton			
Brine shrimp	*Artemia salina*	24 hrs	LC50 >20,000
Brine shrimp	*Artemia sp.*	24 hrs	LC50 20,000
Rotifer	*Brachionus calyciflorus*	24 hrs	LC50 117,933
Rotifer	*Brachionus plicatilis*	24 hrs	LC50 149,589

Common Name	Scientific Name	Exposure period	LC0, LC50, LC100 or NOEC (mg/L)
Water flea	*Ceriodaphnia dubia*	48 hrs	LC50 (20C) 22,600 – 29,700
		48 hrs	LC50 (24C) 6,900 – 13,900
		3 broods control (growth)	NOEC 8,590
		3 broods control (mortality)	NOEC 24,000
Water flea	*Daphnia magna*	24 hrs	LC50 >10,000
		48 hrs	LC50 48,342

All data from Pan Pesticides Database (2006) and The World Health Organisation (2000)

- **Table 19 Algal Ecotoxicity results for Monoethylene Glycol**

Common Name	Scientific name	End point	Concentration (mg/L)
green algae	*Scenedesmus quadricauda*	7 day toxic threshold	>10,000
green alga	*Selenastrum capricornutum*	96-h EC_{50} (growth, cell counts)	6,500-7,500
		96-h EC_{50} (growth, cell volume)	9,500-13,000
		168-h EC_{50} (growth, cell volume)	24,000
Cyanobacteria	*Microcystis aeruginosa*	biomass	2,000

All data from Pan Pesticides Database (2006) and The World Health Organisation (2000)

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4.4 Wastewater Outfall and Dilutions

The number of dilutions required for the outfall is not known because there are no toxicity data for the effluent, therefore it is important that conservatism is built into the design and a high level of initial dilution is achieved. If the number of dilutions required to meet a high level of ecological protection can be determined with some confidence, then the proponent should model the spatial footprint around the outfall where the required dilutions would be exceeded 95% of the time. (This is equivalent to the statistical requirement that the 95th percentile toxicant concentrations at an impact site must not exceed the guideline for that toxicant.).

Proponents Response

The simulation of wastewater discharges in the Draft PER uses both a near field and far field model. The far field model takes into consideration the potential for recirculation of the discharged plume over the discharge location and the results are therefore more conservative than the near field results. The 95th percentile values (that is, the non-exceedence concentrations for 95% of the time) for the maximum concentrations at 25 and 50 m from the discharge location are 0.27% (364 dilutions) and 0.21% (458 dilutions), respectively (see **Figure 12** and **Figure 13**). It should be noted that these figures represent worse case conditions for dilution (transitional season and neap tides). These values are well below the indicative PNEC of 0.5%.

The far field model operates on a 25 m grid and therefore to understand resolution below this size, the near field modelling results must be examined. Near-field modelling results presented in the supplement document indicated that the required dilutions to achieve a PNEC of 0.5% will be met (100% of the time) at approximately 10 m from the discharge point. It is considered that further interrogation of the near-field model to determine the number of dilutions required to meet 95% of the time would not provide any additional or meaningful information at this point in time given that the PNEC value is indicative only. However, the proponent commits to undertaking this spatial interrogation once a PNEC for the actual effluent has been established.

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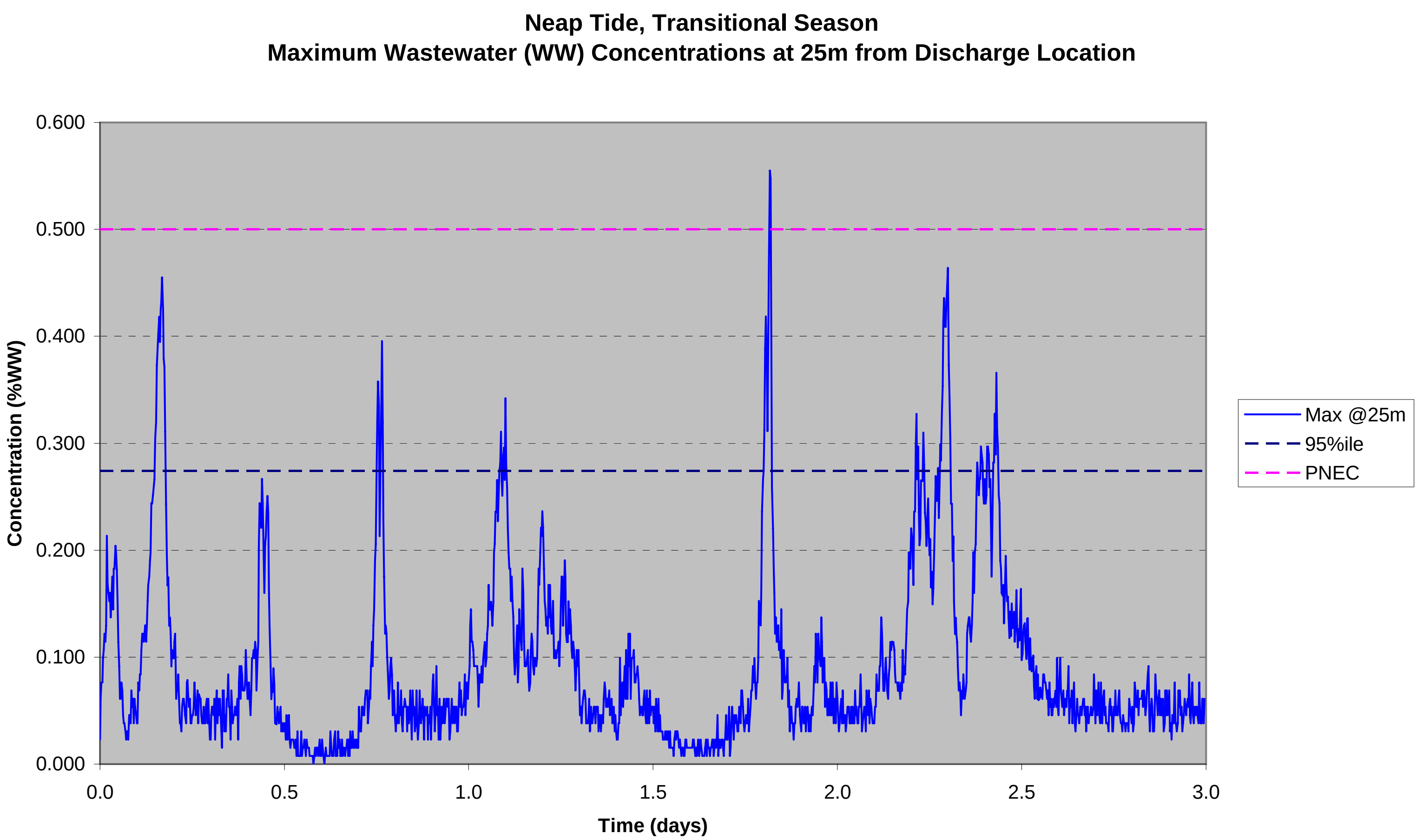
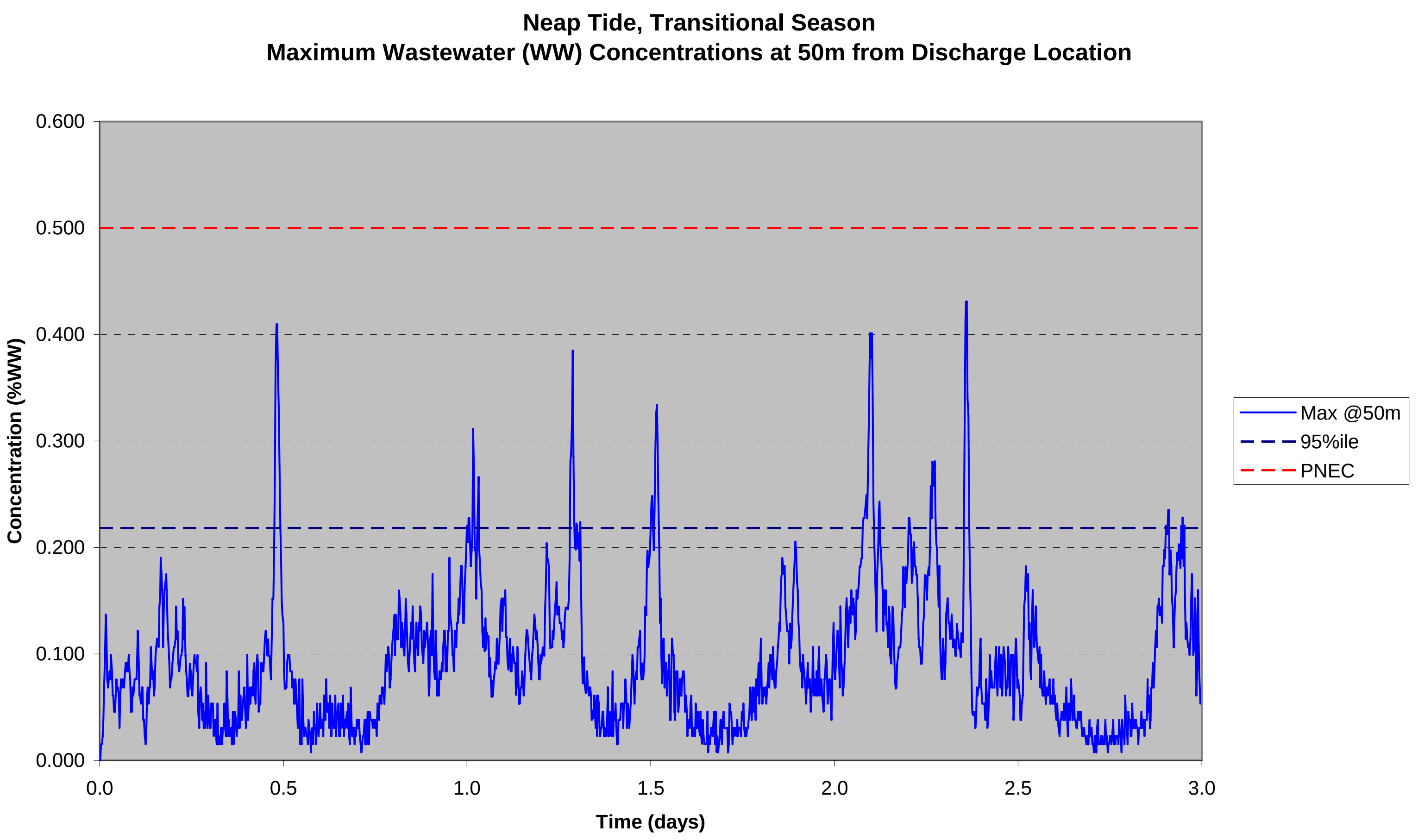


- **Figure 12 Maximum Waste Water Concentrations at 25 m from the Discharge Concentration**



- **Figure 13 Maximum Waste Water Concentrations at 50 m from the Discharge Concentration**

4.5 Environmental Values/Environmental Quality Objectives

The outfall also needs to be considered within the context of the other environmental values/environmental quality objectives that relate to social uses and that apply to the area (maintenance of seafood safe for eating, recreation and aesthetics and industrial water supply. The EPA has an expectation that these environmental values will be protected everywhere and will only consider removal of a value from small areas where the need is well justified and there is community acceptance. (Note: for recreation the main issue is likely to be bacterial concentrations from sewage and grey water).

Proponents Response

The environmental values/environmental quality objectives that relate to social values were previously addressed in Table 5 of the supplement and are further addressed in **Table 20** below.

Based on current waste waster treatment system performance specifications, the treated waste water discharge at the end of the jetty will not result in exceedances of environmental quality criteria for fishing, aquaculture, recreation, aesthetic, industrial or spiritual values. It should be noted also that none of these activities will be permitted to be undertaken in the vicinity of the outfall given its proximity to the proposed jetty and LNG berthing facilities. Should the performance specification of the waste water treatment system change during future detailed design, social values will be maintained. Potential impacts to social values are not expected from the discharge of wastewater into Mermaid Sound

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- **Table 20 Assessment of Discharge Against Social Values**

Environmental Value (EV)	Environmental Quality Objective (EQO)	Proposed EQC	Environmental Quality Guideline/Standard (EQG or EQC)	Assessment of Treated Waste Water Discharge
Fishing and Aquaculture	Seafood for Human Consumption	▪ Thermotolerant faecal coliforms in water ▪ Thermotolerant faecal coliforms in fish flesh ▪ Metals and organics in fish flesh	▪ EQG: The median thermotolerant faecal coliform bacterial concentration should not exceed 14 CFU/100 mL, with no more than 10% of the samples exceeding 21 CFU/100 mL measured using the membrane filtration method. ▪ EQS: Fish destined for human consumption should not exceed a limit of 2.3 MPN *E. Coli* /g of flesh (wet wt.) in four out of five representative samples, and the fifth sample should not exceed 7 MPN *E. Coli* /g, with a maximum total plate count of 250 000 organisms/g. ▪ EQG: A range of metals and organics have environmental quality	Thermotolerant faecal choliform concentrations at end of pipe are not expected to exceed 10 CFU/100 mL. Concentrations will be monitored as part of the waste water management plan. Wastewater will be treated to a very high specification so that biological contaminants, metals, organics and other potential contaminants are highly unlikely to bioaccumulate or otherwise impact on the quality of seafood for human consumption.

Environmental Value (EV)	Environmental Quality Objective (EQO)	Proposed EQC	Environmental Quality Guideline/Standard (EQG or EQC)	Assessment of Treated Waste Water Discharge
			guidelines for levels in fish flesh.	
	Aquaculture	▪ Metals, inorganics and pesticides in water ▪ Dissolved oxygen ▪ pH	▪ EQG for toxicants: The 95th percentile of the sample concentrations from the area of concern (either from one sampling run or all samples over an agreed period of time, or from a single site over an agreed period of time) should not exceed the environmental quality guideline value. ▪ EQG for physio-chemical stressors: The median of the sample concentrations from the area of concern (either from one sampling run or all samples over an agreed period of time, or from a single site over an agreed period of time) should not exceed the following environmental quality guideline values. ▪ Dissolved Oxygen ≥5 mg/L ▪ pH 6-9	EQGs for potential toxicants of concern (ammonia and heavy metals) for a high protection of the marine ecosystem are more stringent than those for aquaculture values (with the exception of zinc) and will therefore be protected through adherence to the ecosystem EQGs. Aquaculture EQGs for metals (including zinc) will be met within a few meters of the discharge point. It should be noted that there are presently no active aquaculture leases in Mermaid Sound and that an exclusion zone of 50 m will apply around the jetty/outfall. It is therefore highly unlikely that any future aquaculture ventures established in close proximity to the discharge point will be impacted. Dissolved oxygen and pH levels at end of pipe are highly unlikely to vary significantly from background levels for these parameters.

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Environmental Value (EV)	Environmental Quality Objective (EQO)	Proposed EQC	Environmental Quality Guideline/Standard (EQG or EQC)	Assessment of Treated Waste Water Discharge
Recreation and aesthetics	Primary contact recreation values	■ Faecal Pathogens ■ pH ■ Water clarity ■ Toxic Chemicals – a range of chemicals including metals, inorganics and organics.	■ EQG: Faecal Pathogens: The 95%ile bacterial content of marine waters should not exceed 200 enterococci/100mL ■ EQS: The median of the sample concentrations from the area of concern (either from one sampling run or from a single site over an agreed period of time) should not exceed the range of 5 – 9 pH units. ■ EQG: To protect the visual clarity of waters used for swimming, the horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m. ■ EQG: Toxic Chemicals – The 95%ile of the sample concentrations from the area of concern (either from one sampling run or	Thermotolerant faecal choliform concentrations at end of pipe are not expected to exceed 10 CFU/100mL. It is considered unlikely that discharged wastewater will cause faecal pathogens to exceed 200 enterococci/100mL in the vicinity of the discharge. pH levels at end of pipe are highly unlikely to vary significantly outside of the EQS. Water clarity is highly unlikely to be impacted by the treated waste water discharge. EQGs for potential toxicants of concern (metals) for a high protection of the marine ecosystem are more stringent than those for primary contact recreation values (except for Benzene – see below) and will therefore be protected through adherence to the ecosystem EQGs. Primary contact recreation EQGs for metals will be met immediately after discharge. Expected concentrations for benzene will be well below the primary recreation EQG (0.02 mg/L), immediately after discharge. It should be noted that a 50 m exclusion zone will apply to the jetty and turning basin. Primary contact recreation activities will therefore not be permitted in the vicinity of the discharge point.

Environmental Value (EV)	Environmental Quality Objective (EQO)	Proposed EQC	Environmental Quality Guideline/Standard (EQG or EQC)	Assessment of Treated Waste Water Discharge
			from a single site over an agreed period of time) should not exceed the environmental quality guideline values.	
	Secondary contact recreation values	▪ Faecal pathogens ▪ pH ▪ Toxic chemicals	▪ EQG: The 95%ile bacterial content of marine waters should not exceed 2000 enterococci/100mL. ▪ The median of the sample concentrations from the area of concern (either from one sampling run or from a single site over an agreed period of time) should not exceed the range of 5 – 9 pH units. ▪ Water should contain no chemicals at concentrations that can irritate the skin of the human body.	Thermotolerant faecal choliform concentrations at end of pipe are not expected to exceed 10 CFU/100mL. It is considered unlikely that discharged wastewater will cause faecal pathogens to exceed 2000 enterococci/100mL in the vicinity of the discharge. pH levels at end of pipe are highly unlikely to vary significantly outside of the EQS. Secondary contact recreation activities will not occur within the vicinity of the waste water discharge, nevertheless the treated waste water is highly unlikely to contain chemicals at concentrations that can irritate the skin of the human body.

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Environmental Value (EV)	Environmental Quality Objective (EQO)	Proposed EQC	Environmental Quality Guideline/Standard (EQG or EQC)	Assessment of Treated Waste Water Discharge
	Aesthetic Values	Water Clarity Fish Tainting Substances – large range of chemicals implicated in fish tainting – related to concentration in water column.	▪ The natural visual clarity of the water should not be reduced by more than 20% ▪ The 95%ile of the sample concentrations from the area of concern (either from one sampling run or all samples over an agreed period of time, or from a single site over an agreed period of time) should not exceed the environmental quality guideline values.	It is highly unlikely that treated waste water will result in impact on water clarity or fish flesh quality relevant to aesthetic values given the high level of treatment of the waste water proposed.
Cultural and Spiritual	Maintenance of cultural and spiritual values	No guidelines are relevant to the area within the vicinity of the discharge for cultural and spiritual values	No guidelines are relevant to the area within the vicinity of the discharge for cultural and spiritual values	No impacts are expected from the discharge of treated waste water on cultural and spiritual values.
Industrial Water Supply	Maintenance of industrial water supply values	No guidelines are relevant to the area within the vicinity of the discharge for industrial water supply values	No guidelines are relevant to the area within the vicinity of the discharge for industrial water supply values	No impacts are expected from the discharge of treated waste water discharge on industrial water supply values.

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4.6 Mixing Zone

The proposed mixing zone is larger than necessary. The modelling shows that it could be reduced to 20m diameter. Modelling shows the zone of initial dilution generally within 10m of the outfall (Figure 3 of the Response to Submissions).

Proponents Response

It is noted that Figure 3 of the Supplement is an output from near-field modelling and as stated earlier, does not account for recirculation of the plume. The size of the proposed mixing zone, needs to be considered in conjunction with the outputs from far field modelling (for example Figure 4 of the Response to Submissions) which indicates concentrations of waste water up to, but not exceeding, approximately 0.43% at 50 m from the discharge location. It is acknowledged that the mixing zone could potentially be reduced in size; however, a 50 m diameter zone is considered to provide a sufficient degree of conservatism given that the toxicity of the effluent has yet to be determined. The proponent remains committed to reducing the size of the mixing zone where results from WET testing and improvements in diffuser design allow (refer to **Section 4.2** for further discussion).

4.7 Framework Waste Water Management Plan

Table 6 of the Response to Submissions contains a framework for waste water management. It includes a commitment to undertaking WET testing of the waste water as soon as it becomes available and periodically after that. The proponent should make a commitment to undertake WET testing of the waste water as soon as waste water becomes available), one month after commissioning and annually thereafter or after a change in the composition of the waste water.

Response

Proponent acknowledges this comment. The Framework Waste Water Management Plan (originally provided in Table G-3 in **Appendix G** of the Draft PER and subsequently revised in the Response to Submission document) has been revised below. Revisions are shown highlighted (in red text) below.

- **Table 21 Framework Waste Water Management Plan**

Waste Water Management Plan Format	
Management Issues	The discharge of waste water may result in marine physical and ecological effects including reduced water quality and toxicity effects to marine biota.
Objectives	To comply with applicable legislation and guidelines. To minimise the potential for adverse impacts on water quality.
Performance Indicators	Performance indicators will be developed consistent with relevant regulatory, local and Development requirements
Management Strategies	▪ The residual total hydrocarbon in water concentration of waste water discharge will be less than 5 mg/l as an annual average for water discharged to Mermaid Sound. ▪ Other measures employed to reduce the potential for environmental impact associated with waste water disposal are process design, procedures for chemical selection, dosing rates and operational maintenance and control of production equipment. ▪ Woodside will put in place reduction targets and mitigation measures should the results of monitoring and/or investigations indicate a potential or actual unacceptable impact. ▪ WET testing on actual treated waste water will be undertaken as soon as first water becomes available, one month after commissioning and annually thereafter or after a significant change in the composition of the treated waste water. Routine monitoring to ensure discharged waste water meets specified criteria. ▪ Construction amenities will be regularly inspected and maintained, and effluent will be disposed of offsite at an appropriate facility. ▪ During operation, approved sewage systems will be provided at Site B. ▪ An appropriate monitoring and maintenance schedule for the sewage treatment system at Site B will be developed and implemented. ▪ The oil-in-water meter will be regularly tested and calibrated as per acceptable standards to ensure its accuracy. ▪ The concentration of total hydrocarbon in waste water discharged to Mermaid Sound will be measured daily. ▪ A contingency plan will be developed to manage waste water in cases where unexpected volumes and/or quality of waste water are produced.
Monitoring	Monitoring of waste water will occur at source prior to commingling and at the discharge point. Waste water will be monitored in accordance with regulatory requirements and will include monitoring of discharge rates. A comprehensive monitoring programme will be put in place to confirm the prediction of no significant impact to nearshore communities and to ensure contaminants are not bio-accumulated by marine organisms. This will include agreed ‘threshold values’ for initiation of further studies and remedial actions as necessary. Monitoring will confirm that an appropriate level of ecological protection is being achieved at the edge of the agreed mixing zone. The concentration of total hydrocarbon in waste water discharged to Mermaid Sound will be measured daily. Routine monitoring to ensure treated waste water meets the EQMF social use values at end of pipe or within a distance, from point of discharge, agreed with the relevant authorities.
Reporting	Reporting procedures consistent with regulatory, local and Development requirements will be developed.

5. General Comments

5.1 Dredging Management Strategies

Given the level of uncertainty over the level of potential impacts from both the dredging and the waste water discharge it is important that as part of the EPA assessment process the proponent research and commit to effective management strategies for managing any unanticipated impacts from these two activities (e.g. Dredge rest periods, no overflow from barges, additional dilution built into the discharge diffuser).

Proponents Response

Dredging

A Framework Dredging and Spoil Disposal Management Plan (Framework DSDMP) for managing dredging and spoil disposal activities was presented in the Draft PER (Appendix I of the Draft PER). The purpose of the framework DSDMP was to provide Woodside, stakeholders and regulatory authorities with the level of assurance that predicted environmental impacts will be reduced to as low as reasonably practicable and that dredging activities are conducted in a manner consistent with Woodside's Environmental Policy.

Under the above Framework Plan, three stages of management strategies will be applied to minimise the environmental impact of dredging works. These are:

- Project design stage strategies – Designing the work to minimise the scope of dredging and avoid direct habitat losses.
- Active management strategies – Measures implemented throughout the dredging works.
- Reactive management strategies – Measures implemented on the basis of threshold limits.

The Framework DSDMP includes examples of protection and mitigation measures that will need to be considered as well as strategies that have been identified to minimise generation of turbidity from dredging and dredge spoil disposal. The environmental management approach and associated measures will be further developed in consultation with the DEC and the dredging contractor; and will be presented in the final DSDMP.

Waste water

Waste water diffusion modelling was based on a preliminary discharge diffuser design. Woodside commits to further work during the detailed design in improving the diffuser effectiveness. Possible improvements relating to port diameter, spacing and discharge rate will be investigated and it is considered likely that increased dilution can be achieved.

5.2 Comment on Revised Pluto LNG Development Dredging Simulation and Impact Assessment

The comment at the bottom of page 9 is noted: 'It also follows that, if the dredging contributes increased quantities of fine sediments to the seabed of Mermaid Sound, the long-term influence of this dredging programme (and previous dredging undertaken by Woodside and others) could be increased turbidity response to wave action.' This comment would also hold for more localised areas around a dredging or dumping site (ie. the longer the activity continues the greater the quantity of fine sediment available for resuspension).

Proponents Response

Results of the modelling indicate, as expected, that management of fines discharge will critical to minimising impacts of the dredging and disposal. Hence procedures that reduce fines discharge or direct the discharge from the Sound would reduce the potential impact.

Reworking of fines from many sources, including suspension by wind-waves and storms, seasonal run-off and shipping traffic is an existing condition. The field data (MScience 2007) indicate that BPPs at reef sites experience and tolerate variations in SSC and sedimentation. It is reasonable to expect that some of the fines that contribute to existing patterns were disturbed by dredging at some time as previously argued. The key to the significance of this source would be the magnitude and pattern of the contribution. The intensity-duration-frequency patterns of SSC and sedimentation that have been observed in the field data have been used to judge levels that are tolerable.

5.3 Spoil Disposal Into Offshore Spoil Ground 2B

It is important to note the prediction that spoil disposal into the offshore spoil ground 2B will result in elevated turbidity around coral habitats near the entrance to Mermaid Sound and that there will be a general southward movement of the fine sediments into Mermaid Sound and the Dampier Archipelago.

Proponents Response

The simulations under winter waves do indicate that uncovered fines will be disturbed from the offshore spoil ground 2B. Under winter currents (chosen as the worst-case), a net southward migration was predicted. This tended to raise SSC and to a lesser extent, sedimentation rates for reef locations around the entrance to Mermaid Sound. A low increase in net sedimentation was indicated due to the relatively high wave-energy affecting this zone. The threshold analysis considers the significance of the predicted levels of SSC and sedimentation.

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5.4 Predicted Cumulative Coral Loss

Under the coral impact assessment for Holden Point (Section 4.1.1) there appears to be an error in the calculations for predicted cumulative coral loss resulting from the revised model. It is predicted that cumulative coral loss increases from 42% to 43% (an increase of 1%), however, by scanning figures 2 and 3 it appears that the likely increase in area of coral loss is in the ballpark of 7 - 10%.

Proponents Response

In response to the point raised above, the calculations for predicted coral loss were checked for potential errors. The values for predicted cumulative coral loss resulting from the revised modelling work are correct and loss increases 42% to 43%, using the original estimate of historical loss (18.6%) and the original threshold levels for sedimentation used in the draft PER. These calculations produce an increase in the estimate of potential corals loss of 1%.

The sensitivity analysis of the sedimentation threshold predicts the loss footprint (i.e. the area of the plume under which corals may be potentially lost) would increase from 43 to 46%, a relatively small increase in area when the threshold was halved. The estimates have been checked and are also confirmed as correct.

It is noted that Section 4.1.1 of the Revised Pluto LNG Development Dredging Simulation and Impact Assessment Report (May 2007), incorrectly states that the revised loss estimate associated with the additional, revised modelling uses the same baseline coral distribution data as were presented in the Draft PER (Figure 4 of the Revised Dredging Simulation and Impact Assessment – May 2007 corresponding to **Figure 14** below). The loss footprint calculations for the revised modelling (Figure 5 of the Revised Dredging Simulation and Impact Assessment – May 2007 corresponding to **Figure 15** and **Figure 16** below) are actually based upon more recent baseline coral distribution data compared to the data presented in the Draft PER. The more recent coral distribution data includes an area of coral habitat identified in Withnell Bay. This additional coral habitat was taken into consideration in above revised coral loss estimates and is the reason why the revised figure for overall coral loss increases by about 1% and not 7-10%.

The areas and percentages used in the calculations that produced the maps of predicted loss depicted in Figure 15 are the original historical loss estimate and the original threshold level and in Figure 16 the sensitivity analysis uses half the original threshold level.

Comparison of the estimates discussed here with the estimates shown in Table 9 in section 2.1 could be confusing, but the apparent disparity in amounts and percentages is easily explained.

In Table 9 of this document the original historical loss estimate used in the draft PER has been now been revised downward slightly from 18.6% to 17.48% because the new distributional data for corals provided by MScience showed that some of the area where corals had been assumed to be lost, actually has some coral cover.

When the revised historical loss estimate of 17.48% is used, then the calculation of potential cumulative loss for the case in the revised modelling where the original threshold is used produces an estimate of 42.5% (revised 100% threshold), which is virtually the same as that predicted in the draft PER.

The revised modelling work undertaken for the Revised Dredging Simulation and Impact Assessment – May 2007 also produced a sensitivity analysis where the original threshold was reduced to 50% of its level and that generated a potential cumulative loss of 45.1%, an increase over the draft PER estimate of 2.6% (see Table 9 in section 2.1).

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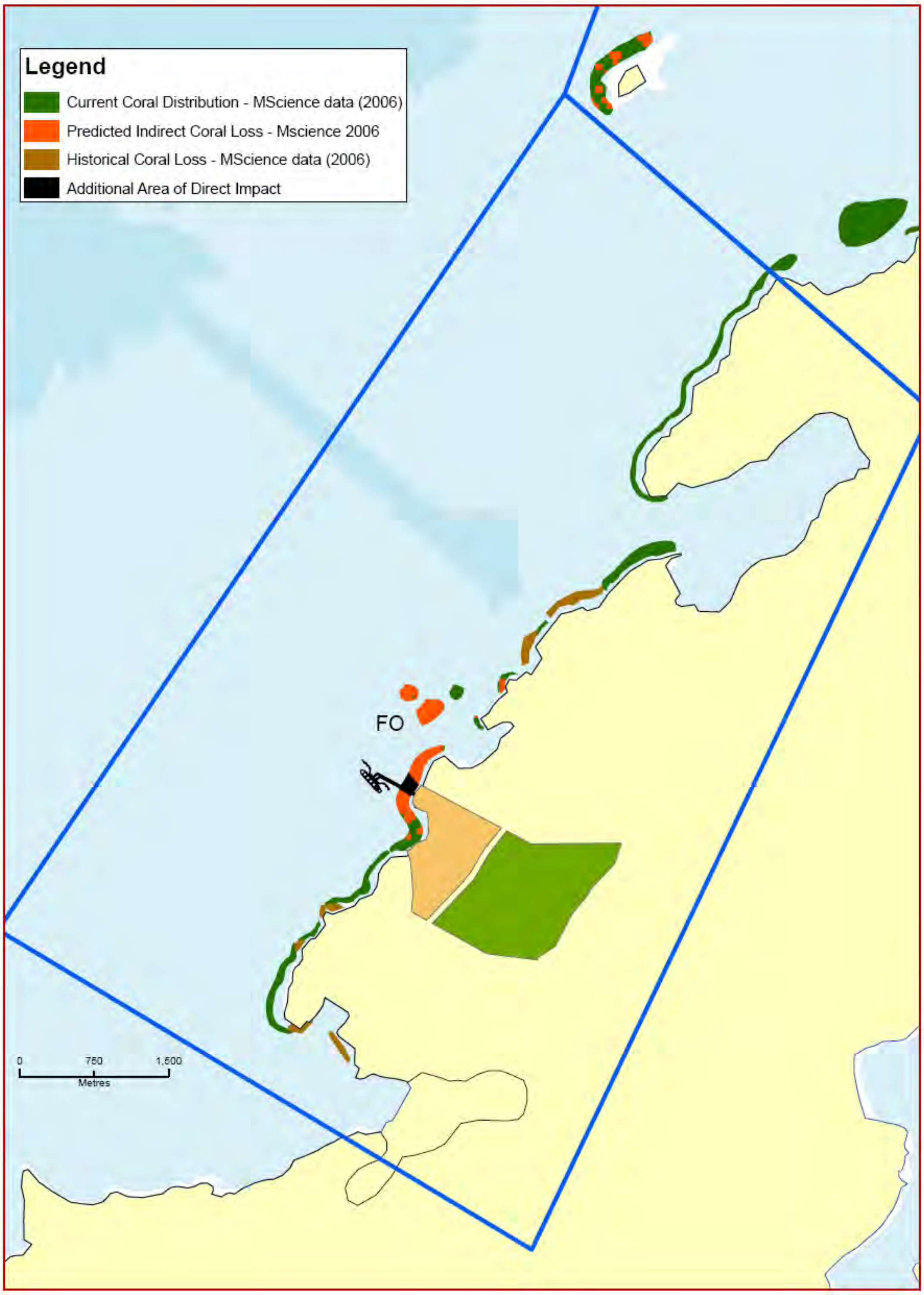
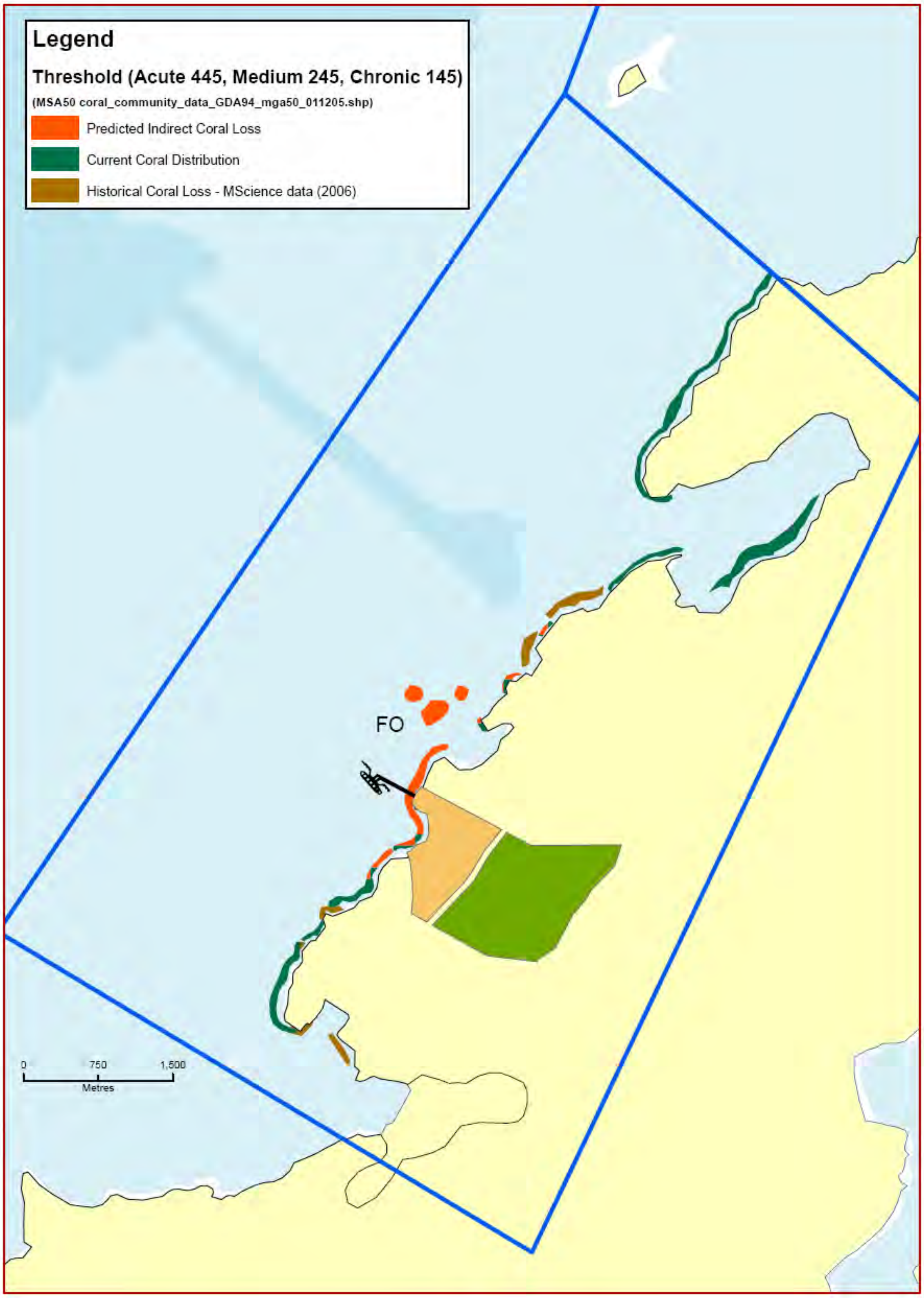


- **Figure 14 Draft PER Loss Predictions (Figure 4 from Revised Dredging Simulation and Impact Assessment – May 2007)**



- **Figure 15 Revised Loss Predictions (Figure 5 from Revised Dredging Simulation and Impact Assessment – May 2007)**

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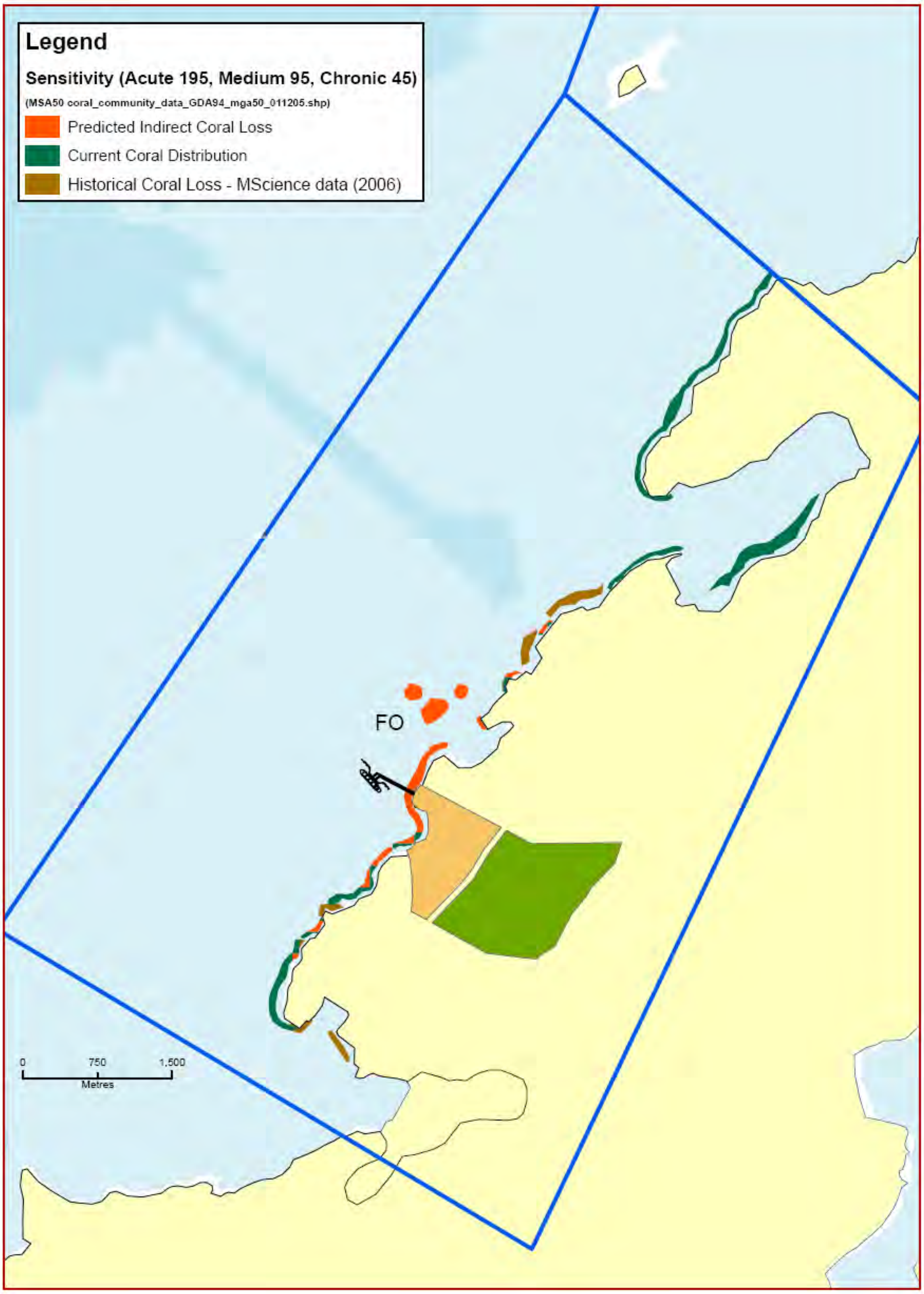

- **Figure 16 Loss Predictions from Sensitivity Analysis (Figure 5 from Revised Dredging Simulation and Impact Assessment – May 2007)**

5.5 Level of Sedimentation

The statement in Section 4.1.1: '…. The model indicates that dredging for longer (than the simulated 6 weeks) will probably not increase the level of sedimentation further than what is predicted during the 6 week simulation' is only an opinion and not supported by data. As stated in (1) above, the longer the activity continues, the greater the quantity of fine sediments likely to be available for resuspension.

Proponents Response

Proponent advises that this statement should be removed.

5.6 Vulnerable Coral Species Thresholds

The findings in the 3rd paragraph of section 4.2 and 2nd paragraph of section 4.3 support the need to develop medium-term and chronic sedimentation thresholds for vulnerable coral species as well as light attenuation thresholds and include them in the modelling.

Proponents Response

The latest outputs for further interrogation of the model findings have included within the scope of this work, the development of medium term and chronic sedimentation thresholds based upon the baseline data and drawing upon the methodology proposed by McArthur (2002).

The rationale for the selection of threshold values is explained in detail in **Section 2.1** and **2.2** and a detailed analysis of the results of the new interrogations is also presented in those sections of the document.

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6. References

Airoldi, L. 2003. The effects of sedimentation on rocky coast assemblages. *Oceanography and Marine Biology: an Annual Review* 2003, **41:**161–236.

Alpha 2003. Alpha Chemical Limited, Material Safety Data Sheet. http://www.gov.ns.ca/enla/ea/alphaRockyLakeDrive/AlphaRockyLake-AddAppendE.pdf

Australian Marine Sciences Association. (AMSA) 1997. *Towards a National Marine Science Policy for Australia*. University of Queensland Press, Brisbane.

Ang Jr., P.O. 1985. Studies on the recruitment of *Sargassum spp* (Fucales: Phaeophyta) in Balibago, Calatagan, Philippines. *Journal of Experimental Marine Biology and Ecology* **(91)**, 293-301.

Asia Pacific Applied Science Associates. 2007. Pluto LNG Development Sediment Dispersion Study: Methods for Revised Dredge Modelling with Inclusion of Sediment Resuspension.

CALM 2000. Major Marine Habitats Map. Department of Conservation and Land Management, Western Australia.

Catterall, C.P., Poiner, I.R. and Kerr, J. 1992. Impact of dredging on the volute *Cymbiolacca pulchra* and its environment at Heron Island, Great Barrier Reef, Australia. *Research Publication (Great Barrier Reef Marine Park Authority) No. 17.*

Department of Environment 2006. Pilbara Coastal Water Quality Consultation Outcomes: Environmental Values and Environmental Quality Objectives. *Marine Report Series MR1 2006.*

Environmental Protection Authority (EPA). 2004. *Benthic Primary Producer Habitat Protection for Western Australia's Marine Environment. Guidance Statement No.29*. Environmental Protection Authority, Perth, WA.

Environmental Protection Authority (EPA). 2005. *Environmental Quality Criteria Reference Document for Cockburn Sound (2003 - 2004) A supporting document to the State Environmental (Cockburn Sound) Policy 2005*. Environmental Protection Authority Report 20, January 2005.

European Chemicals Bureau. 2000. IUCLID Dataset for Ethane-1, 2-diol Substance ID: 107-21-1. http://ecb.jrc.it/IUCLID-Data-Sheet/107211.pdf

European Chemicals Bureau. 2000. IUCLID Dataset for 2,2' –methyliminodiethanol CAS No. 105-59-9. http://ecb.jrc.it/IUCLID-Data-Sheet/105599

Gilmour, J.P, Cooper, T.F., Fabricius K.E and Smith, L.D. 2006. Early warning indicators of change in the condition of corals and coral communities in response to key anthropogenic stressors in the Pilbara, Western Australia Report to EPASU.

Hatcher, B..G. 1990. Coral Reef Primary Productivity: A hierarchy of pattern and process. Trends in Ecology and Evolution. **5**(5): 149-155.

Huisman, J. 2004. Marine benthic flora of the Dampier Archipelago, Western Australia. In Jones, D.S. (ed). Report on the Results of the Western Australian Museum /Woodside Energy Ltd. Partnership to Explore the Marine Biodiversity of the Dampier Archipelago, Western Australia 1998-2002 – Records of the Western Australian Museum Supplement No. 66. Western Australian Museum, Perth, pp 61-68.

Huisman, J.M. and Borowiztka, M.A. 2004. Marine benthic flora of the Dampier Archipelago, Western Australia. In: F.E. Wells, F.E., Walker, D.I. and Jones, D.S. (eds) 2003. The Marine Flora and Fauna of Dampier, Western Australia. Western Australian Museum, Perth

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world.s coral reefs Marine and Freshwater Research. **50:** 839-66

Hutchins, J.B., Slack-Smith, S., Berry, P.F. and D.S. Jones, 2004. Methodology. In: Jones, D.S. (ed). Marine biodiversity of the Dampier Archipelago Western Australia 1998-2002. Records of the Western Australian Museum, Supplement No.66: 3-5.

Jones, D.S. 2004. The Burrup Peninsula and Dampier Archipelago, Western Australia: an introduction to the history of its discovery and study, marine habitats and their flora. In Jones, D.S. (ed). *Report on the Results of the Western Australian Museum /Woodside Energy Ltd. Partnership to Explore the Marine Biodiversity of the Dampier Archipelago, Western Australia 1998-2002 –* Records of the Western Australian Museum Supplement No. 66. Western Australian Museum, Perth, pp 27-49.

Mayakun, J. and Prathep, A. 2005. Seasonal variations in diversity and abundance of macroalgae at Samui Island, Surat Thani Province, Thailand. *Songklanakarin Journal of Science and Technology* **27**(Supplement 3): 653-663.

McArthur C., Ferry, R. and Proni, J. 2002. Development of guidelines for dredged material disposal based on abiotic determinants of coral reef community structure. *Dredging '02 Proceedings of the Third Specialty Conference on Dredging and Dredged Material Disposal Coasts, Oceans, Ports, and Rivers Institute (COPRI) of ASCE May 5, 2002, Orlando, FL USA*

SKM

Morrison, P.F. 2004. A general description of the subtidal habitats of the Dampier Archipleago, Western Australia. In Jones, D.S. (ed). *Report on the Results of the Western Australian Museum /Woodside Energy Ltd. Partnership to Explore the Marine Biodiversity of the Dampier Archipelago, Western Australia 1998-2002* – Records of the Western Australian Museum Supplement No. 66. Western Australian Museum, Perth, pp 51-60.

MScience. 2005. Coral Distribution in the Port of Dampier. Unpublished report by MScience Pty Ltd for the Dampier Port Authority, MSA50R1, Dampier, WA

MScience 2007a. Pluto LNG Development: Baseline Water Quality Assessment Report April 2007. Report to Woodside Burrup Pty Ltd.

MScience 2007b. Review of Recent Dredging Projects in Dampier Harbour. May 2007. Report to Woodside Burrup Pty Ltd.

MScience 2007c. Benthic Habitats West Lewis Island Tip. Memo to Woodside Burrup Pty Ltd.

PAN Pesticides Database. 2006.
http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC34792
Price KS, Waggy GT,Conway RA (1974) Brine shrimp bioassay and seawater BOD of petrochemicals. *Journal of the Water Pollution Control Federation*, 46(1):63-77.

Raju, P.V. and R. Venugopal, 1971. Appearance and growth of *Sargassum plagiophyllum* (Mart.) C.Ag. on a fresh substratum. *Botanica Marina* **14**(1): 36–38.

Shanks, A.L, Grantham, B. and Carr, M.H. 2003. Propagule Dispersal distance and the size and spacing of Marine Reserves. *Ecological Applications*, **13**(1) Supplement, 2003, pp. S159–S169.

Semeniuk V., Chalmer, P.N. and Le Provost, I. 1982. The Marine environments of the Dampier Archipelago. *Journal of the Royal Society of Western Australia* **65**: 97-114.

Stoddart, J.A. and Anstee, S. Water Quality, plume modelling and tracking before and during dredging in Mermaid Sound, Dampier, Western Australia. In: Stoddart, J.M. and Stoddart, S.E. (eds). *Corals of the Dampier Harbour: Their survival and Reproduction during the dredging programs of 2004.* MScience on behalf of Dampier Port Authority and Pilbara Iron Pty. Ltd.

Umar, M.J., McCook, L.J. and Price, I.R. (1998). Effects of sediment deposition on the seaweed *Sargassum* on a fringing coral reef. *Coral Reefs* **17**, 169-177.

Vuki, V.C. and Price, I.R. 1994. Seasonal changes in the *Sargassum* populations on a fringing coral reef, Magnetic Island, Great Barrier Reef region, Australia. *Aquatic Botany* **48**, 153-166.

World Health Organisation. 2000. Concise International Chemical Assessment Document 22 – Ethylene Glycol: Environmental Aspects IPCS Inchem http://www.inchem.org/documents/cicads/cicads/cicad_22.htm.

Appendix A Baseline Water Quality Assessment Report April 2007 (MScience)

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PLUTO LNG DEVELOPMENT

BASELINE WATER QUALITY ASSESSMENT REPORT APRIL 2007

Report: MSA61R12

Report to:

Woodside Burrup Pty Ltd

240 St. Georges Terrace

Perth WA 6000

Australia

MScience Pty Ltd, School of Plant Biology (M090),
University of WA, Crawley, WA 6009, AUSTRALIA

Document Information

REPORT NO.	MSA61R12
TITLE	PLUTO LNG DEVELOPMENT : BASELINE WATER QUALITY ASSESSMENT REPORT APRIL 2007
DATE	17 May 2007
JOB	MSA61
CLIENT	WOODSIDE PLUTO PTY LTD Contract No. 0C00002273
USAGE	This report presents a preliminary evaluation of the Woodside Pluto water quality baseline data collected to mid April 2007 to support modelling of dredging impacts.
PRECIS	Baseline data are analysed to provide estimates of sediment load for use in worts case-best case estimates of coral mortality and estimates intensity-duration-frequency events for suspended sediments in calculating zones of impact for both robust and sensitive coral communities.
KEYWORDS	coral sediments baseline Dampier Woodside

Version-Date	Released by	Purpose
V.1- 17 May 07	JAS	Client Review
V1.1 28 May 07	JAS	Table 4 amended
V.2 30 May 07	JAS	Include client comments

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1.0 INTRODUCTION

Woodside Burrup Pty Ltd (Woodside) commissioned MScience Pty Ltd (MScience) to undertake baseline studies on sediment flux and coral community dynamics within Mermaid Sound to provide baseline information to support environmental permitting and management of the Pluto LNG Development.

Recording of data was planned to occur over the period August 2006 to mid May 2007 to provide the following data:

- Turbidity and sedimentation estimates from in situ sediment meters at 5 locations to characterise the load, duration and frequency of sedimentation events;
- Estimates of change over time in coral cover for communities acting as potential impact and reference sites during the proposed dredging;
- Sediment characteristics for various sediment types and the relationships between sediment measures (NTU, SSC and sedimentation) to evaluate potential differences in the origin of sediments settling on coral communities.

Sediment and coral monitoring sites were established in late August 2006: coral and sediment data are collected monthly. In addition, Woodside has entered into a data sharing arrangement with Pilbara Iron Pty Ltd (PI) to access data from 2 water quality loggers placed close to dredging operations occurring December 2006 – April 2007.

Surveys on the Pluto program conducted to date include:

Survey	Dates	Comment
Baseline	20-24 August 2006	Established corals transects & sediment loggers
1	18-20 Sept 2006	Monthly coral survey & logger download
2	16-20 Oct 2006	Monthly coral survey & logger download, plus recruit counts
3	14-16 Nov 2006	Monthly coral survey & logger download
4	12-14 Dec 2006	Monthly coral survey & logger download
5	9-11 Jan 2007	Monthly coral survey & logger download
6	6-8 Feb 2007	Monthly coral survey & logger download
7	5-8 Mar 2007	Monthly coral survey in part
8	2-4 Apr 2007	Monthly coral survey & logger download

2.0 DATA PROCESSING

2.1 SEDIMENT METERS

Sediment meters used were the SAS meters developed by Dr Peter Ridd of James Cook University. The meters collect optical backscatter data (OBS) from a horizontal sensor and convert this to NTUe via an internal calibration (Thomas and Ridd 2005). That data was calibrated empirically using sediments collected from adjacent to the meter to provide a way to interpolate suspended sediment concentration (SSC) in mg/L (Table 1). Meters use the differential of the OBS from the horizontal sensor and that from a vertical sensor passing through a glass plate wiped every hour to provide an estimate of accumulated sediment surface density (ASSD) in mg/cm^2/d – also called deposition here. Meters were also equipped with light sensors logging PAR. All recordings were logged on a ten minute period.

As meters are placed at the same depth as the coral communities under observation, data on OBS and SSC will only be relevant to water at that depth. Light will be integrated throughout the profile having to pass from the surface through the entire water column.

Care must be taken in comparing estimates of sediment settling (ASSD or deposition) collected from these meters with estimates from sediment traps or models. A flat glass surface which only returns estimates when free of fouling will maximise the influence of resuspension.

Table 1. Calibration of NTU & SSC by station.

Station	Calibration
ANGI	2.4535*NTU + 0
CHC4	5.3199*NTU + 0
HGPT	3.6462*NTU+ 0
MIDR	2.2056*NTU + 0
WINI	2.9757*NTU - 0.8856
TDPL	2.4169*NTU + 0
KGBY	2.2542*NTU + 0
HSHL	3.416*NTU -8.5

2.2 DATA CLEANING & VALIDATION

OBS data can suffer from periodic short spikes due to a variety of factors (such as fish) occluding the omitted signal. SSC data were cleaned by removing any point that was over 5 mg/L and greater than 1.5 times its neighbours. These points were replaced with the average of the 2 neighbours.

ASSD data were examined visually (by an experienced observer of this data from James Cook University School of Mathematical & Physical Sciences) for patterns consistent with sedimentation terminated every hour by a wiper. These readings were aggregated to provide a deposition/d rate.

2.3 SEDIMENT METERS

Sediment meters in the Pluto baseline project were placed in the field in August 2006 (Figure 1; Table 2). The ANGI meter was inadvertently placed at the HSHL site and remained there collecting data until moved in September 2006. Meters at stations TDPL and KGBY were established in November 2006 as part of the monitoring program undertaken by PI.

Several sites did not record any data for the March period as an error in resetting meters in the lead-up to Cyclone George caused some meters to stop recording.

Zones of coral community sensitivity to sediments were established on the basis of coral surveys reported in MScience (2005). Those zones were established primarily on the basis of coral taxonomy and existing literature on which coral species are likely to be more or less robust to the effects of suspended sediment, light attenuation and sedimentation.

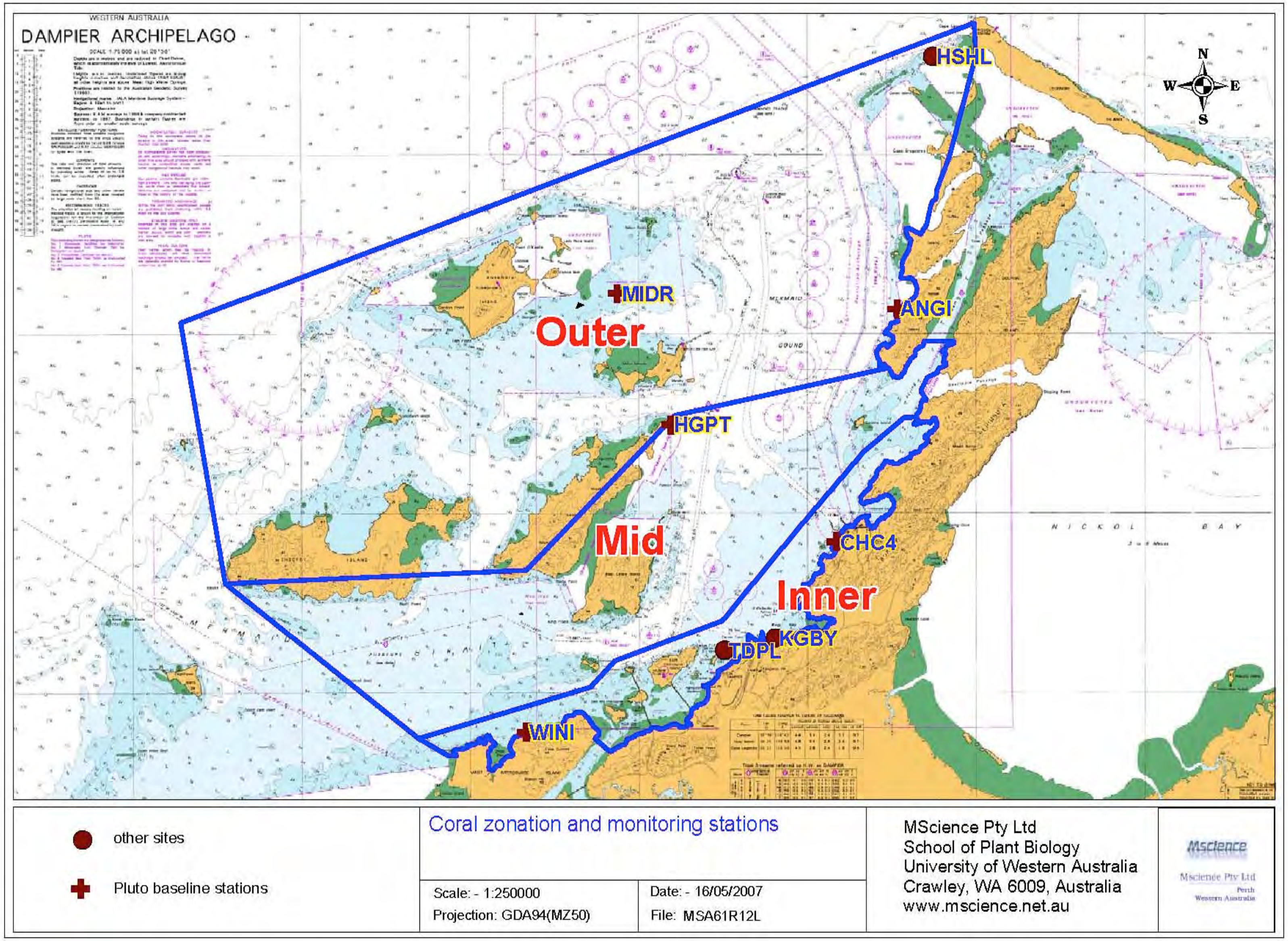
Table 2. Period of data analysed and station zone.

Station	Zone	SSC Data *	ASSD Data	Depth +
ANGI	Outer	15-Apr	Sep-Oct 06	5
HGPT	Mid	6-Mar	Oct 06	2.8
CHC4	Inner	19-Feb	Oct-Dec 06	1.9
MIDR	Outer	6-Mar	-	3.1
WINI	Inner	31-Mar	Dec 06 – Feb 07	0.3
TDPL	Inner	5-Apr	Nov 06 – Jan 07	-0.8
KGBY	Inner	4-Apr	-	0.3
HSHL	Outer	19-Sep-06	-	2.0

* recordings start in August 2006 for all stations except TDPL and KGBY which start in November 2006.

+ depth of the SAS meters is expressed a m below LAT

Figure 1. Location of sediment stations and coral sensitivity zones.



3.0 BACKGROUND DATA

3.1 SSC BASELINE DATA

Various summary statistics for the SSC data are shown in Table 2. Statistics shown in the various zones are the averages of those statistics for the relevant stations in that zone.

Table 3. Suspended sediment concentrations (mg/L) by station and zone.

Site	Mean	Median	80%ile	95%ile	99%ile	Max
ANGI	4.21	2.22	4.3	12.4	51.0	143
HGPT	3.94	2.49	4.9	11.2	29.0	233
CHC4	10.75	7.39	15.6	28.1	58.0	276
MIDR	1.66	1.46	2.2	3.9	7.6	29
WINI	7.52	2.92	9.2	33.1	65.0	160
TDPL	8.43	4.03	10.3	33.8	73.7	273
KGBY	9.28	2.48	8.6	43.1	89.4	252
HSHL	4.81	3.64	5.5	14.5	39.7	145
Inner	9.0	4.2	10.9	34.5	71.5	240
Inner (-TDPL)	9.1	5.2	12.4	30.6	61.5	218
Mid	3.9	2.5	4.9	11.2	29.0	233
Outer	3.6	2.4	4.0	10.3	32.8	106

Statistics, aside for the maximum value, are similar for both the Mid and Outer zones. The high maximum value for the HGPT appears to be real and is one of a series of high values seen over 2 days during a period of strong north-westerly winds.

Removing the site TDPL from the Inner zone reduces the potential for the values of the Inner Zone to be elevated by the effects of dredging (December – April). However, this has only a small impact on lowering the 99%ile and maximum values while raising the mean and median.

In addition to calculating summary statistics above, it is possible to calculate intensity-duration-frequency statistics for SSC levels over the period of the study. Some possible combinations are shown in Table 4. It is clear from those values that the duration of elevated SSC levels is generally quite short – with values above the 80%ile rarely sustained above periods of 1 day.

Table 4. Intensity-duration-frequency data for hours of SSC at each station.

STATION		HOURS					
ANGI	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	30	5	2	1	1	128
	20	15	2	2	2	0	50
	30	9	4	1	1	0	30
	50	8	2	0	0	0	7
	100	0	0	0	0	0	1
	80%ile						
	x1	136	12	4	3	1	180
	x2	38	8	4	1	1	128
	x5	16	2	2	2	0	46
	x10	10	2	1	0	0	19
	95%ile	14	5	3	1	1	101
HGPT	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	56	0	0	0	0	5
	20	16	0	0	0	0	4
	25	9	0	0	0	0	2
	50	2	0	0	0	0	1
	100	0	0	0	0	0	1
	80%ile						
	x1	197	9	0	0	0	11
	x2	58	0	0	0	0	5
	x5	9	0	0	0	0	2
	x10	0	0	0	0	0	1
	95%ile	43	0	0	0	0	4
MIDR	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	1	0	0	0	0	2
	20	0	0	0	0	0	1
	25	0	0	0	0	0	0
	50	0	0	0	0	0	0
	100	0	0	0	0	0	0
	80%ile						
	x1	75	18	10	3	2	6
	x2	11	2	1	0	0	4
	x5	1	0	0	0	0	2
	x10	0	0	0	0	0	0
	95%ile	17	0	0	0	0	4
CHC4	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	263	20	8	2	0	35
	20	88	1	0	0	0	7
	25	53	0	0	0	0	3
	50	3	0	0	0	0	2
	100	0	0	0	0	0	1
	80%ile						
	x1	159	2	1	0	0	12
	x2	30	0	0	0	0	3
	x5	0	0	0	0	0	1
	x10	0	0	0	0	0	1
	95%ile	37	0	0	0	0	3

STATION		HOURS					
WINI	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	135	30	13	2	0	49
	20	96	13	5	0	0	19
	30	73	4	1	0	0	16
	50	28	0	0	0	0	4
	100	4	0	0	0	0	2
	80%ile						
	x1	143	37	15	2	0	50
	x2	104	13	5	0	0	20
	x5	37	0	0	0	0	4
	x10	4	0	0	0	0	3
	95%ile	67	2	1	0	0	16
TDPL	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	96	17	8	2	1	73
	20	54	10	1	0	0	23
	25	40	4	1	0	0	22
	50	17	0	0	0	0	5
	100	4	0	0	0	0	2
	80%ile						
	x1	90	17	7	2	1	73
	x2	52	9	1	0	0	23
	x5	16	0	0	0	0	5
	x10	3	0	0	0	0	2
	95%ile	35	1	0	0	0	7
KGBY	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	95	3	0	0	0	9
	20	59	0	0	0	0	6
	25	55	0	0	0	0	5
	50	18	0	0	0	0	4
	100	5	0	0	0	0	2
	80%ile						
	x1	100	3	0	0	0	9
	x2	64	2	0	0	0	7
	x5	28	0	0	0	0	4
	x10	6	0	0	0	0	2
	95%ile	28	0	0	0	0	4
HSHL	mg/L	**1**	**6**	**12**	**24**	**72**	**MAX**
	10	6	1	1	0	0	13
	20	0	0	0	0	0	1
	25	0	0	0	0	0	1
	50	0	0	0	0	0	0
	100	0	0	0	0	0	0
	80%ile						
	x1	8	5	2	0	0	17
	x2	4	1	1	0	0	13
	x5	0	0	0	0	0	0
	x10	0	0	0	0	0	0
	95%ile	2	0	0	0	0	6

3.2 DEPOSITION BASELINE DATA

Deposition data only exist for part of the monitoring period (Table 2) as the recording of deposition was often disrupted by fouling of the wiper mechanism and the recording plate. Some sites did not return any deposition data – which is often indistinguishable from a return of zero deposition.

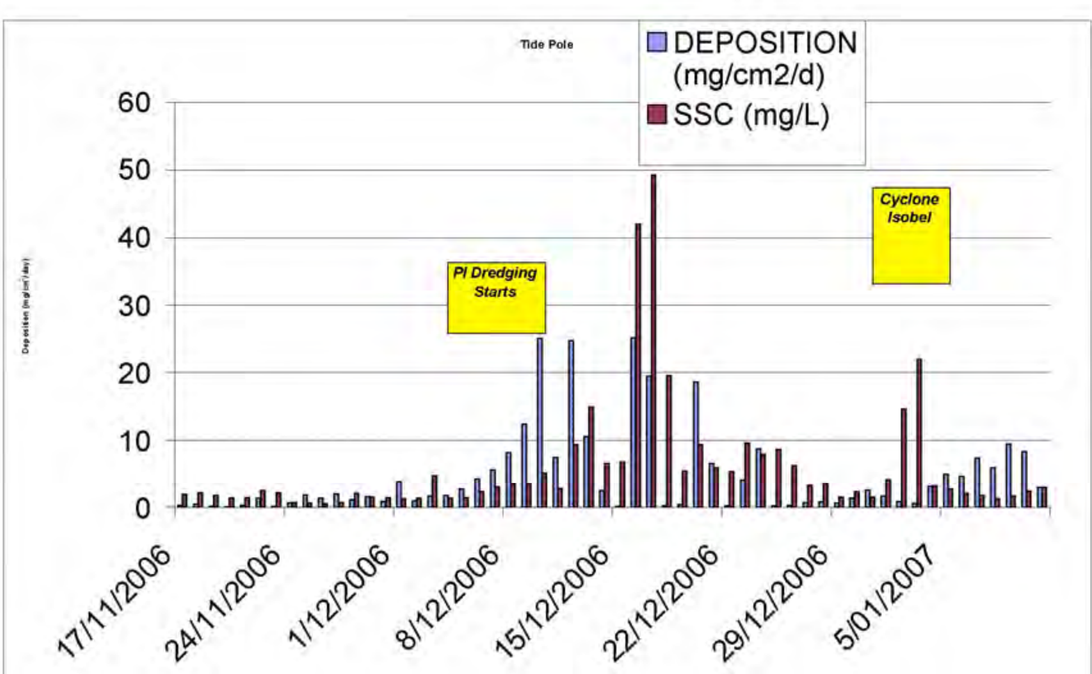
Table 5. Sediment deposition baseline data (mg/cm²/d).

	DEPOSITION					
	Mean	**Median**	**80%ile**	**95%ile**	**99%ile**	**Max**
ANGI	1.4	0.0	2.6	5.8	6.3	6.3
HGPT	0.1	0	0	1.0	2.8	4.4
CHC4	5.0	3.7	8.3	13.5	18.2	23.1
MIDR	no data					
WINI	3.7	1.2	5.2	13.0	32.9	38.0
TDPL	4.7	1.8	7.5	20.8	25.1	25.1
KGBY	no data					
HSHL	no data					
Inner	4.5	2.3	7.0	15.8	25.4	28.7
Inner (- TDPL)	4.4	2.5	6.8	13.3	25.5	30.5
Mid	0.1	0	0	1.0	2.8	4.4
Outer	1.4	0.0	2.6	5.8	6.3	6.3

As for SSC, Mid and Outer zones are very similar and removing the TDPL data from the Inner sites has little effect.

Deposition data is not necessarily well correlated with SSC levels. Resuspension of sediments by bottom stress in strong weather may cause high SSC levels, without any significant increase in sedimentation (Figure 2).

Figure 2. Deposition data vs SSC at the TDPL site.



4.0 LIGHT AND SSC

All meters logged light (PAR) in addition to estimating SSC over the same period. While it is clear that the depth of water over a meter has a significant direct effect on light reduction, SSC can play a larger role when concentrations are high. To examine the relationship between light extinction and SSC, light levels between 1000 hrs and 1400 hrs were correlated with SSC.

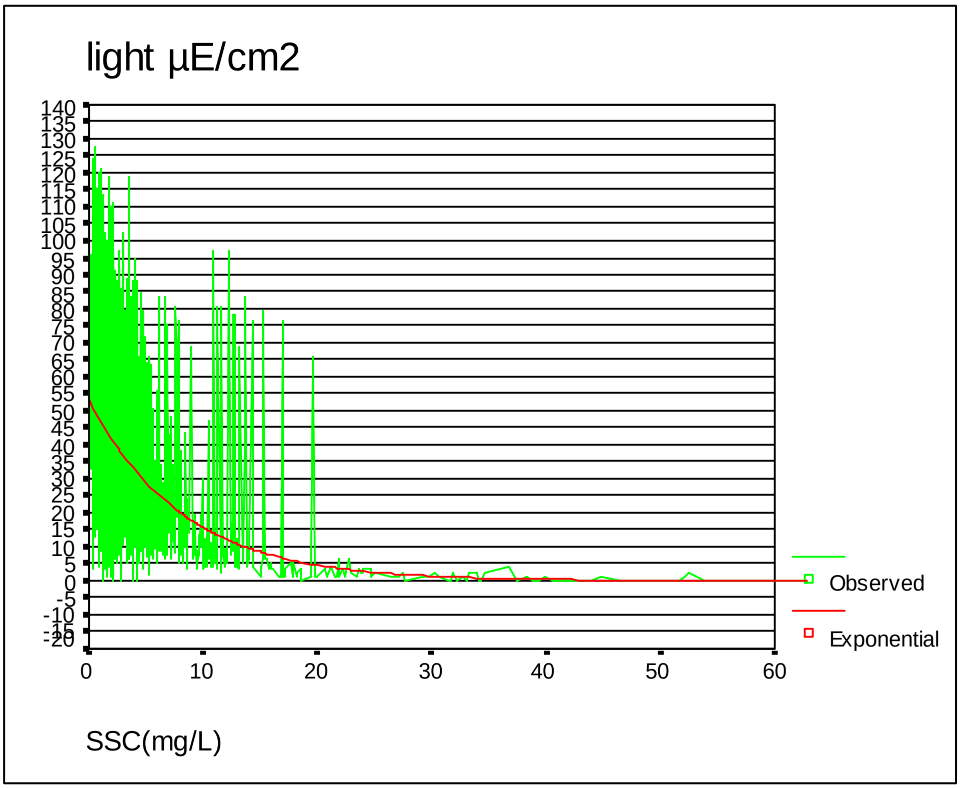
The relationship was examined using the general model

$$\textbf{Light} = \textbf{A}*\textbf{e}^{(B*SSC)}$$

where A and B are derived from the empirical data.

A typical data set is shown in Figure 3 for the ANGI station where A=53 and B=-0.122.

Figure 3. Light versus SSC at ANGI.



Data were 'noisy' and most relationships had R^2 values of less than 0.2 (ie the relationship with SSC alone explains less than 20% of the variation). In addition to other influences such as tidal variation, it must be remembered that the SSC values from the meters only relate to water at the depth of the meter. Stratification of SSC is common in these waters with levels increasing towards the lower profile (Stoddart and Anstee 2005).

Using a combination of the derived relationships and visual assessment of scatter diagrams of SSC vs Light, it is possible to derive a set of values for each station at which light is effectively extinguished by SSC. In practice that value was where light was < 1 μE/cm^2. Estimated values are shown in Table 6.

Table 6. Light extinction levels of SSC by station.

Site	SSC level mg/L
ANGI	40
HGPT	n/a*
CHC4	100
MIDR	n/a*
WINI	70
TDPL	50
KGBY	50
HSHL	n/a*
Inner	50
Mid	
Outer	40

n/a* - at these sites, SSC values did not rise sufficiently high as to cause sufficient reduction in light levels as to allow estimation of extinction level

The variation in values of SSC derived as extinction points for individual stations will depend, amongst other things, on the depth of that station and the optical backscatter properties of local sediments (i.e. the relationship of NTU to SSC). Given those issues (see Tables 1 & 2) and the generally high level of 'noise' around the Light-SSC relationship, we have assumed a single point for all sites of 50 mg/L.

5.0 TRIGGER LEVELS

5.1 MORTALITY INDICATOR

This section is prefaced with a warning against relying heavily on the capacity of data collected during periods in which coral have not died, to be extrapolated to predict levels at which coral will die. The uncertainty of predictions made outside the domain of the data collection conditions has been well documented in ecology (Bradbury et al. 1984).

Derivation of a working indicator of water quality levels which may cause mortality of coral within the Pluto dredging project is based on the following assumptions:

- Acute mortality (mortality events occurring within a period of less than a month) are most likely to be caused by smother of corals from excessive sediment loading rather than low light or irritation form suspended sediments;
- Coral communities at which these water quality data have been recorded have not shown significant levels of coral mortality over the monitoring period.

Thus the indicator used here for a potential mortality is daily sediment load. Based on Table 5 we know that communities in the zones of sensitivity have survived the following maxima: Inner – 30 mg/cm2/d Mid-Outer 6 mg/cm2/d. Thus a mortality indicator will be above that value. It is not possible to determine from this data how far above these maxima sedimentation rates would need to occur to be lethal. In the absence of that knowledge, it may be prudent to use a worst case – best case estimate.

Worst case mortality might be represented as maxima plus 10%. Rather than try to specify the best case, it might be better to undertake a sensitivity test using multiples of the estimates of the 95%ile of sedimentation in Table 3 to produce Table 7.

Table 7. Estimates of worst case to best case mortality using sediment loading.

Case*	Inner $mg/cm^2/d$	Outer-Mid $mg/cm^2/d$
Worst (1.1)	33	7
Best 1 (1.5)	45	9
Best 2 (2)	60	12
Best 3 (5)	150	30

*figures in parentheses represent multiples of the maximum deposition rate

The values of Table 7 represent total deposition values (ie background and dredging).

For calculation of background SSC and sedimentation – see section 5.3.

5.2 ZONE OF IMPACT

There are a variety of estimates which may be used to calculate the level of suspended sediment or other water quality parameter which should be set as indicating one which may potentially cause stress or impact to coral communities. In the current context, the 'stress' or 'impact' is being evaluated for the community of established corals – rather than examining what may impact on the success of recruits.

One mechanism of determining a level indicating stress on adult organisms is to examine the background water quality over a period that these adults have survived and take some measure of the extremes they have survived as a 'stress' but not 'mortality' level. The Pluto PER has committed this project to follow the methods suggested in McArthur et al. (2002). That paper discusses how to establish guidelines for water quality parameters for the management of dredging such that generated sediment and light attenuation levels represent:

> *the natural limits for that environment and thus cause no added stress to individual corals or the coral community.*

McArthur et el. recommend the use of two measures of water quality to reflect the above level:

- the 99th percentile as a never to be exceeded value, and
- the 95th percentile of the frequency of occurrence of the 95th percentile of the distribution of the parameter where that occurs for various durations.

Use of the 99th percentile of SSC for the Inner and Mid-Outer zones values (Table 8) to designate a 'zone of stress' or 'zone of impact' is not appropriate. As these values are exceeded under background conditions at these sites without any dredging input, all sites would be classified as within the Impact Zone. The 99%ile absolute criterion should not be used to designate a zone of impact – although it could be used as a water quality target in managing dredging. Instead, McArthur et al.'s second criterion of intensity-duration-frequency should be used to establish zones of potential impact.

Table 8. Not to be exceeded SSC values by zone.

Zone	99%ile (mg/L)
Inner	60
Mid-Outer	30

Using the 95th percentile for SSC intensity at each station (Table 4) suggests that exceedences of more than 6 hours are rare. Table 9 presents the baseline data for durations below 6 hours where SSC exceeds the 95%ile at each site and a suggested limit trigger for each zone. The limit trigger is based on the 95%ile of each data set assuming that all sites with the exception of HSHL cover about 4 months of data (HSHL covers 1 month).

Table 9. Frequency of exceedences of the 95%ile SSC for various durations.

Location	Hours					mg/L
	1	2	3	4	5	95%ile
CHC4	35	8	0	0	0	28.1
KGBY	28	5	1	0	0	43.1
TDPL	35	15	10	5	3	33.8
WINI	67	35	21	10	4	33.1
INNER*	***16***	***8***	***5***	***2***	***1***	***35***
HGPT	43	8	3	1	0	11.2
MID*	***10***	***2***	***1***	***0***	***0***	***10***
HSHL	2	1	1	1	1	14.5
MIDR	17	3	1	0	0	3.9
ANGI	14	9	9	7	6	12.4
OUTER*	***4***	***2***	***2***	***1***	***1***	***10***

*frequency of exceedences of the 95%ile allowed per month.

As for other statistics the SSC 95%ile is similar for Mid and Outer although the frequency of exceedence is generally less for Outer. Exceedences of the 95%ille at station ANGI relate largely to the elevated SSC experienced around Cyclone George and could be discounted if it were not for the single month of data from HSHL which shows that an exceedence of the 95%ile occurs on one occasion. Thus the amalgamation of the data in Table 9 into an estimate of the frequency of intensity-duration events likely to occur without causing significant stress to coral communities (Table 10) provides for a single one-hour exceedence of the 95%ile SSC for both Mid and Outer sites.

Table 10. Suggested allowable frequency of intensity-duration events per month.

	Inner	Mid	Outer
SSC trigger level (mg/L)	35	10	10
1 hour	16	10	4
2 hours	8	2	2
3 hours	5	1	2
4 hours	2	1	1
5 hours	1	1	1
6 hours	0	0	0

Coral communities in areas where events with a monthly frequency of SSC exceeding those of Table 10 are predicted to occur should be classified as within the zone of predicted impact.

The above events will relate to the potential impacts of sedimentation covering corals, suspended sediments interfering with polyp extension and feeding, and light attenuation. Setting a further value for stress based on light attenuation is probably not able to be justified on the basis of existing understanding of how much light attenuation is likely to cause significant stress to these communities. In any event, were a value to be set based on the SSC levels of Table 6, its duration and frequency level would be likely to much less constraining than those of Table 10. With the capacity of corals living in turbid environments to switch to greater levels of autotrophy when light is limited (Anthony and Connolly 2004) it is likely that periods of light deprivation caused by the 95%ile of SSC at Inner or Mid-Outer zones would be significantly in excess of 6 hours.

5.3 CALCULATING BACKGROUNDS

The current form of the plume dispersion and deposition model from APASA considers only additional sediment caused by dredging. To allow that model to provide a factor to include the background SSC and sedimentation levels, it is necessary to stipulate a background level based on the baseline data.

It is clear that bottom stress is an important factor in driving SSC. The current model uses an estimate of bottom stress which goes from 0 (nil) to 1 (maximum). To convert that into an estimate of background Table 11 assigns a relationship between that factor and SSC exists such that the 2 are linearly related between 0-0 and 0.5B and Mean SSC and then between that mid point an 1B-99%ile SSC.

Table 11. Relationship for estimating background SSC from bottom stress (B).

B	SSC (mg/L)	
	Inner	Mid-Outer
0	0	0
.1	2	1
.2	4	2
.3	5	2
.4	7	3
.5	9	4
.6	12	6
.7	25	12
.8	37	19
.9	49	25
1.0	62	31

6.0 REFERENCES

Anthony KRN, Connolly SR (2004) Environmental limits to growth: physiological niche boundaries of corals along turbidity-light gradients. Oecologia 141: 373-384

Bradbury RH, Hammond LS, Reichelt RE, Young PC (1984) Prediction and explanation as a dialectical pair in ecology. . Search 15: 220-222

McArthur C, ASCE M, Ferry R, Proni J (2002) Development of guidelines for dredged material disposal based on abiotic determinants of coral reef community structure. Proc. 7th Int. Coral Reef Symp.

MScience (2005) Coral Distribution in the Port of Dampier. Unpublished report by MScience Pty Ltd for the Dampier Port Authority, MSA50R1, Dampier, WA

Stoddart JA, Anstee S (2005) Water quality, plume modelling and tracking before and during dredging in Mermaid Sound, Dampier, Western Australia. In: Stoddart JA, Stoddart SE (eds) Corals of the Dampier Harbour: Their Survival and Reproduction During the Dredging Programs of 2004. MScience Pty Ltd, Perth Western Australia, pp 9-30

Thomas S, Ridd P (2005) Field assessment of innovative sensor for monitoring of sediment accumulation at inshore coral reefs. Mar Poll Bull 51: 470-480

Appendix B Review of Recent Dredging Projects in Dampier Harbour (MScience 2007b)

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PLUTO LNG DEVELOPMENT

REVIEW OF RECENT DREDGING PROJECTS IN DAMPIER HARBOUR

Report: MSA75R1

Report to:
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240 St. Georges Terrace
Perth WA 6000
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MScience Pty Ltd, School of Plant Biology (M090),
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Document Information

REPORT NO.	MSA75R1
TITLE	PLUTO LNG DEVELOPMENT : REVIEW OF RECENT DREDGING PROJECTS IN DAMPIER HARBOUR
DATE	24 May 2007
JOB	MSA75
CLIENT	SKM - WOODSIDE BURRUP PTY LTD
USAGE	This report presents data for comparison with modelled projections of sediment dispersion and coral impacts from the Pluto LNG Development dredging.
PRECIS	This report presents a brief review of environmental aspects of major dredging projects undertaken in Dampier Harbour since 2003.
KEYWORDS	coral sediments Dampier dredging

Version-Date	Released by	Purpose
V.1- 24 May 07	JAS	Client Review
V.2-30 May 07	JAS	Include client comments

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EXECUTIVE SUMMARY

Records available for recent dredging programs within Dampier Harbour were reviewed to determine what information may be derived on the impacts that occurred on water quality and corals near to dredging and disposal sites and the distances at which such impacts occur.

Programs below include dredging over extended periods, often by two dredges at the one time and in close proximity to coral communities.

In general it appears that

- Dredging has been bigger impact on water quality or coral health than was spoil disposal;
- Substantial water quality impacts occur only at sites within 1 – 1.5 km of dredging or disposal activity;
- Mortality of corals has only occurred at sites closer than 250m to dredging operations.

2004 (Dampier Port Authority & Hamersley Iron)

Over almost a year of dredging (Jan-Oct) by programs at two sites in the Inner Harbour, substantive water quality impacts were seen only at sites closer than 1.5 km to dredging operations. Water quality impacts from spoil disposal were generally not substantive, even at sites closer than 1km to disposal grounds.

Coral monitoring showed it was likely that disturbance from dredging had no significant impact (adult mortality) at sites further than 200m from the dredge and that disposal operations had no impacts on coral mortality.

Suspended sediment concentrations of 60mg/L were observed at the single site where corals were impacted around the period of impact.

2005-6 (Woodside LNGV)

No mortality was seen at coral communities within 350m of the dredging operation or at sites around the disposal grounds over a 5 month dredging program. No corresponding water quality monitoring program was undertaken.

2006-7 (Pilbara Iron)

An intensive monitoring program of mortality rates of individual corals did not show any increase in gross mortality at sites within 300m of a dredging program lasting 5 months when compared with sites outside the radius of dredging impacts. In situ monitoring of suspended sediment concentrations and sedimentation showed that dredging exerted a bigger effect than a cyclone (for a site 300m from the dredged area) but that disposal was a lesser impact than a cyclone at 4km from the disposal site.

1.0 INTRODUCTION

Woodside Burrup Pty Ltd (Woodside) is undertaking an environmental assessment of the likely effects of the dredging component of the Pluto LNG Development project. That assessment attempts to use baseline data on water quality and figures from the scientific literature to develop predictions (through numerical models) of the lethal and sublethal zones of impact likely to eventuate from the dredging phase of the project.

To provide an additional source of information on what impacts might occur during the project it may be useful to examine the experiences of recent dredging projects with similar characteristics to the proposed Pluto dredging. The set of projects examined here are all similar to the Pluto dredging in that they cover:

- Programs which extend over several months within a relatively small area;
- Programs which move over $2Mm^3$ of spoil
- Programs which use both trailer suction hopper dredges and cutter suction dredges – often simultaneously.

While the total length of dredging for the Pluto LNG Development is considerably more extensive than these programs, much of that work is staged to occur sequentially at several differing locations. Thus examination of the impacts of these programs on water quality and coral mortality may be helpful.

Examination of the long-term impacts of these projects has occurred, but has been largely confounded by new dredging projects and increased ship movements occurring after the project ceases.

2.0 DREDGING IN 2003-4

2.1 PROGRAMS

DPA Bulk Liquids Berth	
Where	Dampier Inner Harbour – Bulk Liquids Berth: Disposal- Northern Spoil Ground
What	Capital: Bulk Liquids berth and approach channel
Dates	8 Jan – 20 May 2004
Volumes	4.1 Mm^3
Dredges	THSD – *Cornelisse Zaanen*; Backhoe dredge - *Storken*

Pilbara Iron – Parker Point	
Where	Dampier Inner Harbour - Parker Point: Disposal- East Lewis Is & Northern Spoil Grounds
What	Capital: Swing basin, berth
Dates	8 May – 23 Oct 2004
Volumes	3.1 Mm^3
Dredges	THSD – *Cornelisse Zaanen*; Cutter Suction – *HAM218*; Backhoe dredge – *Obscured by Clouds* (first 2 dredges concurrent for most of June)

2.2 DATA COLLECTED

Coral monitoring occurred on a fortnightly basis using belt transects at 14 sites for DPA and 16 sites for Pilbara Iron. The primary parameter measured was the percentage cover of living coral which was set a maximum of 10% decline for additional dredge management and 30% decline for a 'cease dredging' limit.

Water quality data (including turbidity (NTU), suspended solids (SSC), pH, dissolved oxygen (DO)) was collected for both programs on a 3-day cycle at all coral monitoring sites. NTU was measured directly while SSC was derived from samples sent to the laboratory for gravimetric analysis.

2.3 OUTCOMES

Water quality impacts

Both projects

Full details of water quality during the dredging program can be found in Stoddart & Anstee (2005).

A general summary of key features includes:

Only weak associations between SSC and NTU were seen – generally around the 1 NTU = 2mg/L SSC range.

No apparent association of dissolved oxygen or pH was seen with elevated NTU or SSC.

Assessment of the NTU-SSC data show that levels were generally low at most sites with relatively short-lived peaks around some dredging events and a Cyclone. Some sites were project-specific and were not monitored for the entire period (See Stoddart & Anstee 2005). Data in Table 1, Figure 1 & Figure 2 show that the upper component of the distribution of NTU or SSC is only elevated substantively at sites close to the source of sediment – less than 1.5km. Sites close to dredging operations suffer much higher impacts on water quality than sites near to disposal grounds.

Critical distance in the two figures refers to the shortest distance from that site to either dredging or disposal grounds.

Table 1. SSC data by site for 2004 dredging.

Site	PERCENTILE (mg/kg)				Km to	
	Median	75	90	95	Disposal	Dredging
ANGI	3	5	8	9	4	15
COBN	4	6	11	12	5	10
CONI	3	5	8	9	2	9
DPAN	6	11	17	23	7	1
ELI1	3	4	10	11	0.2	6
ELI2	3	5	9	11	0.2	5
ELI3	3	6	10	12	0.2	5
GIDI	3	6	9	13	6	17
HGPT	3	4	11	13	6	11
HOLD	6	10	15	18	7	1.5
KGBY	3	6	12	15	6	1
MALI	3	5	9	15	5	12
NWIT	3	6	9	11	5	6
SUPB	7	13	25	42	7	0.2
SWIT	3	6	9	11	6	4
TDPL	3	7	11	12	4	0.4
WINI	3	6	9	12	9	12
WLI1	4	6	11	17	6	11
WLI2	3	5	10	12	7	11

Figure 1. Peak levels of NTU with distance to impact.

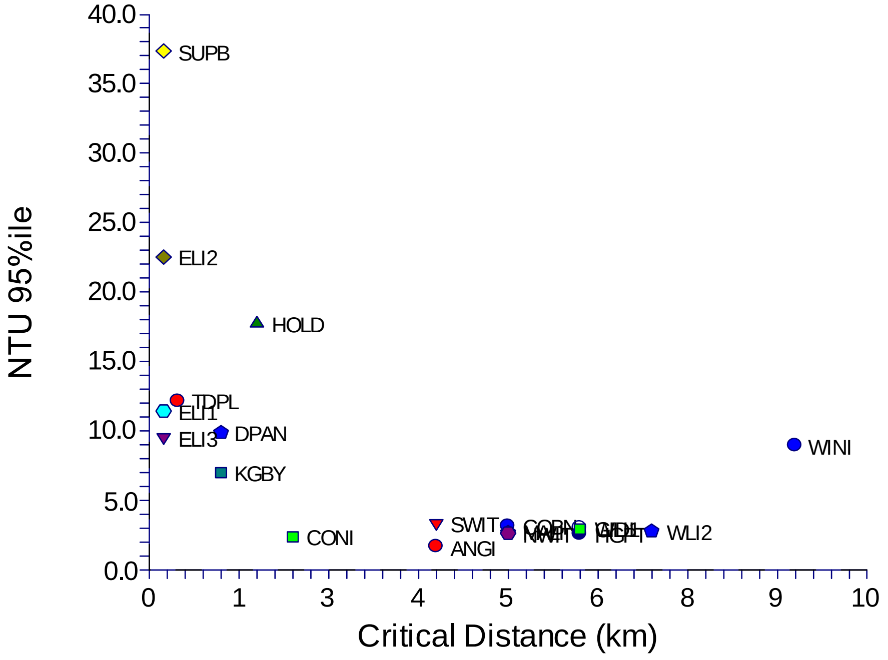
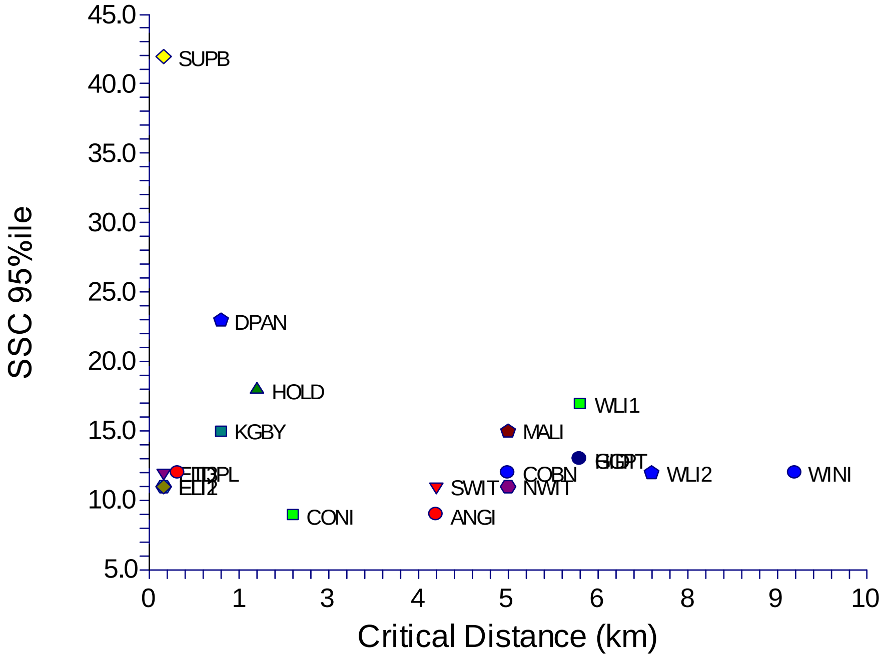


Figure 2. Peak levels of SSC with distance to impact.



Coral impacts

<u>DPA</u>

Several coral monitoring sites showed a clear decline in coral cover:

- substantive mortality occurred at the WLI1 and WLI2 sites due to freshwater inundation as the result of a cyclone;
- an 80% decline occurred at SUPB due to smothering by sediment
- some sites declined temporarily in cover estimates due to seasonal cover by macroalgae, but that did not appear to cause corresponding increases in mortality.

Peak sediment levels of over 60 mg/L were recorded in the 3-d monitoring on two occasions when it is postulated that the mortality occurred at SUPB (Stoddart & Anstee 2005). SUPB was within 200m of the dredging area and it is postulated that manoeuvring by the TSHD resulted in closer proximity of propeller wash.

No increased mortality was seen at sites close to the dredging where there was substantial and sustained increases in NTU/SSC – eg HOLD and DPAN (Figure 1, Figure 2).

No increased mortality was seen in coral communities monitored around the disposal grounds.

<u>Pilbara Iron</u>

The coral monitoring sites nearest to the dredging were the Tidepole Island and King Bay sites which were approximately 400m and 1km (respectively) from operations of the TSHD. Coral communities occurred even closer to the disposal site at East Lewis Island (200m). Divers noted plumes at all of the above sites on many occasions and reported fine sediments on corals and rocks.

Despite the above, the water quality impacts were small (Table 1, Figure 1 & Figure 2) and no significant mortality signal was detected (Stoddart et al. 2005).

3.0 2005-6

3.1 PROGRAMS

Woodside LNG V	
Where	Eastern Burrup – Karratha Gas Plant Disposal – Northern Spoil Ground
What	Capital: New berth & swing basin
Dates	11 Oct 2005 – 20 March 2006
Volumes	4.1 Mm^3
Dredges	TSHD *Cornelisse Zanen*; Cutter suction dredge - *Ursa*

3.2 DATA COLLECTED

Coral monitoring was conducted at 11 sites on 4 occasions (before, during and 2 after) using belt transects. The primary parameter measured was the percentage cover of living coral with the design established to test for a statistically significant decline of 10% against an action level of 50% decline.

MScience is not aware of any water quality monitoring conducted during this project.

3.3 OUTCOMES

Coral Impacts

The monitored coral communities nearest to the dredging occurred 350 and 800 m from the edge of the dredged area. Sites monitored around the disposal site were essentially the same as those in Table 1.

No decline in coral cover was seen at any of the Impact monitoring sites – although significant declines in coral cover did occur at Reference sites over the same period as a result of wave exposure and anchor damage.

4.0 2006-7

4.1 PROGRAMS

Pilbara Iron Pty Ltd	
Where	Parker Point Disposal – East Lewis Island & Northern Spoil Ground
What	Capital & Maintenance: New berth & swing basin, approaches
Dates	6 December 2006 – 24 April 2007
Volumes	3.5 Mm^3
Dredges	TSHD *Volvox Asia*; Cutter suction dredge – *Cyrus II*

4.2 DATA COLLECTED

Coral monitoring was conducted fortnightly at 16 sites using 100 individually located corals at each site. Estimates of partial mortality of the set of corals were compiled for each monitoring period.

Water quality parameters were collected manually on a 3d cycle for NTU (and by interpolation SSC), pH, DO and light attenuation at all coral monitoring sites. In situ meters gathered OBS and light (PAR) data on a 10 minute cycle to provide estimates of turbidity (NTUe), SSC (from laboratory calibrations), accumulated sediment deposition and light.

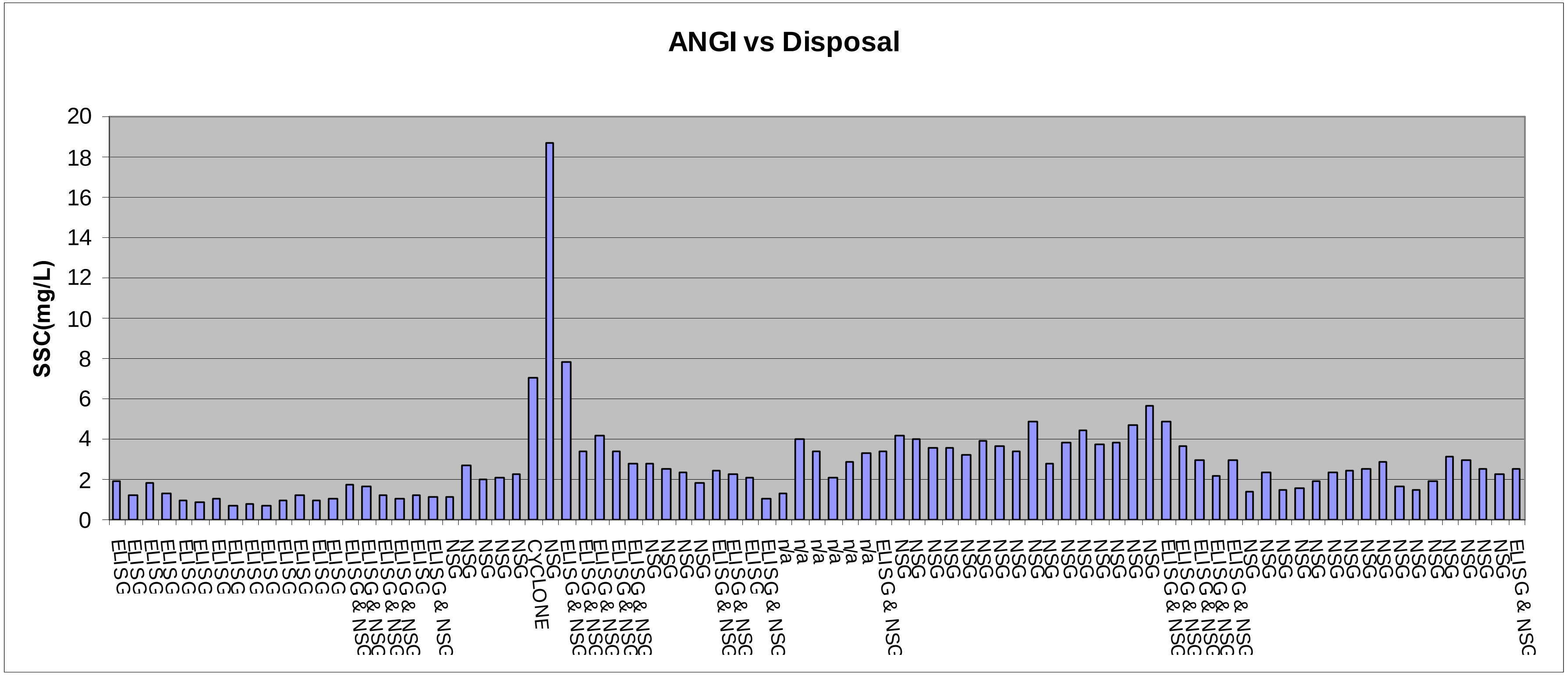
4.3 OUTCOMES

Water quality

This study did not have access to the water quality data collected on the 3-d cycle. Reports of that data have been provided monthly to the WA Department of Environment & Conservation.

Data from daily mean SSC show that cyclones had a larger impact on water quality than spoil disposal at a site approximately 4km from the disposal site. However, dredging impacts exerted a larger impact than cyclones at sites 0.3 and >1km from dredging operations (Figures 3 & 4).

Figure 3. Disposal location vs SSC (mg/L) at nearby site.



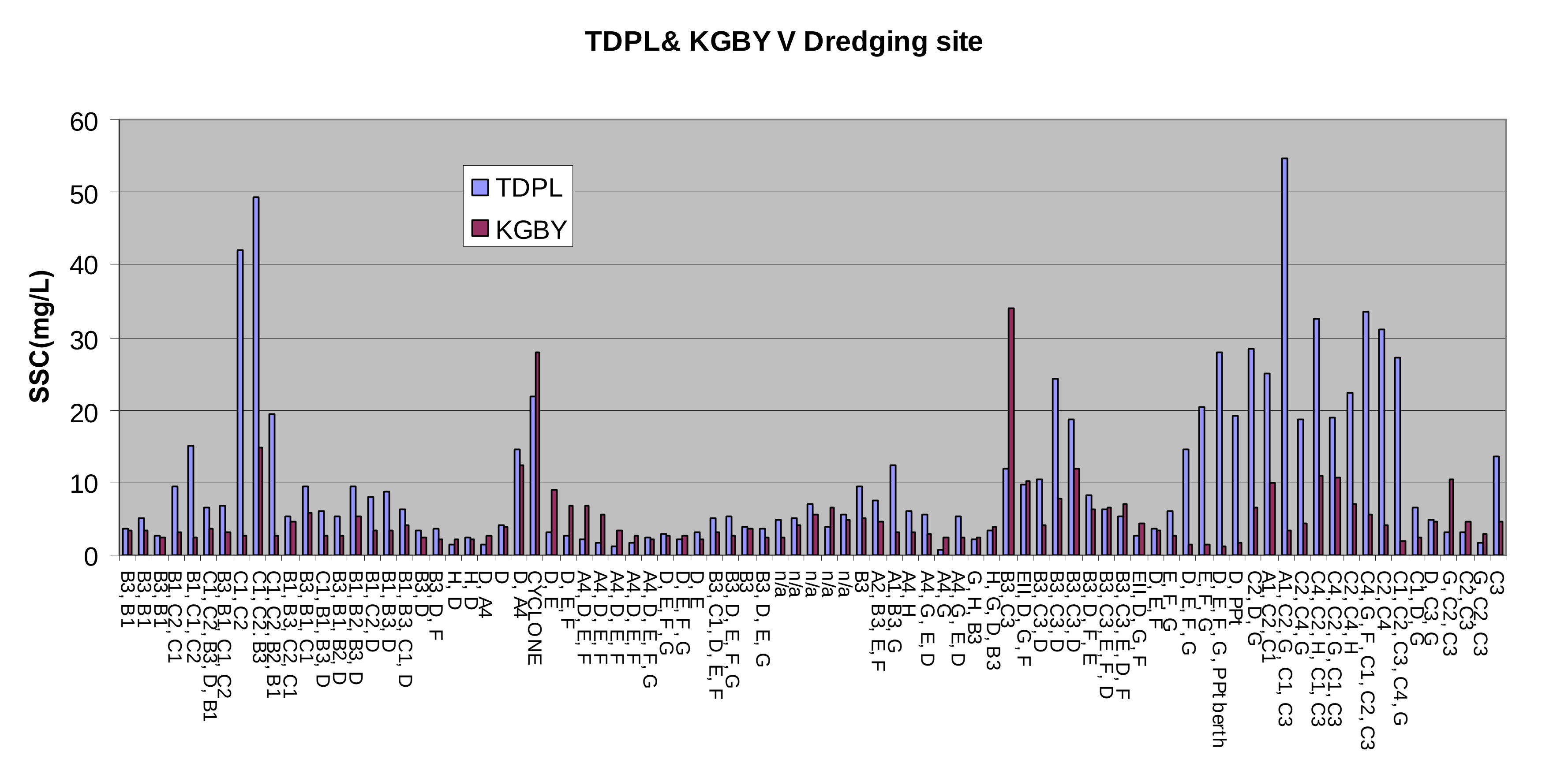
The graph starts in early December 2006 and goes to April 2007

SSC values are daily means

NSG – disposal occurring at the Northern Spoil Grounds

ELI – disposal occurring at the East Lewis Island Spoil Grounds

Figure 4. Dredging location vs SSC (mg/L) at nearby sites.



The graph starts in early December 2006 and goes to April 2007

SSC values are daily means

Site locations refer to dredging blocks as per permit documentation – A,B,C are close to site TDPL and G & E are closer to KGBY

Coral Impacts

Despite the substantial elevation of SSC and sediment deposition at the TDPL site (closer than 300m to dredging in this project), there was no clear elevation of mortality at that site compared to that at a similar exposed shallow-water site (WINI). Divers noted that corals were often covered with a fine layer of silt and in some cases partial mortality of corals was scored in mortality assessments where corals were partially obscured by sediments. Some corals were seen to die entirely. However, similar amounts of sediment-induced partial mortality were seen at sites distant from dredging. Following the cessation of dredging some of the apparent mortality attributed to sediment cover was seen to reverse as sediments cleared leaving live coral.

The above is work in progress and a full analysis of mortality patterns for that project has not been completed.

5.0 References

Stoddart JA, Anstee S (2005) Water quality, plume modelling and tracking before and during dredging in Mermaid Sound, Dampier, Western Australia. In: Stoddart JA, Stoddart SE (eds) Corals of the Dampier Harbour: Their Survival and Reproduction During the Dredging Programs of 2004. MScience Pty Ltd, Perth Western Australia, pp 9-30

Stoddart JA, Grey KA, Blakeway DR, Stoddart SE (2005) Rapid high-precision monitoring of coral communities to support reactive management of dredging in Mermaid Sound, Dampier, Western Australia. In: Stoddart JA, Stoddart SE (eds) Corals of the Dampier Harbour: Their Survival and Reproduction During the Dredging Programs of 2004. MScience Pty Ltd, Perth Western Australia, pp 31-48

Appendix C Benthic Habitats at NE Corner of West Lewis Island (MScience 2007c)

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Memo

MScience Pty Ltd
School of Plant Biology (M090)
University of Western Australia
Crawley, WA 6009
Email: admin@mscience.net.au

To: David Gordon

Cc: Russell Hanley, Stephen Ley

From: James Stoddart

Date: May 28, 2007

Subject:

At the request of the Pluto Project, benthic habitats between High Point and the northeastern tip of West Lewis Island were mapped on Wednesday the 16th of May 2007. The preliminary mapping was done primarily with the boat's depth sounder, then ground-truthed by divers.

Different habitats were distinguished on the sounder by their appearance—low relief and low reflectance indicated sand, moderate topography indicated rock, and irregular spiky topography indicated coral reef. Sand, rock and coral reef were the only benthic habitats encountered in the study area.

Spot dives on snorkel were undertaken to verify the interpretations made from the sounder. A total of 17 dives were undertaken in locations marked on Figure 1. At each location the diver was dropped close to shore and swam offshore, noting the position and width of the rock, sediment and/or coral reef habitats.

Most of the coastline in the survey area is rocky, with low cliffs rimmed by scree slopes of angular boulders. The boulders extend subtidally approximately 50m offshore on average. Boulders in the intertidal zone are lightly colonised by barnacles, and boulders in the subtidal zone are colonised by zoanthids and sparse corals (Rocky reef habitat in map).

Corals are most abundant between approximately 1 and 5m below LAT, where they form thin veneer reefs over the rock substrate. *Pavona* and *Porites* comprise the dominant coral genera based on area covered (Corals in map). At the outer edge of this zone the corals become patchy and give way to a flat medium to fine grained sediment.

Sandy beaches are present in the channel between High Point and West Lewis Island, and in the wide southeast-facing bay on West Lewis Island. The intertidal and subtidal habitats adjacent to the beaches are also sandy, with occasional coral patch reefs (Bommes in map) as indicated in Figure 2. *Pavona* and branching *Acropora* were the most common coral genera on these patch reefs. The surrounding sand is generally relatively thin, and is underlain by a hard flat limestone pavement.

Very little macroalgae or seagrass was observed at any of the dive sites.

Total area of coral mapped is approximately 19 ha in units as marked on Figure 2.

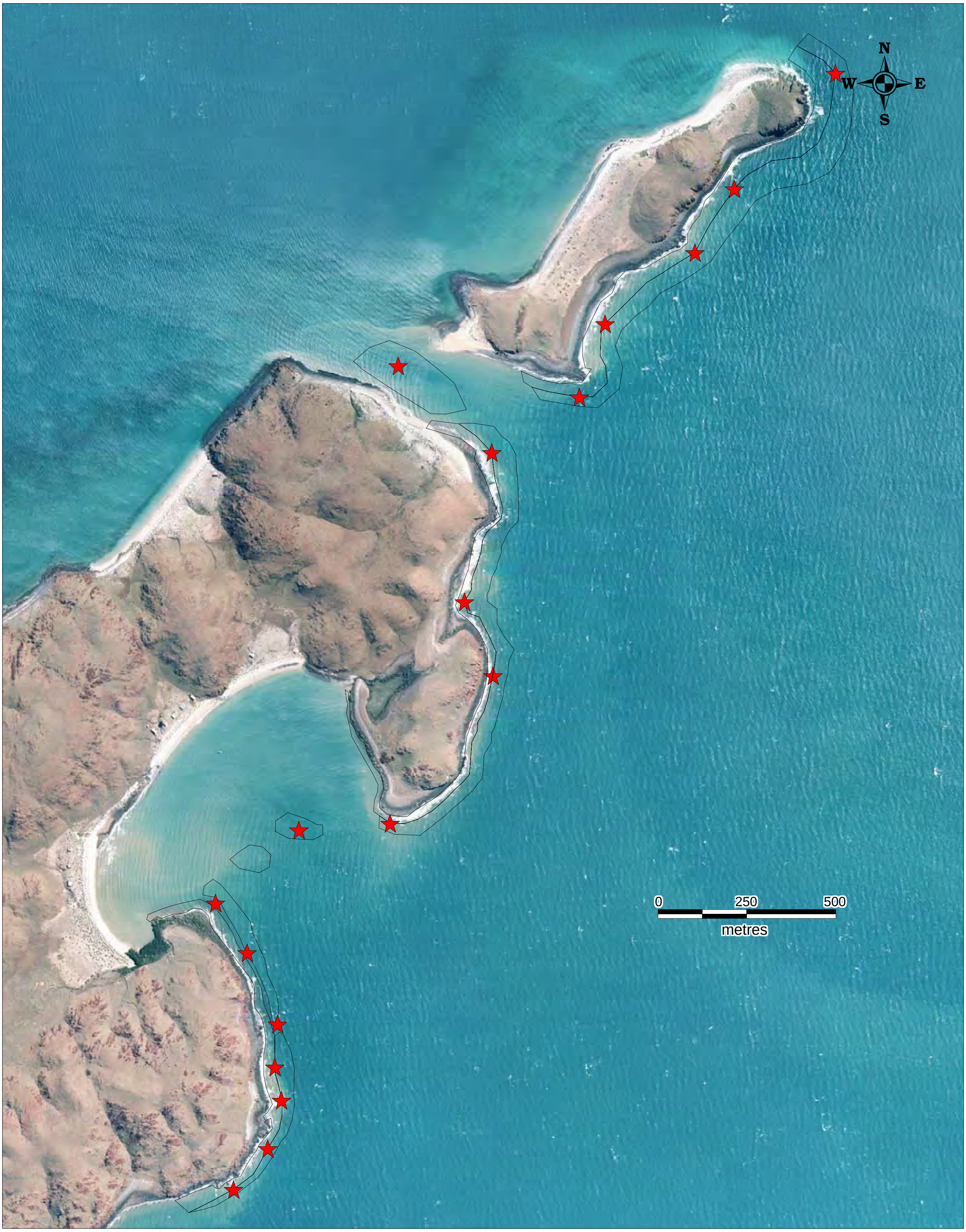

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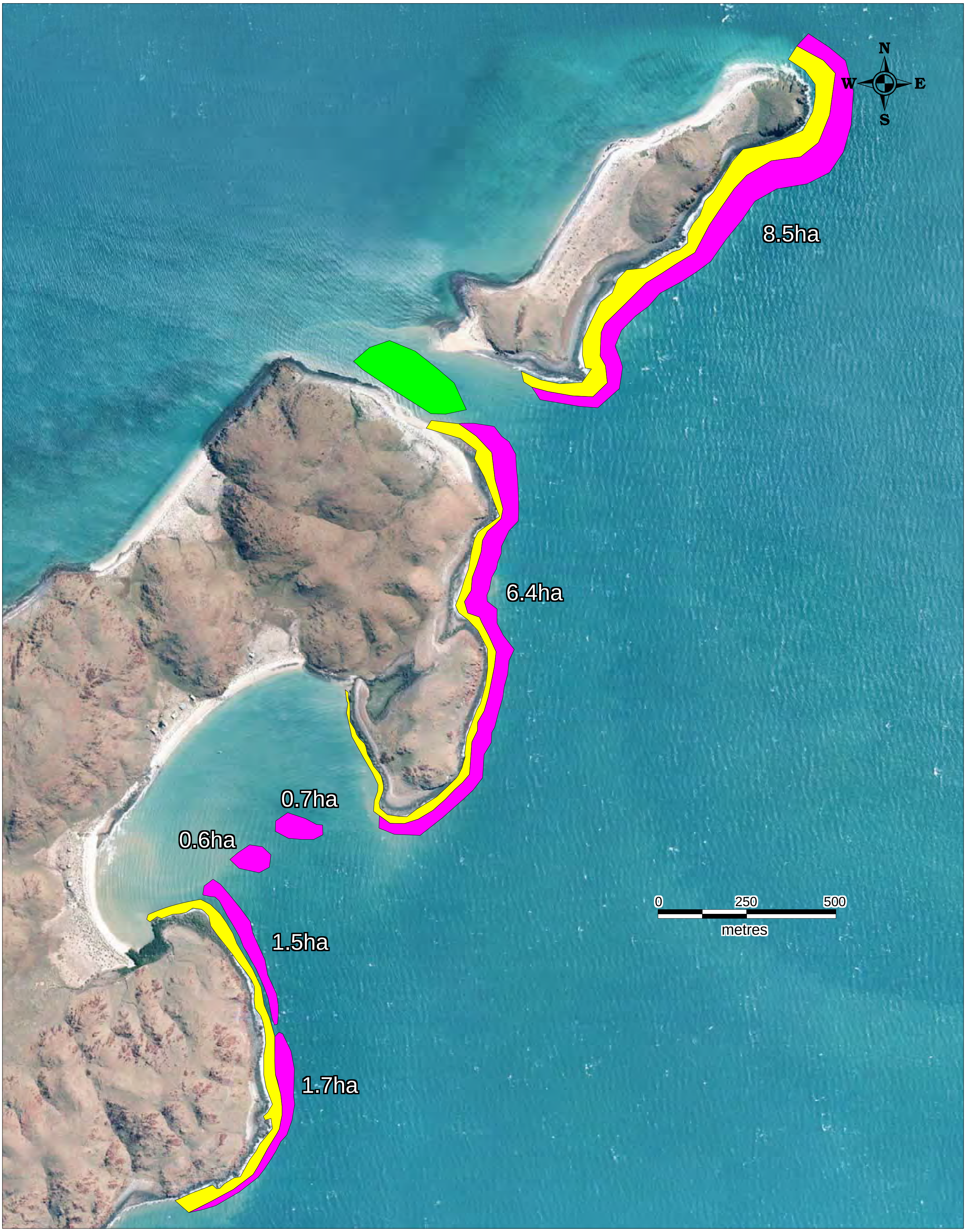
Figure 1: Location of sites for ground truthing

Scale: - 1:15000
Projection: GDA94(MGA50)
Date: - 28/05/2007
File: WLEW1

Benthic Habitat Mapping

★Dive sites



Mscience Mscience Pty Ltd Perth Western Australia	MScience Pty Ltd School of Plant Biology University of Western Australia Crawley, WA 6009 Australia www.mscience.net.au	**Figure 2: Benthic Habitats West Lewis Island Tip** Scale: - 1:15000t Projection: GDA94(MGA50) Date: - 28/05/2007 File: Wlewis0507	Benthic Habitats (coral area shown in ha on ma Bommes Corals Rocky Reef

Appendix D Methods for Revised Dredge Modelling with Inclusion of Sediment Resuspension (APASA 2007)

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Pluto LNG Development - Sediment Dispersion Study:

Methods for Revised Dredge Modelling with the Inclusion of Sediment Resuspension

Prepared by

Asia - Pacific Applied Science Associates
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Document Title: Pluto Dredge Modelling Methods Draft for review.doc

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1 Methods

Numerical modelling was used to understand the effects of dredging on the Dampier Archipelago marine environment in terms of the redistribution of sediments, inclusive of resuspension processes. There are several aspects of the oceanography in the region which are important for inclusion in a model to properly represent the transport of dredged material over the shorter and longer terms. Processes include wind and tidally driven currents as well as locally generated, short-period waves and oceanic long-period swells. Turbulent mixing which is a product of these processes is also important for determining the fate and transport of dredged material. Sediment properties such as grain size and cohesiveness were also considered. The main steps involved in establishing a suitable model to determine the transport of dredged material were:

- Apply a previously validated three-dimensional hydrodynamic model covering the region (Encompassing Mermaid Sound, Dampier Archipelago and approaches) to produce a long-run circulation sample;

- Set up a robust wave model for the whole region, which included input of the hydrodynamic data (elevations and currents) from the hydrodynamic model;

- Validate predictions of the wave model against field measurement of wave characteristics in Mermaid Sound;

- Establish the relevant parameters to appropriately represent each type of dredging operation (derived during earlier calibrations, sensitivity tests and reviews of previous studies)

- Establish suitably conservative vertical mixing parameterisation to suit the processes in the region through sensitivity testing and calibration to field observations

- Conducting sediment transport modelling for defined dredging activity, following the most up to date dredging schedule for key operations:

    - Dredging of the turning circle/shipping berth
    - Dredging for trunkline trenching
    - Disposal at the offshore disposal ground

- Determine the locations likely to experience sedimentation rates known to be harmful to coral by applying thresholds for SSC and sedimentation rates (Acute, medium term and longer term) defined from analysis of field data collected and analysed by MScience [with observations during of a dredging operation]

- Calculate the median, maximum and 80th percentile of total suspended sediments during each operation

- Examine time series of exposure to sedimentation and suspended sediments in the water column at locations of interest within Dampier Archipelago

- Reporting of findings of results in relation to the modeling in APASA (2006) as well as any new effects resulting from the inclusion of waves and resuspension in the modelling process.

1.1 Hydrodynamic Modelling

Hydrodynamic modeling of Dampier Archipelago was performed using HYDROMAP. HYDROMAP is a 3D barotropic coastal model and has been used in previous studies of Dampier Archipelgo (i.e. APASA, 2006). The model was set up and validated in previous dredge modelling in Mermaid Sound and therefore only minor changes to the model input data were required for the present application. APASA (2006) has provided a detailed description of the model setup and input parameters as well as the validation study undertaken against current metering.

For the most recent investigation, HYDROMAP was run in three dimensions over a staggered Cartesian grid with cell sizes ranging from 1km (in the offshore waters) down to 125m. The key difference with APASA (2006) was that the model was run over two years for 2005 and 2006 and therefore different wind data was used. Winds were sourced from the NCEP reanalysis (Kalnay et al. 1996). This is a global surface hindcast model that uses atmospheric observations from the world's array of observation stations, inclusive of stations surrounding the study area. The data is updated six hourly with a spatial resolution of ~1.9° by ~2.0°. The model open boundary cells were forced with tidal phase angles and amplitudes from the Topex/Poseidon v6.2 global tidal model for the eight major constituents, as previously applied and validated.

Hydrodynamic model results were used as input wave model. Current velocities and water levels were converted to an ASCII grid format used by the wave model. Current data from HYDROMAP was also fed directly into the dredge model.

1.2 Wave model

Modelling of the waves through Dampier Archipelago was performed with the SWAN (Simulating WAves Nearshore) model. SWAN is a third-generation wave model and therefore accounts for wave generation process within the model domain as well as propagation of waves from the open boundaries. SWAN accounts for most aspects of wave physics including wave breaking, refraction, diffraction, wave setup as well as non-linear wave-wave interactions.

The model is phase-averaging and thus resolves the average wave field parameters over time (as opposed to phase-resolving where the peaks and troughs of individual wave trains are represented). The phase averaging property ensures that the model does not have grid sizing or time stepping issues and can therefore be applied over a large domain for a long period of time with managable computational requirements.

SWAN was run for a two year period for 2005 and 2006. The output of the model was three hourly which coincides with the period of the wave-input boundary data. Model output variables which are important for the calculation of the bottom stress include significant wave height, wave period, wave direction and maximum bottom orbital velocity.

Model data (including each of the above variables) was prepared as a NetCDF format using the COARDS convention for input into the dredge model.

1.2.1 Wave model Grid

A rectangular Cartesian grid (Figure 1) was used in the SWAN model mainly due to various numerical aspects of the model being more refined for this style of grid. In order to account for the effect the islands of Dampier Archipelago have on the wave field, the model domain had to span beyond the most offshore islands in the region. An optimal resolution of 500m was chosen so that most islands and peninsulas could be represented by the model whilst still being able to process the required temporal sample in a reasonable time. One month of data took approximately three days to run per processor. Hence a combined run time of 72 processor-days was required for this data set.

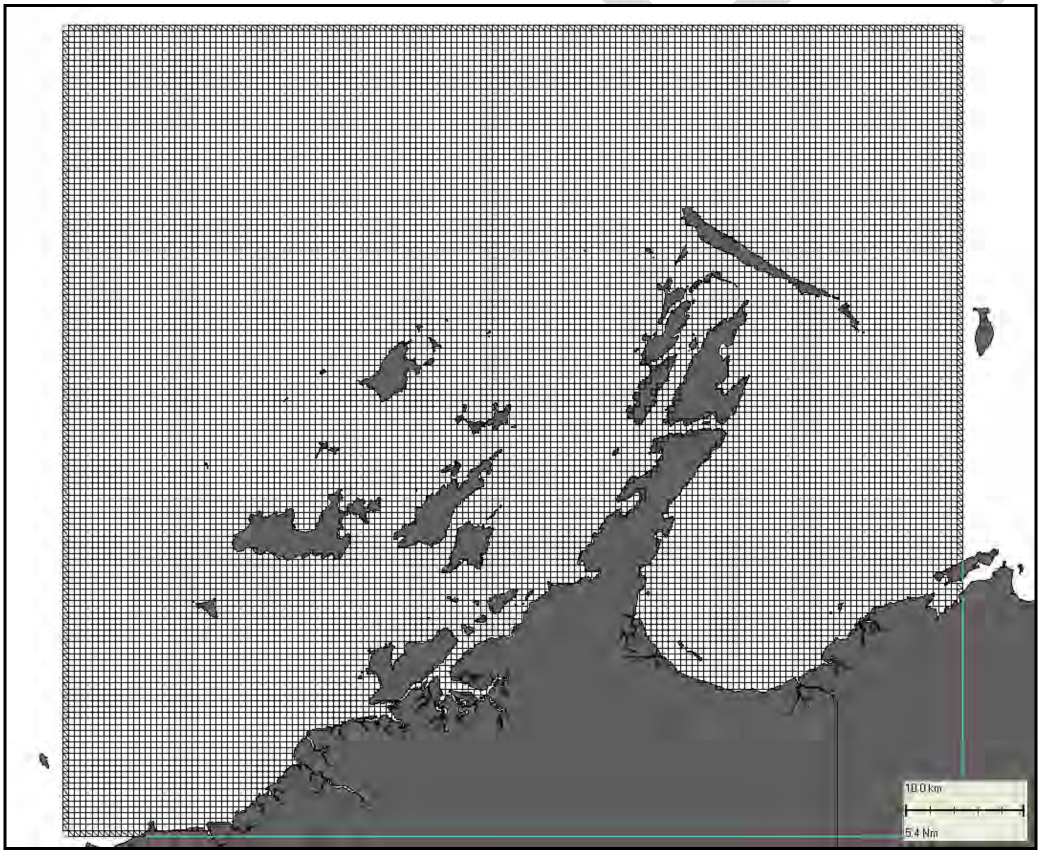

Figure 1: Model domain and grid used for SWAN model.

1.2.2 Wave Model Boundary Conditions

The boundary wave conditions were obtained from the NOAA WaveWatch III global wave model. Data from the adjacent grid point was used to represent conditions for significant wave height, wave period and wave direction at the open boundaries. The location of this point is -20.00° S 116.25° E, approximately 60 km NW of Mermaid Sound. Wind data was also sourced from the global wave model which was originally sourced from the Global Forecast System (GFS). Model boundary data was updated at three hourly intervals.

Analysis of the offshore wave boundary data showed that significant wave heights were generally in the range of 1-2 m but peaked greater than 3m during some events (Figure 2). Waves are predominantly from the southwest which represents swells generated in the southern Indian Ocean. During storm events, where significant wave heights exceed 3m, waves are typically directed from the north. During winter (June –August) offshore waves are directed from the east when the SE trade winds are the strongest at Dampier. Wave periods are commonly lower period seas (4-8 s) from the NE and NW. Swell waves (T > 12s) are only directed from the SW (Figure 3). The scatter plot in Figure 3 shows that only long period waves originate from this direction.

Wind data used to force the SWAN model exhibits good agreement with seasonal trends for the North West Shelf (Figure 4). Both the summer NW monsoon winds and the winter SE trades are represented by the data. Transitional periods such as March, April and October exhibit variable directional winds, as indicated by local measurements.

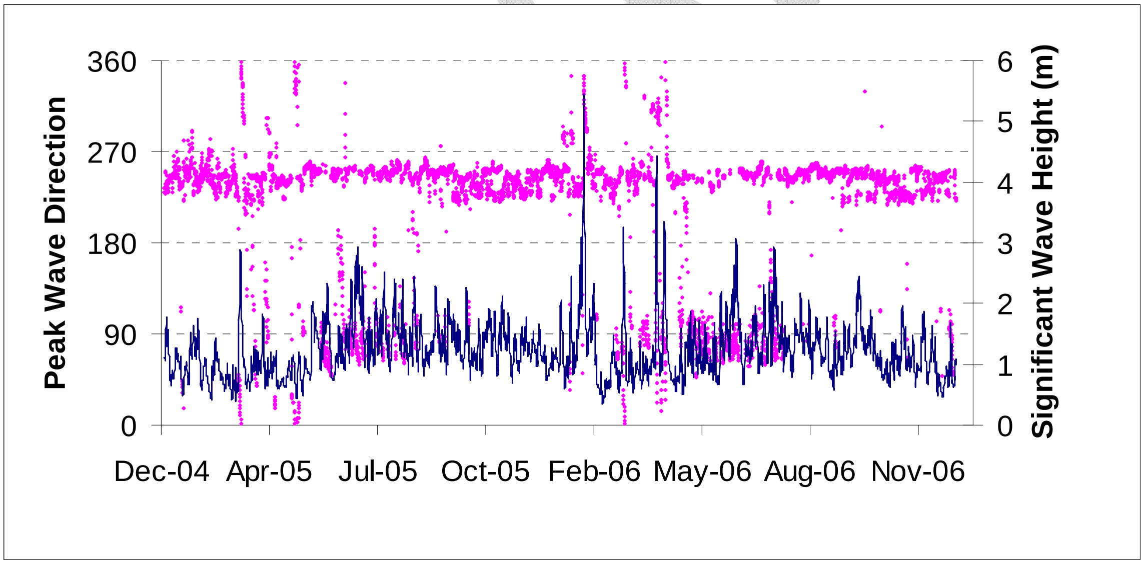

Figure 2: Time series of significant wave height and peak wave direction from the NOAA WaveWatch III model at a point near Dampier Archipelago.

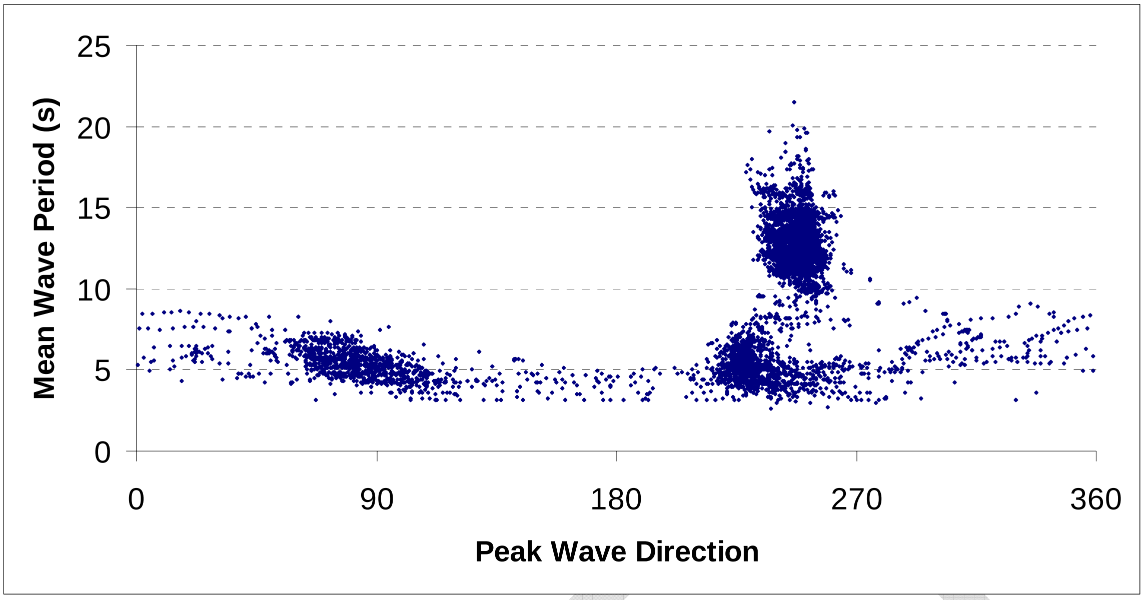

Figure 3: Scatter plot of mean wave period versus peak wave direction from the NOAA WaveWatch III model at a point near Dampier.

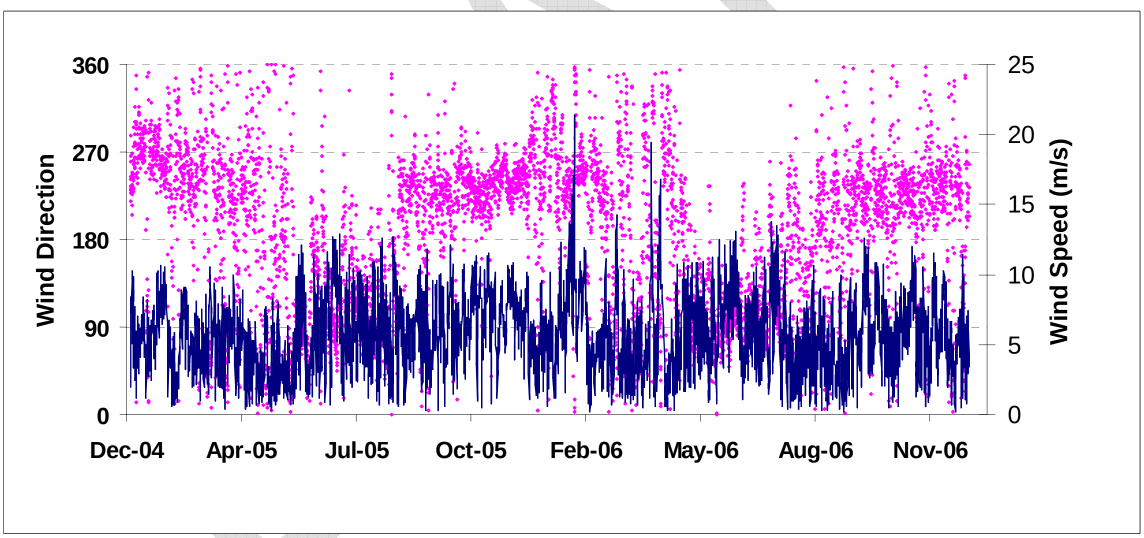

Figure 4: Time series of wind speed and direction from the GFS winds at a point near Dampier.

1.2.3 Input Tides and Currents

The effects of changing water levels and currents are important variables to be included in the wave model. Water levels effect both wave breaking and wave refraction due to alteration of the depth. Currents mainly effect the wave refraction but also contribute to wave setup. Current velocity and water level data were obtained from the HYDROMAP model for use as input into the SWAN model. As the HYDROMAP data did not span the entire wave model domain, certain regions in the model did not account for the effect of tides and currents. These regions were near the SWAN boundary and therefore were not of concern to the final model outcome.

1.2.4 Wave Model Outcomes

Sea breezes are reported to be the dominant mode of wave generation within Dampier Archipelago, with waves and swells tending to occur episodically and independently in any month (Hamilton, 1997). Analysis of a contour plot of the SWAN modeled wave field reveals that longer period swells do not generally propagate into Mermaid Sound (Figure 5). Only very short period (1-2 s) locally generated seas are present in Mermaid Sound. Contour plots of significant wave height reveal that wave energy is dissipated by the islands of Dampier Archipelago (Figure 6). As waves are diffracted by the islands, they diminish in height until they reach the lower reaches of Mermaid Sound. Spoil ground 2B and the northern sections of the trunk line are exposed to a larger proportion of the wave energy propagating from offshore. During intense storms from the north, the wider part of Mermaid Sound is more exposed to higher wave energy.

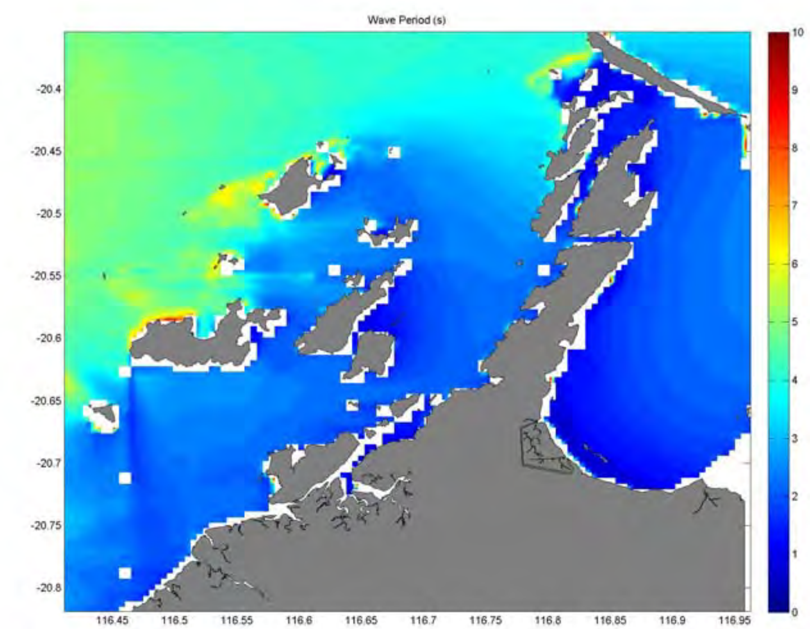

Figure 5: Contour plot of wave period (seconds) from the SWAN model.

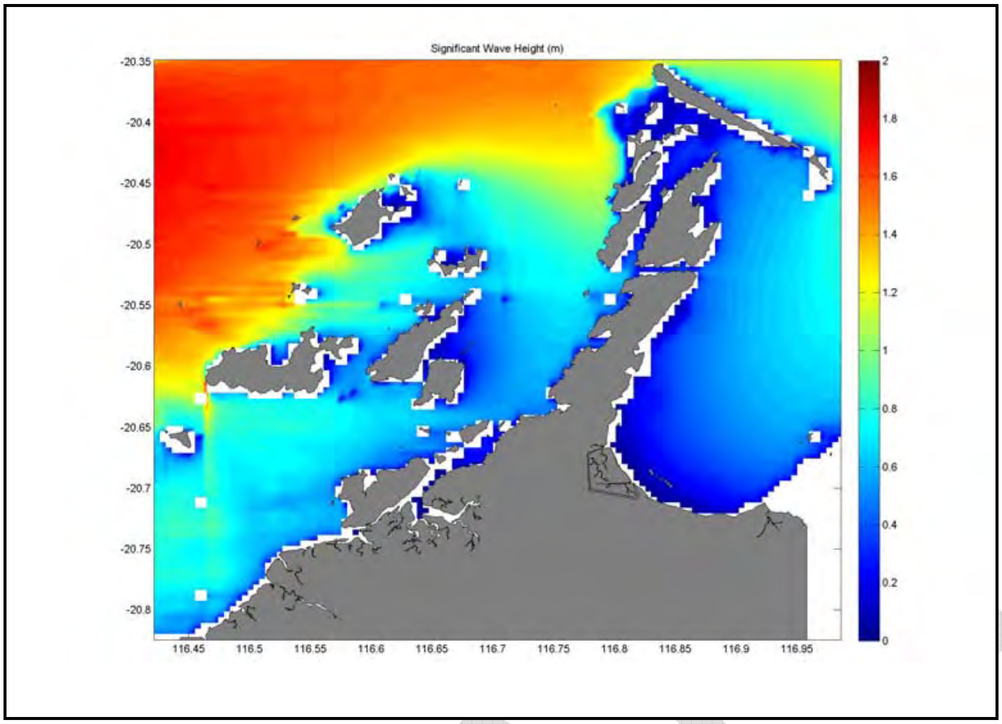

Figure 6: Contour plot of significant wave height (metres) from the SWAN model.

Although the waves within the lower reaches of Mermaid Sound are generally low in amplitude and have a shorter period than offshore conditions bottom-stress calculated from the modeled wave data indicate that they would contribute significantly to sediment resuspension in the Sound. The relative effect of waves on bottom stress is clearly evident from Figure 7, which shows estimates for a location immediately off Holden Point (mean depth 5 m). The bottom stress generated by both currents and waves is considerably larger (τ = 0.1-0.2 Pa) than that generated by currents alone (τ ~0.01 Pa). Current speeds are sufficient to theoretically suspend clays and fine silts (τ > 0.016 Pa) during peak tidal flows. However, currents combined with waves are predicted to generate enough bottom stress to resuspend fine grained sediments for a larger proportion of the time and to resuspend coarser grained sediments from the seabed episodically.

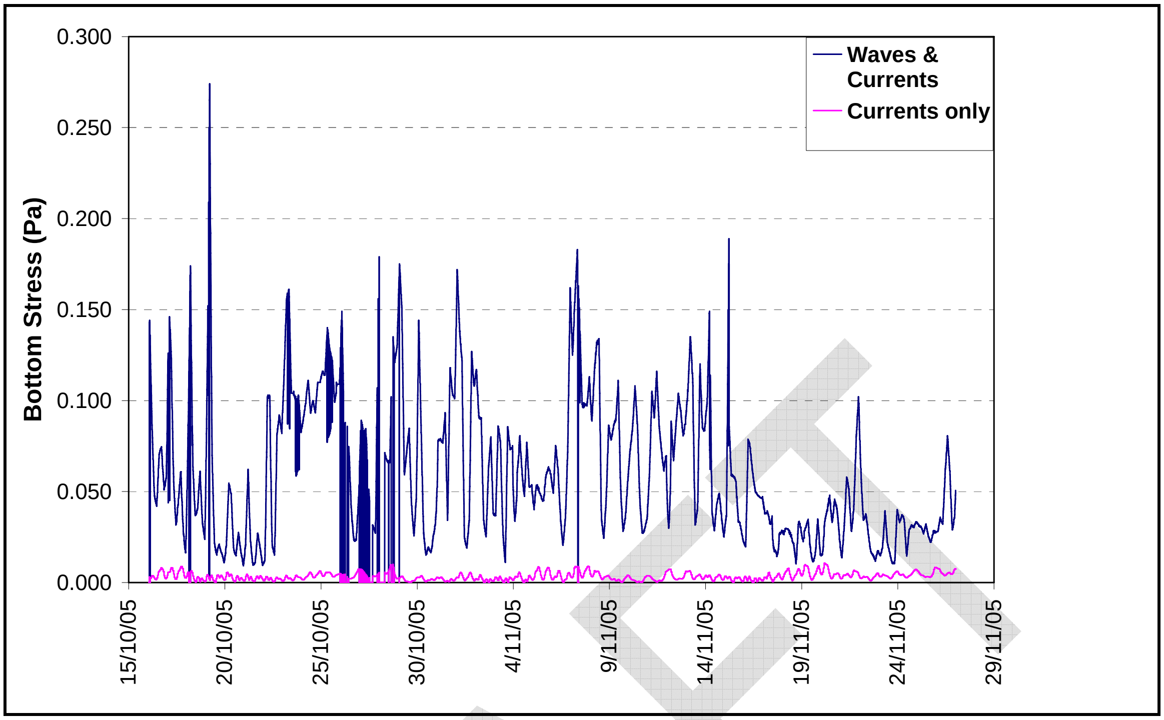

Figure 7: Time series of bottom stress calculated by the SSFATE benthic boundary layer model for a location close to Holden Point.

1.2.5 Wave Model Validation

To validate the SWAN performance, measurements from Mermaid Sound collected by MetOcean Engineers using the Navaid 9 DWR buoy were compared with model results. The buoy was located at 20.5464^o S, 116.7164^o E in 16 metres of water (Figure 8). The significant wave height H_s, the spectral mean wave period T_{01}, and the mean wave direction recorded by the buoy and hindcast by the model from the same point were compared over a 19 month period extending from January 2004 till July 2005. The wave data for the first half of month of October 2004 were missing, and the wave gauge was removed for a major service in the second half of July 2005. Therefore, these two months were excluded from any further consideration.

A comparison was also carried out of the NCEP GDAS 3-hourly wind analyses from the aforementioned NWW3 grid point and locally available wind speed and direction measurements from Karratha Airport (coordinates 20.7097^o S, 116.7742^o E).

Time series plots of the wave parameters for example months are presented in Figure 9 and Figure 10, and some monthly validation statistics are exhibited in Table 1, for all months. The statistics in Table 1 (the mean error *ME*, the root mean square error *RMSE*, the scatter index *SI*, and the correlation coefficient *R*) were computed using the following expressions:

$$ME=\frac{\sum_{i=1}^{N}(y_i - x_i)}{N}, \qquad (1)$$

$$RMSE=\sqrt{\frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N}}, \qquad (2)$$

$$SI=\frac{RMSE}{\bar{x}}, \qquad (3)$$

$$R=\frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2 \sum_{i=1}^{N}(y_i - \bar{y})^2}}. \qquad (4)$$

where x_i is the value observed at the i-th time step, y_i is the value simulated at the same moment in time, N is the total number of data points in the validation, $\bar{x}$ is the mean value of the observations, and $\bar{y}$ is the mean value of the simulations.

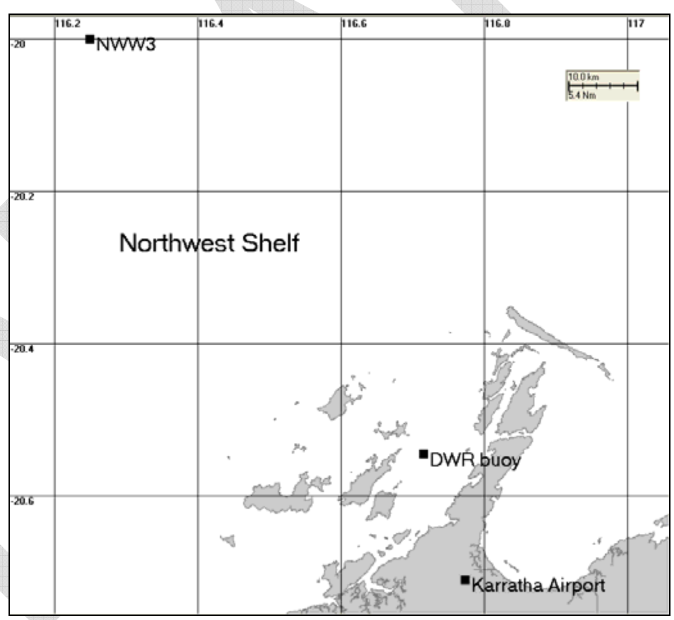

Figure 8: Locations of the observational measurement stations and NWW3 computational grid points.

1.2.6 Validation Results

In general, an analysis of the SWAN wave model outcomes reveals an overall good agreement between the measurements and model results. Figure 9 shows that the modelled wave parameters follow the observed trends and variability of the H_s, T_{01} and wave direction with the peaks well timed (see e.g. the H_s plots for January 2004, March

2005). This conclusion is also confirmed by the validation statistics from Table 1. This highlights that the wave conditions reproduced by the NWWIII global wave model were determining the sea states within Mermaid Sound. There were some local influences, probably local winds, generating local waves at the measurement site that resulted in marginally poorer predictive performance at times (eg. See April and August 2004, and February and April 2005.)

An analysis of the wind model statistics provides a deeper insight into the possible causes of episodic wave model discrepancies. From a wind and wave statistics comparison from Table 1 it follows that the model predicted waves showed highest correlations when synoptic-scale winds were dominating the wave climate. However, relatively only low correlation (> 0.3-0.4) between the NWW3 and local measurements for wind speed and direction were required to give relatively high correlation (0.6-0.9) between modelled and measured waves. Also, there were generally higher correlations between measured and modelled wave directions than between measured and modelled wind directions. One reason for this is that wave directions nearshore are steered by local bathymetry (e.g., under the influence of the refraction and diffraction processes).

For the significant wave height, the values of the *ME* were within the limits of -0.2-0.0m with the *RMSE* staggering between 0.1 and 0.3m. This shows that the bias in the H_s estimates was low. The *SI*, which is an important measure of skill for a wave model, was of order of 0.5-1.0 (with 0 being the theoretical best score). The values of these statistics were in good accord with the results published by other researchers for different areas in the Atlantic and Pacific Oceans (e.g., Guillaume, 1990; Khandekar and Lalbeharry, 1996; Makarynskyy et al., 2001; Pires Silva et al., 2002; Ris, 1997). The value of *R*, which indicates the strength and direction of a linear relationship between two random variables, generally is higher than 0.5, although there are some outliers. The highest correlations were observed in January and March 2004, and March 2005 (Table 1).

The bias in the T_{01} estimates was also low with the *ME* of 1-3s and the *RMSE* of 2-5s. The values of *SI* were of a similar order with the ones calculated for the H_s. The lower values of the correlation coefficients for this wave parameter reflect both its noisier nature - noticed in several wave studies (e.g. Makarynskyy et al., 2005; Makarynskyy and Makarynska, 2007) and some local wind influences in Mermaid Sound.

Notably, the SWAN wave model with forcing functions provided by the NWW3 performed well over the periods of typical seasonal wave conditions, which for the case were January-February and May-June, as well as for a transitional month of March (Hamilton, 1997). This implies that the SWAN model settings are appropriate for the case allowing for capturing the general trends of the sea states behaviour and, therefore, the model can be effectively used in the current dredging studies.

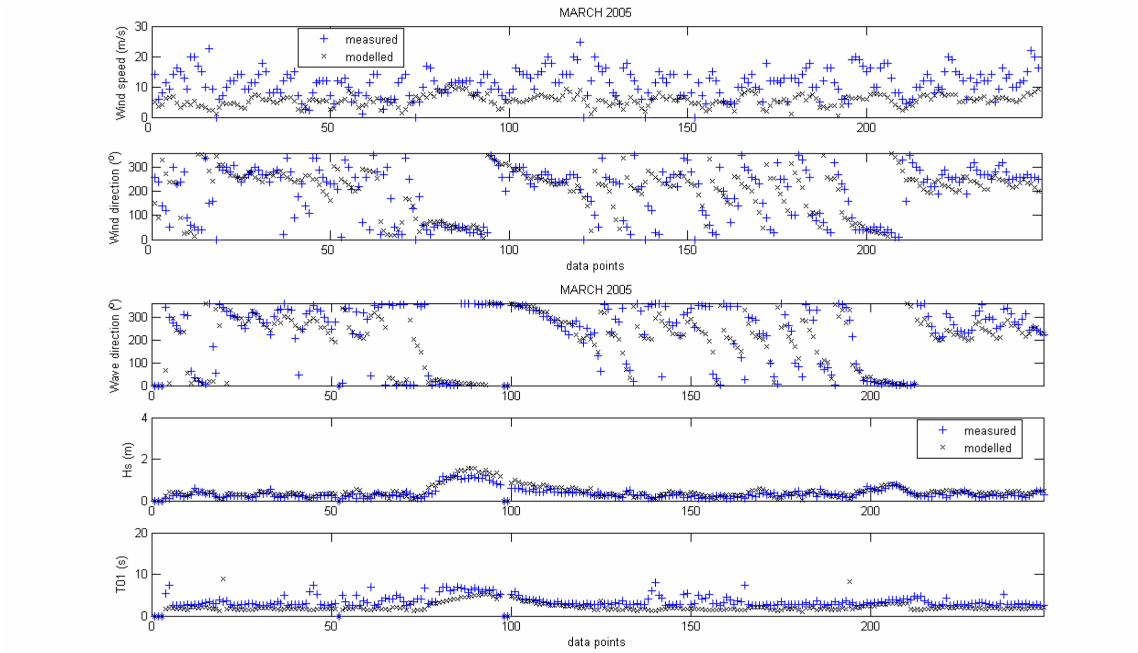

Figure 9: Time series plots of the measured and modelled wind speed and direction, significant wave height, mean wave period and mean wave direction for March 2005.

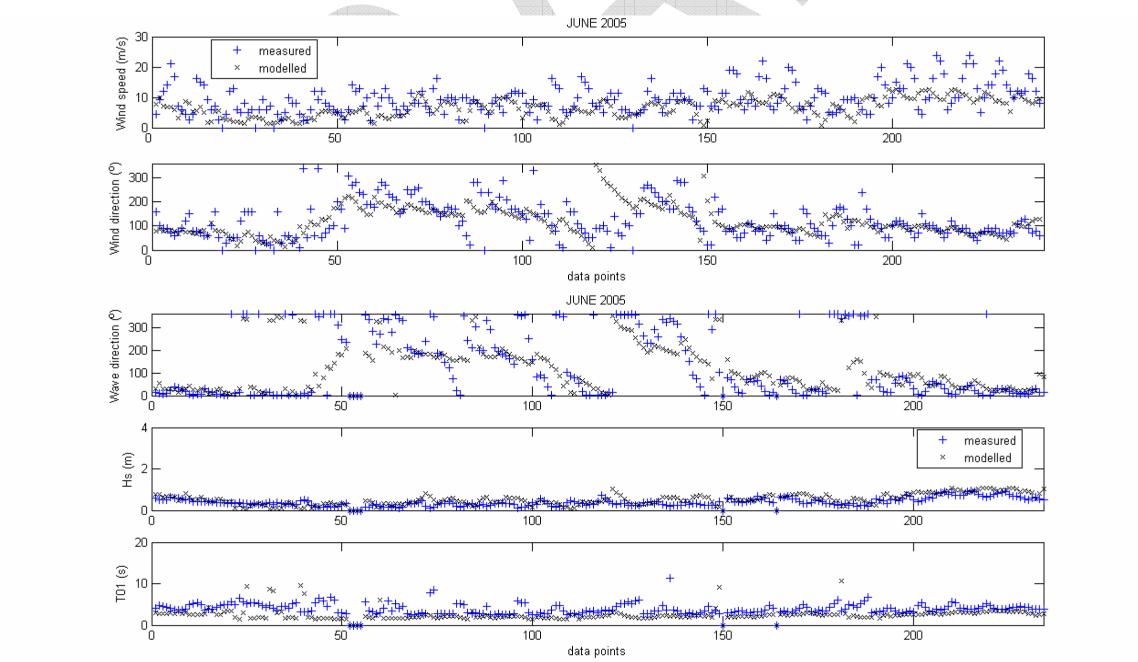

Figure 10: Time series plots of the measured and modelled wind speed and direction, significant wave height, mean wave period and mean wave direction for June 2005.

Table 1: Statistics of NCEP GDAS wind and SWAN wave model hindcast validated against Karratha Airport and DWR buoy measurements, respectively.

January 04	***ME***	***RMSE***	***SI***	***R***
Wind speed	5.95 m/s	7.08 m/s	0.58	0.48
Wind direction	1.02°	N/A	0.40	N/A
Wave direction	13.35°	N/A	0.40	N/A
H_s	-0.10 m	0.18 m	0.47	0.82
T_{01}	1.12 s	1.50 s	0.46	0.37
February 04				
Wind speed	6.18 m/s	7.65 m/s	0.61	0.53
Wind direction	10.96°	N/A	0.42	N/A
Wave direction	15.01°	N/A	0.42	N/A
H_s	-0.12 m	0.23 m	0.58	0.70
T_{01}	1.12 s	1.96 s	0.52	0.28
March 04				
Wind speed	4.75 m/s	7.09 m/s	0.65	0.55
Wind direction	-14.01°	N/A	0.61	N/A
Wave direction	-8.03°	N/A	0.84	N/A
H_s	-0.11 m	0.28 m	0.68	0.80
T_{01}	2.80 s	3.88 s	0.74	0.15
April 04				
Wind speed	4.31 m/s	6.33 m/s	0.72	-0.05
Wind direction	-9.48°	N/A	0.68	N/A
Wave direction	32.05°	N/A	0.72	N/A
H_s	-0.07 m	0.16 m	0.68	0.47
T_{01}	2.60 s	4.40 s	0.87	0.17
May 04				
Wind speed	3.01 m/s	5.59 m/s	0.60	0.34
Wind direction	-7.65°	N/A	0.60	N/A
Wave direction	19.79°	N/A	0.65	N/A
H_s	-0.15 m	0.21 m	0.63	0.61
T_{01}	2.47 s	3.78 s	0.76	0.17
June 04				
Wind speed	1.92 m/s	5.37 m/s	0.66	-0.02
Wind direction	10.18°	N/A	0.60	N/A
Wave direction	57.26°	N/A	0.76	N/A
H_s	-0.18 m	0.24 m	0.70	0.60
T_{01}	3.66 s	4.61 s	0.70	0.37

Table 2 (continued): Statistics of NCEP GDAS wind and SWAN wave model hindcast validated against Karratha Airport and DWR buoy measurements, respectively.

July 04				
Wind speed	3.01 m/s	5.93 m/s	0.64	0.23
Wind direction	1.19°	N/A	0.57	N/A
Wave direction	47.15°	N/A	0.78	N/A
H_s	-0.12 m	0.22 m	0.54	0.56
T_{01}	2.22 s	3.08 s	0.63	0.23
August 04				
Wind speed	3.50 m/s	6.56 m/s	0.64	-0.01
Wind direction	7.21°	N/A	0.51	N/A
Wave direction	62.92°	N/A	0.59	N/A
H_s	-0.20 m	0.28 m	0.83	0.14
T_{01}	2.00 s	3.14 s	0.70	0.01
September 04				
Wind speed	4.82 m/s	6.79 m/s	0.62	0.21
Wind direction	1.56°	N/A	0.41	N/A
Wave direction	43.88°	N/A	0.55	N/A
H_s	-0.17 m	0.24 m	0.75	0.52
T_{01}	2.18 s	3.35 s	0.71	0.20
November 04				
Wind speed	5.51 m/s	7.10 m/s	0.58	0.40
Wind direction	9.94°	N/A	0.40	N/A
Wave direction	29.20°	N/A	0.47	N/A
H_s	-0.13 m	0.19 m	0.67	0.75
T_{01}	1.37 s	2.31 s	0.71	0.41
December 04				
Wind speed	6.59 m/s	7.78 m/s	0.61	0.42
Wind direction	6.80°	N/A	0.42	N/A
Wave direction	28.58°	N/A	0.46	N/A
H_s	-0.13 m	0.21 m	0.64	0.49
T_{01}	1.23 s	2.08 s	0.62	0.17
January 05	*ME*	*RMSE*	*SI*	*R*
Wind speed	5.77 m/s	7.02 m/s	0.58	0.49
Wind direction	-11.39°	N/A	0.41	N/A
Wave direction	23.12°	N/A	0.34	N/A
H_s	-0.10 m	0.16 m	0.47	0.51
T_{01}	1.46 s	2.02 s	0.57	0.13

Table 3 (continued): Statistics of NCEP GDAS wind and SWAN wave model hindcast validated against Karratha Airport and DWR buoy measurements, respectively.

February 05	*ME*	*RMSE*	*SI*	*R*
Wind speed	5.78 m/s	6.99 m/s	0.66	0.46
Wind direction	-9.50°	N/A	0.49	N/A
Wave direction	-5.78°	N/A	0.62	N/A
H_s	-0.01 m	0.18 m	0.59	0.17
T_{01}	1.81 s	2.42 s	0.64	0.29
March 05				
Wind speed	5.78 m/s	7.19 m/s	0.64	0.27
Wind direction	-9.58°	N/A	0.59	N/A
Wave direction	27.94°	N/A	0.58	N/A
H_s	-0.10 m	0.17 m	0.49	0.89
T_{01}	1.37 s	1.87 s	0.54	0.46
April 05				
Wind speed	4.91 m/s	6.44 m/s	0.70	0.20
Wind direction	2.08°	N/A	0.64	N/A
Wave direction	61.43°	N/A	0.70	N/A
H_s	-0.10 m	0.23 m	0.98	-0.05
T_{01}	2.19 s	3.41 s	0.75	-0.01
May 05				
Wind speed	3.88 m/s	6.19 m/s	0.77	0.09
Wind direction	5.38°	N/A	0.70	N/A
Wave direction	27.55°	N/A	0.82	N/A
H_s	-0.01 m	0.17 m	0.49	0.61
T_{01}	2.07 s	3.59 s	0.71	0.29
June 05				
Wind speed	2.96 m/s	5.87 m/s	0.62	0.25
Wind direction	2.83°	N/A	0.59	N/A
Wave direction	20.12°	N/A	0.98	N/A
H_s	-0.12 m	0.23 m	0.59	0.66
T_{01}	1.43 s	2.28 s	0.59	0.13

1.3 Dredge Modelling

1.3.1 SSFATE Background

Sediment dispersion modeling of dredged material was carried out using the SSFATE dredge model (see Swanson et al. 2007). SSFATE is a Lagrangian particle tracking model useful for determining the fate of sediment. Each particle is assigned a mass for the amount of material it represents but is transported based on the properties of a single particle. After the transport calculation stage of the model, the results are applied to an Eulerian concentration grid using a Gaussian distribution of the mass over area. This gives the effect that the particles move as a plume and not as a clump of mass. Horizontal transport of material is due to advection by currents and diffusion. Current velocity fields are imported into the model from a separate hydrodynamic model. Vertical transport is based on particle settling rates and turbulent mixing which the model parameterises with vertical diffusion coefficients. Particle settling velocities are calculated using Stokes' law and through the complex processes of flocculation due to cohesiveness.

Deposition is based on a probability which is a function of bottom stress and concentration. Matter that is deposited can be resuspended if the critical bottom stress is exceeded. The model employs two different resuspension algorithms. The first applies to material deposited in the last tidal cycle (12 hours) and is from Lin et al. (2003). It accounts for the fact that newly deposited material will not be consolidated and will therefore resuspend with less effort than consolidated bottom material. The second algorithm is the Van Rijn method (Van Rijn, 1989) and applies to all other material that has been deposited prior to the start of the last tidal cycle. Swanson et al. (2007) summarise justifications and tests for these schemes.

The characterization of different dredge types is represented by the initial vertical distribution of released material as well as the sediment grain size distribution. For example the majority of sediment release from a trailer suction dredge is due to overflow of fine material. Therefore the initial vertical distribution of material is set to release near the surface and the grain size distribution is biased towards the finer material.

1.3.2 Benthic Boundary Layer Model

SSFATE applies a benthic boundary layer model for the calculation of bottom stress, which drives sediment resuspension. For the case where there are only currents, the quadratic friction law is used to calculate seabed stress which has the form:

$$\tau_c = \rho C_d u_c^2$$

where τ_c is the seabed stress due to currents, ρ is the density of seawater, u_c is the current at the seabed and C_d is a friction coefficient (0.003 was used by SSFATE). If a wave field is applied to the model, bottom stress is calculated using the method in Soulsby (1997) which accounts for the non-linear wave-current interactions.

The maximum stress at the seabed $\tau_{cw,max}$ is given by:

$$\tau_{cw,\max} = \sqrt{(\tau_{cw} + \tau_w \cos\varphi_{cw})^2 + (\tau_w \sin\varphi_{cw})^2}$$

where,

$$\tau_{cw} = \tau_c (1 + 1.2\left(\frac{\tau_w}{\tau_c + \tau_w}\right)^{3.2})$$

$$\tau_w = 0.5 f_w \rho u_{bm}^2$$

$$f_w = \min[1.39\left(\frac{A_w}{z_0}\right)^{-0.52}, 0.3]$$

$$A_w = \frac{u_{bm}}{\omega}$$

τ_w- bottom stress due to waves only
φ_{cw} - angle between the waves and the currents
f_w – wave friction factor
u_{bm} – maximum bottom wave orbital velocity
T – wave period
z_0 – depth at which velocity is zero (~ less than 0.1m)
ω – wave number ($2\pi/T$)

This scheme is a parametric approximation of other boundary layer models. Parameters were calibrated to give an approximate solution to the results of these models. The advantage of this method is that it does not involve any iterative solutions for friction coefficients, thus greatly reducing computational requirements. The Soulsby (1997) scheme for calculating seabed stress from waves-current interactions is also used in the Regional Ocean Modelling Systems (ROMS), a widely accepted model in the international scientific community.

1.3.3 SSFATE Model Scenarios

The sediment transport model SSFATE was used to simulate the effects of dredging on the marine habitat of Dampier Archipelago. Simulations represent key dredging activities. They were chosen based on the amount of activity occurring in an area as well as the proximity to sensitive habitats. For example, simulations for dredging of the turning circle represented the bulk of activities immediately off Holden Point, and the most intensive operation of the wider campaign. The simulations allow testing of various aspects of the dredging impacts for the proposed program. For example, testing of resuspension influences on the potential for subsequent exposure to sensitive receptors, or for accumulation in relatively quiet areas, for inputs at key locations.

The effect of sediment dispersion from dredging activities, and subsequent resuspension by waves and currents, was simulated for three main scenarios:

1) dredging of the turning circle near Holden Point, (summer conditions specifically chosen as worst case);
2) trailer suction dredging of the gas trunk line along the Eastern edge of Mermaid Sound; and
3) dumping of fine material into offshore spoil ground 2B (winter conditions specifically chosen as worst case)

Figure 11 highlights the areas of each dredging and disposal operation.

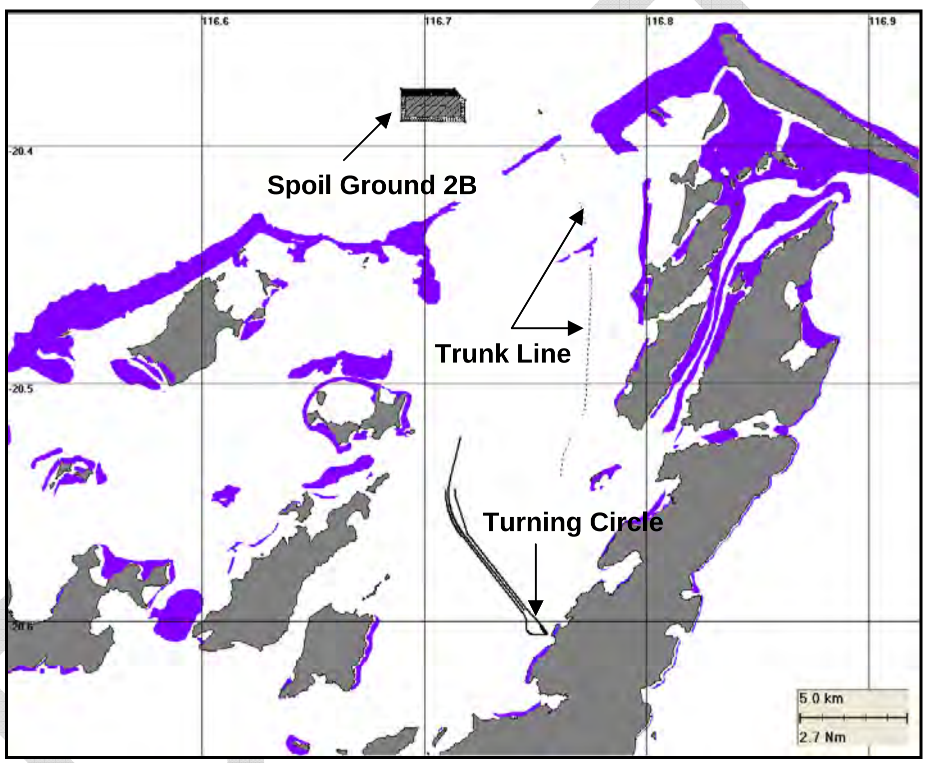

Figure 11: Locations of regions of concern for dredge modeling. Regions coloured purple are known locations of reefs supporting various BPP assemblages.

Simulations of the trunk line dredging and dumping into the spoil ground involved one type of operation, whereas activities within the turning circle involved multiple activities occurring simultaneously. The turning circle activities involved:

- Trailer suction dredging of any unconsolidated material
- Cutter suction dredging of the inner rock margin and discharging the material via a diffuser pipe into a pit
- Trailer suction dredge extracting material from the pit

- Cutter suction dredging of harder material within the turning circle and discharging directly to the seabed
- Trailer suction dredge collecting discharged CSD material from the turning circle
- Propeller wash generated by repeated, pulsed, movements of trailer suction barges moving over the shallow grounds leading to the shipping channel (for transport of spoil to the offshore ground).

The simulation covered 6 weeks of discharge from multiple sources of suspension. (Figure 12 shows the proportion of the entire operation over the turning circle and shipping berth). Wave and current data from October and November were applied as this is the period when this operation is currently proposed (Figure 12). The trunk line operation was also modelled for six weeks, but using wave and current data from February and March (Figure 13). The disposal into spoil ground 2B was simulated over a four week period, with the model ran on for a further 4 weeks to specifically address resuspension of sediments and subsequent retransport. Wave and current data from April and May (Figure 14) were used because winter winds were considered worst case for sensitive receptors closest to the site.

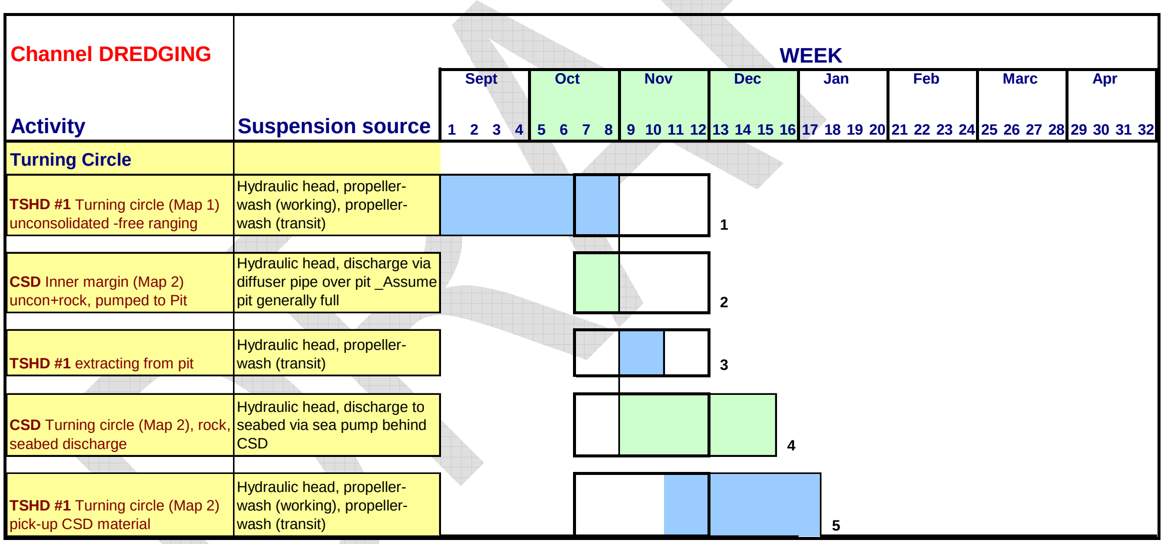

Figure 12: Timeline of the dredging operation within the turning circle. Six week period with border from weeks 7 - 12 is the time selected for modelling, because this was a period when all operations are running concurrently.

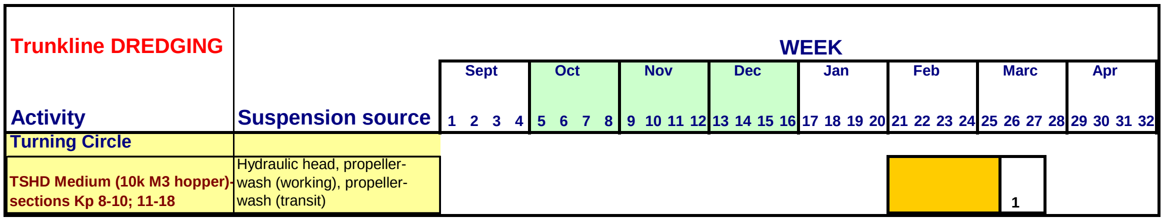

Figure 13: Timeline of the dredging operation for the trunk line. Period from weeks 21-26 is when the model was run. This period extended 2 weeks beyond the operation to test for resuspension of material.

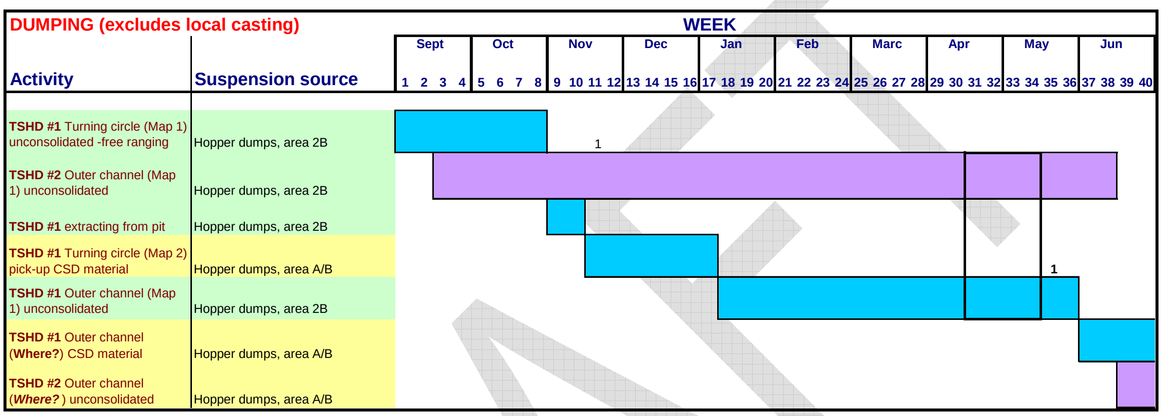

Figure 14: Timeline of the dumping operation. Period from weeks 31-34 is when the dredge model was set to discharge. The simulation was continued for 1 additional month to test resuspension of material under sample winter wind/wave conditions.

1.3.4 Characterisation of Different Dredging Operations

Each dredge type is a source of suspended sediment generation through overflow, direct loss at the dredge source, direct discharge to the water column or through propeller induced suspension. A loss rate was defined as a percentage of the total production rate for each dredge type and was based on of the above processes by which sediment was discharged into the water column. The sediment grain size distribution will vary based on the way the material is discharged into the water column and also by the sediment mixture of the region being dredged.

Trailer suction dredging of unconsolidated material

This operation occurs at the start of the dredging in the turning circle and involves a trailer suction dredge circling at a speed of 2 knots collecting material and transporting it to the spoil ground. The barge takes approximately one hour to fill and two and a half hours to transport the material to the dumping ground before returning. Sources of sediment suspension are through overflow and propeller wash. The loss rate was assumed to be a relatively conservative rate of 3% of the total production rate of 900 m^3/hr (APASA, 2006). Suspended material was skewed towards the finer material (Table 4) and the vertical distribution of material was concentrated higher in the water column (Table 5) to ensure current drift during initial settling was not underestimated.

Table 4: Sediment grain size distribution for TSHD of unconsolidated material

Classification	Passing Size (μm)	% of Total
Clay to medium silt	30	60
Coarse Silt	70	35
Very fine to fine sand	100	5
Fine to medium sand	200	0
Medium sand	500	0
Coarse sand	1000	0

Table 5: Initial vertical distribution of sediments in the water column setup by overflow of the TSHD vessel

Height above seabed (m)	% of suspended sediments
12	29
8	23
6	13
2	17
1	18

Cutter suction dredging with discharge via diffuser pipe
This operation involves cutting rock within the shallow inner margin of the turning circle and discharging the material via a pipe into a pit. The sediment is discharged via a diffuser plate approximately 5m above the seabed. There are two separate sources of sediment release, one at the cutter head and the other at the pit. The loss rate at the cutter head is assumed to be 0.3% of the total production rate of 1200 m^3/hr (APASA, 2006). The grain size distribution of lost material from the cutter suction dredge is heavily biased towards fines (APASA, 2006) (see Table 6). The vertical distribution of released sediments was closer to the seabed due to the discharge practice proposed to reduce the spread of fines.

Table 6: Grain size distribution of material lost at the cutter head of a cutter suction dredge

Classification	Passing Size (μm)	% of Total
Clay to medium silt	30	96
Coarse Silt	70	4
Very fine to fine sand	100	0
Fine to medium sand	200	0
Medium sand	500	0
Coarse sand	1000	0

Table 7: Initial vertical distribution of sediments in the water column setup by loss from the cutter suction dredge

Height above seabed (m)	% of suspended sediments
10	5
7	15
3	20
2	40
1	20

Material released into the pit via the diffuser pipe was a mixture of coarse and fine material (Table 8). The majority of the initial vertical distribution was centered around 5m above the seabed. However, to allow for the effects of billowing and to be conservative some material was released higher in the water column (Table 9).

Table 8: Grain size distribution of cutter suction material released via diffuser pipe into pit

Classification	Passing Size (µm)	% of Total
Clay to medium silt	30	43
Coarse Silt	70	21
Very fine to fine sand	100	11
Fine to medium sand	200	5
Medium sand	500	8
Coarse sand	1000	12

Table 9: Initial vertical distribution of sediments in the water column released via a diffuser pipe into a pit

Height above seabed (m)	% of suspended sediments
15	15
10	20
5	40
2	20
1	5

Trailer suction dredging of CSD material

Both the trailer suction dredging of CSD material from the pit and from the turning circle, have similar characteristics. Both have the same production rate of 690 m^3/hr and the same time to fill the barge. The key difference is that the dredge working the pit is nearly stationary whilst it picks up material. The vertical distribution of overflow material is the same as the previous trailer suction operation (Table 5). Although the trailer suction dredge collects the same material as that discharged by the cutter suction dredge, the grain size distribution is biased towards the fines (Table 10) to represent material lost due to overflow.

Table 10: Grain size distribution of cutter suction material lost via overflow from a trailer suction barge

Classification	Passing Size (µm)	% of Total
Clay to medium silt	30	56
Coarse Silt	70	32
Very fine to fine sand	100	8
Fine to medium sand	200	4
Medium sand	500	0
Coarse sand	1000	0

Cutter suction dredging of the turning circle

This operation involves cutter suction dredging of harder, consolidated material and discharging it via an underwater pipe to the seabed. The dredge has a production rate of 1200 m^3/hr. The discharged material has the same grain size distribution as that which was discharged into the pit (Table 8). The vertical distribution was biased towards the seabed, reflecting the discharge height, but with a proportion released towards the surface to account for billowing of the plume.

Table 11: Initial vertical distribution of sediments discharged via an underwater pipe from a cutter suction dredge

Height above seabed (m)	% of suspended sediments
10	5
7	15
3	30
2	50
1	11

Disposal of material into spoil ground 2B

This operation involved two trailer suction barges alternately dumping into spoil ground 2B. The amount of solid material being dumped each time was 2500 m^3 and dumps occurred randomly every one to three hours. The material was based on the finest mixture found in the SKM sampling (see APASA, 2006). The material had a strong bias towards the finer sediments, with coarser material being evenly distributed (Table 12). The initial vertical distribution from hopper dumping operations tend to be have a distribution spread higher in the water column, but concentrated in the lower half of the water column due to entrainment by the rapid sinking of heavier components (Table 13; Swanson et al. 2004).

Table 12: Grain size distribution of material being disposed into spoil ground 2B

Classification	Passing Size (µm)	% of Total
Clay to medium silt	30	55
Coarse Silt	70	26
Very fine to fine sand	100	12
Fine to medium sand	200	2
Medium sand	500	2
Coarse sand	1000	3

Table 13: Initial vertical distribution of sediments being disposed into spoil ground 2B

Height above seabed (m)	% of suspended sediments
12	15
8	20
6	25
2	29
1	11

Trailer suction dredging of the gas trunk line
The final operation involves trailer suction dredging of unconsolidated sandy material along the trunk line route. The procedure of this operation involves the dredge moving slowly along picking up material and transporting it to the spoil ground. The speed of progress was expected to be 3.5km/week. The production rate was expected to be 2000 m^3/hr in the first two sections of the trunk line and 3000 m^3/hr in the latter two sections where material is less consolidated. The loss rate due to overflow was assumed to be 0.3% and this was due to the mixture comprising of higher amounts of sand (Table 14). The vertical distribution of material from overflow was the same as for other trailer suction activities (Table 5).

Table 14: Grain size distribution collected by trailer suction dredge working along the trunk line route

Classification	Passing Size (µm)	% of Total
Clay to medium silt	30	60
Coarse Silt	70	35
Very fine to fine sand	100	5
Fine to medium sand	200	0
Medium sand	500	0
Coarse sand	1000	0

1.3.5 Propellor Wash Parameterisation

The simulation of dredging of the turning circle also took into consideration the effect of propeller wash generated by barges traversing between the dredge site and the spoil ground. In order to properly quantify the amount of material suspended, two separate methods were tested. Both methods are based on the findings in Damara (2004) however they do used different approaches.

The first method which was used in APASA (2006; PER document), involved replicating the suspended sediment profile in the water column estimated by Damara (2004) after a vessel travels past. The barge was estimated to travel at 12 knots and have an under keel clearance of between 2-5m depending on the state of the tide and the depth. The vertical concentration profile of suspended sediment for a vessel traveling at this speed was approximately 150 mg/L at the seabed and decreasing linearly to approximately 90 mg/L at the surface. In order for the model to replicate these concentrations, the production rate and initial vertical distribution of sediments were adjusted. The problem identified with this method is that water column concentration in SSFATE are calculated as an average over an Eulerian grid cell with a resolution of 100x100x3m. Subsequently, it was identified that this method grossly overestimated the sediment mass being released – hence previous predictions were an overestimation of propeller-wash input.

The revised approach involved estimating the total amount of mass suspended by propeller induced currents during each traverse. The approach involved estimating the flux of sediment from the seabed and converting it to total mass based on the area covered by propeller-wash during the transit (based on effect width reported by Damara 2004 and the length of the transit) and the amount of time required to complete the transit (based on the speed and distance). Sediment flux from the seabed was estimated from propeller-wash velocities reported by Damara 2004, using methods from Van Rijn (1989) which is also the method used to calculate resuspension rates by SSFATE (Swanson et al., 2007). The estimated total mass released during each transit was used as the dredge production rate for each transit in the mode, assuming 100% release to the water column. Van Rijn calculations indicated that the total mass released is highly sensitive to bottom velocity due to propellers. Damara (2004) indicates that propeller induced velocities for a vessel traveling at 12 knots with an under keel clearance of 3 m will be 0.5-0.6 m/s. In order to be conservative and to allow for errors in assumptions, a value of 0.8 m/s was chosen as the propeller induced velocity at the seabed.

Calculations of suspended sediment using the Van Rijn method revealed that the first method was releasing more than 20 times more sediment than would actually occur. If a propeller induced bottom velocity of 0.5 m/s was used the amount of sediment released was over 100 times less than the initial estimation. The production rate in the model was reduced by a factor of 20 in order to be conservative.

1.3.6 Vertical Mixing

The addition of energy to a shallow coastal environment through tides and waves, results in dissipation through bottom friction and turbulent mixing of the water column. The diffusion ([m^2/s]) is the model parameter which describes the degree of turbulent mixing. The vertical diffusion profile is particularly important as it is the only parameter within the model which determines upward transport of dredged material. The amount of turbulence affects the vertical concentration profile of suspended sediment in the water column. Obviously the more sediment that stays higher in the water column, the higher probability there is that it will be advected further by currents.

There is no literature on vertical turbulence estimates within Dampier. Katsumata (2006) estimates that the energy dissipation due to tides on the North West Shelf results in a vertical diffusivity of the order 10^{-4}-10^{-3} m^2s^{-1}. Results of that study were quantified using a large scale numerical model and are not based on any field data, other than to compare tidal magnitudes. However, this work did provide a range of vertical diffusion values to base the sediment transport model upon. The only field study which model results could be based upon was from measurements of suspended sediment after a dredging operation in Dampier by Stoddart and Anstee (2004). Measurements concluded that suspended sediment concentrations were well mixed in the near and far field of the dredging operation.

Four estimations of the vertical diffusion profile were tested. These were: a constant profile; a profile from Pritchard (1960); a profile from van Rijn (1986); and a user defined distribution to replicate a well mixed concentration profile of suspended sediment in the water column. Figure 15 illustrates the vertical diffusion coefficients throughout the water column using different methods. The value for the constant profile was set to 10^{-3} m^2s^{-1}. The Pritchard vertical diffusion profile accounts for the effects of currents only and requires a value for the Richardson number which is a dimensionless term describing the density stratification in the water column. This was given a value 0.1, typical for a well mixed water column. Values of vertical diffusion ranged between 10^{-7} m^2s^{-1}–10^{-4} m^2s^{-1}. The profile from van Rijn (1986) accounts for both waves and currents. It was developed based on suspended sediment concentrations under waves and currents in laboratory conditions. Vertical diffusion values ranged from 10^{-5} m^2s^{-1} at the seabed to 10^{-1} m^2s^{-1} using wave and current conditions representative of Mermaid Sound. The final more conservative profile was based upon the Pritchard values but an order of magnitude greater to be in better agreement to the range specified by Katsumata (2006).

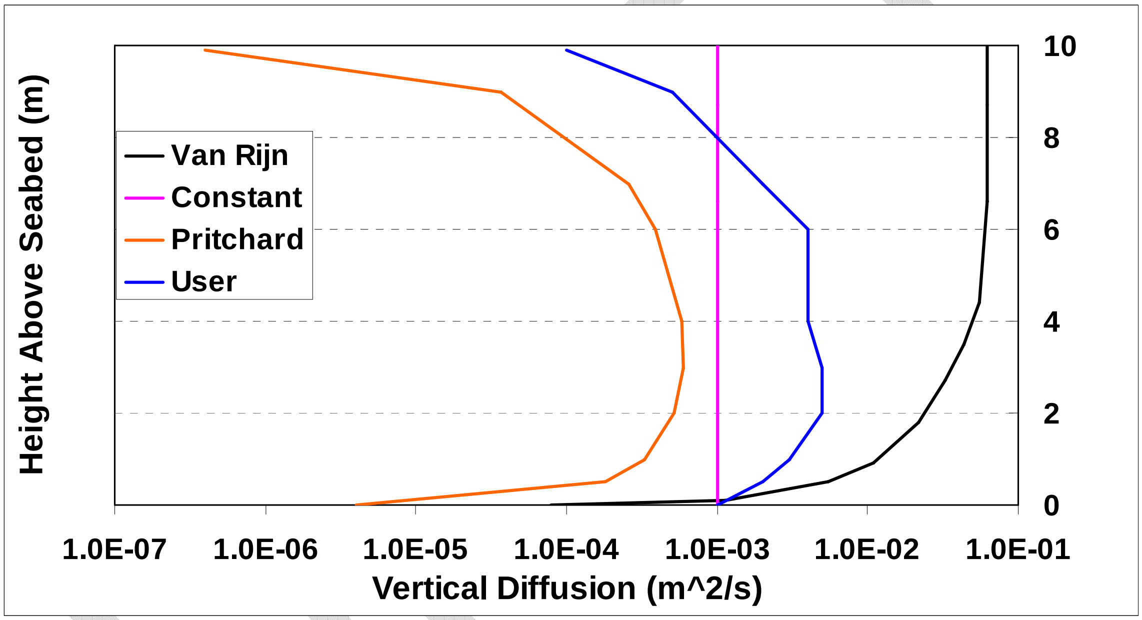

Figure 15: Different vertical diffusion profiles tested in SSFATE. Note that the Pritchard profile will vary with current speed.

Test simulations were run to determine the effect of changing the vertical diffusion profile on the concentration of particles in the water column (Figure 16). Results indicated that the constant coefficient and the Pritchard profile concentrated particles near the seabed, with the effect that transport rates are reduced. The van Rijn profile resulted in particles mixing into the surface layer, however it did tend to restrict the horizontal transport of material other than clay. The more conservative diffusion profile forced the greatest amount of mixing of sediment throughout the water column. It also forced sediment to spread further horizontally, thus the total area affected by sedimentation and suspended sediments was greater in SSFATE predictions. This latter vertical diffusion profile was ultimately chosen for use in SSFATE for operations within the shallower waters of Mermaid Sound, because it provided a conservative estimate for the area impacted by dredging, and providing a good replication of the vertical suspended sediment profile measured by Stoddart and Anstee (2004). The more conservative profile was considered a gross overestimate for the deeper waters of the dump site as this method predicted a high concentration of clay would be forced into the surface water layer, overstating the influence of wave energy penetrating to the depths of this site. This profile was adjusted to have a lower diffusion at the bottom (1.0×10^{-5}).

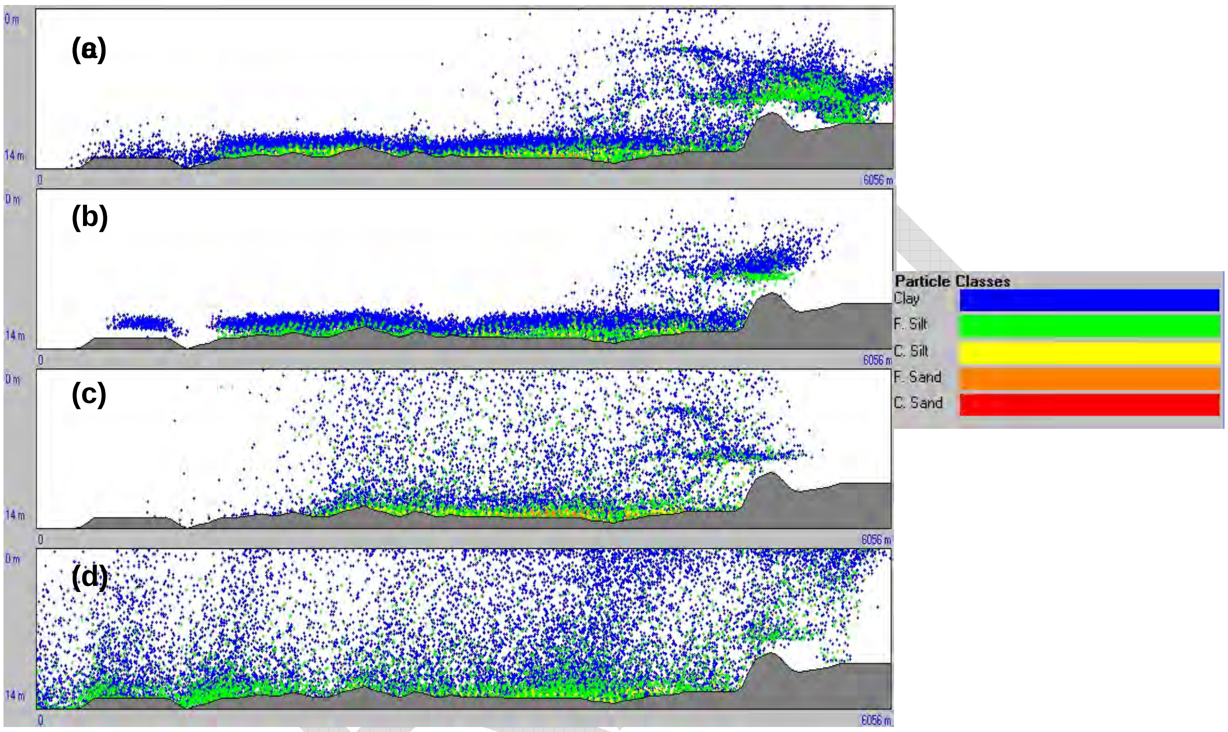

Figure 16: Vertical cross-section of suspended particles using different vertical diffusion profiles. (a) Constant (b) Pritchard (c) Van Rijn (d) User specified profile. Results are from test simulations and show the influence on the vertical distribution and horizontal transport predicted for particles of different size.

1.3.7 Post-processing model results

The SSFATE records a 3 dimensional field of SSC and sedimentation on an hourly time-step. This data was post-processed to apply an array of thresholds of influence defined by SKM and MScience, to derive zones of effect.

Multiple thresholds have been applied, allowing for sensitivity analysis, and comparison to field measures of impact.

2 References

APASA, 2006, Pluto LNG Sediment Dispersion Study-Dredging Operations Associated with Construction of a Navigation Channel, Installation of a Subsea Gas Export Trunkline and Disposal of Spoil*, Report prepared for SKM*

Caplan, P., Derber, J., Gemmill, W., Hong, S.-Y., Pan, H.-L., Parish, D., 1997. Changes to the 1995 NCEP operational medium-range forecast model analysis/forecast system. *Weather Forecasting*, 4, 335-343.

Damara Pty Ltd, 2004. Hamersley Iron Dredging – Dampier. Sediment Suspension through Propeller Action*,* Report to GEMS, April 2004, Presented as Appendix A, in Hamersley Iron Dampier Port Upgrade, Dredging and Spoil Disposal Management Plan prepared by Sinclair Knight Mertz, 2004.

Guillaume, A., 1990. Statistical tests for the comparison of surface gravity wave spectra with application to model validation, *J. of Atmospheric and Oceanic Technology*, 7, 551-567.

Hamilton L.J., 1997, Methods to obtain representative surface wave spectra, illustrated for two ports of north-western Australia*, Marine and Freshwater Research*, 48, pp. 43-57.

Kalnay et al., 1996, The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, 77, 437-470

Kanamitsu , M., Alpert, J.C., Campana, K.A., Caplan, M.P., Deaven, D.G., Iredell, M., Katz, B., Pan, H.-l., Sela, J., White, G.H., 1991. Recent changes implemented into the global forecast system at NMC. *Weather Forecasting*, 6, 425-435.

Katsumata K., 2006, Tidal stirring and mixing on the Australian North West Shelf*, Marine and Freshwater Research*, 57, pp 243-254.

Khandekar, M.L., Lalbeharry, R., 1996. An evaluation of Environment Canada's Operational Ocean Wave Model based on moored buoy data, *Weather and Forecasting*, 11(2), 137-152.

Makarynskyy, O., Makarynska, D., 2007. Wave prediction and data supplementation using artificial neural networks, *Journal of Coastal Research,* 23 (4), 146-155, doi:10.2112/04-0407.1.

Makarynskyy, O., Pires Silva, A.A., Carretero, J.C., Costa, M., 2001. WAM – buoy comparisons in the Portuguese west coast. *1st International Congress "Oceans III Millennium"*, April 24-27, 2001, Pontevedra, Spain, 201-206.

Makarynskyy, O., Pires-Silva, A.A., Makarynska, D., Ventura-Soares, C., 2005. Artificial neural networks in wave predictions at the west coast of Portugal, *Computers & Geosciences*, 31 (4), 415-424, doi:10.1016/j.cageo.2004.10.005.

Pires Silva, A.A., Makarynskyy, O., Monbaliu, J., Ventura Soares, C., Coelho, E.F., 2002. WAM/SWAN Simulations in an open coast: comparisons with ADCP measurements. *Proc.of the 6th Int.Symposium Littoral 2002*, September 22-26, 2002, Porto, Portugal, Vol.II, 169-173.

Pritchard D. W., Carpenter J. H., 1960, Measurements of turbulent diffusion in estuarine and inshore waters, *Bull. Int. Ass. Sci. Hydrol.,* No. 20, 37-50, December, 1960.

Ris, R.C., 1997. *Spectral Modelling of Wind Waves in Coastal Areas*, Ph.D. Thesis, Dept. Civil Engng., Delft Univ. Technology.

Soulsby, 1997, *Dynamics of Marine Sands,* Thomas Telford, London

Stoddart. J.A. & Anstee, S. 2005 Water quality, plume modelling and tracking before and during dredging in Mermaid Sound, Dampier, Western AustraliaIn Stoddart, JA and SE Stoddart (Eds) 2005. *Corals of the Dampier Harbour: Their Survival and Reproduction During the Dredging Programs of 2004*. Mscience Pty Ltd, Perth WA, 78pp.

Swanson, J., Isaji, T, Clarke, D.,and Dickerson C., 2004,Simulations of Dredging and Dredged Material Disposal Operations in Chesapeake Bay, Maryland and Saint Andrew Bay, Florida. Presented at WEDA XXIV / 36th TAMU Dredging Seminar, : July 7-9, 2004, Orlando, Florida

Swanson J.C., Isaji T., Galagan C., 2007, Modeling the Ultimate Transport and Fate of Dredge-Induced Suspended Sediment Transport and Deposition. Proceedings of Wodcon 2007, Lake Buena Vista, Florida.

Tolman, H.L., 2002a. Testing of WAVEWATCH III version 2.22 in NCEP's NWW3 ocean wave model suit. *Technical Note. Ocean Modeling Branch Contribution No.214*. US Dept.of Commerce, NOAA NWC NCEP, Washington DC, US, 106p.

Tolman, H.L., 2002b. User manual and system documentation of WAVEWATCH III version 2.22. *Technical Note. Marine Modeling and Analysis Branch Contribution No.222*. US Dept.of Commerce, NOAA NWC NCEP, Washington

Van Rijn L.C. 1986, Mathematical modelling of suspended sediment in nonuniform flows, *J. Hydraul. Eng., 112, pp. 433-455*

Van Rijn L.C., 1989, Sediment Transport by Currents and Waves, Rep. H461, Delft Hydraul. Lab., Delft, Netherlands