DAMPIER MARINE SERVICES FACILITY:

WATER QUALITY IMPACTS OF THE PLUTO PROGRAM IN AN AREA OF INTENSIVE DREDGING

Report: MSA142R2

Report to:

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Document Information

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JOB	MSA142
CLIENT	Dampier Port Authority
USAGE	This report provides information on data collected under the Pluto LNG Project for use in impact prediction by Dampier Port Authority.
PRECIS	Studies undertaken immediately adjacent to the most intense dredging over the first 3 months of the Pluto LNG Project provide a capacity to evaluate the relationship between water quality and coral health impacts.
KEYWORDS	Dredging coral mortality water turbidity

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V1 5 Nov 2009	JAS	Client Review
V2 30 Nov 2009	JAS	Includes client comments
V3 18 Dec 2009	JAS	Final

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1.0 INTRODUCTION

In undertaking an environmental evaluation of the construction phase of the Dampier Marine Services Facility (DMSF), Dampier Port Authority (DPA) is evaluating what levels of impact on water quality might lead to stress or mortality on surrounding coral communities. As part of that evaluation, DPA have requested MScience Pty Ltd (MScience) to review the results of a study of water quality impacts on corals from a dredging program immediately adjacent to the proposed DMSF.

Woodside Burrup Pty Ltd (Woodside) is conducting a major dredging program within Mermaid Sound adjacent to Holden Point (Figure 1) and along the gas trunkline route KP1-KP85 (SKM 2007b). That dredging is undertaken as part of Woodside's Pluto LNG Project (the Pluto Project).

To assess the environmental impacts of that project a model of the effects of dredging and disposal on water quality was interrogated using water quality triggers for coral mortality. Those triggers were developed from baseline data to indicate levels of suspended sediment or sedimentation above those experienced naturally. The water quality and mortality predictions were presented as an addendum (SKM 2007a) to the initial impact assessment and included as part of the final EPA approval.

The relationship between water quality and coral health is both complex and poorly understood. Thus threshold water quality triggers used to predict stress or mortality of corals tend to be set at precautionary levels as a mechanism to avoid causing impacts that exceed predictions. Predictions for the Pluto Project suggested that all corals within an area with a radius of approximately 1km of the most concentrated dredging would die. That area was called Zone A.

During the first 3 months of dredging (the majority of Dredging Phase 1), monitoring of water quality parameters (suspended sediment/ sedimentation/ light/temperature) was undertaken within Zone A at 3 sites where coral was known to occur and have been monitored quantitatively over the past few years (Figure 1). Coral health has been monitored following completion of that dredging phase.

This report presents data on sedimentation and suspended sediment levels experienced during the above period and the resultant impacts on corals in Zone A. The provision of this data should allow future dredging impact assessments in areas similar to Mermaid Sound to refine water quality triggers directed at avoiding coral mortality.

1.1 THE DATA SET

Dredging commenced on 22nd November 2007 within Zone A. The monitoring program extended until 18th February 2008. During that initial phase of dredging, the early works were undertaken by a large trailer suction hopper dredge which focussed on removing the upper layers of sediments around the turning basin and inner berths (see shaded area in Figure 1). On the 23rd of January 2008, the trailer dredge was joined by a cutter suction dredge operating nearby. These dredges continued to work in the vicinity of the water quality/corals monitoring sites until the conclusion of the monitoring period.

Due to the details of this monitoring program being resolved only shortly prior to the commencement of dredging, the selection of instruments used and the deployment schedule were strongly constrained by availability of appropriate instruments. Instruments used are described in Table 1 and Appendix 1. In some cases, the quality of data from instruments was not suitable for use and in these cases data was either deleted or adjusted (see Sect.2.2). At some sites, the type of nephelometer deployed was changed during the monitoring program when a superior instrument became available.

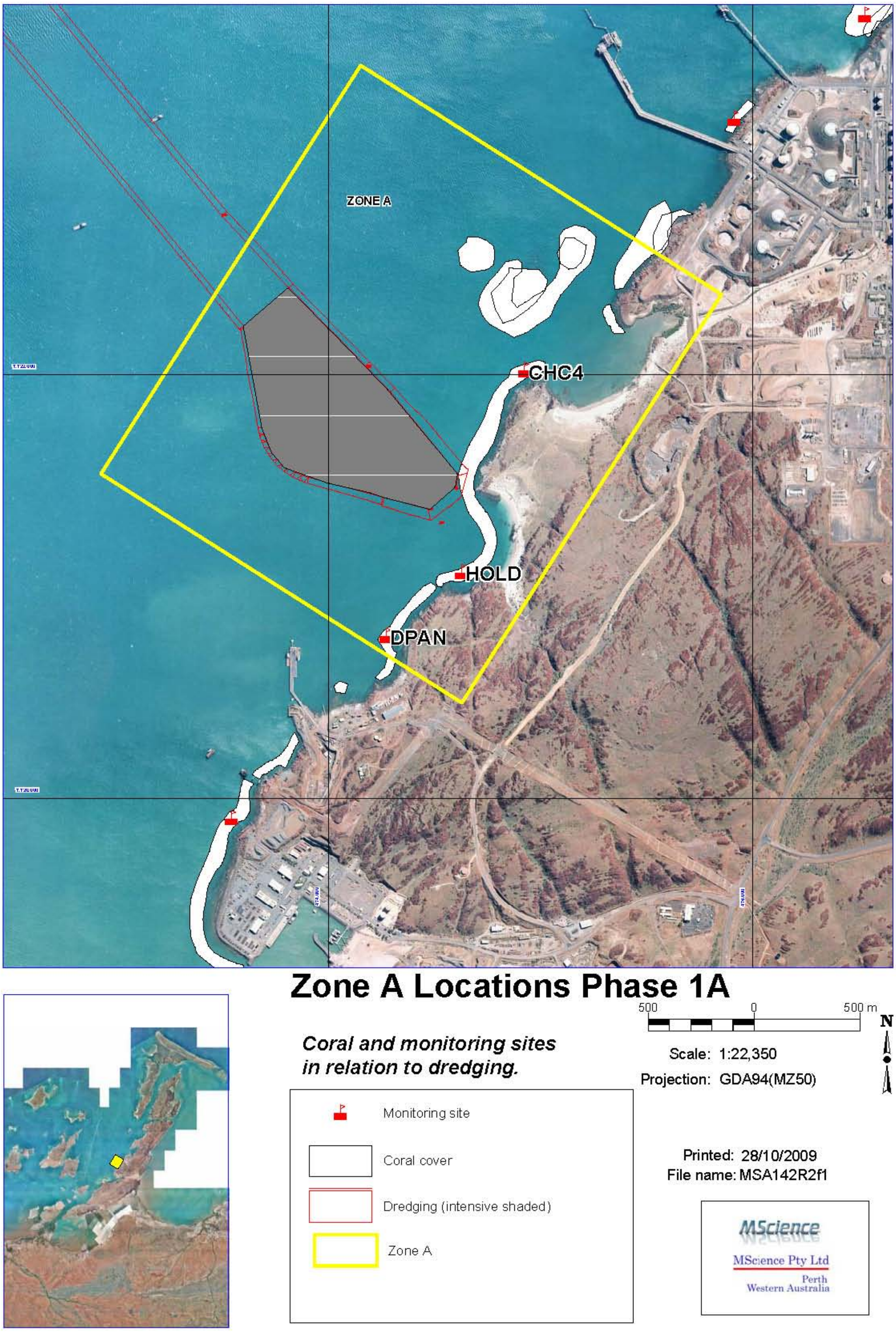
Table 1. Instruments installed during the 3 month program.

1. Logging Nephelometers: 3 were installed inside Zone A adjacent to the coral communities at CHC4, HOLD and DPAN to provide a record of the turbidity (in Nephelometric Turbidity Units [NTU]) and allow estimation of suspended sediment concentrations (SSC) at each coral site.
2. Light meters: 3 pairs of meters, 1 at coral community depth and another 1 m above, were installed at each site to provide light measurements and allow calculation of attenuation coefficients (LAC) estimates.
3. Boat-based : Turbidity and temperature were recorded for surface and bottom waters each week for three months at a set of stations adjacent to the instrument arrays at the coral communities (Figure 2) using a boat deployed meter. Water samples were collected from immediately adjacent to the turbidity instrument and assayed for SSC.
4. Sediment Traps: 3 banks of 4 sediment traps were deployed on frames near the turbidity/light instrument arrays at each site.

Coral monitoring was conducted using fixed belt transects to estimate the percentage cover of live coral at any time (see Stoddart et al. (2005)) for general methods or MScience (2009b) for a detailed discussion. Surveys were unable to be conducted immediately prior to the commencement of dredging and the pre-dredging estimates of coral cover at the sites were taken in July 2006 (HOLD) and May 2007 (DPAN & CHC4).

References to baseline data for water quality in this report relate to a 7 month data collection program (August 2006 to April 2007) conducted at several sites around Mermaid Sound, including CHC4.

Figure 1. Location of coral monitoring sites within Zone A.



2.0 WATER QUALITY

2.1 SEDIMENT DEPOSITION

Sedimentation onto corals is recognised as one possible impact known to cause stress (Stafford-Smith 1993). Sedimentation during dredging in Zone A was measured by the weight of sediment accumulated in sediment traps over various periods. Due to the high turbidity during dredging it was only possible to retrieve traps at a few instances. Meters of the type used to estimate deposition in the baseline were deployed for several weeks as they became available, but instrument failure prevented use of their data.

The Pluto Project developed thresholds for impact prediction based on the maximum sedimentation rates experienced in the 7 month baseline. Sedimentation during the baseline was measured by accumulated deposition of sediment on a glass plate over 2-hour time periods using the SAS meter system from James Cook University, Townsville. At the end of each period, the plate was swept clean and accumulation over the next 2 hours measured. Thus it represents 'net sedimentation' to a degree as it includes some loss of deposited sediment to resuspension within those 2 hour periods. Twelve 2-hour periods are summed to make a day.

As the sedimentation estimates collected during Phase I dredging are from sediment traps, which do not allow any resuspension, they are not directly comparable to those of the thresholds calculated from the baseline data from SAS meters.

2.1.1 PREDICTED SEDIMENTATION TRIGGERS

Predictions used are those of the Inner Sound sites as set out in SKM (2007a).

Mean sedimentation values of 4 -5 mg/cm^2.d were typical during the baseline.

From the baseline, the maximum daily rate of sedimentation seen at any of the inshore sites was around 30mg/ cm^2.d. As no mortality of corals was associated with that level of deposition during the baseline, it was used to set a value above which mortality might occur. Sedimentation triggers were set in a worst case (all corals are sensitive and die at 1.1 times the baseline maximum) to a best case (corals are robust and are not lost until a deposition level of 5 times the baseline is reached). Those triggers are presented in Table 2.

Values of Table 2 were used to interrogate model predictions of water quality and in any area where sediment rates were predicted to be above these values for 1 day, coral was assumed to be lost.

Table 2. Acute deposition triggers used as causing mortality in Zone A.

Case	Deposition ($mg/cm^2/d$)
Sensitive (1.1)	33
Robust (1.5)	45
Very Robust (2)	60
Extremely Robust (5)	150

As sedimentation acts by overwhelming the ability of corals to clear sediment from their tissue surfaces (Hodgson 1990; Stafford-Smith 1993; Wesseling et al. 1999), metrics of sedimentation should consider both “acute” (those above) and “chronic” triggers. Two chronic triggers were developed:

Medium term: 5d in 15d of >60 mg/ cm^2.d

Chronic: 15d in 30d >36 mg/ cm^2.d

2.1.2 Measured Sedimentation

Deposition rates were measured at two of the three sites over a series of different deployment periods (dependent on when instruments were retrieved). Average daily rates of sediment deposition (Table 3) were calculated from each of the four sediment traps set out on the racks at HOLD and CHC4 (the DPAN sediment trap rack was lost) by dividing the weight of sediment by the number of days in the deployment. As sedimentation was not able to be measured daily, it is not possible to compile the ‘chronic’ metrics. Note that these are gross sedimentation rate and likely to be significantly greater than net sedimentation as measured in the baseline.

Table 3: Mean sediment deposition rates observed.

	Average mg/cm2/d		Min to Max (by trap) mg/cm2/d	
Deployment	**HOLD**	**CHC4**	**HOLD**	**CHC4**
Nov-Dec	24 (11)	44 (23)	7 to 35	12 to 79
Dec-Jan	98 (35)		91 to 110	
Dec-Feb		26 (64)		17 to 44
Jan-Feb	44 (30)		27 to 84	

(figures in parentheses are days in each deployment)

Data from sediment traps will overestimate sediment accumulation rates by a factor equal to the resuspension of settled sediment. Measurement of sediment accumulation on an open glass plate (as per the SAS meter) may underestimate the accumulation of sediment on topographically complex structures like coral. Nevertheless, the estimates of sediment accumulation from the monitoring program are within an order of magnitude of those deemed to be likely to be in a range above 'baseline deposition" such that they might cause impact. In some deployments, numbers were below those which were predicted to cause impact (e.g. Nov-Dec at HOLD & Dec-Feb at CHC4).

Despite the indication that numbers from sediment traps were similar to those from plate deposition, neither should be seen as robust and accurate indicators of actual sedimentation. On 2 occasions, sediment racks were found tipped onto their side and sediment traps rapidly developed a fouling community around their aperture which would have altered deposition rates. Equally, the baseline report noted that measured deposition rates were often zero or close to undetectable when SSC levels and diver observations suggested that deposition was occurring. At present, there is no practical method for continuous in situ measurement of sediment deposition and resuspension in a manner that reflects processes on the surface of a coral.

2.2 Suspended Sediment Levels

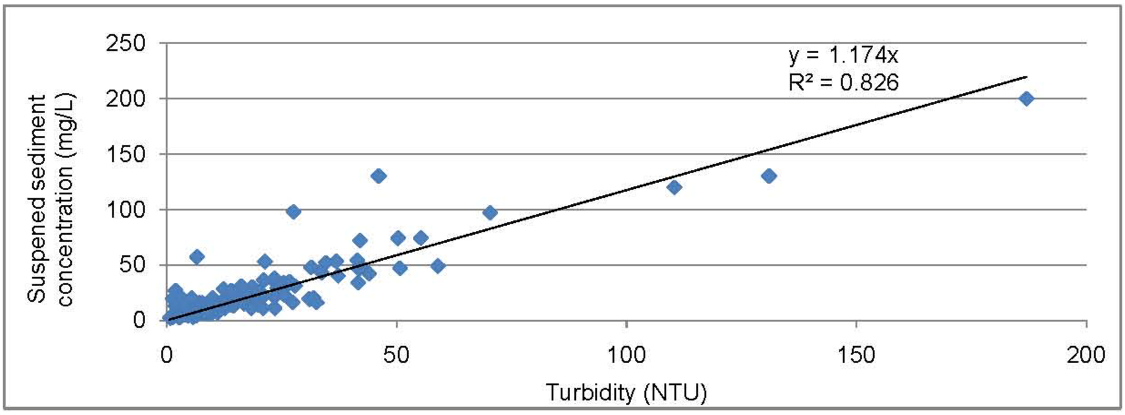
Turbidity was measured by meters using optical backscatter (OBS) sensors. In the nearshore environments of the Pilbara such instruments are prone to fouling and other artefacts – depending on the instrument design. Data processing techniques used here to clean spurious readings from nephelometer data have been described in the first report in this series (MScience 2009a). Within the Zone A monitoring program, as the area was frequently inaccessible or water clarity too poor to find instruments, the deployment periods were often longer than optimal for servicing and several instances of fouling effects causing data 'creep' were noted.

Where data creep was noted, values were 'corrected' by subtracting the daily minimum from each reading. In interpreting the results of later statistics, this process may mean that some values are underestimates of the actual turbidity experienced at meters. Statistics describing the lower levels of distributions (e.g. minima or 10%ile) will be most affected by that correction.

Turbidity data was recorded at 10 minute intervals by all nephelometers. However, this may cause some individual values to be unrepresentative of actual turbidity. Elsewhere, a statistical evaluation of turbidity data around dredging has suggested that a six-hour aggregation period provides a better method of representing data and one with more independence between points (Environmetrics 2007). In a macrotidal environment such as Mermaid Sound, where turbidity is measured in relatively shallow areas with the suspension of sediment strongly influenced by tidal phase and cycle, a six-hour aggregation period for turbidity data is appropriate. Here, we have reduced data points to a six-hour median.

Within the baseline studies for the Pluto Project, a variety of laboratory-derived relationships between NTU and SSC were derived using sediments from around meters at sites across Mermaid Sound. These empirical relationships provided estimates of *b* which ranged from 2.2 to 5.3 for the equation SSC(mg/L) = *b*NTU. However, simultaneous collection of turbidity as NTU from a YSI meter and SSC from filtered water samples taken in Zone A during the dredging program yielded an estimate of 1.2 for *b* (Figure 2). Other studies since then have yielded estimates between 1.1 and 1.7. In the present data we have used a *b* of 1.5 to convert NTU readings to SSC in mg/L.

Figure 2. NTU~SSC relationship derived from water samples collected over the dredging period.



2.2.1 Measured SSC

A number of statistics are available to describe the turbidity regime experienced by coral communities. The metric used should relate to the suspected mechanism of impact. As that mechanism may be complex and is poorly understood at present (Gilmour et al. 2006), there is no single accepted metric that relates turbidity to coral health.

Table 4. SSC statistics measured at the three sites during dredging.

	SSC(mg/L)		
	HOLD	**CHC4**	**DPAN**
Median	16	27	9
Mean	31	43	15
80%ile	44	67	23
95%ile	100	136	45
Maximum	322	266	106

Frequency-intensity-duration metrics are preferred (Gilmour el al. 2005), but durations and intensities are arbitrary. In the case of suspended sediments it is likely that the duration of elevation in intensity required runs to many days before profound physiological stress is reached. In the current case, we report measures of central tendency and upper distribution over the 3 months of monitoring (Table 4) as well as a frequency-intensity-duration metric for each site (Table 5).

As a comparative figure, the 80%ile of site CHC4 in the summer preceding dredging was 5.25 mg/L (based on 1.5 x the 80%ile NTU – see report 1 in this series (MScience 2009a)).

Table 5. SSC F-I-D data from sites during dredging (monthly frequency).

		Consecutive 24 hour periods						
HOLD	**above mg/L**	**1**	**2**	**3**	**4**	**7**	**14**	**Max**
	10	14	7	4	3	1	0	8
	15	12	5	3	2	1	0	5
	20	10	5	3	2			5
	25	9	4	2	1			3
	50	2	1					1
	100	1	0					0
CHC4	**above mg/L**	**1**	**2**	**3**	**4**	**7**	**14**	**Max**
	10	26	12	7	5	2	1	10
	15	17	7	4	3	1	0	7
	20	16	7	4	3	1	0	7
	25	13	6	4	2	1	0	7
	50	8	3	2	1			3
	100	1						1
DPAN	**above mg/L**	**1**	**2**	**3**	**4**	**7**	**14**	**Max**
	10	6	1	1				2
	15	4	1					1
	20	3	1					1
	25	2						1
	50	0						0
	100	0						0

The F-I-D values of Table 5 are calculated as the number of occasions within the monitoring period when the 6hr aggregated data points remained above the trigger value for 24 hours or multiples thereof (for example 8 consecutive data points above 10mg/L would return a frequency of 2 for the 1x24hr duration and 1 for the 2x24hr duration). Frequencies are adjusted to a monthly basis by dividing the total number of exceedences by the number of months of monitoring in the data set. The 'Max' category of Table 5 represents the longest consecutive exceedence (duration) of an intensity level and is expressed as the number of 24hr periods within that exceedence.

Graphs of the entire 6-hour data set are provided in Figures 3-5.

Figure 3. Water quality data at HOLD over the monitoring period.

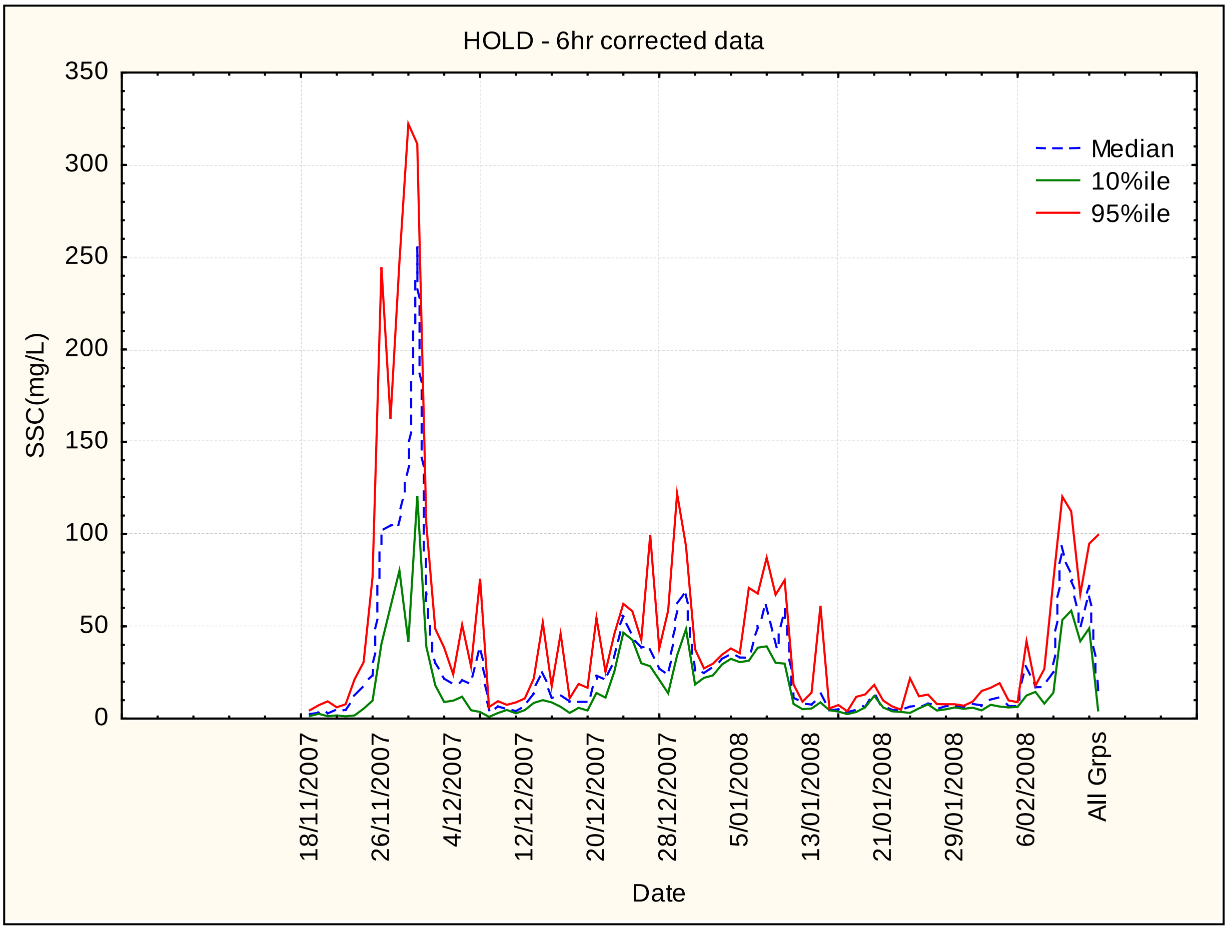


Figure 4. Water quality data at CHC4 over the monitoring period.

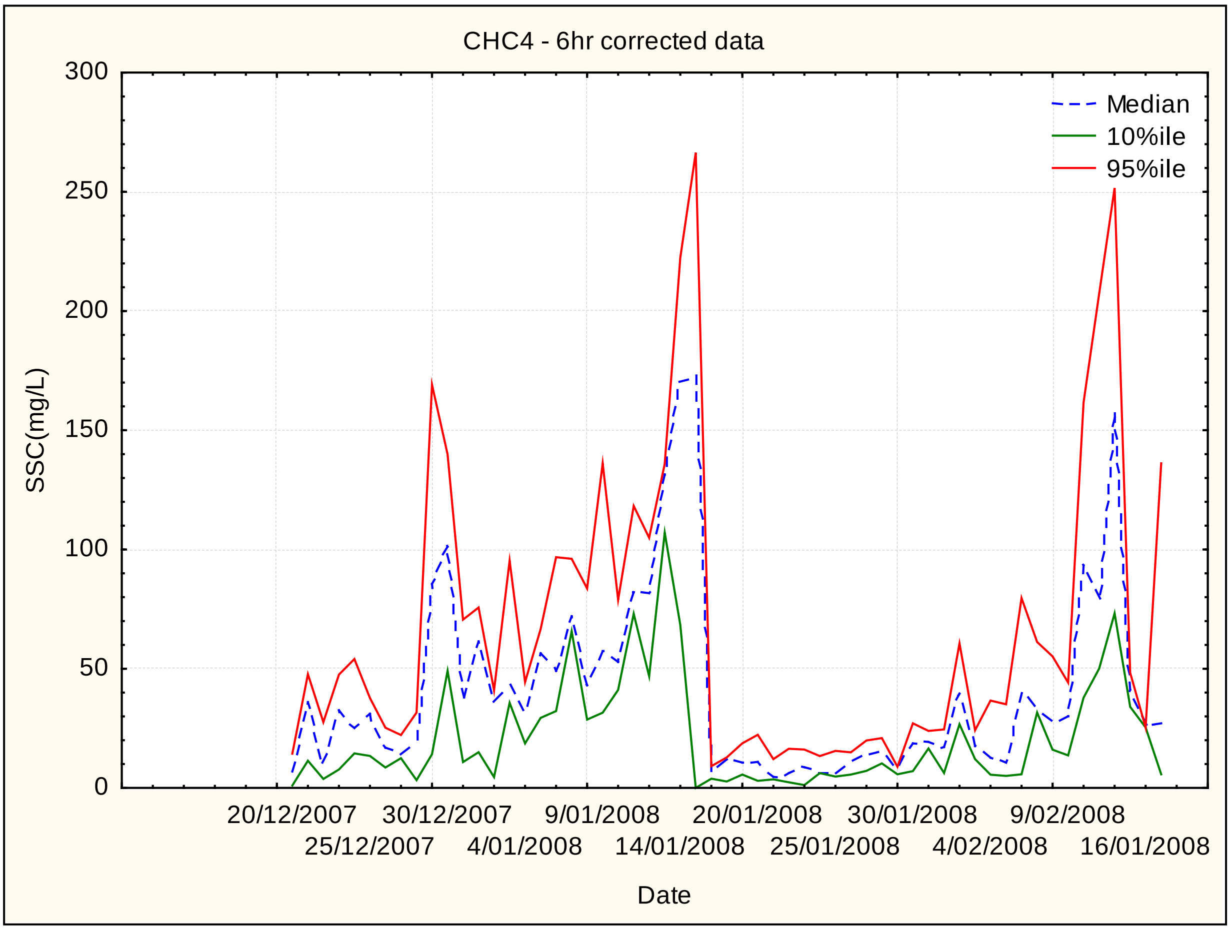
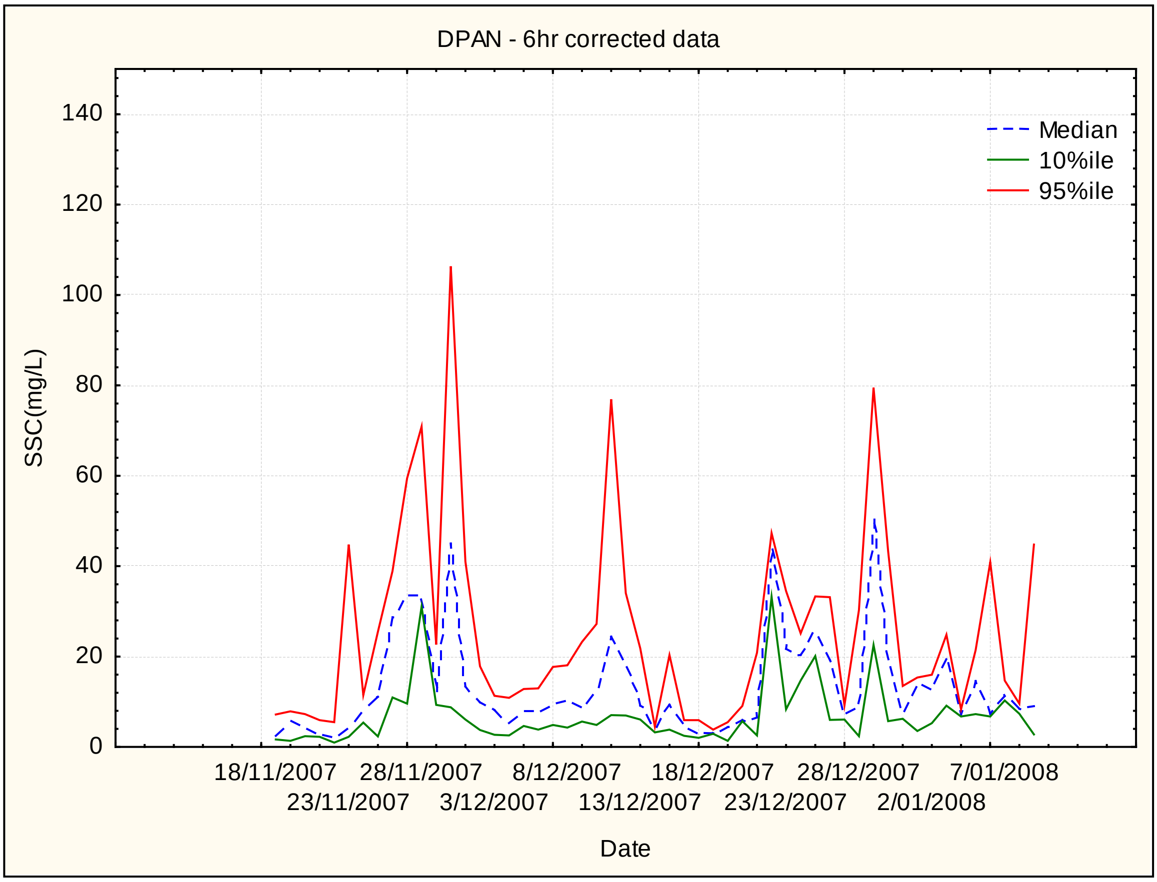


Figure 5. Water quality data at DPAN over the monitoring period.



3.0 CORAL LOSSES

3.1 MEASURED CORAL LOSS

Coral loss within Zone A was predicted to be at 100% of corals. The results of several surveys of these transects from the baseline to mid 2009 are presented in Table 6. After the first 3 months of dredging, results suggested substantive mortality had occurred. However, subsequent monitoring showed that result to be an artefact of poor visibility and extensive bleaching caused by a widespread thermal event. Monitoring during surveys some months and one year after that bleaching event showed levels of live coral cover almost identical to the pre-dredging baseline.

Thus we conclude that the coral community at the monitoring sites with Zone A has not declined as a result of water quality experienced during the dredging program up until June 2009.

We are unable to rule out a suggestion that corals at these sites would have increased cover in the absence of dredging stress and that the lack of an increase in cover reflects a negative effect of dredging. However, coral communities in Mermaid Sound at many kilometres distant from dredging impacts have not been noted as increasing in cover over the last 6 years (MScience unpublished data) and considerable mortality was recorded at sites distant from dredging as a result of the early 2008 thermal bleaching event (MScience 2008).

Other potential sublethal impacts on corals, such as a depression in reproductive output have not been measured during this program.

Table 6. Mean coral cover as an average of the 5 belt transects at each site.

Site	Survey	Cover(%)
HOLD	1-Jul-06	11.6
	19-Mar-08	9.4
	28-Aug-08	12.2
	24-Jun-09	10.7
CHC4	1-May-07	22.2
	19-Mar-08	18.0
	28-Aug-08	23.6
	24-Jun-09	21.6
DPAN	1-May-07	22.8
	19-Mar-08	16.4
	28-Aug-08	23.4
	24-Jun-09	23.5

4.0 DISCUSSION

Dredging for the Pluto LNG Project commenced in Zone A in Mermaid Sound in late November 2007 and continued until April 2008, removing over 2 million cubic metres of seabed from the berth and swing basin close to shore and the channel leading offshore. Monitoring conducted on water quality within the area over the period November 2007 to February 2008 and on corals between 2006 and 2009 has provided some capacity to examine the water quality–coral health relationship in an area where coral mortality was predicted.

The impact assessment for the Pluto Project predicted total loss of corals in Zone A based on interrogation of the outputs of a plume dispersion model with threshold criteria designed to indicate levels of sedimentation or suspended sediment which would cause coral mortality.

Coral communities within Zone A appear not to have suffered any reduction in the cover of live coral during the dredging program. It is clear that those original water quality thresholds substantially underestimated the levels of suspended sediment or sedimentation required to cause detectable mortality.

While the results of the water quality monitoring during the Phase I dredging in Zone A cannot provide estimates of the water quality levels causing coral mortality, they can be used to better reflect levels at which coral mortality does not occur. The metrics and graphs of Section 3 in this report could be used to develop new, less conservative, triggers to apply to these coral communities.

Developing these triggers will require:

- consideration of the mechanism by which the water quality parameter measured might act on coral physiology, to set relevant duration and intensity expectations;
- use of other contextual data from studies published since the Pluto impact assessment;
- consideration of the location and water quality history of the coral communities to which triggers are to be applied.

The coral communities within Zone A have a long history of exposure to sedimentation and suspended sediments at levels above coral communities further offshore in Mermaid Sound or further from centres of development and shipping within the Port of Dampier. Extrapolation of the data in this report to corals in other areas should consider carefully the species composition and water quality history of those other communities.

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APPENDIX A: Abbreviations and Instrument Specifications

CHC4	Most northerly monitoring site in Zone A – used previously as site C4 in Woodside CHEMMS program
DPA	Dampier Port Authority
DPAN	Most southerly site in monitoring program – midway between dredging are and DPA Wharf
EPA	Western Australian Environmental Protection Authority
HOLD	Holden Point monitoring site – nearest to dredging.
JCU	James Cook University
LAC	Light attenuation coefficient
NTU	Nephelometric Turbidity Unit – turbidity unit
OBS	Optical Backscatter Sensor – measures turbidity of the water
PAR	Photosynthetically Active Radiation – light at biologically relevant wavelengths
SAS	Sediment Accumulation Sensor – instrument for measuring real time sedimentation
SSC	Suspended sediment concentration (used here in preference to the term Total Suspended Sediments
Woodside	Woodside Burrup Pty Ltd
INSTRUMENTS USED	
Alec Light Recorder *Compact-LW, Model ALW-CMP*	Alec Electronics Co. Ltd. 7-2-3 Ibukidai Higashi Machi, Nishi-Ku, Kobe 651-2242. Japan
Alec Turbidity Logger *Compact CLW*	Alec Electronics Co. Ltd. 7-2-3 Ibukidai Higashi Machi, Nishi-Ku, Kobe 651-2242. Japan
Troll Turbidity Logger *Troll 9500*	In-Situ Inc., 221 E Lincoln Ave., Ft. Collins, CO 80524 USA
YSI Water Quality Meter *YSI650MDS with 6820 sonde*	YSI Hydrodata Ltd, Unit 8, Business Centre West, Avenue One, Letchworth, Hertfordshire, SG6 2HB. UK
Sediment traps	Custom made PVC cylinders. 95 cm^2 open end area with screw caps on both ends. Includes multiple smaller pipes in the top
JCU Water Quality Loggers (Thomas and Ridd 2005)	Peter Ridd, James Cook University, Townsville, Qld, 4811