Gorgon Gas Development and Jansz Feed Gas Pipeline:

Dredging and Spoil Disposal Management and Monitoring Plan Supplement: Initial Water Quality Criteria

Document No:	G1-NT-PLNX0000702	Revision:	0
Revision Date:	17 March 2010	Copy No:	
IP Security:	Public		

Table of Contents

List of Tables

List of Figures

Terminology, Definitions and Abbreviations

Terms, definitions and abbreviations used in this document are listed below. These align with the terms, definitions and abbreviations defined in Schedule 2 of the Western Australian Gorgon Gas Development Ministerial Implementation Statement No. 800 (Statement No. 800) and the Commonwealth Gorgon Gas Development Ministerial Approval (EPBC Reference: 2003/1294 and 2008/4178).

ANOVA	Analysis of Variance. A collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. In its simplest form, ANOVA gives a statistical test of whether the means of several groups are all equal.
CDEEP	Construction Dredging Environmental Expert Panel
Construction	Construction includes any Proposal-related (or action-related) construction and commissioning activities within the Terrestrial and Marine Disturbance Footprints, excluding investigatory works such as, but not limited to, geotechnical, geophysical, biological and cultural heritage surveys, baseline monitoring surveys and technology trials.
Coral	Marine organisms from the class Anthozoa that exist as small sea-anemone-like polyps, typically in colonies of many identical individuals. Includes 'hard corals' within the order Scleractinia, which secrete calcium carbonate to form a hard skeleton and form reefs; and 'Soft corals' within the order Alcyonacea, which have no hard skeleton and are not considered reef-building organisms.
DEC	Western Australian Department of Environment and Conservation
DEWHA	Commonwealth Department of the Environment, Water, Heritage and the Arts
DoF	Western Australian Department of Fisheries
DoT	Western Australian Department of Transport
DSDMMP	Dredging and Spoil Disposal Management and Monitoring Plan
EIS/ERMP	Environmental Impact Statement/Environmental Review and Management Programme (for the Proposed Gorgon Development dated September 2005 as amended or supplemented from time to time).
EPBC Reference: 2003/1294	Commonwealth Ministerial Approval (for the Gorgon Gas Development) as amended or replaced from time to time.
EPBC Reference: 2008/4178	Commonwealth Ministerial Approval (for the Revised Gorgon Gas Development) as amended or replaced from time to time.
Exceedance	Any monitored reading that goes over a standard.
GEMS	Global Environmental Modelling Systems (a company)

Gorgon Gas Development	The Gorgon Gas Development as approved under in Statement No. 800 and EPBC Reference 2003/1294 and 2008/4178, as amended or replaced from time to time.
Initial Water Quality Criteria	Numerical criteria, based on the link between water quality and coral health, for measurable water quality parameters that, if exceeded, indicate the potential for adverse impacts on coral health.
L	Litre
LNG	Liquefied Natural Gas
LTD	Light, Turbidity, and Deposition
Management Triggers	Are quantitative, or where this is demonstrated to be not practicable, qualitative matters above or below whichever relevant additional management measures must be considered.
Metocean	Meteorological and oceanographic conditions.
mg/L	Milligrams per litre
MGA 50, GDA 94	Map Grid of Australia Zone 50 (WA); projection based on the Geocentric Datum of Australia 1994.
Modified Water Quality Criteria	Revised or amended Initial Water Quality Criteria that better represent the link between water quality and coral health.
MOF	Materials Offloading Facility
NTU	Nephelometric Turbidity Unit
PER	Public Environmental Review for the Gorgon Gas Development Revised and Expanded Proposal dated September 2008, as amended or supplemented from time to time.
QA/QC	Quality Assurance/Quality Control
Reference Site	Monitoring location predicted, under planned activities, to be outside the area at risk of the Gorgon Gas Development and Jansz Feed Gas Pipeline, as identified in the Coastal and Marine Baseline State and Environmental Impact Report (Chevron Australia 2009).
Regionally Significant Areas	Are the regionally significant areas outside the Zones of High Impact, Moderate Impact and Influence on the eastern margins of the Lowendal Shelf to the southern boundary of the Montebello Islands Marine Park, and Dugong Reef, Batman Reef and Southern Barrow Shoals.
REML	In statistics, the Restricted (or Residual) Maximum Likelihood approach is a particular form of maximum likelihood estimation which does not use the full set of observations available, but instead uses a likelihood function calculated from a transformed set so that nuisance parameters have no effect. It is used as a method for fitting linear mixed models. In contrast to conventional maximum likelihood estimation, REML can produce unbiased estimates of variance and covariance parameters.

RPS	RPS Australia/SE Asia (a company)
SKM	Sinclair Knight Merz (a company)
Spoil Disposal Ground	The area where dredge and excavation material is to be disposed of at sea.
Statement No. 800	Western Australian Ministerial Implementation Statement No. 800 (for the Gorgon Gas Development) as amended from time to time.
Statistical Power	The probability of detecting a meaningful difference or effect, if one was to occur.
Telemetry	Automatic transmission and measurement of data from remote sources by wire or radio or other means.
TSS	Total Suspended Solids
Turbidity	The cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality.
WA	Western Australia (or Western Australian)
Zone of High Impact	An area where long-term impacts to corals are predicted to result directly from disturbance during horizontal directional drilling, dredging or construction of infrastructure on the seabed and burial during dredge spoil disposal, or indirectly from smothering due to elevated sedimentation and/or from deterioration in water quality. As set out in Schedule 1 of Statement No. 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.
Zone of Influence	This area is predicted to be indirectly influenced by dredging and spoil disposal activities (e.g. marginal increases in turbidity and sedimentation), but at levels that will have no measurable impact on corals. As set out in Schedule 1 of Statement No. 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.
Zone of Moderate Impact	An area where short-term moderate impacts (e.g. some partial mortality of corals) is predicted to result indirectly from horizontal directional drilling, dredging, dredge spoil disposal, due to deterioration in water quality and/or an increase in sedimentation rates. Moderate impacts are likely to include some partial mortalities among fast growing, more sensitive coral species (e.g. *Acropora* species) but less, if any, mortality of longer living, generally more resilient species (e.g. *Porites* species, *Turbinaria* species). As set out in Schedule 1 of Statement No. 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.

1.0 Introduction

The Gorgon Gas Development and Jansz Feed Gas Pipeline Dredging and Spoil Disposal Monitoring and Management Plan (DSDMMP) (Chevron Australia 2009) was developed as required by Condition 20 of Ministerial Implementation Statement No. 800 (Statement No. 800) for the Revised and Expanded Gorgon Gas Development (Chevron Australia 2008). The DSDMMP (Chevron Australia 2009) was approved by the Western Australian State Minister for the Environment on 10 September 2009. The DSDMMP (Chevron Australia 2009) was also required under Condition 14 of the Commonwealth Approval for the Revised and Expanded Gorgon Gas Development (EPBC Reference: 2003/1294 and 2008/4178) and was approved by the Commonwealth Minister for the Environment, Heritage and the Arts on 26 September 2009.

The Dredging and Spoil Disposal Monitoring and Management Plan Supplement: Initial Water Quality Criteria (this Supplement) has been prepared to meet the requirements of Condition 20.4.iii.d of Statement No. 800 that the DSDMMP (Chevron Australia 2009) addressed in a preliminary way but that required supplementing. This Supplement has also been prepared to meet the requirements of the Western Australian State Minister for the Environment's letter of 10 September 2009 (specifically point 1).

This Supplement has also been prepared to meet the requirements of Condition 21.1 of Statement No. 800 in relation to the establishment of Initial Water Quality Criteria. These are numerical criteria that represent the link between water quality and coral health, for measurable water quality parameters, which, if exceeded, indicate the potential for adverse impacts on coral health. Condition 21.2 sets out that once the Initial Water Quality Criteria are exceeded, there is a requirement to commence coral health monitoring that does not exceed fortnightly intervals, and for coral health monitoring to continue for as long as the Initial Water Quality Criteria are exceeded. Note that there is no requirement under EPBC Reference: 2003/1294 and 2008/417 to establish Water Quality Criteria.

Note that if there is any difference or inconsistency between the DSDMMP (Chevron Australia 2009) and this Supplement in relation to either Condition 20.4.iii.d or Condition 21.1, then this Supplement is to be preferred.

The requirements of this Supplement, as stated in Conditions 20.4.iii.d and 21.1 of Statement No. 800 are listed in Table 1.1. Table 1.1 also references the specific sections of this Supplement where each requirement is addressed.

Table 1.1 Requirements of this Dredging and Spoil Disposal Monitoring and Management Plan Supplement: Initial Water Quality Criteria

Ministerial Document	Condition No.	Requirement	Section Reference in this Supplement
Statement No. 800	20.4.iii.d	Sufficient monitoring sites and replication to be able to have confidence, at a statistical power of 0.8 or greater, or an alternative statistical power as determined by the Minister, on advice of the CDEEP that the objectives of the Plan set out in Condition 20.3 are being achieved.	Section 3.0
Statement No. 800	21.1	The Proponent shall, based on the results of monitoring programs undertaken prior to commencement of any dredging and dredge spoil disposal activities, establish Initial Water Quality Criteria that represent the link between water quality and coral health on advice of the CDEEP, and as determined by the Minister.	Section 2.0 *Note that Appendix 1 presents the results of the assessment of baseline water quality data against the Initial Water Quality Criteria and Appendix 3 presents the preliminary results of an assessment of*

Ministerial Document	Condition No.	Requirement	Section Reference in this Supplement
			telemetered logger data against the Initial Water Quality Criteria

This Supplement should be read in conjunction with the DSDMMP, which includes an overview of the dredging and spoil disposal program, as well as the water quality and coral health monitoring programs. Following approval, this Supplement will be considered to be approved as part of the DSDMMP, but will be maintained as a stand-alone document. Where relevant, amendments made to the DSDMMP will also be considered to be amendments to this Supplement. Any matters or requirements in the Supplement that are taken from the DSDMMP (rather than Statement No. 800) may be amended from time to time in accordance with amendments to the DSDMMP. Amendments to this Supplement may also be made directly in accordance with Section 8.7.3 of the DSDMMP.

1.1 Objectives

The process for reactive monitoring of water quality and coral health is defined by Statement No. 800 (Conditions 20.4.iii, 20.4.iv, 21.1, 21.2 and 21.3) and set out in Section 7.1.1 of the DSDMMP, and includes these steps:

- Step 1. Provide details on how predictive links between water quality, sediment deposition and coral health will be established to enable timely management of dredging and spoil disposal activities (DSDMMP, Section 7.0).
- Step 2. Based on the results of the monitoring program undertaken prior to commencement of any dredging and spoil disposal activities, establish Initial Water Quality Criteria (this Supplement, Section 2.0 and Table 2.1) that represent the link between water quality and coral health.
- Step 3. Continue investigating the link between water quality, sediment deposition and coral health during dredging, spoil disposal activities, and report the findings to the Construction Dredging Environmental Expert Panel (CDEEP). Modified Water Quality Criteria that better represent the link between water quality and coral health may be proposed, and the Minister may set Modified Water Quality Criteria in response to any such recommendations on advice of the independent experts on the CDEEP.
- Step 4. Commence coral health monitoring once the Initial Water Quality Criteria (or the Modified Water Quality Criteria) are exceeded and continue monitoring for as long as these Initial Water Quality Criteria (or the Modified Water Quality Criteria) are exceeded or as a minimum for two fortnightly surveys.

Condition 20.4.iii.d of Statement No. 800 requires that the water quality and sediment deposition monitoring program has sufficient monitoring sites and replication to be able to have confidence that, at a statistical power of 0.8 or greater, the works associated with the construction of the Materials Offloading Facility (MOF) and the Liquefied Natural Gas (LNG) Jetty,[1] will not lead to impacts in excess of the limits set in Condition 18.1 of Statement No. 800 (DSDMMP, Section 7.2.7; this Supplement, Section 3.0).

The key objectives of this Supplement are to:

[1] Note that as set out in Section 1.5 of the DSDMMP, the marine component of the Barge (WAPET) Landing Upgrade is not included within the scope of this Supplement as there are no dredging activities required for this upgrade.

- identify Initial Water Quality Criteria that represent the link between water quality and coral health
- confirm that the proposed telemetered water quality monitoring program has a statistical power of >0.8 of detecting an exceedance of the Initial Water Quality Criteria at the telemetered water quality monitoring sites.

1.2 Stakeholder Consultation

Under Condition 21.1 of Statement No. 800, advice is required to be sought from the CDEEP during the preparation of this Supplement. A Technical Working Group from the CDEEP was established to provide expert advice on the establishment and implementation of the Initial Water Quality Criteria.

Under Condition 20.2 of Statement No. 800 and Condition 14.2 of EPBC Reference: 2003/1294 and 2008/4178, consultation with the CDEEP, the Marine Turtle Expert Panel (for issues relating to marine turtles), the Western Australian Department of Environment and Conservation (DEC), the Western Australian Department of Transport (DoT), the Western Australian Department of Fisheries (DoF) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) is required during the development of the DSDMMP.

This Supplement has been provided to the following agencies and expert panels for their review and comment; and outcomes of these consultations have been incorporated into this revision of the Supplement:

- The Construction Dredging Environmental Expert Panel, who were also provided with a briefing on the Supplement
- The Department of Environment and Conservation
- The Department of Transport
- The Department of Fisheries.

2.0 Initial Water Quality Criteria

The setting of appropriate water quality and coral health Management Triggers for dredging and dredge spoil disposal activities is an important component of any dredging monitoring program. Once these thresholds are reached, or approached, management responses are triggered.

Condition 21.1. sets out that Initial Water Quality Criteria that represent the link between water quality and coral health will be established based on the results of monitoring programs undertaken prior to commencement of any dredging and spoil disposal activities. Inherent in this process is an expectation that it is possible to develop meaningful Initial Water Quality Criteria for the coral communities around Barrow Island before the commencement of the dredging and spoil disposal activities. To date, however, the monitoring of corals during the Marine Baseline Program in Barrow Island waters has not shown any clear trend of coral health that can be associated with any aspect of background water quality, other than the observation that the range of background water quality observed does not appear to have had any deleterious effects on coral health (Chevron Australia 2010). The premise that Initial Water Quality Criteria can be developed from observing the relationship between coral health and water quality during the Marine Baseline Program is feasible, but only if coral health varies sufficiently during the program to enable the development of correlations between water quality and coral health that could then be used to infer where locally relevant Initial Water Quality Criteria should be set. This should ideally include observations of events where water quality deteriorated and corals experienced bleaching or mortality as a consequence. There are, therefore, currently no clearly defined relationships between water quality and coral health for the waters around Barrow Island that could be used to determine Initial Water Quality Criteria.

Furthermore, there is no clear direction from relevant literature, or from recent experience in dredging programs in the Pilbara, that allows ready identification of suitable Initial Water Quality Criteria. Recent summaries of information on corals in the Pilbara (Stoddart and Stoddart 2004; Gilmour *et al*. 2007) and the potential environmental impacts associated with dredging and spoil disposal, provide some discussion on the relationships between water quality and coral health. However, corals species vary in their responses to declines in water quality and there is a substantial knowledge gap with respect to developing suitable Initial Water Quality Criteria that would usefully apply across coral communities at Barrow Island. Regular monitoring of coral health and a variety of water quality parameters during both the baseline studies program and subsequent dredge monitoring programs at Cape Lambert (Sinclair Knight Merz 2008) and at Mermaid Sound (Sinclair Knight Merz 2008a) have provided no further information about the relationships between water quality and coral health, and specifically what set of water quality conditions causes coral mortality. This suggests that turbidity thresholds were set too low to provide meaningful estimates of potential mortality and that the estimates of coral loss were over-estimates. The only observed correlations between a decline in water quality and a decline in coral health on both of these recent projects, was the observation of significant areas of coral bleaching after water temperatures rose to 32^{o}C or more. This occurred during the summer of 2007/2008 and the event was not connected to the dredging activities. Furthermore, these sites are different to the environment at Barrow Island.

In recognition that there is uncertainty around the appropriate levels of water quality that would allow the establishment of reliable Initial Water Quality Criteria, Statement No. 800 provides for the dredging monitoring program to be used to establish predictive links between water quality and coral health to enable the timely management of dredging and spoil disposal activities (Condition 20.4.iii.e) and for investigations into the link between water quality and coral health to continue during dredging and spoil disposal activities (Condition 21.3).

The approach adopted for the dredging and spoil disposal activities will be not to rely on water quality exceedances to initiate coral health monitoring, but to start monitoring coral health prior to the commencement of dredging and spoil disposal activities (DSDMMP, Section 7.3). In the event that the Initial Water Quality Criteria are exceeded at strategically located telemetered water quality sites at the boundary of the Zones of Moderate Impact and the Zones of Influence (DSDMMP, Section 7.3.3.2.2; this Supplement, Section 2.1) and the exceedance is attributable to dredging and spoil disposal activities, a program of targeted coral health monitoring will be triggered (DSDMMP, Section 7.3.3.2.2).

In addition, water quality data will be collected from each coral monitoring site during the coral health monitoring program to assist with the development of linkages between water quality and coral health in the event that corals suffer mortality in the Zones of High Impact or Moderate Impact (DSDMMP, Section 7.2).

2.1 Dredge Plume Modelling

Hydrodynamic modelling was undertaken for the Environmental Impact Statement/Environmental Review and Management Programme (EIS/ERMP) (Chevron Australia 2005, 2006) and refined in the Revised and Expanded Proposal Public Environment Review (PER) (Chevron Australia 2008). Models were developed to predict how fine sediments released during dredging and dredge spoil disposal would disperse through the marine environment under the influence of oceanographic processes.

Three zones were established to reflect the different levels of predicted impact to Coral Assemblages. These zones were established based on sediment load and exposure time above background levels, and took into account published values for acute (short-term), medium-term and chronic (long-term) responses to both sedimentation and elevated total suspended solids (TSS) (Chevron Australia 2005, 2006). These zones are shown in Figure 2.1 and are defined as:

- 'Zones of High Impact' – the areas where long-term impacts on corals are predicted from direct disturbance during dredging or construction of infrastructure on the seabed and burial during dredge spoil disposal; or complete but short-term losses are predicted to be caused by increased sedimentation and/or deterioration in water quality.
- 'Zones of Moderate Impact' – the areas where short-term moderate impacts (e.g. some partial mortality of corals) is predicted to result indirectly from dredging and/or dredge spoil disposal, due to an increase in sedimentation rates and/or a deterioration in water quality. Moderate impacts are likely to include some partial mortalities among fast-growing, more sensitive coral species (e.g. *Acropora* species), but less, if any, mortality of longer-living, generally more resilient species (e.g. *Porites* species, *Turbinaria* species).
- 'Zones of Influence' – these areas are predicted to be influenced indirectly by dredging and dredge spoil disposal activities such that marginal increases in sedimentation and turbidity will occur, but at levels that will have no measurable impact on corals.

2.2 Telemetered Water Quality Loggers

Nine telemetered water quality loggers, which record turbidity (NTU), were deployed in December 2009 at sites at the boundary of the Zones of Moderate Impact and the Zones of Influence. This logger deployment was meant to provide an early indication of changes in water quality that may impact upon coral health outside of the Zones of Moderate Impact where no detectable net mortality of coral is permitted to occur (Condition 18.1.iii) (i.e. as 'protective sentinels', triggering a program of targeted coral health monitoring) (Figure 2.1). The purpose of the telemetered loggers is to provide real-time water quality data during dredging and spoil disposal activities, with a view to capturing the spatial extent of the dredge and spoil disposal plumes, in particular in relation to significant coral assemblages, including Regionally Significant Areas, located north and south of the dredging and spoil disposal activities (DSDMMP, Section 7.2.4.3).

There were two aspects considered in selecting the locations of the telemetered logger sites:

- Distance from turbidity source (turbidity contour)
- Position on the turbidity contour.

Distance from turbidity source

This boundary between the Zones of Moderate Impact and the Zones of Influence (DSDMMP, Section 7.2.2) identifies the extent of the anticipated impacts on coral health, and therefore is the appropriate distance from the turbidity source.

Position on turbidity contour

The positioning of the nine telemetered loggers on the turbidity contour was based on:

- a consideration of the location of areas of significant coral assemblages in proximity to dredging, including Regionally Significant Areas (e.g. the Southern Lowendal Shelf, Dugong Reef, Batman Reef)
- the trajectory of the predicted dredge plume in response to the prevailing meteorological and oceanographic conditions (DSDMMP, Section 7.2).

Number of telemetered loggers

The telemetered loggers have been positioned between the origin of the turbidity at the dredge site and the location of significant coral assemblages, including Regionally Significant Areas. The resultant array of nine telemetered loggers will allow the dredge plume to be intersected before reaching these areas. The deployment of a relatively large number of telemetered loggers, as well as their strategic placement at the boundary of the Zones of Moderate Impact and the Zones of Influence, in particular between the predicted plume and the areas of

significant coral, will provide confidence that if the plume does extend further than predicted, there is a high likelihood of reliable detection.

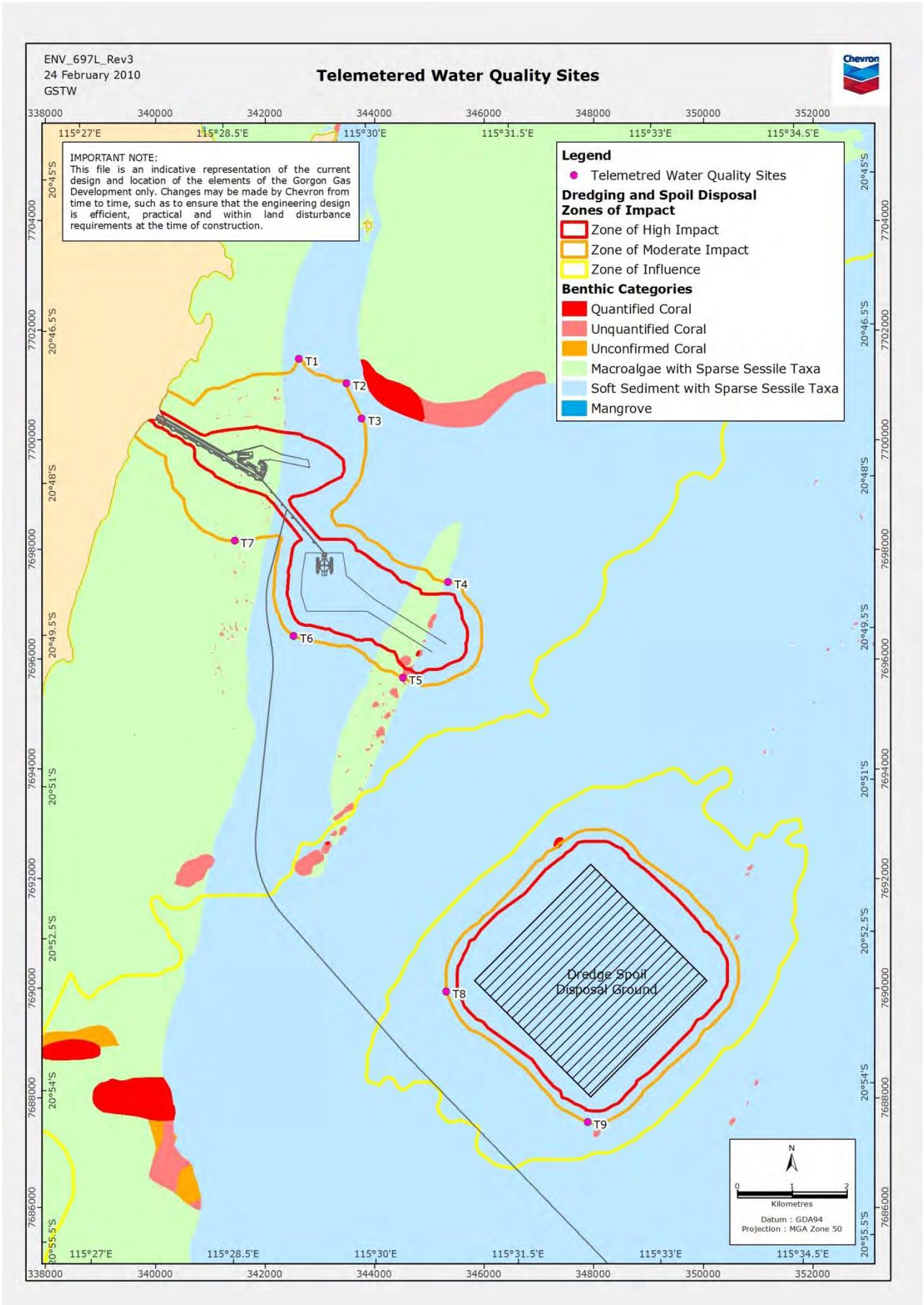


Figure 2.1 Telemetered Water Quality Sites

Turbidity data collected from the telemetered water quality loggers will provide an early indication of changes in water quality that may impact upon coral health. In the event that the Initial Water Quality Criteria are exceeded at any of the telemetered water quality sites at the boundary of the Zones of Moderate Impact and the Zones of Influence and the exceedance is due to dredging and spoil disposal activities, a program of targeted coral health monitoring will be triggered (DSDMMP, Section 7.3.3.2.2). The sites targeted for monitoring will depend on the spatial pattern of any exceedances of the Initial Water Quality Criteria (DSDMMP, Section 7.3.3.2.2), as well as consideration of the forecast metocean conditions.

2.3 Initial Water Quality Criteria

The Initial Water Quality Criteria proposed for the telemetered water quality sites located at the boundary of the Zones of Moderate Impact and the Zones of Influence are the Coral Health Criteria for Total Suspended Solids (TSS). These criteria were used in predicting the Zones of Moderate Impact in the dredge plume modelling (Table 2.1) undertaken for the EIS/ERMP (Chevron Australia 2005, 2006) and PER (Chevron Australia 2008).

Table 2.1 Initial Water Quality Criteria (based on GEMS 2008)

Timeframe	Total Suspended Solids Concentration	Time (cumulative days)
Short-term	≥ 25 mg/L	2 in 6
Medium-term	≥ 10 mg/L	7 in 21
Long-term	≥ 5 mg/L	20 in 60

Note: Exposure for at least 6 hours during daylight hours regarded as satisfying criteria

The Initial Water Quality Criteria do not include background levels of TSS. Note that the Zones of High and Moderate Impact and the Zones of Influence generated from the modelling plotted TSS (and sedimentation) exceedances 'above background' (Chevron Australia 2006). There was no assumption as to what the background level may be, only the rationale that whatever it is, it is not due to dredging.

3.0 Power Analysis

RPS Australia/SE Asia (RPS) undertook the statistical power analyses to confirm that sufficient telemetered logger measurements are collected each day across the nine telemetered logger sites, such that when the Initial Water Quality Criteria are exceeded, the chance that a water quality exceedance is not detected is <0.2 (i.e. that the chance of a type II error is <0.2) and that the telemetered water quality monitoring program has a statistical power of >0.8 of detecting that the Initial Water Quality Criteria have been exceeded.

The analyses were based on computer simulations that replicate how the telemetered loggers would sample in the field during dredging and spoil disposal activities. The analyses took into account sampling error, a 30-minute monitoring frequency, nine sites and model predictions for TSS at the nine sites (from dredge plume modelling undertaken by GEMS, 2008), as well as how the sampled data would be analysed/interpreted during the Dredging and Spoil Disposal Monitoring Program. The proportion of the modelled exceedances that would be detected by the array of telemetered loggers, given the known sampling error in the instruments, was compared with the 0.8 power requirement. If the proposed monitoring array in the simulations was found to have ≥0.8 statistical power to detect exceedances present in the model output, then the array would also be likely to have sufficient power to detect similar exceedances during dredging and spoil disposal activities.

3.1 Overview of the Power Analyses and Methods

The power analyses are based three main sources of information:

- Output of predicted water quality (TSS), at a 30-minute frequency, at each of the nine telemetered logger sites across 10 months of simulated dredging from the GEMS modelling.
- An estimate of the sampling error associated with LTD logger units, based on an analysis of information collected during the Marine Baseline Program (Chevron Australia 2010). Although these are different units to those being used at the telemetered logger sites, it was assumed that the sampling error would be comparable between the loggers.
    - The continuous baseline water quality data from one site (MOF1) was sub-sampled to obtain a representative sample of sampling error from loggers. MOF1 was chosen because it was one of the larger datasets available from the Marine Baseline Program. Furthermore, because these data were collected across the full Marine Baseline Program, data from different loggers that were changed in and out of the site periodically are included, thus the data can be used to calculate an averaged sampling error from a representative sample of logger units.
    - The data were sub-sampled by randomly selecting pairs of data points, separated by 10 minutes, giving a total of 571 independent, paired samples. Water quality is not predicted to vary greatly at this small temporal scale and so the variance between these two consecutive times would mostly consist of sampling error. The analyses assumed that all the variation between subsequent samples was due to sampling error, probably over-estimating the variance and reducing the power of the tests. This would lead to a conservative estimate of the power of the telemetered logger array to detect exceedances.
    - The data were analysed using mixed model (Restricted Maximum Likelihood [REML]) analysis of variance with sample pairs as a factor and individual TSS values as the replicate measures. Variance components were extracted from the error terms. The residual (between times within pairs) variance was 4.273.
- The Initial Water Quality Criteria (Table 2.1).

3.2 The Analyses

The analyses involved the following steps:

1. The GEMS model TSS predictions were treated as though they were an exact measure of water quality at each site through time. From this, the number of modelled exceedances (short-, medium- and long-term) that should be detected across the nine telemetered logger sites was determined.
2. 'Sampling error' was then added to the GEMS model TSS predictions for each telemetered logger site to create a simulated telemetered logger dataset. Thus, at each time, at each site, the measurement recorded by the simulated telemetered logger was set as the GEMS model TSS predictions at that time/site plus a sampling error component.
    - An independent, randomly determined sampling error was added to each measurement, based on a random normal distribution with a mean of 0 and a variance determined from the analysis of variance (ANOVA) of baseline LTD logger data ($\sigma^2 = 4.273$)
    - Normally distributed sampling errors were generated using the dNormalDev function in the Poptools add-in for Excel (http://www.cse.csiro.au/poptools/).
3. Daily medians were calculated for both the GEMS model TSS predictions and the simulated telemetered logger TSS data, based on measurements made every 30 minutes between 6:00 am and 6:00 pm, inclusive (measurements outside this were excluded from calculations).

4. 'Real' exceedances (in the GEMS model TSS predictions) and 'detected' exceedances (in the simulated telemetered logger data) were determined for short-, medium- and long-term Initial Water Quality Criteria across the 10 months of data.
   - Short-term: a 'rolling window' of six sequential days was examined. Any six-day window in which there were two or more days where the daily medians exceeded 25 mg/L was identified
   - Medium-term: a 'rolling window' of 21 sequential days was examined. Any 21-day window in which there were seven or more days where the daily medians exceeded 10 mg/L was identified
   - Long-term: a 'rolling window' of 60 sequential days was then examined. Any 60-day window in which there were 20 or more days where the daily medians exceeded 5 mg/L was identified.
5. Each day, all nine telemetered logger sites were examined for real and detected exceedances of the Initial Water Quality Criteria in the latest rolling short-term and medium-term windows (i.e. 326 and 311 'rolling windows' respectively). There were no 'real' exceedances in the GEMS model TSS predictions for the long-term Initial Water Quality Criterion, so power could not be calculated for these. Short- or medium-term exceedances occurred at telemetered logger sites T1 and T5. Nonetheless, all the sites were included in the analyses, in order to calculate the probability of chance false positive detections (i.e. type I errors).
6. Each day, the occurrence of 'real' and 'detected' exceedances of the short- and medium-term Initial Water Quality Criteria at <u>any</u> of the nine telemetered sites was determined. Thus, there were four potential decisions each day, for each of the Initial Water Quality Criteria:
   - A real exceedance occurred at at least one of the telemetered logger sites and was detected because an exceedance was recorded at at least one of the sites (correct = c1).
   - A real exceedance occurred at at least one of the sites but was missed because an exceedance was not recorded at any of the sites (a type II error = b).
   - A real exceedance did not occur anywhere and a detected exceedance was also not recorded anywhere (correct = c2).
   - A real exceedance did not occur anywhere but a detected exceedance was recorded at at least one site (a type I error = a).

   The total of each of the four decisions were summed across all the days in the time series:
   - a_{total}, b_{total}, $c_{1\ total}$, $c_{2\ total}$
   - Short- and medium-term Initial Water Quality Criteria were assessed separately.
7. Statistical power across the time series was calculated as the probability that a real exceedance was detected:
   - Power = 1 – type II error rate = 1 - $b_{total}/(b_{total}+c_{1\ total})$.
8. The type I error rate across the time series was calculated as the probability of detecting an exceedance when one had not occurred in the modelled dataset:
   - Type I error rate = $a_{total}/(a_{total}+c_{2\ total})$.
9. Long frequency averages for error rates were calculated by repeating the (Monte Carlo) simulations, averaging the errors across the runs. Two hundred independent replicate runs were undertaken for both short-term and medium-term Initial Water Quality Criteria (examination of running averages through the simulations suggested that 200 simulations provided sufficiently precise estimates).

3.3 Results

Exceedances of the medium-term Initial Water Quality Criterion occurred at site T5 (29 exceedances across 311 'rolling windows'), and exceedances of the short-term Initial Water Quality Criterion occurred at sites T1 (five exceedances from 326 'rolling windows'), and T5 (four exceedances) (Table 3.1). The Coral Health Criteria for TSS (Table 2.1) were used to analyse the dredge plume model output, to produce effect zones showing regions affected by turbidity (or sedimentation) that result in high impact, moderate impact or influence (but no impact) (Chevron Australia 2008; GEMS 2008). The reported exceedances of the short-term and medium-term Initial Water Quality Criteria at telemetered logger sites are not inconsistent with this analysis. Note that the modelling was based on a number of underlying assumptions and the process undertaken to translate the model results into the Zones of High and Moderate Impact and the Zones of Influence.

No exceedances of the long-term Initial Water Quality Criterion were recorded in the GEMS model TSS predictions at any telemetered logger site. Thus, it was not possible to determine the power to detect exceedances of the long-term Initial Water Quality Criterion based on the available data.

Table 3.1 Results from Monte Carlo Simulations of Initial Water Quality Criteria across Nine Telemetered Logger Sites

Initial Water Quality Criteria	Number of Daily Decisions	Actual Number of Exceedances in GEMS Model TSS Predictions	Average Number of Type II Errors per Time Series	Average Type II Error Rate	Average Statistical Power	Average Number of Type I Errors per Time Series	Average Type I Error Rate
Short-Term	326	9	1.65	0.183	**0.817**	1.24	0.004
Medium-Term	311	29	0.63	0.022	**0.978**	2.90	0.01
Long-Term	272	0	Not able to be assessed	Not able to be assessed	Not able to be assessed	Not able to be assessed	Not able to be assessed

Notes:
(1) Average error rates and statistical power are based on 200 independent runs of the simulations.
(2) Numbers in bold indicate where statistical power is >0.8.

Analysis of the simulations indicated that, on average, only 1.65 type II errors were made across the 10 months of daily decisions (i.e. across 326 decisions) for the short-term Initial Water Quality Criterion and only 0.63 type II errors were made for the medium-term Initial Water Quality Criterion (i.e. across 311 decisions) (Table 3.1). The type II error rate is the probability of missing an exceedance given that one has occurred. On average, this was less than 0.2 for both the Initial Water Quality Criteria: 0.183 and 0.022 for the short-term and the medium-term, respectively. Thus, the telemetered logger array at nine sites measuring every 30 minutes is predicted to have sufficient power (>0.8) to detect modelled exceedances, for both short-term and medium-term Initial Water Quality Criteria (Table 3.1). Type I error rates were also low (Table 3.1), suggesting that as long as there is no indication of equipment failure or biofouling etc., then any exceedance detected is unlikely to be due to instrument imprecision and thus likely to be 'real'. Whether the cause is natural or dredging-related would still need to be assessed in each case. Because the estimate of sampling error associated with the loggers is probably an over-estimate, the realised power to detect the exceedances in these time series would likely be greater than estimated; how much greater would depend on by how much the sampling error component was overestimated. This overestimation also allows a contingency in the event that the telemetered loggers are less precise than the LTD loggers are.

The long-term Initial Water Quality Criterion was unable to be assessed with the GEMS model TSS predictions because long-term exceedances were not actually predicted at any of the sites by the modelling. Daily water quality medians did exceed 5 mg/L (and were regularly detected as doing so, thus the short-term and medium-term exceedance detections). However, in no window did 20 days out of 60 exceed 5 mg/L at any of the sites. In itself, this suggests that the long-term Initial Water Quality Criterion may be a less likely impact of dredging and spoil disposal activities than short-term and medium-term exceedances (which were detected). In addition, given that the basis of the power of monitoring is how precisely the telemetered loggers measure water quality (which is the same for all the Initial Water Quality Criteria), it is unlikely that the statistical power of monitoring the long-term Initial Water Quality Criterion would inherently be any less powerful than for the other Initial Water Quality Criteria. Furthermore, given that, in general, the larger the sample size, the higher the statistical power, the average statistical power for the long-term Initial Water Quality Criterion (i.e. where the sample size is 60 x 24 30-minute telemetered logger data points compared to 21 x 24 30-minute data points for the medium-term and 6 x 24 30-minute data points for the short-term Initial Water Quality Criteria) is predicted to be considerably higher than that calculated for the short-term and medium-term Initial Water Quality Criteria. What really determines the power of the water quality monitoring program is by how much the daily medians exceed the Initial Water Quality Criteria. However, without any prediction of by how much they might exceed (i.e. a specified effect size to test against), this cannot be determined.

The analyses/simulations undertaken have focused on whether sufficient measurements have been made per day across the nine telemetered logger sites to have 0.8 power of detecting exceedances like the range included in the GEMS modelling output. Simulations evaluate the power of the monitoring program to detect the sorts of exceedances of the Initial Water Quality Criteria, which are expected to occur during dredging and spoil disposal activities at any of these nine sites. The power analyses undertaken do not formally address whether there are sufficient telemetered logger sites to be able to have confidence, at a statistical power of 0.8 or greater, that the objectives of the DSDMMP as set out in Condition 20.3 are being achieved. Thus, the question of whether the number and spatial arrangement of the nine sites is adequate to 'capture' plume concentrations extending further than predicted in the modelling has not been addressed statistically (nor is that useful here). Instead, this issue should be assessed based on what the plume is predicted to do, which is reflected in the output of the dredge plume modelling (Section 2.1). Given the locations of the telemetered loggers on the boundary of the Zones of Moderate Impact and the Zones of Influence, and numbers of telemetered logger sites (nine), the assessment examined whether the telemetered loggers would be likely to detect exceedances of the Initial Water Quality Criteria across any of those sites. The goal was to confirm that this arrangement would have sufficient power to detect exceedances at the sites selected as 'protective sentinels' (to meet the requirements of Condition 20.4.iii.d), rather than determine an optimal array for characterising the spatial/concentration characteristics of the dredge plume. It is also important to note that the fine scale spatial/cell resolution of the dredge plume model means there are enormous numbers of combinations of places/arrangements of monitoring arrays that could be assessed. The results from the analyses undertaken indicate that at any of the nine telemetered logger sites there is a statistical power of >0.8 to detect exceedances like the range included in the GEMS modelling output.

It is important to note that any prospective power analysis conducted prior to a study is only a prediction of what is likely and can never guarantee the realised power of subsequent monitoring, particularly if different sorts of exceedances to those in the GEMS modelled output occurred in reality. Nevertheless, the GEMS model is what is considered likely to occur during dredging and spoil disposal activities, so these results provide confidence that Condition 20.4.iii.d will be met using the telemetered logger array and the frequency of measurements.

4.0 Conclusions

The natural fluctuations in turbidity observed in the Marine Baseline Program water quality data regularly exceeded the Initial Water Quality Criteria that represent the Coral Health Criteria for Total Suspended Solids (TSS) used in predicting the Zones of Moderate Impact in the dredge plume modelling undertaken for the EIS/ERMP (Chevron Australia 2005, 2006) and refined in the PER (Chevron Australia 2008). To date, monitoring of coral during the Marine Baseline Program has not shown any clear trend in coral health that can be associated with any aspect of baseline water quality, other than the observation that the range of baseline water quality observed does not appear to have had any deleterious effects on coral health (Chevron Australia 2010). Assuming that there is no evidence of coral mortality at any of the sites that can be attributed to elevated turbidity levels, then it can reasonably be concluded that corals have not been adversely affected by naturally occurring turbidity levels that approximate and may exceed the Initial Water Quality Criteria. This is consistent with the dredge plume model and the Coral Health Criteria used in the model being conservative predictors of coral health impacts.

As the relationships between water quality and coral health are better refined during dredging and spoil disposal activities, in conjunction with the information from the comparison of the baseline water quality data with the Initial Water Quality Criteria undertaken to date, it will be important to review and revise, as appropriate, the Water Quality Criteria to ensure that the trigger for invoking targeted coral health monitoring is appropriate. Condition 21.3 provides for the setting of Modified Water Quality Criteria. Chevron Australia may recommend Modified Water Quality Criteria that better represent the link between water quality and coral health, and the Minister for the Environment may set Modified Water Quality Criteria in response to Chevron Australia's recommendations on advice of the independent experts on the CDEEP.

5.0 References

Chevron Australia. 2005. *Draft Gorgon Environmental Impact Statement/Environmental Review and Management Programme for the Proposed Gorgon Development*. Chevron Australia, Perth, Western Australia.

Chevron Australia. 2006. *Final Environmental Impact Statement/Environmental Review and Management Programme for the Gorgon Gas Development*. Chevron Australia, Perth, Western Australia.

Chevron Australia. 2008. *Gorgon Gas Development Revised and Expanded Proposal Public Environmental Review*. Chevron Australia, Perth, Western Australia.

Chevron Australia. 2009. *Gorgon Gas Development and Jansz Feed Gas Pipeline Dredging and Spoil Disposal Management and Monitoring Plan*. Chevron Australia, Perth, Western Australia. (G1-NT-PLNX0000373)

Chevron Australia. 2010. *Gorgon Gas Development and Jansz Feed Gas Pipeline Coastal and Marine Baseline State Environmental Impact Report*. Chevron Australia, Perth, Western Australia. (G1-NT-REPX000183)

Gilmour, J.P, Cooper, T.F., Fabricius, K.E. and Smith, L.D. 2007. *Early warning indicators of change in the condition of corals and coral communities in response to key anthropogenic stressors in the Pilbara, Western Australia.* Australian Institute of Marine Science and National Heritage Trust.

Global Environmental Modelling Systems. 2008. *Gorgon Development Dredging Simulation Studies to Support the PER for the Revised Proposal*. Melbourne, Victoria.

Sinclair Knight Merz. 2008. *Cape Lambert Port B Public Environmental Review and Public Environmental Report*. Prepared for Rio Tinto Iron Ore, Perth, Western Australia.

Sinclair Knight Merz. 2008a. *Pluto LNG Development: Dredging and Spoil Disposal Management Plan/Dredge Impact Management Plan*. Prepared for Woodside Energy Ltd., Perth, Western Australia.

Stoddart, J.A. and Stoddart, S.E. (eds). 2004. *Corals of the Dampier Harbour: Their Survival and Reproduction during the Dredging Programs of 2004.* MScience Pty Ltd., Perth, Western Australia.

Appendix 1 Application of the Initial Water Quality Criteria to Baseline Water Quality Data

To assess the level of exceedance or compliance of the baseline water quality data collected during the Marine Baseline Program (Chevron Australia 2010) with the Initial Water Quality Criteria, analysis and comparison of a subset of the baseline water quality data with the Initial Water Quality Criteria (Table 2.1) was undertaken by Sinclair Knight Merz (SKM). This comparison was undertaken to enable an evaluation of the suitability of the Initial Water Quality Criteria and is commensurate with risk(s) of impact arising from the dredging and spoil disposal program. Water Quality Criteria that are set too high run the risk of compromising the health of coral that may be sensitive to subtle changes in water quality, while Water Quality Criteria that are set too low may continually trigger management responses unnecessarily.

Baseline Water Quality Data Included in Analysis

Light, Turbidity and Deposition (LTD) loggers have been progressively deployed at 16 sites in the waters surrounding Barrow Island since December 2007 as part of the Marine Baseline Program (Table 1; Figure 1) (Chevron Australia 2010). These loggers have provided continuous measures of temporal changes in water quality (turbidity) and light climate at the seabed. Data collection is ongoing. The baseline data for 11 sites, representing a range of geographic locations (sites in the Zone of Influence and Regionally Significant Areas) as well as sites near the dredging and spoil disposal activities (Zones of Moderate Impact) were selected for the purposes of the analysis and comparison against the Initial Water Quality Criteria.

Table 1 Baseline Water Quality Data Monitoring Sites and Duration of Deployment included in Data Review for this Supplement

Location	Site (Site Code)	Start Date	End Date	Days of Usable Data
Zones of Moderate Impact	LNG1	16/07/2008	16/07/2009	366
	Lone Reef (LONE)	18/01/2008	20/07/2009	548
	MOF1	22/01/2008	03/08/2009	559
Zones of Influence	Ant Point Reef (ANT)	17/01/2008	15/07/2009	546
	LNG2	18/01/2008	17/07/2009	547
	Southern Lowendal Shelf (LOW)	18/01/2008	02/06/2009	502
	MOF2	16/07/2008	10/10/2009	452
	MOF3	18/01/2008	16/07/2009	546
Regionally Significant Areas	Batman Reef (BAT)	19/01/2008	11/10/2009	632
	Dugong Reef (DUG)	20/01/2008	12/09/2009	602
	Southern Barrow Shoals (SBS)	19/01/2008	07/07/2009	536

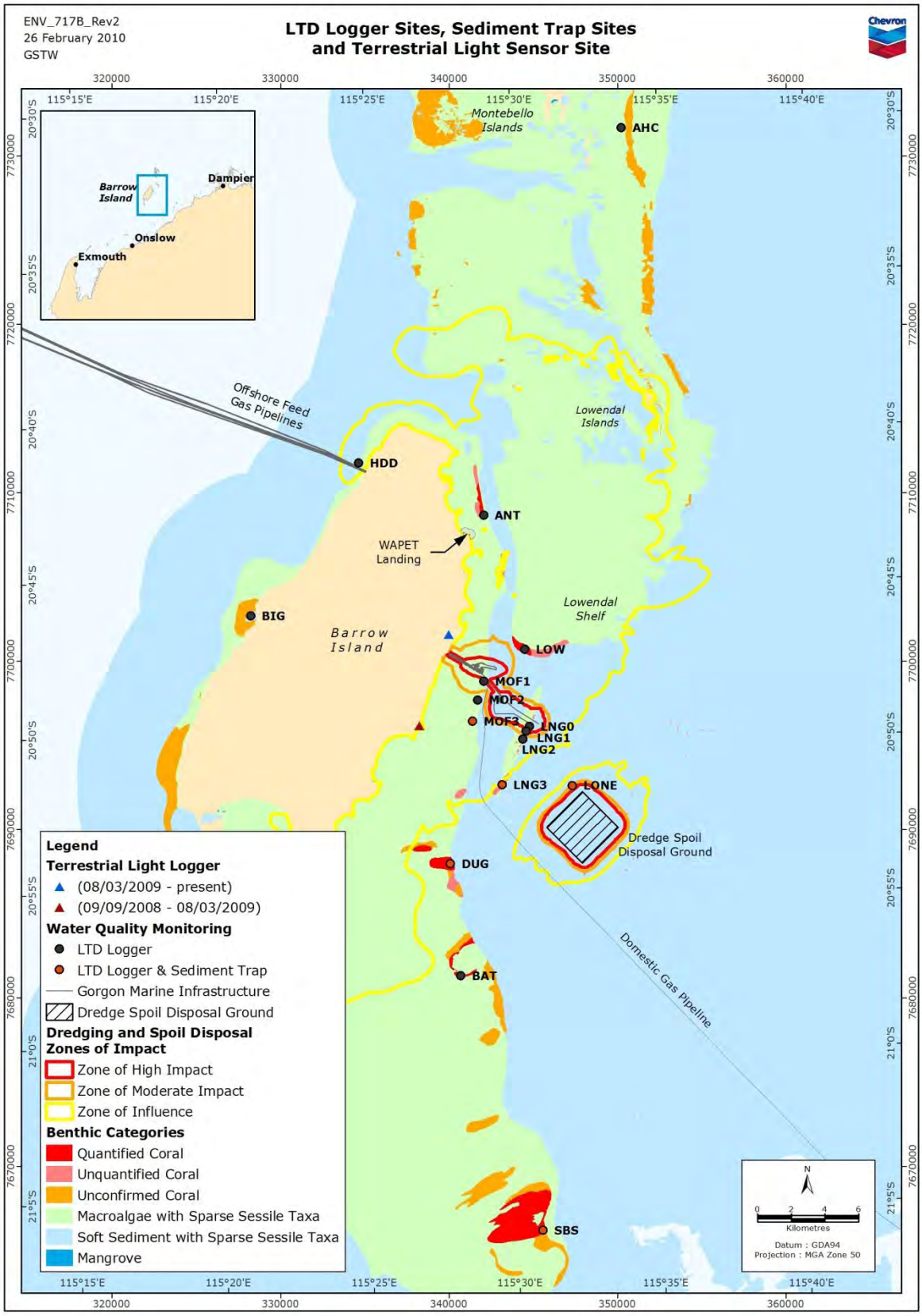


Figure 1 Marine Baseline Program LTD Logger Sites, Sediment Trap Sites and Terrestrial Light Sensor Site

Source: Chevron Australia 2010

Public

Baseline Water Quality Data Analysis and Comparison to the Initial Water Quality Criteria

Methods

Preliminary Baseline Water Quality Data Review

The Marine Baseline Program water quality data were QA/QC'ed and the raw data filtered and corrected by James Cook University and RPS Australia/SE Asia prior to provision of the datasets to SKM. The main sources of errors in the data and the associated filtering and correction applied to those data included: zero point errors, anomalous data spikes, measurement drift caused by marine biofouling, interference by the sensor wipers, disconnected or non-functional sensors, off-scale measurements, calibration changes and incorrect logger start times.

Prior to comparison against the Initial Water Quality Criteria, the baseline water quality (turbidity) datasets were reviewed by SKM to assess whether any further corrections were required:

- The LTD loggers were deployed progressively since December 2007. However, data were initially recorded at 20-minute intervals, rather than at 10-minute intervals, and there were a number of significant data gaps. These data were therefore excluded from the comparison of the baseline water quality data against the Initial Water Quality Criteria.
- Since mid-January 2008, the LTD loggers have recorded data at 10-minute intervals. If there were no data available for a particular 10-minute interval (e.g. due to loggers being downloaded or data not passing quality assurance/quality control [QA/QC] and being deleted) a blank space was inserted in the data column. This process was undertaken so that there were an exact number of 10-minute intervals between the hours of 6:00 am and 6:00 pm to calculate comparable 'daily' medians. This also enabled more robust QA/QC to be implemented by keeping each series synchronised through the 12-hour period.
- Single data points (outliers) that were more than twice the average of the surrounding data (10 minutes either side) were corrected to reduce any high single point anomalies that may be due to material or organisms (e.g. fish or algae) passing in front of the sensor at the time the reading was taken.

  The algorithm used was IF(D3<((D2+D4)/2)*2,D3,((D2+D4)/2))

  Where D3 is the TSS value being investigated

  D2 is the previous TSS value (taken 10 minutes earlier)

  D4 is the next TSS value (taken 10 minutes later).

  This algorithm was applied to each value in the dataset such that each TSS value was compared to the previous value and the next. Where the value being tested was less than twice the average of the values on either side, it remained unchanged. Where the value being tested was greater than the average, it was made equal to the average of the values on either side.
- Review of the baseline water quality data for other anomalies was undertaken. One anomaly was identified in the baseline data for site LNG1; no similar obvious anomalies were observed during a cursory examination of the other datasets. Elevated daily median Total Suspended Solids (TSS, >25 mg/L) were observed in the baseline data for site LNG1 and considered to warrant further investigation. These elevated daily medians were examined for potential correlation with the prevailing wind conditions (speed) and wave height data. For example, a tropical cyclone was located in the vicinity of Barrow Island on 26 January 2009. The daily median TSS at this time was 31 mg/L. Examination of other high daily medians indicated that over the period from 29 November 2008 to 3 December 2008 the daily median TSS exceeded 31 mg/L, while the corresponding mean wave height and wind speed were comparatively low. Daily readings on 4 December 2008 started high and at 10:10 am, the TSS reading was 153 mg/L. This was followed by a number of 10-minute intervals where no data were recorded. At 11:20 am, the TSS reading was 0.7 mg/L. After this time, TSS

readings remained <2 mg/L through to the end of January 2009. This anomaly is best explained by fouling of the logger prior to its replacement on 4 December 2008. These data were subsequently excluded from the analysis and a comparison of the corrected and uncorrected data exceedances was undertaken.

Baseline Water Quality Data Manipulation

- Turbidity (NTU) data were converted into estimates of Total Suspended Solids (TSS, mg/L) using a correction factor from the calibration of the instrument response to water samples with measured concentrations of TSS (Chevron Australia 2010). Site-specific correction factors were derived; however, due to the similarity in the relationships at most sites, as well as the mobility and influence of sediment from surrounding areas and between sites, an average value for the conversion of NTU to TSS was applied across all 11 sites. This average was 1.7.
- Daily median turbidity levels were determined based on the data collected at 10-minute intervals over a 12-hour daylight period between the hours of 6:00 am and 6:00 pm. If the median exceeded any of the TSS threshold concentrations (i.e. 25 mg/L, 10 mg/L or 5 mg/L) then this represents at least 50% of the time (six hours or more) where the TSS level was above the TSS threshold concentration. This is consistent with the dredge plume model criteria which were framed in terms of 'days' of exposure; however, only daylight hours are relevant for turbidity (note that this is not the case for sedimentation).

Comparison of Variable Time Intervals for Recording

The telemetered water quality loggers record NTU readings at 30-minute intervals. To determine whether any information may be lost by reducing the data quantity (from 10-minute intervals as per the Marine Baseline Program to 30-minute intervals), a comparison was made at the Southern Lowendal Shelf (LOW) site for data recorded every 10 minutes versus that recorded every 30 minutes.

Elevation of Background Turbidity Levels

To examine the potential effects of a turbidity plume on exceedances of the TSS threshold concentrations and the Initial Water Quality Criteria, elevated TSS levels (1 and 2 mg/L) were applied to the baseline water quality data for each site. These increases were considered likely to occur at some of the baseline water quality monitoring sites, given their location with respect to the dredging and spoil disposal activities. Refer to the Marine Baseline Report (Chevron Australia 2010) for further information on correlations between the water quality data with meteorological and oceanographic conditions.

Results

The number of times the daily median TSS concentrations for each site equalled or exceeded the TSS threshold concentrations and the number of times the short-, medium- and long-term Initial Water Quality Criteria (e.g. ≥25 mg/L for any two days in six) were exceeded at each site for both the raw data and the high single point anomaly corrected data are summarised in Table 2. Plots of the temporal extent of exceedances of the TSS threshold concentrations (i.e. 25 mg/L, 10 mg/L and 5 mg/L) at each site are included in Appendix 1.

There were no natural exceedances of the Initial Water Quality Criteria observed through examination of the baseline water quality data for sites MOF2, LNG1 (corrected), LNG2, Lone Reef (LONE), Ant Point (ANT) and Southern Lowendal Shelf (LOW). There were exceedances observed at five of the 11 sites (MOF1, MOF3, Batman Reef [BAT], Dugong Reef [DUG] and Southern Barrow Shoals [SBS]). Thus, fluctuations in the turbidity levels observed in the Marine Baseline Program due to natural causes and cycles in weather conditions regularly exceed the Initial Water Quality Criteria. This was particularly the case for the long-term Initial Water Quality Criterion (i.e. ≥5 mg/L for 20 days in 60).

Note that there are a number of occasions where the daily exceedances of the TSS threshold concentrations were counted as a component of more than one exceedance of the Initial Water Quality Criteria. For example, the LTD logger at Dugong Reef [DUG] recorded six incidents where the daily median TSS was ≥25 mg/L, yet there were eight incidents of exceeding the

short-term Initial Water Quality Criterion: ≥25 mg/L for any two days in six (Table 2). Figure 2 illustrates how an exceedance of the short-term Initial Water Quality Criterion was identified and why exceedances of the TSS threshold concentrations may be considered more than once in an assessment of the exceedance of an Initial Water Quality Criterion. In practice, an occurrence of the daily median exceeding any given TSS threshold concentration would be counted only once towards the exceedance of an Initial Water Quality Criterion (i.e. water quality is either 'Not in Exceedance' or 'In Exceedance').

Figure 2 Exceedances of Daily Median TSS (25 mg/L) Threshold Concentrations and Exceedances of the Short-term Initial Water Quality Criterion (≥25 mg/L for 2 days in a 6-day period)

Table 2 Number of Times the Total Suspended Solids Threshold Concentrations and the Short-, Medium- and Long-term Initial Water Quality Criteria were Exceeded for each Site for the Raw Data or when Corrections for High Single Point Anomalies were Applied

Location	Site	Number of Corrections for High Single Point Anomalies	Number of Times Daily Median Equalled or Exceeded 25 mg/L	Number of Times 25 mg/L was Equalled or Exceeded 2 Days in 6	Number of Times Daily Median Equalled or Exceeded 10 mg/L	Number of Times 10 mg/L was Equalled or Exceeded 7 Days in 21	Number of Times Daily Median Equalled or Exceeded 5 mg/L	Number of Times 5 mg/L was Equalled or Exceeded 20 Days in 60
Raw Data:								
Zone of Moderate Impact	LNG1	-	4	6	13	0	39	0
	LONE	-	0	0	8	0	27	0
	MOF1	-	0	0	10	13	55	26
Zone of Influence	ANT	-	0	0	3	0	24	0
	LNG2	-	0	0	4	0	29	0
	LOW -10 min	-	0	0	12	0	40	0
	LOW – 30 min	-	0	0	12	0	38	0
	MOF2	-	1	0	2	0	8	0
	MOF3	-	8	13	29	32	86	62
Regionally Significant Areas	BAT	-	6	4	30	20	95	89
	DUG	-	6	8	22	0	64	2
	SBS	-	15	26	52	64	157	123
High Single Point Anomaly Corrected Data:								
Zone of Moderate Impact	LNG1	100 of 52 704	4	6	13	0	39	0
	LNG1 corrected	100 of 52 704	1	0	9	0	34	0
	LONE	211 of 79 056	0	0	8	0	27	0
	MOF1	173 of 80 496	0	0	10	13	55	26
Zone of Influence	ANT	157 of 78 624	0	0	3	0	24	0
	LNG2	88 of 78 768	0	0	4	0	29	0
	LOW -10 min	81 of 72 288	0	0	12	0	40	0
	LOW – 30 min	1011 of 24 996	0	0	12	0	38	0
	MOF2	147 of 65 088	1	0	2	0	8	0
	MOF3	193 of 78 624	8	13	29	32	86	62
Regionally Significant Areas	BAT	103 of 91 008	6	4	30	20	95	89
	DUG	192 of 86 688	6	8	22	0	64	2
	SBS	66 of 77 184	15	26	52	64	157	123

Elevation of Background Turbidity Levels

The number of times the short-, medium- and long-term Initial Water Quality Criteria were exceeded at each site following increases in TSS levels by 1 and 2 mg/L above naturally occurring baseline levels are presented in Table 3. More exceedances of the Initial Water Quality Criteria were recorded at those sites where natural exceedances of the Initial Water Quality Criteria were observed (Table 2). This assessment demonstrates how similar the baseline TSS conditions are to the existing long-term (60-day) and medium-term (21-day) Initial Water Quality Criteria, in particular at MOF1, MOF3, Batman Reef (BAT), Dugong Reef (DUG) and Southern Barrow Shoals (SBS).

Table 3 Number of Times Short-, Medium- and Long-term Initial Water Quality Criteria were Exceeded at each Site with the Addition of Set Turbidity Increases

Location	Site	Increase (mg/L)	Number of Times 25 mg/L Equalled or Exceeded 2 Days in 6	Number of Times 10 mg/L Equalled or Exceeded 7 Days in 21	Number of Times 5 mg/L Equalled or Exceeded 20 Days in 60
Zones of Moderate Impact	LNG1	0	0	0	0
		1	0	1	0
		2	0	1	48
	LONE	0	0	0	0
		1	0	0	0
		2	0	0	0
	MOF1	0	0	13	26
		1	0	13	26
		2	0	17	75
Zones of Influence	ANT	0	0	0	0
		1	0	0	0
		2	0	0	41
	LNG2	0	0	0	0
		1	0	0	0
		2	0	0	54
	LOW	0	0	0	0
		1	0	0	11
		2	0	0	78
	MOF2	0	0	0	0
		1	0	0	0
		2	0	0	0
	MOF3	0	13	32	62
		1	13	50	202
		2	13	54	219
Regionally Significant Areas	BAT	0	4	20	89
		1	8	46	139
		2	8	64	159
	DUG	0	8	0	2
		1	8	0	2
		2	8	22	64
	SBS	0	26	64	123
		1	26	67	200
		2	26	76	273

Comparison of Variable Time Intervals for Recording

Increasing the recording time interval at the Southern Lowendal Shelf (LOW) site from 10 to 30 minutes resulted in slight decreases in the exceedances of the medium-term Initial Water

Quality Criterion (i.e. ≥10 mg/L for seven days in 21), and there were varying effects on the long-term Initial Water Quality Criterion (i.e. ≥5 mg/L for 20 days in 60) (Table 4).

Table 4 Number of Times the Initial Water Quality Criteria were Exceeded at the Southern Lowendal Shelf (LOW) Site at Two Recording Intervals (10- and 30-minute) with the Addition of Set Turbidity Increases

Site	Increase (mg/L)	Number of Times 25 mg/L Equalled or Exceeded 2 Days in 6	Number of Times 10 mg/L Equalled or Exceeded 7 Days in 21	Number of Times 5 mg/L Equalled or Exceeded 20 Days in 60
LOW – 10 min	0	0	0	0
	1	0	0	11
	2	0	0	78
	5	0	42	443*
LOW – 30 min	0	0	0	0
	1	0	0	**15**
	2	0	0	**71**
	5	0	**41**	443*

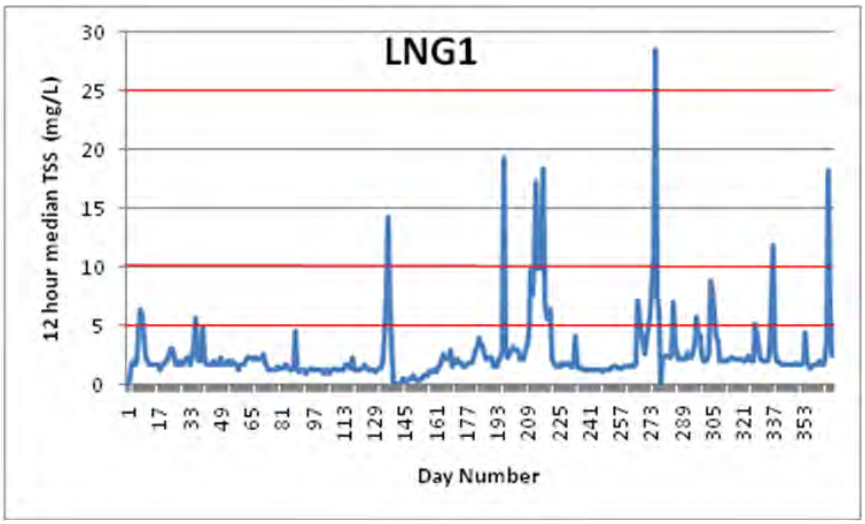
*Note: Bold values show a changed level of exceedance of the Initial Water Quality Criteria in one time interval compared to the other; * represents 100% exceedance. There were 502 days of data less 59 days before an exceedance can be recorded due to the long-term Initial Water Quality Criterion being 20 days in 60.*

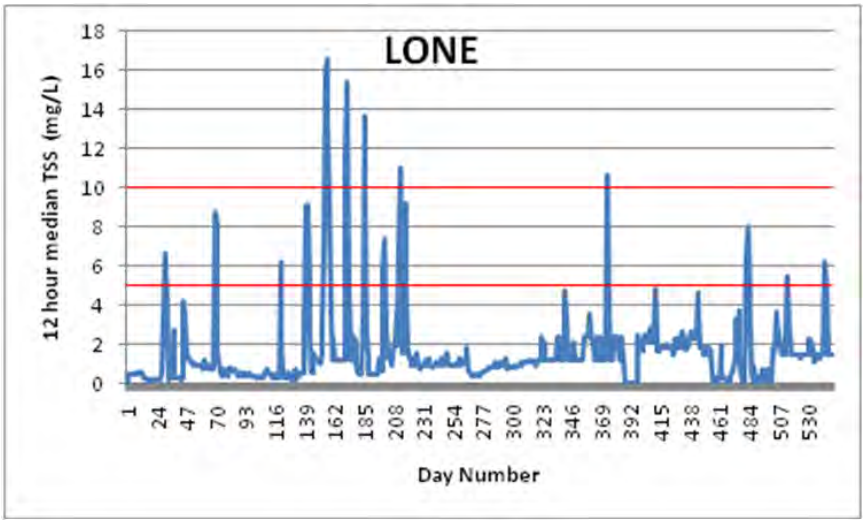
Nevertheless, 30-minute intervals are considered to represent suitable increments for recording turbidity data in the vicinity of Barrow Island. The diurnal tides will result in reversal in the direction of water flow every six hours, over which time (approximately) 12 telemetered logger readings may be collected. Any significant increases in turbidity associated with dredging or spoil disposal activities would be detected during that six-hour window.

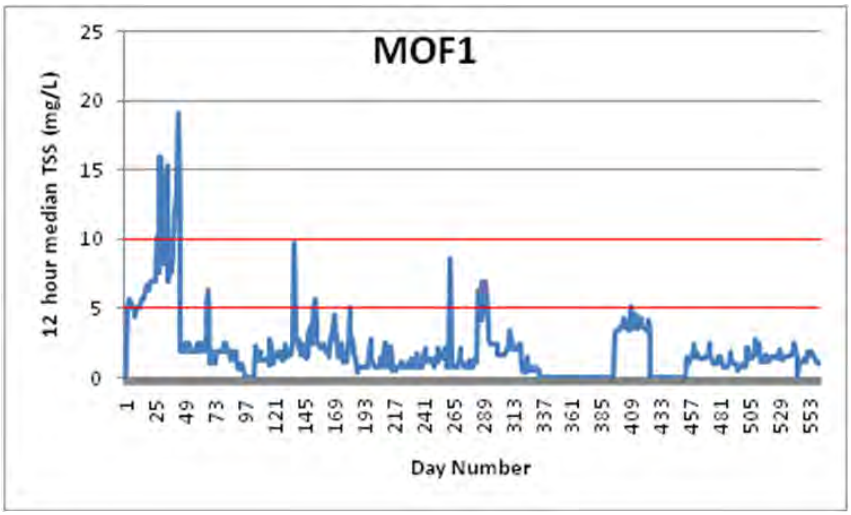
Appendix 2 Total Suspended Solids Threshold Concentrations Exceedances at Baseline Monitoring Sites

Graphs of the temporal extent of exceedances of the Total Suspended Solids (TSS) threshold concentrations at each Baseline Monitoring Site: Red lines represent the TSS threshold concentrations of 5, 10 and 25 mg/L. Note that the scale of each graph is different and for some sites, the 25 mg/L level was not required, as the data did not approach this level.

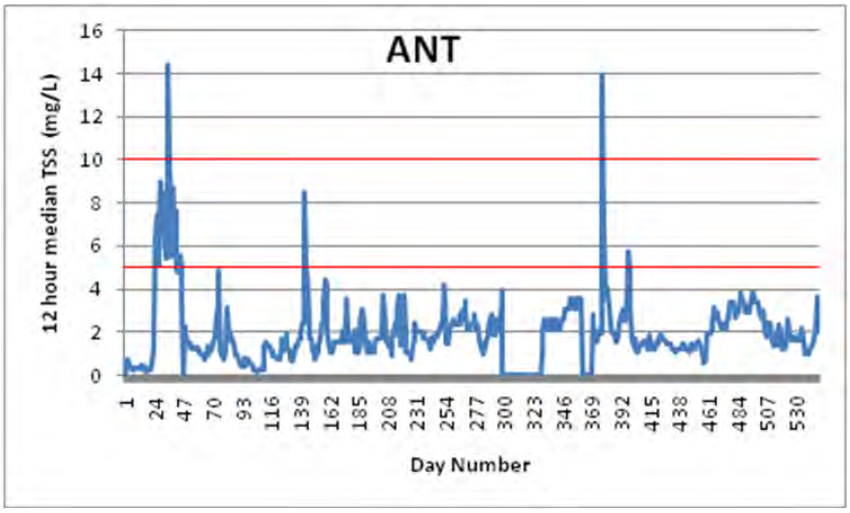
Zone of Moderate Impact

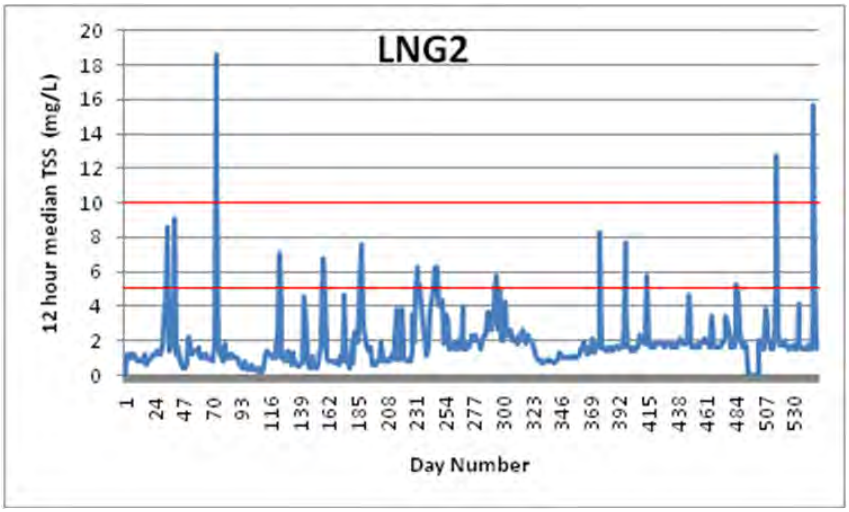


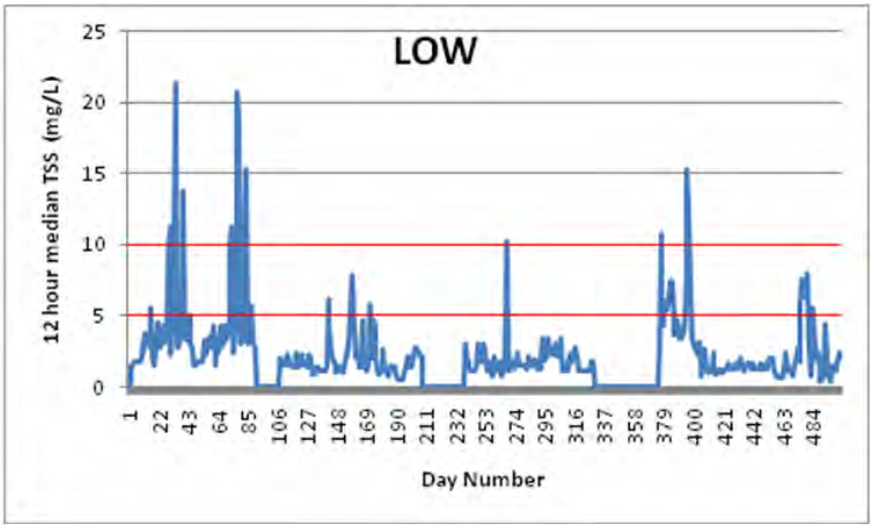


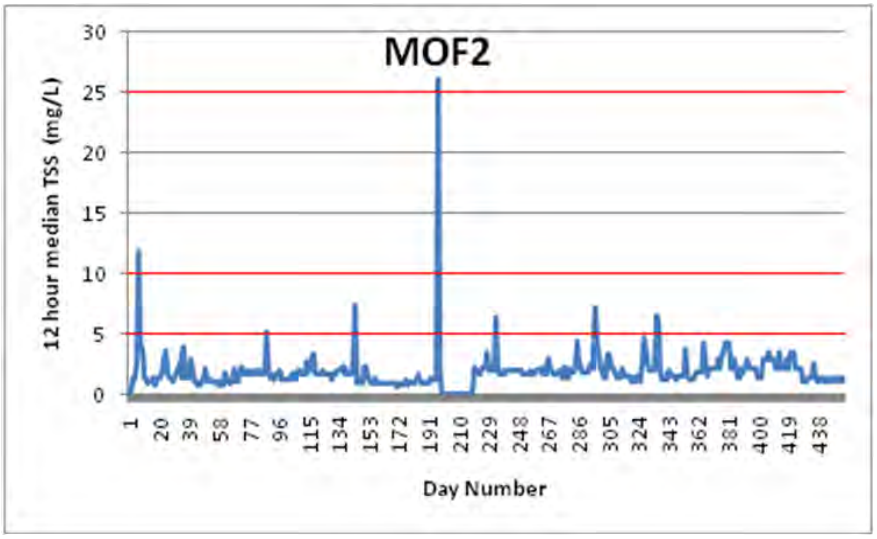


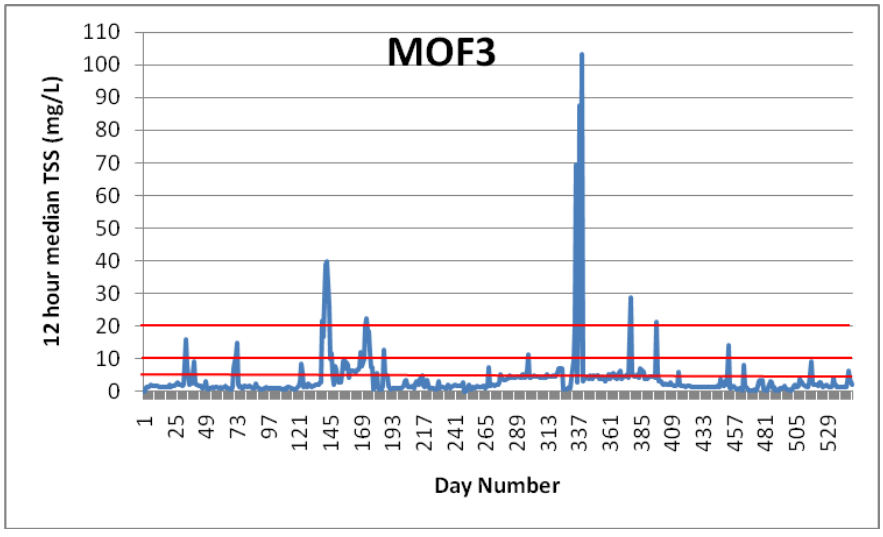
Zone of Influence



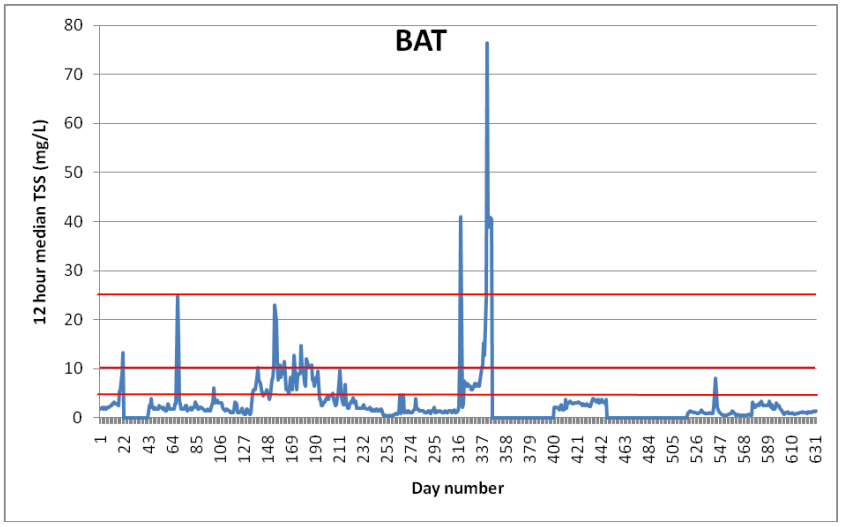


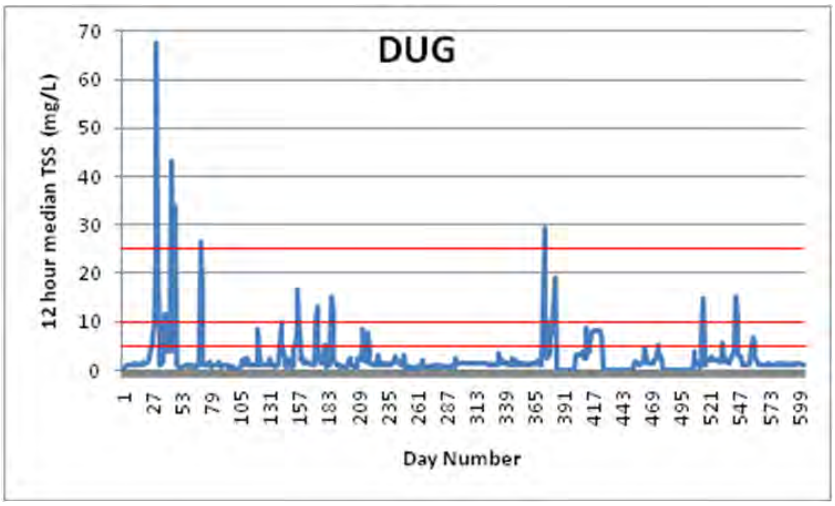

LOW
12 hour median TSS (mg/L)
25
20
15
10
5
0
1
22
43
64
85
106
127
148
169
190
211
232
253
274
295
316
337
358
379
400
421
442
463
484
Day Number

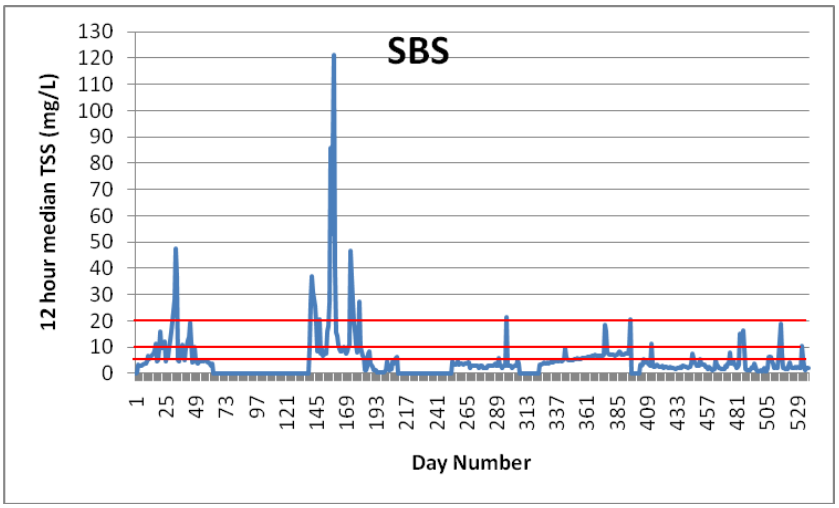

MOF2
12 hour median TSS (mg/L)
30
25
20
15
10
5
0
1
20
39
58
77
96
115
134
153
172
191
210
229
248
267
286
305
324
343
362
381
400
419
438
Day Number


MOF3
12 hour median TSS (mg/L)
110
100
90
80
70
60
50
40
30
20
10
0
1
25
49
73
97
121
145
169
193
217
241
265
289
313
337
361
385
409
433
457
481
505
529
Day Number

Regionally Significant Areas







Appendix 3 Preliminary Telemetered Logger Water Quality Data Analysis and Comparison to the Initial Water Quality Criteria

The telemetered water quality loggers were deployed in December 2009 at nine sites at the boundary of the Zones of Moderate Impact and the Zones of Influence (Figure 2.1). To assess the level of exceedance or compliance of the baseline telemetered water quality data collected over the first 1–2 months of deployment, analysis and comparison of the water quality data with the Initial Water Quality Criteria (Table 2.1) was also undertaken by SKM.

Telemetered Logger Water Quality Data Included in Analysis

The description of the baseline telemetered logger dataset, including the duration of deployment, the number of data points, and the information on missing, removed or high single point anomaly corrected data is summarised in Table 1. Turbidity was measured and logged at 30-minute intervals.

Table 1 Baseline Telemetered Logger Water Quality Logger Data Description Including Durations, Number of Occurrences of Missing Data and Removal of Data

Site	Start date	End Date	Days of Data	Number of Corrections for High Single Point Anomalies	Removed Data (1)	Missing Data (2)	Corrected Median (mg/L)
T1	12/01/2010	08/02/2010	28	35 of 1306	2	12	1.01
T2	13/01/2010	08/02/2010	27	26 of 1264	0	9	0.96
T3	13/01/2010	08/02/2010	27	21 of 1266	0	6	0.94
T4	16/01/2010	08/02/2010	24	51 of 1133	0	0	0.79
T5	14/01/2010	08/02/2010	26	19 of 1231	0	12	1.35
T6	14/12/2009	08/02/2010	57	103 of 2721	9	93	1.16
T7	14/12/2009	08/02/2010	57	45 of 2719	7	21	1.04
T8	14/01/2010	08/02/2010	26	45 of 1280	5	12	0.92
T9	14/01/2010	08/02/2010	26	27 of 1232	0	3	1.25

Notes:

(1) Data points removed due to erroneously high values (possibly because of short-term interference of the logger by biofouling, fish, octopuses or drift algae) over a short duration.

(2) Data points not recorded due to failure in transmission of the data from the surface buoy via the satellite network.

Baseline Telemetered Logger Water Quality Data Analysis and Preliminary Comparison to the Initial Water Quality Criteria

Methods

Preliminary Baseline Telemetered Logger Water Quality Data Review

Prior to comparison against the Initial Water Quality Criteria, the baseline water quality (turbidity) datasets were reviewed by SKM to assess whether any corrections were required:

- Turbidity was measured and logged every 30 minutes. If no data were reported for a particular 30-minute interval (e.g. due to telemetered loggers missing recordings, or data not passing QA/QC and being deleted) a blank space was inserted in the data column. This process was undertaken so that there were an exact number of 30-minute intervals between the hours of 6:00 am and 6:00 pm to calculate comparable 'daily' medians. This also enabled more robust QA/QC to be implemented by keeping each series synchronised through the 12-hour period.

- Erroneous data, defined as abnormally high values that exceed 250 NTU (the limit of the low range logger), were removed as it is considered unlikely that baseline conditions can reach this level of turbidity.
- Single data points (outliers) that were more than twice the average of the surrounding data (10 minutes either side) were corrected to reduce any high single point anomalies that may be due to material or organisms (e.g. fish or algae) passing in front of the sensor at the time the reading was taken (refer to Appendix 2).

Baseline Telemetered Logger Water Quality Data Manipulation

- Turbidity (NTU) data were converted into estimates of Total Suspended Solids (TSS, mg/L) using a correction factor (refer to Appendix 2). The average of all the LTD logger sites (1.7) was used as the correction factor in all calculations.
- Daily median turbidity levels were calculated on a 12-hour daylight period (encompassing all 30-minute intervals between 6:00 am and 6:00 pm). If the median exceeded any of the TSS threshold concentrations (i.e. 25 mg/L, 10 mg/L or 5 mg/L) then this represents at least 50% of the time (6 hours or more) where the TSS level was above the TSS threshold concentration (refer to Appendix 2).

Preliminary Results

The number of times the short-, medium- and long-term Initial Water Quality Criteria (e.g. ≥25 mg/L for any two days in six) were exceeded at each telemetered logger site are summarised in Table 2. Plots of the daily median TSS levels and compliance or exceedance with the short, medium and long-term Initial Water Quality Criteria at each telemetered logger site are included in Appendix 4.

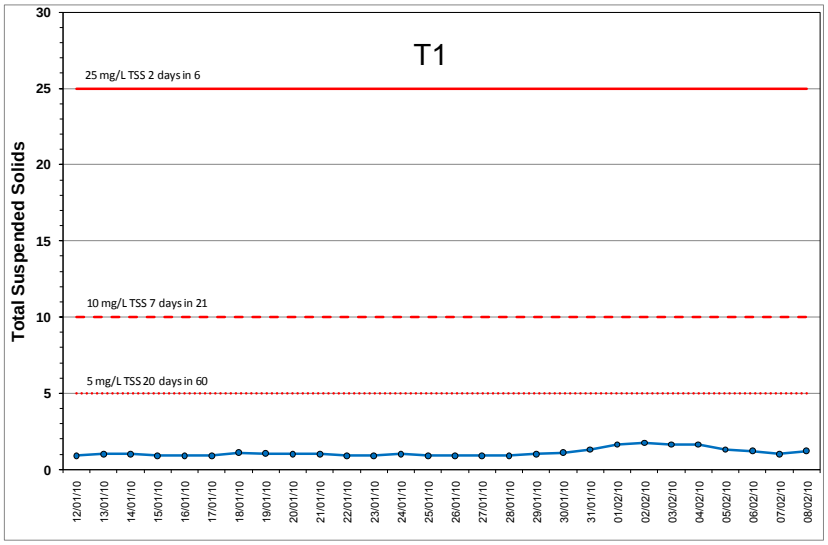
Table 2 Number of Times the Total Suspended Solids Threshold Concentrations and the Short-, Medium- and Long-term Initial Water Quality Criteria were Exceeded at each Telemetered Logger Site

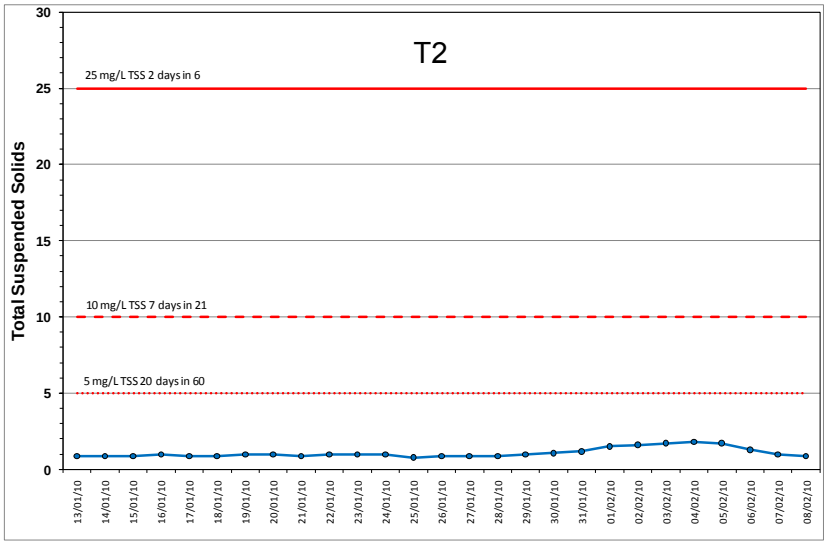
Site	Number of Times Daily Median Equalled or Exceeded 25 mg/L	Number of times 25 mg/L was Equalled or Exceeded 2 Days in 6	Number of Times Daily Median Equalled or Exceeded 10 mg/L	Number of Times 10 mg/L was Equalled or Exceeded 7 Days in 21	Number of Times Daily Median Equalled or Exceeded 5 mg/L	Number of Times 5 mg/L was Equalled or Exceeded 20 Days in 60
T1	0	0	0	0	0	Insufficient data
T2	0	0	0	0	0	Insufficient data
T3	0	0	0	0	0	Insufficient data
T4	0	0	0	0	0	Insufficient data
T5	0	0	0	0	0	Insufficient data
T6	0	0	0	0	0	Insufficient data
T7	0	0	0	0	0	Insufficient data
T8	0	0	0	0	0	Insufficient data
T9	0	0	0	0	0	Insufficient data

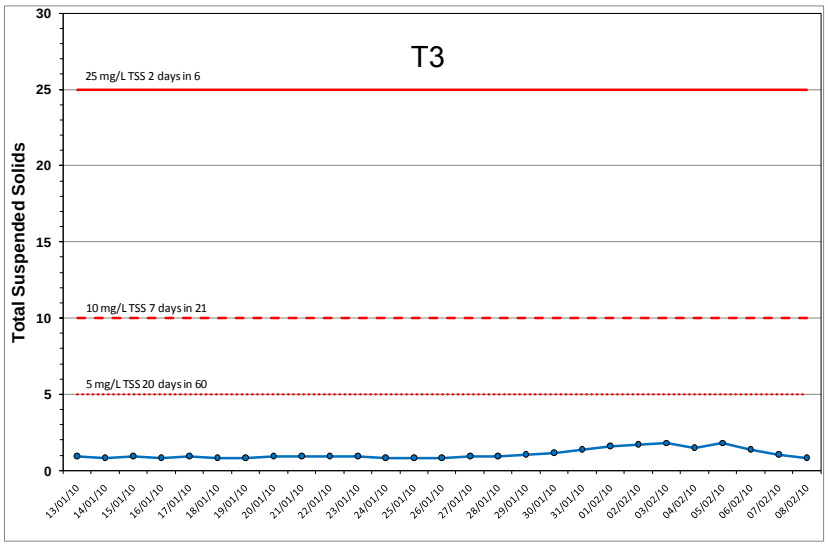
There were no natural exceedances of the Initial Water Quality Criteria observed through examination of the baseline telemetered logger water quality data at any of the nine telemetered logger sites.

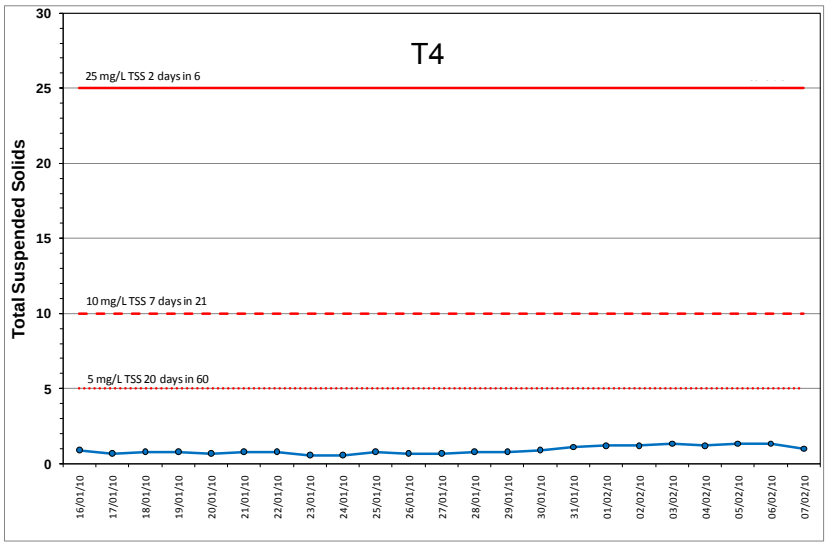
Appendix 4 Daily Total Suspended Solids Medians Compared with the Initial Water Quality Criteria at each of the Telemetered Water Quality Logger Sites

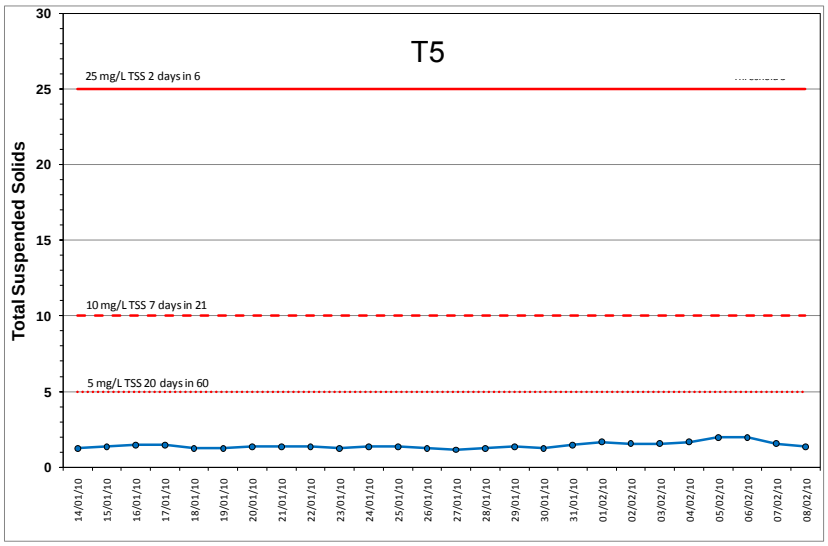
Graphs of the daily Total Suspended Solids medians at each telemetered logger site. Solid line represents the short-term Initial Water Quality Criterion, the dashed line the medium-term Initial Water Quality Criterion and the dotted line the long-term Initial Water Quality Criterion.

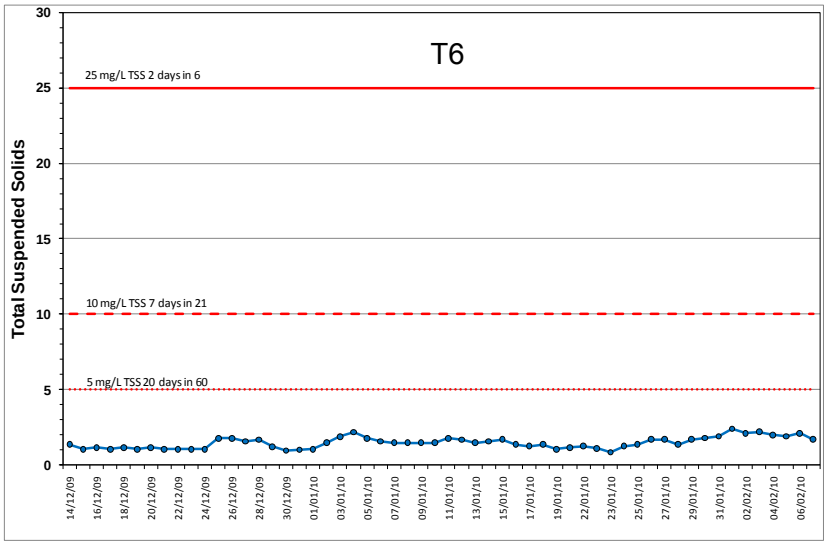


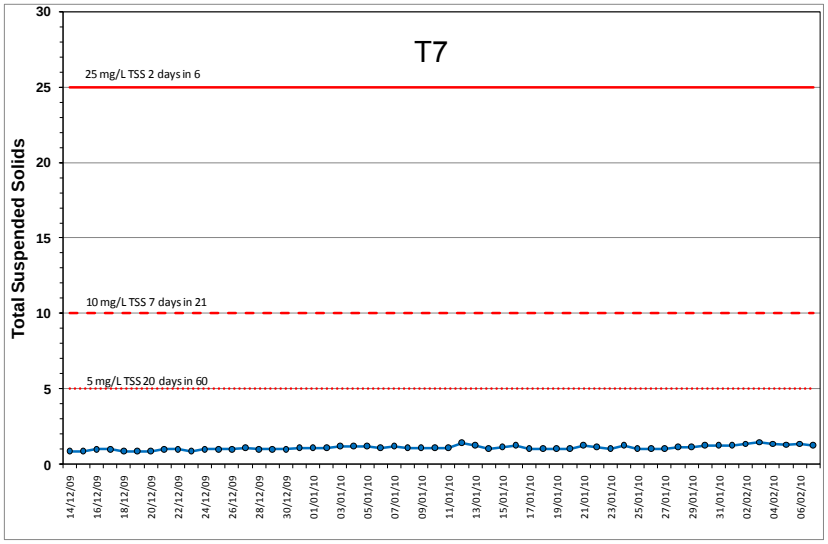


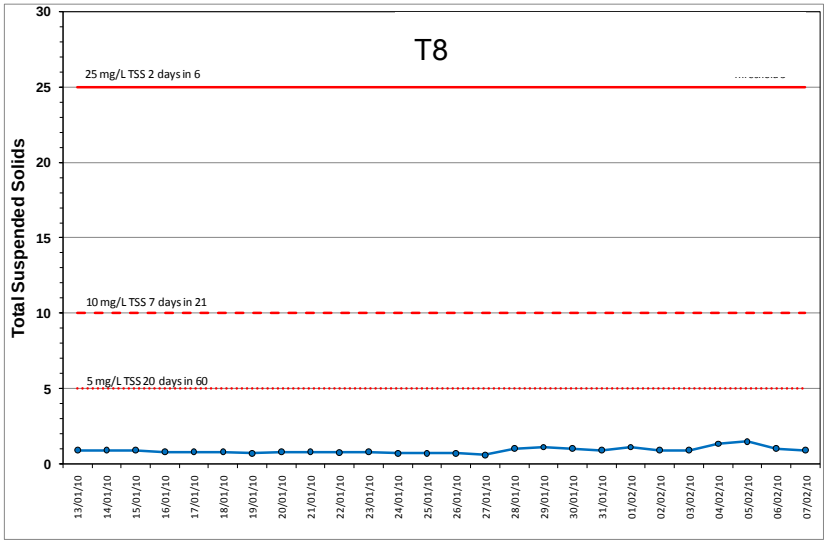







T6
25 mg/L TSS 2 days in 6
10 mg/L TSS 7 days in 21
5 mg/L TSS 20 days in 60
Total Suspended Solids
0
5
10
15
20
25
30
14/12/09
16/12/09
18/12/09
20/12/09
22/12/09
24/12/09
26/12/09
28/12/09
30/12/09
01/01/10
03/01/10
05/01/10
07/01/10
09/01/10
11/01/10
13/01/10
15/01/10
17/01/10
19/01/10
22/01/10
23/01/10
25/01/10
27/01/10
29/01/10
31/01/10
02/02/10
04/02/10
06/02/10


T7
25 mg/L TSS 2 days in 6
10 mg/L TSS 7 days in 21
5 mg/L TSS 20 days in 60
Total Suspended Solids
0
5
10
15
20
25
30
14/12/09
16/12/09
18/12/09
20/12/09
22/12/09
24/12/09
26/12/09
28/12/09
30/12/09
01/01/10
03/01/10
05/01/10
07/01/10
09/01/10
11/01/10
13/01/10
15/01/10
17/01/10
19/01/10
21/01/10
23/01/10
25/01/10
27/01/10
29/01/10
31/01/10
02/02/10
04/02/10
06/02/10


T8
25 mg/L TSS 2 days in 6
10 mg/L TSS 7 days in 21
5 mg/L TSS 20 days in 60
Total Suspended Solids
0
5
10
15
20
25
30
13/01/10
14/01/10
15/01/10
16/01/10
17/01/10
18/01/10
19/01/10
20/01/10
21/01/10
22/01/10
23/01/10
24/01/10
25/01/10
26/01/10
27/01/10
28/01/10
29/01/10
30/01/10
31/01/10
01/02/10
02/02/10
03/02/10
04/02/10
05/02/10
06/02/10
07/02/10