SINCLAIR KNIGHT MERZ

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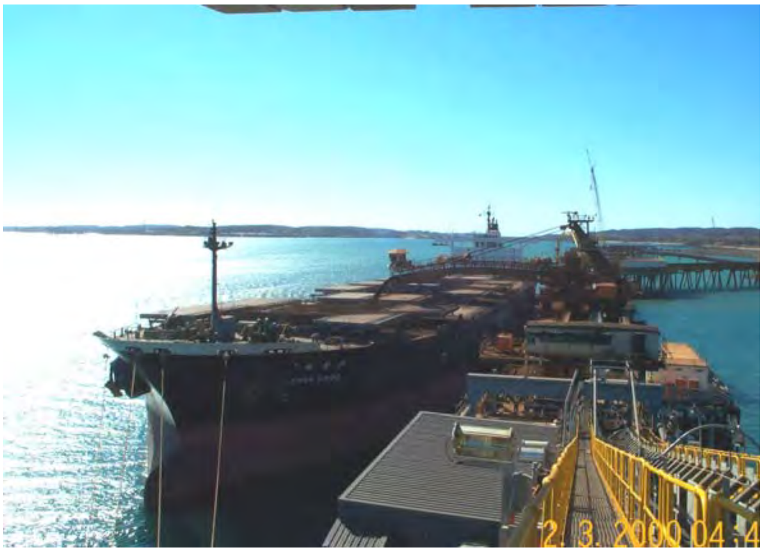
HAMERSLEY IRON

A member of the Rio Tinto Group

Dredging Program for the Dampier Port Upgrade



REFERRAL DOCUMENT

- Revision 2a
- June 2006

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Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft A	8/12/2005	Lyle Banks	R. Galloway	20/1/2006	Draft
Draft B	8/3/2006	Peter Morrison	R. Galloway	8/3/2006	Draft
Draft C	9/3/2006	Peter Royce Ross Dunkley	R. Galloway	16/3/2006	Final draft
Rev 1	17/3/2006	Peter Morrison	R. Galloway	17/3/2006	Final
Rev 2a	9/9/06	Peter Morrison	R. Galloway	9/6/2006	Revised final

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft A	1	1 (email)	Lyle Banks – SKM
Draft B	1	1	Peter Morrison SKM
Draft C	1	1 1	Peter Royce – HI Ross Dunkley - SKM
Rev 1	1	1 2 1	EPA Hamersley Iron SKM File
Rev 2a	1	1 2 1	EPA Hamersley Iron SKM File

Printed:	2 August 2006
Last saved:	2 August 2006 09:18 AM
File name:	I:\WVES\Projects\WV03015\Deliverables\ARI\WV03015 DPU Dreging 145 Mtpa Rev 2a.doc
Author:	Richard Galloway
Project manager:	Peter Morrison
Name of organisation:	Hamersley Iron Pty Ltd
Name of project:	Dredging Program for the Dampier Port Upgrade
Name of document:	Referral Document
Document version:	Revision 2a
Project number:	WV03015

Executive Summary

There has been strong growth in the international market for Australian iron ore, which is expected to increase in the future. An important component to Hamersley Iron is the port facility at Dampier. To ensure port infrastructure can allow sufficient ship movements to meet that demand, Hamersley Iron has needed to continually expand berth, approach and departure facilities. By late 2005, it was clear that there was a need for further dredging to establish a new berth at the Parker Point wharf and to improve the approaches and swing basin areas as well as remove sediment which has accumulated in previously dredged areas.

Dredging will be undertaken using a combination of a trailer hopper suction dredge and a cutter suction dredge. The dredging method will be similar to that carried out at Dampier in 2004 for the construction of extended channels, approaches and berth pockets around the Parker Point wharf facility.

The dredging program will require both capital and maintenance dredging:

- The capital dredging program involves the removal of about 2.9 million m^3 (of mostly previously undisturbed material). Capital dredging is required to establish a new berth on the inside of the Parker Point wharf and to improve the approaches and swing basin areas.
- Maintenance dredging will involve the removal of about 0.54 million m^3 of largely previously disturbed material from areas that have mostly been dredged before.

The above dredging volumes include a contingency for over dredging. The capital and maintenance dredging will be undertaken as essentially one dredging program. Most of the dredging will occur around the Parker Point wharf and its approaches, while a small proportion will be dredged around the East Intercourse Island berth (5,000 m^3)and a single high spot adjacent to the main shipping channel (15,000 m^3).

Material to be dredged will be placed either onshore behind an existing sea wall at Parker Point, or transported to approved spoil ground areas within Dampier harbour. These spoil grounds are located off East Lewis Island and in the Northern Spoil Ground. The same areas were used in the 2004 dredging program.

Separate Sea Dumping Applications have been submitted to the Commonwealth Department of the Environment and Heritage for the capital and maintenance dredging programs. Subject to obtaining all appropriate Commonwealth and State Approvals, dredging is scheduled to commence in Quarter 3 2006. Dredging is expected to continue for about 12 – 15 weeks. Environmental management and monitoring has been addressed in the Dredging and Spoil Disposal Management Plan (**Appendix A**).

1. Introduction

1.1 Introduction

Hamersley Iron Pty Limited (Hamersley Iron) is one of the world's largest exporters of iron ore. The company operates iron mine sites in the Pilbara region of Western Australia, together with a dedicated railway and port facility in Dampier. The port, which is one of Australia's largest tonnage ports, includes two terminals – Parker Point and East Intercourse Island.

To meet the current and expected increase in demand for iron ore, Hamersley Iron need to remove sediment which has accumulated in previously dredged areas and undertake further dredging to establish a new berth at the Parker Point wharf and to improve the approaches and swing basin areas.

1.2 Purpose

The purpose of this document is to formally refer the dredging program to the Environmental Protection Authority (EPA) for setting a level of assessment under Section 38 of the *Environmental Protection Act 1986*. This document has been prepared in accordance with referral guidelines and provides the key environmental information regarding the proposal. A separate EPA referral Form has been completed for the proposal. Discussions with the EPA Service Unit indicate that an Assessment on Referred Information (ARI) may be appropriate for this project. This level of assessment is consistent with that applied to the 2004 dredging program undertaken by Hamersley Iron.

1.3 Proponent Information

1.3.1 Proposal Title

The title of the proposal is "Dredging Program for the Dampier Port Upgrade".

1.3.2 Proponent Details

The proponent for this proposal is:

Hamersley Iron Pty Limited
Level 22, Central Park
152 – 158 St Georges Terrace
PERTH WA 6837

Hamersley Iron is a subsidiary of the international mining group Rio Tinto and is the major business unit within Rio Tinto Iron Ore.

The key contact for this proposal is:

Mr Peter Royce
Hamersley Iron
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152 – 158 St Georges Terrace
PERTH WA 6837

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Email: peter.royce@riotinto.com

1.3.3 Other Approvals

Disposal of the dredge spoil at sea requires approval from the Department of the Environment and Heritage under the *Environmental Protection (Sea Dumping) Act 1981*. Hamersley Iron has submitted separate applications for sea dumping of spoil derived from the capital and maintenance dredging programs to the Department of the Environment and Heritage in early March 2006; sea dumping permits are anticipated in Quarter 2 2006.

As required under Section 38 of the *Environmental Protection Act 1986*, a referral document was submitted to the Environmental Protection Authority (EPA) on 19 January 2006 for the proposal to increase the throughput capacity to 145 Mtpa at Dampier. The EPA advertised its intention to set the level of assessment at Environmental Protection Statement (EPS). The EPS is currently being prepared and will be submitted to the EPA during 2006. The scope of the EPS document covering the proposed increase in throughput to 145 Mtpa specifically excludes the dredging program.

1.4 Location/Locality Details

1.4.1 Locality Details

Hamersley Iron's Dampier Operations are located on the shores of Mermaid Sound at Dampier Western Australia (refer to **Figure 1-1)**. Dampier is situated within the Shire of Roebourne, about 1,300 kilometres north of Perth.

The Parker Point operations are situated to the north east of the town of Dampier, while East Intercourse Island lies to the west south west of Dampier (**Figure 1-1**).

1.4.2 Land Tenure

The area to be dredged is contained within the Hamersley Iron special lease area established under the *Iron Ore (Hamersley Range) Agreement Act 1963* as amended.

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1.4.3 Surrounding Land Use

The town of Dampier lies to the south west of the Parker Point operations, with the nearest residence located approximately 1 km away, (refer **Figure 1-1**). Approximately 1,500 people live in the town of Dampier, which was built by Hamersley Iron in the 1960s. Dampier is no longer a company-run town and is administered by the Shire of Roebourne.

The Dampier Salt operations lie to the south of Parker Point and the Woodside North West Shelf Venture Operations lie to the north east on the Burrup Peninsula (**Figure 1-1**). Woodside is completing a dredging program associated with the proposed Liquified Natural Gas Train Five development that commenced in late 2005. There are a number of other industries planned for the King Bay-Hearson Cove Industrial Estate on the Burrup Peninsula. At the time of writing, only one project (the Burrup Fertilisers Ammonia Plant) was nearing completion.

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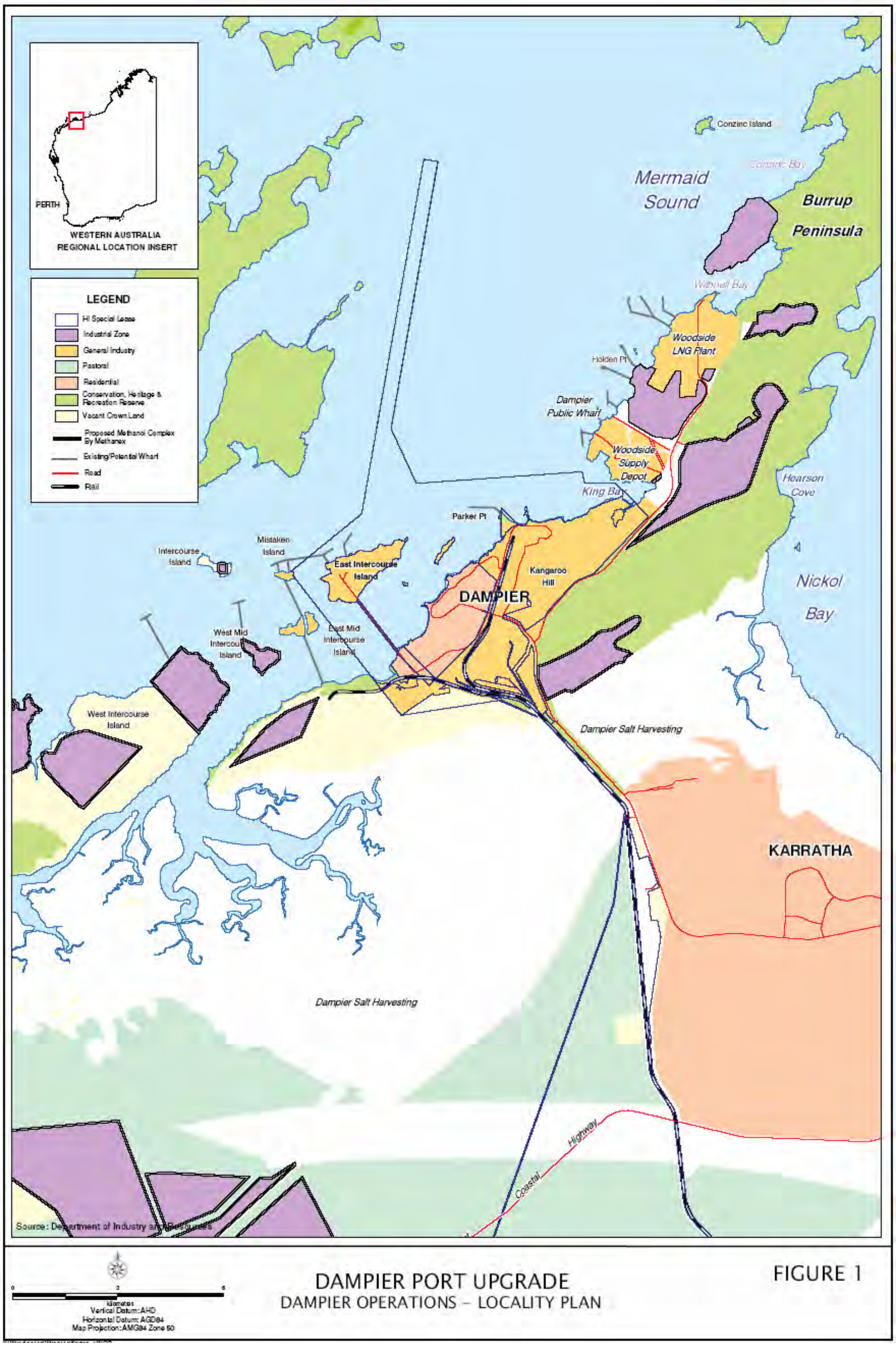

- **Figure 1-1 Dampier Operations – Locality Plan**

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2. Project Justification and Evaluation of Alternatives

2.1 Project Justification

In order for Hamersley Iron to maintain current and future demands for iron ore, dredging will be undertaken to improve the approaches and swing basin areas, increase the number of berth pockets and to remove recent siltation in existing areas, provide for relocation of the existing tanker unloading facilities from the Service Wharf at Parker Point and to allow for increased tonnage to be shipped from the port.

At present, East Intercourse Island has a berth capacity for vessels up to 250,000 DWT while Parker Point has berth capacity for two vessels at 220,00 DWT and one vessel at 180,000 DWT. To allow for the increased tonnage to be shipped from the port, an additional berth at Parker Point needs to be constructed for a 220,000 DWT vessel. The major components of the dredging program (capital and maintenance) are to:

- Extend the existing northern and southern berth pockets at the Parker Point wharf and to enable four vessels (two on the north side and two on the south side) to moor alongside the wharf at any one time, but only two vessels can be loaded at any one time;
- Widen and deepen the southern swing basin to provide safe approaches for 220,000 DWT vessels using the southern berths;
- Widen the northern approach route to provide safe navigation for arriving vessels and provide an escape route to the north of Parker Point in the event of immobilisation of a departing vessel in the channel;
- Dredge a new berth pocket east of the existing Parker Point Wharf to allow for new, upgraded tanker unloading facilities;
- Remove recent siltation in the existing northern approach route and approaches to the Service Wharf facility at Parker Point;
- Remove under wharf spillage from Parker Point and East Intercourse Island berths; and
- Remove a high spot adjacent to the main shipping channel (east of Beacon 7E, Area H) to provide safe navigation for vessels. The channel is essentially a departure channel for loaded vessels requiring additional under-keel clearance. There is insufficient width to the channel to allow vessels to pass one another in opposite directions. With the additional traffic expected in the departure channel from Parker Point and, with the added traffic from the other berths in the Port, removing the high spot reduces the risk of a vessel running aground.

The works will require mobilisation of suitable dredging plant from overseas involving high establishment costs. There is currently a strong demand worldwide for dredging plant and the volume of capital dredging alone is such that there is a risk of dredging contractors not tendering for the works, or not making available the most suitable plant to complete the works in a timely manner. It is therefore proposed to include capital and maintenance dredging under the one campaign to attract suitable dredging plant and maximise value for establishment costs.

2.2 Evaluation of Alternatives

2.2.1 Dredging

The dredging requirements and methodology are based on:

- Dredging to depths to allow access for ship sizes in accordance with Hamersley Iron's strategic needs;
- Optimisation of channel widths, manoeuvring areas and berth pocket dimension through navigation simulation studies;
- Co-ordination of capital and maintenance dredging programs to attract suitable plant; and
- Maximisation of re-use of dredged material.

The method of dredging and the choice of dredging equipment are determined by:

- Quantity to be dredged;
- Spatial extent of dredge areas;
- Required dredging depths;
- Dredged material properties;
- Method of disposal; and
- Availability of dredgers.

Materials anticipated to be encountered during the works typically comprise:

- Silts and silty clays with some sands overlying;
- Gravelly clay/clayey gravel with particles consisting of calcarenite[1], shells and rounded dolerite pebbles overlying; and
- Calcarenite of low to medium strength. Leaching of the calcarenite occurs in some areas and the material removed is replaced by sandy clay.

The spatial extent and nature of materials to be dredged dictates that the shortest duration and most cost-effective method for the dredging works requires a trailer suction dredge to remove soft materials at the surface and a cutter suction dredge to remove harder materials at deeper depths.

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[1] sedimentary rock formed of calcareous particles that have been deposited mechanically rather than from solution

The dredging method to be applied will be similar to that carried out at Dampier in 2004, with dredge material collected from the seabed and handled by one piece of plant only and placed directly from the dredge into the spoil disposal areas (either by bottom dumping or via floating pipeline). This will eliminate the need for double handling of dredged material and enable impacts on water quality, especially turbidity of the dredging and disposal operations to be confined to the smallest practicable area over the shortest practicable duration.

A detailed description of the proposed dredging methodology and equipment is given in **Section 3.2.5**.

2.2.2 Spoil Disposal

The dredge spoil disposal plan is based on maximising the disposal of suitable material to land for re-use for construction purposes, however due to the unsuitability of overlying silts and silty clays for reclamation purposes and the limited availability of onshore areas within a practical pumping distance of dredge areas, land based alternatives will only accommodate a portion of the total volume of material to be dredged. This material will be sourced from the capital dredging program. Approximately 440,000 m^3 (approximately 13% of total) of the deeper materials (i.e. gravels, clays and calcarenite) are suitable for re-use as foundation material for onshore works and will be pumped ashore using a cutter suction dredge. Typically this will comprise materials dredged from generally RL -12 to RL -15.35 to -19.5 CD.

Contaminants identified in the sediment sampling and analysis program (203,000 m^3) are suitable for offshore disposal, and will be dredged first and placed in the deepest sections of the Northern Spoil Ground for subsequent placement of clean materials.

Remaining dredged materials, estimated to amount to approximately 305,000 m^3, will be removed using a trailer hopper suction dredge and will be placed in the offshore spoil grounds.

An assessment of the options for disposal of dredged material is presented in the following sections.

2.2.2.1 Land Based Alternatives

Land around the fringe of the Dampier Harbour is in critical supply and needs to meet demands for tourism, industry and port facilities. Islands close to the Harbour are mostly nature reserves and not suited to land disposal.

The only suitable land based spoil disposal area is behind the existing seawall on the western side of Parker Point. This area has the capacity to receive approximately 440,000 m^3 of dredge material.

Land disposal at Parker Point outside of these areas is impractical, as the land area is either currently occupied by iron ore stockpiles or required for additional iron ore stockpiles as part of the port upgrade. Placement of silty and clayey dredged material into onshore reclamation areas would prevent development of the reclamation area for a number of years, until the material had sufficiently dried out. The limited land area available and total volume of spoil to be dredged (and require disposal) would also make it impractical to meet the water quality criteria for the decant water if all of the dredged material needed to be pumped ashore. In particular it would be difficult to decant fine sediments and prevent them from returning to the sea through the weirs overflow pipes. In addition, the topography of existing land at Parker Point is not suitable to accommodate the total volume of dredge spoil without construction of additional seawalls extending into the sea.

Gravels and calcarenite material dredged by the cutter suction dredge were successfully used as material for the land reclamation works following the 2004 dredging works and are proposed to be used for this purpose again. Gravels and calcarenite material dredged by the cutter suction dredge will also be pumped to an area behind the existing sea wall adjacent on the west side of Parker Point. It has previously been demonstrated that this material rapidly dries out and can be handled and loaded into trucks and transported to construction areas that require clean fill. This option will negate the need to establish an on-land borrow pit that itself may have significant environmental impacts.

Any land-based alternative to marine disposal would involve pumping the dredged material ashore via floating pipeline to the onshore disposal sites. The floating pipeline will vary in length between 500 m and 1,500 m. Return water management would be undertaken to meet DoE water quality criteria.

2.2.2.2 Marine Based Alternatives

Disposal of dredged material at sea within Dampier Port is coordinated by the Dampier Spoil Ground Management Committee. There are currently 3 approved spoil grounds within the Dampier Port limits:

- East Lewis Island Spoil Ground;
- Northern Spoil Ground; and
- Southern Spoil Ground.

The Southern Ground has been reserved by the Dampier Port Authority (DPA) for disposal of competent fill that could be used in future land fill activities and was reported in the meeting of the Dampier Spoil Ground Management Committee of 20 February 2006 to be full as a result of the current disposal program by Woodside Energy Ltd. There are no approved disposal grounds outside these areas. Studies are underway (being co-ordinated by the DPA) to identify options for new or extended spoil grounds with a view of progressing to getting approvals for the preferred option/s. However, the expected timing for identifying and approving any new spoil ground is beyond the scheduled timing requirements for the current dredging program.

It is proposed to place materials not suitable for re-use as construction fill in the onshore works into the designated spoil grounds the East Lewis Island Spoil Ground and the Northern Spoil Ground, in accordance with Dampier Port Authority's Spoil Disposal Management Plan. This includes contaminated materials suitable for offshore disposal and overlying silts and silty clays.

2.2.3 No Development Option

If Hamersley Iron is unable to maintain and expand the capacity of its Dampier operations, a significant opportunity to increase its export earnings will be lost, as well as a significant impact on the development of new mines inland of the port. Potentially, the increased market demand would be met by increased production elsewhere in Australia or overseas. In this case the economic benefits would be lost to the local area, Western Australia and Australia. In addition, if Hamersley Iron is unable to undertake the required dredging, significant operational constraints and risks to vessel safety may result from insufficient manoeuvring capacity and reduced effective depths for large vessels and the reduced capacity to increase throughput to match world demand.

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3. Project Description

3.1 Dampier Port Operations

3.1.1 Existing Operations

The Dampier Port is one of Australia's largest tonnage ports. The Port facilities operated by Hamersley Iron includes two terminals – Parker Point and East Intercourse Island.

Parker Point currently accommodates three ships at the wharf, two of which can be loaded at any given time. This allows empty ships to be brought into the berth and loaded while a fully laden ship is in berth waiting for suitable tides to depart. The existing berths are dredged to RL -19.5 m CD and capacity for vessels of up to 220,000 DWT. A departure channel, dredged to RL -15.35 m CD, connects the berth to the Main Shipping Channel. The Main Channel is dredged to RL-15.6 m CD.

East Intercourse Island has one ship loading facility that is dredged to RL-21.5m CD and has a berth capacity for vessels of up to 250,000 DWT. East Intercourse Island also has a lay-by berth dredged to RL-19.5 m CD adjoining the loading berth, which provides a facility for holding laden ships waiting for a suitable departure tide. This allows empty ships to be brought into the berth and loaded while the fully laden ship is in berth waiting for suitable tides. A departure channel, dredged to RL-15.5 m CD, connects with the Main Channel.

The shipping channel was initially dredged by Hamersley Iron in 1965 to a depth of 13 m. A brief review of historical dredging undertaken for Hamersley Iron's operations is summarised below:

- 1965: capital dredging of shipping channel to Parker Point (volume 2,500,000 m^3);
- 1968: deepening of shipping channel (1,500,000 m^3);
- 1970-71: widening of the channel and extension of the channel to the East Intercourse Island facility (760,000 m^3);
- 1981: Parker Point channel widened and deepened (400,000 m^3);
- 1985: maintenance dredging of East Intercourse Island berth and channel (volume unknown);
- 1989: maintenance dredging of shipping channel (350,000 m^3);
- 1991: maintenance dredging of East Intercourse Island berth (volume unknown);
- 1998: capital dredging of shipping channel (2,000,000 m^3);
- 1998: maintenance dredging around berths (800,000 m^3);
- 2000: minor dredging around berths (5,000 m^3); and
- 2004: Parker Point capital dredging (3,100,000 m^3).

3.1.2 2004 Dredging Program

The 2004 program involved dredging to extend the berth pocket at the Parker Point wharf and to create a new berth pocket on the south side of the wharf. A new swing basin and departure channel was dredged to provide navigable waters for additional berths. In addition, a new approach was dredged to the north and east of the Parker Point wharf to improve navigation.

The maintenance dredging program required the removal of siltation in the existing shipping channel and departure channels from Parker Point and East Intercourse Island. Approximately 85% of spoil was placed in the East Lewis Island Spoil Ground and the remaining 15% in the Northern Spoil Ground. The following summarises the 2004 dredging program.

- The trailer suction hopper dredge (*Cornelius Zanen*) operated from 8/5/2004 to 25/6/2004. In total, the dredge removed approximately 2.1 Mm^3 of material with 1.8 Mm^3 being disposed of at the East Lewis Island Spoil Ground and 0.3 Mm^3 at the Northern Spoil Ground.
- The cutter suction dredge (*HAM218*) operated from 2/6/2004 to 31/8/2004 and from 27/9/2004 to 23/10/2004. A total of 1 Mm^3 of material was dredged and disposed on land in an enclosed area directly east of Parker Point.
- The excavator dredge (*Obscured by Clouds*) operated prior to the commencement of the main dredging contract and removed chain, buoys and other shipping material from the dredging area.

A Dredging and Dredge Spoil Disposal Management Plan was prepared and implemented prior to dredging commencing, and the dredging was completed without any significant environmental impacts. The monitoring programs during and after the 2004 dredging works to date have recorded no significant impact to coral communities resulting from spoil dumping at the East Lewis Island Spoil Ground or the Northern Spoil Ground (refer to **Section 4.7** Environmental Monitoring which discusses the outcome of the 2004 dredging campaign).

3.2 Proposed Dredging Program

3.2.1 Overview

The construction of the additional shiploading facilities at Parker Point will involve dredging to extend the existing berth pockets at the Parker Point wharf and to create a new berth pocket on the south side of the wharf. An extended swing basin and departure channel will also be dredged to provide navigable waters for the additional berth. Dredging will also be undertaken to improve the approaches and swing basin areas and to remove recent siltation in existing shipping channels and provide for relocation of the existing tanker unloading facilities from the Service Wharf at Parker Point.

3.2.2 Areas to be Dredged

The areas to be dredged comprise:

- A westward extension of the existing northern and southern berth pockets at the Parker Point wharf (Dredge to RL-19.5 m CD);
- An eastward extension of the existing southern berth pocket to provide a new berth (Dredge to RL-19.5 m CD);
- Widening of the southern departure area (Dredge to RL-15.35 m CD);
- Widening and deepening of the southern swing basin (Dredge to RL-10.0 m CD);
- Widening of the northern approach route (Dredge to RL-8.0 m CD);
- A new berth pocket east of the existing Parker Point Wharf for the future unloading of tankers (Dredge to RL-12.0 m CD);
- Removal of siltation in the existing northern approach route (Clear to RL-8.5 m CD) and approaches to the Service Wharf (Clear to RL-8.0 m CD);
- Removal of under wharf spillage from Parker Point Berth (Clear to RL-19.5 m CD) and East Intercourse Island Berth (Clear to RL-21.0 m CD); and
- Removal of a high spot adjacent to the main shipping channel (east of Beacon 7E) to provide safe navigation for incoming vessels (Clear to RL-8.5 m CD).

Dredging activities are summarised in **Table 3-1** and **Table 3-2**. The dredge areas are shown geographically in **Figure 3-1** and **Figure 3-2**.

The total volume of material (capital and maintenance) needed to be dredged to achieve the required depths is approximately 3.4 Mm^3. In order to achieve the required dredge depths over the entire dredge areas it will be necessary to dredge below the required depths. The extent of over-dredging is dependent on the material being dredged and the equipment being used and the above figure includes an over depth allowance determined from the 2004 dredging campaign. Approximately 3 Mm^3 will be placed in offshore spoil grounds and approximately 0.44 Mm^3will be pumped ashore.

Table 3-1: Summary of key proposal characteristics

Element	Description / Quantity
Amount of material to be dredged and disposed	**Maximum of 3.45 million cubic metres (estimated)**
Major components (as shown in Figure 3-1 through Figure 3-2):	
▪ **Dredging of material within areas A – D, G and H (capital) to the East Lewis and Northern spoil grounds.**	▪ **Combined maximum of approximately 2.47 Mm^3**
▪ **Dredging of material within areas A and B (capital) to onshore disposal.**	▪ **Approximately 0.44 Mm^3**
▪ **Dredging of material within areas E, F, PP and EII (maintenance) to the Northern spoil ground.**	▪ **Approximately 0.54 Mm^3**
Period of dredging and disposal	**Dredging duration of approximately 8–10 weeks within a 3–4 month period, commencing in Q3 2006**

Table 3-2: Details of dredging and disposal volumes

	Parameters							
Location	Existing sea bed level (RL-m CD)	Dredge depth level (RL-m CD)	Depth of dredging (m)	Area to be dredged (ha)	TBT material for offshore disposal (m^3)	Clean material for offshore disposal (m^3)	Material for onshore disposal (m^3)	Total material to be dredged (m^3)
A	11.0 - 15.4	19.5	4.2 - 8.5	3.2	28,000	52,000	182,000	262,000
B	6.5 - 11.0	15.4	4.4 - 8.9	10.9	54,000	556,000	258,000	868,000
C	6.5 - 8.0	10	2.0 - 3.5	21.5	0	749,000	0	749,000
D	7	8	1	71.8	41,000	880,000	0	921,000
G	8	12	4	2.1	0	95,000	0	95,000
H	7	8.5	1.5	1	0	15,000	0	15,000
E	7.5	8.5	1	30	70,000	230,000	0	300,000
F	6.5	8	1.5	15	0	225,000	0	225,000
PP	19.5	21	1.5	0.3	5,000	0	0	5,000
EII	19	19.7	0.7	0.3	5,000	0	0	5,000
Total								**3,445,000**

3.2.3 Capital Dredging

Total volume to be dredged is in the order of 2.9 Mm^3. The volume of material to be dredged in each area is provided in **Table 3-3**. Approximately 2.47 Mm^3 of this material will be disposed offshore on the spoil grounds while approximately 0.44 Mm^3 will be disposed of onshore in the reclamation area.

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The material to be removed during the capital dredging is comprised of the following:

- **Loose surface sediments**: Much of the capital dredging areas are overlain by loose sediments. Their composition is identical to the bulk of material dredged previously in this section of the harbour by numerous maintenance programs. As for the proposed maintenance program, it is probable that the sediments to be removed here are the fine fractions of those assessed and disposed in the 2004 program. That material was comprised predominately of fine silts with varying amounts of fine to medium grained sand and in some cases, fine calcareous gravel and shell fragments.
- **Consolidated Sediments:** Sediments deeper than 0.5–10 m are consolidated and previously undisturbed by dredging. Previous geotechnical drilling has been used to develop a preliminary geological model which indicates materials likely to be encountered will include:
  - Marine silts and silty clays, overlying;
  - Firm to stiff clays, overlying;
  - Dense clayey gravel, overlying;
  - Low to medium strength calcarenite, overlying; and
  - High strength granophyre or dolerite.

Material for offshore disposal is predominantly sands, silts and clays with a high moisture content. Most sediment samples assayed contained less than 1–2% gravel (>2 mm). Samples distant from the berths (eg at the northern end of Area D) were close to 50% sand, while with the exception of a few areas dominated by clay–silts, most of the samples near the berth were roughly equally divided into sand-silt-clay.

Material going onshore for disposal in the reclamation area is predominantly gravel and sand suitable for compaction and will be used as fill for land based development associated with the upgrade of the Parker Point facilities.

- **Table 3-3 Overview of the 2006 Capital Dredging Program**

Parameters	Locations to be Dredged						
	A	B	C	D	G	H*	Total
Existing sea bed level (RL-m CD)	11.0–15.4	6.5–11.0	6.5–8.0	7.0	8.0	7.0	–
Dredge depth below existing sea bed (m)	19.5	15.4	10.0	8.0	12.0	8.5	–
Depth of dredging (m)	4.2–8.5	4.4–8.9	2.0–3.5	1.0	4.0	1.5	–
Area to be dredged (ha)	3.2	10.9	21.5	71.8	2.1	1.0	125.5
TBT material for offshore disposal (m^3)	28,000	54,000	0	41,000	0	0	123,000
Clean material for offshore disposal (m^3)	52,000	556,000	749,000	880,000	95,000	15,000	2,347,000
Material for onshore disposal (m^3)	182,000	258,000	0	0	0	0	440,000
Total material to be dredged (m^3)	262,000	868,000	749,000	921,000	95,000	15,000	2,910,000

*This area has been included in the maintenance dredging program in the sea dumping permit application lodged with the Department of the Environment and Heritage in March 2006

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NORTH AND SOUTH SPOIL GROUND SETOUT:

POINT	EASTING (m)	NORTHING (m)
B1	473 637.1	7 731 340.9
B2	475 737.1	7 731 340.9
A1	474 797.1	7 729 340.9
A2	474 797.1	7 728 420.9
A3	472 697.1	7 727 530.9
A4	472 697.1	7 729 340.9

REFERENCES:
M-001-18468 DREDGING AREAS , LAYOUT PLAN , SHEET 2
M-001-18469 DREDGING AREAS , LAYOUT PLAN , SHEET 3

REV	BY	DATE	DESCRIPTION	CKD	APP
1	JMS		DRAWING ADOPTED FOR PN 8129 AND ISSUED FOR INTERNAL REVIEW		
2	JMS		ISSUED FOR CLIENT REVIEW		
3	CDF	27.01.06	RE - ISSUED FOR CONSTRUCTION		
4	CDF	7.03.06	RE - ISSUED FOR CLIENT REVIEW		

DRAWN	J M SCHONHUT	22.09.05
TRACED		
CHECKED		
SUPT DRAFT		
PROJ. ENG.		
APPROVED		
APP. FOR CONST.		

PILBARA IRON PTY. LIMITED ACN 107 216 535 — ASSET MANAGER FOR — HAMERSLEY IRON PTY. LIMITED ACN 004 558 276 — ROBE RIVER MINING COMPANY PTY. LIMITED ACN 008 694 246

DAMPIER - PARKER POINT - DPU PHASE B
DREDGING
CAPITAL DREDGING
LAYOUT PLAN - PERMIT APPLICATION

SCALE 1:20000
DRAWING NUMBER M-001-18471
REV 4
PROJECT NUMBER 8129

SHEET SIZE B1

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CAUTION

REFERENCES	
M-001-18468	DREDGING AREAS . LAYOUT PLAN . SHEET 2
M-001-18469	DREDGING AREAS . LAYOUT PLAN . SHEET 3

SHEET SIZE B1

REV	BY	DATE	DESCRIPTION	CKD	APP
1	JMS		DRAWING ADOPTED FOR PN 8129 AND ISSUED FOR INTERNAL REVIEW		
2	JMS		ISSUED FOR CLIENT REVIEW		
3	CDF	27.01.06	RE - ISSUED FOR CONSTRUCTION		
4	CDF	7.03.06	RE - ISSUED FOR CLIENT REVIEW		

DRAWN	J M SCHONHUT	22.09.05
TRACED		
CHECKED		
SUPT DRAFT		
PROJ. ENG.		
APPROVED		
APP. FOR CONST.		

PILBARA IRON PTY. LIMITED ACN 107 216 535
ASSET MANAGER FOR
HAMERSLEY IRON PTY. LIMITED ACN 004 558 276
ROBE RIVER MINING COMPANY PTY. LIMITED ACN 008 694 246

DAMPIER - PARKER POINT - DPU PHASE B
DREDGING
MAINTENANCE DREDGING
LAYOUT PLAN - PERMIT APPLICATION

SCALE 1:20000
DRAWING NUMBER M-001-18472
REV 4
PROJECT NUMBER 8129

CAUTION

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3.2.4 Maintenance Dredging

Total volume to be dredged is approximately 0.54 Mm^3 (see **Table 3-4**). The total volume of material to be dredged under the maintenance dredging program will be displaced of offshore on the Northern Spoil Ground.

- **Table 3-4 Overview of the 2006 Maintenance Dredging Program**

Parameters	Locations to be Dredged				
	E*	F	PP	EII	Total
Existing sea bed level (RL-m CD)	7.5	6.5	19.5	19.0	–
Required dredge depth (RL-m CD)	8.5	8	21.0	19.7	–
Depth of dredging (m)	1.0	1.5	1.5	0.7	–
Area to be dredged (ha)	30.0	15.0	0.3	0.3	30.6
TBT material for offshore disposal (m^3)	70,000	0	5,000	5,000	80,000
Clean material for offshore disposal (m^3)	230,000	225,000	0	0	455,000
Material for onshore disposal (m^3)	0	0	0	0	0
Total material to be dredged (m^3)	300,000	225,000	5,000	5,000	535,000

* Areas E and F have been combined in the sea dumping permit application lodged with the Department of the Environment and Heritage in March 2006

The northern approaches to Parker Point were dredged from a natural seabed depth of around RL-7.0 m CD to RL-7.5 m CD to a declared depth of RL-8.0 m in the 2004 dredging program. Subsequently sediment ingress has occurred which has reduced depths to between RL-7.5 CD and RL-8.0 m CD. Additionally, sedimentation has raised the effective depths of the approach to the Service Wharf to between around RL-6.0 m CD to RL-6.5 m CD from a depth of RL-6.5 m CD. The origin of this sediment is likely to be from the area directly south of the approach route which was used for land disposal of sediment during the 2004 program. Fine sediment liberated during construction of the sea wall and from overflow from the onshore settlement ponds during the 2004 dredging works is likely to constitute the bulk of this infill. In addition, infilling sediments will be derived from remobilisation of this and other sediment from heavy tug activity and shipping around the Parker Point and Service Wharf berths. Thus it is probable that the sediments to be removed here are the fine fractions of those assessed and disposed in the 2004 program.

Spillage of iron ore product while loading over the last 5 - 10 years has led to a build up of material at either end of the ship loading berths at the Parker Point and East Intercourse Island wharves. Material has accumulated at either end of the berths where transfer points for the ore conveyor on the wharf are located above, which lead to concentrations of product spillage. In addition, the entry and physical presence of hulls of large vessels pushes fine sediments to the berth extremities. The likely composition of this material is some iron ore fines and lump plus fine sediment mobilised from the berths and surrounding areas during ship movements and current flow and deposited in the berth pockets (Pilbara Iron 2006a,b).

The material types to be dredged are expected to be identical to the bulk of material dredged in previous campaigns, including the recent 2004 dredging campaign. That material was comprised predominately of fine silts with varying amounts of fine to medium grained sand and in some cases, fine calcareous gravel and shell fragments.

The majority of materials to be dredged comprise high moisture content silts and clays with a high percentage of fines and are unsuitable for re-use as construction material. Accordingly, dredged materials will be placed in approved offshore spoil grounds located within the limits of the Port of Dampier.

3.2.5 Dredging Method

Dredging of large areas is commonly completed with trailer suction hopper dredges. These dredges are the most efficient dredge at removing large volumes of spoil and can cover large areas most efficiently, without the need to use separate disposal barges. Cutter suction dredges are also commonly used in Australia where ever dredging of harder substrates is required. Different methods may be used to reduce turbidity associated with cutter suction dredges, such as the disposal of spoil directly to the seabed where it can be removed with a trailer suction hopper dredge. Small or shallow dredging projects may choose to employ a back hoe dredge from wharves or barges; however these are not suitable for large scale dredging programs such as the Dampier dredging program.

Dredging will be undertaken using a combination of a trailer hopper suction dredge and a cutter suction dredge. The trailer hopper suction dredge will initially remove any contaminated sediments suitable for offshore disposal and place them in the Northern Spoil Ground. The trailer hopper suction dredge will then remove the balance of the sediments and dispose of this material at the East Lewis Island Spoil Ground and to the Northern Spoil Ground to cover the previously dumped contaminated sediments. The trailer suction dredge is anticipated to remove all materials above approximately RL -12m CD.

The cutter suction dredge will operate in the berth pockets and departure basin south of the wharf adjacent to the berths at Parker Point to remove the deeper and harder calcarenite material and pump it to the onshore spoil disposal area at Parker Point.

3.2.5.1 Trailer Suction Hopper Dredge

Trailer suction hopper dredgers are used mainly for maintenance dredging in harbour areas and shipping channels where traffic and operating conditions preclude the use of stationary dredges. This type of dredge is particularly efficient for removal of thin layers of soft material over large

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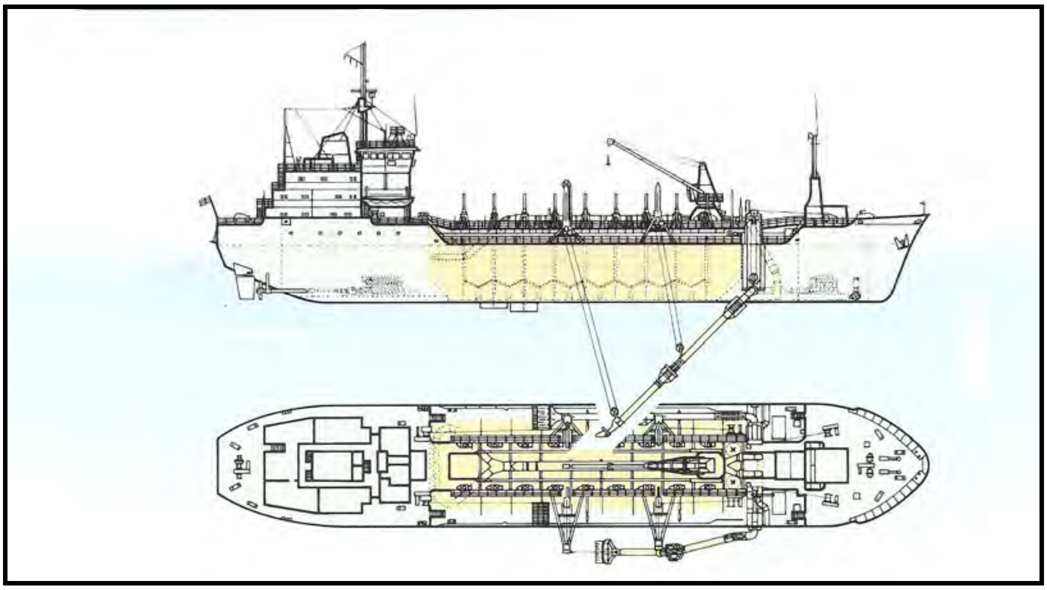
areas, such as dredging of channels. Accordingly, a trailer suction hopper dredge will be used to dredge to remove soft overlying materials from other dredge areas.

The trailing suction hopper dredge operates much like a floating vacuum cleaner. The trailer suction hopper dredge has a hull in the shape of a conventional ship and is both highly sea worthy and able to operate without any form of mooring or spud. It is equipped with a single suction pipe or twin pipes, one on each side, equipped with dragheads (**Figure 3-3**).



- **Figure 3-3 Trailer Suction Hopper Dredge – Side and Plan Views**

The dredger removes material in a series of cycles until the required dredge depth has been achieved. A cycle consists of dredging, sailing to the disposal area, discharging the material from the hopper and sailing back to the dredging site. The dredge contractor will aim to remove the maximum amount of material in the shortest time for each cycle.

During the dredging stage, the dredge moves forward dragheads are lowered to the seabed and a slurry of sediment and water is hydraulically lifted through the trailing pipes by one or more pumps and discharged into a hopper contained within the hull of the dredge. The dredge sails slowly over the area to be dredged filling its hopper as it proceeds. The time required to fill a hopper and the actual quantity of solids in the hopper at the end of the filling process is decided by two main factors:

- The degree of concentration of material that enters the draghead, which depends on the characteristics of the dredged material; and

- The speed of settlement of material in the hopper, which depends mainly on the grain size of the material.

Dredged material settles in the hopper and water is drained through a controllable hopper overflow system to optimise the payload of the dredge, thereby maximising the efficiency of the dredging operation and minimising the duration of dredging.

On completion of loading, the dredge sails to the spoil ground where its contents are discharged by opening the doors or valves in the hull of the dredge.

Whilst sailing to the disposal area, solids will settle in the hopper, leaving water at the top of the hopper with a low concentration of solids. For silts and sands, this surface water is generally pumped overboard during this sailing. With a clay material the surface water is usually retained in the hopper and the weight of the water over the clay is used to assist in pushing the spoil material out of the hopper during discharge.

At the disposal area the vessel will discharge its cargo by gravity dumping through bottom doors or bottom valves. With free running materials like silt, sands and gravels, the discharge is completed very quickly, but the process takes longer with clays.

Material to be removed by the trailer hopper suction dredge will mostly be fine grained and therefore during dredging, the dredge will create some turbidity. This is usually in the form of plumes originating from the following main activities of the dredger:

- Using overflow system that releases material into the water column;
- Using bypass system that releases material into the water column;
- Propellers dislodging seabed material and mixing this into the water column; and
- Draghead movement mixing seabed material into the water column.

Most turbidity results from the first two activities in combination with disturbance of the seabed by propellers. Each activity is described more fully below.

The dredge's overflow and bypass systems are each designed to help optimise the amount of solid material in the hopper within a given dredging cycle time. The overflow discharge point is usually at keel level. During dredging, overflow occurs once the hopper is full with slurry but the solid content in the hopper has not reached its optimum. Overflow is allowed to continue as long as there is a marked difference between concentration of sediment at the intake point (draghead) and the point of overflow. The duration of overflow is also influenced by the time it takes to sail to the disposal area as a proportion of the dredge cycle. The use of overflow will be restricted to dredging of coarse materials, i.e. sandy clays and gravels. Overflow will not be permitted when dredging silts. Typically when silts are dredged, sediment concentrations in the intake and overflow are similar and there is no benefit for overflow. When coarse materials are dredged, the use of overflow techniques will enable the dredge to have greater payload for each cycle and hence will reduce the total duration of the dredging works.

Trailer dredgers are also fitted with a bypass system designed to prevent water or slurry with only a small percentage of solids being discharged into the hopper. The bypass system is used mainly at the commencement and conclusion of the dredging stage, when solid concentrations in the slurry are low. This includes periods when dredging is stopped and re-started, such as whenever the dredger has to turn at the end of passes during dredging. During bypass operations, a low concentration slurry is pumped overboard. Some trailer dredgers are equipped to discharge bypass slurry at keel level. It is in operator’s interest to keep the time for this process to a minimum, usually under a minute.

As the dredger moves, its propellers will mix into the water column material from overflow, bypass or discharge activities. In shallow draft areas the trailer’s propellers may also create turbidity by dislodging seabed material.

When the draghead is operating, any dislodged material is quickly sucked up into it and therefore very little turbidity is created. When the draghead is not operating, it is raised above the seabed, so no turbidity is created.

To ensure that impacts are restricted to the nominated dredging and disposal locations trailer suction hopper dredgers will be required to have Differential Global Positioning Systems on board and vessel positions will be logged during dredging and disposal operations.

Once empty, the dredge returns to the dredge area where the cycle is repeated. The duration of sea dumping of dredge spoil will continue for 24 hours/day, 7 days/week and is expected to last for a period of 4–6 weeks. The dredging will be undertaken effectively as a continuous program, subject to the availability of dredges to undertake the programs.

3.2.5.2 Cutter Suction Dredge

Cutter suction dredging will remove the harder material beneath the loose silty surface layer. A cutter suction dredger is typically a rectangular shaped pontoon. On the front it has a hinged ‘ladder’ fitted with a ‘cutter head’. The ladder can be lowered so that the cutter head touches the seabed. The cutter head is a rotating mechanism fitted with pick-points or teeth to break up the material to be dredged. Dredged material is removed via a suction pipe that passes from the cutter head, up the ladder and to the discharge point(s). On the back of the pontoon the cutter has spuds to connect the pontoon to the seabed and to act as a pivot point for the cutter while slewing the cutter head. These spuds are mounted in ‘spud carriages’. While one spud is fixed to the seabed, the other can be raised and moved forward in its carriage, then lowered and fixed to the seabed. When fixed to the seabed, the spuds provide a horizontal reaction force as the cutter head is pushed forward into the material being dredged.

The dredge operates by swinging about a central working spud using a mooring leading from the lower end of the ladder to anchors. By pulling on alternate sides, the dredge clears an arc of cut, and then moves forward by pushing against the working spud. The cutter breaks up hard material. As dredging proceeds, the dredge creates a 'bench' in the seabed. When there is no more material to be removed from the bench, the spuds at the rear of the cutter are used to advance the whole dredge. The process is repeated, creating new benches in the seabed until the desired seabed level is achieved over the required area.

Cutter suction dredgers are usually not self –propelled and are towed to position at the dredging site. Once in position the ladder and cutter head are lowered to the seabed and the rotating cutter head mechanism is activated. The rotation of the cutter head and pick points at the seabed dislodges seabed material and creates a slurry of seabed material and water. This slurry is sucked up by an under water pump inside the ladder near the cutter head. Slurry is pumped along the pipeline in the ladder for discharge. Further pumps in the dredge are used to pump the slurry to the discharge point. If desired, slurry may be pumped via floating pipes to a discharge point some kilometres distant from the dredge.

During dredging with a cutter suction dredge turbidity may be caused at two points:

- At the cutter head where material is cut and loosened; and
- At the discharge point.

The economics of dredging are greatly affected by material lost near the cutter head. Therefore the prime concern of a dredging contractor is to minimise these losses. The cutter head is designed to minimise material loss – relying on highly efficient suction and generating minimal turbidity. High suction near the cutter head means that most of the material loosened by the cutter head is captured. Some material may be missed and fall to the seabed below the cutter head. These losses are usually small and consist primarily of solid material.

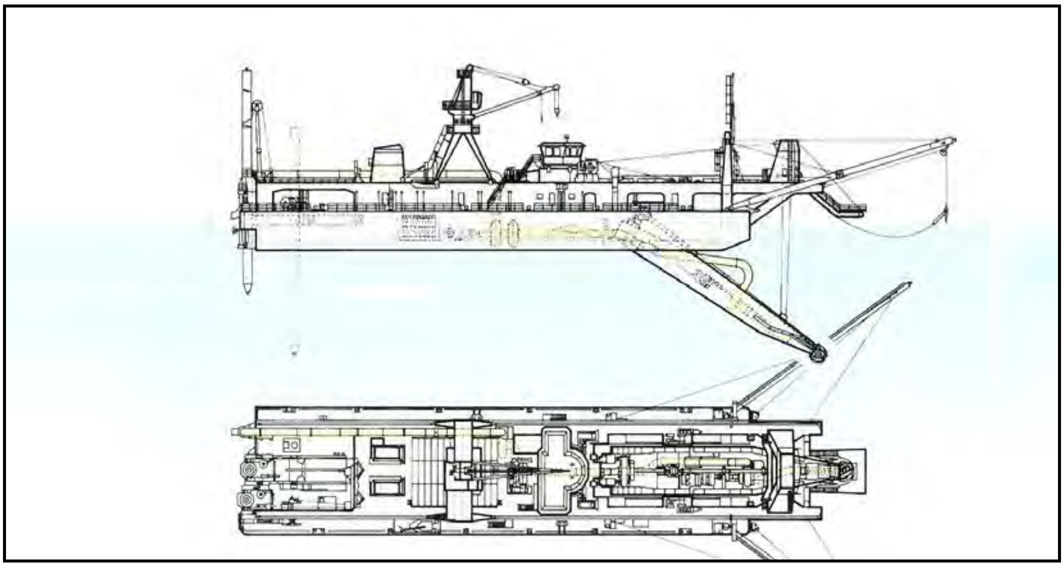


Figure 3-4 Cutter Suction Dredge – Side and Plan Views

A cutter suction dredge with adequate pumping power and floating pipelines can pump materials directly into the Parker Point land based spoil ground.

3.2.6 Spoil Disposal

Approximately 3.01 Mm^3 will be placed in offshore spoil grounds and approximately 0.44 Mm^3 will be pumped ashore to the reclamation area (see **Table 3-5**).

Table 3-5 Overview of the 2006 Dredging Program Spoil Disposal

Program	Offshore	Onshore	Total
Maintenance	0.54		0.54
Capital	2.47	0.44	2.91
Total	**3.01**	**0.44**	**3.45**
Location	**Maintenance**	**Capital**	**Total**
Onshore reclamation area		0.44	0.44
Northern Spoil Ground	0.31	1.70	2.01
East Lewis Island Spoil Ground	0.24	0.76	1.00
Total	**0.55**	**2.91**	**3.45**

Refer to **Sections 3.2.3** and **3.2.4** for a description of the material to be dredged.

3.2.6.1 Onshore Disposal

Approximately 0.44 Mm^3 of material requiring removal by the cutter suction will be used as fill for land based development associated with the upgrade of the Parker Point facilities. The cutter suction dredge will pump dredge material ashore to the existing Parker Point Spoil Area (the area behind the existing seawall adjacent to the Parker Point wharf) where it will be settled in a series of ponds.

Dredge slurry will be pumped via floating and submerged pipeline to the onshore disposal areas. The maximum pumping distance across water (from the furthest western most point of the new departure basin) is approximately 1.5 km.

Land disposal sites will be configured to receive and contain dredge spoil slurry for sufficient time to allow the majority of fines to settle. Recent experience in dredging calcarenite material at Dampier and Port Hedland indicated that more than 98% of sediments settled in the ponds. The water resulting from the settlement of dredge slurry is termed return water. This water will have the majority of slurry removed by settlement or by passive filtration through geotextile lined seawalls. Return water from the land disposal area would diffuse through the seawall and a weir placed at the discharge point to minimise turbidity of the return water ultimately discharging into the harbour waters. As the level of fill builds up in the ponds, return water will discharge through overflow pipes into the sea adjacent to the existing sea wall.

In the detailed design phase of the dredging and disposal program, the final layout of ponds will be revised to take into account the contractor's dredging plant and work methods. In particular, consideration will be given to production rates, pumping capacity and pipe diameter proposed by the dredging Contractor.

3.2.6.2 Offshore Disposal

Approximately 3.0 Mm^3 of material requiring removal by the cutter suction and trailer suction hopper dredges will be disposed of at sea. Disposal of dredged material at sea within the Port of Dampier is coordinated by the Dampier Spoil Ground Management Committee through a Spoil Ground Management Plan. The permitting of sea dumping activities is managed by the Department of the Environment and Heritage under the Environmental Protection (Sea Dumping) Act 1981.

Material from the maintenance dredging program will be placed in the Northern Spoil Ground. Material from the capital dredging program will be placed in the Northern and East Lewis Spoil Grounds.

The East Lewis spoil ground is located between the shipping channel and East Lewis Island. The spoil ground is 5 km long and 1.5 km wide, with sea bed levels varying between RL-4 mCD to RL-11mCD. Hamersley Iron has used this spoil ground for various capital and maintenance dredging programs. Since 1965, this area has received more than 5 Mm^3 of dredged material from various capital and maintenance dredging programs.

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The Northern Spoil ground is located between the Woodside shipping channel and Conzinc Island. The spoil ground is approximately 2 km by 2 km, and is located in deeper water, with sea bed levels varying between RL-11 mCD to RL-16 mCD. The area is designated by the Dampier Port Authority to receive contaminated materials suitable for offshore disposal. Both Woodside and DPA have used this spoil ground for various capital and maintenance dredging programs.

A survey of the spoil grounds undertaken in mid 2004 after the completion of disposal within the 2004 dredging program indicated that there is remaining capacity to accommodate the proposed dredging program.

- **Table 3-6 Estimated Volume Remaining in the East Lewis Island and Northern Spoil Grounds**

Area	Proposed RL Top of Spoil (m)	Spoil Area (m^2)	Estimated Volume Remaining in Spoil Ground 28 Feb'06 (m^3)
East Lewis Spoil Ground	**RL -6.5**	**2,772,000**	**2,022,750**
Northern Spoil Ground	**RL -11.0**	**4,200,000**	**5,060,000**
Northern Spoil Ground	**RL -11.5**	**4,200,000**	**3,800,000**

The coordinates (in GDA94 – decimal minutes and eastings and northings) for the area within the approved East Lewis spoil ground that will receive spoil are:

	Latitude	Longitude	Easting	Northing
NW corner	**20° 30.930'S**	**116° 41.180'E**	**0467163**	**7723915**
NE corner	**20° 30.930'S**	**116° 41.430'E**	**0467603**	**7723915**
SE corner	**20° 37.260'S**	**116° 40.990'E**	**0466843**	**7719600**
SW corner	**20° 37.790'S**	**116° 40.090'E**	**0465295**	**7718624**

Datum is AGD84 Zone 50K

The specified portion of the spoil ground that will receive spoil from this dredging program (coordinates above) is within the greater area of spoil ground designated by DPA and shown on nautical charts.

The coordinates (in GDA94 – decimal minutes and eastings and northings) for the area within the approved Northern Spoil Ground that will receive spoil are:

	Latitude	Longitude	Easting	Northing
NW corner	**20° 30.910'S**	**116° 44.894'E**	**0473637**	**7731341**
NE corner	**20° 30.910'S**	**116° 46.102'E**	**0475737**	**7731341**
SE corner	**20° 31.971'S**	**116° 45.571'E**	**0474797**	**7729341**
SW corner	**20° 31.996'S**	**116° 44.358'E**	**0472697**	**7729341**

Datum is AGD84 Zone 50K

3.2.7 Hours of Operation

Dredging operations will occur 24 hours/day, 7 days per week.

3.2.8 Workforce

The workforce will be dependent on the phase of the dredging activities. The actual size of the workforce will not be known until the finalisation of the dredging contracts. It is anticipated that the workforce will be accommodated within the existing village or existing commercial facilities at Dampier or Karratha.

3.3 Project Schedule

Dredging works are proposed to occur in sequence, subject to availability of dredgers. Dredging is proposed to commence in Q3 2006 and continue for approximately 15 weeks. It is anticipated that dredging with a trailing hopper suction dredge will take 4–6 weeks and a cutter suction dredge for 10–12 weeks. Subject to favourable operating conditions, the dredging duration may well be less than that stated.

Actual dredging time is estimated from 8–15 weeks, with additional time allowed for maintenance, inclement weather conditions and requirements to adjust active dredging and disposal during ongoing shipping movements through the Dampier Harbour. Dredging will be completed by the end of Q4 2006.

There are no other dredging and dredging related works currently planned to be undertaken by Dampier Port Authority or Woodside immediately following the proposed dredging works. Woodside is currently completing a dredging program for the proposed LNG train 5 development. Other dredging programs are being considered for the Pluto Project and another small dredging program is under consideration for the Mermaid Marine facility.

4. Existing Environment

4.1 Physical Environment

4.1.1 Regional Setting

The Dampier operations are located at the southern end of the Burrup Peninsula, on the coast of the Pilbara region in Western Australia. The Burrup Peninsula extends north from the Dampier operations and into the Dampier Archipelago, a group of 42 islands.

The area contains Aboriginal rock art, particularly on the Burrup Peninsula, and has high tourism and recreation values. Major recreational activities include fishing, camping, swimming and walking.

The region is supported by the Port of Dampier, where Dampier Salt, Hamersley Iron, Dampier Port Authority and the North West Shelf Gas Project all have their own ship loading facilities. Dampier Port is considered to be Australia's largest port on the basis of tonnage of cargo handled. With numerous downstream processing industries planned for the Burrup, this region of Western Australia is expected to become a major development and export zone for the state.

4.1.2 Climate

The Burrup Peninsula and Dampier Archipelago have a tropical-arid climate comprising of two dominant seasons; a hot summer with erratic, heavy rainfalls from October to April, and a mild winter with occasional rains from May to September.

Long term meteorological data (including rainfall, temperature, humidity and wind speed and direction) has been recorded by the Bureau of Meteorology since 1969 at the operations of Dampier Salt (BOM 2005). A summary of this meteorological data for the period 1969–2004 is presented in **Table 4-1**.

4.1.2.1 Air Temperature and Humidity

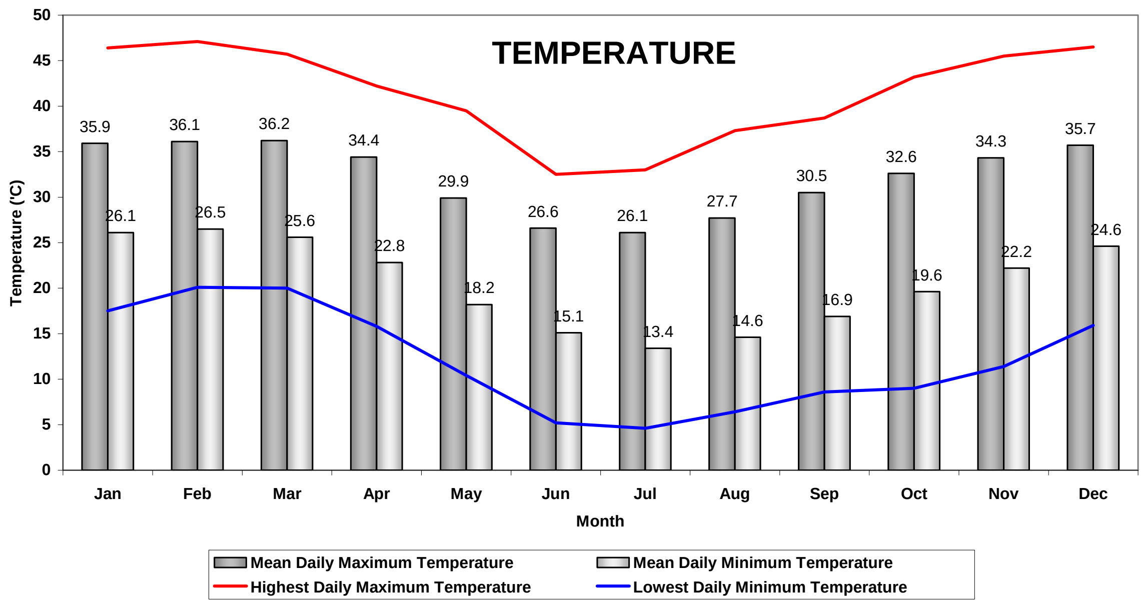
The hot wet summer season for Dampier and Karratha occurs from October to April followed by the mild winter season from May to September. Annual temperature ranges for Dampier Salt are shown in **Figure 4-1**. The annual mean maximum and minimum temperatures at Dampier Salt are 32.2°C and 20.5°C, respectively. Monthly mean maximum temperatures range from 26.1°C in July to 36.2°C in March and monthly mean minimum temperatures range from 13.4°C in July to 26.5°C in February.

Humidity at Dampier Salt is highest in February when the average relative humidity at 9am is 60% dropping to 51% at 3pm. The annual mean relative humidity is 47% at 9am and decreases to 40% at 3pm.

■ **Table 4-1 Summary of climate averages for Dampier/Karratha from 1969 – 2004**

Month	Temperature (ºC)		Relative Humidity (%)		Mean Daily Evaporation (mm)	Mean Rainfall (mm)	Wind Speed (km/hr)	
	Mean Daily Maximum	Mean Daily Minimum	9am Mean	3pm Mean			9am Mean	3pm Mean
Jan	35.9	26.1	58	51	11.3	27.1	15.7	27.6
Feb	36.1	26.5	60	51	10.4	64	15.5	26.4
Mar	36.2	25.6	54	44	10.3	46.4	14.4	23.7
Apr	34.4	22.8	45	37	9.3	20.1	15.3	22.4
May	29.9	18.2	45	38	7.2	26.6	17.8	20.7
Jun	26.6	15.1	47	40	6.1	35	18	20.6
Jul	26.1	13.4	44	36	6.3	13.4	17.1	20.1
Aug	27.7	14.6	43	35	7.3	5.8	15.8	21.5
Sept	30.5	16.9	37	33	9.2	1.3	16.8	24.5
Oct	32.6	19.6	39	37	10.9	0.4	16.6	28.2
Nov	34.3	22.2	41	41	11.9	0.4	16.6	29.2
Dec	35.7	24.6	49	44	11.9	12.5	16.6	28.8
Monthly Mean#	32.2	20.5	47	40	9.3	252.9	16.4	24.5
Annual Total*	—	—	—	—	3407.4	260.6	—	—

#Monthly means based on monthly averages.
**Approximation based upon mean daily values within each monthly period.*



■ **Figure 4-1 Temperatures recorded at Dampier Salt Weather Station**

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4.1.2.2 Rainfall and Evaporation

The Pilbara region of Western Australia has a highly variable rainfall, and is strongly influenced by tropical cyclone activity during the summer months. Rainfall is also often erratic and very localised due to thunderstorm activity and monthly average rainfalls can vary dramatically from year to year.

The first rainfall peak of the year occurs between January to March as a result of tropical thunderstorms and cyclonic activity. The second peak occurs between May to June due to the passage of low pressure systems through the south of Western Australia.

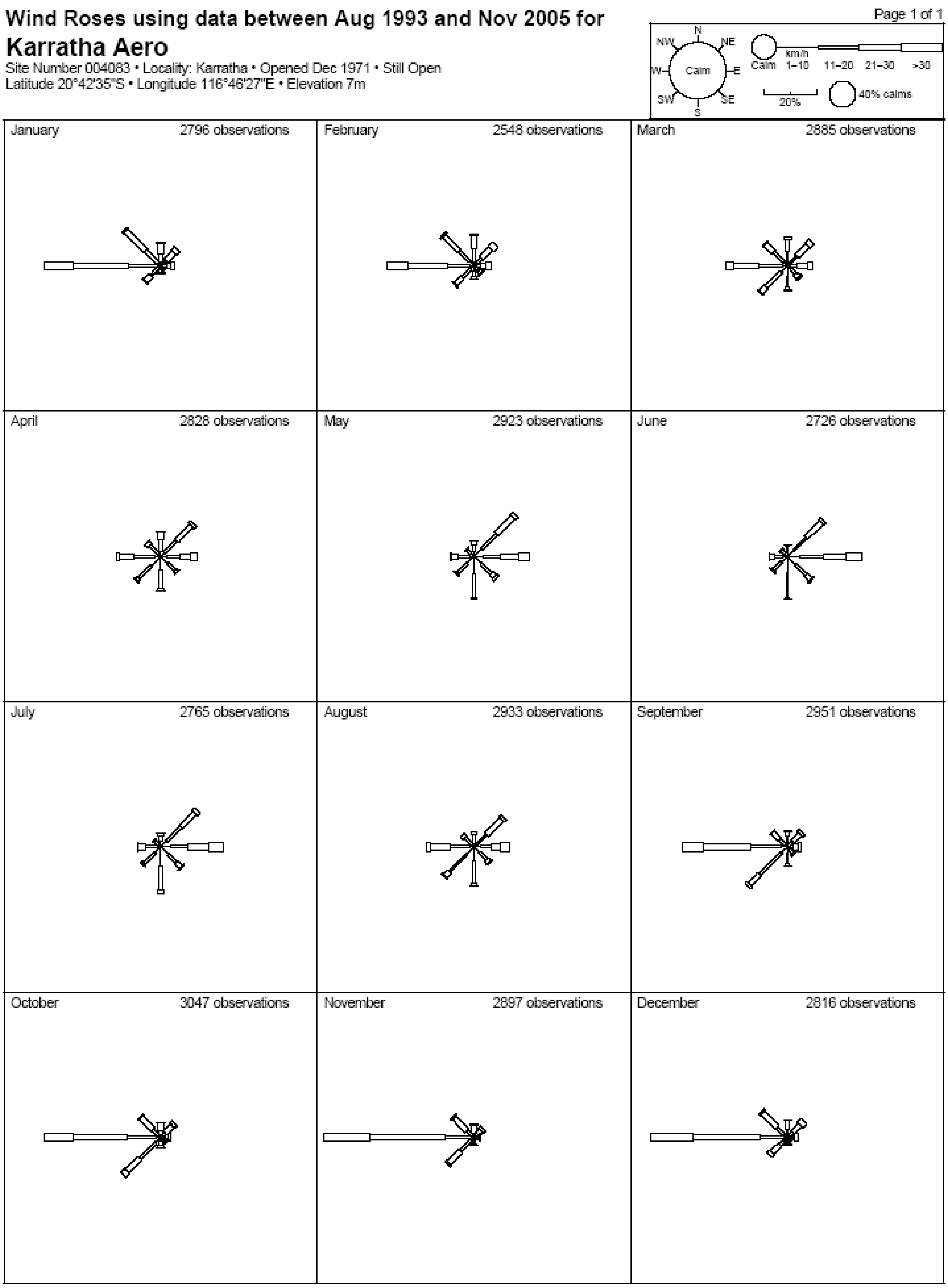
Monthly mean rainfall at Dampier Salt varies from 0.4mm in October and November to 64.0 mm in February. The annual average rainfall is 252.9 mm with an average of 29 rain days. Mean daily mean evaporation ranges from a minimum of 6.1mm in June to a maximum of 11.9 mm in November and December. Total annual evaporation is approximately 3,400mm per year, which exceeds annual rainfall by approximately 3,140 mm (BOM 2005).

4.1.2.3 Wind

Winds during winter are predominantly easterlies changing to westerlies during summer. During winter, east to south easterly winds are dominant in the mornings and shift to north easterlies in the afternoon and ease in the evening in response to diurnal land temperature changes. Average wind speeds range from 16.8 to 24.5 km/hr, however, maximum wind gusts from these directions can exceed 77.8 km/hr (BOM 2005) during storms generated by the interaction of high pressure belts and northern tropical low pressure systems.

During the summer months, westerly winds are dominant in the morning, shifting to north westerly onshore winds in the afternoon. Average wind speeds from these directions are 14.4 and 29.2 km/hr, respectively with an increase in speed from morning to afternoon. Maximum wind gusts of 63.0 and 57.6 km/hr have been recorded for April and November, respectively (BOM 2005).

Wind roses for Karratha Aerodrome are provided in **Figure 4-2**.



- **Figure 4-2 Monthly Wind Roses for Karratha Aerodrome (1993-2005)**

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4.1.3 Bathymetry

The bathymetry of the Dampier Port area is shown in **Figure 4-3**

4.1.4 Oceanography

4.1.4.1 Tides

The tides within the Port of Dampier are moderate and semi-diurnal, with a marked daily inequality between successive tidal ranges (Dampier Port Authority 1994). Tidal streams within the Port of Dampier are generally weak with a maximum rate of approximately 1 knot at spring tides (Dampier Port Authority 2003). A summary of the tidal movements at Dampier is given in **Table 4-2**.

- **Table 4-2 Characteristic Water Levels at Dampier**

Water State	Level (m Chart Datum)
Highest Astronomical Tide (HAT)	5.3
Mean High Water Springs (MHWS)	4.5
Mean High Water Neaps (MHWN)	3.2
Mean Sea Level (MSL)	2.7
Mean Low Water Springs (MLWS)	2.3
Mean Low Water Neaps (MLWN)	1.0
Lowest Astronomical Tide (LAT)	0.1

(adapted from Australian National Tide Tables, 2003).

4.1.4.2 Waves

Long period swell waves which approach from the westerly and north-westerly sectors, are refracted by the complex bathymetry and islands of the Dampier Archipelago and move down Mermaid Sound in a southerly direction. Significant wave heights decrease as the swell progresses from the open ocean waters into the protected waters of the Sound. Within the southern part of the Sound, waves are predominantly wind generated and are generally small (typically 0.5 m in height), except under cyclonic conditions when wave heights can exceed 1.3 m (LeProvost Dames and Moore 1997).

Wave processes can affect marine communities by causing spatially variable sedimentation rates and by sorting sediment fractions (CALM 2000). Suspended sediment concentrations in the water column are characteristically higher in the relatively shallow near-shore regions, compared with deeper sites further offshore. Wind and tidal stirring, combined with relatively low throughflow rates, result in re-suspension of fine sediments, which reduces light penetration through the water column, and may in turn limit the growth of marine plants. The intermediate zone between offshore and nearshore reefs fluctuates in water clarity depending on the seasonal variations in wind and wave action.

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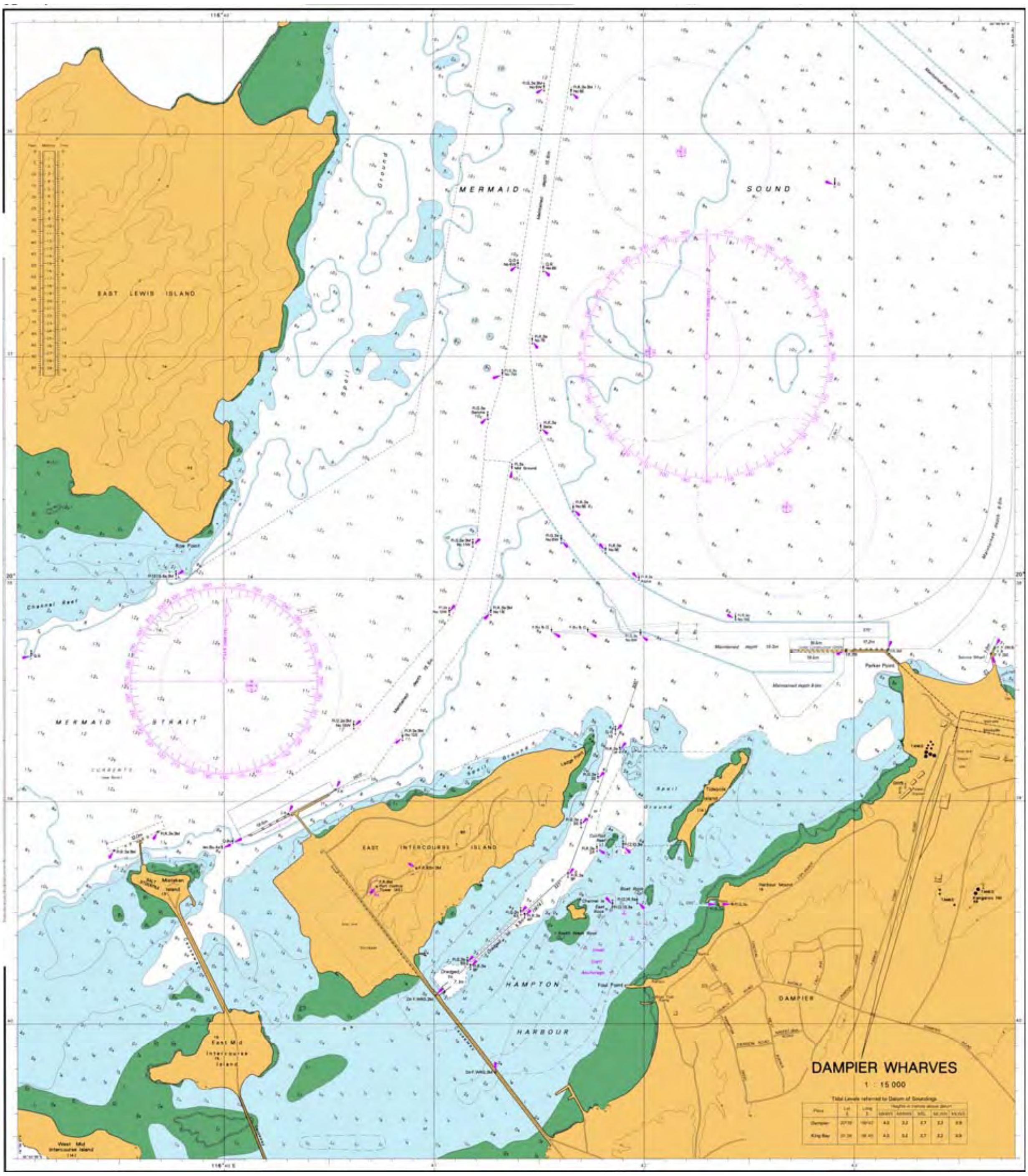

- **Figure 4-3 Bathymetry of Dampier Port area**

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4.1.4.3 Currents

Currents in the Dampier region are spatially and temporally variable due to the area's complex bathymetry and changing tide and wind patterns (CALM 2000). Currents are driven principally by tides and wind stress. Close to the coast, flows are mainly parallel to the shore with speeds ranging from about 5 cm/s (neap tides) to 25 cm/s (spring tides) (CALM 2000). Within the Archipelago, flows are strongly steered by the bathymetry in and around the islands with speeds ranging from 10 to 40 cm/s (CALM 2000). Net residual transport through the area is generally directed towards the north during summer and offshore during winter, in response to the prevailing seasonal wind directions (CALM 2000).

4.1.5 Water Quality

The water quality in King Bay and surrounding area has been investigated by Sinclair Knight Merz on behalf of the Water Corporation as part of the baseline monitoring program for the Burrup Industrial Water Supply System. The monitoring program assessed metals, nutrients (TN, NH_4, NO_3-NO_2, TP, PO_4) chlorophyll, total suspended solids, total dissolved solids, chemical oxygen demand, light attenuation and water column profiles (dissolved oxygen, temperature, salinity, pH, turbidity).

The results of this monitoring have been presented in several unpublished data reports and are summarised as follows:

- Metals in the water column are generally bound to suspended solids thus total metal concentrations (principally copper and zinc) occasionally exceed ANZECC/ARMCANZ 2000 guidelines but filtered samples do not;
- Nitrogen levels, in particular total nitrogen and nitrate-nitrite, in the surface and bottom waters of the area often exceed the ANZECC/ARMCANZ 2000 guidelines; however, the chlorophyll levels do not; and
- The waters close to shore experience much greater extremes of temperature and salinity than those further offshore, particularly during summer.

4.1.6 Water Clarity

The secchi depths for a number of locations in King Bay are presented in **Figure 4-5**. These data clearly show seasonal and spatial variability in water clarity. The high ambient turbidity and light attenuation is generally higher near shore than in the offshore waters. Much of this is as a result of wave action suspending sediments from both the seabed as well as the shoreline itself.

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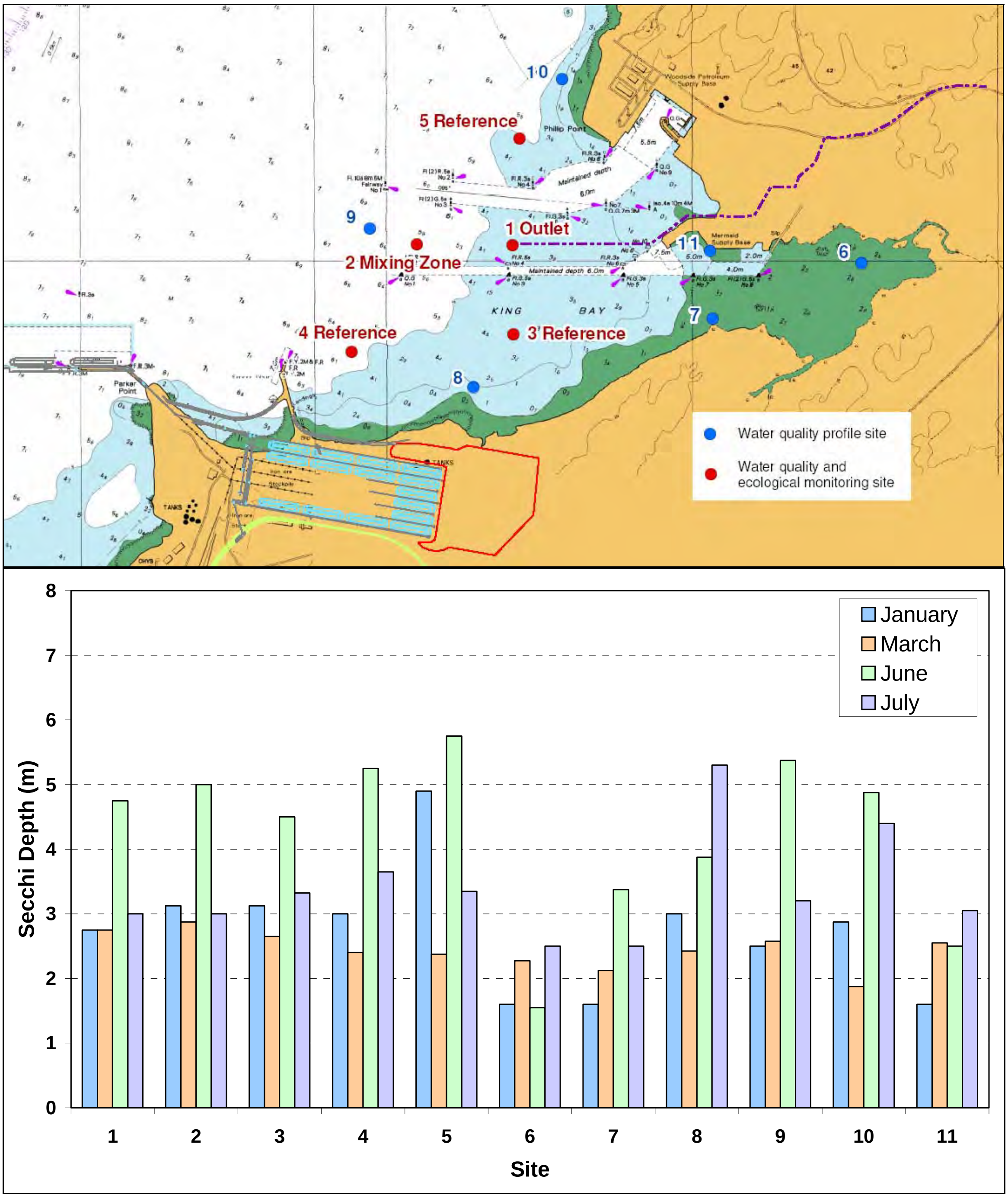
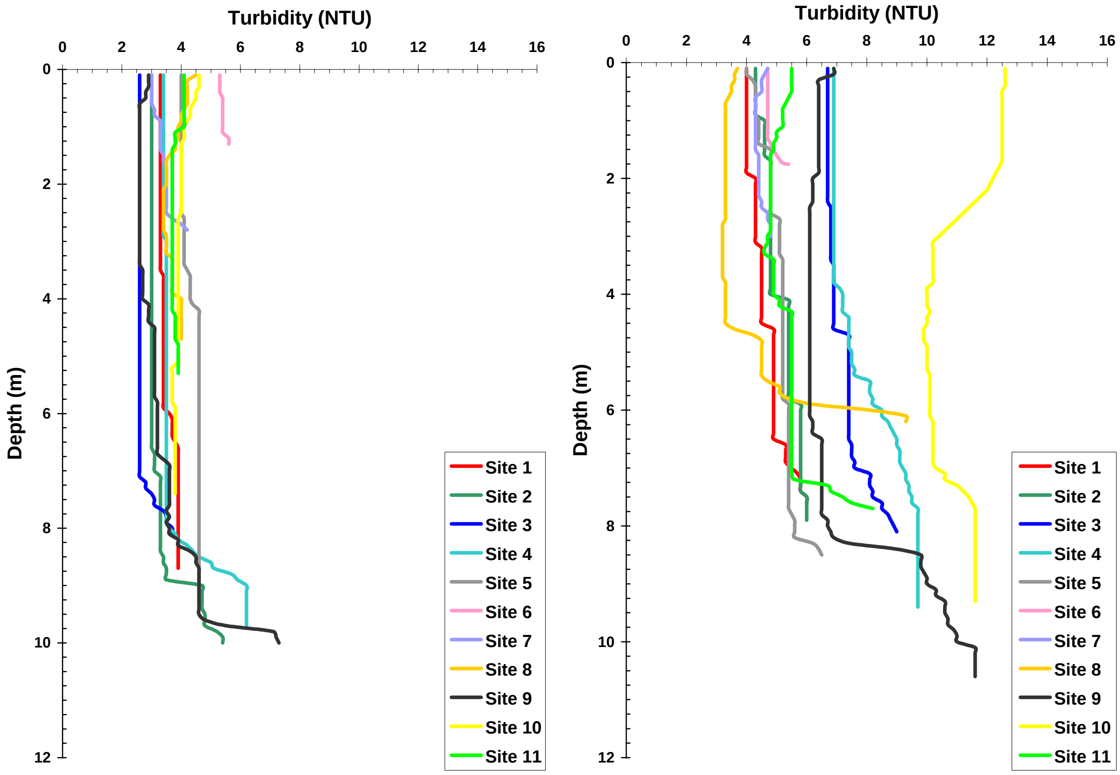


- **Figure 4-4 Secchi depth at several locations in King Bay**
  Source: Water Corporation (SKM 2003)

Turbidity profiles taken on consecutive days in March 2003 also show a spatial variation in water clarity but they also show how conditions change over short time spans (**Figure 4-5**). In addition, the turbidity profiles show that the water clarity near the seabed is often less than that of the water column.



- **Figure 4-5 Turbidity profiles during March 2003 on consecutive days**
  Source: Water Corporation (SKM 2003)

These data indicate that the water clarity in the King Bay area are naturally turbid and variable on temporal (daily and seasonal scales), spatially (distance from shore) and with depth in the water column.

4.1.7 Sediments

A Sampling and Analysis Plan (SAP) was submitted and approved by the Commonwealth Department of the Environment and Heritage for implementation by Hamersley Iron. The objectives of the SAP were to characterise the marine sediments to be removed as part of the dredging program and provide data for the effective management of the dredging activities.

4.1.7.1 Maintenance Dredge Material

Sediment Metals and Tributyltin Assessment

Sediment samples from each of the areas designated for maintenance dredging were analysed for metals and tributyltin (TBT) (standardised to 1% TOC) and were expressed as the 95% Upper Confidence Interval (95% UCL). The data in **Table 4-3** indicate the following:

- The sediments in the Parker Point and East Intercourse Island berths exceeded the National Ocean Disposal Guideline (NODGDM) maximum level for TBT;
- The sediments in Area E and F exceeded the NODGDM screening level for nickel and TBT; and
- The sediment at the East Lewis Spoil Ground exceeded the NODGDM screening level for nickel.

Values found to be above the screening level are not necessarily deemed to be detrimental to biota in the surrounding environment however it is deemed a contaminant of concern as it could adversely impact on organisms. The screening level is a trigger for further investigation such as comparison with the sediment quality at the spoil ground or additional testing to confirm that the material is not harmful to biota. Values above the maximum level indicate that toxic effects to organisms are probable if the substance is biologically available and as such further testing is mandatory.

The elevated levels of nickel were not of concern because the levels found at the East Lewis Island Spoil Ground exceeded that found in Areas E and F.

The elevated levels of TBT were of concern for sea dumping thus further testing was required in accordance with the NODGDM (Environment Australia 2002). Further testing involved the assessment of the potential of TBT to dissolve in the water (elutriate) during dredging. In addition, the assessment of ecotoxicological effects on sensitive biota was required particularly for organisms sensitive to the effects of TBT.

These results of these additional tests are provided below.

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▪ **Table 4-3 Sediment contaminant levels in material for maintenance dredging**

Parameter	Units	LOR	Guidelines a		PP Berth	EII Berth	Area E&F	ELI Spoil Ground
			Screening	Maximum				
Al	mg/kg	10	—	—	8,511	7,400	12,008	13,785
As	mg/kg	0.5	20	70	9.7	5.5	9.2	14.7
Cd	mg/kg	0.1	1.5	10	0.3	0.3	0.6	0.8
Co	mg/kg	0.1	–	—-	6.9	6.0	9.0	9.8
Cr	mg/kg	0.5	80	370	46.9	41.7	77.8	75.2
Cu	mg/kg	0.1	65	270	12.3	9.9	15.1	14.6
Fe	mg/kg	10	–	—-	50,825	108,692	24,052	26,578
Hg	mg/kg	0.1	0.15	1	0.1	0.1	0.1	0.1
Mn	mg/kg	1	–	—-	1330.3	288.1	201.0	232.0
Ni	mg/kg	0.5	21	52	5.8	7.0	25.0	27.0
Pb	mg/kg	1	50	220	4.7	3.9	5.6	5.6
Sb	mg/kg	0.1	2	25	0.1	0.1	0.2	0.1
Se	mg/kg	1	–	—-	0.5	0.5	0.5	0.8
V	mg/kg	1.0	–	—-	29.6	29.3	60.1	60.8
Zn	mg/kg	0.5	200	410	18.8	18.0	20.0	24.7
TOC	%	0.01	–	—-	0.2±0.05	0.3±0.18	0.2±0.05	0.3±0.07
TBT [b]	µg/kg	0.2	5	70	185.3	95.6	24.9	0.8

Source: Mscience 2005a,b.
All values expressed as 95% Upper Confidence Limits with the exception of TOC which is the mean ± standard deviation.
a National Ocean Disposal Guidelines for Dredged Material (NODGDM) (EA 2002).
b Normalised to 1 % Total Organic Carbon (TOC) as per NODGDM Section 3.10.1.
Bolded values exceed the screening level in Table 5 of the NODGDM.
Bolded and italicised values exceed the maximum level in Table 5 of the NODGDM.

Elutriate Assessment

Three sediment samples were collected from each of the two areas where elevated sediment TBT was observed (Parker Point Berth and East Intercourse Island Berth). Elutriates were prepared using water from the site and the results were subjected to a 100 fold dilution in accordance with Section 3.10.3 of the NODGDM to account for dilution during the disposal of the material at the spoil ground. This dilution is an underestimate. The results in **Table 4-4** indicate that the elutriation of TBT would result in concentrations well below the ANZECC/ARMCANZ 2000 guideline level of protection for 99% of species.

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- **Table 4-4 Elutriate TBT levels in material for maintenance dredging**

Parameter	Units	LOR	Guidelines [a]		PP Berth	EII Berth
			99%	95%		
TBT	µg/L	0.002	0.0004	0.006	0.00001	0.00004

Source: Mscience 2005a,b.
All values expressed as 95%iles with an indicative dilution of 100 times as per the NODGDM Section 3.10.3.
a ANZECC/ARMCANZ 2000.

Ecotoxicological Assessment

Three sediment samples were collected from each of the two areas where elevated sediment TBT was observed (Parker Point Berth and East Intercourse Island Berth). Elutriates from these samples at concentrations of 0% to 100% elutriate were used for 48 hr test of the larval development of rock oysters (*Saccostrea commercialis*). The results in **Table 4-5** indicate that there was no significant reduction in normal/survival of larval oysters when compared to background seawater (0% elutriate concentration). The TBT contained in the sediments are not expected to adversely impact on biota.

- **Table 4-5 Ecotoxicological assessment of sediment elutriates**

% Elutriate	Percent normal/survival	
	Parker Point Berth	East Intercourse Island Berth
0	75+5.2	73+4.5
6.25	71+1.0	73+4.9
12.5	70+3.8	72+1.7
25	78+3.2	72+2.1
50	75+3.8	75+1.2
100	74+1.0	71+3.5

4.1.7.2 Capital Dredge Material

Tributyltin Assessment

Sediment samples from each of the six areas designated for capital dredging were analysed for TBT and standardised to 1% TOC and expressed as the 95% Upper Confidence Interval (95% UCL). The data in **Table 4-6** indicate the following:

- The sediments in Area G exceeded the NODGDM screening level;
- The sediments in Area A exceeded the NODGDM maximum level; and
- The sediments in Areas B–D and H were below the NODGDM screening level.

- **Table 4-6 Sediment contaminant levels in material for capital dredging**

Parameter	Units	LOR	Guidelines [a]		Areas					
			Screening	Maximum	A	B	C	D	G	H
TOC	%	0.01	—	—	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.2±0.1
TBT	µg/kg	0.2	5	70	***610***	4.4	1.8	3.3	**31.3**	0.6

Source: Mscience 2005a,b.
All values expressed as 95% Upper Confidence Limits with the exception of TOC which is the mean ± standard deviation.
a National Ocean Disposal Guidelines for Dredged Material (NODGDM) (EA 2002).
b Normalised to 1 % Total Organic Carbon (TOC) as per NODGDM Section 3.10.1.
Bolded values exceed the screening level in Table 5 of the NODGDM.
Bolded and italicised values exceed the maximum level in Table 5 of the NODGDM.

Leachate Assessment

The Australian Standard Leach Procedure (ASLP) provides a method for the preparation of leachates from liquid and solid wastes, sediments, sludges and soils for assessing the potential of inorganic and semi-volatile organic contamination of groundwater, in a variety of disposal-to-land scenarios. The percentage of solids is determined and if sufficient liquid is extracted from the sample, the liquid is analysed separately from the leachate. A separate test portion is reduced in size to pass a 2.4 mm sieve and leached in an end over end manner for 18 hours at 30 rpm using an appropriate extraction solution. The solution used depends on the sample and water pH, acid/base properties and the nature of the landfill (Reference AS 4439.3-1997).

Twelve sediment samples from areas proposed to be used for landfill on shore were investigated for suitability based on Ecological Investigation Levels (EIL) (DoE 2001a). Five sediment samples that exceeded the EIL levels triggered assessment by determining the leachable concentration by ASLP and comparison to guidelines for Inert Landfill (DoE 2001b).

The data in **Table 4-7** indicate the following:

- Three of the twelve sediment samples exceeded the EIL levels for chromium;
- Six of the twelve sediment samples exceeded the EIL levels for manganese; and
- None of the samples exceeded leachability guidelines.

The dredge material therefore is suitable for disposal ashore as landfill in the reclamation area.

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- **Table 4-7 Comparison of sediment and leachate data with landfill guidelines**

Parameter	Guidelines		Sediment		ASLP	
	EIL [a] mg/kg	ASLP1 [b] mg/L	mg/kg	Exceedances	mg/L	Exceedances
As	20	0.5	7.4	0	0.01	0
Cd	3	–	0.3	–	–	–
Co	50	–	5.8	–	–	–
Cr	50	0.5	36.2	3	0.01	0
Cu	60	–	9.7	–	0.01	–
Hg	1	–	0.1	–	–	–
Mn	–	–	810	6	–	–
Ni	60	0.2	3.9	0	0.01	0
Pb	300	0.5	3.7	0	0.01	0
Sb	20	–	0.1	–	–	–
Zn	200	–	14.5	–	0.04	–

Source: Mscience 2005a,b.
a Ecological Investigation Level: Assessment Levels for Soil, Sediment and Water (DoE 2001a).
b Leachable Concentration (ASLP) level 1: Inert Landfill (DoE 2001b).

4.1.7.3 Acid Sulphate Soil Assessment

The potential for dredging material used on shore for reclamation to produce acid once exposed to air was assessed. Five samples were collected and tested for Triatable Actual Acidity (TAA), Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) and total sulphur (for details of methodology refer to **DDSMP Section 3.2.2**).

The data in **Table 4-8** indicate the following:

- All samples had a TPA below detection (2 mol H^+/t); and
- All samples had an Acid Neutralising Capacity (ANCE) > a-S_{Total}.

The dredge material is therefore self-neutralising and is suitable for disposal ashore as landfill in the reclamation area.

Table 4-8 Acid sulphate soil assessment

Parameter	Code	Units	Samples 1	2	3	4	5
pH measurements							
pH of KCl extract	23A	pH_{KCl}	8.90	8.90	8.80	8.80	8.90
PpH of peroxide digestion	23B	pH_{OX}	8.00	7.80	8.00	8.00	8.00
Acidity trail							
Titratable Actual Acidity (TAA)	23F	TAA	<2.00	<2.00	<2.00	<2.00	<2.00
Titratable Peroxide Acidity (TPA)	23G	TPA	<2.00	<2.00	<2.00	<2.00	<2.00
Titratable Sulfidic Acidity	23H	TSA	<2	<2	<2	<2	<2
sulfidic - Titratable Actual Acidity	s-23F	s-TAA	<0.02	<0.02	<0.02	<0.02	<0.02
sulfidic - Titratable Peroxide Acidity	s-23G	s-TPA	<0.02	<0.02	<0.02	<0.02	<0.02
sulfidic - Titratable Sulfidic Acidity	s-23H	sTSA	<0.02	<0.02	<0.02	<0.02	<0.02
Sulfur trail							
Total Sulfur	20A	$\%S_T$	0.69	0.44	0.29	0.34	0.27
acidic - Total Sulfur	a-20A	$a\text{-}S_T$	430	274	181	212	168
KCl Extractable Sulfur	23Ce	$\%S_{KCl}$	0.18	0.14	0.19	0.16	0.11
Peroxide Sulfur	23De	$\%S_P$	0.73	0.52	0.38	0.39	0.32
Peroxide Oxidisable Sulfur	23E	$\%S_{POS}$	0.55	0.38	0.19	0.23	0.21
acidity - Peroxide Oxidisable Sulfur	a-23E	$a\text{-}S_{POS}$	343	237	119	143	131
Calcium values							
KCl Extractable Calcium	23Vh	$\%Ca_{KCl}$	0.37	0.36	0.43	0.38	0.32
Peroxide Calcium	23Wh	$\%Ca_P$	22.20	21.10	16.00	16.40	13.10
Acid Reacted Calcium	23X	$\%Ca_A$	21.8	20.7	15.6	16.0	12.8
acidity - Acid Reacted Calcium	a-23X	$a\text{-}Ca_A$	10893	10349	7769	7994	6377
sulfidic - Acid Reacted Calcium	s-23X	$s\text{-}Ca_A$	17.5	16.6	12.5	12.8	10.2
Magnesium values							
KCl Extractable Magnesium	23Sm	$\%Mg_{KCl}$	0.12	0.11	0.18	0.14	0.10
Peroxide Magnesium	23Tm	$\%Mg_P$	1.03	0.98	0.77	0.77	0.56
Acid Reacted Magnesium	23U	$\%Mg_A$	0.91	0.87	0.59	0.63	0.46
acidity - Acid Reacted Magnesium	a-23U	$a\text{-}Mg_A$	749	716	485	518	378
sulfidic - Acid Reacted Magnesium	s-23U	$s\text{-}Mg_A$	1.20	1.15	0.78	0.83	0.61
Excess Acid Neutralising Capacity							
Excess Acid Neutralising Capacity	23Q	ANC_E	52.40	49.30	39.70	40.50	32.00
acidity-Excess Acid Neutralising Capacity	a-23Q	$a\text{-}ANC_E$	10470	9850	7932	8092	6394
sulfidic-Excess Acid Neutralising Capacity	s-23Q	$s\text{-}ANC_E$	16.79	15.80	12.72	12.98	10.25
Acid Base Accounting							
ANC Fineness Factor			1.5	1.5	1.5	1.5	1.5
Net Acidity (sulfur units)			<0.02	<0.02	<0.02	<0.02	<0.02
Net Acidity (acidity units)			<10	<10	<10	<10	<10
Assessment			**Ok**	**Ok**	**Ok**	**Ok**	**Ok**

4.2 Biological Environment

4.2.1 Marine Habitats

The benthic marine habitat within the Port of Dampier is presented in **Figure 4-6** and consists predominantly of the following three community groups (CALM 2000):

- Soft sediment (silt and sand);
- Macroalgae on hard substrate; and
- Hard coral on hard substrate.

The distribution of the inshore coral communities in the vicinity of the proposed dredging and spoil dumping areas is presented in **Figure 4-7**.

Several marine surveys and desktop studies have been undertaken by Environmental Contracting Services (Environmental Contracting Services 1995) and IRC Environment (2001, 2003a, b, c) to define the benthic habitats in the vicinity of Parker Point and East Intercourse Island. In addition, a number of studies of the marine environment were carried out in conjunction with the dredging and spoil disposal activities associated with the dredging in 2004 in Mermaid Sound for the new berth pocket and channel for the Dampier Port Authority and Hamersley Iron's Dampier Port Upgrade program. These studies are described in **Appendix B**

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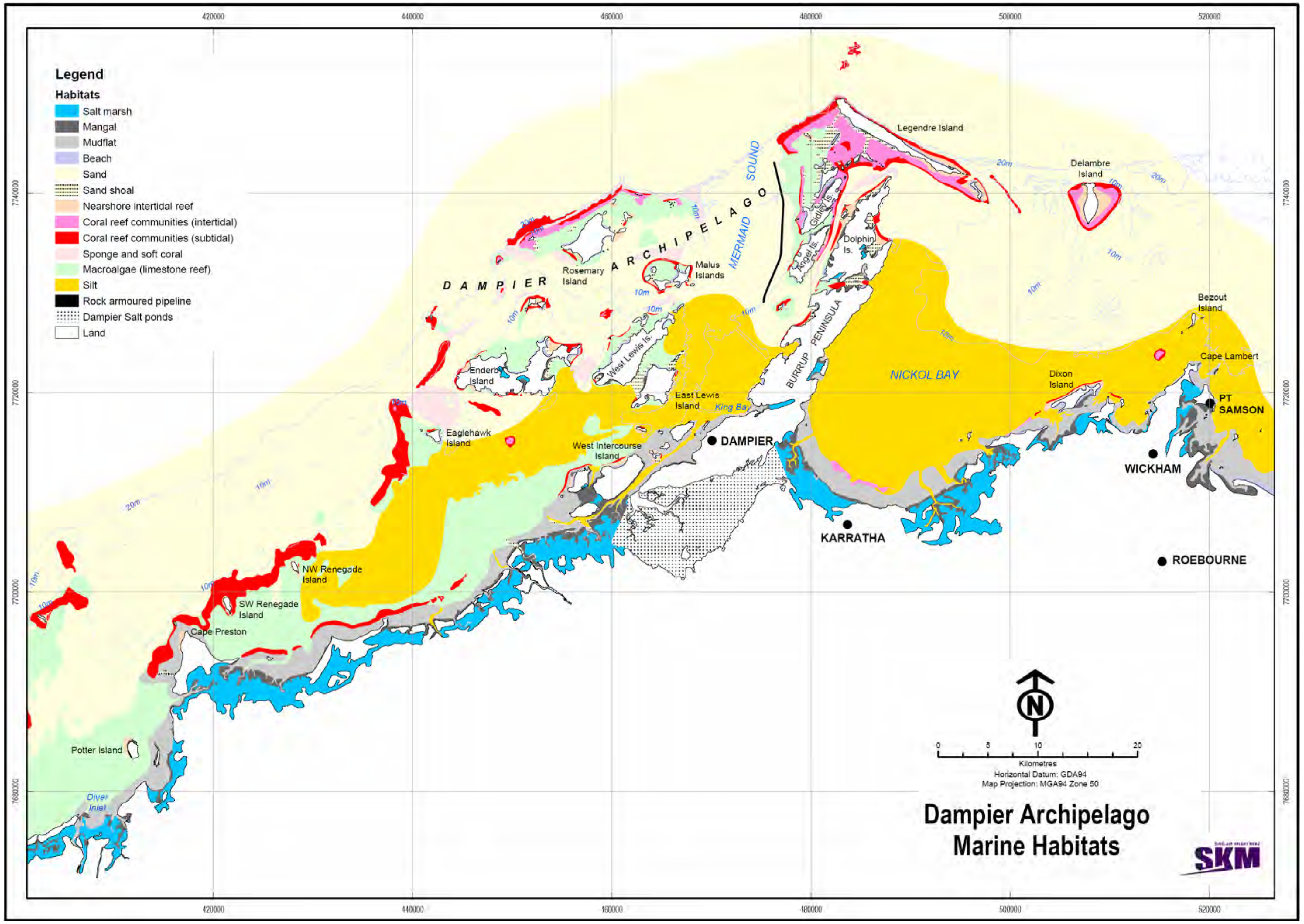

- **Figure 4-6 Predominant marine habitats within the Port of Dampier and adjacent waters**

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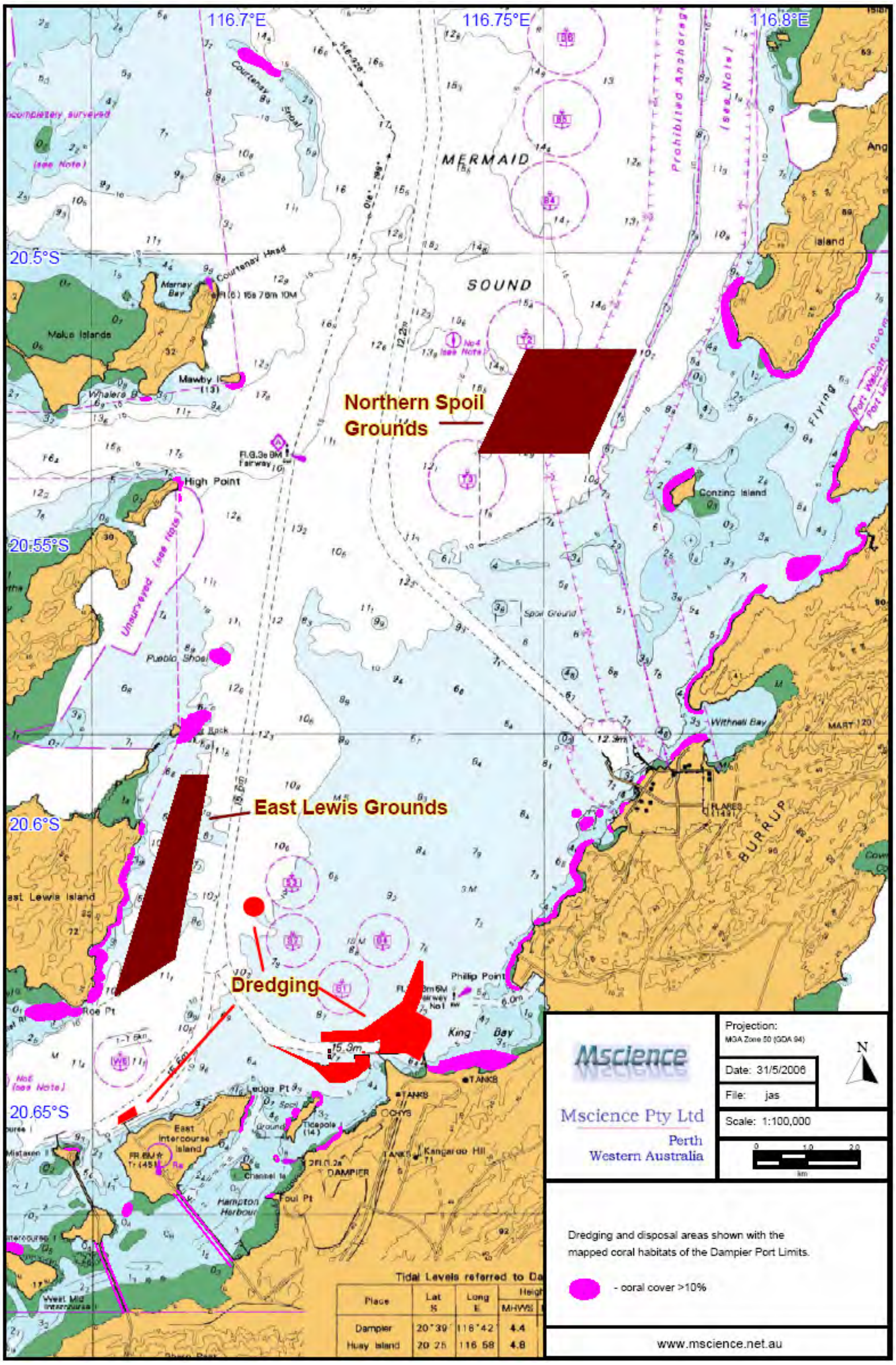


- **Figure 4-7 Coral distribution in the vicinity of the project area**

4.2.1.1 Coral communities

The Dampier Archipelago has a highly diverse coral assemblage exceeded in Western Australia only by Ashmore Reef (Marsh 1978, Veron and Marsh 1988, Veron 1993, Griffith 2004). Recent surveys of the coral reef habitats in the Dampier Port and inner Mermaid Sound recorded 120 species of scleractinian corals from 43 genera (Mscience 2005c). Five coral assemblages were distinguished on the basis of proportional differences in generic composition. Four of the assemblages were dominated by a single genus each: *Acropora* (particularly plate *Acropora*), *Porites*, *Pavona*, and *Turbinaria* respectively. The fifth assemblage was missed, consisting predominantly of faviids, *Turbinaria* and a variety of other scleractinian corals (Mscience 2005c).

The distribution of coral assemblages appears to be correlated with water quality, wave energy and tidal currents. Coral assemblages adjacent to the Dampier townsite and along the western margin of the Burrup Peninsula consist predominantly of the mixed coral assemblage (MScience 2005c).

Coral loss in the Dampier Port area is predominantly in the vicinity ship loading facilities at East Intercourse Island, Parker Point, the Dampier Cargo Wharf and the LNG wharves. Cumulative coral loss is quantified in more detail in **Section 4.3** of this document. These reefs receive substantial levels of natural turbidity and suspended sediment for much of the year, and appear reasonably resistant to it. The natural resilience of this assemblage has probably buffered it to a significant extent against the additional turbidity and sedimentation associated with dredging, construction and ship movements. These effects are described in more detail below.

The high ambient turbidity in the region limits the depth of benthic primary producer distribution such as macroalgae; however, the marine survey undertaken in 2000 by IRCE found no evidence of coral bleaching or coral stress caused by sedimentation (IRCE 2001). Coral abundance ranged from 20 to 60% of seabed composition along various offshore transects, and from 14 to 40% amongst nearshore sites. All coral appeared healthy. Macroalgae and turf microalgae are relatively sparse, although a community dominated by the brown alga Sargassum was found 800 m north of the wharf on East Intercourse Island. The more recent surveys undertaken in 2002 and 2003, undertook evaluations of ecosystem integrity. The ecological status of the three main habitat types in locations surrounding Hamersley Iron's operations were evaluated utilising the classification system derived from ANZECC/ARMCANZ (2000) (see **Table 4-9**).

The confusion between disturbance and damage is due largely to the mixing of ecological units and the use of subjective terms. Disturbance is an ecological term referring to the perturbation of an ecosystem that affects internal system processes. A highly disturbed system will be one that is disturbed frequently or one which has suffered a strong recent disturbance. In areas classified as 'highly disturbed' due to the frequency of disturbance or in areas recovering from severe disturbance, individual organisms may be 'healthy' (a very subjective term). On land, areas infested by healthy weed species may be called 'highly disturbed'.

Surveys of corals may describe corals as healthy or the system as 'healthy' based on its live corals or apparent recovery. However, the species composition and demography of the area may, at the same time, reflect its highly disturbed nature (existing immediately adjacent to a very large stockpiling operation and between two active wharves). It is not correct to infer the system has been degraded between being described as 'healthy' then 'highly disturbed'.

Table 4-9 Ecosystem condition classification for assessing Dampier marine habitats

Ecosystem Condition	Description
Effectively unmodified	Areas where ecological integrity is effectively intact.
Slightly to moderately disturbed.	Areas where ecological integrity has been adversely affected to a relatively small but measurable degree by human activity. Biological communities remain in a health condition and the original ecosystem integrity is largely retained.
Highly disturbed	Areas where ecological integrity has been measurably degraded by human activity. Biological communities are unhealthy and the original ecosystem integrity has been undermined.

Source: IRCE (2003).

The study concluded that areas along the mainland shore in close proximity to Hamersley's Dampier operations are highly disturbed. These areas were identified as:

- Between the East Intercourse and East Mid-intercourse Island causeways;
- Within Hampton Harbour and the areas east of the East Intercourse Island causeway;
- Variable disturbance around Parker Point; and
- Around the East Intercourse Island iron ore load-out wharf.

The classification of disturbance at these sites was based on:

- Observed high water turbidity;
- Lower diversity and abundance of biota compared with reference sites;
- Observed stress in terms of sedimentation; and
- Evidence of anthropogenic wastes such as cooling water from the power station and rubbish.

Surveyed sites close to the loadout wharf and wastewater outlet were also highly disturbed. Sites located to the east were generally unmodified. Nearshore reference areas around Tidepole Island also showed slight to moderate disturbances as a result of sedimentation, coral bleaching and mortality. Coral bleaching was also detected at a reference site at East Lewis Island, where human influences would not be expected to cause bleaching suggesting that bleaching may be a natural occurrence. Sites amongst the Dampier Archipelago and offshore areas of the Dampier Port were found to be unmodified.

A coral bleaching event spread across an area spanning at least 60km of coastline from Cape Lambert to the Dampier Archipelago during March 2005. The proximate cause of the bleaching appears to have been elevated water temperatures, caused by a period of solar heating of nearshore waters. The temperature of waters where these corals were located appears to have risen to around 32°C, which is 1-2°C above normal for that time of year (MScience 2005d).

4.3 Cumulative Coral Loss

A study undertaken by MScience (2005e) on behalf of Hamersley Iron compared the quantity of present day coral habit with that of pre-impact at Dampier in 1957. The study area was comprised of the Hamersley Iron Sea lease (East Intercourse Island to the Service Wharf) totalling approximately 40 km^2. The study found the following:

- The present habitat colonised by coral at greater than 10% cover was 55.9 ha in 2004; and
- The estimated loss of coral ranged between 23–35 % since 1957.

Monitoring undertaken by MScience in 2004 for Hamersley Iron's dredging program found the following:

- A massive reduction in live coral cover in communities on the southern shore of West Lewis Island which was attributed to cyclonic freshwater inundation;
- Acroporids and faviids were apparently most susceptible to sedimentation while species of *Turbinaria*, *Pavona decussate*, *Diploastrea heliopora* and *Porites solida* were most resilient;
- Coral loss is likely to recover over a 10–20 year period; and
- Hamersley Iron's dredging did not adversely affect any corals.

The most recent dredging programs undertaken by Hamersley Iron and the Dampier Port Authority in 2004 resulted in limited coral loss at one location. These losses are likely to recover.

No direct losses are predicted as a result of the proposed 2006 Hamersley Iron dredging program, either for permanent loss of habitat or direct coral mortality. There is a potential for sediment effects to cause the following:

1) physiological stress on some of the corals surrounding the uplift and disposal sites; and
2) some loss of settlement amongst coral larvae which may settle following spawning events in Spring 2006 or Autumn 2007.

However, this would not cause the loss of benthic primary producer communities and would effectively have no net indirect effect.

4.4 Marine Vertebrate Fauna

Marine mammals recorded within Mermaid Sound are *Dugong (Dugong dugon*), Humpback Whale (*Megaptera novaehollandiae*), False Killer Whale (*Pseudorca crassidens*), Bottlenose Dolphin *(Tursiops truncatus*), Indo-Pacific Hump-backed Dolphin (*Sousa chinensis*) and Risso's Dolphin (*Crompids griseus*).

Whales migrate along the Western Australian coast, travelling south in summer and north, towards the tropics in winter. Discussions with the DEH indicated that tracked whales enter Mermaid Sound very infrequently, preferring to pass through the area on the outside of the Archipelago. The Humpback Whale is listed as a vulnerable species and a migratory species under the *EPBC Act 1999*, and has special protection under the *Western Australian Wildlife Conservation Act 1950* where they are described as "rare or likely to become extinct."

The dugong is listed under "*other specially protected fauna*" in Schedule 4 of the *Wildlife Conservation Act 1950*, and although not currently listed under Commonwealth legislation, it is listed as "*vulnerable to extinction*" at a global scale by the World Conservation Union. Current knowledge on the size, distribution and migratory habits of dugong populations within the Dampier Archipelago is limited. However, dugong have been observed grazing in many of the shallow bays and in areas between islands, but are unlikely to occur around Parker Point or near operating vessels due to their sensitivity to noise.

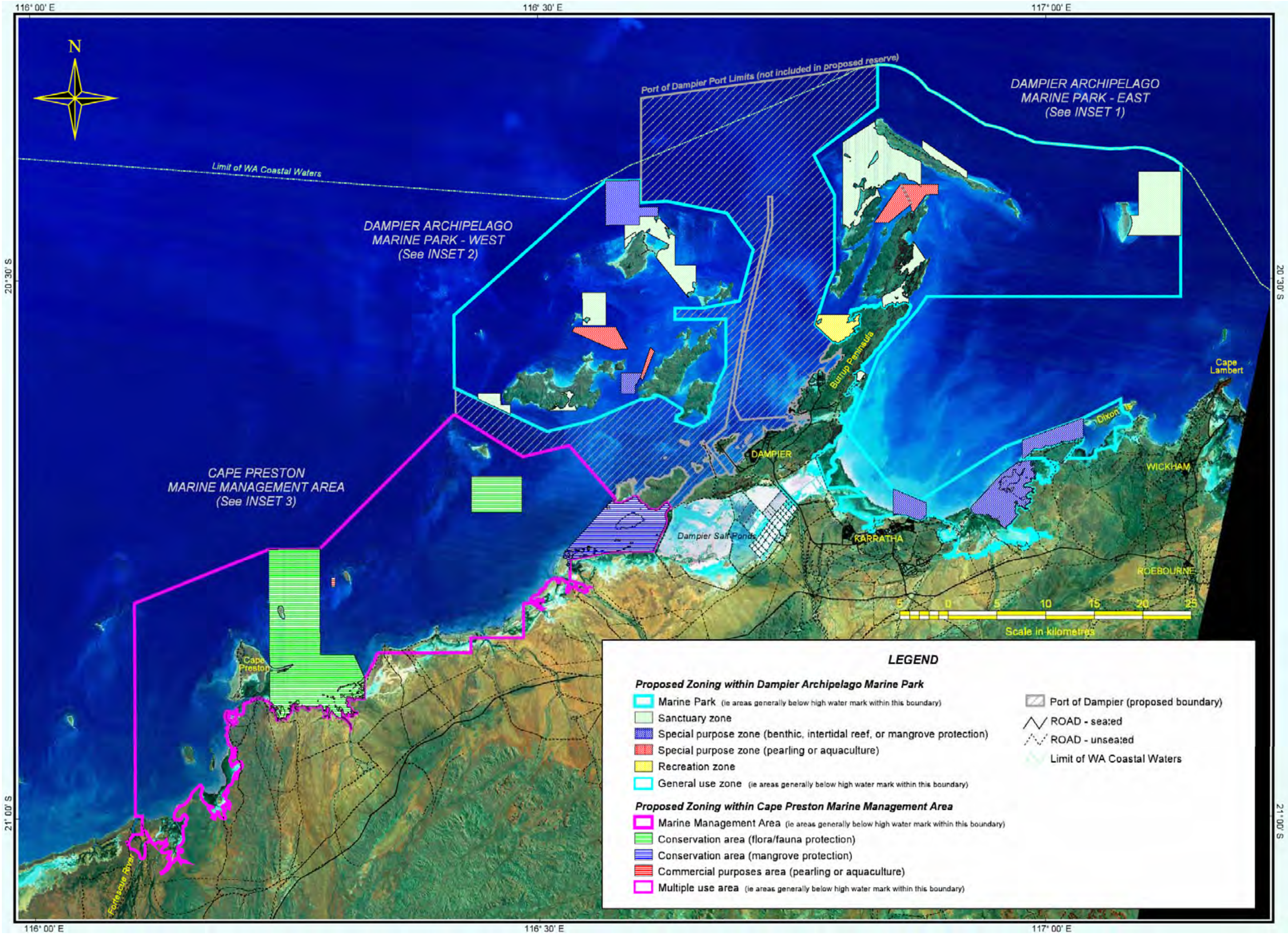
The four species of turtle known to nest in the greater Dampier Archipelago area are the Green (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Flatback (*Natator depressus)* and Loggerhead (*Caretta caretta*). Green, Flatback and Hawksbill turtles are listed as "*vulnerable*" under the EPBC Act and the Loggerhead turtle is listed as "*endangered*" under the Act. Under Western Australian legislation all four turtles are listed as "fauna that is rare or is likely to become extinct" under schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice 1999 under the *Wildlife Conservation Act 1950*. The Dampier Archipelago provides important habitat for marine turtles, particularly the offshore islands where there are significant nesting beaches; these are located well away from the proposed areas of operation.

Twelve species of sea snake have also been found in the Dampier Archipelago, with the Olive Sea Snake (*Aipysurus laevis*) being the most common. Sixteen species of sea and shore birds are known to breed on the islands of the Dampier Archipelago.

4.5 Conservation Areas

Some of the islands of the Dampier Archipelago are contained within nature reserves for the protection of flora and fauna and are managed under the *Dampier Archipelago Nature Reserves Management Plan 1999 – 2000* (CALM 1990). Other islands within the area, including East Lewis Island are reserves for conservation and recreation.

The surrounding waters of the Dampier Archipelago are the subject of the proposed Dampier Archipelago/ Cape Preston Marine Conservation Reserve. The Dampier Port area and the East Lewis Island spoil disposal area will be excluded from the finalised marine park boundaries (**Figure 4-8** and **Figure 4-9**).



- **Figure 4-8 Proposed Dampier Archipelago/Cape Preston Marine Park Zoning**

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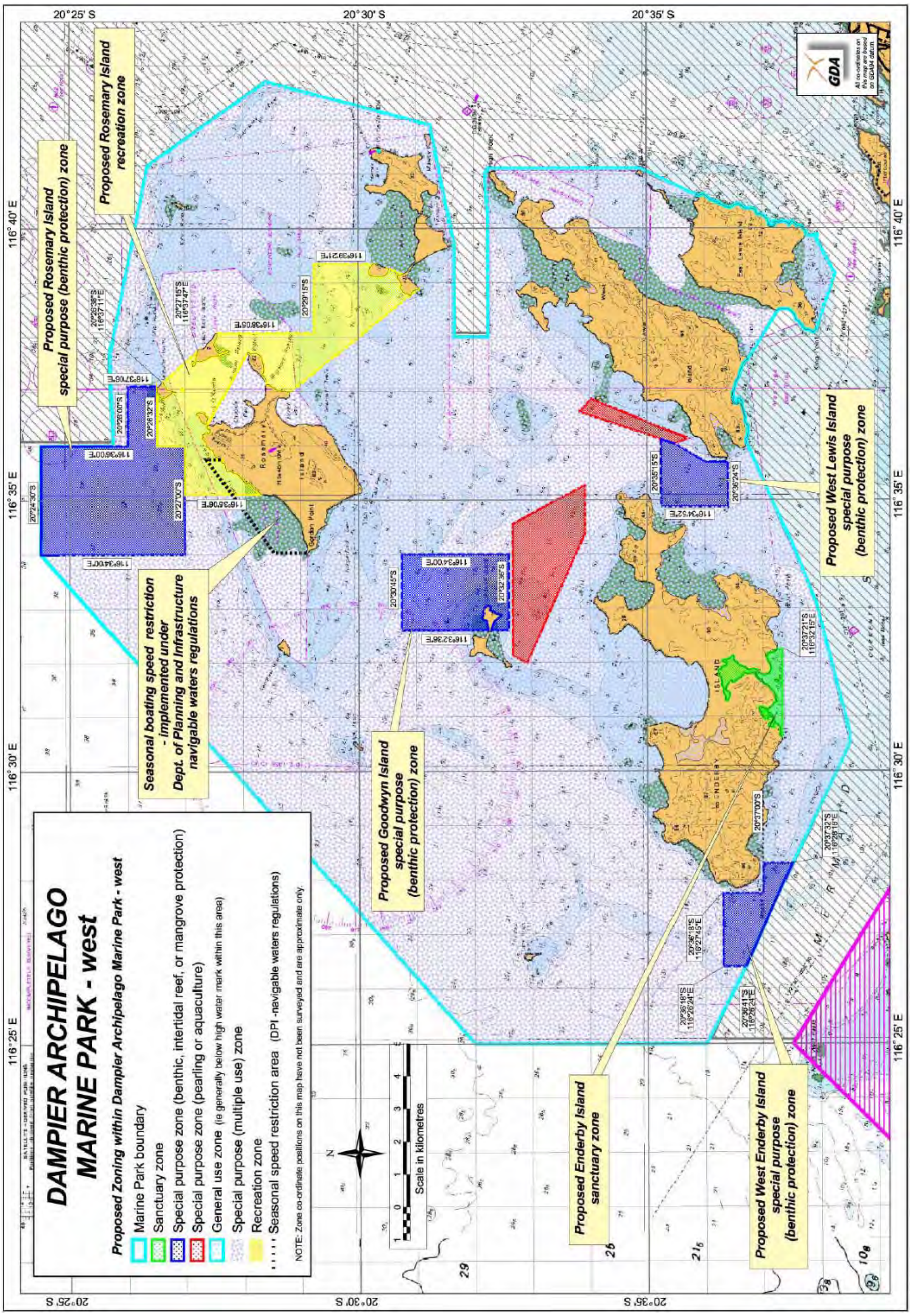

■ **Figure 4-9 Proposed Dampier Archipelago Marine Park West Zoning**

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4.6 Environmental Values

The DoE has recently completed a public consultation program that recommends a set of Environmental Values and spatially allocated Environmental Quality Objectives (see **Table 4-7** and **Figure 4-6**) and Levels of Ecological Protection for the Pilbara coastal waters (see **Table 4-11**). The EPA has given interim approval to this environmental quality management framework for guiding environmental impact assessment and regulation. This framework has been taken into consideration in the preparation of this document in the consideration of the potential environmental impacts.

- **Table 4-10 Environmental values and environmental quality objectives**

Environmental Values	Environmental Quality Objectives
Ecosystem Health (ecological value)	**Maintain ecosystem integrity** This means maintaining the structure (e.g. the variety and quantity of life forms) and functions (eg. the food chains and nutrient cycles) of marine ecosystems.
Recreational and Aesthetics (social use value)	**Water quality is safe for recreational activities in the water (eg. swimming).**
	Water quality is safe for recreational activities in the water (eg. boating).
	Aesthetic values of the marine environment are protected.
Cultural and Spiritual (social use value)	**Cultural and spiritual values of the marine environment are protected.**
Fishing and Aquaculture (social use value)	**Seafood (caught or grown) is of a quality safe for eating.**
	Water quality is suitable for aquaculture purposes.
Industrial Water Supply (social use value)	**Water quality is suitable for industrial supply purposes.**

Source: Pilbara Coastal Water Quality Consultation Outcomes: Environmental Values and Environmental Quality Objectives (DoE 2006).

- **Table 4-11 Levels of ecological protection linked to the maintenance of ecosystem integrity**

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

Source: Pilbara Coastal Water Quality Consultation Outcomes: Environmental Values and Environmental Quality Objectives (DoE 2006).

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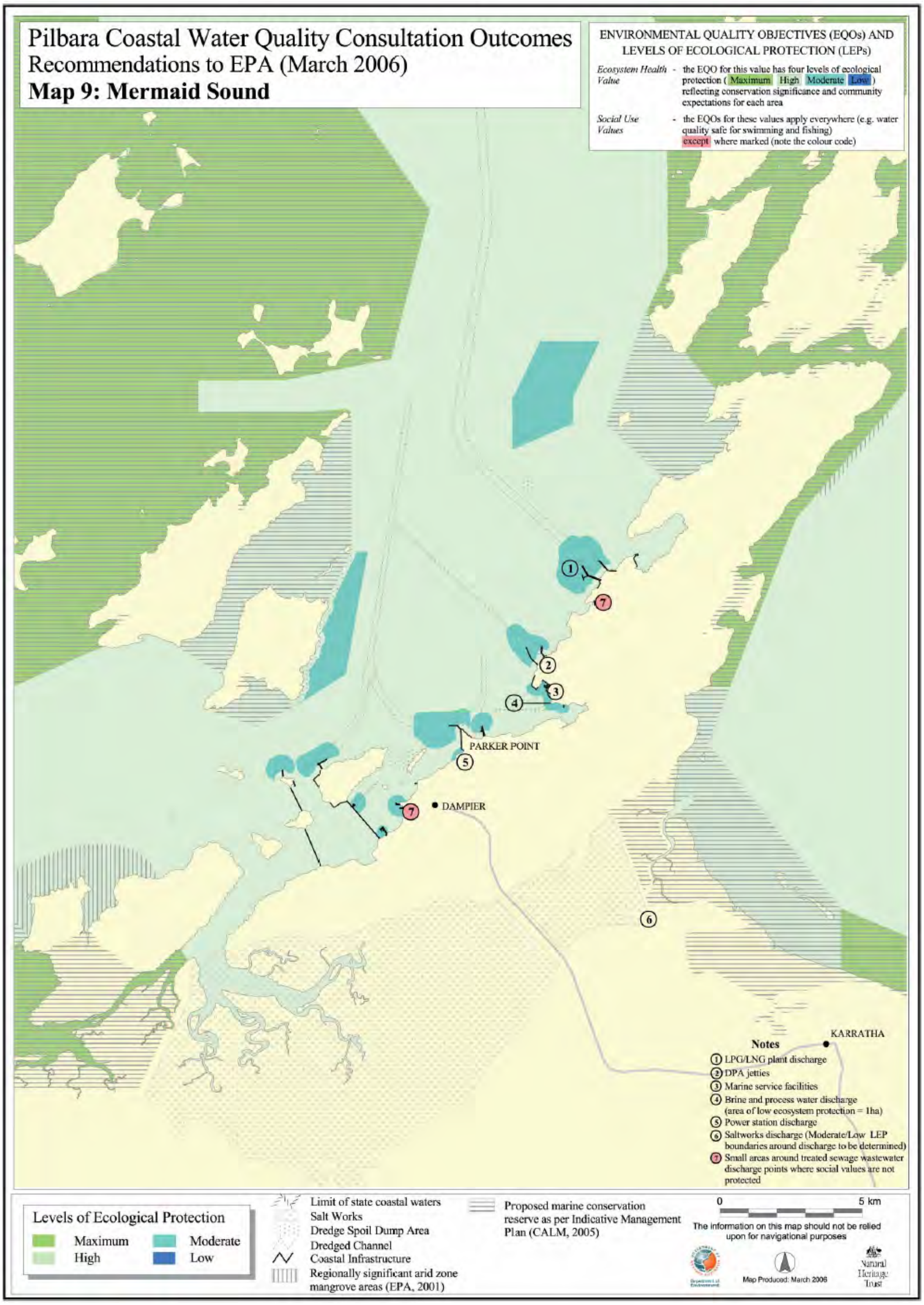

■ **Figure 4-10 Environmental quality objectives for Mermaid sound**

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The Environmental Values that need to be protected on this project are:

- Ecosystem Health;
- Fishing and Aquaculture;
- Recreation and Aesthetics (eg. swimming and diving); and
- Industrial Water Supply (eg. Burrup Desalination Intake in King Bay).

The impact on these values is described below.

4.6.1 Ecosystem Health

The chemical and ecotoxicological testing of elutriates and sediments have demonstrated that water quality will not be contaminated as a result of the dredging and disposal process. Previous monitoring associated with Hamersley Iron's 2004 dredging program indicated that benthic communities in the region were not adversely affected by turbidity or sedimentation. The dredging and disposal program will not lead to contamination in excess of the moderate level of change as prescribed for the waters around Hamersley Iron's facilities at Parker Point and East Intercourse Island as well as the two proposed disposal areas (East Lewis Island Spoil Ground and the Northern Spoil Ground).

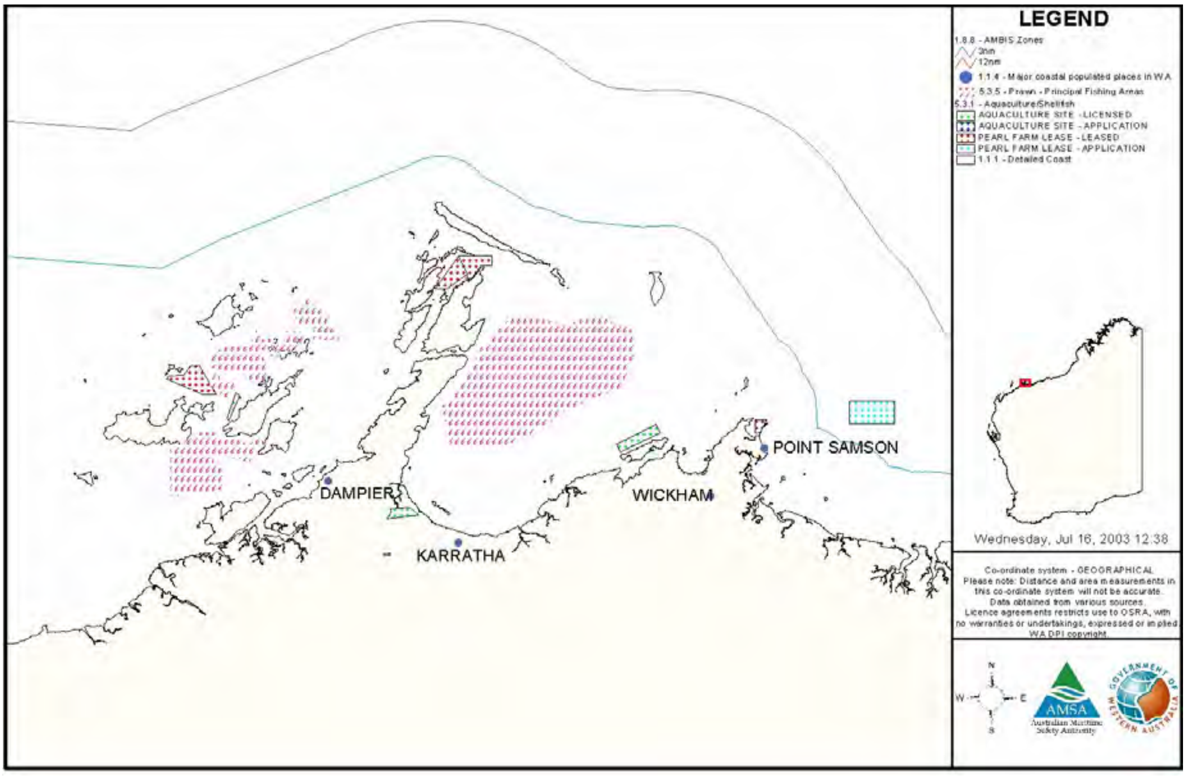
However, it is unclear at this stage what constitutes a moderate level of change for biological indicators. The activity of dredging will most certainly remove essentially all benthic flora and fauna in the berth pockets, swing basins and channel areas. Equally the disposal of material will smother most benthos in the immediate area. These impacts cannot be avoided but will be confined to the area of the spoil grounds or berths — defined as requiring a moderate level of ecological protection. Outside of these areas it is unlikely that the ecosystem health will be adversely affected at the level of ecosystem processes, species or populations. It must be emphasised that the dredging and disposal program is a short-term impact and that recolonisation of disposal areas following cessation of disposal while variable, often approximates the adjacent habitat within 2–3 years.

4.6.2 Fishing and Aquaculture

The major commercial fishing activities in the Dampier Region are prawn and finfish trawling, trapping, wet lining and pearling. None of these activities take place in the vicinity of the areas to be dredged or where existing spoil grounds occur. Commercial fishing areas and aquaculture leases are found outside of the port as shown in **Figure 4-11**. The nearest commercial fishery to the proposed dredging program is WA South Sea Pearls. The operations occupy 136 ha on the western side of West Lewis Island; however, the spoil ground to be used is located to the east of East Lewis Island.

Recreational fishers target coral and sub-tidal rocky reefs offshore and make use of the artificial habitat created by the North Rankin A Gas Pipeline in Mermaid Sound. Sites close to boat launching access west of the Dampier Power Station are also frequented. Some line fishing occurs to the east and north of the spoil ground at East Lewis Island. However, fishers traditionally avoid the shipping lanes within the Port of Dampier. There are numerous coastal line fishing areas within sailing distance of the launching facilities at Dampier; however these areas will not be impacted by dredging operations.

The dredging and disposal program is not expected to affect the activities of fishing and aquaculture nor will it affect the quantity or quality of the taking or harvesting of their catch.



- **Figure 4-11 Commercial fishing in the region**

4.6.3 Recreation and Aesthetics

The waters and islands of the Dampier Archipelago provide opportunities for land and sea-based recreational pursuits. Local boat ownership is high and recreational fishing is popular, as are diving, snorkelling, surface water sports and wildlife viewing. Typically, such activities occur amongst the islands of the Dampier Archipelago, away from Dampier and the proposed dredging activities. Specific areas, such as the proposed Conzinc Bay Recreation Zone (see **Figure 4-12**) are under consideration for protection solely for recreational value.

The Department of Planning and Infrastructure has designated a water skiing area along the south-eastern edge of East Intercourse Island which is well away from the proposed dredging. Similarly, it is unlikely that an 8 knot speed restricted and boating prohibited area (established south west of Foul Point on the edge of Dampier to protect swimmers) will be impacted by the dredging operations. The areas are approximately 3 km from the nearest dredging activities.

The social value of the eastern shoreline of East Lewis Island is considered limited as most visitors utilise the northern shore which is more protected during both summer and winter.

The dredging and disposal program is not expected to affect aesthetics and the recreational activities beyond the life of the dredging project. During dredging and disposal, turbid plumes may be visible within recreation areas.

4.6.4 Industrial Water Supply

The Water Corporation operates an industrial water supply intake adjacent to the Mermaid Marine Base in King Bay. Seawater is abstracted for desalination by a thermal desalination plant. Based on *in situ* sampling, the site has some of the poorest water quality in the region (SKM 2003). Elevated turbidity levels and reduced light attenuation are characteristic of the area. The desalination plant is not adversely affected by elevated turbidity because the process does not require the same level of water quality as reverse osmosis systems.

Minor elevations of turbidity at the industrial water intake are possible but numerical modelling has shown this to be unlikely. The dredging and disposal program is not expected to adversely affect the industrial water supply.

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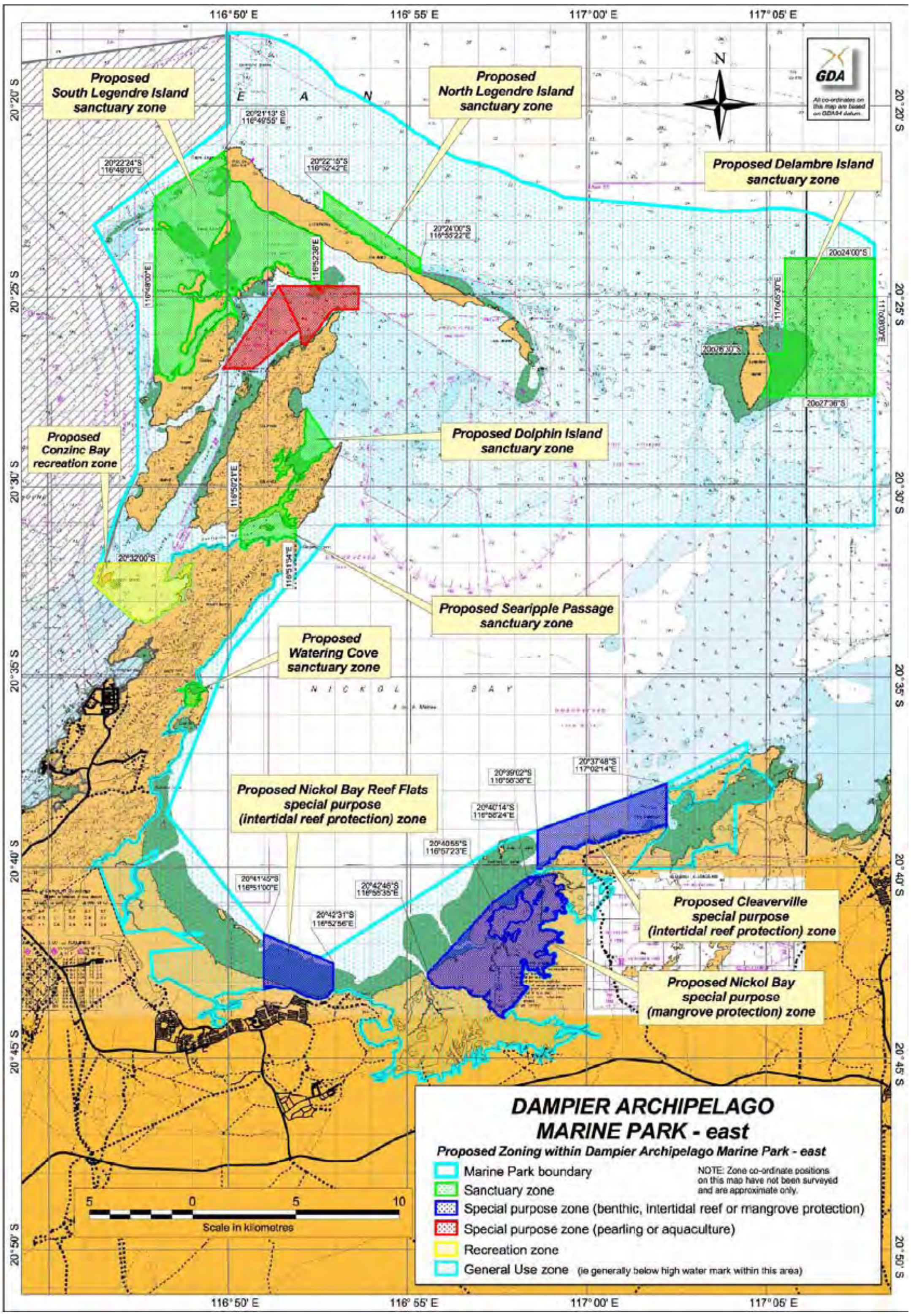

■ **Figure 4-12 Proposed Dampier Archipelago Marine Park East Zoning**

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4.7 Previous Dredging Environmental Monitoring

4.7.1 Effects on Water Quality

4.7.1.1 1998

In 1998 approximately 2.8 million cubic metres of fines sediments were placed on the East Lewis Island Spoil Ground by Hamersley Iron. Plume dispersion modelling and field measurements in 1998 concluded that only a small amount of finer silts and clays would be expected to settle outside the spoil ground.

Observations of spoil disposal from bottom dumping barges in 1998 showed that *"the majority of dredged material fell immediately to the seabed and the finer material was suspended and well mixed through the water column"* (Worley, 1998). Plumes generated by bottom dumping were measured and tracked over a 1 to 2 hour period, during which time plumes were observed to have effectively settled and dispersed. Typically plumes had dispersed within 400m (north-south) of the dump location, and the widths of the plumes were less than 100m (east-west). Turbidity monitoring at the spoil ground boundaries showed no impacts outside the spoil ground boundaries.

4.7.1.2 2004

In 2003, prior to the recent dredging works surveys of the East Lewis Island Spoil Ground were undertaken and comparisons between the post dredging surveys in 1998 and recent surveys undertaken in 2003 showed negligible change in the intervening period which indicates that the deposited material is stable.

More recently, in 2004, approximately 1.8 million cubic metres of fines sediments were placed on the East Lewis Island Spoil Ground. Dredged spoil was placed on the East Lewis Island Spoil Ground over a 7 week period, from April 2004 to June 2004. During the dredging and disposal activities turbidity monitoring and water quality monitoring was undertaken at adjacent coral communities three times/ week and plume monitoring by aerial photography weekly. In addition coral communities were monitored for signs of stress on a fortnightly basis. At the conclusion of the spoil disposal activities there was no measurable impact on coral communities located adjacent to East Lewis Island Spoil Ground.

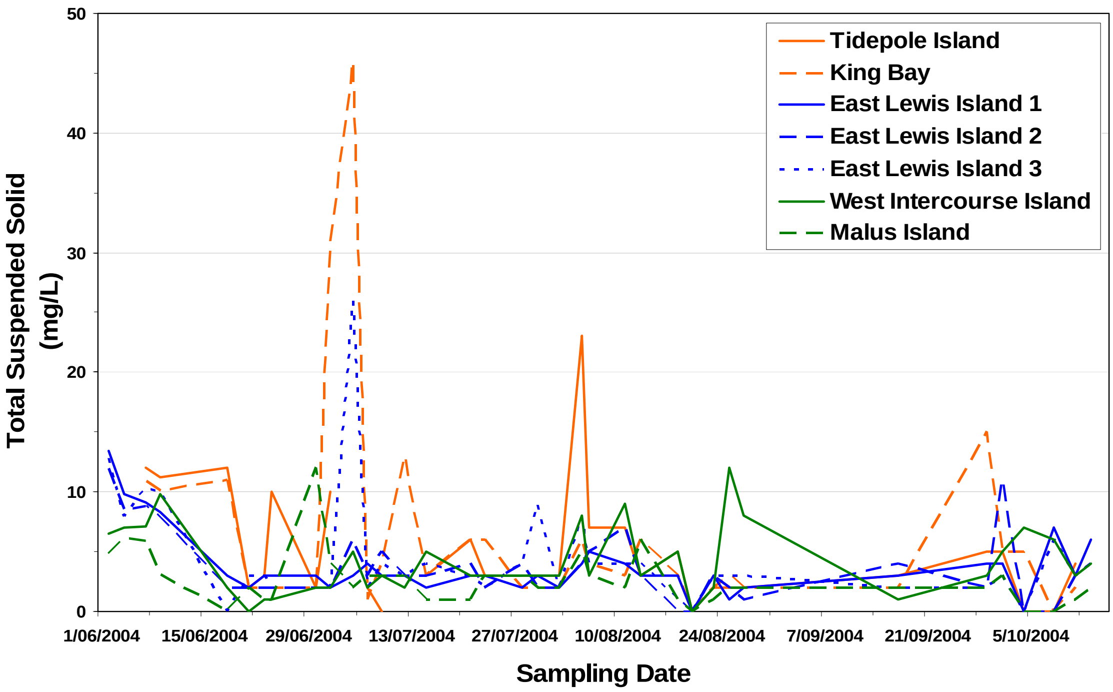
4.7.2 Effects on Water Quality

Significant elevation of total suspended solids levels (TSS) was restricted to sites within 1 km of dredging locations. This elevation of TSS appeared to be primarily as a result of propeller wash generated from the trailer hopper suction dredge while manoeuvring during uplift of dredge material (MScience 2005c).

Fortnightly monitoring did not detect a significant decline of coral cover at any of the impact sites associated with Hamersley Iron's dredging during 2004. The statistical capacity to detect a 10%

decline had a power of around 80% in the monitoring program. Locations showed no mortality when seabed TSS levels varied between 30 and 50 mg/L for short periods of time (1–2 days).

Seabed TSS levels monitored at near Parker Point (King Bay and Tidepole Island), near the East Lewis Island Spoil Ground (East Lewis Island 1–3) and at two reference locations (West Intercourse Island and Malus Island) are presented in **Figure 4-13**.



- **Figure 4-13 Seabed TSS levels during dredging and disposal**

4.7.3 Effects on Coral

Previous dredging undertaken in 2004 had no measurable effects on corals monitored. This is likely to be a result of a combination of coral tolerance to the water quality conditions during the dredging campaign and its duration as well as the management options employed to minimise and mitigate increased turbidity and sedimentation. The only coral mortality during the program was as a result of freshwater runoff from a cyclonic event.

4.8 Numerical Modelling

4.8.1 Model Development

Global Environmental Modelling Systems (GEMS) has undertaken plume modelling of propeller wash and spoil dumping impacts for the DPU dredging program. The modelling quantify impacts on water quality and the fate of sediments associated with the dredging program based on predicted tides and representative winds.

GEMS has completed two models, one for the ‘dry’ season from May to October and one for the ‘wet’ season, approximately November to March. The ‘dry season’ model was developed for the previous dredging program undertaken by Hamersley Iron in 2004, and the ‘wet season’ model developed as part of the current proposed dredging program for completeness. The two models cover any likely period in which dredging could occur (refer to **Appendix C** for a copy of both models). Given the proposed timing of the dredging program, it is likely that the ‘dry season’ model will be applicable.

The scope of work undertaken for the “dry season” models was as follows:

Dredge Spoil Disposal:

- Obtain and analyse suitable wind data for the period of the project;
- Establish, test and run the 3-d hydrodynamic model (GCOM3D) covering the Mermaid Sound region and adjacent waters for a period encompassing the planned dredging program;
- Scope the dredging program of works to develop model assumptions, including, in particular, sediment release volumes and rates resulting from propeller wash, overflow from the hopper and spoil ground dumping;
- Review geotechnical data on sediment types in the dredging;
- Run model simulations covering the period of operation and report on the fate of suspended sediments;

Cyclonic Re-suspension at Spoil Grounds

- Set up and test wave model;
- Select representative cyclone and run cyclone wind model;
- Run wave model and extract near-bed orbital velocities for a range of bathymetric scenarios;
- Run GCOM3D for this event to determine wind/tidal currents
- Run PLUMETRAK system based on combined circulation and wave driven currents for the bathymetric scenarios.

4.8.2 Modelling Results

The results of the modelling program for the 'dry season" show that "… *sediments flush out of the area of operation as a function of the tidal phase and predominating winds. During southwesterly wind events, this flushing tends to occur quickly as sediments move northwards up the Sound, while sediment levels are directed southwestwards under the impact of northeast winds. The easterly wind events increase sediment levels on the eastern side of East Lewis Island* (GEMS 2004)."

In addition "*The response of prospective spoil ground filling was investigated by considering the impacts of a significant tropical cyclone passing with its maximum winds directly over Mermaid the spoil grounds. The changes in bathymetry under these scenarios were found to exhibit very small relative differences in sediment re-suspension/deposition for the East Lewis Island spoil ground scenario. The effect for the 'worst" case at Spoil Ground No. 4 was a little more discernable, but relatively small in the context of likely total sediment movement across the whole of Mermaid Sound in such an event* (GEMS 2004)."

The predictions of the model were tested by a comprehensive water quality monitoring conducted during the 2004 dredging operations and found to be conservative in over-estimating the levels of suspended sediments and the life of plumes. While the extensive spread of plumes predicted by the model was confirmed, these plumes contained very low levels of suspended sediments. The model predictions that the primary source of concern for sediments was propeller wash from the trailer suction hopper dredge was confirmed.

The 2004 model was revisited based on additional data and a new set of predictions for spoil dispersal generated for the 'wet" season model. The model predicts essentially similar distribution of turbidity to the 2004 program. "*The results of the modelling program show that sediments flush out of the area of operation as a function of the tidal phase and predominating winds. During southwesterly wind events, this flushing tends to occur quickly as sediments move northwards up the sound, while sediment levels are directed southwest under the impact of the flood tide. The low frequency of easterly wind events and operation restrictions limit both turbidity and sediment levels on the eastern side of East Lewis Island* (GEMS 2005)."

The 'wet season' models shows that "*TSS levels are most affected at the northern spoil ground location. The locations nearest the dredging operation EL1, EL2 and TI are affected periodically depending on the proximity of operations and wind-tide conditions. The fact that EL2 is relatively unaffected, suggests that the operations restrictions (easterly winds) is limiting impact at that point. Similarly TI is rarely affected and then only to equivalent background levels. King Bay is virtually unaffected throughout the whole period of operation* (GEMS 2005)."

For more detail and modelling outputs, reference should be made to the models (refer **Appendix C**).

5. Environmental Impacts and Management Strategies

5.1 Introduction

The following section outlines the potential environmental impacts that may result from the dredging program. Potential impacts on the marine environment have been identified as:

- Release of contaminants;
- Increased turbidity;
- Decreased water quality (DO, pH);
- Hydrocarbon spills;
- Waste disposal (solid and liquid);
- Introduction of marine pests; and
- Decreased public amenity due to noise levels.

In addition, potential impacts to port operations and recreational vessel users need to be managed and minimised.

To ensure that these impacts are addressed and that the activities associated with the dredging program are managed to minimise impacts, management objectives and strategies have been developed and are detailed below for each environmental factor. To ensure that the management strategies are fulfilled and implemented, a number of management commitments have also been made by Hamersley Iron.

A Dredging and Dredge Spoil Disposal Management Plan (DSDMP) (see **Appendix A**) has been developed to ensure that the environmental impacts are minimised and that any management strategies or commitments detailed in this document are met. The monitoring program and contingency plans developed as part of the DSDMP will ensure that any excessive turbidity is identified within a reasonable timeframe and steps are taken to ensure that these events do not impact upon the marine environment. Hamersley Iron is committed to implementing this plan.

5.2 Marine Ecology

5.2.1 Management Objective

Maintain the integrity, ecological functions and environmental values of the seabed and nearshore areas.

5.2.2 Potential Impacts

Typically, the two main impacts of dredging on water quality are related to the release of contaminants and the effects of turbidity that may impact on marine species that are dependent on light.

5.2.2.1 Tributyltin

As indicated in **Section 4.1.7**, the sediments to be dredged as part of the maintenance program and some sediments from the capital program show contamination concentrations of Tributyltin (TBT) and hence the impacts of dredging and disposal of spoil could to lead to contamination of the area. TBT is used in as an active ingredient in marine antifouling paints and is, therefore, detected in the waters of most major harbours, and especially in sediments in the vicinity of dockyards and berths.

The TBT contaminated sediments will be removed by trailer suction hopper dredge at the commencement of dredging and placed in a depression within the Northern Spoil Ground (to be identified from Woodside post disposal surveys). The contaminated material will be covered with not less than one metre of clean spoil. Deposition of the TBT contaminated material in the midst of the grounds and subsequent cover by clean spoil should restrict the spread of any TBT contaminated material from the grounds. Where sediments escape, they are unlikely to retain any elevated levels of TBT which is likely to have been degraded to DBT or MBT due to oxygenation and mixing.[2]

5.2.2.2 Sediments

An identified risk from dredging is the effect of turbidity on corals. Decreased light penetration has the potential to adversely affect the nearshore coral communities in the area as many are hermatypic species that rely on light for survival. The natural turbidity of the area limits coral distribution to the nearshore waters in depths less than four metres (chart datum). Significant

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[2] A previous spoil disposal exercise by DPA in 2004 which involved the placement of a substantial amount of TBT contaminated spoil on the Northern Spoil Ground did not cause any detectable elevation of TBT in nearby sediments, nor did it lead to an increase in imposex in a nearby mollusc population. In the present instance, it is likely that there will be a similar lack of impact from TBT contaminated sediments to be placed on the Northern Spoil Ground (Pilbara Iron 2006).

turbidity loads could smother the corals reducing their ability to feed and to respire. In addition, if the dredging program spans the autumn coral spawning season (unlikely), the recruitment potential of the area could be reduced. **Figure 5-1** and **Figure 5-2** show the areas where potential physiological effects to coral may take place as a result of sedimentation.

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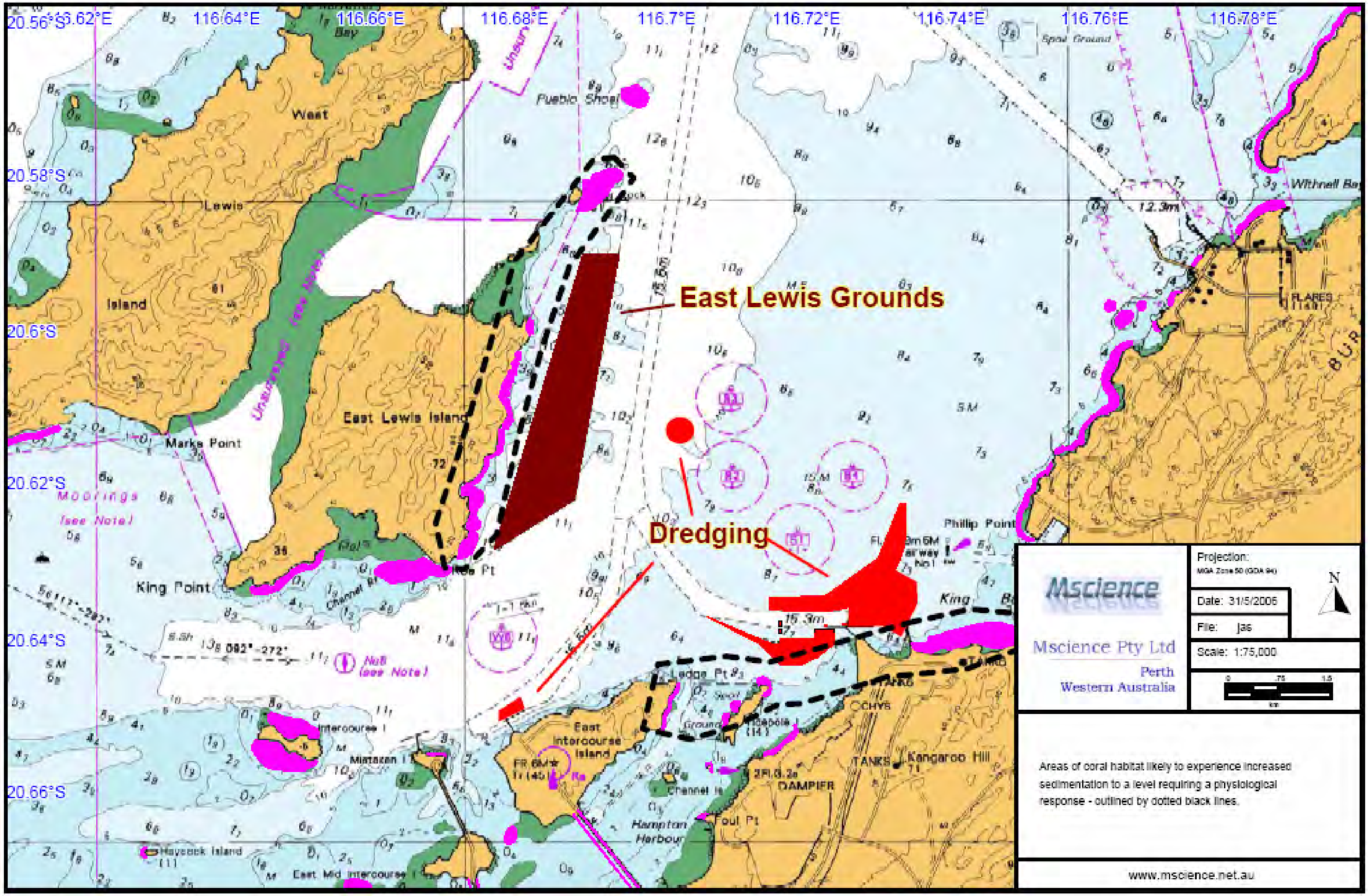

- **Figure 5-1 Potentially affected coral from dredging and disposal to ELI spoil ground**

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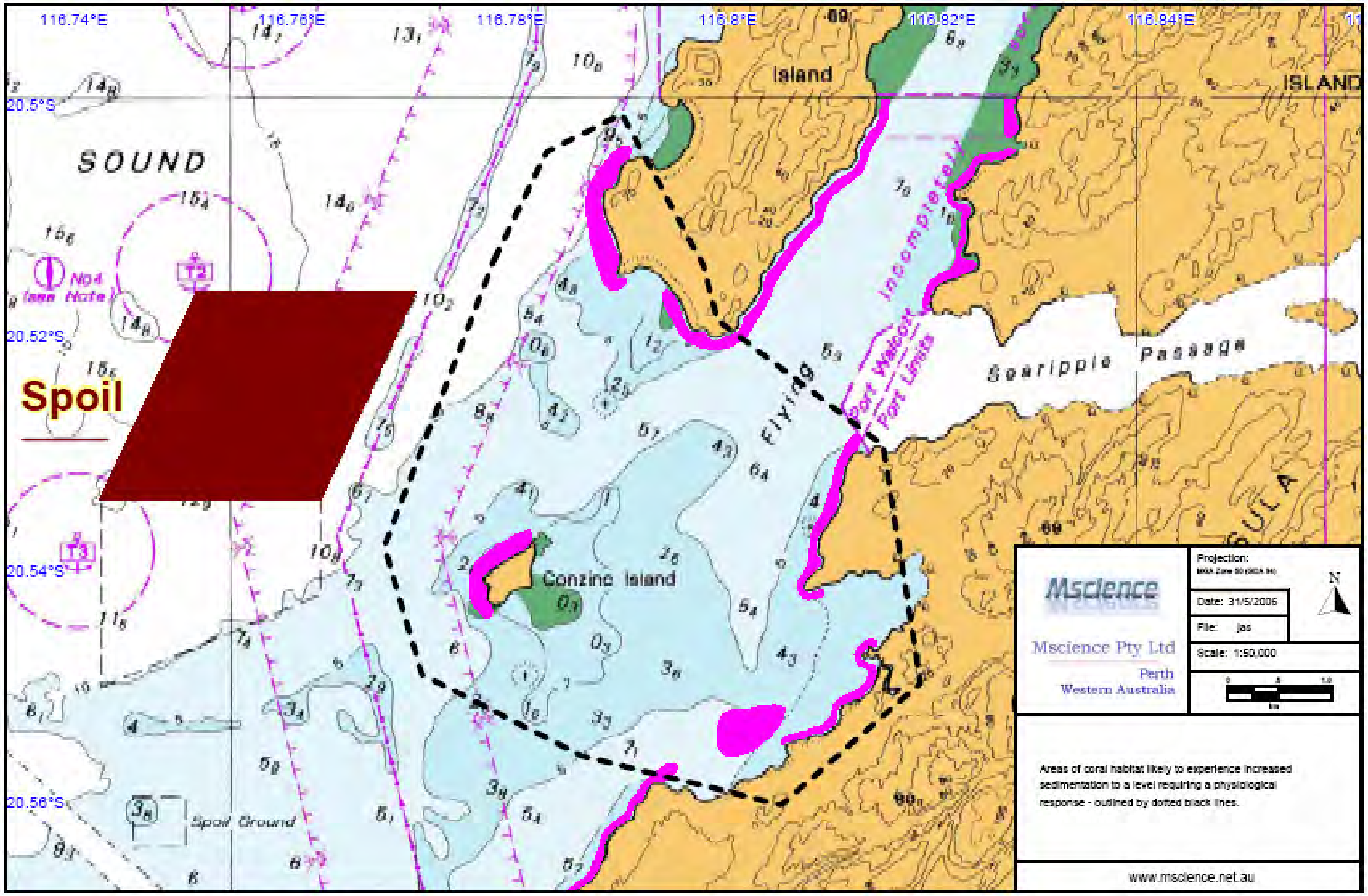

- **Figure 5-2 Potentially affected coral from disposal to Northern spoil ground**

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Past disposal at the East Lewis Island Spoil Ground from dredging at Hamersley Iron's port facilities has been monitored and the findings described in **Section 4.7.1**.

The sea disposal of sediments on the East Lewis Island Spoil Ground and the Northern Spoil Ground will continue to disturb soft bottoms, but presents little risk to the nearby coral communities located just off the East Lewis Island shoreline. Monitoring programs described in MScience (2005a) record no significant impact of spoil dumping at these grounds from the 2004 programs, although significant turbidity occurred over coral communities.

The present hypotheses of impact for the East Lewis Island Spoil Ground sea dumping component would be:

- Sedimentation will be extreme on spoil dumping grounds and cause the temporary loss of all benthic infauna which may have colonised this highly disturbed site since the last disposal program in 2004.[3]
- Plumes of turbid water which are visually apparent will occur for some kilometres around disposal sites, but be within the range of turbidity seen in those areas on windy days. An increase in deposition of fine sediments will occur in areas close to the spoil ground, but decline rapidly with increasing distance. This increase is likely to be within natural levels of variation for the area and not lead to a significant or lasting effect on biota.[3,4]
- Coral communities on the eastern shoreline of East Lewis Island adjacent to disposal sites will experience elevation of fine suspended sediments in the water column, but not suffer any mortality from the dredging program.[3]

The hypotheses of impact for the Northern Spoil Ground sea dumping component would be:

- Sedimentation will be extreme on spoil dumping grounds which will be likely to contain little biota as a result of the immediate past (Q1 2006) spoil disposal operation by Woodside.
- Plumes of turbid water which are visually apparent will occur for some kilometres around disposal sites, but be within the range of turbidity seen in those areas on windy days. An increase in deposition of fine sediments will occur in areas close to the spoil ground, but decline rapidly with increasing distance. This increase is likely to be within natural levels of variation for the area and not lead to a significant or lasting effect on biota. [3,4]

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[3] Based on previous monitoring of similar projects.

[4] Based on GEMS 2005 model.

- Coral communities at Conzinc Island, Conzinc Bay and Angel Island (which are the nearest to the disposal site) will experience elevation of fine suspended sediments in the water column, but not suffer any mortality from the dredging program.[3]

It is therefore considered that based on previous experience by Hamersley Iron (with dredging programs conducted within the Dampier Archipelago) and with similar recent dredging programs where there has been extensive monitoring undertaken, the potential impacts arising from increased turbidity, can be readily managed.

5.2.2.3 Marine Wildlife

There is a minor risk that marine wildlife such as dugong, whales and turtles may be vulnerable to injuries from increased boating activity generated by the dredging program. Marine mammals and reptiles are known to occur within the waters of the Dampier Archipelago and occasionally appear as transitory visitors to areas near the spoil grounds. However, they mainly frequent seagrass beds located in shallow bays and areas between some islands of the Dampier Archipelago (CALM 2005). There are no records of substantial seagrass beds within the project area, and the potential for dugongs and other marine mammals to be impacted by the proposed dumping program is considered to be low.

Marine reptiles recorded in Dampier Archipelago include four species of turtle [Green (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Flatback (*Natator depressus*) and Loggerhead (*Caretta caretta*)] and twelve species of sea snake, the Olive Sea Snake (*Aipysurus laevis*) being the most common. While all four turtle species have been recorded nesting on beaches within the Dampier Archipelago, the nearest nesting site to the project area is a secondary Green Turtle site at the north-eastern tip of West Lewis Island, some 4 km to the north of the spoil ground (Bowman, Bishaw Gorham 1994). This site is sufficiently distant from the spoil ground to expect that it will not be impacted by the proposed dumping program.

To reduce the potential risk of direct impacts on marine fauna, it is proposed to have a "spotter on board" to maintain a look out for dugongs, whales, turtles etc. In the event that dugongs, whales, turtles are sighted within near distance to the dredge or dredge hopper prior to start-up each day, start up will be delayed until the animal is sufficiently far away as not to be at risk from vessel movement. This procedure was applied to the 2004 dredging program with no impact or risk to marine fauna occurring throughout the duration of the dredging program.

5.2.3 Management Strategies

The DSDMP will be implemented for the project to provide the necessary framework such that the dredging program can be implemented efficiently and with minimal environmental impact (**Appendix A**). The objectives of the DSDMP are to:

- Identify potential impacts related to the dredging program;
- To ensure minimal impact on the Port of Dampier and surrounding environment from dredging;
- Monitor so that environmental effects are detected as early as possible;
- Have in place the appropriate contingencies to effectively mitigate impacts upon detection; and
- Report the progress and any environmental issues promptly to the DoE and the Dampier Port Authority.

The most effective means of minimising turbidity is to select the most appropriate work method and perform the works in the shortest duration.

Particular strategies that will be undertaken to minimise turbidity from the dredging program include:

- Turbidity will be minimised by using appropriate dredging methods. In particular, material dredged using a cutter suction dredge will be pumped directly to land disposal areas via a floating pipeline;
- The spatial extent of the dredging is large, which will allow a trailer suction dredge to relocate to alternative areas in the event turbidity levels build up during the works;
- Disposal in the East Lewis Island Spoil Ground will be restricted to a smaller, defined area within the overall limits of the approved spoil ground to minimise turbidity levels beyond the boundaries of the defined spoil ground. Alternate spoil grounds will be used if turbidity levels are raised for extended periods of time at the spoil ground boundary;
- Dredged material will not be double handled. To minimise turbidity when dredging hard material it is not proposed, and Contractors will not be permitted to pump slurry from the cutter suction dredge into hopper barges alongside;
- Overflow of trailer suction hopper dredgers will not be permitted for silty materials. The release of overflow water shall be as deep as possible to minimise surface plumes;
- Washing out of hoppers of trailer suction hopper dredgers and barges will only be permitted while such vessels are within the boundaries of the offshore dredge disposal area;
- Self propelled dredging plant will be equipped with DGPS and track logging equipment to ensure dredging and disposal activities are restricted to the nominated areas;
- Return water from the land disposal ponds will have the majority of slurry removed by settlement or by passive filtration through geotextile lined seawalls to minimise turbid water discharge; and
- Dredging will not occur during coral spawning, which occurs in March/ April each year.

5.2.4 Monitoring

Hamersley Iron will implement a similar monitoring program to that developed in consultation with Department of the Environment for the 2004 dredging program. Monitoring of dredging and disposal (Parker Point Spoil Area and at the East Lewis Spoil Ground) will be undertaken as outlined below:

- Water quality measures taken every three days to confirm that suspended sediment levels are not exceeding those occurring in 2004 to which corals were tolerant; with weekly aerial observations to visually assess migration of turbid plumes;
- Fortnightly estimates of coral health at impact and control sites to allow modification of dredging or disposal operations should mortality triggers be exceeded (should conditions prevent coral health monitoring for one event then management measures will be implemented to reduce turbidity at the site(s) affected. If conditions prevent the monitoring of corals for two consecutive events then dredging will cease until such time as coral monitoring can be undertaken); and
- Prior to and following the dredging program a survey of juvenile coral recruits will be undertaken. Recruits will be from last 2 years (less than 5 cm corals) as more recent recruits would not be visible.

Plume dispersion monitoring will comprise observations of dredge plume dispersal under a diversity of wind and tidal state conditions.

The coral health monitoring will employ the same sites and techniques used in the 2004 program and found to provide acceptable estimates of precision and power to detect change (Ch. 3 MScience 2005c).

The placement of spoil will be monitored through a vessel log maintained by the dredge operator, which will comprise data from the position fixing system corresponding to the times of dredge door opening and closing.

The potential build-up of fine particle fractions generated by dredging will also be investigated. A series of sediment cores will be collected from the upper 50 cm of sediment at sites adjacent to and distant from dredging no less than 2 weeks prior to commencement of dredging and then within 1 month of completion of dredging and disposal. A report will be prepared which will evaluate change in the relative size and coloration of the upper sediment particles and presence of in-fauna between the surveys to describe patterns of sediment change in the respective areas. This investigation will not form part of the compliance plan but rather a separate study.

Following completion of the dredging program, a bathymetric survey of the spoil ground will be undertaken. Data from this survey will be compared with the pre-dredging survey to evaluate changes in the seafloor bathymetry. The results of the post dredging program bathymetric survey will be forwarded to the DEH and the DoE.

Following completion of the disposal of spoil at the Northern Spoil Ground, Hamersley Iron will commence a program over 3 years to assess whether any elevation of sediment TBT in key areas around the spoil ground occurs and whether any impacts of elevated TBT levels are seen in the nearest susceptible populations of molluscs.

A detailed description of these monitoring programs is given in **Sections 7.5.2 – 7.5.3** of the DSDMP (**Appendix A**).

5.3 Hydrocarbon Management

5.3.1 Management Objective

Ensure hydrocarbons are handled and stored in a manner that minimises the potential for impact on the environment through leaks, spills and emergency situations.

5.3.2 Potential Impacts

Quantities of diesel fuel, oil, grease and some chemicals are handled on a regular basis during all dredging operations. The handling of hydrocarbons creates a potential risk to the environment in the event that spillage occurs. These spills may lead to the contamination of marine water within the vicinity of the spill and potential damage to intertidal marine habitats causing mortality of sensitive biota. Oil spills in the Dampier region have the potential of washing ashore into nearshore habitats of King Bay, Mermaid Sound and wider Dampier Archipelago due to the tidal nature of the region.

The main areas of risk during the dredging operation are:

- Refuelling of the dredge (bunkering);
- Storage and handling of oils, grease and chemicals; and
- Breakdown of grease on moving parts such as the cutter ladder and spud carriage.

5.3.3 Management Strategies

Refuelling

Refuelling of the dredge will be carried out in a manner approved by the DPA. DPA currently permits fuel bunkering only to be undertaken while tied up alongside a berth. The chance of an oil spill under these circumstances is minimal. During all fuel transfers the Master of the vessel is responsible for directing and controlling the operation and all crew.

The following mitigation procedures will be used to reduce the risks to as low as reasonably possible:

- Work instruction will be prepared to provide guidelines for all staff and crew to ensure the potential risk is kept to a minimum;
- A project specific Oil Spill Contingency Plan (OSCP) will be prepared by the dredging contractor in consultation with the DPA and will be consistent with Hamersley Iron's OSCP that is in place for the port operation;
- Refuelling will only take place under favourable wind and sea conditions;
- The fuel level in the tanks will be monitored during refuelling in order to avoid overflow;
- The dredge will have a spill kit on board (oil booms, absorbent pads and oil dispersing detergents) ready for prompt response in the unlikely event of a spill; and
- The Master of the vessel will be responsible for reporting any spill of fuel, oil or chemicals to the marine environment and for ensuring spill equipment is deployed in a timely and effective manner if required.

Storage of Oils, Grease and Chemicals

The bulk of all oil and grease will be stored in storage tanks on the dredge and drums will be stored below deck whenever possible. All chemicals, detergents etc will be stored below deck in the appropriate holds.

Hydrocarbons located above deck will be stored within bunded areas to contain any leaks or spills. Spill response kits will be located in close proximity to storage areas for prompt response in the event of a spill or leak.

Breakdown of Grease on Moving Parts

Grease is commonly used to lubricate cutter shafts and spud carriages and these parts are in contact with the water. Consequently there is the risk of small amounts of grease discharged into the water. This will be mitigated by the following measures:

- Work instructions will be prepared to provide guidelines for all crew to ensure the potential for discharge is kept to a minimum;
- Automatic greasing mechanisms will be monitored to minimise grease consumption without affecting functionality of moving parts;
- Where possible, biodegradable greases will be used; and
- The dredge will have scoops/nets on board ready to collect any grease discharged into the water.

5.3.4 Monitoring

Regular inspections of the hydrocarbon storage and handling areas will be undertaken to ensure that hydrocarbon products are being managed in an appropriate manner and that no spillages or leaks have occurred.

5.4 Waste Management

5.4.1 Management Objective

Ensure that the generation of waste is minimised and that any waste products produced are handled and disposed of in an acceptable manner.

5.4.2 Potential Impacts

If not handled correctly, solid waste and sewage produced during the dredging program has the potential to contaminate marine, ground and surface waters, impact upon marine fauna and pose a risk to human health.

5.4.3 Management Strategies

Solid Wastes

Domestic rubbish produced on the dredge and support vessels will be collected and disposed of on land to the Shire of Roebourne Landfill. Empty oil and chemical containers such as metal or plastic drums will be returned to the supplier for reuse or recycled where possible. Absorbent material used to clean up minor oil or chemical spills will be disposed of appropriately as contaminated material.

Sewage Waste

Sewage from toilets at the shore facilities will be disposed to an appropriate sewerage system or to a sullage tank then removed by a licensed contractor. Sewage from the dredge and support vessels will be collected and pumped out and disposed to an appropriate disposal facility by a licensed contractor. No sewage from the dredge or support vessels will be disposed to the marine environment while operating in the Port.

5.4.4 Monitoring

Regular inspections of the waste management areas will be undertaken to ensure that waste products are being managed in an appropriate manner.

5.5 Ballast Water and Marine Pest Management

5.5.1 Management Objective

Ensure that the Australian Quarantine and Inspection Service (AQIS) and Dampier Port Authority guidelines and Mandatory Ballast Water Management Arrangements are complied with.

5.5.2 Potential Impacts

Ballast water from coastal areas in other parts of Australia or overseas has the potential to introduce marine pest species that may impact upon the marine communities of Mermaid Sound and the Dampier Archipelago. Marine pest species can be transported within ballast water or on ship hulls. Large populations of marine pest species are capable of invading new ecosystems, disturbing the ecological balance of existing marine communities and potentially impacting on recreational and commercial fisheries and aquaculture.

5.5.3 Management Strategies

Australian Quarantine and Inspection Service (AQIS) and DPA guidelines and Mandatory Ballast Water Management Arrangements will be followed. These guidelines and arrangements require (as a minimum):

- Accurate reporting to AQIS regarding ballast water arrangements;
- Mandatory access to safe onboard ballast sampling points;
- If required, undertaking exchange and/or other treatment/management options as directed by AQIS prior to discharge of ballast water in Australian waters;
- No discharge of ballast water within Australian water without prior written permission from a Quarantine Officer; and
- Completion of an ‘audit and advice procedure’ as stated in the Port of Dampier Environmental Management Plan which ensures that the vessel has been accepted by AQIS, ballast water exchange has occurred at sea remote from coastal influences and a record of the time and position of re-ballasting is kept.

Should the dredge or support vessels be brought in from outside Australian waters then they will also comply with the Australian Quarantine Regulations 2000. All vessels engaged in the dredging program whose last port is overseas based will be inspected prior to departure for Dampier. This inspection will certify that the vessel is clean and contains no muds or other material that may introduce pests into Australian waters.

The hull of the dredge will be clean and free of attached organisms prior to being brought into Dampier. All internal compartments and associated dredge pipelines and fittings that come in contact with dredge spoil will have been cleaned and thoroughly flushed through with clean seawater prior to arrival. The dredge will be inspected upon arrival and if found to contain evidence of material from previous dredging it will be sent offshore for flushing (outside 12 nautical mile limit and in water depth of at least 200 m).

Any pipelines or fittings found to contain evidence of dredge material will be taken ashore and cleaned using high pressure water hoses. The effluent will be prevented from entering drains or from discharging into the water.

5.5.4 Monitoring

All vessels involved in the project will be monitored for compliance with the above requirements.

5.6 Noise

5.6.1 Management Objective

Ensure that the noise levels from the dredging works comply with statutory requirements and acceptable standards.

5.6.2 Potential Impacts

Limited noise data is available for noise emissions from dredges, however it is anticipated that based on previous dredging programs conducted by Hamersley Iron, noise from the dredges will not be a major contributor to noise levels within the town of Dampier. Hamersley Iron received no noise complaints during previous dredging programs. Most of the dredging works will take place some distance offshore and the town of Dampier is sufficiently far away from the dredge operation such that noise levels received in the town will be almost inaudible.

5.6.3 Management Strategies

Noise from the dredges will be reduced wherever possible.

5.6.4 Monitoring

If complaints in relation to noise from the dredging operations are received on Hamersley Iron's existing complaints hotline, the complaint will be investigated and the identified cause of the noise examined to determine whether any action can be taken.

Occupational noise surveys may be undertaken on the dredge during the dredging operation.

5.7 Vessel Movement Management

5.7.1 Management Objective

Ensure that the dredging works does not result in any interference with commercial shipping vessels and that possible collisions with other vessels are avoided.

5.7.2 Potential Impacts

Hamersley Iron's Parker Point Wharf and East Intercourse Island Facilities are used regularly for loading vessels with iron ore. In addition, commercial vessel movements to and from the Dampier Salt Wharf on Mistaken Island and other areas within the Port of Dampier occur. There are also a number of recreational vessels used within the area. Potential impacts include interference with other vessels by the dredges and in extreme cases, collision with other vessels.

5.7.3 Management Strategies

Collision Prevention

Prevention of collision with vessels including tugs and iron ore carriers servicing other berths in the Port will be the main objective of planning the dredging schedule. The DPA will issue Notices to Mariners prior to commencement of the dredging. Incoming vessels will be made aware of the location of the dredge and any obstructions such as floating or submerged pipes, anchoring cables, piles and support vessels by the DPA. The dredge will be required to give shipping priority. Collision prevention procedures will be discussed between the dredge operator, Hamersley Iron and the DPA.

Scheduling and Communications

Dampier wharfs are actively used for loading vessels. The dredging operations will, therefore, be scheduled to work in with vessel movements. The intention will be to conduct dredging of the berthing pocket of the wharf during periods when no vessels are scheduled to be berthing or departing. The dredge and support vessels will maintain radio contact with Hamersley Iron and the DPA so they can be kept informed of planned shipping movements and can inform Hamersley Iron and the DPA of planned dredge position and support vessel movements.

5.8 Recreational Activities

5.8.1 Management Objectives

Ensure that dredging does not unduly interfere with recreational activities and public boating amenity.

5.8.2 Potential Impacts

The dredging works are mainly restricted to existing navigation channels and berthing areas. These areas are prohibited to recreational craft and therefore impacts should be minimal.

5.8.3 Management Strategies

Notices to Mariners will be issued in conjunction with DPA advising of the location and extent of dredging works.

Table 5-1 Summary of Environmental Issues and Management

Environmental Factor	Management Objective	Existing Environment	Potential Impacts	Management Strategies	Predicted Outcome
Biophysical					
Marine Ecology	Maintain the integrity, ecological functions and environmental values of the seabed and nearshore areas.	Benthic habitat within Port of Dampier consist predominantly of: ▪ Soft sediment (silt and sand); ▪ Macroalgae on hard substrate; and ▪ Hard coral on hard substrate. In King Bay hard coral occurs in small to large patches. Between Parker Point and East Intercourse Island Bay hard coral occurs in small patches. Marine mammals such as dugong and whales are known to occur within the Dampier Archipelago, although are likely to be rare visitors to the southern end of Mermaid Sound adjacent to Parker Point or East Lewis Island. Significant turtle nesting beaches occur on the outer islands of the Archipelago.	The greatest risk from dredging will be the potential effect of turbidity on corals. Significant turbidity loads could smother the corals reducing their ability to feed and to respire. In addition, if the dredging program spans the autumn coral spawning season, the recruitment potential of the area could be reduced. There is a minimal risk of direct impact from boats or propellers on the larger marine animals.	▪ A Dredging and Spoil Disposal Management Plan will be implemented. ▪ Turbidity will be minimised by using appropriate dredging methods. ▪ Disposal in the East Lewis Island Spoil Ground will be restricted to a smaller, defined area within the overall limits of the spoil ground to minimise turbidity levels beyond the boundaries of the spoil ground. ▪ Where practicable, dredged material will not be double handled. ▪ Turbid water discharge from land disposal will be minimised through settlement ponds, or filtration through geotextile lined seawalls. ▪ A monitoring program will be implemented with appropriate contingency plans if trigger values are exceeded. ▪ There will be a "spotter on board" to maintain a look out for dugongs, whales, turtles etc.	The dredging program is unlikely to have a significant long term adverse impact on the marine ecology in Mermaid Sound.
Introduction of Exotic Organisms	To minimise the risk of introduction of unwanted marine organisms by ensuring that the AQIS and DPS guidelines and	No survey of the harbour for exotic organisms has been undertaken.	There is the potential that ballast water and hulls of vessels may introduce exotic marine organisms that may impact upon the marine communities of Mermaid Sound and the wide Dampier Archipelago.	▪ AQIS and DPA guidelines and Mandatory Ballast Water Management Arrangements will be followed. ▪ Should the dredge or support vessels be brought in from outside Australian waters they	The dredging program is considered to have a minimal risk of introduction of exotic marine organisms.

Environmental Factor	Management Objective	Existing Environment	Potential Impacts	Management Strategies	Predicted Outcome
	Mandatory Ballast Water Management Arrangements are complied with.			will comply with the Australian Quarantine Regulations 2000, ie vessels to arrive with non-fouled hulls and undertake hopper washing and ballast water exchanges in full accordance with AQIS ballast water guidelines. ▪ The hull of the dredge will be clean and free of attached organisms prior to being brought into Dampier. All internal compartments and associated dredge pipelines and fittings that come in contact with dredge spoil will have been cleaned and thoroughly flushed through with clean seawater prior to arrival.	
Pollution Management					
Marine water quality	To maintain or improve marine water quality to protect environmental values in accordance with Environmental Quality Criteria defined in *Australia and New Zealand Water Quality Guidelines* (ANZECC 2000)	▪ Water Quality in the area of the dredging program is generally high. ▪ Natural water turbidity varies during the year as a result of wind and wave action. ▪ Sediments to be dredged show contamination concentrations for TBT.	The dredging program will result in a temporary, localised increase in turbidity down stream of dredges.	▪ TBT contaminated sediments will be placed in the Northern Spoil Ground and covered by clean fill. ▪ Turbidity will be minimised by using appropriate dredging methods. ▪ Turbid water discharge from land disposal will be minimised through settlement ponds, or filtration through geotextile lined seawalls. ▪ An extensive monitoring program will be implemented with appropriate contingency plans if trigger values are exceeded.	The dredging program is unlikely to have a significant long term adverse impact on the water quality in Mermaid Sound.
Hydrocarbon	Ensure	▪ There is no offshore refuelling	Large quantities of diesel fuel,	▪ A project specific Oil Spill	Low risk of oil or

Environmental Factor	Management Objective	Existing Environment	Potential Impacts	Management Strategies	Predicted Outcome
Management	hydrocarbons are handled and stored in a manner that minimises the potential for impact on the environment through leaks, spills and emergency situations.	occurring at the Dampier Port. ▪ Oil spills are currently managed through the Port of Dampier Marine Pollution Contingency Plan. ▪ Existing standard operating procedures are in place to prevent spillage during refuelling at the wharf.	oil, grease and some chemicals will be handled during the dredging operations, which creates a potential risk to the environment in the event that spillage occurs. These spills may lead to the contamination of marine water within the vicinity of the spill and potential damage to intertidal marine habitats causing mortality of sensitive biota. The potential for fuel or oil spillage during dredging operations may occur from: ▪ Refuelling of the dredge; ▪ Storage and handling of oils, grease and chemicals; and ▪ Breakdown of grease on moving parts such as the cutter ladder and spud carriage.	Contingency Plan will be prepared in consultation with DPA and implemented by the contractor. The OSCP will be consistent with that which is currently in place and administered by Hamersley Iron. ▪ Appropriate storage of oils, grease and chemicals.	fuel spill and responses to any such spill are efficient in the unlikely case of a spill event.
Liquid and Solid Waste Disposal	Ensure that the generation of waste is minimised and that any waste products produced are handled and disposed of in an acceptable manner.	Waste generated within the Dampier area goes to the Karratha landfill.	If not handled correctly, solid waste and sewage produced during the dredging program has the potential to contaminate marine, ground and surface waters, impact upon marine fauna and pose a risk to human health.	▪ All solid waste will be collected and disposed at a suitable site. ▪ Sewage from dredge and support vessels will be collected and disposed to an appropriate disposal facility by a licensed contractor.	Solid and liquid wastes will have negligible impact on the environment.
Noise	Ensure that the noise levels from the dredging works comply with statutory requirements and acceptable standards.	Current sources of noise include: ▪ Movement of vessels in and out of the Port; ▪ Iron ore bulk handling and other materials handling operations by Hamersley Iron; ▪ Movement of iron ore trains in and out of port facilities.	Dredging and reclamation activities are potential sources of noise. Most of the dredging works will take place some distance offshore and the town of Dampier is sufficiently far away from the dredge operation such that noise levels received in the	Noise from dredges will be reduced wherever possible.	No adverse noise impacts are anticipated as a result of the dredging program.

Environmental Factor	Management Objective	Existing Environment	Potential Impacts	Management Strategies	Predicted Outcome
		▪ Truck and vehicle movements at the port and in the Dampier town	town will be almost inaudible.		
Social Surroundings					
Commercial Vessel Movement Management	Ensure that the dredging works does not result in any interference with commercial shipping vessels and that possible collisions with other vessels are avoided.	Current ship movements within the Dampier Port include: ▪ Vessels loading iron ore at the Parker Point Wharf and East Intercourse facilities; ▪ Vessels accessing the Salt Wharf on Mistaken Island; ▪ Vessels accessing the Woodside Supply Base; ▪ LNG tankers from the Woodside facility; and recreational vessels; and ▪ Recreational vessels around Dampier and the Dampier Archipelago.	Potential impacts include interference with other vessels by the dredges and in extreme cases, collision with other vessels.	▪ Dredging will be scheduled to work in with vessel movements. ▪ The DPA will issue Notices to Mariners prior to commencement of dredging. ▪ The dredge and support vessels will maintain radio contact with Hamersley Iron and the DPA so they can be kept informed of planned shipping movements and can inform Hamersley Iron and the DPA of planned dredge position and support vessel movements.	No adverse impacts on vessel movements are anticipated as a result of the dredging program.

6. Consultation

Hamersley Iron has undertaken an extensive community and stakeholder consultation program for the Dampier Port Upgrade project; this stakeholder consultation program is ongoing. The consultation program focussed on delivering information and seeking feedback from those key stakeholders either participating in the environmental approval process or likely to be affected by the project.

This consultation program involved meetings, briefings and community displays, and involved various stakeholders including:

- Government Departments and Agencies;
- Local Community; and
- Local Hamersley Iron workforce.

For the dredging maintenance and capital works program, Hamersley Iron specifically consulted with:

- Dampier Port Authority;
- Dampier Spoil Ground Management Group;
- Shire of Roeburne;
- Department of Planning and Infrastructure (Karratha);
- Environmental Protection Authority Service Unit;
- Department of Environment Marine Group;
- Conservation and Land Management; and
- Department of the Environment and Heritage.

Other stakeholders less likely to be directly affected have been provided with general information using information displays and an information newsletter. Hamersley Iron has conducted open days including advertised public information displays at Dampier and Karratha shopping centres to provide the community with information on the progress of the construction activities (including dredging) for the Dampier Port Upgrade Project. Public information days were held in October 2005 and February 2006. In addition regular meetings held with the Dampier Community Advisory Group have had briefings and updates on the dredging program provided.

A summary of the community consultation program, showing the stakeholders consulted and the issues and responses raised is given in **Table 6-1**.

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Table 6-1 List of Issues Raised by Stakeholders and Hamersley Iron's Response

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
Department of the Environment and EPA Service Unit	Cam Sim (DoE) Mark Jefferies (EPASU) Peter Royce (PI) Jim Stoddart (MScience) Lyle Banks (SKM) Peter Morrison (SKM) Richard Galloway (SKM)	26/8/2005	Meeting to outline scope of dredging program and approval process.	A copy of minutes of 26/8/2005 meeting is attached.	
				ARI to include: ▪ GEMS Model ▪ Management Plan ▪ Description of areas being dredged and justification	ARI document to EPA will include these inputs
				Issues will be: ▪ Spoil movement – where and what impacts (last cyclone resulted in large volume of material being relocated) ▪ Survey data from Northern Spoil Grounds to be reviewed –stability history	ARI will address these aspects
				GEMS Model to be re-evaluated based on: ▪ Monitoring results from previous dredging, where model over predicted sediment levels) ▪ Hydro dynamic input required ▪ Wind-field data appropriate to the location	GEMS model being re-evaluated and will be included in ARI
				Establishment of permanent transects for monitoring	Permanent transects will be established.
				The inclusion of maintenance dredging in assessment to be discussed with Wally Cox	Action for EPASU.
					DSDMP will be lodged with

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
				Management Plan to be reviewed by CS prior to submission. Discuss issues with CALM in relation to Marine Park (CALM to be present at next DPA meeting 31 August) DPA spoil guidelines available – review for ARI Murray Hogarth to handle assessment with technical input from Marine Branch (back from leave 5/9/05)	ARI and draft submitted to CS in advance. CALM has indicated it has no specific issues with the dredging programs in relation to the Marine Park. CALM sits on Spoil Ground Management Group meetings. Contact to be made upon referral in 2006.
Spoil Ground Management Group – Co-ordination Meeting No. 5	Attendees: Stephen Nicholson (DPA) Ron Hutchinson (Baggermans/DPA) Vic Justice (DPA) Peter Smith (DPA) Angela Kennedy (DPA) Matt Johnston (DEH by phone) Kellie Parker (PI) Peter Royce (PI) Lyle Banks (PI/SKM) Richard Cohen (PI)	31/8/2005	Meeting held at Dampier Port Authority Offices, Dampier. Co-ordinated by DPA.	"The meeting had no issues with accepting the 0.5Mm^3 of maintenance dredging from the HI/PI work into the existing spoil grounds subject to it being suitable for unconfined marine disposal. With respect to capital dredging, there was likely to be capacity however the amount available was subject to capacity surveys to be undertaken following completion of the WEL LNGV dredging due to commence in October 2005."	Comments and questions from a number of attendees are highlighted in the meeting minutes – none required specific follow up.

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
	Neville Bryant (Woodside) Geoff Prior (Chevron Texaco) Anne Trevena (DoE) Jim Stoddart (PI/Mscience) Steve Lewis (DPA CEO) Fran Stanley (CALM)				
Department for Planning and Infrastructure - Karratha	Krissy McNamee Manager Great Northern John Drummond Regional Transport Officer Welcome Road, KARRATHA Peter Royce (PI)	9/9/2005	Briefing and meeting with DPI officers.	Project scope for Dampier Port Upgrade capital and maintenance dredging was outlined, as was port land works and artificial reef/coral translocation. Issues raised in relation to dredging programs: Issue 1. Queried whether the ELI spoil ground (post dredging) would result in exposure at low tide - this is safety issue for recreational boats users Issue 2. Need to ensure that any Mariner Notice that is issued for boating exclusion zones are made very visible at boat launching ramps during both maintenance and capital dredging programs Issue 3. Queried who is managing the dredging works and the duration of the dredging program	Responses to queries were provided at meeting. No written follow-up was provided. Response 1: spoil placement at ELI spoil ground would not result in exposure at low tide. Recreational boats would not be affected post-spoil placement at ELI. Response 2: Any such Marine Notice would be displayed in a highly visible location at the boat launching ramp. Response 3: HI advised DPI that SKM will be managing the dredging works as they did for 2004 dredging program. The duration of dredging was expected to

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
					be 10-12 weeks.
Mine Open Day	37 Dampier/Karratha residents visited displays and sought out personnel manning the display. This was portion of the estimated 400 people that attended the Open Day and went on tours of Dampier port and rail operations	15/10/2005	Information displays and tours of Parker Point and East Intercourse Island and Rail operations. Posters displayed providing information on the DPU95, DPU120 and DPU145, including dredging. Displays manned and based at Dampier Training Centre.	One query related to scope of works associated with dredging/additional berth pocket at Parker Point.	Information provided on the scope of dredging, the environmental approval process and likely timing and the operation of the Parker Point wharf with four berths.
Department for Planning and Infrastructure - Karratha	Raymond Buchholz Regional Services Manager PO Box 429 KARRATHA WA 6714	28/11/2005	Letter outlining capital and maintenance dredging program, approvals process and environmental management. Comments or additional information requested by 16 December 2005.	No response received	Not applicable
Department for Planning and Infrastructure - Fremantle	Cleve Flotman Manager, New Coastal Assets Branch PO Box 402 FREMANTLE WA 6959	28/11/2005	As above	No response received	Not applicable
Department for Planning and Infrastructure - Fremantle	Vivienne Panizza Coastal Policy and Protection Management Unit PO Box 402 FREMANTLE WA 6959	28/11/2005	As above	No response received	Not applicable
Dampier Port Authority	Steve Lewis Chief Executive Officer	28/11/2005	As above	DPA provided written comments in letter dated 8 December 2005 (received 29 December 2005).	PI responded to the issues raised by the DPA in a letter dated 31 January 2006.

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
	PO Box 285 DAMPIER WA 6713			Key issues raised: Issue 1. The DPA commented that the 28 November 2005 letter does not provide a clear reconciliation of dredge material volumes with spoil ground capacity and requests that such reconciliation is provided to the DPA in due course. Issue 2. The DPA stated that it is not clear what the scope is for survey works for the proposed dredging program and that it assumes previously published survey standards set by the Harbour Master will be applied.	Below responses paraphrase HI response. Response 1. PI indicated it will provide the DPA with a copy of our application for a Sea Dumping Permit scheduled to be submitted to the Commonwealth DEH by end January 2006. The requested reconciliation of dredge material volumes against spoil ground capacity at the East Lewis Island Spoil Ground and the Northern Spoil Ground to the DPA will be contained in that sea dumping application. It is envisaged that this reconciliation will use the DPA Spoil Ground Management Plan as the basis for determination of spoil ground capacity. Response 2. PI stated that the Sea Dumping Permit application will show the areas to be dredged and these areas have been surveyed, as did the attachment to the 28 November 2005 letter. Previously published survey standards set by the DPA Harbour Master have been used for the dredging program.

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
				Issue 3. The DPA requested that, as part of the proposed dredging program, PI survey an approach track for East Intercourse and Mistaken Island on the western side of the existing departure channel, Hampton Harbour, infill survey between existing departure channels and the DPA channel.	Response 3. PI advised that areas proposed to be dredged have already been surveyed and that no additional surveys are scheduled. Should PI commission a survey vessel to undertake further survey work in the area, we may discuss commercial arrangements for undertaking the additional survey of the areas specified by the DPA. It should be noted that PI has previously provided the results of the surveys of the Hampton Harbour tug pen channel and spoil grounds to the DPA. Post-dredging surveys undertaken as part of the proposed dredging program will be provided to DPA once completed.
				Issue 4. The DPA advised that all survey work completed in the port should be verified by DPA's authorised representative (Baggerman Associates) and that final verified data and plots should be provided to the Harbour Master to enable the charts to be updated by the hydrographer.	Response 4. HI stated it will provide copies of all survey work for the proposed dredging program to DPA's authorised representatives and the Harbour Master as advised.
				Issue 5. The DPA requested a copy of the engineering report confirming the additional dredging in Area F in 2004 has not reduced the sheet pile toe capacity of the Parker Point	Response 5. HI advised that a stand alone report was not prepared after the last dredging campaign but an

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
				Service Wharf.	engineering check was done which confirmed that the integrity of the service wharf has not been compromised. The dredging was to 3m of the line of caissons and nominally 1m deep. The sheet pile sections are clutched full length and form a number of cylindrical caissons which provide an inherently stable structure with minimal radial (outward) pressure on the pile toes. From the original drawings the sheet piles were driven to refusal.
				Issue 6. The DPA suggests that PI consider completing some beach replenishment in Hampton Harbour as an environmental offset for the dredging program.	Response 6. HI advised that environmental offsets have not been part of routine dredging operations in the past and PI does not believe that the dredging proposed would result in sufficient impact as to require any offset. Thus, no community or environmental offset is planned for the proposed dredging program. Further, the loss of sand from Hampton Harbour beaches is unlikely to be related to dredging per se and it would be inappropriate to link the two

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
					phenomena.
				Issue 7. The DPA requested that PI install new navigational aids in consultation with the Harbour Master at East Cardinal and another at Conflict Reef.	Response7. PI advised it is currently reviewing the operational need for an East Cardinal Marker. With respect to Conflict Reef, PI believes that this is a port operational matter that is un-related to either the maintenance or capital dredging programs and therefore should not be linked to the dredging proposal. In the event that we mobilise vessels and equipment to undertake work on existing or new navigational aides in the near future, PI may enter into negotiations with the DPA in relation to its request and associated costing arrangements.
				Issue 8. The DPA advised that it is planning a study to compare recovery of coral impacted at SUPB by DPA dredging against the recovery of corals at West Lewis Island impacted by freshwater from Cyclone Monty.	Response 8. As this study appears to be a response to Ministerial conditions of the environmental approval for the DPA dredging program conducted in 2004, PI believes this study is best undertaken and sponsored by the DPA. Separate to the current proposed dredging program, PI would be prepared to discuss DPA's wish to pursue the

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Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
					publication of the results of such a study jointly with ongoing coral research supported by PI.
Dampier Port Authority	Peter Smith Manager Environment & Community Liaison PO Box 285 DAMPIER WA 6713	28/11/2005	As above	As above	Not applicable
Hampton Harbour Boat and Sailing Club Inc	John Lally Vice-Commodore. c/o Hampton Harbour Boat and Sailing Club Inc The Esplanade DAMPIER WA 6713 Also Committee member of Dampier Archipelago Marine Reserve and Director of Centre for Whale Research WA	28/11/2005	As above	No response received	Not applicable
Department of Environment, Northwest Regional Office	Anne Trevena Environmental Protection Program Manager PO Box 836 KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
Hampton Harbour Boat and Sailing	Peter Nash	28/11/2005	As above	No response received	Not applicable

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
Club Inc	Commodore c/o Hampton Harbour Boat and Sailing Club Inc The Esplanade DAMPIER WA 6713				
Hampton Harbour Boat and Sailing Club Inc	The Committee Hampton Harbour Boat and Sailing Club Inc The Esplanade DAMPIER WA 6713	28/11/2005	As above	No response received	Not applicable
Shire of Roebourne	Bob Sharkey Manager – Planning Services PO Box 219 KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
Department of Fisheries	Terry Molloy 1/17-19 Crane Circle KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
Department of Conservation and Land Management	Stephen White PO Box 835 KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
Dampier Archipelago Dwellers Association	Mike Fleming PO Box 444 KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
Woodside Marine	Wynne James Manager GPO Box W2006 PERTH WA 6846	28/11/2005	As above	No response received	Not applicable
Australian Maritime Systems Ltd	Nick Bosco 2 Hines Road O'CONNOR WA 6163	28/11/2005	As above	No response received	Not applicable
King Bay Game Fishing Club	Dennis Brian-Smith President PO Box 179 KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
Discovery Sailing Adventures	Brad Beaumont PO Box 960 KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
Dampier Island Tours	Shane Peters PO Box 248 DAMPIER WA 6713	28/11/2005	As above	No response received	Not applicable
Blue Destiny Charters	Shaun Throssell c/o NBS Light Industrial Area KARRATHA WA 6714	28/11/2005	As above	No response received	Not applicable
North West Game Fishing Club	Robbie c/o Karratha Visitors	28/11/2005	As above	No response received	Not applicable

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
	Centre PO Box 1234 KARRATHA WA 6714				
Pilbara Underwater Hunters Association	Kevin McLean Via email to: kalemclean@bigpond.com	28/11/2005	As above	No response received	Not applicable
Dampier Community Association	Bette Inglis PO Box 197 DAMPIER WA 6713	28/11/2005	As above	No response received	Not applicable
Spoil Ground Management Group – Co-ordination Meeting No. 6	Attendees: Stephen Nicholson (DPA) Ron Hutchinson (Baggermans/DPA) Vic Justice (DPA) Peter Smith (DPA) Angela Kennedy (DPA) Matt Johnston (DEH by phone) Kellie Parker (PI) Peter Royce (PI) Lyle Banks (PI/SKM) Richard Cohen (PI) David Lee (Chevron)	9/12/2005	Meeting held at Dampier Port Authority Offices, Dampier. Co-ordinated by DPA.	Spoil Ground Marine Notice Spoil Ground Management Plan Rev D was tabled and a brief overview provided of available disposal areas. On completion of current LNGV Dredging works and proposed PI work, the areas will be filled. Overview of PI capital and maintenance dredging programs provided. Targeting commencement April 2006 (10-12 weeks duration expected) and work will require removal of nominal 3.2Mm3. Letter sent to 22 Government agencies and community groups – sought comments back by 16 December 2005. Sea dumping approval Bulk of dredging to occur around Parker Point Wharf – 0.5Mm^3 to go onshore as reclamation material, rest to go off-shore to the Material Relocation Sites. Two other areas to be dredged – East Intercourse Island berth pocket and high	PI will be cognisant of the Spoil Ground Marine Notice Spoil Ground Management Plan Rev D in preparing its Sea Dumping application. Unchanged, except timing for dredging starting in April now appears remote. Pro-forma letter as issued to these groups attached. No change to scope from that stated.

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
	Petrina Raitt (Chevron) Charles Waterton (Chevron) Murray Jorgensen (DoIR) - dna Cameron Sim (DoE) Anne Trevena (DoE) Chris Ryan (DPA) Jim Stoddart (PI/Mscience) Fran Stanley (CALM) Peter Lardi (WEL Project Pluto) Soolim Carney (WEL Project Pluto)			spot adjacent to main channel to be re-located. <u>Spoil ground requirements</u> About 2.7Mm3 could be placed in East Lewis area. Rest to Northern Spoil ground area. Is potential for TBT contaminated materials of about 25,000m3. PI will know results in January 2006. Permits to be finalised then. Chairman sought whether permits could be expedited to use same dredges, but DEH advised given test data was not available, it was unlikely to occur.	No change to scope from that stated. PI will discuss handling of TBT with the DPA. No comment from PI.
Dampier and Karratha Community Advisory Group	Clint Bain (PI) Toni Salmon (PI) Jan Johnson Sid Hay John Lally Brian Inglis Megan Lally Natalie Gray Ian McGillvray John Soter	12/12/2005	Meeting and discussion of DPU Project, including dredging component, with opportunity for question and comments. Meeting advised that: Open Day scheduled for 2 and 3 February 2006 (will have some information on dredging) in Karratha and Dampier. Maintenance dredging (@1mil m3) in areas already dredged - permit expected	In relation to dredging, a query was raised whether was an opportunity for the dredging machine to dredge near moorings and deposit the sand back on the beach?	Meeting advised that PI will not dredge areas outside that covered in SAPs already submitted. Scope of dredging already defined and any variation (especially placement of sand onto beach) will delay time to get dredging permits and approvals.

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
	Jenny Fox		Mar/Apr 2006 Capital dredging (@2mil m3) in areas that require deepening or widening – expect permit April 2006 Dredging spoil will be placed at approved spoil grounds near East Lewis and at the Northern Spoil grounds. Coral health and water monitoring and conditions likely to be applied as for 2004 dredging – no impact on coral was demonstrated then. A visible plume will occur for 10–12 weeks around the dredge and spoil areas.		
Open Days	Open to any interested members of the public to visit display, view posters and video and other material and ask questions – covered entire DPU145 upgrade both land and marine works	2/2/2006 3/2/2006 All day	Manned displays at Karratha Shopping Centre and Dampier Shopping Centre, with bus tours of construction area from Dampier. Fly-over video shown, advertised in Pilbara News	109 attendees at Karratha 27 attendees in Dampier Issues relating to dredging were limited to request to ensure suitable lighting provided on dredges ensuring they were visible at night	Ensure dredge has suitable lighting
Various	Refer attachment list of organisations	10/2/2006 22/2/2006	Letter issued with copy of posters displayed at Open Days (2 and 3 February 2006) with Feedback Form.	Three responses received to date: Fire and Emergency Services Authority – wanted opportunity to liaise with expansion project team regarding emergency preparedness, especially welcome the opportunity to discuss identified project emergency risks, expectations of FESA in the advent of a major incident and FESA's	Not specifically related to dredging. RTIO will be meeting with FESA representatives to discuss issues raised.

Organisation	Contact or attendees	Date	How	Nature of response/comment/issue	Resolution/follow up
				response capabilities. The intention would be to assist RTIO to develop robust emergency arrangements for the impending construction works. Main Roads Western Australia – number of vehicular movements to be generated by the expansion – frequency, number and type of vehicle movements using the Parker Point and Dampier Highway intersection. Tourism WA – will a visitors centre to be established as part of upgrade.	Not related to dredging. Response provided to MRWA: 100 light vehicles and 20 heavy vehicles a day. Responded by phone (not related to dredging)
Spoil Ground Management Group (part)	DPA invitational list, but included about half normal Group members, plus about 12 other stakeholders with identified interests in new spoil grounds in Dampier	20/2/2006	Workshop in Karratha on the assessment (constraints and opportunities) of options for new or extended spoil grounds. As part of the introductory session, Hamersley Iron outlined its historical spoil dumping requirements (since mid 1960's) and outlined the 2006 dredging and spoil disposal requirements.	Clarifying questions were raised on timing of the 2006 dredging program and on the volumes requiring disposal, especially off-shore disposal. DPA representative advised that the existing spoil grounds will effectively be filled. Minutes not yet produced.	Scheduled to commence dredging mid year 2006. A total of $3Mm^3$ (capital and maintenance), with about $2.5Mm^3$ requiring off-shore disposal. Spoil ground capacity will need clarification post Woodside dumping in Northern/Southern Spoil ground – expected in March 2006

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7. Proponent's Environmental Management Commitments

Hamersley Iron is committed to achieving or exceeding a level of environmental management performance consistent with national and international standards and statutory obligations. The proposed dredging program will be conducted in a manner that will minimise impacts on the surrounding environment. Accordingly, environment management strategies and commitments have been nominated throughout this document and are summarised in **Table 7-1**.

7.1 Environmental Management Responsibilities

7.1.1 Proponent Responsibilities

Hamersley Iron takes a responsible and pro-active response to the environmental management of its activities. To this end its environmental responsibilities with respect to the dredging program will include:

- Obtaining relevant approvals and permits to undertake the dredging works;
- Advising Dredging Contractors of significant environmental issues;
- Appointing and managing suitably qualified Dredging Contractors;
- Ensuring Dredging Contractors meet the obligations outlined in the Dredge Spoil Disposal Management Plan;
- Undertaking monitoring and reporting on the effects of dredging and spoil disposal on significant environmental issues, e.g. corals.

7.1.2 Contractor Responsibilities

The environmental management responsibilities of the appointed Dredging Contractor relate to the specific dredging works and include:

- Complying with the relevant legislation, regulations and approval conditions;
- Complying with the requirements of the Dredge Spoil Disposal Management Plan;
- Compliance with Dampier Port Authority requirements, including DPA's Marine Pollution Plan, Cyclone Policy, Emergency Plan, etc;
- Undertaking monitoring and other environmental management activities as specified in its contract with Hamersley Iron;
- Ensuring an Environmental Officer is engaged throughout the project;
- Ensuring dredging equipment is in good condition and properly maintained for the duration of the works;

- Taking all reasonable measures to protect the environment in and around the site and mitigate and/or protect the environment against impacts of the Works resulting from contaminates, turbidity plumes and reduced water quality; storage and handling of hydrocarbons and chemicals; waste and sewage disposal; and noise; and
- Disposal off site of all rubbish, debris, scrap metals and redundant gear and the like, including implementation of a recycling program to minimise disposal to land fill.

In the event of any non-compliance with the Dredge Spoil Disposal Management Plan or breach of legislative requirements in respect of the environment the Dredging Contractor is obliged to report the type and extent of such non-conformance. The Contract allows for suspension of dredging operations until any and all deficiencies are addressed and corrected by the Contractor.

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Table 7-1 Proponent's Environmental Management Commitments

Commitment No	Topic	Action	Objective	Timing	Advice
1	Dredging and the Dredging and Spoil Disposal Management Plan (DSDMP)	Hamersley Iron will prepare a Dredging and Spoil Disposal Management Plan to address the following: ▪ Produce a detailed description of proposed dredging works and timing; ▪ Publish Notices to Mariners and public regarding location and timing of works; ▪ Management of works to minimise spread of turbid water plumes; ▪ Monitoring of the effects of dredging; and ▪ Contingency Plans to be implemented if: — dredging results in water quality that exceeds trigger values; — if return water discharge results in water quality that exceeds trigger values; or — if a turbidity plume resulting from dumping on the spoil ground is observed to be travelling in the direction of known coral communities.	To minimise adverse effects of maintenance and capital dredging	Pre-dredging	DoE Dampier Port Authority
		Implement the approved DSDMP referred to in Commitment 1	To achieve outcomes of Commitment 1	Dredging	
2	Environmental Management	Implement the approved CEMPs referred to in Commitment 2	To achieve outcomes of Commitment 2.	Dredging	
		Hamersley Iron will develop a monitoring program that will include: ▪ Dredging reactive monitoring program; ▪ Disposal reactive monitoring at the Parker Point Spoil Area; ▪ Disposal Reactive Monitoring at the East Lewis Spoil Ground and northern Spoil Ground; ▪ Dredging Effects Monitoring; and ▪ Disposal Effects Monitoring at the East Lewis Spoil Ground and Northern Spoil Ground.	To monitor impact of the maintenance and capital dredging on relevant environmental factors.	Pre-dredging	DoE Dampier Port Authority
		Implement the approved monitoring program referred to in Commitment 2	To achieve outcomes of Commitment 2.	Dredging	

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Appendix A Dredging and Dredge Spoil Disposal Management Plan

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SINCLAIR KNIGHT MERZ

SKM

HAMERSLEY IRON

A member of the Rio Tinto Group

Dampier Port Dredging

DREDGING AND DREDGE SPOIL DISPOSAL MANAGEMENT PLAN

- Revision 3
- 9 June 2006

Dampier Port Dredging

DREDGING AND DREDGE SPOIL DISPOSAL MANAGEMENT PLAN

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Contents

Figures

Tables

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
A	8/3/06	RG	PFM	9/3/06	Preliminary draft
0	9/3/06	RD, PR	PFM	9/3/06	Final draft
1	13/3/06	RD	PFM	14/3/06	Final
2	26/5/06	RD, PR, JS	PFM	26/5/06	Revised Final
3	9/6/06	RD	PFM	9/6/06	Revised Final

Distribution of copies

Revision	Copy no	Quantity	Issued to
A	1	1 electronic	Richard Galloway
0	1	1 hard copy	Ross Dunkley
0	2	1 hard copy	Peter Royce
1	1–3	3 hard copies	Hamersley Iron
1	4	1 hard copy	DoE
1	5	1 hard copy	SKM project file
2	1	1 electronic	Hamersley Iron
3	1–3	3 hard copies	Hamersley Iron
3	4	1 hard copy	DoE
3	5	1 hard copy	SKM project file
3	6	1 hard copy	SKM library
3	7	1 electronic copy	SKM archive

Printed:	2 August 2006
Last saved:	1 August 2006 12:55 PM
File name:	I:\WVES\Projects\WV03015\Deliverables\DSDMP\HI Phase B Combined Dredging DSDMP rev 3b.doc
Author:	Dr Peter F. Morrison
Project manager:	Dr Peter F. Morrison
Name of organisation:	Hamersley Iron Pty Ltd
Name of project:	Dampier Port Dredging
Name of document:	Dredging and Dredge Spoil Disposal Management Plan
Document version:	Revision 3
Project number:	WV03015

1. Purpose and Objectives of the Plan

1.1 Purpose

The purpose of this Dredging and Spoil Disposal Management Plan (DSDMP) is to provide the necessary framework such that the dredging program for the proposed maintenance and capital dredging at Dampier can be implemented efficiently and with minimal environmental impact in accordance with Hamersley Iron's Environmental Protection Rules for this project (see **Appendix A**).

1.2 Objectives

The objectives of this DSDMP are:

1) To assess the zone of influence of turbidity plumes generated by dredging and spoil disposal;
2) To protect the sensitive marine ecological attributes (ecological values) from the effects of sedimentation, deterioration in light climate, contamination and other forms of pollution associated with dredging and spoil disposal; and
3) To protect the long term values of seafood quality, aquaculture production, recreational values and existing industrial water supply (social values) from the environmental effects of dredging and spoil disposal.

1.3 Scope

This DSDMP addresses key conditions and commitments previously set for the previous (Dampier Port Upgrade Phase A) dredging and disposal program conducted in 2004 under Ministerial Statement 664. An application for a Sea Dumping Permit is presently being assessed by the Department of the Environment and Heritage (DEH). A cross reference of this DSDMP with previous Ministerial conditions and commitments in relation to the dredging and spoil disposal management plan and environmental management plan is provided in **Table 1**.

1.4 Contact Details

Contact details for communications are contained in **Table 1**.

- **Table 1 Contact details for communications**

Organisation	Role	Name	Contact details	
Hamersley Iron Pty Ltd	Approvals Adviser	Peter Royce	Telephone	9322-2351
			Mobile	0438 946 858
Sinclair Knight Merz	Project Engineer	Ross Dunkley	Telephone	9226-6419
			Mobile	0419 814 507
Sinclair Knight Merz	Environmental Officer	David Kabay	Telephone	9143-5021
			Mobile	0417 950 508
Dredging Contractor *	Project Manager	To be advised	Telephone	
			Mobile	
Dredging Contractor *	Environmental Officer	To be advised	Telephone	
			Mobile	
Department of Environment	Emergency Hotline		Telephone	1800 018 800
			Facsimile	9322 1598
			Mobile	0417 946 740
Dampier Port Authority	Harbour Master	Vic Justice	Telephone	9159-6565
			Facsimile	9159-6557
			Mobile	0427 937 877
Department of the Environment and Heritage	Approvals and Audit Section	Matt Johnston	Telephone	02 6274 1428
			Facsimile	02 6274 1620

* Dredging contract has yet to be awarded.

Table 2: Cross reference of the DSDMP with Ministerial Statement 664

Cross referenced Condition and Commitments under Ministerial Statement 664		DSDMP Section
8.1.1	Monitoring requirements and management measures to protect sensitive marine ecological attributes and social values of Mermaid Sound consistent with the operational requirements of the Port, and any other areas within the potential zone of influence of the environmental effects of dredging and spoil disposal	7
8.1.2	Identify the ecological and social values to be protected	3.7
8.1.3	Identify and spatially define appropriate environmental quality objectives to be met during dredging and spoil disposal activities	7.5
8.1.4	Establish the environmental quality criteria to protect social values in the long term	7.5
8.1.5	Describe the type of dredge(s) to be used and mode of operation	4.2.5
8.1.6	Determine most probable and worst-case timing and duration of dredging and spoil disposal activities and contingencies for unforseen delays	7.5
8.1.7	Contain a description of the potential zones of influence of dredging and spoil disposal activities on water quality, and explain the rationale underpinning the predictions	7.5
8.1.8	Specify appropriate reference sites outside the potential zones of influence of dredging and spoil disposal activities on water quality and coral health	7.6 & Appendix B
8.1.9	Specify potential impact sites adjacent to and between the source(s) of turbidity and sensitive marine ecological attributes which require protection from the effects of dredging and spoil disposal activities	7.6 & Appendix B
8.1.10	Set out procedures, including frequency, probable flight paths and methods of recording information (eg. photography), for routine aerial monitoring of the plume and the appropriateness of reference sites for the duration of dredging and spoil disposal activities and for a period after the completion of dredging and spoil disposal to confirm the time taken and area required for dispersion of residual turbidity	7.8
8.1.11	Set out the procedures for monitoring water quality at appropriate reference sites and potential impact sites	7.5
8.1.12	Specify the management actions and contingency measures to be implemented in the event of exceedance of the levels specified in condition 10-5	7.6 & 7.7
8.1.13	Specify reporting procedures	8
Cross referenced Proponent Commitments		**DSDMP Section**
1	Develop a Environmental Management Plan (EMP) that will address the management of:	
	Hydrocarbons	7.2
	Wastes	7.3
	Ballast water and marine pests	7.1
	Vessel movements	7.4

Note: Cross referencing of only the dredging and spoil disposal management conditions contained in Ministerial Statement 664

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2. Background

2.1 Dampier Port Maintenance

The export market for Australian iron ore has grown steeply over the past five years and appears set to continue to grow. To meet the demand for more ore, Pilbara Iron is expanding inland production and rail facilities to the coast. In 2003, Pilbara Iron committed to a substantive upgrade of their port facilities, principally at Parker Point. In 2003/4 dredging works were referred to the Western Australian Environmental Protection Authority (EPA) and the DEH (sea dumping).

The 2004 dredging program was completed; however, there is a need for follow up maintenance and capital dredging works to restore the depths (thus functionality) of berths at East Intercourse Island and Parker Point, an additional berth pocket at Parker Point and the approach areas to Parker Point and to remove a high spot constraining incoming ships adjacent to the main shipping channel (incoming empty ships are not confined to the shipping channel.

2.2 Potential Issues

The potential environmental impacts that may result from the dredging and disposal activities include:

- A quantity of the material to be disposed to sea is contaminated with tributyltin (TBT).
- The dredging works has the potential to impact on corals by the reduction of light and by smothering from turbidity produced during the dredging and spoil disposal works. In addition, if the dredging program spans the autumn coral spawning season, the recruitment potential of the area could be reduced.
- The handling of hydrocarbons creates a potential risk to the environment in the event that spillage occurs. These spills may lead to the contamination of marine water within the vicinity of the spill and potential damage to intertidal marine habitats causing mortality of sensitive biota. Oil spills in the Dampier region have the potential of washing ashore into nearshore habitats of King Bay, Mermaid Sound and wider Dampier Archipelago due to the tidal nature of the region.
- If not handled properly, solid waste and sewage produced during the dredging program has the potential to contaminate marine, ground and surface waters, impact upon marine fauna and pose a risk to human health.
- Ballast water from coastal areas in other parts of Australia or overseas has the potential to introduce marine pest species that may impact upon the marine communities of Mermaid Sound and the wider Dampier Archipelago region. Marine pest species can be transported within ballast water or on ship hulls.

- If not managed, there is the potential for the dredges to interfere or collide with other vessels in the area.

To ensure that these impacts are addressed and that the activities associated with the dredging program are managed to minimise any impacts, management strategies have been developed and are detailed in **Section 7**.

2.3 Legal and Other Requirements

The following acts are applicable to the environmental issues associated with the proposed dredging and disposal program:

- *Environmental Protection (Sea Dumping) Act 1981*;
- *Environmental Protection Act 1986*; and
- *Port Authorities Act 1999*.

Guidance will be taken from the National Water Quality Management Strategy: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) and the National Ocean Disposal Guidelines for Dredged Material (EA 2002) to manage the environmental impacts of the project.

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3. Existing Environment

The bathymetry of the Dampier Port area is provided in **Figure 1**. The benthic marine habitat within the Port of Dampier is presented in **Figure 2** (page 19) and consists predominantly of the following three community groups:

- Soft sediment (silt and sand);
- Macroalgae on hard substrate; and
- Hard coral on hard substrate.

3.1 Water Quality

3.1.1 Water Chemistry

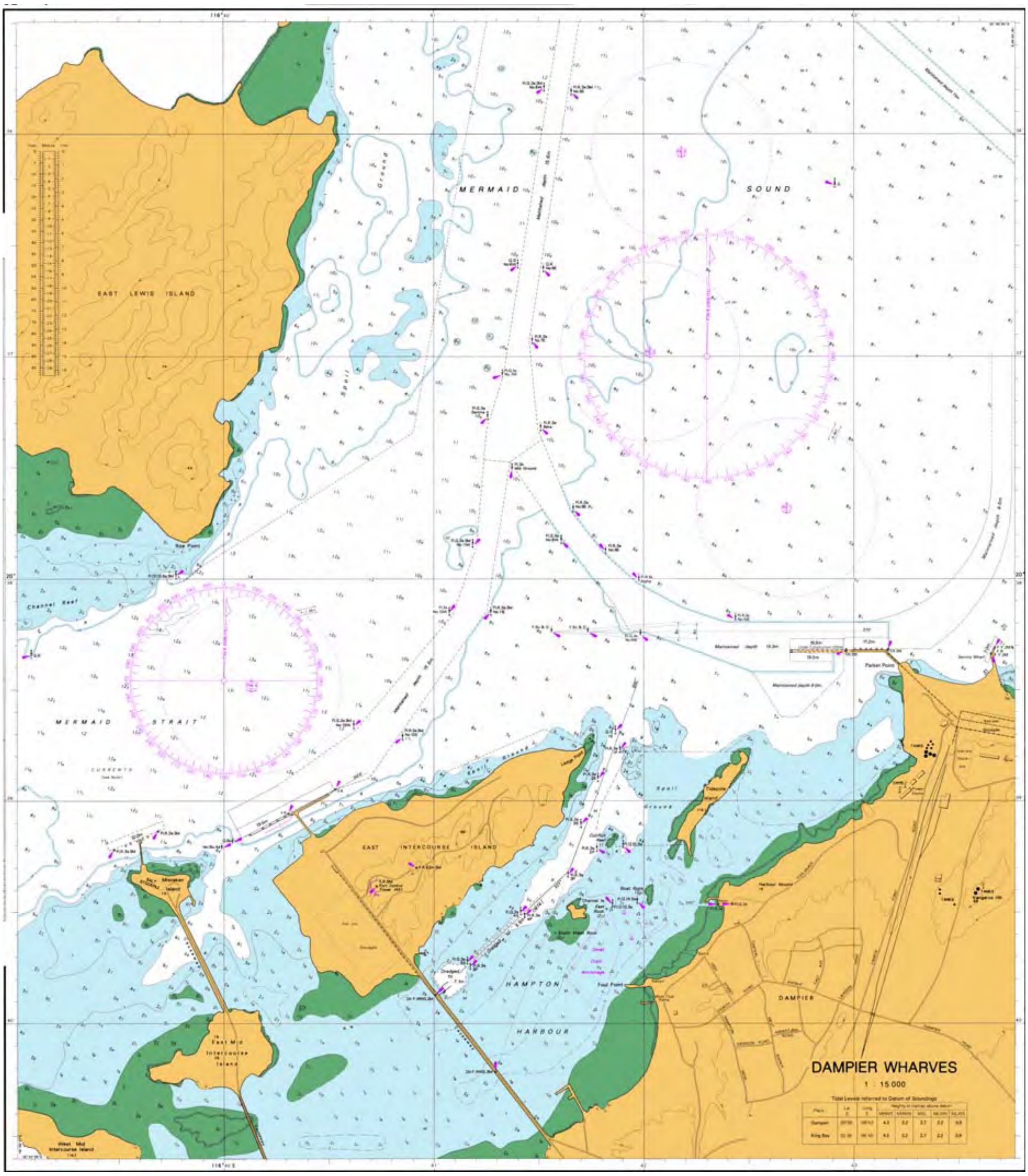
The water quality in King Bay and surrounding area has been investigated by Sinclair Knight Merz on behalf of the Water Corporation as part of the baseline monitoring program for the Burrup Industrial Water Supply System. The monitoring program assessed metals, nutrients (TN, NH_4, NO_3-NO_2, TP, PO_4) chlorophyll, total suspended solids, total dissolved solids, chemical oxygen demand, light attenuation and water column profiles (dissolved oxygen, temperature, salinity, pH, turbidity).

The results of this monitoring have been presented in several unpublished data reports and are summarised as follows:

- Metals in the water column are generally bound to suspended solids thus total metal concentrations (principally copper and zinc) occasionally exceed ANZECC/ARMCANZ 2000 guidelines but filtered samples do not;
- Nitrogen levels, in particular total nitrogen and nitrate-nitrite, in the surface and bottom waters of the area often exceed the ANZECC/ARMCANZ 2000 guidelines; however, the chlorophyll levels do not; and
- The waters close to shore experience much greater extremes of temperature and salinity than those further offshore, particularly during summer.

3.1.2 Water Clarity

The secchi depths and light attenuation for a number of locations in King Bay clearly showed seasonal and spatial variability in water clarity. The naturally high turbidity and light attenuation is generally greater near shore than in the offshore waters. Much of this is as a result of wave action suspending sediments from both the seabed as well as the shoreline itself. Total Suspended Solids (TSS) and turbidity data showed a similar patter to the secchi depth and light attenuation with greater values near the seabed than the water's surface. However, there was only a very low correlation between TSS and light attenuation.



- **Figure 1 Bathymetry of the Dampier Port area**

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3.2 Sediment Quality

A Sampling and Analysis Plan (SAP) was submitted and approved by the Department of the Environment and Heritage for by Hamersley Iron. The objectives of the SAP were to characterise the marine sediments to be removed as part of the dredging program and provide data for the effective management of the dredging activities.

3.2.1 Maintenance Dredge Material

Sediment Metals and Tributyltin Assessment

Sediment samples from each of the four areas designated for maintenance dredging were analysed for metals and tributyltin (TBT) (standardised to 1% total organic carbon or TOC) and were expressed as the 95% Upper Confidence Interval (95% UCL). This is in accordance with the National Ocean Disposal Guidelines for Dredged Material (NODGDM). The data in **Table 3** indicate the following:

- The sediments in the Parker Point and East Intercourse Island berths exceeded the NODGDM maximum level for TBT;
- The sediments in Area E and F exceeded the NODGDM screening level for nickel and TBT; and
- The sediment at the East Lewis Island Spoil Ground exceeded the NODGDM screening level for nickel.

Values found to be above the screening level are not necessarily deemed to be detrimental to biota in the surrounding environment however it is deemed a contaminant of concern as it could adversely impact on organisms. The screening level is a trigger for further investigation such as comparison with the sediment quality at the spoil ground or additional testing to confirm that the material is not harmful to biota. Values above the maximum level indicate that toxic effects to organisms are probable if the substance is biologically available and as such further testing is mandatory.

The elevated levels of nickel were not of concern because the levels found at the East Lewis Island Spoil Ground exceeded that found in Areas E and F.

The elevated levels of TBT were of concern for sea dumping thus further testing was required in accordance with the NODGDM (EA 2002). Further testing involved the assessment of the potential of TBT to dissolve in the water (elutriate) during dredging. In addition, the assessment of ecotoxicological effects on sensitive biota were required particularly for organisms sensitive to the effects of TBT.

These results of these additional tests are provided below.

Table 3 Sediment contaminant levels in material for maintenance dredging

Parameter	Units	LOR	Guidelines [a]		PP Berth	EII Berth	Area E&F	ELI Spoil Ground
			Screening	Maximum				
Al	mg/kg	10	—	—	8,511	7,400	12,008	13,785
As	mg/kg	0.5	20	70	9.7	5.5	9.2	14.7
Cd	mg/kg	0.1	1.5	10	0.3	0.3	0.6	0.8
Co	mg/kg	0.1	—	—-	6.9	6.0	9.0	9.8
Cr	mg/kg	0.5	80	370	46.9	41.7	77.8	75.2
Cu	mg/kg	0.1	65	270	12.3	9.9	15.1	14.6
Fe	mg/kg	10	—	—-	50,825	108,692	24,052	26,578
Hg	mg/kg	0.1	0.15	1	0.1	0.1	0.1	0.1
Mn	mg/kg	1	—	—-	1330.3	288.1	201.0	232.0
Ni	mg/kg	0.5	21	52	5.8	7.0	**25.0**	**27.0**
Pb	mg/kg	1	50	220	4.7	3.9	5.6	5.6
Sb	mg/kg	0.1	2	25	0.1	0.1	0.2	0.1
Se	mg/kg	1	—	—-	0.5	0.5	0.5	0.8
V	mg/kg	1.0	—	—-	29.6	29.3	60.1	60.8
Zn	mg/kg	0.5	200	410	18.8	18.0	20.0	24.7
TOC	%	0.01	—	—-	0.2±0.05	0.3±0.18	0.2±0.05	0.3±0.07
TBT [b]	µg/kg	0.2	5	70	***185.3***	***95.6***	**24.9**	0.8

Source: MScience 2005c & d.
All values expressed as 95% Upper Confidence Limits with the exception of TOC which is the mean±standard deviation.
a National Ocean Disposal Guidelines for Dredged Material (NODGDM) (EA 2002).
b Normalised to 1 % Total Organic Carbon (TOC) as per NODGDM Section 3.10.1.
Bolded values exceed the screening level in Table 5 of the NODGDM.
Bolded and italicised values exceed the maximum level in Table 5 of the NODGDM.

Elutriate Assessment

Three sediment samples were collected from each of the two areas where elevated sediment TBT was observed (Parker Point Berth and East Intercourse Island Berth). Elutriates were prepared using water from the site and the results were subjected to a 100 fold dilution in accordance with Section 3.10.3 of the NODGDM to account for dilution during the disposal of the material at the spoil ground. This dilution is likely to be an underestimate. The results in **Table 4** indicate that the elutriation of TBT would result in concentrations well below the ANZECC/ARMCANZ 2000 guideline level of protection for 99% of species.

Table 4 Elutriate TBT levels in material for maintenance dredging

Parameter	Units	LOR	Guidelines [a]		PP Berth	EII Berth
			99%	95%		
TBT	µg/L	0.002	0.0004	0.006	0.00001	0.00004

Source: MScience 2005c & d.
All values expressed as 95%iles with an indicative dilution of 100 times as per the NODGDM Section 3.10.3.
a ANZECC/ARMCANZ 2000.

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Ecotoxicological Assessment

Three sediment samples were collected from each of the two areas where elevated sediment TBT was observed (Parker Point Berth and East Intercourse Island Berth). Elutriates from these samples at concentrations of 0% to 100% elutriate were used for 48 hr test of the larval development of rock oysters (*Saccostrea commercialis*). The results in **Table 5** indicate that there was no significant reduction in normal/survival of larval oysters when compared to background seawater (0% elutriate concentration). The TBT contained in the sediments are not expected to adversely impact on biota.

- **Table 5 Ecotoxicological assessment of sediment elutriates**

% Elutriate	Percent normal/survival	
	Parker Point Berth	East Intercourse Island Berth
0	75+5.2	73+4.5
6.25	71+1.0	73+4.9
12.5	70+3.8	72+1.7
25	78+3.2	72+2.1
50	75+3.8	75+1.2
100	74+1.0	71+3.5

Source: MScience 2005c & d.

3.2.2 Capital Dredge Material

Tributyltin Assessment

Sediment samples from each of the five areas designated for capital dredging were analysed for TBT and standardised to 1% TOC and expressed as the 95% Upper Confidence Interval (95% UCL). The data in **Table 6** indicate the following:

- The sediments in Area G exceeded the NODGDM screening level;
- The sediments in Area A exceeded the NODGDM maximum level; and
- The sediments in Areas B–D and H were below the NODGDM screening level.

- **Table 6 Sediment contaminant levels in material for capital dredging**

Parameter	Units	LOR	Guidelines [a]		Areas					
			Screening	Maximum	A	B	C	D	G	H
TOC	%	0.01	—	—	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.2±0.1
TBT [b]	µg/kg	0.2	5	70	***610***	4.4	1.8	3.3	**31.3**	0.6

Source: MScience 2005 c & d.
All values expressed as 95% Upper Confidence Limits with the exception of TOC which is the mean±standard deviation.
a National Ocean Disposal Guidelines for Dredged Material (NODGDM) (EA 2002).
b Normalised to 1 % Total Organic Carbon (TOC) as per NODGDM Section 3.10.1.
Bolded values exceed the screening level in Table 5 of the NODGDM.
Bolded and italicised values exceed the maximum level in Table 5 of the NODGDM.

Leachate Assessment

The Australian Standard Leachate Procedure (ASLP) provides a method for the preparation of leachates from liquid and solid wastes, sediments, sludges and soils for assessing the potential of inorganic and semi-volatile organic contamination of groundwater, in a variety of disposal-to-land scenarios. The percentage of solids is determined and if sufficient liquid is extracted from the sample, the liquid is analysed separately from the leachate. A separate test portion is reduced in size to pass a 2.4 mm sieve and leached in an end over end manner for 18 hours at 30 rpm using an appropriate extraction solution. The solution used depends on the sample and water pH, acid/base properties and the nature of the landfill. Reference AS 4439.3-1997.

Twelve sediment samples from areas proposed to be used for landfill on shore were investigated for suitability based on Ecological Investigation Levels (EIL) (DoE 2001a). Five sediment samples that exceeded the EIL levels triggered assessment by determining the leachable concentration by ASLP and comparison to guidelines for Inert Landfill (DoE 2001b).

The data in **Table 7** indicate the following:

- Three of the twelve sediment samples exceeded the EIL levels for chromium;
- Six of the twelve sediment samples exceeded the EIL levels for manganese; and
- None of the samples exceeded leachability guidelines.

The dredge material therefore is suitable for disposal ashore as landfill in the reclamation area.

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Table 7 Comparison of sediment and leachate data with landfill guidelines

Parameter	Guidelines		Sediment		ASLP	
	EIL [a] mg/kg	ASLP1 [b] mg/L	mg/kg	Exceedances	mg/L	Exceedances
As	20	0.5	7.4±4.5	0	0.01±0.00	0
Cd	3	–	0.3±0.06	0	–	–
Co	50	–	5.8±2.0	0	0.01±0.00	0
Cr	50	0.5	36.2±20.7	3	0.01±0.00	0
Cu	60	–	9.7±5.0	0	0.01±0.00	0
Hg	1	–	0.1±0.0	0	–	–
Mn	500	–	810±1003	6	0.012±0.004	0
Ni	60	0.2	3.9±3.7	0	0.01±0.00	0
Pb	300	0.5	3.7±1.8	0	0.01±0.00	0
Sb	20	–	0.1±0.0	0	–	–
Zn	200	–	14.5±8.4	0	0.038±0.048	0

Data expressed as mean ± standard deviation.
a Ecological Investigation Level: Assessment Levels for Soil, Sediment and Water (DoE 2001a).
b Leachable Concentration (ASLP) level 1: Inert Landfill (DoE 2001b).

Acid Sulphate Soil Assessment

The Titratable Actual Acidity or TAA (the first component of the 'acidity trail') is a measure of the soluble and exchangeable acidity already present in the soil, often as a consequence of previous oxidation of sulphides. It is this acidity that will be mobilised and discharged following a rainfall event.

The Titratable Peroxide Acidity (TPA) measurement (the second part of the acid trail) is the net result of the reactions between the acidifying and neutralising components in the soil (following peroxide digestion). A TPA of zero indicates that for a finely-ground sample (under laboratory oxidation conditions), the soil's buffering/acid neutralising capacity exceeds (or equals) the potential acidity from oxidation of sulphides. A valuable feature of the TPA peroxide digestion component of the Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) method is that for soils with pH_{OX} >6.5, any excess acid neutralising capacity (ANCE) can be quantified by means of an HCl titration. This feature is particularly useful when trying to confirm whether a soil has been treated with sufficient lime (including whether an appropriate liming safety factor has been applied, ie. verification testing). The TPA, being a measure of net acidity, includes a contribution from the material's acid neutralising capacity.

The SPOCAS method ensures quantitative recovery of pyritic sulfur and overcomes anomalies of sulfur loss and jarosite precipitation. It also has a titration pH end point (to 6.5) and makes use of suspension titration. The complete SPOCAS method provides 12 individual analytes (plus 5 calculated parameters), enabling the quantification of some key fractions in the soil sample, leading to better prediction of its likely acid-generating potential. Put most simply, the SPOCAS method involves the measurement of pH, titratable acidity, sulfur and cations on two soil sub-samples. One soil sub-sample is oxidised with hydrogen peroxide and the other is not. The differences between the two values of the analytes from the two sub-samples are then calculated.

Another useful parameter that can also be determined in the SPOCAS method (especially for soils with existing acidity and jarosite) is the residual acid soluble sulfur (S_{RAS}). This 4 M HCl acid extraction procedure is performed on the soil residue remaining after peroxide digestion and it measures sulfur from jarosite and other 'insoluble' sulfate-containing compounds originally present in the soil. The acidity retained in these compounds is not recovered in the peroxide digest and subsequent titration.

Reacted calcium (CaA) is calculated from peroxide calcium (Ca_P) and KCl-extractable calcium (Ca_{KCl}) measurements ($CaA = Ca_P – Ca_{KCl}$).

Reacted magnesium (MgA) is calculated from peroxide magnesium (Mg_P) and KCl-extractable magnesium (Mg_{KCl}) measurements ($MgA = Mg_P – Mg_{KCl}$).

Commonly, CaA and MgA values reflect the amounts of 'insoluble' calcium and/or magnesium carbonates, oxides and hydroxides dissolved by the acid generated by the oxidation of sulphides in the peroxide digest. In soils with excess carbonates, CaA and MgA will usually underestimate actual carbonate contents unless the HCl-titration procedure in SPOCAS has been performed. The reacted calcium and magnesium values can be converted to equivalent acid neutralising capacity (eg. a-CaA) assuming two moles of neutralising is provided per mole of calcium and magnesium:

- CaA (%) x 499 = a-CaA (mol H^+/t)
- MgA (%) x 822.6 = a-MgA (mol H^+/t)

This measurement is carried out as part of the peroxide digestion component of the SPOCAS method. When the pH of the soil suspension is >6.5 after the initial peroxide oxidation stage, this may indicate the presence of carbonate or other alkaline minerals in the soil (eg. oxides/hydroxides of calcium and magnesium) in excess of that needed to neutralise the soil's sulfidic acidity. Soil suspensions should be titrated with HCl to pH 4, then digested again with peroxide. After this further peroxide digest, soil suspensions are titrated to pH 6.5 with NaOH (if pH <6.5). This NaOH titration result is subtracted from the HCl-titration result to give the excess acid neutralising capacity (ANCE). As well as producing an estimate of excess ANC, this HCl-titration and re-digestion procedure is necessary to ensure complete peroxide oxidation of sulphides, which is slower and less efficient in the presence of excess carbonates.

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Total sulfur (S_{Total}) can be measured using a variety of chemical and instrumental techniques. The measurement of total sulfur provides a low-cost alternative for estimating the maximum potential environmental risk from acid produced by the oxidation of sulphides. The total sulfur value can be converted to equivalent acid neutralising capacity (eg. a-S_{Total}):

- S_{Total} (%) x 623.7 = a-S_{Total} (mol H^+/t)

Peroxide sulfur S_P is measured on a filtered solution, following soil digestion with peroxide and TPA titration. The S_P measurement by itself has limited application since it includes sulfate salts with no acid-generating potential (such as gypsum), sulfur from the oxidation of organic matter, as well as that derived from sulphides. In acid sulfate soil without appreciable jarositic sulfur or other relatively insoluble acid-producing sulfates, the peroxide sulfur should approximately equal the total sulfur.

Action criteria define when acid sulfate soils disturbed at a site will need to be managed. Action criteria are based on the sum of existing plus potential acidity. The highest result(s) should always be used to assess if the relevant action criteria level has been met or exceeded as using the average or mean of a range of results is not appropriate (Dear *et al*. 2002). If a soil shows evidence of self-neutralising or self-buffering (eg. TPA = 0 or not detectable and the ANCE>a-S_{Total}) then a case may be made for reduced or no treatment (Dear *et al*. 2002).

The potential for dredging material used on shore for reclamation to produce acid once exposed to air required assessment. Five samples were collected and tested for TAA, SPOCAS and total sulphur.

The data in **Table 8** indicate the following:

- All samples had acidity trail parameters below detection; and
- All samples had an ANC_E > Total Sulfur.

The dredge material is therefore self-neutralising and is suitable for disposal ashore as landfill in the reclamation area.

- **Table 8 Acid sulphate soil assessment**

Parameter	Code	Units	Samples				
			1	2	3	4	5
pH measurements							
pH of KCl extract	23A	pH_{KCl}	8.90	8.90	8.80	8.80	8.90
PpH of peroxide digestion	23B	pH_{OX}	8.00	7.80	8.00	8.00	8.00
Acidity trail							

Parameter	Code	Units	Samples				
			1	2	3	4	5
Titratable Actual Acidity (TAA)	23F	TAA	<2.00	<2.00	<2.00	<2.00	<2.00
Titratable Peroxide Acidity (TPA)	23G	TPA	<2.00	<2.00	<2.00	<2.00	<2.00
Titratable Sulfidic Acidity	23H	TSA	<2	<2	<2	<2	<2
sulfidic - Titratable Actual Acidity	s-23F	s-TAA	<0.02	<0.02	<0.02	<0.02	<0.02
sulfidic - Titratable Peroxide Acidity	s-23G	s-TPA	<0.02	<0.02	<0.02	<0.02	<0.02
sulfidic - Titratable Sulfidic Acidity	s-23H	sTSA	<0.02	<0.02	<0.02	<0.02	<0.02
Sulfur trail							
Total Sulfur	20A	$\%S_T$	0.69	0.44	0.29	0.34	0.27
acidic - Total Sulfur	a-20A	$a\text{-}S_T$	430	274	181	212	168
KCl Extractable Sulfur	23Ce	$\%S_{KCl}$	0.18	0.14	0.19	0.16	0.11
Peroxide Sulfur	23De	$\%S_P$	0.73	0.52	0.38	0.39	0.32
Peroxide Oxidisable Sulfur	23E	$\%S_{POS}$	0.55	0.38	0.19	0.23	0.21
acidity - Peroxide Oxidisable Sulfur	a-23E	$a\text{-}S_{POS}$	343	237	119	143	131
Calcium values							
KCl Extractable Calcium	23Vh	$\%Ca_{KCl}$	0.37	0.36	0.43	0.38	0.32
Peroxide Calcium	23Wh	$\%Ca_P$	22.20	21.10	16.00	16.40	13.10
Acid Reacted Calcium	23X	$\%Ca_A$	21.8	20.7	15.6	16.0	12.8
acidity - Acid Reacted Calcium	a-23X	$a\text{-}Ca_A$	10893	10349	7769	7994	6377
sulfidic - Acid Reacted Calcium	s-23X	$s\text{-}Ca_A$	17.5	16.6	12.5	12.8	10.2
Magnesium values							
KCl Extractable Magnesium	23Sm	$\%Mg_{KCl}$	0.12	0.11	0.18	0.14	0.10
Peroxide Magnesium	23Tm	$\%Mg_P$	1.03	0.98	0.77	0.77	0.56
Acid Reacted Magnesium	23U	$\%Mg_A$	0.91	0.87	0.59	0.63	0.46
acidity - Acid Reacted Magnesium	a-23U	$a\text{-}Mg_A$	749	716	485	518	378
sulfidic - Acid Reacted Magnesium	s-23U	$s\text{-}Mg_A$	1.20	1.15	0.78	0.83	0.61
Excess Acid Neutralising Capacity							
Excess Acid Neutralising Capacity	23Q	ANC_E	52.40	49.30	39.70	40.50	32.00
acidity-Excess Acid Neutralising Capacity	a-23Q	$a\text{-}ANC_E$	10470	9850	7932	8092	6394
sulfidic-Excess Acid Neutralising Capacity	s-23Q	$s\text{-}ANC_E$	16.79	15.80	12.72	12.98	10.25
Acid Base Accounting							
ANC Fineness Factor			1.5	1.5	1.5	1.5	1.5
Net Acidity (sulfur units)			<0.02	<0.02	<0.02	<0.02	<0.02
Net Acidity (acidity units)			<10	<10	<10	<10	<10
Assessment			**Ok**	**Ok**	**Ok**	**Ok**	**Ok**

3.3 Coral Communities

The Dampier Archipelago has a highly diverse coral assemblage exceeded in Western Australia only by Ashmore Reef (Marsh 1978, Veron and Marsh 1988, Veron 1993, Griffith 2004). Recent surveys of the coral reef habitats in the Dampier Port and inner Mermaid Sound recorded 120 species of scleractinian corals from 43 genera (MScience 2005a). Five coral assemblages were

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distinguished on the basis of proportional differences in generic composition. Four of the assemblages were dominated by a single genus each: *Acropora* (particularly plate *Acropora*), *Porites*, *Pavona*, and *Turbinaria* respectively. The fifth assemblage was missed, consisting predominantly of faviids, *Turbinaria* and a variety of other scleractinian corals (MScience 2005a).

The distribution of coral assemblages appears to be correlated with water quality, wave energy and tidal currents. Coral assemblages adjacent to the Dampier townsite and along the western margin of the Burrup Peninsula consist predominantly of the mixed coral assemblage (MScience 2005a).

Coral loss in the Dampier Port area is predominantly in the vicinity ship loading facilities at East Intercourse Island, Parker Point, the Dampier Cargo Wharf and the LNG wharves. Cumulative coral loss is quantified in more detail in **Section 3.4** of this document. These reefs receive substantial levels of natural turbidity and suspended sediment for much of the year, and appear reasonably resistant to it. The natural resilience of this assemblage has probably buffered it to a significant extent against the additional turbidity and sedimentation associated with dredging, construction and ship movements. These effects are described in more detail below.

The naturally high turbidity in the region limits the depth of benthic primary producer distribution such as macroalgae; however, the marine survey undertaken in 2000 by IRCE found no evidence of coral bleaching or coral stress caused by sedimentation (IRCE 2001). Coral abundance ranged from 20 to 60% of seabed composition along various offshore transects, and from 14 to 40% amongst nearshore sites. All coral appeared healthy. Macroalgae and turf microalgae are relatively sparse, although a community dominated by the brown alga Sargassum was found 800 m north of the wharf on East Intercourse Island. The more recent surveys undertaken in 2002 and 2003, undertook evaluations of ecosystem integrity. The ecological status of the three main habitat types in locations surrounding Hamersley Iron’s operations were evaluated utilising the classification system derived from ANZECC/ARMCANZ (2000) (see **Table 9**).

The confusion between disturbance and damage is due largely to the mixing of ecological units and the use of subjective terms. Disturbance is an ecological term referring to the perturbation of an ecosystem that affects internal system processes. A highly disturbed system will be one that is disturbed frequently or one which has suffered a strong recent disturbance. In areas classified as ‘highly disturbed’ due to the frequency of disturbance or in areas recovering from severe disturbance, individual organisms may be ‘healthy’ (a very subjective term). On land, areas infested by healthy weed species may be called ‘highly disturbed’.

Surveys of corals may describe corals as healthy or the system as ‘healthy’ based on its live corals or apparent recovery. However, the species composition and demography of the area may, at the same time, reflect its highly disturbed nature (existing immediately adjacent to a very large stockpiling operation and between two active wharves). It is not correct to infer the system has been degraded between being described as 'healthy' then 'highly disturbed'.

- **Table 9 Ecosystem condition classification for assessing Dampier marine habitats**

Ecosystem Condition	Description
Effectively unmodified	Areas where ecological integrity is effectively intact.
Slightly to moderately disturbed.	Areas where ecological integrity has been adversely affected to a relatively small but measurable degree by human activity. Biological communities remain in a health condition and the original ecosystem integrity is largely retained.
Highly disturbed	Areas where ecological integrity has been measurably degraded by human activity. Biological communities are unhealthy and the original ecosystem integrity has been undermined.

Source: IRCE (2003).

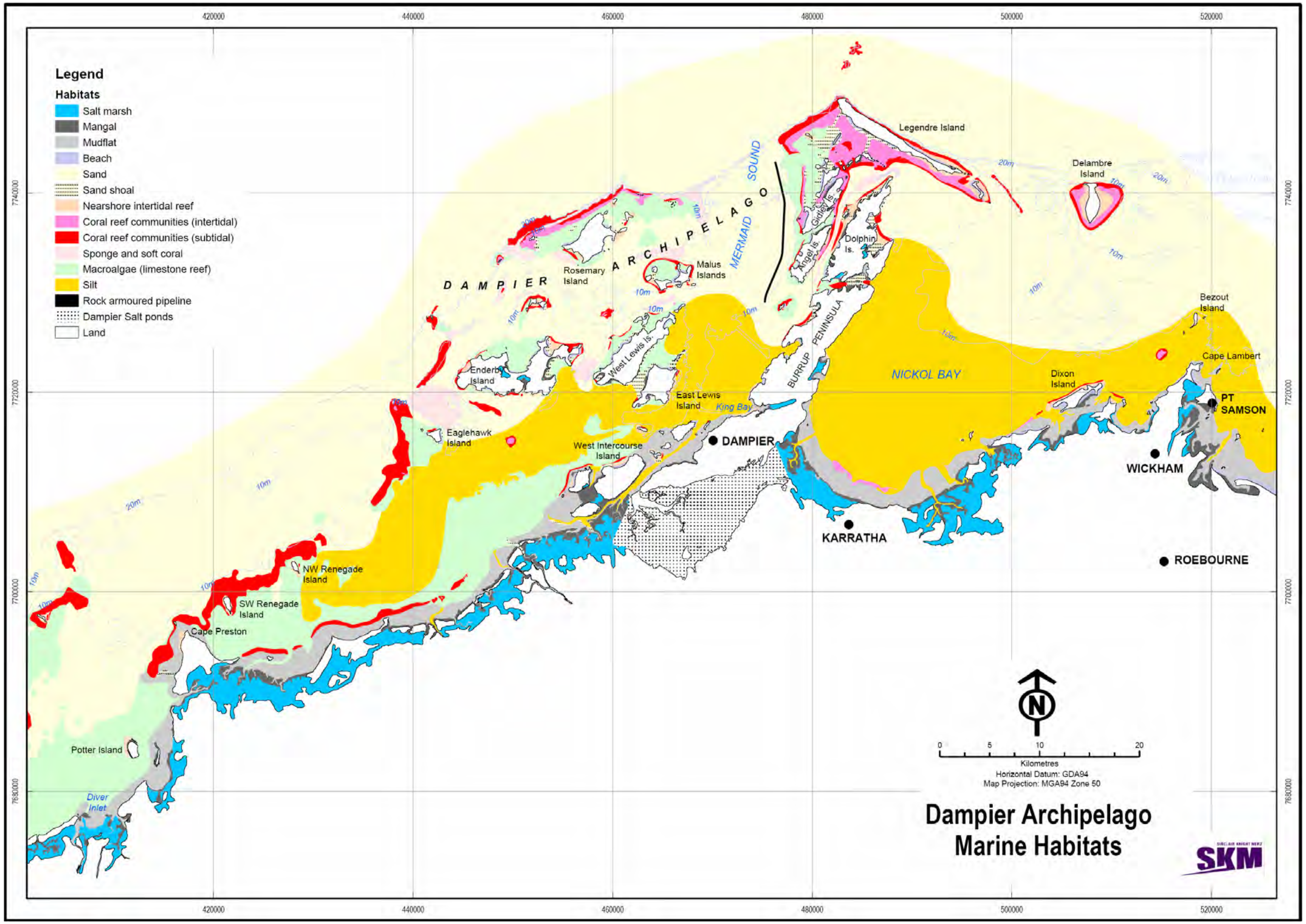
The IRC 3003 study concluded that areas along the mainland shore in close proximity to Hamersley Iron's Dampier operations are highly disturbed. These areas were identified as:

- Between the East Intercourse and East Mid-intercourse Island causeways;
- Within Hampton Harbour and the areas east of the East Intercourse Island causeway;
- Variable disturbance around Parker Point; and
- Around the East Intercourse Island iron ore load-out wharf.

The classification of disturbance at these sites was based on:

- Observed high water turbidity;
- Lower diversity and abundance of biota compared with reference sites;
- Observed stress in terms of sedimentation; and
- Evidence of anthropogenic wastes such as cooling water from the power station and rubbish.

Surveyed sites close to the loadout wharf and wastewater outlet were also highly disturbed. Sites located to the east were generally unmodified. Nearshore reference areas around Tidepole Island also showed slight to moderate disturbances as a result of sedimentation, coral bleaching and mortality. Coral bleaching was also detected at a reference site at East Lewis Island, where human influences would not be expected to cause bleaching suggesting that bleaching may be a natural occurrence. Sites amongst the Dampier Archipelago and offshore areas of the Dampier Port were found to be unmodified.



▪ **Figure 2 Predominant marine habitats within the Port of Dampier and adjacent waters**

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3.4 Cumulative Coral Loss

A study undertaken by MScience (2005b) on behalf of Hamersley Iron compared the quantity of present day coral habit with that of pre-impact at Dampier in 1957. The study area was comprised of the Hamersley Iron Sea lease (East Intercourse Island to the Service Wharf) totalling approximately 40 km^2. The study found the following:

- The present habitat colonised by coral at greater than 10% cover was 55.9 ha in 2004; and
- The estimated loss of coral ranged between 23–35 % since 1957.

Monitoring undertaken by MScience in 2004 for Hamersley Iron's dredging program found the following:

- A massive reduction in live coral cover in communities on the southern shore of West Lewis Island which was attributed to cyclonic freshwater inundation;
- Acroporids and faviids were apparently most susceptible to sedimentation while species of *Turbinaria*, *Pavona decussate*, *Diploastrea heliopora* and *Porites solida* were most resilient;
- Coral loss is likely to recover over a 10–20 year period; and
- Hamersley Iron's dredging did not adversely affect any corals.

The most recent dredging programs undertaken by Hamersley Iron and the Dampier Port Authority in 2004 resulted in limited coral loss at one location; thus the cumulative coral loss in the Dampier Port area is still well below the 10% threshold of the Benthic Primary Producer Habitat – Category E (Industrial and Port areas) in the EPA Guidance Statement No. 29 (EPA 2004).

3.5 Marine Vertebrate Fauna

Marine mammals recorded within Mermaid Sound are *Dugong (Dugong dugon*), Humpback Whale (*Megaptera novaehollandiae*), False Killer Whale (*Pseudorca crassidens*), Bottlenose Dolphin *(Tursiops truncatus*), Indo-Pacific Hump-backed Dolphin (*Sousa chinensis*) and Risso's Dolphin (*Crompids griseus*).

Whales migrate along the Western Australian coast, travelling south in summer and north, towards the tropics in winter. Discussions with the Department DEH indicated that tracked whales enter Mermaid Sound very infrequently, rather they pass through the area on the outside of the Archipelago. The Humpback Whale is listed as a vulnerable species and a migratory species under the *EPBC Act 1999*, and has special protection under the *Western Australian Wildlife Conservation Act 1950* where they are described as "rare or likely to become extinct."

The dugong is listed under "*other specially protected fauna*" in Schedule 4 of the *Wildlife Conservation Act 1950*, and although not currently listed under Commonwealth legislation, it is listed as “*vulnerable to extinction*” at a global scale by the World Conservation Union. Current knowledge on the size, distribution and migratory habits of dugong populations within the Dampier Archipelago is limited. However, dugong have been observed grazing in many of the shallow bays and in areas between islands, but are unlikely to occur around Parker Point or near operating vessels due to their sensitivity to noise.

The four species of turtle known to nest in the greater Dampier Archipelago area are the Green (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Flatback (*Natator depressus)* and Loggerhead (*Caretta caretta*). Green, Flatback and Hawksbill turtles are listed as “*vulnerable*” under the *EPBC Act* and the Loggerhead turtle is listed as “*endangered*” under the Act. Under Western Australian legislation all four turtles are listed as “fauna that is rare or is likely to become extinct” under schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice 1999 under the *Wildlife Conservation Act 1950*. The Dampier Archipelago provides important habitat for marine turtles, particularly the offshore islands where there are significant nesting beaches; these are located well away from the proposed areas of operation.

Twelve species of sea snake have also been found in the Dampier Archipelago, with the Olive Sea Snake (*Aipysurus laevis*) being the most common. Sixteen species of sea and shore birds are known to breed on the islands of the Dampier Archipelago.

3.6 Social Environment

3.6.1 Commercial Fishing

The major commercial fishing activities in the Dampier Region are prawn and finfish trawling, trapping, wet lining and pearling. None of these activities take place in the vicinity of the areas to be dredged or where spoil will be disposed. Commercial fishing areas and aquaculture leases are found outside of the port as shown in **Figure 3**. The nearest commercial fishery to the proposed dredging program is WA South Sera Pearls. The operations occupy 136 ha on the western face of West Lewis Island compared to the spoil ground which is located to the east of East Lewis Island.

3.6.2 Conservation Areas

Some of the islands of the Dampier Archipelago are contained within nature reserves for the protection of flora and fauna and are managed under the *Dampier Archipelago Nature Reserves Management Plan 1999 – 2000* (CALM 1990). Other islands within the area, including East Lewis Island are reserves for conservation and recreation. The surrounding waters of the Dampier Archipelago are the subject of the proposed Dampier Archipelago / Cape Preston Marine Conservation Reserve (**Figure 4**), which is currently under review. The Dampier Port area and the East Lewis Island spoil disposal area will not be included within the finalised marine park.

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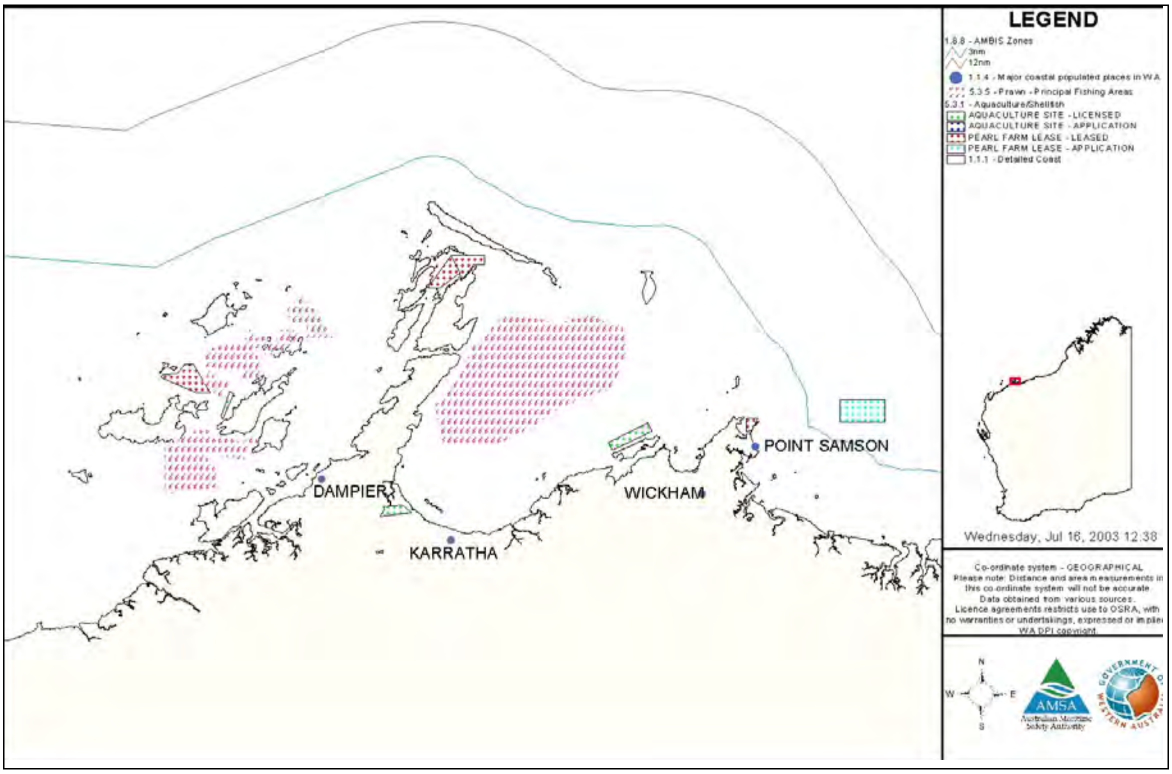


- **Figure 3 Commercial fishing in the region**

3.6.3 Recreation

The waters and islands of the Dampier Archipelago provide opportunities for land and sea-based recreational pursuits. Local boat ownership in Dampier and Karratha is very high and recreational fishing is popular, as are diving, snorkelling, surface water sports and wildlife viewing. Typically, such activities occur amongst the islands of the Dampier Archipelago, away from Dampier and the proposed dredging activities. (CALM 1994).

Fishers target coral and sub-tidal rocky reefs offshore and make use of the artificial habitat created by the North Rankin A Gas Pipeline in Mermaid Sound. Sites close to boat launching access south of the Dampier Power Station are also frequented. Some line fishing occurs to the east and north of the spoil ground at East Lewis Island. However, fishers traditionally avoid the shipping lanes within the Port of Dampier. There are numerous coastal line-fishing areas within sailing distance of the launching facilities at Dampier; however, these areas will not be adversely affected by dredging operations.

The Department of Transport has designated a water skiing area along the south-eastern edge of East Intercourse Island which is well away from the proposed dredging. Similarly, it is unlikely that an 8 knot speed restricted and boating prohibited area which has been established south west of

Foul Point on the edge of Dampier to protect swimmers, will be adversely affected by the dredging operations. The areas are approximately 3 km from the nearest dredging activities.

3.7 Values to be Protected

3.7.1 Ecological Values

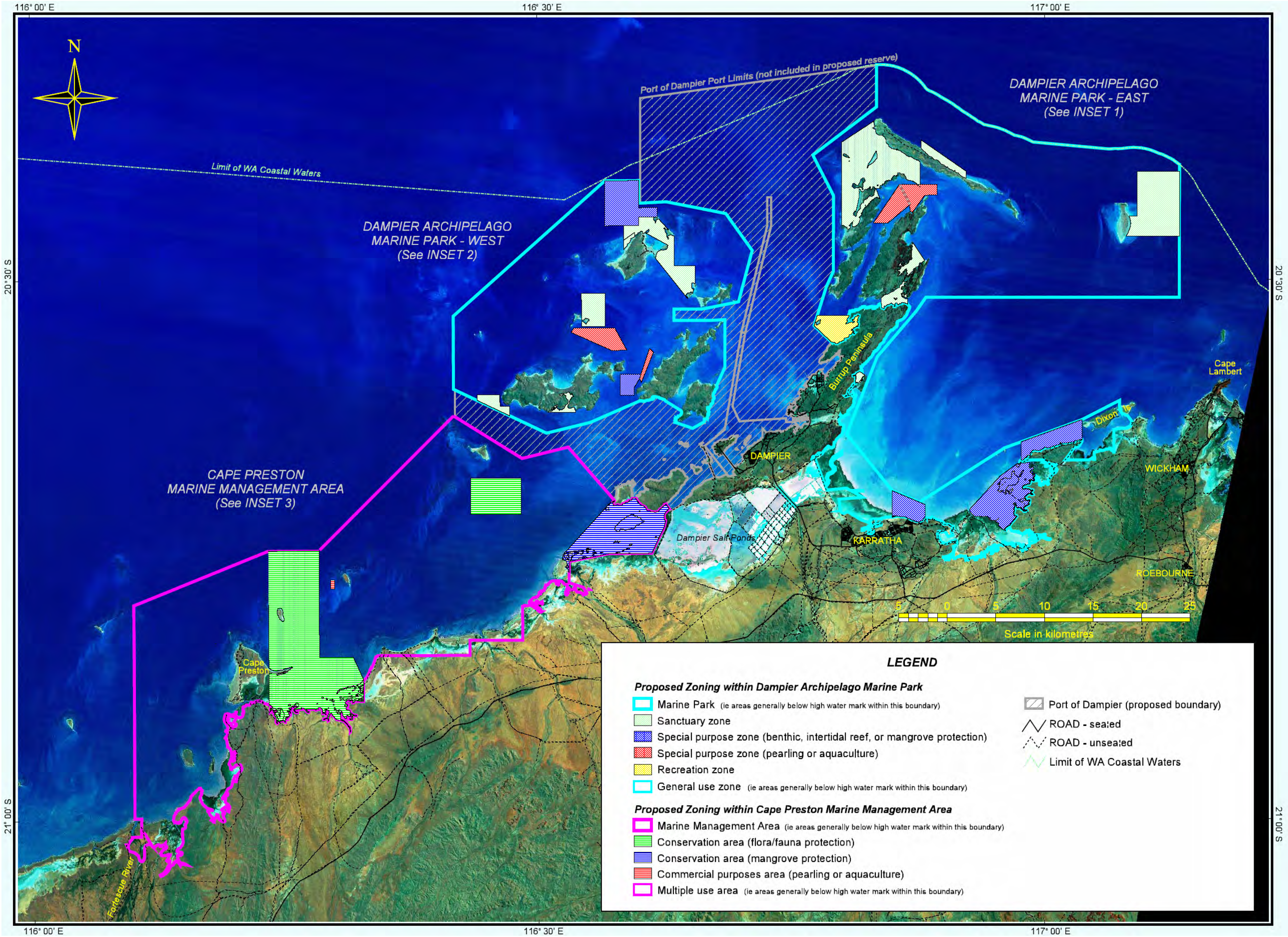
The following ecological values are to be protected:

- Coral diversity and abundance;
- Water quality; and
- Ecological Events – coral spawning.

3.7.2 Social Values

Tourism, fishing, aquaculture, industrial water supply and aesthetics of the area will not be adversely affected by the dredging program. The social value of the eastern shoreline of the East Lewis Island is considered limited as most visitors utilise the northern shore which is more protected during both summer and winter. The following social values are to be protected:

- The potential for aquaculture in the region; and
- The proposed marine park area.



- **Figure 4 Proposed Dampier Archipelago/Cape Preston Marine Park Zoning**

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4. Project Description

4.1 Dampier Port Operations

4.1.1 Existing Operations

The Dampier port is one of Australia's largest tonnage ports. The port facilities operated by Hamersley Iron includes two terminals ─ Parker Point and East Intercourse Island.

Parker Point currently accommodates three ships at the wharf, two of which can be loaded at any given time. This allows empty ships to be brought into the berth and loaded while a fully laden ship is in berth waiting for suitable tides to depart. The existing berths are dredged to RL 19.5 m below Chart Datum (CD) and capacity for vessels of up to 220,000 DWT. A departure channel, dredged to 15.35 m below CD, connects the berth to the Main Shipping Channel. The Main Channel is dredged to 15.6 m below CD.

East Intercourse Island has one ship loading facility that is dredged to 21.5 m below CD and has a berth capacity for vessels of up to 250,000 DWT. East Intercourse Island also has a lay-by berth dredged to 19.5 m below CD adjoining the loading berth, which provides a facility for holding laden ships waiting for a suitable departure tide. This allows empty ships to be brought into the berth and loaded while the fully laden ship is in berth waiting for suitable tides. A departure channel, dredged to 15.5 m below CD, connects with the Main Channel.

The shipping channel was initially dredged by Hamersley Iron in 1965 to a depth of 13 m. A brief review of historical dredging undertaken for Hamersley Iron's operations is summarised below:

- 1965: capital dredging of shipping channel to Parker Point (2.5 Mm^3);
- 1968: deepening of shipping channel (1.5 Mm^3);
- 1970–71: widening of the channel and extension of the channel to the East Intercourse Island facility (760,000 m^3);
- 1981: Parker Point channel widened and deepened (400,000 m^3);
- 1985: maintenance dredging of East Intercourse Island berth and channel (volume unknown);
- 1989: maintenance dredging of shipping channel (350,000 m^3);
- 1991: maintenance dredging of East Intercourse Island berth (volume unknown);
- 1998: capital dredging of shipping channel (2 Mm^3);
- 1998: maintenance dredging around berths (800,000 m^3);
- 2000: minor dredging around berths (5,000 m^3); and
- 2004: capital dredging at Parker Point (3.1 Mm^3).

4.1.2 2004 Dredging Program

The 2004 program involved dredging to extend the berth pocket at the Parker Point wharf and to create a new berth pocket on the south side of the wharf. A new swing basin and departure channel was dredged to provide navigable waters for additional berths. In addition, a new approach channel was dredged to the north and east of the Parker Point wharf to allow ships to enter the berth.

The maintenance dredging program required the removal of siltation in the existing shipping channel and departure channels from Parker Point and East Intercourse Island. Approximately 85% of spoil was placed in the East Lewis Island Spoil Ground and the remaining 15% in the Northern Spoil Ground.

A Dredging and Disposal Management Plan was prepared and implemented prior to dredging commencing, and the dredging was completed without any significant environmental impacts. The monitoring programs during and after the 2004 dredging works recording no significant impact to coral communities resulting from spoil dumping at the East Lewis Island Spoil Ground or the Northern Spoil Ground.

4.2 Proposed Dredging Program

4.2.1 Overview

The construction of the additional ship-loading facilities at Parker Point will involve dredging to extend the existing berth pockets at the Parker Point wharf and to create a new berth pocket on the south side of the wharf. An extended swing basin and departure channel will also be dredged to provide navigable waters for the additional berth. Dredging will also be undertaken to improve the approaches and swing basin areas and to remove recent siltation in existing shipping channels and provide for relocation of the existing tanker unloading facilities from the Service Wharf at Parker Point. The dredging and disposal program is anticipated to take 12–15 weeks.

4.2.2 Areas to be Dredged

The areas to be dredged comprise:

- A westward extension of the existing northern and southern berth pockets at the Parker Point wharf (Dredge to RL-19.5 m CD);
- An eastward extension of the existing southern berth pocket to provide a new berth (Dredge to RL-19.5 m CD);
- Widening of the southern departure area (Dredge to RL-15.35 m CD);
- Widening and deepening the southern swing basin (Dredge to RL-10.0 m CD);
- Widening of the northern approach route (Dredge to RL-8.0 m CD);

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- A new berth pocket east of the existing Parker Point Wharf for future unloading of tankers (Dredge to RL-12.0 m CD);
- Removal of siltation in the existing northern approach route (Clear to RL-8.5 m CD) and approaches to the Service Wharf (Clear to RL-8.0 m CD);
- Removal of under wharf spillage from the Parker Point Berth (Clear to RL-19.5 m CD) and the East Intercourse Island Berth (Clear to RL-21.0 m CD); and
- Removal a high spot adjacent to the main shipping channel (east of Beacon 7E) to provide safe navigation for incoming vessels (Clear to RL-8.5 m CD).

The total volume of material needed to be dredged to achieve the required depths is approximately 3.41 Mm^3. In order to achieve the required dredge depths over the entire dredge areas it will be necessary to dredge below the required depths. The extent of over-dredging is dependent on the material being dredged and the equipment being used and the above figure includes an over depth allowance determined from the 2004 dredging campaign. The dredge areas are shown graphically in **Figure 7** while the dredge location characteristics of each location are provided for maintenance dredging in **Table 10** and capital dredging in **Table 11**.

- **Table 10 Maintenance dredging characteristics**

Parameters	Locations to be Dredged				
	E	F	PP	EII	Total
Existing sea bed level (RL-m CD)	7.5	6.5	19.5	19.0	–
Required dredge depth (RL-m CD)	8.5	8	21.0	19.7	–
Depth of dredging (m)	1.0	1.5	1.5	0.7	–
Area to be dredged (ha)	30.0	15.0	0.3	0.3	30.6
TBT material for offshore disposal (m^3)	70,000	0	5,000	5,000	80,000
Clean material for offshore disposal (m^3)	230,000	225,000	0	0	455,000
Material for onshore disposal (m^3)	0	0	0	0	0
Total material to be dredged (m^3)	300,000	225,000	5,000	5,000	535,000

- **Table 11 Capital dredging characteristics**

Parameters	Locations to be Dredged						
	A	B	C	D	G	H	Total
Existing sea bed level (RL-m CD)	11.0–15.4	6.5–11.0	6.5–8.0	7.0	8.0	7.0	–
Dredge depth below existing sea bed (m)	19.5	15.4	10.0	8.0	12.0	8.5	–
Depth of dredging (m)	4.2–8.5	4.4–8.9	2.0–3.5	1.0	4.0	1.5	–
Area to be dredged (ha)	3.2	10.9	21.5	71.8	2.1	1.0	125.5
TBT material for offshore disposal (m^3)	28,000	54,000	0	41,000	0	0	123,000
Clean material for offshore disposal (m^3)	52,000	556,000	749,000	880,000	95,000	15,000	2,347,000
Material for onshore disposal (m^3)	182,000	258,000	0	0	0	0	440,000
Total material to be dredged (m^3)	262,000	868,000	749,000	921,000	95,000	15,000	2,910,000

4.2.3 Maintenance Dredging

Total volume to be dredged is approximately 0.55 Mm^3 (see **Table 10**). The total volume of material to be dredged under the maintenance dredging program will be placed offshore on the Northern Spoil Ground (see **Section 4.3**).

The Northern Approaches to Parker Point were dredged from a natural seabed depth of around RL-7.0 m CD to RL-7.5 m CD to a declared depth of RL-8.0 m in the 2004 dredging program. Subsequently sediment ingress has occurred which has reduced depths to between RL-7.5 CD and RL-8.0 m CD. Additionally, sedimentation has reduced depths of the approach to the Service Wharf to between RL-6.0 m CD and RL-6.5 m CD from a depth of RL-6.5 m CD. The origin of this sediment is likely to be from the area directly south of the approach route which was used for land disposal of sediment during the 2004 program. Fine sediment liberated during construction of the sea wall and from overflow from the onshore settlement ponds during the 2004 dredging works is likely to constitute the bulk of this infill. In addition, infilling sediments will be derived from remobilisation of this and other sediment from heavy tug activity and shipping around the Parker Point and Service Wharf berths. Thus it is probable that the sediments to be removed here are the fine fractions of those assessed and disposed in the 2004 program.

Spillage of iron ore product while loading over the last 5–10 years has led to a build up of material at either end of the ship loading berths at the Parker Point and East Intercourse Island wharves. Material has accumulated at either end of the berths where transfer points for the ore conveyor on the wharf are located above, which lead to concentrations of product spillage. In addition, the entry and physical presence of hulls of large vessels pushes fine sediments to the berth extremities. The likely composition of this material is some iron ore fines and lump plus fine sediment mobilised from the berths and surrounding areas during ship movements and current flow and deposited in the berth pockets.

The material types to be dredged are expected to be identical to the bulk of material dredged in previous campaigns, including the recent 2004 dredging campaign. That material was comprised predominately of fine silts with varying amounts of fine to medium grained sand and in some cases, fine calcareous gravel and shell fragments.

The majority of materials to be dredged comprise high moisture content silts and clays with a high percentage of fines and are unsuitable for re-use as construction material. Accordingly, dredged materials will be placed in existing offshore spoil grounds located within the limits of the Port of Dampier. Disposal of dredged material at sea within the Port of Dampier is coordinated by the Dampier Spoil Ground Management Committee.

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4.2.4 Capital Dredging

Total volume to be dredged is in the order of 2.91 Mm^3. The volume of material to be dredged in each area is provided in **Table 11**. Approximately 2.46 Mm^3 of this material will be disposed offshore on the spoil grounds while approximately 0.44 Mm^3 will be disposed of onshore in the reclamation area (see **Section 4.3**).

The material to be removed during the capital dredging is comprised of the following:

- **Loose surface sediments:** Much of the capital dredging areas are overlain by loose sediments. Their composition is identical to the bulk of material dredged previously in this section of the harbour by numerous maintenance programs. As for the proposed maintenance program, it is probable that the sediments to be removed here are the fine fractions of those assessed and disposed in the 2004 program. That material was comprised predominately of fine silts with varying amounts of fine to medium grained sand and in some cases, fine calcareous gravel and shell fragments.
- **Consolidated Sediments:** Sediments deeper than 50–100 cm are consolidated and previously undisturbed by dredging. Previous geotechnical drilling has been used to develop a preliminary geological model which indicates materials likely to be encountered will include:
    - Marine silts and silty clays, overlying;
    - Firm to stiff clays, overlying;
    - Dense clayey gravel, overlying;
    - Low to medium strength calcarenite, overlying; and
    - High strength granophyre or dolerite.

Material for offshore disposal is predominantly sands, silts and clays with a high moisture content. Most sediment samples assayed contained less than 1–2% gravel (>2mm). Samples distant from the berths (eg at the northern end of Area D) were close to 50% sand, while with the exception of a few areas dominated by clay–silts, most of the samples near the berth were roughly equally divided into sand-silt-clay.

Material going onshore for disposal in reclamation areas is predominantly gravel and sand suitable for compaction and will be used as fill for land based development associated with the upgrade of the Parker Point facilities.

4.2.5 Dredging Method

Dredging of large areas is commonly completed with trailer suction hopper dredges. These dredges are the most efficient dredge at removing large volumes of spoil and can cover large areas most efficiently, without the need to use separate disposal barges. Cutter suction dredges are also commonly used in Australia where ever dredging of harder substrates is required. Different methods may be used to reduce turbidity associated with cutter suction dredges, such as the disposal of spoil directly to the seabed where it can be removed with a trailer suction hopper dredge. Small or shallow dredging projects may choose to employ a back hoe dredge from wharves or barges; however these are not suitable for large scale dredging programs such as the Dampier dredging program.

Dredging will be undertaken using a combination of a trailer suction hopper dredge and a cutter suction dredge. The trailer suction hopper dredge will initially remove any contaminated sediments suitable for offshore disposal and place them in the Northern Spoil Ground. The trailer suction hopper dredge will then remove the unconsolidated surface sediments and dispose of this material at the East Lewis Island Spoil Ground and to the Northern Spoil Ground to cover the contaminated sediments. The trailer suction dredge is anticipated to remove all materials above approximately RL -12 m CD.

The cutter suction dredge will operate in the berth pockets and departure basin south of Parker Point adjacent to the berths at Parker Point to remove the deeper and harder calcarenite material and pump it to the onshore spoil disposal area at Parker Point.

Trailer Suction Hopper Dredge

Trailer suction hopper dredgers are used mainly for maintenance dredging in harbour areas and shipping channels where traffic and operating conditions preclude the use of stationary dredges. This type of dredge is particularly efficient for removal of thin layers of soft material over large areas, such as dredging of channels. Accordingly, a trailer suction hopper dredge will be used to dredge to remove soft overlying materials from other dredge areas.

The trailing suction hopper dredge operates much like a floating vacuum cleaner. The trailer suction hopper dredge has a hull in the shape of a conventional ship and is both highly sea worthy and able to operate without any form of mooring or spud. It is equipped with a single suction pipe or twin pipes, one on each side, equipped with drag-heads (**Figure 5**).

The dredger removes material in a series of cycles until the required dredge depth has been achieved. A cycle consists of dredging, sailing to the disposal area, discharging the material from the hopper and sailing back to the dredging site. The dredge contractor will aim to remove the maximum amount of material in the shortest time for each cycle.

During the dredging stage, the dredge moves forward drag-heads are lowered to the seabed and a slurry of sediment and water is hydraulically lifted through the trailing pipes by one or more pumps and discharged into a hopper contained within the hull of the dredge. The dredge sails slowly over the area to be dredged filling its hopper as it proceeds. The time required to fill a hopper and the actual quantity of solids in the hopper at the end of the filling process is decided by two main factors:

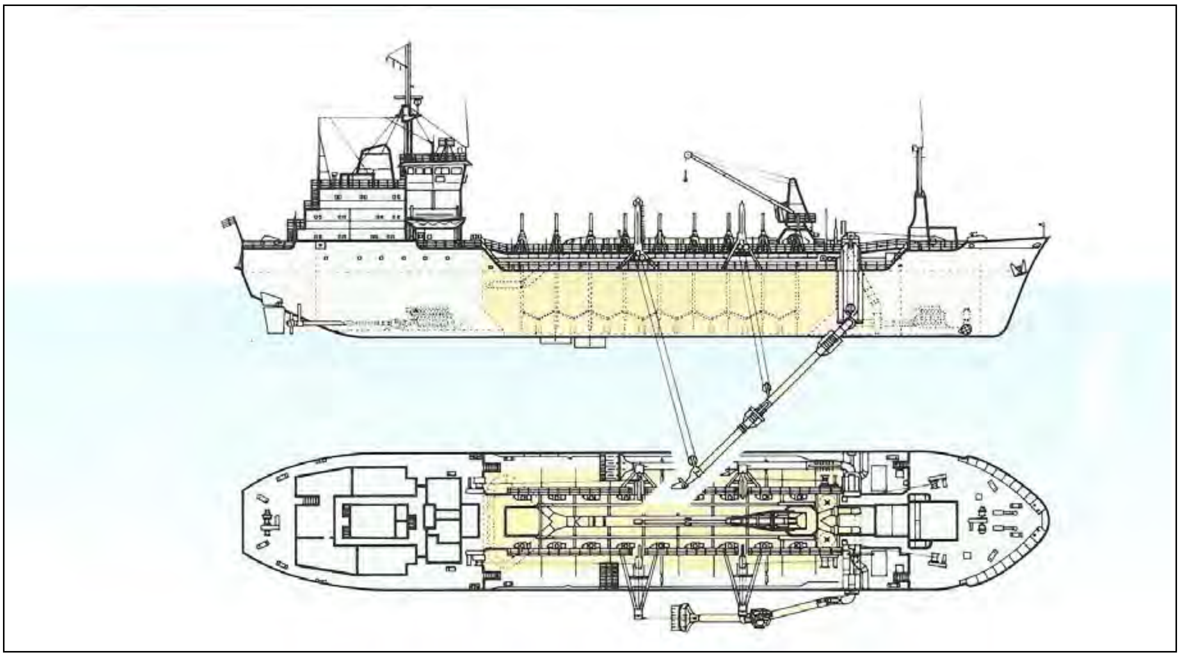
- The degree of concentration of material that enters the drag-head, which depends on the characteristics of the dredged material.
- The speed of settlement of material in the hopper, which depends mainly on the grain size of the material.

Dredged material settles in the hopper and water is drained through a controllable hopper overflow system to optimise the payload of the dredge, thereby maximising the efficiency of the dredging operation and minimising the duration of dredging.

On completion of loading, the dredge sails to the spoil ground where its contents are discharged by opening the doors or valves in the hull of the dredge.

Whilst sailing to the disposal area, solids will settle in the hopper, leaving water at the top of the hopper with a low concentration of solids. For silts and sands, this surface water is generally pumped overboard during this sailing. With a clay material the surface water is usually retained in the hopper and the weight of the water over the clay is used to assist in pushing the spoil material out of the hopper during discharge.

At the disposal area the vessel will discharge its cargo by gravity dumping through bottom doors or bottom valves. With free running materials like silt, sands and gravels, the discharge can be done very quickly, but the process takes longer with clays.



■ **Figure 5 Trailer Suction Hopper Dredge – side and plan views**

Material to be removed by the trailer suction hopper dredge will mostly be fine grained and therefore during dredging, the dredge will create some turbidity. This is usually in the form of plumes originating from the following main activities of the dredger:

- Using overflow system that releases material into the water column.
- Using bypass system that releases material into the water column.
- Propellers dislodging seabed material and mixing this into the water column.
- Drag-head movement mixing seabed material into the water column.

Propeller wash is the most significant source of suspended sediments (Damara 2004) while the first two activities are a significant source of turbidity. Each activity is described more fully below.

The dredge's overflow and bypass systems are each designed to help optimise the amount of solid material in the hopper within a given dredging cycle time. The overflow discharge point is usually at keel level. During dredging, overflow occurs once the hopper is full with slurry but the solid content in the hopper has not reached its optimum. Overflow is allowed to continue as long as there is a marked difference between concentration of sediment at the intake point (drag-head) and the point of overflow. The duration of overflow is also influenced by the time it takes to sail to the disposal area as a proportion of the dredge cycle. The use of overflow will be restricted to dredging of coarse materials, i.e. sandy clays and gravels. Overflow will not be permitted when dredging silts. Typically when silts are dredged, sediment concentrations in the intake and overflow are similar and there is no benefit for overflow. When coarse materials are dredged, the use of overflow techniques will enable the dredge to have greater payload for each cycle and hence will reduce the total duration of the dredging works.

Trailer dredgers are also fitted with a bypass system designed to prevent water or slurry with only a small percentage of solids being discharged into the hopper. The bypass system is used mainly at the commencement and conclusion of the dredging stage, when solid concentrations in the slurry are low. This includes periods when dredging is stopped and re-started, such as whenever the dredger has to turn at the end of passes during dredging. During bypass operations, a low concentration slurry is pumped overboard. Some trailer dredgers are equipped to discharge bypass slurry at keel level. It is in operator's interest to keep the time for this process to a minimum, usually under a minute.

As the dredger moves, its propellers will mix into the water column material from overflow, bypass or discharge activities. In shallow draft areas the dredge's propellers may also create turbidity by dislodging and resuspending seabed material.

When the drag-head is operating, any dislodged material is quickly sucked up into it and therefore very little turbidity is created. When the drag-head is not operating, it is raised above the seabed, so no turbidity is created.

To ensure that impacts are restricted to the nominated dredging and disposal locations trailer suction hopper dredgers will be required to have Differential Global Positioning Systems on board and vessel positions will be logged during dredging and disposal operations.

Once empty the dredge returns to the dredge area where the cycle is repeated. The duration of sea dumping of dredge spoil will continue for 24 hours/day, 7 days per week and is expected to last for a period of 6–8 weeks. The dredging will be undertaken effectively as a continuous program, subject to the availability of dredges to undertake the programs.

Cutter Suction Dredge

Cutter suction dredging will remove the harder material beneath the loose silty surface layer. A cutter suction dredger is typically a rectangular shaped pontoon. On the front it has a hinged 'ladder' fitted with a 'cutter head'. The ladder can be lowered so that the cutter head touches the seabed. The cutter head is a rotating mechanism fitted with pick-points or teeth to break up the material to be dredged. Dredged material is removed via a suction pipe that passes from the cutter head, up the ladder and to the discharge point(s). On the back of the pontoon the cutter has spuds to connect the pontoon to the seabed and to act as a pivot point for the cutter while slewing the cutter head. These spuds are mounted in 'spud carriages'. While one spud is fixed to the seabed, the other can be raised and moved forward in its carriage, then lowered and fixed to the seabed.

When fixed to the seabed, the spuds provide a horizontal reaction force as the cutter head is pushed forward into the material being dredged.

The dredge operates by swinging about a central working spud using a mooring leading from the lower end of the ladder to anchors. By pulling on alternate sides, the dredge clears an arc of cut, and then moves forward by pushing against the working spud. The cutter breaks up hard material. As dredging proceeds, the dredge creates a 'bench' in the seabed. When there is no more material to be removed from the bench, the spuds at the rear of the Cutter are used to advance the whole dredge. The process is repeated, creating new benches in the seabed until the desired seabed level is achieved over the required area.

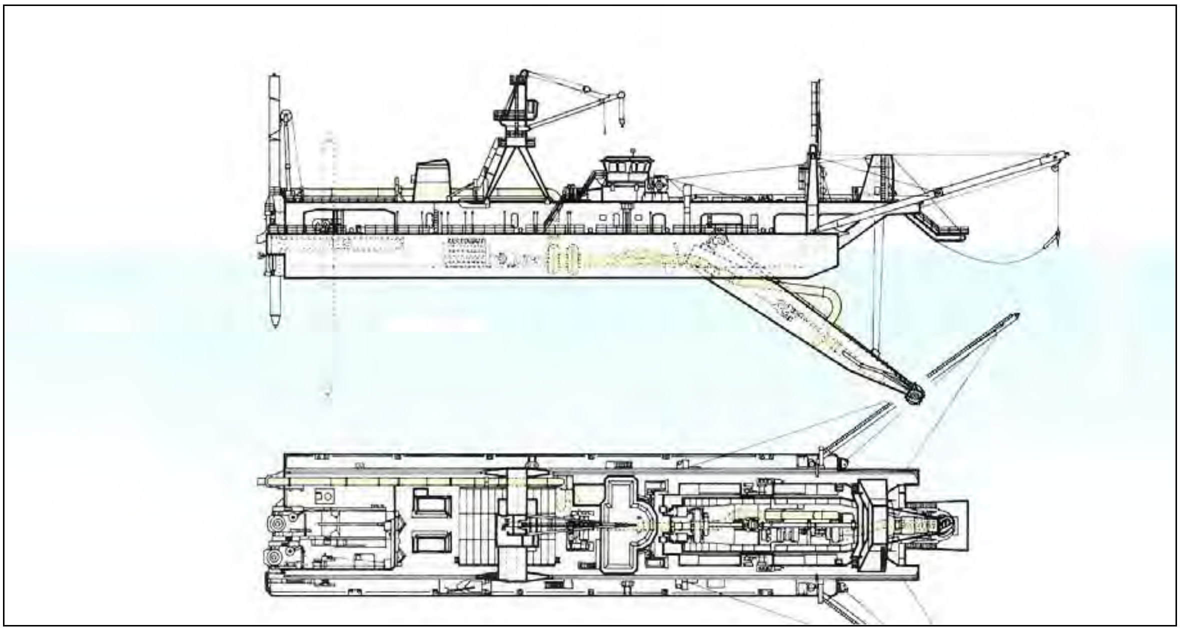
Cutter suction dredgers are usually not self –propelled and are towed to position at the dredging site. Once in position the ladder and cutter head are lowered to the seabed and the rotating cutter head mechanism is activated. The rotation of the cutter head and pick points at the seabed dislodges seabed material and creates a slurry of seabed material and water. This slurry is sucked up by an under water pump inside the ladder near the cutter head. Slurry is pumped along the pipeline in the ladder for discharge. Further pumps in the dredge are used to pump the slurry to the discharge point. If desired, slurry may be pumped via floating pipes to a discharge point some kilometres distant from the dredge.

During dredging with a cutter suction dredge turbidity may be caused at two points:

- At the cutter head where material is cut and loosened.
- At the discharge point.

The economics of dredging are greatly affected by material lost near the cutter head. Therefore the prime concern of a dredging contractor is to minimise these losses. The cutter head is designed to minimise material loss – relying on highly efficient suction and generating minimal turbidity. High suction near the cutter head means that most of the material loosened by the cutter head is captured. Some material may be missed and fall to the seabed below the cutter head. These losses are usually small and consist primarily of solid material.

A cutter suction dredge with adequate pumping power and floating pipelines can pump materials directly into the Parker Point land based spoil ground.



- **Figure 6 Cutter Suction Dredge – side and plan views**

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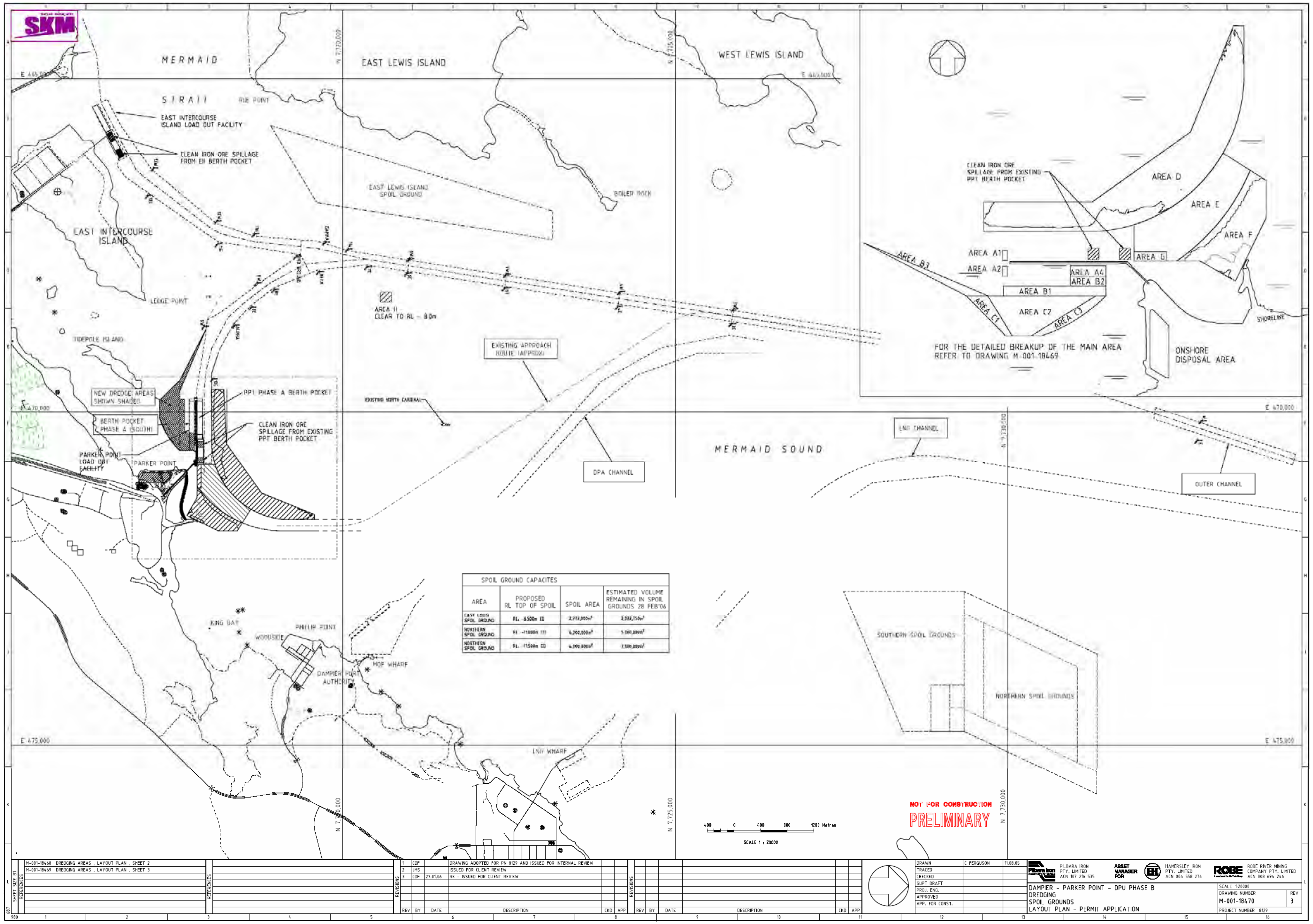

- **Figure 7 Dredging site plan**

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4.3 Spoil Disposal

Approximately 3.01 million cubic metres will be placed in offshore spoil grounds and approximately 0.44 million cubic metres will be pumped ashore to the reclamation area (see **Table 12**).

- **Table 12 Disposal program**

Program	Offshore	Onshore	Total
Maintenance	0.54		0.54
Capital	2.47	0.44	2.91
Total	**3.01**	**0.44**	**3.45**
Location	**Maintenance**	**Capital**	**Total**
Onshore reclamation area		0.44	0.44
Northern Spoil Ground	0.30	1.70	2.01
East Lewis Island Spoil Ground	0.24	0.76	1.00
Total	**0.54**	**2.91**	**3.45**

4.3.1 Offshore Disposal

This process is being managed under the *Environmental Protection (Sea Dumping) Act 1981* through sea dumping applications (maintenance and capital) to the Department of the Environment and Heritage (DEH).

Maintenance Dredge Material

The majority of materials resulting from maintenance dredging are comprised of high moisture content silts and clays with a high percentage of fines and are unsuitable for re-use as construction material but are suitable for offshore disposal. Accordingly, dredged materials will be placed in existing offshore spoil grounds located within the limits of the Port of Dampier. Disposal of dredged material at sea within the Port of Dampier is coordinated by the Dampier Spoil Ground Management Committee through a Spoil Ground Management Plan (see **Appendix E**). The total volume of material to be disposed is approximately 0.54 Mm^3 which will be allocated to the following spoil grounds:

- Approximately 0.30 Mm^3 to the Northern Spoil Ground; and
- Approximately 0.24 Mm^3 to the East Lewis Island Spoil Ground.

Capital Dredge Material

The majority of materials resulting from capital dredging are comprised of low moisture content with a low percentage of fines and are suitable for both re-use as construction material and for offshore disposal. Accordingly, dredged materials will be placed in both the onshore reclamation area and existing offshore spoil grounds located within the limits of the Port of Dampier. Disposal of dredged material at sea within the Port of Dampier is coordinated by the Dampier Spoil Ground Management Committee through a Spoil Ground Management Plan (see **Appendix E**). The total volume of material to be disposed of offshore is approximately 2.46 Mm^3 which will be allocated to the following spoil grounds:

- Approximately 1.70 Mm^3 to the Northern Spoil Ground; and
- Approximately 0.76 Mm^3 will go to the East Lewis Island Spoil Ground.

4.3.2 Onshore Disposal

Approximately 0.44 Mm^3 of material requiring removal by the cutter suction will be used as fill for land based development associated with the upgrade of the Parker Point facilities. The cutter suction dredge will pump dredge material ashore to the existing Parker Point Spoil Area where it will be settled in a series of ponds.

Dredge slurry will be pumped via a floating or submerged pipeline to the onshore disposal areas. The maximum pumping distance across water (from the furthest western most point of the new departure basin) is approximately 1.5 km.

Land disposal sites will be configured to receive and contain dredge spoil slurry for sufficient time to allow the majority of fines to settle. Recent experience in dredging calcarenite material at Dampier and Port Hedland indicated that more than 98% of sediments settled in the ponds. The water resulting from the settlement of dredge slurry is termed return water. This water will have the majority of slurry removed by settlement or by passive filtration through geotextile lined seawalls. Return water from the land disposal area would diffuse through the seawall. As the level of fill builds up in the ponds, return water will enter a weir box and be discharge through overflow pipes into the sea adjacent to the existing sea wall. A silt curtain will be located upstream of the weir box to minimise turbidity of the return water ultimately discharging into the harbour waters. The discharge area is well protected from prevailing wind allowing the deployment of additional silt curtains if required.

In the detailed design phase of the dredging and disposal program, the final layout of ponds will be revised to take into account the contractor’s dredging plant and work methods. In particular, consideration will be given to production rates, pumping capacity and pipe diameter proposed by the dredging Contractor.

4.3.3 Northern Spoil Ground

The Northern Spoil Ground is located between the Woodside shipping channel and Conzinc Island. The spoil ground is approximately 2 km by 2 km, with sea bed levels varying between RL-11 m

CD to RL-16 m CD. Both Woodside and DPA have used this spoil ground for various capital and maintenance dredging programs. Hamersley Iron also placed about 0.47 Mm^3 (15% of DPU project dredging) into the Northern Spoil Ground in 2004. A recent survey data indicated the remaining capacity of the grounds, to be approximately 5.0 Mm^3 (assuming RL -11.0 m CD) The coordinates for the area within the approved spoil ground that will receive spoil are:

	Latitude	Longitude	Easting	Northing
NW corner	20° 30.910'S	116° 44.894'E	0473637	7731341
NE corner	20° 30.910'S	116° 46.102'E	0475737	7731341
SE corner	20° 31.971'S	116° 45.571'E	0474797	7729341
SW corner	20° 31.996'S	116° 44.358'E	0472697	7729341

Datum is AGD84 Zone 50K

Dampier Port Authority's Spoil Ground Management Plan (see **Appendix E**) specifies that TBT contaminated material must be placed within the Northern Spoil Ground. While the chemical assessment of this material using the NODGDM suggests it is suitable for unconfined ocean disposal, it will be treated in a precautionary manner. All spoil from both the East Intercourse Island and Parker Point Berths (0.01 Mm^3), plus a proportion of material from Area E and F (0.07 Mm^3) will be removed early in the dredging program and placed on the Northern Spoil Ground in an area of bathymetry lower than the surrounds. This area will be identified from the post-disposal bathymetry to be obtained following the completion of the Woodside dredging program in March 2006. Subsequent disposal of clean material (1.7 Mm^3) at the Northern Spoil Ground will be placed over the TBT contaminated material.

4.3.4 East Lewis Island Spoil Ground

The East Lewis Island Spoil Ground is located between the shipping channel and East Lewis Island. The spoil ground is 5 km long and 1.5 km wide, with sea bed levels varying between RL-4 m CD to

RL-11 m CD. Hamersley Iron has used this spoil ground for various capital and maintenance dredging programs. Since 1965, this area has received more than 11 Mm^3 of dredged material from various capital and maintenance dredging programs. A survey of the spoil grounds undertaken in mid 2004 after the completion of disposal within the 2004 dredging program indicated the remaining capacity of the grounds, to be approximately 2.0 Mm^3.

The coordinates for the area within the approved spoil ground that will receive spoil are:

	Latitude	Longitude	Easting	Northing
NW corner	20° 30.930'S	116° 41.180'E	0467163	7723915
NE corner	20° 30.930'S	116° 41.430'E	0467603	7723915
SE corner	20° 37.260'S	116° 40.990'E	0466843	7719600
SW corner	20° 37.790'S	116° 40.090'E	0465295	7718624

Datum is AGD84 Zone 50K

Approximately 0.76 Mm^3 of clean material from the capital dredging program and 0.24 Mm^3 from the maintenance dredging program will be disposed to the East Lewis Island Spoil Ground.

4.3.5 Disposal Process

The sea disposal of sediments on the East Lewis Island Ground will disturb soft bottoms, comprising dredge spoil from dredging campaigns, but presents only a moderate risk to the nearby coral communities just off the East Lewis Island shoreline. The sea disposal of sediments on the Northern Spoil Ground will disturb soft bottoms, comprising dredge spoil from dredging campaigns, but presents minimal risk to coral communities. Spoil disposal to both of these grounds will be undertaken according to ambient tide and weather conditions to enhance management of turbidity levels in the marine environment and impact on corals. In the 2004 dredging program 85% of spoil was placed in the East Lewis Island Spoil Ground and the remaining 15% in the Northern Spoil Ground. Monitoring programs during and after the 2004 dredging works recorded no significant impact at adjacent coral monitoring sites arising from spoil dumping at these locations.

The material to be dredged as part of the maintenance program and some material from the capital program show contamination concentrations of tributyltin (TBT). TBT is used in as an active ingredient in marine antifouling paints and is, therefore, detected in the waters of most major harbours, and especially in sediments in the vicinity of dockyards and berths.

The TBT contaminated material will be removed by trailer suction hopper dredge at the commencement of dredging and placed in a depression within the Northern Spoil Ground (to be identified from Woodside post disposal surveys). Clean material will be placed over the contaminated material to a minimum of one metre which will restrict the spread of any TBT contaminated material from the grounds. TBT contamination that escapes is likely to degrade rapidly (2–4 weeks) to DBT or MBT due to oxygenation and mixing.[1]

[1] A previous spoil disposal exercise by DPA in 2004 which involved the placement of a substantial amount of TBT contaminated spoil on the Northern Spoil Ground did not cause any detectable elevation of TBT in nearby sediments, nor did it lead to an increase in imposex in a nearby mollusc population. In the present instance, it is likely that there will be a similar lack of impact from TBT contaminated sediments to be placed on the Northern Spoil Ground.

5. Numerical Modelling of Dredge and Disposal Plumes

A detailed modelling exercise was undertaken by Global Environmental Modelling Systems (GEMS) to simulate the effects of dredging and disposal of dredged material on water quality. The GEMS modelling is summarised below.

The scope of work for the modelling was as follows:

- Obtain and analyse suitable wind data for the period of the project;
- Update model bathymetry including delineation of new channels;
- Establish, test and run the 3-d hydrodynamic model (GCOM3D) covering the Mermaid Sound region and adjacent waters for a period encompassing the planned dredging program;
- Scope the dredging program of works to develop model assumptions, including, in particular, sediment release volumes and rates resulting from propeller wash and spoil ground dumping;
- Run model simulations covering the period of operation based on environmental boundary conditions for the period from a representative year, and
- Report on the fate of deposited and suspended sediments.

The 2004 modelling included dredging and disposal at the East Lewis Island spoil disposal ground. Further work, using the same modelling conditions was undertaken in 2005 to determine the distribution of sediments from both the East Lewis Island Spoil Ground and the Northern Spoil Ground (GEMS 2004, 2005).

Following from the study carried out for the dredging program, two main assumptions were made with respect to the dredging cycle. These were:

1) that the dredge would overflow during the dredging operations which has the effect of reducing the proportion of the finest sediments to be dumped at the spoil grounds; and
2) that the primary source of fines and sediments liberated to the water would come from propeller wash and disposal of hopper load at the spoil ground during TSHD dumping.

5.1 Modelled Dredging Cycle

It is intended that dredging will occur on a near continuous basis. The planned routine cycling time is of the order of 120 minutes, consisting of:

1) Thirty minutes dredging at an average speed of 1.5 to 2 knots (equivalent to about 1.5 km distance traversed);
2) Average, 30 minutes travel to the Spoil Ground;
3) Thirty minutes dumping (traversing 700 m to 1 km); and
4) Major maintenance stoppage of 3 days at 30 days completion.

The model allowed for this cycle to be interrupted for periods where either of the following conditions were met:

- Easterly winds greater than 10 knots; and
- Water levels below 1.0 m Chart Datum (i.e. more than 1.7 m below MSL).

For these events, spoil deposit is shifted to the northern spoil grounds. As with the previous dredging program in 2004, sediment mobilisation is focused on propeller wash effects during dredging, en-route to and within the spoil ground and spoil dumping.

5.2 Results

Dredge plume and sediment modelling was carried out for the period January–February inclusive, being representative of ambient 'wet' season conditions.

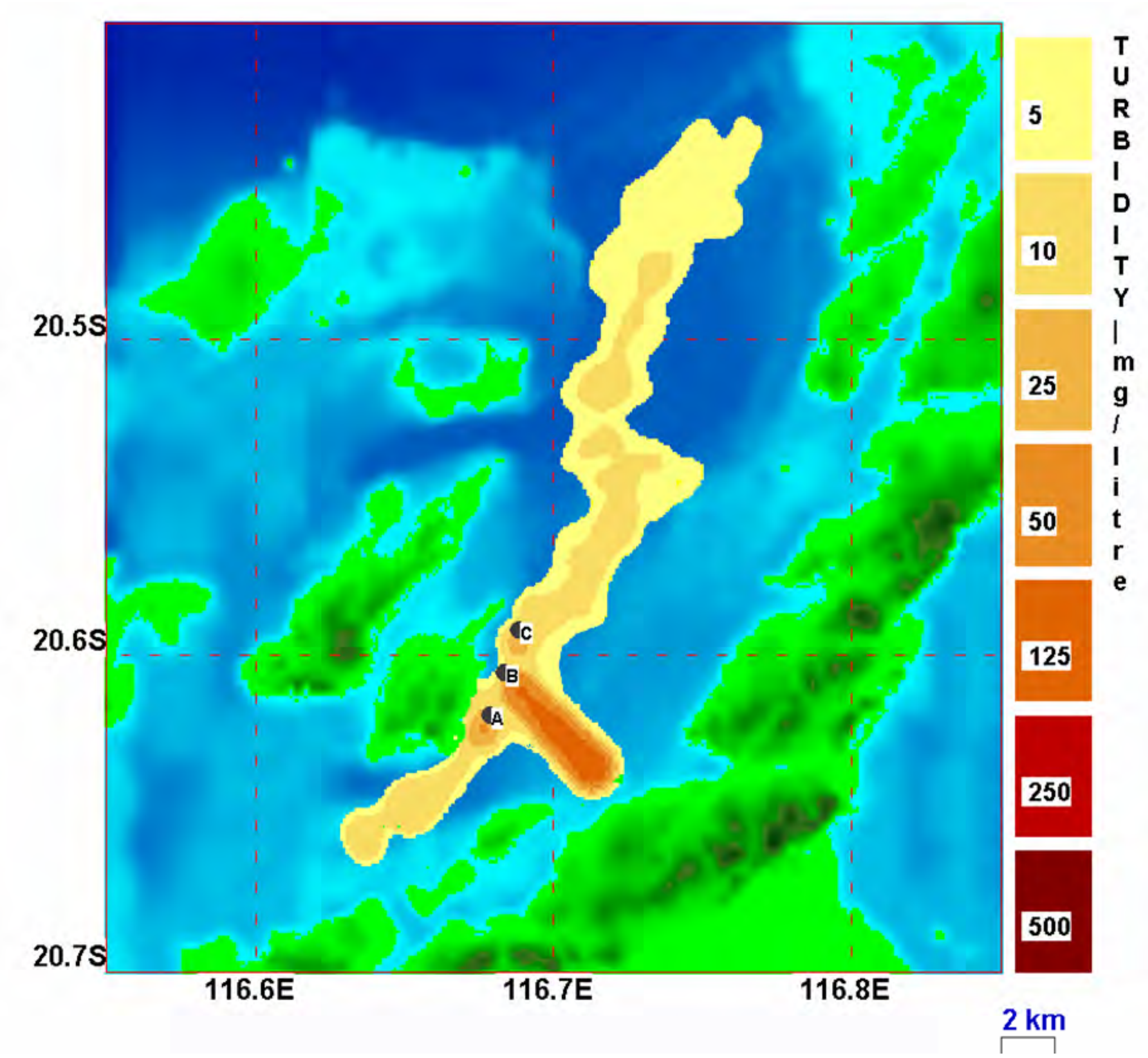
5.2.1 Suspended Sediments

Total suspended solids (TSS) levels were modelled continuously for this period, based on the planned dredging cycle described in the **Section 5.1**. TSS values (modelled at discrete levels though the water column) were averaged in the post-processing to produce hourly mean water column levels.

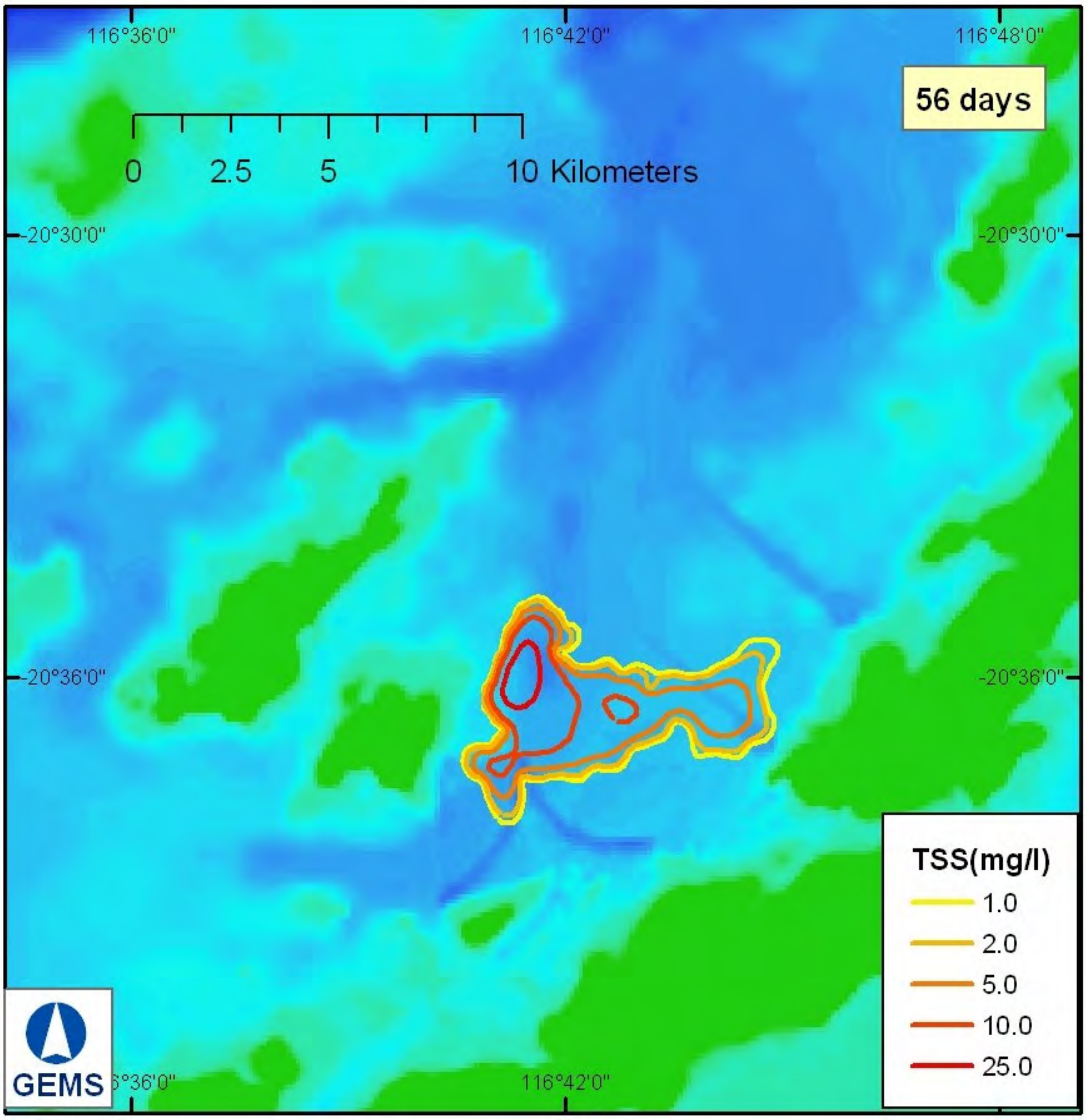
Water quality in King Bay and surrounding waters has previously been investigated by SKM on behalf of the Water Corporation as part of the monitoring program for the Burrup Industrial Water Supply System. The monitoring program included assessment of turbidity and light attenuation. The resultant data indicated that water clarity in the area varies temporally (on daily and seasonal scales), spatially and with depth in the water column. Local waters were found to be naturally turbid, with higher levels of turbidity and light attenuation in near shore areas.

Turbidity values taken on consecutive days in March 2003 recorded background levels of between turbidity between 2 NTU and 13 NTU and some locations increasing threefold over consecutive days. Measured values of total suspended solids at reference sites in Mermaid Sound (Gidley Island, North Withnell Bay, South Withnell Bay and High Point) varied between 0.2–57.9 mg/L. The average background level of total suspended solids measured at these sites over three months was 5.4 mg/L.

The model plots show contours starting from a low as 1 mg/L to 25 mg/L. **Figure 8** shows a plot of mean water column TSS at the end of the dredging program. **Figure 9** depicts the plot of mean water column TSS that was remodelled for disposal to the East Intercourse Island Spoil Ground and the Northern Spoil Ground.



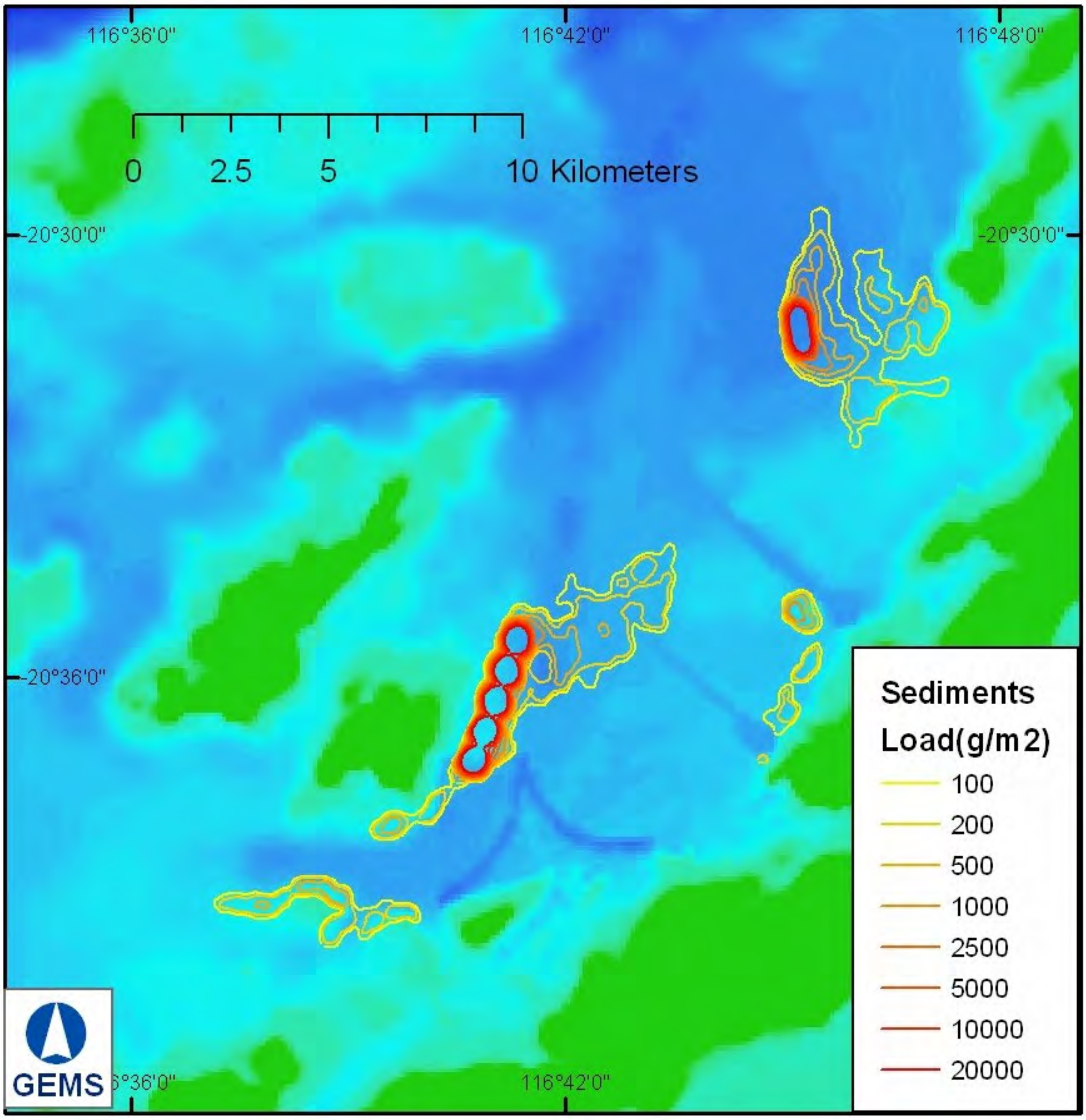
▪ **Figure 8 Distribution of suspended sediments at the end or dredging**



- **Figure 9 Distribution of suspended sediments after disposal**

5.2.2 Deposited Sediments

Figure 10 shows the accumulated bottom sediments at the end of the dredging program. It is noted that this figure does not include deposition associated with the dredging itself. Experience suggests that most of the larger material falls into or immediately adjacent to the dredged area. With respect to the larger, settling particles, the main source is from spoil dumping.



- **Figure 10 Cumulative distribution of deposited sediments**

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6. Previous Effects of Dredging

A comprehensive monitoring program was implemented by Hamersley Iron during the 2004 dredging program. The dredging and disposal program was as follows:

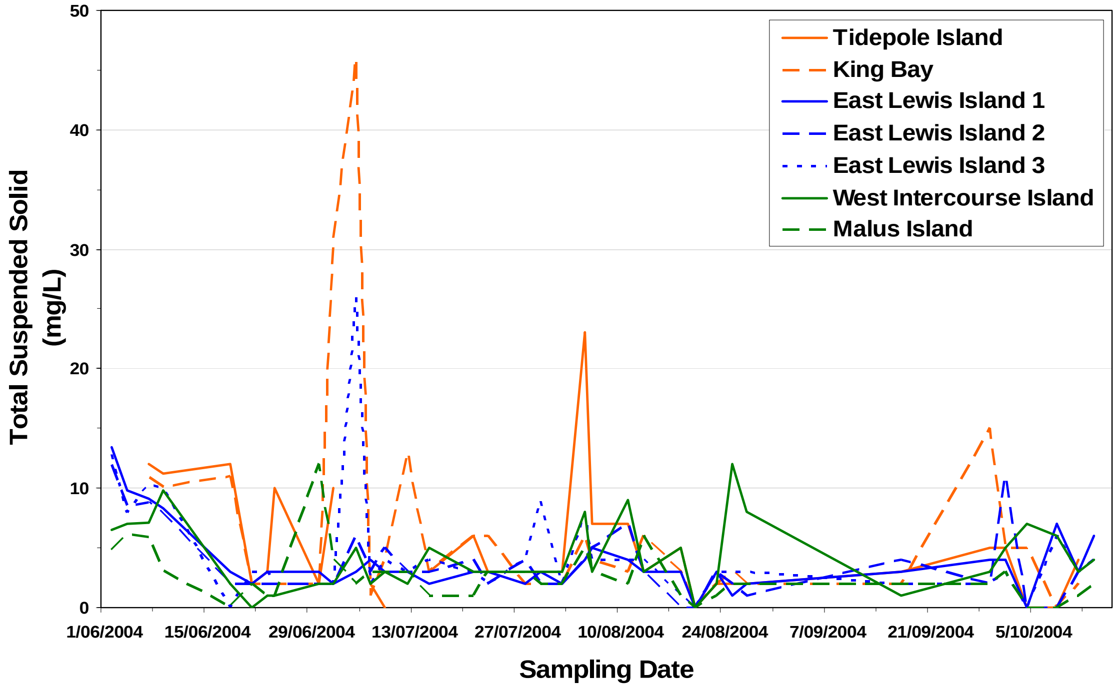
- The trailer suction hopper dredge (*Cornelius Zanen*) operated from 8/5/2004–25/6/2004. In total the dredge removed approximately 2.1 Mm^3 of material with 1.8 Mm^3 being disposed of at the East Lewis Island Spoil Ground and 0.3 Mm^3 at the Northern Spoil Ground.
- The cutter suction dredge (*HAM218*) operated from 2/6/2004–31/8/2004 and from 27/9/2004–23/10/2004. A total of 1 Mm^3 of material was dredged and dispose to landfill in an enclosed area directly east of Parker Point.
- The excavator dredge (*Obscured by Clouds*) operated prior to the commencement of the main dredging contract and removed chain, buoys and other shipping material from the dredging area.

6.1 Effects on Water Quality

Significant elevation of total suspended solids levels (TSS) was restricted to sites within 1 km of dredging locations. This elevation of TSS appeared to be primarily as a result of propeller wash generated from the trailer hopper suction dredge while manoeuvring during uplift of dredge material (MScience 2005a).

Monitoring indicated no coral mortality was associated with Hamersley Iron's dredging for the 2004 program. Locations showed no mortality when seabed TSS levels varied between 30 and 50 mg/L for short periods of time (1–2 days).

Seabed TSS levels monitored at near Parker Point (King Bay and Tidepole Island), near the East Lewis Island Spoil Ground (East Lewis Island 1–3) and at two reference locations (West Intercourse Island and Malus Island) are presented in **Figure 11**. Indicative TSS levels that could affect coral survival have been plotted based on the previous monitoring. These TSS levels are not intended as trigger values; but rather, they place the 2004 monitoring data into context with values that have been observed to affect similar coral communities during dredging undertaken by others in the Dampier region.



- **Figure 11 Seabed TSS levels during previous dredging and disposal**

6.2 Effects on Coral

Previous dredging undertaken in 2004 had no measurable effects on corals monitored. This is likely to be a result of a combination of coral tolerance to the water quality conditions during the dredging campaign and its duration as well as the management options employed to minimise and mitigate increased turbidity and sedimentation. The only coral mortality during the program was as a result of freshwater runoff from a cyclonic event.

7. Management, Monitoring and Reporting

The proposed dredging and disposal management process is depicted in **Figure 12** and detailed in the following sections.

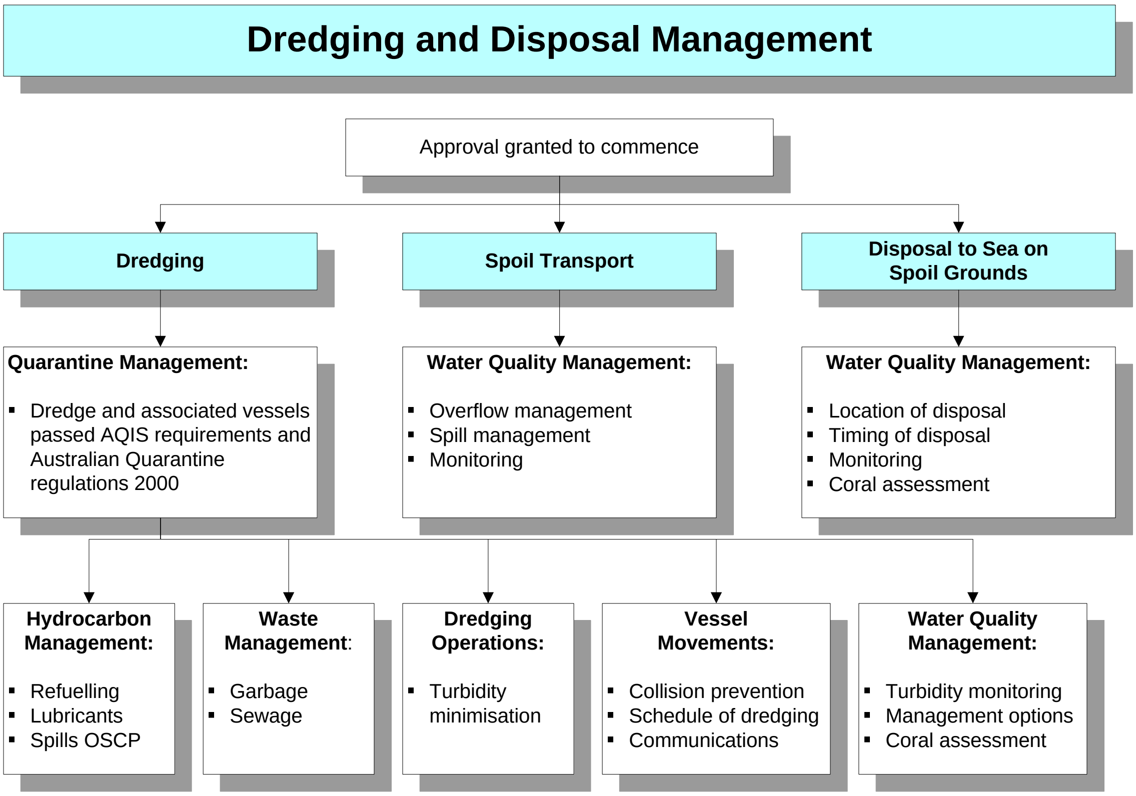


Figure 12 Proposed dredging and disposal management process

7.1 Ballast Water and Marine Pest Management

The dredges used in this project will be inspected by an appropriately qualified person to ensure that:

- there is no sediment in the dredging equipment or any holds;
- the dredging equipment and the hull of the vessel will be free of fouling organisms; and
- ballast water (if any) has been managed according to the Australian Quarantine Inspection Service ballast water requirements.

All vessels engaged in the dredging program whose last port is overseas based will be inspected by an appropriately qualified person prior to departure for Dampier. This inspection will certify that the vessel is clean and contains no sediment or other material that may introduce pests into

Australian waters. Any pipelines or fittings found to contain evidence of dredge material upon arrival at Dampier will be taken ashore and cleaned using high pressure water hoses. The effluent will be prevented from entering drains or from discharging into the water.

The hull of the dredge will be certified as clean and free of attached introduced marine organisms prior to being brought into Dampier. All internal compartments and associated dredge pipelines and fittings that come in contact with dredge spoil will have been cleaned and thoroughly flushed through with clean sea water prior to arrival. The dredge will be inspected upon arrival and if found to contain evidence of material from previous dredging it will be sent offshore for flushing (outside 12 nautical mile limit and in water depth of at least 200 m).

Any discharge of ballast water will occur in accordance to the Australian Ballast Water Requirements (**Appendix C**). Ballast water of all vessels will be exchanged at sea prior to being brought into Dampier. Should the dredge or support vessels be brought in from outside Australian waters then they will also comply with the Australian Quarantine Regulations 2000. Prior to dredging commencing, the results of the inspections and any remedial actions will be reported to the DoE.

7.2 Hydrocarbon Management

Large quantities of diesel fuel, oil, grease and some chemicals are handled on a regular basis during all dredging operations. The handling of hydrocarbons creates a potential risk to the environment in the event that spillage occurs. The main areas of risk during the dredging operation are:

- Refuelling of the dredge (bunkering);
- Storage and handling of oils, grease and chemicals; and
- Breakdown of grease on moving parts such as the cutter ladder and spud carriage.

7.2.1 Refuelling

Refuelling of the dredge will be carried out in a manner approved by the DPA. During all fuel transfers the Master of the vessel is responsible for directing and controlling the operation and all crew. The following mitigation procedures are intended to reduce the risks to as low as reasonably possible:

- A work instruction will be prepared to provide guidelines for all staff and crew to ensure the potential risk is kept to a minimum and all staff and crew will be familiar with the Oil Spill Contingency Plan (OSCP) (refer to attached CD and **Appendix D**).
- Refuelling will only take place under favourable wind and sea conditions.
- The fuel coupling and level in the tanks will be continuously monitored and bunded during refuelling in order to avoid overflow.

- The dredge will have a spill kit on board (oil booms, absorbent pads and oil dispersing detergents) ready for prompt response in the unlikely event of a spill.
- The Master of the vessel will be responsible for reporting any spill of fuel, oil or chemicals to the marine environment and for ensuring spill equipment is deployed in a timely and effective manner if required.

7.2.2 Storage of Oils, Grease and Chemicals

The bulk of all oil and grease will be stored in storage tanks on the dredge and drums will be stored below deck whenever possible. All chemicals, detergents etc will be stored below deck in the appropriate holds. The Master/Captain of the vessel is responsible for checking all storage and operational areas on a daily basis.

Hydrocarbons located above deck will be stored within bunded areas to contain any leaks or spills. Spill response kits will be located in close proximity to storage areas for prompt response in the event of a spill or leak.

7.2.3 Breakdown of Grease on Moving Parts

Grease is commonly used to lubricate cutter shafts and spud carriages and these parts are in contact with the water. Consequently there is the risk of small amounts of grease being discharged into the water. This will be mitigated by the following measures:

- A work instruction will be prepared to provide guidelines for all crew to ensure the potential for discharge is kept to a minimum.
- Automatic greasing mechanisms will be monitored to minimise grease consumption without affecting functionality of moving parts.
- Scoops/nets will be on board ready to collect any grease discharged into the water.
- Where possible, biodegradable greases will be used.

7.2.4 Spill Response and Reporting

Any hydrocarbon spill will be responded to and reported in accordance with the OSCP (refer to attached CD and **Appendix D**)

7.3 Waste Management

7.3.1 Solid Waste

Domestic rubbish will be placed in rubbish bins or skips and recycled or disposed of by a licensed contractor and taken to the Shire of Roebourne landfill near Karratha. Empty oil and chemical containers such as metal or plastic drums will be returned to the supplier for reuse or recycled where possible. Absorbent material used to mop up minor oil or chemical spills will be disposed of appropriately as contaminated material.

7.3.2 Sewage Waste

Sewage from toilets at the shore facilities will be directed to the appropriate sewerage system or to a sullage tank then removed by a licensed contractor. Sewage from the dredge and support vessels will be collected and pumped out and disposed to an appropriate disposal facility by a licensed contractor. No sewage from the dredge or support vessels will be disposed to the marine environment while operating in the Port.

7.4 Vessel Movement Management

Hamersley Iron's Parker Point Wharf and East Intercourse Island Facilities are used regularly for loading vessels with iron ore and as such the dredging operations will be carefully scheduled and coordinated. In addition, vessel movements to and from the Dampier Salt Wharf on Mistaken Island must be taken into account.

7.4.1 Collision Prevention

Prevention of collision with vessels including tugs and iron ore carriers servicing other Berths in the Port will be the main objective of planning the dredging schedule. The DPA will issue Notices to Mariners prior to commencement of the dredging. Incoming vessels will be made aware of the location of the dredge and any obstructions such as floating or submerged pipes, anchoring cables, piles and support vessels by the DPA. The dredge will be required to give shipping priority. Collision prevention procedures will be discussed between the dredge operator, Hamersley Iron and the DPA.

7.4.2 Mitigation Measures for Protection of Cetaceans

The following procedures will be undertaken to protect cetaceans in the area within 500 metres of any point at which dumping activities are planned (monitoring zone):

- Before beginning dumping activities, HI must check, using binoculars from a suitable, high observation platform on the dredge vessel, for cetaceans within the monitoring zone.
- Dumping activities may be commenced only if no cetaceans have been observed in the monitoring zone for ten minutes immediately preceding commencement.
- If any cetaceans are sighted in the monitoring zone, dumping activities must not commence until twenty minutes after the last cetacean is observed to leave the monitoring zone.

Hamersley Iron must document any incidents involving dumping activities that result in injury or death to any cetacean (as defined), other whales and dolphins, dugongs and/or marine turtles. The time and nature of each incident, and the species involved, if known, must be recorded.

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7.4.3 Scheduling and Communications

Dampier wharfs are actively used for loading vessels. The dredging operations will, therefore, be scheduled to work in with vessel movements. The intention will be to conduct dredging of the berthing pocket of the wharf during periods when no vessels are scheduled to be berthing or departing. The dredge and support vessels will maintain radio contact with Hamersley Iron and the DPA so they can be kept informed of planned shipping movements and can inform Hamersley Iron and the DPA of planned dredge position and support vessel movements.

7.5 Water Quality Management

The dredging works will be undertaken in a manner that minimises the generation of turbidity. This will be managed by the dredging contractor in liaison with the Dampier Spoil Ground Management Committee as necessary. The most effective means of minimising turbidity is to select the most appropriate work method and perform the works in the shortest duration. Particular strategies that will be undertaken to minimise the generation of turbidity from the dredging and spoil disposal program may include, but not be limited to:

- The spatial extent of the proposed dredging is sufficiently large enough to allow a trailer suction dredge to relocate to alternative areas in the event turbidity levels build up during the works;
- The use of silt curtains;
- Disposal at the East Lewis Island Spoil Ground will be restricted to a smaller, defined area within the overall limits of the spoil ground to minimise turbidity levels beyond the boundaries of the spoil ground; and
- The Northern Spoil Ground will be used if turbidity levels are raised for extended periods of time at the boundary of the East Lewis Island Spoil Ground.

7.5.1 Environmental Quality Objectives

The environmental quality objectives during dredging and disposal activities are:

1) To minimise the spatial extent, duration and magnitude of changes to water quality; and
2) To minimise the impact on corals.

As described in **Section 4** above, the potential zones of influence of dredging and disposal impacts will be limited to the following areas:

- Plumes originating from trailer suction hopper dredge operations when using overflow and/or bypassing systems.
- By propellers from trailer suction hopper dredge dislodging seabed material (prop-wash).

- At the drag-head on trailer suction hopper dredge movement mixing seabed material into the water column.
- At the offshore disposal during and following bottom dumping operations.
- At the onshore disposal area and associated return water discharge area.

Based on monitoring during Hamersley Iron's 2004 dredging program and the numerical modelling of the proposed works, the spatial extent of these impacts is anticipated to be as follows:

- Within 1,000 m of dredging areas.
- Within the boundaries of the East Lewis Island Spoil Ground and Northern Spoil Ground.
- Within 300 m of the return water discharge area.

The following control measures will be implemented to minimise the impacts of dredging and disposal on corals:

- Dredging and spoil disposal activities shall not occur during the coral mass spawning periods in March 2006 and April 2006.
- A fortnightly coral health monitoring programme will be undertaken for the duration of the dredging and disposal activities.
- If, at any time, net coral mortality exceeds the threshold level (see **Appendix B**) but is less than the limit level, then within 24 hours one or more management measures will be implemented (see **Table 14**). The exceedance and the management measures implemented will be reported to the DoE but dredging and spoil disposal activities may continue.
- If at any time during the period of dredging and spoil disposal activities the net coral mortality at any monitoring site(s) exceeds the limit level (see **Appendix B**) dredging and spoil disposal activities shall immediately cease adjacent to site(s) where that limit level is exceeded and shall report the exceedance to the DoE within 24 hours.
- Dredging and/or spoil disposal activities shall not recommence following any stoppage until such time that it can be demonstrated to the satisfaction of the Minister for the Environment, upon advice from the EPA, that:
  - any such activity that is proposed to recommence would not contribute to further net mortality of corals at any impact monitoring site(s) at which the limit level has been exceeded; and
  - the ambient environmental conditions at any impact monitoring site(s) at which the limit level has been exceeded are such as to not prevent recovery.

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7.5.2 Water Quality Monitoring Program

Monitoring Frequency:

Not exceeding three days between measurements for the duration of the dredging and disposal program unless the sea state prevents safely undertaking the work, as well as for two weeks either side of dredging/disposal.

Monitoring Locations:

Potential impact and reference sites are the same as coral monitoring sites and are are provided in **Table 13** and shown in **Figure 13**. Measurements will be taken near the surface and near the bottom of the water column.

Monitoring Method:

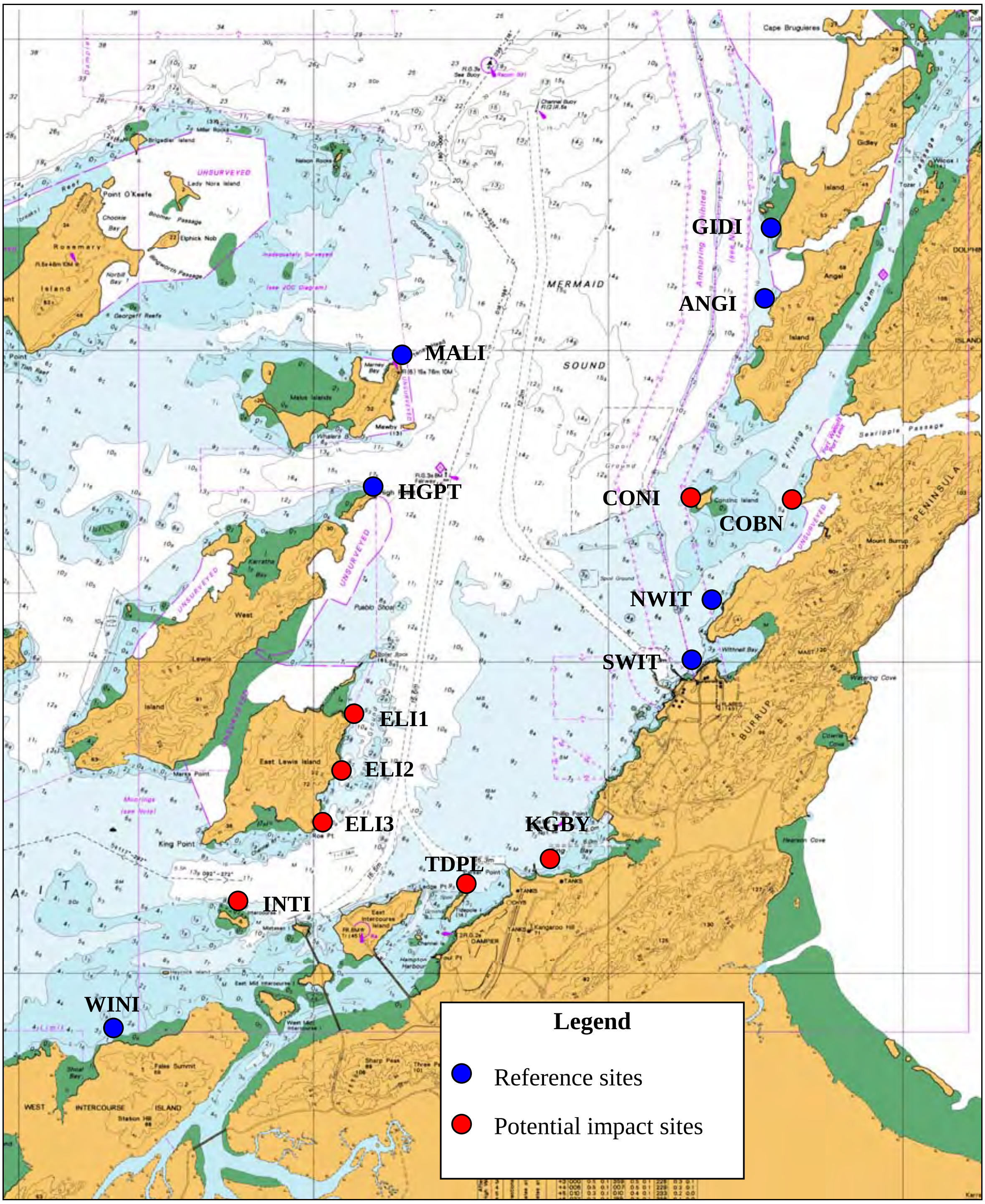
At each site, Salinity (mg/L), Turbidity (NTU), dissolved oxygen (DO in ppm and % saturation) and pH measured with a water quality metre. Turbidity values will be converted to estimates of suspended solids concentration through use of field calibration for different sediment types. Total suspended solids (mg/L) will be periodically measured by laboratory assessment of collected samples to validate the relationship.

An in-situ instrument (OBS or SAS metre) will be deployed throughout the dredging period at the TDPL site and at a Reference Site. This will be calibrated to provide an estimate of suspended sediment or sedimentation for continuous monitoring and comparison with the 3d water quality data.

- **Table 13 Water quality and coral health monitoring sites**

Site Name	Site Code	Function	Latitude	Longitude	General Description
Angel Island North	ANGI	U Disposal	20°29.241' S	116°47.751' E	NW side of Angel Island
Conzinc Bay North	COBN	I Disposal	20°32.417' S	116°48.193' E	Northern tip of Conzinc Bay
Conzinc Island	CONI	I Disposal	20°32.174' S	116°46.669' E	SW corner of Conzinc Island
East Lewis Island 1	ELI1	I Disposal	20°35.952' S	116°40.695' E	Northern tip of East Lewis Island
East Lewis Island 2	ELI2	I Disposal	20°36.655' S	116°40.510' E	Mid East Lewis Is (E shore)
East Lewis Island 3	ELI3	I Disposal	20°37.650' S	116°40.170' E	Southern tip of East Lewis Is
Gidley Island	GIDI	R Disposal	20°28.262' S	116°47.794' E	SW corner of Gidley Island
High Point	HGPT	R Disposal	20°32.460' S	116°41.046' E	NW tip of West Lewis Island
Intercourse Island	INTI	I Disposal	20°39.006' S	116°38.636' E	North shore of Intercourse Is
King Bay	KGBY	I Dredging	20°38.293' S	116°44.077' E	Shoreline of King Bay
Malus Island	MALI	R Disposal	20°31.310' S	116°41.635' E	Southern tip of Malus Island
North Withnell	NWIT	U Disposal	20°34.281' S	116°46.793' E	North of Withnell Bay
South Withnell	SWIT	R Dispsal	20°35.137' S	116°46.487' E	South of Withnell Bay
Tidepole Island	TDPL	I Dredging	20°38.721' S	116°42.609' E	Eastern tip of Tidepole Island
West Intercourse Island	WINI	R Dredging	20°40.966' S	116°36.633' E	West Intercourse Is (N shore)

Datum is WGS84
I = Impact, R = Reference, U = Uncertain.



■ **Figure 13 Water quality and coral monitoring sites**

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7.6 Coral Health Monitoring

Coral health will be assessed using the Coral Health Monitoring Plan attached in **Appendix B**. Coral health will be monitored at the fifteen sites where water quality monitoring will be undertaken. Monitoring is defined as the successful collection of videography/still images and the subsequent analyses of data from transects established at each site such that coral health can be assessed and compared against relevant criteria in accord with the requirements of those conditions in Ministerial Statement 664 that applied to the Hamersley Iron 2004 dredging program. All coral communities are located in areas for which historic monitoring data exist from previous Hamersley Iron coral monitoring programs between November 2003 and December 2004.

Coral health monitoring surveys will be undertaken at the following frequencies:

Pre-dredging Survey:	Should occur as close as possible to the start of dredging, preferably two weeks prior to commencement of dredging. Should any major disturbance event (such as a cyclone or bleaching event) occur between the initial baseline and the commencement of dredging, it may be necessary to resurvey a new baseline.
Impact Site Surveys:	Should occur fortnightly to allow dredging management to adapt to any mortality event before the mortality is repeated or becomes widespread.
Reference Site Surveys:	Should occur whenever a significant decline in Impact Sites is noted to allow that result to placed in the context of regional change.
Post-dredging survey:	1–2 months post completion of disposal and dredging with the final survey being a full survey of all sites.

Should turbidity prevent the completion of any Impact Site coral monitoring survey then management options will be utilised to improve the water quality. Should the conditions lead to the failure to undertake two consecutive Impact Site coral monitoring surveys then dredging will cease until such time as the water quality improves sufficiently to allow monitoring to be undertaken.

7.6.1 Recruitment of Juvenile Corals

Recruitment of juvenile corals will be monitored in pre and post dredging surveys to determine whether there is a difference in mortality levels between Impact and Reference Sites. These surveys will be conducted at all impact and reference sites. The survey will include:

- Use of 0.5 m^2 quadrats;
- 20 quadrats per site;
- Random distribution of quadrats at each site; and

- Counting of juvenile coral species within each quadrat. Juveniles will be considered as corals <5cm in size (depending on species).

The juvenile recruitment surveys can be conducted as part of the pre and post dredging surveys outline in **Section 7.6**.

7.6.2 Management Options

Management options to improve water quality and/or improve coral health are separated into two stages (**Table 14**). Management options will be initiated when coral mortality at the potential impact sites is exceeds the threshold level but is less than the limit level.

- **Table 14 Management options**

Options for Trailer-hopper Suction Dredge	Options for Cutter Suction Dredge
Reduce prop-wash using tide height	Relocate the dredge
Reduce trailer suction hopper dredge overflow	Reduce overflow on barges
Relocate the dredge	Fill barges further away from sensitive areas using pumping of slurry
Disposal further away from the potential impact sites (within spoil area)	Disposal further away from the potential impact sites (within spoil area)
Deploy silt curtain barrier to protect corals	Deploy a silt curtain at return water outlet
Reduce dredging to single shift	Reduce dredging to single shift

7.7 Reactive Monitoring and Reporting Process

The reactive monitoring and reporting is structured as a flowchart to more effectively represent the process and to simplify its use (**Figure 15**). The flowchart will be enlarged, laminated and provided to contractors.

7.8 Aerial Monitoring

Aerial surveillance will be undertaken to assess the extent of plumes generated during dredging and disposal activities. The monitoring may also assist with distinguishing plumes generated from other dredging programs. Prior to dredging commencing, a high resolution aerial photographic record will be obtained of the region to assist with the overlaying of routine monitoring imagery.

Routine monitoring will be undertaken weekly using fixed wing aircraft as was undertaken during 2004 dredging program. The extent of the area of coverage is shown in **Figure 16**.

7.9 Post-dredging TBT Survey

7.9.1 Objective

To assess whether tributyltin (TBT) contamination remains in surface sediments on the Northern Spoil Grounds and/or spreads from the spoil grounds towards potentially sensitive habitats at Conzinc Island.

7.9.2 Design

Four samples from the Northern Spoil Ground area used for disposal of TBT contaminated sediments – split into upper (0–10 cm) and lower (10–50 cm) profiles. The upper 10 cm of sediment is the most likely to be routinely exposed to the water column or biota: the lower 10–50 cm represents what might be remobilised by extreme weather.

Six samples from surface sediments between the spoil ground and Conzinc Island located roughly as in **Figure 14**. These will be surface samples (0–10 cm) because:

a) sediments in these areas are quite shallow (overlying limestone); and

b) any migrating contamination will settle in the surface layer.

Each sample site will yield two samples, each of three homogenised cores collected from the corners of a one metre triangle. Triangles will be approximately two metres apart. Sediments will be analysed for TBT and total organic carbon (for standardising the TBT).

7.9.3 Imposex Monitoring

Samples of 100 specimens of *Morula granulata* to be collected from the western margins of Conzinc Island and each of three appropriate reference sites (within the Harbour but unlikely to be affected by TBT from the Northern Spoil Ground). Assessment methods for imposex would be consistent with the recommendations in ANZECC/ARMCANZ Guidelines (ANZECC/ARMCANZ 2000, Vol.2 Ch. App. 3) and methods used most recently for similar assessments in Dampier Harbour.

7.9.4 Timing

Sediments

There will be a series of sediment surveys undertaken as follows:

- **Pre-dumping survey of spoil ground:** Conducted following completion of spoil disposal by Woodside and prior to commencement of Hamersley Iron disposal.
- **Post-dumping survey:** Within two months of completion of all spoil disposal from the proposed program.

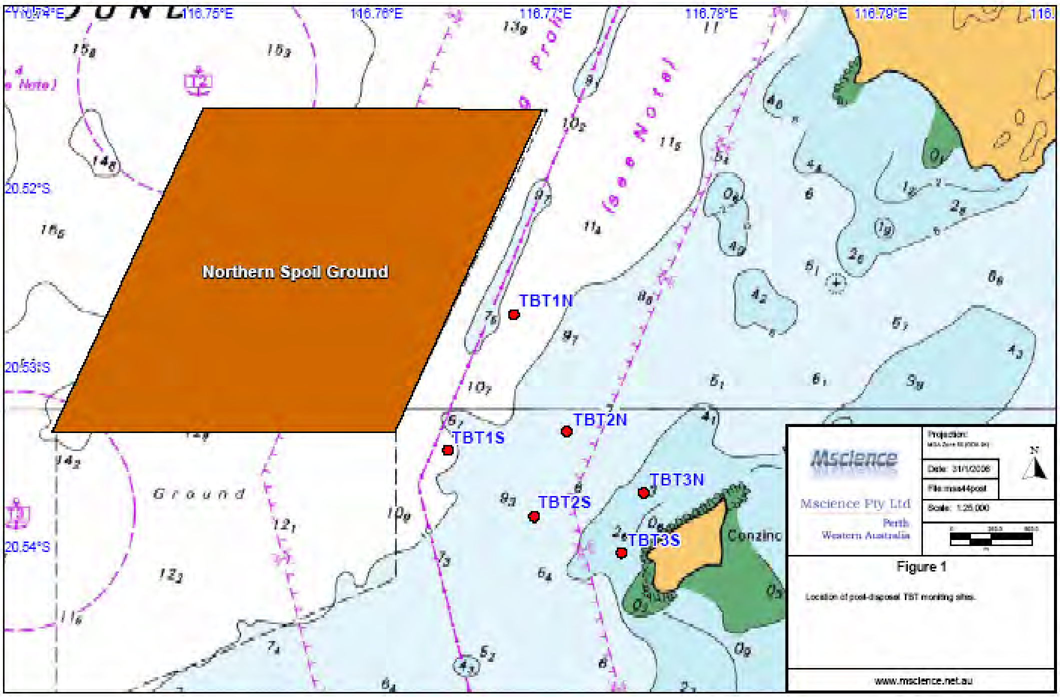
- **Annual follow-up surveys:** Surveys would be conducted annually in April following the cyclone season, for three years after dumping ceases — or until spoil dumping on the site by a third party obscures the ability to interpret results. If TBT contamination outside the spoil ground is evident after two years, monitoring will be continued on an agreed schedule.

Imposex

A survey of imposex level in *Morula granulata* at Conzinc Island and other Dampier Harbour sites was conducted for Dampier Port Authority/Woodside in mid 2005. That study would provide baseline data to represent the pre-dumping distribution of imposex. Surveys would be conducted annually for three years following cessation of dumping — or until further dumping of TBT-contaminated spoil occurs in this area.

7.9.5 Management Outcomes

Should TBT contamination still be present (i.e. above the NODGDM screening level 5 ugSn/kg) at the end of the 2nd year of monitoring and a significant increase in imposex levels of *Morula granulata* noted at that time, Hamersley Iron will conduct a detailed assessment of the likely timing for breakdown of the residual TBT and the potential for ongoing impacts on biota prior to final breakdown. This assessment would be reported to DoE/DEH and if deemed necessary, a mitigation program implemented.



- **Figure 14 Post-dredging TBT sampling locations**

7.10 Sediment Particle Size Survey

7.10.1 Objective

To investigate whether sediments near the dredging operation undergo a substantive change in the particle sizes or composition of the upper layers.

7.10.2 Method

A series of sediment cores will be collected prior to the commencement of dredging from sites surrounding the uplift area and at two sites distant from that area but within the central part of Dampier Harbour. Five paired samples will be collected from proximate and from distal sites. The sediment profile over 2cm increments of the upper 10 cm and then at 10cm increments for the next 50 cm will be characterised for particle size, colour, composition and the presence of in-fauna.

7.10.3 Timing

Samples will be collected two weeks before dredging commences then one week after dredging ceases, then 2 months after that survey. A final report will identify change by site.

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8. Reporting

8.1 Frequency of Reporting

Reporting associated with monitoring will involve:

- Monthly water quality progress reports and coral monitoring reporting with the first reports due one month after the commencement of dredging;
- Immediate reporting of any water quality or coral health exceedances; and
- A final report one month after the termination of the coral monitoring.

8.1.1.1 Monthly Water Quality Reporting

Monthly progress reports will be sent to the DoE and will contain the following information:

- Dredging progress and water quality monitoring results for the reporting period; and
- Exceedances incurred during the period and any action implemented.

8.1.1.2 Monthly Coral Health Reporting

Monthly progress reports will be sent to the DoE, CALM and the DEH and will contain the following information:

- Dredging progress and coral health monitoring results; and
- Exceedances incurred during the period and any action implemented.

8.1.1.3 Exceedance Reporting

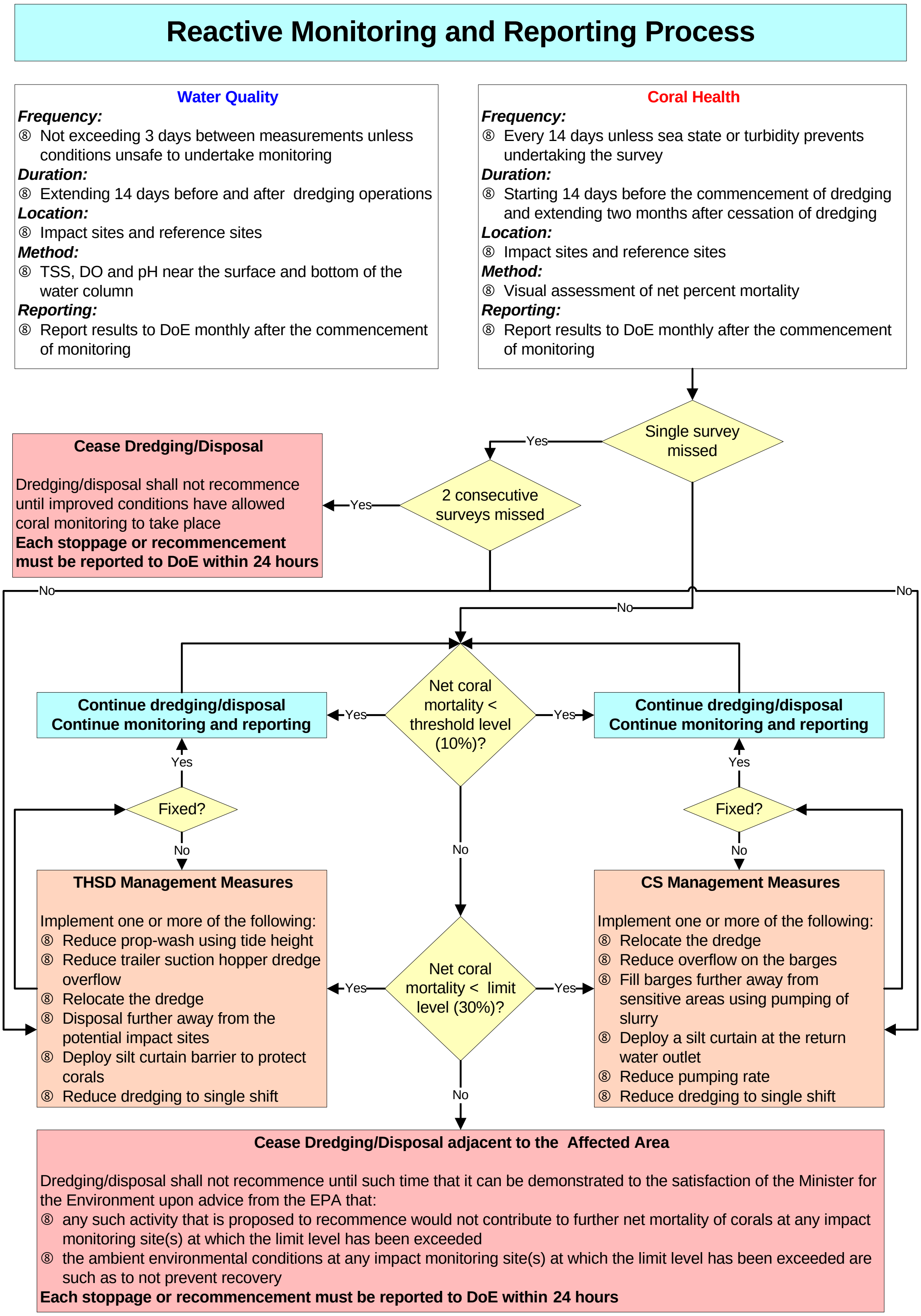
Exceedances will be reported to the DoE and will be followed up by confirmation when the exceedance has been rectified. Exceedances will be included in progress reporting.

8.1.2 Final Report

A final report will be submitted to the DoE and the DEH one month after the completion of the coral monitoring program which summarises the following:

- A summarisation of the dredging and disposal undertaken;
- A summarisation of the water quality monitoring and analyses;
- A summarisation of the coral health monitoring; and
- A summarisation of exceedances (if any) during the program and any management measures undertaken.
- A final stand-alone coral monitoring report will be submitted which includes monitoring undertaken up to two months post-dredging.
- A final stand-alone post-dredging TBT survey report.

A final stand-alone particle size survey report.



▪ **Figure 15 Reactive monitoring and reporting process**

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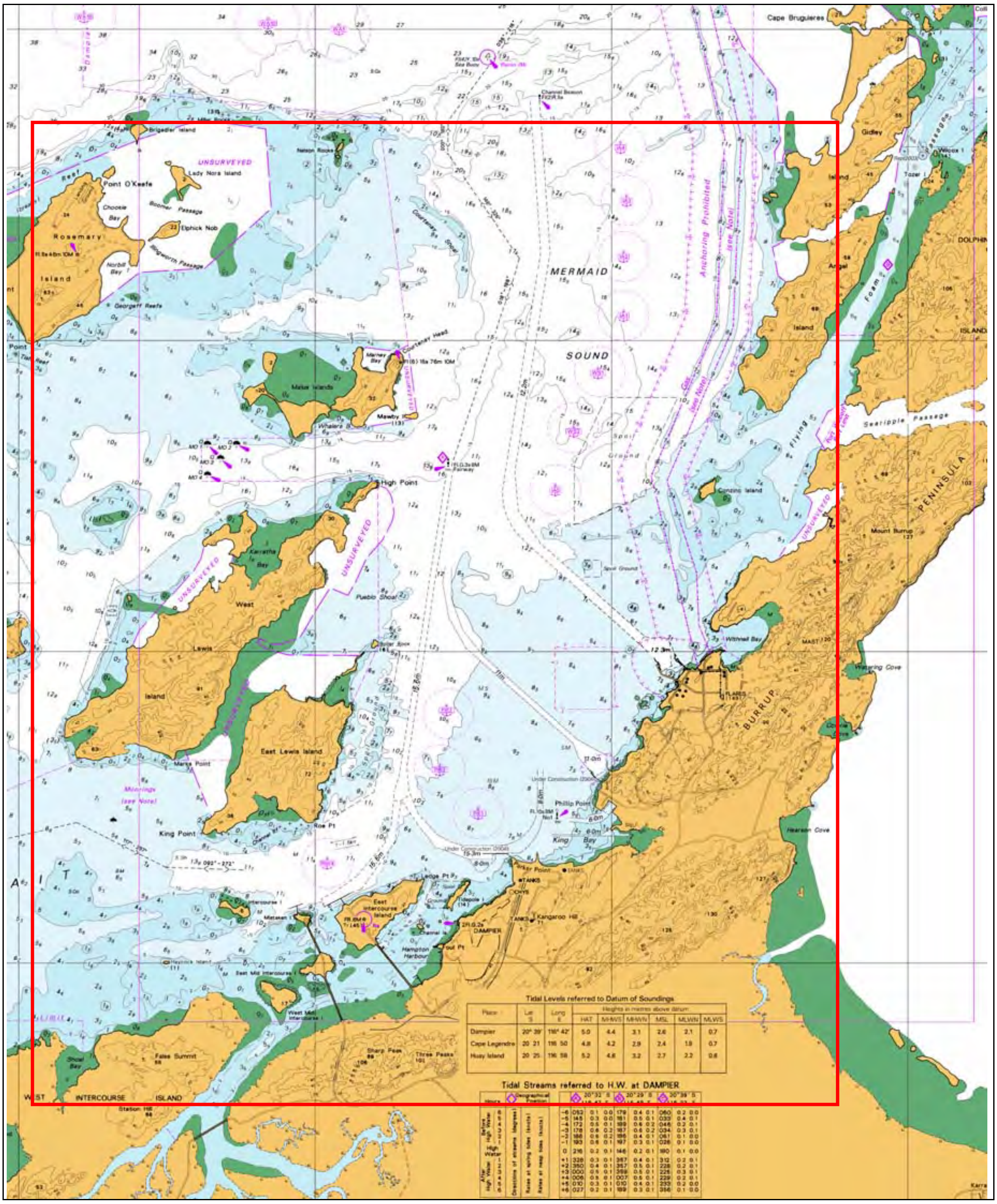

■ **Figure 16 Extent of aerial imagery**

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10. Glossary

Bathymetry	Measurement of the changing ocean depth to determine the sea floor topography.
Benthic	Bottom dwelling.
Benthos	All biota living upon or in the sediment of an aquatic habitat.
Bioavailability	Degree to which chemicals can be taken up by organisms.
Biodiversity	The variety of all life forms the different biota, the genes they contain and the ecosystems they form.
Capital Dredging	Dredging for navigation, to enlarge or deepen existing channel and port areas or to create new ones.
Cetaceans	The group containing whales, dolphins and porpoises. Migratory whales are identified as of significance under the Environment Protection and Biodiversity Conservation Act 1999
Contaminant	Any physical, chemical or biological substance or property which is introduced into the environment.
Ecological function	The combined biological characteristics and processes occurring within an area.
Ecological Integrity	The condition of an unimpaired ecosystem as measured by combined chemical, physical (including physical habitat), and biological attributes.
Ecological value	Mitigation measure to improve water quality, sediment quality or to protect a habitat such as coral or seagrass or a sensitive marine ecological attribute such as coral spawning, whale migration or turtle nesting (ecological value).
Ecology	The study of the relations of animals and plants, particularly of animal and plant communities, to their surroundings.
Ecosystem	The biological and physical environments and their interactions.
Ecosystem integrity	The ability to support and maintain a balanced, integrative, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of natural habitat of the region.
Elutriate test	A test which involves mixing sediment with 4 times its volume of seawater under specified conditions, to estimate the amounts of contaminants that will be released during dredging and during sea disposal.
Environment	The surroundings of an organism including the other biota with which it interacts.

Environmental disturbance	Disturbance is an ecological term referring to the perturbation of an ecosystem that affects internal system processes. A highly disturbed system will be one that is disturbed frequently or one which has suffered a strong recent disturbance. In areas classified as 'highly disturbed' due to the frequency of disturbance or in areas recovering from severe disturbance, individual organisms may be 'healthy' (a very subjective term).
Environmental health	Surveys of habitats may describe biological features as healthy or the system as 'healthy' based on living components. However, the species composition and demography of the area may, at the same time, reflect its highly disturbed nature (existing immediately adjacent to a very large stockpiling operation and between two active wharves). It is not correct to infer the system has been degraded between being described as 'healthy' then 'highly disturbed'.
Environmental Management Plan	A procedure that identifies potential impacts and methodologies necessary to prevent or mitigate them.
Environmental Management System	A set of procedures incorporated into a documented framework that defines the environmental policy and organisational responsibility for planning, recording, auditing, and resolving non-conformances through a process of review leading to continual improvement of an organisations environmental management.
Environmental Quality Criteria	The scientific benchmarks upon which a decision may be made concerning the ability of an environment to maintain certain designated environmental quality objectives.
Environmental Quality Objectives	The long-term goals of an environmental management programme in relation to the maintenance of the environmental values of natural systems (ecological and social).
Environmental value	Particular values or uses of the environment that are important for the healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharges and deposits.
Fauna	Collectively, the animal life of any particular region.
Flora	Collectively, the plant life of any particular region.
Habitat	The place where the physical and biological elements of ecosystems provide a suitable environment including the food, cover, and space resources needed for plant and animal livelihood.
Heavy Metals	Metals such as zinc, copper and chromium which accumulate in sediments and tissues or biota and may be passed up the food chain.

Impact	The change in the chemical, physical (including habitat) or biological quality or condition of a waterbody caused by external sources.
Light attenuation	Light attenuation usually refers to a reduction or decrease in available light which occurs with increasing depth of water. The light attenuation coefficient quantifies the rate at which light is attenuated as a result of all absorbing and scattering components of the water column. These components include a background rate (0.1 m^{-1} of clear water), and varying components of total suspended solids, phytoplankton, dissolved organic matter and coloured dissolved organic matter (dissolved organic molecules sometimes called humics or gilvin). The light level at a depth of 'z' metres can be calculated from: $Iz = I_0 \exp(-K_d z)$ where I_0 is the surface light, and K_d is the attenuation coefficient..
Macroalgae	Large algae commonly called seaweed.
Maintenance Dredging	Dredging to ensure that channels, berths or construction works are maintained at their designed dimensions.
Management action	Management option once initiated.
Management option	Mitigation measure to improve water quality, sediment quality or to protect a habitat such as coral or seagrass or a sensitive marine ecological attribute such as coral spawning, whale migration or turtle nesting (ecological value).
Pollution	Degradation or impairment of the purity of the environment by causing a condition that is hazardous to public health, safety aesthetics or welfare, or to biota.
PQL	The Practical Quantitation Limit (PQL) is the lowest level achievable among laboratories within specified limits during routine laboratory operations. The PQL represents a practical and routinely achievable detection level with a relatively good certainty that any reported value is reliable (Clesceri *et al*. 1998). The PQL is often around 5 times the method detection limit.
Reference Site	Specific locality on a waterbody which is unimpaired or minimally impaired and is representative of the expected biological integrity of other localities on the same waterbody or nearby waterbodies.

Sensitive marine ecological attribute	Coral reefs, seagrass meadows and mangrove forests, and the biota associated with these habitats (ecological value).
Total Suspended Solids (TSS)	A measure of the mass of fine inorganic particles suspended in the water. In the model, TSS enters the estuary in the freshwater replacement time. The concentration of TSS in the estuary depends on the load and the loss rate to sinking (a function of salinity) and dilution (a function of ocean flushing time (or tidal range) and inflow rate), and the resuspension rate. Limits: Low 0.1 to 0.5 g/m^3 Medium 0.5 to 10 g/m^3 High 10 to 100 g/m^3
Toxicity	The quality or degree of being poisonous, or harmful, to humans or biota.
Turbidity	Measure of the clarity of a water body and generally represented in Nephelometric Turbidity Units (NTU).

Appendix A Environmental Protection Rules

A.1 INTRODUCTION

A1.1 The Dampier Port Upgrade Project is the type of construction operation which may cause adverse environmental impacts.

A1.2 Project Management is committed to a policy of minimising all adverse environmental impacts that may be caused by the Project and expects the cooperation of its employees, consultants and Contractors, their Subcontractors and employees to achieve that policy.

A1.3 An Environmental Management Program has been prepared to control the impact of the project. The Environmental Management Program covers all aspects of design, construction, reinstatement and management for the mine, infrastructure and railway construction components of the Project.

The Environmental Management Program is divided into the following elements:

- groundwater management;
- surface water management (mine);
- surface water management (railway);
- flora;
- fauna;
- waste materials (non hydrocarbons);
- hydrocarbons;
- dust;
- noise;
- fire;
- workforce;
- rehabilitation;
- decommissioning.

Water control (ground and surface) is considered a key environmental issue.

A1.4 The Contractor is required to actively participate in the environmental management of the Project through the control of the individual contracts and comply with the directions of the Engineer.

A1.5 These Environmental Protection Rules are included as a part of each Contractor's obligations. Other environmental management requirements may be specified in Contract specifications.

A1.6 The Contractor may view the entire Environmental Management Program by request to the Engineer.

A.2 GENERAL

A2.1 The Contractor must ensure that its employees adhere to these Environmental Protection Rules. Project Management reserves the right to withdraw a Contractor's accommodation if a Contractor fails to ensure compliance with these Environmental Protection Rules.

A2.2 Any environmental harm that results from a Contractor failing to comply with these Environmental Protection Rules may be required to be repaired at the Contractor's expense.

A2.3 No person shall bring onto the Project Site or have in his possession at Site or other areas associated with any part of any Contract associated with this Project, any firearm or weapon capable of projecting a missile, except equipment designed to implant fixing devices and structures.

This requirement also applies to all Company leases on which the Project Site is located and adjacent Pastoral Leases.

A.3 ROADS

A3.1 Access to and from the Project Site should be along specified access routes only.

A3.2 The perimeter of the construction area for each Contract shall be clearly defined and marked up on drawings by the Engineer. Movement outside these perimeters is prohibited without a written site instruction from the Engineer.

A3.3 All movements of motor vehicles and any other machinery within the Project Site shall be on surveyed road alignments, either pegged or constructed or under construction, unless permitted by a written site instruction from the Engineer. Such permission shall only be granted for specified movements by specified types of vehicles and machinery for a specified period and purpose. To the maximum extent practicable, where permitted movements off surveyed road alignments should be along the contour unless otherwise specified by the Engineer in a written site instruction.

A3.4 After the specified movements off the surveyed road alignments have been completed corrective treatment to the route may be required. The requirement and responsibility for corrective treatments may be specified by the Engineer in a written site instruction.

A.4 FAUNA

A4.1 No animals (mammals, marsupials, birds, reptiles or fish of any kind including pets) shall be introduced to the Project area.

A4.2 No animals (mammals, marsupials, birds, reptiles or fish) shall be captured from within the Project area.

A.5 FLORA

A5.1 No Contractor shall cut down, dig out, burn or in any way disturb trees, shrubs or saplings on the Project Site unless required to do so as a part of a Contract and where required to do so will not do so without a written site instruction from the Engineer which instruction may specify the nature and means of that disturbance of those trees, saplings or shrubs.

A5.2 No Contractor shall disturb the formation of protective bunds, water courses, etc. unless required to do so as a part of a Contract and where required to do so will not do so without a written site instruction from the Engineer which instruction may specify the nature and means of that disturbance.

A5.3 No Contractor shall excavate, dig or otherwise disturb the natural soil surface at the Project Site unless required to do so as a part of a Contract and where required to do so will not do so without a written site instruction from the Engineer which instruction may specify the nature and means of that disturbance. . A written site instruction may specify the nature of remedial revegetating and stabilisation of the reformed soil surface to be carried out by the Contractor at the conclusion of the disturbance.

A5.4 No Contractor shall disturb the formation, revegetation or other stabilisation of reformed soil surface unless required to do so as a part of a Contract and where required to do so will not do so without a written site instruction from the Engineer which instruction may specify the nature and means of that disturbance. Such disturbance includes passage of vehicles and machinery over reformed surfaces which have been revegetated or otherwise treated and shall also include unauthorised movement across the formation of protective downslope of a totally cleared area.

A5.5 The Engineer may require topsoil to be taken separately, stockpiled and used for rehabilitation. This requirement will be specified in earthmoving contracts.

A.6 FIRES

A6.1 No Contractor shall light a fire in the open within the Project Site unless approved by the Engineer in a written site instruction except in portable barbeques or stoves.

A6.2 No waste materials shall be burnt or disposed of by fire in any part of the construction area unless approved by the Engineer in a written site instruction.

A.7 WASTE MATERIALS

A7.1 Waste materials shall only be deposited in approved locations nominated by the Engineer from time to time.

A7.2 All waste materials, rubbish or litter, including concrete, formwork, structural steel and the like, containers, paper, plastics and cans shall be removed by Contractors from construction areas to disposal points nominated by the Engineer.

A7.3 Any noxious, toxic or otherwise hazardous waste materials or containers of such materials shall be disposed of by methods and in locations approved by the Engineer in writing.

A7.4 Handling and disposal of all litter and waste packaging materials used by Contractors during construction shall be as directed by the Engineer.

A7.5 Servicing, lubricating and mechanical repairing of vehicles and machinery shall be undertaken in areas nominated by the Engineer. These areas shall be provided with suitable containers to hold waste oils and lubricants prior to disposal as directed by the Engineer.

A7.6 Servicing, lubricating and mechanical repairing of vehicles and machinery which cannot be moved to approved servicing areas shall only be carried out if approved by the Engineer in a written site instruction.

A7.7 Vehicles and machinery shall only be washed down in areas nominated by the Engineer.

A7.8 Access to sewage disposal areas is prohibited.

A7.9 All toilet facilities must be approved by the Engineer in a written site instruction.

A7.10 Toilet and other liquid wastes shall only be disposed of in a manner approved by the Engineer in a written site instruction.

A7.11 Unless approved otherwise by the Engineer in a written site instruction , sewage effluent shall be treated in a package type treatment plant to ensure compliance with regulations for effluent quality before release to the environment.

A7.12 Domestic garbage shall only be disposed of in the landfill site nominated by the Engineer.

A7.13 Dust control measures shall be employed at all times in accordance with directions of the Engineer and the release of any dust other than from unsealed roads into the open is strictly prohibited unless otherwise authorised by the Engineer in a written site instruction.

Dust control measure and work place monitoring shall be carried out in accordance with the Mines Regulation Act during operations.

A.8 HAZARDOUS AND TOXIC MATERIALS

A8.1 No hazardous or toxic material may be brought onto Site without the written permission of the Engineer.

A.9 NOISE

A9.1 Contractors shall not use equipment with faulty or inefficient mufflers/noise dampers. If in the opinion of the Engineer the equipment is operating at a noise level in excess of the statutory requirements, the contractor will be expected to repair or replace the offending piece of equipment.

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Appendix B Coral Health Monitoring Plan

B.1 Scope of the Plan

This plan covers the design and timing of the coral monitoring to be undertaken to provide a pre-dredging baseline, fortnightly monitoring during dredging and a post-dredging assessment of any impacts. It covers the statistical basis of monitoring and the level of coral community data to be collected in case a pre-dredging reference is needed to scope remediation.

Timing of surveys and trigger values for action in response to coral mortality are essentially the same as those developed to fulfil Ministerial Conditions 10 to 12 of Statement 644 covering the Hamersley Iron 2004 dredging program.

B.2 Project Accountabilities

Table B1 shows the primary contacts for issues relating to this plan.

- **Table B1: Accountability matrix**

Name	Role	Accountability	Contact details
Ross Dunkley	Liaison with dredging & disposal management contractors	Provide details of dredging and disposal plans on a fortnightly basis – link requirements of the Plan to operational dredging	Mobile: 0419 814 507
David Kabay	Project Environmental Officer	Report to government	Mobile: 0417 950 508
Jim Stoddart	MScience Project Manager	Conduct the monitoring program on behalf of Hamersley Iron	Mobile: 0419 914 569
Leon Payne	Manager Environment – RTIO EP	Ensure that project complies with legal conditions	Mobile: 0419 859 602

B.3 Design

B.3.1 Selection of Monitoring Sites

Objective

Identify and monitor sites which provide replicated representative areas of ‘at risk’ and ‘unimpacted’ coral communities which can be used as Reference sites to factor out decreases in coral cover occurring as a result of influences on coral mortality and growth unrelated to the dredging or disposal.

Criteria

Impact sites: establish sites in coral communities which are as near as possible to the source of dredging or disposal and contain significant amounts of coral cover. Based on past studies showing that the level of power for relevant statistical tests of change to detect 10% decline in coral cover increases rapidly above coral cover levels over 30% (Stoddart *et al*. 2005), monitoring sites should be placed in the highest density of coral cover.

Reference sites: sites which are similar to Impact sites in coral community structure, coverage of live coral, physical setting and are likely to be outside the influence of dredging/disposal impacts.

A further criterion in the selection of sites was their location in areas monitored previously by Woodside, Dampier Port Authority or Hamersley Iron, either during dredging and disposal operations or in the assessment of general change. In this way, sites established in this program could have an inferred history of variation over a decade or more in some cases.

A further site near Angel Island will be added as part of the baseline survey.

Action

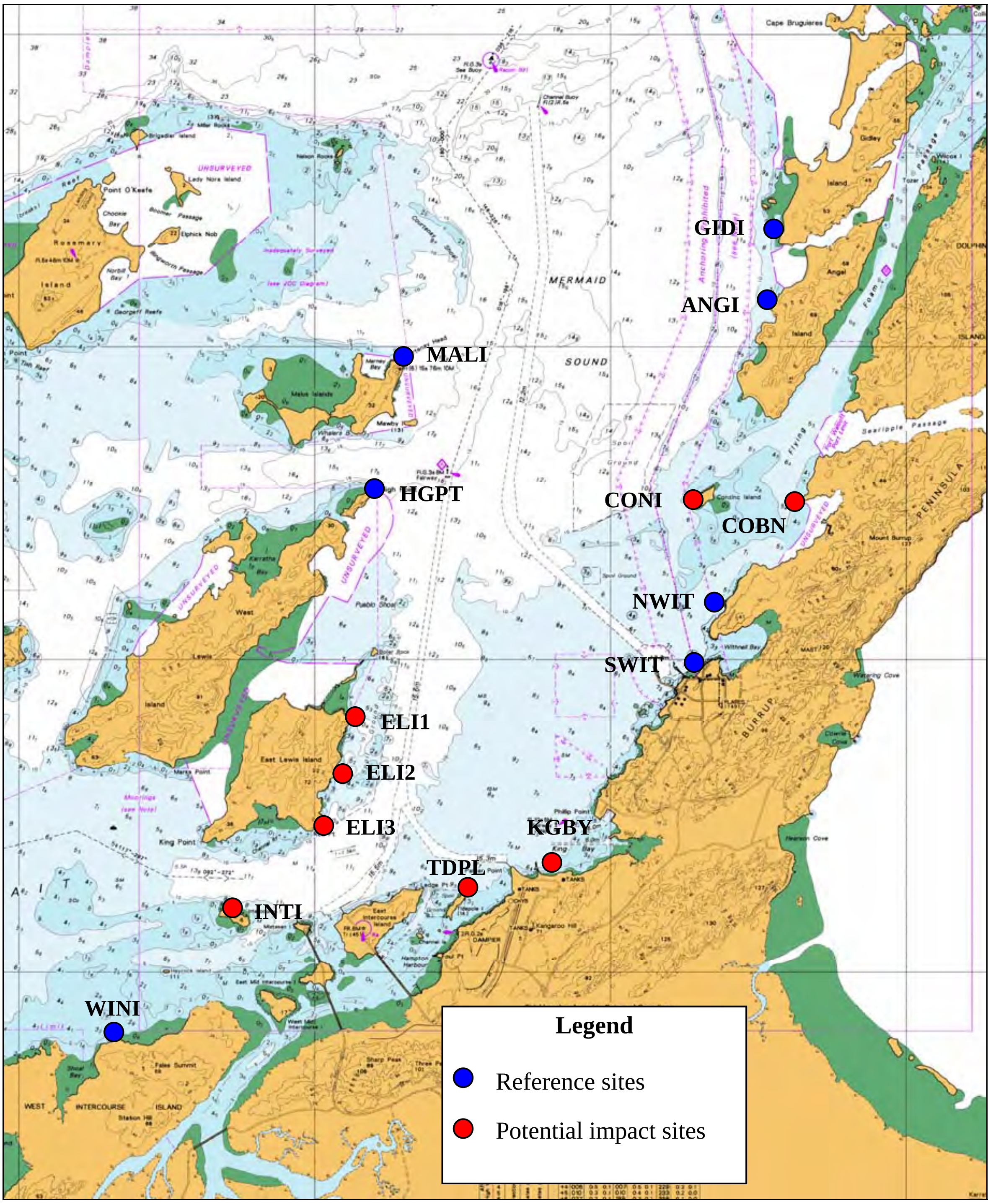
ESTABLISH REFERENCE AND IMPACT SITES				
What	How	Who	When	Where
Establish a set of impact and reference sites to be used for the project duration and follow-up monitoring	Use past data, sediment transport models, field survey and log sites with GPS and shore-mark location references.	MScience	Pre-dredging	Dredging and disposal areas

Outcome

Fifteen monitoring sites are proposed to be established at least two weeks prior to dredging commencing (see **Table B2** and **Figure C1**). Sites here have been designated as:

- Impact – within a 'possible' radius based on previous monitoring; and
- Uncertain – outside of the 'possible' radius and a site which did not decline in 2004 monitoring – but retain a very small risk of impact.

Reference - sites well outside a possible impact radius and used for detection of regional impact events such as bleaching. The distance required between Reference and Impact sites result in the two classes of site being subject to differing environmental influences on coral. Interpretation of change at either site must consider the actual source of impact.



■ **Figure C1 Location of proposed monitoring sites**

- **Table B2 Reference and impact sites proposed**

Site Name	Site Code	Position (WGS84)		Community Type^	Function
		Latitude	Longitude		
Angel Island North	ANGI	20°29.241' S	116°47.751' E	Ac	Uncertain - Disposal
Conzinc Bay North	COBN	20°32.417' S	116°48.193' E	FO	Impact – Disposal
Conzinc Island	CONI+	20°32.174' S	116°46.669' E	Pr	Impact – Disposal
East Lewis Island 1	ELI1	20°35.952' S	116°40.695' E	Pv	Impact – Disposal
East Lewis Island 2	ELI2	20°36.655' S	116°40.510' E	Pv	Impact – Disposal
East Lewis Island 3	ELI3	20°37.650' S	116°40.170' E	Pv	Impact – Disposal
Gidley Island	GIDI	20°28.262' S	116°47.794' E	Ac	Reference - Disposal
High Point	HGPT	20°32.460' S	116°41.046' E	Pv	Reference – Disposal
Intercourse Island	INTI	20°39.006' S	116°38.636' E	Pv	Impact – Disposal
King Bay	KGBY	20°38.293' S	116°44.077' E	FO	Impact - Dredging
Malus Island	MALI	20°31.310' S	116°41.635' E	Pr	Reference – Disposal
North Withnell	NWIT	20°34.281' S	116°46.793' E	FO	Uncertain - Disposal
South Withnell	SWIT	20°35.137' S	116°46.487' E	FO	Reference – Disposal
Tidepole Island	TDPL	20°38.721' S	116°42.609' E	Pv	Impact - Dredging
West Intercourse Island	WINI	20°40.966' S	116°36.633' E	FO	Reference - Dredging

^- community type is based on the classification in (Blakeway and Radford 2005) – or on subsequent field surveys.
+- site relocated north to higher coral cover since the 2004 monitoring program.

Monitoring using techniques comparable to those proposed here was conducted most recently for these sites in June and October 2005. Those surveys did not use the same transects as the previous monitoring and did not actively seek the most abundant corals at those sites. Nevertheless, results (**Table B3**) can be used to indicate the likely coral cover for baseline surveys. Site INTI is a new site added on the basis of the predictions of the sediment dispersal model (GEMS 2005).

Where previous transects have been removed, selection of sites in the field will seek areas of coral cover above 30%. However, on a risk assessment basis, it will be more effective to establish sites with lesser cover closer to impact sources than to have monitoring sites with higher statistical power to detect change sited outside the radius of impact. Previous work in the area (Blakeway 2005) shows that dredging impacts are generally profound and thus detected readily, but do not extend far beyond a few hundred metres. While Reference WINI has a low cover of coral, it is retained on the basis of its substantial baseline monitoring which provides better interpretation of the causality of change.

Site INTI has not been monitored previously but visual inspections suggest community composition and level of cover will be similar to ELI sites.

- **Table B3: Percent cover of live coral in 2004 and 2005 survey**

Site	Type	2004	2005 (June)	2005 (Oct)
ANGI	R	42%	34%	38%
COBN	I	44%	34%	34%
CONI	I	32%	45%	40%
ELI1	I	71%	58%	not sampled
ELI2	I	75%	61%	not sampled
ELI3	I	30%	34%	not sampled
GIDI	R	36%	35%	15%
HGPT	R	53%	30%	51%
MALI	R	41%	33%	40%
NWIT	R	31%	23%	25%
SWIT	R	36%	36%	31%
WINI	R	18%	21%	not sampled

B.3.2 Monitoring Protocols

Objective

Apply a monitoring technique which will yield timely and robust data on the impacts of dredging or spoil disposal on coral communities at Impact and Reference sites and provide a statistical power of at least 0.8 to detect a 10% decline in coral cover.

Criteria

Monitoring protocols should provide the following:

- the capacity to underpin statistical tests of change in the cover of live coral;
- allow evaluation of change in the common taxa of coral present which might be caused by selective mortality during elevated sediment levels;
- provide a high definition image record able to be analysed in the future for other parameters, including taxonomy;
- be repeatable, not heavily subject to observer bias, practical and able to be conducted rapidly to provide an operational tool for management; and
- be relevant to other studies of coral community composition and change over time and be capable of building into a long term data set to assist future environmental management within the Port.

The methodology developed by Stoddart *et al*. (2005) to meet these criteria for monitoring corals in Dampier Harbour in previous dredging projects will be used. Transect placement of monitoring frames (quadrats) will be refined to improve the repeatability of images scored for coral cover over subsequent monitoring trips.

Action

MONITORING PROTOCOL				
What	How	Who	When	Where
Design and test a monitoring program to meet above requirements.	Adapt protocols which have been developed and tested during 2004 coral monitoring in this Harbour	MScience	Pre-dredging	Impact and Reference sites

Outcome

A baseline survey will be conducted for the sites selected above approximately two weeks prior to dredging. Each site will be represented by 5 transects of 10 m – with an effective width of 70 cm (the camera frame being 50 x 70 cm). Each transect will consist of 20 frames sited at regular 0.5 m intervals along the transect and including the entire area under the transect (with over sampling).

Other modifications to the technique will include the use of a fixed mid-transect marker and reduction of point intercept sampling within images from 50 to 25 points. On sites with greater than 30% coral cover, reduction of frame sampling intensity to 25 points per frame should have little impact on the level of precision (Stoddart *et al*. 2005).

B.3.3 Triggers for Action

Objective

This DSDMP commits to managing dredging and disposal activities and to active remediation of any unacceptable impacts on coral communities. Within the period of potential impacts from the dredging program the most likely form of impact will be mortality of coral from sediment smothering. Thus the Plan needs to develop criteria to be tested by monitoring that will allow a decision on whether impacts are unacceptable and require remediation.

Criteria

Coral communities are dynamic and change in abundance can be a natural phenomenon (Connell *et al*. 1997; Nelson and Mapstone 1998). During recent assessments of the level of loss of corals in Dampier Harbour the EPA determined that 10% loss was cause for concern and 30% loss was unacceptable change (EPA 2003).

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Action

MONITORING PROTOCOL				
What	How	Who	When	Where
Establish trigger criteria to determine what action may be required during and post dredging	Apply levels agreed under previous coral monitoring plan	MScience	Pre-dredging	Impact Sites

Outcome

A trigger-action framework is outlined below:

- **Table B4: Trigger levels of coral loss and required actions**

Trigger	Action
Site does not exceed 10% Net Mortality	No further action required

Trigger	Action
Site declines by >10% but <30% Net Mortality	Notify dredging manager that evidence of dredging or disposal related mortality
Site declines by >30% Net Mortality	Notify dredging manager that unacceptable levels of mortality have been reached. Prepare assessment of change in community structure.

B.3.4 Statistical Analysis

Objective

Set up a statistical testing protocol capable of detecting significant (10% or greater) increase in gross coral mortality caused by dredging/disposal and calculate net mortality through the use of reference site data. Be able to quantify the statistical power of the monitoring protocol to determine when real changes have occurred.

Criteria

Over the dredging period (approx. six months), the 'gross cumulative mortality' is assumed to be equal to the difference between the baseline cover of live coral and the cover of live coral at the time of monitoring – at both Impact and Reference sites.

Net Mortality is the Gross Mortality at an Impact site less the average of any Gross Mortality over the same period at comparable reference sites (see **Table B2**).

The statistical testing procedure will need to assess firstly whether Gross Mortality at any site significantly exceeds the threshold decline (10%) and then test whether Net Mortality significantly exceeds threshold (10%) or limit (30%) levels.

Action

STATISTICAL ANALYSIS				
What	How	Who	When	Where
Describe the inferential statistical tests and their power to assess whether trigger levels have been exceeded.	A priori: Relate the sample design to previous monitoring programs. A posteriori: Conduct power tests on the numbers returned	MScience	A priori: Pre-dredging A posteriori: during the program	Impact and Reference sites

Outcome

The basic unit of data is the 'frame'. This is a 0.5 x 0.7 m image captured using a 5 megapixel digital camera at each frame site of the 10m transect (see **Section B.3.2**), assessed for cover of living coral type divided into the 6 common classes of coral found in the area (see Stoddart *et al*. 2005). Each frame returns a score of x% cover of living coral and y% cover of recently dead coral[2]. Percentage points are not subject to arcsine transformation as most are within the range 20–80%. Transect means and variance for %Live_Coral are calculated from 20 frames. Sites are characterised as the mean and variance of 5 Transects – this mean is the Gross Coral Cover for that site.

Testing will address the initial question as to whether there has been a decline in percent cover of coral at any site between the baseline and subsequent sampling period.

Hypothesis 1 – Gross Coral Mortality: for each Impact Site ($\alpha = 0.05$)

H_o – live coral cover has not declined more than 10% of the baseline value
H_1 – live coral cover has declined more than 10% of the baseline value

Test: A paired t-test of the 5 transect means for each site at the Baseline and Current time, using 10% change as the effect size – with *t* being for 1-tail and adjusted using a Bonferroni correction for multiple simultaneous tests (i.e. multiple Impact sites).

Should the hypothesis of no decline be rejected, then Net Mortality will be calculated using Reference sites and tested as below. Note that Net Mortality will only be calculated for a site where the average coral cover at the appropriate Reference sites [Mean($\text{Reference}_{\text{TimeX}}$)] is less than that at the baseline [Mean($\text{Reference}_{\text{Time0}}$)].

[2] NOTE: Using this method overestimates coral mortality as temporary effects like bleaching or sediment covering will be classified as mortality at that survey when scored from images.

Hypothesis 2 – Net Coral Mortality

H_o – Net Coral Mortality is not greater than 10% of the baseline value
H_1 – Net Coral Mortality is greater than 10% of the baseline value

Where:

Effect Size = 10% + RM%

RM= [Mean(Reference$_{Time0}$) – Mean(Reference$_{TimeX}$)] / Mean(Reference$_{Time0}$)

Should Ho be rejected in this case, the 10% effect size will be replaced with a 30% effect size and the test repeated (to relate to **Table B3** criteria).

Statistically, this test, which adds Reference mortality (a constant at any single time) to the effect size, is equivalent to subtracting Reference mortality from the estimates of Gross Mortality in Impact sites at Time$_X$.

Power analyses conducted for previous studies (Stoddart *et al*., 2005) show that where coral cover exceeds 30% the above tests should provide a better than 80% chance of detecting these effect sizes.

Section B.5 shows a worked example of tests.

B.4 Reporting

B.4.1 Reporting Protocol

Objective
Define a reporting protocol that will meet the needs of Hamersley Iron's environmental management commitments and government's regulatory responsibilities.

Criteria
Reporting should provide the following:

- Provide as rapid a transfer of the implications of monitoring to the dredge management program and the DoE-Karratha office as is consistent with quality controls on data and analysis; and
- A sufficient data content to underpin decisions on management.

Action

REPORTING PROTOCOL				
What	How	Who	When	Where
Specify the content of reporting events	On the basis of the agreed EMP	Hamersley Iron	Project duration and after	N/A

Outcome

The timeline for analysis and reporting will be as follows:

Standard reports for the coral health monitoring program will contain:

- A table of means and variances of live and dead coral cover at each site separated into taxonomic groups;
- Results of any statistical analyses conducted; and
- Other observations of divers carrying out the monitoring that are relevant to coral impacts.

Reports will be provided following each trip and will be sent from Hamersley Iron to the Dampier Port Authority and CALM-Karratha in addition to DoE-Karratha.

B.4.2 Timing

Objective

Implement the planned program to provide baseline data before the project commences, data for adaptive management during the project and assess changes in coral cover after completion of dredging.

Criteria

The pre-dredging study should occur as close as possible to the start of dredging. Should any major disturbance event (such as a cyclone or bleaching event) occur between the initial baseline and the commencement of dredging, it may be necessary to resurvey a new baseline.

During dredging, surveys should occur with sufficient frequency to allow dredging management to adapt to any mortality event before the mortality is repeated or becomes widespread.

A post-dredging survey should be conducted 1–2 months after dredging and disposal cease to provide a final assessment as to whether any impact has occurred. This period is sufficient for any sediment-related mortality to develop to a noticeable stage – a longer period would allow any recently dead coral to lose its white coloration and be difficult to identify from background.

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Action

MONITORING TIMING				
What	How	Who	When	Where
Implement a monitoring program to meet above requirements.	Action planned surveys	MScience	Pre, during and post the project.	Impact and Reference sites

Outcome

Timing of monitoring is planned to be:

Baseline: Two weeks prior to commencement of dredging.

During: Fortnightly during the dredging program.

Final: Once >1 month but <2 months after cessation of dredging and disposal.

B.5 Calculation Example

For Impact Site IMPC and Reference Site REFR

%Live Coral Cover at Baseline (Time 0)

Transect	IMPC	REFR
1	40	85
2	30	65
3	50	75
4	30	80
5	40	90
Site Mean	38	79

%Live Coral Cover at Time 1

Transect	IMPC	REFR
1	34	80
2	26	60
3	45	70
4	25	75
5	35	85
Site Mean	33	74

Gross Mortality

Site IMPC = (38-33)/38 = 13.2%

Site REFR = (79-74)/79 = 6.3%

Hypothesis 1:

Test of Gross Mortality at Impact Site

Result: Mortality at IMPC is significantly greater than 10% of baseline mean

Effect size (Gross 10%) =3.8% absolute change

The effect size for Net Mortality is then calculated:

Site REFR is then surveyed and 6.3% added to the effect size

Hypothesis 2:

Test of Net Mortality

Result: Mortality at IMPC is not greater than 16.3% of baseline mean

Effect size (Net 16.3%) = 6.19% absolute change

Outcome:

No further action required.

Appendix C Australian Ballast Water Requirements

AQIS
AUSTRALIAN QUARANTINE AND INSPECTION SERVICE

Department of AGRICULTURE FISHERIES & FORESTRY - AUSTRALIA

Australian Ballast Water Management Requirements

AGRICULTURE FISHERIES AND FORESTRY - AUSTRALIA

C.1 Introduction

The reason for the introduction of the mandatory Australian ballast water management arrangements is to help minimise the risk of the introduction of harmful aquatic organisms into Australia's marine environment through ship's ballast water.

C.2 Background

The Australian Quarantine and Inspection Service (AQIS) is the lead agency for the management of international vessels ballast water. Australia was the first country in the world to introduce voluntary ballast water management guidelines for international shipping, which have been in use by since 1991.

In September 1999, the Australian Government announced that mandatory ballast water management arrangements would be introduced for all international vessels arriving in Australian ports or waters from 1 July 2001.

Since that announcement, AQIS, in consultation with State / Territory Governments and the shipping industry, has developed new ballast water management arrangements which help minimise the introduction of harmful aquatic organisms into Australia's marine environment.

The new arrangements will incorporate a Decision Support System (DSS), which will provide vessels with a risk assessment of the ballast water as to the likelihood of introducing exotic species into Australian ports or waters. A revised ballast water reporting system and verification inspections will also be an integral part of the new arrangements.

The mandatory Australian ballast water management requirements have been developed to be consistent with the International Maritime Organisation (IMO) Guidelines for minimising the uptake of harmful aquatic species when vessels are performing ballasting operations.

Australia's new ballast water management requirements have legislative backing and will be enforced under the ***Quarantine Act 1908*.**

Safety of vessels and crew are of paramount importance, therefore vessels undertaking ballasting operations to meet Australia's ballast water management requirements must do so in accordance with the IMO Guidelines.

C.3 What the new arrangements mean for the shipping industry

C.3.1 Mandatory ballast water management requirements

From 1 July 2001, all international vessels will be required to manage their ballast water in accordance with AQIS requirements and not discharge high risk ballast water in Australian ports or waters.

C.3.2 Ballast water management options

The ballast water management options approved by AQIS that vessel Masters may undertake to minimise the risk of introduction of harmful aquatic organisms into Australian ports or waters are as follows.

C.3.3 Non-discharge of 'high risk' ballast tanks in Australian ports or waters

This method may be employed where the vessel does not need to discharge any ballast water in Australian ports or waters, or where the vessel has undertaken a DSS risk assessment and the risk assessment was 'low'.

C.3.4 Tank to tank transfer

This method may be employed where the vessel is able to move high risk ballast water from tank to tank within the vessel to avoid discharging high risk ballast water in Australian ports or waters.

C.3.5 Full ballast water exchange at sea using one of the following methods

- Flow through method
- Sequential method (empty/refill)
- Dilution method.

Full ballast water exchange may be employed where the vessel has high risk ballast water intended for discharge in Australian ports or waters. Vessels should conduct full ballast water exchange in deep mid ocean water, as far as possible from shore and outside the Australian 12 nautical limit. Exchange at sea must be undertaken to a minimum 95% volumetric exchange and should be undertaken in water greater than 200 metres in depth.

Where full ballast water exchange could not be undertaken due to safety reasons, such as weather, sea conditions or operational impracticability, the Master should report this to AQIS on the Quarantine Pre-Arrival Report (QPAR) as soon as possible and prior to entering Australian waters.

Other comparable treatment methods will be considered by AQIS on a case by case basis. You should contact AQIS prior to undertaking any treatment methods other than those specified above.

C.4 The AQIS Decision Support System

The Australian Ballast Water Decision Support System (DSS) is a computer software application developed by AQIS in consultation with industry. The DSS undertakes a biological risk assessment that predicts the likelihood of entry of harmful aquatic organisms and pathogens on a tank by tank basis based on uptake and discharge information entered by the vessels Master or agent. Information maybe lodged with the DSS at the last port of call or as early as possible prior to entering Australian waters (12 nautical mile limit). After submitting information into the DSS, you will receive a risk assessment number (RAN) which must be entered on the vessel's QPAR. This will allow AQIS officers to search the DSS for the risk assessment when undertaking a verification inspection of the vessel.

Masters are encouraged to use the DSS for 'scenario testing' to allow the best possible ballast water management option for the vessel. Low risk ballast water will not require any treatment prior to discharging in Australian ports or waters.

Entering information as early as possible into the DSS will allow Masters more time to perform an AQIS approved treatment prior to arrival in Australia saving time, money and inconvenience.

Access to the DSS can be through either of the following methods:

- Internet
- Inmarsat-C / Email

C.5 Ballast water reporting

All vessels arriving in Australia from international waters are required to submit a QPAR to AQIS. The QPAR details the condition of the vessel including human health, cargoes and ballast water management.

Vessel Masters / agents are required to send the QPAR to AQIS between 12 – 48 hours prior to arrival in Australia. This will allow efficient processing of the QPAR and avoid any disruption to the vessels arrival.

Vessel Masters / agents that do not submit the QPAR to AQIS will not be given formal quarantine clearance to enter port. This will cause delays to the vessel and will incur additional AQIS charges.

Vessels will require written permission to discharge any ballast water in Australian ports or waters which may be given following lodgement of the QPAR with AQIS. If the vessels ballast water details change, a revised QPAR must be sent to AQIS prior to discharging any ballast water.

Vessel Masters will be required to complete 2 other AQIS forms:

- The AQIS Ballast Water Uptake/Discharge Log. This log can also be used to provide the shipping agent with uptake and discharge information for entry into the DSS.
- The AQIS Ballast Water Treatment/Exchange Log. This log must be used to record all ballast water treatment / exchanges at sea.

These forms should not be sent to AQIS, however, they must be held on the vessel for a period of 2 years and produced to AQIS on request.

C.6 Verification Inspections

AQIS Officers will conduct ballast water verification inspections on-board vessels to ensure compliance with Australia's ballast water management requirements.

AQIS Officers will use the QPAR/DSS results, the AQIS ballast water logs and the vessels deck and engineering logs to verify the information supplied to AQIS is correct.

The verification inspection will take around 30 minutes to complete and in most cases will be conducted at the same time as a routine vessel inspection.

Vessels that have a poor quarantine history or have not previously complied with AQIS requirements will be inspected on each visit to Australia.

C.7 Co-regulation

AQIS Ballast Water Compliance Agreements will be available to vessels who regularly visit Australian ports and who have demonstrated a good quarantine compliance history.

The Agreement sets out the details of the activities, how they will be conducted and who has responsibility for ensuring they comply with AQIS requirements.

Ballast Water Compliance Agreements are subject to formal audit by AQIS on a regular basis.

C.8 Tank stripping

The discharge of ballast tank sediment must not occur in Australian waters.

Ballast tank stripping must not occur where this operation involves the discharge of sediment in Australian waters. Written approval from AQIS must be obtained prior to performing ballast tank stripping or sediment removal.

C.9 Access to sampling points

The AQIS sampling program is currently being reviewed, however, there will still be a requirement for vessel Masters to provide access to safe ballast water sampling points within the vessel.

Ballast water samples may be required to ensure compliance with Australia's ballast water management requirements or for further ballast water research.

Where a ballast water sample is required, AQIS Officers will avoid delays to vessels wherever possible.

Further Advice & Information

Further information can be obtained by contacting AQIS.

Log on to the AQIS web site

Home page address:	**www.aqis.gov.au/shipping**
AQIS Seaports Program address:	**seaports@aqis.gov.au**
	dss@aqis.gov.au
	dssadmin@aqis.gov.au

Contact AQIS by phone or fax

Calling within Australia	Phone:	(02) 6272 3933
	Fax:	(02) 6272 3276
Overseas enquires:	Phone:	+61 2 6272 3933
	Fax:	+61 2 6272 3276

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Appendix D Marine Spill Action Plan

ACTION PLAN

- **INITIAL RESPONSE PROCEDURE- follow the procedure below.**

1.	**REMAIN CALM** and read the procedure below. An extra 10 minutes doing the report properly will stop injury and save time later on. To respond correctly we need you to follow the steps below and stay safe.		
2	Fill out the initial report (see below) and notify the Marine Schedulers by **PHONE** This report will be what the authorities will ask for so that they can respond effectively. The more detail the better. **Give them your name and contact number.**	Phone or	9143 5710 9143 5925
3	**FAX, or RELAY** this report to the Marine Schedulers, as they will need as much information as possible and will be busy trying to notify people.	Fax	9143 5804
4	**LOG** what you have done (see below) so the spill can be audited later on.		
5	Once the spill is over- Contact the Marine Department to replace any used documents (report and log sheets etc).	Phone	9143 5707

- **IMPORTANT NOTE**

This Action Plan outlines the steps required for the immediate response to marine oil pollution incidents at Pilbara iron Pty Ltd, Dampier.

Details of procedures and other information can be found in the Pilbara iron (Dampier) Oil Spill Contingency Plan, the Dampier Port Authority Marine Oil Pollution Contingency Plan and the Western Australian Marine Oil Pollution Emergency Management Plan (WestPlan-MOP).

SKM

Initial Report Information Checklist

Question			Prompt/Answer	
1	Full Name of Reporter.			
2a	Contact details:	Telephone No..	Bus:	
2b			A/H:	
2c		Fax		
2d		E-mail		
3	Position of observer when sighting made		Aircraft _____ Vessel _____Ground ____ Other (*Details*):_________________	
4	Position of the slick			
5	Source of spill (*If known*).			
6	Type of substance spilled (*If known*).			
7	Amount of substance spilled (*If known*).			
8a	Description of slick	General		
8b		Colour	Black ___ Brown ___ Rainbow ___ Silver ____ Other (*Specify*)_______________________	
8c		Area	Length ________ (m), Width _____(m)	
8d		Other	Broken up? Yes _____ No __ _ Windrows (Streaks)?Yes ______ No ______	
9	Direction of slick movement (*If known*)			
10	Weather/sea conditions.			
11	Other information			
12	Name of person receiving report			
13	Agency/Division/Role			
14	Report to be forwarded to:		Name	
			Position	
			Address	

LOG OF EVENTS

For legal reasons please record anything you do on this page
This should include phone numbers, and faxes sent etc.

Date	

Time	Person contacted	Description or reason for call, include radio or fax messages

Appendix E DPA Spoil Ground Management Plan

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Dampier Port Authority
PO Box 285
Dampier 6713

Port Communications
Tel (08) 91596 556
Fax (08) 91596 558
Harbour Master
Tel (08) 91596 555

PORT OF DAMPIER
MARINE NOTICE

Number: **/2005** **Date: 8th December 2005**

Spoil Ground Management Plan

Rev. no.	Date	Description	Prepared	Checked	Approved
B	11/10/05	Revised and updated	RMD		
C	21/11/05	NRMS & SRMS updated volume	RMD		
D	8/12/05	Additional of appendix D	RMD		

Approval of current revision

	Prepared by	Approved by
Name:	Robin Douglass	
Function		
Date	8th December 2005	
Signature		

Section	Change
	Addition of appendix covering LNG V dredging

Contents

Spoil Ground Management Plan

1. Introduction

The Admiralty Hydrographic Chart[1] of the "Dampier Archipelago" shows three[2] spoil grounds within Port Limits[3].

The DPA has various responsibilities for the gazetted port areas and has determined that the management of the spoil grounds within port limits shall be undertaken by a "Spoil Ground Management Group" (SGMG).

2. Spoil Ground Management Group

The SGMG meets on a "needs basis", is chaired by the DPA and comprises representatives of:

- Dampier Port Authority;
- Hamersley Iron;
- Woodside Energy Limited;
- Department of Industry and Resources
- Other stakeholders by invitation;

Observers from:

- Western Australia Department of the Environment;
- Department of Environment and Heritage;
- Others on an interest basis

The aim of the SGMG is to use stakeholder experience and needs to manage and allocate spoil ground capacity for the ultimate benefit of all users

3. Dredge Spoil

Dredge material can be broadly categorised into five basic conditions:

Category 1 - Contaminated material not suitable for marine disposal

Category 2 - Contaminated material suitable for confined marine disposal

Category 3 - High Moisture content marine silts and ooze with varying proportions of silts, sand and clay;

Category 4 - Material with an inherent structural strength e.g. cut stiff to hard clays, ripped rock or rocklike material granular material with varying percentages of fines. Much of this material may be suitable for use as an engineering fill material but is discounted due to the propensity

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[1] Aus 58 published by Hydrographic Service R.A.N.

[2] Onshore Spoil Disposal Areas at the Supply Base and East Intercourse Island are not included in this assessment.

[3] Port of Dampier (Seabed Area) and Port of Dampier (Water Area) as shown on Land Administration Act Statutory Services Plan

of the material to break down into colloidal material when handled causing excess turbidity and environmental concerns.

Category 5 - Engineering grade fill material with nominal 100% to 90% coarser than 75 microns. This material is suitable for use onshore as a reclamation material.

4. Requirements

Spoil grounds are repositories for low quality bulk dredged materials. The spoil grounds need to generally be in deep water in order to:

- prevent re deposition by wind, wave, current and extreme cyclonic conditions;
- at a depth which allows access by large trailer suction hopper dredges;
- remote from corals, seagrass beds and other sensitive environmental areas.

The environmental issues are set by the nomination of the spoil ground site.

The economic operation of large trailer suction hopper dredges requires that have sufficient:

- sea room to operate at speeds of 10 to 18 knots and slowing down to less than 5 knots for dumping;
- under keel clearance to allow for the opening of bottom doors of up to 2-3 metres/;
- sufficient area to turn at speed;
- sufficient depth to allow approximately 6,000 to 30,000 cubic metres of material to be dumped in a normal 5 minute dumping period while travelling at1 to 5 knots.
- The above requirements generally require minimum spoil ground depths of 8-10 metres plus 2 metres of under keel clearance or 10-12 metres water depth. With 1 to 2 metres of tide spoil grounds need to have minimum depths of 9 to 11 metres for access.

5. Capacity of Spoil Grounds

Assessing the capacity of spoil grounds involves a number of factors including bulking, losses and consolidation. Once a soil or rock mass is disintegrated prior to lifting to the surface it increases in volume. The bulking varying from zero where material is dredged at or near its natural content to fifty percent or more where stiff to hard clays are broken down and liquefied through the erosion and abrasion action of drag heads, cutters, pumps and pipelines.

Coarser material can be expected to settle close to the dredging and disposal areas while the finer factions can be separated from the soil or rock mass and dispersed into the natural environment under the action of wind, tide and currents. Extreme weather events such as cyclonic conditions will also disperse material.

In addition material placed in a spoil ground can be expected to consolidate and granular material containing calcareous rock flour can be expected to re-cement.

The combined impact of losses, accretion, erosion and consolidation are easily measured. The impact varies with both time and the cycle of extreme weather conditions. The volumes and depths in the spoil grounds should be monitored by hydrographic surveys on a regular basis.

The spoil ground capacity assessments in this report have been reduced by a nominal 30% to allow for the above affects.

6. Port of Dampier Spoil Grounds

The spoil grounds located within Port Limits are:

- East Lewis (ex HI Spoil Ground) comprising Southern, Centre and Northern Sections;
- Adjacent to Woodside Channel Beacon #11 (Not in use) ;
- Conzinc Island Spoil Ground (ex Woodside Spoil Ground) comprising a Northern and Southern Section.

See **figure 1** below for location of spoil grounds

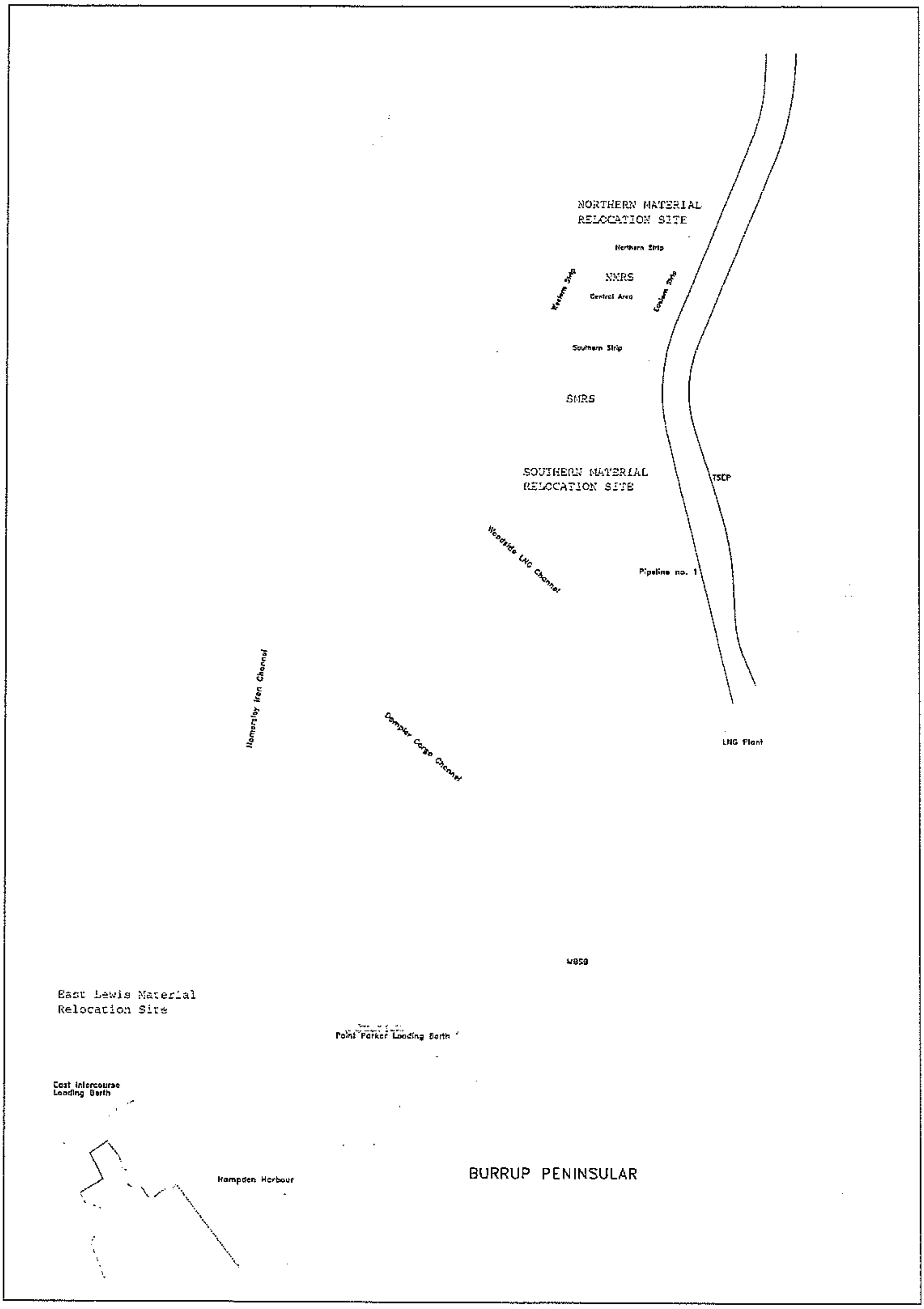


Figure 1 Location of Dampier Material Relocation Sites

6.1 Northern Material Relocation Site (Conzinc Island)

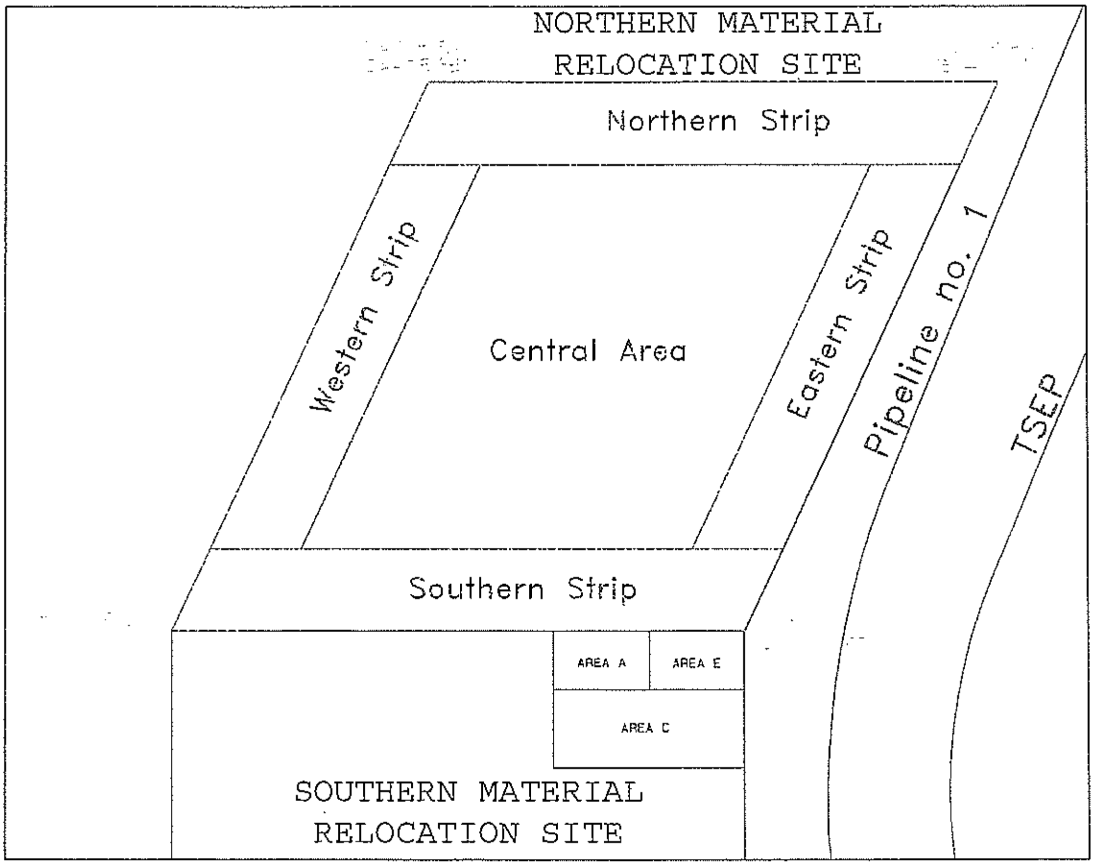


Figure 2 Northern Material Relocation Site

The Northern Material Relocation Site (NMRS) is 4,200,000 square metres (420 Hectares) in area and is nominally defined[4] by the following WGS 84 coordinates. An upper minimum **post dumping depth of -11.5 metres** (ACDD[5]) is maintained.

Table 1 Northern Material Relocation Site (Approx) Coordinates

Latitude (South)	*Longitude (East)*	*Easting* AGD 84	*Northing* AGD 84
20deg. 30.910min	116deg. 44.894min	473 637.1m	7 731 340.9m
20deg. 30.910min	116deg. 46.102min	475 737.1m	7 731 340.9m
20deg. 31.971min	116deg. 45.571min	474 797.1m	7 729 340.9m
20deg. 31.996min	116deg. 44.358min	472 697 1m	7 729 340.9m

[4] Section 4 Sea Dumping Permit for Harbour Works No: DPA2003/01 and DPA2003/02 issued to Dampier Port Authority in 18th December 2003.
[5] ACDD is Admiralty Chart Datum Dampier and is 7.4777m below mark PWD BMA958 at the northern end of the King Bay Supply Base Wharf.

The Northern Material Relocation Site was initially developed by Woodside Energy about 1980. The area was not used until the DPA relocated a nominal 4.5 million cubic metres of dredged spoil from the Bulk Liquids Product Berth area. This work was undertaken between 8th January and 30th April 2004.

For administrative purposes the NMRS has been subdivided into the following management sub areas comprising a **central core** with an outer boundary 300 metres wide, parallel with the above limits as shown at **Figure 2**.

The area is further subdivided into cells each being 200 metres long by 100 metres wide as shown at **Figure 2.**

NRMS Disposal Requirements

The DPA's requirements for the relocation of material to the NRMS (Figure 2) are:

- Category 2 – Contaminated material suitable for confined marine disposal is placed in the deepest sections of the NMRS in cells in the **central** core generally in water depths deeper than 13 metres (no further capacity available). The Category 2 material placed below 13 metres in 2004 is capped with a minimum 1 metre layer thickness of clean material Category 3 material;
- Category 3 material may be placed within the **central** core section to a depth of -11.5 metres CDD;
- Category 4 and 5 material may be placed to form a protection berm in the peripheral 300 metre strip around the Northern and western sides of the NSG in cells Y to Z - 0 to 8, and Y to O line 8 to a depth of -11.5 metres ACDD. DPA prefers that, as far as practical, Category 5 material is relocated to the Southern Material Relocation Site.

At the conclusion of the DPA 2004 dredging campaign the Northern Material Relocation Site had a theoretical capacity as shown in **Appendix A.**

6.2 Southern Material Relocation Site (SMRS)

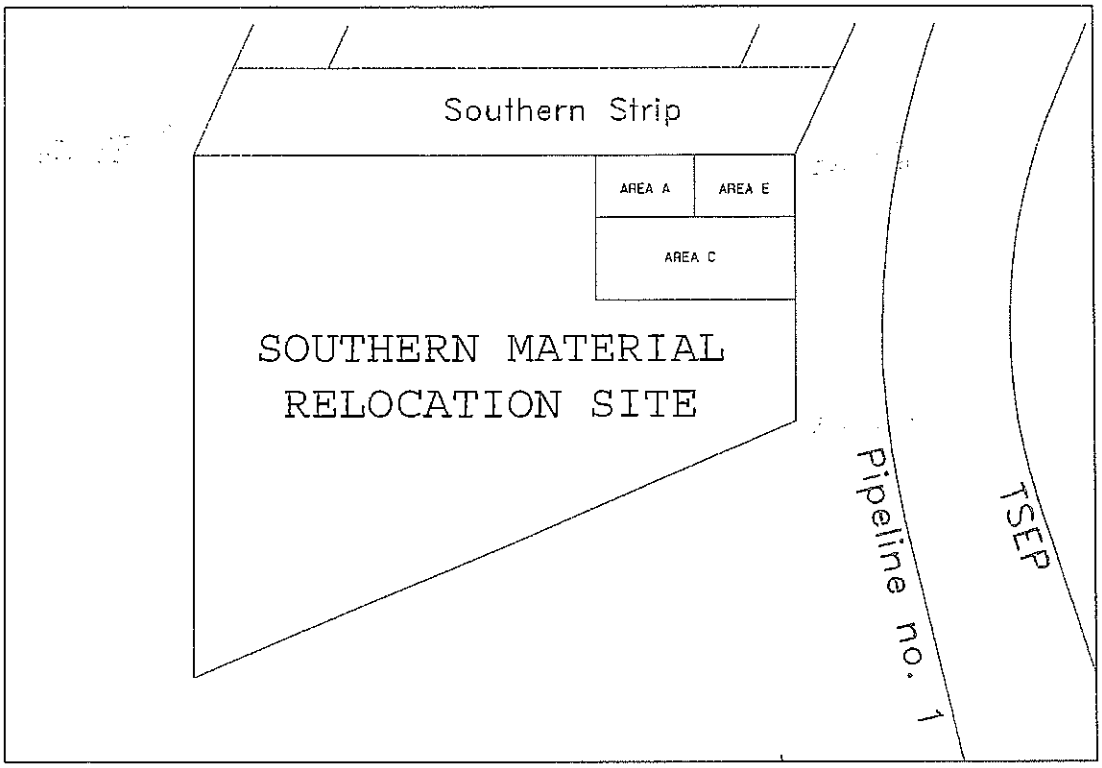


Figure 3 Southern Material Relocation Site

The Southern Material Relocation Site (SMRS) is 2,866,500 square metres (286 Hectares) in area and is nominally defined[6] by the following WGS 84 coordinates. An upper minimum **post dumping depth of -9.3 metres** (ACDD[7]) is maintained. The SMRS is shown at **Figure3.**

Table 2 Southern Material Relocation Site (Approx) Coordinates

Latitude (South)	*Longitude (East)*	*Easting (m)* AGD 84	*Northing (m)* AGD 84
20deg. 31.971min	116deg. 45.571min	474 797.1 (A1)	7 729 340.9
20deg. 32.294min	116deg. 45.344min	474 797.1 (A2)	7 728 420.9
20deg. 32.972min	116deg. 44.364min	472 697.1 (A3)	7 727 530.9
20deg. 31.996min	116deg. 44.358min	472 697.1 (A4)	7 729 340.9

[6] Section 4 Sea Dumping Permit for Harbour Works No: DPA2003/01 and DPA2003/02 issued to Dampier Port Authority in 18th December 2003.
[7] ACDD is Admiralty Chart Datum Dampier and is 7.4777m below mark PWD BMA958 at the northern end of the King Bay Supply Base Wharf.

The SMRS was originally developed by WEL in the nineteen eighties and dredged material from the WEL channel, swinging basin, berths and pipeline trenches was relocated to this area. The SMRS is characterised by shallow ground on the southern side with minimum depth of -8.33 CDD and on the western side by -8.86 metres CDD.

DPA policy is to place coarse clean sand, crushed rock and rocklike material and igneous rock into SMRS. Generally course sand is placed to the west and east of the area (excluding areas A and E), crushed rock to the centre and igneous rock to area E.

At the conclusion of the WEL TSEP 2003 dredging campaign the SMRS had a theoretical capacity as shown in **Appendix B.**

6.3 East Lewis Material Relocation Site (ELMRS)

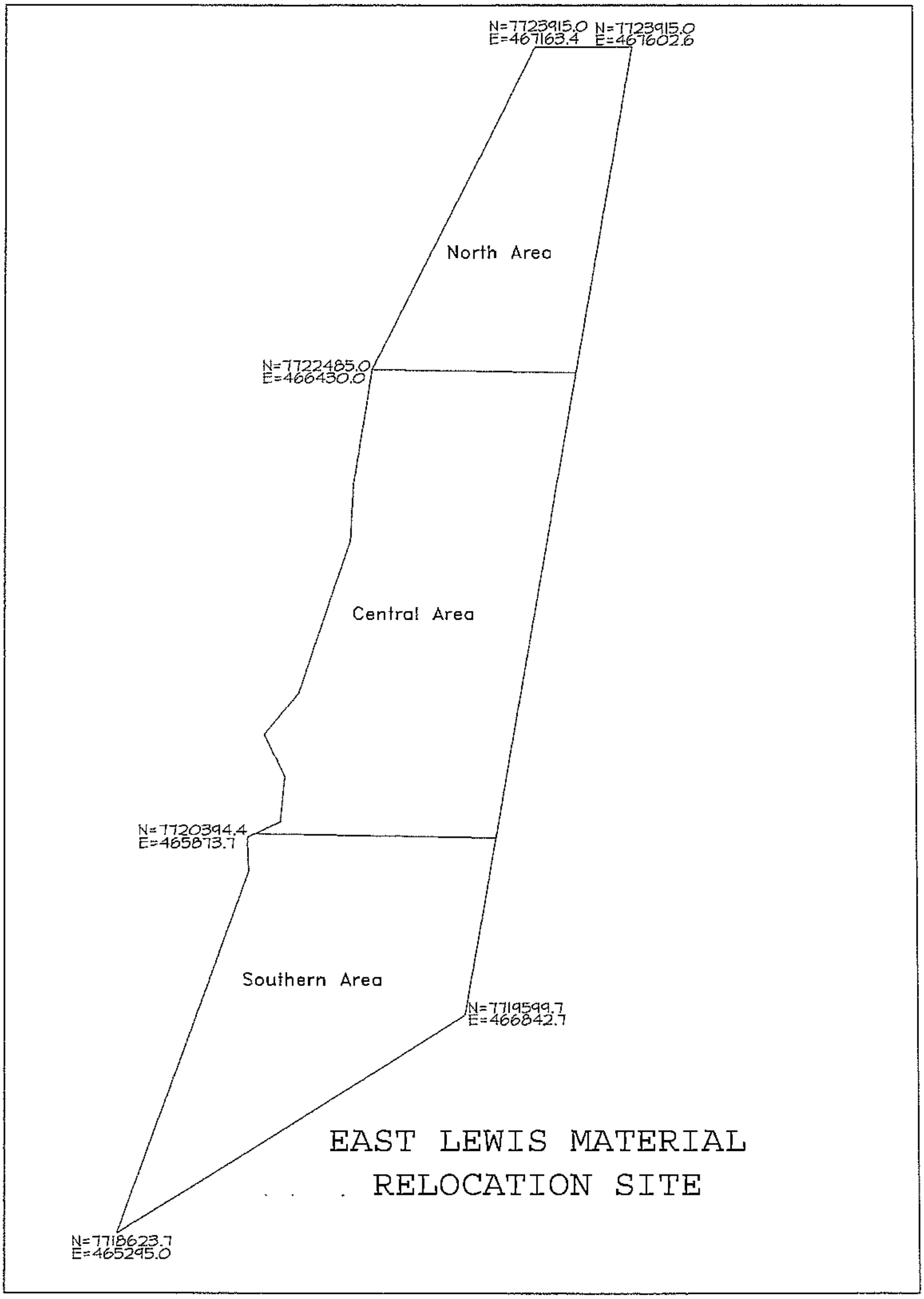


Figure 4 East Lewis Material Relocation Site

The East Lewis Material Relocation Site (ELMRS) is 445,150 square metres (445) Hectares) in area and is nominally defined[8] by the following WGS 84 coordinates. An upper minimum **post dumping depth of -5.5 metres** (ACDD[9]) is maintained. ELMRS was used during 2004 for disposal of spoil during Hamersley Iron's dredging of the new Parker point berth and channel extension.

The ELMRS is segregated into three compartments comprising, northern, central and southern sections with nominal areas as follow:

- Northern section 978,675 square metres (97,8 Hectares);
- Central section 1,985,779 square metres (198.5 Hectares)'
- Southern section 1,487,042 square metres (148.7 Hectares).

Table 3 East Lewis Material Relocation Site (Approx) Coordinates

Latitude (South)	*Longitude (East)*	*Easting (m)* AGD 84	*Northing (m)* AGD 84
20deg. 34.93min	116deg. 41.18min	467163.40	7723915.00
20deg. 34.93min	116deg. 41.43min	467602.60	7723915.00
20deg. 37.26min	116deg. 40.99min	466842.70	7719599.70
20deg. 37.79min	116deg. 40.09min	465295.00	7718623.70

The theoretical remaining capacity at the conclusion of the Hamersley Iron 2004 dredging campaign is shown in **appendix C.**

8 Section 4 Sea Dumping Permit for Harbour Works No: DPA2003/01 and DPA2003/02 issued to Dampier Port Authority in 18th December 2003.
9 ACDD is Admiralty Chart Datum Dampier and is 7.4777m below mark PWD BMA958 at the northern end of the King Bay Supply Base Wharf.

7. Summary

Companies undertaking capital or maintenance dredging works in the port are required to:

(i) Advise the DPA as soon as possible of the scope and best date timing of any proposed dredging works prior to advising other agencies.
(ii) Provide information on scope, volumes, and area preferred prior to requests to any Federal or State Agencies;
(iii) Advise DPA, who in consultation with the Spoil Ground Management Group, will make a determination on the allocation of capacity in the material relocation sites.
(iv) Provide drafts of their proposed "Dredging and Spoil Management Plan" taking into account the management criteria for the relevant material relocation sites outlined above.

Appendix A

Northern Material Relocation Site Capacity

Time of Survey (campaign)	Max Fill Depth	Remaining Capacity cubic metres					
		N Strip	E Strip	S Strip	W Strip	Central	Total
Pre DPA campaign Jan-April 2004	9.5m CD						
	10.5m CD						
	11.5m CD	Awaiting Survey data					
	9.5m CD						
	10.5m CD						
	11.5m CD						
Post DPA campaign Jan-April 2004	9.5m CD						
	10.5m CD						
	11.5m CD	Awaiting Survey data					
	9.5m CD						
	10.5m CD						
	11.5m CD						
Post HI campaign 2004	9.5m CD	2,893,000	1,809,000	2,109,000	1,466,000	6,455,000	14,732,000
	10.5m CD	2,263,000	1,345,000	1,479,000	1,002,000	4,443,000	10,532,000
	11.5m CD	1,633,000	881,000	849,000	538,000	2,431,000	6,332,000
	9.5m CD	**2,225,000**	**1,392,000**	**1,622,000**	**1,128,000**	**4,965,000**	**11,332,000**
	10.5m CD	**1,741,000**	**1,035,000**	**1,138,000**	**771,000**	**3,418,000**	**8,102,000**
	11.5m CD	**1,256,000**	**678,000**	**653,000**	**414,000**	**1,870,000**	**4,871,000**
Pre WEL LNG V Expansion Project Oct 2005 to Apr 2006	9.5m CD	2,880,000	1,805,000	2,105,000	1,487,000	6,430,000	14,707,000
	10.5m CD	2,250,000	1,341,000	1,475,000	1,023,000	4,418,000	10,507,000
	11.5m CD	1,621,000	877,000	845,000	559,000	2,406,000	6,308,00[illegible]
	9.5m CD	**2,215,000**	**1,388,000**	**1,619,000**	**1,144,000**	**4,946,000**	**11,313,000**
	10.5m CD	**1,731,000**	**1,032,000**	**1,135,000**	**787,000**	**3,398,000**	**8,082,000**
	11.5m CD	**1,247,000**	**675,000**	**650,000**	**430,000**	**1,851,000**	**4,852,000**
Prog WEL LNG V Expansion Project Nov 16 2005	9.5m CD						
	10.5m CD						
	11.5m CD	1,620,000	771,000	816,000	549,000	1,945,000	5,701,000
	9.5m CD						
	10.5m CD						
	11.5m CD						

Note: Bold Figures are in-situ capacity - (insitu + 30% = capacity calculated from survey). These figures should be used when planning for spoil disposal.

LNG V Expansion Project Drilling, blasting, dredging and ancillary works

Northern Material Relocation Site Available Dumping volumes (cu.m) to -11.5m ACDD

Axis - X	Axis - Y								
	0	1	2	3	4	5	6	7	8
A	29,930	20,566	11,418	12,259	14,569	12,849	30,810	27,692	33,510
B	23,222	12,375	6,883	9,378	12,963	11,145	16,975	23,557	29,159
C	21,306	11,935	9,569	12,162	18,569	18,800	23,899	24,236	32,952
D	23,434	10,760	8,841	10,547	18,065	25,034	23,977	31,416	30,783
E	23,323	13,472	7,782	11,043	16,334	19,991	16,645	27,101	29,533
F	23,724	15,141	11,034	12,213	17,316	18,174	17,921	31,982	32,612
G	25,518	19,960	15,473	12,964	11,614	19,285	20,663	33,601	39,756
H	25,779	24,904	18,771	11,449	11,264	22,545	21,871	23,996	34,771
I	25,812	23,673	22,755	11,426	10,841	21,138	24,707	22,439	45,387
J	30,240	29,521	23,038	17,494	10,656	22,410	33,257	30,864	51,656
K	37,007	33,091	30,917	19,489	22,907	24,283	24,928	33,684	55,176
L	40,883	43,008	36,540	28,829	34,693	26,821	28,841	42,254	62,283
M	33,550	34,504	37,724	40,379	43,524	36,751	44,478	55,375	65,927
N	23,688	31,991	38,569	39,569	44,518	47,531	54,165	60,059	66,338
O	27,599	28,945	35,560	36,758	44,039	48,767	54,415	61,018	65,552
P	25,917	27,925	35,753	39,050	42,471	41,562	51,522	61,371	66,223
Q	20,237	23,620	36,196	38,199	38,950	37,368	50,620	62,576	65,821

Computed from pre-dredge survey Sept/Oct 2005 (Boskalis)

Total volume available in boxes **5,292,139**
Additional volume in 100m outer border **1,018,286**

Figure 4 Northern Material Relocation Site – breakdown of capacity available at start of LNG V Dredging Project

Appendix B

Southern Material Relocation Site Capacity

Note: Bold Figures are in-situ capacity - (insitu + 30% = capacity calculated from survey). These figures should be used when planning for spoil disposal.

Survey date (campaign)	Remaining Capacity cubic metres					
	9.3m CD	10.5m CD	12m CD	9.3m CD	10.5m CD	12m CD
Post WEL TSEP 2003	7,473,000	2,852,000	927,000	**5,748,000**	**2,194,000**	**713,000**
Pre WEL LNG V 2005	7,394,000			**5,688,000**		
LNG V Prog 16Nov05	7,069,434			**5,438,000**		

Appendix C

East Lewis Material Relocation Site Capacity

Time of Survey (campaign)	Max Fill Depth	Remaining Capacity cubic metres					
		North	South	Central	**North**	**South**	**Central**
Late 2002 (West Ham)	5.5m CD	4,408,000	4,668,000	4,115,000	**3,391,000**	**3,591,000**	**3,165,000**
	9.0m CD	1,276,000	352,000	154,000	**982,000**	**271,000**	**118,000**
	10.0m CD	692,000	53,000	544	**532,000**	**41,000**	**0**
	11.5m CD	221,000	0	0	**170,000**	**0**	**0**
Post HI campaign 2004	5.5m CD	4,094,000	3,068,000	3,274,486	**3,149,000**	**2,360,000**	**2,519,000**
	9.0m CD	1,089,000	261,000	99,604	**838,000**	**201,000**	**77,000**
	10.0m CD	614,000	52,000	0	**472,000**	**40,000**	**0**
	11.5m CD	217,000	0	0	**167,000**	**0**	**0**
	5.5m CD						
	9.0m CD						
	10.0m CD						
	11.5m CD						
	5.5m CD						
	9.0m CD						
	10.0m CD						
	11.5m CD						
	5.5m CD						
	9.0m CD						
	10.0m CD						
	11.5m CD						
	5.5m CD						
	9.0m CD						
	10.0m CD						
	11.5m CD						

Note: Bold Figures are in-situ capacity - (insitu + 30% = capacity calculated from survey). These figures should be used when planning for spoil disposal.

Appendix D

NWSJV LNG V EXPANSION PROJECT

Drilling, blasting, dredging & ancillary works

Scope of works

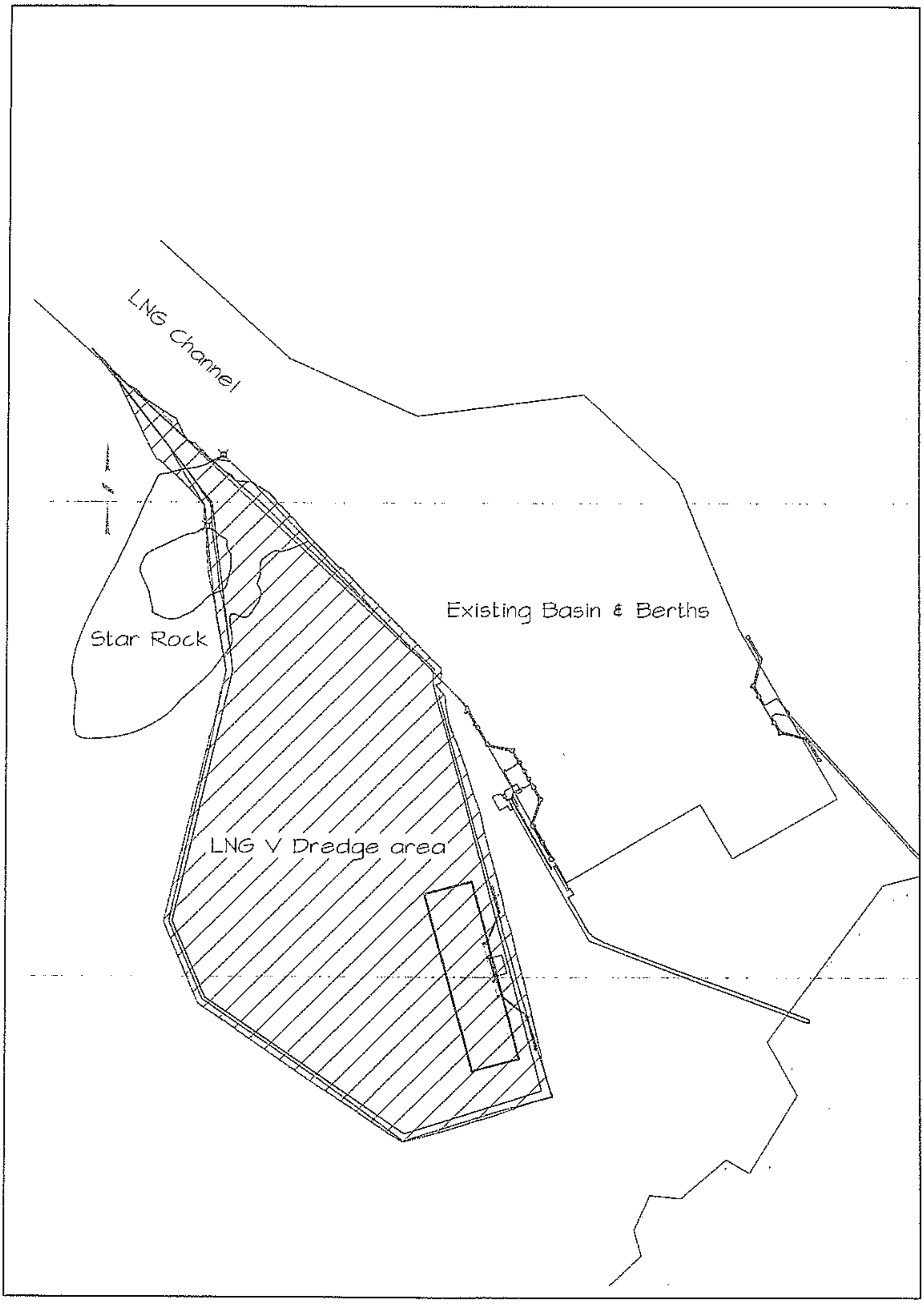
To dredge a new berth, basin and channel junction for a new LNG jetty to the south west of the existing LNG jetty.

The work requires the removal of in excess of 2,900,000 m^3 of material comprising some 800,000 m^3 of high moisture content marine sediments to be relocated in NMRS, some 515,000 m^3 of granular and soft rock and rocklike materials to be relocated in the SE & SW corners of SMRS, some 1,461,000 m^3 of cut and crushed non-igneous material to be relocated in the central area of SMRS, 20,000 m^3 of superficial igneous blocks, slabs, boulders, cobbles and gravel from around Star Rock and some 80,000 m^3 of drilled and blasted igneous rock to be relocated in area E in SMRS.

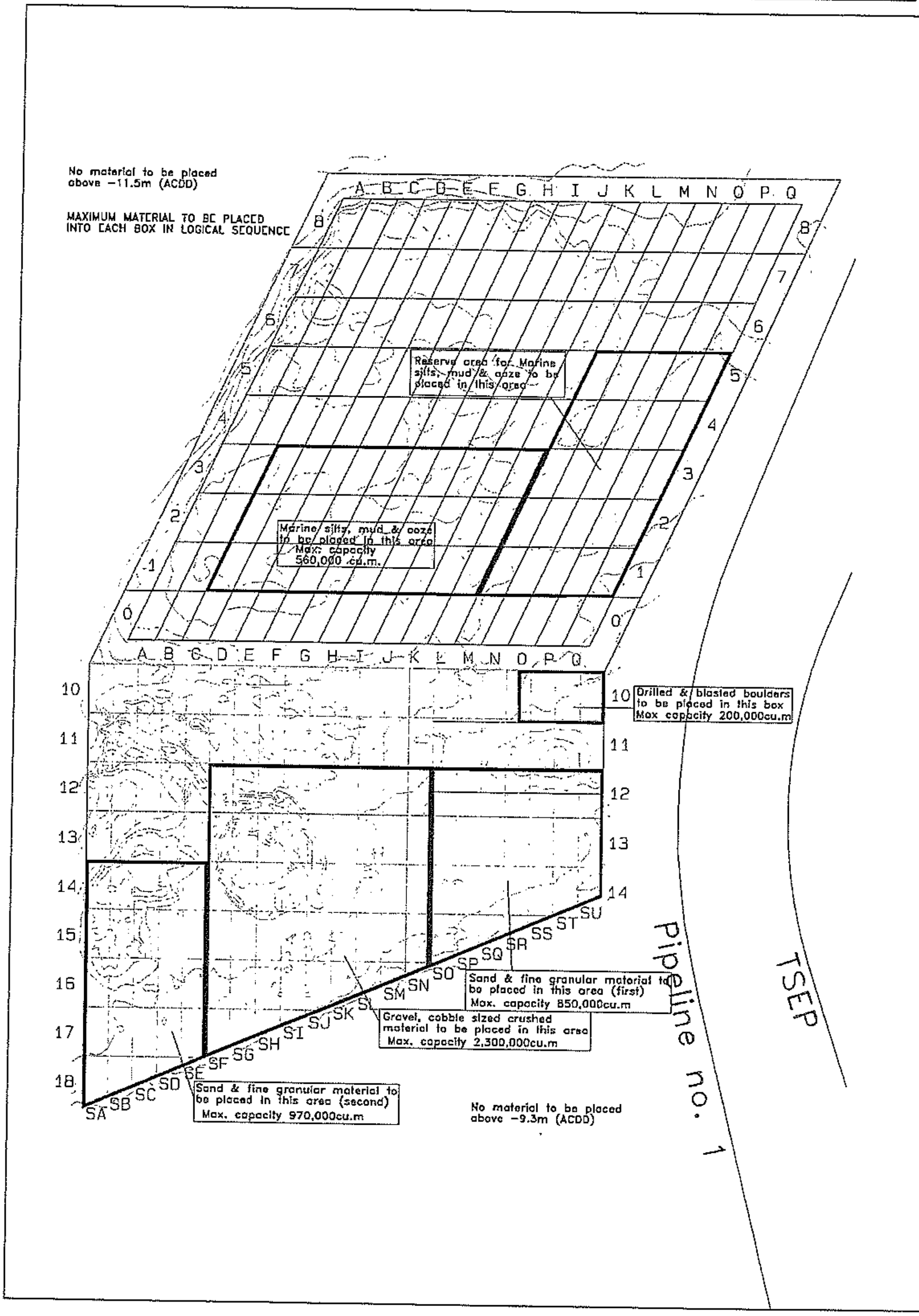
Material will be removed using a variety of methods including drilling and blasting, direct trailer dredging, cutting and crushing material with a cutter-suction dredge for subsequent re-dredging and removal to the relocation site using a trailer dredge and removal of loose boulders, slabs, blasted material with a backhoe dredge and/or grab dredge loading into a split hopper barge.

Vessels to be used in performing the dredging operation include:

Trailer Suction Dredge "Cornelis Zanen"
Cutter Suction Dredge "Ursa"
Back-hoe dredge "Obscured by Clouds"
Grab dredge "Goomai"
Jack-up platform "Sirius" – drilling & blasting
Multi-cat support vessel "BKM 103"
Tug "Reliance"
Survey vessel "Orion"
Split hopper barge "Yea"



LNG V Expansion Project – Drilling, blasting & dredging area



Areas allocated for dumping of material from LNG V Expansion Project Dredging

Appendix B *Corals of the Dampier Harbour*

Their Survival and Reproduction During the Dredging Programs of 2004

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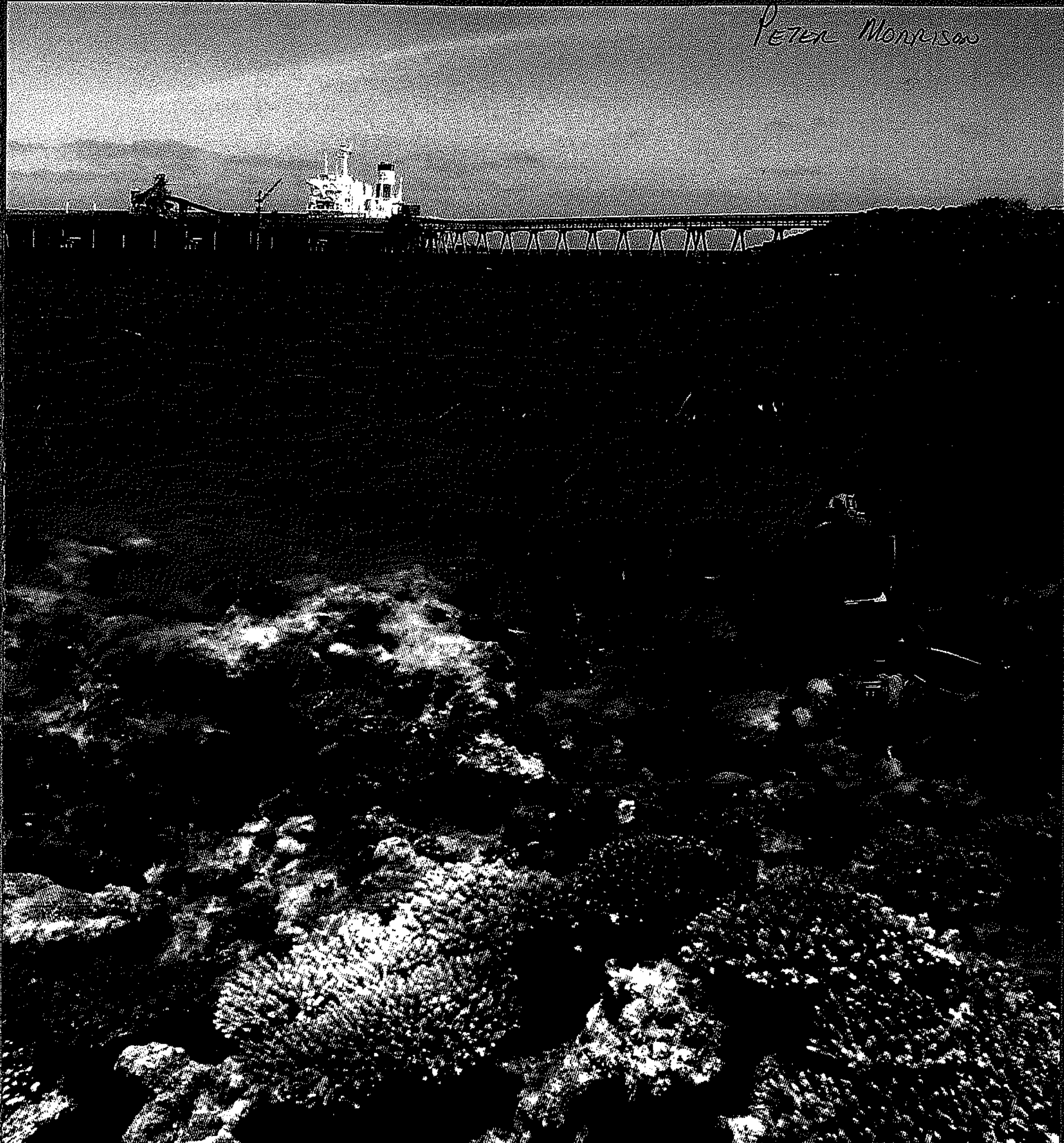

Corals of the Dampier Harbour:

Their Survival and Reproduction during the Dredging Programs of 2004

DAMPIER PORT AUTHORITY
H.M.S. ROEBUCK 1699

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Pilbara Iron
A member of the Rio Tinto Group

CORALS OF THE DAMPIER HARBOUR

Their Survival and Reproduction During the Dredging Programs of 2004

Editors: JA Stoddart & SE Stoddart

Published by MScience Pty Ltd on behalf of

Dampier Port Authority
MOF Road, Burrup Peninsula

Pilbara Iron Pty Ltd
152-158 St Georges Tce
Perth, Western Australia

ISBN: 0-646-44498-0

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Foreword

The Port of Dampier on Western Australia's Pilbara Coast is one of the largest tonnage ports in Australia and an important base for the North-West Shelf oil and gas industry. In response to expanding opportunities for resource development in the region, two proposals involving dredging of new berths and channels to increase port capacity went before the Western Australian Environmental Protection Authority in 2003. As a result of the environmental impact assessment of these proposals, a number of studies of the marine environment were commissioned to be carried out in conjunction with the dredging and spoil disposal activities proposed.

This document presents the results of the marine studies conducted during dredging by:

Dampier Port Authority (DPA): 8 January – 20 May 2004; and

Hamersley Iron Pty Limited (HI): 8 May – 23 October 2004.

Acknowledgements

The authors would like to acknowledge the following people and companies who assisted with the conduct of this work and its subsequent transformation into this document:

Hamersley Iron Pty Limited: for sponsoring the monitoring and other studies and the writing of the technical papers: Peter Royce for managing the day to day stresses, Lyle Banks for linking us to the dredging management and John Wood for pushing the need for published science.

Dampier Port Authority: for sponsoring the field program and the production of the book: Stephen Nicholson for the project management and impetus and Peter Smith for helping with diving and collecting all the DPA water quality data and commenting on the manuscript.

Oceanic Offshore: Kev and Troy Nuttall for providing vessels and diving support in the field, as well as local knowledge and looking after us in the ocean on days of good and bad weather.

Woodside Energy Limited: for allowing us access to their lease and data: Greg Oliver for making available past information and providing helpful comments on the manuscript

URS: who shared similar concerns and past data with us: largely via Ian Le Provost with field assistance from Dr Anthony Rouphael

WA Department of Environment: for considerable technical input into scoping the original monitoring program: Dr Ray Masini for the early program development which was then taken up by Dr Cameron Sim: with local input from Petrina Raitt in Karratha.

Western Australian Museum: for assistance in the identification of coral species: with advice from Loisette Marsh, facilitation from Dr Jane Fromont and access to preliminary versions of publications from Diana Jones.

Australian Institute of Marine Science: who provided advice on undertaking field programs for coral monitoring and reproductive studies, principally through the agency of Dr Andrew Heyward.

CSIRO Marine: with Dr Russ Babcock reviewing the early proposals for coral reproductive monitoring.

Steve Berrick: for compiling the many inputs into a coherent document fit for publishing.

Uniprint for publishing the final.

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PREFACE

Coral reefs are one of the most ecologically and socially important ecosystems in the world. Unfortunately they are also one of the most threatened. Current indications are that the integrity of approximately half of the world's coral reefs is threatened by human pressures, and it is estimated that approximately 20 percent of the world's reefs have been severely damaged and show no signs of recovery.

The worldwide decline of coral reefs is driven by a number of processes ranging from global climate change and associated seawater warming through to local and more direct human pressures such as habitat loss. Human activities such as overfishing, ocean disposal of nutrient and toxicant enriched wastes, sedimentation from terrestrial run-off and dredging, and direct impacts on coral reefs to accommodate coastal infrastructure developments are among the top ten global threats to coral reefs.

Compared with other parts of the world, in Australia and Western Australia we are lucky that our coral reefs are still in relatively good condition. While this may be so now, the pressures and threats to these reefs are increasing and appropriate and effective management is needed to protect them from human activities that can adversely affect their vigor and hence their resilience to natural stressors such as cyclones. We also need frameworks to manage and limit the cumulative human-induced losses of reefs to levels that will ensure ecosystem integrity is maintained in the long-term.

There is particular concern for inshore reefs which are most at risk from human activities such as port and harbour and other maritime infrastructure developments. Dredging and ocean disposal of dredge spoil is an emerging issue in WA and is of particular concern because of its potential to generate spatially widespread and persistent environmental effects.

The Environmental Protection Authority assesses development proposals that involve large scale dredging and coastal infrastructure in locations which support coral communities. Unfortunately, the ecological information on which to predict and assess the environmental implications and to develop effective management strategies for these proposals is often limited.

Scientific information that will help us to meet our global responsibility to ensure that we take local action to protect Western Australia's coral reefs from the effects of human pressures is therefore welcomed. To this end, I hope that this publication will contribute to a strategic information base to assist proponents predict and manage the potential impacts of their development proposals and amongst other things, inform the Environmental Protection Authority's environmental impact assessment of those proposals.

W. J. Cox

Dr Walter Cox

CHAIRMAN

ENVIRONMENTAL PROTECTION AUTHORITY

Scleractinian Corals of the Dampier Port and inner Mermaid Sound: species list, community composition and distributional data.

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Abstract

Surveys of coral reef habitats in the Dampier Port and inner Mermaid Sound recorded 120 species of scleractinian coral from 43 genera. This is a relatively high species count for an inshore reef system, and represents a significant contribution to the region's marine biodiversity.

Five coral assemblages were distinguished on the basis of proportional differences in generic composition. Four of the assemblages are dominated by a single genus each: *Acropora* (particularly plate *Acropora*), *Porites*, *Pavona*, and *Turbinaria* respectively. The fifth assemblage is mixed, consisting predominantly of faviids, *Turbinaria*, and a variety of other scleractinian corals.

The distribution of the 5 assemblages appears to be correlated with prevailing water quality, wave energy and tidal current strength. Reefs adjacent to the Dampier townsite and along the western coast of the Burrup Peninsula, where the 2004 dredging programs were undertaken, consist predominantly of the mixed coral assemblage. These reefs are exposed to substantial natural turbidity and sedimentation for much of the year, and appear reasonably resistant to it. The *Pavona*, *Porites* and plate *Acropora* assemblages are likely to be more susceptible to dredging-related turbidity and sedimentation.

Information on the composition and distribution of coral assemblages within Mermaid Sound may provide a useful background for future monitoring and environmental management of the marine areas of inshore Dampier Harbour. In particular, it might be used to select spoil dumping sites for minimal impact, to ensure reference sites can be located in similar assemblages to impact sites, and to define ecological management areas for estimates of cumulative habitat loss.

Keywords: coral, diversity, communities

Introduction

Scleractinian coral communities of the Dampier Archipelago have been studied relatively intensively as a consequence of the industrial developments in Dampier's marine and coastal environment. Prior to the present study, a cumulative total of 229 scleractinian coral species from 57 genera had been recorded in the Dampier Archipelago—more than any other Western Australian location except Ashmore Reef (Marsh 1978; Veron and Marsh 1988; Veron 1993; Griffith 2004). Studies in coral community ecology have been carried out by Simpson (1988) and monitoring of coral health has been undertaken by several private sector companies (eg. LDM 2000; Blakeway this volume). Taxonomic surveys and ecological research have concentrated mainly on the outer Archipelago, whereas the monitoring studies have concentrated on the western coast of the Burrup Peninsula, where much of the industrial development has taken place.

The lack of detailed taxonomic information on the corals of the Inner Harbour has resulted in environmental protection and management efforts relying on the assumption that the species present, and their ecology, are similar to offshore habitats. This has hampered the Western Australian Environmental Protection Authority's (EPA's) ability to provide a robust scientific basis to the assessment of likely conservation significance of impacts associated with two major dredging programs carried out in the Harbour in 2004 (Stoddart & Anstee this volume). A better understanding of species distribution within potentially impacted areas could greatly enhance assessments regarding likely changes in coral distribution within ecological management units under the (WAEPA) Benthic Primary Producer Habitat policy (EPA 2004 ; MScience 2004; URS 2004).

Methods

Site Locations

Coral community composition and distribution were assessed quantitatively using data collected in the 2004 coral health monitoring programme undertaken by Mscience Pty Ltd for Hamersley Iron and the Dampier Port Authority (Stoddart et al. this volume). Selection of sites for the monitoring programme attempted to cover all substantial coral populations adjacent to dredging and spoil disposal operations, plus a range of reference sites not at risk. In total, 19 sites were selected for monitoring in that program, spanning an onshore to offshore gradient along the east and west coasts of Mermaid Sound (Table 1; Fig. 1). Several other sites within the Harbour were surveyed as single time samples to provide additional data on relative abundance of corals and for taxonomic lists. Substrates at all sampling locations were rock or boulder slopes partially to completely covered by corals, and bordered on the seaward side by mixed carbonate/terrigenous sediments. Maximum water depths at all sites were within the range of 6 to 10 m below mean lower low water (MLLW).

Sampling Methods

Coral communities of the Dampier Harbour exist most commonly as linear features fringing shorelines of islands or the Burrup Peninsula. In general they occur in a narrow depth range of 2 to 6m below MLLW. Within the coral health monitoring sites, quantitative assessment of the cover of living coral was undertaken every fortnight between November 2003 and December 2004. Digital photographs, each covering approximately 50 cm x 70 cm of the substrate taken at 1 m intervals along transects were used to provide a precise assessment of percent cover (see Stoddart et al. this volume). Cover of hard corals was subdivided into categories of *Acropora*, *Porites*, *Pavona*, Faviid, *Turbinaria*, "other" (including all hard corals not included in the former groups and hydrozoans such as *Millepora*). Non-coral categories included "other fauna" (including soft corals), "flora" and "abiotic" (including sand and rubble). Three additional sites (see Fig. 1 for locations) that were not part of the monitoring program—Outer Tidepole Island (OTPW), East Intercourse Island (EIIE) and an unnamed reef inside Tidepole Island (TCIR) - were surveyed in late 2004 on a single occasion using the same assessment method.

A species list for the area was compiled by surveying sites on SCUBA and either identifying species in-situ or, if they could not be positively identified, collecting fragments for later identification. Two initial surveys of approximately one hour duration were made at the Service Wharf Reef (SWR, Fig. 1) in addition to opportunistic surveys of up to 20 minutes at many of the coral health sites. Coral samples were bleached in chlorine then washed in fresh water and dried. A comprehensive collection of photographs was made of in-situ corals at all survey sites and also of the bleached skeletal samples. Identification was undertaken by comparison to specimens in the WA Museum collection and by reference to taxonomic literature including Griffith (2004), Veron (2000), Veron and Marsh (1988), Veron and Wallace (1984), Veron and Pichon (1976, 1980, 1982) and Veron et al. (1977).

To determine how well our coral species list represented the known coral community of the Dampier Archipelago, it was compared to species lists and distributional data from three previous quantitative surveys (Marsh 1978; Fisk 1991; Griffith 2004) and to a regional species list for the North West Shelf (Veron & Marsh 1988).

Statistical analyses

Coral composition - cluster analysis and non-metric multidimensional scaling

Relationships between the proportional composition of coral groups at each site were investigated using cluster analysis on the coral component of the transect data. Using the relative abundance of each group, a Euclidean distance matrix was generated for cluster analysis using Ward's minimum variance method (as reviewed in Legendre and Legendre 1998). A matrix dendrogram was used to aggregate coral sites into groups based on similarity in coral composition.

Following the recommendations of Legendre and Legendre (1998), the validity of the site groupings delimited by cluster analysis were checked using a second independent method—non-metric multidimensional scaling (NMDS). Kruskal's NMDS (Cox and Cox 2001) was performed using 10 random starts. Convergence on a 2-dimensional solution occurred after 8 iterations. Convergence was determined by performing Procrustes analysis with each iteration to the previous until it became non-significant, as outlined by Minchin (1987). NMDS dimension 1 and 2 scores for both sites and coral genus were plotted and overlaid with the site groupings produced by cluster analysis.

Co-occurrence of coral genera - cluster analysis of Pearson's correlation coefficient.

The distribution of coral genera between sites was compared using Ward's minium variance cluster analysis. The analysis was essentially the same as that used to group sites based on their proportions of coral genera, but instead grouped coral genera in terms of similarities in their distribution among sites. Pearson's correlation coefficients were calculated for each genus pair as a validation test.

Spatial analysis – Mantels test with permutation.

Following the method of Legendre and Legendre (1998), a comparison of linear geographic distance between sites and the similarity of genus composition was conducted using a Mantels test with permutation. Two Euclidian dissimilarity matrices were generated; one comparing coral composition of site pairs and one comparing linear distances between site pairs. The Mantel statistic was calculated as the correlation between two dissimilarity matrices. Its significance was calculated by permuting rows and columns of the dissimilarity matrix 5000 times and calculating "r" and "p" statistics (this is analogous to the procedure used for significance calculations in ANOSIM, see Clarke and Warwick 1994).

Results

Species list

We recorded a total of 120 scleractinian coral species from 43 genera (App.1) from the Dampier Harbour coral communities. Only one of these species, *Acropora kosurini*, has not been recorded previously in the Dampier Archipelago, despite having a large distribution range encompassing the entire North West Shelf (Veron 2000). An additional six coral species were not included in this species total as they could not be identified reliably. They are listed in Table 1 as *Acropora* sp. A, B, C, *Platygyra* sp. A, *Echinopora* sp. A and *Porites* sp. A.

Our species list appears to be a broadly representative subset of all species known to occur in the Dampier Archipelago. In terms of species richness within genera, our list (Fig. 2A) shows similar patterns to those of previous studies (Fig. 2B, compiled from data in Griffith 2004; Fisk 1991; LSC 1991; Veron and Marsh 1988). *Acropora* is the most speciose genus in our data set, contributing 21 species (17.5% of the species total). *Favia* is the second most speciose, contributing 9 species (7.5%). The genera *Favites*, *Goniastrea*, *Platygyra* and *Turbinaria* are each represented by 7 species (5.8% each), and the genera *Montipora*, *Goniopora*, *Porites* and *Psammocora* are each represented by 4 species (3.3% each). An additional three genera are represented by three species each, eight genera by two species each and 21 genera by one species each.

Figure 1. Location of monitoring sites in Mermaid Sound.

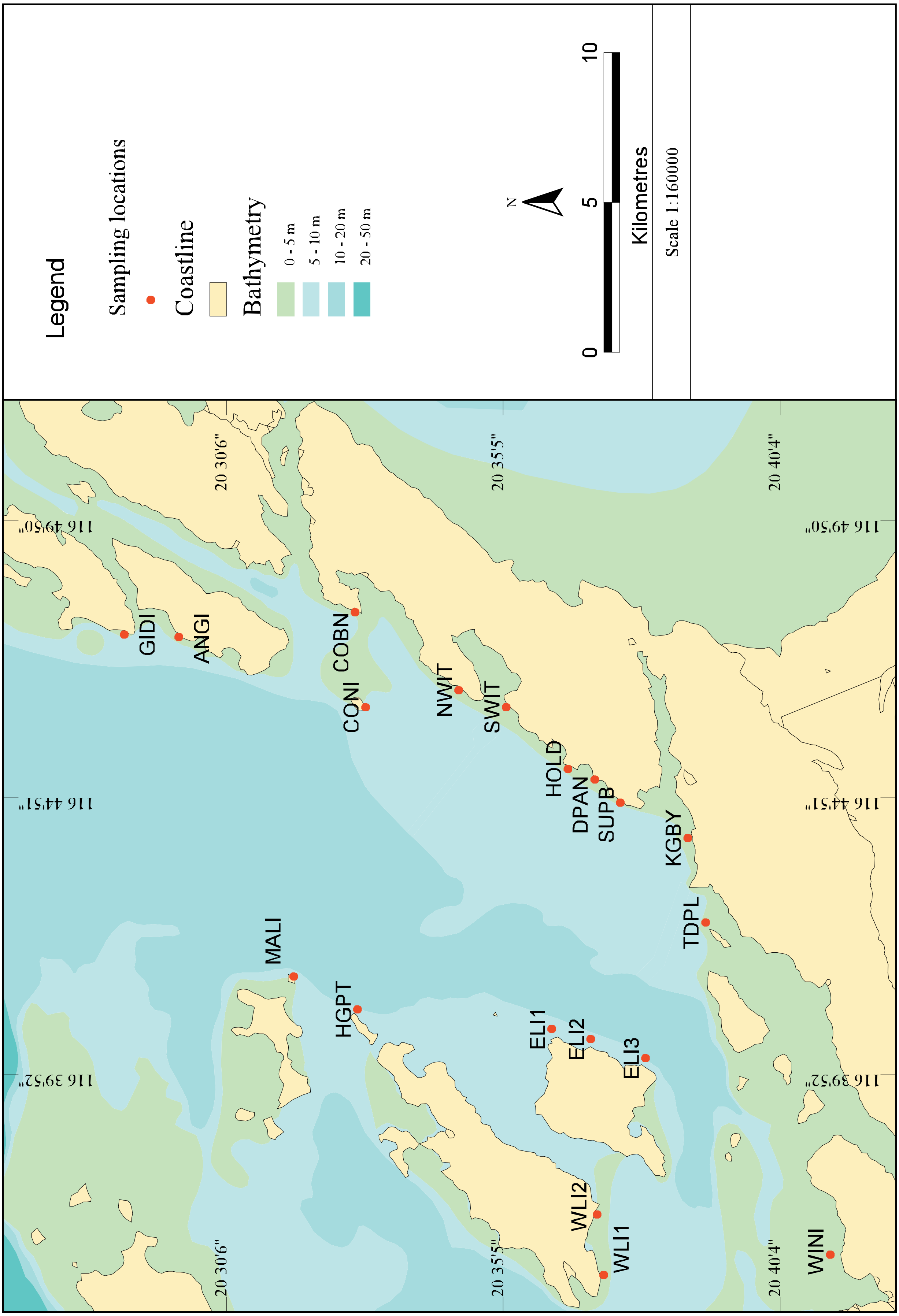


Figure 2: (a) Number of species in each coral genus recorded during this quantitative survey (b) Number of species in each coral genus recorded during pervious qantitative surveys (Marsh 1978; Fisk 1991;Griffith 2004)of the Dampier ArchipelagoHistograms # of species by genus.

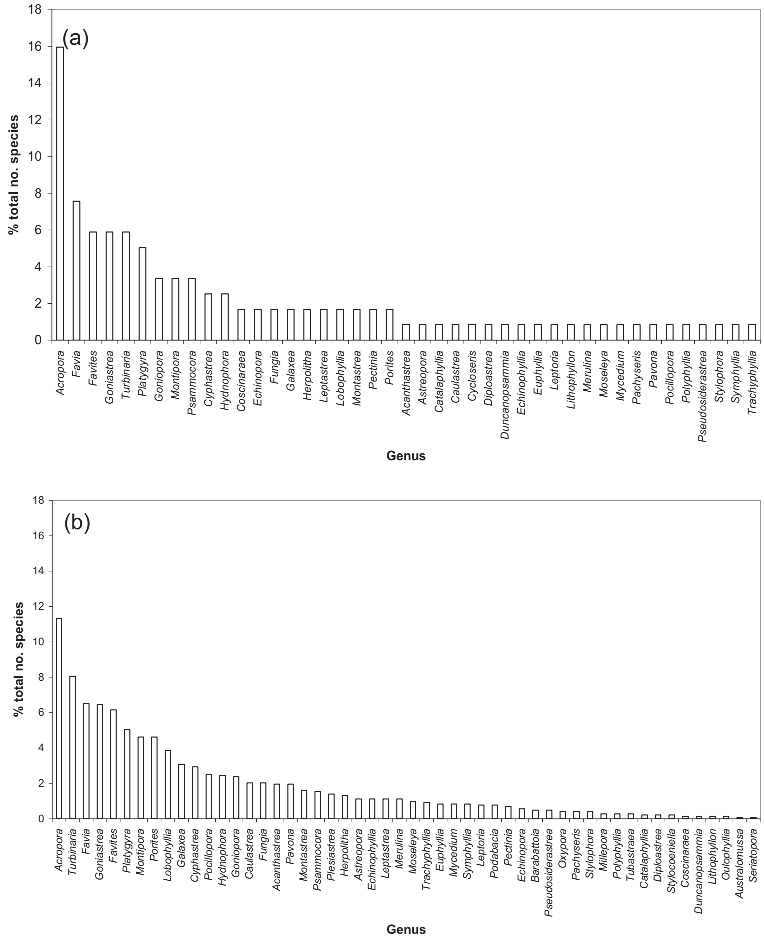


Figure 3: Dendrogram depicting sites grouped according to their similarity in coral genera composition

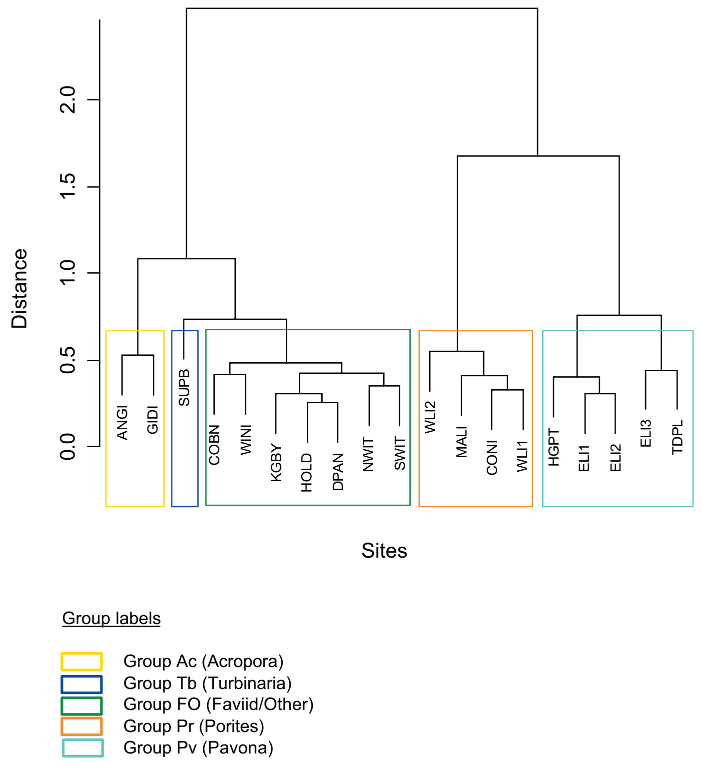


Figure 4: Non-metric multidimensional scaling plot depicting the six groups distinguished by cluster analysis.

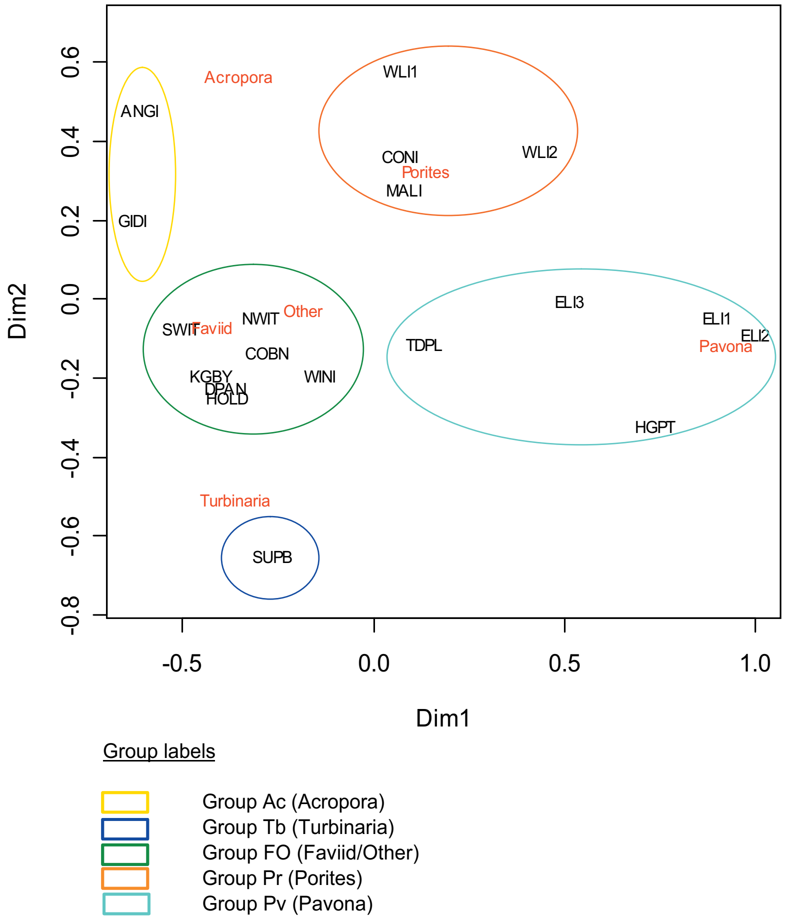
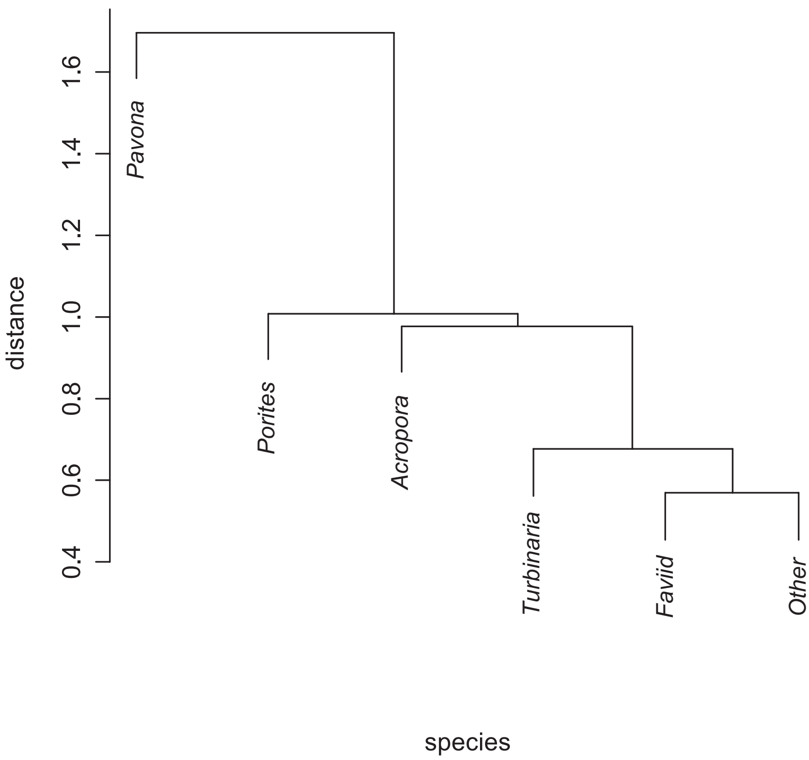


Figure 5: Dendrogram depicting coral taxa grouped according to similarity in distribution.



Although we did not record the abundance of individual species in our study, our qualitative impression was that the majority of species occurred at a relatively low frequency. This is supported by a comparison of our species list against the species abundance records from earlier quantitative studies—almost half of the species on our list occurred at only 10% or less of the cumulative 63 sites surveyed by Marsh (1978), Fisk (1991) and Griffith (2004). Although uncommon in Dampier, most of these species are common elsewhere in the Indo-Pacific (based on species data in Veron 2000). The few species that are uncommon both in Dampier and the wider Indo-Pacific include *Acropora kosurini*, *Acropora dendrum*, *Favia veroni*, *Duncanopsammia axifuga*, *Turbinaria conspicua* and *Favia maxima*. Not surprisingly, corals that are common at Dampier are also common in the wider Indo-Pacific (based on species data in Veron 2000). Thus it seems that Dampier has a fairly cosmopolitan coral community, with relatively few rare species. This statement should be qualified, in that some of the species we were unable to identify could be rare species, and there could also be misidentifications in our species list.

Community composition

Cluster analysis divided the 19 sites into five groups (Fig. 3). Although the process of selecting groups from a dendrogram is always somewhat arbitrary, this particular grouping is supported by the NMDS results (Fig. 4). The NMDS plot indicates that four of the five groups are characterised by the predominance of a single genus. Dominant genera include *Acropora* (particularly plate *Acropora*) for the group consisting of sites ANGI and GIDI, *Porites* for the group including sites WLI1, WLI2, MALI and CONI, *Pavona* for the HGPT, ELI1, ELI2, ELI3 and TDPL group, and *Turbinaria* for SUPB (Fig. 5). The fifth group of sites, comprising COBN, WINI, KGBY, HOLD, DPAN, NWIT and SWIT, is characterised by an abundance of faviids, *Turbinaria* and 'other corals'. The most abundant taxa in the latter category include *Lobophyllia*, *Echinophyllia*, *Goniopora* and *Caulastrea* inshore, and *Millepora* further offshore.

Co-occurrence of coral genera

The distributions of the six major taxonomic groups appear to be relatively independent; although all six groups occur at most sites, none co-occur in consistent proportions (Fig. 6). The closest relationship is between Faviids and 'other corals' (Fig. 5), which are distributed relatively evenly across most sites. The distributions of all other taxa are skewed toward one or more sites. The most extreme example is the genus *Pavona*, which constitutes 50% to 70% of the coral cover along the eastern shores of East and West Lewis Islands, but less than 10% at most other sites.

Spatial analysis

Spatial analysis indicates that physical distance between sites is not a good predictor of their similarity in generic composition (correlation coefficient $r = 0.05722$, significance $p = 0.254$). Despite the lack of a linear relationship, some of the variation in coral assemblages is clearly spatially associated. However, this is more likely to reflect the spatial pattern of habitat occurrence than limited dispersal patterns. For example, the *Pavona*-dominated assemblage consistently occurs on east-facing shores and the mixed coral assemblage on northwest-facing shores (Fig. 6).

Discussion

Coral species and assemblages

Many scleractinian coral species in the Dampier Archipelago are found over the entire inshore-to-offshore range of habitats, but a few species are restricted to turbid inshore reefs and others are restricted to outer reefs (Semeniuk et al. 1982; Marsh 1978, Paling 1986, Simpson 1988). Not surprisingly, our species list shows a bias toward the inshore species and includes species from all five of the predominantly inshore genera defined by Marsh (1978)—*Duncanopsammia*, *Caulastrea*, *Trachyphyllia*, *Moselya* and *Euphyllia*, but neither of the two offshore species—*Pocillopora eydouxi* and *Pavona minuta*. The relatively low proportion of *Montipora* species in our data set may be a further indication of a predominantly inshore fauna.

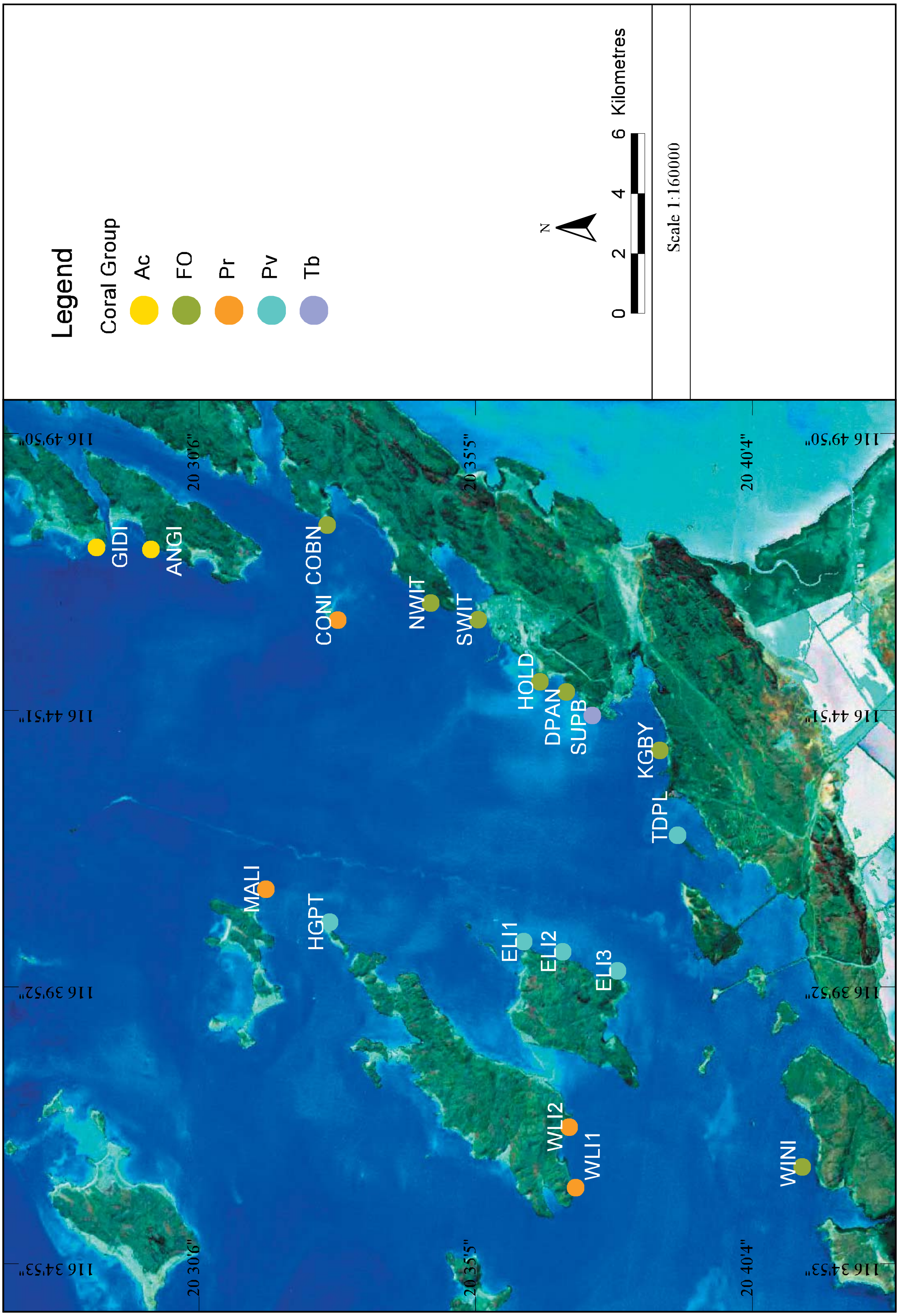
Previous authors on coral diversity within the Dampier area have suggested that inshore diversity will be much lower than that reported offshore (Veron & Marsh 1988, Simpson 1988). Given that context, the species diversity recorded in our surveys is surprisingly high, comprising just over half the total species pool recorded from the entire Dampier Archipelago. It is likely that additional species will be encountered at inshore sites with more exhaustive sampling. Clearly the inshore reefs of the Dampier Harbour and inner Mermaid Sound are species-rich, and are likely to be an important component of the inner shelf ecosystem.

Several authors have examined the relationship between corals and habitats within Mermaid Sound. Simpson and Grey (1989) found that corals were most abundant on upper seaward reef slopes of the islands and less abundant along the mainland coastline. Semeniuk et al. (1982) described differences between the coral communities of sloping rocky shores, where coral colonies reach a large size and are closely packed, or on flat limestone pavements, where coral colonies are small and interspersed with other sessile invertebrates. They also depicted coral depth zonation at several Burrup Peninsula sites and their diagram of Angel Island in particular (Fig. 8A of Semeniuk et al. [1982]) shows a consistent feature of several outer Mermaid Sound sites; the occurrence on the lower reef slopes of *Turbinaria* and other sediment-tolerant species which are generally more characteristic of shallow inshore sites.

Despite these indications of habitat-specific patterns in coral distribution, quantitative analyses have in the past failed to detect distinct associations between species assemblages and habitats within the Dampier Archipelago (Paling 1986; Griffith 2004). Those analyses relied solely on species presence or absence in comparing sites. When sites are compared using proportional composition of coral taxa, as suggested by Griffith (2004), clear associations between coral assemblages and habitats become apparent (eg. Fig. 3, 4 and 6).

Factors controlling these relationships can be inferred but cannot be ascertained with any certainty. Habitat-

Figure 6: Map showing proportion of each coral genus recorded at monitoring sites and total coral cover



specific variations in recruitment, growth or mortality could all potentially be responsible for the observed coral distribution. Perhaps the simplest explanation is that virtually all species in the regional pool can recruit to and survive in any of the available habitats (thus accounting for the lack of detectable pattern in the presence/absence data) but only a relatively small subset of species will thrive and become abundant in any particular habitat.

Based on our underwater observations through the year, and the water quality data (see Stoddart & Anstee this volume) coral assemblage distribution appears to be correlated with three environmental factors: wave exposure, turbidity (i.e. natural 'background' turbidity) and tidal currents. The *Acropora*-dominated assemblage (Fig. 7a) occurs in relatively exposed sites with low to moderate turbidity, the *Porites*-dominated assemblage (Fig. 7d) occurs at sites with good current flow and low to moderate turbidity, the *Pavona*-dominated assemblage (Fig. 7e) is found in relatively sheltered sites with moderate turbidity, and the *Turbinaria*-dominated assemblage (Fig. 7b) occurs in highly turbid environments.

The mixed faviid/*Turbinaria*/"other" coral assemblage (Fig. 7c) can perhaps be considered the default coral community of the inner Mermaid Sound. This assemblage is widespread in nearshore environments with intermediate levels of exposure, turbidity and current flow. There are several other influences on coral distribution in the Dampier Archipelago that are not well understood, including cyclones and floods. However, the apparent relationships outlined above suggest that coral distribution is determined more by prevailing conditions than by brief high-impact events.

The most striking feature of the inner Mermaid Sound coral community is the abundance of *Pavona decussata* along the eastern shores of East and West Lewis Islands. *P. decussata* colonies occur at these sites as dome-shaped clumps up to approximately 3m in diameter and can cover up to 75% of some reef areas. Veron (2000) notes that *P. decussata* is divisible into semi-distinct taxonomic units. This subspecies-level variation is evident at the East and West Lewis Island sites as noticeable differences in the scale of the characteristic cellular skeletal structure (Fig. 7f).

In addition to scleractinian corals, several other groups of sessile benthic organisms were recorded on the transects. The most common were soft corals of the genera *Sarcophyton*, *Lobophytum*, *Sinularia*, and *Nephthea*, hydrozoans of the genus *Millepora*, a variety of sponges, and at least two species of zoanthid. We did not undertake analyses of these individual taxa, but qualitatively it was apparent that soft corals tend to occur in the *Porites* and *Pavona* assemblages, *Millepora* tends to occur in the *Porites* assemblage (but was also abundant in the mixed assemblage at COBN), sponges tend to be more abundant in deeper environments and zoanthids occur on boulders in shallow environments on both sides of Mermaid Sound.

Management implications

The descriptions presented above of the differentiation and distribution of coral assemblages within Mermaid Sound may provide a useful background for future monitoring and environmental management of the marine areas of inshore Dampier Harbour. In particular, where impact monitoring is proposed, appropriate reference sites can now be located within similar community types and better ecological information is available to define meaningful ecological management areas for estimates of cumulative habitat loss (e.g. EPA 2004).

In terms of predicting the effects of impacts from dredging and infrastructure development, we estimate the 5 assemblages to rank, from lowest to highest susceptibility as *Turbinaria*, mixed (faviid/*Turbinaria*/other), *Pavona*, *Porites*, and *Acropora*. Most of the industrial development around Dampier has occurred near the townsite and on the west coast of the Burrup Peninsula, where coral reefs consist predominantly of the mixed coral assemblage (Fig. 5). These reefs receive substantial levels of natural turbidity and suspended sediment for much of the year, and appear reasonably resistant to it. The natural resilience of this assemblage has probably buffered it to a significant extent against the additional turbidity and sedimentation associated with dredging, construction and ship movements.

While some reefs located close to shiploading facilities, dredge sites and spoil grounds have suffered reductions in coral abundance and diversity (MScience 2004, Blakeway this volume), most of the mixed assemblage reefs in the Dampier Port and Mermaid Sound appear to be in reasonably good condition. The *Pavona*, *Porites* and *Acropora*-dominated assemblages also appear to be in good condition at present, but are likely to be more sensitive to turbidity and sedimentation than the *Turbinaria* and mixed coral assemblages. Consequently it should not be assumed that they will respond in the same way to dredging impacts as more resistant assemblages, and extra caution should be taken if dredging activities are planned near these assemblages.

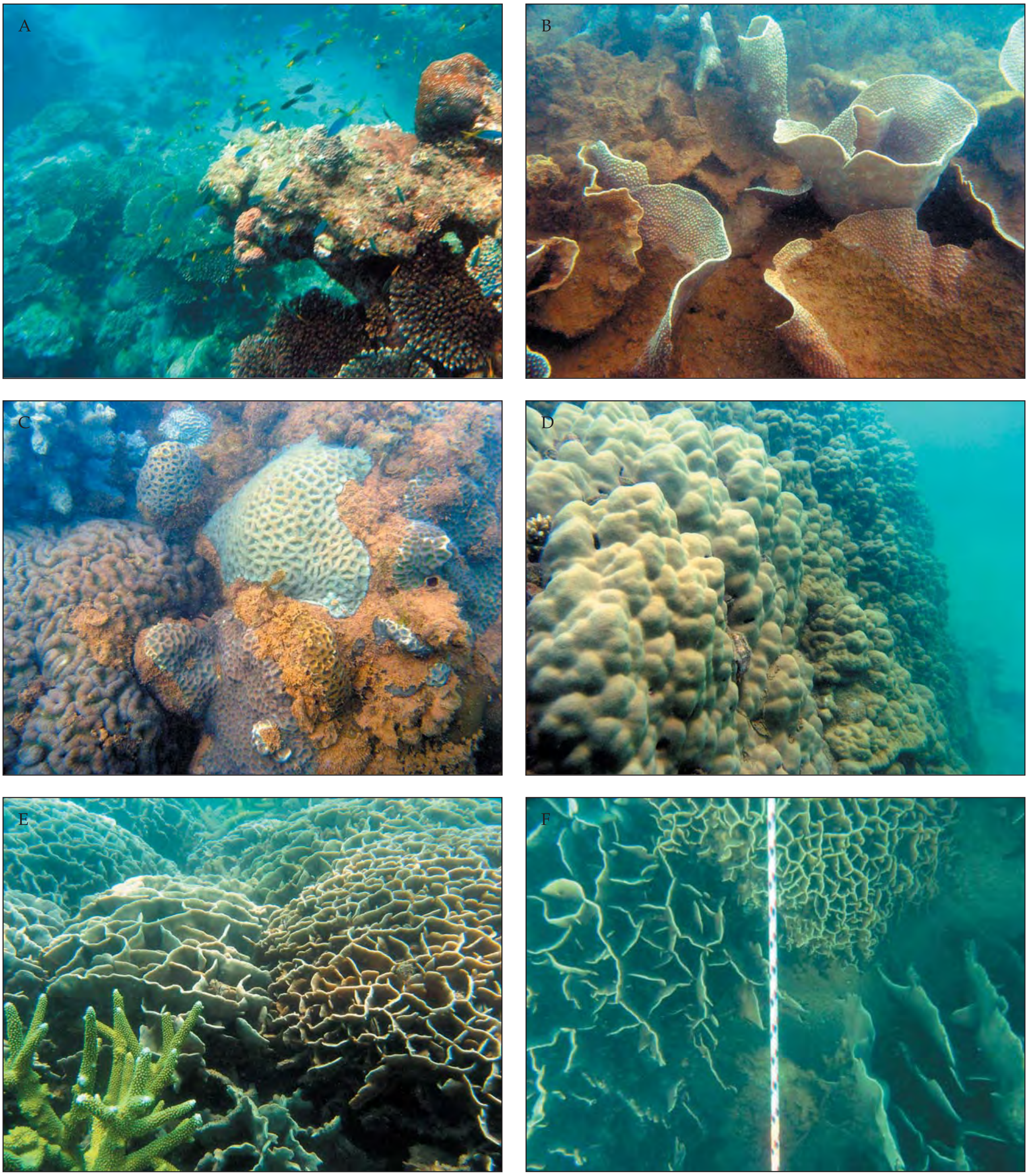


Figure 7:

A) Acropora-dominated assemblage, Angel Island. This image shows the steep drop-off at the edge of the reef flat.

B) Turbinaria-dominated assemblage, Supply Base.

C) Faviid/other coral assemblage, King Bay.

D) Porites-dominated assemblage, Conzinc Island. Porites colonies at this site are up to 3m in diameter.

E) Pavona-dominated assemblage, East Lewis Island 1. Branching Acropora lower left.

F) Morphological differences between adjacent Pavona decussata colonies (site ELI2)

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Appendix 1. Scleractinian coral species identified from Dampier Harbour.

Family Acroporidae
Acropora austera
Acropora clathrata
Acropora cytherea
Acropora dendrum
Acropora florida
Acropora formosa
Acropora gemmifera
Acropora glauca
Acropora humilis
Acropora hyacinthus
Acropora kosurini
Acropora latistella
Acropora microphthalma
Acropora millepora
Acropora nobilis
Acropora robusta
Acropora samoensis
Acropora solitaryensis
Acropora tenuis
Acropora verweyi
Acropora yongei
Acropora sp. A
Acropora sp. B
Acropora sp. C
Astreopora myriophthalma
Montipora danae
Montipora hispida
Montipora informis
Montipora turgescens

Family Agariciidae
Pachyseris rugosa
Pavona decussata

Family Caryophylliidae
Catalaphyllia jardinei
Euphyllia ancora

Family Dendrophylliidae
Duncanopsammia axifuga
Tubastraea diaphana
Turbinaria biffrons
Turbinaria conspicua
Turbinaria frondens
Turbinaria mesenterina
Turbinaria peltata
Turbinaria reniformis

Family Faviidae
Caulastrea tumida
Cyphastrea chalcidium
Cyphastrea microphthalma
Cyphastrea serailia
Diploastrea heliopora
Echinopora gemmacae
Echinopora lamellosa
Echinopora sp. A
Favia favus
Favia marshae
Favia matthaii
Favia maxima
Favia pallida
Favia rotumana
Favia speciosa
Favia stelligera
Favia veroni
Favites abdita
Favites chinensis
Favites complanata
Favites flexuosa
Favites halicora
Favites pentagona
Favites russelli
Goniastrea aspera
Goniastrea australensis
Goniastrea edwardsi
Goniastrea favulus
Goniastrea palauensis
Goniastrea pectinata
Goniastrea retiformis
Leptastrea pruinosa
Leptastrea transversa
Leptoria phrygia
Montastrea curta
Montastrea valenciennesi
Moseleya latistellata
Platygyra daedalea
Platygyra lamellina
Platygyra pini
Platygyra ryukyuensis
Platygyra sinensis
Platygyra verweyi
Platygyra acuta
Platygyra sp. A

Family Fungidae
Fungia cyclolites
Fungia fungites
Fungia repanda
Herpolitha limax
Lithophyllon undulatum
Podabacia crustacea
Polyphyllia talpina

Family Meruliniidae
Hydnophora exesa
Hydnophora microconos
Hydnophora pilosa
Merulina ampliata

Family Mussidae
Acanthastrea echinata
Lobophyllia corymbosa
Lobophyllia hemprichii
Symphyllia agaricia

Family Oculinidae
Galaxea astreata
Galaxea fascicularis

Family Pectiniidae
Echinophyllia aspera
Mycedium elephantotus
Pectinia lactuca
Pectinia paeonia

Family Pocilloporidae
Pocillopora damicornis
Stylophora pistillata

Family Poritidae
Goniopora djiboutiensis
Goniopora pendulus
Goniopora stutchburyi
Goniopora tenuidens
Porites cylindrica
Porites lutea
Porites lobata
Porites solida
Porites sp. A

Family Siderastreidae
Pseudosiderastrea tayami
Coscinarea columna
Coscinarea exesa
Psammocora contigua
Psammocora digitata
Psammocora profundacella
Psammocora superficialis

Family Trachyphylliidae
Trachyphyllia geoffroyi

Water quality, plume modelling and tracking before and during dredging in Mermaid Sound, Dampier, Western Australia.

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Abstract

In areas with relatively unpolluted bottom sediments, such as at Dampier Harbour, the primary impacts of dredging on water quality will be the elevation of turbidity levels in the water column and the associated transport of sediments onto benthic communities. During the environmental impact assessment process for two recent Dampier dredging projects, considerable emphasis was placed on the likely extent to which turbidity and sedimentation would be elevated at various spatial scales.

A water quality monitoring program established to coincide with the dredging program assessed turbidity, suspended sediments and other parameters every three days. The monitoring program was designed to assess the degree to which water quality at sites over sensitive coral communities was impacted by dredging and to test the predictions of a numerical model of the effects of dredging on sediment suspension and transport.

Monitoring results showed that despite having a significant overall relationship, turbidity and total suspended solids (TSS) measures often showed dissimilar patterns of variation over time at the same site and TSS explained only a small portion of variation in turbidity levels. This was assumed to result from different spectral qualities of sediments in suspension at differing times and at various locations.

Average turbidity levels were clearly elevated at monitoring sites within 1-2km distance of dredging or spoil disposal sites ($\bar{x}$ ~ 4 NTU) when compared to Reference sites outside this radius ($\bar{x}$ ~1 NTU). Although some Reference sites did show occasional episodes of elevated turbidity unrelated to dredging or disposal impacts, these were rarely greater than 50% of the peak episodes of turbidity at impact sites.

Significant elevation of TSS levels was restricted to sites within 1km of dredging locations ($\bar{x}$ ~ 10 mg/L vs $\bar{x}$ ~ 4 mg/L at Reference sites). Consistent with a priori model assumptions, elevated TSS levels seem due primarily to the propeller wash generated from the trailer hopper suction dredge while manoeuvring during uplift of dredge material.

While turbidity was high at many sites, the one site where coral mortality occurred was characterised by high TSS, suggesting that the cause of coral mortality during these two dredging programs was one or more acute episodes of sedimentation. In this case, suspended sediment concentrations from bottom samples which exceeded 60 mg/L in waters within a few hundred metres of coral appeared to be the sole cause of mortality.

Dissolved oxygen and pH varied little between sites and times and there was no evidence that these parameters were influenced by dredging effects.

The sediment suspension and transport model was highly conservative and actual effects were more localised and ephemeral than predicted. The principal cause of this difference appears to be that sediments settle out of the water column much faster than the model had predicted.

Keywords: sediment, turbidity, modelling, dredging

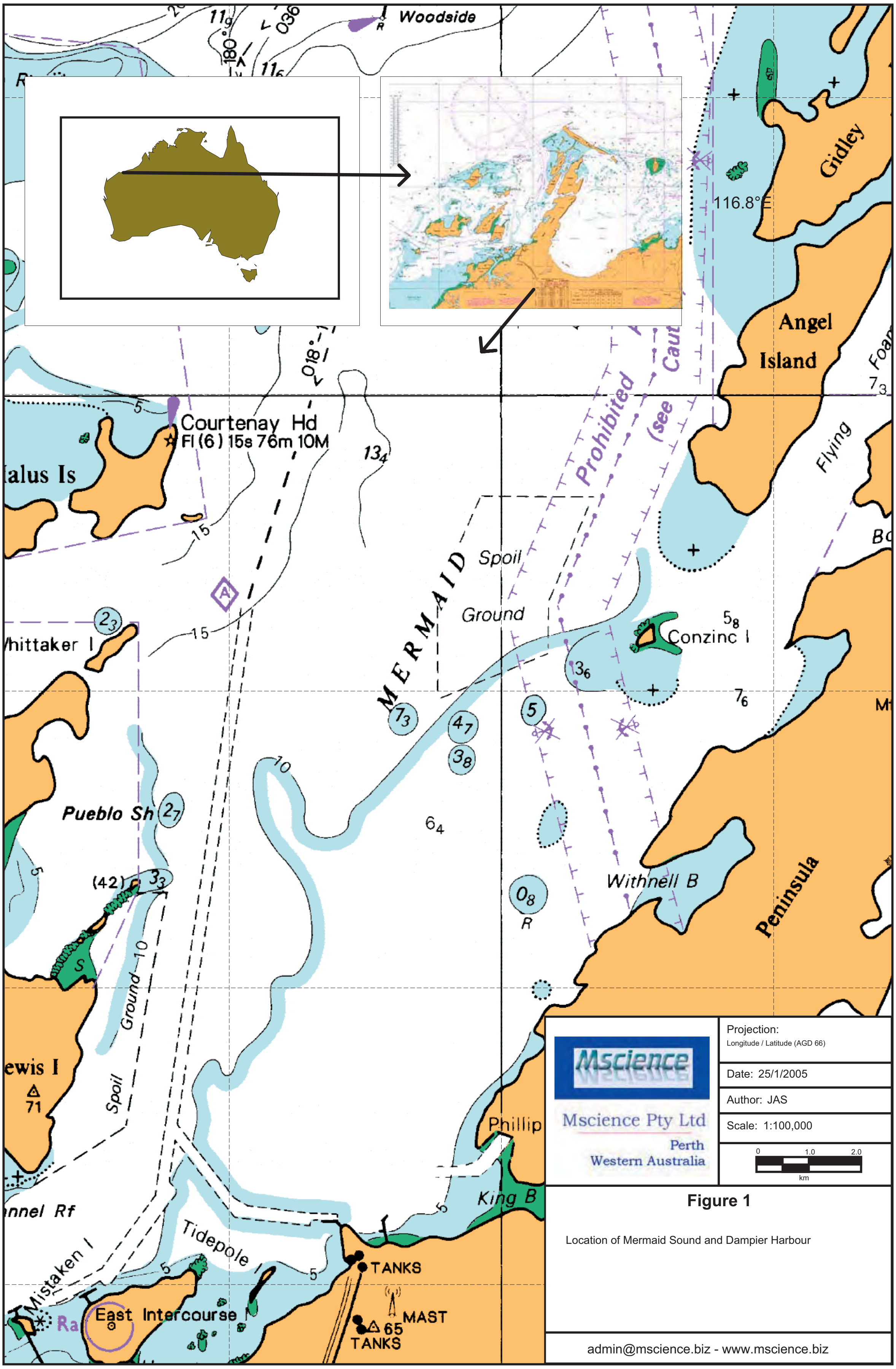
Introduction

Environmental effects during dredging stem from both the removal of habitat in the area being dredged and the effects of suspension of sediments during the uplift and deposition of the dredged material. While the former may be profound and permanent, the latter effect is always spread over a much greater area. An understanding of the distribution and intensity of mobilised sediments is essential to adequately manage the likely extent of impacts of dredging, whether as an input to environmental impact assessment (EIA) or in the design of monitoring programs to measure actual impacts.

Mobilisation of sediments into the water column during dredging will occur from the excavation of sediments at the bed, the loading process, transport and dumping of sediments at spoil grounds, or return water from land disposal, and by disturbance of the bottom by the dredge hull and propellers. The relative importance of each of these sources depends critically on the methods and machinery used for dredging (IADC/CEDA 1998).

Other important considerations in predicting the behaviour of suspended sediments will include the physical composition of sediments in and around the area targeted for dredging, tides, current movements and weather patterns during operations and the bathymetry around uplift and deposition areas. In addition to controlling the fate of sediments mobilised during dredging and deposition, these factors will also control the re-mobilisation of sediments from spoil grounds post dumping and prior to eventual consolidation.

Figure 1. Location of Mermaid Sound in the Pilbara Region of Western Australia.



Environmental impacts of sediments will be derived from physical smothering or abrasion of benthos, or changes to water chemistry such as the addition of nutrients or toxicants, the depletion of oxygen, or the alteration of pH.

This paper describes a study of water quality undertaken in conjunction with two large dredging and disposal programs in the Port of Dampier, Western Australia.

Mermaid Sound

Mermaid Sound is a large northern-facing embayment situated on the coastline of Western Australia's Pilbara Region (Fig. 1). The majority of the Sound represents a drowned coastal environment of plains surrounded by higher ridges which have now become islands or the Burrup Peninsula (Semeniuk et al. 1982). Depths range from 5-20 m with some shallower shoals. Much of the bottom consists of soft sediments (silts and clays), the bulk of which have terrestrial origins, either from before the rise in sea level or from subsequent riverine and surface flows entering the embayment.

Mermaid Sound sits almost entirely within the limits of the Port of Dampier. The Port services export facilities at a number of wharves for iron ore, liquid natural gas, salt and general cargo. It is amongst the largest tonnage ports in Australia with annual movements of cargo well over 80Mt and has a strong and growing industrial usage around much of the southern and south-eastern shoreline. Originally created in the 1960s to support the export of iron ore, the port environment has been subject to a long history of dredging operations and contains a number of active and historic spoil disposal grounds. Most dredging has been of a capital nature and true maintenance dredging to clear sediment influx has been rare.

Within the relatively shallow embayment, significant wave and current action can occur and cause substantial re-suspension of sediments leading to elevated turbidity throughout the water column (Forde 1985). Waves and currents in this area are generated primarily by strong winds (Pearce et al. 2003), the most extreme of which occur during tropical cyclones. Throughout the summer periods, tropical cyclone effects and strong westerly winds frequently cause re-suspension of sediments, as do easterly winds in winter. As weather intensity increases, sediment re-suspension extends to deeper parts of the Sound (Forde 1985) and the direction of winds affects the amount of fetch over various bottom types. The large bulk container and gas transport vessels transiting the port daily also create bottom eddies that lift sediments into the water column. Thus while Mermaid Sound is frequently subject to high turbidity, the location of turbid plumes is complex and varies widely and on short time scales.

Within Mermaid Sound, there exist a number of areas with well developed coral communities (Blakeway & Radford this volume). While previous descriptions of corals in the Dampier area have been focussed on offshore areas of the Dampier Archipelago (Marsh 1978, Simpson 1988, Griffith 2004), it is clear that there are also populations of significance in the nearshore. Susceptibility of corals to adverse impacts of sedimentation has been widely documented (eg Rogers 1990) and environmental assessments of previous dredging programs in the Harbour have nominated coral communities as the local biota most likely to be at risk from dredging impacts on water quality.

The Dredging Program

Dredging undertaken in 2004 in Mermaid Sound included two distinct operations (Fig. 2). The first component comprised dredging to create a new berth pocket and channel for the Dampier Port Authority's Bulk Liquids Berth Project, while the second formed part of Hamersley Iron Pty Limited's Dampier Port Upgrade to extend berth pockets and approaches to their Parker Point facility. These projects are hereafter referred to respectively as the DPA and HI components.

The DPA component:

Technical details of the DPA dredging component can be found in DPA (2004). In summary, the project removed 4.1Mm3 of spoil comprised of 3.8Mm3 of soft marine sediments – mostly silt and clays with some fine sand and over 0.2Mm3 of coarser materials such as gravel and cobble.

Dredges: DPA used two dredges to complete this component.: The *Cornelius Zanen*, a trailer suction hopper dredge, 132m in length with a laden draft of 8.8m for a hopper of 8,000m3 capacity, and the *Storken*, a 37 m long backhoe dredge with a bucket capacity of 3.5-5m3.

Dredging commenced on 8 January 2004 and was completed by 20 May 2004 with all spoil disposed at the Northern Grounds.

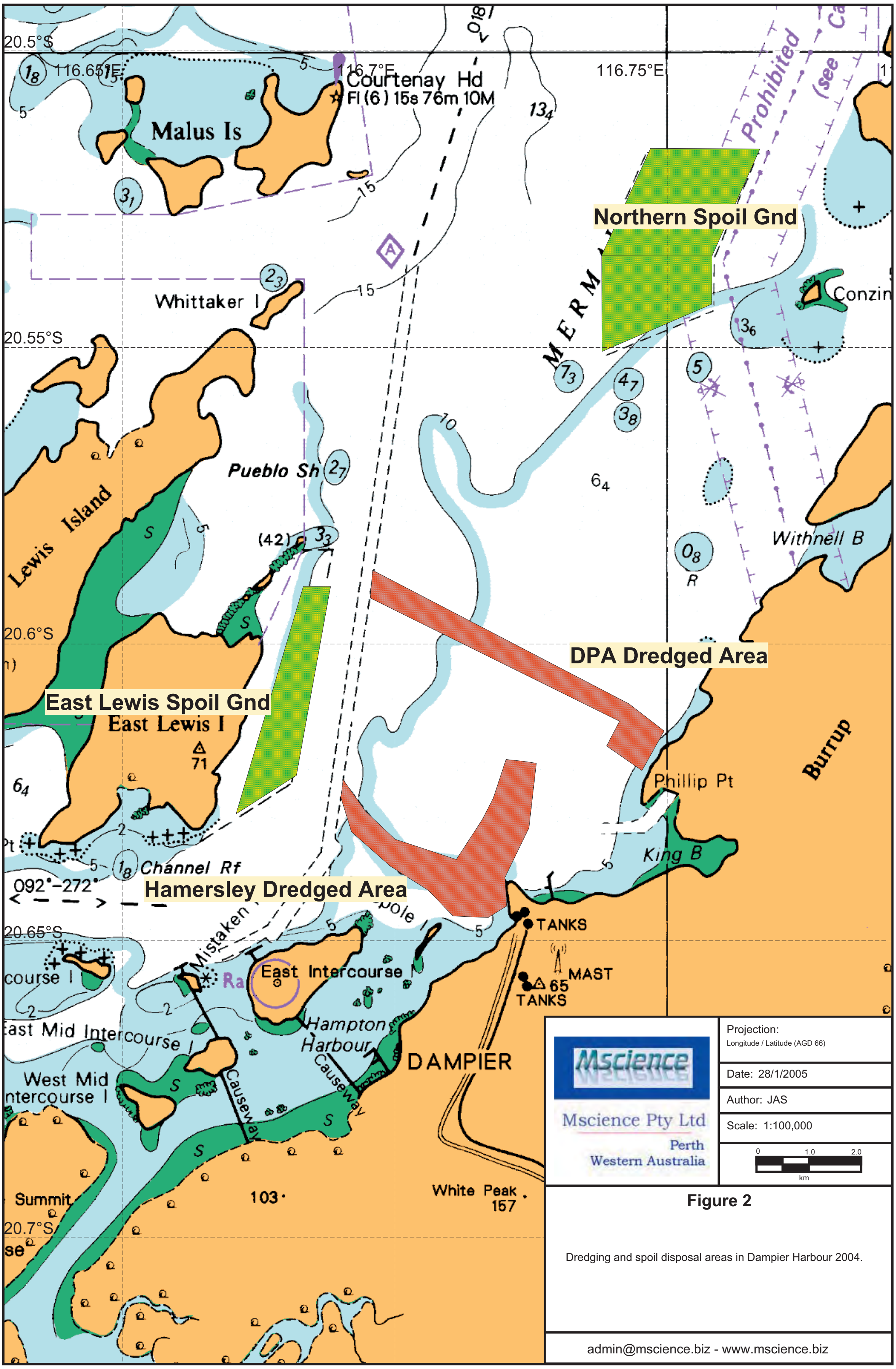
The Hamersley (HI) component

Hamersley dredging operations involved the construction of extended channels, approaches and berth pockets around the Parker Point wharf facility (Fig. 2). Technical details of the program can be found in SKM (2004).

Dredges: Hamersley used 3 dredge types:

- The *Cornelius Zanen*: a trailer suction hopper dredge which operated between the 8th of May and 25th of June 2004. In total the Cornelius Zanen removed approximately 2.1 Mm3 of material. 1.8 Mm3 was disposed of at the East Lewis Island Spoil ground and 0.3Mm3 to the Northern Spoil ground.
- The *HAM218*: a cutter suction dredge, operated from the 2nd of June to the 31st of August and from the 27th of September to the 23rd of October 2004. A total of 1Mm3 was dredged and disposed to landfill in an enclosed area directly east of Parker Point.
- The *Obscured By Clouds*. An excavator dredge, operated prior to the commencement of the main dredging contract and removed chain, buoys and other shipping material from the dredging zone.

Figure 2. Dredging and disposal sites in Dampier Harbour in 2004.



Sediment levels in waters adjacent to the landfill area were elevated from sediment loads in return water and seawall construction activities also occurring at that time. Due to perceived impacts on water quality at the adjacent King Bay monitoring site a management program was commenced in October which deployed sediment curtains around the outflows. Observer records (surface and diver) suggested that these controls were effective and that the major effects on water quality from these operations were confined to 27 Sept – 5 Oct and 18-23 October.

Description of sediments dredged.

Sediment sampling and analysis programs have been undertaken at several locations and on several occasions from the early 1990s to the present. Due to a lack of riverine input and a low level of industrial activity dealing with toxicants around the Harbour shoreline , Dampier sediments are rarely found to be contaminated (MScience 2004). The most commonly occurring contaminant is the antifoulant tributyltin (TBT), which is usually found in berth pockets at concentrations above the National Ocean Disposal Guidelines for Dredged Material (EA 2002). Around the Hamersley wharves and drainage points for surface runoff, Fe levels and some trace metals associated with iron ore are elevated. Previous testing of these sediments (controlling for Fe levels) has shown that toxicity is extremely low at even the highest levels found around these sites (Tsvetnenko & Black 2001). Elsewhere throughout the inner harbour a metals fraction associated with fine clays (as indicated by Al levels) controls abundance of a suite of metals (MScience 2004).

The Models

During the assessment of these dredging projects by the Western Australian Environmental Protection Authority in 2003, there was no clear agreement on the likely spatial extent of sedimentation anticipated on corals (EPA 2003 a&b). To assist in predicting where impacts might occur and monitoring be required, both dredging proponents commissioned modelling exercises to predict the levels and extent of suspended sediments in the water column likely to eventuate from dredging, disposal and subsequent re-suspension from spoil grounds.

The model of sediment transport developed for the DPA program considered that the major sources of sedimentation would be propeller wash at the dredging site and dumping at the disposal site (GEMS 2003). In line with the precautionary principle, where there was uncertainty in model parameters, conservative values were chosen such that the model would tend to overestimate the extent and magnitude of impact. The model predictions were aligned to the dredging schedule current at the time, which was December to March.

Model predictions included the evolution of bottom sediment load through the period and monthly averages of turbidity in the water column throughout the Sound. It predicted a build up of deposited sediments in the immediate vicinity of the dredging area and spoil ground from the settlement of the larger (> 75µm) sediments. Sediment loads were expected to be high at the HOLD and DPAN sites, with SUPB relatively unaffected (Fig. 3) – largely due to a postulated predominantly northerly drift.

Finer sediment fractions were assumed to remain suspended for longer periods and lead to a steady increase in turbidity which would spread widely throughout the Sound. After approximately 3 months of dredging, the model predicted that a widespread plume would have developed over much of the Sound with sites along the Burrup subjected to around 10mg/L TSS or 3-4 times background levels (GEMS 2003, Fig 6.6). Around the dredging site, SUPB was still predicted to be less impacted than DPAN or HOLD, principally due to the northerly flows caused by predominant summer south-westerlies.

The sediment transport model developed for the HI dredging (GEMS 2004) also used propeller wash and sediment dumping as the primary sources of sediment. It modeled dredging over the period May – June.

The model for the HI dredging predicted that the evolution of plumes would not reflect steady accumulation of turbidity across the Sound, but would be more variable in time and more spatially limited.

A one-day study of water column sediment directly around dredging operations (Damara 2004) validated the GEMS model assumption that propeller wash was the major source of resuspension. Levels of resuspension were highly dependent on the under keel clearance and on the particle size distribution of sediments.

The Study

While the models of sediment suspension and transport were based on the best available information, it was recognised that their predictions were subject to considerable uncertainty. To provide a test of the validity of model predictions and a history of water quality around sites established as at risk of impact from sedimentation, a water quality monitoring program was put in place to accompany other environmental monitoring during the dredging operations.

Monitoring included a 3 day cycle of water quality testing and 6 day cycle of aerial photography over the life of dredging. A pre-dredging baseline monitoring program was not conducted due to the exogenous effects of seasonal variation in water quality and potential for significant short term water quality impacts from other sources in this busy harbour.

Although the predictive models presented data on suspended sediments as depth-averaged values, the actual monitoring program was designed to detect any stratification of effects over the depth profile and collected surface and bottom water samples. From an impacts perspective, bottom levels will be most relevant for sedimentation on corals, while surface values will relate better to light attenuation and the visual detection of plumes. Forde (1985) confirms that, in common with most waters, suspended sediments at Dampier are generally more elevated at the bottom than at the surface.

Methods

Site Locations

The water quality monitoring program for the Mermaid Sound dredging projects incorporated 19 monitoring locations throughout the Dampier Archipelago. The two dredging programs used some common sites and some different to cover the range of locations potentially at risk of altered water quality. The names, designation and locations of each of the monitoring sites are given below in Table 1 and shown in Fig. 3.

Table 1. List of monitoring sites used by both programs.

Site	Function	Program
Angel Island (ANGI)	Reference (Near)	DPA/HI
Conzinc Bay North (COBN)	Impact	DPA/HI
Conzinc Island (CONI)	Impact	DPA/HI
Dampier Wharf North (DPAN)	Impact	DPA
East Lewis Island 1 (ELI1)	Impact	HI
East Lewis Island 2 (ELI2)	Impact	HI
East Lewis Island 3 (ELI3)	Impact	HI
Gidley Island (GIDI)	Reference (Near)	DPA/HI
High Point (HGPT)	Reference (Far)	DPA/HI
Holden Point (HOLD)	Impact	DPA
King Bay (KGBY)	Impact	HI
Malus Island (MALI)	Reference (Far)	DPA/HI
North Withnell (NWIT)	Reference (Near)	DPA/HI
South Withnell (SWIT)	Reference (Near)	DPA/HI
Supply Base (SUPB)	Impact	DPA
Tidepole Island (TDPL)	Impact	HI
West Intercourse Island (WINI)	Reference (Far)	DPA/HI
West Lewis Island 1 (WLI1)	Reference (Far)	DPA
West Lewis Island 2 (WLI2)	Reference (Far)	DPA

The monitoring sites were selected to coincide with the location of nominated monitoring sites in the benthic coral monitoring program (see Stoddart et al. this volume). They provide a uniform distribution of monitoring at varying distances and directions from the source of the sediment plume at the dredging and disposal areas. This allows for an assessment of the influence of tidal currents, wind direction and other meteorological variables on the migration of a sediment plume away from the dredging operations.

Reference sites were selected on the basis of similar bathymetry and weather aspect wherever possible and as sites outside the immediate impact of dredging. As the most similar biotic communities were usually located close to each other, there was a concern that the 'Near Reference' sites might be impacted by the same factors influencing the Impact sites. To provide confidence that a data set from unimpacted sites would be available, a second set of Reference sites was selected on the basis of being distant from any impacts. These 'Far Reference' sites were less similar to Impact sites than the 'Near Reference' set.

The DPA monitoring program commenced on 6 January 2004 and concluded on 8 May 2004. The HI program started on 8 May 2004 and concluded on 23 October 2004. These dates coincided with the period during which dredges operated.

Sampling Methods

DPA Program

Water quality sampling at 14 sites was undertaken 32 times over a period of 18 weeks from 6 January 2004 to 24 May 2004. Monitoring was conducted every three days from 6 January 2004 to 24 March 2004. Following approval from the Department of Environment, the frequency was reduced to weekly monitoring for the remainder of the sampling program. On occasions the monitoring frequency varied slightly as a result of sea conditions and safe access to the monitoring locations. Monitoring was undertaken over a full range of tidal and weather conditions.

Hamersley Iron

Monitoring of the 13 sites was undertaken at a frequency not exceeding every third day, as specified in the state environmental approval conditions. Monitoring frequency did vary, however, as a result of sea conditions and safe access to the monitoring locations. Monitoring was undertaken over a full range of tidal and weather conditions.

At each site water quality was measured at near bottom and near surface, actual depths varied depending on swell conditions at the time of sampling. In situ readings were recorded using a multi parameter probe. Parameters recorded at each site using this instrument included:

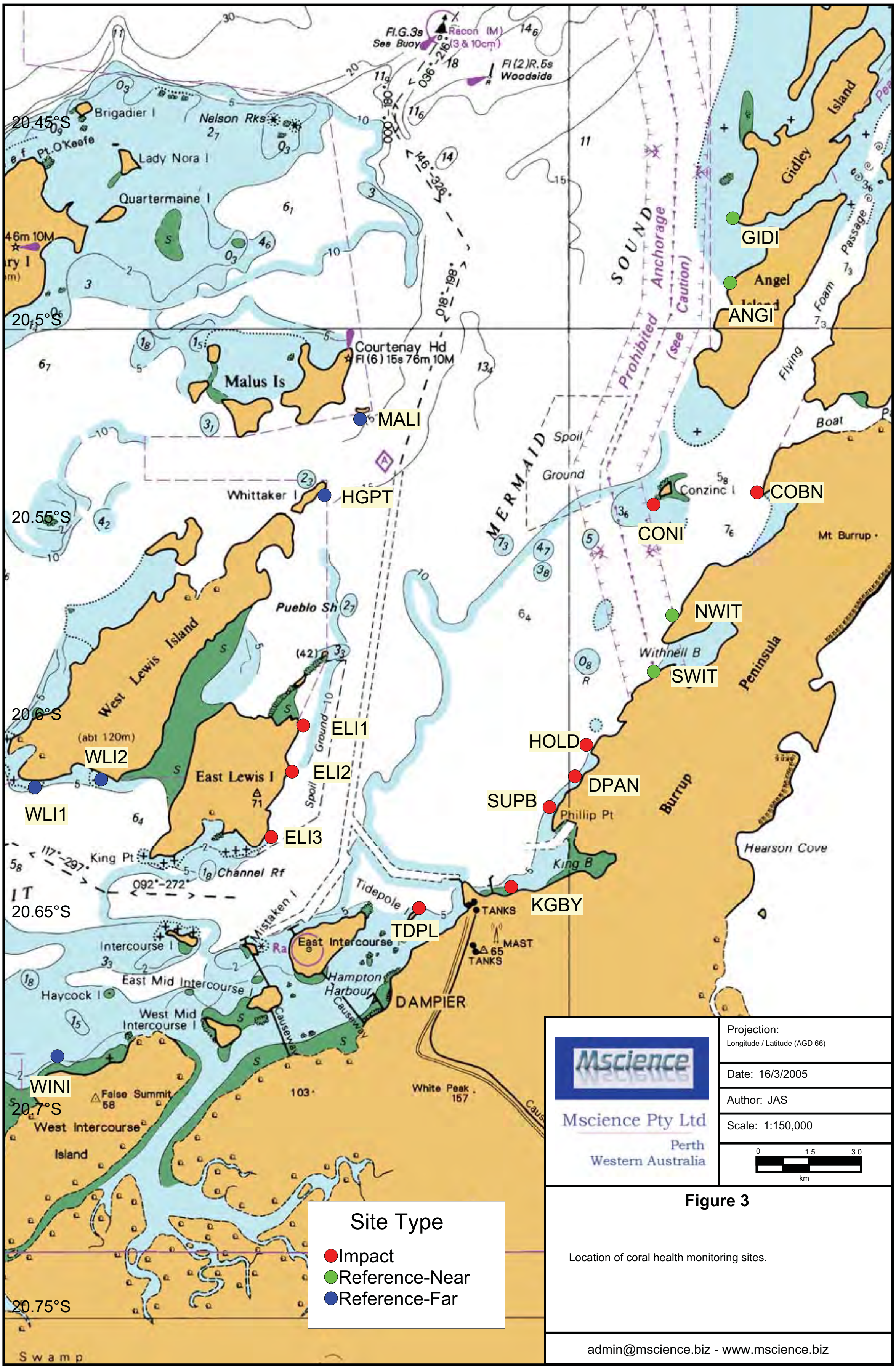
- Depth of Sample (m);
- Dissolved Oxygen (mg/L);
- pH:
- Turbidity (NTU);
- Temperature (°C); and
- Salinity (mg/L).

Throughout the duration of the dredging program three models of multi-parameter probe were used as a result of damage or failure of the instrument. The models used included:

- In situ Troll 9000;
- YSI Sonde 6820; and
- Yeo-Kal YK-611.

Each instrument in use was calibrated for each parameter on a fortnightly basis. Analysis of the data shows no significant fluctuation as a result of the transition between the three instruments.

Figure 3. Location of monitoring sites in Mermaid Sound.



Total Suspended Solids (TSS) at each monitoring site was measured by laboratory analysis of collected water samples. Two litres of water was taken from both the bottom and surface levels at each of the sites, resulting in a laboratory accuracy of +/- 1 mg/L. Samples were taken using a 12 volt pump connected to a 15mm hose weighted with 1.5kg of lead. Duplicate samples were taken during most monitoring trips.

Aerial photography

Throughout the dredging program aerial surveys of the dredging location, monitoring locations and surrounding areas were undertaken on a weekly basis. Surveys were flown on the same day as the water monitoring trip to allow for cross-referencing of visual observations and actual data. Surveys were flown over midday to reduce glare from the water surface and increase visibility of the dredge plume. All surveys were flown at a height of 770m in a Cessna 172 light aircraft.

Photographs were taken of all monitoring sites and some surrounding areas regardless of plume density. Photographs of other areas were also taken where increased turbidity was observed, whether resulting from dredging or natural occurrences. Photographs were taken at 5 or 6 mega pixels using a digital SLR camera with polarizing lens.

Dredge plumes were interpreted visually from the resulting aerial photography and classified as either high, medium or low intensity. Resulting classifications and spatial distribution of the plume were recorded for later analysis.

Results

Turbidity or total suspended solids

Overall, there was a weak but significant relationship between turbidity and TSS (Table 2) with an R-squared of 0.189 ($p<0.01$). No differences were found between relationships based on profile (Surface or Bottom samples) and the general solution for the prediction of turbidity from TSS was

$$\text{Turbidity (NTU)} = 0.4 + 0.27\ \text{TSS (mg/L)}$$

The relationship between turbidity and TSS did not improve when viewed on a site by site basis. However, it was apparent that sites with elevated turbidity produced a closer relationship than at other sites (Tables 2, 4, 6).

Table 2. Relationship between turbidity and TSS by site.

SITE	N	r-sq
ANGI	131	0.014
COBN	62	0.001
CONI	131	0.076
DPAN	66	0.461
ELI1	72	0.243
ELI2	72	0.167
ELI3	72	0.091
GIDI	132	0.003
HGPT	133	0.017
HOLD	66	0.170
KGBY	66	0.049
MALI	133	0.004
NWIT	131	0.015
SUPB	65	0.261
SWIT	124	0.000
TDPL	61	0.535
WINI	130	0.032
WLI1	57	0.006
WLI2	60	0.001

Total Suspended Solids

Concentrations of total suspended solids ranged from virtually 0 to 75 mg/L. Levels in bottom samples were generally similar to surface samples within the normal range of variation, but were more prone to occasional very high levels (Fig. 4). From examination of later graphs and comparisons of duplicate samples, the very high levels in bottom samples originate both from occasional episodes of very high sediment mobilisation from dredging or from wave surge, as well as through sampling errors when the sample inlet was very close to the substrate.

In summary, TSS for both bottom and surface samples was higher at Impact Sites than at either the Near or Far Reference sites in both surface and bottom waters (Table 3, $P<0.000$, Fig. 5). There was no obvious seasonal signal to TSS levels at any site, and values appeared to respond to immediate conditions (such as heavy swell).

Table 3. TSS statistics at impact and reference sites.

Total Suspended Sediment (mg/L)				N	Mean	Maximum	Std. Deviation
Profile	Bottom	Site type	Impact	445	6.9	75	8.67
			Near Reference	267	4.5	58	5.47
			Far Reference	264	4.5	24	4.01
	Surface	Site type	Impact	446	5.4	42	5.16
			Near Reference	263	4.0	17	3.28
			Far Reference	262	4.2	20	3.57

Figure 4. Levels of total suspended sediments from surface and bottom samples.

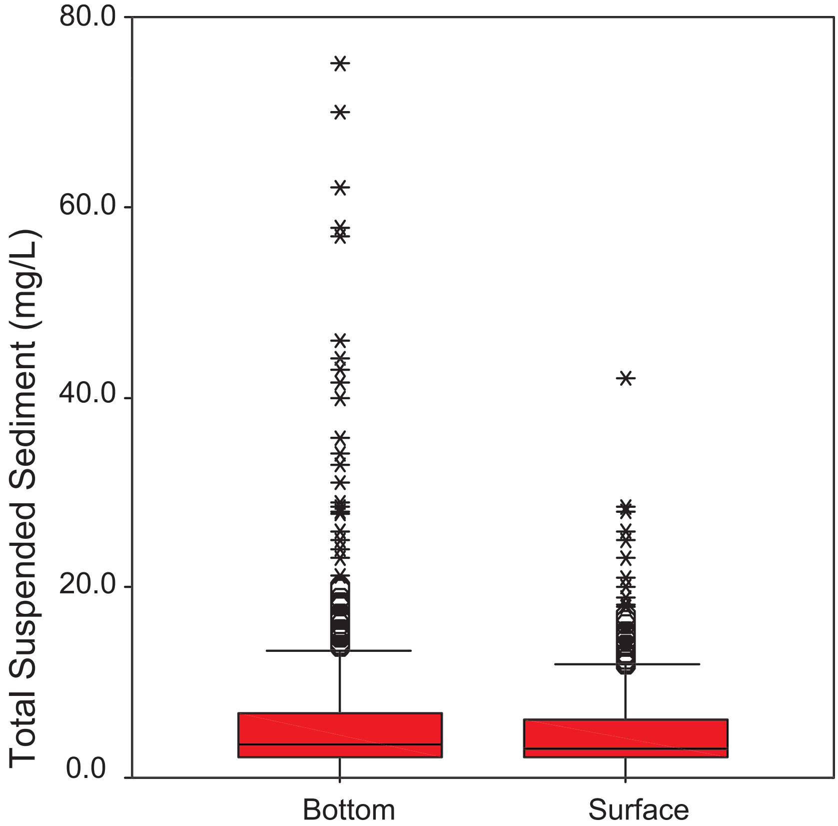


Figure 5. Comparison of TSS at impact and reference sites.

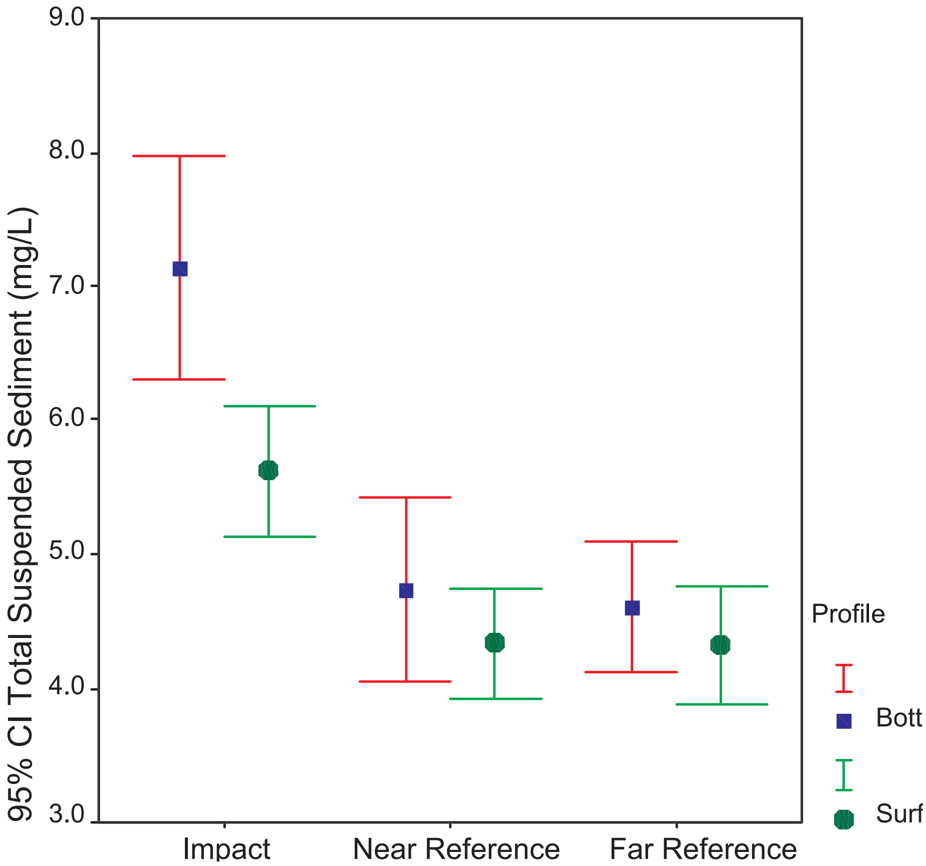


Table 4. TSS levels by site over both programs.

SITE	Surface Samples		Bottom Samples	
	Mean	Maximum	Mean	Maximum
ANGI	3.55	12	4.00	40
COBN	4.20	12	5.41	16
CONI	3.71	25	3.81	12
DPAN	7.16	28	8.65	43
ELI1	4.06	12	3.78	13
ELI2	4.50	19	3.67	12
ELI3	4.44	13	4.50	26
GIDI	4.22	17	5.03	58
HGPT	3.96	17	4.45	21
HOLD	6.34	28	9.07	57
KGBY	4.21	14	6.67	46
MALI	3.98	20	4.08	23
NWIT	4.19	15	3.99	15
SUPB	8.57	42	14.12	75
SWIT	4.06	12	4.83	28
TDPL	4.85	15	4.63	12
WINI	4.29	12	4.71	18
WLI1	4.80	18	5.42	24
WLI2	4.07	12	3.95	12

When individual sites are examined, it was clear that the greatest impact of sediment occurred at site SUPB, which was located within 200m of the DPA additional berth dredged by the trailer suction hopper dredge. Average and maximum values for both surface and bottom samples were around twice those of most other sites (Table 4, Fig. 6). Other sites that stand out as having received high sediment loadings are HOLD, DPAN and KGBY (bottom only). These sites are discussed further under the Turbidity section.

Occasional very high (>50 mg/L) TSS was recorded from the bottom samples at GIDI. This site was the most affected by swell action coming from the open ocean.

Turbidity

As for TSS, turbidity was similar between surface and bottom samples, although in this parameter the greater abundance of high outliers in bottom samples was less pronounced (Fig. 7). Turbidity ranged from close to 0 to almost 50 NTU.

For both surface and bottom samples, Impact Sites were more turbid than either Near or Far Reference sites (Table 5, Fig. 8, P<0.000). While Far Reference site means were above those of the Near Reference sites, this was not a significant difference. Examination of individual sites (Fig.s 9,10) suggests that it arises due to elevated turbidity at WINI – a site frequently noted as affected by terrestrial runoff or freshwater seepage.

Figure 6. Mean and 95% confidence intervals for TSS by site.

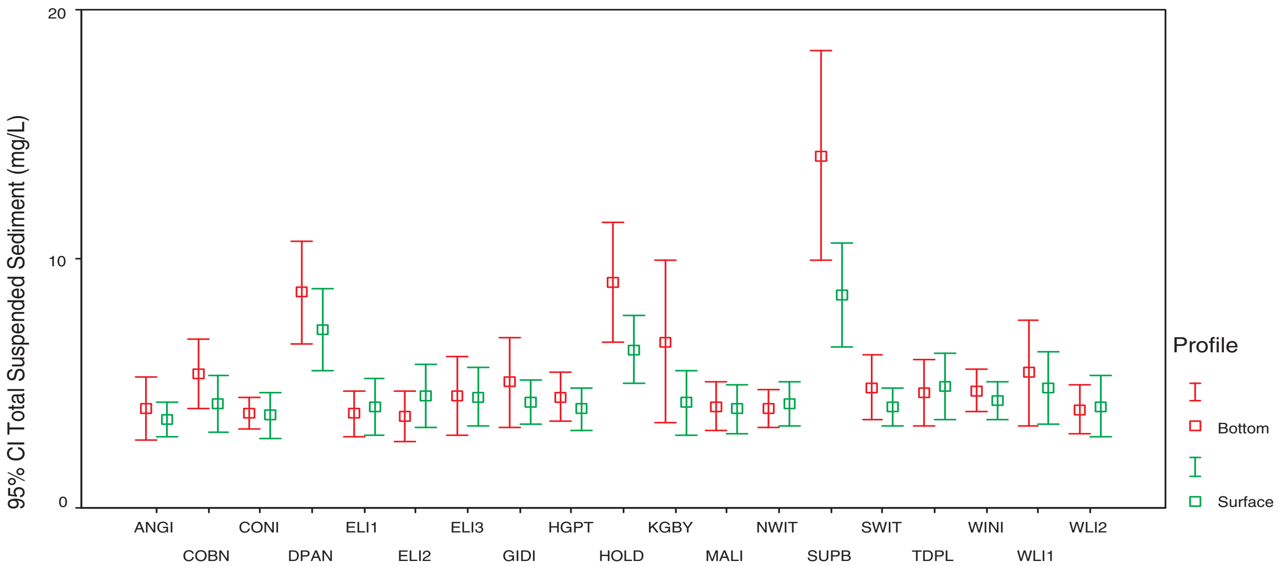


Table 5. Turbidity statistics at impact and reference sites.

Turbidity (NTU)				N	Mean	Maximum	Std. Deviation
Profile	Bottom	Site type	Impact	433	3.75	48	5.873
			Near Reference	304	0.73	7	1.021
			Far Reference	290	1.24	17	1.971
	Surface	Site type	Impact	426	2.83	37	4.042
			Near Reference	300	0.72	8	1.078
			Far Reference	286	1.03	13	1.831

Figure 7. Levels of turbidity from surface and bottom readings.

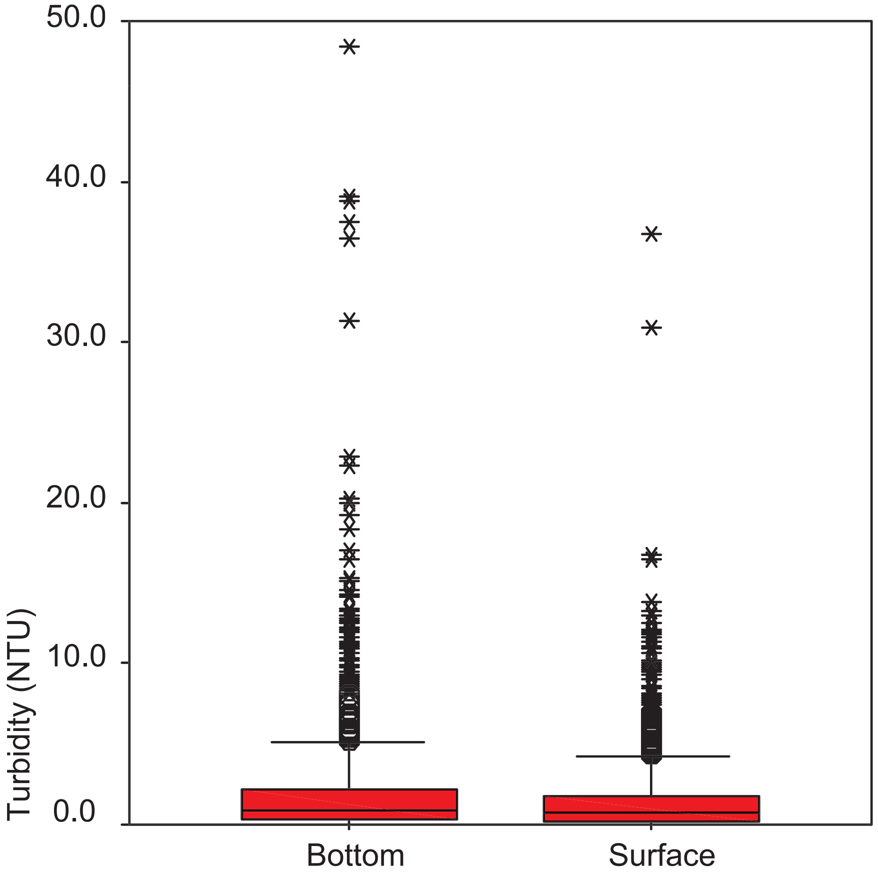
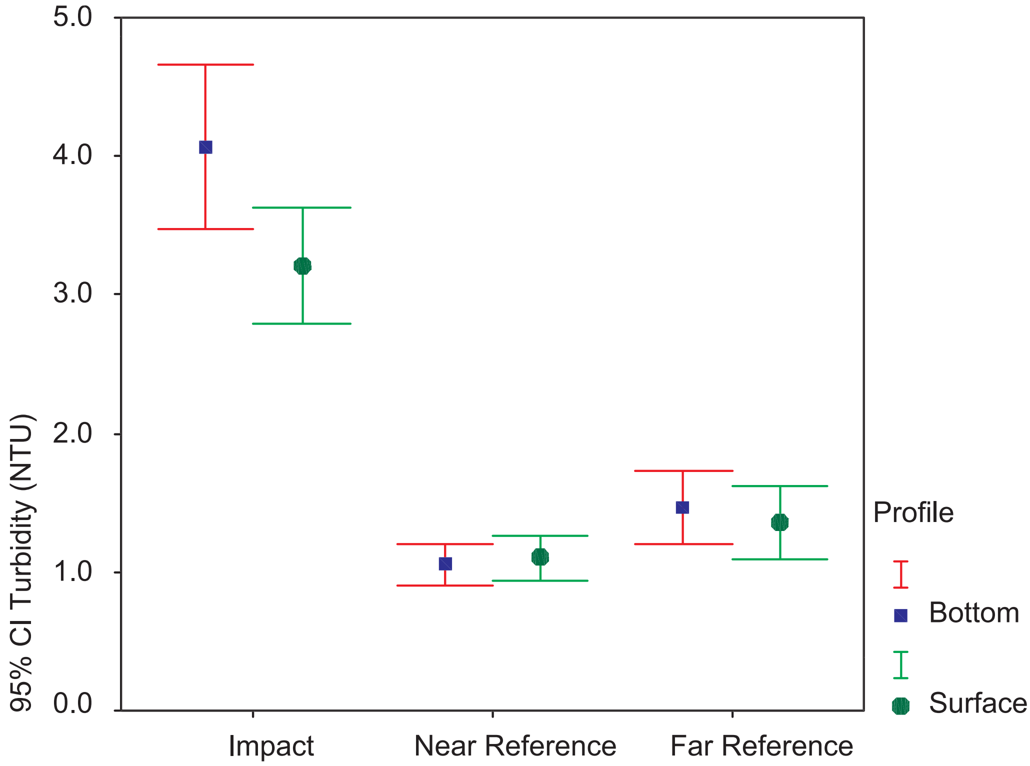


Figure 8. Comparison of turbidity at impact and reference sites.



Unlike the outcome for TSS, the clear difference between impact and Reference sites seen in Fig. 8 is indicative of elevated turbidity levels at the majority of impact sites (Table 6, Fig. 9 & 10). The exception is turbidity levels at CONI and COBN which are similar to those at Reference sites. Amongst the Reference sites, turbidity at WINI was elevated around the cyclone event and for some time after for both surface and bottom samples. This seems to have been associated with freshwater runoff and seepage at that area leading to substantial levels of microalgae in the water column for long periods at that site.

Figure 10 shows that for all sites the onset and recovery from turbidity or suspended sediment events is usually rapid and brief. The exceptionally high levels of suspended sediments at SUPB in February (Fig. 11) seem to have been the principal factor associated with coral mortality at that site.

Temperature, Dissolved Oxygen, pH and salinity

Unlike the turbidity and TSS measures, other water quality parameters showed little apparent effect of the dredging. Dissolved oxygen, pH and salinity showed no correlation with elevated levels of turbidity or TSS.

The water column around sites monitored usually showed little evidence of stratification and surface and bottom samples are similar at most times of the year (Fig. 12, 13). A notable exception is the drop in salinity in surface samples seen immediately after the intense rainfall from tropical cyclone Monty at the beginning of March (Fig. 13).

Dissolved oxygen levels (Fig. 14) were correlated with both temperature and pH (r = 0.38 for T alone and 0.5 for T and pH, both p<0.000). While pH might be expected to remain around 8.2 +/- 0.1 units for most of the year, the mid-year fluctuations seen to around 8.6 (Fig. 15) may be more than instrument error. Monitoring at King Bay 2003 by the Western Australian Water Corporation (unpublished data) shows that pH rose steadily from around 8.1 in January to 8.35 by June suggesting a consistent seasonal pattern.

Table 6. Turbidity levels (NTU) by site over both programs.

SITE	Surface Mean	Surface Maximum	Bottom Mean	Bottom Maximum
ANGI	0.40	4	0.54	7
COBN	0.57	2	1.17	6
CONI	0.59	4	0.83	11
DPAN	3.18	10	4.72	18
ELI1	3.18	17	3.53	23
ELI2	4.68	37	4.72	39
ELI3	3.16	11	3.09	12
GIDI	0.70	6	0.64	5
HGPT	0.92	11	0.88	9
HOLD	2.54	11	5.59	22
KGBY	2.91	10	2.50	7
MALI	0.73	8	0.66	3
NWIT	0.87	8	0.73	6
SUPB	4.96	31	10.91	48
SWIT	0.91	5	1.02	4
TDPL	3.95	14	4.06	13
WINI	2.02	13	2.44	17
WLI1	0.34	2	0.98	4
WLI2	0.34	2	0.90	8

Figure 9. Mean and 95% confidence interval for turbidity at all sites.

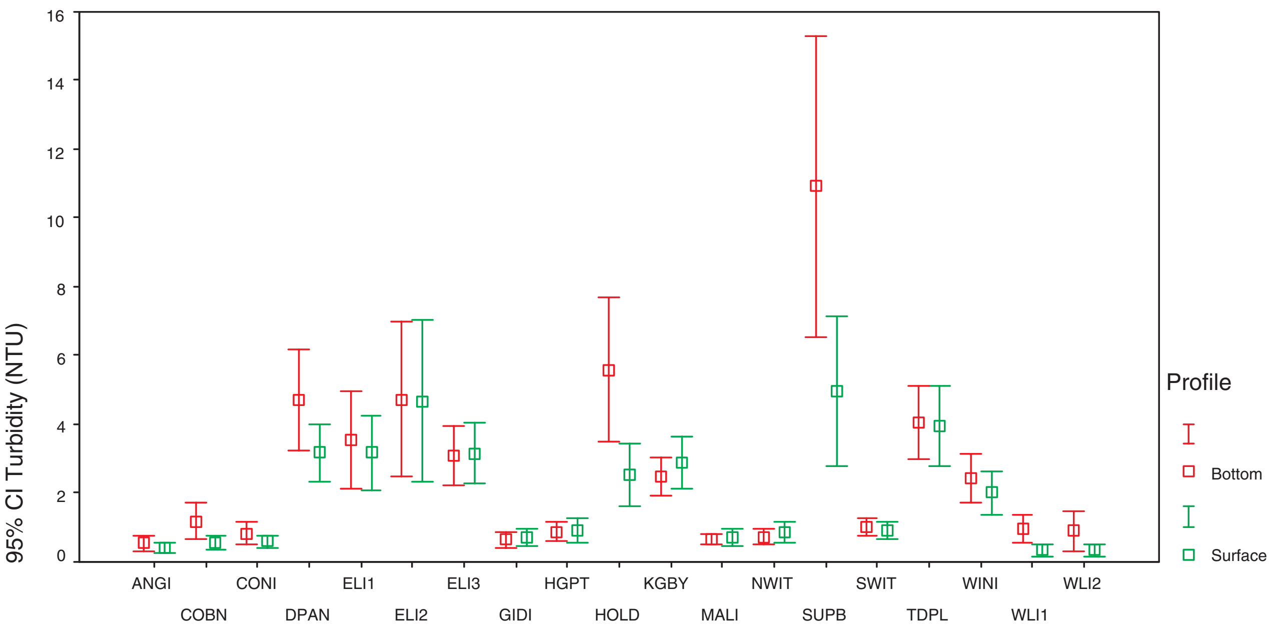
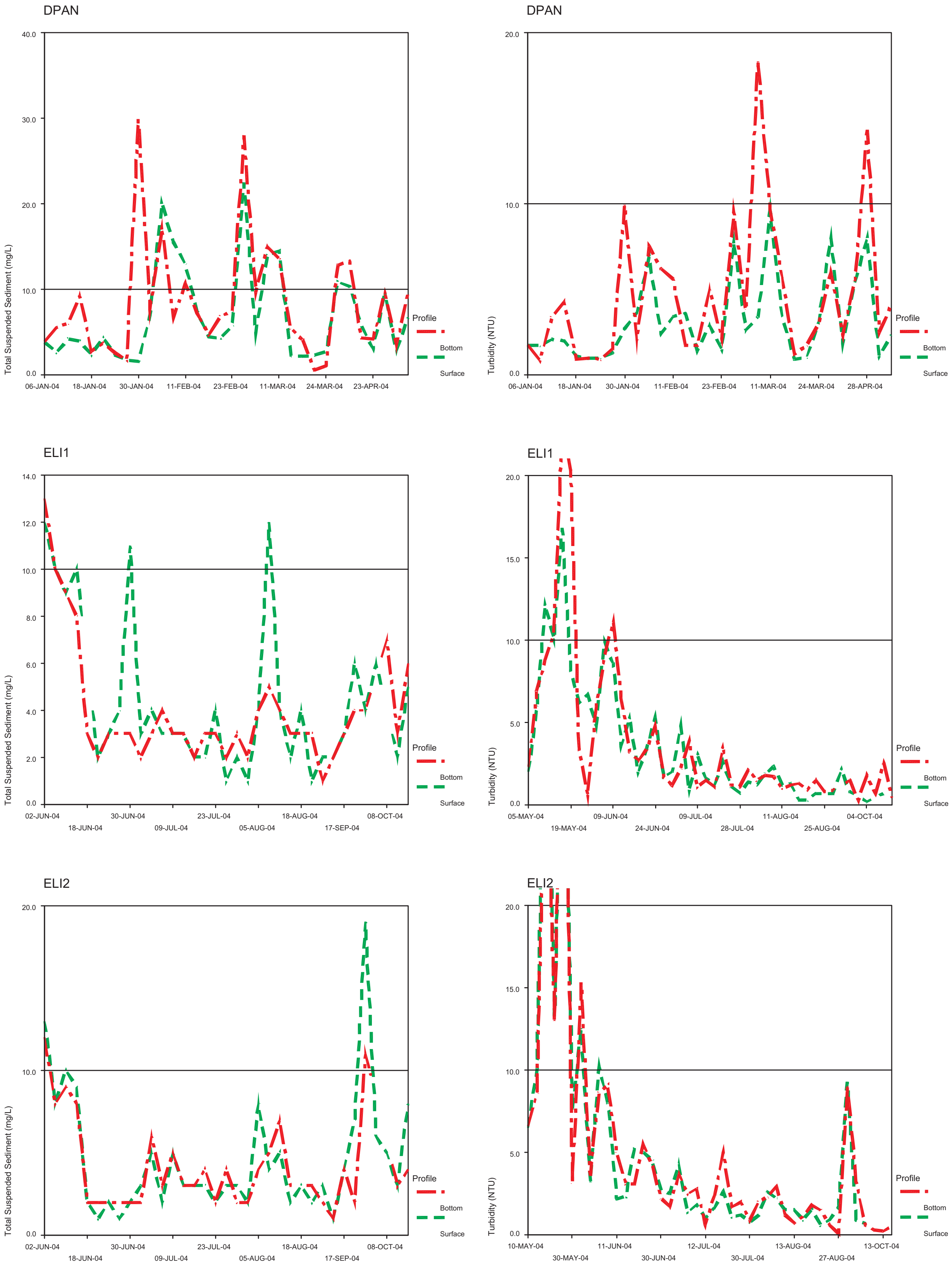
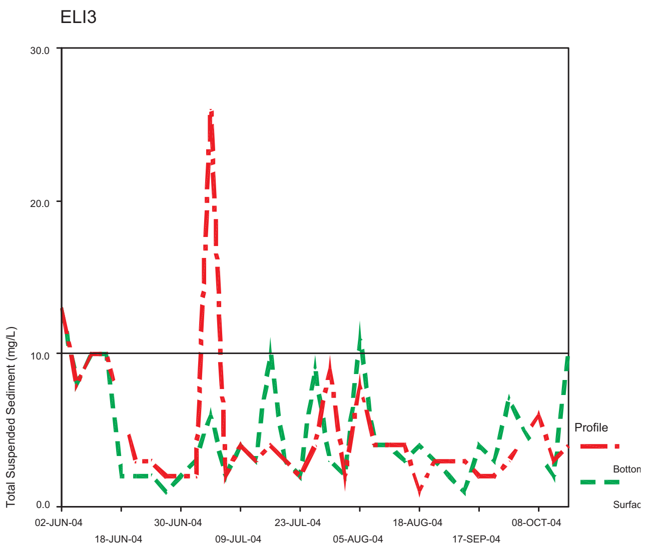
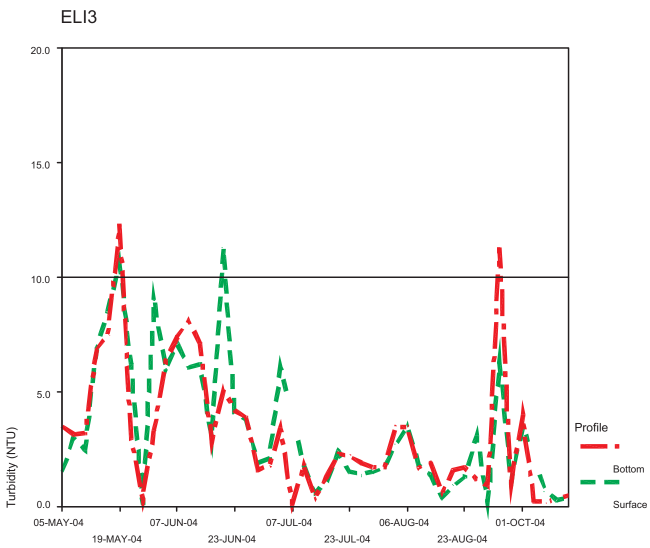
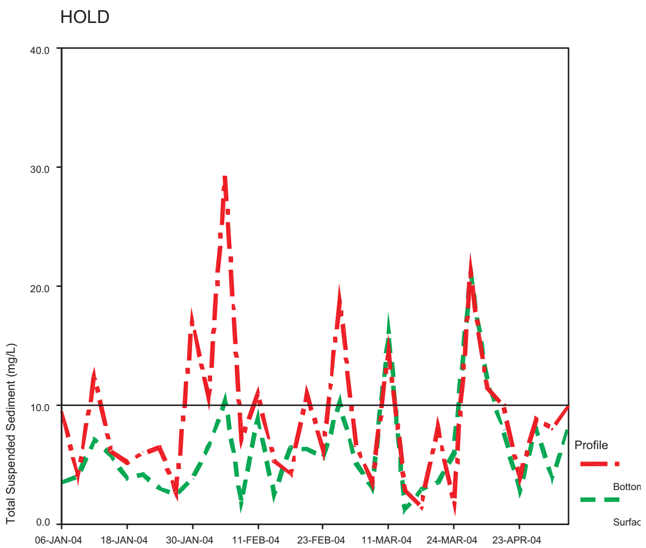


Figure 10. Comparison of TSS and turbidity over time at individual sites.




ELI3
Total Suspended Sediment (mg/L)
30.0
20.0
10.0
0.0
02-JUN-04
18-JUN-04
30-JUN-04
09-JUL-04
23-JUL-04
05-AUG-04
18-AUG-04
17-SEP-04
08-OCT-04
Profile
Botton
Surfac


ELI3
Turbidity (NTU)
20.0
15.0
10.0
5.0
0.0
05-MAY-04
19-MAY-04
07-JUN-04
23-JUN-04
07-JUL-04
23-JUL-04
06-AUG-04
23-AUG-04
01-OCT-04
Profile
Bottom
Surface


HOLD
Total Suspended Sediment (mg/L)
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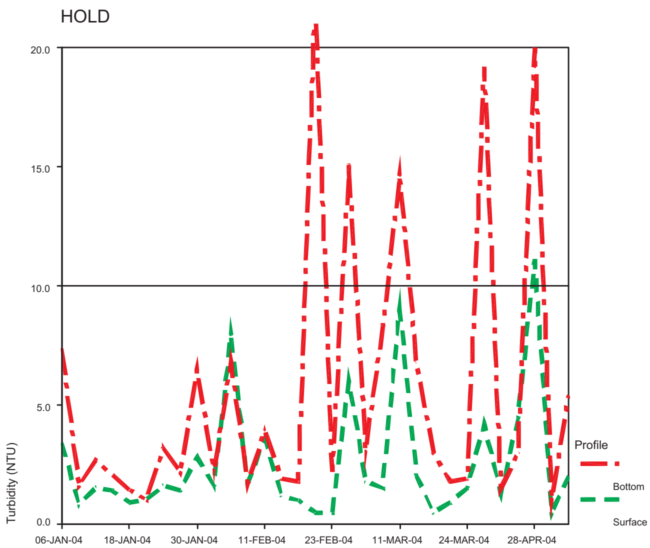
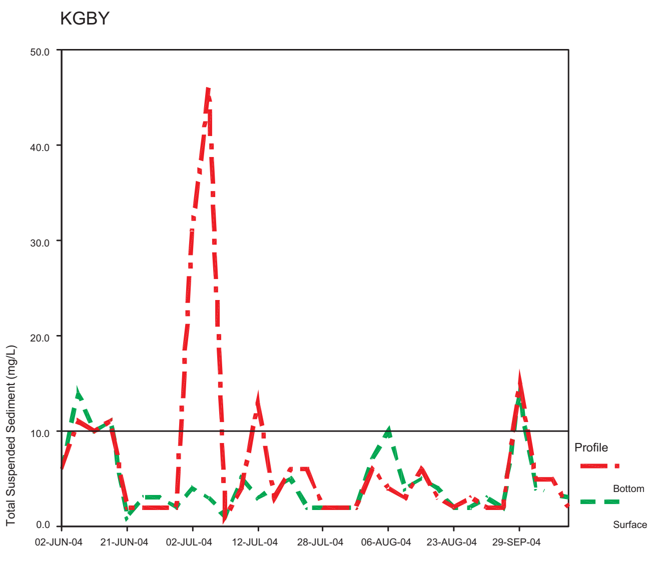
30.0
20.0
10.0
0.0
06-JAN-04
18-JAN-04
30-JAN-04
11-FEB-04
23-FEB-04
11-MAR-04
24-MAR-04
23-APR-04
Profile
Botton
Surfac


HOLD
Turbidity (NTU)
20.0
15.0
10.0
5.0
0.0
06-JAN-04
18-JAN-04
30-JAN-04
11-FEB-04
23-FEB-04
11-MAR-04
24-MAR-04
28-APR-04
Profile
Bottom
Surface


KGBY
Total Suspended Sediment (mg/L)
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20.0
10.0
0.0
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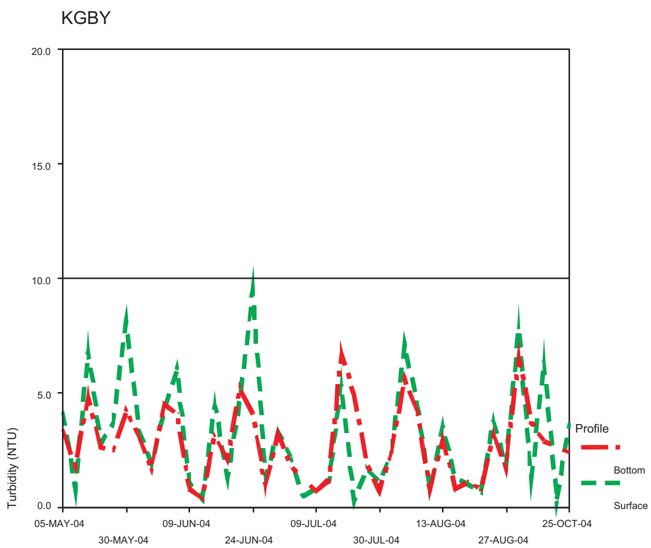
21-JUN-04
02-JUL-04
12-JUL-04
28-JUL-04
06-AUG-04
23-AUG-04
29-SEP-04
Profile
Bottom
Surface


KGBY
Turbidity (NTU)
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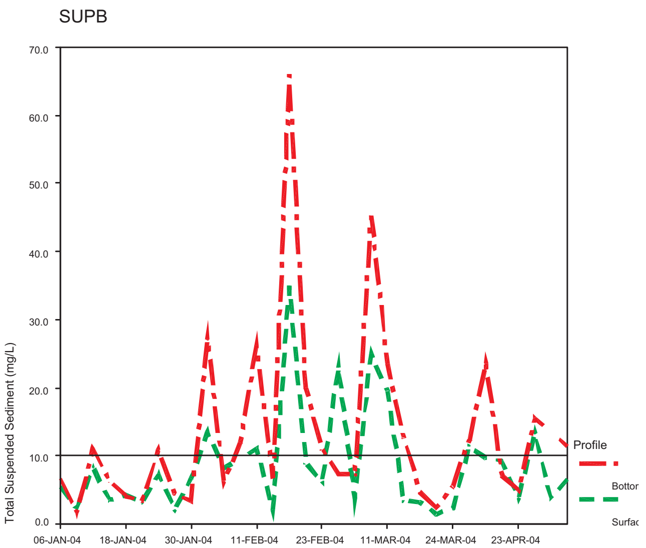
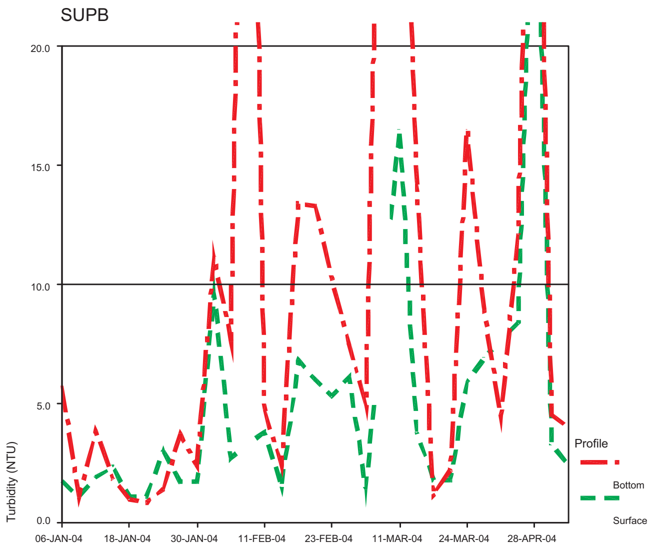
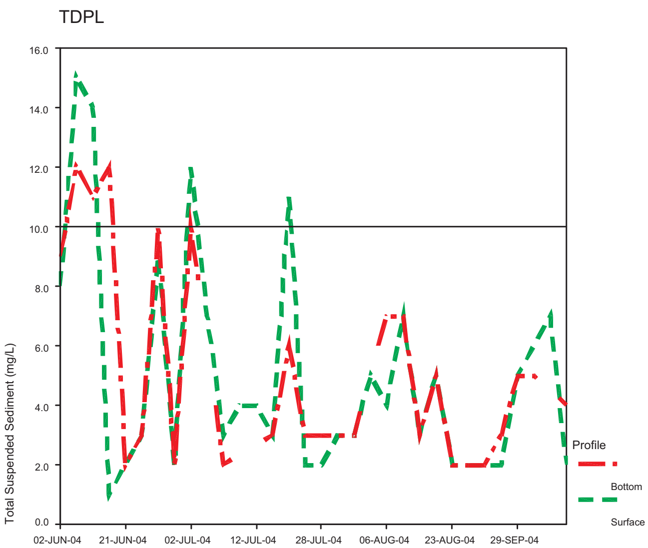
15.0
10.0
5.0
0.0
05-MAY-04
30-MAY-04
09-JUN-04
24-JUN-04
09-JUL-04
30-JUL-04
13-AUG-04
27-AUG-04
25-OCT-04
Profile
Bottom
Surface


SUPB
Total Suspended Sediment (mg/L)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
06-JAN-04
18-JAN-04
30-JAN-04
11-FEB-04
23-FEB-04
11-MAR-04
24-MAR-04
23-APR-04
Profile
Bottor
Surfac


SUPB
Turbidity (NTU)
20.0
15.0
10.0
5.0
0.0
06-JAN-04
18-JAN-04
30-JAN-04
11-FEB-04
23-FEB-04
11-MAR-04
24-MAR-04
28-APR-04
Profile
Bottom
Surface


TDPL
Total Suspended Sediment (mg/L)
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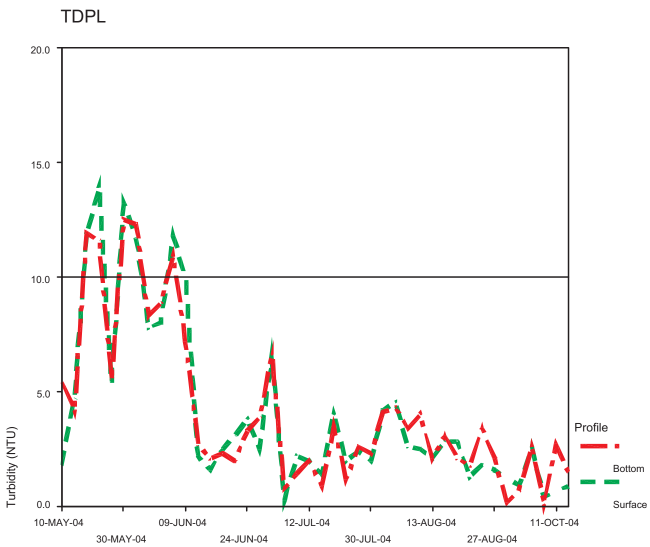
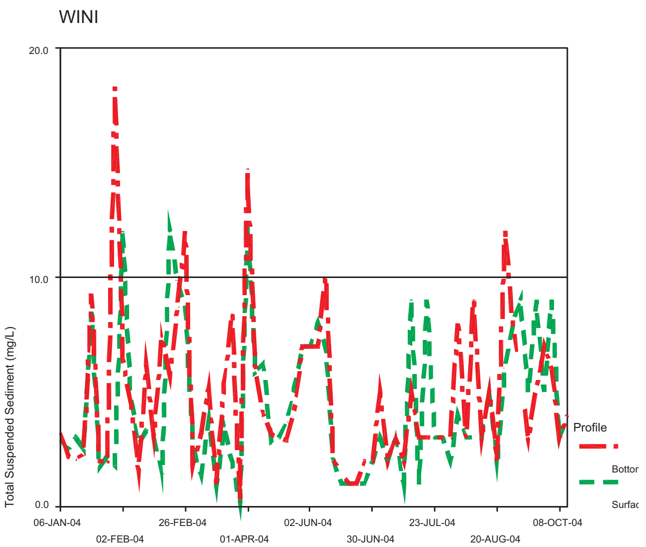
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
02-JUN-04
21-JUN-04
02-JUL-04
12-JUL-04
28-JUL-04
06-AUG-04
23-AUG-04
29-SEP-04
Profile
Bottom
Surface


TDPL
Turbidity (NTU)
20.0
15.0
10.0
5.0
0.0
10-MAY-04
30-MAY-04
09-JUN-04
24-JUN-04
12-JUL-04
30-JUL-04
13-AUG-04
27-AUG-04
11-OCT-04
Profile
Bottom
Surface


WINI
Total Suspended Sediment (mg/L)
20.0
10.0
0.0
06-JAN-04
02-FEB-04
26-FEB-04
01-APR-04
02-JUN-04
30-JUN-04
23-JUL-04
20-AUG-04
08-OCT-04
Profile
Bottor
Surfac

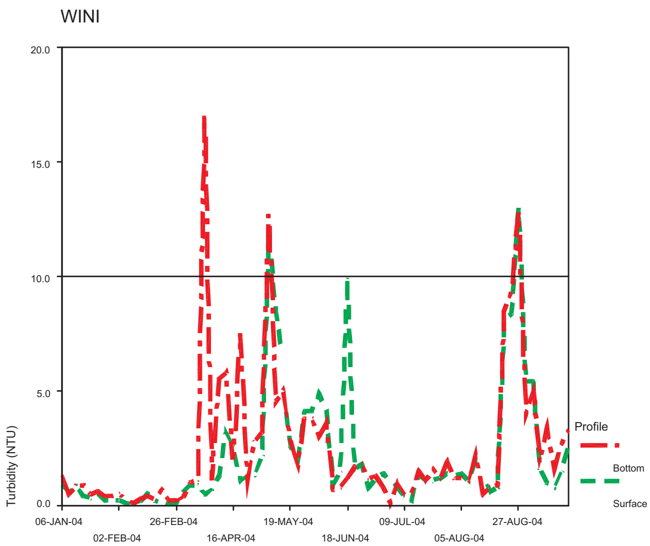

WINI
Turbidity (NTU)
20.0
15.0
10.0
5.0
0.0
06-JAN-04
02-FEB-04
26-FEB-04
16-APR-04
19-MAY-04
18-JUN-04
09-JUL-04
05-AUG-04
27-AUG-04
Profile
Bottom
Surface

Figure 11. Suspended sediment levels at SUPB at the time of postulated coral mortality (maximum values from Bottom samples).

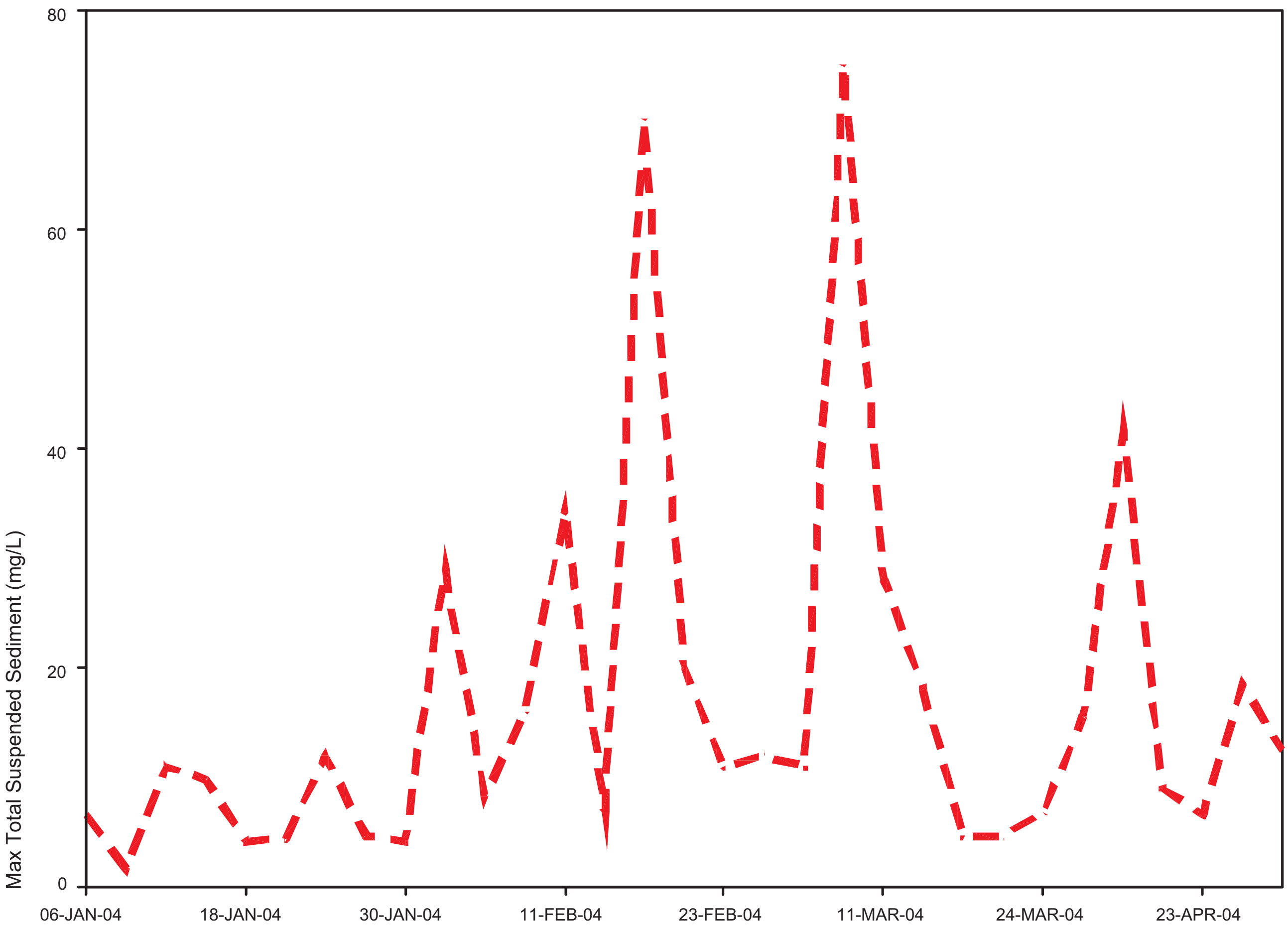


Figure 12. Water temperature over the monitoring period.

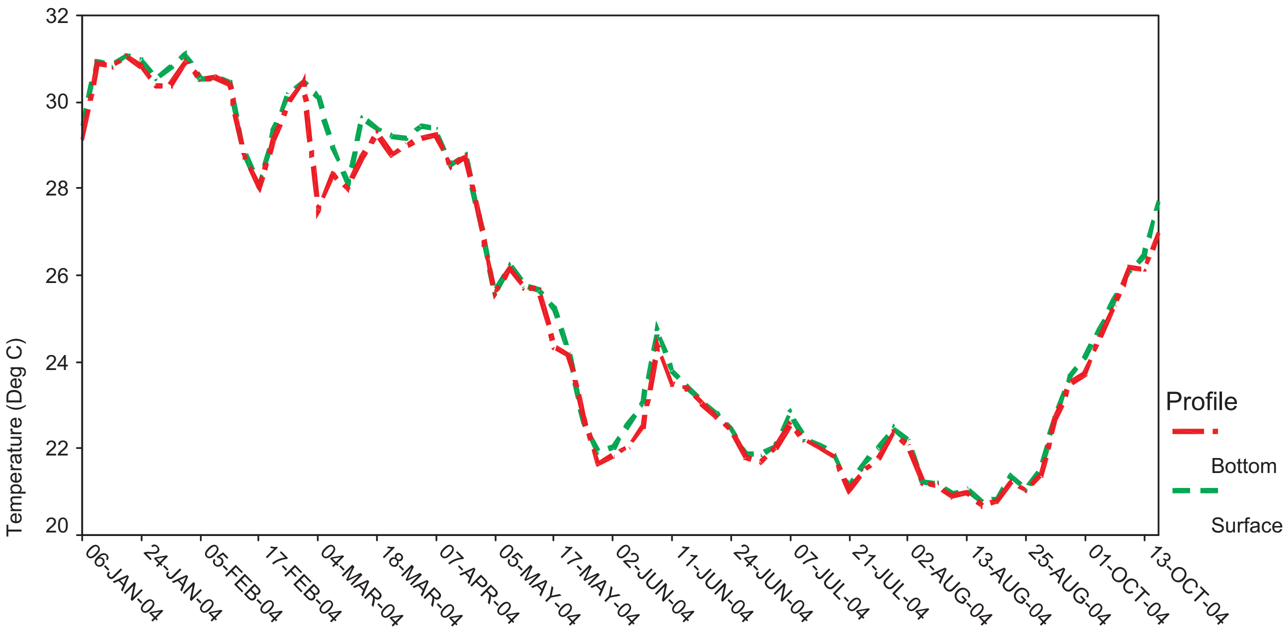


Figure 13. Fluctuation in salinity during the year.

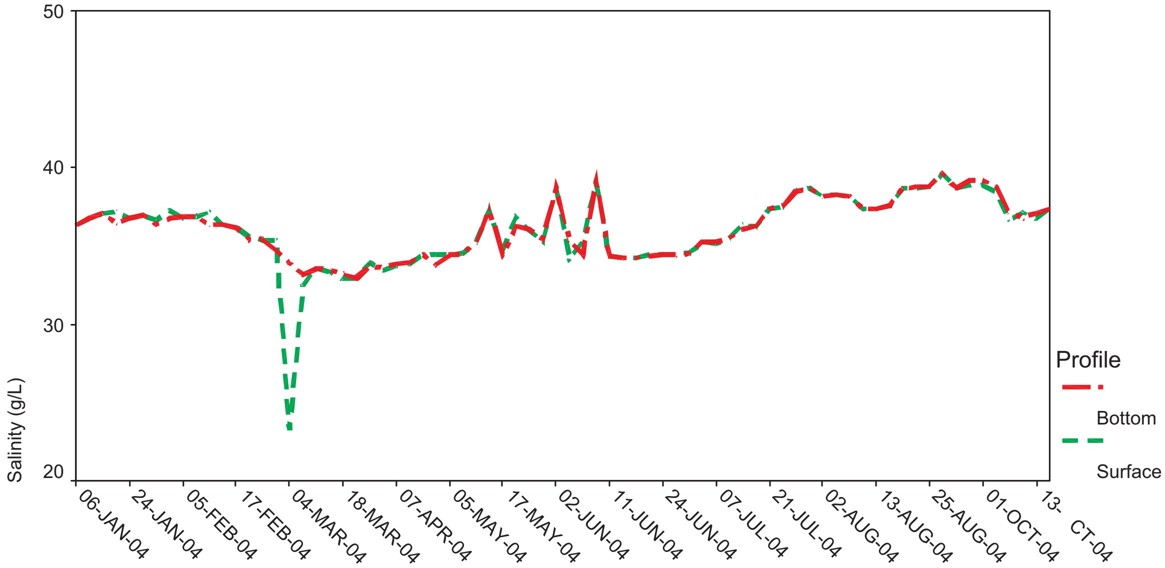


Figure 14. Dissolved oxygen levels over the monitoring period.

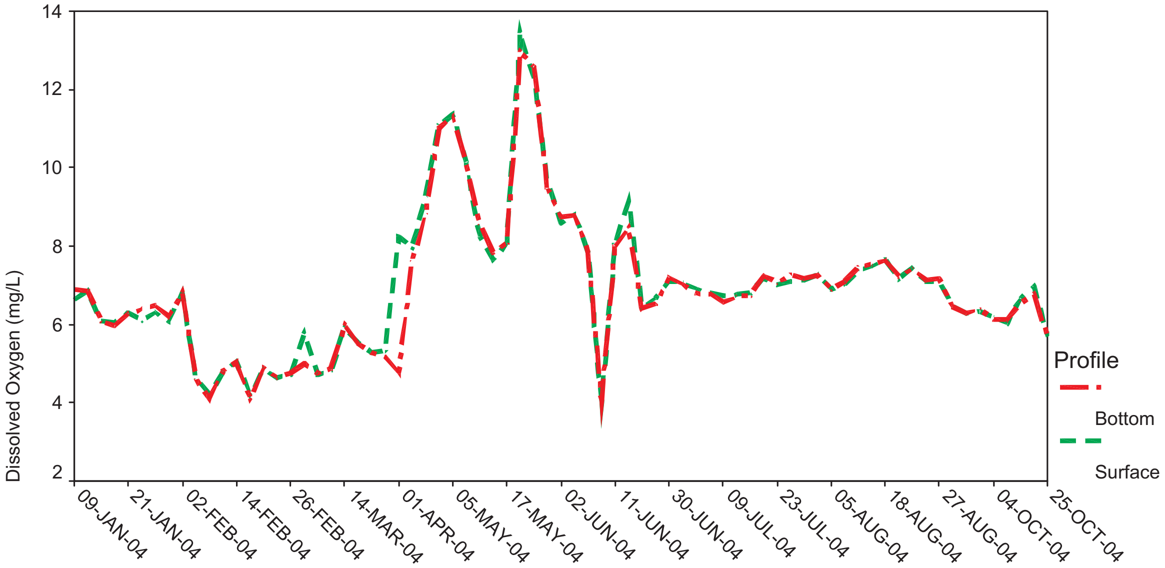
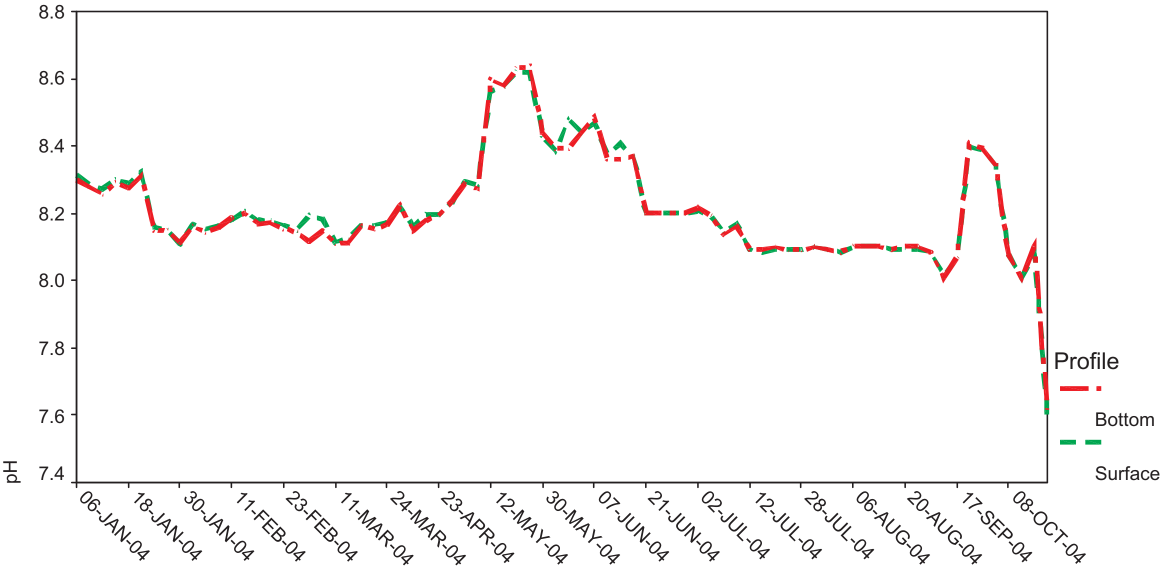


Figure 15. Variation in pH during monitoring



Comparisons with the GEMS Model

Contrasting the GEMS (2003) prediction of levels of suspended sediments at sites around the dredging uplift at Dampier Wharf (Fig. 16) with actual measured levels during dredging (Fig. 17) shows that the prediction of suspended sediment levels (labelled as Turbidity in GEMS Figure 11) rising steadily as dredging proceeds was not met. Rather the actual elevation occurred as a series of short-lived peaks in suspended sediments mostly at SUPB. Levels were well below those predicted.

Discussion

Turbidity vs TSS

Turbidity is a measure of the amount of light scattering through water caused by particles suspended in the water column. It responds to the spectral qualities of suspended particles as well as their density. The higher turbidity, the greater the scattering and thus the more opaque the water appears.

Total suspended solids (TSS) is a measure of the mass of suspended solids per litre of water.

These two parameters are often used interchangeably in discussion of water quality impacts, but in areas such as Dampier, they are not necessarily related and have differing impact pathways. Turbidity as a measure of scattering is also a direct measure of light attenuation as light passes through the water column. Thus it represents the potential for light starvation of corals and other photo-dependent organisms.

TSS is a direct measure of the potential amount of sediment likely to fall onto benthic organisms – after correction for density of the particles.

Assessed from the entire data set collected here, while significantly related, TSS and turbidity would be poor predictors of each other at Dampier when assessed over different sites or at different times. Forde (1985) noted a similar effect with the relationship of suspended sediment load and light attenuation varying substantially between two assessment periods. The Damara study for the DPA project showed a close correlation between turbidity and TSS (Figure 5 of Damara 2004) but only included data from a single day at a single site. The relationship between turbidity and TSS from this study and the Damara work were similar with turbidity (in NTU) about 0.25 to 0.3 of TSS (in mg/L).

In addition to the concentration of suspended sediments, turbidity will be affected by the particles' size distribution, composition and refractive and reflective index (Sadar & Engelhardt undated). It is likely that much of the error variance in the TSS-turbidity relationship seen here arises from temporal and spatial differences in these parameters of sediments over space and time.

Some spatial variance can be avoided by examining relationships on a site by site basis. However, when relationships were examined by site here, correlations were not increased except for samples with higher levels of turbidity.

What is background?

While the water quality at Mermaid Sound is seen as seasonal, at any location this may be more dependent on the local effects of weather conditions over the previous few days. The frequency of strong westerly winds in summer and residual effects of cyclones leads to elevated turbidity across much of the inner half of the Sound. Easterly winds in winter may also raise turbidity across large parts of the Sound. Nevertheless, periods of calm weather in either season lead rapidly to improved visibility.

Local variation in exposure to wind and wave conditions may cause some sites to react differently from adjacent sites within a kilometre or so. Forde (1985) notes that sediment traps near Gidley Island contained the largest loads of sediment post-cyclone and this was of a calcareous nature. This is consistent with diver observations of coarse sediments on corals at that site after Cyclone Monty and the occasional peak of TSS in bottom samples from GIDI. There was also a clear effect of non-dredging plumes noted at the adjacent Angel Island and Conzinc Island sites. During falling tides, a fine light-coloured plume was noted coming down Flying Foam Passage. This plume frequently affected visibility adversely at these sites before turning northwards and passing offshore of Gidley Island.

Thus the 'background' level of turbidity or TSS is highly site-dependent. As a result, the status of local benthic communities can vary naturally in response to isolated effects - such as the decline in some corals seen at GIDI following impact from coarse sediments resuspended by wave action (Stoddart et al. this volume).

Comparisons with model

Overall:

The GEMS model substantially over-predicted the impacts of the DPA dredging and disposal operations. The model was designed to be conservative in allowing for an overly large resuspension of sediments from the dredging activities. However it also predicted that suspended sediments would spend much more time in the water column than actually occurred and would thus travel farther and impact over greater areas than occurred (Fig. 18). TSS effects were in fact extremely localised in time and space: in most cases, the effect of sediment suspension episodes seen in one monitoring period were rarely detectable in the next monitoring period (3d later).

Predictions of widespread effects at increments of 1-5mg/L contained in the DPA model were unable to be verified by visual plume tracking or measured water quality. This may be because a) they didn't occur, or b) changes at that scale are within observed daily variation in this area.

The agreement between the predictions of the location and duration of plumes and the visual assessments done from aerial photographs was much closer for the HI dredging model than the DPA model. The primary difference between the model predictions was that the sensitivity of modelling in the HI model was decreased to a 5mg/L step – which equates better to a visual ability to detect plumes above natural background in this area.

Figure 16. GEMS prediction of the evolution of sediment around the Dampier dredging operations (GEMS Fig 6.9 showing depth-averaged sediment levels).

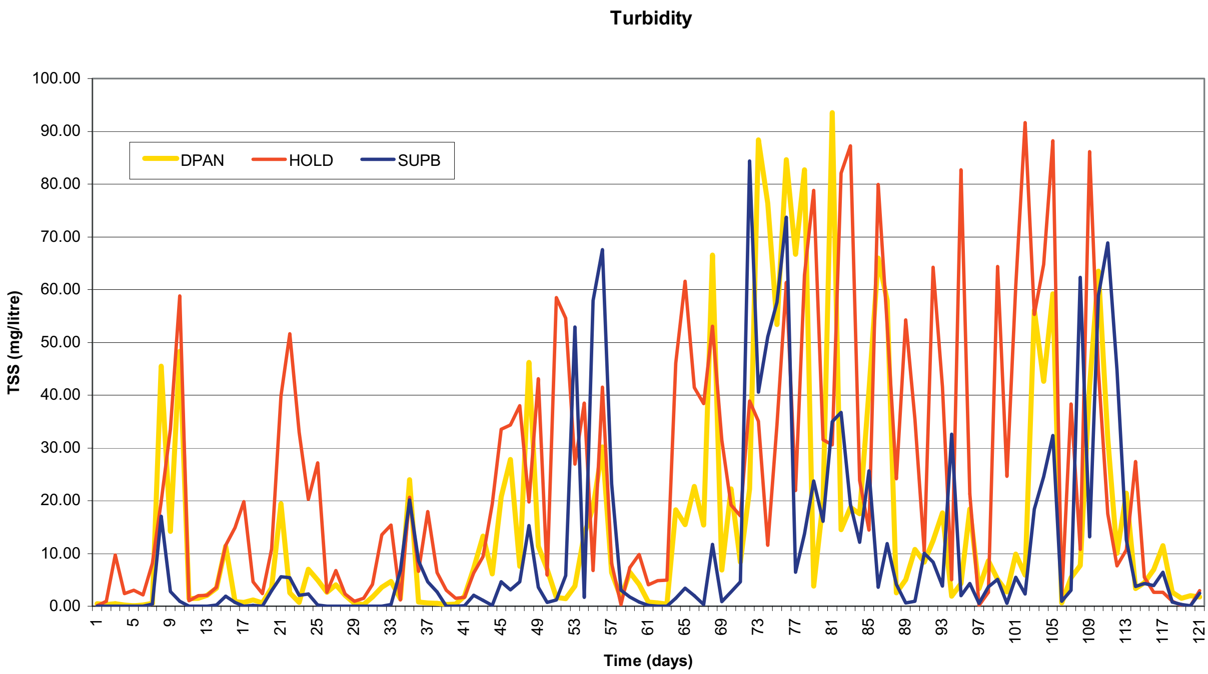
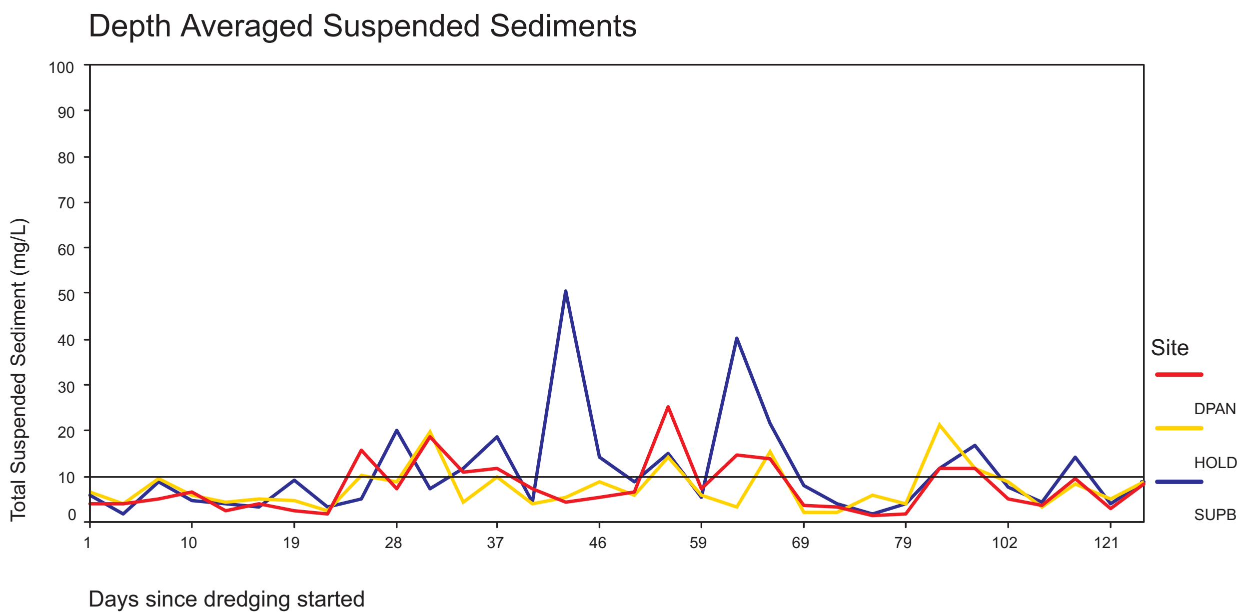


Figure 17. Actual levels of TSS at sites near DPA dredging.



Around the dredging site:

In the model of localised impacts around the DPA dredging site, the GEMS model predicted the steady evolution of very high levels of suspended sediments as dredging progressed. The model assumed that sediment would accumulate locally during dredging and be continually resuspended by subsequent dredging activity. Actual levels seen were much lower than predicted and tended to be short-lived peaks, consistent with rapid settlement of suspended sediment and minimal resuspension of sediment settling locally.

The model also predicted that dredging around the site of the new berth would result in impacts on water quality predominantly on sites to the northeast of the area to be dredged. Due to predominant westerly winds and the shape of the coast, GEMS predicted that turbidity at sites HOLD and DPAN would be greater than at SUPB as a result of northerly drift. In fact, SUPB was by far the most effected site for both TSS and turbidity. The localisation of effects seems to result from:

- the dredge spending much more time in the very immediate area of SUPB than originally assumed;
- sediment build up from prop wash being extremely localised;
- local boundary effects limiting flow – observations of turbidity on many occasions suggested that there was a boundary layer of water around 50m wide along the shoreline which remained roughly in place except under very heavy wind or wave conditions.

What is too much sediment?

As an indicator of light attenuation, turbidity needs to be elevated for considerable periods to produce impacts by depriving corals of photosynthetic energy from zooxanthellae. Similarly, chronic elevation of sediment levels might stress corals by diverting energy towards sediment removal processes (such as mucus production). Acute sedimentation on the other hand is likely to cause mortality by overwhelming corals with a layer of sedimentation (Nugues & Roberts 2002).

Divers observing corals every two weeks during dredging did occasionally observe sediment covering live coral, but did not report unusually high levels of mucus production – except for *Millepora* which appeared to be a response to water temperature rather than to sediment cover. At sites where turbidity/sedimentation episodes occurred immediately prior to diver visits, visibility was too limited to allow safe diving and thus very short term sediment cover or mucus production was unable to be assessed.

The only dredging related mortality observed by the coral health monitoring program (Stoddart et al. this volume) was at the Supply Base site (SUPB) during the DPA program. Following the commencement of dredging adjacent to this site, turbidity was sufficiently high or weather sufficiently rough, so as to prevent observation of corals over an extended period and when corals were finally observed on 11 April, approximately 80% mortality had occurred – almost entirely by direct smothering.

The Supply Base site shows the highest levels of mean and maximum turbidity and TSS. On 42% of monitoring days, TSS in bottom samples from SUPB was above 10mg/L and 22% for turbidity. However, it is more likely that the important figure is the TSS in excess of 60mg/L in mid February. Once the capacity of coral to clear sediments is overwhelmed, further sediment will add to the depth of the layer.

Elsewhere corals have been shown to tolerate a variety of acute sediment loads – Larcombe et al (2001) show coral reefs at Magnetic Island often experience suspended sediment concentrations above 20mg/L for over 24hrs, but rarely over 40mg/L for that period.

At the HOLD and DPAN sites adjacent to the SUPB mortality turbidity was frequently high for extended periods and prevented observations many weeks. However, once visibility improved at these sites, there was no observable mortality or other visible effects of that high turbidity.

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Rapid high-precision monitoring of coral communities to support reactive management of dredging in Mermaid Sound, Dampier, Western Australia.

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Abstract

Embarking on a major dredging program with a lack of agreement on the potential risk to adjacent coral communities, there was a need to develop a rapid-turnaround monitoring program for adaptive management of the dredging activity. Triggers for management were agreed to be measures of decline in coral community status. Practical considerations made the decline of cover of live coral the only viable indicator for this area.

A program was designed to support fortnightly assessment of any decline in coral cover above 10%. A fortnightly monitoring program was implemented at 19 sites for a period of 12 months to cover 2 dredging projects in the Dampier Harbour, Western Australia.

Between November 2003 and December 2004, the majority of change seen in these coral communities resulted from natural phenomena, including freshwater inundation, wave action and competition with macroalgae. Mortality from dredging activities was apparent at one site only, where a coral community occurred within a few hundred metres of intense dredging. Mortality appeared to be due to direct smothering of corals by coarse and fine sediments. Other populations within 1km of dredging and spoil disposal sites were exposed to greatly elevated turbidity for weeks at a time, but showed no resulting change in coral cover.

While video or photographic recording of coral cover using line transects is commonly used in surveys of coral abundance, accuracy and precision are rarely made explicit for these techniques. The survey technique used here employed 5 replicated transects at each monitoring site, assessed by 10 images from fixed intervals along the transect. Using 50 intercept points per image allowed this technique to test the hypothesis of 10% change with statistical power between 0.35 (for sites where coral cover was low, <30%, and patchy) and 0.95 (for sites where coral was abundant, >50%, and more even).

An assessment of the effect of changing the sampling intensity within images (using 5, 10, 25 & 50 points) showed that at sites where coral cover was low and patchy, increasing sampling intensity greatly increased precision, but at sites where coral cover was high and even, it had little effect.

Keywords: sediment, turbidity, coral, monitoring, dredging

Introduction

Monitoring Impacts of Dredging/Disposal on Coral Reefs

Dredging and the subsequent disposal of spoil result in the suspension of bottom sediments into the water column at sites of uplift and disposal. Ignoring the issue of liberation of chemical toxicants or nutrients from contaminated sediments, the principal factors likely to impact corals will be limited to direct sedimentation and decreased light availability. Even with this simple set of impacts, predicting potential responses and how to monitor them is not straightforward. Sediment and turbidity can impact on a variety of ecological and physiological process including growth, mortality, reproduction and recruitment (Rogers 1990) as well as competition with other biota (Nugues & Roberts 2002).

A large number of studies describe change (or lack thereof) in response to increased sedimentation or turbidity in corals for differing parameters. Some examples include:

- community structure (Loya 1976, Dodge & Vaisnys 1977, Cortes & Risk 1985) - generally a long term issue this is more relevant where dredging may change the sediment/turbidity pattern over several years;
- short term mortality (Brock et al 1966; Dodge & Vaisnys 1977, Stafford-Smith et al 1993) – the most commonly assessed and described response;
- sub lethal indicators of stress – including growth rate and reproduction (Brown & Howard 1985, Stafford Smith et al 1993, Jones 1997; Bourke 2004)

Ideally, monitoring conducted as an input to adaptive management of dredging operations should be directed at sublethal effects whenever practical. However, in many cases this is not practical as the measurement of these indicators can require time frames unsuited to operational dredge management or their interpretation can be confounded by the indicator's response to factors unrelated to dredging. Bleaching of coral tissues through the expulsion of zooxanthellae has been used as an indicator for adaptive management of dredging programs on the Great Barrier Reef, where it has formed part of a broader decision-making scheme (Stafford-Smith et al 1993). While there are suggestions that the technique is not sufficiently sensitive to isolate dredge-related impacts (Hoegh-Gulberg et al 1996), its use as a monitoring tool continues around dredging projects.

Similar concerns would apply to the use of pulse amplitude modulation (PAM) fluorescence measurement from zooxanthellae in corals (Jones et al 1999) as a sublethal indicator of dredging effect. Again, this is primarily an indicator of the relationship between coral and zooxanthellae, which may be affected by many other factors unrelated to sediment stress (Hoegh-Gulberg et al 1996).

Recent studies on the ratio of structural and storage lipids in corals show some promise of providing sub-lethal indication of stress (Harriott 1993; Ward 1995). However techniques currently in use may not be practical in providing rapid assessments and lipid metabolism may be confounded by differing responses from coral taxa with differing levels of resilience to sedimentation (Bourke 2004, Saunders et al. in prep).

Monitoring of the Dampier Dredging Programs

During 2003, two major dredging programs proposed in Mermaid Sound, Dampier Harbour, Western Australia (see Stoddart & Anstee, this volume) were referred to the Western Australian Environmental Protection Authority (EPA) for assessment. Coral communities were known to exist within distances where water quality was likely to be affected by these sediments and the potential for impact on these populations was considered a significant factor (EPA 2003 a+b).

While dredging and sea dumping had occurred previously within similar areas of the Harbour without documented impacts on these coral populations, the intensity of monitoring undertaken for those programs was deemed insufficient to allay fears of impact for these large, possibly contemporaneous, projects. Therefore the EPA assessment recommended implementation of a program of adaptive management for dredging and disposal, governed by the results of coral impact monitoring.

Initial attempts to develop a monitoring program reviewed the efficacy and practicality of using coral bleaching as a sublethal indicator. In addition to the uncertainty in interpreting results, there were substantial practical problems that mitigated against such a technique. The Dampier Harbour marine environment is a naturally turbid area (Stoddart & Anstee, this volume), and visibility can be reduced to effectively zero in waters adjacent to dredging operations. In such an environment, visual data can be unavailable for long periods.

Further, partial mortality of coral colonies resulting from sedimentation occurs when fine sediments smother corals. In this case, bleaching is only visible once the sediment covering is brushed from the coral to reveal the underlying tissue. Such an intervention would invalidate any sampling design using repeated sampling of regularly brushed corals to reflect the broader population.

It was decided to use estimates of actual mortality as indicators of impact. For monitoring to be used as a trigger for change in management of the dredging, the program needed to be able to identify the occurrence of dredging-related mortality before unacceptably large proportions of coral communities were destroyed.

Using Connell (1997) as a basis, the EPA determined that a 30% mortality event would represent an unacceptable level of impact for these populations. As an arbitrary management trigger and to allow for the routinely dynamic nature of corals, it was agreed that a 10% mortality effect would represent an indication that dredging- induced mortality had started and the management should be applied to avoid breaching the 30% criterion. Based on a similar mix of practical constraints and biological processes, the frequency of mortality monitoring was set to a fortnightly cycle.

Previous studies of coral communities in the Harbour have confirmed that the amount of live coral cover can change substantially in response to weather-related and other phenomena (Blakeway, this volume). To avoid unnecessary restrictions on dredging and disposal that could result from mortality caused by the impacts of a widespread factor unrelated to dredging, Net Mortality (i.e. Impact less Reference level) was used as the management trigger.

In practice, the assessment of mortality usually involves repeated measures of live cover over time. Monitoring coral cover in benthic communities has a long history from very fine scale observations (sensu Connell et al 1997) to large scale surveys (sensu Carleton & Done 1995). Studies using the latter methods are often more concerned with a broad description of the status of coral reefs as a whole (English et al. 1997) rather than in precise, repeatable measures appropriate to assessing coral mortality. The majority of past studies allow little assessment of their precision or accuracy and thus their statistical power to detect change.

Previous studies of change in coral cover over time have been conducted within the Dampier Harbour as part of long-term monitoring of coral communities for Woodside Energy (see summary in Blakeway, this volume) or the assessment of dredging impacts (ECS 1998). All used fixed location adaptations of the Australian Institute of Marine Science (AIMS) video assessment technique developed for rapid assessment of reef status (Abdo et al. 2003). The methodology of the former surveys has been criticised for a very low statistical power to detect change (Harvey et al., 2000) and the latter would have had similar characteristics (unpublished data).

While there are no accepted standards in setting the level of power for an analysis of change (see Methods for explanation), the EPA considered that the low level (or unspecified level) of power in previous studies was unacceptable in the present case and required that the current study explicitly consider power. The design of the monitoring program was to provide a solution with a level of statistical power appropriate to the 10% mortality effect trigger (EPA 2003a&b).

Under management plans developed in response to the EPA assessments, the task for the monitoring program to be developed for the Dampier Port Authority (DPA) and Hamersley Iron Pty Limited (Hamersley) dredging programs was to

- Assess the extent of coral mortality at sites likely to be impacted by dredging or disposal
- Assess the extent of coral mortality at sites which would suffer similar background mortality but avoid dredging-related mortality

- Assess the above at a level of precision capable of detecting a 10% shift in coral cover with an acceptable level of statistical power;
- Complete the assessment of all monitoring sites throughout the Harbour from starting a field survey to finalising the statistical test within the fortnightly period.

Methods

Site Locations

Monitoring sites were selected to represent the major coral populations adjacent to dredging and disposal (Table 1, Figure 1). They provided a uniform distribution of monitoring at varying distances and directions from the source of the sediment plume at the dredging and disposal areas. This allowed for an assessment of the influence of tidal currents, wind direction and other meteorological variables on the migration of a sediment plume away from the dredging operations.

Reference sites were selected on the basis of similar bathymetry and weather aspect wherever possible and as sites outside the immediate impact of dredging. As the most similar biotic communities were usually located close to each other, there was a concern that the 'Near Reference' sites might be impacted by the same factors influencing the Impact sites. To provide confidence that a data set from unimpacted sites would be available, a second set of Reference sites was selected on the basis of being distant from any impacts. These 'Far Reference' sites were less similar to Impact sites than the 'Near Reference' set.

Table 1. Monitoring sites and their function for the two dredging programs.

Site	Function	Program
Angel Island (ANGI)	Reference (Near)	DPA/HI
Conzinc Bay North (COBN)	Impact	DPA/HI
Conzinc Island (CONI)	Impact	DPA/HI
Dampier Wharf North (DPAN)	Impact	DPA
East Lewis Island 1 (ELI1)	Impact	HI
East Lewis Island 2 (ELI2)	Impact	HI
East Lewis Island 3 (ELI3)	Impact	HI
Gidley Island (GIDI)	Reference (Near)	DPA/HI
High Point (HGPT)	Reference (Far)	DPA/HI
Holden Point (HOLD)	Impact	DPA
King Bay (KGBY)	Impact	HI
Malus Island (MALI)	Reference (Far)	DPA/HI
North Withnell (NWIT)	Reference (Near)	DPA/HI
South Withnell (SWIT)	Reference (Near)	DPA/HI
Supply Base (SUPB)	Impact	DPA
Tidepole Island (TDPL)	Impact	HI
West Intercourse Island (WINI)	Reference (Far)	DPA/HI
West Lewis Island 1 (WLI1)	Reference (Far)	DPA
West Lewis Island 2 (WLI2)	Reference (Far)	DPA

Sampling Methods

Constraints on the sampling included the need to:

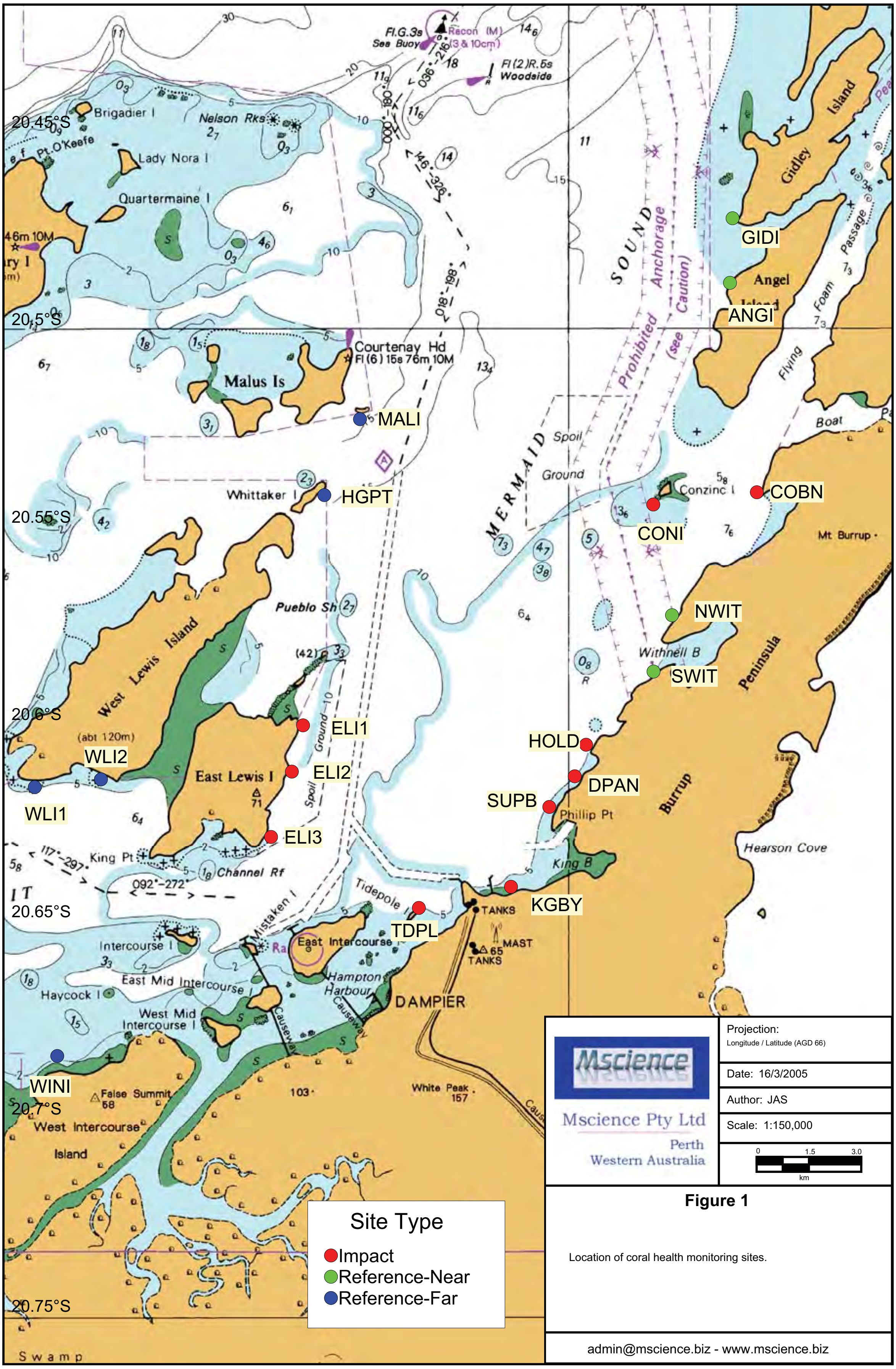
- cover an ecologically (or socially) meaningful amount of coral;
- cover many sites
- allow rapid turnaround
- be measurable in poor visibility
- remove as much subjectiveness as possible
- cover over 12 months at fortnightly intervals.

Based on the above needs, a design was developed as an adaptation of the Coral Reef Assessment & Monitoring Program of the University of Hawaii (Brown et al 2004). This design used 5 x 10m transects to represent coral at each site – 10m was chosen as a suitable length to represent local cover while allowing precise relocation of the transect. Cover for each transect was estimated as the mean of 10 frames. Variance between times for individual frames was not estimated as this would be swamped by error terms from variation in exact placement of the frame.

Initially, images of frames were captured from video recordings. A digital 3 CCD underwater video camera was swum slowly (3-4m/min) along the transect perpendicular to the bottom at a distance yielding a frame size of around 50 x 70 cm. Subsequently, the recording was transferred to a compressed digital file and the time taken to record the 10m transect noted. Frames were then captured from the file at the beginning of the transect and at even time spacing thereafter to provide 10 frames in total (covering about 50% of the area under the transect). Variability in replicating exact frame locations between sampling events (Trips) was problematic in this technique due to currents and swell making it difficult to swim at a constant speed on each occasion. To reduce that variability and improve the quality of images obtained for analysis, recording methods were altered to use a still camera on a leg at 1m distance intervals on the transect line. Trips 1-9 used video and trips 10-30 used the still camera.

Most coral communities around Mermaid Sound exist as relatively narrow bands fringing shorelines wherever suitable rocky habitat exists at depths between extreme spring low tide and around 6m below MLW (Blakeway & Radford, this volume). Thus the 5 transects were placed along an essentially linear arrangement parallel to the shoreline. The initial transect was placed in an area visually assessed as having amongst the highest coral cover at the site. Following transects were started approximately 5m distance at 45° from the end post of the prior transect.While not providing fully random spatial replicates, this technique covers a broad section of the longitudinal and depth range of coral communities.

Figure 1. Location of coral monitoring sites in Dampier Harbour.



Scoring of Coral Cover within Images

Digital images were colour balanced using commercial photo-enhancement software. In turbid conditions, this was essential to allow recognition of benthos. Images were then processed using Photogrid 1 (courtesy of C.Bird, University of Hawai'i) to overlay 50 points using the program's Stratified Random option. Points were then assigned by scorers to one of 10 categories: 6 coral groups, other fauna, flora, sand-rock-rubble, or unknown. The project used two scorers; each trained using the AIMS C-Nav system. Over the 14 months of scoring, it was necessary to cross-calibrate scorers regularly by standardising their scoring of several standard transects. Comparison of data from standardisation exercises suggested that inter-scorer effects could show consistent differences of 5-10% in coral cover in the absence of regular cross calibration.

Standard scoring methods use a category of Unknown to hold points obscured by transect equipment or unable to be identified from the image. Points in this category are excluded from analysis (eg in a transect with 100 Unknowns, averages will be calculated from 400 points). However, a consistent bias in assignment of benthic category to Unknown can bias results. In highly turbid conditions (visibility <1.5m) the frequency of Unknown points rises.

Working in very turbid waters can bias results. Within our digital images, the distribution of light returned to the camera lens was not uniform. Bulky complex light sources were unsuited to working in shallow conditions where swell was frequently present and simple light sources were negated by backscatter from suspended solids. Recording under incident light was most effective, but meant that surfaces closer to the camera were better lit (and thus more easily discriminated) than surfaces on the bottom substrate (sometimes in shadow). Coral morphology and size were key factors, such that large arborescent, plate or massive colonies were resolved much more readily than small encrusting corals. Estimates of cover by the former can be biased upwards from sampling trips where turbidity was high, while estimates for transects dominated by the latter may bias downward. Consistent bias can also occur if observers differentiate coral from substrate by recognising regular complex structures in coral. In low light conditions it is difficult to identify structure and corals may be assigned to unknown or incorrectly identified as 'abiotic'.

Not only are images captured from video of much lower acuity than routinely used still image cameras (around 640x480 pixels vs 2600x2000 pixels), but they frequently suffer from motion-blur. The frequency of Unknown points was significantly reduced when image capture techniques switched from video frames to digital still frames (mean Unknown 27.1 vs 14.8, $p<.001$).

The intensity of sampling within each image affects the precision and accuracy of the estimate of cover for each frame. To date, the most common technique has been to follow the AIMS method (Carleton & Done 1995) using 5 points per frame. Harvey et al (2000) point to the inability of this level of image sampling to support levels of precision and power appropriate to testing small changes in coral communities over time and suggest 40-60 dots per frame are required on the basis of Monte Carlo simulations. Brown et al (2004) provide some hypothetical and some empirical data to support a similar level of intensity in frame sampling.

Here, we used 50 points per frame as recommended by Brown et al (2004), but conducted trials using Monte Carlo and empirical scores to investigate the effects of frame sampling intensity for two monitoring sites – one with a high level of coral cover evenly spread between transects (ELI2) and one with a low level of cover and higher between-transect variance (HOLD). For both sites the Monte Carlo sampling involved selecting random points from transects scored for 50 points to produce estimates of means and variance based on 5, 10, 25 and 50 points. The empirical tests used two scorers scoring each transect three times for each of intensity levels.

Statistical assessment

The sampling design was constructed with the intention of supporting a BACI analysis using Repeated Measures Analysis of Variance (RMANOVA). Brown et al (2004) provide estimates of power analysis for RMANOVA in detecting change over time at a site using the Transect as the base subject and frames within a transect as a nested measure. They report the results of a study using statistical bootstrap and actual studies to investigate the effects of varying numbers of points per frame, frames per transect and transects per site on the power of this technique to detect change over time at their Hawaiian sites. Based on their analyses, the present design (50 points per transect; 5 transects per site) was estimated a priori to provide a statistical power in excess of 0.8 in detecting a 20% change or 0.7 for a 15% change in coral cover at any site.

The primary task for monitoring was to test whether any Impact site had suffered more than 10% mortality of its baseline coral abundance after adjustment for any mortality at Reference sites (derived from EPA 2003 a & b). In practice, this was translated into estimates of decline in coral cover with only Impact sites monitored routinely. Where Impact Sites showed a significant decline Reference sites could then be evaluated to provide any offset in calculating net change.

The working hypothesis for monitoring was

H_0 – live coral cover has not declined more than 10% of the baseline value, with

H_1 – live coral cover has declined more than 10% of the baseline value

The spatial abundance of corals is typically highly patchy at scales of metres to tens of metres. Variation in coral cover between frames within a transect and between transects within a site was high – usually well above the 10% relative cover trigger. To allow the test statistic to concentrate on change in cover, it was decided to test the above hypothesis with a paired t-test for each Impact site using individual transects paired between the baseline and the current trip result.

Power of a test is defined as the ability to reject the null hypothesis when it should be rejected. It is the inverse of β, the probability of a Type II error. It is dependent on the effect size (in this case a decline of 10% of baseline) and its relationship to error variance terms which can obscure real shifts in the mean. While the significance level for rejecting null hypotheses, α, is conventionally set at 0.05, there is no general level accepted for β. Rather, power should be set on the basis of the consequences of the test missing a positive result.

Underwood and Chapman (2003) suggest that the power of detection of effects of Pulse impacts (here mortality from short-term elevation in suspended sediments) can be increased most effectively through the use of multiple sampling periods, rather than large numbers of control sites. While the present program used many sampling periods, that was principally for the early detection of impacts and would not have improved the power of tests as the hypothesis tested here related to change between the baseline period and any single survey trip. Multiple estimates of impact, such as in repeated measures ANOVAs, are thus not applicable.

Power analysis for the monitoring program used here was calculated using NCSS-PASS software (Hintze 2001). Power was estimated using the assumption that for sites where there was little obvious change over the monitoring period, between- trip differentials should reflect error terms alone. Power was estimated for a number of such sites with a range of coral cover, using at least 10 between-trip comparisons to provide an average variance estimate to compare against an effect size of 10% change against the baseline for each site.

Sampling events

Sampling was conducted prior to dredging commencing to provide an estimate of the baseline level of cover of Impact and Reference Sites. Where possible, baseline values were calculated from the average of 2 or 3 monitoring trips conducted over Nov/Dec 2003. As details of the dredging program evolved during that period and later, some site baselines are calculated from a single trip. As the Hamersley dredging program did not start until mid 2004, after the impacts of Cyclone Monty in 1-3 March, it was decided to re-estimate the baseline from those Impact and Reference sites during April.

Following the commencement of dredging, monitoring trips were conducted fortnightly. The DPA dredging program ran from 8 January 2004 until 20 May 2004 and the Hamersley program from 8 May to 23 October 2004. Monitoring of each program's Impact Sites continued for 2 months beyond the cessation of dredging.

Results

Change in coral communities over 12 months of dredging

Coral cover in communities surveyed in the Dampier Harbour ranged from 18% to almost 80% (Table 2). In most cases, the standard error of the mean was around 10%, supporting the decision to use a test of paired transects rather than a RMANOVA which would retain this inter-transect variance. In hindsight, several of the Reference sites would not have served as adequate controls for impacts as the composition of coral community was different from their targeted Impact Sites.

When the change against baseline cover levels was assessed by site for the entire monitoring period there was no clear indication of dredging and disposal impacts yielding an outcome where Impact sites declined and Reference sites did not (Fig. 2). Indeed, only 1 Impact Site dropped by over 10% of coral cover (SUPB) while several Reference sites showed a strong decline.

Table 2. Baseline means of coral cover and standard error of the mean (ie between transect variation).

Site	DPA Base	S.E.	HI Base	S.E.	Dominant Corals
ANGI	39.1	3.65	38.6	4.21	Acropora
COBN	47.0	3.50	39.5	3.33	Other/Faviid
CONI	33.8	9.99	30.6	10.80	Porites
DPAN	37.2	3.95	-	-	Faviid/Turbinaria
ELI1	77.3	3.39	69.3	5.26	Pavona
ELI2	74.5	3.84	70.2	4.49	Pavona
ELI3	-	-	30.1	3.97	Pavona
GIDI	41.3	3.97	32.1	3.20	Acropora/Faviid
HGPT	55.2	5.39	49.5	3.31	Pavona
HOLD	18.2	4.59	-	-	Faviid/Other
KGBY	46.1	3.69	40.9	4.42	Faviid/Other
MALI	41.1	7.51	39.0	6.49	Porites
NWIT	32.4	4.45	31.2	5.11	Faviid/Turbinaria
SUPB	49.7	4.95	-	-	Turbinaria
SWIT	34.1	1.10	37.2	2.26	Faviid/Other/ Turbinaria
TDPL	49.7	3.44	37.8	5.49	Pavona/Faviid
WINI	23.1	2.46	10.2	3.18	Turbinaria/ Porites/Faviid
WLI1	39.0	3.36	-	-	Porites
WLI2	46.9	10.5	-	-	Porites/Other

Closer examination of how sites changed over time (Fig.3 a & b) together with diver observations provides a means of interpreting these changes. Clearly, there were many different causes of mortality which impacted one or a small number of sites:

- Dredging related mortality: the only site where a clear impact of dredging was seen was SUPB where coral cover declined by around 80% - this was immediately adjacent to the DPA dredge operation and corals were smothered by sediments which remained in place for the remainder of monitoring;
- Seasonal competition with plants: At WINI and TDPL coral cover declined substantially between November 2003 and April 2004: scores for benthic cover of macroalgae and diver observations demonstrated that this was due to strong growth of *Sargassum* spp. overtopping the corals. Although some mortality occurred, once the *Sargassum* had disappeared (around June/July) coral cover figures recovered to close to original levels;

- Seasonal wave conditions: prior to the onset of Cyclone Monty (1-2 March 2004) and as a result of the cyclone, many sites experienced strong wave and swell conditions. At GIDI and ANGI coarse sediments and plant material liberated by the wave action was seen settling on corals – especially tabulate *Acropora* (which was only found in any abundance at these sites). Subsequent mortality of these individuals caused these Reference sites to fall by almost 10%.
- Cyclonic rainfall: during the passage of Cyclone Monty the Dampier Harbour experienced very heavy rainfall and runoff. Salinity of surface waters dived sharply (Stoddart & Anstee, this volume) and remained low for some time. Surveys immediately after the cyclone showed that corals exposed to low salinity surface waters and terrigenous sediments suffered very high mortality. Live coral at WLI2 was almost totally lost and the shallow transects at WLI1 were also affected. Some recovery of corals occurred with bleached colonies regaining zooxanthellae over a few months. Initially this was included in mortality estimates as it is not possible to identify whether bleached corals are alive or dead from recorded images.

$$p = \frac{s/\sqrt{n}}{\bar{x}}$$

Figure 2. Change in site means for coral cover from baseline values over the year (mean and 95% confidence intervals). The dotted line represents a 10% decline against baseline.

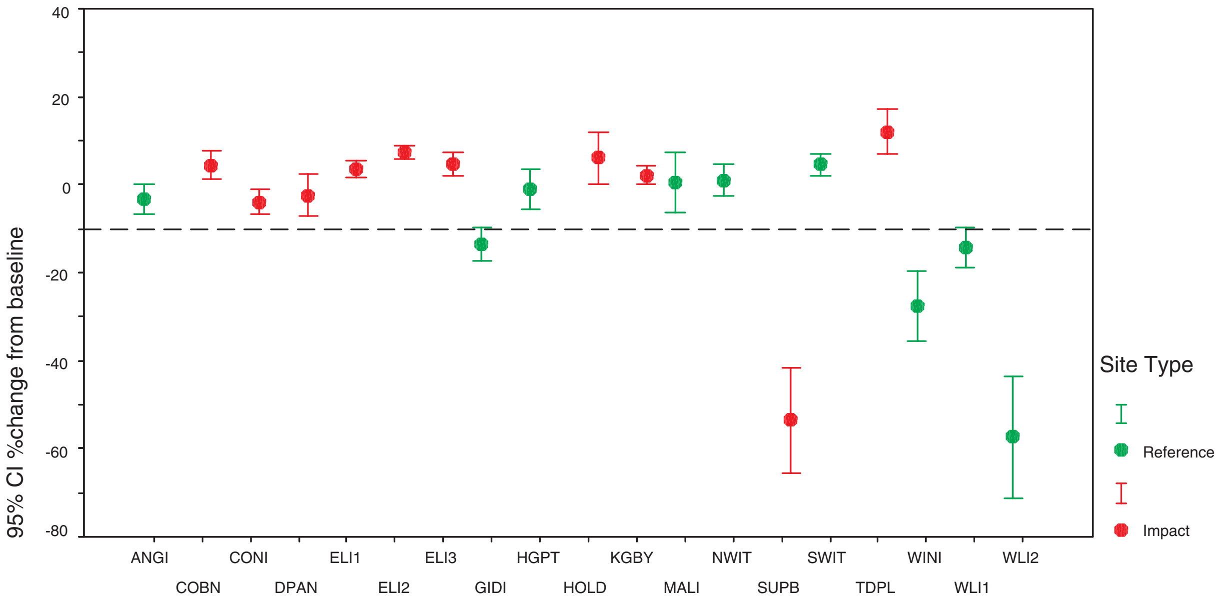
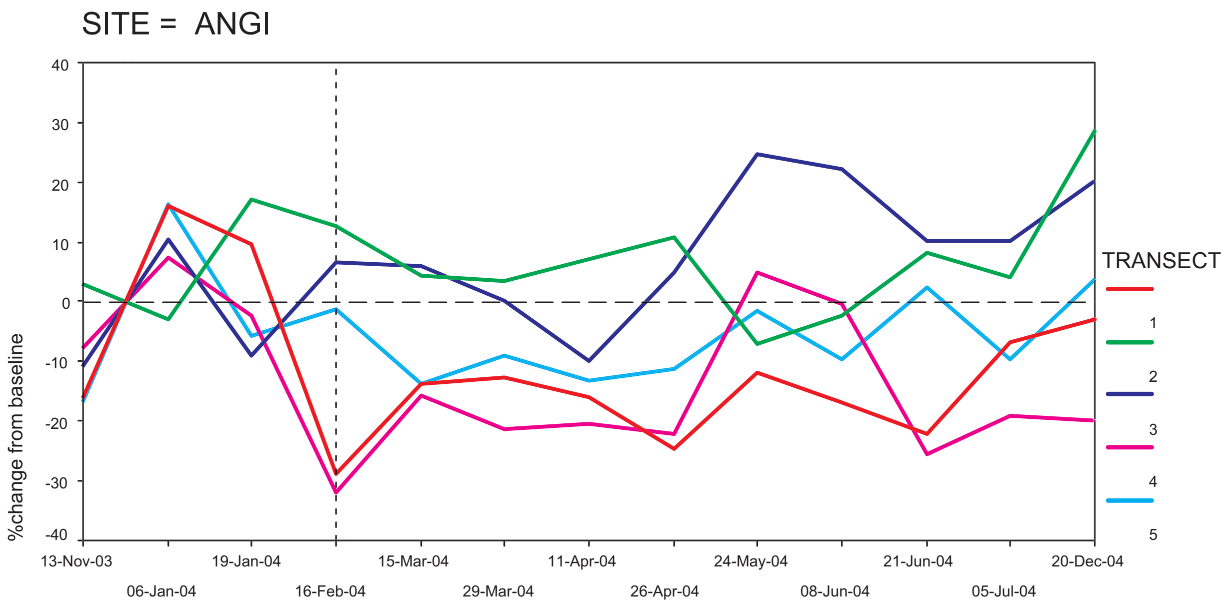
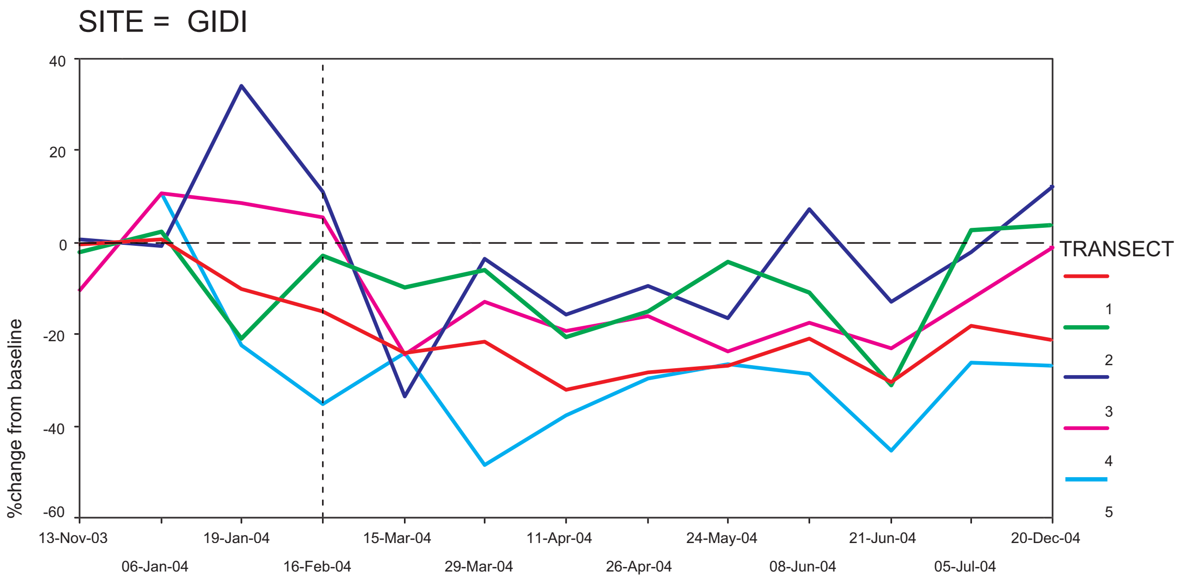


Figure 3. Differential from baseline during coral monitoring. Dotted line represents the last period before the impact of Cyclone Monty. a) Reference sites




SITE = GIDI
40
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%change from baseline
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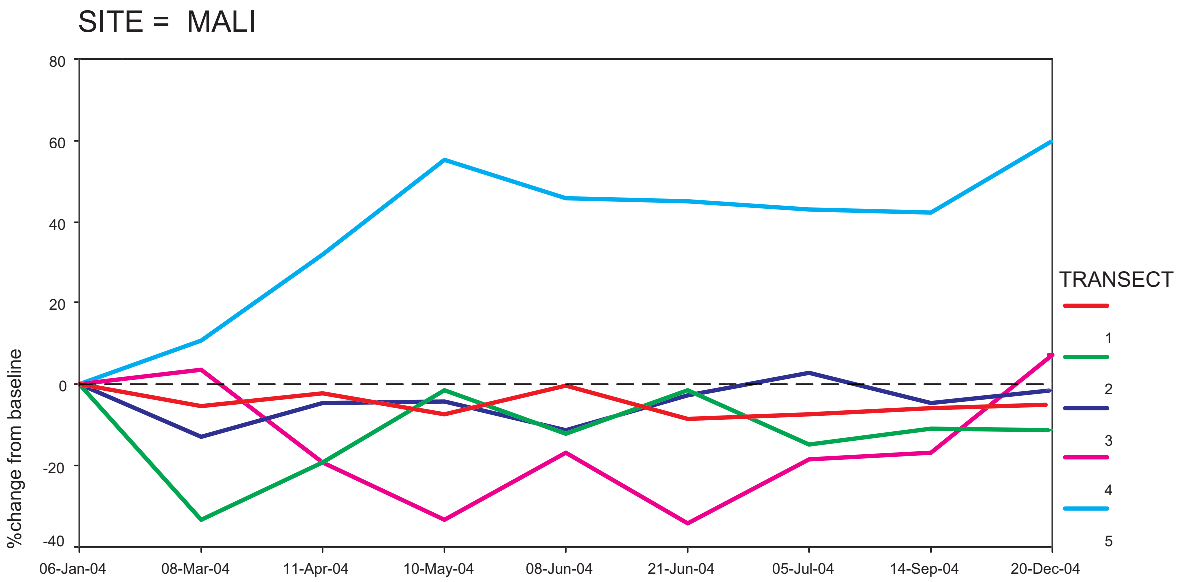
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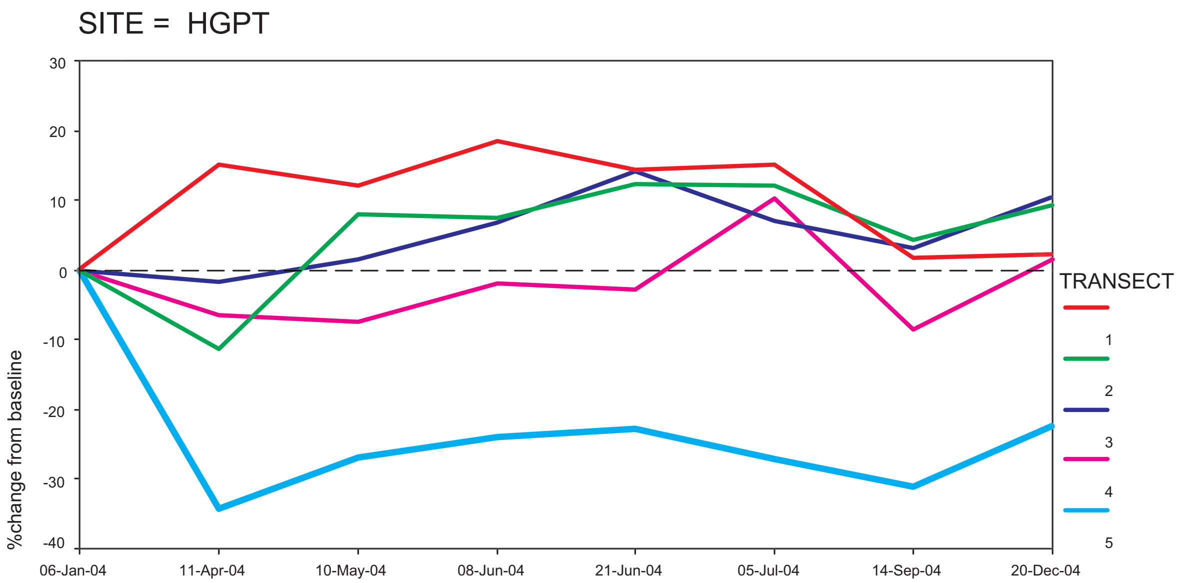
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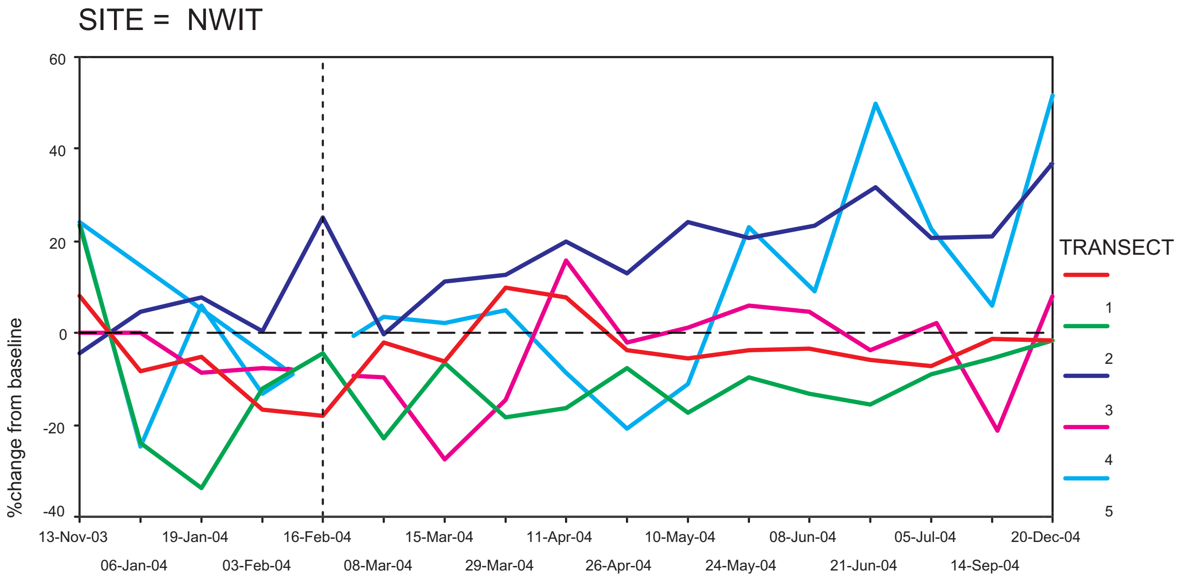
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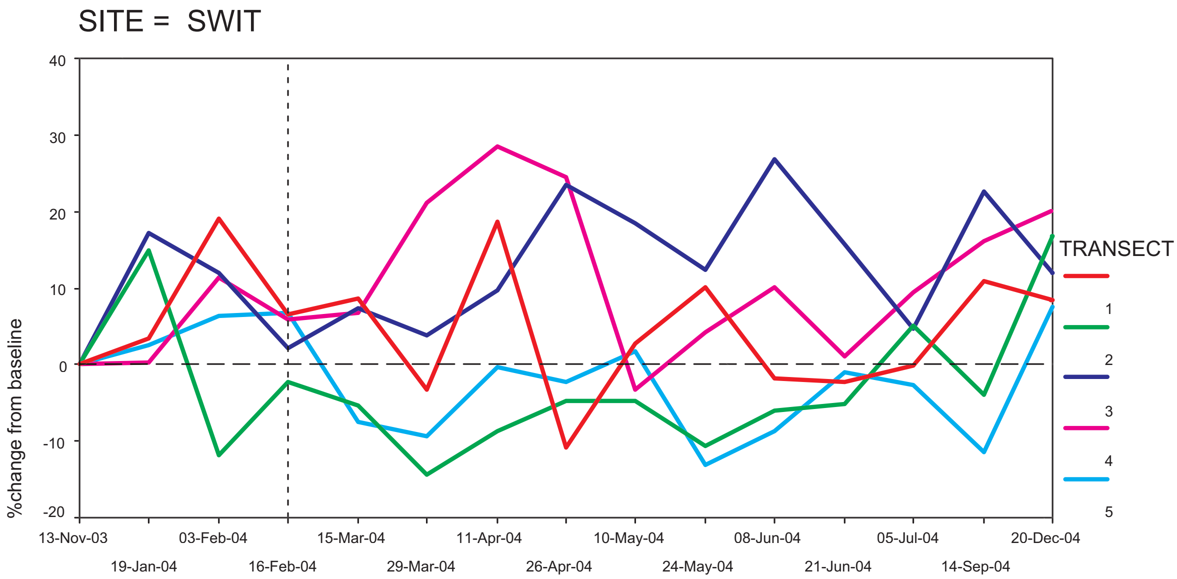
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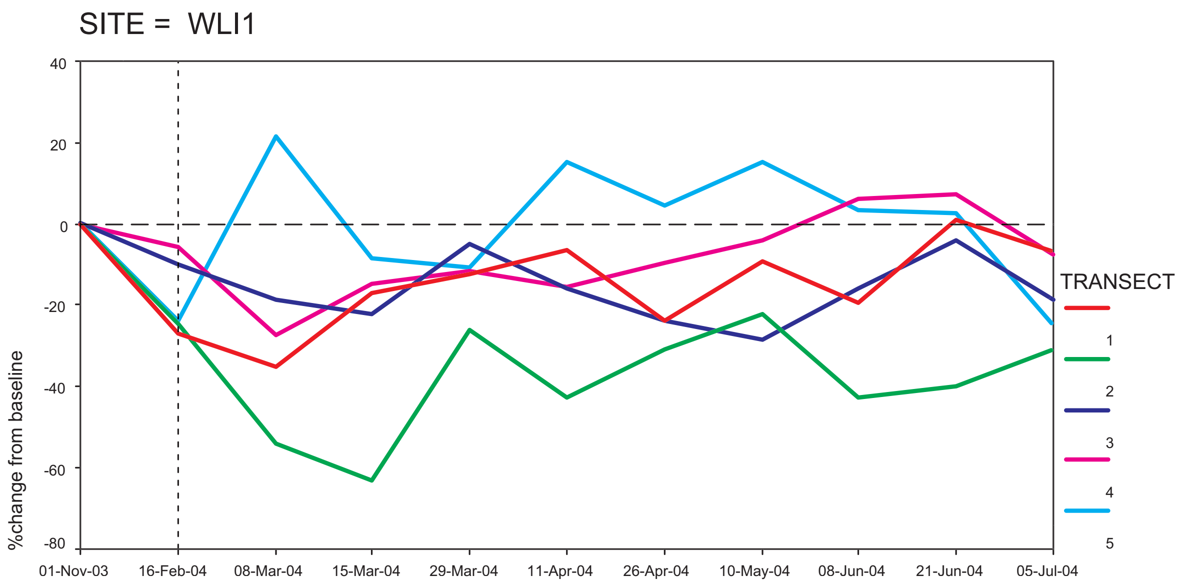
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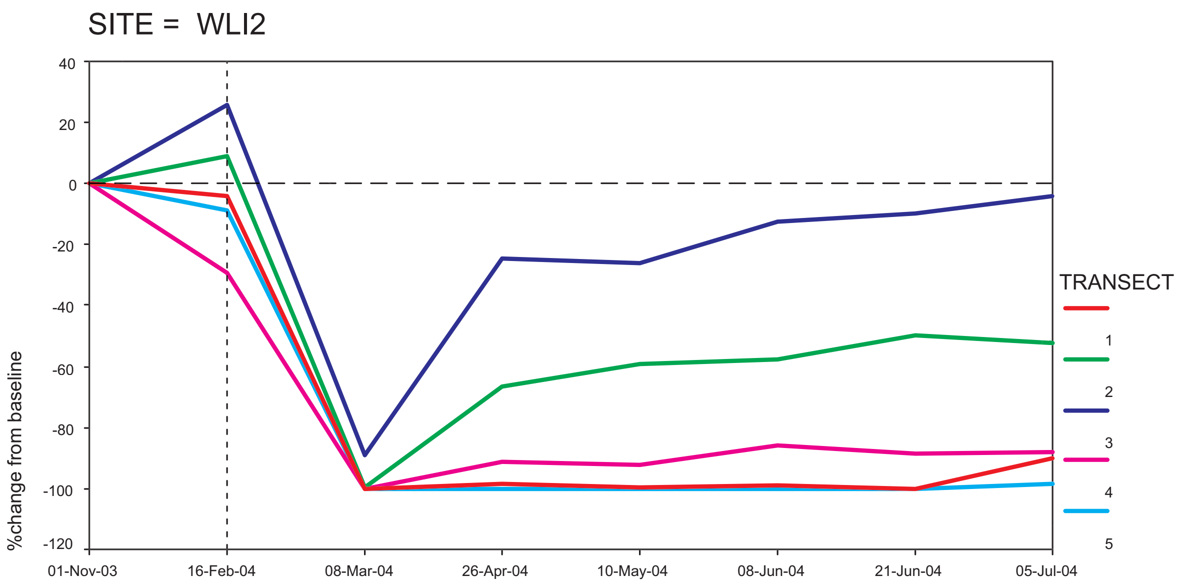
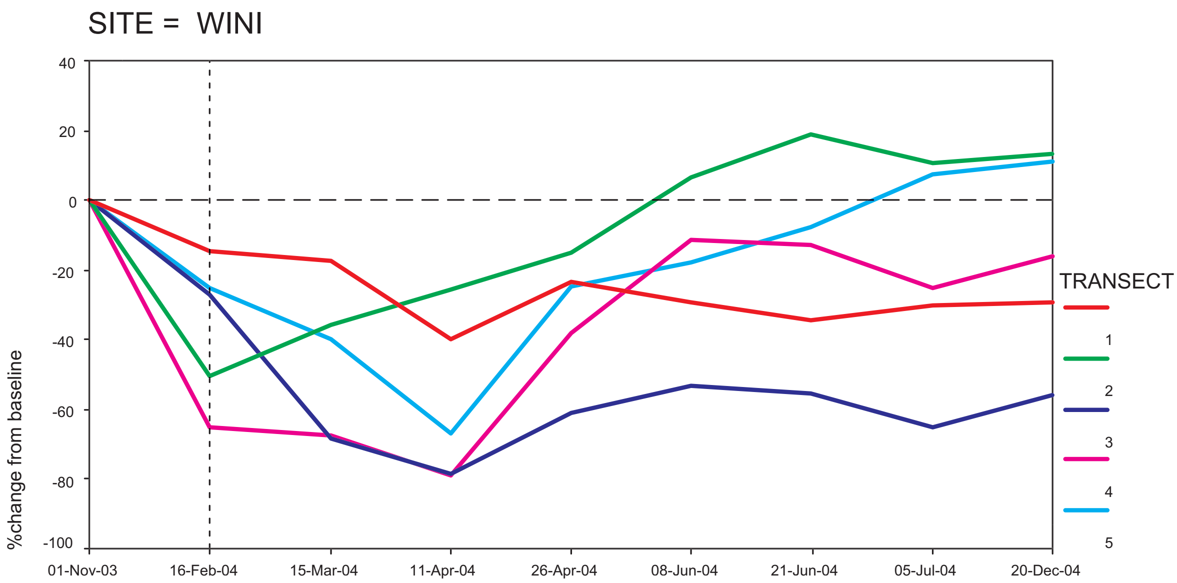
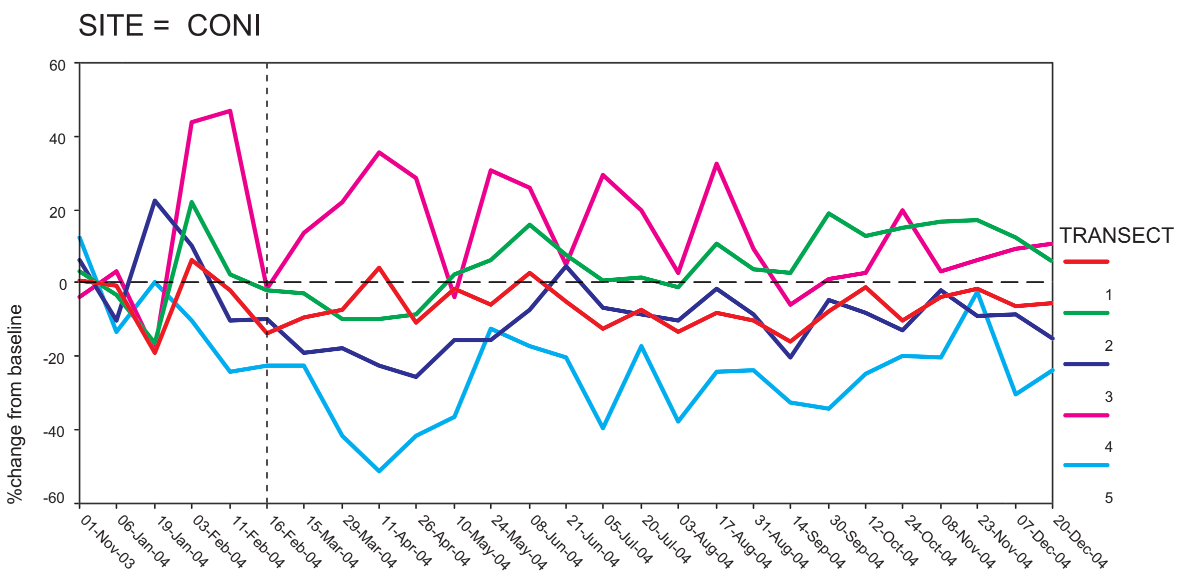




b) Impact sites



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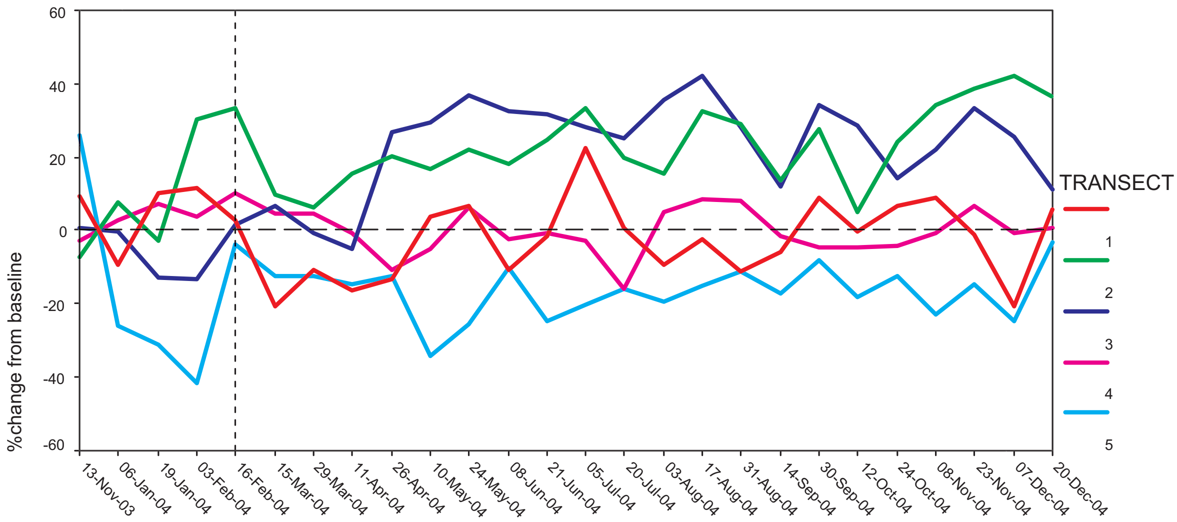

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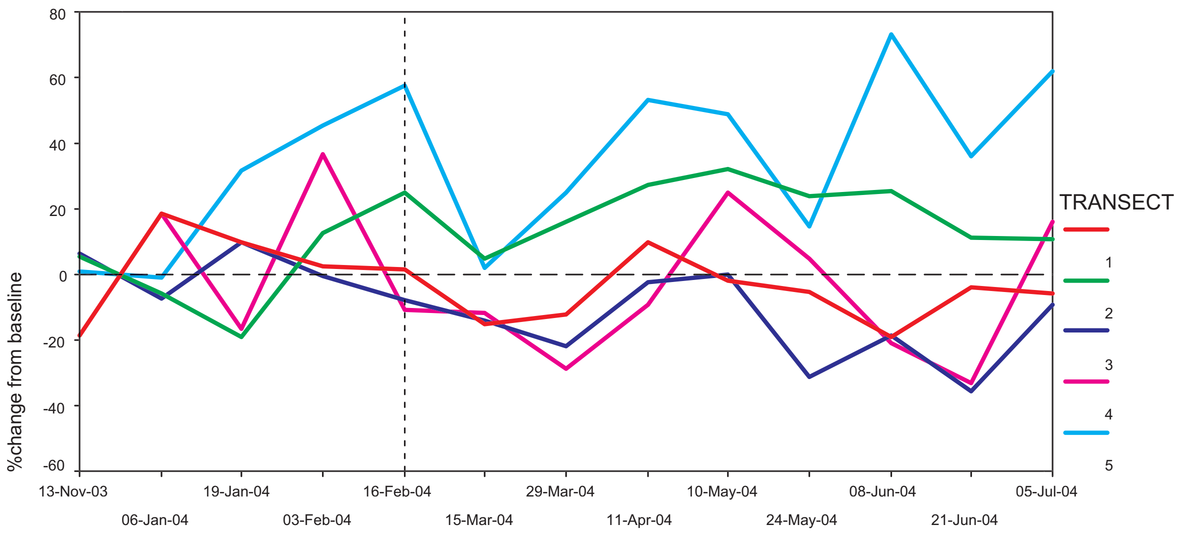

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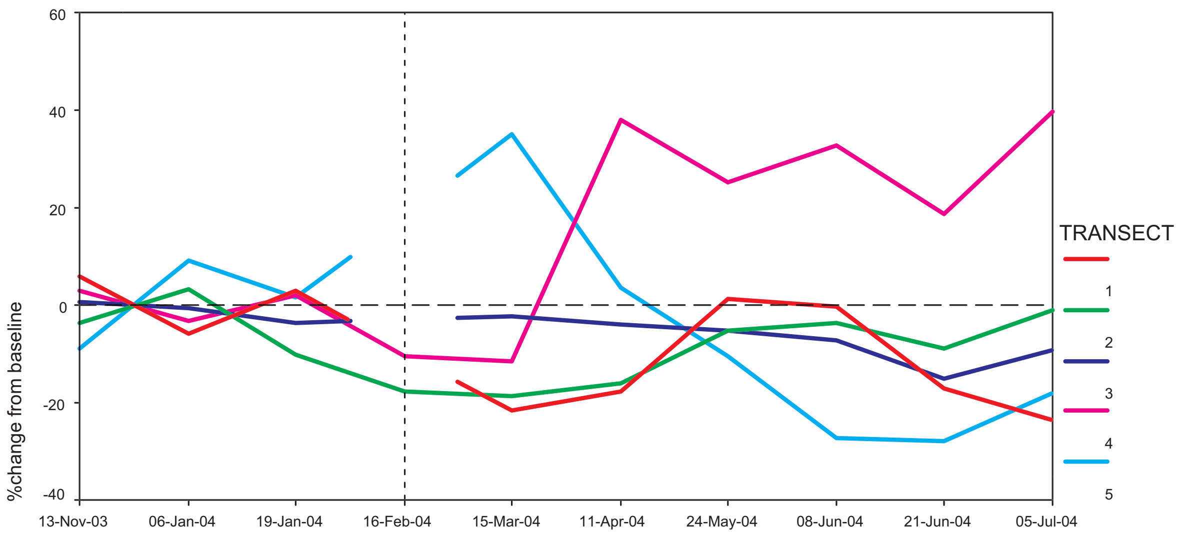

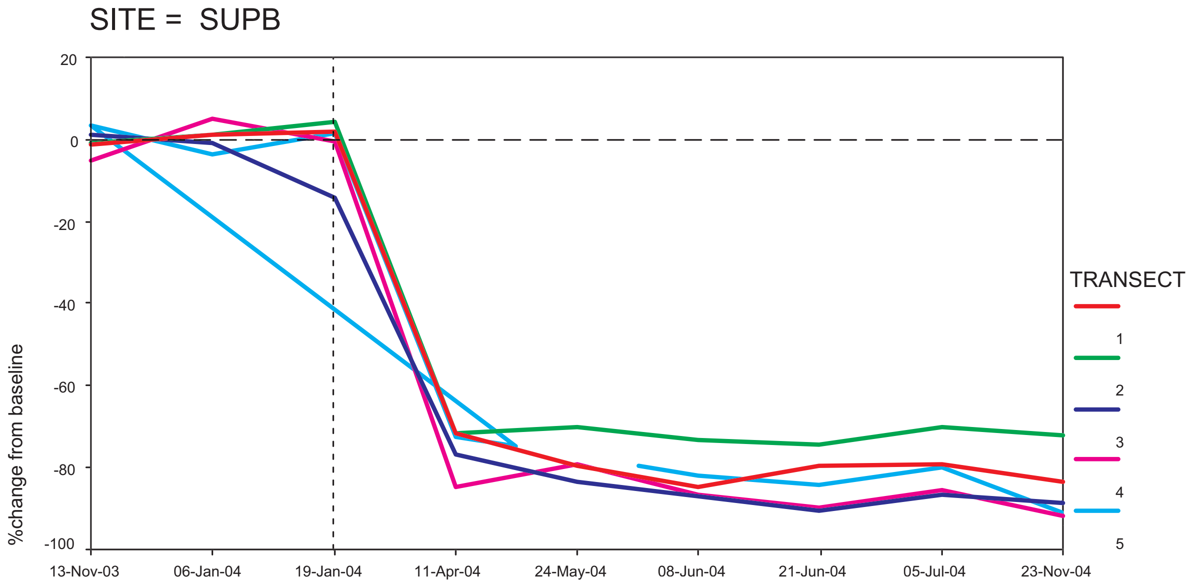
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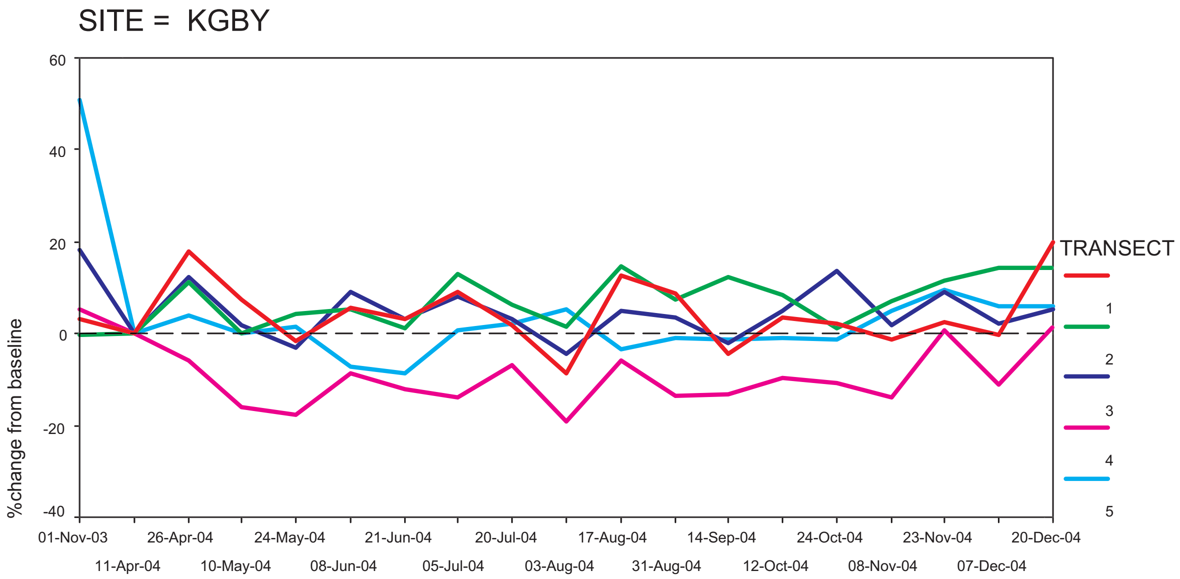
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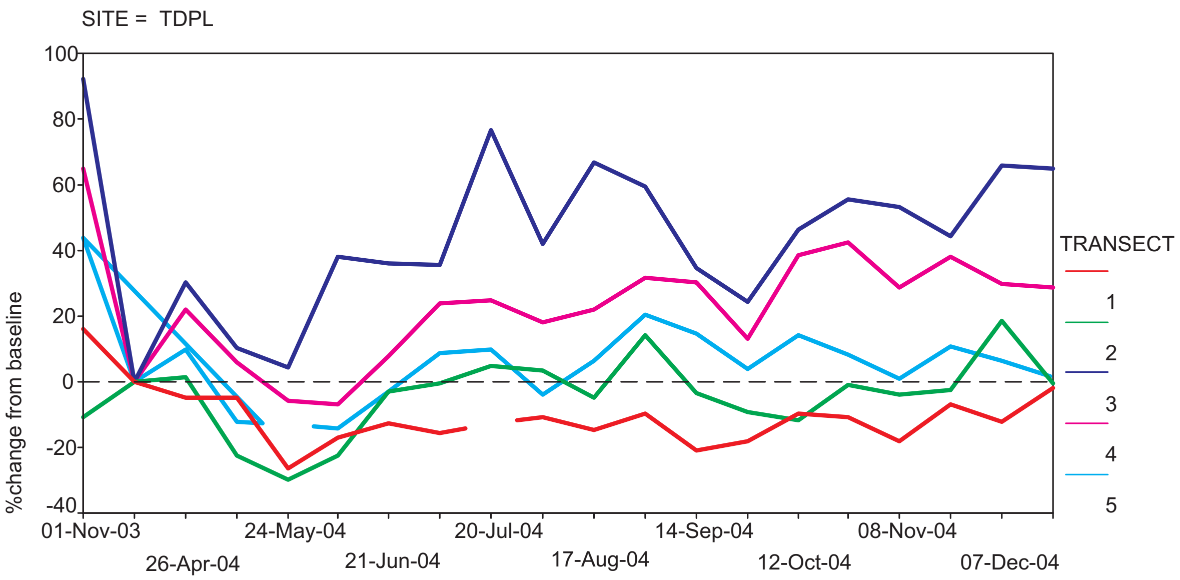
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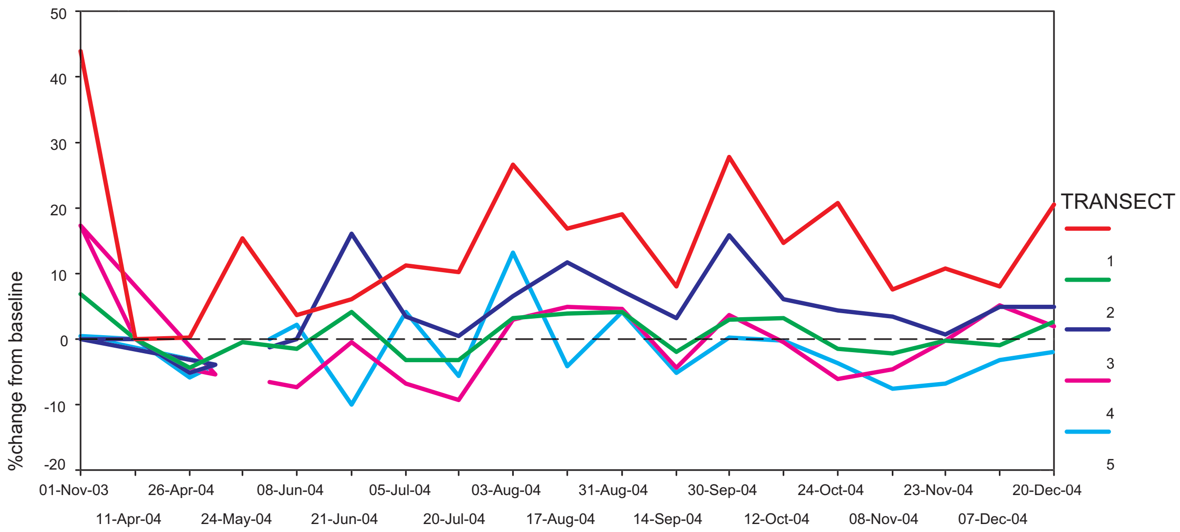

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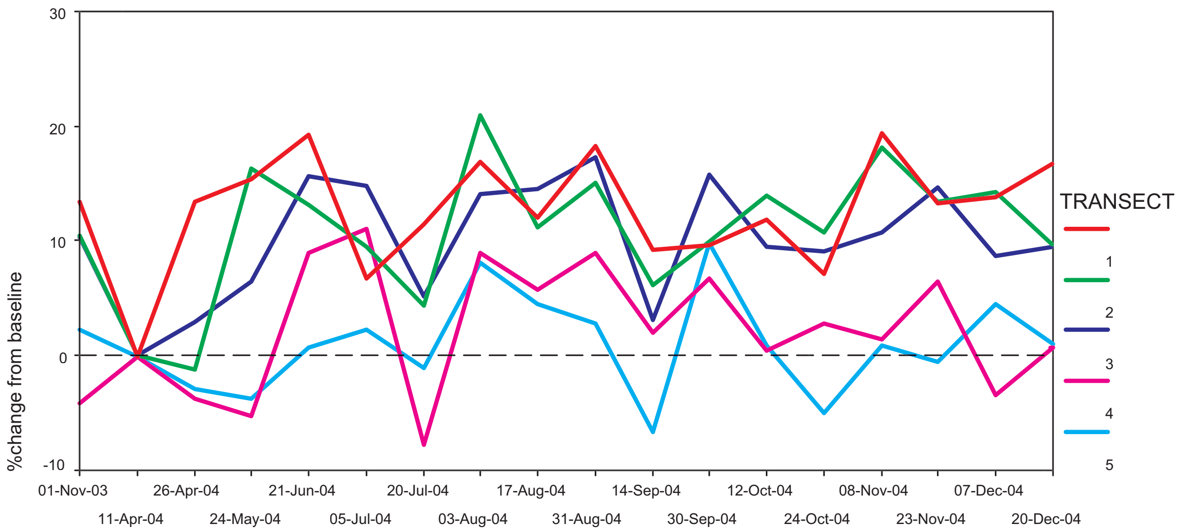

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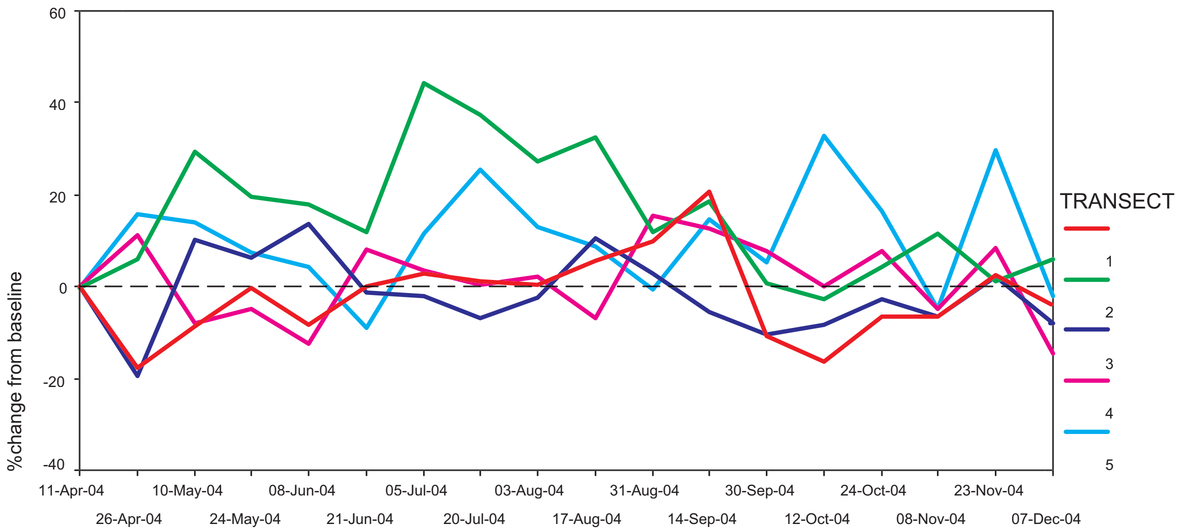


Sampling intensity & Power analyses

For comparability with earlier studies such as Harvey et al (2000), assessment of the effects of increasing the intensity of points sampled used precision (*p*) estimated as

where s = standard deviation and n = the number of estimates (here 6) – i.e. lower *p* values are more precise (higher power). The precision of estimates for the HOLD site with low (18%) and variable cover was substantially improved by raising the number of points sampled, but for the ELI2 site with higher (70%) and more even cover, increasing point sampling intensity was of marginal return (Fig. 4). Examining the confidence intervals for individual transects shows a similar outcome (Fig.5).

Examination of estimates of the power of this technique to detect a 10% decline in coral cover shows that power was heavily dependent on absolute level of coral cover at a site (Fig.6). This pattern resulted from a similar level of error variance for sites independent of the actual mean cover.

Figure 4. Effects of sampling intensity within images on precision.

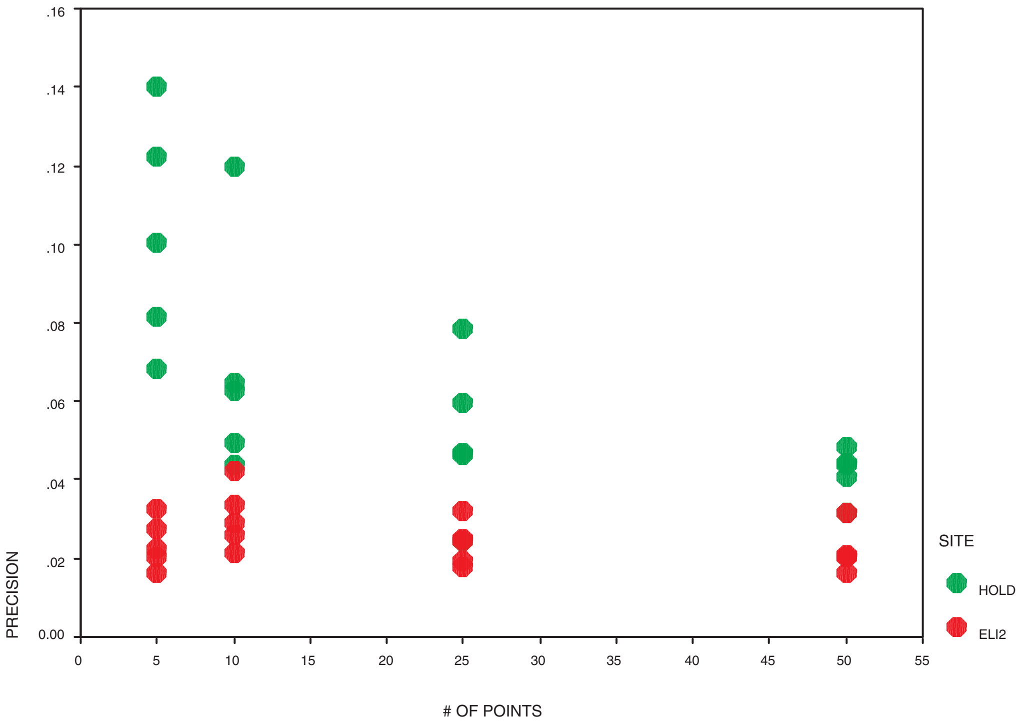


Figure 5. Confidence intervals and means for two sites with varying sampling intensity.

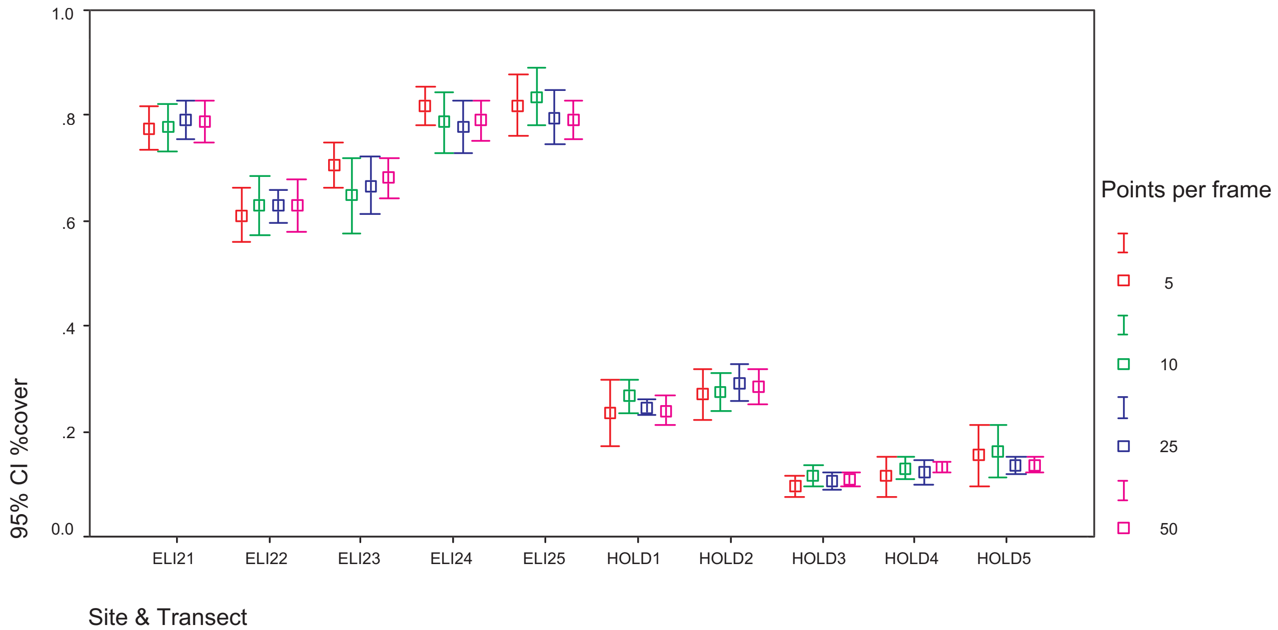
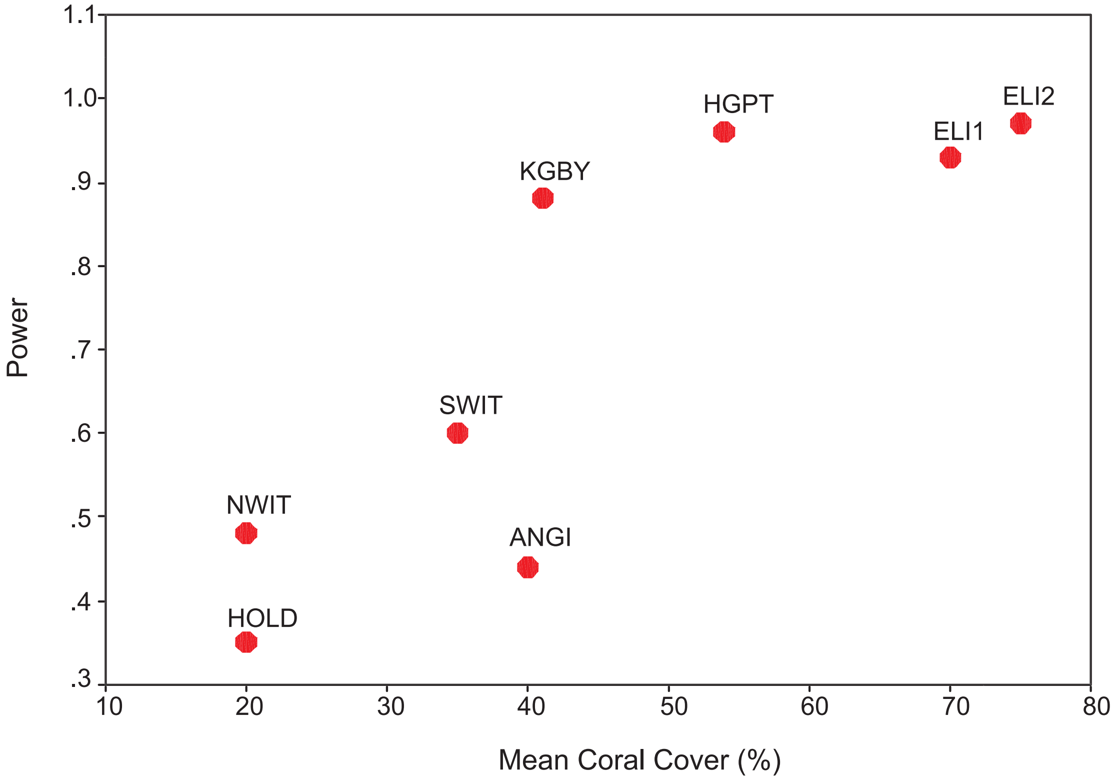


Figure 6. Power analysis for paired-tests of 10% decline.



Discussion

Changes in Dampier Harbour coral communities

The dynamic nature of coral communities has been well established and their continual cycles of disturbance and recovery documented in detail (Connell 1997). Coral communities are resilient to short-term impacts such as cyclones or predator outbreaks, from which they recover relatively rapidly (eg Connell et al 1997). However, chronic impacts such as overfishing or habitat destruction can force ecosystems into permanently altered states where coral communities disappear entirely (Pandolfi et al 2003).

Dredging impacts such as the resuspension of sediments during uplift or disposal are relatively brief in timescales relevant to coral ecology. Unless these impacts result in loss of habitat or in indirect long-term change to the environment such as changing the hydrodynamic or sedimentary environment, coral communities should recover to pre-impact states. Past monitoring of dredging effects in Dampier Harbour has suggested little or no change has occurred in coral cover as a result (Leprovost et al 1990; ECS 1998).

Over the 14 months of monitoring conducted for this program, the changes seen in coral abundance were principally the result of natural phenomena. The occurrence of Cyclone Monty at the beginning of March had a profound impact on the coral communities. Heavy swells and wind waves from the Category 4 cyclone (winds up to 280 km/hr) affected many of the sites, but the most damaging impact came from the rainfall (>300mm in 24hrs) and associated runoff. Surface salinity in many areas dropped dramatically (see Stoddart & Anstee, this volume) and a considerable amount of terrigenous sediment was deposited on corals.

Many of our monitoring sites showed a decline associated with the cyclone, but effects were most pronounced at WLI1 and WLI2 where the Maitland River freshwater plume overtopped the communities and mortality in the shallows along the entire southern shore of West Lewis Island was over 75%. Extensive mortality was also observed by divers in shallow coral communities around other islands where freshwater collecting in onshore catchments would have spilled into the sea. While initial visual estimates of coral mortality at many of these sites by divers were close to 100%, many individual corals were only bleached and regained their zooxanthellae (and thus colour) over the following months.

Following the extensive late summer rains associated with the cyclone, almost permanent freshwater seeps were observed around the WINI site and microalgal growth often obscured visibility or covered corals, leading to a decline in cover. Of greater impact at this site was the seasonal growth of the macroalgae *Sargassum* spp.. At WINI and at the TDPL site, summer growth of this species overtopped about 40% of coral – leading to an apparent decline in cover (with intercept points in images assigned to algae rather than coral). Although live coral cover rose rapidly following disappearance of the *Sargassum* over winter, it did not return to the level of spring 2003, suggesting that some coral had died as a result.

Elsewhere, wave action during strong weather has been documented as a natural cause of coral mortality. Despite the unusually high waves and swell recorded over many of our sites during Cyclone Monty, there was little evidence of physical damage. At Gidley Island (GIDI) where the coral community lies on a reef facing the ocean swells, strong swell conditions in late January/February were observed to deposit floating macroalgae and coarse sediments on many corals. In particular, this led to partial mortality of individuals of several species of *Acropora* causing coral cover to decline around 15-20%.

Dredging related mortality

The only site where mortality was related to dredging was at SUPB. Corals affected at that site were within a few hundred metres of intense dredging where propeller wash from constant positioning of a large trailer hopper suction dredge deposited substantial amounts of sediment directly on corals (Stoddart & Anstee, this volume). Blakeway (this volume) provides a discussion of the relationship between mortality and coral morphology at that site.

At sites between 500m and 1km from dredging and spoil disposal sites, coral communities were subject to turbidity levels elevated well above background for weeks at a time, or in very intense events of a few days (Stoddart & Anstee, this volume). No effects of this turbidity were apparent in cover estimates at these sites (HOLD, DPAN, ELI1, ELI2, ELI3, CONI) and at the East Lewis sites, several transects showed an increasing trend in cover.

Statistics of coral monitoring

The use of repeated estimates of coral cover to monitor coral mortality resulting from anthropogenic impacts or natural events is common. However, many reported studies provide little detail on the relationship between the statistical power of their methodology and the question they addressed. With considerable interest in the worldwide decline of coral reefs (Pandolfi et al 2003) much of the methodology used within research institutions or non government organisations (e.g. www.reefcheck.org) targets broad indicators which can be assessed rapidly over large areas of reef. The need for more precise repeatable estimates to detect small changes in coral communities has been recognised as requiring a different approach to monitoring (Brown et al 2004). Typically, the early detection of a decline in coral abundance (i.e. the start of mortality) associated with anthropogenic impacts is more likely to be successful using the latter methods rather than the former.

The requirement for this study was to provide a test design to detect a 10% effect size with a level of power appropriate to safeguard corals against an 'unacceptable level of mortality'. The latter was defined to be a 30% decline on which dredging near the effected site was to cease (EPA 2003a&b). In that regard, the post hoc estimates of power as varying between 0.35 and 0.95 suggest that the current design effectively met EPA requirements.

The positive correlation of power and mean coral cover appears to stem from 2 factors. Firstly, a 10% change in communities with sparse coral will be a smaller effect size than for more dense cover. Secondly, the variance of estimates between sampling events was relatively constant for many sites, resulting in the mean:variance ratio (an indicator of power) rising with mean coral cover. Where there is a requirement for monitoring programs to yield power above 50% for sparse coral communities, the only option may be to increase the number of transects surveyed.

Underwood and Chapman (2003) point out that in addition to the underlying distribution of the parameter being measured, power will also be a function of sampling error. A large variety of factors may influence apparent coral cover as a result of method error between setting foot in the water on each trip and results entering the database. One which played a large part here was the differences in depth and exposure to swell between the 19 sites. As well as having high coral cover, sites which returned high estimates of power were generally protected from strong wave action allowing divers to place and record transects accurately on most trips.

Our assessment of the importance of the sampling intensity of images for improving the precision of estimates of benthic cover agrees with the results of Harvey et al (2000) where coral cover is sparse (<30%). Where coral cover is more abundant (>60%) sampling intensity is less important and even the 5-point per frame scoring of the rapid survey techniques (Abdo et al 2003) can yield data with adequate precision.

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Patterns of reproduction of in-shore corals of the Dampier Harbour, Western Australia, and comparisons with other reefs.

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Abstract

Predictable mass-spawning over a few nights a year is a well established reproductive phenomenon in corals. However, corals show many other patterns of reproduction that may also vary between locations and communities. To date, the reproduction of corals from off-shore reefs has been better documented than that for corals growing in turbid near-shore environments. Management of near-shore communities requires a better understanding of their patterns of reproduction.

During the development of environmental protection plans for a major dredging program within the Dampier Harbour in 2004, concerns were raised that dredging and disposal during the predicted mass-spawning might pose an unacceptable hazard. The timing and magnitude of this risk was evaluated on assumptions that mass-spawning played a significant ecological role in these populations, similar to that described for off-shore populations in the nearby Dampier Archipelago.

A program was established in conjunction with the dredging environmental protection works to investigate the reproductive status of populations of corals in the Dampier Harbour during the period of mass-spawning. Based on distributional data, a large proportion of species belonged to families that are typically hermaphroditic mass-spawners. For these species (including many species of Faviidae and Acroporidae) the timing of gametogenesis and spawning during 2004 occurred as expected, and was split between the months of March and April because of the early full moon in March. However, some of the most abundant species of corals apparently did not participate in the mass-spawning, which included species of *Porites*, *Pavona* and *Turbinaria*, and the patterns of reproduction in these species remains uncertain.

Keywords: sedimentation, coral, reproduction, dredging

Introduction

General patterns of reproduction in scleractinian corals

Although knowledge of reproduction in corals has improved dramatically in the last few decades, there is still not a detailed understanding of cycles of gametogenesis and breeding for many species of corals at many locations. Nor is there a good understanding of how reproductive cycles of a single species may vary across their geographic range in response to genetic or environmental factors.

Scleractinian corals display four general patterns of reproduction, depending on their sexuality and how fertilisation and gametogenesis occur (Harrison and Wallace 1990, Richmond and Hunter 1990). These modes of reproduction are:

- Hermaphroditic brooders
- Hermaphroditic spawners
- Gonochoric brooders
- Gonochoric spawners

Hermaphroditic corals have male *and* female gametes within their polyps or colonies (sometimes sequentially), whereas gonochoric corals have separate sexes and either male *or* female gametes. In brooding corals, the eggs are fertilised within the colony's polyps and they develop into the larvae that are eventually released; whereas, spawning corals release both eggs and sperm synchronously and fertilisation, gametogenesis and larval development occur in the water column.

Most corals have distinct breeding cycles, and gametogenesis may occur monthly, seasonally, annually, or periodically among years (Fadlallah 1983, Harrison and Wallace 1990, Richmond and Hunter 1990). Gamete maturation often follows lunar or annual cycles, with egg development taking up to 10 months and sperm development around 3 months. Brooding corals tend to have one, two, or multiple gametogenic cycles within a year, and can therefore have overlapping gamete stages within a coral (Harrison and Wallace 1990). In contrast, most spawning corals have only one gametogenic cycle a year, although some populations and even some individuals have multiple cycles (Harrison and Wallace 1990, Oliver et al. 1988, Mildner 1991, Stobart et al. 1992). The number of gametogenic cycles within populations and individual corals is strongly influenced by environmental conditions and the levels of disturbance to which they are exposed (e.g. Szmant Froelich et al. 1980, Robertson 1981, Harrison and Wallace 1990). Corals in optimal conditions may reproduce many times within a year, whereas those under disturbed conditions may not reproduce at all.

Gametogenesis culminates in the maturation of gametes for breeding, when the mature eggs are either fertilised within the polyp (brooders) or in the water column (spawners). Breeding most commonly occurs during the night in late spring, summer, or autumn, but has been documented at other times (Harrison and Wallace 1990, Richmond and Hunter 1990). The proximate cues for breeding are not known; temperature certainly plays an important role, but solar insolation, day length, moonlight and tide cycles are also influential (Harrison and Wallace 1990, Richmond and Hunter 1990, Penland et al. 2004). Gamete maturation is usually synchronised within an individual, and to varying degrees among individuals within a population. Breeding and larval development is less synchronous among brooding corals, and can occur over a protracted period of consecutive months (Harrison and Wallace 1990, Richmond and Hunter 1990, Tanner 1996). Breeding by most spawning corals is more synchronous than for brooders, and on some reefs a remarkable number of hermaphroditic spawning corals release gametes over just a few nights a year within one or two months, but on most reefs spawning is more protracted over a few months during a breeding period. Breeding periods tend to be less synchronous among gonochoric spawners (Harrison and Wallace 1990).

Many corals have been documented to participate in mass-spawning events on reefs around the world, but there is considerable variation in this general pattern of reproduction. There are still few long-term studies documenting the proportion of colonies and species that spawn their gametes during different months, but patterns clearly vary among regions, years, and species (Simpson 1988, Harrison and Wallace 1990, Richmond and Hunter 1990, Oliver et al. 1988, Babcock et al. 1994, Baird et al. 2001, Guest et al. 2002).

The mass-spawning paradigm was born out of research conducted on the Great Barrier Reef, where the greatest number of corals and species spawn synchronously over short periods each year (Harrison et al. 1984). On other reefs around the world, such as those around the equator, Okinawa, or Hawaii, spawning is far less synchronous and occurs over a greater number of months (Harrison and Wallace 1990, Richmond and Hunter 1990). In the Caribbean and Red Sea, there is comparatively little synchrony in spawning (Shlesinger and Loya 1985, Harrison and Wallace 1990). The time of mass-spawning within a location also varies by days or months among years, of which a notable example is the case of split-spawning (Willis et al. 1985). Split-spawning occurs over consecutive months when the full moon comes early in the first month and not all colonies have mature gametes. In addition to regional and temporal variation in the time of spawning, patterns of spawning and even modes of reproduction vary within some species.

Patterns of reproduction in scleractinian corals on Australian reefs

On corals reefs around Australia, reproduction has been best studied for hermaphroditic spawning corals on the Great Barrier Reef. There, around 100 species of corals have been reported to spawn within three to six nights after the full moon in October or November, and many more over the nights either side of this period (Babcock et al. 1986). However, there is variation in the pattern of mass-spawning, which can occur days before or after the predicted dates, a month earlier on near-shore reefs, and even during different seasons for some species in some regions. Additionally, there is evidence of populations and some individuals spawning twice a year, in October/November and in March/April on the Great Barrier Reef (e.g. Stobart et al. 1992, Wolstenholme 2004).

The release of larvae by brooding corals on the Great Barrier Reef is less understood, but tends to follow a lunar cycle and occurs over consecutive months, often during the spring or summer (Harrison and Wallace 1990). However, there is apparently considerable variation in this pattern and detailed cycles of gametogenesis and larval release have been described for only a few brooding corals on the Great Barrier Reef (e.g. Kojis 1986, Tanner 1996).

On Western Australian reefs, synchronous mass-spawning events have also been documented (Simpson 1985, Babcock et al. 1994). In contrast to the Great Barrier Reef, mass-spawning on Western Australian reefs occurs around six to ten nights after the full moon, in early autumn during March and/or April. At present, there is no accepted explanation as to why mass-spawning should occur in early Autumn on Western Australian reefs but in late Spring on the Great Barrier Reef (see Simpson 1985, Babcock et al. 1994).

Timing of mass-spawning on Western Australia reefs is similar to that of some corals on Indo-Pacific reefs near the equator (Oliver et al. 1988, Baird et al. 2001, Guest et al. 2002). At Scott Reef, in far north Western Australia, there are two mass-spawning events each year; a secondary spawning at the same time as on the Great Barrier Reef and a primary spawning at the same time as most other corals on Western Australian reefs, with evidence that some populations participate in both events (Australian Institute of Marine Science (AIMS) , unpublished data). On reefs further south in Western Australia, mass-spawning events of similar magnitude have not been documented during October/November, but some species do spawn in October/November, in January, and possibly other months around this period (AIMS, unpublished data).

Patterns of reproduction in scleractinian corals in the Dampier Archipelago

Mass-spawning by corals on mid- and off-shore reefs within the Dampier Archipelago was originally described by Simpson (1985) and occurs at the same time as other reefs in Western Australia in March/April. Spawning typically occurs around six to ten nights after the full moon on neap tides and involves many colonies of around 50 species of corals, although more than 80% of these species belong to the Families Acroporidae and Faviidae (Simpson 1988). In addition to the March/April spawning, mature eggs have been observed in many colonies of at least three species of *Acropora* during October/November over two years (AIMS unpublished data). The proportion of colonies and species that participate in the October/November spawning is not known, but it is certainly a smaller spawning event. Simpson (1988) sampled intensively during this period but found no mature gametes.

Patterns of reproduction by corals on near-shore reefs of the Dampier Archipelago have not been described. Indeed, patterns of reproduction have not been described for many of the dominant corals on near-shore reefs around Australia, as research is usually conducted on hermaphroditic spawning corals on mid- or off-shore reefs. Near-shore reefs tend to have many species of corals that are not hermaphroditic spawners and whose patterns of reproduction are more difficult to describe.

Within the Damper Harbour, the relative abundance of species of corals differs from that on the off-shore reefs of the Dampier Archipelago (Blakeway & Radford, this volume). The most abundant corals are evenly split between species that have been described elsewhere to mass-spawn, and species that either do not mass-spawn or whose modes of reproduction are poorly described. Many of the most abundant corals on near-shore reefs include species of *Porites*, *Pavona* and *Turbinaria*, which are generally not hermaphroditic spawners. Simpson (1988) found no evidence of colonies of these genera with ripe eggs or larvae on off-shore reefs in the Dampier Archipelago prior to the mass-spawning, but mature eggs have been observed in female *Porites* colonies on off-shore reefs in other years prior to the mass-spawning (unpublished data).

The Dredging Program

During January to May 2004, the Dampier Port Authority (DPA) undertook a substantial dredging program within the south-east of Mermaid Sound in the Dampier Harbour (Figure 1). Dredging involved removal and disposal of over $4Mm^3$ of spoil to complete the construction of a new berth and channel as part of the Bulk Liquids Berth Project (Stoddart & Anstee, this volume).

The project was referred to the Western Australian Environmental Protection Authority (EPA) in September 2003 and the recommendations of the EPA (EPA 2003) included a variety of controls in response to concerns that elevated levels of sediments or water turbidity may adversely impact coral reproduction. EPA recommendations included cessation of dredging during mass-spawning and investigation of the impacts of dredging on coral reproduction, especially spawning. In response to these concerns, the Dampier Port Authority's Interim Environmental Management Program (DPA, 2003) required an investigation into the proportion of species and corals participating in the mass-spawning during March and April 2004. Programs were conducted within this study to investigate the timing and distribution of gametogenesis in corals adjacent to the dredging and spoil disposal areas.

Methods

Site Locations

Study sites were chosen that:

- could be easily located
- had an abundance of species known to participate in mass-spawning elsewhere
- were within the predicted area of increased turbidity and sediment deposition resulting from spoil disposal, or
- were beyond the predicted area of impact from spoil disposal

On this basis, the following sites were selected (Figure 1):

- Impact Sites – Conzinc Island (CONI), Conzinc Bay (COBN)
- Control Sites – Angel Island (ANGI), North Withnell Bay (NWIT)
- Observation site – east of the Dampier Public Boat Ramp (TCIR)

Table 1. Timing of field surveys around the predicted dates of mass-spawning in March and April 2004

Trip	Dates	Objective
1.	8-10 March 2004	Initial establishment of survey sites and the inspection of coral fragments to determine the developmental stage of their gametes
2.	14-17 March 2004	Inspection of coral fragments during the March spawning
3.	29-30 March 2004	Inspection of coral fragments after the March spawning and during the April spawning
4.	10-15 April 2004	Inspection of coral fragments prior to the April spawning

The Observation site was accessible from the shore at night so that corals could be checked for their participation in the mass-spawning.

Sampling events

Field surveys were conducted during 5 trips, which spanned the predicted period of mass-spawning within the Dampier Archipelago in 2004 (Table 1). During these trips, sampling was focussed on species from the families Acroporidae and Faviidae, which are widely documented to participate in mass-spawning (Willis et al. 1997), in addition to the species from other families that were most abundant within the study area.

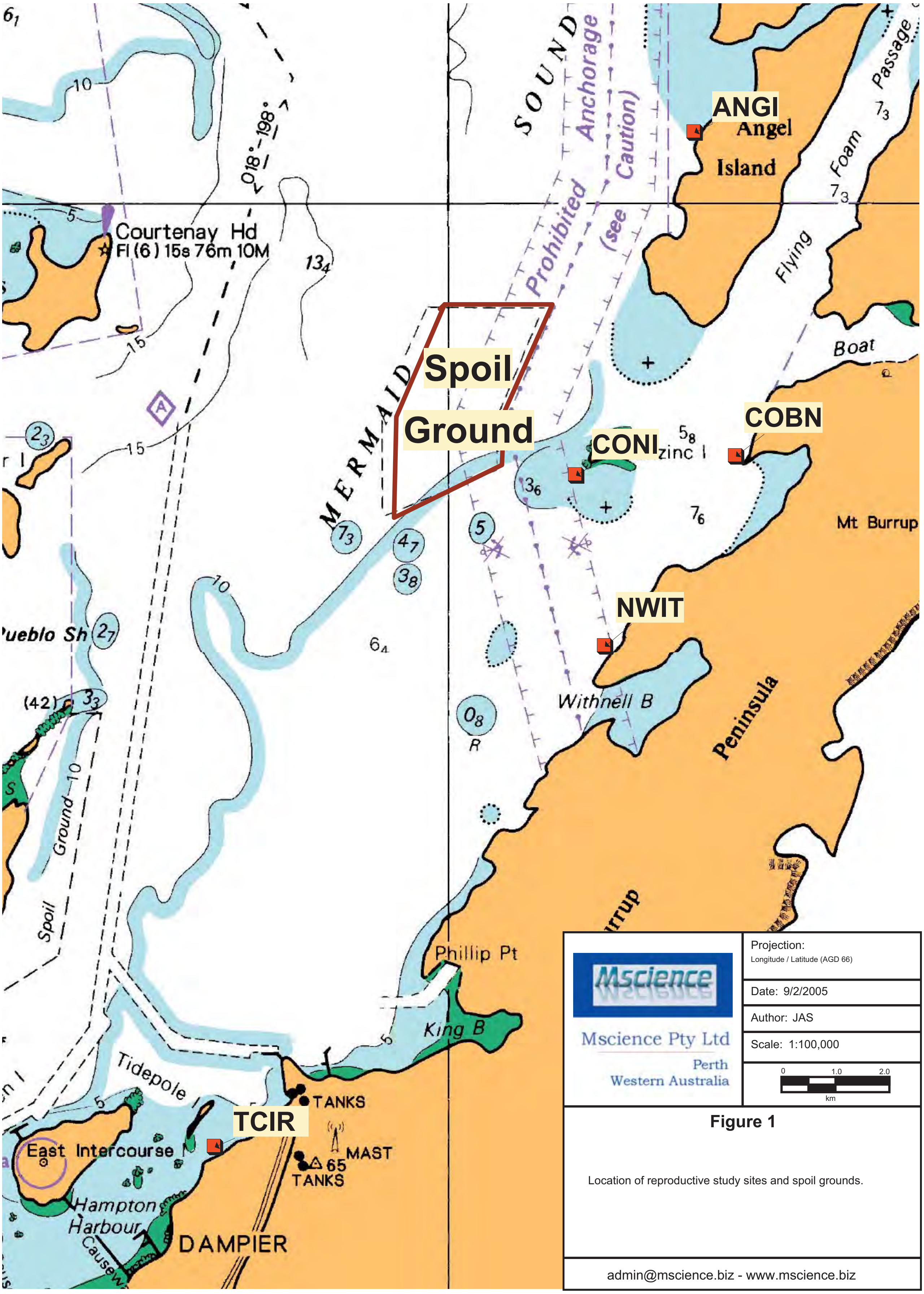
Trip 1: 8-10 March 2004

The first trip was postponed from 1-5 March due to Cyclone Monty, and conducted from 8-10 March in a limited extent because poor visibility prevented sampling at many sites. Some sites examined during this trip were severely impacted by freshwater inundation following rainfall from Cyclone Monty over a 24-48 hr period.

During the 8-10 March, divers investigated all Impact and Control sites to determine where visibility was sufficient to allow sampling. Of the sites visited, sampling was only possible at Impact Site COBN and Control sites NWIT and ANGI. At COBN, poor visibility made it impossible to locate 20 replicate colonies of different species, and replicate colonies of *Acropora* were not tagged as planned because of their sparse distribution.

A variety of species and replicate colonies of the most abundant species, were sampled. The tips of branching corals were broken below the area of recent growth and polyps examined *in situ*. Massive and sub-massive colonies were cracked with a hammer and chisel to examine polyps away from the growing edge. Samples of colonies were examined microscopically when the developmental stage of their gametes was not obvious *in situ*. Depending on the developmental stage of the gametes within polyps, colonies were scored at:

Figure 1. Location of reproductive study sites and spoil grounds.



- Stage 1: spermaries were full, eggs were large and pigmented, spawning was likely in March
- Stage 2: eggs were medium to large, not pigmented, spawning was likely in April
- Nil: no sperm or eggs were observed

Trip 2: 14-17 March 2004 (predicted spawning)

Three methods were used to determine whether corals participated in the mass-spawning in March:

1. Dives 1-2 hours after sunset at the Observation site over a patch of near-shore reef to the east of the Dampier Public Boat Ramp to directly observe spawning;
2. Indirect tests looking for the 'next day' evidence of spawning, such as the presence of eggs or slicks of spawn around bays and other sites where slicks would have been located from these inshore sites
3. Direct 'next day' tests looking at the disappearance of eggs from corals in populations tested previously.

While species of *Acropora* are most often used for the observation of spawning in the field, these do not occur in abundance in near-shore communities in Dampier. Consequently, the Observation site was chosen because it had species of Faviidae and Mussidae that had been seen elsewhere with eggs. 'Next day' tests looking for the disappearance of eggs from corals following the predicted dates of spawning were conducted at several reefs with populations of *Acropora*.

Trip 3: 29-30 March 2004

Corals were sampled as for Trip1 to determine whether they participated in the March spawning, except that all scoring was undertaken on shore. Corals were scored using a hand lens or under a dissecting microscope.

To determine whether corals would participate in the April spawning, a range of species of *Acropora*, Faviidae and Mussidae were sampled.

Trip 4: 10 -15 April 2004 (predicted spawning)

The three methods used in Trip 2 were again used to determine whether corals participated in the April spawning. However, the 'next day' examination of gametes was only done for *Acropora* species at NWIT, which was identified as the site with the highest proportion of colonies with mature eggs in Trip 3.

Trip 5: 27-30 April 2004.

To determine whether corals participated in the April spawning, fragments of colonies of *Acropora* and Faviidae were scored *in situ* and microscopically.

Table 2. Gamete stages within colonies of different species sampled *in situ* during Trip 1 (8-10 March 2004)

Family	Species	Site	Status		
		(sample size)	**1**	**2**	**X**
Acroporidae	*Acropora* sp.1	NWIT (14)	5	8	1
		COBN (12)	4	6	2
		ANGI (19)	1	14	4
	Acropora sp.2	NWIT (15)	4	10	1
		COBN (10)	2	7	1
		ANGI (12)	0	12	0
	Other *Acropora*	NWIT (5)	2		3
		COBN (0)	-	-	-
		ANGI (6)	2	2	2
Dendrophylliidae	*Turbinaria* spp	NWIT (6)			6
Faviidae	Various	NWIT (21)			21
		COBN (14)			14
		ANGI (9)	2		7
Oculinidae	*Galaxea fasicularis*	NWIT (2)			2
		ANGI (2)			2
Mussidae	*Lobophyllia hemprichii*	NWIT (1)			1
Poritidae	*Porites ?lobata?*	NWIT (3)			3

Results

Gamete Development in Corals

Samples of over 250 corals from 20 species were examined. Of these, only species of *Acropora* were scored *in situ*. Eggs were visible within fragments of a few faviids *in situ*, but most were examined microscopically. Approximately 100 individuals from 18 species were examined microscopically during Trips 1 and 3.

Acroporids

When observed in early March, approximately 25% of colonies (n=109) of seven species of *Acropora* appeared ready to spawn in March, having Stage 1 eggs (Fig. 2), and approximately 50% of the colonies were expected to spawn in April, having unpigmented Stage 2 eggs (Table 2, 3). *In situ* observations of eggs indicated some variation in gamete maturation among colonies within species at each of the sites, although there was less variation among individuals examined microscopically.

Table 3. Gamete stages within colonies of different species examined microscopically during Trip 1 (8 – 10 March 2004)

Family	**Species**	**Sampled**	**Status**			
			# with eggs	**colour**	**size* (um)**	**spawn**
Acroporidae						
	Acropora sp.1	4	4	cream	400	April
	Acropora sp.2	3	3	cream	400	April
	Acropora sp.3	2	2	white	300	April
	Acropora sp.4	2	2	red	500	March
	Acropora sp.5	1	1	red	600	March
	Acropora sp.6	2	2	red	450	March
	Acropora digitifera	4	3	red	500	March
			1	cream	400	April
Agariciidae	*Pavona decussata*	5	0			?
Dendrophylliidae	*Turbinaria* spp	3	0			?
Faviidae						
	Favites abdita	2	1	red	250	March
			1	cream	200	April
	Favites pentagona	1	1	green	150	April
	Goniastrea australensis	5	5	cream	200	April
	Goniastrea retiformis	3	3	white	150	April
	Goniastrea sp.	2	2	pink	300	March
	Platygyra sinensis	3	3	red	250	March
	Montastrea curta	1	1	green	200	March or April
Oculinidae	*Galaxea fasicularis*	3	2	red	300	March
			1	cream	200	April
Mussidae	*Lobophyllia hemprichii*	1	1	cream	200	April
Poritidae	*Porites ?lobata?*	4	0			?

*- modal egg size

Resampling in late March was also consistent with a split-spawning by the *Acropora*, with almost 30% of colonies expected to spawn in April, almost 70% lacking eggs, and 3% having unpigmented eggs that were potentially spawned in May (Table 4).

During both Trip 1 and Trip 3, there was a consistently lower percentage of colonies with mature gametes at the ANGI site than at any of the other sites examined (Table 5).

Faviids

Microscopic examination of fragments of several species of Faviidae indicated that around half were ready to spawn in March, and half in April (Table 3, 4). Gamete development appeared consistent among individuals, but replication was limited. Resampling in late March confirmed the pattern of split-spawning by faviids during March and April, with some indication of variation among different species. All of the colonies of *Platygyra sinensis* that were sampled contained ripe eggs in March and April (Fig. 3), but samples were collected from different sites during each month. Some *Goniastrea* spp. from the different sites had ripe and immature eggs in March, and ripe eggs in April. *Favites halicora?* from the different sites consistently had ripe eggs in April, but was not sampled prior to the March spawning.

The most abundant species within the study area were in the genera *Pavona*, *Turbinaria* and *Porites*. During Trips 1 and 3, fragments of these species from all sites were examined to search for the presence of eggs or sperm (Table 2, 3, 4). Five colonies of *Pavona decussata*, 13 colonies of *Turbinaria* sp., and 4 colonies of *Porites lobata*(?) were sampled, and no gametes were observed in any of the polyps examined.

Observations of Spawning

Field and microscopic observations reported above confirmed that ripe eggs occurred commonly in many species (and individuals within species) prior to the predicted dates of spawning. Despite many dives from 1-2 hours after sunset during both the predicted spawning periods, no spawning or corals displaying eggs in the polyp mouth were seen. Neither were any slicks of floating spawn observed, despite calm conditions over much of both periods.

Discussion

Reproductive patterns in Dampier Harbour Corals

Spawning behaviour of corals at the inshore Dampier Harbour during 2004 was not uniform and was probably less synchronous than for the off-shore coral communities. Some of the most abundant species of inshore corals in the Dampier Harbour (species of *Turbinaria* and *Pavona*) do not mass-spawn over a few nights each year, although others (Acroporidae, Faviidae, Mussidae, Oculinidae) did spawn at similar times to corals on other reefs within the Dampier Archipelago, and Western Australia. In particular, mass-spawning by these latter corals was split over the months of March and April as a result of the full moon falling early in March.

Patterns of reproduction for *Turbinaria*, *Pavona* and *Porites* have not been widely investigated around the world. The dominant species of *Porites* on near-shore reefs in the Dampier Archipelago are *Porites solida* and *P. lobata*, of which *P. lobata* is best studied. Within the eastern Pacific and on the Great Barrier Reef, *P. lobata* is predominately a gonochoric spawner that undergoes short annual periods of spawning during one or a few months a year (Kojis and Quinn 1981, Glynn et al. 1994). However, other species of *Porites* have been found to spawn gametes over more protracted periods (Harriott 1983, Harrison and Wallace 1990).

On the Great Barrier Reef, *Turbinaria mesenteria* has been observed to spawn over extended periods between March and May, which is around five months later than the mass-spawning (Willis 1987). Eggs in colonies were apparently of sufficient size to be spawned in October, but they were retained until after March and another gametogenic cycle commenced so that the two cycles overlapped within the colonies. However, some colonies of *T. retiformis* have been observed to spawn in October, and it is possible that a proportion of colonies of both species spawn at the two times. The spawning of many *T. mesenteria* colonies months after the mass-spawning on the Great Barrier Reef suggests a similar variation in timing could exist in the Dampier Archipelago, but rather than spawning months later, colonies may be spawning earlier, possibly during October/November.

There is little reliable information about the pattern of reproduction in species of *Pavona* on the Great Barrier Reef (including *P. decussata*) although there are suggestions of spawning (Willis, pers com, 2004). Glynn et al. (1996,

Table 4. Gamete stages within colonies of different species during Trip 3 (29 – 30 March 2004)
a) Acropora

SITE	STATUS		
	I	II	X
ANGEL IS	2	-	20
CONI	5	-	7
COBN	3	1	8
NWIT	6	1	6
TOTALS	16	2	41

Figure 2. Mature eggs in *Acropora* spp

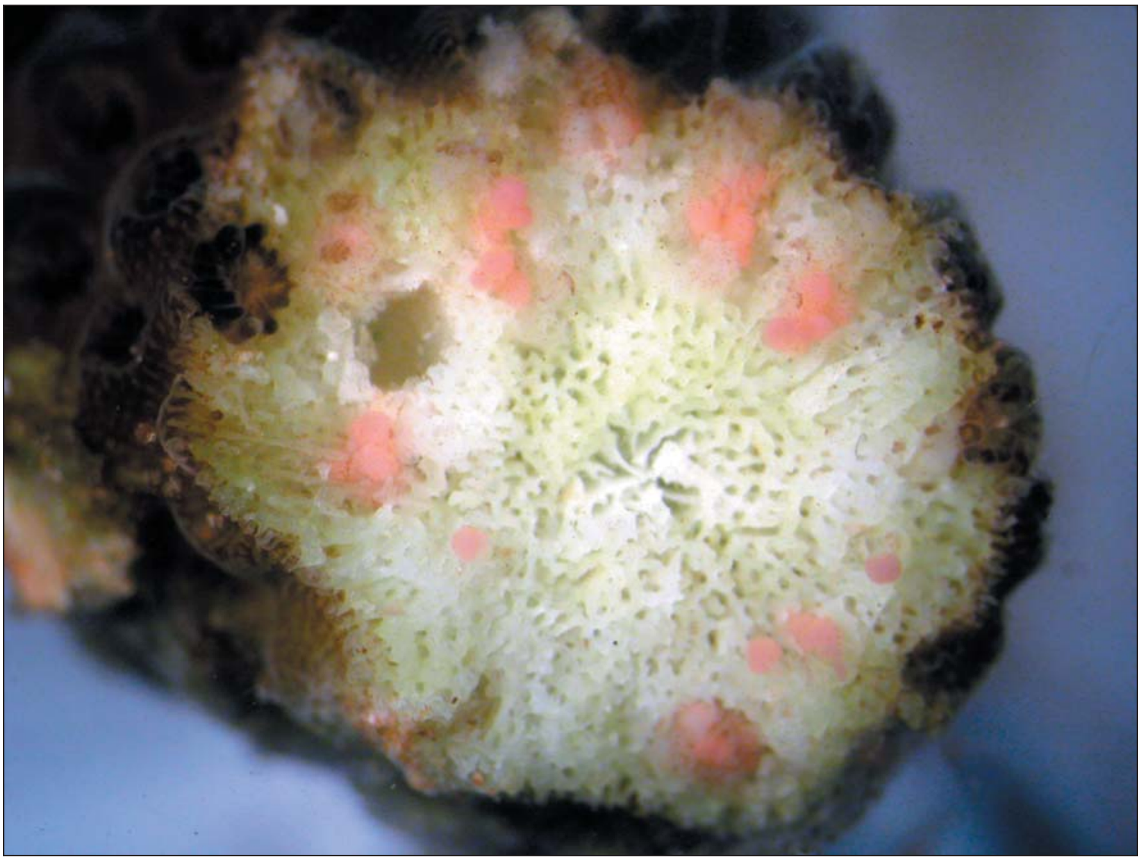


Figure 3. Eggs in *Platygyra* sinensis

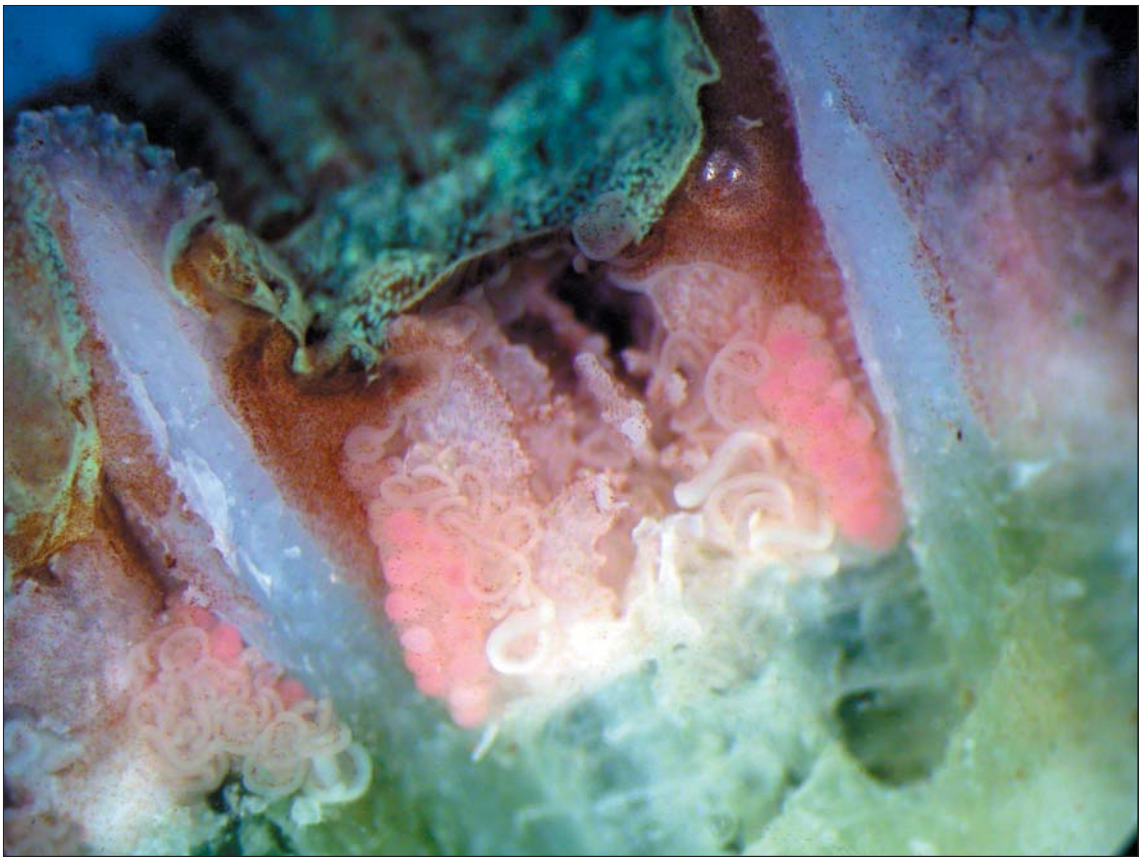


Table 4. (cont)
b) Favlids / Mussids

Family	Species	Sampled	Status # with eggs	colour	Size (μm)	spawn
Location - ANGI						
Acroporidae	*Montipora* sp	1	0			-
Faviidae	*Favites abdita*	1	0			-
	Favites sp	4	0			-
	Favites sp	1	?sperm			?
	Goniastrea australensis	3	3	pink	<150	April
	Platygyra sinensis	2	2	red	350-400	April
	Lobophyllia hemprichii	1	1	pink	500	April
Mussidae						
Location - COBN						
Dendrophyllidae	*Turbinaria mesenterina*	3	0			-
	Turbinaria peltata	2	0			-
Faviidae	*Favites halicora*	3	3	red	250-350	April
	Platygyra sinensis	3	3	red	400-450	April
	Montastrea curta	2	0			-
Merulinidae	*Merulina* sp?	1	0			-
Mussidae	*Lobophyllia hemprichii*	1	1	pink	500	April
Location - CONI						
Faviidae	*Favites halicora*	3	3	pink	250-300	April
	Favites sp?	1	0			-
	Goniastrea sp?	1	1	pink	450	April
Location - NWIT						
Dendrophyllidae	*Turbinaria mesenterina*	3	0			-
	Turbinaria peltata	2	0			-
Faviidae	*Caulastrea tumida*	1	0			
	Favites sp?	1	2	pink	250-300	April
	Favites halicora	1	1	red	250-300	April
Mussidae	*Platygyra sinensis*	1	0			-
Oculinidae	*Lobophyllia hemprichii*	1	0			-
Siderastreidae	*Galaxea fasicularis*	2	0			-
	Coscinarea columna	1	0			

Table 5. Egg development in *Acropora* spp at various sites (% of individuals sampled with mature eggs - sample sizes ranged from 11 - 22 individuals per site).

Site	Type	Trip 1	Trip 3
COBN	Impact	27	25
CONI	Impact	N/A	42
ANGI	Reference	4	9
NWIT	Reference	31	46

2000) conducted detailed long-term studies of several other species of *Pavona* on reefs near the equator in the Eastern Pacific. There was some variation among the populations, and among individuals within the populations, but these species of *Pavona* spawned gametes and colonies were mostly sequential hermaphrodites, although some were gonochoric. Colonies had gametes year round and they spawned regularly, as often as every two or four weeks within a six to twelve month breeding season. In such cases, eggs and sperm were released alternately over consecutive spawning episodes, and the overlapping oogenic and spermatogenic cycles within colonies of *Pavona* has caused much confusion. However, corals on equatorial reefs tend to have a more protracted breeding period and less synchronous spawning than those on the Great Barrier Reef, or in Western Australia, and potentially a greater number of gametogenic cycles. Thus, the multiple spawning and even the patterns of reproduction documented on equatorial reefs probably do not apply to the Dampier Archipelago.

There was no evidence from *in situ* and microscopic examination of individuals of *Pavona*, *Turbinaria* and *Porites* from the inner Dampier Harbour that these species participated in the mass-spawning in 2004. Similarly, Simpson (1988) found no evidence of colonies of these genera with ripe eggs or larvae on off-shore reefs in the Dampier Archipelago prior to the mass-spawning, but mature eggs have been observed in female *Porites* colonies on off-shore reefs in other years prior to the mass-spawning (unpublished data).

In evaluating this result, it is important to consider that very few colonies were sampled, and that:

- eggs of these species are small and difficult to see *in situ*, and some do not pigment when they become mature, making it difficult to distinguish them from the skeletal and polyp mesenteries,
- most of these species are probably gonochoric, so it is possible that only males were collected, and spermaries are particularly difficult to see even under a microscope unless they are mature,
- there is typically variation in patterns of reproduction for species within these genera, so that some colonies during some years may not spawn, or may spawn at different times to other colonies.

Effects of dredging

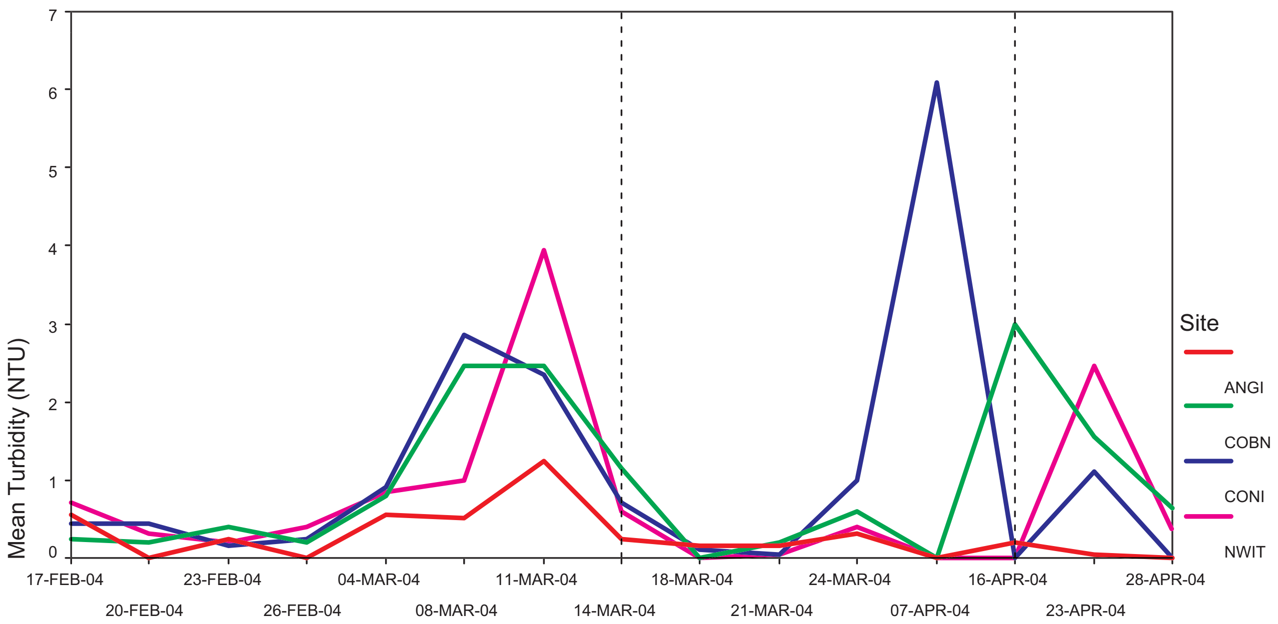
Much of the intended sample design to assess whether dredging operations impacted on coral spawning was negated by the inability to sample corals immediately adjacent to areas being dredged, as water turbidity was too high to allow diving at those sites. Sites which were sampled adjacent to the spoil disposal area, showed elevated turbidity levels prior to spawning (Fig.4) – although of much lesser elevation than around dredging sites where turbidity commonly reached values above 10 NTU (Stoddart & Anstee, this volume).

Qualitative findings from the observations here confirmed that many species did spawn as predicted over both months. Data from the *Acropora* species suggested that inter-site differences in the frequency of spawning corals were larger than observed differences between the Control and Impact sites, confounding our attempt to evaluate the effects of dredging on reproductive output.

Non-spawning indicators of dredging impact

Spawning is an easy part of the reproductive cycle to observe, but reproductive success also requires gametes released to be fertilised, develop into planulae and to settle successfully. Post-spawning processes are much harder to quantify.

Figure 4. Turbidity levels at reproductive study sites - dotted lines represent start of predicted spawning periods.



Several authors have commented on the potential for suspended sediments to adversely impact on fertilisation of coral spawn in the water column and Gilmour (1999) has shown that suspended sediments may significantly decrease fertilisation, larval survival and settlement, – although without inhibiting subsequent development of embryos post-fertilisation. Sediments used in Gilmour's studies were derived from Dampier Harbour dredge spoil – although they were applied to corals from clearer waters at Coral Bay, WA.

Other factors relevant to Dampier may also impact on the survival of coral spawn in the water column. Richmond (1996) shows that freshwater from rainfall or runoff can cause total loss of reproductive popagules when salinity drops below 28g/L. Had the rainfall from Cyclone Monty occurred 3 weeks later, consequences may have been severe and widespread.

Successful settlement of coral planulae can be retarded by sediments both from a layer of fine sediment coating substrates when planulae attempt to attach to the bottom and by the smothering of newly settled corals which are highly susceptible to sedimentation. Many studies have shown that these effects can be significant threats to successful establishment of new corals (Babcock and Davies 1991; Hodgson 1990; Stafford-Smith 1993).

While Hughes et al. (2000) postulate that larval supply of corals is dependent on the abundance and reproductive intensity of adult populations, those populations may be spread over large areas. In the case of near-shore Dampier coral populations, larvae may be derived locally or from corals further off-shore (depending on current movements in the weeks after spawning). Subject to future events within the Harbour, investigation of the density of coral recruits surviving during 2005-2008 could provide the best test of the impacts of dredging and the cyclone on reproduction in 2004.

Suggestions for further research

To provide a better understanding of the reproductive patterns of inshore Dampier corals to aid in future management decisions, research into the following would be most productive:

- Establish the reproductive characteristics and timing the abundant species of *Turbinaria*, *Porites* and *Pavona* decussata at this location;
- Assess the known mass-spawning species for any evidence of spawning during October/November which has been suggested to occur on off-shore reefs of the region;
- Evaluate the degree to which spawning in all species occurs in the months either side of the predicted mass-spawning event.

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Patterns of mortality from natural and anthropogenic influences in Dampier corals: 2004 cyclone and dredging impacts.

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Abstract

Understanding patterns of coral mortality and recovery at Dampier is essential in assessing the potential impacts of industrial development on the coast and hinterland. Monitoring coral communities in the eastern Dampier Harbour over a period of 20 years has revealed a general pattern of constant or gradually increasing coral cover for several years, interrupted by occasional events that significantly reduce live coral cover.

Two significant mortality events were recorded by coral health monitoring conducted for dredging programs within the harbour in 2004. The first was a massive reduction in live coral cover in communities on the southern shore of West Lewis Island (up to 95% at site WLI2) attributed to cyclonic freshwater inundation. The second was an 80% reduction in live coral cover at one site (SUPB) on the western shore of the Burrup Peninsula attributed to dredge-generated sedimentation when dredging came within a few hundred metres of coral communities.

Sedimentation at SUPB impacted most species and most colonies. Acroporids and faviids were apparently most susceptible to sedimentation while species of *Turbinaria*, *Pavona decussata*, *Diploastrea heliopora* and *Porites solida* were most resilient. Freshwater stress at WLI2 caused total mortality of all corals shallower than approximately 3m below mean lower low water. Most other sessile invertebrates, including *Tridacna* clams, were also killed. The shallowest live corals recorded post-flooding were *Porites lutea* and *Pavona decussata*, possibly indicating their greater resilience to freshwater stress.

Both SUPB and WLI2 are likely to regain their coral cover over the following 10-20 years. The predominance of partial mortality over whole-colony mortality at SUPB should be advantageous to recovery, as the remnant colonies should persist and provide a focus for regrowth without the need for recruitment of new corals. However, residual fine sediment is likely to hinder successful recruitment for some time. The reef top at WLI2, in contrast, is now essentially a blank slate, which can only be colonised by recruitment. The dead coral skeletons are a good substrate for recruitment, however, and should be colonised relatively quickly if the supply of larval corals and other invertebrates is adequate and in the absence of further natural or anthropogenic disturbance.

Keywords: coral mortality, salinity, sedimentation, turbidity,

Introduction

Mortality in scleractinian corals

An unusual and important aspect of coral life history is that corals do not senesce and die of old age like most other organisms. Consequently there is no theoretical upper limit on coral lifespan. Despite this, dead coral colonies can be found on virtually all reefs, even those considered to be in pristine natural condition. Coral mortality results from a range of natural and anthropogenic causes including wave impact, sedimentation, thermal stress, salinity stress, desiccation, overexposure or underexposure to light, oxygen depletion, pollution, predation, competition, parasitism and disease. Several of these processes, particularly the biological ones, operate continuously on most reefs, resulting in a chronic background level of coral mortality. In undisturbed communities, this background loss of coral is usually more or less balanced by recruitment of new colonies and growth of existing colonies, such that the overall percentage of live coral cover on the reef (the value typically measured in field surveys) remains relatively constant (eg. Hughes and Jackson 1985).

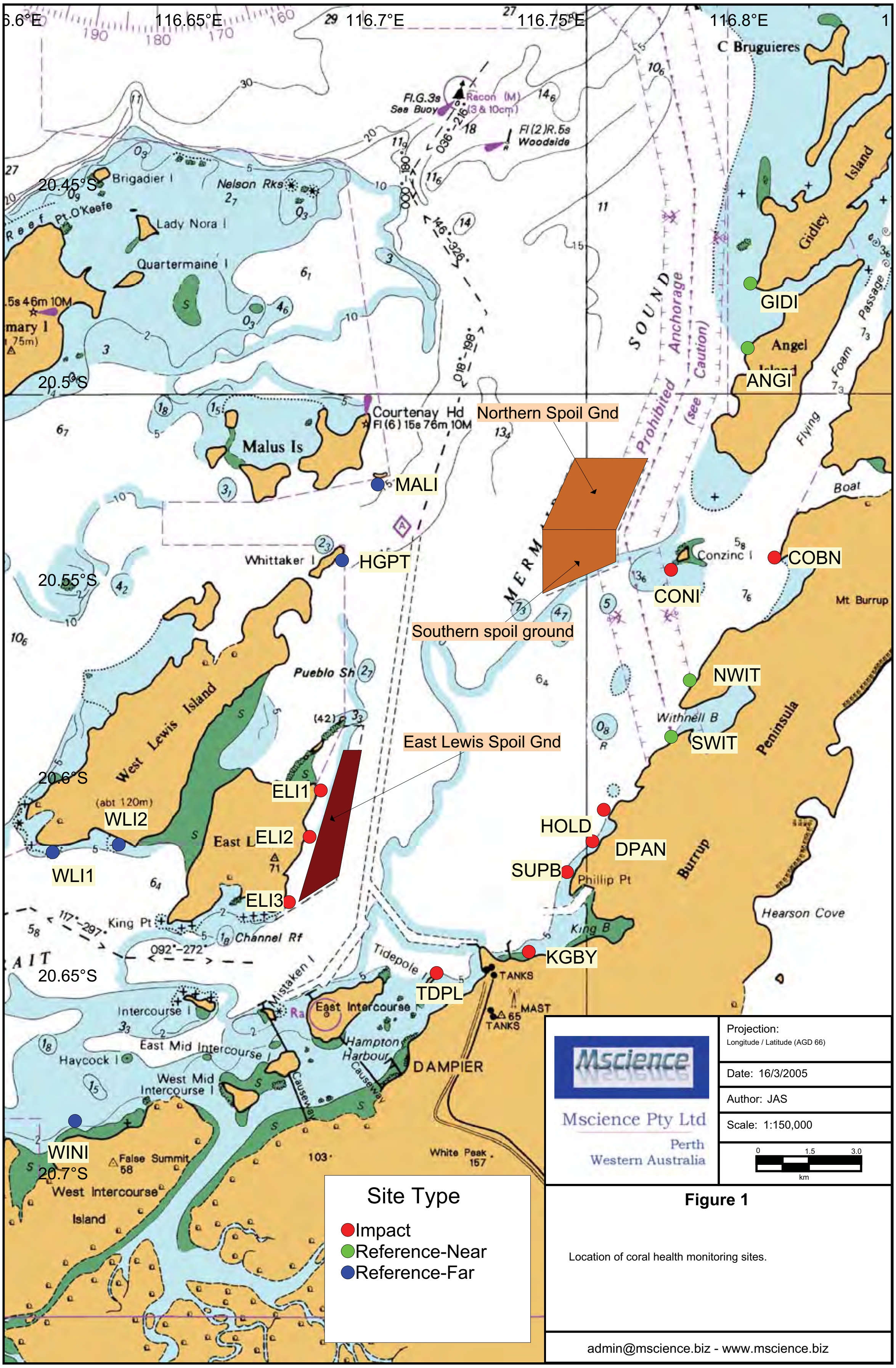
Several types of physical and biological events can result in rapid and extensive coral mortality, often well above background levels. These include cyclones, storms, floods, extreme high or low surface water temperatures, and outbreaks of predators, competitors, parasites or pathogens. Reef recovery following such events may take years to decades, or may be delayed indefinitely if the agent of mortality remains in place or if the community settles into an alternative stable state (eg. Knowlton 1992).

Coral mortality at Dampier

From a management perspective, understanding patterns in coral mortality and recovery at Dampier is essential in assessing the potential impacts of industrial development on the coast and hinterland. Maintenance of coral health and diversity is one of the fundamental requirements stipulated by the Western Australian Environmental Protection Authority (EPA) for proposed operations and developments in the marine environment. Proponents of development projects are required to monitor reef communities at regular intervals and take action to protect them if coral mortality exceeds a defined trigger value. Consequently, Dampier's reefs are probably amongst the most comprehensively-monitored in Western Australia, with records extending back 20 years in the case of Woodside Offshore Petroleum's monitoring program (LDM 1994b).

Within the coral communities of the Dampier Harbour, monitoring programs have captured the ongoing processes of natural background mortality, recruitment and growth, and have also documented instances of coral mortality following short-term natural and anthropogenic impacts including cyclones (LSC 1990), coral bleaching (LDM 1994a, b; 1999) and dredging (LSC 1988). The typical pattern

Figure 1. Location of sites in the 2003/4 coral health monitoring program.



revealed by monitoring is one of constant or gradually increasing coral cover for several years, interrupted by occasional events that significantly reduce live coral cover.

Of the events recorded as producing substantive mortality of Dampier Harbour corals, cyclones have had the most impact, with corals of the fast-growing and relatively fragile genus *Acropora* generally being the hardest hit (Marsh 1978; LSC 1990). Cyclones Ilona and Orson in particular (December 1988 and March 1989 respectively) caused major damage to reefs along the eastern shore of Mermaid Sound, breaking up and killing many coral colonies, and reducing live coral cover at most sites by 50% to 100% (LSC 1990).

Coral mortality attributed to bleaching (loss of symbiotic algae) has been relatively minor in comparison to cyclone impact. Widespread but sparse bleaching, affecting a range of genera but less than 1% of colonies, was reported throughout Mermaid Sound in March 1994 (LDM 1994a). Several recently-dead *Acropora* colonies, and bleached but live colonies of many other genera, were recorded at two eastern Mermaid Sound sites in May 1998 (LDM 2000). Most of the non-Acroporid colonies had recovered and regained colour before the next survey in May 1999 (LDM 2000). Both the 1994 and 1998 bleaching incidents were correlated with surface water temperatures above 30°C (LDM 1996b, 1999; ECS 1998).

Predation by the Crown-of-Thorns Starfish *Acanthaster planci* (Johnson & Stoddart 1988; Simpson & Grey 1989; LSC 1990) and the snail *Drupella cornus* (LDM 1996, 2000) has also been recorded as a source of mortality on offshore Dampier reefs. These corallivores do not appear to be abundant in the Archipelago however, and have never been recorded at densities comparable to the outbreaks of *A. planci* in the Great Barrier Reef (Johnson & Stoddart 1988; Benzie & Stoddart 1992) or *D. cornus* at Ningaloo (Turner 1994). It is not clear whether these species have the potential to attain outbreak-level populations in the Archipelago or Dampier Harbour. Either the structure of coral communities of the Harbour (Blakeway & Radford, this volume) may not be favourable to supporting dense aggregations of predators, or other environmental conditions promoting outbreaks have not been met.

Grazing of corals by fish is common within the Harbour. During the 12 months of coral monitoring associated with dredging (Stoddart et al., this volume) divers noted widespread occurrence of grazing scars on *Porites* and removal of branch tips of *Acropora* species. Mortality of whole colonies was not observed.

Relatively little is known about natural background coral mortality from competition, parasitism and disease in Dampier reefs. These are all potentially significant agents of mortality, and the lack of information about them represents a significant gap in our understanding of natural coral community dynamics in the region.

The most significant acute cause of coral mortality noted in past monitoring reports is dredging. Coral mortality resulting from dredge-generated sedimentation has generally been described as localised and relatively limited in these reports. Mortality attributed to dredging by Woodside Offshore Petroleum over the 1986/87 summer was confined to two sites within 1.3 km from the dredged channel, which lost less than 10% coral cover (LSC 1988). A follow-up maintenance dredging program in 1989 had no detectable effect on coral cover (LSC 1990), nor did another dredging program in the same area in 1994, although divers did note tissue mortality due to sediment accumulation on a few Porites, Lobophyllia and faviid colonies (LDM 1994a).

In some cases, the spoil disposal component of dredging programs has been closer to coral communities than the uplift of spoil. In 1998, a substantial spoil disposal program by Hamersley Iron Pty Limited was undertaken using the East Lewis spoil grounds, the western limits of which come within 250 m of rich coral communities off the eastern shore of East Lewis Island. Quantitative monitoring of coral transects at various depths before and after the disposal program failed to detect any decline in coral cover from what was a clear increase in turbidity and sedimentation (ECS 1998).

Figure 2. Abundance and diversity of corals at monitoring sites along the eastern shore of Mermaid Sound during the baseline survey.

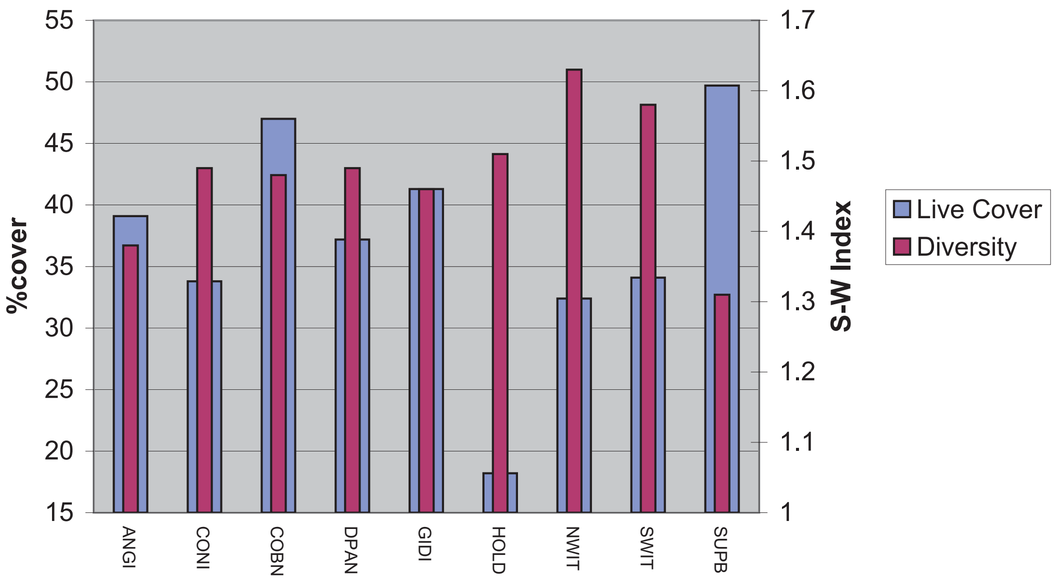
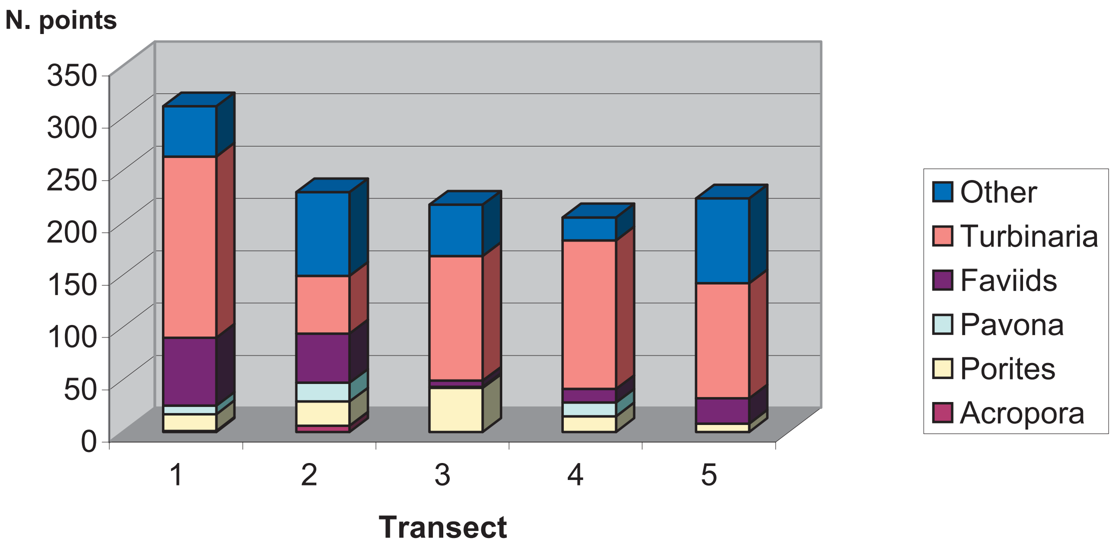


Figure 3. Distribution of major taxa groupings at SUPB during the baseline survey



A variety of additional anthropogenic sources of mortality—including anchor damage, fishing line damage, boat impacts and collection of aquarium coral—occur around various sites within the Dampier Harbour, but have never been specifically measured.

2004 mortality events

During January to October 2004, the Dampier Port Authority (DPA) and Hamersley Iron Pty Limited undertook sequential capital dredging programs within the south-east of Mermaid Sound in Dampier Harbour, involving the removal and disposal of over 6Mm^3 of spoil (Stoddart & Anstee, this volume). A fortnightly coral reef monitoring program was established at several sites around the dredging and disposal locations to allow rapid assessment of, and response to, any developing mortality (Stoddart et al, this volume). A number of reference sites were established outside the immediate area of dredging to provide a context of natural change in coral mortality. Due to concern that these reference sites could themselves become impacted by dredge-generated sediments, an additional set of Far Reference Sites were established several kilometres distant from the dredging and disposal locations.

Two significant mortality events were recorded during the 2004 monitoring program. The first was a dramatic reduction in live coral along the southern shore of West Lewis Island (Fig. 1) related to inundation by freshwater following heavy rain during Cyclone Monty in early March (Stoddart and Anstee, this volume; Stoddart et al, this volume). One of the Far Reference Sites, WLI2, lost around 95% of live coral cover, with another nearby site, WLI1, losing over 15%. WLI1 was impacted by the same freshwater event that reduced coral cover at WLI2 but was not affected as strongly, probably due to the greater depth at WLI1. Shallow coral communities around the shoreline of several other inshore islands of the Dampier Archipelago were also severely impacted, with coral mortality estimated visually at > 50% (unpublished data).

The second major mortality event recorded in the monitoring program was an 80% reduction of live coral cover at the Supply Base site (SUPB, 500m south of the principal dredge site, see Fig. 1), which was attributed to dredge-generated sedimentation (MScience 2004; Stoddart et al, this volume). While the actual onset of mortality was unable to be observed due to weather conditions of very high turbidity during dredging, the pattern of mortality and physical distribution of sediment were consistent with smothering as the primary cause of mortality.

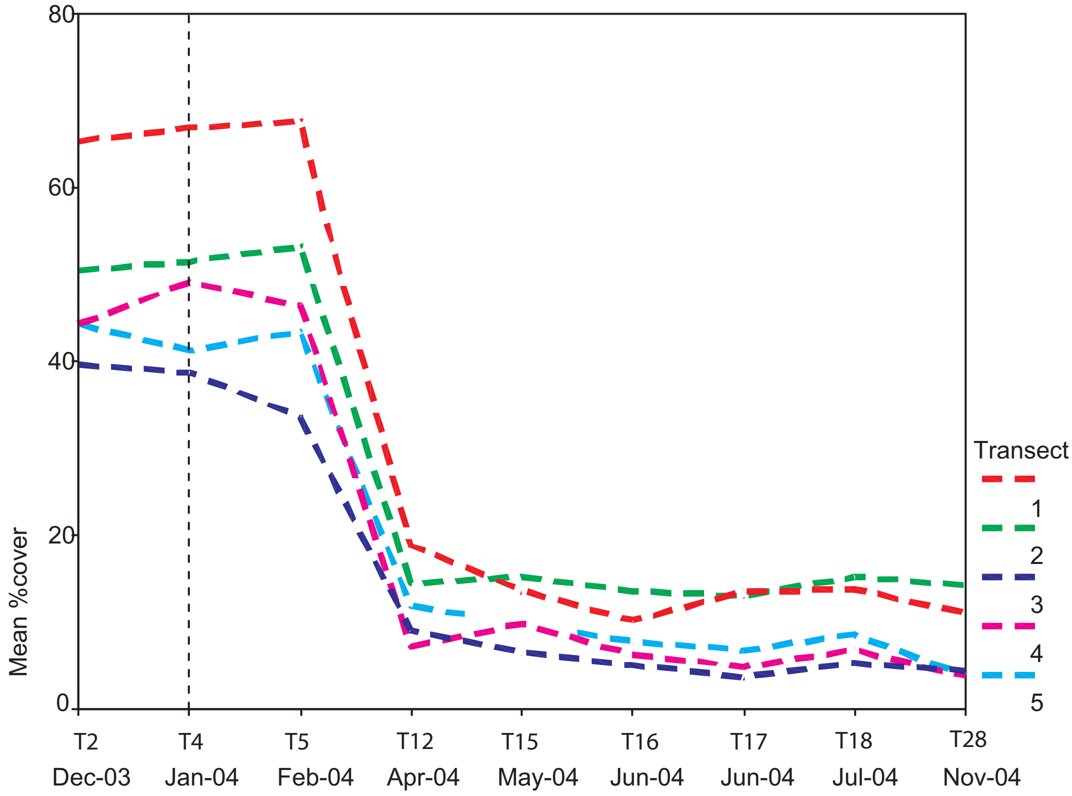
Smaller mortality events were detected at other sites such as GIDI, WINI and TDPL (Fig. 1) Mortality (of 10-20%) at GIDI was caused by coarse sediment and plant material deposited on tabulate *Acropora* colonies by strong swells prior to and during Cyclone Monty. At TDPL and WINI, monitoring recorded an apparent loss of >25% of live coral cover, but this was largely due to overgrowth by the macroalgae *Sargassum* during summer. When the *Sargassum* receded over winter, monitoring showed that actual mortality of corals had been less than 10% (Stoddart et al, this volume).

A detailed analysis of the patterns of mortality in the major events was conducted to assist in assessing what species or populations might be at risk from future challenges. At SUPB a comprehensive taxonomic and size frequency analysis of mortality was undertaken in response to a commitment in the DPA's Interim Environmental Management Plan for further research in the event of significant dredge-related mortality (URS 2004). That analysis (MScience 2004) is summarised below, followed by a summary of mortality at WLI2 and other sites.

Coral mortality at SUPB

Coral abundance (measured as % live cover) at SUPB during baseline surveys in late 2003 was the highest of any of the monitoring sites along the eastern edge of Mermaid Sound, averaging 49% over the five 10m transects surveyed (Fig. 2). Coral diversity (Shannon-Weiner index using the six coral classes identified) was the lowest however (Fig. 2),

Figure 4. Coral cover at SUPB from December 2003 to July 2004 – the vertical dotted line indicates the start of dredging. Points on the x axis are trips (T) and their relevant dates, when SUPB could be sampled.



due to the domination of live coral cover by species of *Turbinaria* (Fig. 3).

The chronology of coral decline at SUPB is difficult to assess, as between late January and mid April 2004 weather conditions or poor visibility precluded successful capture of video or still images for analysis. When dredging was suspended for 5 days in mid April, water quality improved sufficiently to allow a survey to proceed. Analysis of resultant images revealed a decline in coral cover from almost 50% in the pre-dredging period to around 10%. Since then, coral cover appears to have stabilised and is varying within limits of the method of measurement (Fig. 4).

Water quality monitoring (Stoddart & Anstee, this volume) and examination of corals at the SUPB site suggested physical covering of corals by sediment appeared to be the primary cause of mortality. Massive suspension of sediments by propeller wash during a few brief episodes when dredging was within 100-200 m of corals appeared to be the primary cause. Corals at nearby sites were subjected to effectively similar levels of light attenuation and turbidity, but showed no mortality (Stoddart et al., this volume).

Taxonomy of coral loss

There were no clear species-specific mortality effects at SUPB, with the majority of species present being affected to some degree. Statistical assessment of whether dredging-induced mortality affected some species more than others would have been of little use as most species identified from the transect records were represented by only 1-3 individuals. The pattern of coral loss is summarised in Table 1. Table 2 breaks down the loss into species within families, while Table 3 shows impacts on individual species.

Qualitatively, it appeared that the Acroporids and the faviids were the taxa impacted most heavily. Of the faviids, *Diploastrea heliopora* seemed most robust and all three recorded individuals survived without loss of tissue. Only one other species, the fungiid *Lithophyllon edwardsi*, survived without tissue loss, but as this species was represented by one individual only, the result may not be general.

Corals of the genus *Turbinaria* appeared reasonably resistant to sedimentation. Although colonies of all 7 *Turbinaria* species at SUPB suffered significant partial

Table 1. Changes in species abundance and cover over the DPA dredging period at SUPB.

	Base	June 04
Percent cover living coral	49%	9%
Number of colonies	168	95
Number of species	37	21
Diversity (S-W) – major groups	1.31	1.19
Diversity (S-W) - species	2.81	2.21
Species lost entirely	16	
Species losing over 75% of cover	11	
Species losing up to 70%	8	
Species unaffected	2	

Table 2. Mortality at SUPB recorded by family.

Family	N. of Species (Base)	N. of Colonies (Base)	N. of Species by average loss per colony			
			100%	70-100%	10-70%	0-10%
Acroporidae	3	4	3			
Agariciidae	2	7		1	1	
Dendrophylliidae	7	87		3	4	
Faviidae	13	30	8	2	2	1
Fungiidae	3	6	1		1	1
Merulinidae	1	1	1			
Mussidae	1	2	1			
Oculinidae	1	2		1		
Pectiniidae	3	11	1	2		
Pocilloporidae	1	1		1		
Poritidae	1	16		1		
Trachyphylliidae	1	1	1			
TOTALS	**37**	**168**	**16**	**11**	**8**	**2**

mortality, most of the individual colonies survived and none of the 7 species were lost from the site. *Turbinaria mesenterina*, the most abundant coral at SUPB, typified this response. A total of 47 *T. mesenterina* colonies were recorded in the baseline survey. Although these colonies suffered an average 57% tissue loss during dredging, the majority of them (39) were still alive in the June survey. The Agariciid coral *Pavona decussata* showed a similar pattern; despite sustaining an average 55% partial mortality, each of the original 6 colonies survived.

Photographs taken in December 2004 indicate that most colonies remained in the same state as the July survey. There appears to have been a minor loss of faviids and a minor gain of *Porites* in the intervening months, but neither was sufficient to register in the analyses.

Based on observations by divers when recording transects at SUPB, colony morphology has a strong influence on susceptibility to sedimentation effects at moderate levels of sedimentation. Colonies with flattened upper surfaces (encrusting corals and plate corals) or branching corals, where branches were sufficiently dense to hold a raft of sediment, were particularly prone to mortality. Colonies with vertical faces (such as *Pavona decussata* and many *Turbinaria* species) shed sediment easily and were resistant

Figure 5. Vase-shaped Turbinaria colony at SUPB infilled with burrowed fine sediment, April 2004.

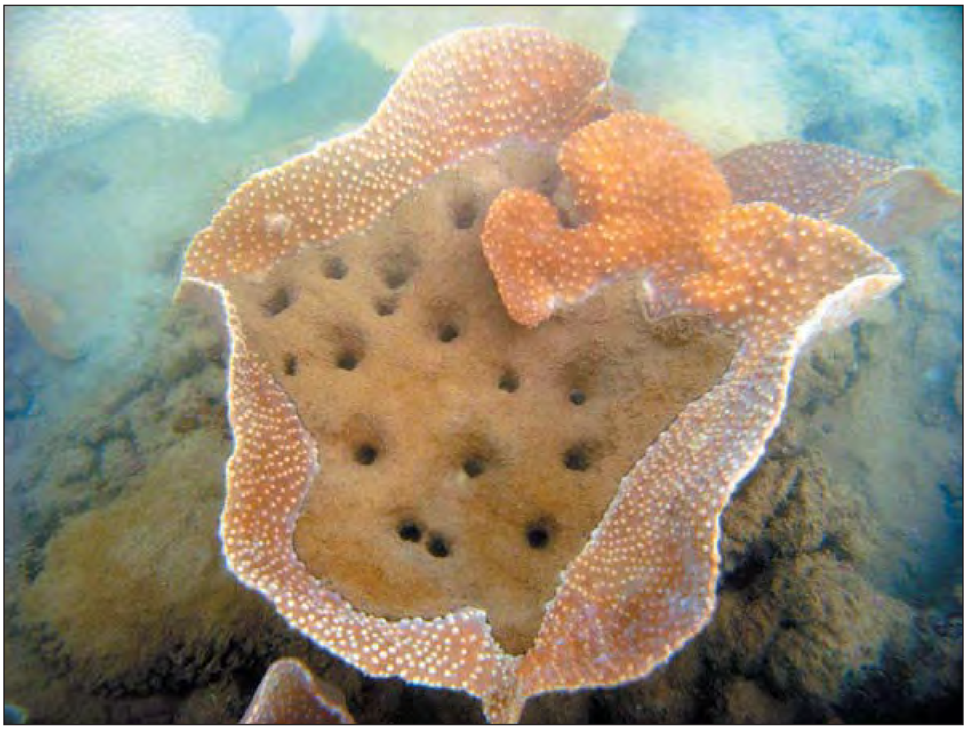


Table 3. Estimates of partial mortality and loss of entire colonies by species at SUPB.

Family	Genus	Species	N	avg. % loss per colony	% colonies lost
Species losing all tissue					
Acroporidae	*Acropora*	*verweyi*	1	100	100%
Acroporidae	*Acropora*	*?latistella*	2	100	100%
Acroporidae	*Montipora*	*?turtlensis*	1	100	100%
Faviidae	*Montastrea*	*?curta*	2	100	100%
Faviidae	*Favia*	*pallida*	1	100	100%
Faviidae	*Favites*	*flexuosa*	1	100	100%
Faviidae	*Favites*	*abdita*	3	100	100%
Faviidae	*Favites*	*complanata*	2	100	100%
Faviidae	*Goniastrea*	*indet*	1	100	100%
Faviidae	*Platygyra*	*sinensis*	1	100	100%
Faviidae	*Platygyra*	*pini*	3	100	100%
Merulinidae	*Hydnophora*	*exesa*	1	100	100%
Trachyphyllidae	*Trachyphyllia*	*geoffroyi*	1	100	100%
Fungiidae	*Herpolitha*	*limax*	3	100	100%
Mussidae	*Lobophyllia*	*hemprichi*	2	100	100%
Pectiniidae	*Echinophyllia*	*aspera*	6	100	100%
Species losing most of their tissue					
Dendrophylliidae	*Turbinaria*	*bifrons*	3	98	67%
Pectiniidae	*Mycedium*	*elephantotus*	3	95	67%
Agariciidae	*Pachyseris*	*rugosa*	1	95	0%
Pocilloporidae	*Pocillopora*	*damicornis*	1	95	0%
Pectiniidae	*Pectinia*	*paeonia*	2	92	50%
Dendrophylliidae	*Turbinaria*	*reniformis*	19	88	53%
Faviidae	*Goniastrea*	*australensis*	1	82	0%
Poritidae	*Porites*	*?solida*	16	79	38%
Faviidae	*Caulastrea*	*tumida*	4	75	75%
Oculinidae	*Galaxea*	*fascicularis*	2	75	50%
Dendrophylliidae	*Turbinaria*	*frondens*	12	75	33%
Species losing some tissue					
Faviidae	*Favites*	*indet*	1	70	0%
Faviidae	*Goniastrea*	*pectinata*	7	60	43%
Dendrophylliidae	*Turbinaria*	*mesenterina*	47	57	17%
Agariciidae	*Pavona*	*decussata*	6	55	0%
Fungiidae	*indet*	*indet*	2	50	50%
Dendrophylliidae	*Turbinaria*	*indet*	3	43	33%
Dendrophylliidae	*Turbinaria*	*conspicua*	2	28	0%
Dendrophylliidae	*Turbinaria*	*peltata*	1	20	0%
Unaffected species					
Faviidae	*Diploastrea*	*heliopora*	3	2	0%
Fungiidae	*Lithophyllon*	*edwardsi*	1	0	0%
TOTAL			**168**	**80**	**60%**

N=number of colonies at baseline monitoring

Figure 6. Live colonies of Pavona (top), Porites lutea (middle) and P. australiensis (lower right) at -3 m depth WLI2 post-Cyclone Monty (photo December 2004).

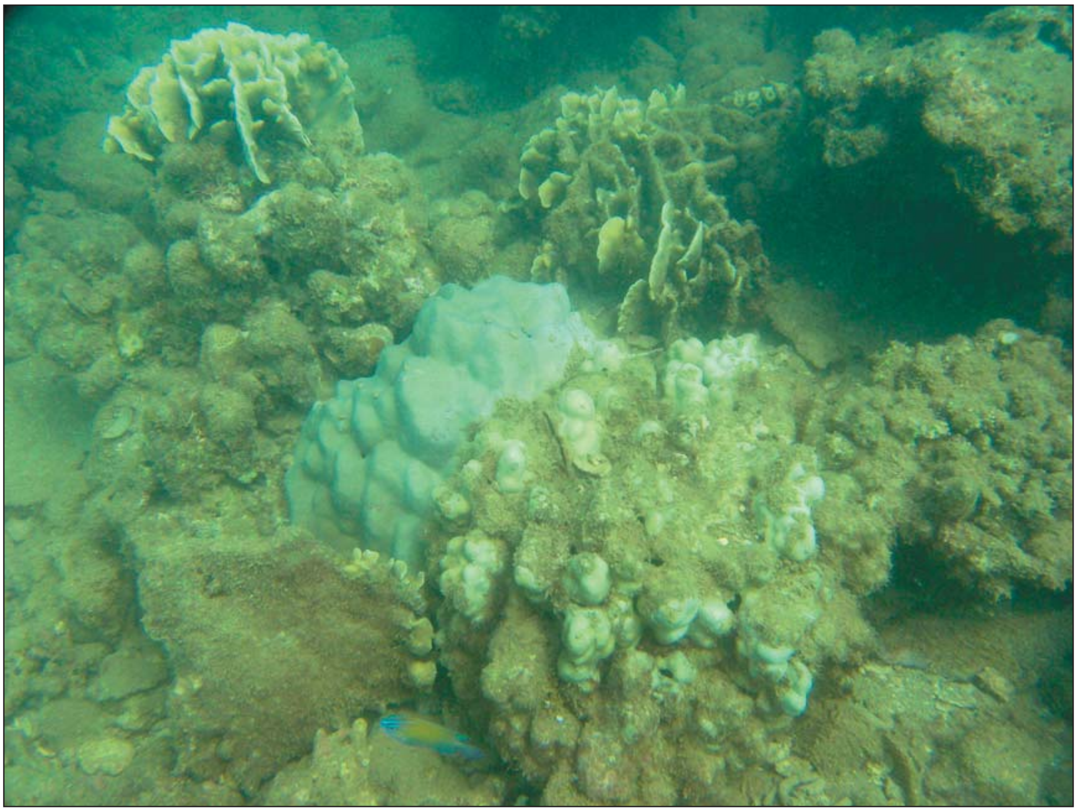
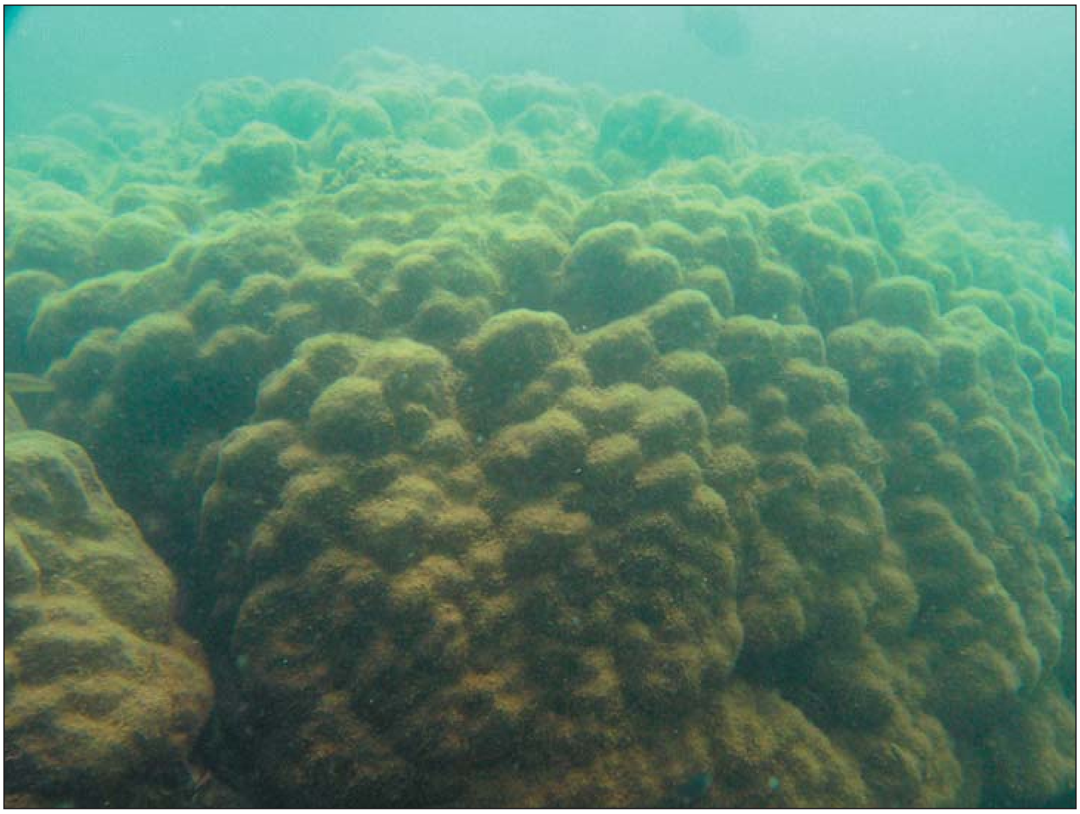


Figure 7. Dead 1.5m diameter Porites colony at WLI2 post-Cyclone Monty (photo March 2004).



to moderate sedimentation. As sedimentation increased to very high levels, even the resistant species were impacted—either by direct burial as sediment rises, or by infilling of structures like the vase-shaped interiors of *Turbinaria* (Fig. 5) or the spaces between the *P. decussata* blades.

Like most of the shallow nearshore reefs of Mermaid Sound, SUPB was dominated by small coral colonies, with over 50% of colonies having a surface area less than 400 cm2 (eg a 20 x 20 cm coral). Estimates of the initial area and final area of coral colonies did not provide any clear patterns. As would be expected, the average size of colonies decreased due to shrinkage of most corals from partial mortality (Fig. 6), but there was no clear association between colony size and survival.

Coral mortality at WLI2

When first surveyed in late 2003, WLI2 had 47% live coral cover, composed predominantly of Porites lutea and P. australiensis, with significant proportions of Pavona decussata, faviids, and several corymbose Acropora colonies. During the passage of Cyclone Monty on the 1st – 3rd of March 2004, Dampier and the hinterland experienced very heavy rainfall and runoff (over 300mm in 24 hrs), much of which was delivered to the coast via the Maitland River, approximately 20 km southwest of West Lewis Island. Surface water salinity in Mermaid Sound dived sharply to approximately 20 mg/L and remained low for several days (Stoddart & Anstee, this volume).

Surveys immediately after the cyclone recorded the total mortality of all corals at WLI2 down to a depth of approximately 3 m below mean lower low water (MLLW). Most of the dead corals and many of the deeper live corals were bleached and several corals were covered in a thin layer of fine terrigenous sediment. Shallow corals at WLI1 were also affected and spot surveys on the southwestern shore of East Lewis Island and the southern shore of Enderby Island showed a similar near-complete mortality of shallow coral communities. In all, it is likely that several hundred hectares of shallow reef were impacted.

Monitoring over the following months showed that many of the bleached corals at WLI1 regained their zooxanthellae. This was seen predominantly in corals in the depth zone between shallow permanently impacted areas and deeper unaffected areas.

Impacts on other sessile fauna were equally severe. Oysters were the only benthic invertebrates observed to survive in the reef shallows, presumably being able to avoid the freshwater impact by closing tightly for several days. Tridacna clams, in contrast, were unable to survive and many small dead individuals were noted.

Small reef fishes including Pomacentrids, Acanthurids and Labrids remained relatively abundant after the flood. Presumably they had migrated to the deeper reef during the flood and returned to the shallow habitat when water quality returned to normal.

Taxonomy of coral loss

No coral species were able to survive on the shallow reefs impacted by the freshwater inundation. The shallowest living coral colonies, at approximately 3 m below MLLW, were Pavona decussata and Porites lutea, most of which suffered significant partial mortality (Fig. 6). All the Acropora, Lobophyllia and faviid colonies observed at this depth were dead, suggesting that these taxa may be more susceptible to freshwater stress than P. decussata and Porites. The number and diversity of live corals increased significantly below 3m, and corals deeper than approximately 5m below MLLW appeared unaffected.

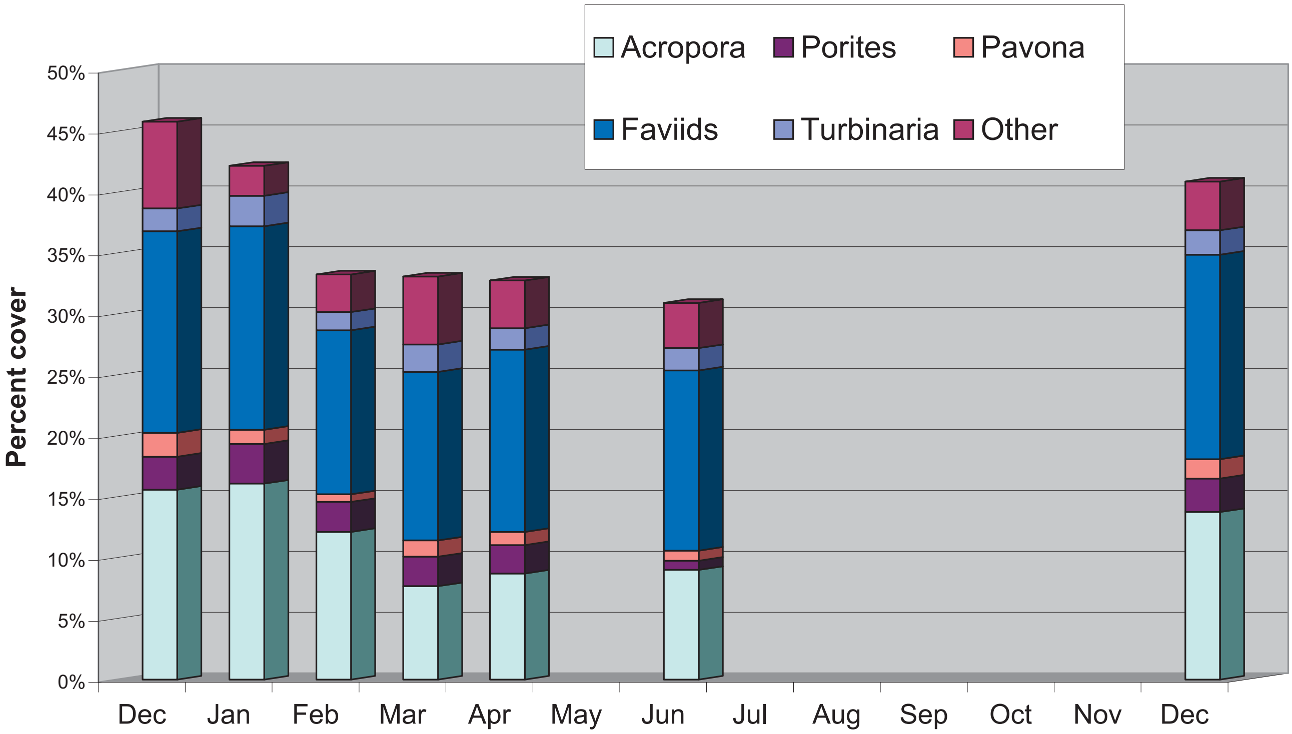
Several of the shallow coral colonies that died were relatively large, including numerous Porites lutea colonies from 1 to 2.5m in diameter (Fig. 7). Based on the average extension rate of Porites measured on the Great Barrier Reef of approximately 13mm per year (Lough and Barnes 2000), the larger colonies were probably around one hundred years old. Thus the flood conditions that killed them can be considered approximately a once-in-one-hundred year event.

Coral mortality at other sites

GIDI – The coral community at the GIDI site occurs on a shelf and drop-off facing west-northwest off Gidley Island. Being towards the outer part of Mermaid Sound, it is exposed to the predominant summer westerly swells (Pearce et al. 2003). During late Summer 2003-4, divers visiting the site noted that many corals, in particular tabulate *Acropora* species, were partially covered with small amounts of coarse sediment and macroalgal drift material. Subsequent quantitative assessment of change in cover saw a drop of almost 20% by April with a subsequent rise for the latter part of the year (Stoddart et al., this volume). When the contribution of the various coral taxa to live cover is examined, it is clear that this drop was principally due to the susceptibility of *Acropora* species to physical damage (Fig. 8), and subsequent recovery, presumably through growth of existing colonies.

TDPL and WINI – Both sites are located towards the southern margins of Mermaid Sound, but are quite different in aspect and coral community composition (Blakeway & Radford, this volume). During the fortnightly coral health monitoring, both showed a strong decline in living coral cover (WINI >50% and TDPL around 20%) between December 2003 and April 2004. Over the summer period, strong growth of *Sargassum* (probably at least 2 species Huisman & Borowitzka 2003) overtopped much of the lower coral colonies. Following almost total loss of the *Sargassum* cover over the winter period (May – July), coral cover at TDPL recovered to around the December 2003 level, but a residual mortality of close to 10% was evident at WINI. It is not certain that this mortality related to the *Sargassum* effect, as freshwater inundation and micro-algal blooms also occurred at that site in the period.

Figure 8. Composition of GIDI corals by taxon during the year.



Discussion

Cyclone mortality

In terms of extent and severity of impact, cyclones appear to be the major source of coral mortality at Dampier over the timescales covered by this and previous monitoring programs. Cyclone-related coral mortality occurs by several mechanisms, including mechanical damage by wave impact, smothering by sediment deposition and osmotic stress caused by freshwater influx. Coral taxa vary significantly in their susceptibility to cyclone impacts. *Acropora* species appear highly susceptible to all three mechanisms described above, and are usually the first to succumb to cyclones. However, *Acropora* can also recruit and grow rapidly allowing populations to recover relatively quickly between cyclones. For example, tabulate *Acropora* are now abundant at Angel and Gidley Islands, despite being heavily damaged by Cyclone Ilona in December 1988 (LSC 1990).

The genera *Porites* and *Pavona* appear more resistant to cyclones and are more likely to survive them, albeit with significant partial mortality. The fact that *Porites* and *Pavona* were the most abundant corals at WLI2 even before Cyclone Monty may indicate that the community at that site has been shaped to some extent by similar cyclonic floods in the past. Further analysis would be required to evaluate this possibility. What does seem clear is that both *Porites* and *Pavona* are robust genera, able to cope with all but the most severe natural environmental stresses that occur in Dampier's marine environment.

Sedimentation mortality

Sedimentation at SUPB during the DPA dredging program was both heavier and more protracted than any natural event to which these coral communities would be routinely exposed. As at WLI2, *Pavona* and *Porites* withstood this extreme stress better than many other coral genera. Overall however, *Turbinaria* stood out as the best survivor to sedimentation. Again *Turbinaria* was the most abundant genus at this site before the mortality event. Indeed *Turbinaria* were far more abundant at this site than at any other surveyed site (Blakeway and Radford, this volume) suggesting that the coral community structure there may have been modified by a high frequency of natural sedimentation events.

The pattern of mortality at SUPB gives some indication of which coral species may be most at risk from dredge-generated sedimentation. However, because this site has been subject to high natural turbidity, even the pre-dredging species list represents a reasonably sediment-tolerant community that would not contain highly sediment-sensitive species. Extrapolation of these results to other sites would need careful consideration of the past environmental history of corals at each site.

The three small *Acropora* colonies recorded in the baseline survey at SUPB were among the first corals to die. However, Dampier's inshore habitat appears to be marginal for *Acropora*, judging by the low numbers and small size of inshore *Acropora* colonies. Even in the absence of anthropogenic impacts, they are likely to be ephemeral in this habitat and unlikely to persist for many years.

The heavy loss of faviid species is more concerning. Several reasonably large (~1000cm2) *Favites* and *Favia* colonies suffered complete mortality shortly after the commencement of dredging. These species are widespread and abundant in Dampier's inshore habitat, implying a tolerance to sedimentation. It is likely that mortality resulted when the extremely high sediment load from dredge propeller wash exceeded a threshold of sedimentation tolerance, resulting in complete mortality rather than the gradual partial mortality exhibited by many other genera.

The preceding assessment of dredging-related mortality must be qualified with the outcomes of water quality monitoring which showed that the sedimentation event most likely to cause mortality was probably one or two periods of massive sedimentation caused by propeller wash from a large dredge working within a few hundred metres of corals in calm conditions (Stoddart & Anstee, this volume). Outside of a radius of 1 km, mortality was no different to that of sites in the Reference or Far Reference categories. The actual distance over which sedimentation caused adverse effects on corals may have been less, as there were no monitoring sites in the band 500m - 1km distant from dredging.

Recovery

Both SUPB and WLI2 are likely to gradually regain their coral cover. Partial mortality was far more common than loss of the whole colony at SUPB which should be advantageous to the recovery of this site. As judged by the stability of the 9% cover since May 2004, the remnant colonies should persist and provide a focus for regrowth without the need for recruitment of new corals. Recovery is therefore likely to produce an even greater predominance of *Turbinaria* than that recorded in the baseline survey. With the sea floor in this area now dominated by soft sediments, recruitment of larval corals could be depressed for several years, which could impede the return of species that were lost from the site. Next summer's cyclones could enhance recovery in this respect, as they may sweep fine sediment from the coral skeletons to provide more recruitment space.

The reef top at WLI2 is now essentially a blank slate, which can only be colonised by recruitment. The dead coral skeletons are a good substrate for recruitment and should be colonised relatively quickly if the supply of larval corals and other invertebrates is adequate. How the community will subsequently develop is an open question. Future surveys of the WLI2 transects should provide a good picture of the process.

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Recommendations for Future Research.

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MScience Pty Ltd, University of Western Australia, Crawley, Western Australia

Abstract

Scientific research is necessary for good environmental management. In places like the Port of Dampier, where there is a strong development focus, sustaining ecological function while progressing economic development will require a sound understanding of the local marine ecology. Although there have been many studies of the marine biological resources of Dampier Harbour, few are based on consistent methodologies and none address ecosystem-level topics. Studies often progress in isolation and there has been no synthesis of past works aimed at developing research needs for existing management or future development.

Recommendations for future research topics and research facilitation made here include:

- Establishment of a database to allow easy access to past reports;
- A mechanism for standardising future studies to allow comparison of results;
- Basic studies on the mode and timing of reproduction amongst the common species of inshore corals;
- Comparative studies of the patterns of recovery in coral populations impacted by natural versus dredging impacts;
- Extending the understanding of marine biodiversity and effects of development within the Dampier Harbour beyond corals.

Keywords: marine management, ecology, research, dredging

Introduction

Under Australia's Oceans Policy, one of the key principles for the ecologically sustainable use of oceans is that of basing management on sound science (Commonwealth of Australia 1998). The principle states

- *Ocean planning and management decisions should be based on the best available scientific and other information, recognising that information regarding ocean resources will often be limited.*

Management of the marine environment of Dampier Harbour and its flora and fauna will be the responsibility of various Australian state and federal agencies as well as the private users of the Harbour. The distinct management questions addressed by these various managers will require differing information on the distribution of natural resources and ecological processes. While the fundamental basis of some of these questions may be common, specific applications are likely to differ.

In recommending priorities for research, this section addresses topics which are likely to be of broad interest to several managers rather than location-specific issues. Further, it concentrates on those ecological and management aspects likely to be of relevance to dredging projects.

Recommendations

Database of past research

Much research has been undertaken in the Dampier Harbour and adjacent Dampier Archipelago starting in the mid 1970s when interest in protecting the marine environment first became serious. Not only is it difficult to locate copies of studies and their data, but the very existence of many reports is not widely known. Studies are mostly in grey literature from consultants, but also exist in technical publications of some government agencies and scientific papers.

A GIS-based listing of meta-data was established under the North West Shelf Joint Environmental Management Study (NWSJEMS) by the WA Department of Environment and CSIRO. However, this is not generally available at present.

- *The NWSJEMS database should be revived and made available to managers, researchers and the general public in a readily searchable format.*

Make future data compatible

To date there has been no coordination of research methods (or data collection methods) to allow direct comparison of results. Other areas in environmental studies have benefited from mandated approaches to study methods or suggested standard procedures. While studies will need to answer specific questions and will sometimes need to be uniquely designed, a suggested set of standard operating procedures (in the sense of the Cockburn Sound document - EPA 2004a) could be developed for commonly repeated studies - like coral monitoring or water quality and sediment monitoring.

- *Develop a suite of standard operating protocols for the collection of ecological data and make them available to studies conducted for marine management of the Dampier Harbour.*

Better understand coral reproduction

Chapter 4 of this publication (Stoddart & Gilmour) points to specific areas where the reproductive characteristics of these inshore species of coral are poorly understood. The overall importance of annual reproduction events will be addressed in the next topic. Until that understanding is in place, the timing and intensity of reproductive phenomena like mass spawning will continue to be important to management, and research priorities should include:

- *Establish the reproductive characteristics and timing of the abundant species of Turbinaria, Porites and Pavona decussata at this location;*
- *Assess the known mass-spawning species for any evidence of spawning during October/November which has been suggested to occur on off-shore reefs of the region;*
- *Evaluate the degree to which spawning in all species occurs in the months either side of the predicted mass-spawning event.*

Sustaining coral populations & recovery post-disturbance

Chapter 5 of this publication (Blakeway) discusses past studies of coral mortality occurring in the Dampier Harbour either as a result of anthropogenic or natural perturbations. It points to a considerable body of information on mortality events for the area, but little documentation on the process of community recovery. Clearly, coral communities do recover from cyclone events, although the temporal and taxonomic pattern of that recovery is not well known for this area. There is less information concerning recolonisation following impacts caused by massive sediment deposition.

Blakeway (this volume) describes the aftermath of several distinct mortality events. Following cyclones, mortality is widespread and a mixture of whole colony and partial mortality, with the remaining habitat composed of dead coral and rubble. Following freshwater inundation, mortality is spatially extensive and virtually complete within a depth band, with the remaining habitat essentially dead coral in situ. After a sedimentation event, mortality is more localised, largely with partial colony death, but much of the remaining habitat is composed of a layer of sediment which may consolidate or be resuspended by wave and current action. These differing scenarios have distinct implications for the pattern and timing of recolonisation - especially the relative importance of new recruitment from larvae versus growth of existing live colonies.

- *Compare the sequence of recovery in coral communities following loss of coral caused by a natural process, such as cyclones or freshwater inundation, with recovery in communities impacted by sediments*

Marine biodiversity beyond corals

While hard corals (Order Scleractinia) are the most pervasive feature of the Dampier Harbour coral communities and supply much of the basic physical structure within those associations, they contribute only a part of the total biodiversity present therein. This visual prominence, the public popularity of corals and their importance as benthic primary producers (EPA 2004b) has made corals the almost single focus of past biological monitoring associated with dredging projects or other Harbour developments.

Corals of Dampier Harbour are now relatively well studied, compared to the other invertebrates in these nearshore communities. Sponges, anemones, bryozoans, hydroids, urchins, holothurians and a host of other groups occur throughout the coral and adjacent habitats. In addition, there is a considerable and virtually unstudied, infauna within the surrounding soft bottom habitats. Many of these species may be rare or more vulnerable to sediment or turbidity impacts than corals, and thus at greater risk from dredging or other development.

- *Encourage taxonomic, inventory and ecological studies of non-coral invertebrates from the inner Dampier Harbour.*

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Appendix C Global Environmental Modelling Systems (GEMS)

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Morrison, Peter F (SKM)

From: Dr Graeme D Hubbert [graeme.hubbert@gems-aus.com]
Sent: Tuesday, 6 June 2006 23:25
To: Morrison, Peter F (SKM)
Subject: Re: DPU Dredge Modelling

Dear Peter,

With respect to your query about previous modelling at Dampier Port I can confirm the following:

a) The modelling did include the major sources of turbity plumes generated by the dredging (overflow, prop-wash and dumping at the spoil ground).
b) Monitoring and anecdotal reports since the completion of the project suggest that we over-predicted the turbidity, particularly from the prop-wash.
c) Based on the above, and on your assurance that the present program involves similar dredging amounts, is working in a deeper channel (because of the previous work) and will be carried out in a similar manner to the earlier dredging, I would expect the impacts of the present program to be somewhat less than we predicted last time.

I hope these comments are useful

Regards

Graeme

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DREDGE DISPOSAL IMPACT MODELLING
Port of Dampier

Prepared For

HAMERSLEY IRON

GEMS Report No 19/04 (Draft)
April 2004

GLOBAL ENVIRONMENTAL MODELLING SYSTEMS
Oceanography & Meteorology

Disclaimer

This report and the work undertaken for its preparation, is presented for the use of the client. Global Environmental Modelling Systems (GEMS) warrants that the study was carried out in accordance with accepted practice and available data, but that no other warranty is made as to the accuracy of the data or results contained in the report.

GEMS notes that the report may not contain sufficient or appropriate information to meet the purpose of other potential users. GEMS, therefore, does not accept any responsibility for the use of the information in the report by other parties.

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Acknowledgements

GEMS wishes to acknowledge Woodside Energy Ltd for its contribution to this study in making available historic winds from its FAR-14 anemometer site in Mermaid Sound.

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1 INTRODUCTION

Hamersley Iron Pty Limited (Hamersley Iron) is one of the world's largest exporters of iron ore. The company operates iron mine sites in the Pilbara region of Western Australia, together with a dedicated railway and port facility in Dampier. The port, which is one of Australia's largest tonnage ports, includes two terminals – Parker Point and East Intercourse Island. Hamersley Iron is proposing to upgrade its port facilities at Dampier from its licensed capacity of 80 Mtpa to 95 Mtpa. An important component of the port upgrade will be to undertake a major capital and maintenance dredging program to increase the flexibility of ship loading operations and limit the effect that the large tidal range has on the current port operations.

Dredging is expected to commence at the end of April 2004, and to be completed by the end of June 2004. It will be carried out using a medium sized trailer suction hopper dredge (TSHD), with some two million cubic metres of spoil to be transported and dumped at designated spoil grounds shown in Figure 1.

Global Environmental Modelling Systems Pty Ltd (GEMS) has been commissioned to undertake a modelling study to determine:

(i) The impact of propeller wash and spoil dumping on water quality (suspended sediment), and

(ii) The potential for re-suspension of sediments from alternative spoil during cyclone events for a range of (spill ground) scenarios.

To assist the modelling process, there is considerable information available from previous dredging programs carried out in Mermaid Sound. Included in these is the modelling program carried out by GEMS in support of the Dampier Port Authority (DPA) dredging program [1] and a subsequent monitoring project undertaken by Damara Pty Ltd [2]. This monitoring program was specifically designed to validate sediment release due to propeller wash.

There was also a significant data collection exercise during a dredging program during the development of the Woodside LNG channel [3]. This included sediment load sampling at fixed sites in the region and over time, from drogues following the sediment plume. Modelling of dredging and spoil disposal activities was also undertaken for Hamersley Iron in 1998 and monitoring of turbidity and plume tracking were undertaken during execution of the dredging works to calibrate the models.

2 SCOPE OF WORKS

2.1 Outline of Study Requirements

The scope of work set out for the current study was as follows:

2.1.1 Dredge Spoil Disposal

(i) Obtain and analyse suitable wind data for the period of the project;

(ii) Establish, test and run the 3-d hydrodynamic model (GCOM3D) covering the Mermaid Sound region and adjacent waters for a period encompassing the planned dredging program;

(iii) Scope the dredging program of works to develop model assumptions, including, in particular, sediment release volumes and rates resulting from propeller wash and spoil ground dumping;

(iv) Review geotechnical data on sediment types in the dredging;

(v) Run model simulations covering the period of operation and report on the fate of suspended sediments;

2.1.2 Cyclonic Re-suspension at Spoil Grounds

(vi) Set up and test wave model;

(vii) Select representative cyclone and run cyclone wind model;

(viii) Run wave model and extract near-bed orbital velocities for a range of bathymetric scenarios;

(ix) Run GCOM3D for this event to determine wind/tidal currents

(x) Run PLUMETRAK system based on combined circulation and wave driven currents for the bathymetric scenarios.

2.2 Assumptions

For the water quality component of the study, two main assumptions emerged in the scoping stage. These were first, that the dredge would overflow during the dredging operations and, second, that the primary source of fines and sediments liberated to the water would come from propeller wash and disposal of hopper load at the spoil ground during TSHD dumping.

The assumption of overflow has effect of reducing the proportion of the finest sediments to be dumped at the spoil grounds.

The treatment of sediment discharge disposal at the spoil ground is relatively straightforward and GEMS has successfully modelled the process previously. The parameterization of propeller wash impact is more complex; Mr. Matt Elliot (Damara WA), an experienced coastal engineer and modeller, was commissioned to report on this aspect of the project for the DPA study and this model has been updated and extended based on monitoring during the DPA dredge program (Appendix A).

2.3 Calibration and Validation Studies

The ocean model (GCOM3D) has been validated in a range of studies both within and outside Australia. Some specific verification data for Mermaid Sound has previously been reported [4].

3 PHYSICAL ENVIRONMENT

3.1 Meteorology

3.1.1 Overview

The climate of the region is effectively dominated by two main seasons. During the 'dry' season from May to October a belt of high pressure known as the sub-tropical ridge forms over the continent and results in semi-persistent easterly flow across the Pilbara. This flow may weaken and strengthen as individual high pressure centres evolve to the south in response to cold frontal activity. The easterly flow is characterized by low moisture content and stable weather conditions.

Warming of the continent following the winter solstice results in a gradual southward migration of the subtropical ridge. This has a two-fold effect by which the general strength of the easterlies weaken, and a persistent 'heat' trough (area of low pressure) forms along the Pilbara coast. Seaward of the trough, the general flow then trends to be southwesterly. Closer to the coast diurnal variations in terrestrial temperatures cause local sea-breeze impacts to become important.

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

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

Impacts from cyclone events occur outside the proposed dredging period. The greater proportion of the program will be affected by easterly quarter winds. However, during the early stages (May), there is a greater probability of sustained southwesterly winds.

3.1.2 Wind Data

In order for the modelling to reflect the wind climate of the area, appropriate wind data must be sourced for the region of interest. Two main options were available. These were:

(i) Apply archived (spatially varying) numerical weather prediction data, or

(ii) Apply archived (single point) anemometer data from at least one of the sites in the Mermaid Sound area available.

The advantage of the first option is that model winds vary spatially as well as temporally. However, the data available was not of sufficiently high resolution to adequately reflect mesoscale influences such as seas-breezes. Using anemometer winds has the disadvantage that only a single point source is available. However, because of the relatively limited modelling domain, the proximity to the coast and the data quality, it was decided that the anemometer data should be used.

The most representative data is from the Woodside FAR-14 anemometer at the end of the LNG jetty at Withnell Bay. The instrument is on a tower at a height of 34 metres, so that wind speeds needed to be adjusted to 10-metre height by applying a standard logarithmic boundary layer profile. Mean wind speed, direction and peak gust data are recorded at 10-minute intervals. The data record is near continuous from 1994 to the present.

The data were subjected to directional-magnitude analysis for the period May to June covering the proposed dredging schedule. Figure 2 shows a plot of the data for all years for the months of May and June. The general predominance of easterly winds s during these months is clearly evident.

3.2 Oceanography

Mermaid Sound, and the regions offshore from the Burrup Peninsula, can be affected by a range of oceanographic (and related meteorological) influences, including tropical cyclones, wind and tidal driven currents and waves.

3.2.1 Ocean Currents

The dominant forcing of ocean currents in Mermaid Sound is derived from the winds and the tides. The tidal currents associated with the flooding and ebbing tide flow predominantly along the axis of Mermaid Sound with strong currents exhibited in the channels between the islands due to the narrow passages and the shallow bathymetry. The net flow through the channel is either to the north or southwest depending on the predominant winds.

3.2.2 Ambient Waves

The wave climate in Mermaid Sound is strongly affected by the coastal bathymetry and open ocean waves have been significantly attenuated by the time they propagate down Mermaid

Sound. As a result, except during cyclone events, the wave climate in Mermaid Sound is controlled by fetch-limited, low energy waves with wave heights generally well below 2 metres in the southern reaches of the Sound.

It is expected that there would be some re-suspension of fine sediments due to wave action over the spoil grounds, but it is considered that the impact on general turbidity will be small compared with resulting from the dredge operations.

3.2.3 Tropical Cyclone Storm Surge and Waves

During Tropical Cyclone Orson in May, 1986 Mermaid Sound experienced a storm surge of just over 3 metres together with hurricane force winds and breaking waves heights over 3 metres. Events like this are infrequent but need to be considered when the extremes of environmental forcing are required for coastal engineering and/or environmental impact assessments.

2.2.4 Thermal Structure

The waters on the Northwest shelf can exhibit significant vertical variation in temperature and density. The existence of such stratification can affect the behavior of plumes, particularly buoyant discharges from near the ocean floor (e.g. pipeline ruptures or hydrotest fluid discharges). The existence of stratification can also result in the propagation of internal tides such as has been measured at the Woodside North Rankin platform. The thermal structure however should have limited impact on the fate of sediment plumes in Mermaid Sound, because of the shallow depth.

2.3 Sediments

The following stratigraphy is typical of materials anticipated to be encountered at Parker Point in areas not previously dredged:

- Silts and silty clays with some sands to a depth of the order of 3.0 m overlying;
- Gravelly clay/clayey gravel with particles consisting of calcarenite, shells and rounded dolerite pebbles overlying; and
- Calcarenite of low to medium strength. Leaching of the calcarenite occurs in some areas and the material removed replaced by sandy clay.

Soft surface sediments, such as silts and clays, will be removed using the TSHD; whereas, the harder materials will be dredged using a cutter suction dredge (CSD) and pumped directly ashore via a floating pipeline.

The sediments to be dredged by the TSHD from the existing shipping channels are dominated by fine grain sizes with significant fractions of the material less than 38 µm in size.

The sediments to be dredged by the TSHD in the new berth area and the outer channel, are dominated by medium silts as well as an even distribution of course silts and fine sands (<180 µm). There are generally only small differences between the surface and lower strata particle size distribution.

3. MODEL DESCRIPTIONS

3.1 Oceanographic Model – GCOM3D

For studies of hydrodynamic circulation and sea level variation under ambient and extreme weather conditions, GEMS has developed the GEMS 3-D Coastal Ocean Model: GCOM3D. GCOM3D is an advanced, fully three-dimensional, ocean-circulation model that determines horizontal and vertical hydrodynamic circulation due to wind stress, atmospheric pressure gradients, astronomical tides, quadratic bottom friction and ocean thermal structure. The model scale is freely adjustable, and nesting to any number of levels is supported in order to suit the hydrodynamic complexity of a study area. As the model is fully three-dimensional, output can include current data at any or all levels in the water column.

The model set-up characteristics are described in the next section.

3.2 Wave Model - SWAN

The wave model employed for this study is the near-shore model SWAN, developed by the DELFT University in the Netherlands. SWAN is a third generation spectral model with a nesting facility allowing input of time changing water depth at varying spatial and temporal resolution. The model contains implicit shallow water subroutines to allow for shoaling, frictional dissipation, wave breaking and refraction.

Since SWAN is fully scalable, the model is able to be set up at different grid resolutions to capture both the broad cyclone-scale forcing as well detailed effects such as refraction and wave breaking.

GEMS has previously undertaken validation of SWAN for tropical cyclone events over the North-west shelf. This includes a recent assessment of waves during TC Monty, where model output was compared with wave data from North Rankin A platform.

3.3 Plume Model

PLUMETRAK is the integrated, high-resolution 3D dispersion model developed by GEMS for modelling a wide variety of discharge materials including sediments, sewerage, thermal discharges, oils and chemical releases.

The model suite quantifies the distribution of each substance spilled or released under controlled conditions. The model reports mass and concentration levels on the water surface, on shorelines, on the ocean floor or through the water column as required. Horizontal and vertical cross-sections are available to better illustrate the three dimensional distributions.

Where multiple chemical constituents are involved, the model can report the distribution of each constituent individually.

For the current project, particle tracking occurred continuously with periodic sediment input based the dredging program and the output from GCOM3D. Post-processing then allowed for production of:

(i) Instantaneous depth averaged plots of Total Suspended Solid (TSS) concentrations.

(ii) Monthly averages of depth averaged TSS concentrations;

3.4 Propeller Wash Model

The propeller wash model developed for the DPA project was modified and extended based on the DPA validation program. A significant improvement to the model is an algorithm which allows for varying keel clearance depth (based on load, location and tide). The model is described in detail in Appendix A.

4 MODEL INPUTS & ASSUMPTIONS

4.1 Water Quality Impacts

4.1.1 GCOM3D

For this project, the GCOM3D was set up to include Mermaid Sound and adjacent waters. Tides were based on previous detailed regional modelling and include the M2, S2, N2, K2, O1, K1, P1, Q1, and 2N2 tidal constituents. Figure 3 shows general tidal variability for the period.

GOM3D Setup parameters are summarized in Table 1. GCOM3D was run continuously for a period corresponding to May 2004 to April 2004 (tides) with equivalent period winds from the equivalent 2002 season.

Figures 4(a) and (b) show the current flow during a period of southwesterly winds and easterly winds respectively.

4.1.2 PLUMETRAK

For the current study, PLUMETRAK was set up to track suspended sediments and register deposition. Particle size bins were set at 5-micron increments below 100 micron. The model allowed for re-suspension due to wind/tidal currents but not for wave action. Horizontal resolution was 25 metres and vertical increments were 1 metre. PLUMETRAK setup details are given in Table 2.

Quantitative sediment inputs used are described in the next Section.

4.1.3 Sediments

Sediment sizes were based on an analysis provided by Hamersley. Based on the experience of the DPA, it was assumed the lowest 10 per cent of fines would be lost through overflow. Figure 5 shows the assumed sediment distribution by size .

Settling rates were based on the DPA program.

4.1.4 Propeller Wash

GEMS has been advised that the majority of dredging will occur with overflow, thereby reducing the amount of the finest materials in the spoil. However, as born out by the DPA program, it is expected that propeller wash from the vessel will create a significant sediment source.

The propeller wash model developed in conjunction with Damara Pty Ltd was applied for the expected bottom sediment particle distribution described in the previous section. The water column distribution of sediments was then determined as a function of under-keel clearance. Figure 6 shows the distributions for two sample clearance depths.

4.1.5 Dredging Cycle & Production Rates

It is intended that dredging will occur on a near continuous basis. The planned cycling time is of the order of 120 minutes, consisting off:

(i) 30 minutes dredging at an average speed of 1.5 to 2 knots (equivalent to about 1.5 km distance traversed);
(ii) average, 80 minutes travel to spoil ground, and
(iii) 10 minutes dumping (traversing 700m to 1km).

For the current study, sediment mobilization is focused on propeller wash effects en-route to and within the spoil ground and spoil dumping.

4.1.6 Vessel Track

PLUMETRAK was setup to allow random location of the dredger start-finish line from the dredging area to the East Lewis Island spoil grounds – propeller wash was included for three routes starting from the dredge and terminating at three locations within the spoil grounds.

4.1.7 Spoil Grounds

Based on the previous program, each spoil dump was set to 2500 cubic metres of sediments. The model assumed release at a depth of 4 metres below the surface. The location of dumping was based on a random selection of start and end points within the designated dumping area.

4.2 Cyclonic Re-suspension and Deposition

4.2.1 Representative Cyclone

The aim of the cyclone modelling was to compare the effect of a range of spoil finish levels under the effect of a tropical cyclone impact. Selection of an appropriate cyclone event is problematic, since the impact of a particular cyclone on the spoil grounds will be dependent on the storm's wind field (which is in turn dependent on the cyclone intensity, track, speed and size) and the tide phase.

Ideally, a very large number of combination of these factors would be considered in order to specify the probability of any combination of such events and their impact on the spoil grounds. Since this is well beyond the scope and timeframe of the current study, we have selected a representative cyclone and used it for this baseline study.

Cyclone 'Monty' which occurred at the end of February this year was a Category 4 cyclone with a lowest central pressure of 935 hPa. The storm weakened slightly as it approached and finally crossed the coast east of Onslow (central pressure near 950 hPa). A previous, detailed cyclone analysis carried out as part of the Karratha Storm Surge Study [6], showed that a storm of such intensity crossing the coast represents about a 1 in 20 year (cyclone) event for a particular location. Accordingly, we have shifted the track of Monty so that it crosses the coast with radius of maximum winds directed over Mermaid Sound (Figure 8). By applying the wind forcing of this storm to the wave and ocean models we then have a baseline event for conditions in Mermaid Sound broadly representative of a 1 in 20 year 'spoil ground event'.

4.2.2 Tidal Scenarios

Clearly, the total impact of any given cyclone will depend on which part of the tidal cycle with which it coincides. The change of water depth with the tidal cycle will impact the wave height and associated near-bed orbital velocities as well as the tidally driven current. By running the wave model at fixed (MSL) depth, we are ensuring that representative waves are being considered.

Similarly, GCOM#D was run based on cyclone winds but without tides - this effectively models for a mean tidal condition, in terms of sediment transport.

4.2.3 Spoil Fill Scenarios

The spoil ground regions under consideration are shown in Figure 1. Spoil ground fill options to be considered were:

a) East Lewis Island spoil grounds filled to RL-6.5m CD;
b) Northern/Southern Spoil Grounds- North filled to RL-11.5m/South filled to RL-9.3m CD;
c) Northern/Southern Spoil Grounds - North filled to RL-10.5m/South filled to RL-9.3m CD, and
d) Northern/Southern Spoil Grounds - North filled to RL-9.5m/South filled to RL-9.3mCD.

4.2.4 Wave Grids

For the cyclone wave simulations in the current study the model was established at spatial resolutions of 0.2 degrees, 0.002 and 0.0002 degrees (approximately 20m) respectively. Separate high resolution grids were set up for the two spoil grounds, referred to as ELI (East Lewis Island) and SG4 – see Figure 7. Table 3 provides a summary of the model settings and outputs for the wave model runs.

5 RESULTS

5.1 Spoil Disposal – Water Quality Impacts

The dredge spoil fate modelling was carried out for the period May 1 to June 30 inclusive.

Total suspended sediment (TSS) levels were modelled continuously for this period, based on the planned dredging cycle described in the Section 5. PLUMETRAK computes TSS at discrete levels though the water column and these values were averaged in the post-processing to produce hourly mean water column levels.

Water quality in King Bay and surrounding waters has previously been investigated by Sinclair Knight Merz on behalf of the Water Corporation as part of the monitoring program for the Burrup Industrial Water Supply System. The monitoring program included assessment of turbidity and light attenuation. The resultant data indicated that water clarity in the area varies temporally (on daily and seasonal scales), spatially and with depth in the water column. Local waters were found to be naturally turbid, with higher levels of turbidity and light attenuation in near shore areas.

Turbidity values taken on consecutive days in March 2003 recorded background levels of between turbidity between 2 NTU and 13 NTU and some locations increasing threefold over consecutive days. Water quality monitoring has also been undertaken by the DPA from January 2004 to April 2004. Measured values of total suspended solids at reference sites in Mermaid Sound (Gidley Island, North Withnell Bay, South Withnell Bay and High Point) varied between 0.2 mg/L and 57.9 mg/L. The average background level of total suspended solids measured at these sites over three months was 5.4mg/L. Accordingly, the model plots show contours starting from background levels, ie. 5 mg/l.

Examination of the wind data used for the modelling shows a dominance of south westerly winds for the first three weeks of dredging and then after May 24 the wind regime is more mixed, including the occurrence of north easterly events which may result in impacts on East Lewis Island. Figures 9 to 11 show instantaneous plots of TSS during the modelling period which represent these important changes in wind climatology. Figure 9 shows the TSS values on May 23, after the period of southwesterly winds; figure 10 shows TSS values 7 days later after dominant northeasterly winds and figure 11 show TSS values at the end of the dredging (June 30). Figures 12 and 13 show long-term averages of TSS from May 1 to 23 (after sustained southwesterly winds) and from May 24 to the end of dredging (after a more mixed wind climatology).

The results show a mean increase in turbidity around the eastern flank of East Lewis Island but only up to about twice background levels. During a period of sustained southwest to southerly winds, the eastern tip of West Lewis Island is similarly affected , but otherwise increases in turbidity are confined to a relatively narrow region up and down Mermaid Sound.

5.2 Cyclonic Re-suspension

The revised Cyclone Monty track was used to generate wind fields over the three coarse, fine and two micro-scale grids described in Section 5. These winds were used, in turn to drive the SWAN and GCOM3D models.

Near-bed orbital velocities were combined with the GCOM3D currents to initialize PLUMETRAK. PLUMETRAK then computed sediment mobilization and tracked sediments through the cyclone event. In each case, sediment re-suspension was limited to the spoil grounds and not from across the whole of Mermaid Sound.

The wave model was run firstly for the baseline case of no change to the current bathymetry and then for each of the bathymetry cases A-D described in Section 4.2.3. It was expected that resulting changes to the near-bed wave induced orbital velocities resulting from the bathymetry changes would be small. This is demonstrated in Figure 14(a) which shows time series of near-bed orbital velocities for each scenario at a location in the northern section of Spoil Ground 4. The speed differences are only of the order of a few cm/s; this will result in only very small differences in sediment re-suspension.

Somewhat more significant current-speed differences occur in the wind driven component of the current fields in the region of Spoil Ground No.4. These are of the order of 0.2 to 0.3 m/s in Spoil Ground No. 4 for Scenario D. The current speed differences at the East Lewis Spoil Ground are much less significant – see Figure 14(b).

In order to establish a baseline case the model was run based on the existing bathymetry for each spoil ground. The model was then re-run for each spoil ground under changed bathymetry conditions – Scenario A at east Lewis Island Spoil Ground and Scenario D for Spoil Ground No. 4 (corresponding the to case with largest increase in currents). The results shown in Figures 15 and 16 delineate relative deposition after 11 hours and 24 hours respectively. During the first 11 hours the cyclone is approaching the spoil grounds driving northeasterly winds across the region; the next 11 hours are for the cyclone to the south of the spoil grounds with resulting southwest to westerly winds. Figures 15(a) and 16(a) show sediment deposition for the 'current condition while Figures 15(b) and 16(b) show the equivalent results for the changes bathymetry – the contours are dimensionless contours of relative sediment fractions.

The plots show :

(i) most of the sediment quickly re-settles at both spoil grounds;

(ii) there is only a very marginal difference between the before and after cases for the East Lewis Spoil Ground;

(iii) there is a greater relative difference between the before and after cased for the largest current change scenario at Spoil Ground 4 (there is approximately 10 per cent increase in the material mobilized in this case), and

(iv) the (finer fraction) materials moving away from the spoil ground represent a small amount of the total mobilized sediments and that these continue to settle and remobilize though the coarse of the cyclone event.

During this particular event, the direction of transport from Spoil Ground No. 4 is initially to the southwest and then the finer fractions move more to the east. Other cyclone events (different track/tidal condition) are likely to produce a range of orientations in sediment relocation.

It should be noted that the 10 per cent difference in mobilized sediments is relative the sediments in the spoil grounds themselves; this would represent a much smaller fraction of the total amount of sediment in Mermaid Sound being re-suspended and re-settling across Mermaid Sound during such an event.

6 SUMMARY & CONCLUSIONS

GEMS has undertaken a program modelling sediment response to ambient circulation and cyclone impact in Mermaid Sound.

Plume modelling of propeller wash and spoil dumping impacts were determined for the period May to June based on predicted tides and representative winds. The results of the modelling program show that sediments flush out of the area of operation as a function of the tidal phase and predominating winds. During southwesterly wind events, this flushing tends to occur quickly as sediments move northwards up the sound, while sediment levels are directed southwestwards under the impact of northeast winds. The easterly wind events increase sediment levels on the eastern side of East Lewis Island.

The response of prospective spoil ground filling was investigated by considering the impacts of a significant tropical cyclone passing with its maximum winds directly over Mermaid the spoil grounds. The changes in bathymetry under these scenarios were found to exhibit very small relative differences in sediment re-suspension/deposition for the East Lewis Island spoil ground scenario. The effect for the ‘worst” case at Spoil Ground No. 4 was a little more discernable, but relatively small in the context of likely total sediment movement across the whole of Mermaid Sound in such an event.

7 REFERENCES

[1] Dampier Bulk Liquids Berth Project; Dredge Modelling Study. GEMS Report No. 024/03. December 2003.

[2] Dampier Bulk Liquids Berth Project; Model Verification Survey. Damara WA Report. March 2004.

[3] Provost, Semeniuk and Chalmer, 1987. Woodside LNG Shipping Channel Spoil Dumping Permit –Water Quality Surveys to June 1987. Report No. R173.

[4] Bureau of Meteorology, Special Services Unit, 1995. Verification of the Three-Dimensional Oil Spill Trajectory Model in Mermaid Sound.

[5] Karratha Storm Surge Study. Buraeu of Meteorology Special Services Unit Report.

[6] Dredging and Contracting Rotterdam B.V. 1998, *Dampier Port Upgrade Project Dredging Monitoring Environmental Management Plan*, Unpublished report prepared for Hamersley Iron Pty Ltd by Dredging and Contracting Rotterdam B.V., Perth.

Table 1: Summary of GCOM3D settings used for hydrodynamic modelling

Model dimensions	3 (latitude, longitude and depth).
Depth layers	20 of variable thickness. Surface layer 2 m thick.
Output depth layer	All layers
Model domain size	0.75 deg x 0.55 deg
Bathymetric grid resolution	150 m
Forcing terms	
- Astronomical tides	9 tidal constituents: k2, s2, m2, n2, k1, o1, q1,p1,sa
- Wind shear	Hourly wind speed and direction data from the Woodside shore facility
Model period	May 1 to June 30, 2002 (using 2004 tides)

Table 2: PLUMETRAK Settings

Minimum Latitude	20^0 42' (S)
Maximum Latitude	20^0 24' (S)
Minimum Longitude	116^0 33' (E)
Maximum Longitude	116^0 52' (E)
Horizontal resolution	20 metres
No. vertical levels	Up to 60
Vertical resolution	1 metre layers
Start Date	May 1, 2004
End Date	June 30, 2004

Table 3: Wave model settings.

Parameter	Coarse Grid	Fine Grid	ELI Grid	SG4 Grid
Spatial resolution (deg)	0.02	0.002	0.0002	0.0002
Directional resolution (deg)	20	20	10	10
Spectral resolution (sec)	1.5	1.5	1.5	1.5
Time step	900	900	900	900
Output parameters	Spectral	Spectral	Hs, Tp, Dir, Vorb	Hs, Tp, Dir, Vorb

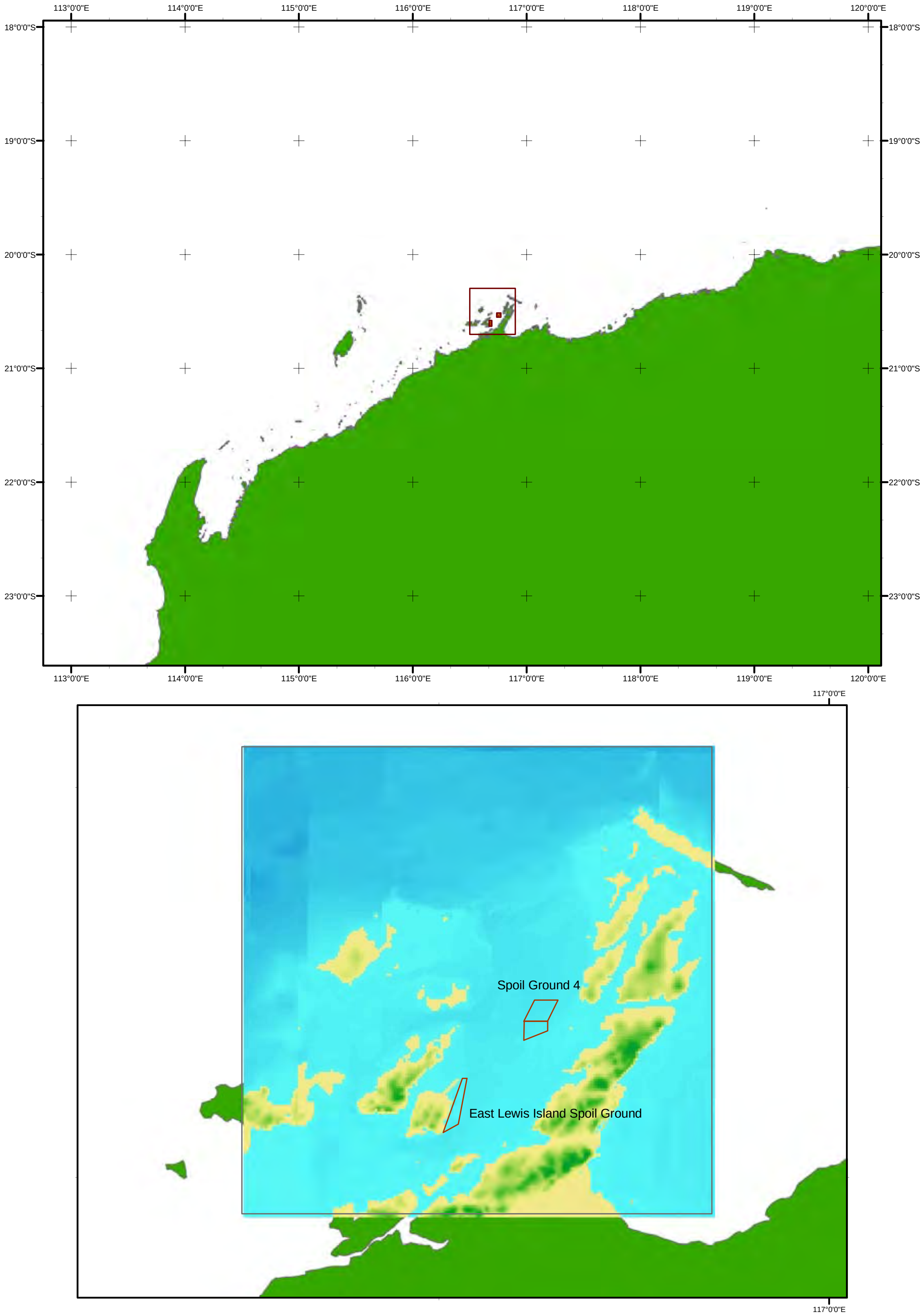
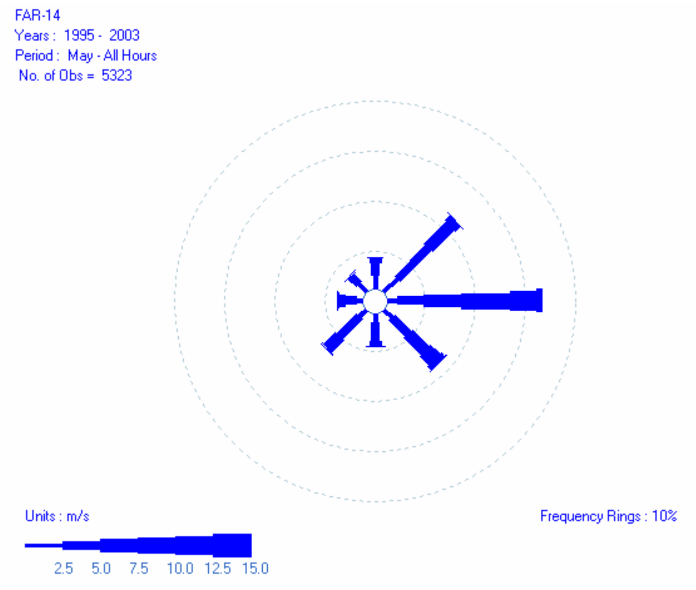


Figure 1. Study region including two spoil ground areas considered in the current study.



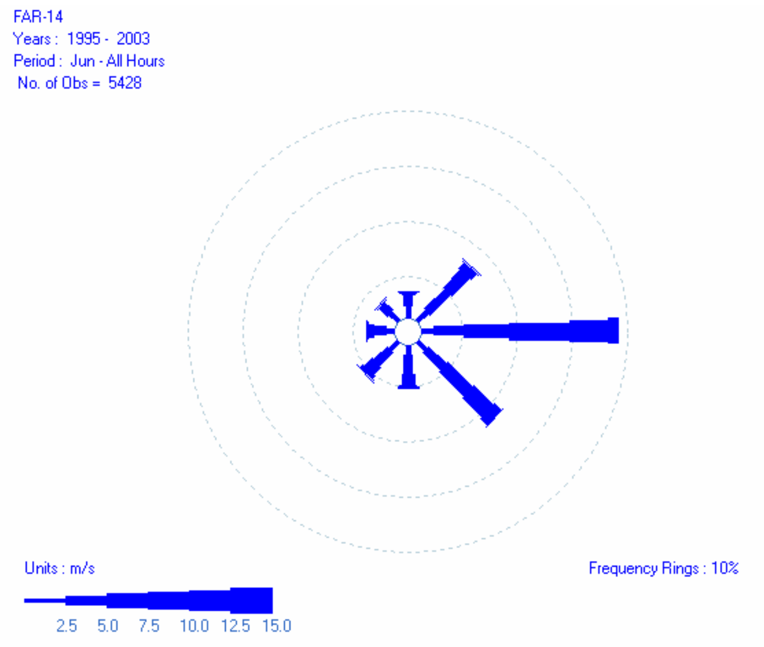


Figure 2. Polar wind diagrams for each month of the proposed operation (based on FAR-14 Automatic Weather Station).

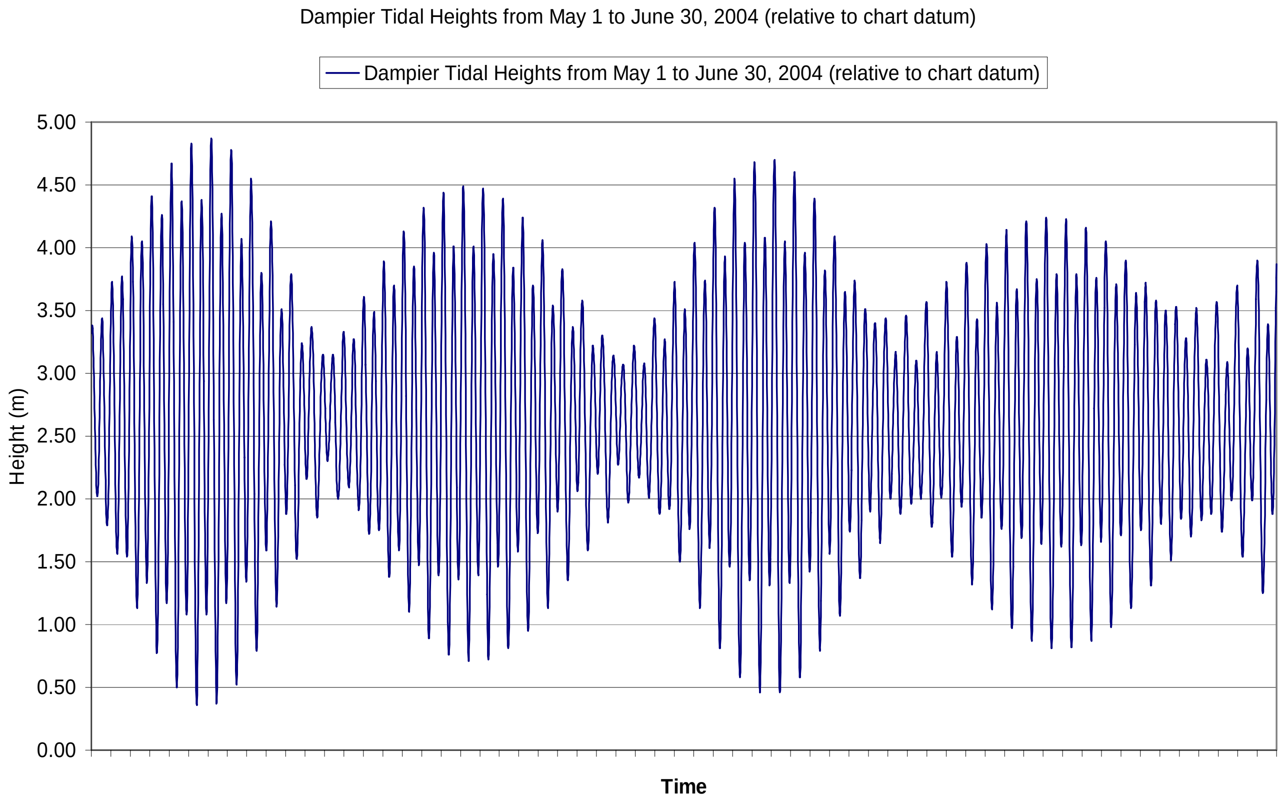


Figure 3. Tidal variation during the modelling period (May to June 2004).

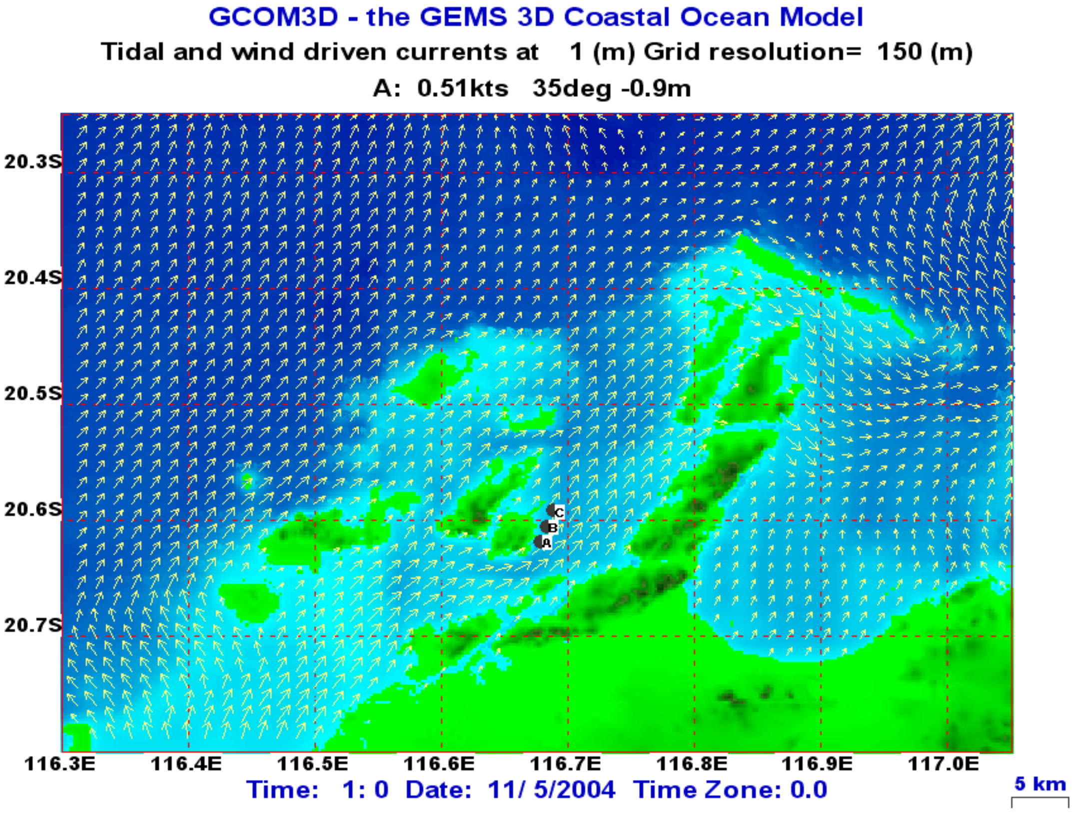


Figure 4(a): Example of currents during southwest wind event.

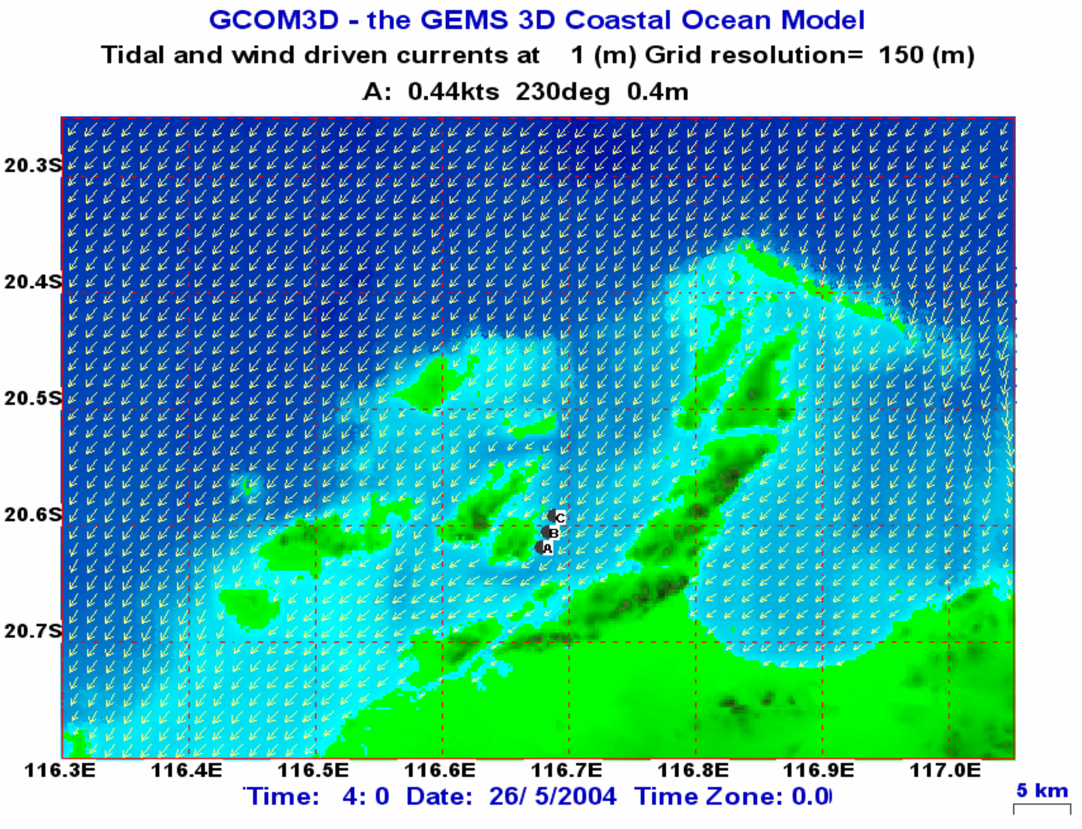


Figure 4(b) Example of currents during northeast wind event.

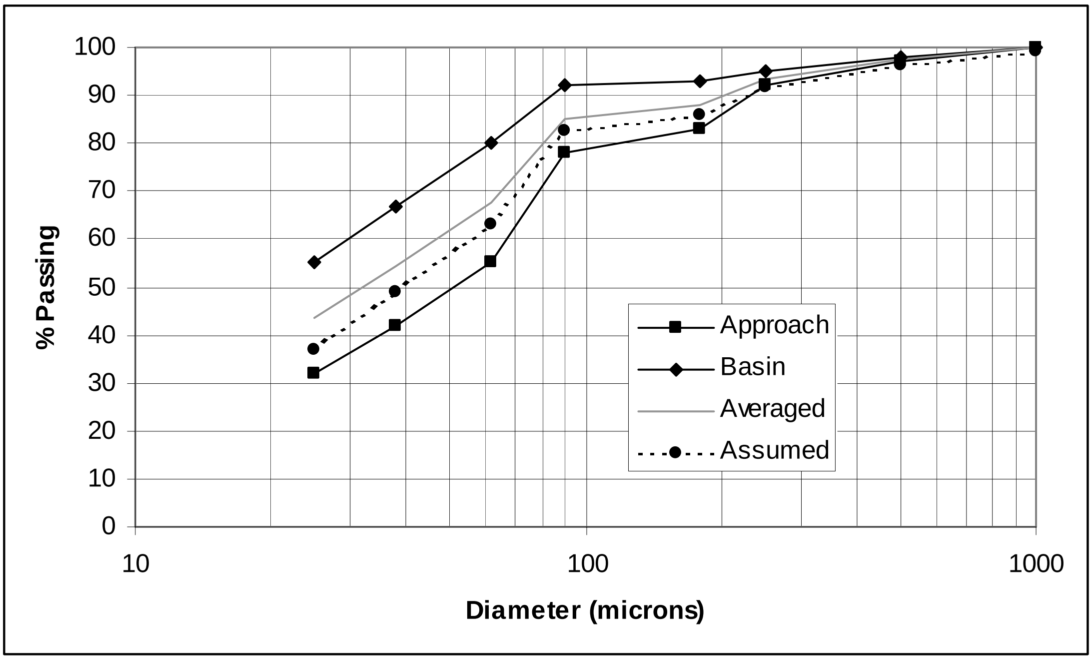
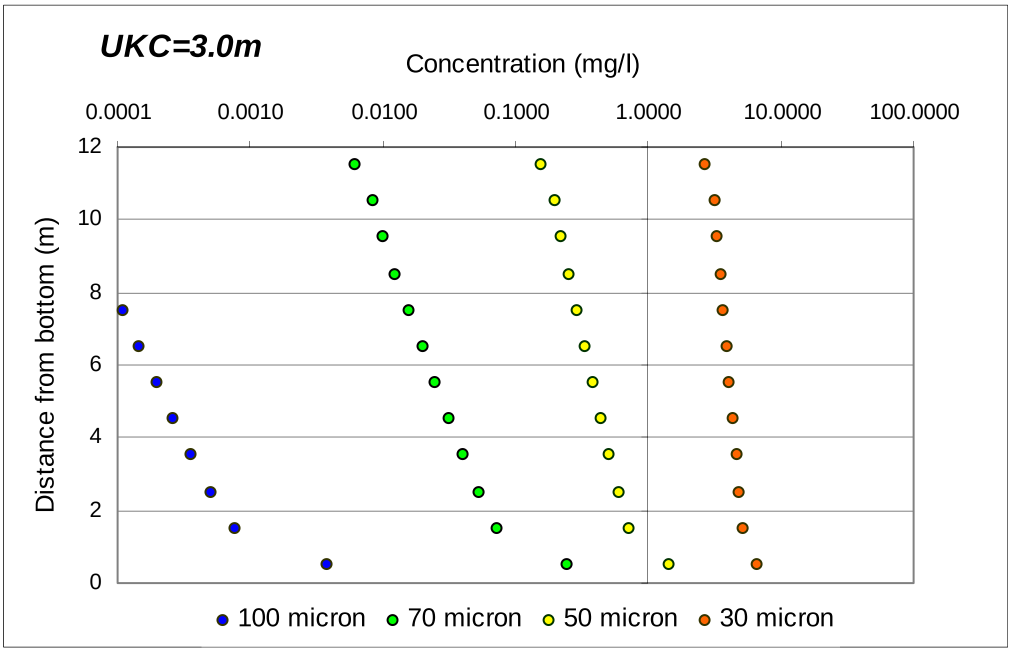


Figure 5. Mean instantaneous water column TSS levels at the end of May.



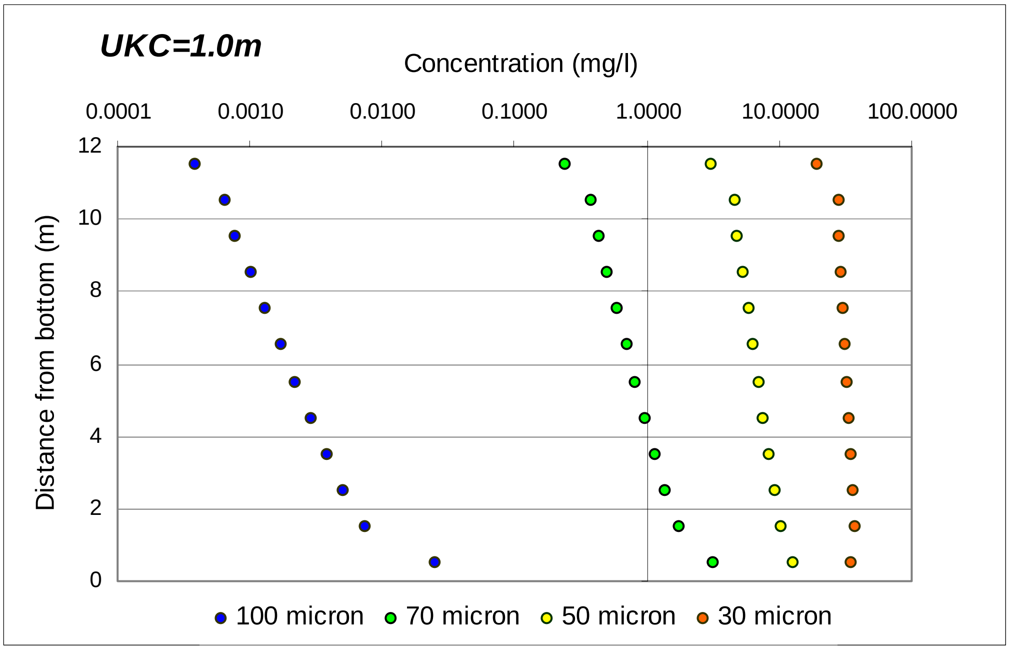


Figure 6. Propeller wash sediment mobilisation as a function of under-keel clearance (UKC)

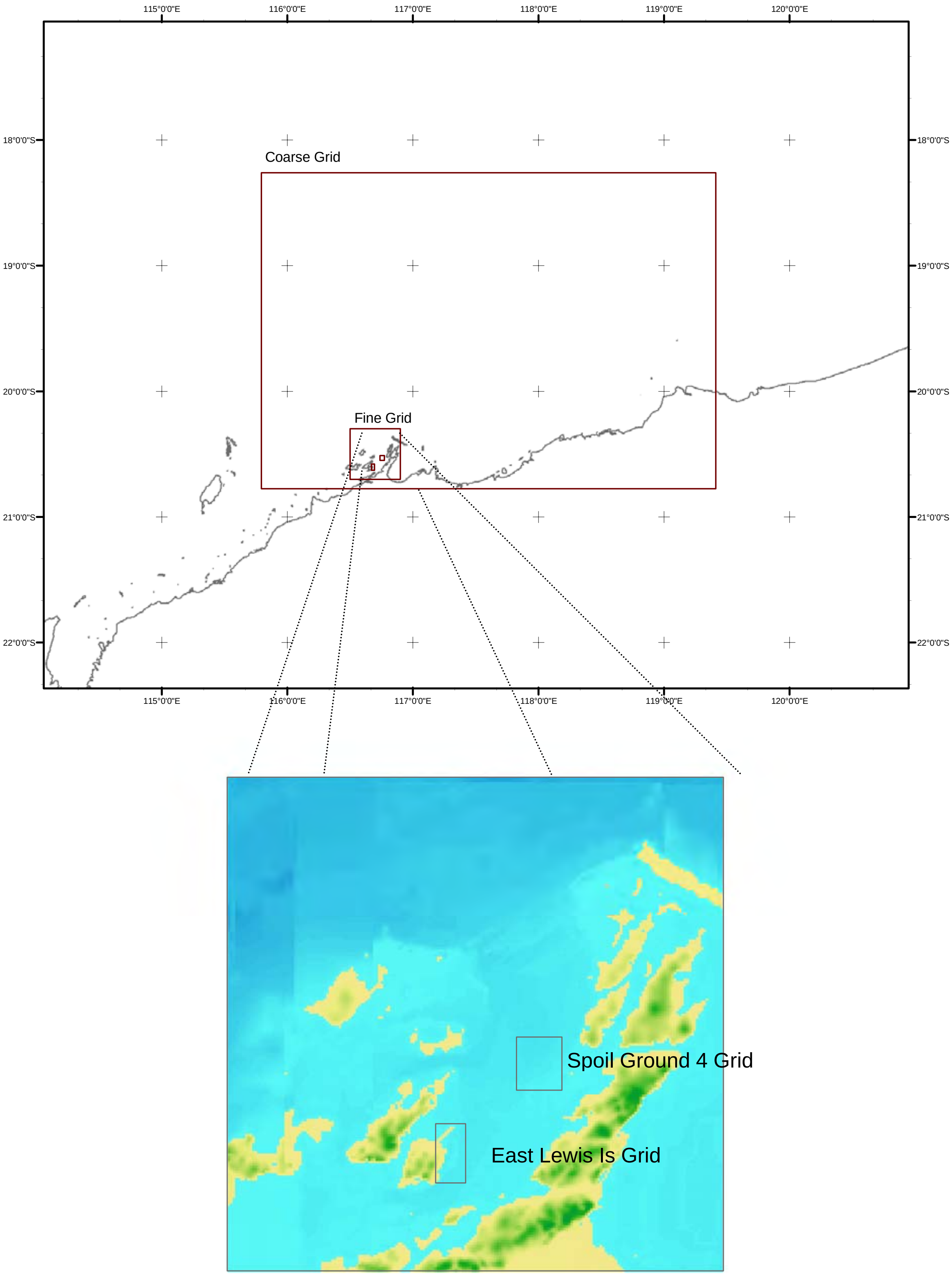


Figure 7. Wave model grid system, showing bathymetry at 0.002 deg resolution over Fine Grid.

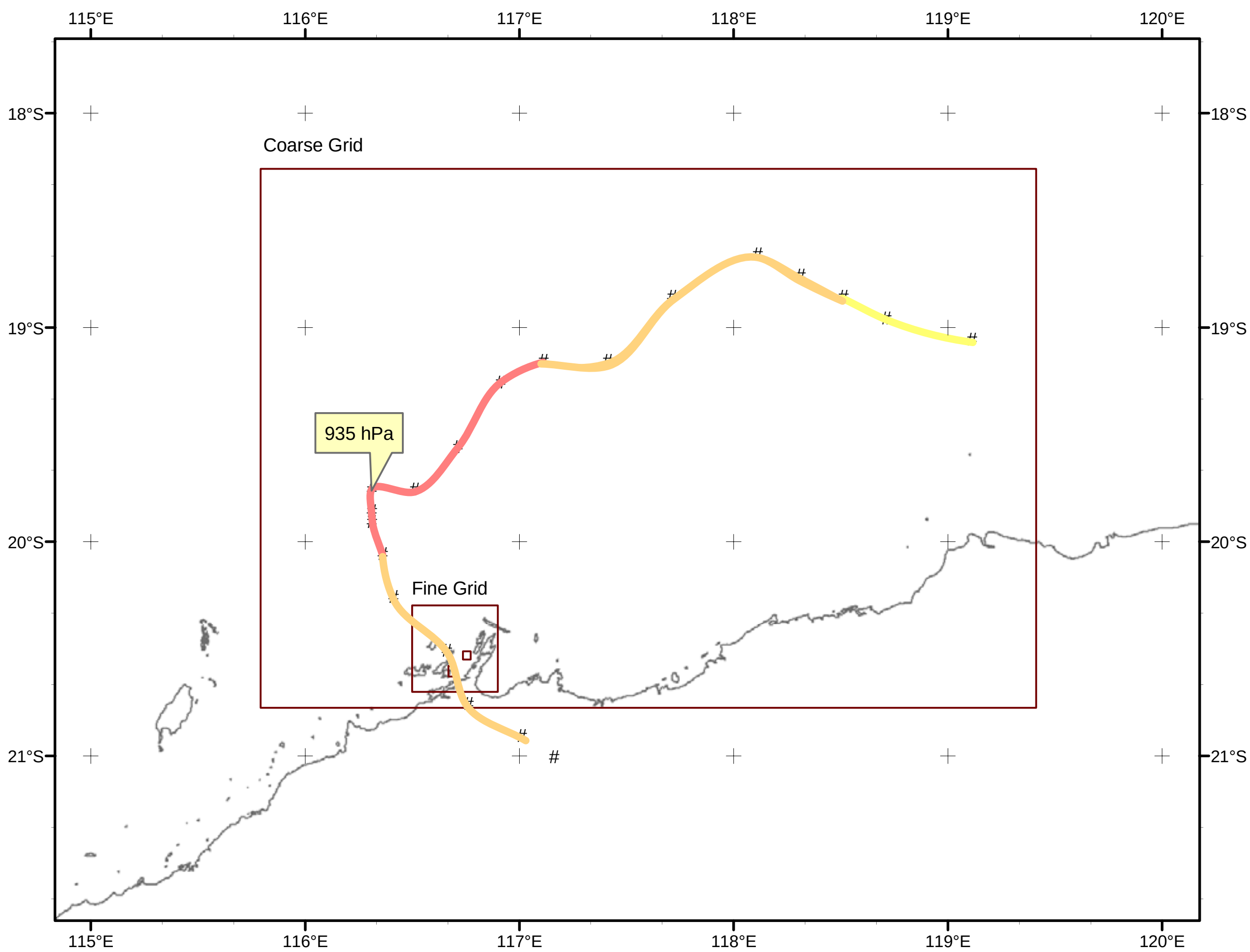


Figure 8. Track of TC 'Monty' shifted to pass just west of Mermaid Sound.

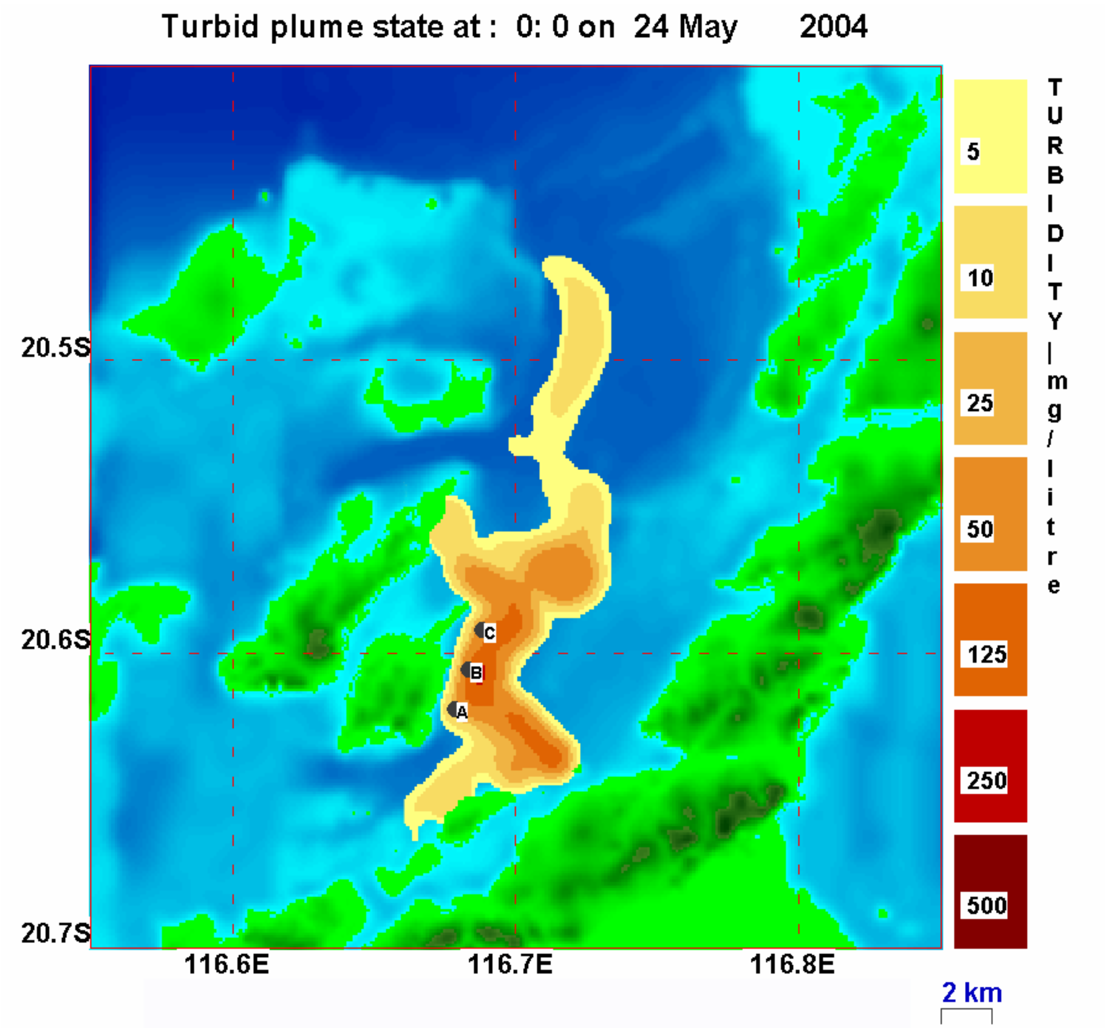


Figure 9: Mean instantaneous water column TSS levels on May 23 after sustained south westerly winds

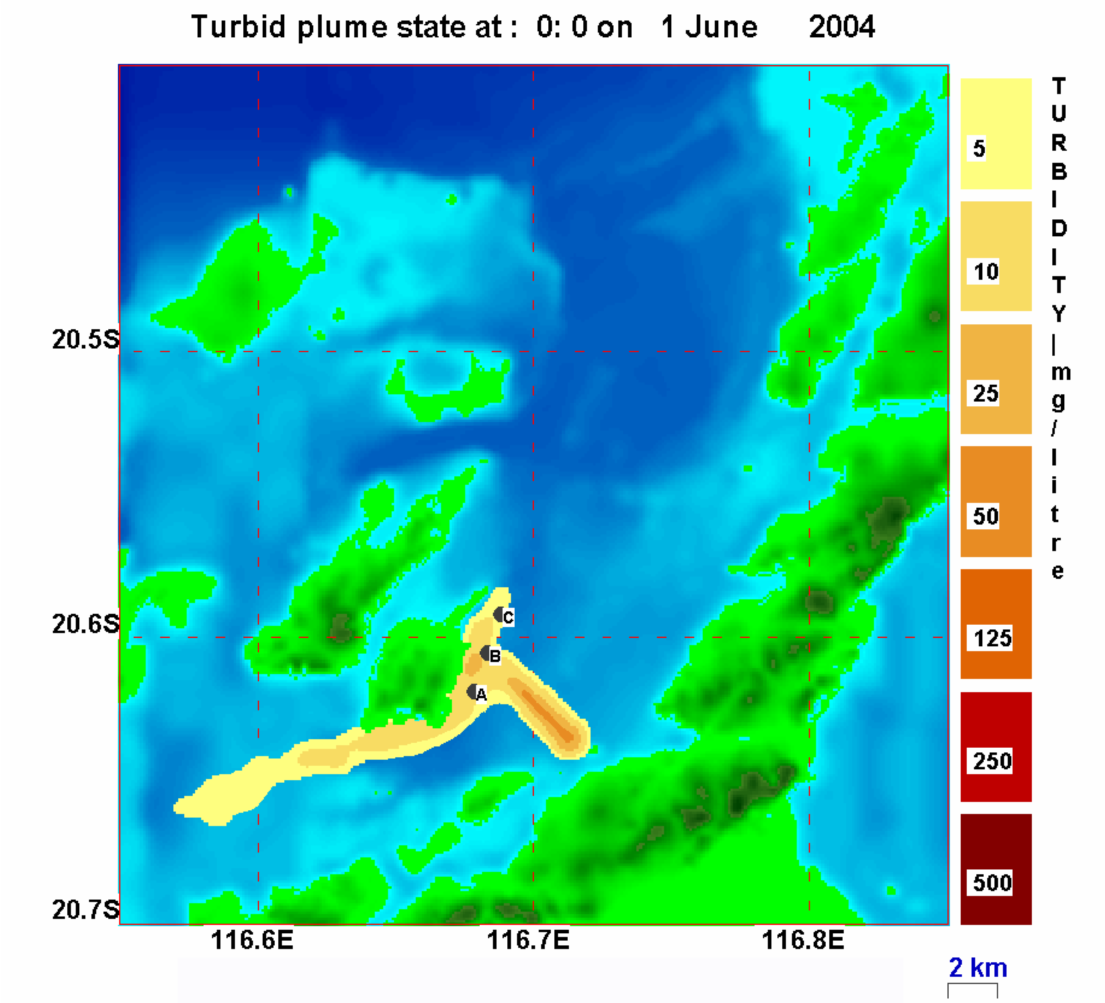


Figure 10. Mean instantaneous water column TSS levels on May 31 at the end of a period dominated by north easterly winds.

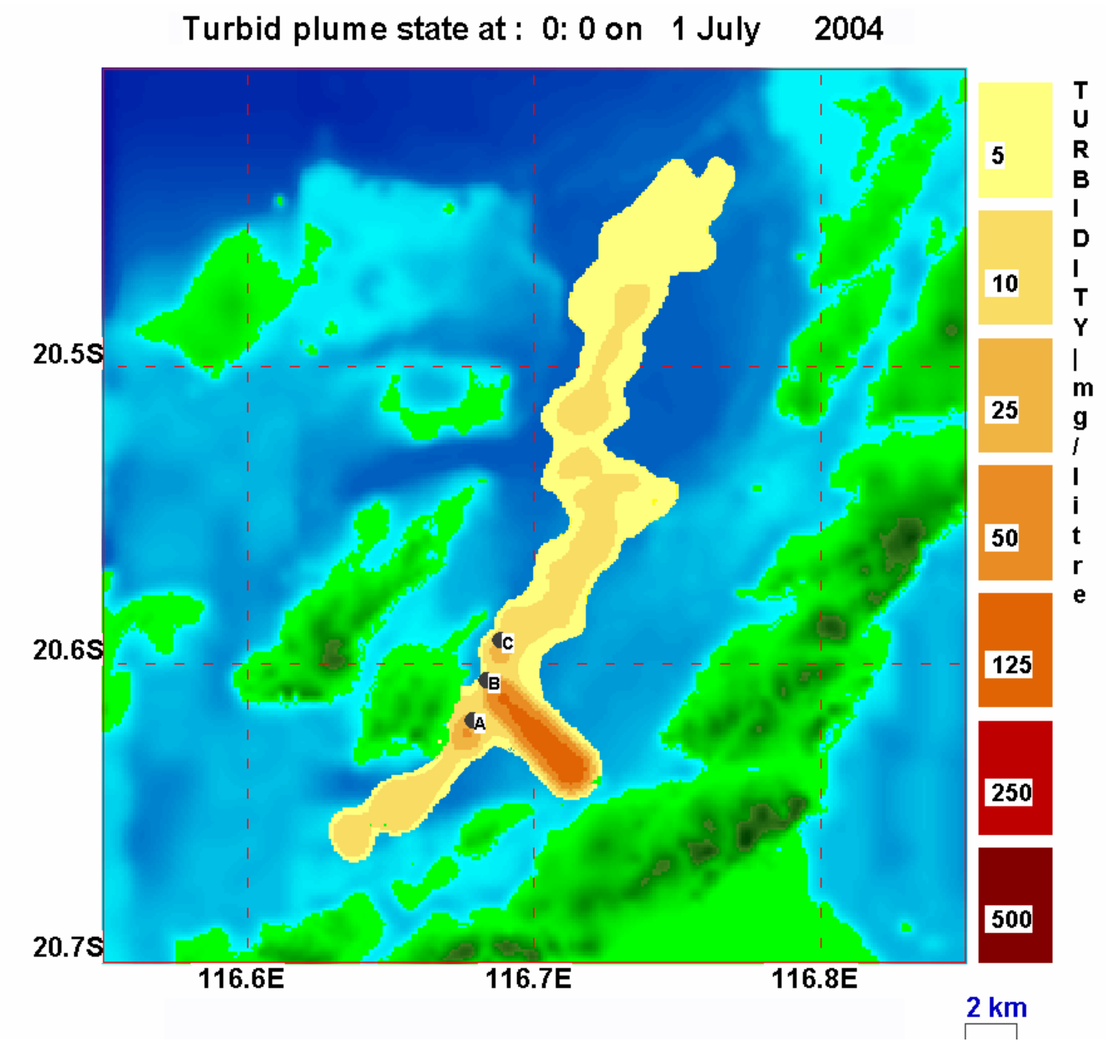


Figure 11. Mean instantaneous water column TSS levels at the end of the dredging (June 30).

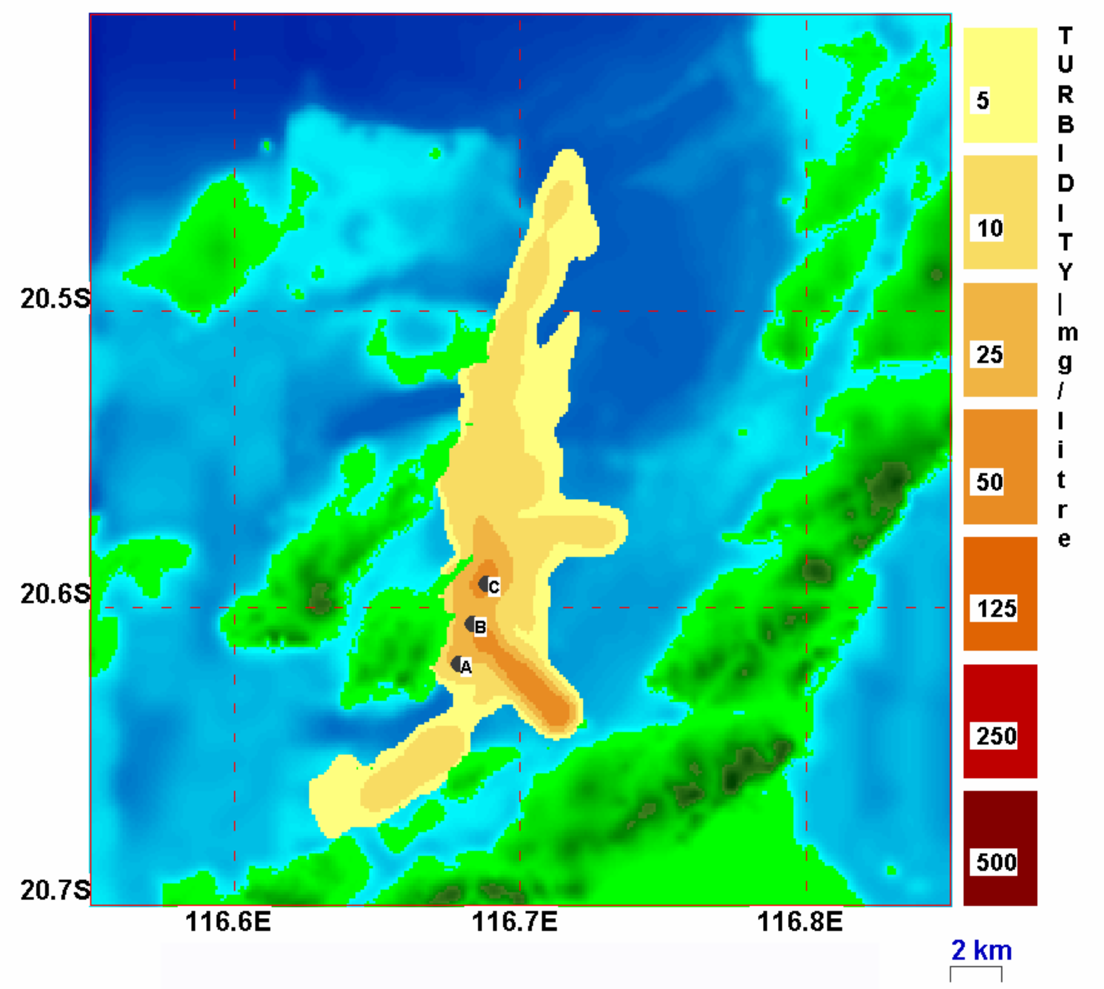


Figure 12. Mean monthly water column TSS levels for the first twenty-three days of modelling (after sustained south westerly winds).

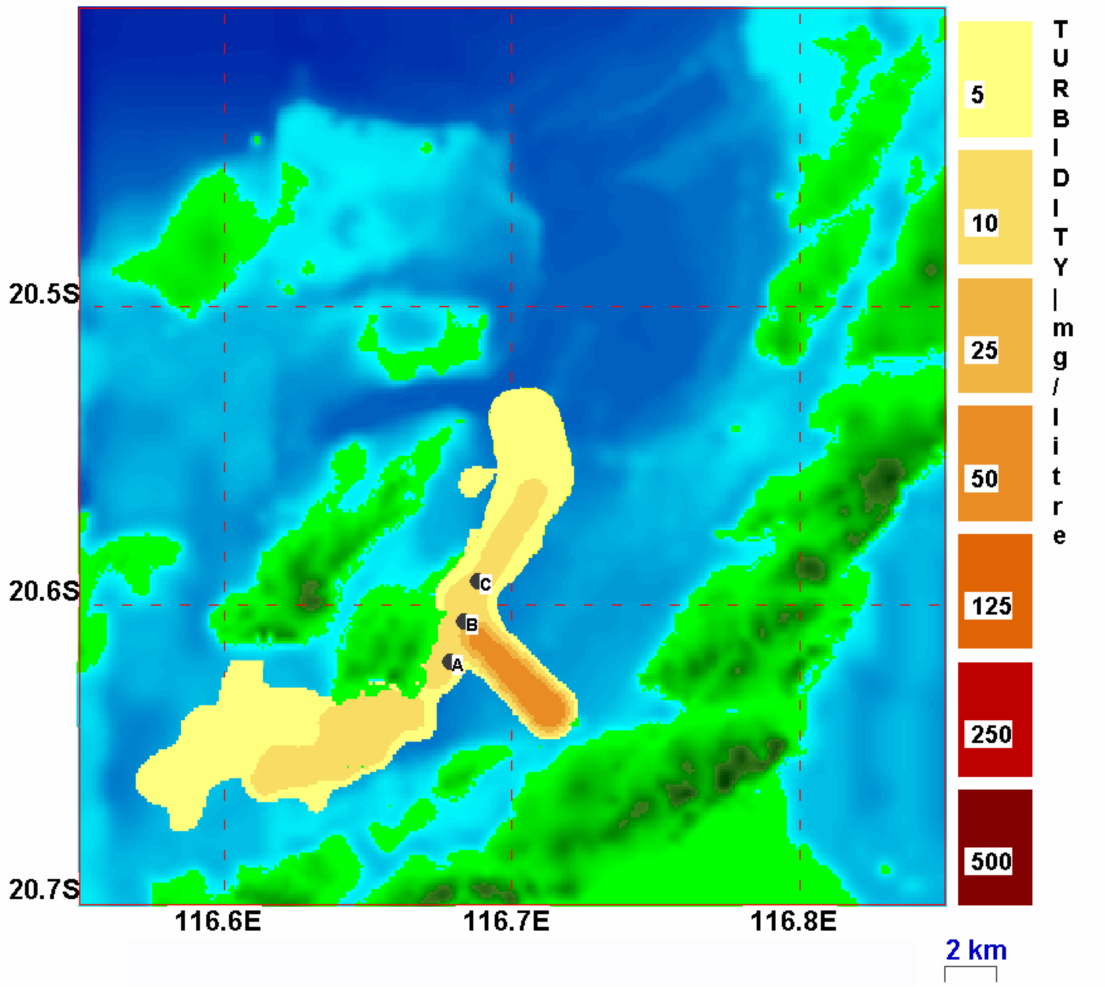


Figure 13. Mean monthly water column TSS levels from May 24 to June 30 (after a more mixed wind regime).

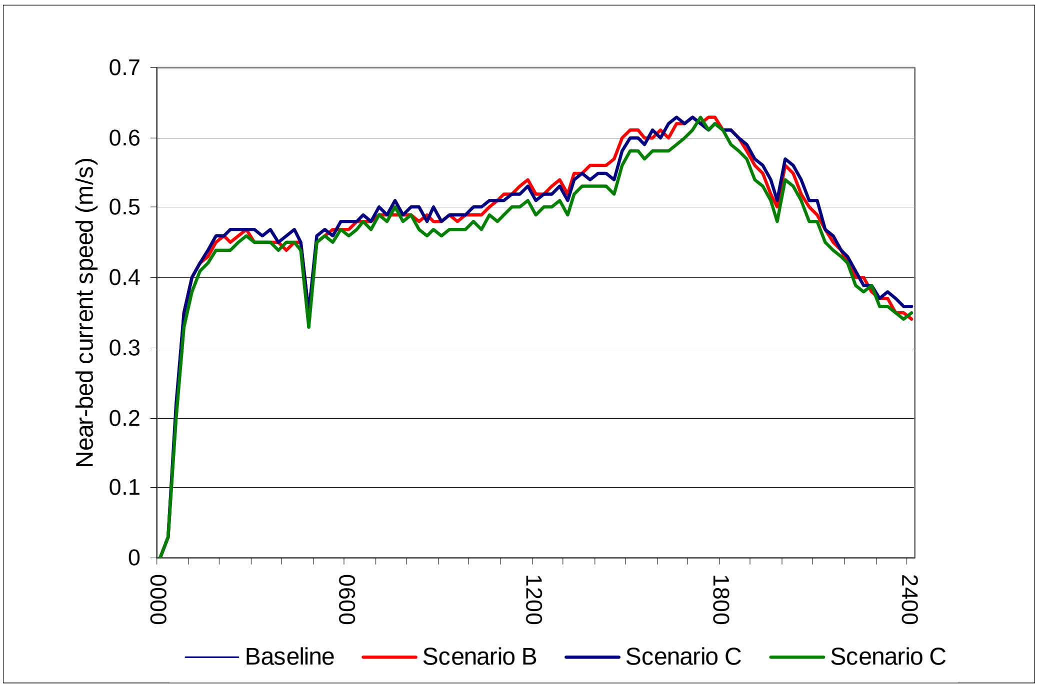


Figure 14(a). Time series of *wave* induced near-bed currents for the Spoil Ground No. 4 scenarios.

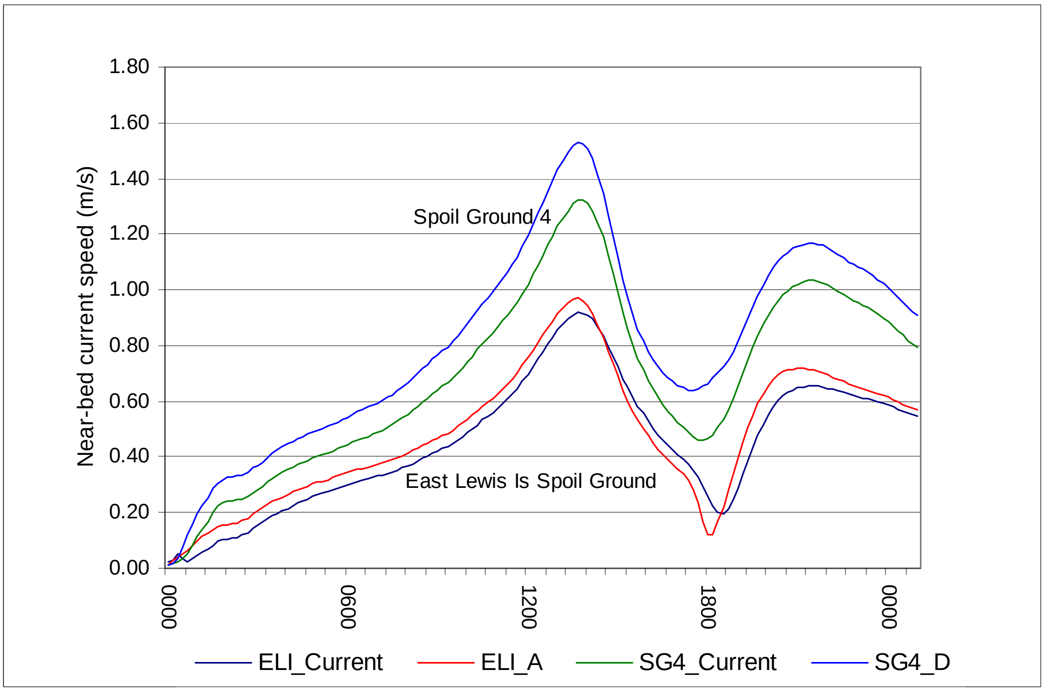


Figure 14(b). Time series of near-bed currents resulting from *cyclonic* winds.

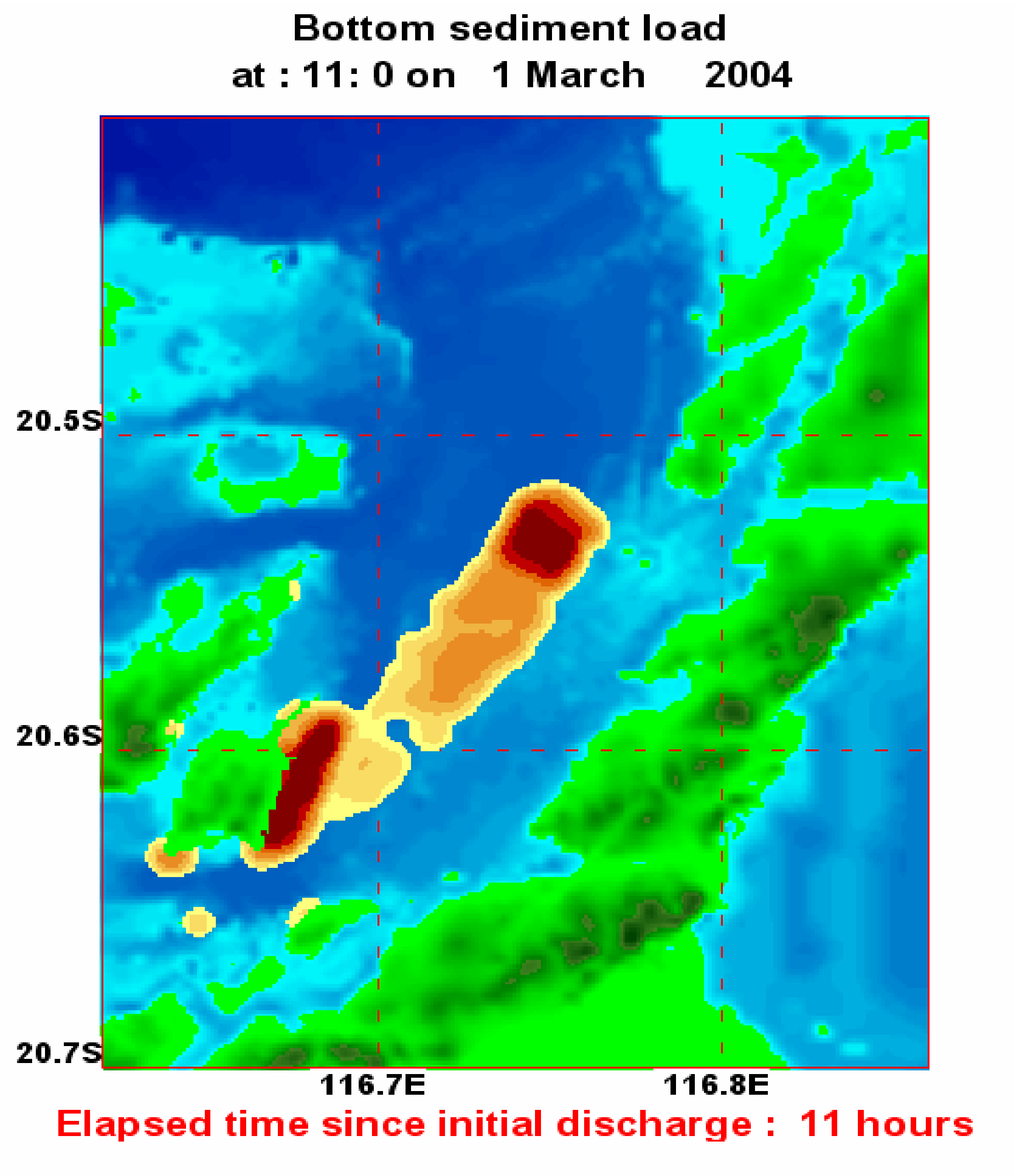


Figure 15(a). Deposition from the spoil grounds – *current bathymetry* - after 11 hours (cyclone approaching).

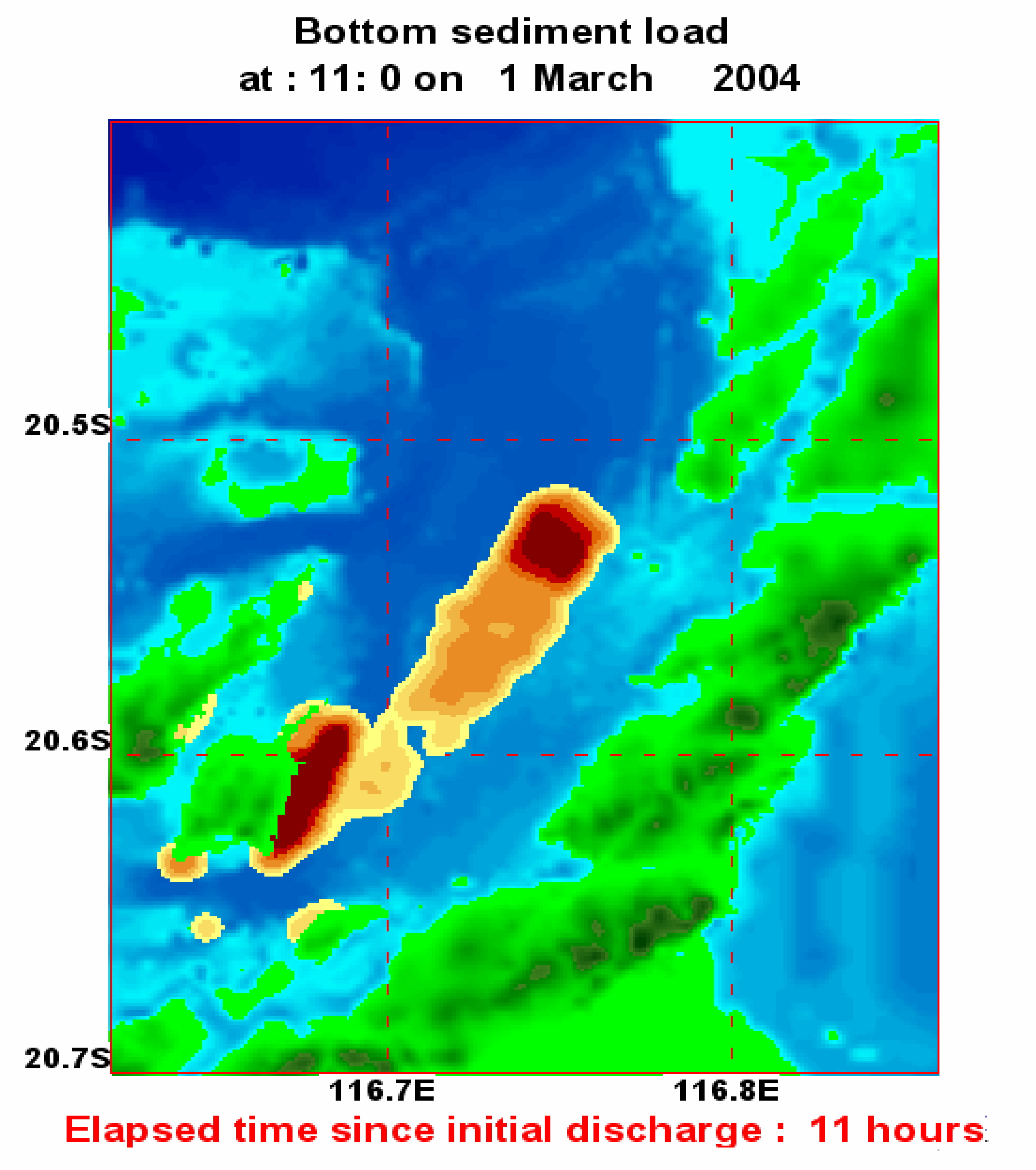


Figure 15(b). Deposition from the spoil grounds – *changed bathymetry* - after 11 hours (cyclone approaching).

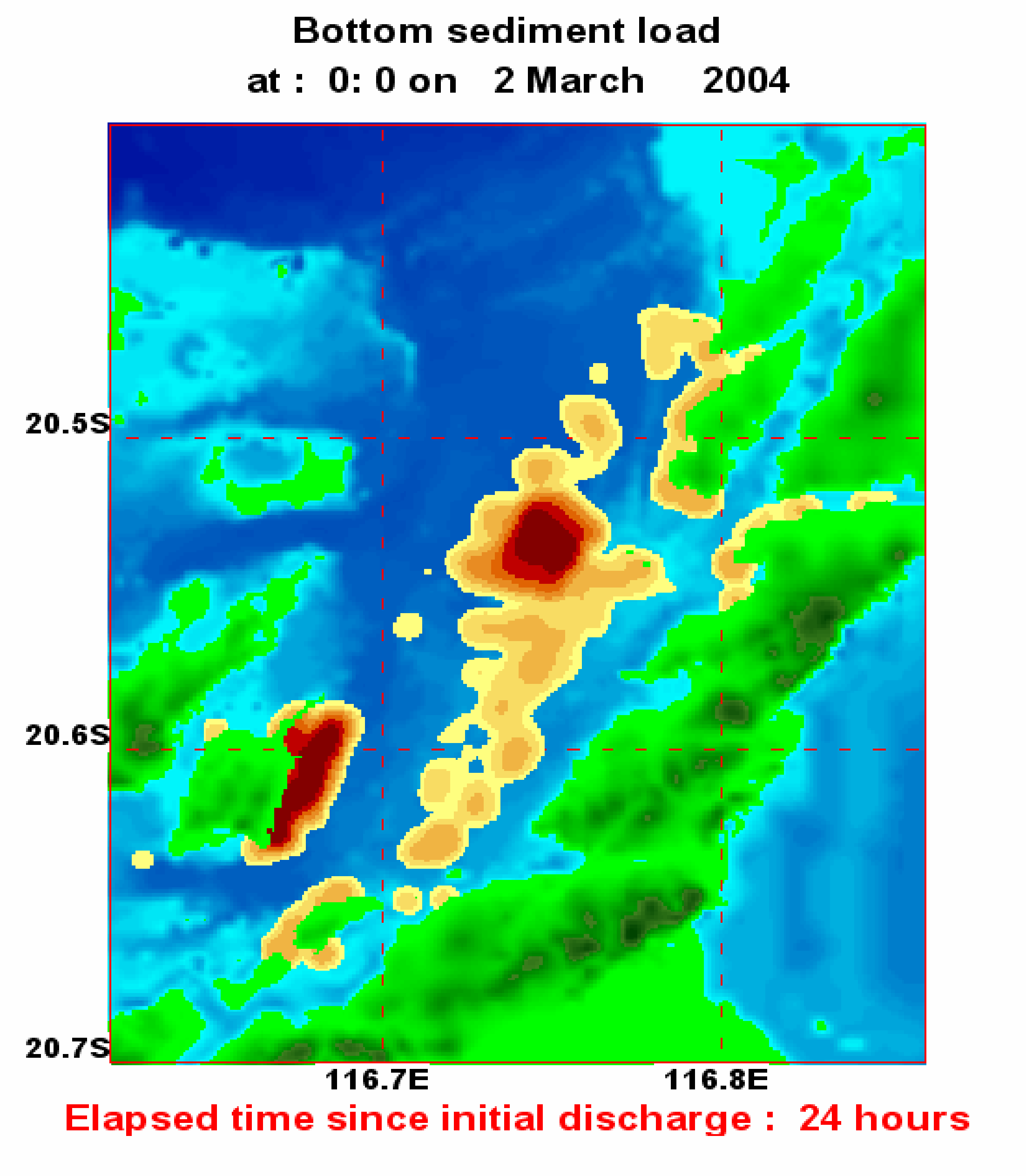


Figure 16(a). Deposition from the spoil grounds – *current bathymetry* - after 24 hours (back of cyclone).

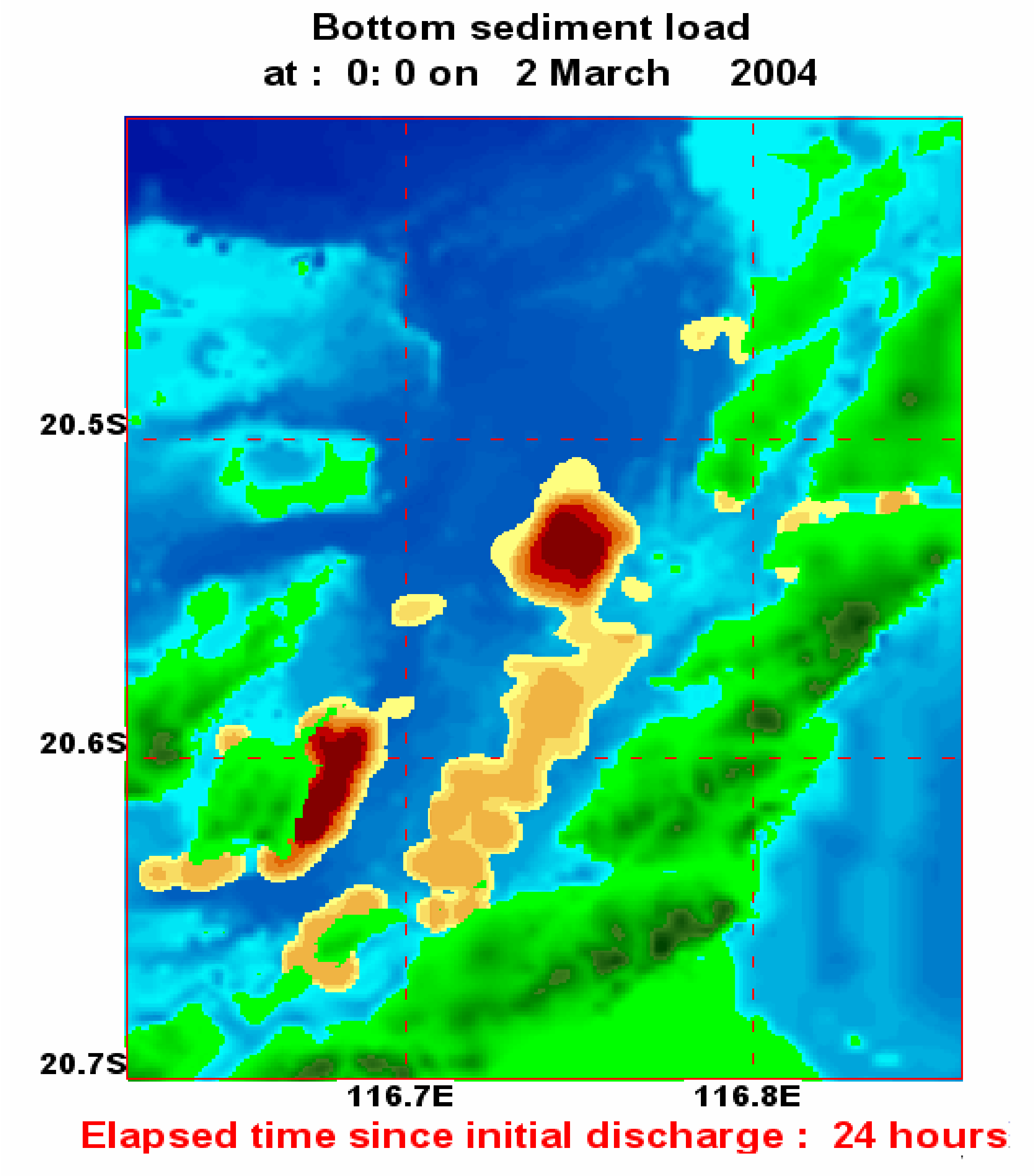


Figure 16(b). Deposition from the spoil grounds – *changed bathymetry* - after 24 hours (cyclone approaching).

DREDGE PLUME MODELLING

PORT OF DAMPIER DREDGING

PHASE B

Prepared For

PILBARA IRON

GEMS Report No 2005/391
November 2005

GLOBAL ENVIRONMENTAL MODELLING SYSTEMS
Oceanography & Meteorology

Disclaimer

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1 INTRODUCTION

Pilbara Iron is one of the world's largest exporters of iron ore. The company operates iron mine sites in the Pilbara region of Western Australia, together with a dedicated railway and port facility in Dampier. The port, which is one of Australia's largest tonnage ports, includes two terminals – Parker Point and East Intercourse Island.

Pilbara Iron proposes to increase the number of berths at the Parker Point ship loading facility to four as an extension to the upgrading works currently nearing completion at Dampier Port. An important component of this Phase B port upgrade will be to undertake further dredging to increase the flexibility of ship loading operations and limit the effect that the large tidal range has on the current port operations; a further 2.7 million cubic metres of spoil is to be transported and dumped at designated spoil grounds shown in Figure 1.

Phase A of the Dampier Port Upgrade included the dredging and disposal of 3.1 million cubic metres of marine sediments between April and October 2004. As part of the previous approvals Global Environmental Modelling Systems Pty Ltd (GEMS) carried out a dredge impact modelling study for dredging during the 'dry' season from May to October. This current study extends the earlier modelling study so as to quantify impacts on water quality and the fate of sediments associated with the new dredging program in the event that it were to occur during the 'wet' season period, approximately November to March.

To assist the modelling process, there is considerable information available from previous dredging programs carried out in Mermaid Sound. Included in these is the modelling program carried out by GEMS in support of the Dampier Port Authority (DPA) dredging program [1] and a subsequent monitoring project undertaken by Damara Pty Ltd [2]. This monitoring program was specifically designed to validate sediment release due to propeller wash.

There was also a significant data collection exercise during a dredging program during the development of the Woodside LNG channel [3]. This included sediment load sampling at fixed sites in the region and over time, from drogues following the sediment plume. Modelling of dredging and spoil disposal activities was also undertaken for Hamersley Iron in 1998 and monitoring of turbidity and plume tracking were undertaken during execution of the dredging works to calibrate the models.

2 SCOPE OF WORKS

2.1 Outline of Study Requirements

The scope of work set out for the current study was as follows:

(i) Obtain and analyse suitable wind data for the period of the project;

(ii) Update model bathymetry including delineation of new channels;

(iii) Establish, test and run the 3-d hydrodynamic model (GCOM3D) covering the Mermaid Sound region and adjacent waters for a period encompassing the planned dredging program;

(iv) Scope the dredging program of works to develop model assumptions, including, in particular, sediment release volumes and rates resulting from propeller wash and spoil ground dumping;

(v) Run model simulations covering the period of operation based on environmental boundary conditions for the period from a representative year, and

(vi) Report on the fate of deposited and suspended sediments.

2.2 Assumptions

2.2.1 Representative Period of Modelling

The duration of the modelling is approximately two months, based on the expected duration of the planned dredging program. The aim of the current modelling is to represent the fate of liberated sediments for such a program carried out during the 'wet season' months. The earlier modelling was focused on 'dry season' months.

Since the wind climate through this period is broadly consistent (see Section 3.1), it is reasonable to select a start and end period contained well within the 'wet season' period. Accordingly, the modelling was commenced at the start of January.

As the dredging occurs over a two-month period, the modelling covers several spring-neap tidal cycles. Clearly, the particular tidal cycles that occur during the actual dredging program will depend on the chosen start time, but the range of modelled (tidal) conditions can be expected to well represent those tidal conditions to be experienced for operations in the wet season.

2.2.2 Dredging

Following from the study carried out for 2004 dredging program, two main assumptions are made with respect to the dredging cycle; these are first, that the dredge would overflow during the dredging operations and, second, that the primary source of fines and sediments liberated to the water would come from propeller wash and disposal of hopper load at the spoil ground during TSHD dumping.

The assumption of overflow has effect of reducing the proportion of the finest sediments to be dumped at the spoil grounds.

The treatment of sediment discharge disposal at the spoil ground is relatively straightforward and GEMS has successfully modelled the process previously. The parameterization of propeller wash impact is more complex; Mr. Matt Elliot (Damara WA), an experienced coastal engineer and modeller, was commissioned to report on this aspect of the project for the DPA study and this model has been updated and extended based on monitoring during the DPA dredge program [2].

2.3 Calibration and Validation Studies

The ocean model (GCOM3D) has been validated in a range of studies both within and outside Australia. Some specific verification data for Mermaid Sound has previously been reported [4].

3 PHYSICAL ENVIRONMENT

3.1 Meteorology

3.1.1 Overview

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

Warming of the continent following the winter solstice results in a gradual southward migration of the subtropical ridge. This has a two-fold effect by which the general strength of the easterlies weaken, and a persistent ‘heat’ trough (area of low pressure) forms along the Pilbara coast. Seaward of the trough, the general flow then trends to be southwesterly.

Closer to the coast diurnal variations in terrestrial temperatures cause local sea-breeze impacts to become important.

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

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

Impacts from cyclone events may occur during the dredging period if it occurs during the 'wet season'. However, should a cyclone occur operations would shut down and in the event of direct impact, it is likely that sediments in Mermaid Sound would be significantly redistributed by such a storm.

3.1.2 Wind Data

In order for the modelling to reflect the wind climate of the area, appropriate wind data must be sourced for the region of interest. Two main options were available. These were:

(i) Apply archived (spatially varying) numerical weather prediction data, or

(ii) Apply archived (single point) anemometer data from at least one of the sites in the Mermaid Sound area available.

The advantage of the first option is that model winds vary spatially as well as temporally. However, the data available was not of sufficiently high resolution to adequately reflect mesoscale influences such as sea-breezes. Using anemometer winds has the disadvantage that only a single point source is available. However, because of the relatively limited modelling domain, the proximity to the coast and the data quality, it was decided that the anemometer data should be used.

The most representative data is from the Woodside FAR-14 anemometer at the end of the LNG jetty at Withnell Bay. The instrument is on a tower at a height of 34 metres, so that wind speeds needed to be adjusted to 10-metre height by applying a standard logarithmic boundary layer profile. Mean wind speed, direction and peak gust data are recorded at 10-minute intervals. The data record is near continuous from 1994 to the present.

The data were subjected to directional-magnitude analysis for the period January to February covering the proposed dredging schedule. Figure 2 shows a plot of the data for the January-February for all years and for the year 2002 only. Winds are predominantly from the westerly quadrant during this period; this is a result of the permanent presence of the heat trough that lies on or just inland along the Pilbara coast through the hot months. The general similarity of the two diagrams confirms that the use of year 2002 environmental boundary conditions is a suitable analogue for the long-term 'average' conditions.

Figure 3 shows a polar plot for all wet season months over eight years. The close similarity of the January-February plots and the 'wet months' plot confirms that modelling for January-February will provide good representation of outcomes for dredging anytime during the 'wet months'.

3.2 Oceanography

Mermaid Sound, and the regions offshore from the Burrup Peninsula, can be affected by a range of oceanographic (and related meteorological) influences, including tropical cyclones, wind and tidal driven currents and waves.

3.2.1 Ocean Currents

The dominant forcing of ocean currents in Mermaid Sound is derived from the winds and the tides. The tidal currents associated with the flooding and ebbing tide flow predominantly along the axis of Mermaid Sound with strong currents exhibited in the channels between the islands due to the narrow passages and the shallow bathymetry. The net flow through the channel is either to the north or southwest depending on the predominant winds.

3.2.2 Ambient Waves

The wave climate in Mermaid Sound is strongly affected by the coastal bathymetry and open ocean waves have been significantly attenuated by the time they propagate down Mermaid Sound. As a result, except during cyclone events, the wave climate in Mermaid Sound is controlled by fetch-limited, low energy waves with wave heights generally well below 2 metres in the southern reaches of the Sound.

It is expected that there would be some re-suspension of fine sediments due to wave action over the spoil grounds, but it is considered that the impact on general turbidity will be small compared with that resulting from the dredge operations.

3.2.3 Tropical Cyclone Storm Surge and Waves

During Tropical Cyclone Orson in May, 1986 Mermaid Sound experienced a storm surge of just over 3 metres together with hurricane force winds and breaking wave heights over 3 metres. Events like this are infrequent but need to be considered when the extremes of environmental forcing are required for coastal engineering and/or environmental impact assessments.

2.2.4 Thermal Structure

The waters on the Northwest shelf can exhibit significant vertical variation in temperature and density. The existence of such stratification can affect the behavior of plumes, particularly buoyant discharges from near the ocean floor (e.g. pipeline ruptures or hydro test fluid discharges). The existence of stratification can also result in the propagation of internal tides such as has been measured at the Woodside North Rankin platform. The thermal structure however should have limited impact on the fate of sediment plumes in Mermaid Sound, because of the shallow depth.

3.3 Sediments

The following stratigraphy is typical of materials anticipated to be encountered at Parker Point in areas not previously dredged:

- Silts and silty clays with some sands to a depth of the order of 3.0 m overlying;
- Gravelly clay/clayey gravel with particles consisting of calcarenite, shells and rounded dolerite pebbles overlying; and
- Calcarenite of low to medium strength. Leaching of the calcarenite occurs in some areas and the material removed replaced by sandy clay.

Soft surface sediments, such as silts and clays, will be removed using the TSHD; whereas, the harder materials will be dredged using a cutter suction dredge (CSD) and pumped directly ashore via a floating pipeline.

The sediments to be dredged by the TSHD from the vicinity of Parker Point are dominated by fine grain sizes with significant fractions of the material less than 38 µm in size. There are generally only small differences between the surface and lower strata particle size distribution.

4 MODEL DESCRIPTIONS

4.1 Oceanographic Model – GCOM3D

For studies of hydrodynamic circulation and sea level variation under ambient and extreme weather conditions, GEMS has developed the GEMS 3-D Coastal Ocean Model: GCOM3D. GCOM3D is an advanced, fully three-dimensional, ocean-circulation model that determines horizontal and vertical hydrodynamic circulation due to wind stress, atmospheric pressure gradients, astronomical tides, quadratic bottom friction and ocean thermal structure. The model scale is freely adjustable, and nesting to any number of levels is supported in order to suit the hydrodynamic complexity of a study area. As the model is fully three-dimensional, output can include current data at any or all levels in the water column.

The model set-up characteristics are described in the next section.

4.2 Plume Model

PLUMETRAK is the integrated, high-resolution 3D dispersion model developed by GEMS for modelling a wide variety of discharge materials including sediments, sewerage, thermal discharges, oils and chemical releases.

The model suite quantifies the distribution of each substance spilled or released under controlled conditions. The model reports mass and concentration levels on the water surface, on shorelines, on the ocean floor or through the water column as required. Horizontal and vertical cross-sections are available to better illustrate the three dimensional distributions. Where multiple chemical constituents are involved, the model can report the distribution of each constituent individually.

Particle tracking occurred continuously based on the proposed dredging program assumed performance and the output from GCOM3D. Post-processing then allowed for production of:

(i) Instantaneous depth averaged plots of Total Suspended Solid (TSS) concentrations;

(ii) Monthly averages of depth averaged TSS concentrations, and

(iii) Cumulative sediment deposition (bottom load)

4.3 Propeller Wash Model

The propeller wash model developed for the DPA project was modified and extended based on the DPA validation program. A significant improvement to the model is an algorithm, which allows for varying keel clearance depth (based on load, location and tide) [7].

5 MODEL INPUTS & ASSUMPTIONS

5.1 GCOM3D

For this project, the GCOM3D was set up to include Mermaid Sound and adjacent waters. Tides were based on previous detailed regional modelling and include the M2, S2, N2, K2, O1, K1, P1, Q1, and 2N2 tidal constituents.

GOM3D Setup parameters are summarized in Table 1. GCOM3D was run continuously for a period corresponding to January to February 2002. Figure 4 shows validation of tide levels for King Bay carried out for the previous modelling. Figures 5 and 6 show the current flow across Mermaid Sound over a flood-ebb tide cycle in early January 2002.

5.2 PLUMETRAK

For the current study, PLUMETRAK was set up to track suspended sediments and register deposition. Particle size bins were set at 5-micron increments below 100 micron. The model allowed for re-suspension due to wind/tidal currents but not for wave action. Horizontal resolution was 25 metres and vertical increments were 1 metre. PLUMETRAK setup details are given in Table 2.

Quantitative sediment inputs used are described in the next Section.

5.3 Sediments

Sediment sizes were based on the analysis undertaken for the previous study. Based on the experience of the DPA project, it was assumed the lowest 10 per cent of fines would be lost through overflow. Figure 7 shows the assumed sediment distribution by size.

Settling rates were also based on the DPA program.

5.4 Propeller Wash

GEMS has been advised that the majority of dredging will occur with overflow, thereby reducing the amount of the finest materials in the spoil. However, as borne out by the DPA program, it is expected that propeller wash from the vessel will create a significant sediment source.

The propeller wash model developed in conjunction with Damara Pty Ltd was applied for the expected bottom sediment particle distribution described in the previous section. The water column distribution of sediments was then determined as a function of under-keel clearance. Figure 8 shows the distributions for two sample clearance depths.

5.5 Dredging Cycle & Production Rates

It is intended that dredging will occur on a near continuous basis. The planned routine cycling time is of the order of 120 minutes, consisting off:

(i) 30 minutes dredging at an average speed of 1.5 to 2 knots (equivalent to about 1.5 km distance traversed);
(ii) average, 30 minutes travel to East Lewis Spoil;
(iii) 30 minutes dumping (traversing 700m to 1km), and
(iv) major maintenance stoppage of 3 days at 30 days completion.

The model allowed for this cycle to be interrupted for periods where either of the following conditions were met:

- easterly winds greater than 10 knots
- water levels below 1.0m Chart Datum (i.e more than 1.7m below MSL).

For these events, spoil deposit is shifted to the northern spoil grounds and travel time is increased to 60 minutes.

As for the previous study, sediment mobilization is focused on propeller wash effects during dredging, en-route to and within the spoil ground and spoil dumping.

5.6 Vessel Track

PLUMETRAK was setup to allow random location of the dredger start-finish line from the dredging area to the East Lewis Island spoil grounds – propeller wash was included for routes starting from the dredging area and terminating at five locations within the East Lewis spoil ground and at one location within the northern spoil ground.

5.7 Spoil Grounds

Based on advice from the client, it was assumed a total of 2700 cubic metres of sediment would be shifted, most to be dumped at the East Lewis Island spoil ground, subject to the operating conditions set out above.

The model assumed release at a depth of 4 metres below the surface. The location of dumping was based on a random selection of start and end points within the designated dumping area.

6 RESULTS

Dredge plume and sediment modelling was carried out for the period January 2002 to February 2002 inclusive, being representative of ambient 'wet' season conditions.

Deleted: ¶

6.1 Suspended Sediments

Total suspended sediment (TSS) levels were modelled continuously for this period, based on the planned dredging cycle described in the Section 5. PLUMETRAK computes TSS at discrete levels though the water column and these values were averaged in the post-processing to produce hourly mean water column levels.

Water quality in King Bay and surrounding waters has previously been investigated by Sinclair Knight Merz on behalf of the Water Corporation as part of the monitoring program for the Burrup Industrial Water Supply System. The monitoring program included assessment of turbidity and light attenuation. The resultant data indicated that water clarity in the area varies temporally (on daily and seasonal scales), spatially and with depth in the water column. Local waters were found to be naturally turbid, with higher levels of turbidity and light attenuation in near shore areas.

Turbidity values taken on consecutive days in March 2003 recorded background levels of turbidity between 2 NTU and 13 NTU and some locations increasing threefold over consecutive days. Water quality monitoring has also been undertaken by the DPA from January 2004 to April 2004. Measured values of total suspended solids at reference sites in Mermaid Sound (Gidley Island, North Withnell Bay, South Withnell Bay and High Point) varied between 0.2 mg/L and 57.9 mg/L. The average background level of total suspended solids measured at these sites over three months was 5.4 mg/L.

The model plots show contours starting from as low as 1 mg/L to 25 mg/L. Figures 9 to 11 show plots of mean water column TSS at three 'snapshot' times during the modelled program.

The areas impacted by the turbid plume are different for each case, being a function of the location of the dredge and the meteorological and oceanographic conditions at the time.

A more instructive approach is to examine the overall variability of TSS levels over the whole period of operation. Figure 12 shows the locations of six model output points. Time series of mean daily TSS at each of these points were extracted from the model at each of these points and the results are shown in Figures 13 and 14.

These indicate that TSS levels are most affected at the northern spoil ground location. The locations nearest the dredging operation EL1, EL2 and TI are affected periodically depending on the proximity of operations and wind-tide conditions. The fact that EL2 is relatively unaffected, suggests that the operations restrictions (easterly winds) is limiting impact at that point. Similarly TI is rarely affected and then only to equivalent background levels. King Bay is virtually unaffected throughout the whole period of operation.

By way of comparison, the model results can be compared with the sampling data taken during the 2004 dredging (Figure 15). This suggests that the model is producing similar magnitude TSS levels as to that observed during the previous dredging campaign.

One noticeable difference is for King Bay, which experienced periodic jumps in TSS levels during the 2004 dredging; however, the modelling for ‘wet season’ dredging shows no such incidents.

6.2 Deposited Sediments

Figure 16 shows the accumulated bottom sediments at the end of the dredging program.

It is noted that this figure does not include deposition associated with the dredging itself – experience suggests that most of the material larger sediments fall into or immediately adjacent to the dredged area. With respect to the larger, settling particles, the main source is from spoil dumping.

Accordingly, Figure 16 shows the deposit maxima in the spoil ground areas. Low-level deposition (up to 500 gm /m^2) is found within about 3 km to the northeast of both spoil grounds and there is similar deposition in a small area 5 to 6 km south of the East Lewis Island spoil ground. In all cases, deposition associated with spoil disposal is clear of existing channels.

7 SUMMARY & CONCLUSIONS

GEMS has undertaken a further program to model sediment response to ambient circulation and cyclone impact in Mermaid Sound.

Plume modelling of propeller wash and spoil dumping impacts were determined for the period January to February, being representative of ‘wet’ season weather conditions, based on predicted tides and representative winds. The results of the modelling program show that sediments flush out of the area of operation as a function of the tidal phase and predominating winds. During southwesterly wind events, this flushing tends to occur quickly as sediments move northwards up the sound, while sediment levels are directed southwestwards under the impact of the flood tide. The low frequency of easterly wind events and operation restrictions limit both turbidity and sediment levels on the eastern side of East Lewis Island.

8 REFERENCES

[1] Dampier Bulk Liquids Berth Project; Dredge Modelling Study. GEMS Report No. 024/03. December 2003.

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[5] Karratha Storm Surge Study. Buraeu of Meteorology Special Services Unit Report.

[6] Dredging and Contracting Rotterdam B.V. 1998, *Dampier Port Upgrade Project Dredging Monitoring Environmental Management Plan,* Unpublished report prepared for Hamersley Iron Pty Ltd by Dredging and Contracting Rotterdam B.V., Perth.

[7] Dredge Disposal Impact Modelling Port Of Dampier (Hamersley Iron). GEMS Report No.19/04, April 2004.

Table 1. Summary of GCOM3D settings used for hydrodynamic modelling

Model dimensions	3 (latitude, longitude and depth).
Depth layers	20 of variable thickness. Surface layer 2 m thick.
Output depth layer	All layers
Model domain size	0.75 deg x 0.55 deg
Bathymetric grid resolution	150 m
Forcing terms	
- Astronomical tides	9 tidal constituents: k2, s2, m2, n2, k1, o1, q1,p1,sa
- Wind shear	Hourly wind speed and direction data from the Woodside shore facility
Model period	January – February 2002

Table 2. PLUMETRAK Settings

Minimum Latitude	20^0 42' (S)
Maximum Latitude	20^0 24' (S)
Minimum Longitude	116^0 33' (E)
Maximum Longitude	116^0 52' (E)
Horizontal resolution	20 metres
No. vertical levels	Up to 60
Vertical resolution	1 metre layers
Start Date	May 1, 2004
End Date	June 30, 2004

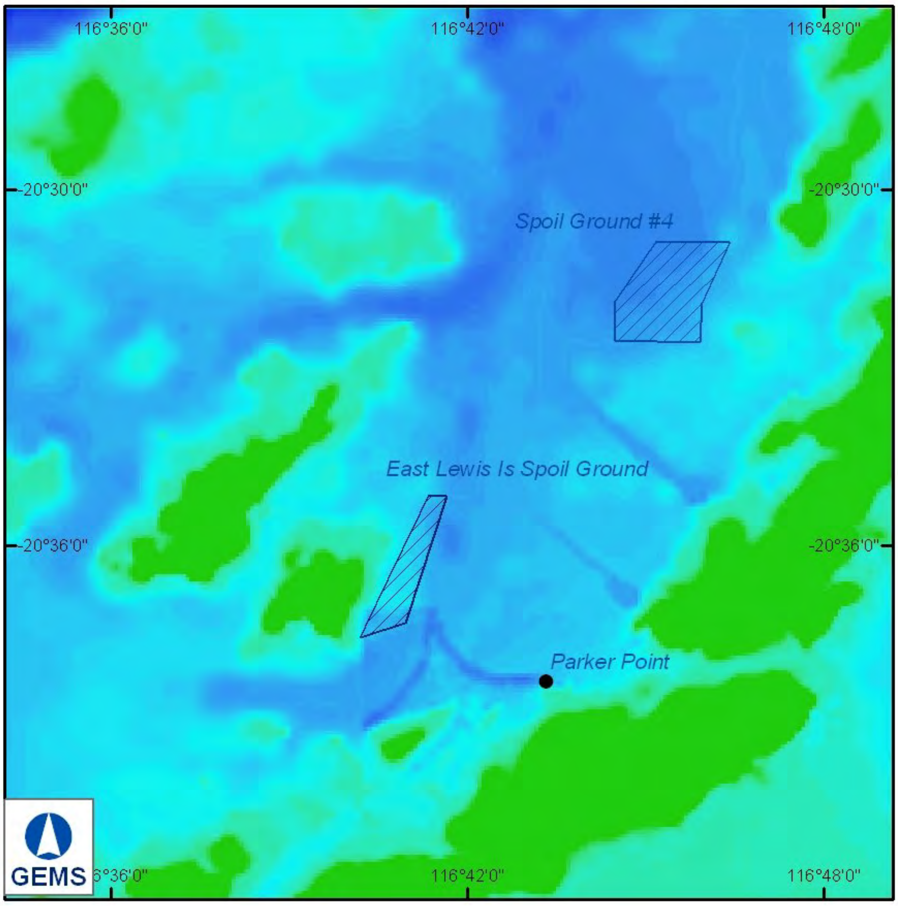


Figure 1. Study region including two spoil ground areas considered in the current study.

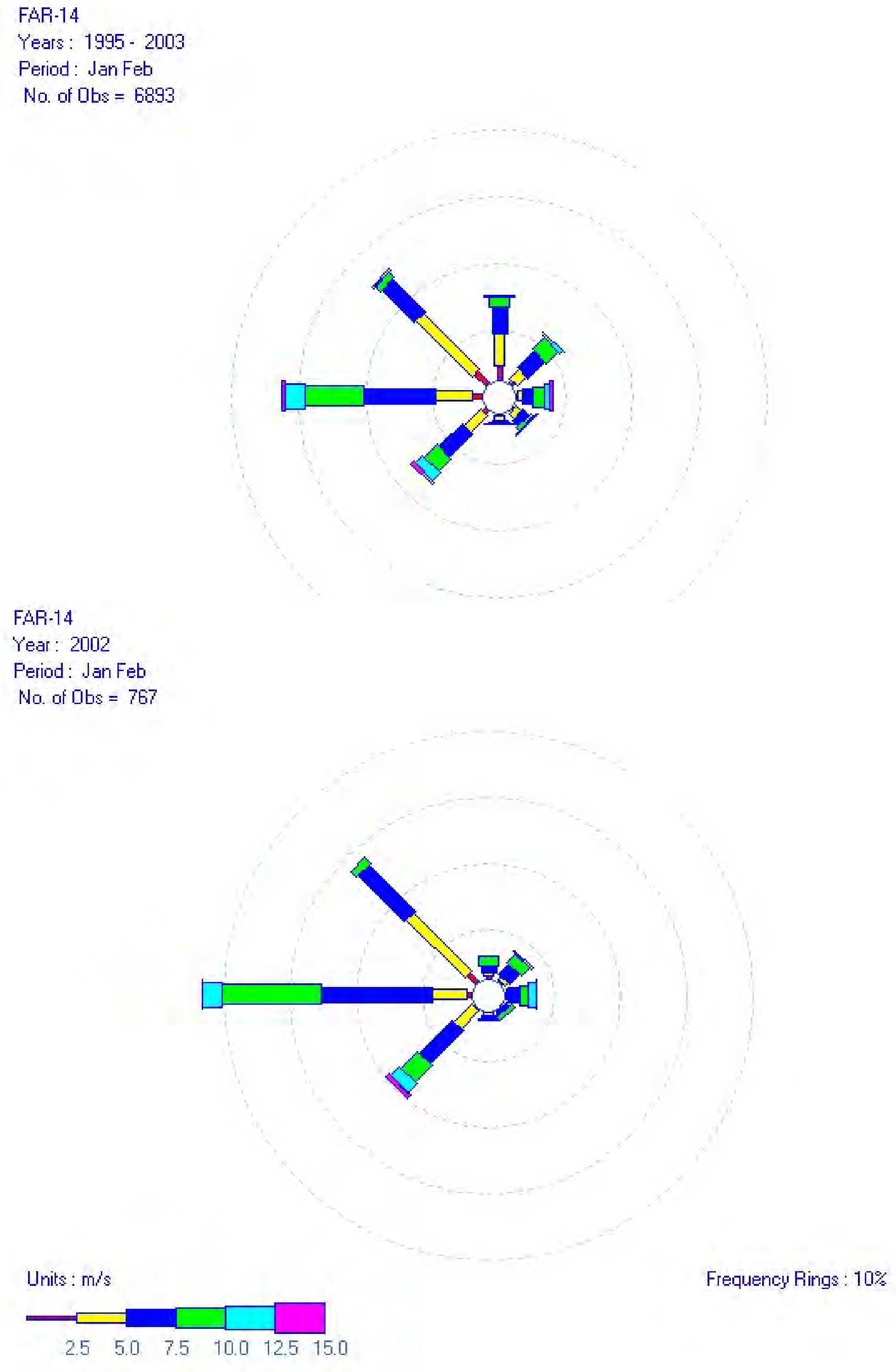


Figure 2. Polar wind diagrams for January – February period over eight years and for 2002 only (based on FAR-14 Automatic Weather Station).

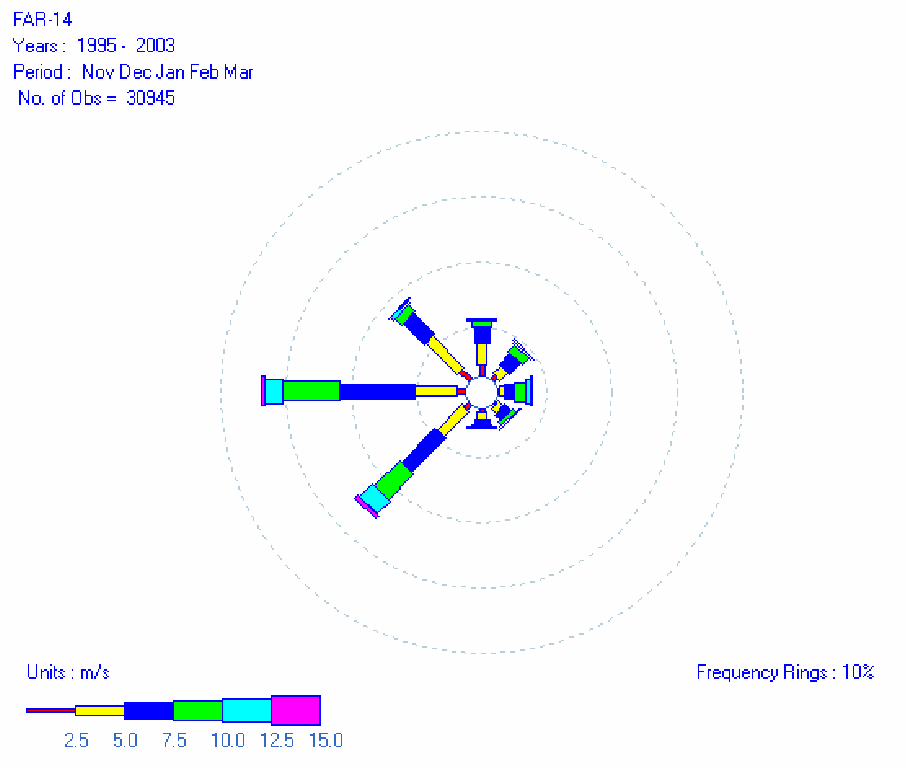


Figure 3. Polar wind diagram for all wet season months, November – March (based on FAR-14 Automatic Weather Station).

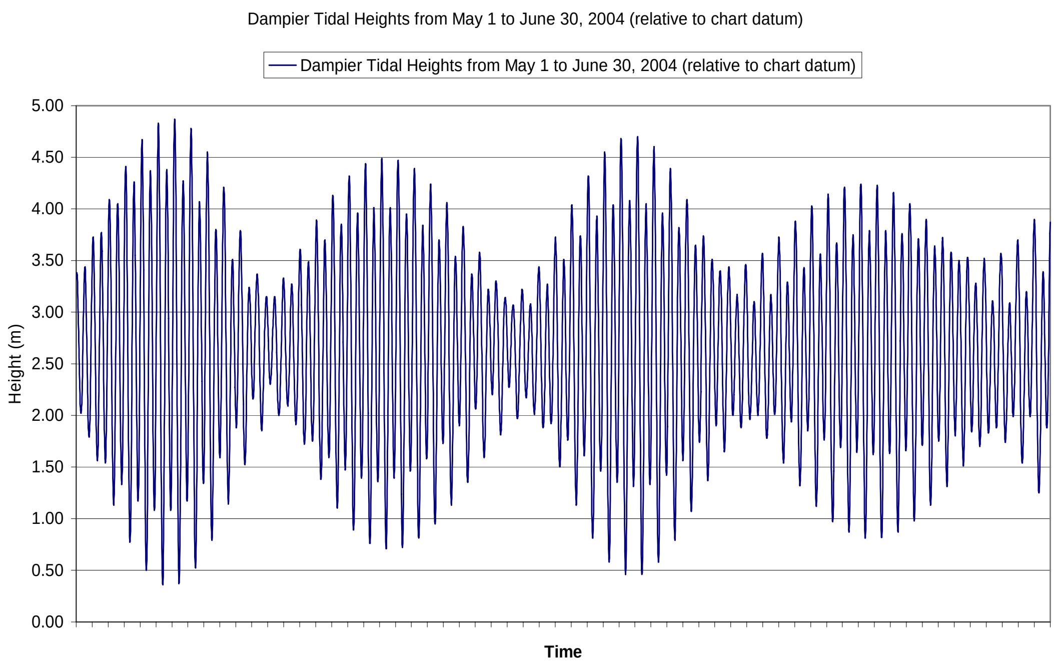
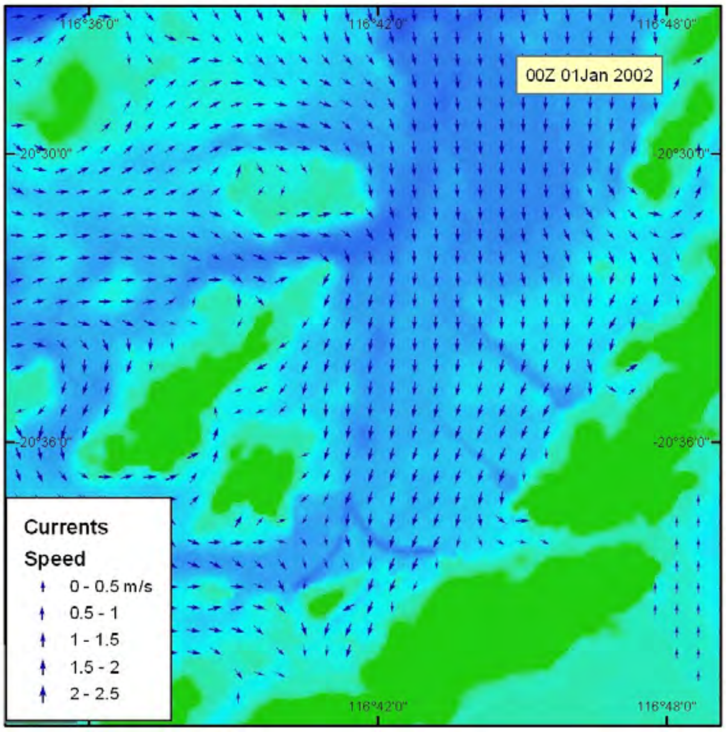


Figure 4. Tidal variation validated during the previous modelling period (May to June 2004).


116°36'0"
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116°48'0"
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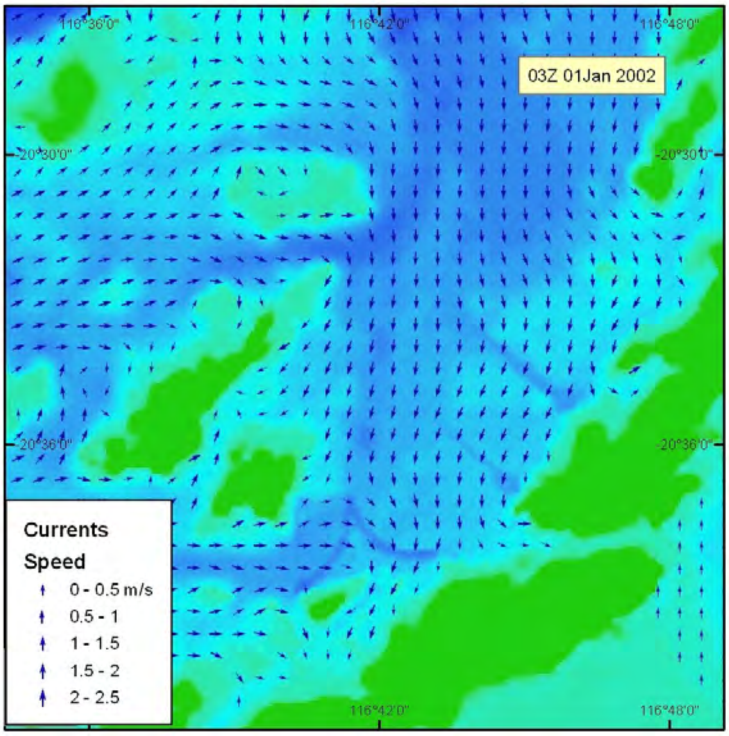
-20°30'0"
-20°36'0"
Currents
Speed
0 - 0.5 m/s
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5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Currents
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1.5 - 2
2 - 2.5

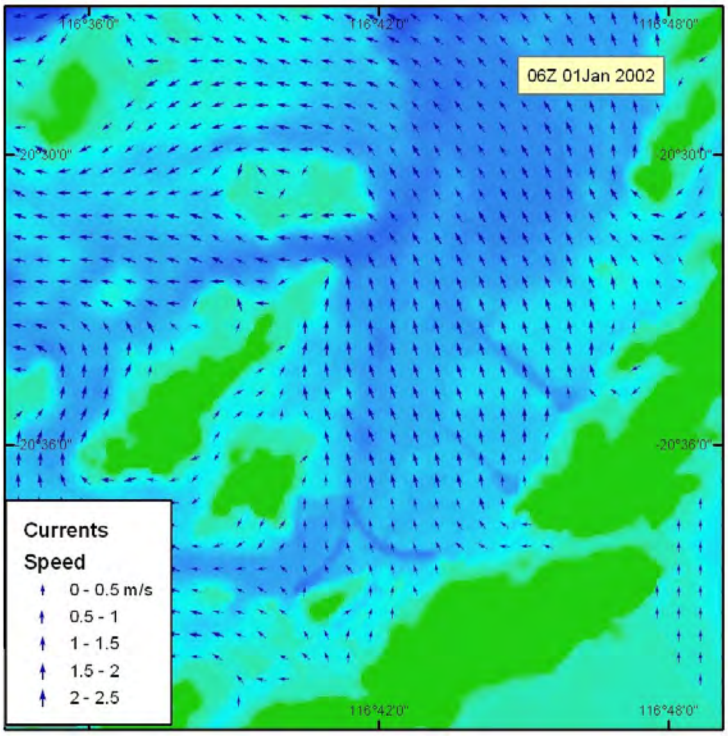
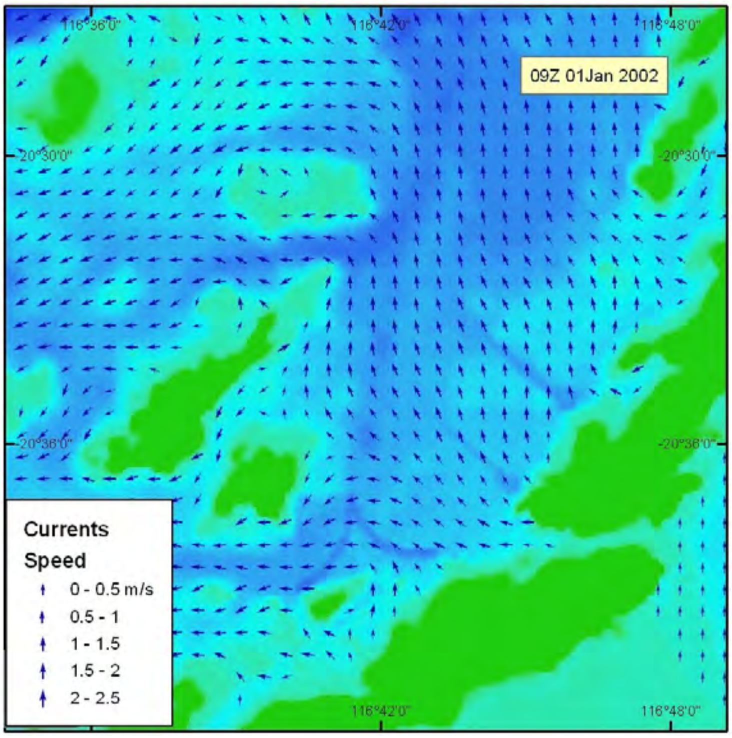


Figure 5. Currents during a flooding tide in early January.



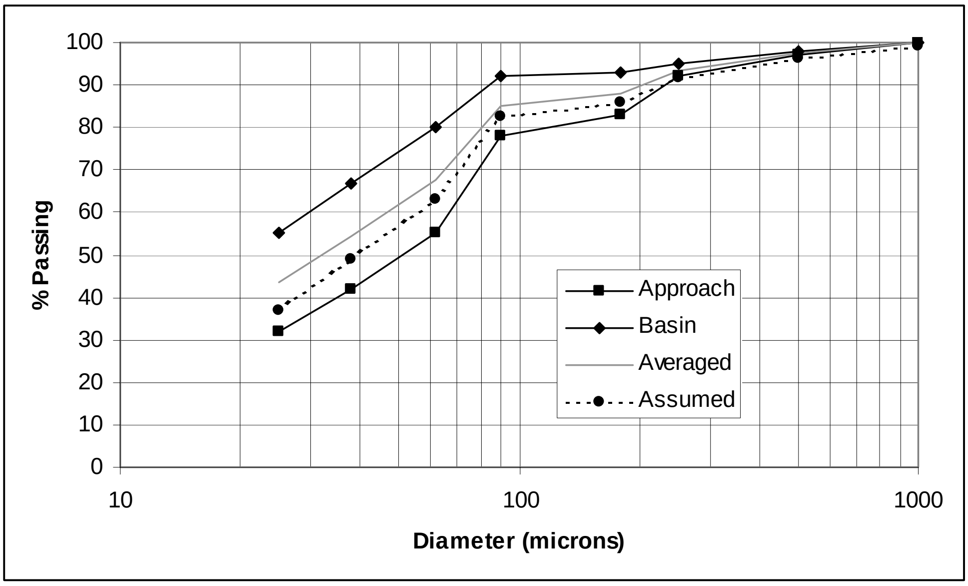


Figure 6. Currents during an ebbing tide in early January.

Figure 7. Particle size distribution.

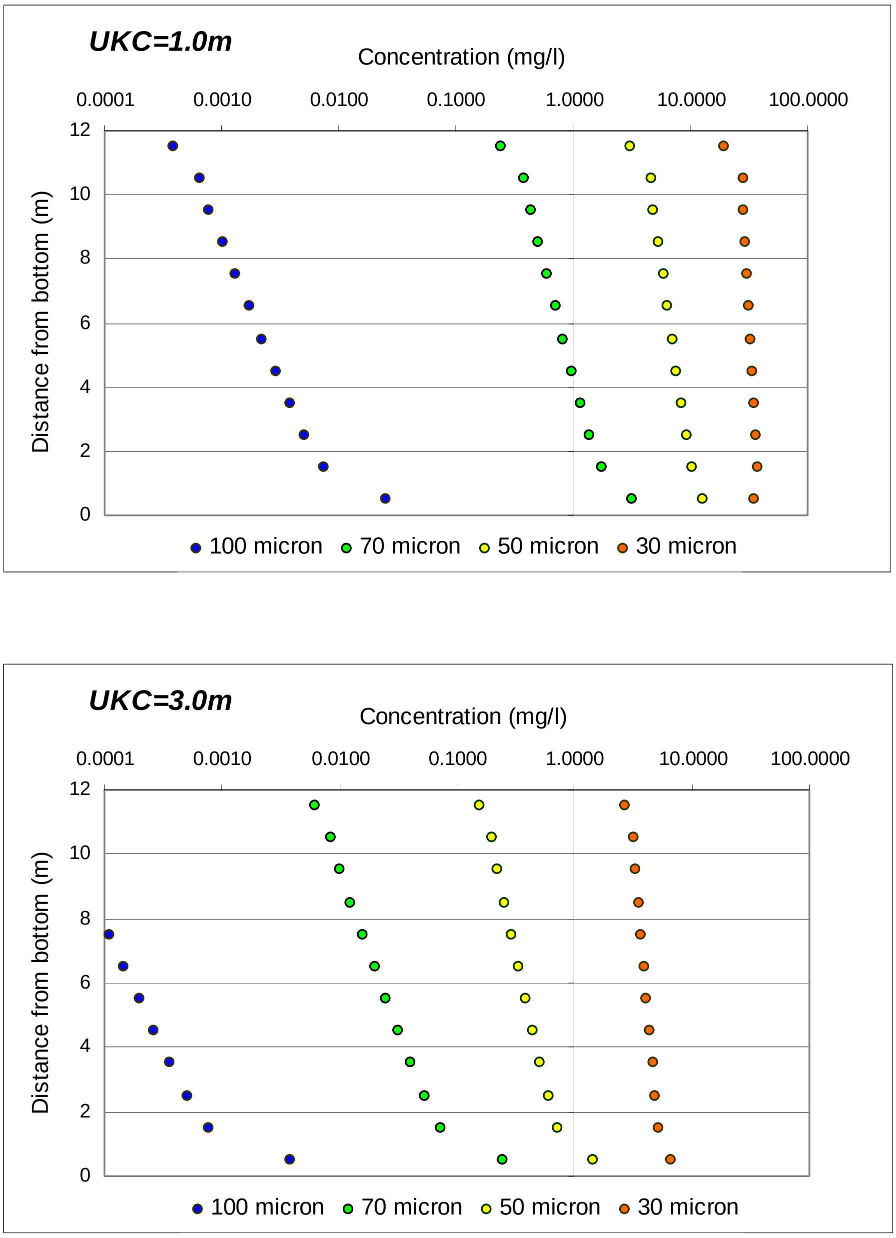


Figure 8. Propeller wash sediment mobilisation as a function of under-keel clearance (UKC).

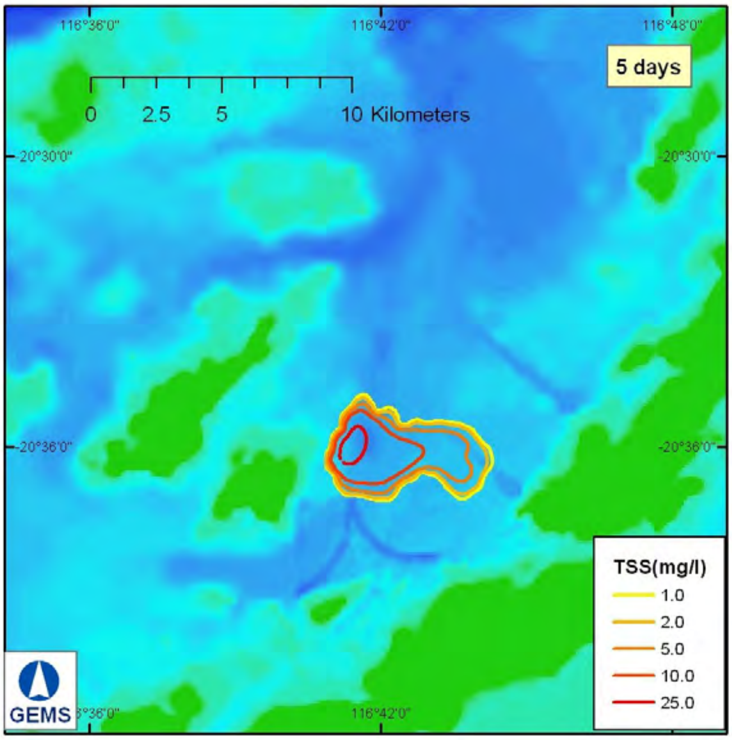


Figure 9. Instantaneous distribution of suspended sediments at 5 days.

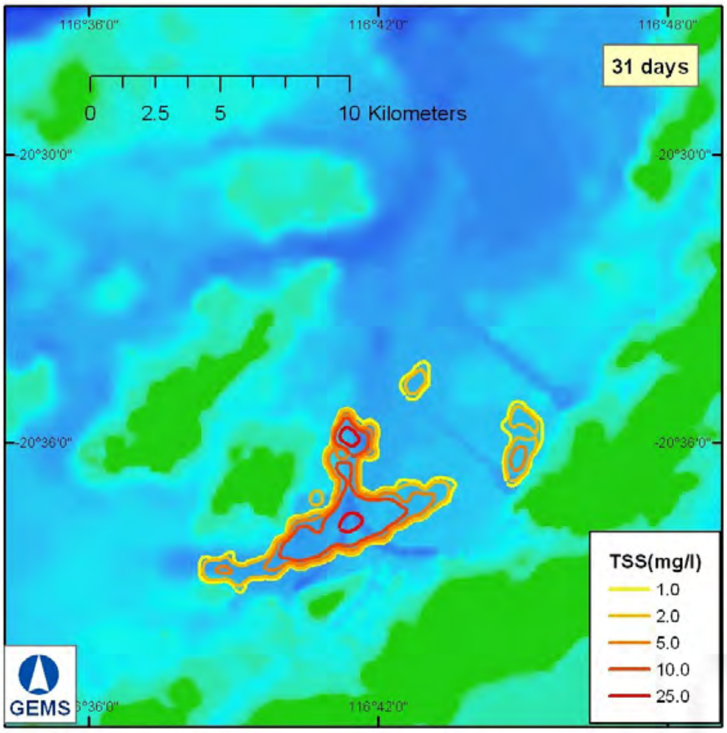


Figure 10. Instantaneous distribution of suspended sediments at 31 days.

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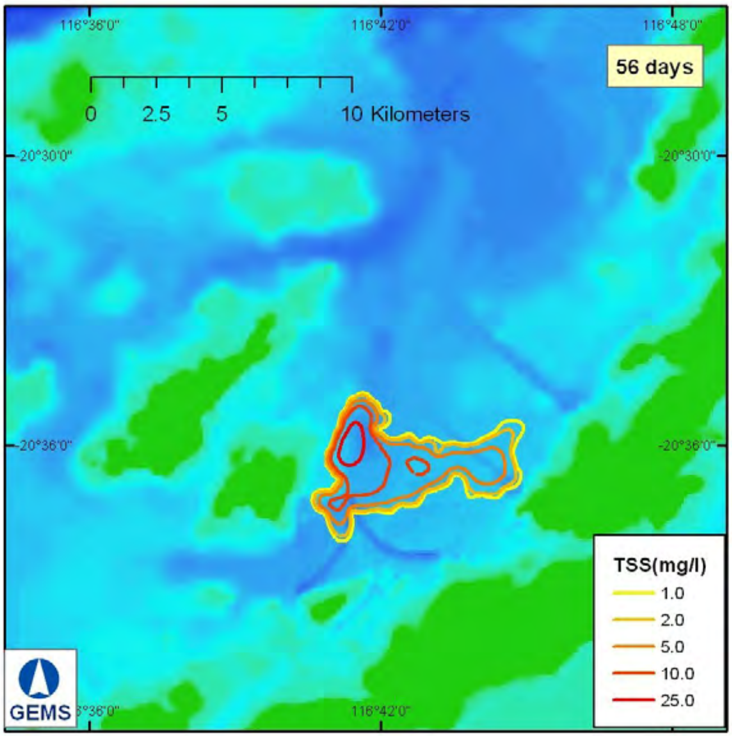


Figure 11. Instantaneous distribution of suspended sediments at 56 days.

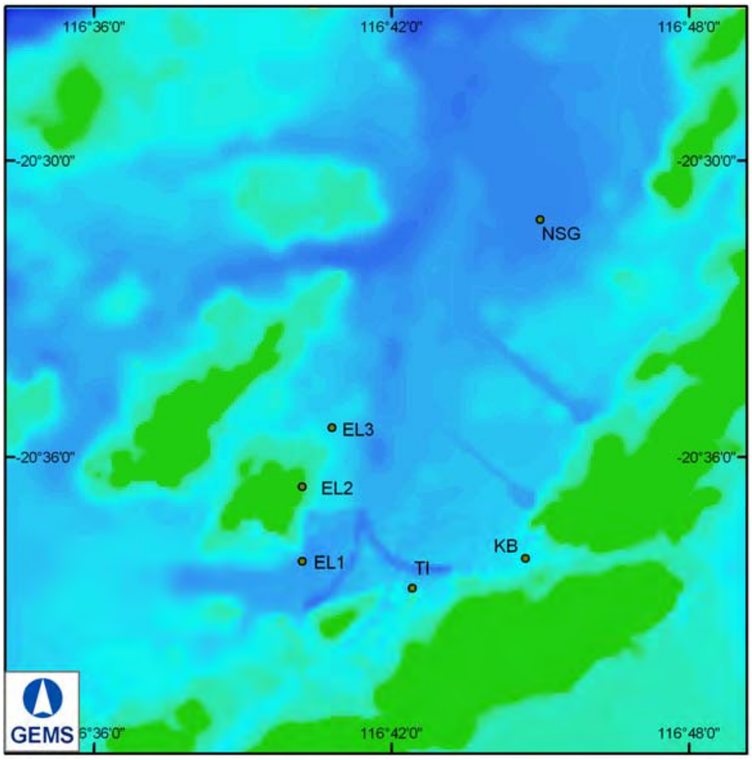


Figure 12. Location of time series output points.

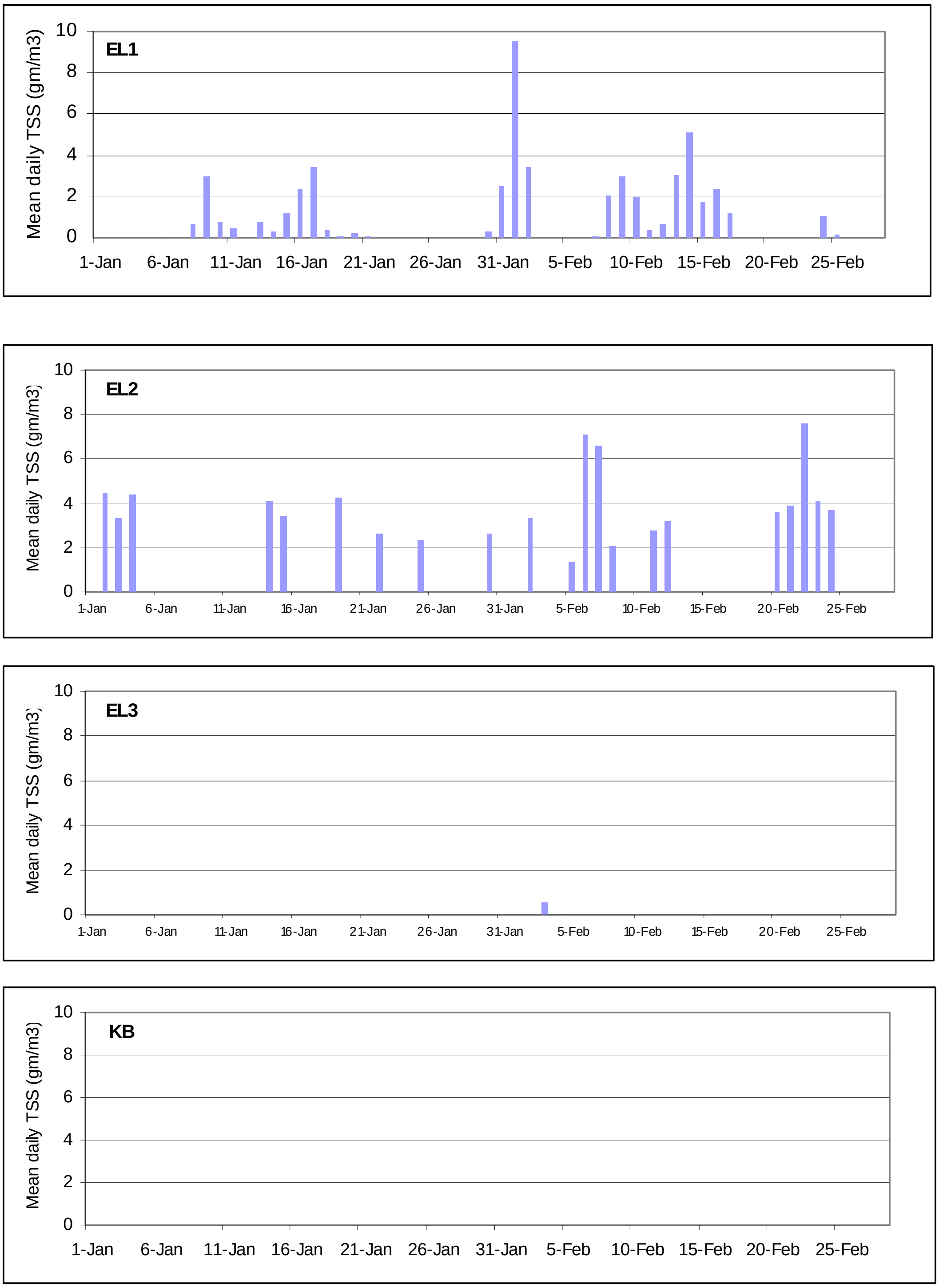
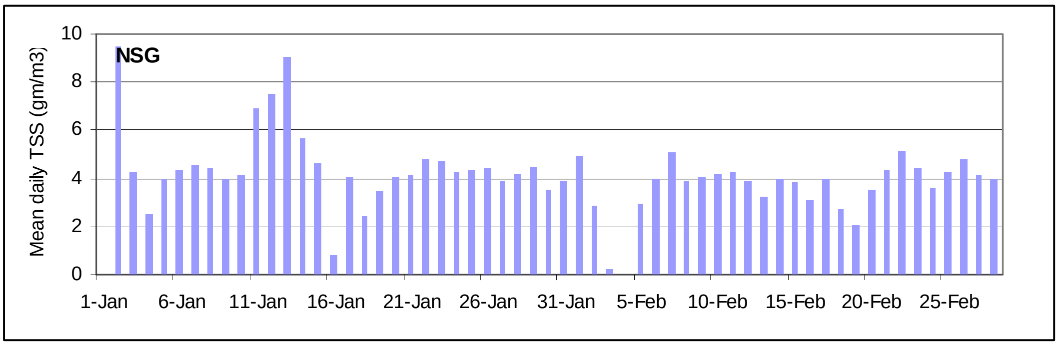


Figure 13. Mean daily TSS (gm/m^3) for stations EL1,EL2, EL3 and KB.



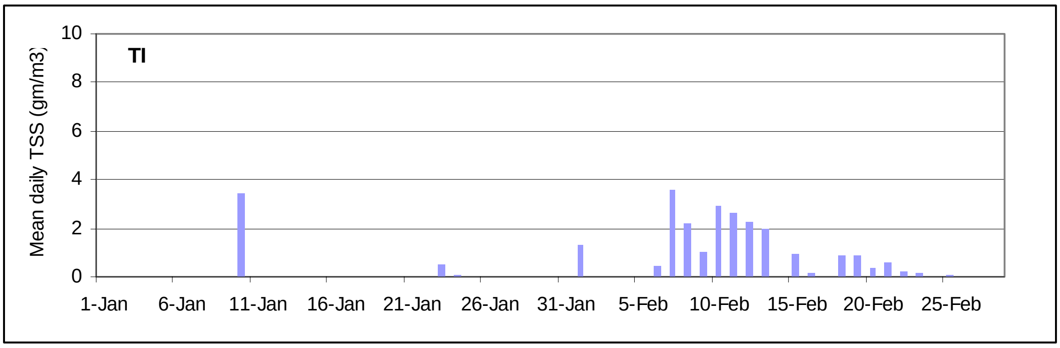
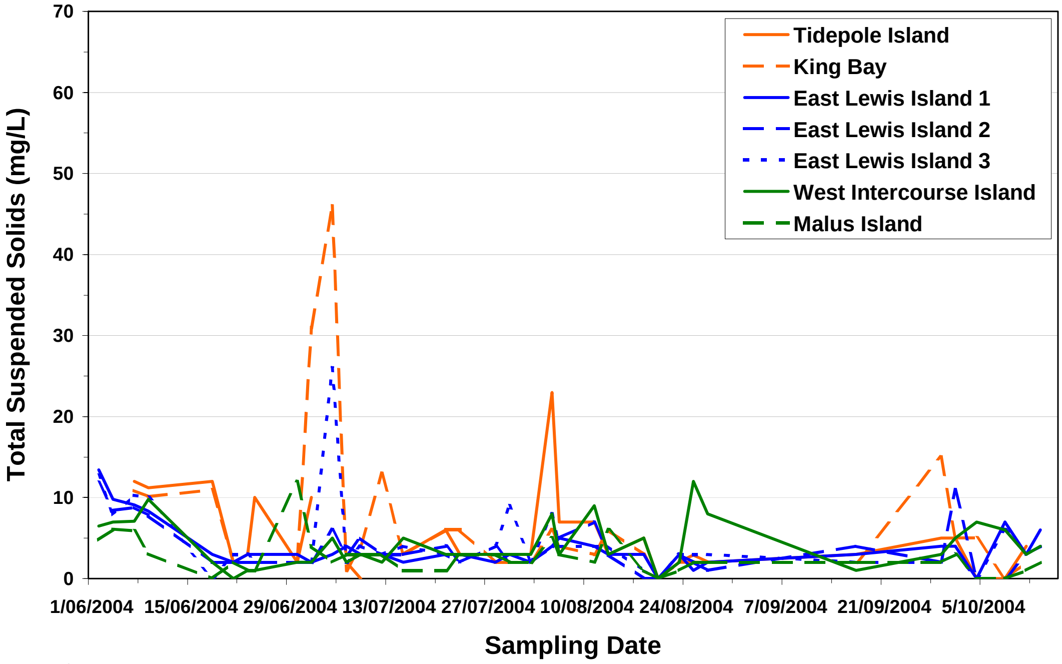


Figure 14. Mean daily TSS (gm/m^3) for stations KSG and TI.



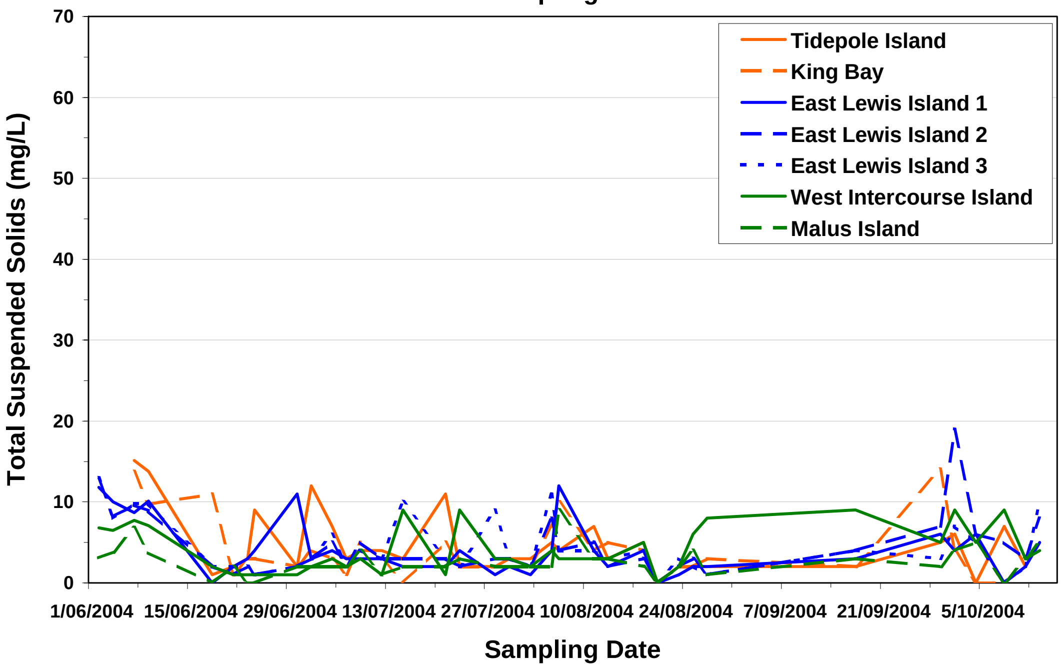


Figure 15. TSS sampling data from 2004 dredging campaign for surface (top) and seabed (bottom).

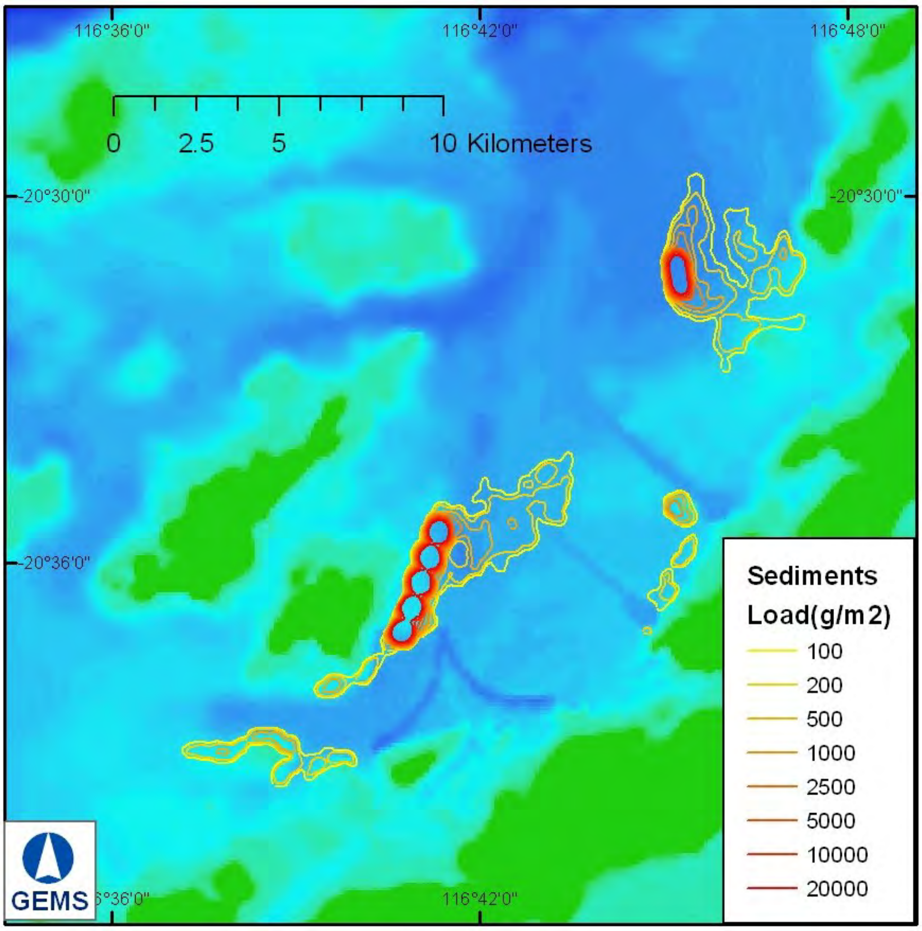


Figure 16. Cumulative distribution of deposited sediments at the end of the dredging program.