

Appendix G Marine Water Quality Assessment



Report

Marine Water and Sediment Quality Assessment

10 MAY 2011

Prepared for
Northern Territory Department of Lands and Planning
Ground Floor Enterprise House
28-30 Knuckey Street
Darwin NT
0800

42214006-2163

URS

Project Manager:



Peter Collins
Senior Consultant Marine
Ecologist

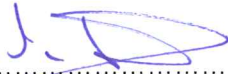
URS Australia Pty Ltd

**Level 4, 226 Adelaide Terrace
Perth WA 6000
Australia**

T: 61 8 9326 0100

F: 61 8 9326 0296

Principal-In-Charge:



Ian Baxter
Senior Principal Marine
Environmental Scientist

Authors:

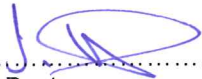


Peter Collins
Consultant Marine
Ecologist



Sophie Campagna
Associate Marine
Environmental Scientist

Reviewer:



Ian Baxter
Senior Principal Marine
Environmental Scientist

Date:

10 May 2011

Reference:

42214006-

Status:

2163/M&C3468/

R1593/0

Final

Table of Contents

1	Introduction	1
1.1	Background	1
1.2	Objectives and Scope.....	1
2	Proposed Activities in Relation to Water Quality Impacts.....	3
2.1	Marine Infrastructure and Associated Activities	3
2.1.1	Tug and Small Vessel Moorings.....	3
2.1.2	Railway loop and dredge spoil ponds	4
2.1.3	Marine Supply Base.....	5
2.1.4	Barge Ramp and Hardstand Area	6
2.2	Water Quality Impacting Activities	6
3	Environmental Setting of the Project Area	9
3.1	Bathymetry	9
3.2	Rainfall and Runoff	9
3.3	Oceanography and Hydrodynamics	10
4	Water Quality	15
4.1	Background	15
4.2	Water temperature	18
4.3	Salinity	18
4.4	Dissolved oxygen	18
4.5	pH	19
4.6	Turbidity and light attenuation	19
4.7	Total suspended solids	20
4.8	Nutrients and phytoplankton	20
5	Sediment Quality.....	23
5.1	Surface sediments	23
5.1.1	Introduction	23
5.1.2	East Arm Sediments	23
5.2	Sediment Quality.....	25
5.2.1	Interpretation of data	25
5.2.2	Metals	26
5.2.3	Hydrocarbons.....	27

5.2.4	Tributyltin.....	27
5.2.5	Acid sulphate soils (ASS)	28
5.2.6	Total organic carbon	28
5.2.7	Nutrients	28
5.2.8	Particle size distribution	29
5.3	Sub-surface sediments	29
6	Beneficial Uses and Water Quality Guidelines	31
7	Project Impacts	33
7.1	Introduction	33
7.2	Construction Impacts	33
7.2.1	Impacts from planned construction activities	33
7.2.2	Accidental discharges during construction.....	35
7.3	Operational Impacts	35
7.3.1	Impacts associated with routine operations.....	35
7.3.2	Routine discharges during operations.....	36
7.3.3	Accidental discharges during operations	36
8	Risk Management.....	37
8.1	Risks to Water and Sediment Quality	37
8.2	Environmental management plans	38
9	References and Bibliography.....	41
10	Limitations	45

Tables

Table 3-1	Predicted storm tide heights for locations adjacent to the development area	13
Table 4-1	Summary of natural processes affecting water quality in Darwin Harbour	16
Table 4-2	Average water quality levels recorded in East Arm	17
Table 5-1	Geological units of East Arm.....	30
Table 8-1	Summary of impact assessment, mitigating factors and management controls for water and sediment quality	38
Table 8-2	Summary of impact assessment, mitigating factors and management controls for dredge spoil disposal	39

Figures

Figure 2-1	General arrangement concept design (Aurecon 2009)	3
Figure 2-2	Tug and small vessel mooring locations concept design (Aurecon 2009)	4
Figure 2-3	Concept design for East Arm Port MSB and barge ramp and hardstand area (Aurecon 2009)	5
Figure 3-1	Average monthly rainfall for Darwin (mm)	10
Figure 3-2	Major currents during ebb tide in Darwin Harbour (Source: INPEX 2010)	11
Figure 3-3	Major currents during flood tide in Darwin Harbour (Source: INPEX 2010)	12
Figure 4-1	Water quality sampling sites (Source: URS 2008)	17
Figure 5-1	Sediment sampling sites (URS 2008)	24
Figure 5-2	Sediment sampling sites (AECOM 2010)	25

Abbreviations

Abbreviation	Description
ANZECC & ARMCANZ	Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand
BOM	Bureau of Meteorology
CD	chart datum
Coffey	Coffey Geotechnics Pty Ltd
DEH (now DSEWPac)	Department of Environment and Heritage
DEIS	Draft Environmental Impact Statement
DEWHA (now DSEWPac)	Department of Environment, Water, Heritage and the Arts
DHAC	Darwin Harbour Advisory Committee
DSEWPac	Department of Sustainability, Environment, Water, Population and Communities
DLP	Department of Lands and Planning
DPC	Darwin Port Corporation
DPI	Department of Planning and Infrastructure
EAW	East Arm Wharf
LAT	lowest astronomical tide
LDC	Land Development Corporation
m	metres
MSB	Marine Supply Base
NAGD	National Assessment Guidelines for Dredging (DEWHA 2009)
NRETAS	Natural Resources, Environment, the Arts and Sport
ppt	parts per thousand
s	seconds
TBT	Tributyltin (component of anti fouling paint)
TSS	Total suspended solids
URS	URS Australia Pty Ltd
WMB	Water Monitoring Branch

Introduction

1.1 Background

The East Arm Wharf (EAW), managed by the Darwin Port Corporation (DPC), is located in Darwin Harbour approximately 4 km directly southeast of the Darwin Central Business District. The wharf precinct currently consists of a 754 m berth wharf, approximately 18 ha of hardstand area (located on reclaimed land), and a single rail line spur linking the wharf to the main rail line. The industries it accommodates include cattle export, oil and gas (supply and service), mining, agriculture, horticulture, construction, research, fishing and pearling. Expansion of the Port of Darwin, i.e. creation of the EAW, was initially approved via a Draft Environmental Impact Statement (Draft EIS) and Supplement prepared by Acer Vaughan and Consulting Environmental Engineers in 1993.

To facilitate trade growth and local and regional economic development, a Masterplan was prepared for managing land and sea-based activities at EAW to the year 2030 (GHD 2010). The opening of the Adelaide to Darwin railway in 2004 increased the demands on the EAW for export of bulk minerals. Increased storage area requirements have led to the decrease in available space for traditional cargoes. In addition, further berth space is required for the increased throughput as trade increases.

Given these demands on infrastructure, as well as further requirements of the Department of Defence and industry, a number of staged additions to existing EAW infrastructure are proposed. As described in the Department of Planning and Infrastructure (DPI) (now Department of Lands and Planning [DLP]) Gap Analysis, the project brief and EAW Facilities Masterplan 2030 (GHD 2010), these include construction of the following:

- Tug and small vessel berths on the north side of EAW including the construction of (floating) wharves and associated dredging to -7 m CD
- A rail loop on reclaimed bund on the north side of the existing EAW
- A Marine Supply Base, which includes the construction of reinforced concrete wharfs supported by steel piles and dredging of an access channel to -7.7 m CD generating approximately 750,000 m³ in dredge spoil
- A barge ramp and hardstand area, which will involve the construction of three bunds and filling of the area between them to reclaim an area of approximately 1 ha and dredging of an access channel to -2 m CD.

The proposed development is consistent with the existing industrialised character of the Port of Darwin, described under the DEIS developed for the Darwin Port Expansion in 1993.

1.2 Objectives and Scope

Potential sources of impact on water quality during construction and operation of the port expansion can include pile driving, dredging activities and general vessel traffic, including waste emissions and potential spills of fuel and product.

This review focuses principally on the known and potential impacts of dredging and other construction activities on the water quality of Darwin Harbour based on studies undertaken for previous construction related activities.

To place these issues into context and to facilitate informed assessment, the report also presents a literature review on water quality in Darwin Harbour.

A key driver is the requirement to support the water quality objectives for Darwin Harbour. These are included in a Water Quality Protection Plan initiated in 2006 as part of the National Water Quality

1 Introduction

Management Strategy, (a long term plan developed by the Commonwealth, State and Territory governments). The plan aims to maintain the current quality of water resources in Darwin Harbour and a key component of this management strategy has been the development of water quality guidelines and objectives (Fortune & Maly 2009). These are based on the “declared beneficial uses” under the Water Act (NT), which are defined for the Harbour as “protection of aquatic ecosystems, recreational water quality and aesthetics” (DHAC 2007). The Project will aim to conform to the existing water quality objectives for Darwin Harbour.

Proposed Activities in Relation to Water Quality Impacts

2.1 Marine Infrastructure and Associated Activities

Marine infrastructure to be installed and associated activities proposed at EAW are illustrated in Figure 2-1 and summarised in the following sections.

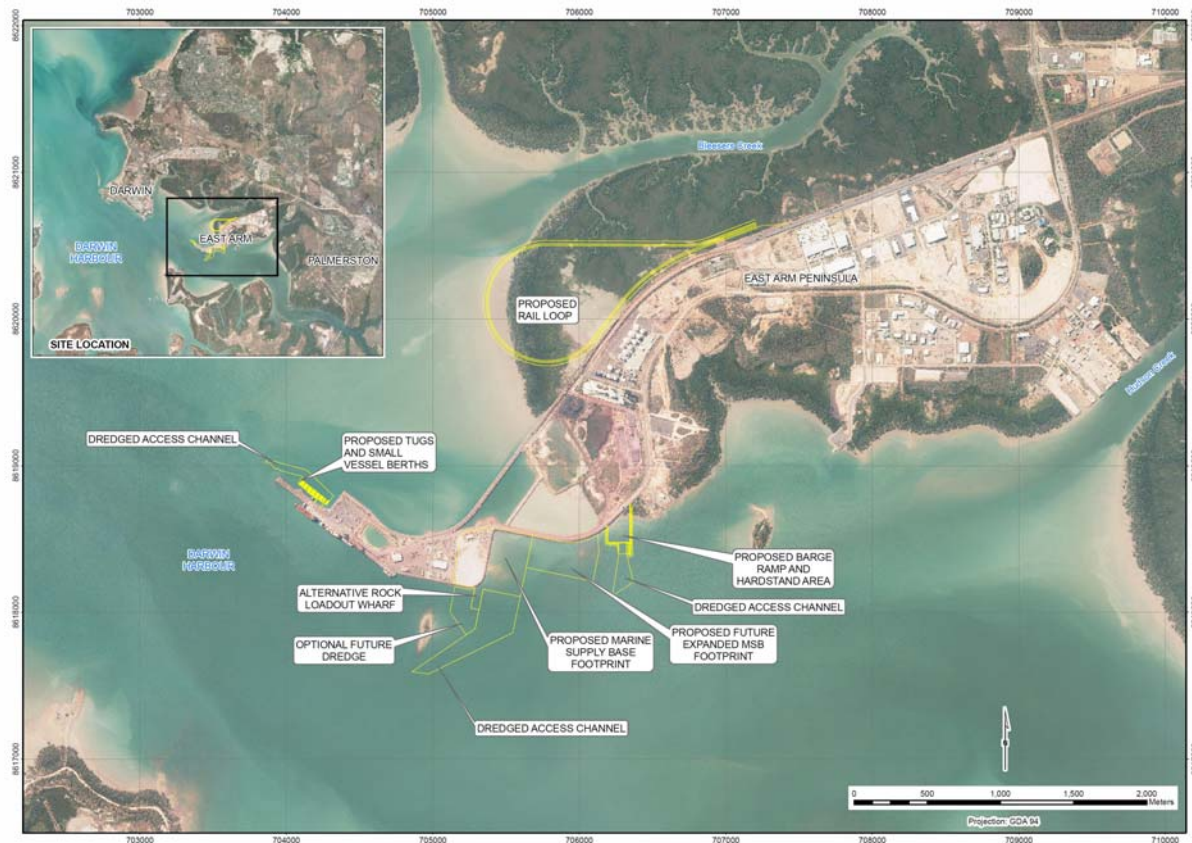


Figure 2-1 General arrangement concept design (Aurecon 2009)

2.1.1 Tug and Small Vessel Moorings

An area north west of the liquids berth (at the western end of EAW) is proposed to accommodate up to 12 tugs and smaller vessels (DPC pilot boats, security boats, workboats, Northern Territory police vessels) (Figure 2-2).

The deeper draft tugs will be moored to finger pontoons connected to a series of main pontoons 200 m long. The pontoons will be restrained in position by vertical steel piles along which the pontoons can rise and fall with the tide. A ramp will connect the pontoons to a fixed walkway to provide access to the tugs. A dredged access channel to -7 m CD will provide all tide access to the moorings for the tugs.

The lower draft vessels will be similarly accommodated at another pontoon mooring facility in shallower water to the east of the tugs. Access to these moorings will be by an extension of the dredging for tugs to only -3.5 m CD.

2 Proposed Activities in Relation to Water Quality Impacts

The construction sequence will be:

- dredge to -7.0 m CD (115,000 m³) and -3.5m CD (45,000 m³)
- drive steel piles to locate pontoons
- erect fixed walkway
- install prefabricated pontoons
- install ramps.

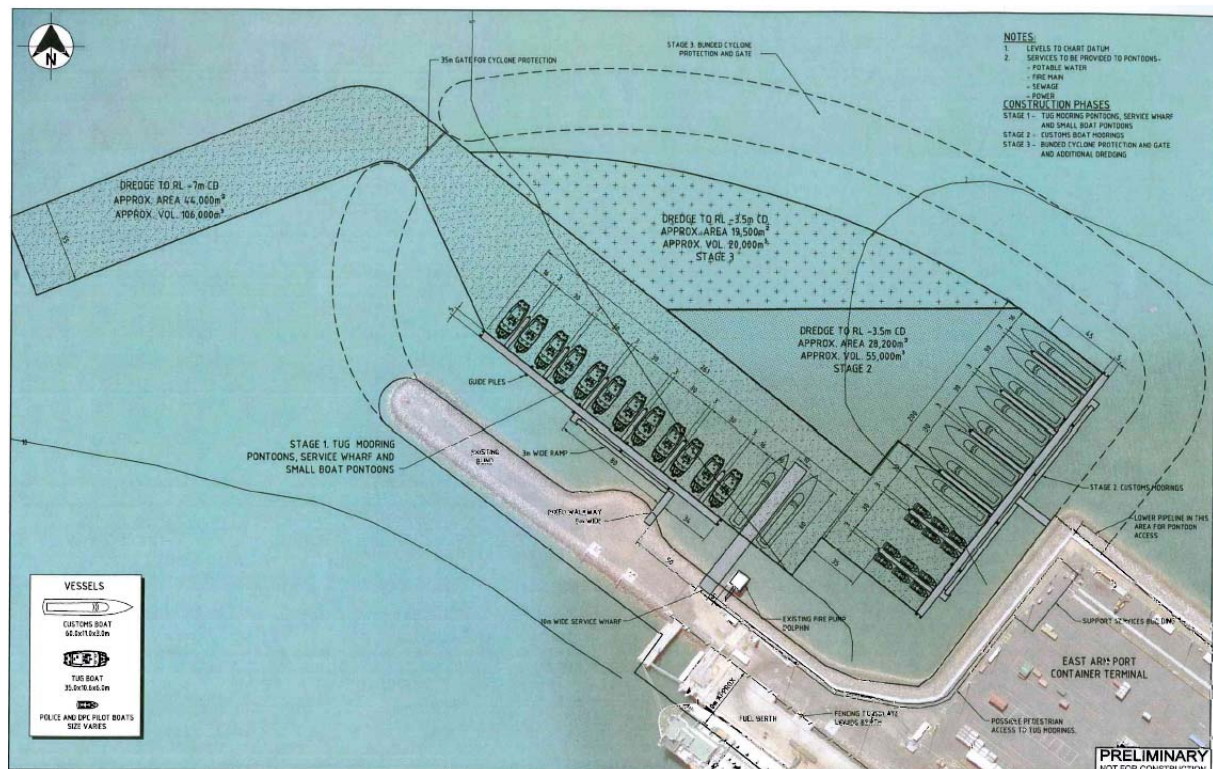


Figure 2-2 Tug and small vessel mooring locations concept design (Aurecon 2009)

2.1.2 Railway loop and dredge spoil ponds

A bund to carry the future railway turning loop (Figure 2-1) will be required in a location north east of the wharf and west of the fuel storage area. In an area where mud is quite deep, the removal of significant quantities of mud before construction of the earthen bund will be necessary to limit settlement and propagation of mud waves. The bund will be approximately 3,000 m long and will be constructed by trucks dumping fill on two fronts as the arms of the loop diverge, until eventually the bund loop will be joined. The seaward faces of the bund will require rock armour and the inner faces would be protected with riprap.

Adjacent to and southwest of the rail loop, it is proposed to construct ponds for future dredge spoil reclamation. The mud below the bunds will need to be removed before delivery of the fill to form the core of the bunds. Truck access along the bunds will enable the extension of the bunds until three ponds are completed. The seaward faces of the bunds will require rock armour and the inner faces would be protected with riprap.

2 Proposed Activities in Relation to Water Quality Impacts

The construction sequence for both activities will be:

- remove the mud at the location of the bund walls
- dump earth fill to form the bund core
- provide rock armour to the seaward slopes
- provide riprap to the inner slopes.

2.1.3 Marine Supply Base

The proposed Marine Supply Base (MSB) will be located east of the existing reclamation at East Arm (Figure 2-3). It will comprise reinforced concrete wharf decks supported by steel piles to provide berths for offshore platform supply vessels (rig tenders). The initial wharf structure will be used for rock loadout for the proposed INPEX Ichthys Gas Field Development Project. Dredging to -7.7 m CD is proposed for these deep draft vessels. Anticipated dredge spoil volume for the first stage is approximately $750,000 \text{ m}^3$.

The construction sequence will be:

- dredge to -7.7 m CD
- drive steel piles
- construct reinforced concrete decks.
- fit fenders and bollards
- provide services (power, water, fire fighting, waste receipt).

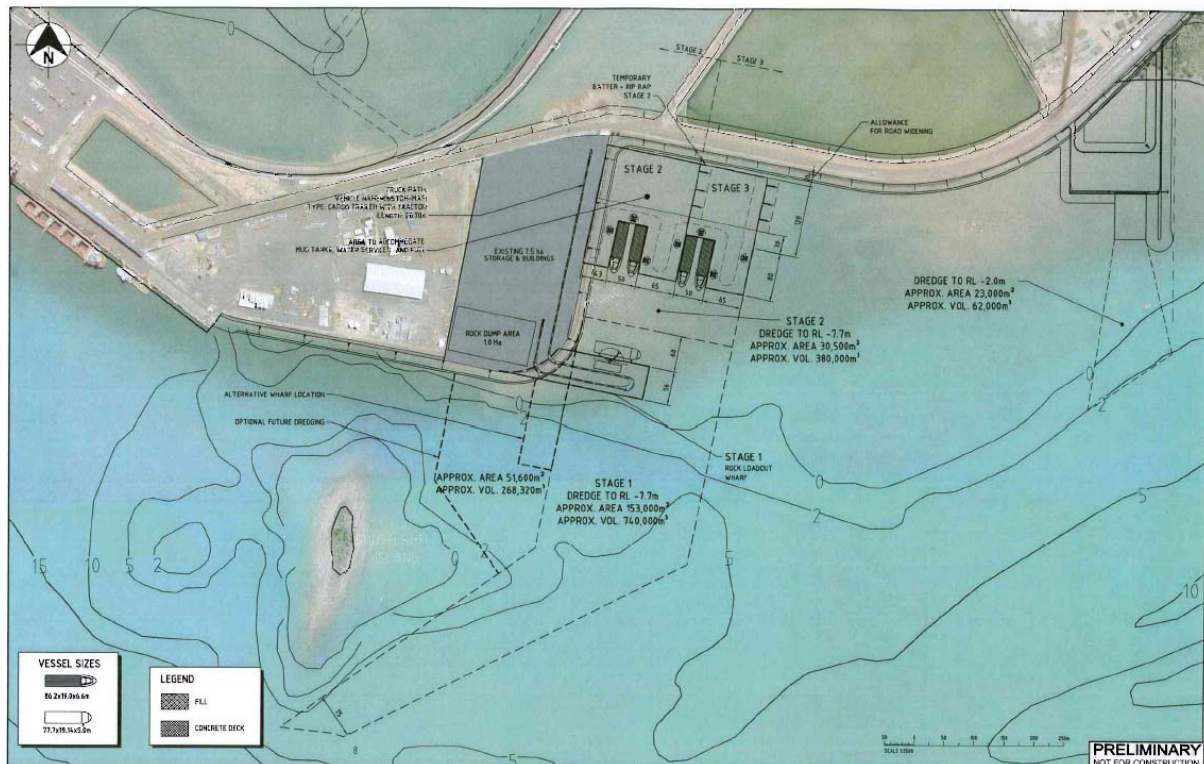


Figure 2-3 Concept design for East Arm Port MSB and barge ramp and hardstand area (Aurecon 2009)

2 Proposed Activities in Relation to Water Quality Impacts

2.1.4 Barge Ramp and Hardstand Area

A barge ramp and hardstand area of 1 ha is proposed for commercial barge operations, located just west of the Paspaley lease and east of EAW (Figure 2-1). The method of construction will be:

- Construct a bund 330 m long (with an 8 m wide access road at the top) from imported fill, probably phyllite, delivered by truck and dumped directly in position, starting from Berrimah Road.
- A second bund 110 m long (with a 5 m wide emergency escape road at the top) will be placed in a similar manner parallel to, and 150 m west of, the first bund.
- A third bund 150 m long will connect the two bunds.
- The seaward batters of all bunds will be armoured with two layers of rock (600 kg) on an underlayer of 60 kg rock with geotextile.
- The inner area between the three bunds will be filled with imported fill until an area of 1ha is achieved. The area will be drained into pipes along the southern edge of the reclamation with the stormwater passing through an oil interceptor before discharge into the sea. The internal batters will be protected with riprap.
- A concrete barge ramp 50 m wide and approximately 76 m long (sloped at 1:8) will be provided on the southern face for access by landing craft and barges.
- The two roads on top of the bunds will be sealed and provided with Armco barriers.
- A channel dredged to -2 m chart datum (CD) will provide all tide access to the ramp. The dredged volume will be approximately 62,000 m³.

2.2 Water Quality Impacting Activities

Construction and associated activities will result in temporary impacts on water quality in and about EAW and more generally in East Arm. These alterations could affect transitory and resident marine flora and fauna within the vicinity of these activities.

Specific activities which will generate impacts on water quality are:

- dredging of ~1,363,000 m³ of estuarine sediment
- disposal at sea of ~1,093,000 m³ of sediment at the offshore disposal area
- disposal within reclamation areas of approximately 270,000 m³ of dredge spoil
- return to the harbour of decant water of estuarine origin
- excavation of intertidal and shallow subtidal sediments, bund wall construction and armouring
- pile driving generating minor localised turbidity
- increases to general shipping/ vessel traffic (pre, during and post construction) including operational emissions and accidental spills.

During the project construction the water quality will be influenced by dredging occurring in areas one, two and three which will, at least locally, increase the turbidity and suspended sediment levels present in the water. Clearing of land for reclamation bunds, excavation of the shallow sediments and construction of reclamation bunds (including that for the rail loop), rock armouring, pile driving, sediment run-off from cleared land and the return of reclamation decant water to the harbour will also impact on physical water quality to varying degrees.

At present there is no information available on actual suspended sediment or turbidity levels likely to be generated from this project, or the exact frequency and duration of these activities, as well as the time of year these activities are likely to occur.

2 Proposed Activities in Relation to Water Quality Impacts

Operational effects on water quality of the reclaimed land area, dredged channels and pilings may result from localised changes to current patterns and velocity. Other potential operational impacts include routine discharges of waste water, including storm water and domestic waste water and accidental emissions of product and fuel spills.

Representative data from analogous harbour development projects have been drawn from the available literature for the purpose of risk assessment.

Environmental Setting of the Project Area

3.1 Bathymetry

Darwin Harbour is a large ria system, or drowned river valley, with an area of about 500 km². In its southern and south-eastern portions the Harbour has three main components - East Arm, West Arm and Middle Arm - that merge into a single unit, along with the smaller Woods Inlet, before joining the open sea.

Over the 6000–8000 years since the Harbour was formed by rising sea levels, erosion from the adjoining terrestrial environment has carried substantial quantities of sediment into its waters. This sediment now forms much of the intertidal flats which veneer the bedrock.

The proposed onshore development area is situated about EAW at the entrance to East Arm, between Frances Bay and East Arm. East Arm is the estuary of the Elizabeth River which drains the hinterland behind Darwin and Palmerston during the wet season.

The main channel of the Port of Darwin is around 15–25 m deep, with a maximum depth of 36 m. The channel favours the eastern side of the Harbour, with broader shallower areas occurring on the western side. Intertidal flats and shoals are generally more extensive on the western side of the Harbour than on the eastern side. The channel continues into East Arm at water depths greater than 15 m below Lowest Astronomical Tide (LAT); the bathymetry in this area has been modified by dredging for the development of EAW.

A slightly deeper channel extends into Middle Arm, up to the western side of Channel Island.

3.2 Rainfall and Runoff

Darwin has a mean annual rainfall of 1711 mm, with rain falling on an average of 111 days, mainly in the wet season (November to March). A range of monthly rainfall averages received at Darwin Airport (highest, mean and lowest monthly rainfall) is presented in Figure 3-1 (BOM 2008).

During the wet season winds in Darwin are predominantly from the west and west-north-west. Dry season winds vary from the southeast through to the north. The monsoonal tropics also experience cyclone activity. The strongest winds and heaviest rainfall are associated with the passage of tropical cyclones, which can occur in the region at any time during the period November to April.

Freshwater inflow to the harbour occurs from January to April, when estuarine conditions prevail in all areas (Hanley 1988). The major inflow of fresh water to East Arm is from the Elizabeth River.

3 Environmental Setting of the Project Area

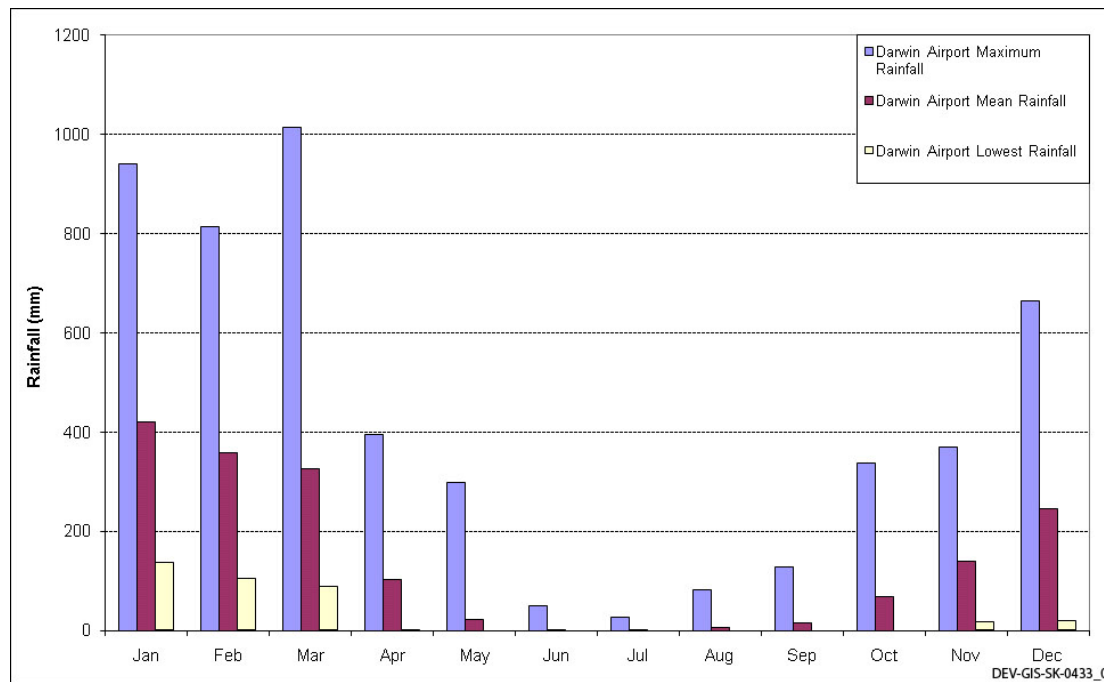


Figure 3-1 Average monthly rainfall for Darwin (mm)

3.3 Oceanography and Hydrodynamics

Darwin Harbour is characterised by a macrotidal regime. Tides are predominantly semidiurnal (two highs and two lows per day), with a slight inequality between the successive tides during a single day. For a two day period during neaps, there are nearly diurnal tide conditions. The lowest spring tides of the year occur during October, November and December. Mean sea level is approximately 4.0 m above LAT. Spring tides can produce tidal ranges of up to 7.5 m (0.0 m above LAT at low tide to 7.5 m above LAT at high tide), while the neap tide range can be as small as 1.4 m (3.1 above LAT at low tide to 4.5 m above LAT at high tide) (URS 2009).

Tidal excursions (the net horizontal distance over which a water particle moves during one tidal cycle of flood and ebb) range from 8 to 15 km during springs and 2 to 8 km during neaps (Semeniuk 1985; Hanley & Caswell 1995). The large tidal ranges produce strong currents that peak at speeds of up to 2–2.5 m/s. Tidal flows are also large; peak spring-tide flows have been measured along a line from East Point to Mandorah and are in the order of 120 000 m³/s. Over a spring tide up to 1000 GL/s can pass through this area (Williams & Wolanski 2003). The major currents in the Harbour are illustrated for ebb tide and flood tide in Figure 3-2 and Figure 3-3 respectively.

3 Environmental Setting of the Project Area

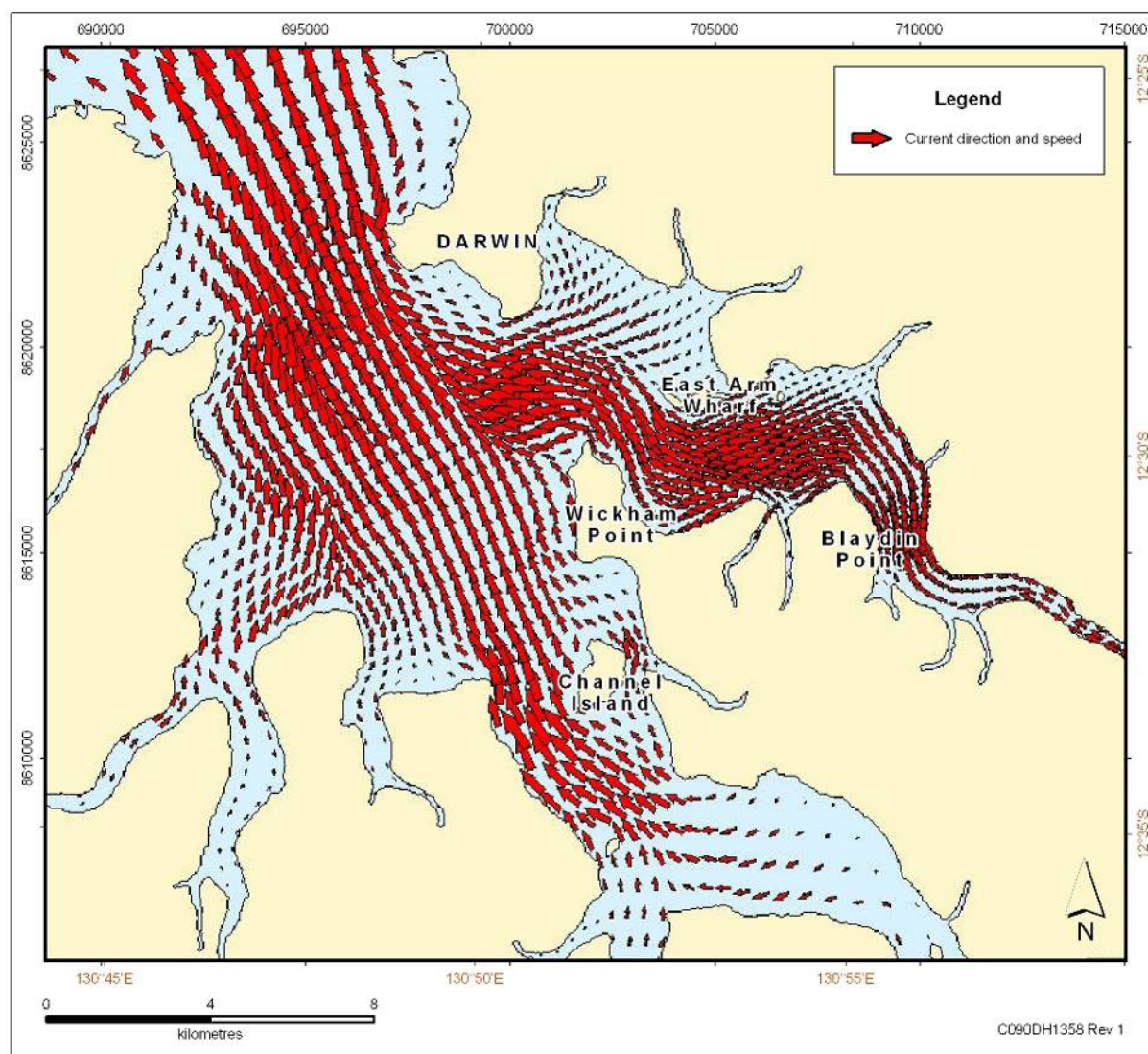


Figure 3-2 Major currents during ebb tide in Darwin Harbour (Source: INPEX 2010)

3 Environmental Setting of the Project Area

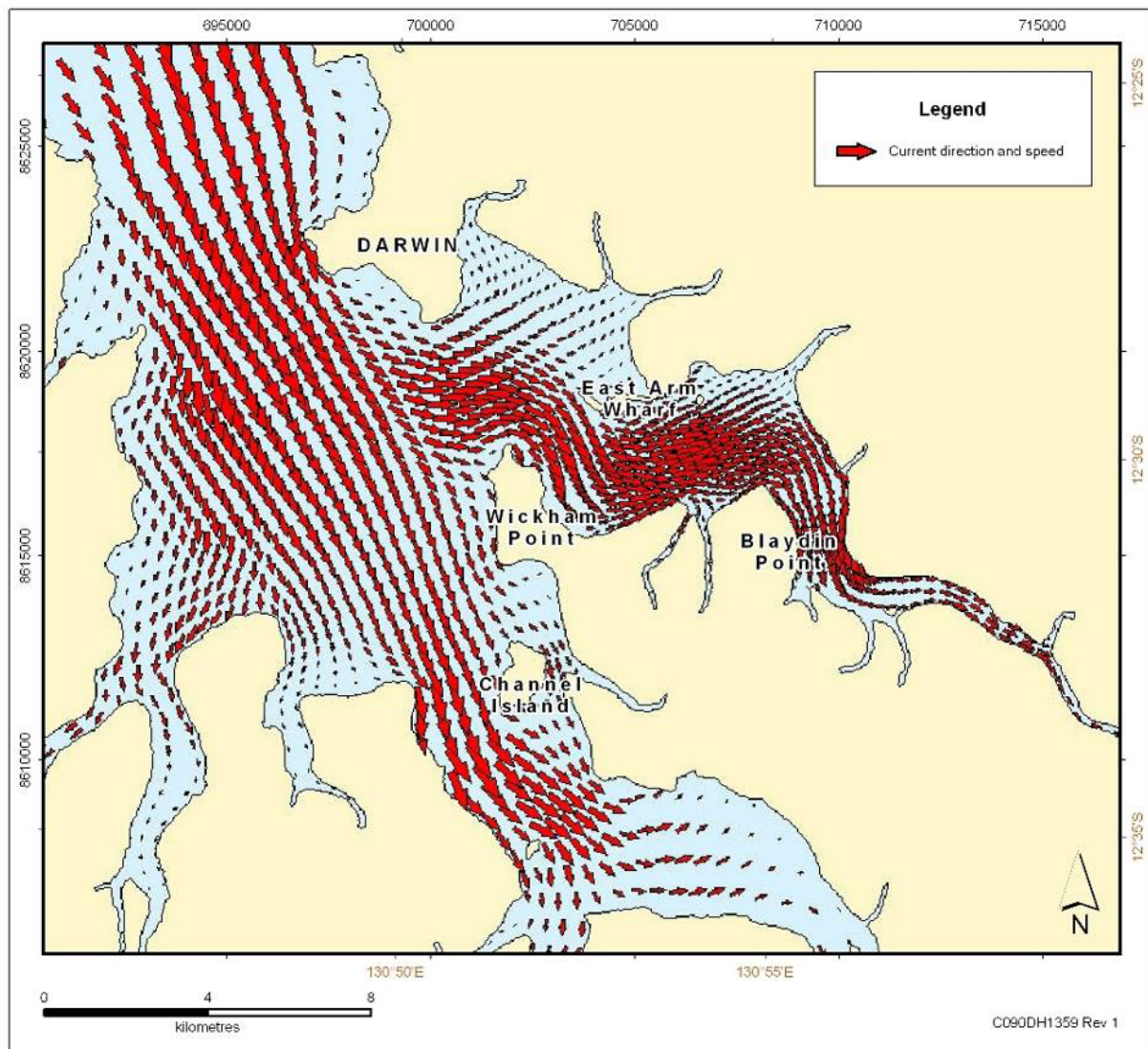


Figure 3-3 Major currents during flood tide in Darwin Harbour (Source: INPEX 2010)

The Harbour is considered to be well protected, with the majority of waves generated within the Harbour or in Beagle Gulf (Byrne 1988). The ambient wave climate during the summer months could reach heights of up to 1 m, although average wave height would be less than 0.5 m with periods of 2-5 s (Byrne 1988; GHDM 1997). Average wave conditions during the winter months are predicted to be even lower. It is considered that tsunamis and swell waves (long-period waves) are unlikely to occur in Darwin Harbour as a consequence of its orientation and the protection from ocean swells afforded by the Tiwi Islands (Melville Island and Bathurst Island) (GHDM 1997).

Extreme wave conditions were modelled by GHDM (1997) using wind data from Cyclone Tracy in 1974. Waves with significant wave height of 4.5 m, and average periods of around 7.5 s, were found to occur at the entrance to the Harbour. However, these waves were found to be affected by bathymetry and reduced to a height of around 0.7 m in shallower waters in the inner parts of the Harbour (GHDM 1997).

3 Environmental Setting of the Project Area

Storm tide predictions - which include cyclone storm surge together with the effects of frequent breaking waves ("wave set-up") and the influence of astronomical tide - indicate that temporary increases in sea level would occur during cyclone conditions, at sites around Middle Arm Peninsula and East Arm (Table 3-1). The largest storm tide expected over a 100-year period (1-in-100 year event) is 4.9–5.1 m above mean sea level. Mean sea level is estimated at 4 m above LAT, therefore this storm tide would bring nearshore waters to a height of 8.9–9.1 m above LAT. Predictions over longer return periods, for 1-in-1000 and 1-in-10 000-year events indicate even higher storm tides (VIPAC Engineers and Scientists Ltd 1994).

Table 3-1 Predicted storm tide heights for locations adjacent to the development area

Location	Storm tide height (m) relative to mean sea level (4 m above LAT)		
	1-in-100 years	1-in-1,000 years	1-in-10,000 years
East Arm Wharf	4.9	6.0	7.0
Wickham Point	5.1	6.4	7.7
Channel Island	5.1	6.4	7.7
West Arm	5.1	6.4	7.6

Source: VIPAC Engineers and Scientists Ltd 1994

Water Quality

4.1 Background

The range of water-related studies in Darwin Harbour is diverse with respect to the objectives, time frames, water-quality variables measured, and locations. The majority of the studies undertaken have been of short term duration (less than one year) where the objectives were to obtain baseline information. Most of the other studies are associated with environmental monitoring in response to potential impacts such as dredging, sewage discharge and runoff (Padovan 2003).

The first comprehensive water-quality study of Darwin Harbour was undertaken during 1990–91 for the main body of the Harbour and the entrances to East Arm, West Arm and Middle Arm. More recent comprehensive water-quality monitoring of the Harbour, from 2001 to 2005, expanded the range of locations, which included the upper reaches of East Arm and Middle Arm, tidal creeks and Shoal Bay (WMB 2005).

Water quality in the Harbour is generally high, although naturally turbid most of the time. Water quality parameters vary greatly with the tide (spring versus neap), location of sampling (inner versus outer harbour), and with the season (wet season versus dry season). The Darwin wet season extends from November to March and its effects on harbour water quality (due to high surface runoff from the land) can last until April or May depending on rainfall. Dry season climate conditions prevail from May to September.

Tides have a marked effect on water clarity in the Harbour, with waters of neap tides being the clearest, while spring tides carry quantities of sediment from the fringing mangroves (DHAC 2007). The areas with the highest natural sedimentation are in the upper reaches of East and Middle Arms. Medium levels of sedimentation occur in the seaward end of West Arm and the lowest levels are in the more open water areas such as EAW, Larrakeyah to the seaward boundary of the Harbour (DHAC 2006). It is estimated that 60% of the Harbour's sediments originate from offshore. The remainder is deposited by rivers and creeks, derived predominantly from erosion of channel walls. Direct contribution to the Harbour from sheet erosion is likely to be limited because of the very low hillslope gradients adjacent to the Harbour (DHAC 2006).

There is no evidence of widespread water or sediment pollution in the Harbour, although there is some localised pollution (Padovan 2003). Anthropogenic influences to Harbour water quality include the port operations at East Arm, historic industrial activities at Darwin Waterfront, Sadgroves Creek and wastewater outfalls (URS 2004). Power and Water Corporation discharges untreated, macerated sewage to the Harbour from a sewage plant at Larrakeyah, near the Darwin central business district (CBD), at rates of around 80 000 to 130 000 kL per month. Nutrient loads associated with these monthly discharges range between 3.16–6.98 t of total nitrogen, and 0.72–1.36 t of total phosphorus (Power and Water Corporation 2006a).

There are increased levels of nutrients in Buffalo Creek and metals in the sediments at Iron Ore Wharf (near Fort Hill Wharf); however the ecological significance of these localised impacts is unclear. In addition, there is no evidence of hydrocarbon or pesticide pollution in the Harbour (DHAC 2007).

A summary of the seasonal, spatial and tidal processes affecting water quality in Darwin Harbour is presented in Table 4-1 and is described further below.

4 Water Quality

Table 4-1 Summary of natural processes affecting water quality in Darwin Harbour

Parameter	Influencing factors	
	Open harbour	Tidal Creeks
Temperature	Season	Season
Salinity	Season, location	Season, tide
Dissolved oxygen	Tide (minor)	Tide
pH	(none)	Season, tide
Turbidity and light attenuation	Season (minor), tide	Tide
Nutrients	(none)	Location

Source: Padovan (2003)

In order to characterise the existing conditions in the nearshore development area a water-quality survey was undertaken by URS on behalf of INPEX, Browse Pty Ltd (INPEX) from April to August 2008, designed to capture the effects of both the wet and dry seasons. The study included measurement of physico-chemical water quality parameters in the water column, as well as assessment of total suspended solids (TSS). Sampling sites included in the survey are shown in Figure 4-1, while a summary of the average levels recorded is provided in Table 4-2. The results of the study are discussed below. The full technical report is presented as Appendix 8 of the INPEX EIS (URS 2008).

4 Water Quality

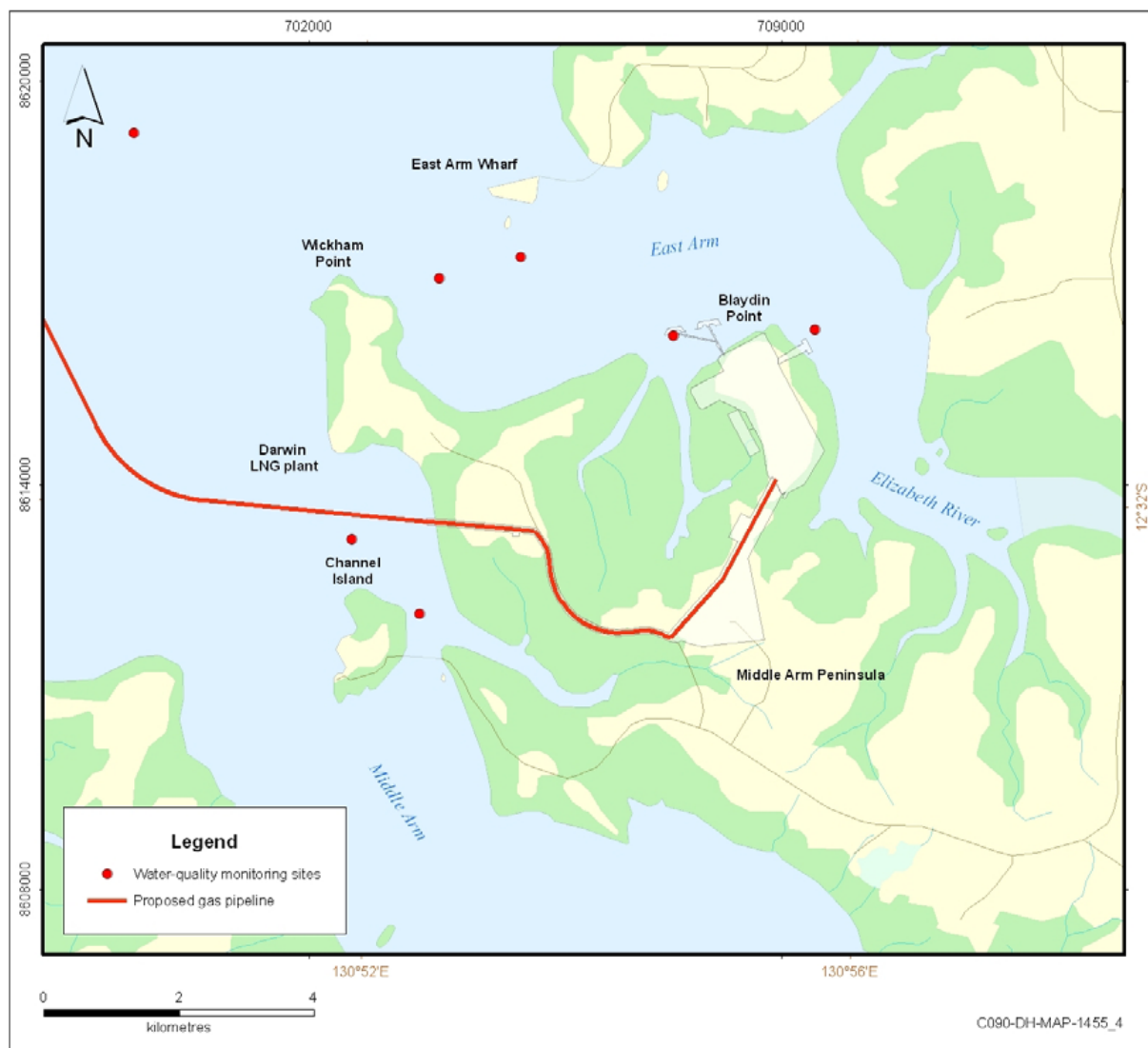


Figure 4-1 Water quality sampling sites (Source: URS 2008)

Table 4-2 Average water quality levels recorded in East Arm

Parameter	Dry Season	Wet Season
Temperature	24.5°C	30.6°C
Salinity	25.5 ppt*	29 ppt*
Dissolved oxygen	93.3%	87.8%
pH	8.4	8.1
Turbidity	3 NTU _†	10.5 NTU
Total suspended solids (TSS)	14.0 mg/L	14.1 mg/L

* ppt = parts per thousand

† NTU = nephelometric turbidity unit

Source: URS 2008

4 Water Quality

4.2 Water temperature

Water temperatures in Darwin Harbour are typically high, and some seasonal variations do occur. Temperatures are lowest (23°C) in June-July and highest (33°C) in October-November (Padovan 1997).

Water temperature measured in the nearshore development area by URS (2008) ranged from 23.5 to 32.7°C, with an average temperature of 30.6°C in the wet season and 24.5°C in the dry season. Comparison between sites over both the wet and dry seasons found that the water temperature was elevated by about 5°C in the wet season. These distinct seasonal variations in sea-surface temperature have been shown in previous studies of the Harbour (e.g. Michie et al. 1991). No significant difference in temperature was observed at any site as a result of either water column position (surface or bottom) or tidal flow (ebb or flood). Spatial uniformity in the Harbour has also been found to occur at sites located both in the upper reaches of Middle Arm and close to the Darwin CBD (Michie et al. 1991).

4.3 Salinity

Salinity in Darwin Harbour varies considerably during the year, particularly in East, Middle and West Arms where freshwater influence is greatest during the wet season. Seawater has a global average salinity of 35 parts per thousand (ppt) however salinities throughout Darwin Harbour are about 37 ppt during the dry season, with surface and bottom depths having similar levels. Salinity tends to be higher in the dry season owing to increased evaporation and less fresh water inflow. At the height of monsoonal inflow during February to March, areas in the middle of the harbour such as Weed Reef can experience salinity levels of 27 ppt (Parry & Munksgaard 1995).

Salinities in the arms, which are largely influenced by freshwater inflow, can drop as low as 17 ppt. The water at this time is highly stratified, with freshwater input from land-based catchments flooding the Harbour and overlying the intrusion of more dense, higher-salinity water from outside the Harbour, forming a classic “salt wedge” that is typical of estuarine systems. Parry and Munksgaard (1995) reported salinities on the bottom of the Harbour to be as much as 12 ppt higher than on the surface. As the rains cease, runoff decreases and salinities return to their higher dry-season levels (Parry & Munksgaard 1995).

Salinity levels recorded in the East Arm area by URS (2008) ranged from 19.1 to 36.3 ppt. Average salinity was 32.7 ppt and was higher in the dry season than the wet season. Under dry season conditions, salinity was higher in upstream areas than downstream, but this trend was reversed in the wet season with freshwater input to the arms from rainfall. These variations in salinity according to location in the Harbour and according to season have also been previously reported by Michie et al. (1991) and Padovan (1997). No significant differences in salinity levels attributable to position in the water column were observed (URS 2008) - this may have been a result of water sampling occurring in April and not earlier in the wet season when a significant salt wedge underlying a freshwater lens would likely have been present. Tidal flushing and a lack of major rainfall events during the wet season sampling period may have also assisted with mixing of the water column at the sampling sites.

4.4 Dissolved oxygen

Harbour waters remain well oxygenated throughout the year, with levels ranging from 74% to 96% saturation, typically around 84%. In a study by Padovan (1997) no seasonal effects were observed,

4 Water Quality

and there were minor changes in oxygen levels with location in the main body of the Harbour. Dissolved oxygen levels at sites closest to the Harbour's mouth were slightly higher than sites further into the estuary. In addition, oxygen levels during a spring tidal cycle were 7% higher at high tide than at low tide (Padovan 1997).

Dissolved oxygen levels in tidal creeks fluctuate with the tidal cycle, with oxygen concentrations lowest during low tide. Oxygen levels in Blessers Creek (adjacent to EAW, on the west side) at low neap tide have been recorded at 60% saturation, compared with 90% at high tide (Parry & Munksgaard 1996). This indicates a certain oxygen demand in tidal creeks, probably from mangrove root systems and sediment infauna. To date there are no reports of anoxia in undisturbed tidal creeks, and it is not known whether the conditions under which anoxia is most likely to occur have ever been sampled. These conditions are during small tidal movements in October–November when temperatures are highest and calm conditions prevail (Padovan 2003).

Dissolved oxygen levels measured in the nearshore development area by URS (2008) ranged from 74.4% to 119.3%, with an average saturation of 93%. Overall, dissolved oxygen was generally found to be higher in the dry season and in the main body of the Harbour, with decreasing levels further upstream. Higher dissolved-oxygen levels were recorded towards the surface than at the bottom of the water column. No significant differences in dissolved oxygen levels were observed between flood and ebb tides (URS 2008).

4.5 pH

The pH of Darwin Harbour waters generally remains within a narrow range (8.3–8.6 with a mean of 8.5) throughout the main waterbody. Padovan (1997) found no seasonal or spatial effects on pH, and no tidal effects.

The pH of tidal creeks varies to a greater degree than the open Harbour waters, and is affected predominantly by tide and season. During the dry season or periods of no freshwater inflow, the pH of Blessers Creek and Middle Arm was 0.3 pH units lower at low tide than at high tide (Parry & Munksgaard 1996). This indicates that processes occur in the mangrove environment that results in the slight acidification of inflowing waters.

Measurements in the nearshore development area by URS (2008) recorded a mean pH of 8.4, and a range from pH 7.8 to 9.2. In the upper reaches of the Harbour, mean pH levels were found to be lower (more acidic), with pH levels increasing (becoming more alkaline) in the main body of the Harbour in both wet- and dry-season sampling. No significant difference in pH attributable to water column position or tidal state was observed (URS 2008).

4.6 Turbidity and light attenuation

Light levels reaching the sea surface in the Harbour are very high. However, because of the high levels of suspended solids in the water column the light is rapidly dissipated, and even within a depth of a few metres light levels can be greatly reduced. Turbidity is a measure of this “light scattering” effect, and is measured in nephelometric turbidity units (NTU). The turbidity of the main waterbody is typically in the range 1–35 NTU.

The most important factors affecting turbidity are the tidal cycle and location within the Harbour (Padovan 1997). Turbidity is highest during spring tides when current velocity, and therefore capacity

4 Water Quality

of the water to move sediment, is greatest (DHAC 2005). During the spring-tide cycle, turbidity is greatest at the midpoint between high and low water, and lowest at slack water.

Turbidity is higher in the wet season than the dry season because of the influx of terrigenous sediments to Harbour waters through the rivers and, to a lesser extent, from surface-water sheetflow. Even at a depth of only 3 m below the surface, light levels during the wet season can be as low as 7.7% of surface levels. Light levels at the bottom of the Harbour can be as low as 1% of surface levels during the wet season (DHAC 2005).

In analysing turbidity data from the EAW development, Munksgaard (2001) found statistically significant effects of season where turbidity was highest during the wet season. However, the mean change in turbidity was relatively minor, from 4 to 12 NTU over the range of conditions analysed. These differences are much lower than the range typically found in the Harbour, between 1 and 35 NTU (Padovan 1997). It can be concluded that season has only a minor effect on turbidity in the main body of the Harbour. There have been no studies on turbidity in the upper reaches of East Arm and Middle Arm where the Harbour is most affected by freshwater inflows during the wet season. Seasonal effects on turbidity, if present, would most likely be found here (Padovan 2003).

Turbidity levels recorded in the nearshore development area by URS (2008) were up to 73.6 NTU, with a mean reading of 6.9 NTU. Predictably, higher NTU values were found at the bottom of the water column than at the surface, with higher levels also being recorded in the wet season when compared with the dry. During ebb tides turbidity levels were higher upstream than in the Harbour; this was reversed during flood tides (URS 2008).

4.7 Total suspended solids

Measurements of total suspended solids (TSS) and turbidity both indicate the levels of solids suspended in the water column, whether mineral (e.g. soil particles) or organic (e.g. algae). However, TSS measures an actual weight of material per volume of water, while turbidity, as described above, measures the amount of light scattered.

DIPE (2004) recorded an annual TSS average of 6–10 mg/L, with a minimum recording of 3.12 mg/L and a maximum of 73.5 mg/L. TSS levels around Blaydin Point measured by URS (2008) ranged from 1.5 to 83 mg/L, with an average measurement of 14.6 mg/L. Elevated TSS levels were found to occur in the wet season at the bottom of the water column on a flood tide at all sites. Generally, TSS levels were not as high in Harbour waters as in the upper reaches of East and Middle Arms. No clear distinction was found between wet and dry season TSS levels at the surface (URS 2008).

4.8 Nutrients and phytoplankton

Studies on nutrients in the sediments of Darwin Harbour are few and their scopes have been limited. Padovan (1997; 2002) and Sly et al. (2002) found total nitrogen in the main body of the Harbour to be in the range 0.2–0.6 mg/L. The concentration of total nitrogen in most of the inflowing river waters was similar to that found in the Harbour and therefore wet season inflows are not expected to affect nitrogen concentrations in the main waterbody (Padovan 1997, 2003).

Phytoplankton is an important water quality measure as its abundance and composition are directly influenced by environmental factors including nutrients and light. The abundance of phytoplankton is typically quantified through the enumeration of cell numbers and through the measurement of chlorophyll-a, the main light absorbing pigment used in photosynthesis.

4 Water Quality

Planktonic organisms, along with mangrove plant and animal communities, can form the basis of the food web in coastal marine ecosystems. About 250 different species of phytoplankton have been found in Darwin Harbour, which is typical of tropical, oceanic waters in northern Australia (WMB 2005). Results from the monitoring study by WMB (2005) demonstrated that for most of the year the amount of phytoplankton in the Harbour was very low (less than 2 µg/L of chlorophyll-a), though some measurements in the Blackmore River were up to ten times higher than this.

No seasonal or inter-annual changes in concentrations of chlorophyll-a in the Harbour have been found, though concentrations vary with tide cycle (Padovan 1997, 2002). Concentrations were highest during the midpoint of a spring tide, suggesting the re-suspension of algal cells from the bottom. Overall, the concentrations measured in the Harbour are similar to those found in other north Australian waters (Padovan 1997).

The formation of cyanobacteria blooms (also known as blue-green algal blooms) occurs naturally in Darwin Harbour during the dry season (Drewry et al 2010) and remnants of blooms may be found washed up on harbour beaches at this time.

Sediment Quality

5.1 Surface sediments

5.1.1 Introduction

Michie (1988) divided Darwin Harbour sediments into four types:

- Terrigenous gravels, which occur primarily in the main channel.
- Calcareous sands with greater than 50% biogenic carbonate, which are among or close to the small coral communities at East Point, Lee Point and Channel Island. Biogenic carbonate sediments, largely derived from molluscan shell fragments, also occur in spits and shoals close to the Harbour mouth.
- Terrigenous sands on beaches and spits. This type of sediment is predominantly quartz and clay, with 10–50% carbonate, again largely derived from molluscs.
- Mud and fine sand on broad, gently inclined intertidal mudflats that occur in areas characterised by low current and tidal velocities, such as in Kitchener Bay (prior to the construction of the Darwin City Waterfront).

Soft surfaces consisting of muds and fine sand are estimated to cover approximately 80% of the seafloor (Acer Vaughan Consulting Engineers 1997). Soft surfaces with varying amounts of gravel and sand are found in the main channels around reefs, on beaches and on spits and shoals near the mouth of the Harbour. The spatial extent of these surfaces is sometimes difficult to determine because of the gradual transition between muddy, sandy and coarser sediments and sediment movement associated with large tidal influences (Fortune 2006).

The physical and biotic structure of soft substrates is governed by grain size, oxygen state and sediment chemistry. The rate of sediment chemistry processes (e.g. carbon, nitrogen and sulphur cycles) and the fauna and flora composition in and on the sediment are linked (e.g. Kristensen & Blackburn 1987, Pearson & Rosenberg 1978). However, the extent to which the sediment biogeochemistry determines flora and fauna assemblages, and vice versa, is largely unknown for Darwin Harbour (Smit 2003).

Coarser material appears to be located in the central channels of tributaries and the main body of the Harbour, as opposed to the landward margins, demonstrating the influence of tidal movement, bathymetry and potential transport capacity in these regions (Fortune 2006).

5.1.2 East Arm Sediments

In 2008, URS sampled surface sediments at 145 sites, and subsurface sediments at 18 sites in East Arm and along the route proposed for the gas pipeline route by INPEX within Darwin harbour (Figure 5-1). The surface sediments were analysed for a range of parameters: a suite of metals occurring both naturally and as a result of potential man-made contamination (iron, manganese, cobalt, manganese, aluminium, antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc); tributyltin; nutrients (nitrogen and phosphorus); total organic carbon; particle size distribution; total petroleum hydrocarbons; polynuclear aromatic hydrocarbons; and benzene, toluene, ethylbenzene and xylene compounds (BTEX). In addition, organochlorine pesticides, polychlorinated biphenyls and radionuclides were investigated at some sites. Subsurface sediments were analysed for metal concentrations and acid sulphate soil (ASS) potential.

5 Sediment Quality

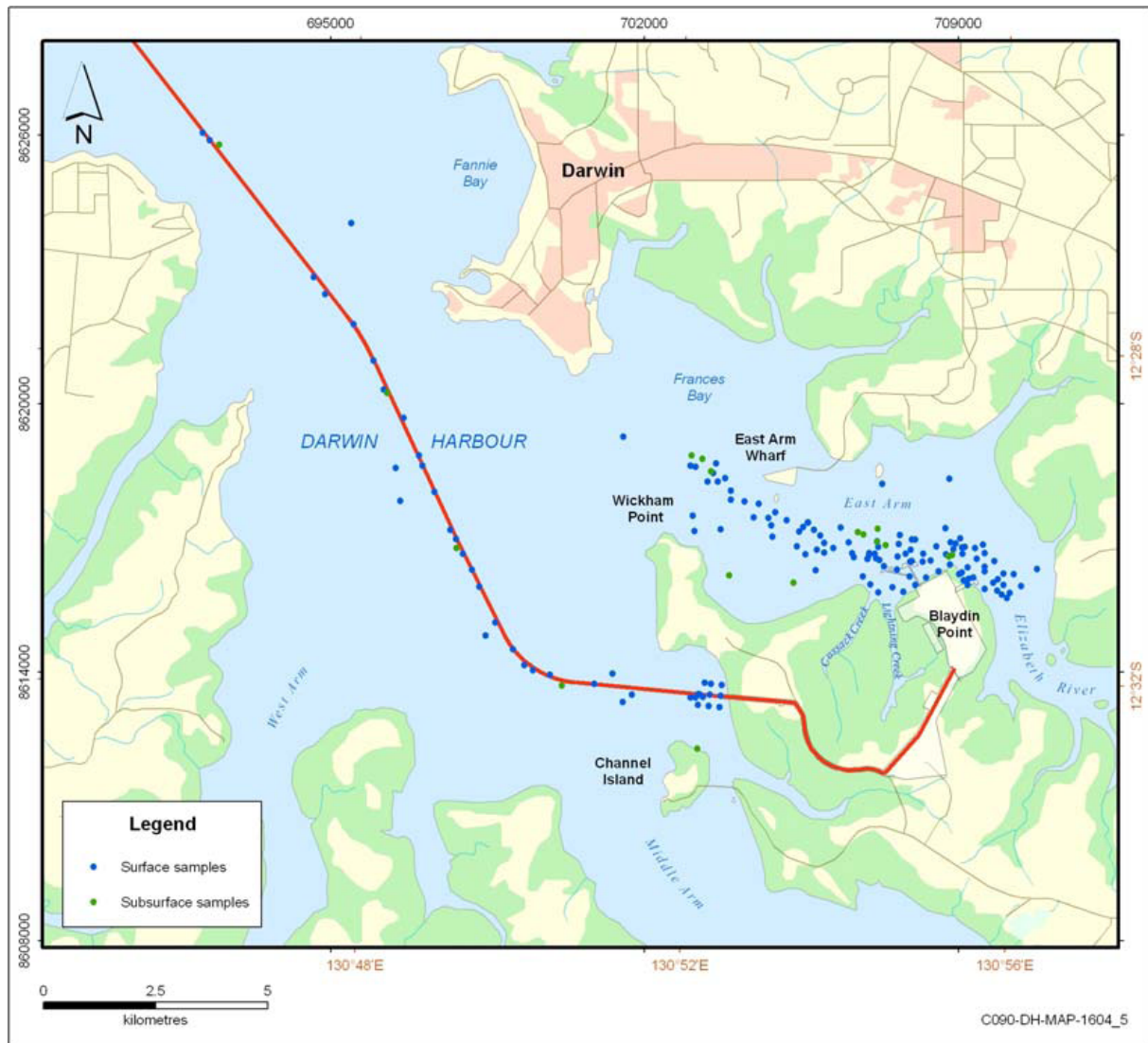


Figure 5-1 Sediment sampling sites (URS 2008)

More recently, a survey of sediments has been undertaken in the proposed dredging areas (Figure 5-2) by AECOM in 2010 (AECOM 2011 pers com.).

Results of both sediment surveys are discussed below.

5 Sediment Quality

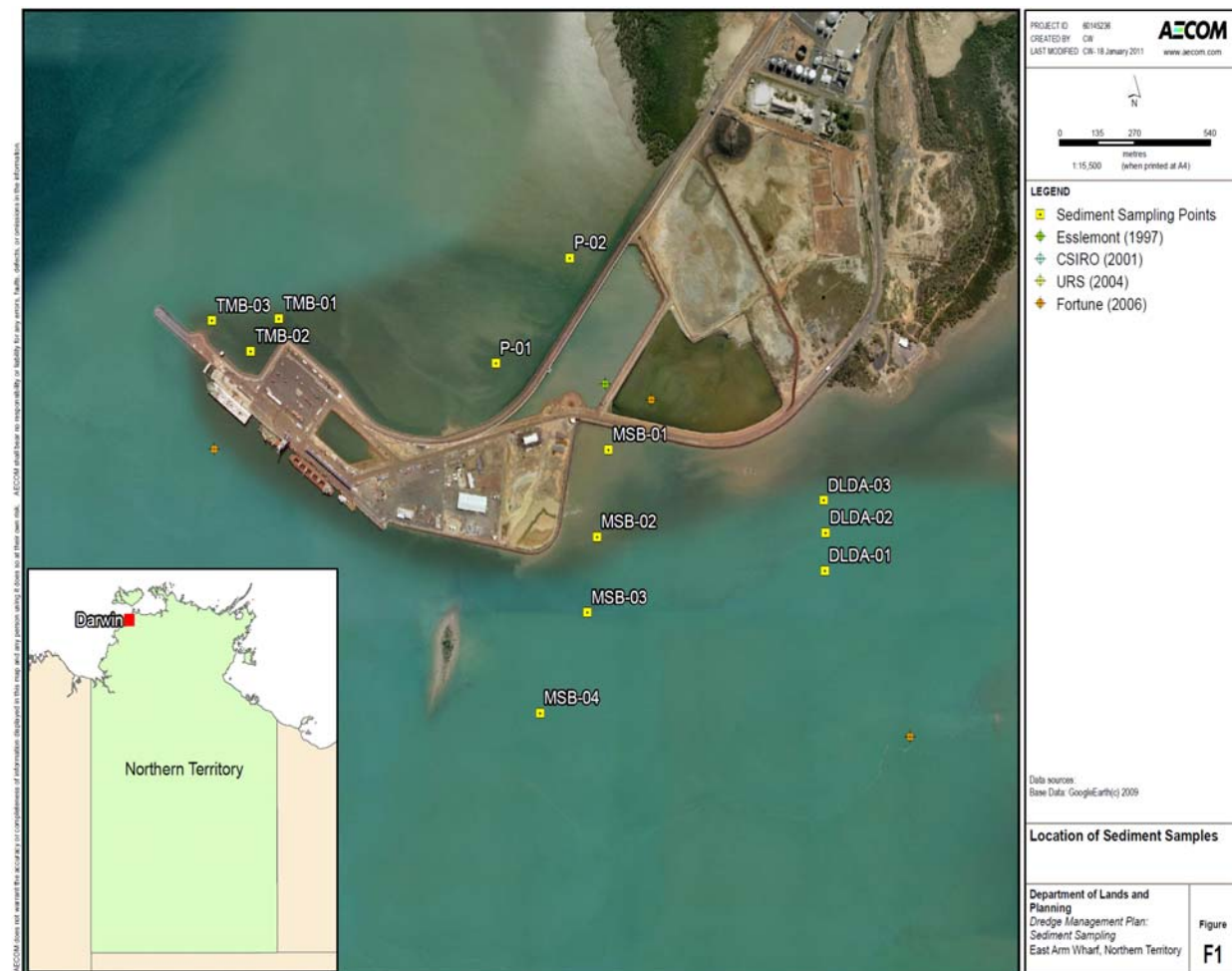


Figure 5-2 Sediment sampling sites (AECOM 2010)

5.2 Sediment Quality

5.2.1 Interpretation of data

The Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) Guidelines were used by URS to ensure that all sampling and analysis was undertaken in accordance with standard protocols and to ensure that the data collected could be compared against these guidelines. The ANZECC and ARMCANZ (2000) Guidelines outline the screening levels of a substance in the sediment below which toxic effects on organisms are not expected. The Interim Sediment Quality Guidelines (ISQG) are a subset of the ANZECC and ARMCANZ (2000) Guidelines and were adapted from North American effects-based guidelines because there was a paucity of local toxicological data. The “effects range–low” (ERL) and “effects range–median” (ERM) guidelines were renamed ISQG-Low and ISQG-High guidelines respectively (ANZECC & ARMCANZ 2000). These values correspond to the lower 10th percentile (ERL) and 50th percentile (ERM) of chemical concentrations associated with adverse biological effects in field studies and laboratory bioassays.

5 Sediment Quality

5.2.2 Metals

Sediments play a key role in the geochemical and biological processes of an estuarine ecosystem such as Darwin Harbour. Sediments can act as sinks for metals and organics that enter the Harbour; however, the following physical factors may bring about the exchange of heavy metals between water and sediments:

- Hydrodynamic effects that may cause sediment suspension at the sediment– water interface
- Bioturbation in sediments that may tend to redistribute heavy metals in the profile
- Salinity of the interstitial water in the sediments (Fortune 2006).

The ANZECC and ARMCANZ (2000) guidelines provide ISQG levels (as discussed above) for many heavy metals, at both at the “ISQG-Low” concentration (below which toxic effects on organisms are not expected), and the “ISQG-High” concentration (at which toxic effects on organisms could occur). Previous studies of heavy-metal concentrations in Darwin Harbour sediments (e.g. Peerzada and Ryan 1987; Peerzada 1988; Currey 1988; Hanley and Caswell 1995; Parry and Munksgaard 1995; Padovan 2002) all recorded levels below the ANZECC & ARMCANZ ISQG guideline screening levels. In many cases, the readings from these studies were an order of magnitude, and sometimes two orders of magnitude, lower than the recommended upper 95% confidence limit (UCL) of the mean (95% UCL).

More recently, Fortune (2006) undertook a detailed study of heavy metal concentrations in sediments throughout the Harbour. A number of sites in the study had concentrations of metals above ISQG-Low values or were considered elevated. Arsenic was the only metal notably higher in the East Arm area however this is likely to be an indication of local geology rather than anthropogenic sources.

Sampling by URS in 2008 was conducted using a Van Veen grab, as well as a piston corer in some areas. Metals concentrations recorded during laboratory testing were compared against the “National Ocean Disposal Guidelines for Dredged Materials”, developed by Environment Australia. These have been superseded by the National Assessment Guidelines for Dredging (NAGD) (DEWHA 2009). The guidelines provide levels for many heavy metals, at both a “screening” concentration (below which toxic effects on organisms are not expected), and a “maximum” concentration (at which toxic effects on organisms could occur). The complete results of this sampling program are provided in Appendix 8 of the INPEX EIS (URS 2008).

Metals concentrations recorded in East Arm surface sediments were generally found to be below the screening concentration, with the exception of arsenic, chromium and mercury. Arsenic concentrations were elevated above the maximum concentration at six sites. Tests using mild acid digests showed that this arsenic is unlikely to be toxic in the marine environment as only a very small proportion is bioavailable. Arsenic concentrations in some subsurface samples in East Arm also exceeded screening levels, and a slightly elevated nickel concentration was recorded at one site.

A study in 2010 by the Australian Institute of Marine Science (Parry 2010) of the sediments in the immediate area of the copper concentrate loadout at EAW found elevated copper concentrations compared to background levels for Darwin Harbour. While the total acid-extractable concentrations exceeded ANZECC & ARMCANZ (2000) ISQG-Low and High levels in one sample, the 1N HCl (“mild acid digest”) extractable copper concentrations, a measure of “potentially bioavailable” metals in sediments, were below the ANZECC & ARMCANZ (2000) ISQG-Low level and therefore would not be considered to have a biological impact (Parry 2010).

5 Sediment Quality

Testing in the vicinity of EAW by AECOM in 2010 also found concentrations of arsenic and chromium elevated above the ISQG-Low level, with all other metals tested returning levels below the ISQG-Low level (AECOM, pers com. 2011).

Similar to the conclusions drawn in previous studies, the elevated concentrations of arsenic, chromium and nickel detected in Darwin Harbour sediments by URS and AECOM are considered to be attributable to the local geology, and not to contamination by anthropogenic sources. These heavy metals are unlikely to be bioavailable to any significant extent, and would not result in toxic effects to marine biota.

5.2.3 Hydrocarbons

Potential sources of hydrocarbons around Darwin Harbour include:

- Seasonal stormwater inflow from Darwin and Palmerston storm water drainage networks
- Underground pressurised fuel lines to the Fort Hill Wharf
- The Naval Fuel Installation, Stokes Hill
- Former fuel storage at the Channel Island Power Station
- Bulk hydrocarbon storage at EAW
- Bulk hydrocarbon storage at the Darwin LNG plant
- Inventories in recreational, commercial vessels and shipping.

The NAGD screening concentration for petroleum hydrocarbons in sediments is 550 mg/kg (DEWHA 2009). A survey by URS (2004) sampled 12 sites around the Darwin Wharf Precinct and one reference site in Elizabeth River. The highest concentrations of petroleum hydrocarbons recorded (11–16 mg/kg) were present at sites in Kitchener Bay, Fort Hill Wharf and landward of the Iron Ore Wharf. Concentrations at the remaining sites were between 6 and 10 mg/kg. Petroleum hydrocarbons were also present at the reference site (Elizabeth River), though the concentration (4.9 mg/kg) was lower than in any of the sample from the Wharf Precinct sites.

In sampling conducted in 2008, URS detected petroleum hydrocarbons, particularly in the C15–C28 range, in surface sediments at a number of sites in East Arm. However, the BTEX compounds were below PQLs at all sites, as were polynuclear aromatic hydrocarbons at the majority of sites (URS 2008).

Sampling by AECOM at the proposed dredging sites in 2010 (AECOM, pers com. 2011) did not return reportable levels of BTEX, PAHs or petroleum hydrocarbons.

5.2.4 Tributyltin

Tributyltin compounds (TBTs) are chemicals that contain the $(C_4H_9)_3Sn$ group, forming the main active ingredients in broad-spectrum biocides. In the late 1960s, TBTs, especially tributyltin oxide, came into widespread use as antifoulant additives to marine paints applied to the hulls of vessels. The leaching of TBT from the paint was effective in preventing the growth of fouling organisms on hulls, but also had detrimental environmental effects on biota in the surrounding waters. These compounds are persistent organic pollutants that biomagnify up the marine food chain and also tend to accumulate in sedimentary environments, particularly in fine sediments. In port sediments TBTs are typically associated with paint flakes, which may be dislodged from vessel hulls during berthing or while alongside wharves.

5 Sediment Quality

In 1999, the International Maritime Organization initiated the development of a legally binding instrument to address the harmful effects of antifouling systems used on ships throughout the world. That instrument, the International Convention on the Control of Harmful Anti-fouling Systems on Ships, was adopted in 2001 and entered into force in September 2008. Australia became a party to the Convention in January 2007 and the Commonwealth Government has reinforced its commitment to the control of harmful antifouling compounds by passing the *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* which also came into force in September 2008. The Convention prohibits the use of harmful organotins in antifouling paints used on ships and establishes a mechanism to prevent the potential future use of other harmful substances in antifouling systems.

A survey of marine sediment quality by URS (2004) found that there were elevated levels of TBTs across Darwin Harbour. However, although they were detected at most sites, the guideline screening level for TBT (at that time 5 ngSn/g) was exceeded at only one location—Fort Hill Wharf, which has received large numbers of vessels since the late 1960s.

Recent sampling of marine sediments in the adjacent INPEX nearshore development area at Blaydin Point did not detect TBTs above the PQL at any of the sampling sites (URS 2008).

5.2.5 Acid sulphate soils (ASS)

Marine and estuarine sediments containing significant amounts of sulphur, present as sulphides, have the potential to generate acidity when exposed to oxygen.

Such sediments are known to occur in the mangrove soils of Darwin Harbour. Their presence and potential acid generation capacity within construction areas will be determined in pre-construction monitoring and the appropriate management measures implemented.

5.2.6 Total organic carbon

Total organic carbon (TOC) is not a contaminant but has a major influence on both the chemical and biological processes that take place in sediments. At very low TOC levels, little food is available for consumers resulting in a low-biomass community. At very high TOC levels, enhanced sediment respiration rates lead to oxygen depletion and accumulation of potentially toxic reduced chemicals. Hyland et al. (2000) found that TOC levels below 0.5 mg/g (0.05% w/w) and above 30 mg/g (3.0% w/w) were related to decreased benthic abundance and biomass.

TOC levels recorded in the Blaydin Point nearshore area averaged 0.3% in East Arm and the main body of the Harbour (URS 2008) - these levels were at the low end of the range supporting normal biomass growth.

5.2.7 Nutrients

Nitrogen and phosphorus are major plant nutrients and their availability in marine systems most often determines the limits on plant growth. An overabundance of bioavailable nitrogen and phosphorus can lead to the eutrophication of waterways and the proliferation of macroalgae and phytoplankton, which can choke estuaries and other confined marine systems. Large quantities of these nutrients can be held in sediments, mostly in non-bioavailable forms.

Sediment sampling by URS (2008) indicated average total nitrogen levels of 581 mg/kg in the main body of the Harbour and 356 mg/kg in East Arm. Mean total phosphorus levels ranged from

5 Sediment Quality

315 mg/kg in the main body of the Harbour to 509 mg/kg in East Arm, which is within the range of that reported by Parry et al. (2002) in a similar study. Total sulphur, another essential plant nutrient, was present in concentrations ranging from 0.18% to 0.8% (URS 2008).

No guideline criteria are available for sediment nutrient levels.

5.2.8 Particle size distribution

Fortune (2006) reported on a sediment grain-size study that included 29 sampling sites extending from the main port area of the Harbour through to the upper reaches of the Elizabeth River. This work was conducted in 1993 prior to infrastructure development and dredging of the EAW facility, with sampling effort concentrated in this area (Fortune 2006). Sediment distribution in the area largely comprised coarse to fine-grained sand (62–500 µm) with variable distribution of granules and finer fraction (silt and clay) among sites. Silt represented no greater than 13% in those sites in the East Arm section and the finer clay fraction constituted no greater than 4.5% by weight for all sites sampled.

URS (2008) conducted particle size analyses in sediment samples from East Arm including the adjacent INPEX nearshore development area. Samples taken from East Arm consisted of a combination of predominantly fine sand to gravel-sized particle fractions.

5.3 Sub-surface sediments

Coffey Geotechnics Pty Ltd (Coffey) conducted geotechnical and geophysical investigations in the INPEX nearshore development area in 2008, drilling a total of 29 boreholes (Coffey 2009). The major geological units identified in the area are described in Table 5-1. The stratigraphy of the EAW area is expected to be similar.

Sediments in East Arm to the north of Blaydin Point generally show several metres thickness of unconsolidated sediments overlying the phyllites and sandstone of the Burrell Creek Formation (Coffey 2009). The upper 5–15 m of the phyllites are weathered in some areas, whereas unconsolidated recent sediments directly overlie competent phyllite and sandstone rock in other areas.

Subsurface sediment quality testing was performed by URS (2008) on samples from 18 boreholes developed during the geotechnical drilling program in nearshore areas proposed for disturbance by the INPEX Project. Sediment quality parameters were measured in laboratory testing and compared against the “National Ocean Disposal Guidelines for Dredged Materials”, developed by Environment Australia. Complete results of the sampling program are provided in Appendix 8 of the INPEX EIS (URS 2008).

Metals levels in subsurface sediments were lower than the relevant screening levels, with the exception of arsenic at a number of sites, and nickel at one site. When averaged across all sites, all metals were below screening levels. Elevated arsenic levels are common in the Darwin region, and are believed to be a reflection of local geology rather than an indication of anthropogenic contamination (URS 2008).

Other contaminants such as petroleum hydrocarbons, tributyltin, and organochlorine pesticides were not detected above the minimum limits of the laboratory tests in subsurface sediments (URS 2008).

5 Sediment Quality

Table 5-1 Geological units of East Arm

Stratigraphic order	Unit	Name	Age	Material description
Recent marine	1a	Channel deposits	Recent/Quaternary	Mainly sands with some silts, clays and gravels
	1b	Mangrove muds	Recent/Quaternary	Mainly silts and clays with some sands, locally organic and or calcareous. Marine and intertidal alluvium adjacent to mangrove swamps.
	1c	Channel lag deposits	Recent/Quaternary	Mainly gravels and clayey gravels at base of live and historical channel.
	1d	Coral	Recent/Quaternary	Live coral
	1e	Lateritic/colluvial soils	Tertiary/Quaternary	Lateritic/colluvial material (clay, sand, silt and gravel).
Burrell Creek Formation	2ai	Phyllites and Sandstones (residual soils)	Early Proterozoic	Residual soils derived from sandstones and phyllites of the Burrell Creek Formation (silts and clays with some sands and gravels).
	2aii	Phyllites and Sandstones (weak, extremely weathered rock)	Early Proterozoic	Extremely to very low strength weathered sandstones and phyllite of the Burrell Creek Formation.
	2aiii	Phyllites and Sandstones (rock)	Early Proterozoic	Competent phyllites and sandstones (generally low strength or greater) of the Burrell Creek Formation.
	2b	Conglomerate	Early Proterozoic	High strength conglomerate of the Burrell Creek Formation, possibly an ancient debris flow.
Undifferentiated granite	3	Weathered granodiorite	Early Proterozoic	Weathered granodiorite/granite.

Source: Coffey 2009

Beneficial Uses and Water Quality Guidelines

Beneficial Uses for Darwin Harbour, including the waters in which the port is located, have been declared under the Water Act as:

- Aquatic Ecosystem Protection (habitat for plants and animals)
- Cultural: aesthetics (visual amenity), recreation (e.g. swimming or fishing) , collecting food (fish, crabs, shellfish) and spiritual values

In order to protect those uses, water quality objectives have been determined for various areas within the harbour, appropriate to the physical setting (e.g. outer harbour and upper estuary) in which they are located. This is typically determined by freshwater input and flushing times.

Water quality guidelines have been developed which can be used to assess whether the objectives are being met and, by extension, whether the nominated beneficial uses can be sustained.

The waters in which the East Arm Port is located and where the modelling indicates that most effects of dredging will be seen, are defined as Upper Estuary. However the port lies close to the boundary with the Middle Estuary, which has slightly more stringent guidelines for some physico-chemical water quality parameters.

Key water quality objectives for East Arm Port and adjacent areas are:

- Maintain dissolved oxygen between 80 and 100% saturation
- Maintain pH between 6.0 and 8.5 (upper estuary) and 7.0 and 8.5 (mid estuary)
- Maintain TSS less than 10 mg/L

(Fortune & Maly 2009).

In the absence of site specific guidelines, toxicant concentrations are referred to the ANZECC & ARMCANZ (2000) Guidelines for Fresh and Marine Water Quality.

Project Impacts

7.1 Introduction

The potential impacts on water and sediment quality associated with the development of EAW as described in Section 2 are identified below.

The development area includes the coastal areas around the EAW and the adjacent marine area.

The environmental assessment presented in this section includes discussion of potential impacts of the project on water and sediment quality the development area and in Darwin Harbour generally.

To minimise environmental impacts of the Project, management controls are described in Section 8 that will be implemented by DLP to mitigate possible negative impacts from Project activities.

7.2 Construction Impacts

7.2.1 Impacts from planned construction activities

The major contribution to impacts on water quality arising during construction is from the disturbance of sediments and release of particulates into the water column associated with the following activities:

- dredging and spoil disposal operations
- pile driving
- bund wall excavation/construction and reclamation
- propeller wash from construction vessels associated with each of the above activities.

Dredging

The dredging for the three proposed port development projects comprises a total volume of approximately 1.36 Mm³, of which it estimated that approximately 1% or 14,000 m³ will be lost into the water column at the dredge head over the period of dredging.

URS/Scott Wilson (2011) has undertaken sediment fate modelling to predict the dispersal of turbid plumes from dredging activities, and to predict the areas in which suspended sediments will accumulate. The results of the modelling are presented in URS/Scott Wilson (2011).

Modelling of the dispersion and resettlement of this volume of suspended sediment predicts that suspended sediment concentrations will rise during dredging by 5 to 10 mg/L in the vicinity of the dredging operation, falling to <2 mg/L outside of the immediate port area, against a background range of 6-10 mg/L (DIPE 2004). Depending on the management of the spoil further release of sediment to the water column may be experienced during transfer to barges for disposal offshore, or through the return of decant water from spoil disposed of onshore.

It is likely that, when added to background levels, the suspended sediment concentration in the immediate vicinity of dredge operation will exceed the water quality guideline value of 10 mg/L while the dredge is working. However, such levels are expected to reduce to within guideline concentrations within a short time of the dredge ceasing operations.

The sediments of East Arm have been shown to have low levels of contamination (URS 2008, AECOM, pers com. 2011). Based on the results of construction monitoring studies for East Arm Port, the Darwin LNG plant and Darwin City Waterfront projects, disturbance of the sediments by dredging and other construction activities is not expected to result in release of contaminants at concentrations likely to exceed water quality guideline values for other water quality parameters (DO, pH and

7 Project Impacts

toxicants) or, in the case of substances occurring at naturally elevated levels such as arsenic, to exceed natural background concentrations for Darwin Harbour.

Similarly, disturbance of sediments due to dredging, when considering the high levels of mixing which occur through tidal exchange, is considered highly unlikely to result in the presence of nutrients at concentrations which will lead to the development of nuisance phytoplankton blooms.

Sedimentation – East Arm

The deposition of unconsolidated fine sediments is expected to be small, with thicknesses of 5 mm occurring in the deeper portions of a number of the embayments either side of the port, and lesser thicknesses (0.1 to 1.0 mm) accreting onshore (URS/Scott Wilson 2011).

The Water Research Laboratory (Wasko et al. 2010) examined options for the management of sediments from the dredging of a conceptual design for the MSB. One scenario, based on 100% onshore disposal with return of turbid decant water with a suspended sediment load some 25x higher than that modelled for dispersion at the dredge cutter head, showed potential accumulation on small areas of the harbour bed in the vicinity of the port of up to 50 mm of sediment and shoreline accretion over a wider area of up to 20 mm. It is noted that the proposed construction methodology will result in less than 25% of the total dredged volume being discharged onshore and management of the decant water quality would result in a smaller than modelled quantity of sediment being returned to the harbour. Consequently, it is anticipated that the actual outcome, depending on the method of spoil handling and disposal adopted and the management measures applied, will lie at the lower end of the range described by the values quoted above.

Spoil disposal – Offshore

The majority of the spoil from the dredging operations is proposed to be disposed of at the offshore spoil ground, i.e. outside of Darwin Harbour in Beagle Gulf. The dumping of each barge load of spoil, at a rate of approximately one barge load every three hours, is predicted to give rise to an instantaneous suspended sediment concentration of 10.0 - 20.0 mg/L within a plume 50 - 100 m in diameter. The plume will then disperse following the prevailing current direction, increasing in diameter and reducing in concentration to generally less than 5.0 mg/L. Modelling results show the suspended sediment concentration arising from dredging remaining below 3.0 mg/L in Beagle Gulf over the period of dredging (URS/Scott Wilson 2011).

Subsequent accretion of fine sediment in Darwin Harbour is predicted to occur only at the entrance to the Harbour however, the thickness of sediment deposition is again predicted to be less than 0.5 mm over the dredging period.

Disposal of the sediments offshore will not result in release of significant acidity as any acid which is generated will be neutralised by seawater.

Spoil disposal – Onshore

Sediment disposed on land has the potential to release acidity which may need to be neutralised (typically with lime) if there is insufficient natural acid neutralisation capacity present in the dredged sediment and decant water. This will be determined by monitoring the acidity of sediment held within any reclamation ponds and neutralising the decant water, as required, prior to discharge.

7 Project Impacts

Management of potential impacts from the dredging and reclamation works are addressed in the Dredge Management Plan (AECOM 2011).

Pile driving, bund wall excavation/construction and reclamation

Pile driving, bund wall excavation/construction and reclamation will all cause sediment disturbance of a localised nature. These activities will be principally shore-based and in all cases sediment disturbance leading to increased turbidity and suspended sediment concentrations is expected to be less than that associated with dredging.

Propeller wash

The operation of construction vessels (tugs, workboats, survey vessels, anchor handling boats, etc.) in the comparatively shallow water of the construction area, particularly at low tide, can be expected to resuspend sediment due to the turbulence created by propellers, known as propeller wash. This typically results in localised redistribution of sediment, raises the concentration of suspended sediments in the water column and causes increased levels of turbidity in the immediate vicinity of the vessel.

7.2.2 Accidental discharges during construction

Accidental spills into the harbour during construction may occur during refuelling (diesel fuel) or less frequently due to fractured hoses (diesel fuel/hydraulic oil) or as a result of rupture of a fuel tank due to a collision between vessels or between a vessel and a wharf or other solid structure.

Management of spills will be addressed under the Port's Oil Spill Contingency Plan.

7.3 Operational Impacts

7.3.1 Impacts associated with routine operations

Impacts on water quality as a result of routine operations may include:

- disturbance of sediments due to propeller wash
- maintenance dredging
- over-water maintenance (e.g. of steel piles)

Propeller wash

The operation of additional vessels in the port area can be expected to result in more frequent re-suspension of sediment due to propeller wash with associated intermittent increases in the concentration of suspended sediments and levels of turbidity in the port area.

Maintenance dredging

There may be a requirement to undertake periodic maintenance dredging to maintain the navigable depth of the channels and berthing basins, however the required frequency is yet to be determined. The impacts would be similar in nature to those previously discussed under construction impacts, but the volumes of material to be dredged and the resultant suspended sediment loads and resettlement

7 Project Impacts

depths would be much smaller. Maintenance dredging will be undertaken under separate environmental approvals to be sought when the requirements are more fully understood.

Over-water maintenance

Over-water maintenance of steel structures will be periodically required for corrosion control. This typically involves abrasive blasting or grinding/sanding of surfaces to remove paint and anti-fouling residues and corrosion (rust). The majority of this material will comprise inert particulates (paint chips, rust flakes, blasting grit, etc.) but there may be a release of toxins (most likely copper-based) from anti-fouling. Procedures have previously been developed for use in Darwin Harbour to minimise the quantity of particulates entering the water during such operations.

7.3.2 Routine discharges during operations

The main discharge from the port area to the harbour will be stormwater and this will increase as a result of the development due to the additional hard stand area created. The discharge of the stormwater in itself poses no threat to water quality however there is a need to manage potential contaminants including solids, hydrocarbons from grease or oil spills and leaks, and any material from vessel repair/maintenance that may accumulate on the hard stand between rainfall events.

Sewage will be transported offsite and will not be discharged to the harbour.

7.3.3 Accidental discharges during operations

Potential accidental spills to the marine environment during operations include:

- refuelling spills
- contaminated stormwater (e.g. from oily surfaces or where product spills may have occurred)
- waste handling spills
- sewage pump-out spills

The potential for such spills occurs across all areas of port operations, and will be addressed in specific procedures under the Port's Environmental Management Plan (EMP) and Oil Spill Contingency Plan.

It is noted that the Marine Supply Base may in future handle a significant volume of waste from offshore rigs and platforms, including potentially hazardous wastes, e.g. NORMs, spent mercury filter beds etc. Additional specific procedures may be required under the Port EMP to ensure safe handling of such materials and avoid spillage during unloading or while stored on the hardstand, with subsequent potential to wash off into the harbour. This may include the use of interceptor drains on all drainage lines and on any ramp where maintenance work on hulls is undertaken.

Risk Management

8.1 Risks to Water and Sediment Quality

Onshore and nearshore activities that have potential to impact on the marine environment include the construction of facilities at EAW, including both land clearing and land and harbour reclamation, and a dredging campaign with associated deposition of dredge spoil.

Reclamation will be required for the construction of the barge landings and hard stand areas and also for the rail bund. This work will be largely undertaken using land-based equipment but will involve some disturbance of marine sediments with localised impact on water and sediment quality.

Dredging is required to construct the berthing areas and channels from these areas into existing channels in Darwin Harbour. The short term effect of the proposed dredging during the construction phase will be to increase turbidity and the concentration of suspended sediment in the water column.

Turbid plumes arising from dredging will be mainly restricted to East Arm. Potential effects of the plumes include a reduction in light through the water column. Modelling shows turbidity caused by the dredging will vary with tidal currents. Suspended sediment levels in the water column in many areas of East Arm will decrease to near background levels as the sediment settles to the bottom during slack water periods. Some of the settled material will be re-suspended as the tidal flow resumes. It is predicted from modelling that sediment will not accumulate to any substantial extent in areas where sensitive receptors are present.

Dredging also has the potential to release nutrients, metals and toxicants (where present) from the sediments; these will be rapidly dispersed within the water column and it is unlikely that they will be sufficiently concentrated to cause any measurable increase in primary productivity (nutrients) or toxicity (metals and other contaminants), either on the surface of the seabed or in the water column.

There is also a risk of accidental hydrocarbon spills and other waste discharges during the construction or operational phases, including refuelling spills and loss overboard of materials during vessel loading and unloading.

The risks of these events occurring and their possible consequences were evaluated by analysis of hydrodynamic modelling undertaken for the project, comparison with previous similar activities in Darwin Harbour, particularly the original development of EAW, and baseline studies undertaken for the present project.

The impact assessment was undertaken in consideration of the impacts to water and sediment quality that may then impact on sensitive environmental receptors in the region, including the marine benthic biota and macrofauna that occurs in the area of EAW and on users of the harbour (i.e. impacts on aesthetics, commercial and recreational fishing).

The reduction of risk includes the implementation of management controls and other mitigating factors. Management controls will be implemented to ensure the potential environmental impacts of the Project are minimised. Monitoring programs will be developed to ensure that DLP is able to determine the effectiveness of the management controls.

Summary tables are presented below that describe the activity, management controls and mitigating factors. Management controls outlined in this section will be further developed in consultation with stakeholder groups, and will continue to be developed throughout life of the project.

8 Risk Management

The overall level of management and risk mitigation for the EAW Project constitutes a conservative and proactive approach to maintaining marine water and sediment quality. The risks to water quality are considered to be at an acceptably low level for the maintenance of sediment and water quality consistent with the water quality objectives for Darwin Harbour.

8.2 Environmental management plans

As described above, management plans will be developed for the Project. These will describe the proposed management controls to be undertaken to reduce the risk of adverse environmental impacts resulting from the Project. The provisional plans will form the basis for more detailed plans as the Project proceeds. The plans outline the objectives, targets, actions and monitoring that will be undertaken to manage a variety of potential impacts. The provisional plans will include measures to manage the impacts of the Project on water and sediment quality from:

- dredging and dredge spoil disposal and other sediment disturbing activities (Dredge Management Plan)
- fuel leaks and spills (Oil Spill Contingency Plan)
- stormwater disposal (Port EMP).

A summary of the potential impacts, mitigating factors and management controls for the alteration of sediment and water quality due to dredging and other sediment disturbing activities during construction is presented in Table 8-1.

Table 8-1 Summary of impact assessment, mitigating factors and management controls for water and sediment quality

Aspect	Activity	Potential impacts	Mitigating factors and management controls
Sediment resuspension and sediment deposition	Dredging of access channels, construction of reclamation area and railway bunds and return of decant water	Increased concentrations of suspended sediments and increased turbidity in the port area and sedimentation of seafloor and shorelines around East Arm, causing impacts on affected marine communities.	The harbour environment is dynamic and receives regular natural influxes of sediments which results in erosion and accretion under ambient conditions at levels in excess of those that will result from dredging. The seabed outside of the dredging areas is predicted to recover quickly from the effects of the additional inputs due to dredging. Water quality impacts, which are predicted to be largely of a physical nature are expected to return to natural levels soon after the completion of dredging. Management Control: The disturbance footprint will be minimised where possible within the constraints of infrastructure engineering and operability. Dredges will be equipped with navigational aids to ensure that dredging occurs within the specified dredging footprint. Dredge Management Plan.

8 Risk Management

Aspect	Activity	Potential impacts	Mitigating factors and management controls
Sediment re-suspension and sediment deposition	Dredging of access channels, construction of reclamation area and railway bunds and return of decant water	Release of compounds from the sediments at potentially toxic levels, including heavy metals, hydrocarbons and acid sulphate sediment. Release of sediment borne nutrients at concentrations likely to cause plankton blooms.	The sediments of East Arm have been shown to have low levels of contamination and disturbance due to dredging is not expected to result in release of metals or hydrocarbons at concentrations likely to adversely impact on water quality. The presence of acid sulphates in reclaimed sediments will be monitored and the sediment and decant water neutralised as required. Similarly, the disturbance of sediments due to dredging, when considering the high levels of mixing which occur through tidal exchange, is considered highly unlikely to result in the release of nutrients at concentrations leading to the development of nuisance phytoplankton blooms. Management Controls: Dredge Management Plan.

A summary of the potential impacts, mitigating factors and management controls for dredge spoil disposal is presented in Table 8-2.

Table 8-2 Summary of impact assessment, mitigating factors and management controls for dredge spoil disposal

Aspect	Activity	Potential impacts	Mitigating factors and management controls
Seabed disturbance	Offshore dredge spoil disposal	Sedimentation causing smothering of the seabed. Alteration of seabed sediments.	Sediment types are common throughout Beagle Gulf and impact will be restricted to a small area. Management Controls: Dredge Management Plan.
Turbid plumes	Offshore dredge spoil disposal	Low light penetration through the water column.	The plumes are transported to coastal areas on spring tides only. The tidal cycle results in clear water conditions between turbid spring tides.
Coastal sedimentation	Offshore dredge spoil disposal	Deposition of sediments on coastal habitats.	Predicted sedimentation levels are very small (<1 mm), insufficient to modify habitats.. Affected areas are naturally depositional environments where marine communities are adapted to sedimentation.

References and Bibliography

- Acer Vaughan Consulting Engineers and Consulting Environmental Engineers 1993, Draft Environmental Impact Statement, Darwin Port Expansion – East Arm. Prepared for the Northern Territory Department of Transport & Works, Darwin, Northern Territory.
- AECOM 2011. Dredge Management Plan, East Arm Wharf Expansion. AECOM Australia Pty Ltd, Darwin, Northern Territory.
- Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. 2000. *Australian and New Zealand guidelines for fresh and marine water quality*. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra ACT.
- Australian Institute of Marine Science. 2008. Darwin Harbour water quality monitoring project: status report-Darwin Harbour December 2002 – September 2003. Report prepared by the Australian Institute of Marine Science, Townsville, Queensland.
- Bureau of Meteorology 2008. Climate statistics for Australian locations; Darwin Airport. Viewed 10 October 2008 at <http://www.bom.gov.au>.
- Byrne, T. 1988. Darwin Harbour hydrodynamics and Coastal Processes. In H.K. Larson et al. (Eds) *Proceedings of the Workshop on Research and Management in Darwin Harbour*. Australian National University, North Australia Research Unit, Mangrove Monograph 4.
- Coffey Geotechnics Pty Ltd. 2009. Phase 1 Nearshore Geotechnical Interpretive Report Ichthys Gas Field Development Phase 1 Nearshore Geotechnical investigation Prepared for INPEX Browse Ltd, Perth.
- Currey, N. 1988, *Darwin Harbour Ambient Water Quality*, in *Proceedings of a Workshop on Research and Management*, H.K. Larson, M.G. Michie and J.R. Hanley (eds), held in Darwin, 2-3 September 1987, Mangrove Monograph 4, Australian National University, North Australia Research Unit, Darwin, Australia.
- Darwin Harbour Advisory Committee. 2003. *Darwin Harbour Regional Plan of Management*. Department of Infrastructure, Planning and Environment. Darwin.
- Darwin Harbour Advisory Committee. 2005. *A review of Environmental Monitoring of the Darwin Harbour Region and Recommendations for Integrated Monitoring*. Darwin Harbour Advisory Committee, Darwin.
- Darwin Harbour Advisory Committee. 2006. *Sediment, nutrients, organic matter and metals input to Darwin Harbour from its catchment, and the ecological impacts on the Harbour*. Darwin Harbour Advisory Committee, Darwin.
- Darwin Harbour Advisory Committee. 2007. *Status on the implementation of the Darwin Harbour Regional Plan of Management 2005–2006*. Darwin Harbour Advisory Committee, Darwin.
- Department of Environment, Water, Heritage and the Arts 2009. *National Assessment Guidelines for Dredging*. Commonwealth of Australia, Canberra.
- Department of Natural Resources, Environment, the Arts and Sport. 2009. *Marine Biodiversity, Research and Monitoring Projects*. Viewed 18 June 2009 at <http://www.nt.gov.au/nreta/wildlife/marine/research.html>.

9 References and Bibliography

- Drewry, J., Dostine, P, Fortune, J., Majid, M., Schult, J. and Lamche, G. 2010. Darwin Harbour Region Report Cards 2010. Department of Natural Resources, Environment, The Arts and Sport. Report No. 25/2010D. Palmerston, NT, Australia.
- Environment Australia. 2000, *National Ocean Disposal Guidelines for Dredged Material*. Commonwealth of Australia, Canberra, Australia.
- Fortune, J. 2006. *The grainsize and heavy metal content of sediment in Darwin Harbour*. Environmental Protection Agency, Department of Natural Resources, Environmental and the Arts. Report No. 14/2006D.
- Fortune, J. & Maly G. 2009. Toward the Development of a Water Quality Protection Plan for the Darwin Harbour Region. Department of Natural Resources, Environment, the Arts and Sport, Aquatic Health Unit, Darwin.
- GHD-Macknight (GHDM). 1997. *Darwin Harbour Wave Study*. Prepared for Bechtel Australia Pty Ltd.
- Hanley, JR 1988, Invertebrate fauna of marine habitats in Darwin Harbour. Pp 135-152. In: Larson HK (ed.), *Proceedings of the Workshop on Research and Management in Darwin Harbour*. Australian National University North Australia Research Unit, Mangrove Monograph No. 4.
- Hanley, J.R. and Caswell, G.M. 1995. *East Arm Port - Stage 1. Water Quality Monitoring Program*. Report on Setup Phase and Baseline Data Collection. Marine Ecology Technical Report 95/1.
- INPEX Browse, Ltd 2010. *Ichthys Gas Field Development Project: Draft Environmental Impact Statement*.
- Kristensen, E. and Blackburn, T. 1987. The fate of organic carbon and nitrogen in experimental marine sediment systems: influence of bioturbation and anoxia. *Journal of Marine Research* 49: 681-716.
- Michie, M.G., Grey, D.L. and Griffin, R.K. 1991. *Sea water salinity and temperature measurements in the Darwin Harbour area 1972-1978*. Department of Primary Industries and Fisheries, Darwin, Northern Territory.
- Michie, M.G. 1988. *Sediments, Sedimentary Environments and Palaeoenvironmental in Port Darwin*. Cited in Dames and Moore (1997). Darwin LNG Plant Draft Environmental Impact Statement. Prepared for Phillips Oil Company Australia.
- Munksgaard, N.C. 2001. *Darwin Harbour East Arm turbidity and metal data 1994-96*. Prepared for DIPE.
- Padovan, A.V. 1997. *The water quality of Darwin Harbour: October 1990–November 1991*. Water Quality Branch, Water Resources Division, Department of Lands, Planning and Environment, NT Government, Report No. 34/1997D December 1997.
- Padovan, A.V. 2002. *Darwin Harbour Water Quality Monitoring 2001/02*. Report 23/2002. Department of Infrastructure, Planning and Environment, Darwin, Northern Territory.
- Padovan, A.V. 2003. Darwin Harbour water and sediment quality. pp. 5–18 in *Darwin Harbour Region: current knowledge and future needs*. Proceedings of public presentations hosted by the Darwin Harbour Advisory Committee at the Northern Territory University, Darwin, on 11, 19 and 26 February 2003. Department of Infrastructure, Planning and Environment, Darwin, Northern Territory.

9 References and Bibliography

- Parry, D.L. and Munksgaard, N.C. 1995. *Physiochemical Baseline Data for Darwin Harbour-East Arm Port Development*. Northern Territory University, Darwin NT.
- Parry, D.L. and Munksgaard, N.C. 1996. *Environmental investigation of effluent disposal systems, impact of Leanyer-Sanderson sewage outfall on the water quality of Buffalo Creek*. Prepared for Power and Water Authority, Northern Territory.
- Parry, D.L., Munksgaard, N.C., Foti, F., Langeveld, M. and Gilmore, R. 2002. *Monitoring of a tropical estuary for impacts of urbanisation*. National Heritage Trust Coast and Clean Seas Project No. 9703. Charles Darwin University Darwin, Northern Territory.
- Parry 2010. Investigation of Copper Concentrate Loadout at East Arm Port: Water and Sediment Quality. Prepared for Northern Territory Government Department of Natural Resources, Environment, the Arts and Sport by Professor David Parry, Australian Institute of Marine Science.
- Peerzada, N. and Ryan, P. 1987. Determination of lead, zinc, copper and cadmium in Darwin Harbour. *Marine Pollution Bulletin* 18: 458-461.
- Peerzada, N. 1988. Distribution of Heavy Metals in Darwin Harbour, in Proceedings of a Workshop on Research and Management, H.K. Larson, M.G. Michie and J.R. Hanley (eds), held in Darwin, 2-3 September 1987, Mangrove Monograph 4, Australian National University, North Australia Research Unit, Darwin, Northern Territory.
- Power and Water Corporation. 2006a. *Wastewater Treatment, Reuse and Discharge Report 2006*. Viewed 18 February 2009 at: <<http://www.powerwater.com.au/newsroom/publications>>.
- Power and Water Corporation. 2006b. *The Darwin Water Story*. Viewed 15 September 2008 at <http://www.powerwater.com.au/powerwater/docs/campaigns/drw_water_story/the_darwin_water_story_2006.pdf>
- Semeniuk, V. 1985. Development of mangrove habitats along ria shorelines in North and North-Western tropical Australia. *Vegetation* 60:3-23.
- Sly, S.G., Marshall, A.J. and Williams, T.N. 2002. *Integrated monitoring of water quality and biological diversity in Darwin Harbour and its marinas*. Technical Report No. 4 (Fisheries). Department of Business, Industry and resource Development, Darwin, Northern Territory.
- Smit, N. 2003. Marine invertebrate life in the Darwin Harbour region and management implications. pp. 37-64 in *Darwin Harbour Region: current knowledge and future needs*. Proceedings of public presentations hosted by the Darwin Harbour Advisory Committee at the Northern Territory University, Darwin, on 11, 19 and 26 February 2003. Department of Infrastructure, Planning and Environment, Darwin, Northern Territory.
- URS Australia Pty Ltd. 2004. *Darwin City Waterfront Redevelopment Project: Draft Environmental Impact Assessment*. Prepared for Department of Infrastructure, Planning and Environment, May 2004.
- URS Australia Pty Ltd. 2008. *Marine Water and Sediment Quality Study*. 42906729-1892: R1359. Prepared for INPEX Browse Ltd, Perth.
- URS/Scott Wilson. 2011. Darwin Harbour, Dredge dispersion and spoil disposal modelling for the East Arm Wharf Environmental Impact Statement. Technical Report, March 2011.

9 References and Bibliography

- VIPAC Engineers and Scientists Ltd 1994. Tropical cyclone storm surge risk for the Greater Darwin region: final report. Report 24113-2 prepared by VIPAC Engineers and Scientists Ltd for the Department of Lands Housing and Local Government, Darwin, Northern Territory.
- Wasko, C.D., Williams, D., Miller, B.M. and Mehrabi, S. 2010. *Hydrodynamic and Sedimentation Modelling for the East Arm Port Expansion, Darwin Harbour*. The University of New South Wales School of Civil and Environmental Engineering, Water Research laboratory. WRL Technical Report 2010/02.
- Water Monitoring Branch. 2005. *The health of the aquatic environment in the Darwin Harbour region, 2004*. Report No. 5/2005D. Natural Resources Management Division, Department of Natural Resources, Environment and the Arts, Darwin, Northern Territory.
- Williams, D. and Wolanski, E. 2003. Darwin Harbour hydrodynamics and sediment transport. pp. 3–4 in Darwin Harbour Region: current knowledge and future needs. Proceedings of public presentations hosted by the Darwin Harbour Advisory Committee at the Northern Territory University, Darwin, on 11, 19 and 26 February 2003. Department of Infrastructure, Planning and Environment, Darwin, Northern Territory.

Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of the Northern Territory Department of Lands and Planning and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 4 August 2010.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between October 2010 and May 2011 and is based on the information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.



URS Australia Pty Ltd
Level 4, 226 Adelaide Terrace
Perth WA 6000
Australia
T: 61 8 9326 0100
F: 61 8 9326 0296

www.ap.urscorp.com