oceanica
marine & estuarine specialists

# Pilbara Iron Ore and Infrastructure Project

## Sediment Contaminants and Acid Sulphate Soils

March 2005

# Pilbara Iron Ore and Infrastructure Project

## Sediment Contaminants and Acid Sulphate Soils

*Prepared for:*

**Fortescue Metals Group**

*Prepared by:*

**Oceanica Consulting Pty Ltd**

**March 2005**

Report No. 423/2

## Client: Fortescue Metals Group

| Report | Version | Prepared by | Reviewed by | Submitted to client | |
|---|---|---|---|---|---|
| | | | | Copies | Date |
| DRAFT | 1 | SPENCER SHUTE | MARK BAILEY | ELECTRONIC PDF | 23/11/04 |
| DRAFT | 2 | SPENCER SHUTE | MARK BAILEY | ELECTRONIC PDF | 21/12/04 |
| DRAFT | 3 | SPENCER SHUTE | IAN BAXTER | ELECTRONIC PDF | 23/12/04 |
| DRAFT | 4 | SPENCER SHUTE | NICKY HOGARTH | ELECTRONIC PDF | 25/01/05 |
| DRAFT | 5 | SPENCER SHUTE | | ELECTRONIC PDF | 23/02/05 |
| FINAL | 6 | SPENCER SHUTE | | | 01/03/05 |

# Contents

## List of Tables



## List of Figures



## List of Appendices

# 1. Introduction

## 1.1 Objectives

The Public Environmental Review (PER) for the Pilbara Iron Ore and Infrastructure Project is currently out for public review. Fortescue Metals Group (FMG) were requested by the EPA to undertake some additional work prior to the EPA's assessment as follows:

- Undertake a sediment quality survey in accordance with guidance provided in the National Ocean Disposal Guidelines (Commonwealth of Australia, 2002) and an assessment of return water quality; and
- Undertake a comprehensive sampling program to determine the extent of Acid Sulphate Soils (ASS) in the FMG port project area, based on expert advice in accordance with the Department of the Environment (DoE) guidelines for "Identification and investigation of acid suphate soils and groundwater" (DEP/WRC, 2003) and the National Strategy for the Management of Coastal Acid Sulfate Soils.

## 1.2 Proposed works

### 1.2.1 Port facility

FMG's proposed port facility will be developed at Anderson Point on the south-western side of Port Hedland harbour. The final location and configuration for the facility has been selected on the basis of environmental investigations, engineering constraints and land access issues (Figure 1.1).

Dredging of the harbour will be required to accommodate the additional berths at Anderson Point. An area of approximately 36.8 ha requires dredging, with this area being divided into intertidal mudflats (17.8 ha) and subtidal substrate (19.0 ha). Dredging is proposed to a depth of 14.6 m to 19.5 m CD and this will require the removal of approximately 3,300,000 $Mm^3$ of material.

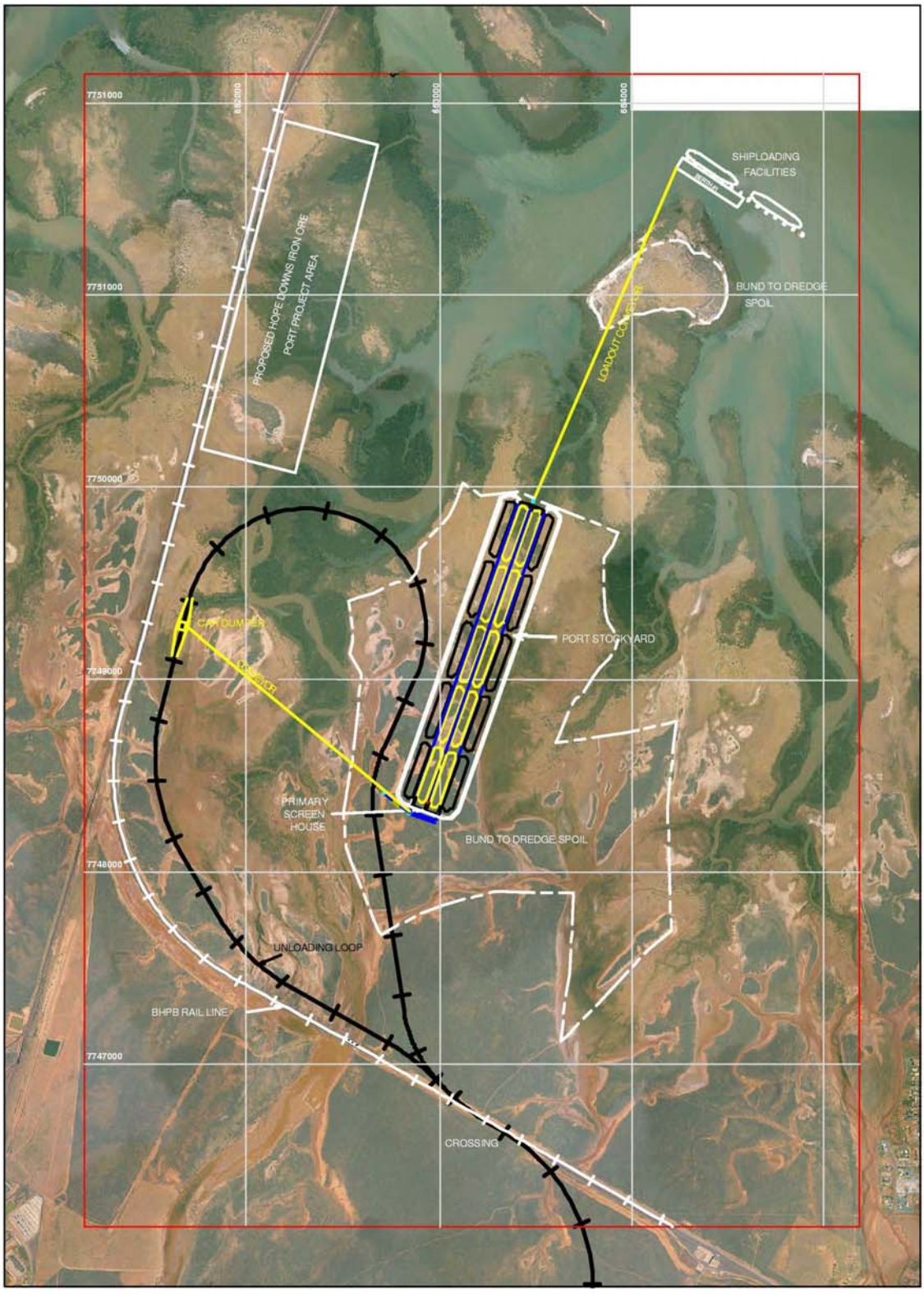



**Figure 1.1 Configuration and location of proposed FMG port facility**

Dredging works will be undertaken in four separate areas (Figure 1.2) as follows:

1. Area A: This area, located immediately north of the proposed berths, has been previously dredged to approximately -9.1 m Chart Datum (CD), and will require further dredging to approximately -14.6 m CD.
2. Area B: This area is located immediately east of the proposed berths and will require dredging from its existing level, at approximately +0.5 m CD to -9.1 m CD.
3. Area C: This area is located within the berthing pocket and will require dredging from its current level of 0.0 to +2.5 m CD, to a depth of -19.5 m CD.
4. Area D: This area is located immediately south of the berthing pocket and will require battered dredging from its current level to tie in with Area C at -19.5 m CD.

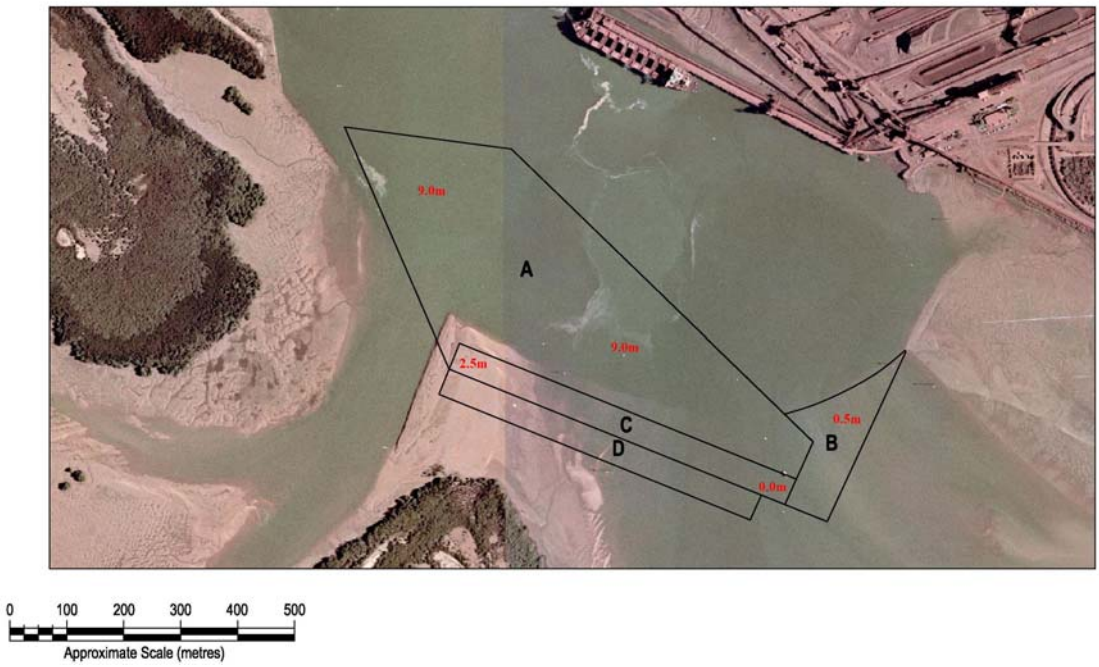



**Figure 1.2 Fortescue Metals Group Port Dredging Areas with approximate depths in red (Source: Coffey Geosciences Pty Ltd, 2004a)**

### 1.2.2 Ore Stockpile and conveyor

The stockpile areas are proposed to provide the necessary flexibility to ensure continuity of supply of iron ore to steel mill customers. The construction of a dredge spoil bund is planned, using sandy material from within the proposed stockpile (~40 ha) and sourced externally if required (Figure 1.3). These works will involve the drainage of the area and the disturbance of soils to a depth of approximately 2 m (FMG pers comm). Works at the Train Unloader site are anticipated to reach a depth of 15 m.

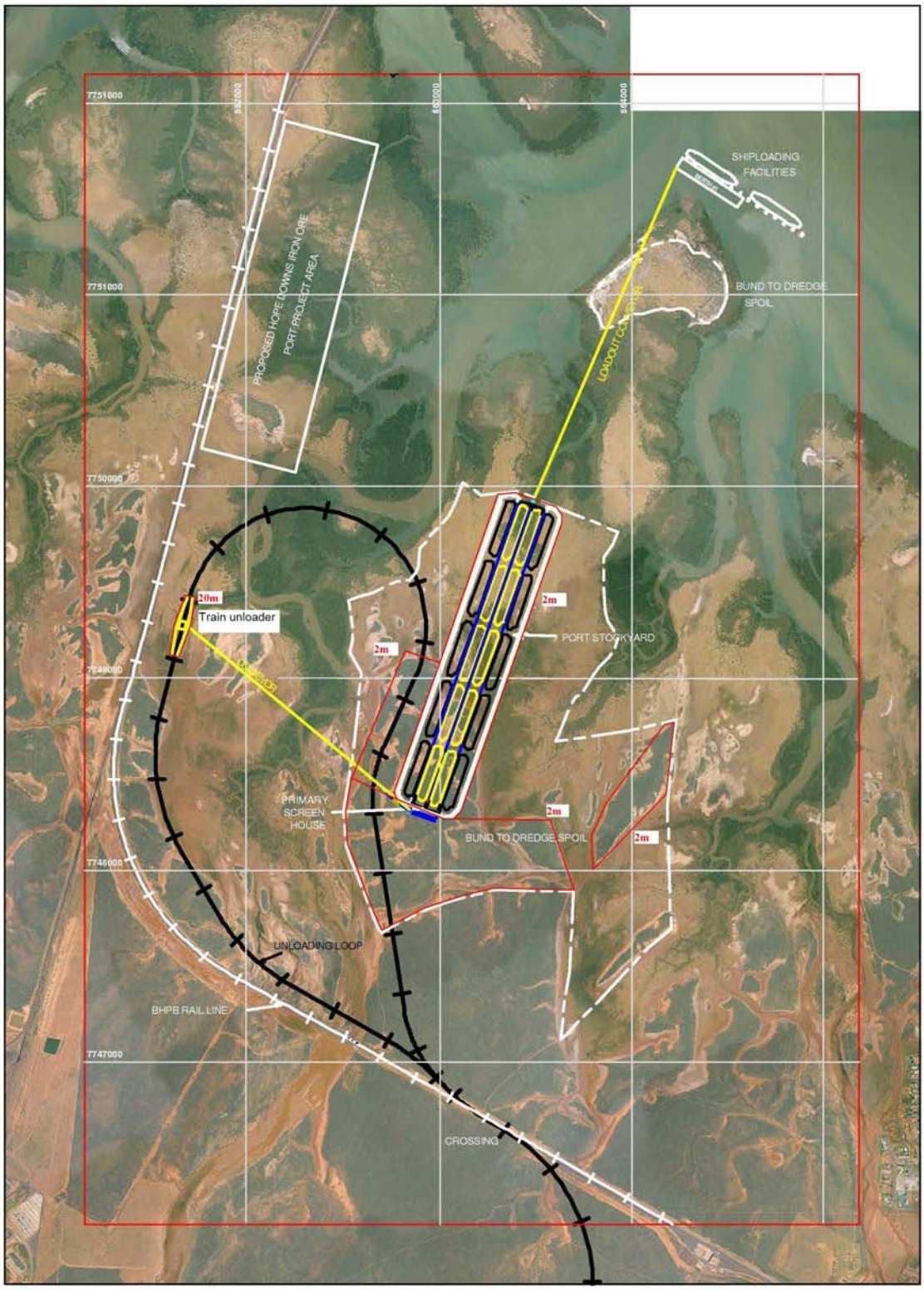



**Figure 1.3 Proposed areas and depths of disturbance surrounding stockpile**

# 2. Methods

## 2.1 Sediment sampling

### 2.1.1 Contaminants of concern

Recent sediment sampling work carried out within Port Hedland harbour suggested that surface sediments towards the centre of the turning basin (in the north-west of the proposed FMG dredging areas) are currently contaminated by Tributyltin (TBT) and nickel, with chromium, silver and cadmium levels also found to be close to the screening levels (or detection limits close to screening levels) (Oceanica, 2004; DALSE, 2004; URS, 2004). Much of this surface material has since been removed by maintenance dredging (PHPA, 2004), but these contaminants could potentially have become re-established as siltation of the basin recommences. In addition, following discussion with the EPA's Marine Branch, Arsenic, Mercury, Lead, Copper and Zinc were added to the contaminants of concern list having been recorded at concentrations approaching or exceeding the screening levels in sediments within Port Hedland harbour during a recent survey commissioned by BHP Billiton.

In addition to these analyses, selected samples were taken for the identification of acid sulphate soils (ASS) within the proposed dredging areas. Acid sulphate soils contain iron sulphides which, when exposed to air, produce sulphuric acid. They can be classed as either; actual acid sulphate soils which are already exhibiting acidity, or potential acid sulphate soils which have the potential to oxidise and produce acidity following drainage or excavation.

### 2.1.2 Site selection

The number of sampling sites required was calculated on the basis of the volume of soft sediment being dredged, using Table 2 of the Guidelines (Commonwealth of Australia, 2002), with the availability of recent sediment quality data from the proposed dredging areas allowing the requirements for sampling sites to be halved (Oceanica, 2004).

**Figure 2.1 Anderson Point intertidal area**

Sampling was undertaken at 10 sampling locations within the mid-basin subtidal area (MB), 10 within the Anderson Point subtidal area (AP) and 7 in the intertidal area (INT) (Figure 2.1; Figure 2.2; Figure 2.3) (total 27). A combination of benthic grabbing and hand coring was used to sample sediments to a maximum depth of 1.2 m.

The positions of these sampling locations were chosen using a grid to cover each area and the selection of squares using a random number table (Zar, 1984).

Sediment contaminant data from these locations adds to the data previously obtained (March 2004) from sites within the intertidal area of Anderson Point (Figure 2.4) (DALSE, 2004).


Figure 2.2: Sediment sampling locations (Hand-cores)

N

70 0 70 Meters

22-Nov-04 GDA94(MGA50)

Asia-Pacific Applied Science Associates
Ref: C:\dalse\requests\request423\project_files\req423-2.apr

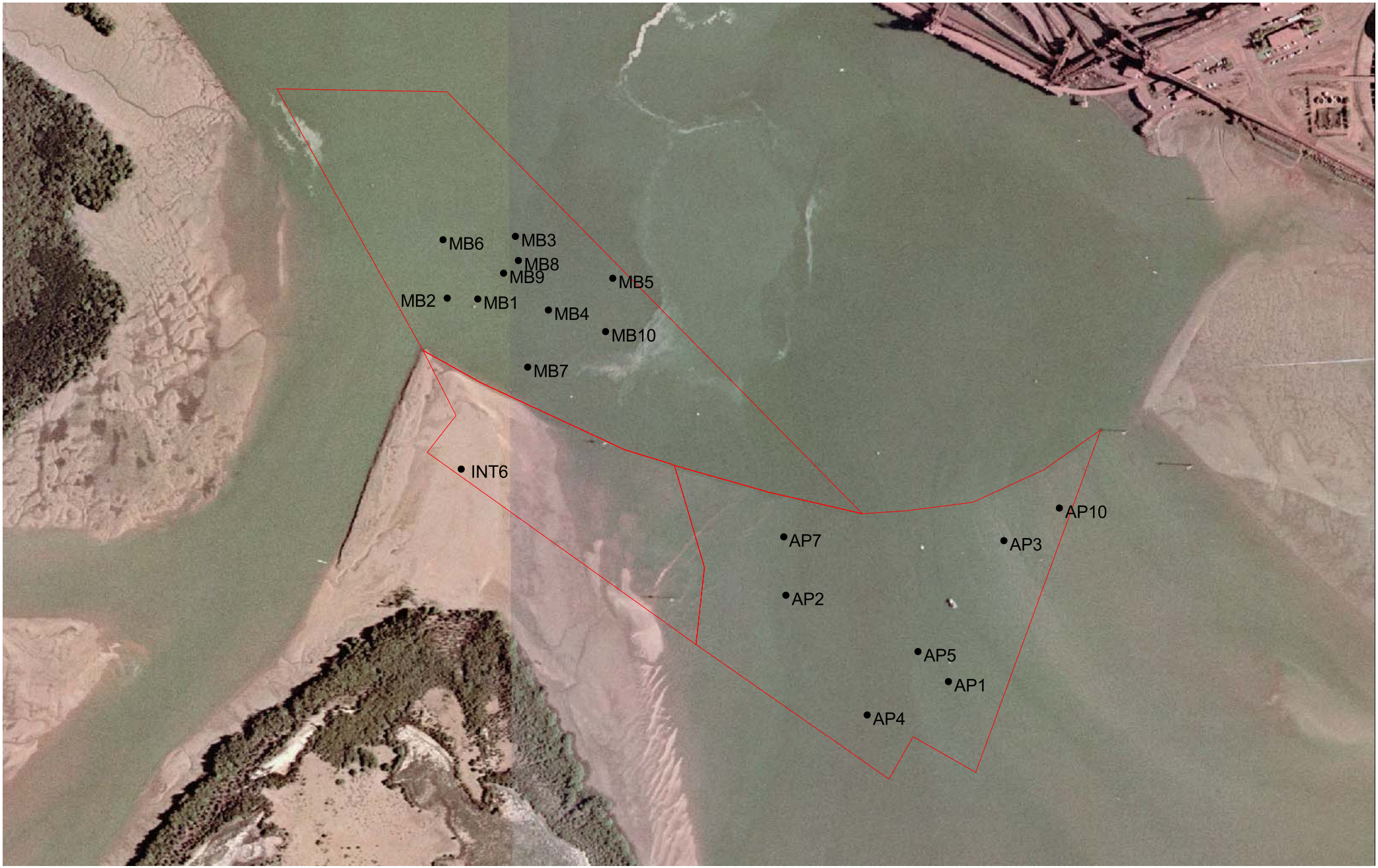



Figure 2.3: Surface sediment sampling locations (grabs/surface scrapes)

N

70 0 70 Meters

22-Nov-04 GDA94(MGA50)

Asia-Pacific Applied Science Associates
Ref: C:\dalse\requests\request423\project_files\req423-2.apr


Figure 2.4: Recent surface sediment sampling sites at Anderson Point (DALSE,2004)

N

70 0 70 Meters

22-Nov-04 GDA94(MGA50)

Asia-Pacific Applied Science Associates
Ref: C:\dalse\requests\request423\project_files\req423-2.apr

### 2.1.3 Sediment sampling methods

The collection of sediment contaminant data from the top 0.1 m of the sediment column was undertaken using grab sampling, with 17 locations within the subtidal areas being sampled (Figure 2.3). Sub-samples were taken from within the grab, taking care to avoid sediment in contact with the grab sides. Samples were obtained from the top 0.1 m of the sediment profile, including the ≤0.05 m deep silt layer identified at the top of the sediments. Surface samples were also obtained at site INT2 and INT6 to supplement the ten surface sediment samples previously taken within the intertidal area (DALSE, 2004).

Hand-coring, using a 50 mm diameter PVC pipe, was employed to obtain sediment samples from deeper than 0.1 m and determine the depth of any potential contamination, samples were collected at 12 sites (in water depths ≤1.0 m) (Figure 2.2). Sub-samples were taken from the bottom of the core tube using a clean plastic scoop. Samples were obtained from a depth of 0.30-0.50 m (core penetration 0.5 m) for sampling the top 0.5 m of the sediment, and from a depth of 0.80-1.0 m (core penetration 1.0 m) to sample the 0.5-1.0 m sediment depth layer. This method enabled the collection of sediment samples covering a range of sediment depths whilst avoiding cross-contamination. Sediment samples were stored on ice until they could be frozen on completion of the day's sampling.

### 2.1.4 Geotechnical coring

Although the depth of soft sediment, and therefore the sediment likely to exhibit contamination, is generally less than 1 m in the areas to be dredged (Coffey, 2004a), the guidelines and the EPA require the characterisation of the sediment throughout the column to be dredged. Therefore the collection of sediment samples from the geotechnical work has been carried out (Figure 2.5). A selection of the sediment core lengths collected were sub-sampled for sediment contaminants and acid sulphate soils alongside the sub-sampling for geotechnical testing (Table 2.1; Figure 2.6). Sediment sub-samples were taken from a range of sediment horizons covering the total sediment depth to be dredged, although many were composed of rock which underlies the surface sediments. These samples were considered to be additional to the hand grab and core samples detailed above. It was acknowledged that some contamination of the sediment core samples by the cellulose ether-based drilling muds was likely. This was not, however, expected to affect the concentrations of the contaminants of concern (Section 2.1.1) as none of these elements are present within the drilling muds (Australian Mud Company Ltd). Further, the results of any analyses are considered to be conservative as the collection by this method will not result in less contamination.

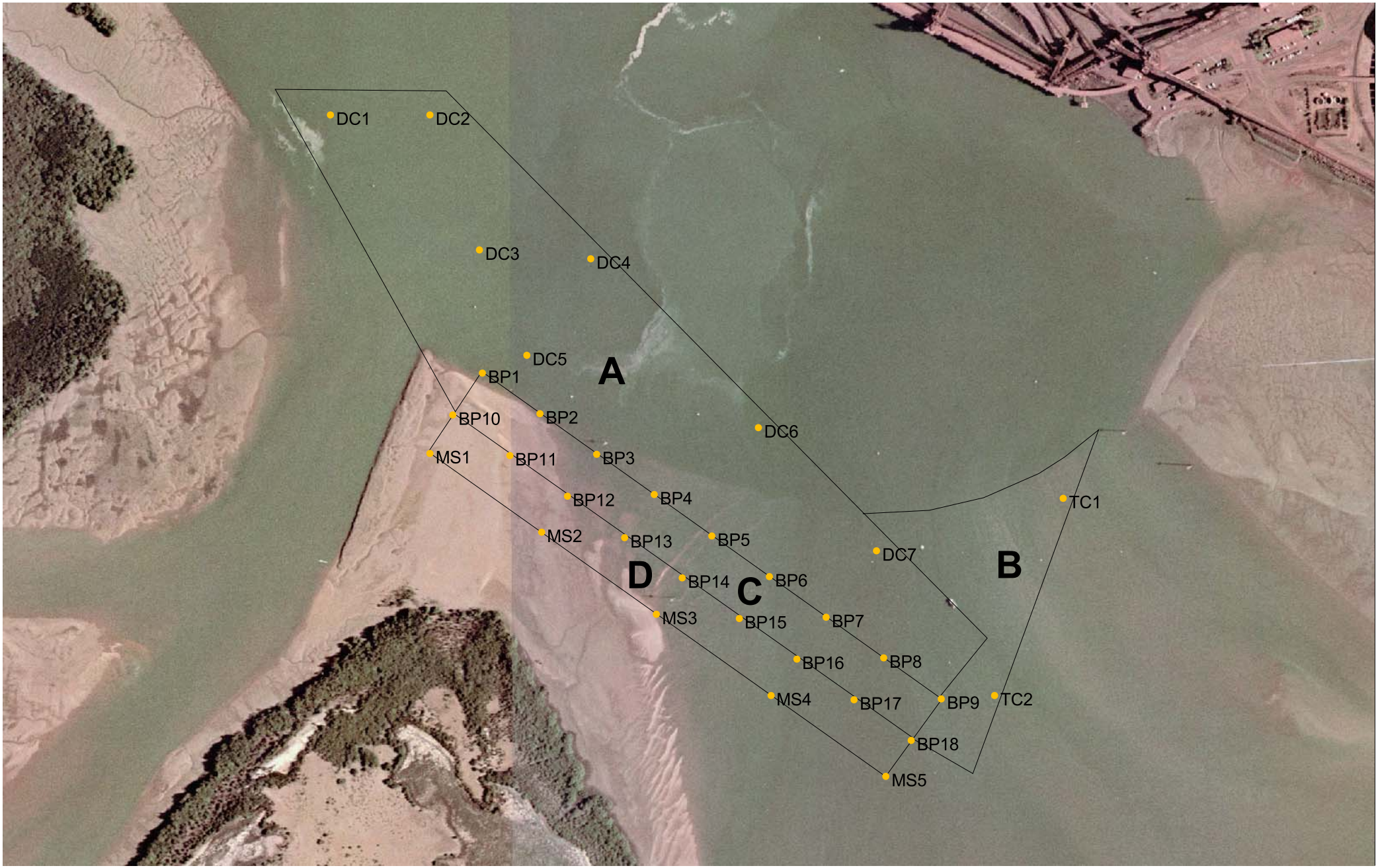



Figure 2.5: Location of proposed geotechnical core sampling sites (Coffey)

N

70 0 70 Meters

22-Nov-04 GDA94(MGA50)

Asia-Pacific Applied Science Associates
Ref: C:\dalse\requests\request423\project_files\req423-2.apr

**Table 2.1 Coffey geotechnical core samples taken for analysis**

| Hole ID | Depth of sample (m) | Sample taken for analysis | | |
|---|---|---|---|---|
| BP5 | 1.4 | ASS | TBT | |
| | 3.7 | ASS | TBT | |
| | 6.2 | ASS | TBT | |
| BP7 | 0.0-0.5 | ASS | | |
| | 1.5 | ASS | TBT | |
| | 3.8 | ASS | TBT | |
| | 5.2 | ASS | TBT | METALS |
| PB9 | 0.0-0.5 | ASS | | |
| | 1.5 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 6.0 | ASS | TBT | METALS |
| | 7.5 | ASS | TBT | METALS |
| | 9.0 | ASS | TBT | METALS |
| | 10.25 | ASS | TBT | |
| | 14.8 | ASS | TBT | METALS |
| | 16.3 | ASS | TBT | METALS |
| | 17.8 | ASS | TBT | METALS |
| BP10 | 1.3 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 4.2 | ASS | TBT | METALS |
| | 6.0 | ASS | TBT | METALS |
| | 10 | ASS | TBT | METALS |
| | 11.3-11.75 | ASS | TBT | METALS |
| | 12.5 | ASS | TBT | METALS |
| | 14.5 | ASS | TBT | METALS |
| | 16.0 | ASS | TBT | METALS |
| | 17.5 | ASS | TBT | METALS |
| | 19.0 | ASS | TBT | METALS |
| BP14 | 4.0 | ASS | TBT | METALS |
| BP18 | 1.5 | ASS | TBT | |
| BP16 | 1.4 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 4.5 | ASS | TBT | METALS |
| DC1 | 0.0 | ASS | | |
| | 1.8 | ASS | | |
| | 3.0 | ASS | | |
| DC4 | 0.3 | ASS | TBT | METALS |
| | 1.0 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 4.4 | ASS | TBT | METALS |
| DC7 | 0.3-0.75 | ASS | TBT | METALS |
| | 1.5 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 4.5 | ASS | TBT | METALS |
| | 7.5 | ASS | TBT | METALS |
| | 12 | ASS | TBT | METALS |
| MS1 | 0.0-0.45 | ASS | | |
| | 0.8-1.25 | ASS | | |
| | 2.6-3.05 | ASS | | |
| | 3.7-4.15 | ASS | | |
| | 5.1-5.4 | ASS | | |
| MS2 | 1.5 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 4.5 | ASS | TBT | METALS |
| | 6.0 | ASS | TBT | METALS |

| Hole ID | Depth of sample (m) | Sample taken for analysis | | |
|---|---|---|---|---|
| MS3 | 1.5 | ASS | TBT | METALS |
| | 3.0 | ASS | TBT | METALS |
| | 6.0 | ASS | TBT | METALS |
| MS5 | 1.5 | ASS | TBT | METALS |
| | 3.25 | ASS | TBT | METALS |
| | 4.65 | ASS | TBT | METALS |
| | 5.95 | ASS | TBT | METALS |
| TC1 | 0.0-0.45 | ASS | | |
| | 2.0 | ASS | TBT | METALS |
| | 3.8 | ASS | TBT | METALS |
| | 5.0 | ASS | TBT | METALS |
| | 6.5 | ASS | TBT | METALS |
| | 8.0 | ASS | TBT | METALS |


**Figure 2.6 Geotechnical core**

### 2.1.5 Sample analysis

A selection of the hand coring and grab samples (>20% of the total) collected towards the beginning of the program were analysed initially in order to generally characterise the sediments and identify any contaminants present. Contaminants not detected could then be eliminated from the analysis list (Section 2.1.2 of Guidelines (Commonwealth of Australia, 2002).

The selection of samples for initial analysis for all potential contaminants included samples from each of the three areas identified (Figure 2.2; Figure 2.3) but was targeted towards sites and surface sediment layers considered to have the greatest chance of exhibiting contamination. In addition to these samples, a number were selected from deeper sediment layers to investigate the potential contamination depth.

Under guidance from the EPA marine branch, further sediment samples in excess of the recommended 20% were analysed for the full metals suite. These included samples obtained from the geotechnical survey work which enabled characterisation of the deeper sediment layers. Following exceedence of the screening levels, a number of samples were also tested to determine the bioavailability of nickel and chromium within the sediments.

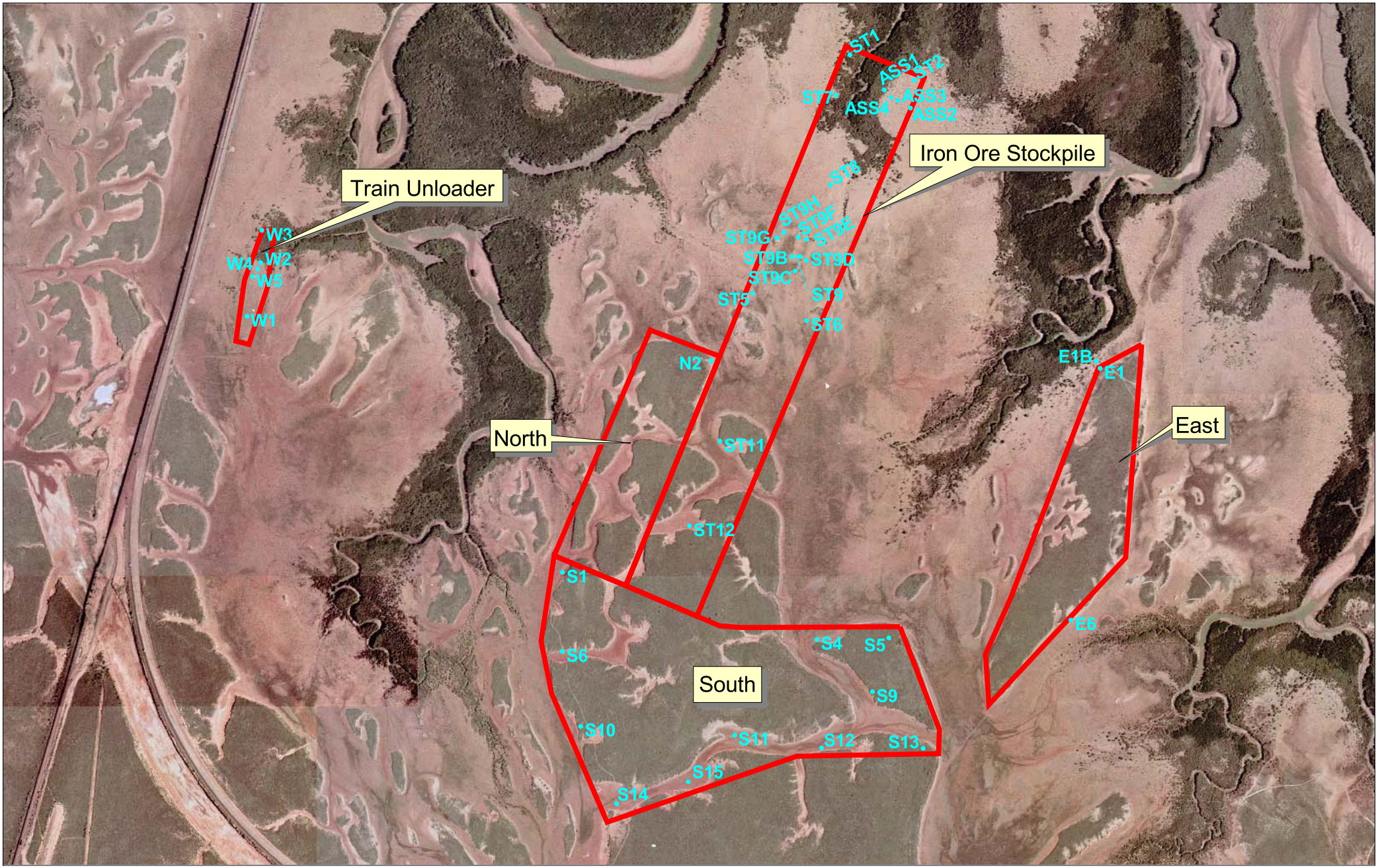
## 2.2 Soil investigation

### 2.2.1 Sampling methods

Soil sampling was required within the proposed dredge spoil reclamation area, in five areas of excavation of approximately 16 ha (North), 52 ha (South), 18 ha (East), 2 ha (Train Unloader) and 40 ha (Iron Ore Stockpile) (Figure 2.8) for the identification of acid sulphate soils.

The latest guidelines (DoE, 2004a) suggest a minimum of two cores per hectare of disturbance (when extent of site project exceeds 4 ha) to provide sufficient sample coverage for ASS investigations (Table 1; DoE, 2004a). However, due to the remoteness and extent of the site requiring investigation, and following consultation with Dr Steve Appleyard (DoE/WRC), the number of sampling locations was reduced to 39 throughout the areas to be disturbed (Figure 2.8), with the use of hand auger sampling (Figure 2.7).

**Figure 2.7 Hand augering to obtain soil samples to a depth of 2.6 m**




APASA

oceanica

Asia-Pacific Applied Science Associates
Ref: C:\dalse\requests\request423\project_files\req423-2.apr

Figure 2.8: Acid Sulphate Soil sampling locations (Oceanica)

Sampling Sites
Areas of Proposed Disturbance

N

200 0 200 Meters

22-Nov-04 GDA94(MGA50)

### 2.2.2 Field testing

Selected sub-samples of soil from the different horizons identified during the first two days of the survey were field tested for potential and actual acidity ($pH_{Field}$ and $pH_{FOX}$ tests). The results of this testing allowed the identification of any acid sulphate soils present. Following further consultation with Dr Steve Appleyard, the soil sampling programme was then adjusted to focus more closely on those areas exhibiting or expected to exhibit acid sulphate soils, in order to allow the future development of an acid sulphate soils management plan. This follows the staged approach as outlined in Ahern *et al*. (1998). The more targeted sampling sites were chosen following an examination of all the proposed excavation areas, with areas physically similar to those already sampled and not exhibiting acid sulphate soils given lowest priority for further sampling.

Sampling was carried out to a maximum depth of 2.6 m. The maximum depth of disturbance at all sites is 2 m, except at the Train Unloader site at which excavation to 15 m is proposed.

### 2.2.3 Laboratory testing

In addition to the sub-samples taken for field testing, a number were taken for submission for laboratory analysis using the chromium suite for the detailed description of ASS properties. The selection process was not carried out randomly, but with the aim of characterising each sediment horizon identified and obtaining the 'worst case' in terms of acidity (Dr Steve Appleyard pers comm.; Ahern *et al*, 1998). Results from the initial laboratory analyses will be discussed with DoE to determine the need for the laboratory analysis of further samples.

The chromium reducible sulphur suite method for the assessment of acid sulphate soils is due to become a published Australian Standard in late-2004/early-2005. The chromium reducible sulphur suite enables an accurate measure of the reduced inorganic sulphur compounds present within the sediment via a series of steps and provides a measure of the potential acid sulphate soil (Appendix A).

The first step in the chromium reducible sulphur method is the determination of the reduced inorganic sulphur content (SCR) which provides an estimate of the potential sulphuric acidity of the sediment. Following this, the soil pH, in a potassium chloride suspension (pHKCL), is determined as a means of estimating the actual acidity of the sediment. Depending upon these results (Appendix A), it may be necessary to analyse for Titratable Actual Acidity (TAA) to determine the actual acidity and/or analyse for the Net Acid Soluble Sulphur (SNAS) to estimate the retained acidity. The acid neutralising capacity (ANC) of the sediment provides an estimate of the ability of the soil to naturally neutralise any acid produced (for example due the presence of carbonate material).

# 3. Results

## 3.1 Sediment contaminants

Sediment samples were taken from a number of surface sediment layers (≤1.2 m depth) within the proposed dredging areas and the sediment type described (Table 3.1).

**Table 3.1 Sediment sample description**

| Site | GDA94 zone 50 | | Sampling depth (m) | Samples taken | Sediment description |
|---|---|---|---|---|---|
| | Easting | Northing | | | |
| **INT1** | 664538 | 7751515 | 0.3-0.5 | Metals | Clean medium sand with pebbles |
| **INT2** | 664368 | 7751657 | 0.0-0.1 | TBT | Muddy coarse quartz sand with shell and stones. Water on surface |
| | | | ~0.3-0.5 | Metals | Muddy coarse quartz sand with shell and stones |
| | | | ~0.6-0.7 | ASS | Muddy coarse quartz sand with shell and stones |
| **INT3** | 664425 | 7751600 | 0.3-0.5 | Metals & TBT | Sandy mud |
| | | | 0.8-1.0 | Metals & TBT | Grey muddy medium/coarse sand |
| | | | 1.2 | ASS | Brown compact clay |
| **INT4** | 664481 | 7751572 | 0.3-0.5 | Metals & TBT | Compact red/brown clay |
| **INT5** | 664368 | 7751685 | ~0.3-0.5 | ASS | Muddy clay |
| | | | ~0.5-0.7 | Metals and TBT | Black medium/coarse sand. |
| **INT6** | 664311 | 7751685 | 0.0-0.1 | Metals and TBT | Muddy clay. Filamentous green algae on surface. |
| | | | ~0.8-1.0 | Metals, TBT & ASS | Muddy coarse sand |
| **INT7** | 664283 | 7751798 | ~0.6-0.75 | TBT | Clean coarse quartz sand. |
| | | | ~0.6-0.75 | Metals | Clean coarse quartz sand. |
| | | | ~0.75-0.85 | ASS | Clean coarse quartz sand. |
| | | | | | |
| **AP1** | 664970 | 7751397 | 0.1 | Metals & TBT | Muddy medium/coarse sand |
| **AP2** | 664750 | 7751514 | 0.1 | Metals, TBT & ASS | Muddy coarse/medium sand |
| **AP3** | 665045 | 775188 | 0.1 | Metals & TBT | Clean coarse/medium sand |
| **AP4** | 664860 | 7751352 | 0.5-0.7 | Metals & ASS | Not recorded-sample frozen |
| | | | 0.1 | Metals & TBT | Not recorded-sample frozen |
| **AP5** | 664929 | 7751438 | 0.1 | Metals & TBT | Dark grey mud with medium sand |
| **AP6** | 664856 | 7751332 | 0.5-0.6 | Metals & TBT | Red/brown compact clay |
| **AP7** | 664747 | 7751593 | 0.1 | Metals & TBT | Clean medium/coarse sand |
| **AP8** | 664700 | 7751475 | 0.8-1.0 | Metals & TBT | Clean grey coarse sand |
| **AP9** | 664824 | 7751322 | 0.8-1.0 | Metals, TBT & ASS | Grey muddy coarse sand with pebbles and shell |
| **AP10** | 665120 | 7751632 | 0.8-1.0 | Metals & ASS | Grey medium/coarse sand |
| | | | 0.1 | Metals & TBT | Muddy coarse sand |

| Site | GDA94 zone 50 | | Sampling depth (m) | Samples taken | Sediment description |
|---|---|---|---|---|---|
| | Easting | Northing | | | |
| **MB1** | 664333 | 7751915 | 0.1 | Metals & TBT | 1-2 cm silt over muddy medium/coarse sand |
| **MB2** | 664292 | 7751916 | 0.1 | Metals, TBT & ASS | 1-2 cm silt over muddy medium/coarse sand |
| **MB3** | 664384 | 7752000 | 0.1 | Metals, TBT & ASS | 1 cm silt over muddy sand |
| **MB4** | 664429 | 7751900 | 0.1 | Metals & TBT | 1 cm silt over 2 cm thick black mud overlying grey muddy clay |
| **MB5** | 664516 | 7751943 | 0.1 | Metals, TBT & ASS | 1 cm brown silt over grey muddy clay |
| **MB6** | 664286 | 7751995 | 0.1 | Metals, TBT & ASS | 1 cm silt over muddy medium sand |
| **MB7** | 664401 | 7751823 | 0.1 | Metals & TBT | 1 cm silt over muddy medium/coarse dark grey sand |
| **MB8** | 664388 | 7751967 | 0.1 | Metals & TBT | 0.5 cm brown silt over grey mud |
| **MB9** | 664368 | 7751950 | 0.1 | Metals & TBT | Grey mud/clay |
| **MB10** | 664506 | 7751871 | 0.1 | Metals, TBT & ASS | 1 cm silt over dark grey/brown mud |

Analysis of the initial samples showed that the concentration of all contaminants, with the exception of nickel, fell below the National Ocean Disposal Guideline Screening Levels (Commonwealth of Australia, 2002) (Table 3.2). Both the intertidal (INT) and Anderson Point subtidal (AP) areas were found to exhibit no contamination over Screening Levels.

**Table 3.2 Sediment contaminant results (batch 1)**

| Site | Sampling Depth (m) | Concentration (mg/kg) | | | | | | | | | (µgSn/kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ag | As | Cd | Cr | Cu | Ni | Pb | Zn | Hg | MBT | DBT | TBT |
| **Reporting Limit** | | **<1** | **<1** | **<0.06** | **<0.2** | **<0.2** | **<0.4** | **<1** | **<0.5** | **<0.01** | **0.5** | **0.5** | **0.2** |
| **Screening Level** | | **1.0** | **20** | **1.5** | **80** | **65** | **21** | **50** | **200** | **0.15** | **n/a** | **n/a** | **5** |
| **AP8** | 1.0 | <1 | 5 | <0.06 | 28 | 3.2 | 5.4 | 3 | 15 | <0.01 | 0.6 | 1.7 | <0.2 |
| **AP10** | 0.1 | <1 | 10 | <0.06 | 21 | 3.8 | 7.5 | 3 | 19 | <0.01 | 1.7 | 1.9 | 0.3 |
| **AP10** | 1.0 | <1 | 9 | <0.06 | 24 | 3.7 | 8.2 | 2 | 8.3 | <0.01 | - | - | - |
| **INT6** | 0.1 | <1 | 12 | <0.06 | 42 | 7.6 | 18 | 8 | 25 | <0.01 | 0.8 | 0.6 | 0.2 |
| **INT6** | 1.0 | <1 | 11 | <0.06 | 19 | 1.9 | 5.0 | 2 | 3.8 | <0.01 | # | # | # |
| **MB2** | 0.1 | <1 | 10 | <0.06 | 54 | 12 | 25 | 6 | 34 | <0.01 | 1.0 | 2.7 | 1.5 |
| **MB3** | 0.1 | <1 | 12 | <0.06 | 66 | 18 | 33 | 11 | 47 | 0.01 | 1.1 | 3.0 | 1.5 |
| **MB10** | 0.1 | <1 | 13 | <0.06 | 64 | 15 | 31 | 9 | 45 | 0.02 | <0.5 | 1.7 | 1.9 |

# Sample destroyed in transit
Screening level exceeded

A second selection of samples was subsequently sent for analysis for the full metals suite, with the nickel, chromium and arsenic concentrations recorded from some samples exceeding the screening levels (Table 3.3). It is of note, however, that the nickel and chromium levels within several of the deep samples (≥3 m below the sediment surface), considered to represent deep, consolidated and uncontaminated sediment layers, also exceeded the screening levels (Table 3.3). This supports the view that these elements naturally occur at relatively high levels within the region. The elevated concentrations at depth are also likely to be a result of the higher fines content of the sediments (for example sample BP10b was composed of medium/coarse sand whilst BP10c was composed of sandy clay (Coffey, unpublished)), since particle size is one of the dominant influences on contaminant levels in sediments (Commonwealth of Australia, 2002).

A dilute acid extraction of nickel and chromium was added to the analyses carried out on some of these samples to investigate the bioavailability of these elements (Section 3.10.4 of guidelines) (Section 3.5.5.2 of ANZECC/ARMCANZ, 2000), and showed that despite high concentrations being present within the Anderson point (AP) and intertidal (INT) sediments, only very low levels are likely to be bioavailable (less than screening levels) (Table 3.3).

As these studies indicate that the bioavailability of nickel and chromium is acceptably low (compared against the National Ocean Disposal Guideline Screening Levels (Commonwealth of Australia, 2002)), the sediments can be classified as non-toxic in terms of the nickel and chromium content (Commonwealth of Australia, 2002). A single exceedence of the arsenic screening level from a sample obtained at BP10b from a sediment depth of 3 m (36 mg/kg), was investigated, and repeat analysis of the sample gave a result of 11 mg/kg, below the screening level. A dilute acid extraction of arsenic from this sample showed this element to also be non-bioavailable (below screening levels) (Table 3.3).

The 95% UCLs of the surface sample results have been calculated (95% confidence limits of the mean calculated within STATISTICA Release 6) and compared to the Screening Levels (as per the guidelines) (Table 3.4). This analysis shows that within the surface (<0.1 m depth) sediments of the Anderson Point (AP) and mid-basin (MB) areas, only nickel levels within the MB area exceeded the screening levels. The 95% UCLs for the surface intertidal (INT) sediments were also determined (Table 3.5) and showed no metals to exceed the screening levels. Calculation of the 95% UCLs was not carried out on the deep (>0.1 m) sediment results because of the low number of samples analysed from comparable locations and depths.

**Table 3.3 Sediment contaminant results (batch 2)**

| Site | | Sampling Depth (m) | Concentration (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ag | As | As (DAE*) | Cd | Cr | Cr (DAE*) | Cu | Ni | Ni (DAE*) | Pb | Zn | Hg |
| **Reporting Limit** | | | **<1** | **<1** | **<1** | **<0.06** | **<0.2** | **<0.2** | **<0.2** | **<0.4** | **<0.4** | **<1** | **<0.5** | **<0.01** |
| **Screening Level** | | | **1.0** | **20** | **20** | **1.5** | **80** | **80** | **65** | **21** | **21** | **50** | **200** | **0.15** |
| **AP1** | | 0.1 | <1 | 6 | - | <0.06 | 36 | - | 1.7 | 5.0 | 0.4 | 2 | 13 | <0.01 |
| **AP4** | | 0.1 | <1 | 10 | - | <0.06 | 36 | - | 7.4 | 14 | 1.0 | 5 | 29 | <0.01 |
| **AP4** | | 0.5-0.7 | <1 | 7 | - | <0.06 | 84 | 1.1 | 13 | 40 | 1.8 | 12 | 18 | <0.01 |
| **AP7** | | 0.1 | <1 | 5 | - | <0.06 | 17 | - | 1.4 | 2.9 | <0.4 | 2 | 8.6 | <0.01 |
| **BP9a** | **AP** | 0.0-0.45 | <1 | 4 | - | <0.06 | 78 | - | 11 | 42 | 0.9 | 10 | 16 | <0.01 |
| **BP9b** | | 1.5 | <1 | 5 | - | <0.06 | 82 | - | 16 | 46 | 1.5 | 10 | 20 | <0.01 |
| **BP9c** | | 3.0 | <1 | 3 | - | <0.06 | 54 | - | 8.2 | 31 | 0.8 | 6 | 13 | <0.01 |
| **BP10a** | **INT** | 1.3 | <1 | 14 | - | <0.06 | 41 | - | 6.2 | 13 | 1.1 | 5 | 11 | <0.01 |
| **BP10b** | | 3.0 | <1 | 11 | <1 | <0.06 | 34 | - | 6.2 | 14 | 1.9 | 4 | 10 | <0.01 |
| **BP10c** | | 4.2 | <1 | 9 | - | <0.06 | 100 | 2.0 | 15 | 53 | 2.4 | 18 | 23 | <0.01 |
| **BP10d** | | 6.0 | <1 | 8 | - | <0.06 | 150 | 3.7 | 20 | 78 | 2.1 | 15 | 45 | <0.01 |
| **MB1** | | 0.1 | - | - | - | - | - | - | - | - | 1.1 | - | - | - |
| **MB2** | | 0.1 | - | - | - | - | - | - | - | - | 1.2 | - | - | - |
| **MB3** | | 0.1 | - | - | - | - | - | - | - | - | 1.8 | - | - | - |
| **MB8** | | 0.1 | - | - | - | - | - | - | - | - | 2.1 | - | - | - |
| **MB9** | | 0.1 | - | - | - | - | - | - | - | - | 2.1 | - | - | - |
| **MB10** | | 0.1 | - | - | - | - | - | - | - | - | 1.7 | - | - | - |

* Dilute acid extraction (DAE)
Screening level exceeded
DAE showing element not to be bioavailable at this site/depth

**Table 3.4 Comparison of 95% UCLs of surface samples against the screening levels**

| Site | Sampling Depth (m) | Concentration (mg/kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ag | As | Cd | Cr | Cu | Ni | Pb | Zn | Hg | TBT |
| **Reporting Limit** | | **<1** | **<1** | **<0.06** | **<0.2** | **<0.2** | **<0.4** | **<1** | **<0.5** | **<0.01** | **0.2** |
| **Screening Level** | | **1.0** | **20** | **1.5** | **80** | **65** | **21** | **50** | **200** | **0.15** | **5** |
| **AP1** | 0.1 | <1 | 6 | <0.06 | 36 | 1.7 | 5.0 | 2 | 13 | <0.01 | - |
| **AP4** | 0.1 | <1 | 10 | <0.06 | 36 | 7.4 | 14 | 5 | 29 | <0.01 | - |
| **AP7** | 0.1 | <1 | 5 | <0.06 | 17 | 1.4 | 2.9 | 2 | 8.6 | <0.01 | - |
| **AP10** | 0.1 | <1 | 10 | <0.06 | 21 | 3.8 | 7.5 | 3 | 19 | <0.01 | - |
| **95% UCL** | | n/a | 12 | n/a | 43 | 8.0 | 15.0 | 5 | 31.5 | n/a | - |
| **MB2** | 0.1 | <1 | 10 | <0.06 | 54 | 12 | 25 | 6 | 34 | <0.01 | 1.5 |
| **MB3** | 0.1 | <1 | 12 | <0.06 | 66 | 18 | 33 | 11 | 47 | 0.01 | 1.5 |
| **MB10** | 0.1 | <1 | 13 | <0.06 | 64 | 15 | 31 | 9 | 45 | 0.02 | 1.9 |
| **95% UCL** | | n/a | 15 | n/a | 77 | 22 | 40 | 15 | 59 | 0.03 | 2.2 |

Screening level exceeded

The surface sediments of the intertidal area can be considered 'clean' as none of the metals concentrations exceeded the Screening Levels (Table 3.2; Table 3.5).

**Table 3.5 Sediment contaminant concentrations recorded from Anderson Point in March 2004 (DALSE, 2004)**

| | Contaminant Levels recorded | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Site** | **As** | **Cd** | **Co** | **Cr** | **Cu** | **Ni** | **Pb** | **Zn** |
| | (mg/kg) | | | | | | | |
| Screening Level | 20 | 1.5 | NA | 80 | 65 | 21 | 50 | 200 |
| **1** | 5 | <0.06 | 0.7 | 14 | 0.3 | 1.2 | <1 | 4.9 |
| **2** | 8 | <0.06 | 2.1 | 23 | 2.4 | 5.9 | 2 | 12 |
| **3** | 7 | <0.06 | 1.5 | 18 | 1.7 | 4.2 | 1 | 11 |
| **4** | 6 | <0.06 | 0.7 | 13 | 0.5 | 1.4 | <1 | 5.8 |
| **11** | 9 | <0.06 | 1.6 | 19 | 1.6 | 4.5 | 1 | 8.2 |
| **12** | 7 | <0.06 | 1.8 | 21 | 2.2 | 4.9 | 2 | 9.8 |
| **95% UCL** | 8 | n/a | 2.0 | 22 | 2.4 | 5.7 | 2 | 12 |

The mid-basin area has recently been dredged (PHPA, 2004). It is likely that any contamination previously present within the surface sediments of the mid-basin area (MB) was removed during the recent maintenance dredging operation (PHPA, 2004). The persistence of high nickel levels suggests an active source within the area.

## 3.2 Acid Sulphate Soils

### 3.2.1 Sediments – Port Facility

A small selection of hand core samples taken from within the Anderson Point (AP) and Intertidal (INT) proposed dredging areas (Figure 2.2) were analysed for acid sulphate soils (Table 3.6). Although the sediments did not exhibit the characteristics of acid sulphate soils, the samples selected for analysis were those thought to be most likely to contain ASS following an examination of their physical properties.

As noted above (Section 2.2.3), the actual *in situ* acidity may be determined from the $pH_{KCL}$ values. For all samples analysed, the $pH_{KCL}$ values were greater than 9 and indicate none of the samples taken were actually acidic (Table 3.6).

One of the chromium reducible sulphur values ($\%S_{CR}$) exceeded the values of the Action Criteria (0.03%)(DoE, 2004a), indicating the presence of slight potential acidity at this site at a depth of 1.2 m. Due to limited hand core penetration, sampling to this depth was not carried out at any other sites by this method. The geotechnical work has yielded samples from approximately this depth (Table 2.1), and comprehensive core logs from this work describe the nature of sediments at each core location.

**Table 3.6 Acid sulphate soils laboratory results for dredging area samples**

| Site | Sediment depth (m) | $pH_{KCL}$ | Action Criteria for soils* (%S) | %S ($S_{CR}$) | $ANC_{BT}$ (% $CaCO_3$) |
|---|---|---|---|---|---|
| **AP4** | 0.5-0.7 | 9.5 | 0.03 | <0.01 | 0.9 |
| **INT3** | 1.2 | 9.5 | 0.03 | 0.08 | 8.2 |
| **INT7** | 0.75-0.84 | 9.9 | 0.03 | <0.01 | 3.7 |

* Action Criteria for disturbance of >1000 tonnes of soils (DoE, 2004a)
Action criteria exceeded

To determine whether acid sulphate soils were likely to be present within the deeper sediment layers, field testing was carried out on a small selection of samples taken during the Coffey geotechnical study (Table 3.7).

**Table 3.7 Acid sulphate soils field testing results for dredging areas**

| Hole ID | Depth of sample (m) | pH Field | Reaction | pH FOX |
|---|---|---|---|---|
| **AP10** | 1.0 | 8.71 | Low | 6.63 |
| **BP9** | 0.0-0.45 | 9.19 | Low | 7.21 |
| **BP9** | 1.5 | 8.73 | None | 6.79 |
| **BP9** | 3.0 | 8.23 | None | 6.67 |
| **BP9** | 6.0 | 8.35 | None | 6.47 |
| **BP10** | 1.3 | 8.17 | None | 6.67 |
| **BP10** | 3.0 | 7.94 | None | 6.41 |
| **BP10** | 4.2 | 8.62 | None | 7.06 |
| **BP10** | 6.0 | 8.63 | Low | 6.64 |
| **MS2** | 1.5 | 9.00 | Low | 6.70 |

Results interpretation:

- $pH_F$ <4 – AASS present
- $pH_{FOX}$ <3 – strongly indicates PASS
- Change in pH ($pH_F \rightarrow pH_{FOX}$) ≥2.5 – suggests PASS
- Volcanic or high reaction indicates likely ASS but other constituents e.g. organic matter can cause reaction.

None of the deeper samples field tested were found to exhibit actual or potential acidity. Examination of the core log from MS2, approximately 15 m WNW of INT3, revealed a sediment layer composed of a 'clayey sand, dense/very stiff, grey brown, medium grained quartz, low plasticity material' (Coffey, unpublished) to lie between 1.14 m and 1.50 m below the sediment surface. A sample from 1.5 m at this site, but composed of brown clayey sand and not the grey material more likely to be ASS, was field tested in the laboratory and did not produce the drop a pH indicative of ASS (Table 3.7). A similar sediment layer was not recorded from any adjacent core locations (MS1, MS3, BP1, BP3, BP5, BP10, BP12, BP14) (Coffey, unpublished) so the ASS material is thought to be extremely limited in its horizontal extent, likely to extend inshore from MS2 but not far within the proposed dredging areas. The very limited vertical extent of the ASS layer also suggests that the amount of this material within the areas to be dredged is relatively small. This material contains a high proportion of calcium carbonate (Table 3.6), as does the surrounding material

(Coffey, unpublished), so it is likely that any acid produced following excavation and subsequent disposal would be rapidly neutralised.

To investigate the availability and reactivity of the carbonate within the material to be dredged, two bulked samples from BP5 (samples from 1.4 m, 3.7 m and 6.2 m combined) and BP16 (samples from 1.4 m, 3.0 m and 4.5 m combined) were tested for ANC and for their pH-buffering properties (acidimetric auto-titration). It was found that sample BP16 contained a high proportion of reactive carbonate minerals and would be effective in the near-neutral buffering of acidity produced from any of the PASS layers. Sample BP5 was found to contain little carbonate and to be ineffective as a buffer (Appendix F).

### 3.2.2 Soils – Iron Ore Stockpile and Conveyor

Soil layers identified from the 39 hand auger sites (Figure 2.8) were described and selectively sampled for acid sulphate soils (Appendix B). The high relief vegetated areas within the proposed stockpile, and within the areas to be used for sourcing bund material ('North', 'South' and 'East') (Figure 2.8), were found to consist of dry sandy soil overlying red clay. A limestone layer was also identified at some locations (Appendix C). The creek beds were found to be composed of red sand and clay in varying proportions (Appendix B). Soils within low-lying areas within the Train Unloader and northern stockpile areas were found to consist of brown muds and clays overlying red clay, with an intermediate grey clay layer identified at some sites. The presence of a grey clay layer, identified as likely to contain potential acid sulphate soils (Table 3.8), seemed to be related to the proximity of the site to mangroves, although some areas separated from mangroves but distinguished by numerous crab burrows also exhibited this soil layer.

#### *Acid sulphate soils field testing*

Selected sub-samples of soil from the different horizons identified during the first two days of the survey were field tested for potential acid sulphate soils (PASS) and actual acid sulphate soils (AASS) ($pH_{Field}$ and $pH_{FOX}$ tests) (Table 3.8). The results of this testing allowed the identification of any acid sulphate soils present and the focussing of the remaining investigation on those areas anticipated to contain acid sulphate soils.

**Table 3.8 Acid sulphate soils field testing results for stockpile and conveyor sites**

| Sample | Soil depth (m) | pH Field | Reaction | pH FOX |
|---|---|---|---|---|
| **S4** | 0.9 | 8.04 | High/volcanic | 7.8 |
| **S11** | 0.5 | 8.19 | Low | 6.88 |
| **S11** | 1.0 | 8.26 | None | 6.93 |
| **S11** | 1.8 | 8.28 | Low | 6.81 |
| **S12** | 0.4 | 8.12 | Low | 5.79 |
| | | | | |
| **W2** | 0.3 | 8.08 | Medium (delayed) | 6.95 |
| **W2** | 1.0 | 7.69 | Medium | 4.96 |
| **W2** | 1.2 | 7.84 | Volcanic | 1.49 |
| **W2** | 1.4 | 7.93 | Volcanic | 2.16 |
| **W2** | 1.8 | 8.16 | None | 6.37 |
| | | | | |
| **ST1** | 0.75 | 7.46 | Volcanic | 1.48 |
| **ST1** | 1.0 | 7.55 | Volcanic | 1.65 |
| **ST1** | 1.1 | 7.65 | Low | 6.29 |
| **ST8** | 0.4 | 7.67 | None | 6.35 |

Results interpretation:

- $pH_F$ <4 – AASS present
- $pH_{FOX}$ <3 – strongly indicates PASS
- Change in pH ($pH_F \rightarrow pH_{FOX}$) ≥3 – suggests PASS
- Volcanic or high reaction indicates likely ASS but other constituents e.g. organic matter can cause reaction.

Likely potential ASS

### *Acid sulphate soils laboratory testing*

For all samples analysed, the $pH_{KCL}$ values were greater than 7 and indicate none of the samples taken were actually acidic (Table 3.9).

Six of the chromium reducible sulphur values ($\%S_{CR}$) exceeded the values of the Action Criteria (0.03%)(DoE, 2004a). Hence, the chromium method confirms that samples ST1 (0.75), ST2 (1.0), W2 (1.0), W2 (1.2), W2 (1.5) and W5 (2.0) were potential acid sulphate soils (PASS) (Table 3.9).

**Table 3.9 Acid sulphate soils laboratory results for stockpile and conveyor sites**

| Site | Soil depth (m) | $pH_{KCL}$ | Action Criteria for soils* (%S) | %S ($S_{CR}$) | $ANC_{BT}$ (% $CaCO_3$) |
|---|---|---|---|---|---|
| **N2** | 0.5 | 8.5 | 0.03 | <0.01 | 0.2 |
| **N2** | 2.0 | 8.2 | 0.03 | <0.01 | 0.1 |
| **S6** | 1.0 | 7.9 | 0.03 | <0.01 | 0.0 |
| **S6** | 2.5 | 7.8 | 0.03 | <0.01 | 0.1 |
| **S15** | 0.5 | 8.5 | 0.03 | <0.01 | 0.3 |
| **S15** | 1.0 | 8.0 | 0.03 | <0.01 | 0.1 |
| **S15** | 1.8 | 8.2 | 0.03 | <0.01 | 0.1 |
| **ST1** | 0.75 | 7.9 | 0.03 | 0.76 | 0.4 |
| **ST1** | 1.1 | 8.4 | 0.03 | 0.03 | 0.2 |
| **ST2** | 1.0 | 8.5 | 0.03 | 0.34 | 0.5 |
| **ST9** | 0.3 | 9.4 | 0.03 | <0.01 | 8.4 |
| **ST12** | 0.5 | 8.2 | 0.03 | <0.01 | 0.4 |
| **ST12** | 1.0 | 8.1 | 0.03 | <0.01 | 0.4 |
| **W2** | 1.0 | 8.9 | 0.03 | 0.36 | 1.4 |
| **W2** | 1.2 | 8.6 | 0.03 | 3.90 | 7.0 |
| **W2** | 1.5 | 9.4 | 0.03 | 0.07 | 2.7 |
| **W5** | 1.5 | 9.1 | 0.03 | 1.10 | 9.5 |

* Action Criteria for disturbance of >1000 tonnes of soils (DoE, 2004a)
Action criteria exceeded

The acid neutralising capacity (ANC) of the soil layers indicates their ability to neutralise any acid produced. Several of the sediment layers tested exhibited relatively high ANCs (>7% $CaCO_3$) (Table 3.9). This neutralising capacity can be compared against the potential acidity (mol $H^+$/tonne) to determine whether effective neutralisation is likely to occur following the oxidation of the soil (Table 3.10).

**Table 3.10 Acid neutralising capacity compared against potential acidity**

| Site | Soil depth (m) | %S ($S_{CR}$) | Equivalent acidity (mol $H^+$/tonne) | $ANC_{BT}$ (% $CaCO_3$) | ANC (mol $H^+$/tonne) | Net acidity (acidity-ANC) (mol $H^+$/tonne)* |
|---|---|---|---|---|---|---|
| **ST1** | 0.75 | 0.76 | 474.0 | 0.4 | 79.9 | +394.1 |
| **ST2** | 1.0 | 0.34 | 212.1 | 0.5 | 99.9 | +112.2 |
| **W2** | 1.0 | 0.36 | 224.5 | 1.4 | 279.7 | -55.2 |
| **W2** | 1.2 | 3.90 | 2432.4 | 7.0 | 1398.6 | +1033.8 |
| **W2** | 1.5 | 0.07 | 43.7 | 2.7 | 539.5 | -495.8 |
| **W5** | 1.5 | 1.10 | 686.1 | 9.5 | 1898.1 | -1212.0 |

* Positive value = excess acid, negative value = excess neutralising capacity

The comparison of relative potential acidity and acid neutralising capacity for each soil layer (Table 3.10) shows three of the sediment layers exhibiting potential acidity (W2 1.0 and W5 1.5) to be effectively buffered by the other components of the soil. The excess neutralising capacity within the soils at W2 (1.5) and W5 (1.5) also exceeds the recommended safety factor (addition of 1.5 times the required neutralising agent) when calculating the neutralising requirements (DoE, 2004a).

# 4. Conclusions

## 4.1 Sediment contamination

The surface (≤1 m deep) sediment layers within the areas to be dredged have been found to be uncontaminated by metals or TBT with the exception of nickel and chromium.

High concentrations of nickel and chromium have previously been recorded within marine sediments in the Port Hedland region, often exceeding the screening levels (ENV, 2001; URS, 2003), even at sites remote from the harbour (URS, 2004). This suggests that high background levels, possibly a result of the weathering of terrestrial rock, exist in this region. The EPA, however, requested that further testing be carried out on nickel within the sediments to be dredged, as per the guidelines.

Having recorded nickel levels within the mid-basin surface sediments that exceed the screening levels, bioavailability testing was carried out. These studies indicated that the bioavailability of nickel was acceptably low (compared against the National Ocean Disposal Guideline Screening Levels (Commonwealth of Australia, 2002)), and therefore the spoil can be classified as non-toxic (Commonwealth of Australia, 2002). Similarly, bioavailability testing of chromium was carried out on a small number of the INT and AP sediment samples following exceedence of the screening levels during analysis of the second batch of samples, with chromium found to be non-bioavailable.

## 4.2 Acid sulphate soils

Acid sulphate soils have been identified within the proposed Stockpile and Train Unloader areas. The material consists of a readily visually identifiable grey clay layer which is generally in close association with mangroves. The layer was found to have an upper depth limit of 0.5 to 1.0 m.

For projects that disturb ≥1000 tonnes of ASS with ≥0.03 %S, a detailed management plan (ASSMP) is required (DoE, 2004a). The results suggest that the grey clay material identified within the northern Stockpile area, and within the northern Train Unloader area, exceeds both the acidity and weight criteria for the requirement of a detailed ASSMP covering both these areas. FMG will produce an ASSMP prior to the commencement of excavation. Estimation of the volume of the acid sulphate soils in each area, together with consideration of the natural acid neutralising capacity of the different sediment/soil layers, will be fundamental to the management options.

Acid sulphate soils were recorded from one site (INT3) and suggested at another site (MS2) within the proposed dredging areas during the marine component of the acid sulphate soils investigation. However, following an examination of the geotechnical core logs, it was found that this material, composed of a clayey grey brown sand (Coffey, unpublished), was not present within any adjacent cores. In addition, this material was found to lie between 1.14 m and 1.50 m below the sediment surface. Thus the ASS material is thought to be extremely limited in its horizontal and vertical extents, suggesting that the amount of this material within the areas to be dredged is relatively small. This material is not highly acidic (upon oxidation) and contains, as do the surrounding sediment layers, a high proportion of calcium carbonate, so it is likely that any acid produced following excavation would be rapidly neutralised. Tests on the availability and reactivity of the calcium carbonate within the sediments have shown this material to be reactive and available for the neutralisation of any acid produced.

# 5. References


Ahern, C.R., Ahern, M.R. and Powell, B. (1998). Guidelines for sampling and analysis of Lowland Acid Sulphate Soils (ASS) in Queensland 1998. Department of Natural Resources, Indooroopilly, Queensland, Australia. DNRQ980124.

ANZECC/ARMCANZ. (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

Coffey Geosciences Pty Ltd. (2004a). Pilbara Iron Ore and Infrastructure Project Desktop study and site visit. Prepared from Fortescue Metals Group Ltd. Report No. P6514.03-AB.

Coffey Geosciences Pty Ltd. (2004). Pilbara Iron Ore and Infrastructure Project over water geotechnical investigation project quality plan. Prepared from Fortescue Metals Group Ltd. Report No. P6514.02.

Commonwealth of Australia. (2002). National Ocean Disposal Guidelines for Dredged Material.

DALSE. (2004). *Pilbara Iron Ore and Infrastructure Project: Marine Environmental Impacts and their Management*. Prepared for Fortescue Metals Group. Report No. 389/1.

DEP/WRC. (2003). Identification and investigation of acid sulphate soils and groundwater. Acid Sulphate Soils Guideline Series.

DoE. (2003). Preparation of acid sulphate soil management plan (ASSMP). Acid Sulphate Soil Guideline Series.

DoE. (2004a). Identification and investigation of acid sulphate soils. Acid Sulphate Soils Guideline Series.

DoE. (2004b). . Treatment and management of disturbed acid sulphate soils. Acid Sulphate Soils Guideline Series.

ENV. (2001). *Sea Dumping Permit Application for dredged material from Wharf 1*. Prepared for Port Hedland Port Authority.

Oceanica. (2004). *Pilbara Iron Ore and Infrastructure Project. Sampling and Analysis Plan.* Prepared for Fortescue Metals Group. Report No. 423/1.

Paling, E. I. (2002). Assessment of issues relating to acid sulphate soils at Port Hedland.

Port Hedland Port Authority. (2004). Sampling and Analysis Plan. Maintenance dredging of Port Hedland Harbour and Entrance Channel. Prepared for Port Hedland Port Authority by URS Australia Pty Ltd. Report No.: R976.

URS Australia Pty Ltd. (2003). *Port Hedland Harbour Marine Monitoring Programme. Sediment Quality Study 2003*. Unpublished report to BHPB-IO Billiton Iron Ore by URS Australia. Report No. R962.

URS Australia Pty Ltd. (2004). *Port Hedland Harbour and Shipping Channel Sediment Quality February 2004.* Prepared for Port Hedland Port Authority. Report No. R1016.

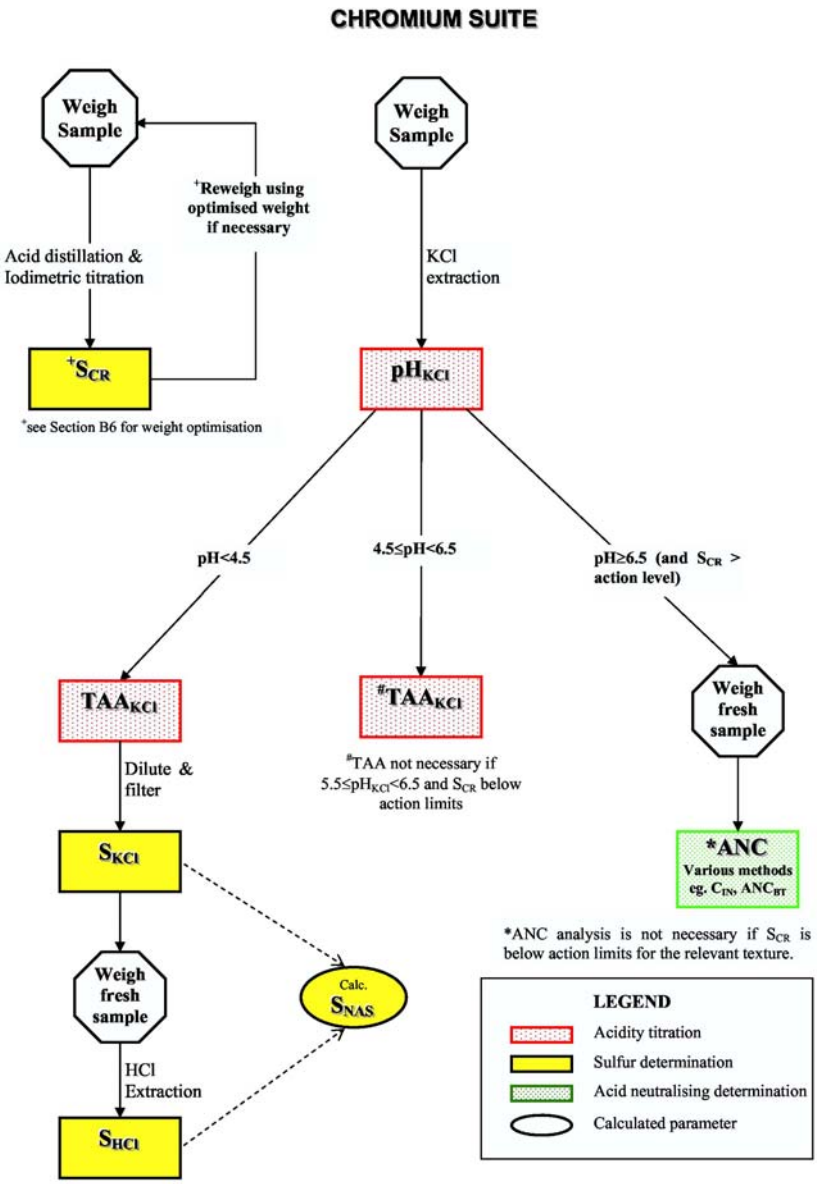
QEPA. (2001). Instructions for the Treatment and Management of Acid Sulphate Soils.

Zar, J.H. (1984). Biostatistical Analysis. Prentice-Hall International, Inc.

# Appendix A

# Chromium Suite – ASS Analysis

## Appendix A Chromium suite – ASS analysis



# Appendix B

# Acid sulphate soil investigation notes

## Appendix B Acid sulphate soil investigation notes

| Site | Easting | Northing | Sediment depth (m) | Samples taken | Sediment description | Sampling details |
|---|---|---|---|---|---|---|
| **ASS4** | 663537 | 7749814 | 0.0-1.0 | Core | | 1m penetration. Full core taken. |
| | | | 0.0-0.3 | | Light brown muddy medium sand | |
| | | | 0.40 | | As above + grey mud marbling | |
| | | | 0.50 | | As above plus grey clay | |
| | | | 0.60 | | Grey clay | |
| | | | 1.0-1.1 | | End of grey clay, beginning red clay | |
| | | | | | | |
| **ASS3** | 663556 | 7749806 | 0.0-0.3 | | Muddy light brown medium sand | |
| | | | 0.40 | | As above with grey marbling | |
| | | | 0.50 | | As above. Water table. | |
| | | | 0.60 | | Red muddy sand | |
| | | | 0.70 | | Red clay with sand | |
| | | | 0.80 | | Red clay with some medium sand | |
| | | | | | | |
| | | | | | | |
| **ASS2** | 663593 | 7749783 | 0.00 | 1 | Compact brown sandy clay | |
| | | | 0.60 | | Slight grey clay marbling | |
| | | | 0.70 | | As above | |
| | | | 0.75 | | Red/brown mud with medium sand | |
| | | | 0.85 | | Red/brown clay with medium sand | |
| | | | 1.10 | | Red clay. Water table. | |
| | | | | | | |
| **ASS1** | 663516 | 7749837 | 0.0-1.0 | Core | | 1m penetration. Compressed to 0.7m. Recovered bottom 0.5m. |
| | | | 0.0-0.5 | | Brown/red wet clay with grey clay marbling | |
| | | | 0.55 | 1 | Black organic material with grey clay | |
| | | | 0.70 | | Grey clay | |
| | | | 1.50 | | Dark grey muddy coarse sand. | |
| | | | | | | |
| **E1** | 664149 | 7749021 | 0.0-0.55 | | Light brown muddy sand | |
| | | | 0.55 | | As above with slight grey clay marbling | |
| | | | 0.60 | | Red clay | |
| **E1B** | 664138 | 7749042 | 0.0-0.4 | | Light brown muddy sand | |
| | | | 0.50 | | Red/brown clay | |
| **E6** | 664063 | 7748284 | 0.0-0.3 | | Brown clay with medium sand | |
| | | | 0.3-0.5 | | As above plus grey clay marbling | |

| Site | Easting | Northing | Sediment depth (m) | Samples taken | Sediment description | Sampling details |
|---|---|---|---|---|---|---|
| | | | 0.5-1.0 | | Sandy red/brown clay | |
| | | | 1.10 | | Dry sandy brown clay with pebbles | |
| | | | 1.1-1.3 | | Brown/red clay with some coarse sand | |
| | | | | | | |
| **S1** | 662575 | 7748424 | 0.0-0.5 | 1 | Clay with medium sand | |
| | | | | | | |
| **S4** | 663320 | 7748227 | 0.20 | 1 | Clay with sand | |
| | | | 0.50 | 1 | Wet coarse sand and clay | |
| | | | 0.90 | Field | As above | |
| | | | | | | |
| **S5** | 663530 | 7748232 | 0.0-0.8 | | Dry sandy soil | |
| | | | 0.8-1.0 | 1 | Sandstone fragments, clay and medium sand | |
| | | | 1.00 | | Dry soil with sand | |
| | | | | | | |
| **S6** | 662575 | 7748192 | 0.0-0.2 | | Medium sand | |
| | | | 0.2-2.3 | 3 | Thick clay with medium sand | |
| | | | 2.30 | 1 | Wet mud with sand | |
| | | | | | | |
| | | | | | | |
| **S9** | 663482 | 7748074 | 0.0-0.8 | 1 | Dry sandy soil | |
| | | | 0.8-1.0 | 1 | Moist sandy soil | |
| | | | | | | |
| **S10** | 662628 | 7747973 | 0.0-1.0 | | Sandy dry soil | |
| | | | | | | |
| **S11** | 663079 | 7747947 | 0.0-1.5 | 2 & 2xField | Brown medium sand with clay | |
| | | | 1.5-1.9 | 2 & Field | Grey clay with coarse sand | |
| | | | 1.90 | 1 | Red clay | |
| | | | | | | |
| **S12** | 663333 | 7747909 | 0.0-0.08 | 1 | Muddy coarse sand | |
| | | | 0.08-0.4 | Field | Red clay with coarse sand | |
| | | | 0.4-1.0 | 2 | Red clay with coarse sand and pebbles | |
| | | | | | | |
| **S13** | 663631 | 7747908 | 0.0-0.6 | | Dry sandy soil | |
| | | | 0.6-1.0 | 2 | Sandy moist soil | |
| | | | 1.0-1.9 | 1 | Red clay with medium sand | |
| | | | 1.90 | 1 | Coarse sand with pebbles and clay | |
| | | | | | | |
| **S14** | 662733 | 7747746 | 0.0-0.5 | 2 | Coarse red muddy sand | |
| | | | 0.5-0.6 | 1 | Coarse red sand with clay | |
| | | | 0.6-1.1 | | Wet red clay with sand | |
| | | | | | | |
| **S15** | 662943 | 7747811 | 0.0-0.5 | | Clay with some medium sand | |
| | | | 0.5-1.0 | 1 | As above | |
| | | | 1.0-1.6 | 1 | Wet clay with sand | |
| | | | 1.6-1.8 | 1 | Coarse sand with mud | |
| | | | | | | |
| **ST1** | 663416 | 7749939 | 0.0-0.65 | | Brown mud with medium sand | |
| | | | 0.65-1.1 | 2 & | Grey clay/mud | |

| Site | Easting | Northing | Sediment depth (m) | Samples taken | Sediment description | Sampling details |
|---|---|---|---|---|---|---|
| | | | | 2xField | | |
| | | | 1.1-2.0 | 1 & Field | Brown clay with sand | |
| | | | | | | |
| ST2 | 663604 | 7749865 | 0.0-0.9 | | Light brown sandy clay | |
| | | | 0.9-1.55 | 1 | Grey clay | |
| | | | 1.55 | | Red clay | |
| | | | | | | |
| ST5 | 663131 | 7749240 | 0.00 | | Brown sandy clay | |
| | | | 0.25 | | As above with grey clay marbling | |
| | | | 0.30 | | Red clay | |
| | | | | | | |
| ST6 | 663290 | 7749161 | 0.0-0.25 | | Light brown muddy medium sand | |
| | | | 0.25 | | Red clay | |
| | | | | | | |
| ST7 | 663375 | 7749821 | 0.0-0.7 | | Sandy mud | |
| | | | 0.7-0.75 | | Grey clay | |
| | | | 0.75-1.0 | | Brown mud with medium/coarse sand | |
| | | | | | | |
| ST8 | 663359 | 7749558 | 0.0-0.4 | | Wet brown mud | |
| | | | 0.4-0.55 | Field | Grey sandy mud | |
| | | | 0.55 | | Red/brown muddy sand | |
| | | | | | | |
| ST9 | 663271 | 7749348 | 0.00 | | Wet light brown clay | |
| | | | 0.10 | | Brown clay with slight grey marbling | |
| | | | 0.20 | | Sand brown clay | |
| | | | 0.30 | 1 | Grey clay with black organic material | |
| | | | 1.90 | | Grey muddy coarse sand | |
| | | | | | | |
| ST9B | 663246 | 7749348 | 0.00 | | Light brown clay with sand | |
| | | | 0.3-0.5 | | As above with grey clay marbling | |
| | | | 0.50 | 1 | As above | |
| | | | | | | |
| ST9C | 663256 | 7749306 | 0.0-0.5 | | Red/brown clay with sand | |
| | | | | | | |
| ST9D | 663289 | 7749337 | 0.0-0.15 | | Brown medium/coarse sand | |
| | | | 0.30 | | Brown mud/clay | |
| | | | 0.60 | | Grey mud | |
| | | | | | | |
| ST9E | 663288 | 7749399 | 0.30 | | Brown clay with grey clay marbling | |
| | | | 0.60 | | Grey clay | |
| | | | | | | |
| ST9F | 663265 | 7749405 | 0.0-0.6 | | Brown clay | |
| | | | 0.60 | | Grey clay | |
| | | | | | | |
| ST9G | 663203 | 7749403 | 0.0-0.1 | | Brown clay/mud/sand | |
| | | | 0.10 | | As above with grey marbling | |
| | | | 0.90 | | Red clay | |
| | | | | | | |
| ST9H | 663223 | 7749419 | 0.40 | | Brown sandy clay with some grey marbling | |
| | | | 0.60 | 1 | More grey marbling | |

| Site | Easting | Northing | Sediment depth (m) | Samples taken | Sediment description | Sampling details |
|---|---|---|---|---|---|---|
| | | | 0.70 | | Red clay | |
| | | | | | | |
| **ST11** | 663036 | 7748808 | 0.0-1.5 | 2 | Medium sand with clay | |
| | | | 1.5-1.8 | 1 | Grey clay with coarse sand | |
| | | | 1.90 | 1 | Red clay | |
| | | | | | | |
| **ST12** | 662947 | 7748560 | 0.0-0.08 | 1 | Wet muddy coarse sand | |
| | | | 0.08-0.4 | | Red clay with coarse sand | |
| | | | 0.4-1.0 | 2 | Red clay with pebbles and coarse quartz sand | |
| | | | | | | |
| **W1** | 661651 | 7749173 | 0.0-0.3 | | Red mud with coarse sand | |
| | | | 0.3-0.7 | 1 | Brown clay with fine/medium sand | |
| | | | | | | |
| **W2** | 661691 | 7749331 | 0.0-0.3 | 1 & Field | Light brown clay | |
| | | | 1.00 | Field | Light grey clay | |
| | | | 1.20 | 1 & Field | Dark grey clay with organic matter | |
| | | | 1.40 | 1 & Field | Light grey clay | |
| | | | 1.50 | 1 | Brown mud with sand | |
| | | | 1.5-1.7 | Field | As above | |
| | | | | | | |
| **W3** | 661695 | 7749425 | 0.0-0.7 | | Brown mud with some fine sand | |
| | | | 0.7-1.0 | | Grey clay | |
| | | | 1.0-1.1 | 1 | Grey clay with brown clay marbling | |
| | | | 1.10 | | Brown mud with fine sand | |
| | | | | | | |
| **W4** | 661683 | 7749313 | 0.0-0.6 | | Brown mud with fine sand | |
| | | | 0.60 | 1 | Grey clay | |
| | | | 0.65-1.1 | | Grey sandy clay | |
| | | | 1.10 | | Red clay | |
| | | | | | | |
| **W5** | 661667 | 7749290 | 1.00 | | Grey clay | |
| | | | 1.90 | 1 | Compact grey clay | |
| | | | 2.00 | 1 | Compact grey clay | |
| | | | | | | |
| **N2** | 663010 | 7749043 | 0.0-0.1 | | Muddy sand | |
| | | | 0.1-1.0 | 1 | Clay with medium/coarse sand | |
| | | | 2.00 | 1 | Wet clay | |
| | | | 2.0-2.6 | 1 | Coarse muddy sand | |

*Notes:* - *Suspected acid sulphate soils (from field testing)*
*Field – sample taken for field testing ($pH_F$ & $pH_{FOX}$ (Section 3.2.2)).*

# Appendix C

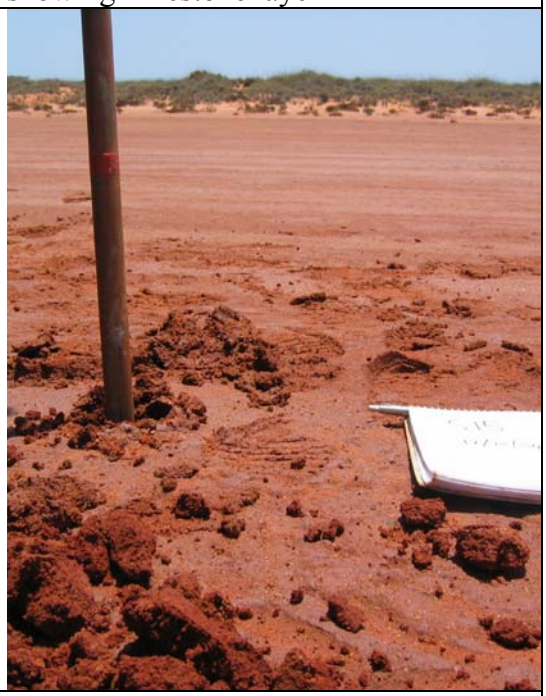
# Acid sulphate soil investigation photos

## Appendix C Acid sulphate soil investigation photos

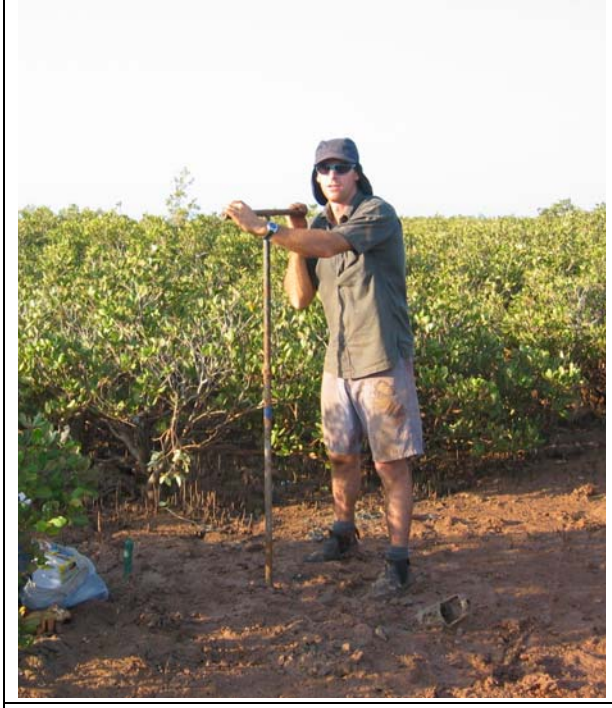
Site S5 – Vegetated dry sandy soil

Site ST3 – Side of vegetated area showing limestone layer

Site S12 – Creek bed



Site S15 – Creek bed



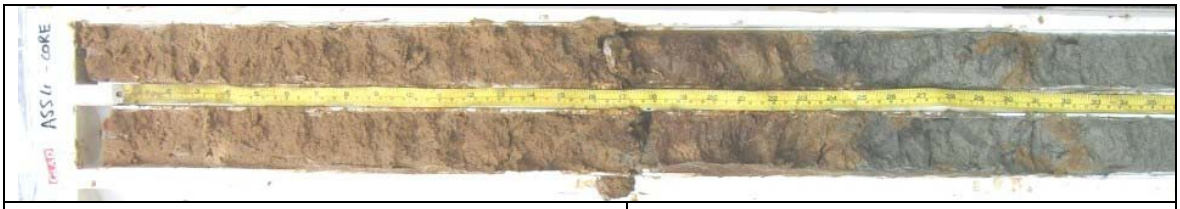
Site W2 – Sampling at the edge of mangrove

Site W2 – Grey clay sub-layer

Centre of stockpile area – isolated mangroves

Centre of stockpile area – evidence of grey clay sub-layer from crab burrows


Site SS1 - Core




| | |
|---|---|
| Site ASS4 - Core | |

# Appendix D

# Interpretation of acid sulphate soil field testing

**Appendix D Interpretation of acid sulphate soil field testing (Reproduced from Appendix 2 (DoE, 2004a)**

It is important to note that whilst a useful exploratory tool, soil field pH tests are indicative only and cannot be used as a substitute for laboratory analysis to determine the presence of ASS. Laboratory analysis is needed to quantify the amount of existing plus potential acidity. This appendix provides information on how to interpret the results from soil field pH tests. For further information on how to conduct and interpret these tests, consult the latest version of the *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998.*

**1. Field pH test ($pH_F$) i.e. pH of soil and water paste**

The $pH_F$ test measures the existing acidity of a 'soil:water' paste, and is therefore used to help identify if ASS are present. If the measured pH of the soil paste is $pH_F < 4$, oxidation of sulfides has probably occurred in the past, indicating the presence of AASS. Highly organic soils or heavily fertilised soils may also return a $pH_F$ close to 4. A $pH_F > 4$ but $< 5$ indicates an acid soil, but the cause of the acidity will need to be further investigated by laboratory analysis. The $pH_F$ test does not detect any unoxidised sulfides (i.e. PASS). For this reason, this test must be used in conjunction with the $pH_{FOX}$ test.

**2. Field pH peroxide test ($pH_{FOX}$) i.e. pH of soil and peroxide mix and reaction with peroxide**

The $pH_{FOX}$ test is used to indicate the presence of iron sulfides or PASS. This test involves adding 30%

hydrogen peroxide (pH adjusted to 4.5–5.5) to a sample of soil. If sulfides are present a reaction will occur.

The reaction can be influenced by the amount of sulfides present in the sample, the presence of organic matter or the presence of manganese. Once the reaction has occurred, the pH is measured.

A combination of three factors is considered in arriving at a 'positive field sulfide identification':

**A reaction with hydrogen peroxide**. The strength of the reaction with peroxide is a useful indicator but cannot be used alone. Organic matter, coffee rock and other soil constituents such as manganese oxides can also cause a reaction. Care should be exercised in interpreting a reaction on surface soils and high organic matter soils such as peats and coffee rock, and some mangrove/estuarine muds and marine clays.

**The actual value of $pH_{FOX}$**. If the $pH_{FOX} < 3$, and a significant reaction occurred, then it strongly indicates a PASS. The more the $pH_{FOX}$ drops below 3 the more positive the presence of inorganic sulfides.

**A much lower $pH_{FOX}$ than field $pH_F$**. The lower the final $pH_{FOX}$ value and the greater the difference between the $pH_{FOX}$ compared to the $pH_F$, the more indicative the presence of PASS. This difference may not be as great if starting with an already very acid $pH_F$ (close to 4), but if the starting pH is neutral or alkaline then a larger change in pH should be expected. Where fine shell, coral or carbonate, is present the change in pH may not be as large due to buffering.

# Appendix E

# Texture-based ASS ‘Action Criteria’

## Appendix E Texture-based ASS 'Action Criteria' (Reproduced from Appendix 3 (DoE, 2004a))

The *Action Criteria* are based on the sum of existing plus potential acidity, calculated as equivalent sulfur (e.g. s-TAA + SCR in %S units) or equivalent acidity (e.g. TAA + a- SCR in mol H+/tonne). The highest laboratory result(s) is always used to assess against the action criteria. For further information refer to *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998.*

As clay content tends to influence a soil's natural pH buffering capacity, the action criteria are grouped by three broad texture categories – coarse, medium and fine. The criteria are used to define when ASS disturbed at a site will need to be treated and managed.
For projects that disturb >1000 tonnes of ASS with >0.03 %S or >18 mol H+/tonne equivalent acidity, a detailed management plan and development consent will be required.

**Texture-based acid sulfate soils 'action criteria'**

| Type of material | | Action Criteria if 1-1000 tonnes of materials is disturbed Existing + Potential Acidity | | Action Criteria if >1000 tonnes of materials is disturbed Existing + Potential Acidity | |
|---|---|---|---|---|---|
| Texture range McDonald et al. (1990) | Approx. clay content (%) | Equivalent sulfur (%S) (oven-dry basis) | Equivalent Acidity (mol H+/tonne) (oven-dry basis) | Equivalent sulfur (%S) (oven-dry basis) | Equivalent Acidity (mol H+/ tonne) (oven-dry basis) |
| **Coarse Texture** Sands to Loamy sands | ≤ 5 | 0.03 | 18 | 0.03 | 18 |
| **Medium Texture** Sandy loams to light clays | 5 – 40 | 0.06 | 36 | 0.03 | 18 |
| **Fine Texture** Medium to Heavy clays and silty clays | ≥ 40 | 0.1 | 62 | 0.03 | 18 |

The action criteria refer to existing and potential acidity for given volume of ASS. The highest result(s) should always be used to assess if the relevant action criteria level has been made or exceeded; using the average or mean of a range of results is no longer considered appropriate.

Total actual acidity (TAA) is determined by titration of a 1M KCl salt solution to pH 5.5 using NaOH. This is a measurement of the soil's existing acidity prior to oxidation of sulfidic material.

Total potential acidity (TPA) is determined by peroxide double oxidation. This is estimated by titration to pH 5.5 of total acidity after oxidation of the soil with 30% hydrogen peroxide. When determining lime requirements, subtracting TAA from Total Potential Acidity (TPA) to get Total Sulfidic Acidity (TSA) is acceptable.

# Appendix F

# Laboratory analysis reports

**INTERIM REPORT**
MARINE AND FRESHWATER RESEARCH LABORATORY

## SEDIMENT DATA

Client: Spencer Shute, Oceanica
Address: PO Box 3172, Broadway, Nedlands, WA 6009

Date of Issue:
Reference: OCA04-17

| Method | | ICP002 | ICP002 | ICP002 | ICP002 | ICP002 | ICP002 | ICP002 | ICP002 |
|---|---|---|---|---|---|---|---|---|---|
| Sample Code | Date | Ag mg/kg | As mg/kg | Cd mg/kg | Cr mg/kg | Cu mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg |
| Reporting Limit | | <1 | <1 | <0.06 | <0.2 | <0.2 | <0.4 | <1 | <0.5 |
| File: | | 04111001 | 04111001 | 04111001 | 04111001 | 04111001 | 04111001 | 04111001 | 04111001 |
| AP8 1.0 | 15/10/2004 | <1 | 5 | <0.06 | 28 | 3.2 | 5.4 | 3 | 15 |
| AP10 1 | 15/10/2004 | <1 | 9 | <0.06 | 24 | 3.7 | 8.2 | 2 | 8.3 |
| AP10 2 | 15/10/2004 | <1 | 10 | <0.06 | 21 | 3.8 | 7.5 | 3 | 19 |
| INT6 | 15/10/2004 | <1 | 12 | <0.06 | 42 | 7.6 | 18 | 8 | 25 |
| INT6 (1.0) | 15/10/2004 | <1 | 11 | <0.06 | 19 | 1.9 | 5.0 | 2 | 3.8 |
| MB2 | 15/10/2004 | <1 | 10 | <0.06 | 54 | 12 | 25 | 6 | 34 |
| MB3 | 15/10/2004 | <1 | 12 | <0.06 | 66 | 18 | 33 | 11 | 47 |
| M10 | 15/10/2004 | <1 | 13 | <0.06 | 64 | 15 | 31 | 9 | 45 |

**Batch:** PEB1576
**Sub Batch:** 0
**Date of Issue:** 11/11/2004
**Client:** .
**Client Reference:**

# CERTIFICATE OF ANALYSIS

| | | | | SAMPLE IDENTIFICATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Laboratory I.D. | | 1 | 2 | 3 | 4 | 5 | 6 | | | | |
| | | Date Sampled | | 15/10/2004 | 15/10/2004 | 15/10/2004 | 15/10/2004 | 15/10/2004 | 15/10/2004 | | | | |
| METHOD | ANALYSIS DESCRIPTION | UNIT | LOR | AP8 1.0 | AP10 0.1 | INT 6 * | MB2 | MB3 | MB10 | | | | |
| EA-055 | Moisture Content (dried @ 103'C) | % | 0.1 | 19.0 | 17.8 | 30.5 | 37.6 | 44.5 | 44.0 | | | | |
| **EP-090-SS** | **ORGANOTIN COMPOUNDS** | | | | | | | | | | | | |
| EP-090-SS | Monobutyltin | ugSn/kg | 0.5 | 0.6 | 1.7 | 0.8 | 1.0 | 1.1 | <0.5 | | | | |
| EP-090-SS | Dibutyltin | ugSn/kg | 0.5 | 1.7 | 1.9 | 0.6 | 2.7 | 3.0 | 1.7 | | | | |
| EP-090-SS | Tributyltin | ugSn/kg | 0.2 | <0.2 | 0.3 | 0.2 | 1.5 | 1.5 | 1.9 | | | | |
| **EP-090S-SS** | **ORGANOTIN COMPOUND SURROGATE** | | | | | | | | | | | | |
| EP-090S-SS | Tripropyltin | % | 1 | 64 | 63 | 57 | 57 | 59 | 40 | | | | |

* INT 6 (1.0m) DESTROYED IN TRANSIT (PERTH ALS – QLD ALS)

# BATCH QUALITY CONTROL

## ALS EP-090 : ORGANOTINS

**QC LOT No. :** **TBTS603** ANALYST: Craig Beinke

**MATRIX:** **Sediment**

| COMPOUND | Blank Conc | Spike Level | SPIKE QC RESULTS | | | | Control Limits | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | SCS Conc | DCS Conc | Average Rec. | RPD | Rec. | | RPD |
| | ug Sn/kg | ug Sn/kg | ug Sn/kg | ug Sn/kg | % | % | Low | High | % |
| **Surrogate Recovery** | | | | | | | | | |
| Tripropyltin | 18.9 | 25 | 19.3 | 19.6 | 77 | 0 | 0 | 121 | 20 |
| **Target Compounds** | | | | | | | | | |
| Monobutyltin | <0.5 | 25 | 16.7 | 17.8 | 69 | 6 | 28 | 99 | 50 |
| Dibutyltin | <0.5 | 25 | 17.1 | 17.0 | 68 | 1 | 15 | 106 | 35 |
| Tributyltin | <0.2 | 25 | 7.5 | 8.9 | 33 | 17 | 12 | 111 | 20 |

**COMMENTS:**

1) * : Recovery or RPD falls outside of the recommended control limits.

*GRAEME CAMPBELL & ASSOCIATES PTY LTD*
*Specialists in Mine-Waste Geochemistry,*
*& Soil-Moisture-Retention Testing*

*P.O. Box 247, Bridgetown, Western Australia 6255*
*Phone: (61 8) 9761 2829 Fax: (61 8) 9761 2830*
*E-mail: gca@wn.com.au*

0417/5

COMPANY: Fortescue Metals Group Ltd

ATTENTION: Nicky Hogarth

FROM: Graeme Campbell

SUBJECT: Assessment of Acid-Consuming Properties of Marine-Sediment Samples

NO. PAGES (including this page): 9 DATE: 27th January 2005

---

Nicky,

Please find herein the findings of the testing carried out on the marine-sediment samples earlier provided by Mr Spencer Shute (Oceanica, Nedlands). It is understood that these samples are derived from recent drilling investigations for geotechnical assessment.

## 1.0 SAMPLES AND TESTING

The samples provided to GCA for testing were:

- BP16a 1.4 m, BP16b 3.0 m, and BP16c 4.5 m
- BP5a 1.4 m, BP5b 3.7 m, and BP5c 6.2 m

Each sample (*c.* 0.5 kg dry-solids basis) was in the form of moist sediments, and were oven-dried (80 $^{0}$C for *c.* 24 hrs), and crushed in a jaw-crusher with clearance set to 2-3 mm (nominal). Equal-weight-based composites (viz. **BP16** and **BP5**) were prepared from the respective individual samples.

The Acid-Neutralisation-Capacity (ANC) values of the samples were determined by SGS Environmental Services (Welshpool). The acidimetric auto-titrations were performed in the GCA Testing-Laboratory (Bridgetown). Copies of the laboratory reports are attached.

## 2.0 TESTWORK RESULTS

### 2.1 ANC Values

Sample BP16 had an ANC value of 83-92 kg $H_2SO_4$/tonne, and was calcareous as inferred from the vigorous effervescence (viz. "fizzing") produced upon addition ('in-the-cold') of HCl in the ANC-testwork.

Sample BP5 had an ANC value of 5.3 kg $H_2SO_4$/tonne, and a paucity of carbonate-minerals (e.g. calcite), as inferred from the lack of "fizzing" upon reaction with HCl.

### 2.2 pH-Buffering Properties

The pH-buffering curves are shown on Figures 1 and 2.

The shape of the pH-buffering curve for sample BP16 (Figure 1) is consistent with that for the consumption of acid by reactive carbonate-minerals (e.g. calcite, aragonite, etc.). The consumption of *c.* 80-90 kg $H_2SO_4$/tonne when the pH=3 end-point was reached is also consistent with the ANC value for this sample.

The shape of the pH-buffering curve for sample BP5 (Figure 2) is consistent with that for a "gutless-groundmass" deficient in carbonate-minerals.

## 3.0 CONCLUSIONS

The testwork results indicate that the location corresponding to sample BP16 comprise calcareous marine-sediments in which reactive carbonate-minerals are an accessory component, and for which alkalinity-forms are readily-available for circum-neutral buffering.

The location corresponding to sample BP5 is deficient in carbonate-minerals.

……..

I trust the above is satisfactory to you.

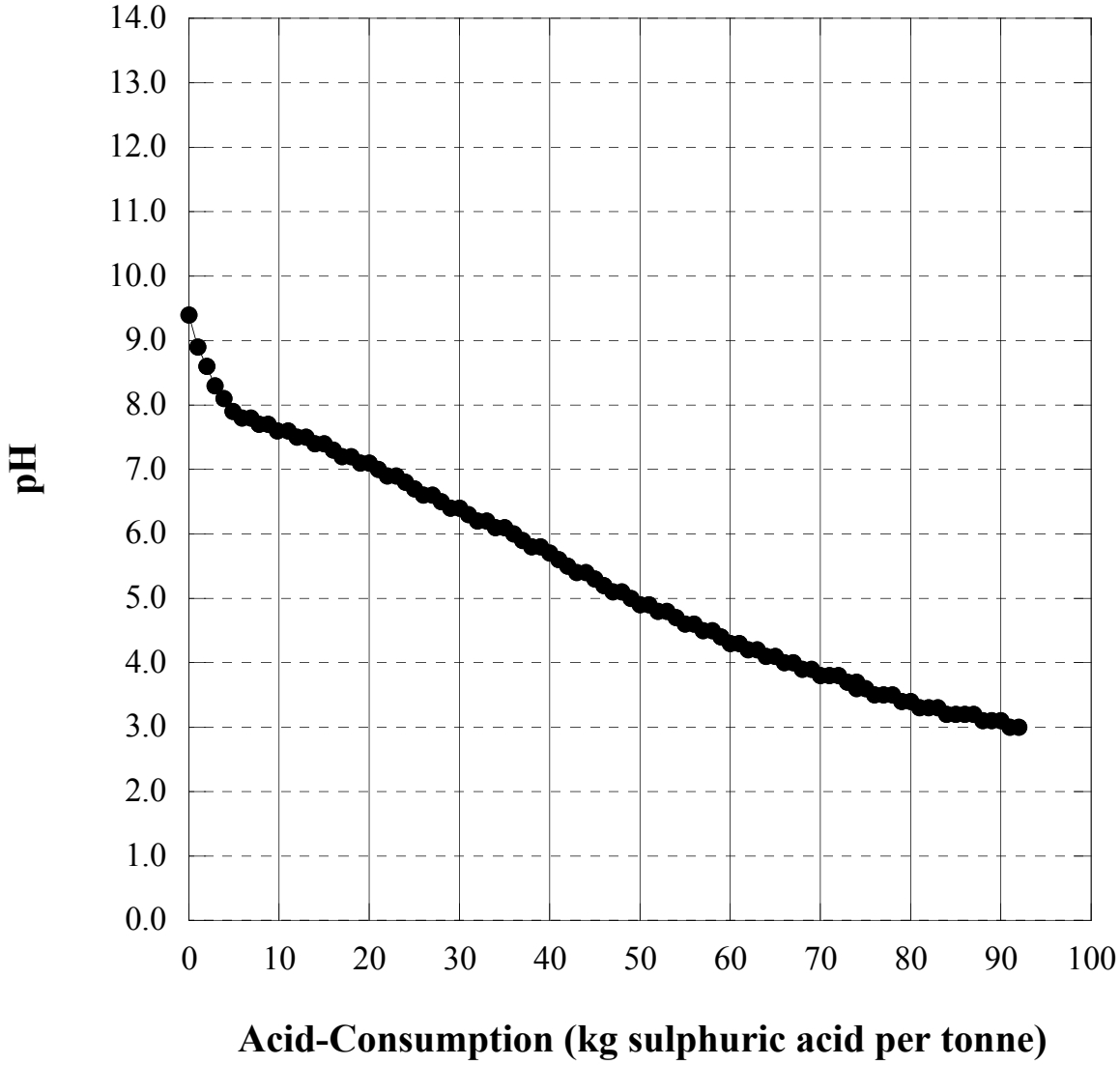
Regards,

**Dr GD Campbell**
**Director**

Encl. Figures (2 pages), and laboratory reports (5 pages).

## Figure 1

## pH-Buffering Curve for Sample B16

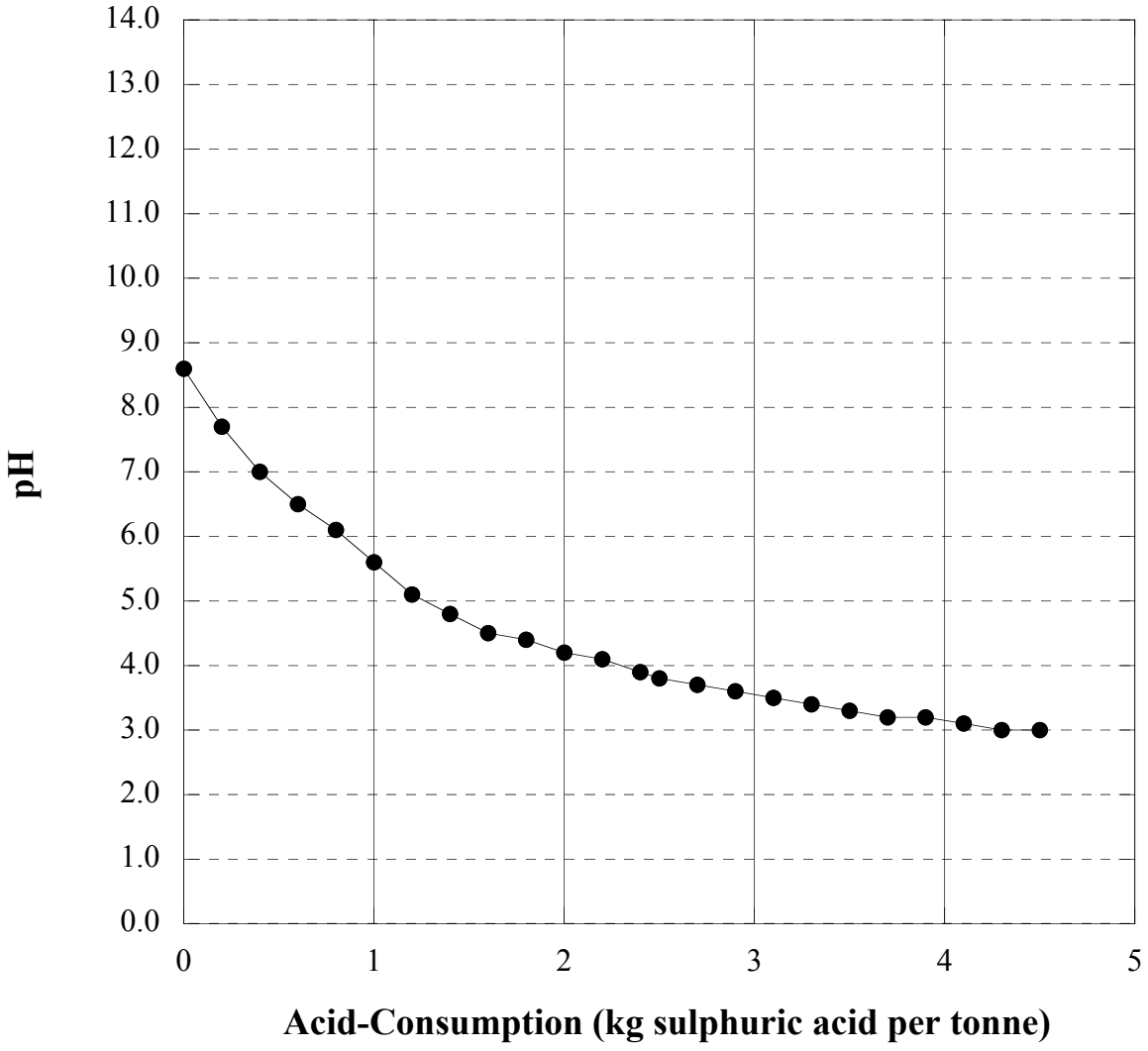



Note: The $H_2SO_4$-addition rate employed in the auto-titration corresponds to a sulphide-oxidation rate (SOR) of *c.* 6-7 x $10^5$ mg $SO_4$/kg/week (= *c.* 3-4 x $10^4$ kg $H_2SO_4$/tonne/year).

This SOR is therefore up to $10^4$-$10^5$ **faster** than that typical for the weathering (at circum-neutral-pH) of soils/sediments, regoliths and bedrocks that contain "minute/trace-sulphides".

## Figure 2

### pH-Buffering Curve for Sample BP5




Note: The $H_2SO_4$-addition rate employed in the auto-titration corresponds to a sulphide-oxidation rate (SOR) of *c.* 1-2 x $10^5$ mg $SO_4$/kg/week (= *c.* 5-6 x $10^3$ kg $H_2SO_4$/tonne/year).

This SOR is therefore up to $10^3$-$10^4$ **faster** than that typical for the weathering (at circum-neutral-pH) of soils/sediments, regoliths and bedrocks that contain "minute/trace-sulphides".

13 January, 2005

Graeme Campbell & Associates Pty Ltd
Attn: Dr G Campbell
PO Box 247
BRIDGETOWN WA 6255

Our Reference: 86294
Your Reference: GCA0417/5
NATA Accreditation: 2562(1705)

Dear Sir

On the 10th January 2005 you forwarded test work instructions for two (2) waste rock samples that were received on the 11th January 2005 at our laboratory.

Results of all test work performed follow:

Acid Neutralisation Capacity (ANC):

| Sample Number | Fizz Rating | Sample Weight (g) | Titre NaOH (mL) | Normality HCl/NaOH (N) | Initial Effervescence | Effervescence on Warming | ANC Solution pH | ANC (kg $H_2SO_4$/tonne) |
|---|---|---|---|---|---|---|---|---|
| BP 5 | 0 | 4.9869 | 19.60 | 0.1 | Nil | Nil | 1.4 | 5.3 |
| BP 16 | 2-3 | 1.9570 | 17.80 | 0.5 | Slight | Nil | 0.7 | 92 |
| RPT BP 16 | 2-3 | 2.0208 | 18.30 | 0.5 | Slight | Nil | 0.7 | 83 |
| ANC Std 20 | - | 1.9935 | 17.20 | 0.1 | - | - | 1.4 | 19 |
| ANC Std 200 | - | 1.4738 | 13.60 | 0.5 | - | - | 0.7 | 191 |

*NOTES:*

1. *Acid neutralisation capacity was determined on the as received crushed sample. Unless otherwise stated, 25mL of HCl is used. Reagent blank titre of 0.5N NaOH was 25.20mL and 0.1N NaOH was 25.00mL.*

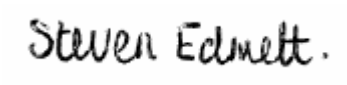
2. *ANC Std20 and Std200 are internally produced standards of $CaCO_3$ and quartz pulped to a nominal 75µm particle size which has nominal ANC of 20kg and 200kg of $H_2SO_4$/tonne, respectively.*

3. *This procedure is based on Sobek et al, 1978.*


SGS Australia Pty Ltd Environmental Services 52 Murray Road, Welshpool 6106 Western Australia www.sgs.com
ABN 44 000 964 278 t +61 8 9458 7278. f + 61 8 9451 3505 Member of the SGS Group

**CLIENT:** **Graeme Campbell & Associates Pty Ltd** **OUR REFERENCE: 86294**
**PROJECT NO:** **GCA0417/5**

Yours faithfully,



STEVEN EDMETT
Client Liaison Manager

JANICE VENNING
Manager, Perth

*This report supersedes our preliminary results sent by facsimile on the 12th January 2005.*

*Graeme Campbell & Associates Pty Ltd*

*Laboratory Report*

# pH-BUFFERING TESTWORK (B16)

| Cumulative Volume of Acid Added (mL) | Cumulative Acid Consumption (kg $H_2SO_4$/tonne) | pH | Cumulative Volume of Acid Added (mL) | Cumulative Acid Consumption (kg $H_2SO_4$/tonne) | pH |
|---|---|---|---|---|---|
| 0.00 | 0.0 | 9.4 | 14.00 | 34 | 6.1 |
| 0.40 | 1.0 | 8.9 | 14.40 | 35 | 6.1 |
| 0.80 | 2.0 | 8.6 | 14.80 | 36 | 6.0 |
| 1.20 | 2.9 | 8.3 | 15.20 | 37 | 5.9 |
| 1.60 | 3.9 | 8.1 | 15.60 | 38 | 5.8 |
| 2.00 | 4.9 | 7.9 | 16.00 | 39 | 5.8 |
| 2.40 | 5.9 | 7.8 | 16.40 | 40 | 5.7 |
| 2.80 | 6.9 | 7.8 | 16.80 | 41 | 5.6 |
| 3.20 | 7.8 | 7.7 | 17.20 | 42 | 5.5 |
| 3.60 | 8.8 | 7.7 | 17.60 | 43 | 5.4 |
| 4.00 | 9.8 | 7.6 | 18.00 | 44 | 5.4 |
| 4.40 | 11 | 7.6 | 18.40 | 45 | 5.3 |
| 4.80 | 12 | 7.5 | 18.80 | 46 | 5.2 |
| 5.20 | 13 | 7.5 | 19.20 | 47 | 5.1 |
| 5.60 | 14 | 7.4 | 19.60 | 48 | 5.1 |
| 6.00 | 15 | 7.4 | 20.00 | 49 | 5.0 |
| 6.40 | 16 | 7.3 | 20.40 | 50 | 4.9 |
| 6.80 | 17 | 7.2 | 20.80 | 51 | 4.9 |
| 7.20 | 18 | 7.2 | 21.20 | 52 | 4.8 |
| 7.60 | 19 | 7.1 | 21.60 | 53 | 4.8 |
| 8.00 | 20 | 7.1 | 22.00 | 54 | 4.7 |
| 8.40 | 21 | 7.0 | 22.40 | 55 | 4.6 |
| 8.80 | 22 | 6.9 | 22.80 | 56 | 4.6 |
| 9.20 | 23 | 6.9 | 23.20 | 57 | 4.5 |
| 9.60 | 24 | 6.8 | 23.60 | 58 | 4.5 |
| 10.00 | 25 | 6.7 | 24.00 | 59 | 4.4 |
| 10.40 | 25 | 6.7 | 24.40 | 60 | 4.3 |
| 10.80 | 26 | 6.6 | 24.80 | 61 | 4.3 |
| 11.20 | 27 | 6.6 | 25.20 | 62 | 4.2 |
| 11.60 | 28 | 6.5 | 25.60 | 63 | 4.2 |
| 12.00 | 29 | 6.4 | 26.00 | 64 | 4.1 |
| 12.40 | 30 | 6.4 | 26.40 | 65 | 4.1 |
| 12.80 | 31 | 6.3 | 26.80 | 66 | 4.0 |
| 13.20 | 32 | 6.2 | 27.20 | 67 | 4.0 |
| 13.60 | 33 | 6.2 | 27.60 | 68 | 3.9 |

| Cumulative Volume of Acid Added (mL) | Cumulative Acid Consumption (kg $H_2SO_4$/tonne) | pH |
|---|---|---|
| 28.00 | 69 | 3.9 |
| 28.40 | 70 | 3.8 |
| 28.80 | 71 | 3.8 |
| 29.20 | 72 | 3.8 |
| 29.60 | 73 | 3.7 |
| 30.00 | 74 | 3.7 |
| 30.40 | 74 | 3.6 |
| 30.80 | 75 | 3.6 |
| 31.20 | 76 | 3.5 |
| 31.60 | 77 | 3.5 |
| 32.00 | 78 | 3.5 |
| 32.40 | 79 | 3.4 |
| 32.80 | 80 | 3.4 |
| 33.20 | 81 | 3.3 |
| 33.60 | 82 | 3.3 |
| 34.00 | 83 | 3.3 |
| 34.40 | 84 | 3.2 |
| 34.80 | 85 | 3.2 |
| 35.20 | 86 | 3.2 |
| 35.60 | 87 | 3.2 |
| 36.00 | 88 | 3.1 |
| 36.40 | 89 | 3.1 |
| 36.80 | 90 | 3.1 |
| 37.20 | 91 | 3.0 |
| 37.60 | 92 | 3.0 |

**Note:** Titration performed using a Metrohm® 736 Titrino auto-titrator, and 0.05 M-$H_2SO_4$. Equilibration time between titrant additions was 15 minutes. 2.0 g of crushed (*c.* 2-3 mm), oven-dried (80 $^0$C) sample initially dispersed in 150 mL of deionised-water.
Test mixture in contact with air, at ambient temperature, and continuously stirred.
Calibration of pH-Glass Electrode:
Immediately prior to titration: asymmetry potential = -12 mV (pH=7.00); slope-point = 163 mV (pH=4.00); 99.0 % of Nernstian response for 25 $^o$C.
Immediately following titration: pH=7.00 buffer read pH=7.02 and pH=4.00 buffer read pH=4.03. These discrepancies represent drift in pH-Glass electrode response during course of auto-titration.

**Dr GD Campbell**
**10th January 2005**

*Graeme Campbell & Associates Pty Ltd*

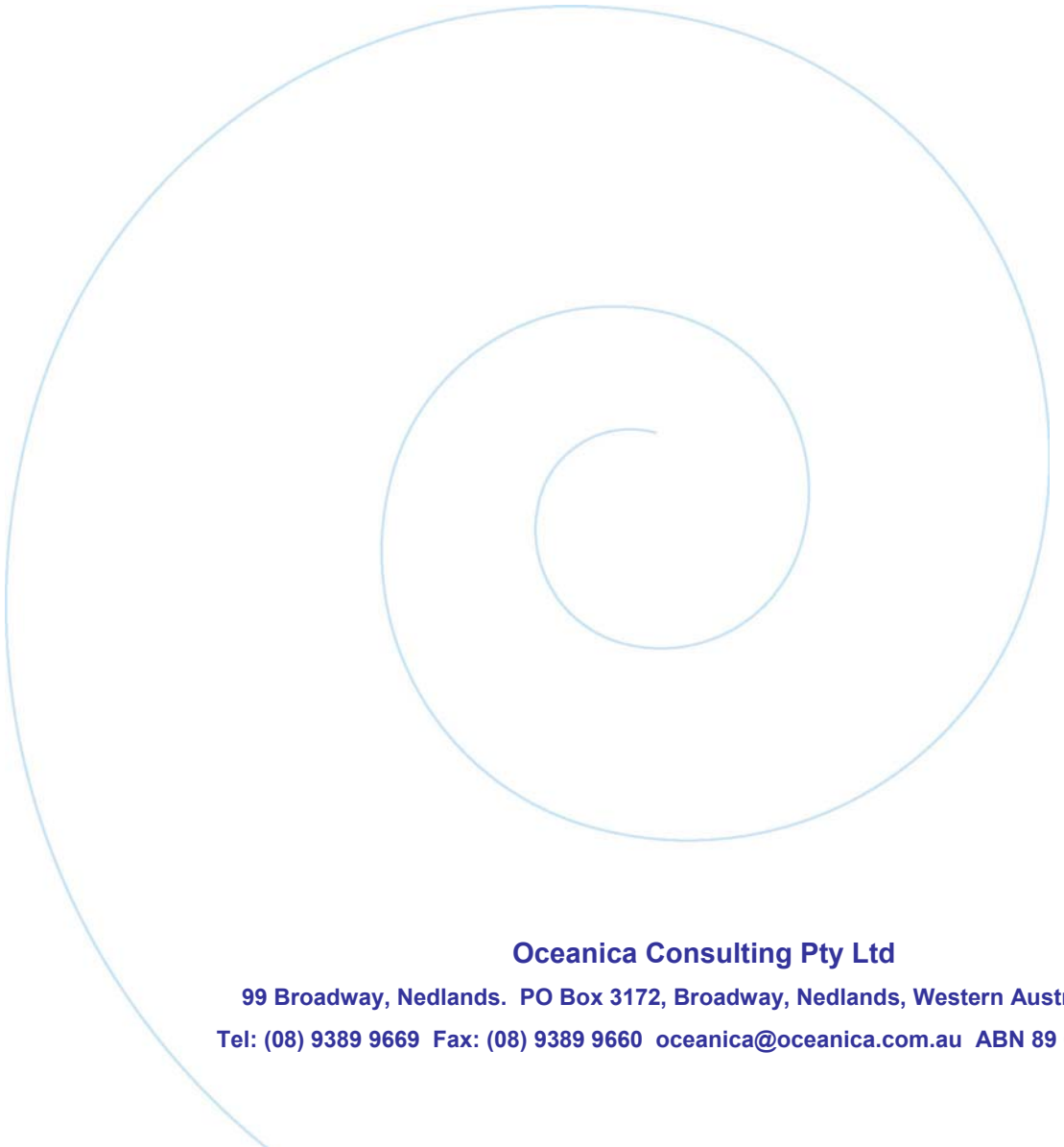
*Laboratory Report*

# pH-BUFFERING TESTWORK (B5)

| Cumulative Volume of Acid Added (mL) | Cumulative Acid Consumption (kg $H_2SO_4$/tonne) | pH |
|---|---|---|
| 0.00 | 0.0 | 8.6 |
| 0.40 | 0.2 | 7.7 |
| 0.80 | 0.4 | 7.0 |
| 1.20 | 0.6 | 6.5 |
| 1.60 | 0.8 | 6.1 |
| 2.00 | 1.0 | 5.6 |
| 2.40 | 1.2 | 5.1 |
| 2.80 | 1.4 | 4.8 |
| 3.20 | 1.6 | 4.5 |
| 3.60 | 1.8 | 4.4 |
| 4.00 | 2.0 | 4.2 |
| 4.40 | 2.2 | 4.1 |
| 4.80 | 2.4 | 3.9 |
| 5.20 | 2.5 | 3.8 |
| 5.60 | 2.7 | 3.7 |
| 6.00 | 2.9 | 3.6 |
| 6.40 | 3.1 | 3.5 |
| 6.80 | 3.3 | 3.4 |
| 7.20 | 3.5 | 3.3 |
| 7.60 | 3.7 | 3.2 |
| 8.00 | 3.9 | 3.2 |
| 8.40 | 4.1 | 3.1 |
| 8.80 | 4.3 | 3.0 |
| 9.20 | 4.5 | 3.0 |

**Note:** Titration performed using a Metrohm® 736 Titrino auto-titrator, and 0.05 M-$H_2SO_4$. Equilibration time between titrant additions was 15 minutes. 10.0 g of crushed (*c.* 2-3 mm), oven-dried (80 $^0$C) sample initially dispersed in 150 mL of deionised-water.
Test mixture in contact with air, at ambient temperature, and continuously stirred.
Calibration of pH-Glass Electrode:
Immediately prior to titration: asymmetry potential = -21 mV (pH=7.00); slope-point = 155 mV (pH=4.00); 99.6 % of Nernstian response for 25 $^o$C.
Immediately following titration: pH=7.00 buffer read pH=7.02 and pH=4.00 buffer read pH=4.03. These discrepancies represent drift in pH-Glass electrode response during course of auto-titration.

**Dr GD Campbell**
**15th January 2005**



**Oceanica Consulting Pty Ltd**

**99 Broadway, Nedlands. PO Box 3172, Broadway, Nedlands, Western Australia 6009**

**Tel: (08) 9389 9669 Fax: (08) 9389 9660 oceanica@oceanica.com.au ABN 89 093 752 811**