PORT OF **WEIPA**

APPENDIX F

Sediment properties report

Sediment Properties Report

Port of Weipa and Amrun

18/07/18

Level 31, 12 Creek St
Brisbane QLD 4000
Australia

301001- 02056-00-EN-REP-0002

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Synopsis

Purpose of study

The purpose of this study was to identify and classify marine sediment materials and investigate their acid generating capacity and geotechnical properties for subsequent consideration of potential beneficial reuse options. The study included sampling and analysis of sediments from locations within Port of Weipa and Amrun navigational areas.

Broad study approach

Representative samples were collected from all Port navigational areas in February 2018. Laboratory analysis was conducted to determine:

- Particle size distribution (sieve and hydrometer)
- Carbonate content
- Moisture content
- Atterberg limits and linear shrinkage
- Particle density (specific gravity)
- Uncompacted and compacted bulk density
- Minimum / maximum density
- Direct shear box (100mm) – Single Stage
- Consolidated undrained (CU) triaxial – Three Stage
- 1D consolidation (eight loadings)
- Constant head permeability
- Falling head permeability
- Acid Sulfate Soils presence/potential
- X-ray diffraction
- X-ray fluorescence

Key findings – Port of Weipa

- Naturally accumulating material encountered in the Port of Weipa navigational areas varied considerably between and within areas with typically high fines (clay and silt) content.
- The areas where coarse-grained sediments appear to prevail include most of the Approach and Departure Channel and the eastern portion of the Southern Channel.
- The fine-grained sediments may be suitable for low to medium load applications following adequate drying out and compaction, noting that this material may take many months to many years to consolidate, dependent on drainage path length.
- The coarser sediments may be suitable for medium to high loading applications following adequate compaction.
- Poor drainage characteristics were reported for the silt / clay samples and good drainage characteristics for the sand samples.

- The relatively high water and fines contents would limit the use of sediments in high end concrete products; however, the areas with relatively low fines, and high silica and sand content could be useful (with treatment) as an alternative source of fine sand in some concrete and concrete products.
- Potential Acid Sulphate Soil (PASS) was detected in all samples; however, analysis of the Acid Neutralising Capacity (ANC) of these samples indicated that if bought ashore, the marine sediments are unlikely to require treatment via neutralisation with lime.
- All samples are considered highly saline and therefore if sediments are placed on land without treatment, salinity will degrade the quality of terrestrial soils and may impact the quality of receiving waters.

Key findings – Amrun Port

- Naturally accumulating material encountered in Amrun Port were predominately silts and clays with relatively high fines contents of greater than 80%.
- The sediments contain high plasticity silt and clay, and strength tests suggest that these fine-grained sediments may be suitable for low to medium load applications following adequate drying out and compaction, noting that this material may take many months to many years to consolidate, dependent on drainage path length.
- The sediments were very wet muds with excessive fines, and it is considered that these sediments would not easily be used in concrete products.
- Potential Acid Sulphate Soil (PASS) was detected in all samples; however, analysis of the Acid Neutralising Capacity (ANC) of these samples indicated that if bought ashore, the marine sediments are unlikely to require treatment via neutralisation with lime.
- All samples are considered highly saline and therefore if sediments are placed on land without treatment, salinity will degrade the quality of terrestrial soils and may impact the quality of receiving waters.

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Executive summary

The purpose of this investigation was to identify and classify marine sediment materials and investigate their acid generating capacity and geotechnical properties for subsequent consideration of potential beneficial reuse options. The investigation included sampling and analysis of sediments from locations within Port of Weipa and Amrun navigational areas.

Geotechnical testing

The geotechnical testing was undertaken using a phased approach. Phase 1 comprised general classification testing to determine characteristics such as particle size, moisture content, carbonate content and plasticity. From the field samples taken, 24 samples were selected for Phase 1 analysis to ensure adequate coverage across the range of material types observed from both Port of Weipa and Amrun areas. Phase 2 testing was undertaken on a subset of samples which were selected for analysis based on the Phase 1 results, and to assess more detailed engineering properties including permeability, density, strength and consolidation.

Port of Weipa

The sediments encountered in the Port of Weipa navigational areas varied considerably between and within areas with typically high fines (clay and silt) content. The areas where coarse-grained sediments appear to prevail include most of the Approach Channel and the western portion of the Southern Channel. The Departure Channel contains both fine-grained and coarse-grained materials. Zones of coarse-grained sediment were present within the berth areas, particularly at Evan’s Landing and Lorim Point where clayey sand / gravel materials were identified.

The carbonate content testing indicated a range of results across all areas (between 8% and 57%); however, only one test result was greater than 50% carbonate content. Based on this, the sediments may be generally considered “calcareous soils”.

Atterberg limits testing (liquid limit and plastic limit) is designed to reflect the influence of water content, grain size and mineral composition on the mechanical behaviour of clays and silts. The plasticity of the sediments is relatively variable across the sites. The fine-grained sediments range from low to high plasticity clay and low to high plasticity silt, with many samples falling close to the “A-Line”, meaning that these materials will exhibit engineering behaviour bordering between that of silt and clay.

Linear shrinkage results indicate a generally low potential for volume change for most of the materials tested, with a medium / medium to high potential for volume change indicated by a sample in the Southern Channel and a combined sample from the Tug Berths. The weighted plasticity index (WPI) was calculated and used to estimate the Volume Change Classification based on the method proposed by Look (1994). The Volume Change Classification for the sediments ranges from “very low” to “low” in general, “moderate” in places and “high” for a combined sample from the Tug Berths.

The sediment particle densities ranged between 2.51 t/m^3 and 2.63 t/m^3 across the Port of Weipa.

Bulk density testing was undertaken to provide an indication of the densities that may be achieved during future placement of the dredged sediments. The samples were dried to a moisture content of 25% before being tested in both the "uncompacted" and "compacted" states. The results suggest that only relatively low dry densities (1.12 t/m^3 to 1.37 t/m^3) can be achieved for the dredge sediments; however, a higher range of dry densities (1.42 t/m^3 to 1.81 t/m^3) was able to be achieved during the other Phase 2 laboratory tests on remoulded samples. Minimum / maximum dry density testing was performed on four sand / silty sand samples from the Approach, Departure and Southern Channel. The results indicate that the dry densities of the coarse-grained dredge sediments will range between approximately 1.22 t/m^3 and 1.81 t/m^3, depending on the level of compaction or method of placement utilised onshore. As expected, as the fines content increases the density decreases. The minimum and maximum dry density of the material can be used to assess compaction criteria for the dredged material.

Strength and consolidation tests were undertaken on samples of remoulded and moisture conditioned sediments to provide indicative parameters for the dredged materials following reworking and field placement. Direct shear testing was undertaken on four samples of sand / silty sand from the Port of Weipa to measure the angle of internal friction of the sediment. The test results indicate that the coarse-grained sediments may achieve friction angles of 33° to 44° after compaction and loading. These values are within the range generally associated with medium dense to very dense sand deposits and suggest that the coarse-grained sediments may be suitable for medium to high loading applications following adequate compaction.

Consolidated undrained (CU) triaxial testing was undertaken on two samples of silt / clay and two samples of sandy silt to measure effective cohesion and effective friction angle of the fine-grained sediments. Prior to testing, the samples were dried back to a moisture content of 25% to 30% and remoulded to a target density of 1.5 tm/^{3}. The test results indicate that the average cohesion (c') of the samples after compaction and loading ranges from 3 kPa to 13 kPa, and the average friction angle ranges from 33° to 36°. These strengths suggest that the fine-grained sediments may be suitable for low to medium load applications following adequate drying out and compaction.

The four samples selected for CU triaxial testing were also subjected to 1-dimensional consolidation (oedometer) testing to measure the consolidation parameters of the fine-grained sediments. Prior to testing, the samples were dried back to a moisture content of 25% to 30% and remoulded to a target dry density of 1.5 t/m^3. The coefficient of consolidation (c_v) values for the three samples with high fines content (Southern Channel, Humbug and Tug Berth samples) are within the typical range expected for clays and silts, and the results for the remaining sample (Approach Channel) are within the range expected for a sandy silt. The c_v values for the samples with high fines content indicate that this material may take many months to many years to consolidate, dependent on drainage path length; albeit that consolidation times can vary significantly and can be better estimated by undertaking field trials (e.g. trial embankment with wick drains and surcharge).

To provide an indication of the post-compaction permeability of the dredged sediments, permeability testing was carried out on eight of the Phase 2 samples from the Port of Weipa, including four coarse-grained samples (constant head permeability test) and three fine-grained samples (falling head permeability test). The permeability test results are generally within the range expected for the types of sediments tested, with "poor" drainage characteristics being reported for the silt / clay samples and "good" drainage characteristics for the sand samples. The only exception to this was an Approach Channel sample (37% fines content, i.e. borderline sandy silt / silty sand), which behaved more like a sand with few fines rather than a sandy silt / silty sand material.

In addition to the geotechnical testing, cement laboratory testing was undertaken on four samples from the Port of Weipa to determine the binding characteristics of the sediments and assess their suitability as a binding agent in cement products. Summary results include:

- Most of the samples tested had a relatively high water and fines contents, which would limit their use in high end concrete products.
- Humbug and Lorim Point sediments may be suitable for use in flowable fill applications; however, additional testing on larger samples of the target material would be required to examine the effectiveness of stabilisation when mixed with Portland Cement.
- The Southern Channel sediments with relatively low fines, and high silica and sand content could be useful as an alternative source of normal fine sand in concrete and concrete products. For general premixed concrete use, the fines and relatively high level of chlorides present would need to be washed. This fine sand would typically be used at a rate of 200kg per m^3 of concrete (or <10% by weight). For other concrete uses (blocks or flowable fill) where reinforcement is not present, it could be used at substantially higher levels, with less pre-treatment. The Southern Channel sediments with excessive fines would not easily be used in concrete products.

Amrun Port

The sediments encountered in Amrun Port (Approaches and Berths) were predominately silts and clays with relatively high fines content. The carbonate content test results ranged between 33.2% and 35.3%, indicating that these sediments may be considered "calcareous soils".

Atterberg limits testing (liquid limit and plastic limit) indicated that the Amrun sediments contain high plasticity silt and clay.

Linear shrinkage results indicate a low to medium potential for volume change for the materials tested. The WPI was calculated and used to estimate the Volume Change Classification using the same method as the Port of Weipa samples. The Volume Change Classification for the Amrun sediments ranges from "low" to "moderate".

The sediment particle densities ranged between 2.53 t/m^3 and 2.60 t/m^3 at Amrun Port. Bulk density testing was undertaken using the same method as for the Port of Weipa samples. The results suggest that only relatively low dry densities (1.13 t/m^3 to 1.21 t/m^3) can be achieved for the Amrun dredge sediments; however, dry densities of 1.49 t/m^3 to 1.50 t/m^3 were able to be achieved during the other Phase 2 laboratory tests on remoulded samples. No minimum / maximum dry density testing or direct shear testing was carried out on the Amrun Port samples due to the fine-grained nature of the sediments.

The CU triaxial testing was undertaken on a single sample from Amrun Port. Prior to testing, the sample was dried back to a moisture content of 25% to 30% and remoulded to a target density of 1.5 tm/^{3}. The test results indicate that the cohesion (c') of the sediment after compaction and loading is approximately 10 kPa and the friction angle is approximately 29°. This strength suggests that the fine-grained sediments at Amrun Port may be suitable for low to medium load applications following adequate drying out and compaction.

The Amrun sample was also subjected to oedometer testing. Prior to testing, the sample was dried back to a moisture content of 25% to 30% and remoulded to a target dry density of 1.5 t/m^3. The coefficient of consolidation (c_v) values for the Amrun sample is within the typical range expected for clay / silt. The c_v value for the Amrun sediment sampled indicates that this material may take many months to many years to consolidate dependent on drainage path length. As noted above, consolidation times can vary significantly.

No permeability testing was carried out for the material from Amrun Port; however the test results for similar materials from the Port of Weipa are considered likely applicable to the Amrun sediments i.e. "poor" drainage characteristics for the silt / clay samples at Amrun.

Cement laboratory testing was undertaken on two samples from the Amrun Port. The Amrun sediments were very wet muds with excessive fines, and it is considered that these sediments would not easily be used in concrete products.

Geochemical testing

Based on the Acid Sulfate Soils (ASS) analysis, Potential Acid Sulfate Soils (PASS), in concentrations greater than the Queensland Acid Sulfate Soil Technical Manual (QASSIT) action criteria of 0.03% and 18 moles H+ / t, was detected in all samples analysed for ASS parameters from the navigational areas of the Port of Weipa and Amrun. Samples with the highest chromium suite of analysis (S_{CR}) concentrations (i.e. >100 moles H+ / t) were samples where the predominant component was silt and/or clay (i.e. Southern Channel, Tug Berth and Amrun samples).

Acid Neutralising Capacity (ANC) was detected in all samples submitted for ASS analysis with concentrations sufficient to negate acidity i.e. net acidity was less than the laboratory practical quantitation limit (PQL) of 10 moles H+ / t and therefore below the QASSIT guideline of 18 moles H+ / t. This buffering potential is expected to arise from the presence of carbonate within the sediments. These data indicate that the marine sediments from the Port of Weipa and Amrun may not require treatment through neutralisation using lime, dependent on the dredging and management methods applied to the sediments.

All samples are considered highly saline. If sediments are placed on land without treatment, salinity will degrade the quality of terrestrial soils and may impact the quality of receiving waters.

Low Organic Material (OM) was reported for all samples analysed. The highest OM (i.e. >3%) was detected in finer textured samples. Samples with a gravel component had the lowest OM, <1%.

1 Introduction

The Port of Weipa is located within Albatross Bay in the Gulf of Carpentaria, on the North-West coast of Cape York Peninsula (Figure 1-1). North Queensland Bulk Ports (NQBP) manages the Port of Weipa which consists of a main shipping channel in Albatross Bay (South Channel) and an Inner Harbour. The Inner Harbour consists of four shipping berths, namely Lorim Point (two berths), Humbug Wharf and Evans Landing. The Inner Harbour also includes an inner Approach Channel and an inner Departure Channel (Figure 1-1).

Rio Tinto Alcan (RTA) is currently proceeding with the Amrun Project, which will see the expansion of its bauxite reserves south of the Embley River and new port facilities constructed at Boyd Point. This project is expected to commence production and export by mid-2019.

NQBP has commenced work on a strategic assessment for ongoing management of marine sediments at the Port of Weipa and Amrun known as the Port of Weipa - Sustainable Sediment Management (SSM) Assessment for Navigational Maintenance ('The SSM Project'). As part of the SSM Project, NQBP commissioned Advisian to assess the properties of marine sediment that naturally accumulate in the navigational areas of the Port of Weipa and Amrun (maintenance material) and undertake an investigation of options for beneficial reuse of the marine sediments.

Advisian's work for the SSM project has been undertaken as a two-phased approach:

1. A sampling and analysis program to assess the geotechnical engineering and Acid Sulfate Soil (ASS) properties of marine sediments recently deposited within the navigational areas at the Port of Weipa and Amrun.

2. Comprehensive identification and analysis of beneficial reuse options for the maintenance material marine sediments.

This report provides a description of the works undertaken to complete the first phase of the program and the associated results as a factual report of marine sediment properties for the maintenance material.

1.1 Purpose

The purpose of the marine sediment properties assessment is to identify and classify marine sediment materials and to investigate their acid generating capacity and geotechnical properties in order to facilitate subsequent consideration of potential beneficial reuse options.

1.2 Scope of work

The marine sediment properties assessment scope of works included the following:

- Review of historical acid sulfate and geotechnical information pertaining to the sampling areas

- Collection of sediment grabs from locations across Port of Weipa dredge areas including the Southern Channel (including channel extension), inner Approach and Departure channels, Lorim Point Wharf and Tug Berths, Humbug Wharf and Evans Landing along with Amrun Port
- Description (log), photographing and collection of sediment samples and subsequent dispatch to laboratory for analysis and testing
- Laboratory analysis of ASS and geotechnical properties of the marine sediment
- Summary and tabulation of the results of the laboratory analysis and testing
- Preparation of this marine sediment properties report.

1.3 Guidelines and standards

The Department of Environment and Science (DES) is the custodian of comprehensive guidelines for ASS management, sampling and analysis. These guidelines also provide technical and procedural advice to avoid environmental harm and achieve best practice environmental management. They include:

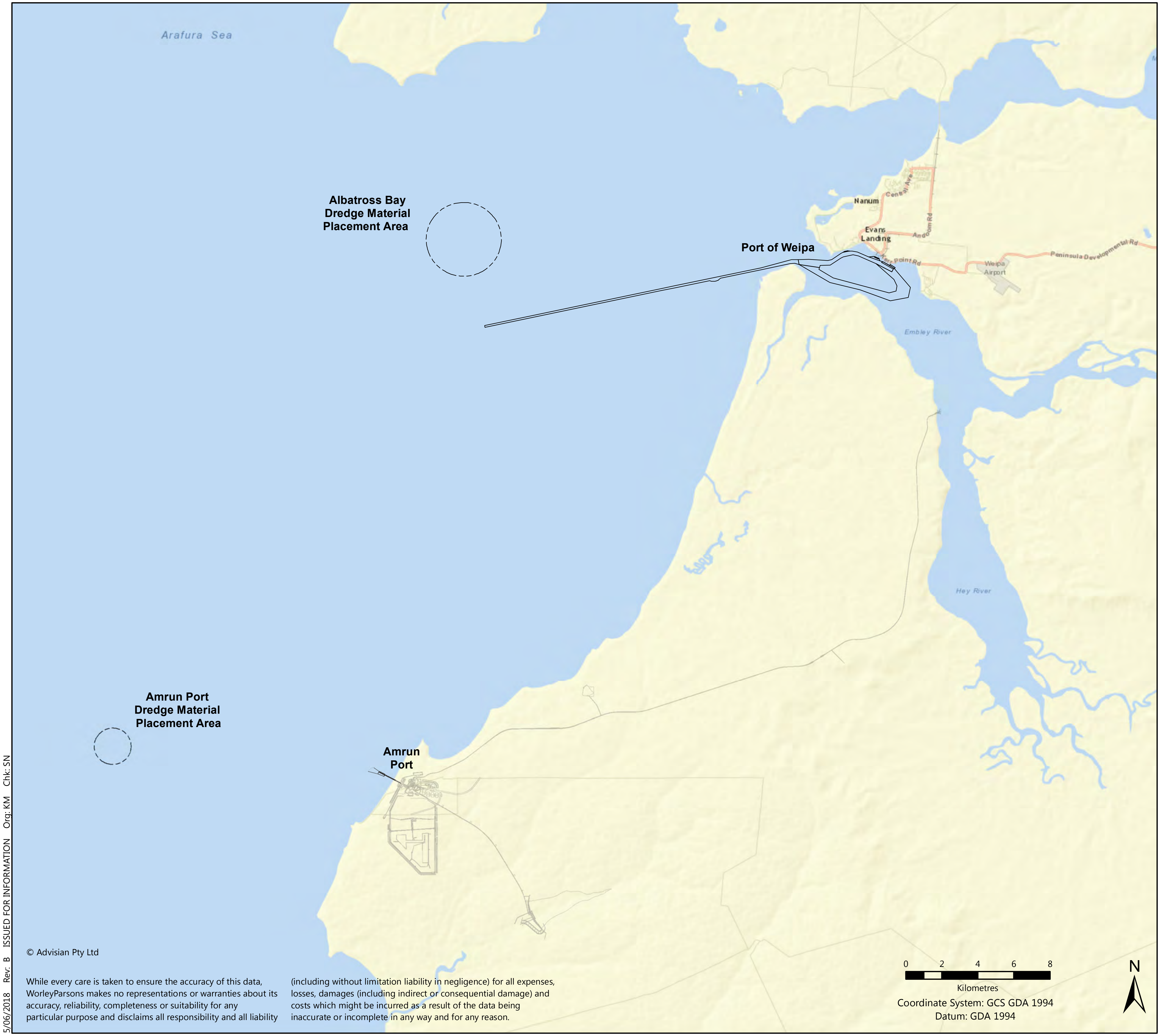
- Queensland Acid Sulfate Soil Technical Manual – Legislation and Policy Guide, version 2.2 (Dear *et al.*, 2004)
- Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland 1998, version 4.0 (Ahern *et al.*, 1998)
- Queensland Acid Sulfate Soil Technical Manual – Soil Management Guidelines, 2002, version 3.8 (Dear *et al.*, 2002)
- Queensland Acid Sulfate Soil Technical Manual Acid Sulfate Soils – Laboratory Methods Guidelines, 2004, version 2.1 (Ahern *et al.*, 2004).

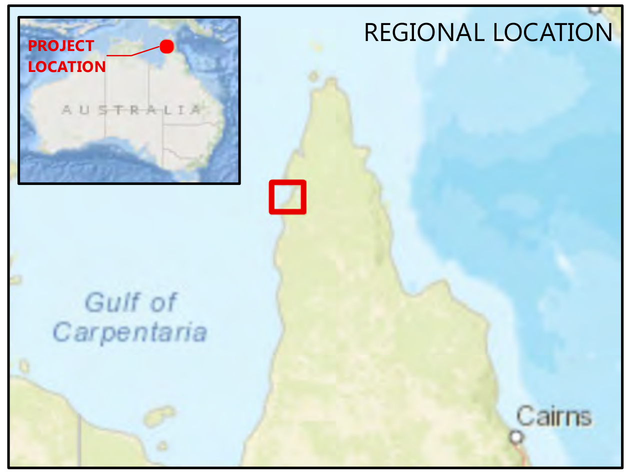
In addition to the above the following guidelines and standards were used to inform the sediment assessment method for geotechnical assessment:

- Australian Standard (AS) 1726-2017: Geotechnical site investigations.

Sediment Properties Report 2018

Figure 1-1: Project Locality





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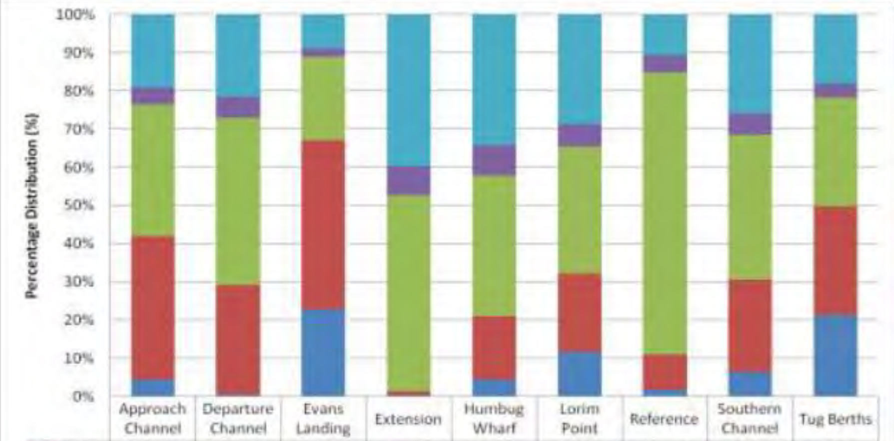
2 Previous studies

A succession of sediment contamination surveys for dredging operations in the Port of Weipa has been conducted over the last seventeen years. NQBP has commissioned multiple assessments in preparation for the 2000, 2002, 2003, 2004, 2005 and 2009 and 2013 maintenance dredging campaigns, as well as the 2006/2007 capital dredging campaign and the extension of the Southern Channel during 2012. These investigations have typically focused on potential contaminants in accordance with the National Assessment Guidelines for Dredging (NAGD, 2009) or previously applied guidelines (National Ocean Disposal Guidelines for Dredged Material, 2002). Of note, Particle Size Distribution (PSD) analysis is a component of contaminant studies and this component is most useful for this assessment with relevant information summarised in Table 2-1.

Table 2-1: Summary of contaminant studies information relevant to this report

Report reference	Relevant information
Rio Tinto, 2017	This report includes particle size, moisture content and particle density testing for capital dredge material for the Amrun Port. According to Rio Tinto, the Amrun dredge footprint sediments were dominated by silt and clay fractions, representing ~86% of the sediment to be dredged. The remaining 14% of sediments comprised 13% sand and 1% gravel. Sediment moisture within the dredge footprint ranged from 46% to 72%, with an average of 61%.
Maintenance Dredging Characterisation Report 2013	This document reported particle size percentage distribution (%) of gravel, sand, silt, clay and sub-clay fractions for eight dredge areas and reference locations (illustrated below). Overall, targeted sediments presented a makeup of silts (40.2%), sand (23.4%) and sub-clay fractions (22.9%), gravels (8.2%) and clay (5.3%). The extension presented the greatest distribution of fine silts, clays and sub-clay fractions, approaching 100%. The Southern Channel, Approaches, Departure Channel, Humbug and Lorim point ranged between ~60% and 80% fine sediments. Gravels and sands were larger in quantity at Evans Landing and the Tug Berths ranging ~50% to 65%.

Report reference	Relevant information



	Approach Channel	Departure Channel	Evans Landing	Extension	Humbug Wharf	Lorim Point	Reference	Southern Channel	Tug Berths
Sub-clay	19.00	21.45	8.81	39.76	34.22	28.70	10.69	25.84	17.94
Clay	4.47	5.54	2.21	7.41	8.00	5.83	4.56	5.65	3.85
Silt	34.37	43.82	21.97	51.40	36.69	33.21	73.72	37.87	28.44
Sand	37.78	28.62	44.16	0.98	16.72	20.61	9.24	24.23	28.28
Gravel	4.37	0.56	22.85	0.44	4.38	11.65	1.79	6.41	21.49

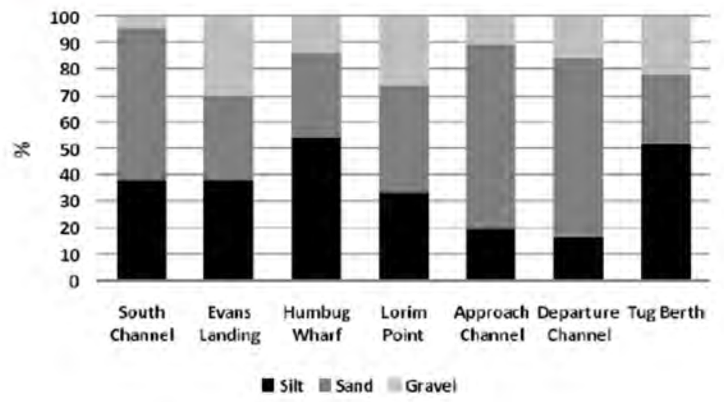
Maintenance Dredging Characterisation Report 2008

This document reported the findings of particle size percentage distribution (%) of gravel, sand, silt, clay and sub-clay fractions for seven dredge areas. The data represented a total of 81 samples and was collated during the 2008 sediment characterisation program by SKM (2008). Results indicate dredged sediments are primarily comprised of medium to fine grained sands (~51%) and a silt and clay fraction (~37%). Coarse sands and gravels make up the remainder (~13%).

Material from the South Channel, where most dredged material was to be removed, consisted mainly of sand and gravel, with only a small amount of fine silts. The approach and departure channels were comprised of a similar composition of grain sizes, having slightly more fine silts. The shipping berths had lower sand content and higher fine silt content. A summary of the PSD information from the report, including a weighted average of sediment fractions from all dredged areas is shown below.

Report reference	Relevant information

Gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Coarse silt	Fine silts and clays
6%	3%	4%	11%	17%	23%	7%	30%



Report reference	Relevant information
Capital Dredging Environmental Impact Statement and SAP 2005	This documentation reported the findings of particle size percentage distribution (%) of gravel, sand and mud for ten areas. Particle size distribution (PSD) analysis showed that, on average, 66 – 67% of the material to be dredged was in the sand fraction (0.075 – 2.36 mm), with 20 – 25% of the remaining material being in the finer silt and clay fraction (<0.075 mm). Summary information for the dredge areas is provided below.

Report reference	Relevant information

Sampling location	Laboratory Id	% Gravel (> 2mm)	% Sand (0.075 - 2 mm)	% Mud* (< 0.075 mm)
Lorim Point Wharf				
LP2A	A05/0379-A/10	0.4	12.3	87.3
LP3A	A05/0379-A/20	0.3	9.1	90.6
LP4A	A05/0379-A/12	1.1	12.8	86.1
LP5A	A05/0379-A/14	77.8	6.3	15.9
LP2B	A05/0379-A/44	30.1	26.0	43.8
LP3B	A05/0379-A/46	2.8	10.4	86.7
LP4B	A05/0379-A/36	0.7	13.3	86.0
LP5B	A05/0379-A/38	3.5	23.7	72.8
LP5B (QC3)	A05/0379-A/40	4.2	27.6	68.2
LP5B (QC4)	A05/0379-A/41	4.7	25.4	70.0
Approach Channel				
LPE3	A05/0379-A3	1.6	39.1	59.4
Entrance Channel				
CH27	A05/0379-A/5	8.0	88.6	3.5
South Channel				
CH17	A05/0379-A/4	2.2	94.3	3.4
CH9	A05/0379-A/9	0.9	36.1	63.0
CH8	A05/0379-A/35	0.7	15.5	83.8

Report reference	Relevant information

Sampling location	Laboratory Id	% Gravel (> 2mm)	% Sand (0.075 - 2 mm)	% Mud* (< 0.075 mm)
CH4	A05/0379-A/34	0.7	7.1	92.1
Evans Landing Berth				
ELA	A05/0379-A/22	2.7	24.9	72.4
ELA (QC1)	A05/0379-A/24	1.4	26.1	72.5
ELA (QC2)	A05/0379-A/25	4.0	29.7	66.3
ELB	A05/0379-A/26	0.0	8.0	92.0
ELC	A05/0379-A/16	66.2	18.2	15.6
ELD	A05/0379-A/18	6.1	31.8	62.1
Humbug Wharf				
HWA	A05/0379-A/1	1.7	25.3	73.0
HWB	A05/0379-A/43	11.2	48.2	40.6
HWC	A05/0379-A/42	9.5	36.8	53.7
HWD	A05/0379-A/2	0.1	8.7	91.1
Spoil Ground				
AB1	A05/0379-A/28	6.6	42.8	50.6
AB1 (QC7)	A05/0379-A/29	6.5	50.3	43.2
AB1 (QC8)	A05/0379-A/30	5.0	35.0	59.9
Control Site (Albatross Bay)				
CS1	A05/0379-A/31	1.1	22.9	75.9
CS1 (QC9)	A05/0379-A/32	4.8	31.0	64.2
CS1 (QC10)	A05/0379-A/33	1.9	22.4	75.8
Control Site (Embley-Estuary)				
CS2	A05/0379-A/6	1.7	59.8	38.4
CS2 (QC5)	A05/0379-A/7	2.3	74.1	23.6
CS2 (QC6)	A05/0379-A/8	1.9	72.4	25.6
Tug Berth				
TB1	A05/0379-C/1	0.0	15.0	85.0
TB2	A05/0379-C/2	3.2	23.1	73.7
TB3	A05/0379-C/3	3.5	17.7	78.8
TB4	A05/0379-C/4	0.4	6.9	92.6
Averages (all samples)		7.2	30.2	62.6

* % Mud = % clay + % silt + % very fine sand

Maintenance Dredging SAP 2004	This document reported the findings of particle size percentage distribution (%) of gravel, sand and mud for nine areas. Averages for the Lorim Point Wharf and Evans Landing Wharf samples of this study (if considered together), were 59% mud, 27% sand and 14% gravel. Lorim Point Wharf samples typically contained higher levels of gravel (being mostly bauxite material) than did samples from Evans Landing and Humbug wharves. South channel samples were found to have an average gravel of very much less than 1%, 23% sand and 77% mud. Interestingly, of the non-gravel fraction of samples, Lorim Point Wharf had similar percentages of sand and mud to South Channel, whereas Evans Landing and Humbug wharves were more

Report reference	Relevant information

comparable with 60% and 52% mud respectively.

Results of the 2004 data are presented below.

Area	Sampling Location	% Gravel (> 2 mm)	% Sand (2 mm - 0.075 mm)	% Mud* (< 0.075 mm)
Lorim Point Wharf				
	LP2A	0.5	12.5	87
	LP3A	8.5	19	72.5
	LP4A	11.2	26.6	62.2
	LP5A	71.9	4.9	23.2
	LP2B	30.8	25	44.2
	LP3B	20.7	23.3	56
	LP4B	45.4	25.3	29.3
	LP5B	0.3	6.7	93
	LP5B (QC3)	0.4	6.1	93.5
	LP5B (QC4)	0.1	5.9	94
Evans Landing Berth				
	ELA	10.6	25.9	63.5
	ELA (QC1)	6.6	29.7	63.7
	ELA (QC2)	13.6	27.9	58.5
	ELB	6.6	26.4	67
	ELC	19.5	36	44.5
	ELD	6.7	54.3	39
Humbug Wharf				
	HWA	17.2	42.8	40
	HWB	4.2	50.1	45.7
	HWC	2.7	58	39.3
	HWD	0.7	30.7	68.6
Approach Channel				
	LPE3	1.7	33.6	64.7
Entrance Channel				
	CH27	3.3	85.5	11.2
South Channel				
	CH4	0.1	12.2	87.7
	CH8A	0	1.6	98.4
	CH8B	0	8.7	91.3
	CH9A	0	25.1	74.9
	CH9B	0	23.9	76.1
	CH17	0	67.8	32.1
Spoil Ground				
	AB1	8.3	20.1	71.7
	AB1 (QC7)	6	18.3	75.6
	AB1 (QC8)	0	26.9	73.2
Control Site - Albatross Bay				
	CS1	8.8	40.8	50.5
	CS1 (QC9)	12.7	28.1	59.3
	CS1 (QC10)	1.9	34.4	63.7
Control Site - Embley Estuary				
	CS2	2	67.5	30.5
	CS2 (QC5)	1.6	78.3	20
	CS2 (QC6)	2.3	71.2	26.6

* % Mud = % (clay + silt + very fine sand)

3 Site Information

3.1 Location and environmental setting

Albatross Bay is a large, shallow embayment, varying in depth from 0 to -20m (LAT) (GHD 2005). Tides are predominantly semi-diurnal, with a strong daily inequality that occasionally results in a fully diurnal tidal cycle. The mean spring and neap tidal ranges are 2.2 m and 0.7 m, respectively and mean tidal current velocity is 0.7 m/s (URS 2002).

There are two main seasons at Weipa, with the wet season usually commencing in October-November and finishing in late April. The dry season encompasses the period May through to September. However, the monsoonal climate is variable, with the start, duration and intensity of rainfall varying for each wet season.

Tropical cyclones regularly form in the Gulf of Carpentaria and cyclones in the area result in strong to gale force winds and high wave action, which causes substantial resuspension and transport of seabed material within Albatross Bay (GHD 2005). Average annual rainfall in Weipa is 1,884 mm, 95% of which is received during the wet season (GHD 2005). Air temperatures range between 13 – 35 °C in winter (mean 26 °C) and 18 – 38 °C in summer (mean 28 °C) (BoM 2009). South-easterly land breezes are predominant during the dry winter season and winds are generally lighter, more variable and with more northerly and westerly components during the summer.

The catchment area for Albatross Bay consists of four relatively small river systems, the Pine River to the north, the Mission and Embley Rivers to the east, and the Hey River, which flows from the south into the Embley River before it discharges into the bay. The rivers and bay form an extensive estuarine system that supports a diversity of habitats, including seagrass beds, mangrove communities, soft bottom habitats and rocky reefs (NQBP, 2012). Bordering catchments include the large Wenlock River system to the east, the Pennefarther River system to the north, and the Watson River system to the south.

3.2 Geology

Port of Weipa geology has been mapped by the Department of National Resources, Bureau of Mineral Resources, Geology and Geophysics and the Department of Mines, State of Queensland and the Geological Survey of Queensland, 1977 as the 1:250,000 Weipa Sheet SD 54-3. There are five mapping units relevant to the site (Figure 3-1):

- Qhm: Quaternary: Holocene younger beach ridges comprising coquina, calcarenite, shelly quartzose sand (Holocene)
- Qac: Quaternary: Holocene and Pleistocene coastal flat deposit comprising silt clay, minor sand
- T&Qa: Tertiary and Quaternary aluminous laterite, including bauxite and the 'ironstone' below it (Tertiary and Quaternary)

- KTi: Late Cretaceous or Early Tertiary Bulimba Formation comprising poorly sorted clayey quartzose sandstone and granule conglomerate, pebbly in places; interbedded sandy claystone
- Klr: Early Cretaceous Rolling Downs Group comprising Labile glauconitic sandstone and siltstone; shale and siltstone calcareous in part.

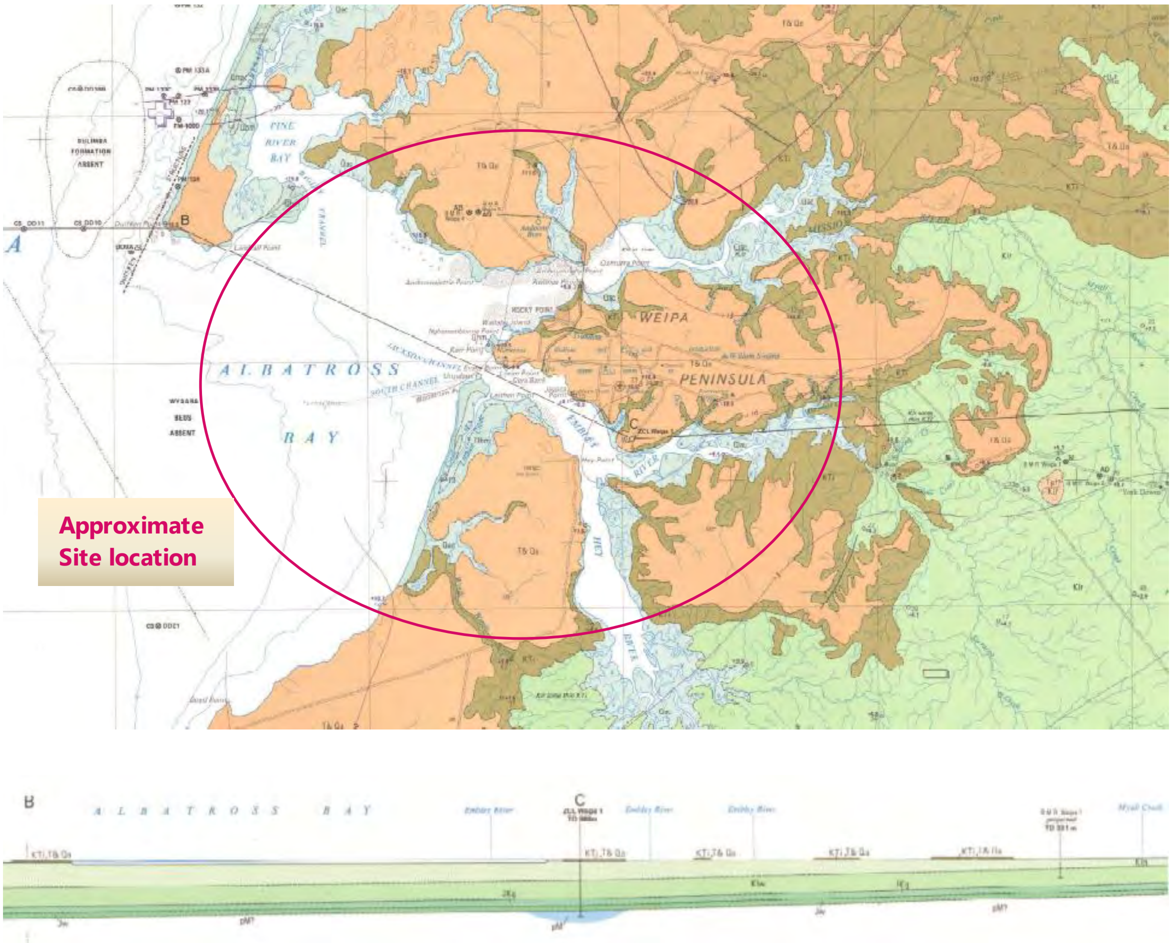


Figure 3-1 Geology (Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T, or the Geological Survey of Queensland, Brisbane, Australia Sheet SD 54-3)

3.3 Land use

The main land uses in the Weipa region include:

- Bauxite mining and mine site rehabilitation on RTA mining leases
- Port activities at the Port of Weipa and small scale urban land uses in Weipa township
- Military activities at RAAF Base Scherger
- Cattle grazing
- Tourist activities related to four-wheel driving, fishing and camping
- Indigenous practices.

4 Method

4.1 General

The marine sediment properties assessment was comprised of two components:

- Assessment of existing information, preselection of sampling location and development of a sampling plan
- Assessment of marine sediments including a sampling program.

The latter was comprised of grab sampling at a number of locations focused on understanding the geotechnical engineering and ASS properties of the marine sediments.

4.2 Sampling locations and intensity

The number of sampling locations was determined as a pilot study using Table 6 (Minimum number of sampling locations) of the NAGD, 2009. Although the NAGD focuses on contaminant studies, it provides a robust framework for sample program design (based on potential dredge volumes) and ensures a consistent approach with previous studies completed. Based on the NAGD approach, the sampling locations were randomly assigned within each dredge area with samples containing high clay and silt content collected for ASS analysis. Samples collected for geotechnical testing were selected based on an approximate even spatial distribution across each navigational area at a rate of two geotechnical samples (each approximately 5-8kg in weight) per three contaminant samples. Where there was a large variation in texture, an additional sample for geotechnical testing was collected.

All total of 60 sites were sampled for environmental purposes (PSD and contamination), 54 from the Port of Weipa and 6 from the Amrun Port. The environmental analysis results are summarised in the *Port of Weipa Sediment Characterisation Report* (Advisian, 2018) and the *Amrun Port - Sediment Sampling Characterisation Report* (RioTinto, 2017).

A subset of the environmental sampling locations was sampled for ASS and Geotechnical properties. The total number of ASS sampling locations was 28, while the total number of geotechnical samples was 32. This number of locations is considered an appropriate intensity for both the ASS sampling and geotechnical components of this study. Sediment samples from six sites were chosen for testing of potential use for concrete-related purposes; four from the Port of Weipa and two from Amrun Port. All sampling locations, sampling type and their respective co-ordinates are provided in Table 4-1 and are presented as Figure 4-1 to Figure 4-6.

Table 4-1: Sampling locations

Location ID*	Location Description	Sampling type				Lat (WGS84)	Long (WGS84)	Easting (MGA54)	Northing (MGA54)
		Environmental	Acid Sulphate	Geotechnical	Cement				
H-1	Humbug	●				-12.66850	141.86197	593599	8599369
H-2	Humbug	●				-12.66877	141.86238	593643	8599340
H-3	Humbug	●	●	●		-12.66884	141.86277	593685	8599331
H-4	Humbug	●				-12.66911	141.86317	593729	8599302
H-5	Humbug	●				-12.66910	141.86348	593762	8599302
H-6	Humbug	●	●	●	●	-12.66934	141.86375	593791	8599276
EL-1	Evans Landing	●	●			-12.66565	141.84832	592118	8599689
EL-2	Evans Landing	●				-12.66563	141.84806	592090	8599691
EL-3	Evans Landing	●	●	●		-12.66576	141.84777	592058	8599677
EL-4	Evans Landing	●				-12.66573	141.84748	592027	8599680
EL-5	Evans Landing	●	●			-12.66587	141.84732	592009	8599666
EL-6	Evans Landing	●	●	●		-12.66586	141.84707	591982	8599667
AC-1	Approach Channel	●		●		-12.67659	141.83282	590430	8598484
AC-2	Approach Channel	●		●		-12.68218	141.84558	591815	8597862
AC-3	Approach Channel	●	●	●		-12.68590	141.86067	593452	8597445
AC-4	Approach Channel	●				-12.68853	141.87159	594636	8597151
AC-5	Approach Channel	●		●		-12.68754	141.87701	595225	8597258
AC-6	Approach Channel	●	●			-12.67992	141.87338	594834	8598102
DC-1	Departure Channel	●				-12.67149	141.82602	589694	8599051
DC-2	Departure Channel	●				-12.67188	141.83706	590893	8599004
DC-3	Departure Channel	●	●	●		-12.66691	141.85162	592475	8599549
DC-4	Departure Channel	●				-12.66875	141.85722	593083	8599343
DC-5	Departure Channel	●		●		-12.6713	141.86304	593714	8599059
DC-6	Departure Channel	●	●			-12.67471	141.86924	594386	8598679
SC-1	Southern Channel	●		●		-12.67086	141.8199	589029	8599123
SC-2	Southern Channel	●				-12.67210	141.81457	588450	8598988
SC-3	Southern Channel	●				-12.67336	141.81006	587960	8598850
SC-4	Southern Channel	●		●		-12.67564	141.80043	586914	8598601
SC-5	Southern Channel	●		●	●	-12.67661	141.79529	586355	8598495
SC-6	Southern Channel	●	●	●		-12.67921	141.782	584911	8598212
SC-7	Southern Channel	●				-12.68101	141.77267	583897	8598016

Location ID*	Location Description	Sampling type				Lat (WGS84)	Long (WGS84)	Easting (MGA54)	Northing (MGA54)
		Environmental	Acid Sulphate	Geotechnical	Cement				
SC-8	Southern Channel	●				-12.68246	141.76691	583272	8597857
SC-9	Southern Channel	●	●	●		-12.68445	141.75716	582213	8597641
SC-10	Southern Channel	●				-12.68698	141.74396	580778	8597364
SC-11	Southern Channel	●				-12.69030	141.72928	579183	8597002
SC-12*	Southern Channel	●	●	●		-12.6944	141.70954	577038	8596555
SC-13*	Southern Channel	●	●	●		-12.69618	141.70174	576190	8596360
SC-14*	Southern Channel	●		●		-12.69727	141.69518	575478	8596241
SC-15	Southern Channel	●	●			-12.69968	141.68391	574254	8595978
SC-16*	Southern Channel	●		●	●	-12.70108	141.67786	573597	8595825
SC-17*	Southern Channel	●		●	●	-12.70196	141.67238	573001	8595729
SC-18*	Southern Channel	●	●	●	●	-12.70297	141.66803	572529	8595619
TB-1*	Tug Berths	●	●	●		-12.67379	141.87179	594664	8598781
TB-2	Tug Berths	●				-12.67346	141.87144	594625	8598817
TB-3*	Tug Berths	●	●	●		-12.67339	141.87092	594569	8598825
TB-4	Tug Berths	●				-12.67301	141.87054	594528	8598867
TB-5	Tug Berths	●				-12.67284	141.86991	594460	8598886
TB-6	Tug Berths	●	●	●		-12.67262	141.86971	594438	8598910
LP-1	Lorim Point	●	●	●		-12.67134	141.86619	594056	8599054
LP-2	Lorim Point	●				-12.67189	141.86698	594141	8598992
LP-3	Lorim Point	●	●	●		-12.67255	141.86845	594301	8598918
LP-4	Lorim Point	●				-12.67301	141.86926	594389	8598868
LP-5	Lorim Point	●				-12.67364	141.87011	594480	8598798
LP-6	Lorim Point	●	●		●	-12.67417	141.87118	594597	8598739
AMRUN-1	Amrun Port	●	●		●	-12.92527	141.60981	566150	8571050
AMRUN-2	Amrun Port	●	●	●		-12.92428	141.61104	566283	8571160
AMRUN-3	Amrun Port	●	●	●		-12.92559	141.61145	566328	8571014
AMRUN-4	Amrun Port	●	●			-12.92541	141.61303	566499	8571033
AMRUN-5	Amrun Port	●	●	●		-12.92643	141.51487	566698	8570920
AMRUN-6	Amrun Port	●	●		●	-12.92744	141.61620	566842	8570808
Totals		**60**	**28**	**24**	**6**				

Note:
MGA54: Map Grid of Australia – central meridian (54)
WGS84: World Geodetic System 1984
*** geotechnical samples combined with nearby sample(s) of similar sediment characteristics to make one sample (there were three combined samples in total: SC-12/13/14; SC-16/17/18; TB-1/3), samples from SC-16/17/18 were combined for cement testing**

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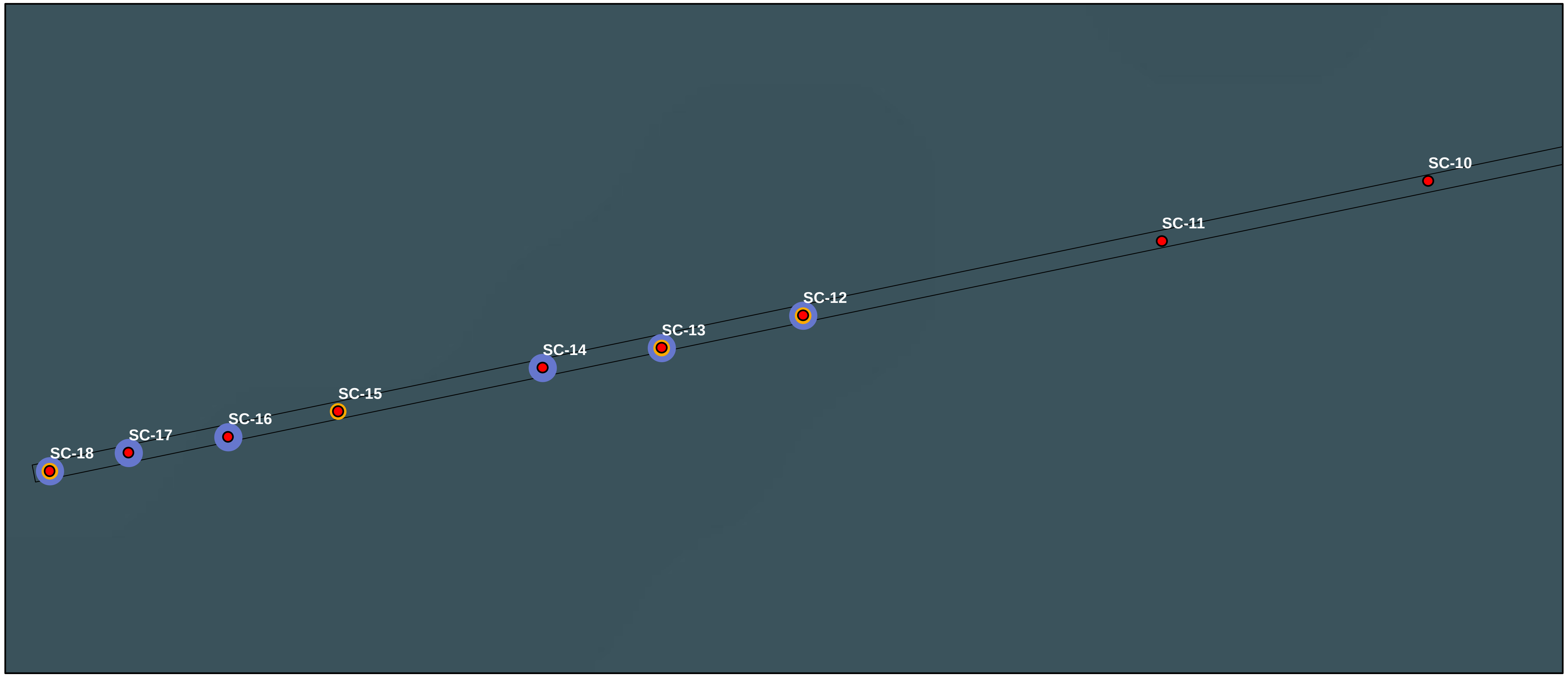
Figure 4-1: Sampling Locations Southern Channel including Channel Extension



- Sediment sample location
- Acid Sulfate Soils (ASS) sample location
- Geotech sample location
- Dredge area

Coordinate System: GCS WGS 1984
Datum: WGS 1984

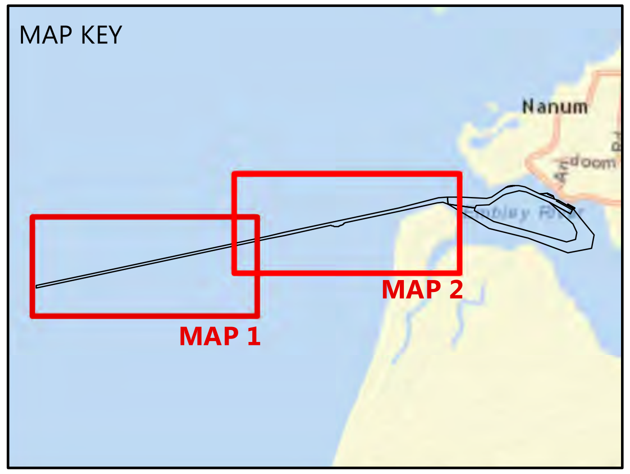


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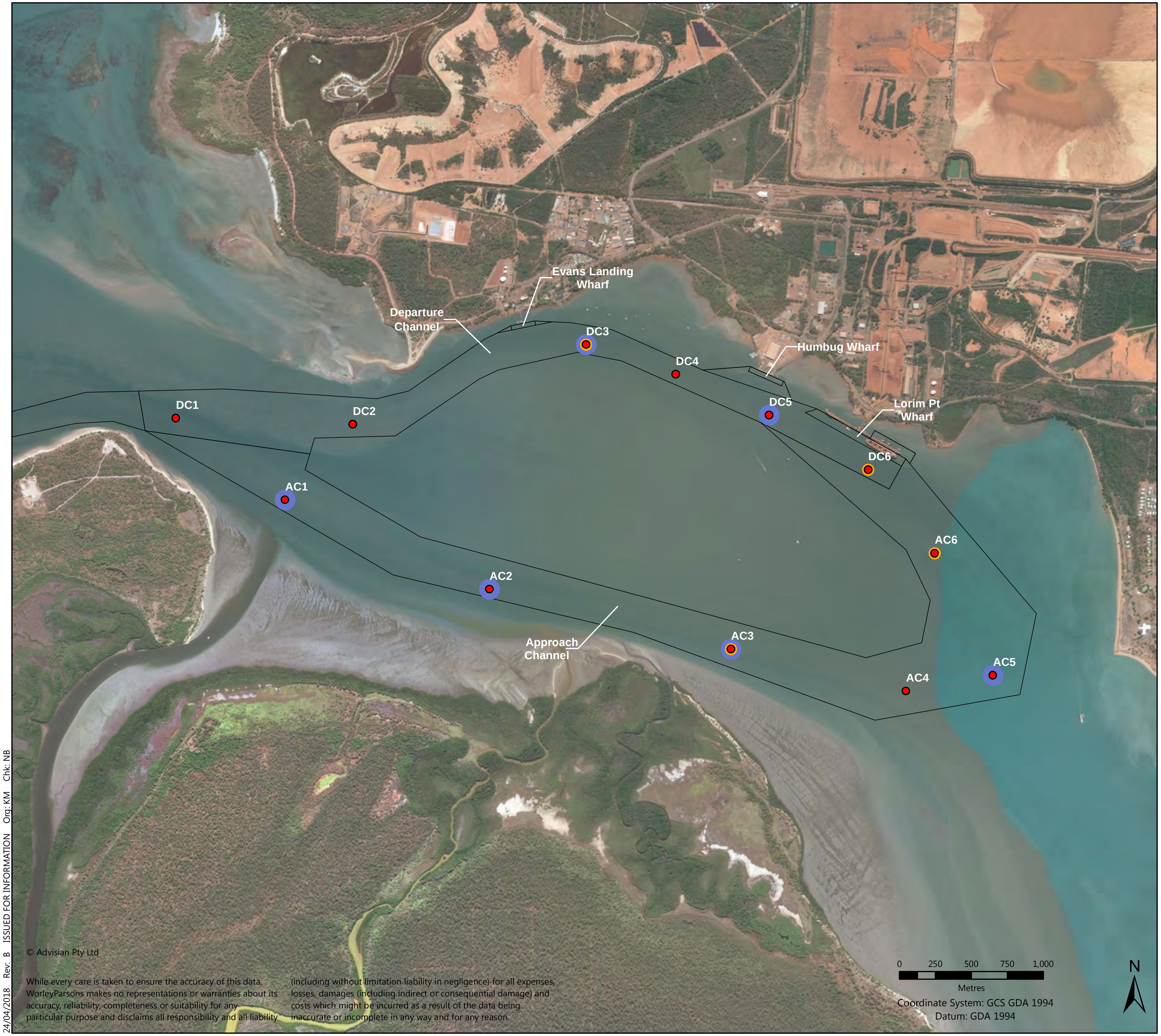
Figure 4-2: Sampling Locations Approach and Departure Channels



- Sediment sample locations
- Acid Sulfate Soils (ASS) sample location
- Geotech sample location
- Dredge area

MAP KEY

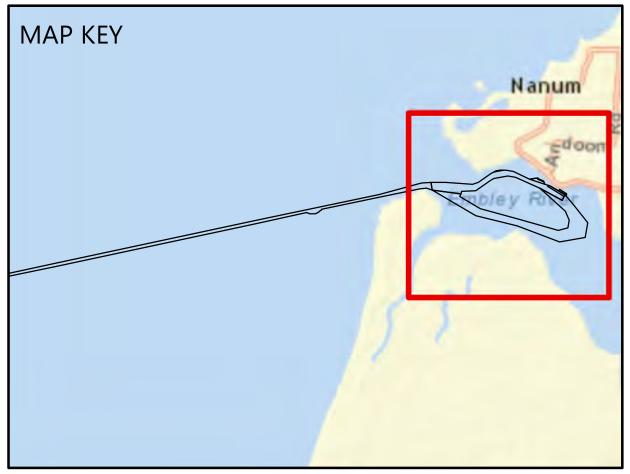


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Figure 4-3: Sampling Locations Lorim Point Wharf and Tug Berths

MAP KEY

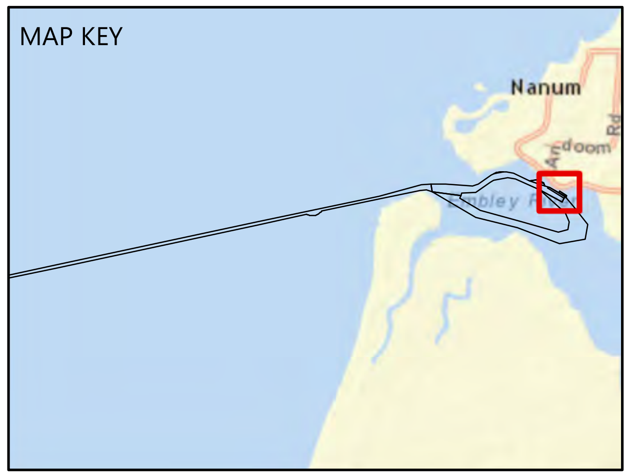

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Figure 4-4: Sampling Locations Humbug Wharf

- Sediment sample locations
- Acid Sulfate Soils (ASS) sample location
- Geotech sample location
- Dredge area

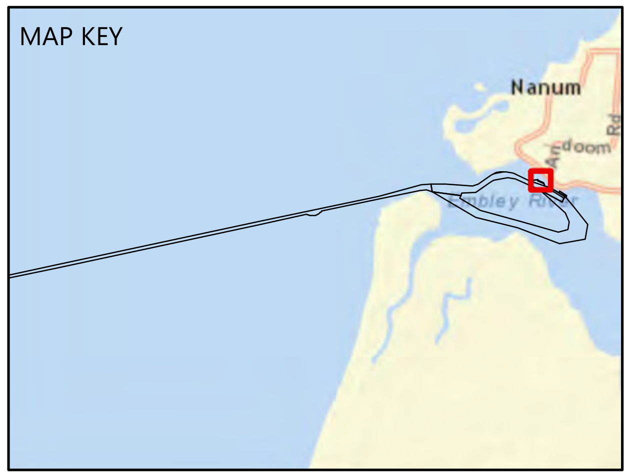

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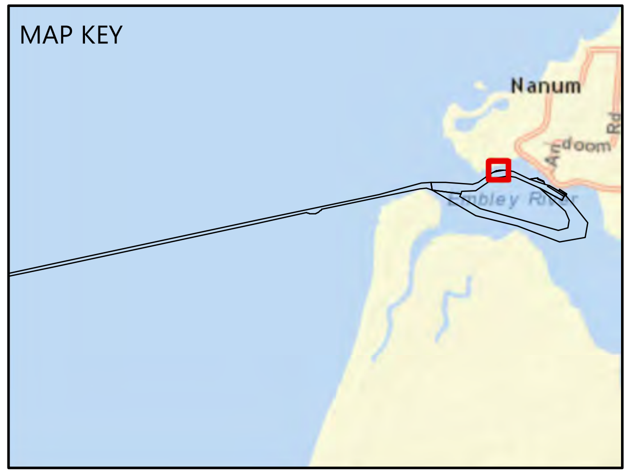
Figure 4-5: Sampling Locations Evans Landing

Sediment sample locations
Acid Sulfate Soils (ASS) sample location
Geotech sample location
Dredge area

MAP KEY



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Datum: GDA 1994

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Sediment Properties Report 2018

Figure 4-6: Sampling Locations Amrun Port

- Sediment sample locations
- Acid Sulfate Soils (ASS) sample location
- Geotech sample location
- Mine and port infrastructure
- Dredge footprint

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User

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4.3 Field method

Field sampling procedures, conforming to *Appendix F Field and laboratory quality assurance and quality control* of the NAGD, 2009 and Advisian's Quality Assurance / Quality Control (QA/QC) protocols, was carried out to minimise the potential for cross contamination and preserve the sample integrity. Table 4-2 provides a summary of the sediment sampling activities undertaken.

Table 4-2 Field activities

Activity	Details
Sampling locations	The co-ordinates of the sampling locations were uploaded onto a Garmin 76CSx Global Positioning System (GPS) unit with an accuracy of +/-5m. The Garmin was used to navigate to the locations and re-position the locations due to site conditions.
Survey vessel	The vessel (the 'Dolphin') used for sampling is commercially registered and licensed for operation within the study area. The vessel is suitably sized for the conditions to allow the progress of field works within a nominal sea state of 0.5m and winds to 15 knots. The vessel has two engines, adequate shade cover and is suitable for any open water operations.
Sediment sampling	Samples were collected using a boat deployed Van veen grab sampler ($0.25m^3$). The grab sampler is constructed of stainless steel and has an approximate grab payload of 3kg. Using a pulley system, the grab sampler was deployed from the boat and lowered to the sea floor where it would trigger shut and capture sediments. The grab sampler was then lifted back to the surface where it was opened and sediments placed directly into steel mixing bowls.

Activity	Details
Sediment logging	The following information was recorded at each sampling location: ▪ Name of client ▪ Sampling date ▪ General location of sample collection ▪ Sample identifiers assigned ▪ Name of the sample collector ▪ Type of sampler used ▪ Weather conditions at the time of sampling ▪ Sea state at time of sampling ▪ General comments (e.g. Wind speed, level of shipping etc.) ▪ GPS location (easting and northing) ▪ Time of sampling ▪ Water depth ▪ Photograph of sediment sample. The sediment log for each grab was recorded on separate field data sheets, which describe each sample per the following information: ▪ Colour ▪ Field texture ▪ Observed sand grain size ▪ Plasticity ▪ Moisture content of sample (e.g. Wet, moist, dry) ▪ % stones ▪ Presence of shell/shell grit ▪ Odour (e.g. marine, sulphurous). For geotechnical purposes the materials were classified by laboratory testing in accordance with AS1726: Geotechnical Site Investigations (2017).
Sediment sampling & storage	Once logging was completed the sample was placed separately into a stainless-steel mixing bowl, where samples for ASS analysis were homogenized using powderless nitrile gloves. Homogenised sediment material was then placed into laboratory supplied 250 ml and 125 ml glass jars leaving zero head space and into zip lock bags. Label information was completed on each sample container and the containers were stored on ice in eskies. Samples collected for geotechnical testing were not homogenised and simply placed into zip lock bags.

Activity	Details
Labelling	Sample bags and jars were labelled with the date, the abbreviated project location (Weipa), the location number / depth, sampler's initials and date of sampling. For instance, a grab sample collected at 4SC-1 was labelled as follows: SC-1 grab (sample I.D) NB (initials of sampler) 25/02/18 (date sampled)
Dispatch	All ASS samples collected were delivered frozen to TNT or TOLL courier depots (Weipa Airport). Samples were transported under chain of custody documentation to ALS Brisbane. Here, samples were logged into their system and stored in refrigerated storage until the sample was analysed. All geotechnical samples collected were delivered to Seaswift Weipa at completion of the site trip. Samples were transported under email custody documentation via Seaswift barge and Startrack road freight to Trilab, Brisbane whereupon the samples were logged into their system and prepared for analysis.
QA/QC	The methods employed in field sampling quality assurance to ensure validity of the analyses results was ensured by: ▪ Using suitably qualified environmental staff and support personnel experienced in sediment grabs, field supervision and sediment logging ▪ Samples contained in appropriately cleaned, pre-treated and labelled sample containers that are provided by the analytical laboratory ▪ Samples kept cool (4°C) after sampling and during transport, stored in eskies with ice packs ▪ Transportation of samples under chain of custody documentation ▪ Decontamination between samples included washing of all sampling equipment with ambient sea water and a laboratory grade detergent (Decon 90), and successive rinsing with deionised water.

4.4 Laboratory methodology

4.4.1 Acid Sulfate Soils analysis

The presence of potential acid sulfate soils (PASS) was assessed using the chromium suite of analysis (S_{CR}). The chromium suite, along with the Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) suite, is the ASS assessment recommended by Ahern et al (2003) and the most recent guidelines, *Queensland Acid Sulfate Soil Technical Manual – Soil Management Guideline* (Dear *et al.*, 2002).

A total of 28 sediment samples were collected for laboratory analysis. All samples collected were submitted to ALS, a National Association of Testing Authorities (NATA) laboratory, for analysis. NATA accredited analysis undertaken at the laboratory, included:

- Chromium Suite (S_{CR})

- Electrical conductivity (EC)
- Salinity (total soluble salts) (TSS)
- Salinity Chloride (Cl^-)
- Organic Matter (OM).

Additional analysis, not NATA accredited, included preliminary ASS screening field pH (pH_f) and field peroxide pH (pH_{fox}).

4.4.2 Acid Sulfate Soils Quality Assurance / Quality Control

A limited field Quality Assurance / Quality Control (QA/QC) program was undertaken for the purpose of providing an assessment of ASS heterogeneity. This included the collection of three replicate samples: H-3 T1, H-3 T2 and H-3 T3. Field QA/QC results are discussed in Section 6.1.

4.4.3 Geotechnical testing

The geotechnical testing was undertaken using a phased approach. Phase 1 comprised general classification testing to determine characteristics such as particle size, moisture content, carbonate content and plasticity. A total of 24 Phase 1 samples were selected to ensure adequate coverage across the range of material types observed during the field sampling. Following Phase 1, Phase 2 testing was undertaken on a total of 17 samples to assess the more detailed engineering properties including permeability, density, strength and consolidation. The Phase 2 samples comprised seven coarse-grained (sand) and ten fine-grained (silt / clay) materials. A summary of the geotechnical laboratory testing performed is provided in Table 4-3.

Table 4-3: Summary of geotechnical testing

Testing Phase	Test	Quantity
Phase 1	Particle size distribution (sieve and hydrometer)[1]	24
	Carbonate content	24
	Moisture content	24
	Atterberg limits and linear shrinkage	24
	Particle density (specific gravity)	24
Phase 2	Uncompacted and compacted bulk density	10
	Minimum / maximum density	4
	Direct shear box (100mm) – Single Stage	4
	Consolidated undrained (CU) triaxial – 3 Stage	5
	1D consolidation (8 loadings)	5

Testing Phase	Test	Quantity
	Constant head permeability	5
	Falling head permeability	3

Note: In addition to the Phase 1 geotechnical samples, PSD testing was undertaken on several supplementary samples collected from the sampling locations to assist in the PSD assessment

Summary tables of the geotechnical test results are provided in Section 5.4. The laboratory test certificates are provided in Appendix C.

4.4.4 Cement Laboratory Testing

In addition to the geotechnical testing, cement laboratory testing was undertaken on a total of six samples to determine the binding characteristics of the sediments and assess their suitability as a binding agent in cement products. Consideration was given to the use of sediments in the production of a range of concrete based products including:

- Bricks, blocks and pavers
- Low strength (5 – 10 MPa) flowable fill type concrete (e.g. for construction pads and pavement sub-base)
- Low strength (2 – 6 MPa) grout backfill for trenches

Two different process courses were investigated for activating the dredge material into a binder for reuse in concrete products as follows:

1. Traditional Portland cement based treatment
2. Geopolymer binder based treatment

X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) testing was undertaken to determine the theoretical chemical elemental composition and the crystal structure (reactivity measure) respectively of the different materials. A summary of the cement laboratory testing performed is provided in Table 4-4.

Table 4-4: Summary of cement laboratory testing

Test	Quantity
X-ray diffraction	6
X-ray fluorescence	6

Summary tables of the cement laboratory test results are provided in 5.4.8.

5 Results

5.1 General

This section describes the findings from the field investigation undertaken, including the sediment materials encountered (Section 5.2) and results of laboratory analysis (Sections 5.3 and 5.4). Sediment logs are presented in Appendix A, summary result tables are provided in Appendix B and the laboratory reports and QA/QC certificates, along with chain of custody and sample receipt documentation are provided in Appendix C.

5.2 Physical description

The sediment textures encountered in the field are summarised in Table 5-1. These are consistent with geology mapping (Section 3.2) for the region.

Table 5-1: General field description of sediments observed during sampling

Navigational area	General description
SC and extension	Grey, low plasticity sandy clayey SILT with fine and coarse sand and trace shell/biota, with the exception of silty SAND at SC-1, SC-3, SC-4 and SC-5
AC	Grey silty SAND with fine and coarse sands and with shell/biota
DC	Grey silty SAND with gravel and shell/biota. DC-1 was brownish grey sandy GRAVEL
LP	Grey silty gravely SAND with the exception of LP-3 sandy gravely CLAY
H	Grey silty SAND with high sand content in most samples with the exception of sandy SILT in H-4 and H-5
EL	Grey gravelly silty SAND with coarse shell fragments and bauxite
TB	Grey silty CLAY with some fine sands and bauxite with the exception of silty sandy GRAVEL in TB-4.

5.3 Acid sulfate soils

5.3.1 Background

The *Queensland Acid Sulfate Soil Technical Manual – Soil Management Guidelines* (Dear et al. 2002) provides action criteria that are used to compare the results of laboratory analysis. These action criteria are based on texture (fine, medium, coarse) with the most stringent criteria (0.03 %S or 18 mol H^+/tonne) applied to course textured sediments and disturbances greater than 1000 tonnes.

Although a range of textures were encountered, the 0.03 %S or 18 mol H^+/tonne criteria is used in this report as the assumed disturbance would be greater than 1000 tonnes.

5.3.2 Preliminary screening

These tests are used to provide an indication of the presence of actual and potential acidity by measuring the difference between pH_F to pH_{FOX}. Changes greater than 1 pH unit, pH_{FOX} values less than 3 and a strong reaction rate can be indicative of a PASS. The following results were reported:

- pH_F values ranged from pH 8.2 to pH 9.4. This indicates the sediment material selected for screening tests are strongly alkaline to very strongly alkaline
- pH_{Fox} values ranged from pH 6.1 to pH 6.6. These results indicate that AASS may not be of concern due to the high pH (>5). However, PASS may still be of concern due to the shell content within a number of samples that may contribute to the increase of pH
- Initial reactions were assessed following the addition of hydrogen peroxide and ranged from slight (25% of samples) to extreme (EL-6) with eight samples having strong reactions. These strong reactions may be indicative of shell content (carbonate).

Used in combination with soil profiling and other field observations, screening results can be used as a preliminary assessment of ASS. However, these results are inconclusive and further laboratory assessment using the Chromium Suite is provided in Sections 5.3.3 to 5.3.6 below.

5.3.3 Actual acidity

Actual acidity is assessed by the measurement of Titratable Actual Acidity (TAA). The determination of pH potassium chloride (pH_{KCl}) is a means of estimating the actual soil acidity which is used to calculate TAA.

All samples had a pH_{KCl} value >8.6 indicating strongly alkaline sediments, likely to contain properties (i.e., carbonates) in large enough quantities to neutralize any existing acidity. This correlates well with field data that identified shell content in the sediment and secondary carbonate sources described in Section 5.4.2.

The TAA at all sample locations was less than the laboratory practical quantitation limit (PQL) of 2 mole H^+/t, which is also less than the QASSIT guideline of 18 mole H^+/t. This indicates all samples have very little or no actual acidity.

5.3.4 Retained acidity

Retained acidity is the acidity stored in largely insoluble compounds such as jarosite and other iron and aluminium sulfate minerals which are not measured by the TAA titration. Retained acidity is only measured when the pH_{KCl} is <4.5 or when yellow mottles of jarosite, natrojarosite, schwertmannite, etc. have been noted in the sample. Retained acidity (or net acid soluble sulfur (S_{NAS})) is estimated by subtracting S_{KCl} from S_{HCl}.

As pH_{KCl} is greater than pH 4.5 in all samples analysed, retained acidity was not determined.

Note that the total extractable sulfate (S_{KCl}) result provides a measure of adsorbed and soluble sulfate, including gypsum if present i.e. both inorganic (ASS) and organic forms of sulfur and is determined during the TAA process (Section 5.3.3). As retained acidity was not determined, S_{KCl} data is not used to assess ASS.

5.3.5 Potential acidity

Potential acidity is assessed through the measurement of Chromium Reducible Sulphur (S_{CR}). All 28 samples analysed have S_{CR} concentrations greater than the QASSIT guideline of 0.03% and 18 moles H+ / t. These samples generally contained a substantial fine fraction. These S_{CR} concentrations ranged from 0.072 to 0.348 % and 45 to 217 moles H+ / t. Samples with the highest S_{CR} concentrations (i.e. >100 moles H+ / t) were samples where the predominant component was silt and/or clay (i.e. Southern Channel, Tug Berth and Amrun samples).

5.3.6 Acid Neutralising Capacity, Net Acidity and Liming

Acid neutralizing capacity (ANC) is the natural ability of soil to buffer acidity either through the dissolution of calcium and/or magnesium carbonates (i.e. shells), cation exchange reaction, reaction of organic and clay fractions or other soil minerals. The effectiveness of neutralization can be hindered somewhat depending on the available forms for acid buffering. For example, where carbonates are stored in coarse shells, acid buffering may not be readily available. In the laboratory, samples are ground making any carbonates (such as shell fragments) more available for neutralisation therefore 'over estimating' ANC. This is somewhat accounted for by 1.5 correction factor incorporated into liming rates reported with the final acid base accounting. A pH_{KCl} greater >6.5 (Section 5.3.3) is one attribute that indicates the presence of carbonates. The greater the pH is above 6.5, the more likely that the ANC will be effective.

Net acidity is the final measure of acidity within a sample once the acid neutralising capacity has been subtracted from the sum of all acids (actual, potential and retained) and is known as acid-base accounting (ABA). In general, the following equation describes the ABA used in ASS determination:

Net Acidity = Potential Sulfidic Acidity + Actual Acidity + Retained Acidity – measured ANC/FF

Note: FF refers to the fineness factor (generally 1.5) applied to liming rates.

Net acidity was below the laboratory PQL (10 moles H^+/t) in all samples analysed and hence below the QASSIT guidelines of 18 moles H^+/t. This correlates to a liming rate which is also below a laboratory PQL of 0.75 kg CaCO3/t, i.e. as there is no net acidity in samples, no liming (i.e. treatment) is required.

5.3.7 Salinity and Organic Matter

A range of salinity parameters and organic matter were determined for selected samples to provide an indication of the initial environmental risk to native vegetation, groundwater and surface water and rehabilitation if maintenance sediment is untreated and reused on land. Based on the analysis the following ranges were reported:

- Salinity – Total Soluble Salts (TSS) ranged from 7720 to 23200 mg/kg
- Chloride (Cl-) ranged from 4990 to 40100 mg/kg
- Electrical Conductivity (EC) ranged from 2380 to 7140 µS/cm
- Organic Matter (OM) ranged from 1 to 6%.

Higher salinity, CL- and EC (i.e. >15000 mg/kg and >15000 µS/cm) are reported for samples with finer textures (i.e. silts and clays), with the highest concentrations detected in Southern Channel, Tug Berth and Amrun samples.

Sandy textured sediments generally located in Approach Channel, Departure Channel, Lorim Point, Humbug and Evan's Landing samples were reported with lower salinity, Cl- and EC values (generally <15000 mg/kg, <15000 mg/kg and <5000 µS/cm).

All samples are considered extremely saline (i.e. > 1210 µS/cm) according to Rayment and Lyons, 2011 salinity ratings.

The OM ranged from 1 to 6% with finer textured samples containing the highest (generally >3 %) OM. Samples with a gravel component had the lowest OM, <1%.

5.4 Geotechnical testing

5.4.1 Particle Size Distribution

The Phase 1 samples were subjected to PSD testing to determine the grading characteristics of the sediments and enable classification based on AS1726-2017 (Geotechnical Site Investigations). In addition to the Phase 1 geotechnical samples, particle size distribution (PSD) testing was undertaken on several supplementary samples collected from a majority of the sampling locations to assist in the PSD assessment. The PSD database was also supplemented with the test results reported by Rio Tinto (2017) for the Amrun Port approaches (samples DP17, DP25, DP27, DP33, DP35, DP41, DP44, DP46, DP52, DP59, DP68 and DP76) and berths (samples DP04, DP14, DP20, DP30 and DP39).

It is noted the AS1726-2017 method of classification differs from the superseded AS1726-1993 standard and the Unified Soil Classification System (USCS) in that the boundary between "fine-grained" and "coarse-grained" soil is defined by a fines fraction of 35%. This is based on a behavioural approach. That is, a soil with >35% fines (<0.075 mm particle diameter) is classified as a fine-grained soil (silt / clay) as the behaviour of the soil will be predominantly controlled by the fines fraction. A soil with <35% fines is classified as a coarse-grained soil (sand / gravel).

The PSD results of the Phase 1 samples, in combination with the plasticity test results, have been used to define the classification of the Phase 1 samples in accordance with AS1726-2017, as summarised in Table 5-2). The results indicate that most the Phase 1 sediments had relatively high fines (clay and silt) content, with an average fines content of 48% from all tests. The areas of the site where coarse-grained sediments appear to prevail include most of the Approach Channel (only one sample, AC-3 was reported as borderline fine-grained) and the western portion of the Southern Channel & Extension (SC-1 to SC-5). The Departure Channel is expected to contain both fine-grained and coarse-grained materials, with one of two samples (DC-3) reported as fine-grained and the other (DC-5) as coarse-grained. There also appear to be zones of coarse-grained sediment present within the berth areas, particularly at Evan's Landing and Lorim Point where clayey sand / gravel materials were identified.

The PSD results from the Phase 1 samples have been combined with the PSD results from the supplementary samples and the Rio Tinto (2017) Amrun samples to provide an estimate of the average particle sizes within each area of the site. This is presented graphically in Figure 5-1 and Figure 5-2. Note the Southern Channel and Extension has been split into two separate areas (SC-1 to SC-5 and SC-6 to SC-18) based on the distinct change in grain size that occurs in the approximate location of SC-6.

Table 5-3 provides an estimate of the total volumes based on average PSD by dredge area

5.4.2 Carbonate Content

Due to the presence of shells and secondary carbonate in the seabed sediments, carbonate content testing was undertaken on the Phase 1 samples. It is important to define this property as soils composed of calcium carbonate can have high porosity and low crushing strength.

The carbonate content test results are presented in Table 5-2 and indicate a range of results between 8% and 57% with an average value of 26%.

A carbonate content of 50% is generally taken as the threshold value for a soil being regarded as a "carbonate soil" for the purposes of engineering design. On that basis, only a single sample from Evan's Landing (EL-3) is regarded as carbonate soil as the value for this sample was reported as 57%. The sample with the next highest carbonate content below the EL-3 result was SC-16/17/18, where a value of 40% was reported. Note that soils with a carbonate content less than 50% may be referred to as "calcareous soils".

Table 5-2: Summary of particle size distribution and carbonate content test results

Area	Sample ID	Group Symbol (AS1726-2017)	Particle size distribution					Carbonate Content
			Gravel	Sand	Fines (silt & clay)	Silt	Clay	
			%	%	%	%	%	% CaCO3
Approach Channel	AC-1	SP-SM	0	89	11	9	2	11.5
	AC-2	SM	16	64	20	13	7	31.3
	AC-3	ML	0	63	37	29	8	18.9
	AC-5	SM	0	77	23	14	9	16.0
Departure Channel	DC-5	SM	6	79	15	9	6	29.4
	DC-3	CL-ML	2	47	51	40	11	22.3
Southern Channel & Extension	SC-1	SP-SM	3	89	8	6	2	26.9
	SC-4	SP	12	85	3	3	0	34.6
	SC-5	SP	5	90	5	4	1	33.6
	SC-6	CL	0	52	48	32	16	16.8
	SC-9	MH	0	6	94	60	34	26.0
	SC-12/13/14	CH-MH	0	7	93	64	29	34.0
	SC-16/17/18	CH-MH	0	6	94	66	28	40.0
Evans Landing	EL-3	SC	39	44	17	11	6	57.1
	EL-6	CI	16	36	48	32	16	33.7
Humbug	H-3	ML	0	32	68	40	28	13.8
	H-6	CI	1	47	52	31	21	15.0
Lorim Point	LP-1	CI	6	38	56	40	16	17.3
	LP-3	GC	42	32	26	17	9	8.4
Tug Berth	TB-1/3	CH-MH	0	8	92	57	35	18.0
	TB-6	CH-MH	0	25	75	42	33	19.6
Amrun Approaches	Amrun-2	CH	0	29	71	58	13	33.7
	Amrun-3	MH	0	20	80	68	12	35.3
Amrun Berths	Amrun-5	MH	0	33	67	59	8	33.2

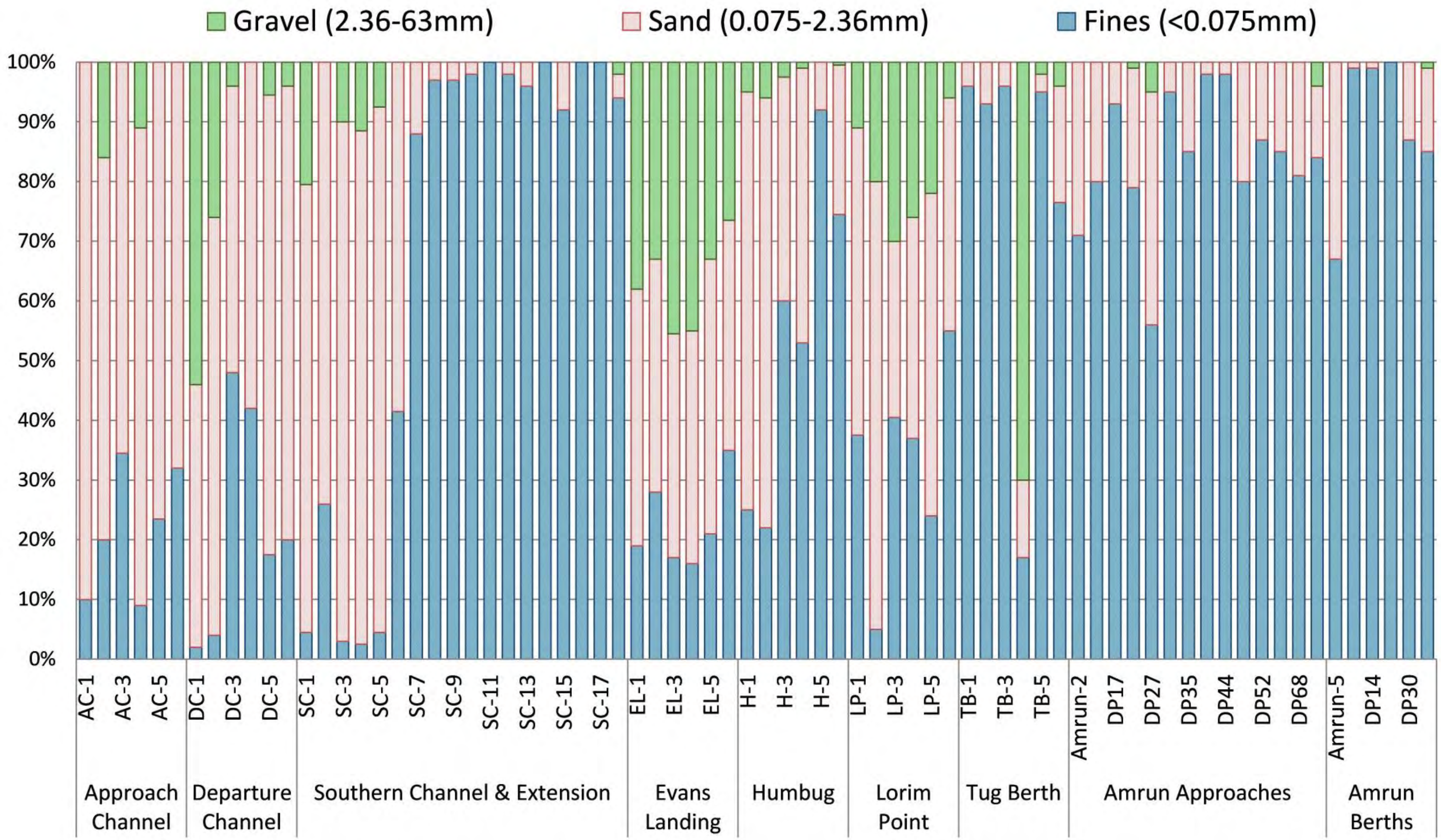

Figure 5-1: Particle Size Distribution (gravel / sand / fines proportions) by sample location

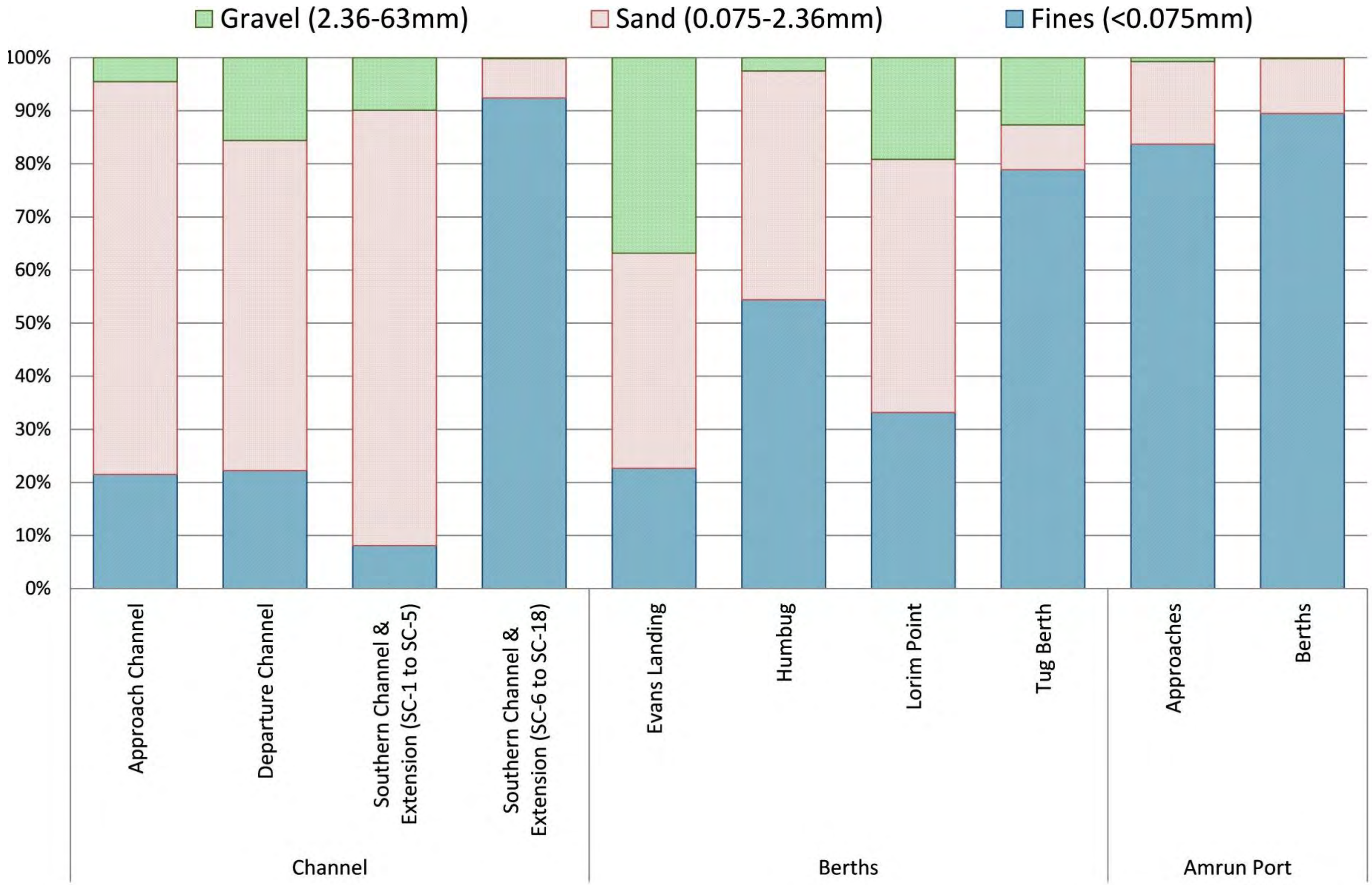

Figure 5-2: Average Particle Size Distribution (gravel / sand / fines proportions) by area

Table 5-3: Estimated dredge volumes based on average Particle Size Distribution by area

Area	Average Particle Size Distribution (%)			Approximate Total Dredge Volume Estimate (m^3)[1,3]	Approximate Dredge Volumes by Particle Size (m^3)		
	Fines	Sand	Gravel		Fines	Sand	Gravel
Approach Channel	22	73	5	11,000	2,400	8,000	600
Departure Channel	22	62	16	11,000	2,400	6,800	1,800
Southern Channel and Extension - Total	75	22	3	532,000	399,000	117,000	16,000
Southern Channel & Extension (SC-1 to SC-5) [20% of total][2]	*8*	*82*	*10*	*106,000*	*8,500*	*86,900*	*10,600*
Southern Channel & Extension (SC-6 to SC-18) [80% of total][2]	*92*	*7*	*1*	*426,000*	*391,900*	*29,800*	*4,300*
Evans Landing	23	40	37	10,000	2,300	4,000	3,700
Humbug	54	43	3	10,000	5,400	4,300	300
Lorim Point	33	48	19	10,000	3,300	4,800	1,900
Tug Berth	79	8	13	10,000	7,900	800	1,300
Port of Weipa Weighted Averages/Totals	**71**	**25**	**4**	**594,000**	**422,700**	**145,700**	**25,600**
Amrun Approaches	84	15	1	25,000	21,000	3,800	300
Amrun Berths	90	10	0	17,000	15,300	1,700	0
Amrun Port Weighted Averages/Totals	**86**	**13**	**1**	**42,000**	**36,300**	**5,500**	**300**

Notes:

1. Approximate total dredge volumes in both Ports are based on results of April 2018 dredging campaign provided by NQBP.
2. The proportions of dredged sediment from SC-1 to SC-5 and SC-6 to SC-18 are assumed to be approximately 20% and 80% of the overall dredging volume in the Southern Channel and Extension, respectively, based on the relative lengths of these two sections.
3. The proportions of dredged sediment within the Amrun Approaches and Amrun Berths are assumed to be approximately 60% and 40% of the overall Amrun dredging volume, respectively.

5.4.3 Moisture Content

The moisture content of a soil is defined as the ratio of the mass of water to the mass of solids. The moisture content provides an indication of the amount of effort that may be required to dry out the dredged sediment for various reuse options, for example if the optimum moisture content of a soil were required to be achieved for compaction works.

The Phase 1 geotechnical samples were tested for moisture content and the results are presented in Table 5-4. The coarse-grained samples (sand / gravel) recorded values between 22% and 42% and the fine-grained samples (silt / clay) recorded values between 41% and 231%. The moisture content results lower than 100% are considered generally within the range expected for marine sediments. There were some samples showing relatively high moisture contents, but it is not clear whether this was due to mineral characteristics or sample disturbance.

It is noted there may be some level of inaccuracy associated with the moisture content results due to the nature of the grab sampling method, which is carried out unseen at seabed level and causes significant sample disturbance.

5.4.4 Atterberg Limits and Linear Shrinkage

Atterberg limits testing (liquid limit and plastic limit) is designed to reflect the influence of water content, grain size and mineral composition on the mechanical behaviour of clays and silts. The results are also used to classify soils in accordance with AS1726-2017.

Atterberg limits testing was undertaken on all the Phase 1 geotechnical samples. The results are summarised in Table 5-4 and illustrated on the plasticity chart in Figure 5-3. The plasticity of the soils is relatively variable across the site. The fine-grained sediments range from low to high plasticity clay and low to high plasticity silt, with many samples falling close to the "A-Line", meaning these materials will exhibit engineering behaviour bordering between that of silt and clay. For all fine-grained samples tested, the moisture contents were found to be higher than the corresponding liquid limits, indicating these in-situ sediments are likely to be sensitive. If the natural moisture content (w_N) of the soil is greater than the liquidity index ($LI=(w_N-PL)/(LL-PL)$), the soils may be stable in an undisturbed state, but a sudden change in stress may transform them into a liquid state.

Linear shrinkage results between 1.0% and 18.5% and plasticity index (PI) results between 3% and 34% were recorded. This indicates a generally low potential for volume change for most of the materials tested, with a medium / medium to high potential for volume change indicated by the test results at SC-9, TB1/3 and Amrun 2. The weighted plasticity index (WPI) has also been calculated (refer Table 5-4) and used to estimate the Volume Change Classification based on the method proposed by Look (1994). As shown in Table 5-4, the Volume Change Classification for the sediments "very low" to "low" in general, "moderate" in places and "high" at TB-1/3.

Table 5-4: Summary of moisture content and plasticity test results

Area	Sample ID	Group Symbol (AS1726-2017)	Moisture Content (w_N)	Atterberg Limits and Linear Shrinkage				WPI (% passing 0.425mm x PI)	Volume Change Classification (Look, 1994)
				LL	PL	PI	LS		
			%	%	%	%	%	-	-
Approach Channel	AC-1	SP-SM	33.3	NO	NO	NP	NO	-	-
	AC-2	SM	28.0	NO	NO	NP	NO	-	-
	AC-3	ML	40.6	27	24	3	1.0	297	Very Low
	AC-5	SM	40.8	NO	NO	NP	NO	-	-
Departure Channel	DC-5	SM	29.4	NO	NO	NP	NO	-	-
	DC-3	CL-ML	56.9	31	23	8	5.0	728	Very Low
Southern Channel & Extension	SC-1	SP-SM	31.1	NO	NO	NP	NO	-	-
	SC-4	SP	27.4	NO	NO	NP	NO	-	-
	SC-5	SP	22.3	NO	NO	NP	NO	-	-
	SC-6	CL	53.9	29	20	9	3.0	882	Very Low
	SC-9	MH	218.7	65	34	31	18.5	3100	Moderate
	SC-12/13/14	CH-MH	167.6	58	31	27	14.5	2673	Moderate
	SC-16/17/18	CH-MH	127.7	55	30	25	11.5	2475	Moderate
Evans Landing	EL-3	SC	41.0	28	18	10	2.5	360	Very Low
	EL-6	CI	70.9	39	21	18	7.5	1224	Low
Humbug	H-3	ML	113.4	49	32	17	11.5	1513	Low
	H-6	CI	74.6	42	20	22	10.0	1738	Low
Lorim Point	LP-1	CI	77.4	38	22	16	8.5	1296	Low
	LP-3	GC	42.1	45	21	24	10.5	864	Very Low
Tug Berth	TB-1/3	CH-MH	184.4	67	33	34	16.5	3366	High
	TB-6	CH-MH	151.5	59	30	29	14.0	2523	Moderate
AMRUN Approaches	Amrun-2	CH	190.3	63	29	34	15.0	2652	Moderate
	Amrun-3	MH	191.8	61	36	25	13.5	2175	Low
AMRUN Berths	Amrun-5	MH	231.0	56	39	17	10.0	1326	Low
LL = Liquid Limit; PL = Plastic Limit; PI = Plasticity Index; WPI = Weighted Plasticity Index; NO = Not Obtainable; NP = Non-plastic									

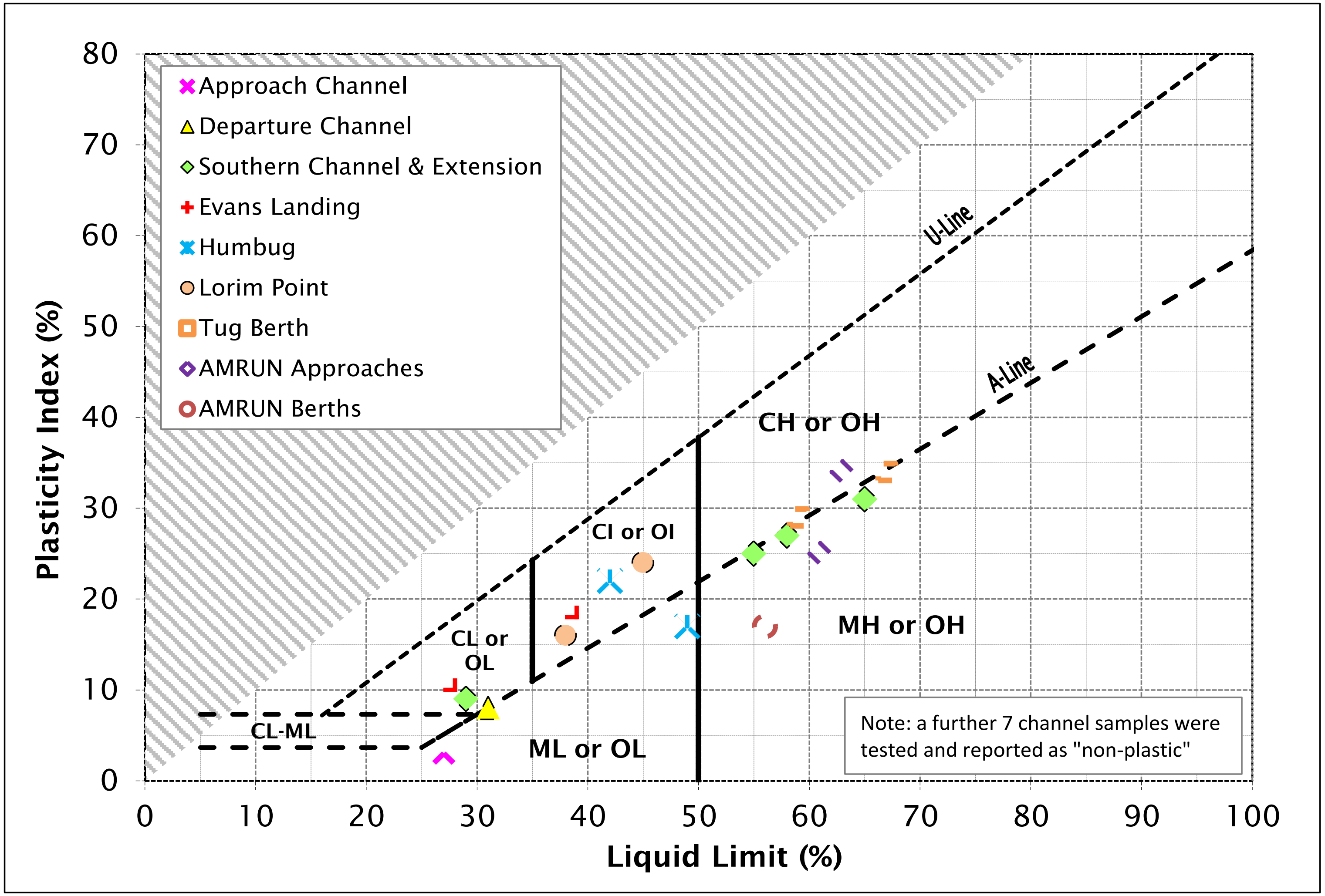

Figure 5-3: Plasticity chart showing results of Atterberg Limits testing

5.4.5 Density

Several different types of density testing were carried out on the geotechnical samples. These tests are discussed in the following sections and the results are summarised in Table 5-5. The results are also presented graphically in Figure 5-4 which shows a plot of dry density versus sample fines content for a range of test methods.

Particle Density

Particle density (effectively equivalent to specific gravity) testing was undertaken on the 24 Phase 1 geotechnical samples. The recorded particle densities ranged between 2.51 t/m^3 and 2.63 t/m^3 with an average value of 2.57 t/m^3.

In-situ Dry Density

Particle density and moisture content results can be used to approximate the in-situ bulk dry density of marine sediments using phase relationships. For grab sample specimens, which are collected underwater and are significantly disturbed during the sampling process, there is some degree of inaccuracy associated with this method. However, where there is a lack of undisturbed samples available (e.g. piston core samples) it can be useful for providing indicative values of seabed density, which can then be compared with other density values such as the uncompacted / compacted dry density results obtained using the AS1141.4 method. The following formula has been used to estimate in-situ density based on the classification test results:

$$Dry\ Density, \rho = \frac{G_s}{1 + \frac{wG_s}{S_r}} \rho_w$$

Where:

G_s = specific gravity of the soil (obtained from particle density testing)

w = moisture content

S_r = degree of saturation (assumed as ~1 for seabed sediments)

ρ_w = density of water (~1 t/m^3)

As can be seen in Table 5-5 and Figure 5-4, the results of this estimation show a clear trend of decreasing in-situ density with an increase in fines content. This trend is to be expected for the types of sediments encountered at the site, however there are some very low values of density estimated and this is attributed to the sampling process which has likely resulted in an overestimate of moisture content in some cases.

Uncompacted / Compacted Dry Density

Bulk density testing was undertaken on a total of ten samples in accordance with AS1141.4 to provide an indication of the densities that may be achieved during future placement of the dredged sediments. The AS1141.4 method is from the aggregate testing standard and was utilised to assist with the estimation of the compaction potential of the dredge sediments. Ideally the compaction characteristics of a soil would be assessed using the Standard or Modified Maximum Dry Density compaction test methods (AS1289.5.1.1, .5.2.1), but these methods require large sample quantities and were not a practical option for this project.

The AS1141.4 samples were dried back to a moisture content of 25% before being tested in both the “uncompacted” and “compacted” states. The results are presented in Table 5-5 and Figure 5-4 and suggest that only relatively low dry densities (1.12 t/m^3 to 1.37 t/m^3) can be achieved for the dredge sediments. However, the AS1141.4 results are an unrealistic representation of the density / compaction characteristics of the samples based on a comparison of these values with the results of the minimum / maximum density tests and the remoulded densities that could be achieved with strength / consolidation / permeability samples, as shown in Figure 5-4.

Minimum / Maximum Dry Density

Minimum / maximum dry density testing was performed in accordance with AS1289.5.5.1 on four sand / silty sand samples from the channel, including AC-2, DC-5, SC-1 and SC-4. The results are presented in Table 5-5 and Figure 5-4 and indicate that the dry densities of the coarse-grained dredge sediments will range between approximately 1.22 t/m^3 and 1.81 t/m^3 depending on the level of compaction or method of placement utilised onshore.

Table 5-5 Summary of density test results

Area	Sample ID	Group Symbol (AS1726-2017)	Particle Density	Estimated in-situ dry density using phase relationships		Uncompacted / Compacted Dry Density (AS1141.4)		Minimum / Maximum Dry Density (AS1289.5.5.1)	
				Moisture content	Dry density	Uncom-pacted	Comp-acted	Min	Max
			t/m^3	%	t/m^3	t/m^3	t/m^3	t/m^3	t/m^3
Approach Channel	AC-1	SP-SM	2.63	33.3	1.40	1.19	1.37	-	-
	AC-2	SM	2.57	28.0	1.49	-	-	1.26	1.81
	AC-3	ML	2.61	40.6	1.27	-	-	-	-
	AC-5	SM	2.63	40.8	1.27	1.16	1.36	-	-
Departure Channel	DC-5	SM	2.63	29.4	1.48	-	-	1.24	1.71
	DC-3	CL-ML	2.58	56.9	1.05	-	-	-	-
Southern Channel & Extension	SC-1	SP-SM	2.62	31.1	1.44	1.05	1.21	1.22	1.60
	SC-4	SP	2.61	27.4	1.52	-	-	1.36	1.63
	SC-5	SP	2.56	22.3	1.63	-	-	-	-
	SC-6	CL	2.59	53.9	1.08	1.07	1.28	-	-

Area	Sample ID	Group Symbol (AS1726-2017)	Particle Density	Estimated in-situ dry density using phase relationships		Uncompacted / Compacted Dry Density (AS1141.4)		Minimum / Maximum Dry Density (AS1289.5.5.1)	
				Moisture content	Dry density	Uncom-pacted	Comp-acted	Min	Max
			t/m³	%	t/m³	t/m³	t/m³	t/m³	t/m³
	SC-9	MH	2.52	218.7	0.39	1.06	1.19	-	-
	SC-12/13/14	CH-MH	2.57	167.6	0.48	1.03	1.18	-	-
	SC-16/17/18	CH-MH	2.59	127.7	0.60	-	-	-	-
Evans Landing	EL-3	SC	2.51	41.0	1.24	-	-	-	-
	EL-6	CI	2.55	70.9	0.91	-	-	-	-
Humbug	H-3	ML	2.53	113.4	0.65	-	-	-	-
	H-6	CI	2.57	74.6	0.88	-	-	-	-
Lorim Point	LP-1	CI	2.61	77.4	0.86	-	-	-	-
	LP-3	GC	2.51	42.1	1.22	1.02	1.18	-	-
Tug Berth	TB-1/3	CH-MH	2.55	184.4	0.45	1.00	1.12	-	-
	TB-6	CH-MH	2.53	151.5	0.52	-	-	-	-
Amrun Approaches	Amrun-2	CH	2.53	190.3	0.44	1.04	1.21	-	-
	Amrun-3	MH	2.6	191.8	0.43	-	-	-	-
Amrun Berths	Amrun-5	MH	2.59	231.0	0.37	1.01	1.13	-	-

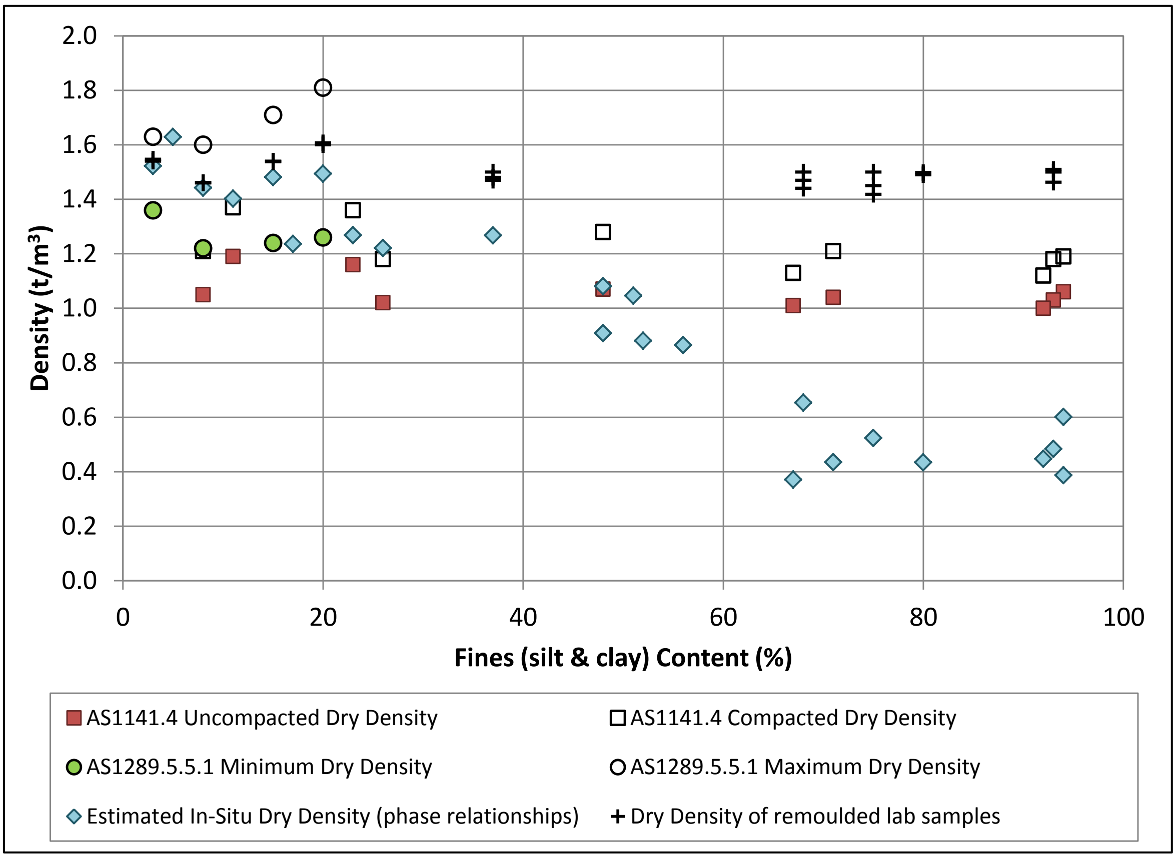

Figure 5-4: Dry density test results vs. fines content

5.4.6 Strength and Consolidation

Strength and consolidation tests were undertaken on samples of remoulded and moisture conditioned sediments to provide indicative parameters for the dredged materials following reworking and field placement. The sample preparation and test results are summarised below.

Direct Shear

Direct shear testing (single stage) was undertaken on four samples of sand / silty sand to provide indicative strengths (angle of internal friction) for the coarse-grained sediments. The samples were remoulded to a target relative density of 70% (based on the results of the minimum / maximum dry density testing) and sheared under a target vertical pressure of 100 kPa. The direct shear test results are summarised in Table 5-6, and indicate that the coarse-grained sediments may achieve friction angles of 33° to 44° after compaction and loading. These values are within the range generally associated with medium dense to very dense sand deposits and suggest that the coarse-grained sediments may be suitable for medium to high loading applications following adequate compaction.

Table 5-6 Summary of direct shear test results

Area	Sample ID	Group Symbol (AS1726 -2017)	Remoulded Sample Details			Effective Friction Angle (assuming zero cohesion)	
			Moisture Content	Wet Density	Density Index	Peak	Residual
			%	t/m^3	%	°	°
Approach Channel	AC-2	SM	17.6	1.89	70	44.2	43.9
Departure Channel	DC-5	SM	21.6	1.87	70	32.8	32.7
Southern Channel & Extension	SC-1	SP-SM	23.8	1.81	70	42.4	42.1
	SC-4	SP	22.8	1.90	70	38.0	37.1

CU Triaxial

Consolidated undrained (CU) triaxial testing (3 stage) was undertaken on three samples of silt / clay and two samples of sandy silt to provide indicative strengths (effective cohesion and effective friction angle) for the fine-grained sediments. Prior to testing, the samples were dried back to a moisture content of 25% to 30% and remoulded to a target density of 1.5 tm/^{3}. The CU testing was performed at target confining pressures of 50 kPa, 100 kPa and 200 kPa, and the results are summarised in Table 5-7 and indicate that the average cohesion (c') of the samples after compaction and loading ranges from 3 kPa to 13 kPa, and the average friction angle ranges from 29° to 36°. These strengths suggest that the fine-grained sediments may be suitable for low to medium load applications following adequate drying out and compaction.

Table 5-7 Summary of CU triaxial test results

Area	Sample ID	Group Symbol (AS1726-2017)	Remoulded Sample Details		Average Effective Cohesion (average of 3 stages)	Average Effective Friction Angle (average of 3 stages)
			Moisture Content	Dry Density		
			%	t/m^3	kPa	°
Approach Channel	AC-3	ML	26.9	1.47	3.2	34.4
Southern Channel & Extension	SC-12/13/14	CH-MH	29.4	1.51	11.9	35.9
Humbug	H-3	ML	28.4	1.47	5.0	32.5
Tug Berth	TB-6	CH-MH	29.2	1.45	13.4	32.6
Amrun Approaches	Amrun-3	MH	25.8	1.49	9.6	29.4

1D Consolidation (Oedometer)

The five samples selected for CU triaxial testing were also subjected to 1-dimensional consolidation (oedometer) testing to assess the consolidation parameters of the fine-grained sediments. Prior to testing, the samples were dried back to a moisture content of 25% to 30% and remoulded to a target dry density of 1.5 t/m^3. The oedometer sample was loaded, unloaded and reloaded at pressures ranging from 20 kPa to 640 kPa. The results are provided on the laboratory certificates in Appendix C and a summary of the compression index (c_c) and coefficient of consolidation (c_v) values is provided in Table 5-8. The c_v values for the four samples with high fines content (68-93%) are within the typical range expected for clays and silts, and the results for AC-3 (37% fines content) are within the range expected for a sandy silt. Figure 5-5 (Look, 2007) shows typical drainage times associated with various materials and against approximate c_v.

Table 5-8 Summary of Oedometer test results

Area	Sample ID	Fines Content (%)	Compression Index (c_c) during final stage of test	Typical range of Coefficient of Consolidation, c_v (m^2/yr)
Approach Channel	AC-3	37	0.04	100-300
Southern Channel & Extension	SC-12/13/14	93	0.19	1-100
Humbug	H-3	68	0.21	1-100
Tug Berth	TB-6	75	0.19	1-100
Amrun Approaches	Amrun-3	80	0.23	1-100

Material	*Approximate coefficient of consolidation, C_v (m^2/yr)*	*Approx. time for consolidation based on drainage path length (m)*			
		0.3	*1*	*3*	*10*
Sands & Gravels	100,000	<1 hr	<1 hr	1 to 10 hrs	10 to 100 hrs
Sands	10,000	<1 hr	1 to 10 hrs	10 to 100 hrs	1 to 10 days
Clayey sands	1000	3 to 30 hours	10 to 100 hrs	3 to 30 days	1 to 10 mths
Silts	100	10 to 100 hours	3 to 30 days	1 to 10 mths	10 to 100 mths
CL clays	10	10 to 100 days	1 to 10 months	1 to 10 yrs	10 to 100 yrs
CH clays	1	3 to 30 months	1 to 10 yrs	30 to 100 yrs	100 to 1000 yrs

Note: The "drainage path length" is the distance that water has to travel to exit the consolidating sediment when it is under compression (e.g. in a 5m thick clay deposit overlain and underlain by free-draining sand, the maximum drainage path length would be 2.5m). The drainage path length can be reduced by various engineering solutions such as prefabricated vertical "wick" drains.

Figure 5-5 Time required for drainage (reproduced from Look, 2007)

5.4.7 Permeability

To provide an indication of the post-compaction permeability of the dredged sediments, permeability testing was carried out on eight of the Phase 2 samples, including four coarse-grained and three fine-grained samples. The coarse-grained samples were remoulded in the same manner as the direct shear samples (target 70% relative density) and tested using the constant head permeability test method. The fine-grained samples were remoulded in the same manner as the CU triaxial and 1D consolidation samples (target 25% to 30% moisture content and 1.5 t/m^3 dry density) and all but one were tested using the falling head permeability test method. The borderline sandy silt / silty sand sample from AC-3 (37% fines content) was tested using the constant head permeability test method due to the fast flow rate observed during testing in accordance with Australian Standards.

The permeability test results are summarised in Table 5-9 and indicate that the permeabilities are generally within the range expected for the types of sediments tested, with "poor" drainage characteristics being reported for the silt / clay samples and "good" drainage characteristics for the sand samples. The only exception to this was sample AC-3 (37% fines content, i.e. borderline sandy silt / silty sand), which behaved more like a sand with few fines rather than a sandy silt / silty sand material.

Table 5-9 Summary of permeability test results

Area	Sample ID	Group Symbol (AS1726-2017)	Remoulded Sample Details			Permeability
			Moisture Content	Dry Density	Density Index	
			%	t/m^3	%	m/s
Approach Channel	AC-2	SM	10.9	1.60	69.8	2.5E-05
	AC-3	ML	26.2	1.50	-	3.3E-04
Departure Channel	DC-5	SM	12.9	1.54	70.6	5.8E-05
Southern Channel & Extension	SC-1	SP-SM	15.7	1.46	69.5	1.9E-05
	SC-4	SP	14.7	1.54	70.1	1.1E-04
	SC-12/13/14	CH-MH	29.2	1.50	-	2.8E-10
Humbug	H-3	ML	27.3	1.50	-	2.2E-10
Tug Berth	TB-6	CH-MH	29.2	1.50	-	1.9E-10

5.4.8 Cement Laboratory Testing and Mineralogy

High moisture contents (up to 231%) were recorded in the fine-grained samples during the Phase 1 geotechnical testing. Although there may be some inaccuracy associated with these values due to the sampling method, the true moisture contents of these materials are still expected to be reasonably high.

High moisture content indicates a high void ratio, which can be associated with the presence of the "montmorillonite" mineral group. This group of soils can cause problems in civil / geotechnical engineering works due to the potential to undergo large volume changes (shrinking and swelling) with changes in moisture content.

The results of the XRD testing (Table 5-10) showed all samples to be highly crystalline, with very little amorphous material. This is particularly true of the silica minerals present. The crystalline form (e.g. Quartz) is unsuitable for direct geopolymer reaction and would largely remain as an "inert" filler.

Table 5-10 Results of the XRD testing

Sample	Moisture Content (DWB %)	Gravel	Sand	Fines	Quartz	Ca minerals	Al minerals
Amrun-1	200%	0	30%	70%	35%	50%	10%
Amrun-6	200%	0	30%	70%	75%	20%	5%
Humbug-6	74.6%	0	50%	50%	55%	38%	5%
LP-6	56.8%	10%	46%	44%	55%	25%	20%
SC-5	22.3%	5%	90%	5%	75%	25%	0%
SC 16/17/18	127.7%	0	6%	94%	40%	45%	5%

Cement laboratory testing results indicate that:

- Most of the sediment had a relatively high water and fines contents, which would limit their use in high end concrete products.
- Amrun sediments were very wet muds with excessive fines. These sediments would not easily be used in concrete products.
- Humbug and Lorim Point sediments may be suitable for use in flowable fill applications; however, additional testing on larger samples of the target material would be required to examine the effectiveness of stabilisation when mixed with Portland Cement.
- Some Southern Channel sediments have relatively low fines, and high silica and sand content. This material could be useful as an alternative source of normal fine sand in concrete and concrete products. For general premixed concrete use, the fines and relatively high level of chlorides present would need to be washed. This fine sand would typically be used at a rate of 200kg per m^3 of concrete (or <10% by weight). For other concrete uses (blocks or flowable fill) where reinforcement is not present, it could be used at substantially higher levels, with less pre-treatment. Other Southern Channel sediments were similar to the those found in Amrun Port and would not easily be used in concrete products.

6 Data Validation

This section examines the validity of the analytical data obtained in the study. It provides confidence in the results presented.

6.1 Field QA/QC

The Relative Standard Deviation (RSD) was calculated on primary samples H-3 T1, H-3 T2 and H-3 T3, the results of which are presented in Table 3 of Appendix B. All RSD values were within the 50% criteria indicating that S_{CR} concentrations were homogenises.

6.2 Laboratory Analysis

The Quality Control Report provided by ALS are included with laboratory analysis reports in Appendix B**.** Table 6-1 identifies outliers in their QA/QC analysis.

Table 6-1 QA/QC laboratory outliers summary table

QA/QC Method	Laboratory Outliers	Comments
Laboratory Duplicates	There were no laboratory duplicates breaches that impact ASS parameters	
Laboratory control spike	There were no laboratory control spike breaches that impact ASS parameters	
Surrogate Spikes	There were no surrogate spike breaches that impact ASS parameters	
Matrix Spikes	There were no matrix spike breaches that impact ASS parameters	
Holding times	Holding time breaches exist for the following: ▪ Extraction / preparation: organic matter: TB-1 (EB1805135), EL-6, AMRUN1 to 6 (EB1805737) ▪ Extraction / preparation: conductivity: EL-6, AMRUN1 to 6 (EB1805737) ▪ Extraction / preparation: S_{CR} suite and pH field screen: EL-3, EL-5, EL-6, SC-12, SC-13, SC-15, SC-18, AMRUN 1 to 6 (EB1805737); ▪ Extraction / preparation: pH field screen: AC-3, AC-6, SC-9, DC-3, H-3(T1), H-3(T2), H-3(T3), H-6, EL-1 (EB1805205) ▪ Analysis: pH field screen: EL-3, EL-5, EL-6, SC-12, SC-13, SC-15, SC-18, AMRUN 1 to 6 (EB1805737)	These breaches occurred due to courier delays from Weipa to Brisbane, with these delays expected to impact actual acidity results. However, actual acidity was below the laboratory detection for all S_{CR} samples analysed, therefore these breaches have not impacted the data quality. Breaches in the organic matter extraction times may indicate associated samples are estimates. Breaches in conductivity are not considered to impact data quality as the associated samples results are within expected ranges.

7 Conclusion

7.1 Geotechnical characteristics

The sediments encountered in the Port of Weipa navigational areas varied considerably between and within areas; however, most of the sediments had relatively high fines (clay and silt) content. The areas of the site where coarse-grained sediments appear to prevail include most of the Approach Channel and the western portion of the Southern Channel. The Departure Channel contains both fine-grained and coarse-grained materials. There also appear to be zones of coarse-grained sediment present within the berth areas, particularly at Evan's Landing and Lorim Point where clayey sand / gravel materials were identified. The sediments encountered in Amrun Port (Approaches and Berths) were predominately silts and clays.

The carbonate content test results indicate a range of results across all areas of between 8% and 57%. A carbonate content of 50% is generally taken as the threshold value for a soil being regarded as a "carbonate soil" for the purposes of engineering design. On that basis, only a single sample from Evan's Landing is regarded as carbonate soil as the value for this sample was reported as 57%. Amrun Port carbonate contents ranged between 33.2% and 35.3%.

Atterberg limits testing (liquid limit and plastic limit) indicated that the plasticity of the soils is relatively variable across the sites. The fine-grained sediments range from low to high plasticity clay and low to high plasticity silt, with many samples falling close to the "A-Line" (as shown in Figure 5-3) meaning these materials will exhibit engineering behaviour bordering between that of silt and clay. For all fine-grained samples tested, the moisture contents were found to be higher than the corresponding liquid limits, indicating that these in-situ sediments are sensitive.

Linear shrinkage results indicate a generally low potential for volume change for most of the materials tested, with a medium / medium-to-high potential for volume change indicated by the test results at SC-9, TB1/3 and Amrun 2. The Volume Change Classification for the sediments was "very low" to "low" in general, "moderate" in places and "high" in two locations in the Tug Berth.

The recorded particle densities ranged between 2.51 t/m^3 and 2.63 t/m^3 across the Port of Weipa and between 2.53 and 2.6 t/m^3 at Amrun Port. The particle densities and the associated moisture content results were used to approximate the in-situ bulk dry density of marine sediments using phase relationships. The results of this estimation show a clear trend of decreasing in-situ density with an increase in fines content. This trend is to be expected for the types of sediments encountered at the site; however, there are some very low values of density estimated and this is attributed to the sampling process which has likely resulted in an overestimate of moisture content in some cases.

Bulk density testing results suggest that only relatively low dry densities (1.12 t/m^3 to 1.37 t/m^3) can be achieved for the dredge sediments; however, the results are an unrealistic representation of the density / compaction characteristics of the samples based on a comparison of these values with the results of the minimum / maximum density tests and the remoulded densities that could be achieved with strength / consolidation / permeability samples. Minimum / maximum dry density testing was undertaken on sand / silty sand samples and results indicate that the dry densities of the coarse-grained dredge sediments will range between approximately 1.22 t/m^3 and 1.81 t/m^3 depending on the level of compaction or method of placement utilised onshore.

Direct shear test results indicate that the coarse grained sediments may achieve friction angles of 33º to 44º after compaction and loading. These values are within the range generally associated with medium dense to very dense sand deposits. If adequately compacted, the coarse grained sediments are suitable for medium to high loading applications.

The CU testing results indicate that the average cohesion (c') of the samples after compaction and loading ranges from 3kPa to 13kPa, and average friction angles ranges from 29º to 36º. These strengths suggest that the fine grained sediments may be suitable for low to medium load applications following adequate drying out and compaction.

The oedometer testing results indicate that the c_v values for the four samples with high fines content (68-93%) are within the typical range expected for clays and silts, and the results for AC-3 (37% fines content) are within the range expected for a sandy silt. The c_v values for the samples with high fines content indicate that this material may take many months to many years to consolidate, dependent on drainage path length, although it is notable that consolidation times can vary significantly and can be better estimated by undertaking field trials (e.g. trial embankment with wick drains and surcharge).

The permeability test results indicate that the permeabilities are generally within the range expected for the types of sediments tested, with "poor" drainage characteristics being reported for the silt / clay samples and "good" drainage characteristics for the sand samples. The only exception to this was sample AC-3 (37% fines content, i.e. borderline sandy silt / silty sand), which behaved more like a sand with few fines rather than a sandy silt / silty sand material.

Cement laboratory testing results indicate that:

- Most of the sediment had a relatively high water and fines contents, which would limit their use in high end concrete products.
- Amrun sediments were very wet muds with excessive fines. These sediments would not easily be used in concrete products.
- Humbug and Lorim Point sediments may be suitable for use in flowable fill applications; however, additional testing on larger samples of the target material would be required to examine the effectiveness of stabilisation when mixed with Portland Cement.
- Some Southern Channel sediments have relatively low fines, and high silica and sand content. This material could be useful as an alternative source of normal fine sand in concrete and concrete products. For general premixed concrete use, the fines and relatively high level of chlorides present would need to be washed. This fine sand would typically be used at a rate of 200kg per m^3 of concrete (or <10% by weight). For other concrete uses (blocks or flowable fill) where reinforcement is not present, it could be used at substantially higher levels, with less pre-treatment. Other Southern Channel sediments were similar to the those found in Amrun Port and would not easily be used in concrete products.

7.2 Geochemical Characteristics

Based on the ASS analysis, PASS, in concentrations greater than the QASSIT action criteria was detected in all samples analysed for ASS parameters from the navigational areas of the Port of Weipa and Amrun.

Acid Neutralising Capacity was detected in all samples submitted for ASS analysis with concentrations sufficient to negate acidity. This buffering potential is expected to arise from the presence of carbonate within the sediments. These data indicate that the marine sediments from the Port of Weipa and Amrun may not require treatment through neutralisation using lime, dependent on the dredging and management methods applied to the sediments.

All samples are considered highly saline. If sediments are placed on land without treatment, salinity will degrade the quality of terrestrial soils and may impact the quality of receiving waters.

Low Organic Material (OM) was reported for all samples analysed. The highest OM (i.e. >3%) was detected in finer textured samples. Samples with a gravel component had the lowest OM, <1%.

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