Australia Pacific LNG Project
Supplemental information to the EIS

Acid Sulfate Soils Assessment of "The Narrows" - Pipeline

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Executive Summary

An Acid Sulfate Soils (ASS) assessment was undertaken along the proposed Australia Pacific Liquefied Natural Gas (LNG) gas pipeline Route 3H where it crosses the Narrows near Gladstone from KP 352.3 to 357.7 (5.4km total). The purpose of this assessment is to provide an understanding of the potential acid generating capacity of soils along this portion of the route and identify the impacts to the environment based on the broad construction methodology proposed for a 'stand alone' and 'co-location' pipeline scenario.

A field program undertaken in two components: Narrows sub-tidal and Narrows mudflats, consisted of 52 sampling locations based on a sampling intensity of 1 location per 100m as advised by DERM. Sampling was predominately undertaken using a vibracore to depth of refusal, however in locations with access and soil type restrictions, a hand auger and piston corer were used.

Three generalised profiles were encountered within the Narrows sub-tidal area. These were divided into the east, west and central areas of the channel. Both the east and west sides were indicative of material encountered on their respectively adjacent landforms on the mainland and Curtis Island: very weak silty layer on the surface which graded into weak silty clay to approximately 1.0m. Below this depth, firm to very firm silty clay was encountered. All profiles generally contained appreciable quantities of organic material and shells and often had a sulfurous odour. Mixed sediments with a high proportion of coarse materials were encountered within the third profile. Here, the deposition of fine sediments in this area is likely to be limited due to significant tidal velocities. All profiles encountered in the Narrows sub-tidal area were PASS.

The mudflats are comprised of a number of landforms: tidal creeks, intertidal (mangrove) flats, supratidal (salt) flats and extratidal flats, all of which are traversed by the proposed gas pipeline route. The tidal creeks, intertidal and supratidal flats have been classified as having high potential for acid generation at varying depths within the soil profile. Extratidal flats have been classified as having a low probability for ASS occurrence.

The surface soil profiles at most locations across the mudflats were noted as very firm brown silty clay. This surface sheet washed material is likely to have been deposited by erosion from adjacent terrestrial sources. To the west of Targinie Creek this material was non ASS, however to the east was identified as PASS, and in some instances AASS, as it was generally very thin and intermixed with subsurface PASS profiles. Below this surface horizon in the supratidal flats (east of Targinie Creek), a weak to firm, dark to very dark grey silty clay was encountered down to approximately 1.0mBGL. This layer continued to approximately 2.0mBGL, but with few fine shells. Adjacent to Port Curtis a firm, dark grey silty clay on the surface and a weak to firm dark to very dark grey silty clay down to approximately 2.5mBGL was encountered. Both dark grey silty clay profiles encountered across the mudflats are PASS.

Field screening tests were carried out on a total of 369 samples at nominal 0.25m intervals at each sample location to provide preliminary assessment of the presence of ASS. These tests indicated that there was limited actual acidity within both the sub-tidal and mudflat portions of the study area which was consistent with data reported within GLNG (URS, 2009 and GeoCoastal, 2009) and QCLNG (ERM, 2009) reports. Field oxidised samples (pH_{FOX}) indicated 38% of locations within the sub-tidal area and nearly all locations along the mudflats contained PASS. This was also consistent with data reported within GLNG and QCLNG reports.

All discrete samples (total 238) collected at nominal 0.5m intervals at each sample location were tested using the Chromium suite analysis. This indicated AASS were not present within the sub-tidal area, but at some locations within the first 1m, and in some cases, first 1.5m of the soil profile of intertidal and supratidal flats. Laboratory results also indicated that all samples collected from the sub-tidal area and all very dark grey silty clay or sand collected within the mudflats were PASS. This ranged from 0.02%S to 2.94% sulfur, Sample points where no actual (AASS) or potential acidity (PASS) were collected from the extratidal flat (west of Targinie Creek).

Based on the laboratory data alone and the proposed disturbance volume, most soils located within mudflats and the sub-tidal area (where there was insufficient acid neutralising capacity) will require an extra high level of treatment i.e. in excessof 25 kg of lime per tonne of soil. As a result, an ASS Management Plan (ASSMP) will need to be developed as the proposed development has the potential to pose a significant risk to the environment through disturbance of already acidic soil (AASS) and PASS causing oxidisation of sulfides and therefore the generation of sulfuric acid.

This disturbance, through the fluctuation of tides in the study area, rainfall and groundwater movement, has the potential to lead to the migration of acidic fines to the receiving waterways of the Great Barrier Reef World Heritage Area. The potential impact of this acidic sediment to the environment may be the deoxygenation of waterways, release of heavy metals, such as aluminium and fish kills. Where these impacts have the potential to occur or where environmental monitoring detects breaches in development conditions imposed by regulatory bodies, there is the potential for lengthy delays to construction.

The ASSMP will need to be developed in consultation and co-ordination with design engineers and DERM in order to achieve a balance between best practice ASS objectives and project engineering design, construction, logistics and cost.

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1. Introduction

An Acid Sulfate Soils (ASS) assessment was undertaken along the proposed Australia Pacific Liquefied Natural Gas (LNG) gas pipeline Route 3H where it crosses the Narrows near Gladstone.

The previous gas pipeline Route 3F presented in the Australia Pacific LNG draft EIS, was subject to minor alterations in response to local environmental values and constraints. As a result and since the Draft EIS submission, Route 3H has been generated. This route is to be shared by all four LNG proponents from approximately Kilometre Point (KP) 352.3 on the mainland to KP 357.7 on Curtis Island. This section of the route which traverses the Narrows is approximately 5.4km in length and for the purpose of this assessment is known as the study area represented by hatching (100m in width) on Figure 1.1. This figure indicates the section of the route where ASS have the potential to occur.

1.1 Purpose

The purpose of this assessment is to identify and assess ASS along Route 3H from KP 352.3 to 357.7 in accordance with State ASS guidelines in order to understand the potential acid generating capacity of these soils and identify the impacts to the environment based on the broad construction methodology proposed.

1.2 Proposed works

It is unclear at this stage as to which of the two scenarios for the crossing of the Narrows listed below will be adopted, however the gas pipeline route for both will be the same as that shown in Figure 1.1.

- A stand alone option in which Australia Pacific LNG would construct its gas pipeline in isolation from other proponents
- A co-location option in which all proponents pipelines will be constructed in one joint construction exercise

In order to conduct a thorough ASS assessment, some fundamental understanding of the proposed works is required. These include the proposed type of work (excavation / filling), volume of disturbance, location and duration of works, and the proposed disturbance depth.

The preferred construction method for the stand-alone Australia Pacific LNG option is open cut trenching using conventional dredging methods. This would require the trenching of approximately 262,000m^3 from the Narrows. The trench invert would be approximately 5m wide at the base. Trench depth would range from 3-7m (average 5m), with surface widths ranging from 25-45m (average 35m).

For the co-located pipeline option, the preferred approach is open cut trenching using conventional dredging methods, due to the size and complexity of the four pipe bundle. For the purpose of this assessment, the disturbance areas, length and depth have been adopted from the report '*GLNG Pipeline FEED Report for Mechanised Marine Crossing Installation Concept - GHD Doc # 21386-P-RP-002 Rev D*' completed by GHD (GHD, 2010).

The GHD report indicates two trenches will be required to be excavated to a depth of 2.3m Below Ground Level (BGL) across the mudflats (i.e. within the intertidal zone of the Kangaroo Island Wetlands). Each trench will have two gas pipelines to be installed separately. The total disturbance volume within the mudflats will be approximately 726,204m^3.

This report also indicates a single trench will be cut along the seabed floor for the sub-tidal crossing. The estimated dredge disturbance will be to a nominal depth of 3-7m (average 5m) and width of 45m-65m (average 55m). This methodology states a total dredge volume of 464,332m^3 will be removed from the sub-tidal areas and dumped in a pre-approved underwater stockpile or reclamation area. The proposed disposal location for this dredge material has yet to be determined.

The ASS assessment presented within this report has been undertaken to generally comply with ASS sampling intensity described in legislation (see below). However, due to some limitations in sampling depth experienced during site investigations, it is expected that additional sampling and validation testing will be required during the construction program.

1.3 Legislative Framework

In Queensland, the State Planning Policy (SPP) 2/02 sets out the State's interest concerning development involving ASS in low-lying coastal areas. The SPP 2/02 has effect under the *Sustainable Planning Act 2009* (SPA) and applies to all land, soil and sediment at or below 5mAHD where the natural ground level is less than 20mAHD (Queensland Government 2002). Within this area, the SPP2/02 applies to all development involving excavating or removing 100m^3 or more of soil or sediment, or filling of land involving 500m^3 or more of material with an average depth of 0.5m or greater.

DERM (previously known as NR&M) has published 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:

- Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) 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)

The methodology for undertaking this assessment has been guided by the above policies and guidelines and is presented in Section 2 below.

LEGEND

- Pipeline kilometre points
- Watercourse
- Gas pipeline route
- Cadastral boundaries
- APLNG acid sulfate soils study area

Source Information

Watercourses (based on 250k topography)
Commonwealth of Australia (Geoscience Australia) 2009
Gas pipeline route
Supplied by APLNG 17/05/2010
Cadastre
Department of Environment and Resource Management (DERM) 2010
Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Pipeline kilometre points
Supplied by APLNG 04/06/2010

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Figure 1.1
The Narrows
Acid Sulfate Soil Investigation
Study Area Location

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2. Assessment methodology

2.1 Sampling intensity and field assessment

The field assessment was undertaken from 27 April to 15 May 2010. It consisted of soil and sediment sampling at 52 locations (refer Table 2.1) along the proposed 5.4km length of pipeline across the Narrows specified within the GHD (2010) report. Sampling at 54 locations was initially proposed, however two locations were inaccessible during the field assessment. These are illustrated on Figure 2.1. The sampling intensity selected was based on advice given in a DERM meeting held on 22/03/2010, where one sampling location every 100m (rather than 50m as specified in the State Planning Policy 2/02 [SPP2/02] and the guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland 1998) of linear infrastructure was deemed adequate. This sampling intensity reflects the existence of a sound data base from previous investigations in the area (e.g. Ross, 2002, 2004 and 2005). This means, for the purpose of this assessment, an 'area' methodology was not required.

Due to current uncertainties regarding the proposed construction technique, final location of the gas pipeline and foreseen complexities of the investigation, the Narrows was divided into two components: Narrows mudflats (including Targinie, Humpy and Mosquito Creeks) and the Narrows sub-tidal crossing (marine portion). Locations across the Narrows sub-tidal portion were accessed using a flat bottom boat during both low and high tides. In deeper areas of the Narrows (i.e. locations W6 to W16) commercial divers were used to guide coring equipment underwater. Locations along the mudflats were accessed by hovercraft and supported by boat as vehicular access was not allowed through private property. These locations were reviewed by a cultural heritage monitor prior to sampling and sampling points adjusted based on their findings or access restrictions.

Each location was to be sampled to at least 1m beyond the depth of potential disturbance. This meant sampling to approximately 3.5mBGL in the mudflats and an average depth of 5.5m below the sea floor in the Narrows sub-tidal crossing. As noted within a similar study completed for the Gladstone Port Corporation (GPC) EIS of dredge areas 1b and 2a (Golder Associates, 2009), stiff material at approximately 3m sediment depth restricted deeper coring even when a pneumatic vibracorer was used. Any coring below this depth would therefore need more powerful drilling equipment operated from specialised jack-up barges to penetrate hard materials. This approach was considered to be cost and time prohibitive for the purposes of this investigation. As a result, the less powerful but more versatile vibracoring method operated from a flat bottom boat was selected (refer Plate 2-1). This equipment was easily transferred to the mudflats with use of a hovercraft. Here, the vibracore was supported by a portable A-frame which was re-established at each location (refer Plate 2-2).

Sampling was predominately undertaken using a vibracore to depth of refusal (refer Section 4.1). However, where dry terrestrial pre-Holocene soils were predominant (i.e. MF05 to MF10, refer Section 4.1) instantaneous vibracore refusal occurred. Such locations were hand augered to refusal (between 1.25mBGL and 3mBGL). A piston corer was used at locations MF1 and MF2 due to access restrictions which prohibited the use of the boat and hovercraft and therefore transport of the vibracorer.

Table 2.1 Investigation Locations

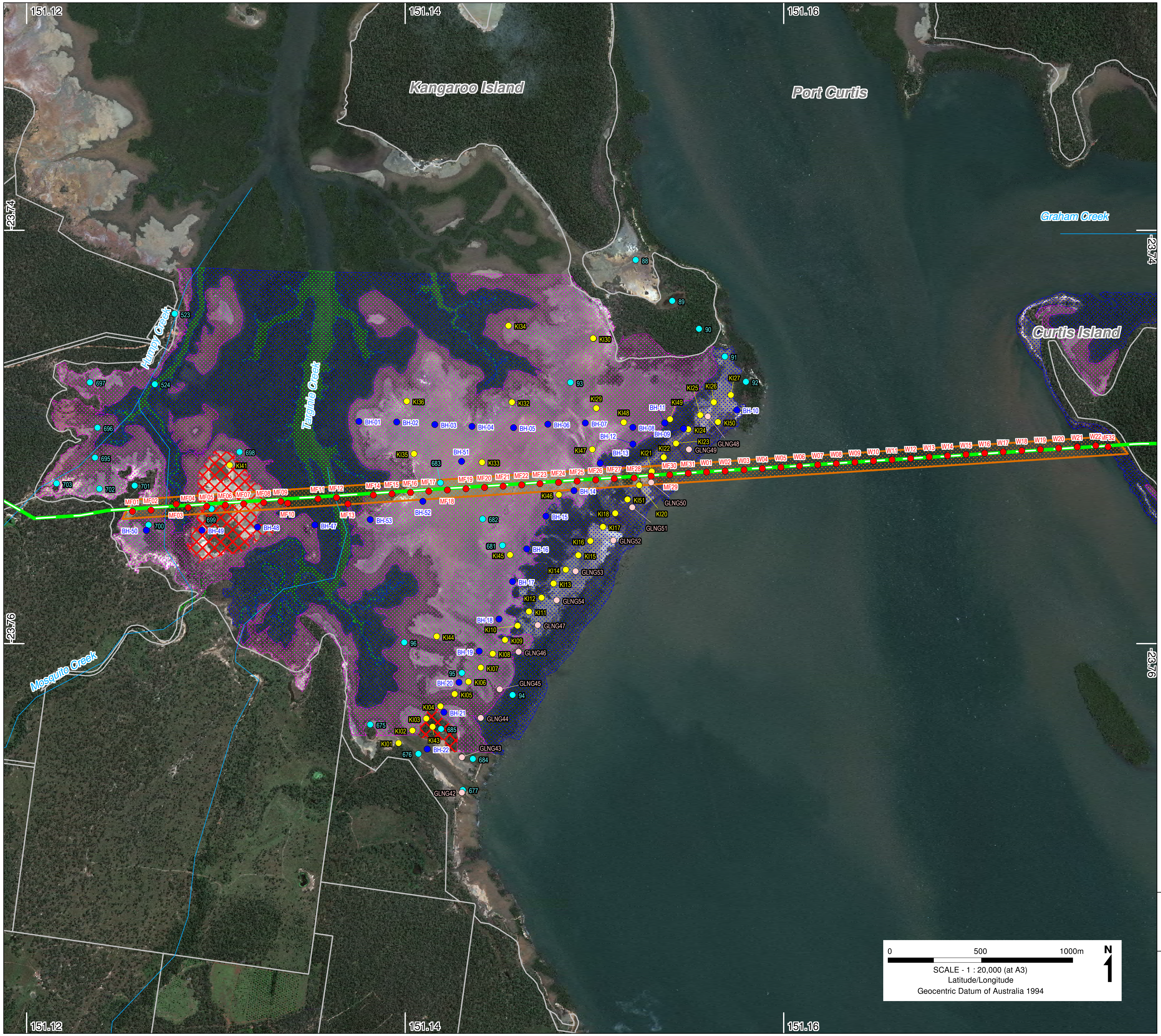
Sampling location ID	Southing	Easting	Depth of core (m below sampling surface)	Comments
MF01	S23 45.216	E151 07.536	1.3	
MF02	S23 45.213	E151 07.595	1.75	
MF03	S23 45.195	E151 07.674	0.3	Relocated due to dense mangrove vegetation
MF04	S23 45.205	E151 07.712	1.2	
MF05	S23 45.202	E151 07.771	2.25	
MF06	S23 45.198	E151 07.830	3.0	
MF07	S23 45.194	E151 07.888	2.2	
MF08	S23 45.141	E151 07.571	2.0	Adjusted in the field
MF09	S23 45.187	E151 08.006	1.25	
MF10	S23 45.192	E151 08.028	1.75	Relocated due to dense mangrove vegetation
MF11	S23 45.180	E151 08.123	-	Inaccessible / not tested due to dense mangrove vegetation
MF12	S23 45.176	E151 08.182	0.4	
MF13	S23 45.194	E151 08.218	1.8	Relocated due to dense mangrove vegetation
MF14	S23 45.169	E151 08.299	1.6	
MF15	S23 45.165	E151 08.358	2.2	
MF16	S23 45.161	E151 08.417	2.6	
MF17	S23 45.158	E151 08.476	2.4	
MF18	S23 45.154	E151 08.534	2.2	
MF19	S23 45.150	E151 08.593	2.4	
MF20	S23 45.147	E151 08.652	2.4	
MF21	S23 45.143	E151 08.710	2.9	

Sampling location ID	Southing	Easting	Depth of core (m below sampling surface)	Comments
MF22	S23 45.139	E151 08.769	2.4	
MF23	S23 45.136	E151 08.828	1.8	
MF24	S23 45.132	E151 08.887	2.4	
MF25	S23 45.128	E151 08.945	2.6	
MF26	S23 45.125	E151 09.004	1.15	
MF27	S23 45.121	E151 09.063	2.5	
MF28	S23 45.119	E151 09.126	1.8	Relocated due to dense mangrove vegetation
MF29	S23 45.114	E151 09.180	2.85	
MF30	S23 45.110	E151 09.239	2.4	
MF31	S23 45.106	E151 09.298	-	Inaccessible / not tested due to tide restrictions
MF32	S23 45.022	E151 10.648	0.6	Relocated due to tide restrictions
W01	S23 45.103	E151 09.356	1.1	
W02	S23 45.099	E151 09.415	2.4	
W03	S23 45.095	E151 09.474	1.8	
W04	S23 45.092	E151 09.533	1.2	
W05	S23 45.088	E151 09.591	1.8	
W06	S23 45.084	E151 09.650	2.6	
W07	S23 45.080	E151 09.709	1.8	
W08	S23 45.077	E151 09.767	1.2	
W09	S23 45.073	E151 09.826	0.5	
W10	S23 45.069	E151 09.885	0.2	
W11	S23 45.066	E151 09.944	0.05	

Sampling location ID	Southing	Easting	Depth of core (m below sampling surface)	Comments
W12	S23 45.062	E151 10.002	0.08	
W13	S23 45.058	E151 10.061	0.1	
W14	S23 45.055	E151 10.120	0.45	
W15	S23 45.051	E151 10.178	2.3	
W16	S23 45.047	E151 10.237	2.2	
W17	S23 45.044	E151 10.296	0.75	
W18	S23 45.040	E151 10.355	0.6	
W19	S23 45.036	E151 10.413	1.6	
W20	S23 45.033	E151 10.472	1.1	
W21	S23 45.029	E151 10.531	1.0	
W22	S23 45.025	E151 10.590	0.9	

Plate 2-1 Vessel vibracore setup

Plate 2-2 Mudflats vibracore setup



LEGEND

- APLNG soil sampling locations
  (NOTE: MF11 and MF31 were inaccessible)
- QCLNG Borehole locations - Friend Point
- GLNG onshore soil sample locations
- GLNG soil sample locations
- DNRW sampling location - The Narrows
- Watercourse
- Gas pipeline route
- Cadastral boundaries
- APLNG acid sulfate soils study area
- Tidal creeks
- Intertidal flats
- Supratidal flats
- Extratidal flats

Source Information

Watercourses (based on 250k topography)
Commonwealth of Australia (Geoscience Australia) 2009
Gas pipeline route
Supplied by APLNG 27/03/2010
Cadastre
Department of Environment and Resource Management (DERM) 2009
Satellite imagery
Captured by GeoEye-1 on 24 March 2009
QCLNG borehole locations - Friend Point
Environmental Resource Management (ERM), 2009, Queensland Curtis LNG Project LNG Facility and Associated Infrastructure - Acid Sulfate Soils Investigation, Friend Point and Curtis Island, Gladstone, QLD, Queensland Gas Company Limited (QGC), Brisbane.
Tidal creeks, intertidal flats, supratidal flats & extratidal flats
Digitised from GeoEye-1 imagery by WorleyParsons 07/06/2010

GLNG onshore soil sample sites
URS Australia Pty Ltd (URS) 2009, GLNG EIS Supplement E5 : Acid Sulfate Soils: Common Pipeline Infrastructure Corridor : ASS assessment of additional field data. Santos Petronas, Brisbane.
GLNG soil sample locations
Manually extracted. GeoCoastal (Australia) Pty Ltd (GeoCoastal) 2009, Terrain Soils and Land Capability : Gladstone LNG Facility Final Report prepared for Santos Ltd, Santos Petronas, Brisbane.
DNRW sampling location - The Narrows
Ross, D. 2004, Acid Sulfate Soils Tannum Sands : Gladstone Area Central Queensland Coast (QNRM04285), Department of Natural Resources and Mines Queensland, Rockhampton.
Ross, D. 2005, Acid Sulfate Soils of the Narrows Area, Central Queensland Coast (QNRM05524), Department of Natural Resources and Mines Queensland, Rockhampton.

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Figure 2.1
The Narrows
Acid Sulfate Soil Investigation
Sampling Locations

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2.2 Soil sampling methodology

Field sampling procedures conformed to WorleyParsons Quality Assurance / Quality Control (QA/QC) protocols to minimise potential for cross contamination and preserve the sample integrity. The following sections provide a brief description of the testing methods used, while Table 2.2 provides a summary of the soil sampling activities.

Table 2.2 Soil sampling methods

Activity	Details
Site access	The Narrows sub-tidal crossing was accessed using a 7m surveyed flat bottom vessel on both low and high tides. The mudflats were accessed using both a hovercraft and boat. Activities were organised around tidal movement due to the large variation. As a result, the hovercraft could only land on the mudflats during high tide and was used to transport the vibracore and associated equipment to each location. A boat was used during high and ebbing tides to ferry staff to and from the mudflats daily.
Sampling locations	Sampling locations were selected and plotted prior to field activities. These pre-recorded locations were then found using a Garmin 76CSx hand held Global Positioning System (GPS) unit with an accuracy of +/-4m. Where required, locations were re-located using this GPS device.
Soil coring	An air driven 40mm diameter stainless steel vacuum vibracore was used at all sampling locations with the exception of MF01, MF02, and MF05 to MF10. Vibracored locations were extended to refusal which ranged from approximately 0.05m (W11) to 2.6m (W6) below the seabed floor within the Narrows sub-tidal crossing and 0.3m (MF03) to 3.0m (MF06) BGL across the mudflats and Humpy and Targinie Creeks. A handheld 60mm diameter stainless steel piston corer was used at locations MF01 and MF02. This was extended to refusal which occurred at 1.3mBGL and 1.75mBGL at MF01 and MF02 respectively. A 82mm diameter hand auger was used at locations MF5 to MF10. Augering at these locations was extended to refusal which ranged from 1.25m (MF09) to 3mBGL (MF06).
Core recovery	Vibracoring is most efficient in water-saturated sediments and therefore was ideal within the Narrows sub-tidal channel. It operates by raising the pore-pressure and generating a thin-layer of liquefaction along the wall of the core barrel. This generally produces an undisturbed continuous sediment core, however stiff, sticky and drier sediments can act as a plug, thereby causing the vibracore to displace, rather than retain lower sediments. The result is a sample core length which maybe less than the coring depth. This issue can also occur within piston corers, but usually at or near the refusal depth. Core recoveries within firm and sticky sediments were generally less than the coring depths. These are indicated on the borelogs provided in Appendix 1.
Core collection	Sample cores were collected directly from the vibracore by reversing compressed air flow to extrude the sample into a plastic sheath for transport to the sample processing area. Sample cores from the piston corer were extruded in a similar fashion, however the piston is manually pushed with a rod into a plastic sheath for transport to the sample processing area. Sediment / soil brought to the surface by hand augering was placed into plastic sheaths in 0.25m segments for transport to the sample processing area.

Activity	Details
Abandonment	The vacuum vibracore does not produce any spoil so the 40mm diameter hole remained open following the completion of the vibracoring. The piston corer also does not generate spoil as the entire core is extruded into plastic sheathing therefore a 60mm diameter hole is left open. Remaining soil from hand augered locations was backfilled to the existing natural ground level using soil retrieved during augering.
Standing water level	The standing water level (SWL) was measured across the mudflats using a Solinst Interface meter following the completion of coring. SWL ranged from 0 (due to high tide inflows) and 1.0mBGL.
Sample processing	Sample processing was undertaken from two locations due to the logistics of the study area access. These are as follows: Sample processing for the Narrows sub-tidal crossing was completed at a designated area on Fishermans Landing. Sample cores were returned twice daily to the processing area where the plastic core sheath was split open length ways for lithological logging and discrete sample collection. Samples were collected using new disposable nitrile gloves and placed into laboratory supplied resealable plastic bags. These were then placed with dry ice prior to transport to the Australian Laboratory Services (ALS) Gladstone laboratory for daily dispatch. Sample processing for the mudflats was completed at a designated area within ALS's Gladstone laboratory. Due to tidal restrictions sample cores were delivered once daily. These were transported directly to the laboratory for processing (as described above) and daily dispatch.
Labelling	Sample bags were labelled with the date, the abbreviated project location (APLNG) and the location number / depth. For instance a sample collected at MF15 at a depth of 0.7m to 0.8m BGL was labelled as follows: APLNG 11/05/2010 BH15 / 0.7-0.8
Dispatch	ASS samples were stored on dry ice and delivered daily to ALS Gladstone under chain of custody documentation.

2.3 Soil descriptions

Soil characteristics at all 61 locations were described in accordance with the Australian Soil and Land Survey Field Handbook (NCST, 2009) and the Australian Soil Classification (Isbell, 2002). This is presented as borelogs in Appendix 1 and included the soil horizon information provided in Table 2.3. Photographs of the cores showing the profiles were also taken once they were retrieved for sample processing (refer Appendix 2).

Table 2.3 Soil horizon information

Soil horizon descriptions
Subgroup classification
Horizon name
Depth
Colour (matched to the Munsell Colour Chart paint chip)
Texture

Soil horizon descriptions
Structure
Consistence
Coarse fragments
Mottles
Presence of carbonates and/or salts
Rooting description

2.4 Field Screening Tests

Field screening tests were carried out on a total of 369 samples at nominal 0.25m intervals at each sample location to provide preliminary assessment of the presence of ASS. The pH of a 1:5 soil/water extract (pH_F) and the pH of an extract after the addition of 30% hydrogen peroxide (pH_{Fox}) were measured using a spear point double reference Ionode IJ44 pH electrode, connected to a Lutron PH-207HA meter. The meter was calibrated to two points of reference (two-point calibration: pH 4 and pH 7) prior to sampling.

In addition to recording pH_F and pH_{Fox}, the initial reactions between the soil and the 30% hydrogen peroxide mixture were recorded. Results of field screening tests are provided in a summary of results table in Appendix 3.

2.5 Soil Sampling and Laboratory Analysis

A total of 238 samples were collected for laboratory analysis from 52 locations in the Narrows sub-tidal crossing (81 samples) and mudflats (157 samples). These discrete grab samples were collected approximately every half metre of the profile within a uniform horizon or adjusted to take into account specific visually or texturally discrete horizons that were not intercepted within the half metre interval. All discrete samples collected were tested for Chromium suite analysis at ALS's National Association of Testing Authorities (NATA) accredited laboratory in Brisbane. A summary of results is provided in Appendix 3, while all laboratory certificates are provided in Appendix 4.

2.6 Quality Control / Quality Assurance

Field sampling procedures conformed to WorleyParsons' Quality Assurance / Quality Control (QA/QC) protocols to minimise potential for cross contamination and preserve the sample integrity. This incorporated decontamination measures, QA/QC protocols, and field sampling techniques that ensured sample integrity and reliability of the analytical results. The field procedures that were followed included:

- Handling and collection of samples using new single use nitrile gloves
- Storing samples in laboratory supplied resealable bags
- Storing of samples on dry ice in an esky until delivered to the laboratory

ALS undertakes an internal QA/QC program that monitors the integrity and reliability of the analytical results. This program included the following:

Preparation and Analysis of Laboratory Duplicate Samples

Laboratory duplicate samples are randomly selected samples from an inter-laboratory batch which are split and tested to provide an indication of the precision of the laboratory method and sample heterogeneity. This is assessed through the comparison of relative percentage differences (RPD) with a permitted range. All random samples selected for RPD assessment were within the laboratory prescribed limit of 0% to 20%. The results of these samples are provided within the internal ALS QA/QC in Appendix 4.

Analysis of Method Blank

Method blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. All method blanks analysed reported non-detectable concentrations. The results of these samples are provided within the internal ALS QA/QC Appendix 4.

Holding Times

Holding times refer to the time from when the sample was collected in the field and to when the analysis was undertaken at the laboratory. This time must be minimised to ensure the representativeness of the result obtained. Increased holding times may lead to a change in analytes due to processes such as oxidisation. All samples submitted for Chromium Suite analysis were delivered frozen and therefore within the prescribed holding time. A review of holding time compliance is provided within the internal ALS QA/QC in Appendix 4.

The QA/QC program undertaken for this assessment confirms the representativeness of the samples analysed. Therefore, the analytical data reported is considered to be valid and suitable for interpretation in this investigation report.

2.7 Assessment Criteria

The Queensland Acid Sulfate Soil Technical Manual – Soil Management Guidelines (Dear et al., 2002) provides action criteria for when ASS is disturbed at a site and should be managed (refer Table 2.4). To account for a soil's natural ability to resist pH change (buffering capacity), generally influenced by clay content, the action criteria have been grouped into the following three broad soil texture categories - coarse, medium and fine.

Table 2.4 Soil Management Guidelines Action Criteria

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

(Dear *et al*. 2002)

Action criteria for disturbances greater than 1,000 tonnes have been selected as the appropriate criteria based on the earthworks that are likely to occur.

In addition to the action criteria above, changes in pH (both pH_F to pH_{FOX} [field screening tests] and pH_{KCl} to pH_{OX} [laboratory screening tests]) greater than 1 pH unit can be indicative of AASS and PASS. A change greater than 1 pH unit in pH_F to pH_{FOX} can also assist in sample selection for laboratory analysis. These screening results are summarised in Section 4.2.

3. Study area information

The study area is located within the Narrows. This section of the pipeline traverses approximately 5.4km across tidal and sub-tidal areas (refer Figure 1.1). The tidal area is comprised of a number of landforms (refer Section 3.1) commonly referred to as mudflats, while the sub-tidal crossing of the Narrows forms the body of water in the northern portion of Port Curtis between Curtis Island and Kangaroo Island.

3.1 Landform

Specific landform characteristics relevant to the study area are described within a report completed by Ross, 2002: *Acid Sulfate Soils Tannum Sands to St Lawrence Central Queensland Coast (QNRM02008)*. This report was completed to assess the ASS hazard from Tannum Sands to St Lawrence across several landforms along the coast. This broad section of coastline includes the gas pipeline study area adopted for this assessment and also describes the landforms which occur within it. These landforms include tidal creeks, intertidal flats, supratidal flats and extratidal flats.

Section 3.1.1 briefly describes the study area landforms based on information provided within Ross, 2002.

3.1.1 Tidal creeks

Three creeks occur within the study area: Targinie, Humpy and Mosquito Creek (refer Figure 1.1). These creeks are tidally influenced and are characterised by steep and often near vertical banks lined with dense mangroves and small inlets (refer
Plate 3-1) [Ross, 2002]. They occur adjacent to intertidal flats (refer Section 3.1.2) and supratidal flats (refer Section 3.1.3). The ASS located within these creeks has been rated by Ross (2002) as low to extreme.

Plate 3-1 Humpy Creek

3.1.2 Intertidal (mangrove community) flats

These flats are characterised by mangrove vegetation, shallow channels and regular saline tidal inundation and are situated between low and high tides (Ross, 2002) [Refer Figure 1.1]. Ross (2002) identified that the highest levels of oxidisable sulfur are associated with the mangroves in these flats as the mangroves provide a constant source of rotting organic matter under anaerobic conditions essential for ASS formation. Plate 3-2, taken near sampling location MF10, provides an example of these intertidal flats within the study area.

Plate 3-2 Intertidal (mangrove) flat

3.1.3 Supratidal (salt) flats

These flats occur adjacent to intertidal flats and are generally bare of vegetation, salt-encrusted, are very gently sloping and occupy the area between high and spring tides (Ross, 2002) [Refer Figure 1.1]. Some small areas of marine grasses can occur, however the extreme soil salinity restricts mangrove growth (Ross, 2002). The PASS within these flats has been rated as low to extreme, however the extreme rating is more common (Ross, 2002). Plate 3-3, taken near sampling location MF17, provides an example of these supratidal flats within the study area.

Plate 3-3 Supratidal (salt) flat

3.1.4 Extratidal flats

These flats are elevated above the supratidal flats but occur below the extreme storm surge level (Ross, 2002). They are generally occupied by marine couch grassland but can have occurrences of tea tree and eucalypt woodland on the landward margin of confined areas, while on the seaward side can have a characteristic step created by erosion (Ross, 2002). Plate 3-4 was taken from sampling location MF05 looking towards the extratidal flat where MF06 is located. The ASS hazard is rated from very low to extreme, however a low rating is common (Ross, 2002).

Plate 3-4 Extratidal flat

3.2 Geology

The regional geology of the study area has been mapped by the Geological Survey of Queensland (GSQ) in the Geoscience Datasets and geological 1:100,000 series mapping of Gladstone.

The geology identified surrounding the study area and within the vicinity of the Mount Larcom Range and Curtis Island, comprises predominantly Late Devonian to Early Carboniferous Volcaniclastic sedimentary rocks of the Wandilla Province.

The Wandilla Province extends in a band from Shoalwater Bay to the north and south into northern New South Wales. The Wandilla Province comprises numerous deep water sedimentary and volcanic rocks which, in general, are steeply dipping, structurally complex, and sparsely fossiliferous. Quaternary alluvium and soil occur in low-lying areas, adjacent to major waterways of this region and is located within the Narrows intertidal and sub-tidal areas.

As mapped in the GSQ Geoscience Datasets, several of the geological mapping units identified have similar characteristics in terms of age, rock type and region. The geological units relevant to the study area are summarised in Table 3.1 and presented in Figure 3.1.

Table 3.1 Study area geologic unit summary

General Location	Description	Major geological unit	Age	Lithology summary	Dominant rock	Map symbol
Study area	Quaternary (Holocene) Alluvium and estuarine sediments	Alluvium	Holocene	Mud, sandy mud, muddy sand and minor gravel forming estuarine channels and banks, supratidal flats and coastal grasslands	Miscellaneous unconsolidated sediments	Qa
		Alluvium	Quaternary	Sand, silt, mud, gravel from residual soils	Miscellaneous unconsolidated sediments	
		Alluvium	Quaternary – Pleistocene	Clay, silt, sand, gravel; floodplain alluvium	Alluvium	
Regional	Tertiary Alluvium	Alluvium	Late Tertiary – Quaternary	Locally red-brown mottled, poorly consolidated sand, silt, clay, minor gravel; high level alluvial deposits, generally dissected, and related to present stream valleys	Poorly consolidated sediments	Ta
		Poorly consolidated sediments	Tertiary	Semi consolidated clayey sandstone and conglomerate, associated with deep weathered profiles	Poorly consolidated sediments	
		Floodout and residual sand, soil and gravel	Late Cainozoic	Sand, soil and gravel	Miscellaneous unconsolidated sediments	
	Devonian to Carboniferous	Wandilla Formation	Late Devonian –	Mudstone, lithic sandstone	Arenite-Mudrock	DCc

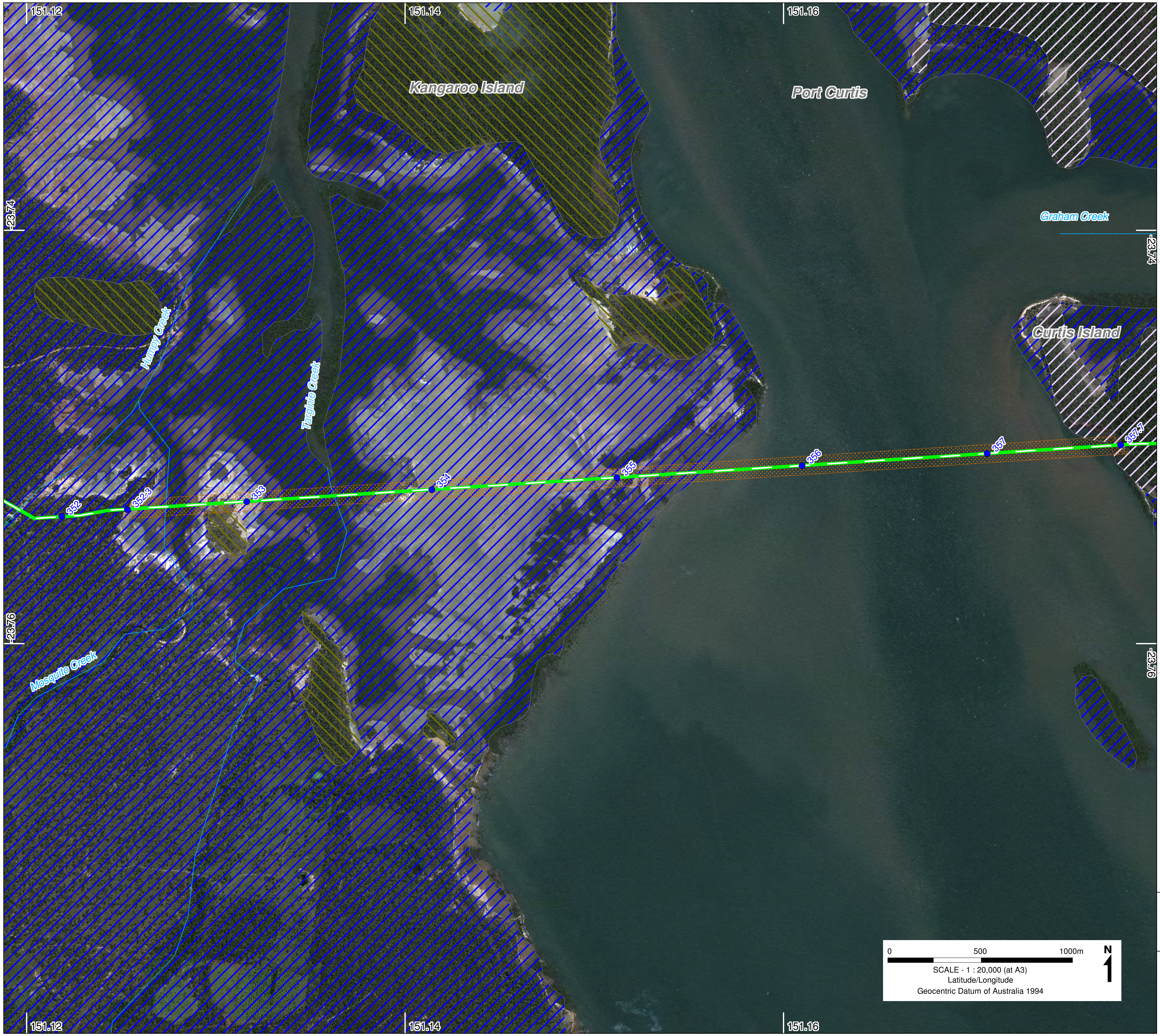
General Location	Description	Major geological unit	Age	Lithology summary	Dominant rock	Map symbol
	Sediments - Curtis Island Group		Carboniferous	(localised containing silicified ootlites), siltstone, jasper, chert, slate, localised schist		

The geologic formations most likely to contain ASS primarily relate to deposition in the last major sea level rise which occurred in the late Quaternary Period: Holocene Epoch. Based on the data presented in Table 3.1, this includes alluvium material such as mud, sandy mud, muddy sand and minor gravel forming estuarine channels and banks, supratidal flats and coastal grasslands. In some instances, ASS may also occur in the sand, silt, mud and gravel from terrestrial soils where seawater has mixed with land sediments containing iron oxides. Earlier periods, such as the Pleistocene Epoch, are less likely to have ASS sediments, however in some circumstances, ASS sediments may occur in alluvium from the penultimate interglacial high sea level period in the late Pleistocene period. This includes floodplain alluvium: clay, silt, sand and gravel.

Within the mudflats portion of the study area, landforms which are likely to contain ASS include the tidal creeks, intertidal flats and supratidal flats. These landforms have already been noted by Ross, 2002 as having a high occurrence of ASS. Extratidal flats are less likely to have occurrences of ASS and are more likely to be associated with terrestrial soils mentioned above.

Within the Narrows sub-tidal portion of the study area, Holocene aged and ASS bearing sediments are also likely to exist.

Tertiary and Devonian to Carboniferous geology noted within Table 3.1 are highly unlikely to contribute the formation of ASS.



LEGEND

- Pipeline kilometre points
- Watercourse
- Gas pipeline route
- APLNG acid sulfate soils study area

Geology

- Qa
- Ta
- DCc

A full description of geology is provided in Table 3.1

Source Information

Watercourses (based on 250k topography)
Commonwealth of Australia (Geoscience Australia) 2009
Gas pipeline route
Supplied by APLNG 17/05/2010
Cadastre
Department of Environment and Resource Management (DERM) 2009
Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Geology
Geology is a combination of Queensland geological 100k mapping (polygonised vector) data and Queensland geological 250k mapping (polygonised vector) data.
Pipeline kilometre points
Supplied by APLNG 04/06/2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 3.1
The Narrows
Acid Sulfate Soil Investigation
Study Area Geology

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3.3 Soil types – overview

The study area occurs within single land system (Ct) as mapped by *Land Systems of the Capricornia Coast, map 3 Calliope Area, 1: 250,000, DPI, Brisbane*. This map indicates the associated landform character, most common soil types and typical native vegetation characteristics (where intact). An extract of this map is provided in Table 3.2 where it is applicable to the study area.

The Australia Pacific LNG draft EIS describes soil types / soil mapping units within the land system report described above and designates soil groupings to enable a common description of soil characteristics and management issues relevant to the Australia Pacific LNG Project. A standardised soil key for the Australia Pacific LNG Project is provided within the draft EIS, however the soil group relevant to the study area of this assessment is provided in Section 3.3.1 below, illustrated on Figure 3.2 and indicated in (see brackets) the soils column of Table 3.2.

Note that land system mapping has not been developed for Curtis Island. However, land zone generated for Regional Ecosystems (RE) mapping provides an indication of soil types that are likely to occur in the study area on Curtis Island. REs are a combination of bioregions (13 in Queensland), land zones and vegetation communities. Of the nine RE's identified within the study area (refer Australia Pacific LNG draft EIS), only three land zones occur. These are described in Table 3.3.

Table 3.2 Mainland study area land systems

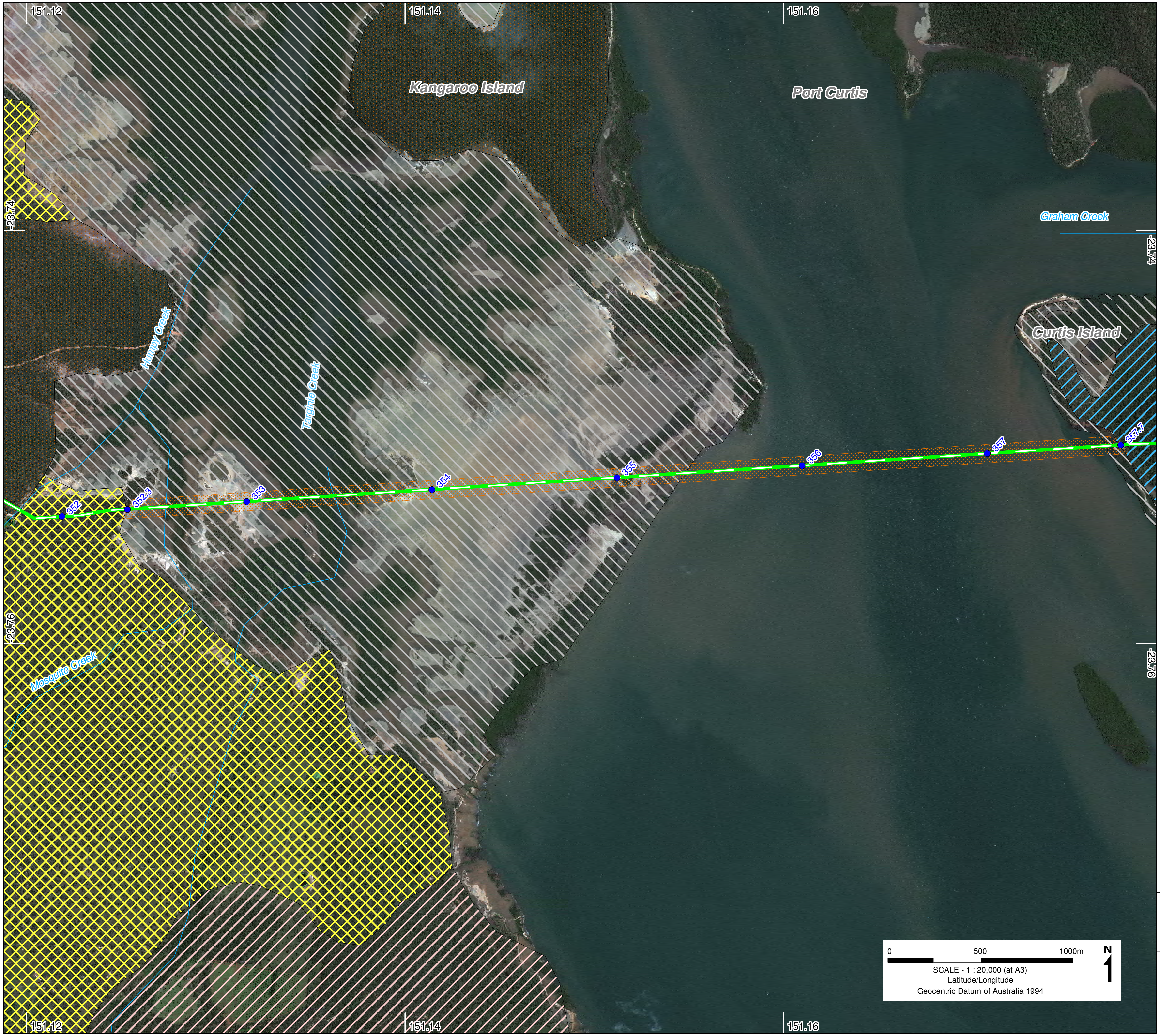
Map code	Land system	Landform	Soils*	Vegetation
Ct	Marine plains - Carpentaria	Marine plains with extensive bare tidal flats inundated by tidal waters and dissected by tidal channels	Crusting surface, grey mottled, saline cracking clays; saline muds and sands (6)	Mangrove low closed forest; marine couch grassland; samphire
Tr	Undulating plains and Rises – Terise	Gently undulating rises and plains on sedimentary rocks	Red structured gradational clay loams and uniform clays; bleached loamy surface, grey and brown acid sodic duplex soils (3a)	Eucalypt open forest (narrow-leaved ironbark, blue gum, gum-topped bloodwood); eucalypt woodland (Queensland peppermint, narrow-leaved ironbark)
Nw	Old alluvial plains and alluvial fans – The Narrows	Alluvial fans and lower colluvial slopes of the coastal hills	Bleached silty surface, brown and grey, alkaline sodic duplex soils (2a/2c)	Eucalypt woodland (blue gum, narrow-leaved ironbark, swamp mahogany) with tea-tree understory
Fs	Fanside	Undulating footslopes and rises on sedimentary rocks, and gently undulating fans below rolling hills	Red, structured gradational clay loams and uniform clays; shallow, bleached sandy and loamy surface, red duplex soil (2c/3a)	Eucalypt woodland (pink bloodwood, blue gum, swamp mahogany, poplar gum) with mixed shrub understory

Note: * Australia Pacific LNG Project soil groups (described below) presented in brackets.

Table 3.3 Curtis Island study area land zones

Land zone	Description
1	Quaternary estuarine and marine deposits subject to periodic inundation by saline or brackish marine waters. Includes mangroves, saltpans, off-shore tidal flats and tidal beaches. Soils are predominantly Hydrosols (saline muds, clays and sands) or beach sand. (6)
11	Primarily lower Permian and older sedimentary formations which are generally moderately to strongly deformed. Includes low to high-grade and contact metamorphics such as phyllites, slates, gneisses of indeterminate origin and serpentinite and interbedded volcanics. Soils are mainly shallow, gravely Rudosols and Tenosols, with Sodosols and Chromosols at lower slopes and gently undulating areas. Soils are typically of low to moderate fertility. (1c/2c)

Note: * Australia Pacific LNG Project soil groups (described below) presented in brackets.



LEGEND

- Pipeline kilometre points
- Watercourse
- Gas pipeline route
- APLNG acid sulfate soils study area

Soil Grouping

- 1c/2c
- 2a/2c
- 2c/3a
- 3a
- 6

A full description of Soil grouping is provided in Table 3.2 and Table 3.3

Source Information

Watercourses (based on 250k topography)
Commonwealth of Australia (Geoscience Australia) 2009
Gas pipeline route
Supplied by APLNG 17/05/2010
Soils
Soil groupings combined and interpreted from Department of Environment and Resource Management Area maps by WorleyParsons October 2009.
100k mapping (polygonised vector) data and Queensland geological 250k mapping (polygonised vector) data.
Pipeline kilometre points
Supplied by APLNG 04/06/2010
Satellite imagery
Captured by GeoEye-1 on 24 March 2009

AUSTRALIA PACIFIC LNG PROJECT

Figure 3.2
The Narrows
Acid Sulfate Soil Investigation
Study Area Soils

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3.3.1 Study area soils – existing information review

The mudflats portion of the study area is exclusively located in the Marine plains – Carpentaria land system. This land system is comprised of Hydrosols (soil group 6) which are commonly associated with ASS. ASS is a term that is generally used to describe both actual ASS (AASS) and potential ASS (PASS).

PASS are typically waterlogged soils, rich in pyrite, which have not been oxidised (Ahern et al. 2004). Exposure of PASS to air, causing oxidation, can lead to the creation of AASS: extremely acidic soil layers with field pH values of . 4 (Ahern et al. 2004). Actual and potential ASS can occur together in the same profile. Typically however, AASS overlie PASS, but may still have reserves of unoxidised sulfides (Ahern et al. 2004).

A study undertaken by Ross (2005) of ASS in The Narrows area indicated ASS, classified as having a high potential for acid generation, are present along the coast at varying depths south of Targinie Creek up to Connor Point. The area of this study relevant to the gas pipeline study area occurs south of Targinie Creek up to the northern point of Worthington Island and east to Friend Point. Locations from this study are illustrated on Figure 2.1. A similar study, also undertaken by Ross (2004) indicated ASS, classified as having a high potential for acid generation, are present along the coast at varying depths from Tannum Sands to an area north of Fishermans Landing near Targinie Creek. This forms the boundary between both of these studies. Both studies indicate ASSs occur within 0.5m of the ground surface and have been classified as having a high potential for acid generation. This is illustrated on ASS hazard mapping undertaken by Ross (2004 and 2005) and re-mapped across the pipeline study area (refer Figure 3.3). Another study completed by Ross (2002) and already mentioned within Section 3.1, also describes ASS as a high hazard occurring in a number of landforms which occur within the study area: tidal creeks, intertidal flats, supratidal flats and to a lesser extent extratidal flats.

ASS hazard mapping undertaken by Ross (2004 and 2005) indicates that almost all the pipeline route across the mudflats has AASS and PASS within the top 0.5m of the ground surface. This is indicated by mapping unit A0S0 on Figure 3.3 and as the seaward (east of Targinie Creek) supratidal flats on Figure 2.1. ASS hazard mapping further illustrates a large portion of the pipeline route traverses mapping unit S0 which indicates PASS occurs within 0.5m of the ground surface on the intertidal flats (refer Figure 2.1).

Other ASS hazard areas which are traversed by the pipeline route, but occur in smaller portions include mapping units S1 and a2LP (refer Figure 3.3). Mapping unit S1 indicates PASS occurs within 0.5 to 1.0m below the ground surface. This mapping unit occurs within the landward (west of Targinie Creek) supratidal flats but adjacent to the extratidal flats (refer Figure 2.1). ASS hazard mapping unit a2LP indicates a strongly acidic layer occurs from 1.0 to 2.0m below the ground surface in land with a low probability of ASS occurrence. This unit represents the extratidal flats on Figure 2.1.

This DERM mapping does not extend to Curtis Island, however the above mentioned landforms (supratidal and intertidal flats) do occur and therefore indicate a high probability of similar ASS characteristics on the Island. Assessments previously undertaken by WorleyParsons and more recently ERM for Australia Pacific LNG have confirmed this statement with the identification of highly acidic soil and sediments (WorleyParsons, 2010 and ERM, 2010). There is only a small portion of the gas pipeline study area which traverses the ASS on Curtis Island. This is located on intertidal flats and illustrated on Figure 2.1. As mentioned above, this landform is likely to contain PASS within 0.5m of the ground surface.

The ASS assessment undertaken for the Gladstone LNG Project (GLNG) [GeoCoastal, 2009] incorporated sampling along the coastal fringe from Friend Point to approximately 1km north of Fisherman's Landing. This sampling involved the testing of samples from 13 borehole locations (#42 to #54) [refer Figure 2.1] and reported laboratory results for samples down to 3mBGL. Samples reported ranged in actual acidity (TAA) from 0.01% to 0.32%S and potential acidity (Chromium Reducible Sulfur) from 0.01%S to 3.95%S (low to high). Some surface and near surface colluvial and Pleistocene clays samples were also reported to have acid neutralising capacity which reduced the calculated liming rate.

A separate study also completed for the Gladstone LNG (GLNG) Project as part of the GHD FEED geotechnical investigation summarised within the GLNG EIS Supplement E5 – Acid Sulfate Soils (URS, 2009) noted an absence of actual acidity within most samples along the coast and minimal actual acidity in samples collected within the supratidal flats. Of the samples submitted for laboratory analysis, significant levels of potential acidity were reported ranging from 0.57 to 2.42 %S with the highest levels reported for locations closest to the coastline The locations tested for this study are also presented on Figure 2.1 with the prefix 'KI'.

An ASS investigation undertaken for Queensland Curtis (QCLNG) project at Friend Point (refer Figure 2.1) reported a thin soft to firm silt / clay generally non-acidic capping layer overlying a highly organic dark grey silty clay to clay (generally 0.25-1.25mBGL) and a deeper layer of shelly silty clay (ERM, 2009). Both deeper layers of silty clay were reported with potential acidity ranging from 0.2 to 2.0%S (ERM, 2009). Locations tested (29 total) were separated at 200m intervals along the proposed disturbance routes. Field pH (pH_F) tests ranged from slightly acidic to slightly alkaline, while the majority of pH_{FOX} values were very strongly acidic (<4.5). Of the samples submitted for laboratory analysis, it was reported that soils had limited acid neutralising capacity and require very high to extremely high treatment (ERM, 2009). This investigation did not encounter the deeper Pleistocene soils discussed in the GLNG reports and concluded the disturbance of soils located in and around Friend Point will require the development of a stringent ASS Management Plan (ASSMP) [ERM, 2009]. This report also concluded that treatment of these soils may be too costly or ineffective given the extreme liming rates required (ERM, 2009).

Typical characteristics of soils within the study area (as noted by Ross, 2002, 2004 and 2005) are as follows:

- Intertidal flats consist mainly of dark grey to dark greenish grey silty clays with a greyish brown surface horizon. These profiles are nearly always saturated and are generally covered with mangroves. They have the highest frequency of ASS occurrence with oxidisable sulfur levels up to 5.12%S_{POS} which can occur at or near the surface
- Supratidal flats consist mainly of a thin brown, structured, medium to heavy clay surface horizon overlying greyish brown clay subsoil with abundant pale yellow jarosite mottles or dark brown clays grading into dark yellowish brown structured clays with red and orange mottles. A low pH is common. The subsoils consist of a thin grey layer with jarosite overlying dark grey silty clay with organics which have a near neutral pH. The PASS hazard of soils ranges from very low to extreme with an extreme rating common
- Extratidal flats consist of grey mottled medium to heavy clays, strongly acid at shallow depths with a thick layer of jarosite. Angular chert gravels occur throughout the profile. They typically have low levels of potential acidity and in some cases may contain negligible levels of oxidisable

sulfur and are non-acid sulfate soils. Where PASS layers occur, the acid sulfate hazard ranges from very low to extreme with a low rating common

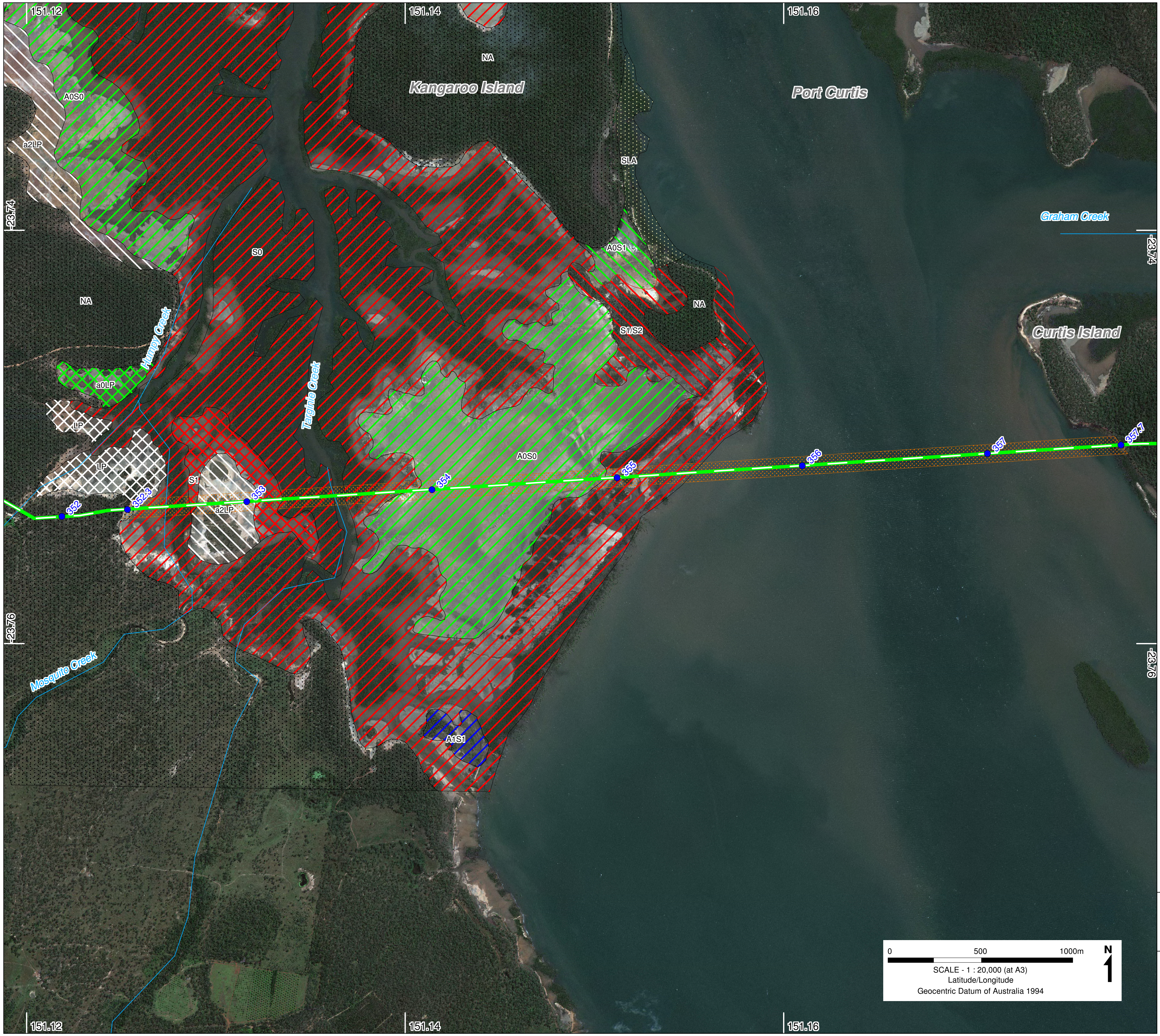
- Deeper Pleistocene (pre-Holocene) subsoils are mottled olive grey heavy clay, moist and very firm. These are generally not ASS
- Significant areas comprised already oxidised acidic soils with some unoxidised sulfides
- Surface gravel and iron segregations are soil features at narrow saltpans
- Soils were saturated with a high organic content
- All soils are likely to have a low load-bearing strength (barely able to support the weight of a person)

Typical characteristics of PASS within the study area (as noted by Ross 2002, 2004 and 2005) are as follows:

- PASS are dominant throughout soil group (6) (refer Table 3.2) and land zone 1 (refer Table 3.3) and are mostly associated with intertidal flats, but occur at depth within the supratidal salt flats
- PASS hazard within the intertidal flats ranges from very low to extreme with a very high rating common. These dark grey to dark greenish grey sediments contain very high levels of organic carbon (>5%) and oxidisable sulfur (>2%)
- Generally, sediment within tidal creeks consist of variable surface layers ranging from coarse sands to heavy clay. The ASS located within these creeks has been rated from low to extreme
- Located within Targinie Creek, PASS have oxidisable acid levels ranging from 0.01% (low) to 9.4% (extreme). Moderate to high acidity levels are common near the surface (within 0.5m)
- They are generally dark grey, grey or greenish grey silty clays with greyish brown surface horizon
- Significant organic content occurs throughout the profile
- PASS have a high potential for acid generation but may contain appreciable quantities of shells (carbonate material), so much so that net acidity generation may become close to zero – that is, they are self-neutralising enough that no treatment would be required if disturbed

Based on existing data sources, the implications for the proposed pipeline development in areas of PASS and AASS are:

- There is a high risk of exposure of acid sulfate soils resulting in the oxidation of sulfides and the production of sulfuric acid
- There is potential for the release of heavy metals such as aluminium and iron and deoxygenation of waterways
- Corrosion of unprotected concrete and steel infrastructure including pipes, foundations and bridges may occur
- The soils present would provide a poor foundation base due to very low load bearing strength
- There may be a prohibitive treatment cost where extremely acidic or potentially acidic layers occur



LEGEND

- Watercourse
- Gas pipeline route
- Acid sulfate soils study area

Acid Sulfate Soils - Depth to potential

- S0
- S1
- S1/S2
- A0S0
- A0S1
- a0LP
- A1S1
- a2LP
- SLA
- LP
- NA

S0 - PASS within 0.5m of ground surface
S1 - PASS within 1.0m of ground surface
A0 - AASS within 0.5m of ground surface
A1 - AASS within 1.0m of ground surface
a2LP - Strongly acidic layers occur from 1.0m to 2.0m below ground surface in land with a low probability of ASS occurrence
SLA - Not classified
LP - Land with low probabity of acid sulfate soil occurrence
NA - Land not assessed

Source Information

Watercourses (based on 250k topography)
Commonwealth of Australia (Geoscience Australia) 2009
Gas pipeline route
Supplied by Origin Energy 17/05/2010
Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil hazard mapping
Derived from Department of Environment and Resource Management (DERM) 2010.
Ross, D. 2005, Acid Sulfate Soils of the Narrows Area, Central Queensland Coast (QNRM05524), Department of Natural Resources and Mines Queensland, Rockhampton.

AUSTRALIA PACIFIC LNG PROJECT

Figure 3.3
The Narrows
Acid Sulfate Soils Hazard Mapping

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4. Results

As described within Section 2, this assessment was undertaken in two separate components: sub-tidal crossing and mudflats crossing. As such the laboratory results and discussion are summarised in a similar fashion. The summary of results tables are provided within Appendix 3, while laboratory reports, laboratory QA/QC and chain of custody/sample receipt documentation are provided in Appendix 4.

4.1 Physical

Sample cores were lithologically logged during sample processing for each coring location. The borelogs produced are provided in Appendix 1 while stratigraphic transects across the study area are illustrated on Figure 4.1. Generalised soil types and depths encountered are provided in Table 4.1.

Narrows sub-tidal (*W samples*)
Twenty-two (22) cores were completed within the Narrows sub-tidal crossing with refusal depths ranging from 0.05 to 2.6m below the sea floor. Very shallow refusal depths (ranging from 0.05m to 0.5m) were encountered at W9 to W14 which are located within the centre of the Narrows sub-tidal crossing. Refusal occurred in very firm clay and coarse material such as coarse (20-60mm) fragments and shells. Refusal at W06, W08, W09, W17, W18 and W19 occurred as a result of very firm clays which may or may not be the very stiff non-ASS Pleistocene clay as described in proponent work. The fine Holocene sediments (refer Table 3.1) were generally not encountered at these locations as they are thought to have been removed by currents. Such currents are understood to run at approximately 2 knots or 1.1m/s (Qld Govt, 2009), i.e. strong enough to prohibit fine sediment settling. This is supported by particle size distribution undertaken on 0.5m interval samples and reported within The Narrows Pipeline Crossing - Sediment Characterisation Report (WorleyParsons, 2010) and provided in Appendix 5. This data indicates there is a greater proportion of coarse material on the western margin of the crossing, while indicating a greater proportion of finer material (clay and silts) on the east. This was also reflected within borelogs (refer Appendix 1).

The material encountered on the western margin of the Narrows sub-tidal crossing is indicative of material found on Curtis Island. For example, coarse brown sand present on the beach of Laird Point, Curtis Island is evident in the layers of sample points W08 to W19. Closer to Curtis Island (W20 to W22 and MF32), sediment encountered is indicative of intertidal material located on the eastern edge of Curtis Island where the pipeline route traverses.

The material encountered on the eastern margin of the Narrows sub-tidal crossing is indicative of the material encountered on the Narrows mudflats crossing: dark to very dark grey silty clay. Here, the vibracore could penetrate deeper into the sediment as it was not restricted by unconsolidated coarse sediments. These silty clays were generally very weak and wet on the surface (approximately 0.05-0.4m thick) with limited plasticity. Deeper, these silty clays become less moist, firm to very firm and very plastic.

Organic matter in the form of thin fibrous mats / layers and thick coarse roots were common at most locations and ranged in size from very fine (<1mm) to coarse (>5mm) and in quantity from few (1-10 fine roots per 0.01m^2) to abundant (5 medium to coarse roots per 0.01m^2). This organic matter is expected to have originated from fringing mangroves which occur on both the mainland and Curtis Island. Soils supporting these mangroves are also known to have the highest levels of oxidisable sulfur (refer Section 3.1.2). Sulfur odours detected at many locations are expected to have occurred as a result of the anaerobic decomposition of organics material.

Shell material was encountered at each sub-tidal sampling location. This material ranged in size from very fine (<2-6mm) to coarse (20-60mm) and in quantity from very few (<2%) to abundant (>90%). This material contributes to a soil's natural acid buffering capacity, so much so that all acid generating capacity may be neutralised in some cases (refer Section 4.3.3 and 4.3.4).

Narrows Mudflats (*MF samples*)

Thirty (30) cores were completed within the Narrows mudflat crossing. These cores encountered two main soil types: brown silty clays and dark to very dark grey silty clays. The brown silty clays were generally encountered as a crusty surface layer at most locations, with the exception of MF03, MF12, MF29, MF30 and MF32. This sheet washed soil is suspected of originating from terrestrial sources adjacent to the mudflats deposited by erosion. Sample points MF03, MF12 are located within tidal creeks. MF29 and MF30 are located within the intertidal flat adjacent to the sub-tidal crossing therefore periodically submerged even during smaller high tides. MF32 is located on the intertidal flat adjacent to Curtis Island but is still located within the sub-tidal crossing and therefore periodically submerged on smaller tides.

The brown silty clays transitioned into the underlying dark to very dark grey silty clays which were encountered at each location with the exception of MF05, MF06 and MF07. MF06 is located on an extratidal flat which has been classified as having a commonly low ASS hazard rating (refer Section 3.1.4 and Figure 2.1, Figure 3.3). This is a similar result to that reported by ERM (2009). Greyish green silty clay was also encountered at MF05, MF06 and MF07. This texture was firm to very firm and generally occurred from approximately 1mBGL.

Grey, brown, red and yellow mottling was noted at several locations, however, the iron segregation (red, yellow and brown mottling) illustrated by Ross (2005) was only encountered in surface samples at MF13, MF14 and MF17 (refer Appendix 1 and Appendix 2). This generally indicates the oxidation of sulfides (if present) has occurred and actual acidity may be present. However, as described later in Section 4.3, actual acidity results (TAA results) were negligible. Grey, brown, yellow and red mottling was also noted within samples collected at MF05, MF06 and MF07, all of which were non-AASS and non-PASS. In these soils, this mottling is likely to be the result of oxidisation of non-sulfidic compounds.

The dark to very dark grey silty clays reported by ERM (2009) were encountered on the intertidal and supratidal flats, but also identified within the eastern portion of the sub-tidal crossing. These soils were generally weak to firm, very sticky, very plastic and moist near the surface. Deeper levels of the profile become firm to very firm. On occasion, fine to medium sand was encountered, however thick layers were noted at MF02, MF22 and MF26. Based on ASS hazard identification (refer Section 3.1 and Figure 3.3), silty clays and sands within the intertidal and supratidal flats were rated as very high and extreme respectively.

Refusal depths across the mudflats ranged from 0.3 to 3.0m below the sampling surface with the shallowest refusal depths encountered within Humpy Creek (0.3m) and Targinie Creek (0.4m). These two locations were both submerged at the time of coring. Refusal at MF03 was encountered on light yellowish brown silty sandy clay which is evident in the surrounding surface soils encountered at many locations (described above) but most dominant on the landward side (west) of Targinie Creek. Refusal at MF12 was encountered on very dark grey silty clay which is representative of the surrounding subsoils encountered across the mudflats.

Across the intertidal and supratidal flats, refusal depths ranged from 0.6mBGL to 3.5mBGL. The shallowest refusal depth was encountered in coarse gravel at MF32 which was located on the intertidal flat of Curtis Island. As noted within the Australia Pacific draft EIS, colluvial material (gravel) on Curtis Island was identified as material originating from the underlying geology, i.e. the Wandilla Formation. Refusal at MF09, MF10, MF15 and MF18 occurred as a result of very firm or stiff clays, which may or may not be the very stiff residual material of Pleistocene origin. Other locations where refusal occurred were the result of firm to very firm Holocene clays. In many cases, core recovery rates were not equal to refusal depth, but were generally close to the proposed disturbance depth of 2.3m. As described in Table 2.2, this was attributed to the very sticky nature of these clays 'plugging' the vibracore.

With the exception of MF05, MF06, MF07 and MF08, organic matter in the form of thin fibrous mats / layers and thick coarse roots were common at most locations and ranged in size from very fine (<1mm) to coarse (>5mm) and in quantity from few (1-10 fine roots per $0.01m^2$) to abundant (5 medium to coarse roots per $0.01m^2$). This organic matter, which generally occurred in soil layers thicker than 1m, is expected to have originated mainly from mangroves fringing the tidal creeks. Sulfur odours detected at many locations are expected to have occurred as a result of the anaerobic decomposition of the organic material.

Shell material was encountered at mudflat sampling locations MF15 to MF30. Shells generally occurred at nominal depths ranging from 1mBGL to 2mBGL within the subsoil layers of dark grey silty clay and were generally fine (2-6mm) in size and few (2-10%) in quantity. This was a similar results to that reported by ERM (2009). Medium and coarse occurrences were noted within MF15 and MF28 respectively. Shell quantity was such that it was insufficient to neutralise all the acid generating capacity (refer Section 4.3.3 and 4.3.4).

Very shallow groundwater was encountered at all sample points across the mudflats. This ranged in depth from 0.2mBGL to 1.0mBGL. Where high tides advanced over locations at the time of sampling, the standing water level was recorded as 0.0m as high tides will obviously cause a fully saturated profile for soils located in the intertidal zone. The brown surface soil was generally dry for the full profile depth, however the remainder of the profiles across all mudflat sampling locations had some moisture.

In addition to the above generalised soil descriptions, no straw yellow jarosite was noted during the investigation.

Table 4.1 Generalised Site Soil Characteristics

General location	Approximate Depth of profile (m)	Texture	Colour	Consistency	Organics	Shells	Odour
Sub-tidal – east	0.0 – 0.4	Silty CLAY / clayey SILT	Dark to very dark grey	Very weak, slightly plastic, very sticky, wet	Very few to abundant very fine to coarse	Few to abundant fine to coarse	Sulfurous
	0.4 – 1.0	Silty CLAY	Dark grey	Weak, very plastic, very sticky, moist	Few to many fine to medium	Few to abundant fine to coarse	Sulfurous
	1.0 – 2.6	Silty CLAY	Dark grey	Firm to very firm, very plastic, very sticky, dry to moist	Common to abundant fine to coarse	No shells to abundant fine to coarse	No odour to sulphurous
*Sub-tidal – central	0.0 – 0.5	Silty, gravelly CLAY	Dark grey	Weak, slightly plastic, very sticky	Abundant fine to coarse	Common fine	No odour
Sub-tidal - west	0.0 – 0.3	Clayey SILT	Very dark grey	Very weak, slightly plastic, very sticky	Many to abundant fine to coarse	Many to abundant fine to coarse	Sulfurous
	0.3 – 1.0	Silty CLAY	Dark grey	Weak to firm, very plastic, very sticky	Common to abundant fine to coarse	Few to many very fine to fine	Sulfurous
Tidal creek	0.0 – 0.15	Silty CLAY	Very dark grey	Weak to firm, very plastic, very sticky, wet	Few fine	No shell	No odour
	0.15 – 0.3	Sandy CLAY	Light yellowish brown	Weak, very plastic, very sticky, wet	No organics	No shell	No odour
	0.0 – 0.3	Gravelly SAND	Brown	Loose, non plastic, non sticky, wet	No organics	No shell	No odour
	0.3 – 0.4	Silty CLAY	Very dark grey	Firm, very plastic, moderate stickiness, dry	No organics	No shell	No odour
Intertidal flat	**0.0 – 0.1	Silty CLAY	Brown	Weak to firm, very plastic, moderately to very sticky, dry	Many fine to coarse organics	No shell	No odour
	***0.0 – 0.1	Silty CLAY	Dark grey	Firm, very plastic, very sticky, moist	Abundant fine to coarse organics	No shell	Sulfurous
	**0.1 – 1.75	Silty CLAY	Greenish grey	Firm to strong, very plastic, slightly to very sticky, dry	Few to many fine to coarse organics	No shell	Sulfurous
	***0.1 – 2.5	Silty CLAY	Dark to very dark	Weak to firm, very plastic,	Abundant fine to	Few fine	Sulfurous

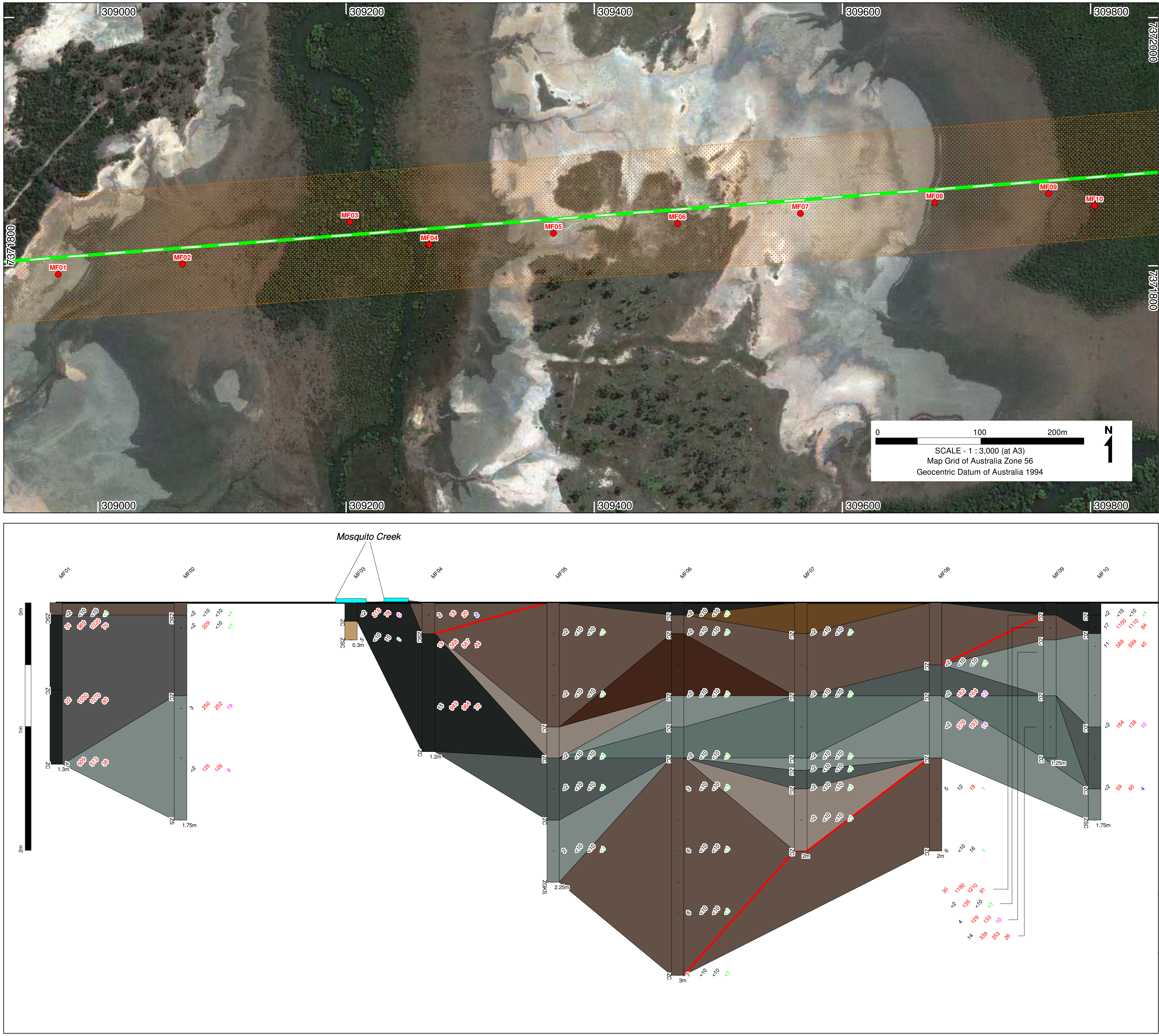
General location	Approximate Depth of profile (m)	Texture	Colour	Consistency	Organics	Shells	Odour
			grey	very sticky, moist	coarse		
Supratidal flat	0.0 – 0.1	Silty CLAY	Brown	Very firm, very plastic, very sticky	No organics	No shell	No odour
	**0.1 – 1.5	Silty CLAY	Very dark greenish grey	Firm to strong, very plastic, very sticky, dry	No organics to very few fine	No shell	No odour
	***0.1 – 1.0	Silty CLAY	Dark to very dark grey	Weak to firm, very plastic, very sticky, moist	Abundant fine to coarse	No shell	Sulfurous
	1.0 – 2.0	Silty CLAY	Dark to very dark grey	Weak to firm, very plastic, very sticky, dry to moist	Few to abundant fine to coarse	Few fine	Sulfurous
	2.0 – 2.5	Silty CLAY	Very dark grey	Firm, very plastic very sticky, moist	Abundant fine to coarse	No shell	Sulfurous
Extratidal flat	0.0 – 0.1	Silty CLAY (topsoil)	Very dark greyish brown	Firm, very plastic very sticky, dry	Many fine	No shell	No odour
	0.1 – 0.75	Silty CLAY	Brown to dark brown	Firm to very firm, very plastic, moderately sticky, dry	No organics	No shell	No odour
	0.75 – 1.25	Silty CLAY	Greyish green to grey	Firm, very plastic moderate to very sticky, dry	No organics	No shell	No odour
	1.25 – 3.0	Silty CLAY	Brown with yellowish red mottle	Very firm, very plastic, slightly sticky, dry	No organics	No shell	No odour

Notes:

* Mixed sediments (sand, silt, clay, gravel, shells) were encountered in this portion of the sub-tidal crossing.

** Indicate general soil profile encountered on the landward (west) side of Targinie Creek

*** Indicate general soil profile encountered on the seaward (east) side of Targinie Creek



LEGEND

- Acid sulfate soils sampling locations *(NOTE: MF11 and MF31 were inaccessible)*
- Gas pipeline route
- Acid sulfate soils study area

Cross Sections

- MF03 — Sample location ID
- Inferred boundary based on labratory results
- Munsell soil colour (Refer to borelogs)
- Profile containing shells
- ZC — Soil texture (Refer to borelogs)
- 0.3m — Core depth (Displayed with vertical exaggeration of 100)
- <2 216 78 6 — Labratory results (mol H+/t) TAA, Scr, net acidity, liming rate*

NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg

Source Information

Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Labratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 1 of 7

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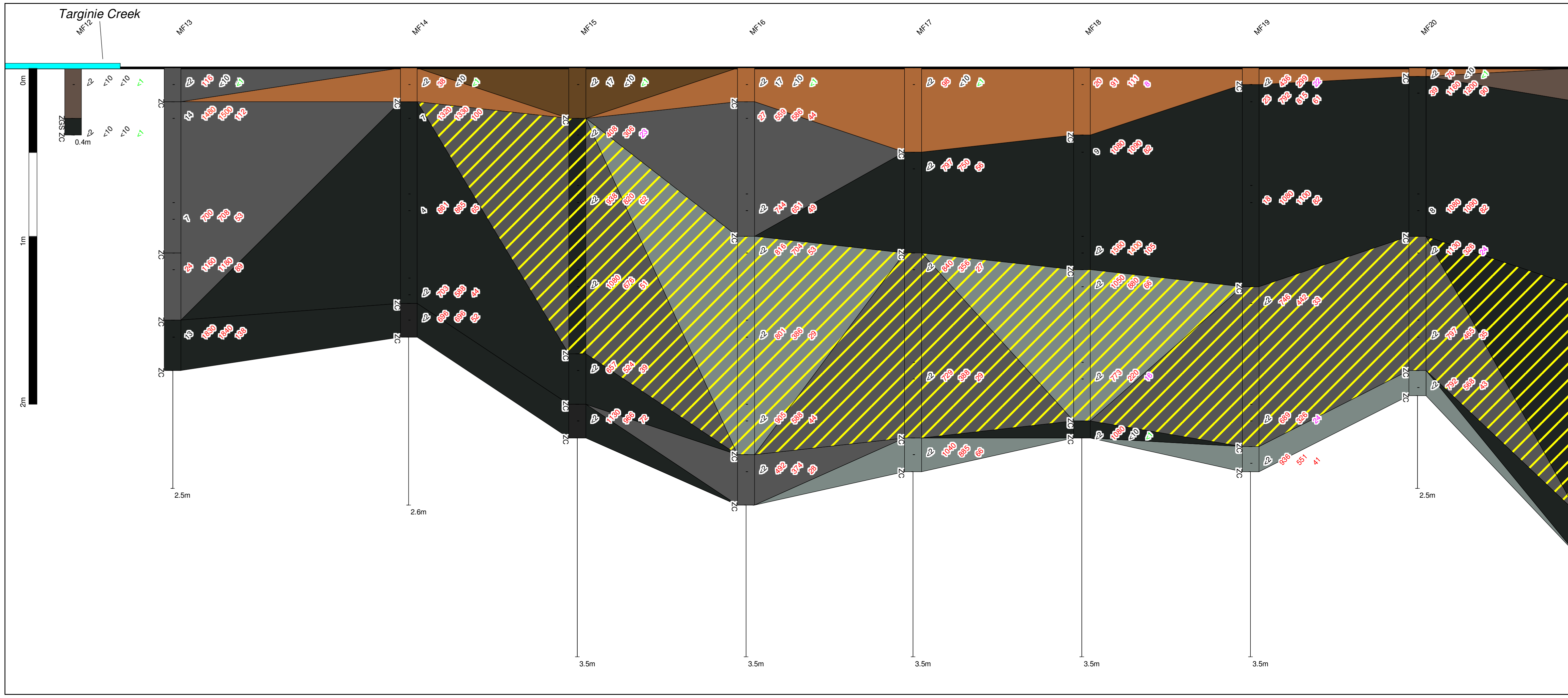

LEGEND

- Acid sulfate soils sampling locations
  (NOTE: MF11 and MF31 were inaccessible)
- Gas pipeline route
- Acid sulfate soils study area

Cross Sections

- MF03 — Sample location ID
- Inferred boundary based on labratory results
- Munsell soil colour (Refer to borelogs)
- Profile containing shells
- ZC — Soil texture (Refer to borelogs)
- 0.3m — Core depth (Displayed with vertical exaggeration of 100)
- 216 78 6 — Labratory results (mol H+/t)
  TAA, Scr, net acidity, liming rate*

  NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg

Source Information

Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Labratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 2 of 7

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LEGEND

- Acid sulfate soils sampling locations *(NOTE: MF11 and MF31 were inaccessible)*
- Gas pipeline route
- Acid sulfate soils study area

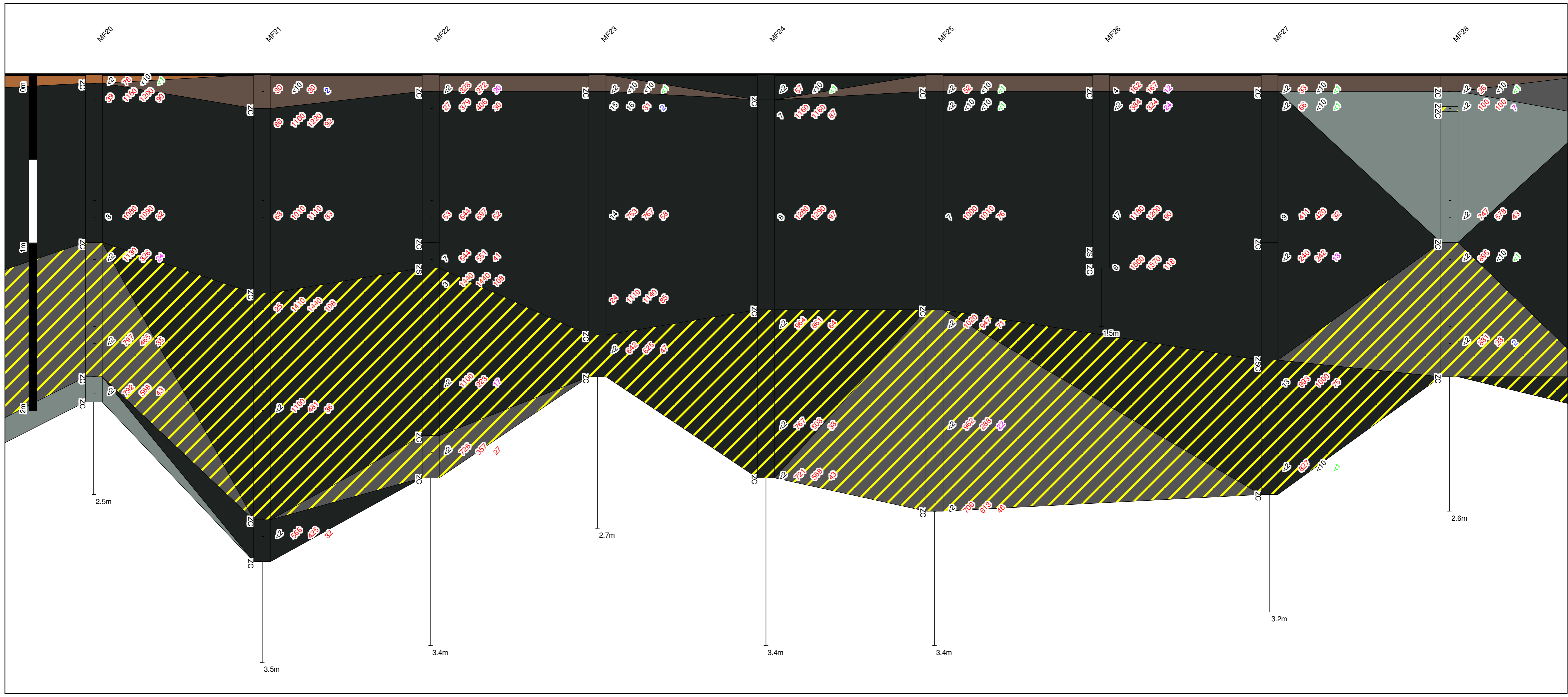
Cross Sections

- MF03 — Sample location ID
- Inferred boundary based on labratory results
- Munsell soil colour (Refer to borelogs)
- Profile containing shells
- ZC — Soil texture (Refer to borelogs)
- 0.3m — Core depth (Displayed with vertical exaggeration of 100)
- 216 78 6 — Labratory results (mol H+/t) TAA, Scr, net acidity, liming rate*

NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg

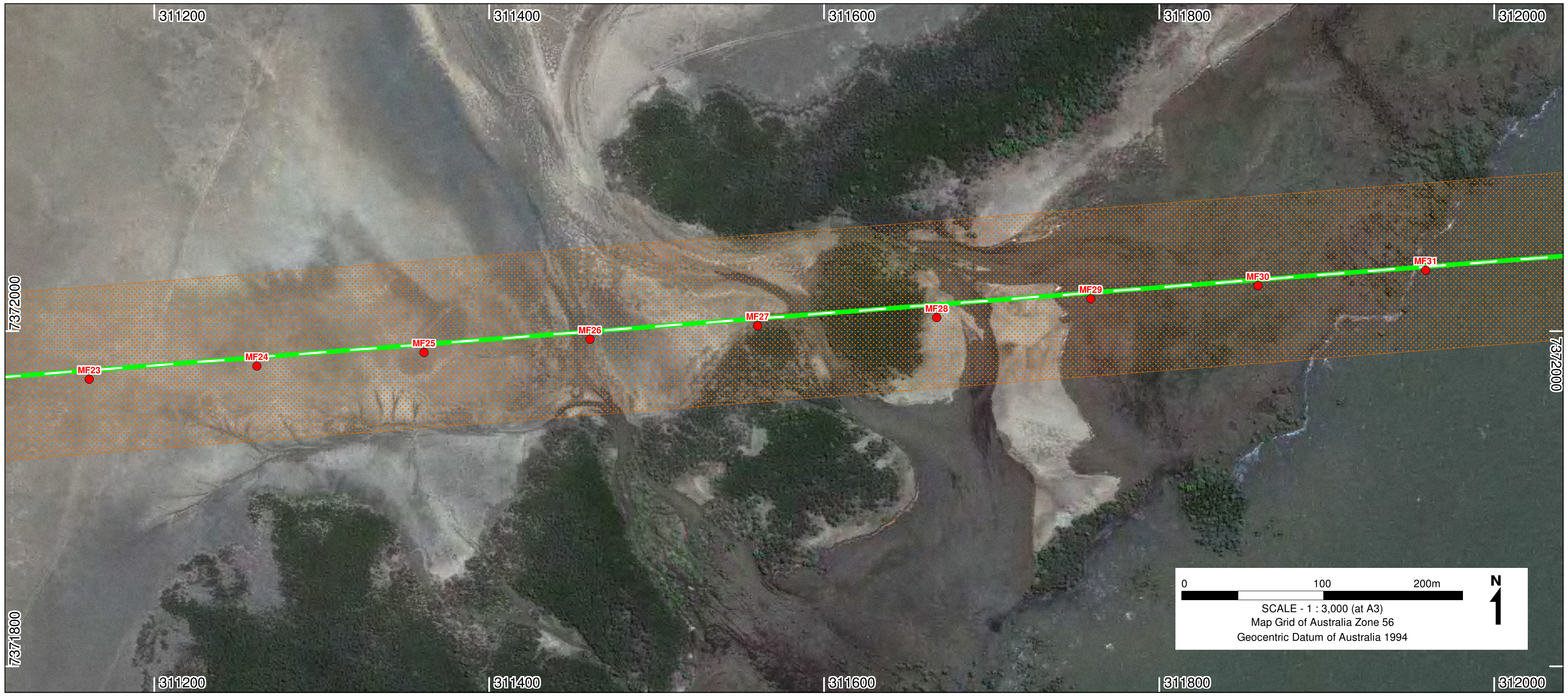


Source Information

Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Labratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 3 of 7



LEGEND

- Acid sulfate soils sampling locations *(NOTE: MF11 and MF31 were inaccessible)*
- Gas pipeline route
- Acid sulfate soils study area

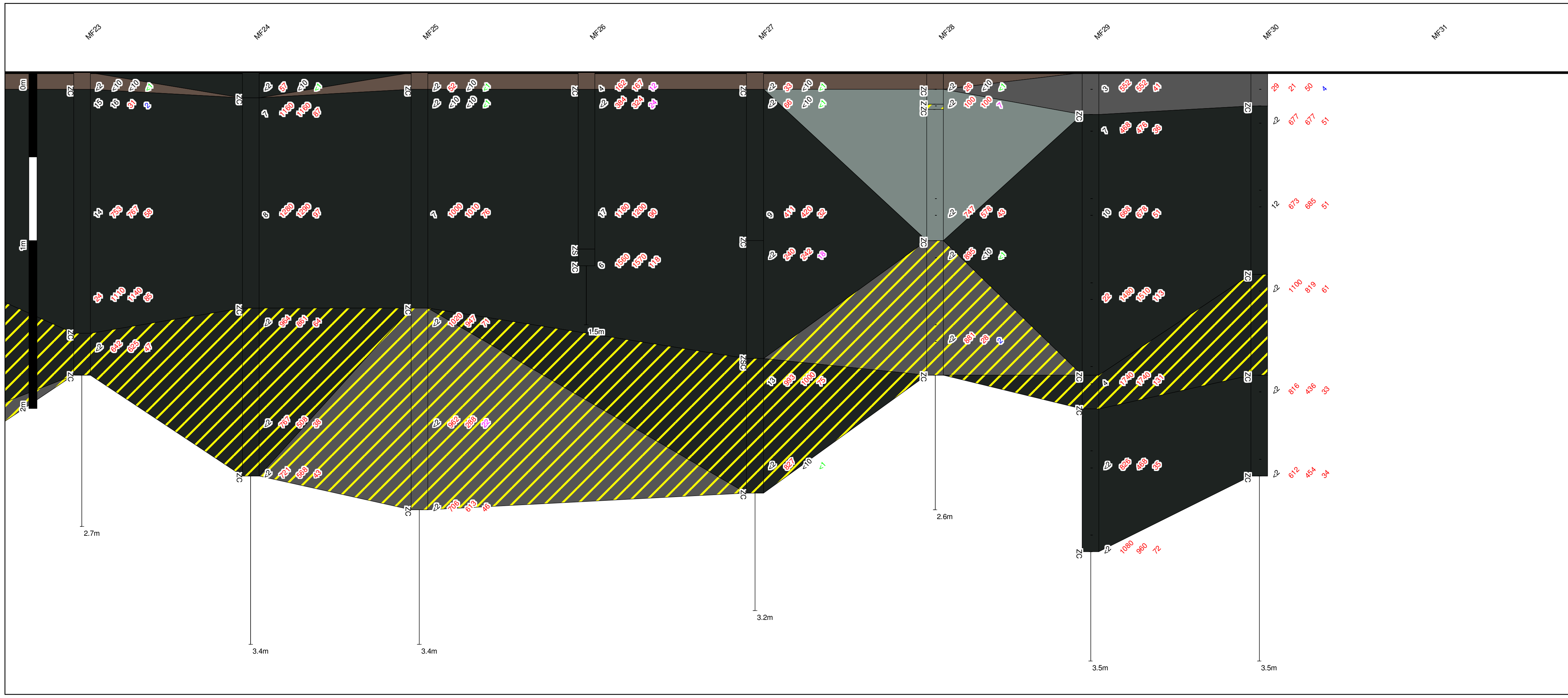
Cross Sections

- MF03 — Sample location ID
- Inferred boundary based on labratory results
- Munsell soil colour (Refer to borelogs)
- Profile containing shells
- ZC — Soil texture (Refer to borelogs)
- 0.3m — Core depth (Displayed with vertical exaggeration of 100)
- 216 78 6 — Labratory results (mol H+/t) TAA, Scr, net acidity, liming rate*

NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg



Source Information

Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Labratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 4 of 7

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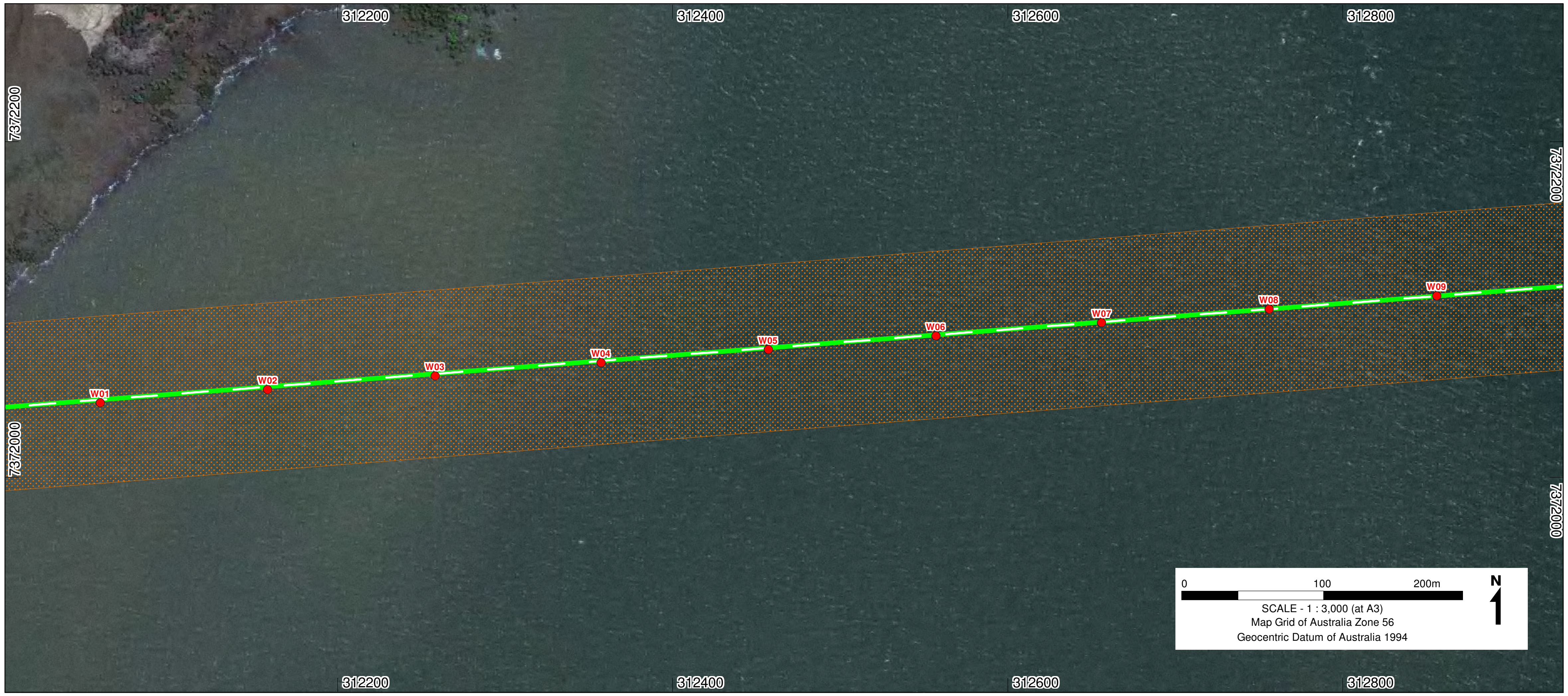


LEGEND

Acid sulfate soils sampling locations
(NOTE: MF11 and MF31 were inaccessible)

Gas pipeline route

Acid sulfate soils study area

Cross Sections

MF03 — Sample location ID

Inferred boundary based on labratory results

Munsell soil colour (Refer to borelogs)

Profile containing shells

CZ — Soil texture (Refer to borelogs)

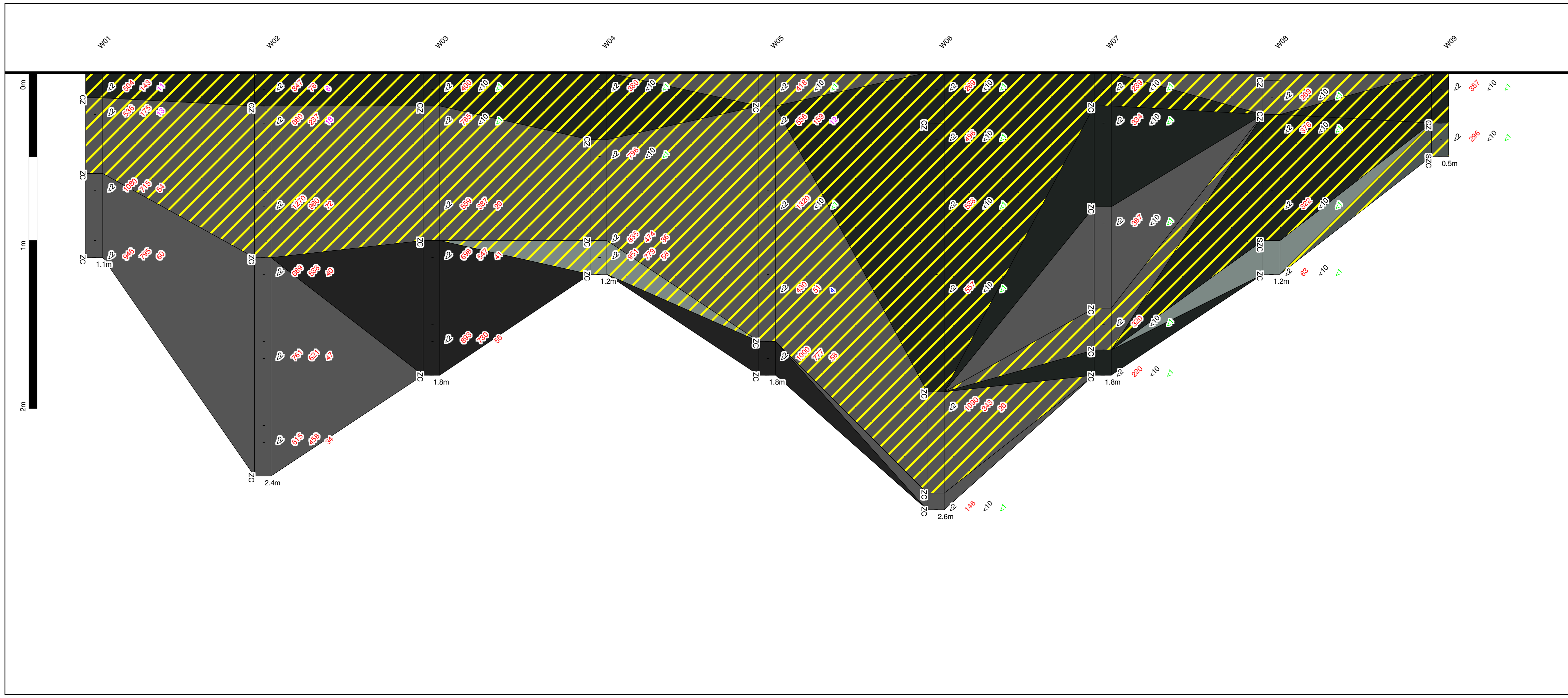
0.3m — Core depth (Displayed with vertical exaggeration of 100)

216 78 6 — Labratory results (mol H+/t)
TAA, Scr, net acidity, liming rate*

NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg



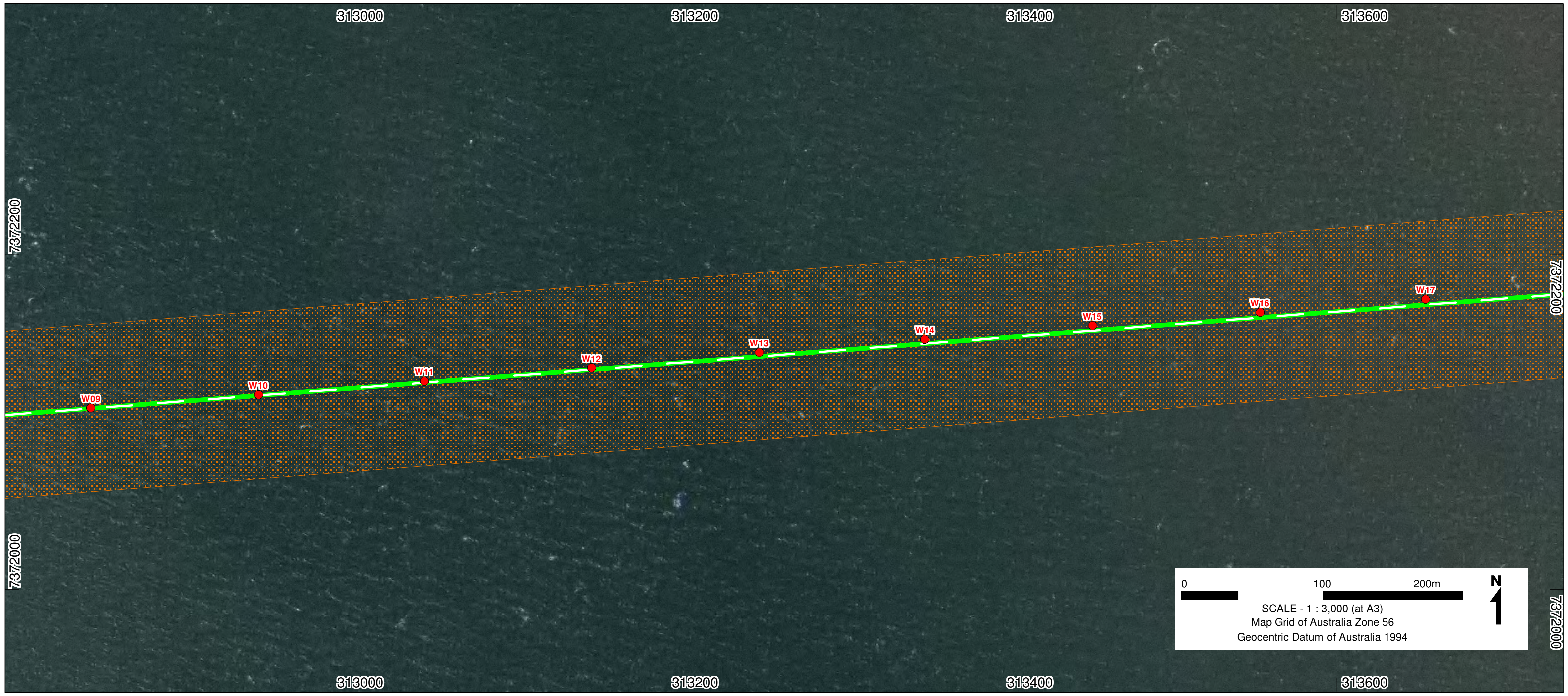
Source Information

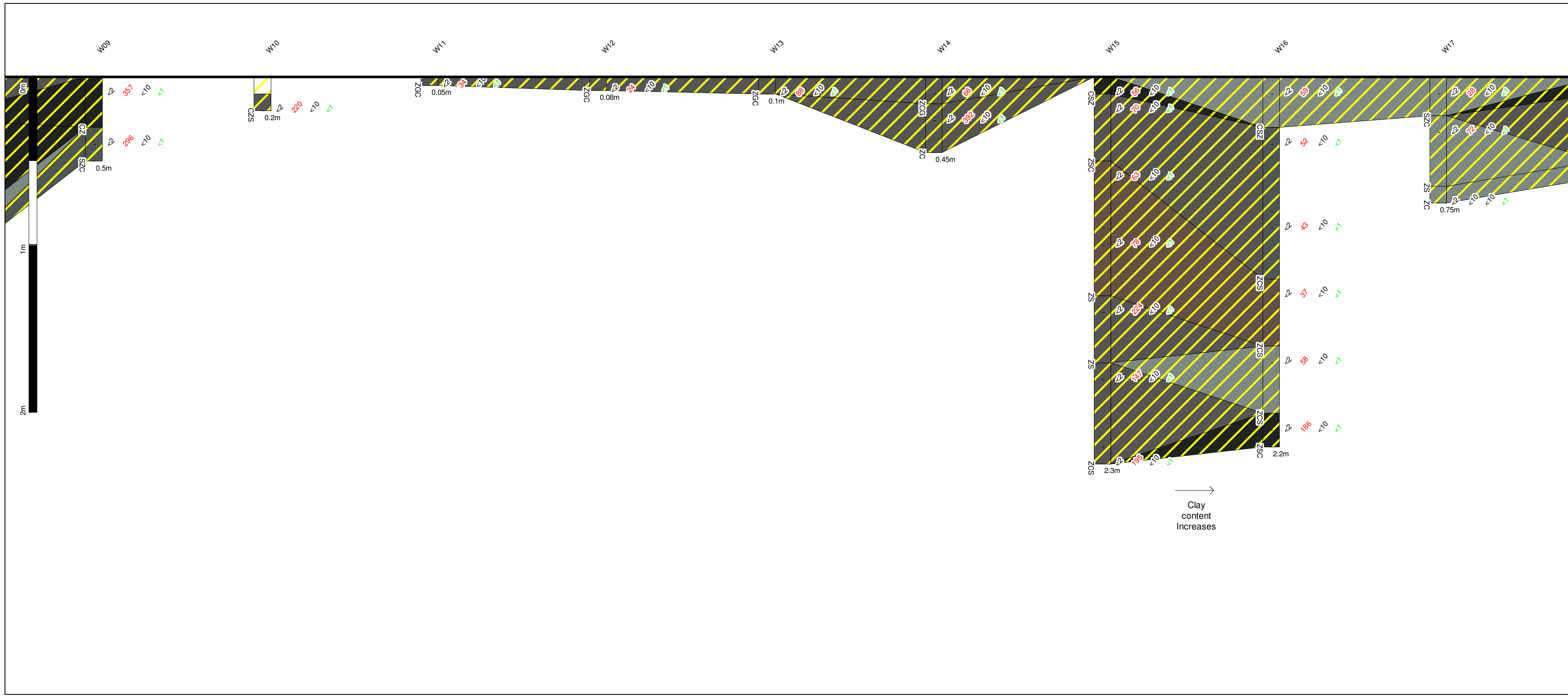
Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Labratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 5 of 7

K:\ORIGIN\301001-00448\GIS\Maps\00448-00-EN-DAL-3102-A(Stratigraphic_Transects_SA_Map5of7).wor





LEGEND

- Acid sulfate soils sampling locations *(NOTE: MF11 and MF31 were inaccessible)*
- Gas pipeline route
- Acid sulfate soils study area

Cross Sections

- MF03 — Sample location ID
- Inferred boundary based on labratory results
- Munsell soil colour (Refer to borelogs)
- Profile containing shells
- ZC — Soil texture (Refer to borelogs)
- 0.3m — Core depth (Displayed with vertical exaggeration of 100)
- <2 216 78 6 — Labratory results (mol H+/t) TAA, Scr, net acidity, liming rate*

NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg

Source Information

Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Labratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 6 of 7

K:\ORIGIN\301001-00448\GIS\Maps\00448-00-EN-DAL-3103-A(Stratigraphic_Transects_SA_Map6of7).wor

LEGEND

- Acid sulfate soils sampling locations
  (NOTE: MF11 and MF31 were inaccessible)
- Gas pipeline route
- Acid sulfate soils study area

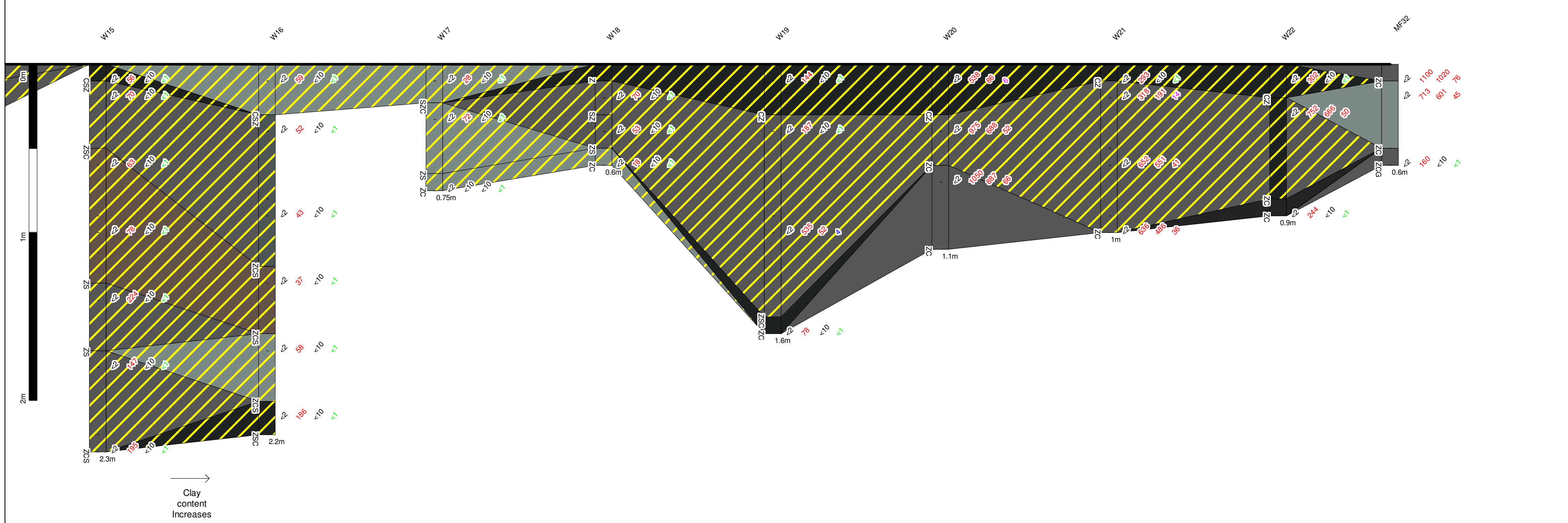
Cross Sections

- MF03 — Sample location ID
- Inferred boundary based on labratory results
- Munsell soil colour (Refer to borelogs)
- Profile containing shells
- ZC — Soil texture (Refer to borelogs)
- 0.3m — Core depth (Displayed with vertical exaggeration of 100)
- 216 78 6 — Labratory results (mol H+/t)
  TAA, Scr, net acidity, liming rate*

NOTE: Results exceeding QASSIT guidelines of 18 mole H+/t are indicated in red)

***Liming Rate**

- <=0.1kg
- >0.1 - 1kg
- 1 - 5kg
- 5 - 25kg
- >25kg



Source Information

Satellite imagery
Captured by GeoEye-1 on 24 March 2009
Acid sulfate soil sampling locations
Supplied by WorleyParsons 31/05/2010
Acid sulfate soils study area
Supplied by WorleyParsons 03/06/2010
Laboratory Results
Determined by Australian Laboratory Services (ALS)
for soil samples collected by WorleyParsons May 2010

AUSTRALIA PACIFIC LNG PROJECT

Figure 4.1
Study area stratigraphic transects
Map 7 of 7

K:\ORIGIN\301001-00448\GIS\Maps\000448-00-EN-DAL-3104-A(Stratigraphic_Transects_SA_Map7of7).wor

4.2 Preliminary field screening

Field screening tests were carried out on 370 samples, the results of which are provided in Appendix 3. This test is used to compare the measured differences between pH_F to pH_{FOX} to assess the presence of actual and potential acidity. Changes greater than 1 pH unit can be indicative of a PASS. The following results were reported:

Narrows sub-tidal (*W samples*)

- Field screening tests were carried out on 126 samples collected from the Narrows sub-tidal crossing, all of which had pH_F values greater than 6.5. This indicates each sampled tested has limited or no actual acidity
- Initial reactions (rated by severity of bubbling) assessed following the addition of hydrogen peroxide to soil samples ranged from 1 to 2 across a range of depths. This indicated a generally minor reaction and an absence or low presence of sulfides
- pH_{FOX} values for field screening samples collected within the Narrows sub-tidal crossing ranged from 2.05 to 8.75 pH units. This indicates a range of sulfidic or organic matter levels with a highly variable potential to oxidise and generate acid
- Four (4) samples returned pH_{FOX} values less than pH 3. These samples also decreased from pH_F values by more than 1 pH unit. This strongly indicates a PASS
- Three (3) samples returned pH_{FOX} values between pH 3 and pH 4. The pH_F of these samples also decreased by more than 1 pH unit. This indicates a PASS
- Ten samples returned pH_{FOX} values between pH 4 and 5, all of which decreased from pH_F values by more than 1 pH unit. These values are less indicative of PASS and were considered to require laboratory testing for the assessment of PASS
- All other remaining samples returned pH_{FOX} values greater than pH 5 and were thus not considered likely to be PASS

Narrows Mudflats (*MF samples*)

- Field screening tests were carried out on 243 samples collected from the Narrows mudflats crossing
- pH_F values ranged from pH 3.68 to pH 8.21. Of these, five samples had pH_F values between pH 4 and pH 5, while there was only one sample with a pH_F value less than 4. Furthermore, these six (6) samples were collected from only two locations: MF20 and MF21. This indicates there was little actual acidity within samples collected from the Narrows mudflats, with the exception of MF21 and MF21. These two sample points were located on the supratidal flats
- pH_F values for nearly all surface soil layers originating from terrestrial sources (i.e. brown silty clays) were either just below pH 7 or above. This indicates an absence of actual acidity within this soil type. The exceptions to this were surface soil samples collected from MF20 and MF21. The surface samples from these two locations were transitional layers with a mixture of both terrestrial soil and the very dark grey silty clay classified as PASS (refer Section 4.3)
- Initial reactions assessed following the addition of hydrogen peroxide ranged from 1 to 3, with the most significant reactions noted in samples containing significant organic matter and shells

- pH_{FOX} values for field screening samples collected within the Narrows sub-tidal crossing ranged from 1.39 to 8.64 pH units. This indicates a range of sulfide or organic matter levels with a highly variable potential to oxidise and generate acid
- Fifty-five (55) samples returned pH_{FOX} values less than pH 3. This strongly indicates a PASS. These samples also decreased from pH_F values by more than 1 pH unit
- Thirty-seven (37) samples returned pH_{FOX} values less than pH 4. This indicates a PASS, however a comparison with laboratory results was considered necessary. These samples also decreased from pH_F values by more than 1 pH unit
- Thirty-four (34) samples returned pH_{FOX} values between pH 4 and 5, all of which decreased from pH_F values by more than 1 pH unit. These values are less indicative of PASS and were considered to require laboratory testing for the assessment of PASS
- All other 117 remaining samples, returned pH_{FOX} values greater than pH 5. This indicates a comparison of laboratory results is required as these samples are neither AASS nor PASS. Notably, however all soil surface samples, which originated from terrestrial sources (i.e. brown silty clay), with the exception of MF09, MF21, and MF22, returned pH_{FOX} values just below pH 7 or above. This would normally suggest an absence of potential acidity within this soil type

In summary, these screening results indicate limited actual acidity within both the sub-tidal and mudflat portions of the study area (with the exception of MF20 and MF21). They also suggest, that a portion of locations within the sub-tidal area (W1, W2, W3, W5, W6, W20, W21, W22) [approximately 36% of locations, but only approximately 6% of samples] are PASS.

Ninety-two (92) out of 243 samples (approximately 38%) collected across nearly all locations (84% of locations) in the mudflats were indicative of PASS (with the exception of MF05-MF08 and MF12). These samples occurred within very dark grey silty clay or sand.

Both pH_F and pH_{FOX} values for surface soils derived from terrestrial sources present within the most MF sample locations were either just below or above pH 7. This would normally suggest the absence of actual and potential acidity within this soil type. Notably, terrestrial soil where it occurs within the extratidal flat (refer Figure 2.1) is mapped as having low rating. This is also where sample points MF05, MF06 and MF07 are located.

Generally speaking, screening results do not provide definitive data which can be used to assess ASS. They merely provide preliminary data from which subsequent test work requirements and early management strategies may be formulated. Laboratory testing is always required to provide an accurate assessment of the presence of ASS. This testing is described below.

4.3 Laboratory analysis

A total of 238 samples collected from across 52 locations in the Narrows sub-tidal crossing (81) and mudflats (157) were all submitted to ALS laboratories for Chromium Reducible Sulfur (S_{CR}) analysis, the results of which are provided in Appendix 3. These results, as well as actual acidity (TAA), net acidity and lime treatment rates, are also illustrated (reported in mole H+ / t) on Figure 4.1.

4.3.1 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. The following results were reported:

Narrows Sub-tidal (*W samples*)

- Samples ranged in pH_{KCl} values from 7.0 to 9.2. As no soil samples tested returned pH_{KCl} results below 4.5, samples were not tested for retained acidity
- Samples collected from all locations within the Narrows sub-tidal crossing reported TAA values less than the laboratory detection level of 2.0 mole H+ / t. This is also less than the QASSIT guideline of 18 mole H+ / t. This indicates all samples collected have very little or no actual acidity. This result is expected as all sampling locations are continuously submerged and therefore in an anaerobic state

Narrows Mudflats (*MF samples*)

- pH_{KCl} values ranged from 4.4 to 9.0 with only one sample (MF21/0.75-0.85) returning a pH_{KCl} value less than 4.5. As a result, no soil samples, with the exception of MF21/0.75-0.85 were tested for retained acidity. Retained acidity is the acidity generally stored as insoluble compounds such as jarosite or other iron and aluminium sulfate minerals. The retained acidity measured within MF21/0.75-0.85 was 33 mole H+ / t. Interestingly, no jarosite or mottles were noted for this location. Furthermore, no jarosite was noted at any mudflat sampling locations
- TAA values ranged from less than the laboratory detection level of 2.0 mole H+ / t to 68 mole H+ / t with nearly all locations exhibiting some levels of actual acidity. Locations with samples which exceeded the QASSIT guideline of 18 mole H+ / t were located within intertidal and supratidal flats. These samples were also generally collected within the top 1m of the soil profile, with the exception of MF21, MF23 and MF29 where TAA concentrations exceeding the QASSIT guideline were reported within the top 1.5mBGL. TAA values for samples collected deeper than approximately 1mBGL, or 1.5mBGL in the case of MF20, MF21 and MF23, were below the QASSIT guideline of 18 mole H+ / t indicating an absence of actual acidity beyond this depth
- Higher levels of actual acidity occur in MF20 to MF23. These sample points appear to be located on a subtly elevated area of the supratidal flat (refer Figure 2.1)
- TAA values of all samples collected within brown silty clays derived from terrestrial sources, with the exception of MF18 and MF21 were either below laboratory detection level of 2.0 mole H+ / t or below the QASSIT guideline of 18 mole H+ / t. This result indicates an absence of actual acidity within this soil type and confirms field screening tests described above
- Locations where all TAA values were reported below the QASSIT guideline of 18 mole H+ / t included MF05 to MF08, MF12, MF14, MF15, MF17, MF24, MF25, MF27, MF28 and MF32

4.3.2 Potential acidity

Potential acidity is assessed through the measurement of S_{CR}. The following results were reported:

Narrows Sub-tidal (*W samples*)

- S_{CR} values ranged from 0.03 to 2.12%S, all of which are above the QASSIT guideline of 0.03%S. These values were reported across a range of depths from all locations
- Approximately 26% of samples collected from the Narrows sub-tidal crossing were considered high with S_{CR} values greater than 1.0%S reported. These high values were reported in samples collected on either side (east and west) of the sub-tidal crossing (i.e. W1 to W6 and W17, W20 to W22)
- Approximately 27% of samples collected from the Narrows sub-tidal crossing were considered moderately high with S_{CR} values ranging from 0.5 to 1.0%S. These moderate S_{CR} values were similarly reported for samples collected on either side of the sub-tidal crossing (i.e. W1 to W9, W14 and W19 to W21)
- Approximately 47% of samples collected from the Narrows sub-tidal crossing were considered low with S_{CR} values less than 0.5%S reported. The lowest S_{CR} values were generally reported for samples collected within the central portion of the sub-tidal crossing (W9 to W19). As described in Table 4.1, this area contained mixed sediments but had a lower proportion of fine material, the majority of which is thought to have been removed by currents (refer Section 4.1). Only a few samples (W6 to W8 and W20 to W22) collected from both the east and west sides were reported with low S_{CR} values

Narrows Mudflats (*MF samples*)

- S_{CR} values ranged from 0.02 to 2.94%S. Samples with S_{CR} values below the QASSIT guideline of 0.03%S were generally reported surface samples collected from MF01, MF02, MF08, MF10, MF22 MF23 and the entire profiles of MF05 to MF07. All remaining samples, collected over the full depth of sampling, were above the QASSIT guideline and were generally collected within very dark grey silty clay or sand from the existing ground surface to refusal depth
- Approximately 51% of samples collected from the mudflats were considered to have high potential acidity with S_{CR} values greater than 1.0%S reported. The majority of these values occurred in samples collected on the seaward side of Targinie Creek within intertidal and supratidal flats ranging in depth from near ground surface to depth of refusal. High values were also reported for the landward intertidal and supratidal flats. This result is similar to those reported by Ross (2002, 2004 and 2005) and indicated by ASS hazard mapping (A0S0) (refer Figure 3.3)
- Approximately 11% of samples collected from the mudflats were considered moderately high with S_{CR} values ranging from 0.5 to 1.0%S. These moderate S_{CR} values were similarly reported for samples collected near surface and to the depth of refusal across both the supratidal and intertidal flats
- Approximately 38% of samples collected from the mudflats were considered to have a low potential acidic with S_{CR} values less than 0.5%S reported. The lowest S_{CR} values were expectedly reported in samples collected within soils derived from terrestrial sources. As

mentioned in Section 4.1, these soils were noted at most locations within surface samples or where the supratidal flats interfaced with the extratidal flat (i.e. MF05 to MF08)

4.3.3 Acid neutralising capacity

Acid neutralising capacity (ANC) is a soil's natural ability to buffer acidity either through the dissolution of calcium and/or magnesium carbonates (i.e. shells), cation exchange reactions, reaction of organic and clay fractions or other soil minerals. The effectiveness of neutralisation can be hindered somewhat depending on the available forms of 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 (refer Section 4.3.4). The following results were reported:

Narrows Sub-tidal (*W samples*)

- ANC values ranged from 128 to 7440 mole H+ / t and were detected within all samples submitted for analysis
- Most ANC values are expected to have originated from shells noted within profiles (refer Appendix 1)

Narrows Mudflats (*MF samples*)

- ANC values ranged from 25 to 2370 mole H+ / t and were recorded at various depths from nearly all locations with the exception of MF04. Notably, it was only detected within the top 1m of MF05 to MF08 where terrestrial soil was dominant
- Most ANC values are expected to have originated from shells noted within profiles (refer Appendix 1), with the exception of MF05 to MF08 where the inherent mineralogy of the constituent clay fractions are likely to have contributed to any acid buffering

4.3.4 Net acidity and liming

Net acidity is the final measure of acidity within a sample once the acid neutralising capacity has been subtracted from the sum of all acid (actual, potential and retained). The following results were reported:

Narrows Sub-tidal (*W samples*)

- Net acidity ranged from less than the laboratory detection level of 0.02%S to 1.54%S. Up to 72kg of lime will be required per tonne of soil at some locations to neutralise acidity, while no lime will be required at others. Locations where no net acidity was reported were sample points W7 to W18

Narrows Mudflats (*MF samples*)

- Net acidity ranged from less than the laboratory detection level of 0.02%S to 2.96%S. Up to 138kg of lime will be required per tonne of soil at some locations to neutralise acidity, while no lime will be required at others. Locations where no net acidity was reported were sample points MF05 to MF07 and MF12

The results for liming rates have been categorised according to QASSIT guidelines. These have been colour coded and illustrated on Figure 4.1 and Appendix 3. These categories are provided in Table 4.2.

Table 4.2 Treatment categories

Category		Liming rate (kg lime / t soil)
L	Low treatment	≤0.1
M	Medium treatment	0.1 – 1
H	High treatment	1 – 5
VH	Very high treatment	5 – 25
XH	Extra high treatment	>25

5. Summary of investigation

The purpose of this assessment was to assess the risk of disturbing AASS and PASS along the gas pipeline Route 3H. This risk was assessed in conjunction with previous information presented in reports such as that by Ross (2002, 2004 and 2005). This existing information indicated that ASS in The Narrows area is classified as having a high potential for acid generation at varying depths within a number of landforms comprising tidal creeks, intertidal flats and supratidal flats (Ross, 2002).

Other investigations undertaken by GLNG (GeoCoastal, 2009) and QCLNG (ERM, 2009) confirmed this hazard by reporting %S values up to 3.95%S and 2.0%S respectively within grey silty clays which were capped by a soft to firm and generally non-acidic silt / clay (ERM, 2009). A second investigation also completed by GLNG (URS, 2009) reported minimal actual acidity in samples collected within the supratidal flats, but significant levels of potential acidity closest to the coastline within intertidal flats.

A summary of this investigation is provided in the following sections.

5.1 Soil type

Narrows Sub-tidal

There were three generalised profiles which were encountered within the Narrows sub-tidal area. These were divided into the east, west and central areas of the channel. Both the east and west sides were indicative of material encountered on their respectively adjacent landforms (i.e. Curtis Island to the east and the mudflats to the west). Sediment profiles of these two areas generally comprised of a very weak silty layer on the surface which graded into weak silty clay to approximately 1.0m. Below this depth, firm to very firm silty clay was encountered. All profiles generally contained appreciable quantities of organic material and shells and often had a sulfurous odour.

The third profile encountered in the Narrows occurred within the central area. Here mixed sediments with a high proportion of coarse materials were encountered as the majority of fine sediments are thought to have been removed by strong currents. Here, vibracore refusal depths were shallow due to the abundant coarse fragments and shells.

All profiles encountered in the Narrows sub-tidal area were PASS.

Narrows Mudflats

The mudflats are comprised of a number of landforms: tidal creeks, intertidal flats, supratidal flats and extratidal flats, all of which are traversed by the proposed gas pipeline route. The surface soil profiles of the landward (west of Targinie Creek) intertidal and supratidal flats are influenced by the deposition of sheet wash material eroded from adjacent terrestrial sources. This was evident as very firm brown silty clay on the surface which was generally non-acid as described in Section 5.3. Where locations were tested on or adjacent to the extratidal flat (MF05, MF06, MF07, MF08), this surface layer graded into a firm, greyish green to grey silty clay which was also generally not PASS at these locations. However, where this greyish green to grey silty clay occurred closer to mangrove vegetation (intertidal and supratidal flats) [i.e. MF09, MF10, MF13], laboratory results indicated these soils were PASS. A very firm brown with yellowish red mottle silty clay was also encountered on and adjacent to the extratidal flat. This was also not PASS.

The very firm brown silty clay surface layer described above also occurred on the intertidal and supratidal flats east of Targinie Creek. However, this layer is PASS, and in some instances AASS, as it was generally very thin and intermixed with subsoil profiles. Below this surface horizon in the supratidal flats, a weak to firm, dark to very dark grey silty clay was encountered down to approximately 1.0mBGL. This layer continued to approximately 2.0mBGL, but with few fine shells. This was considered a separate profile as indicated on Figure 4.1. Both these layers are PASS.

Two profiles were encountered on the intertidal flat adjacent to Port Curtis: firm, dark grey silty clay on the surface and a weak to firm dark to very dark grey silty clay down to approximately 2.5mBGL, both of which are PASS. The second profile is also common to the supratidal flats.

Very shallow groundwater was encountered at all sample points across the mudflats. This ranged in depth from 0.2mBGL to 1.0mBGL or obviously fully saturated in the intertidal zone. The brown silty clays were generally dry (i.e. MF06, MF07, MF08), however the remainder of the profiles across all mudflat sampling locations had some moisture.

5.2 Field screening tests

In this investigation completed for Australia Pacific LNG, field screening tests carried out on 369 samples indicated that there was limited actual acidity within both the sub-tidal and mudflat portions of the study area. Within the sub-tidal portion of study area, this is an expected result as the sample locations are submerged. However, a greater proportion of samples were expected to have actual acidity along the mudflats as this area is intermittently exposed to aeration through tidal variation therefore allowing oxidisation. The results recorded however may be attributed to the residual saturation of soils. For example, at the time of sampling the standing groundwater level ranged from 0m (due to high tides) to 0.83mBGL with nearly all samples collected retaining some moisture which would therefore restrict oxidisation. The pH_F measured is generally consistent with data reported within the GLNG and QCLNG reports mentioned above.

pH_{FOX} values for approximately 36% of sample locations within the sub-tidal portion (W1, W2, W3, W5, W6, W20, W21, W22) were indicative of PASS, while nearly all locations on the mudflats (with the exception of MF05-MF08 and MF12) [approximately 38% of samples] collected within very dark grey silty clay or sand were indicative of PASS. Notably, these tests indicated samples collected within brown soils derived from terrestrial sources were generally not PASS. This is consistent with data reported within the GLNG and QCLNG reports mentioned above and S_{CR} results discussed below.

5.3 Laboratory results

Laboratory TAA data generally agreed with the field screening tests conducted on samples collected from both the sub-tidal and mudflats areas, however TAA data for some near surface samples collected from the mudflats indicated there is some actual acidity above the QASSIT guideline of 18 mole H+ / t, within the first 1m, and in some cases, first 1.5m of the soil profile. These samples were located within the intertidal and supratidal flats. Notably, a higher proportion of actual acidity occurs from what appears to be a subtly elevated area from MF20 to MF23 (refer Figure 2.1).

S_{CR} values for all samples collected within the sub-tidal portion were above the QASSIT guideline of 0.03%S. S_{CR} values for all very dark grey silty clay or sand collected within the mudflats were above the QASSIT guideline of 0.03%S. Only a few samples collected within the brown soil deposited from terrestrial sources reported S_{CR} values above the QASSIT guideline. These samples were generally collected within transitional layers which were a mixture of both brown sheet wash material derived from the erosion of adjacent terrestrial landforms and very dark grey silty clay or sand. Sample points where S_{CR} values were below the QASSIT guideline for the entire profile collected included MF05, MF06 and MF07. These sample points were located within an extratidal flat, which has been classified by DERM mapping as land with a low probability of ASS occurrence.

5.4 ASS risk

This investigation has indicated that specific ASS management measures will need to be applied to most areas of the mudflats to be disturbed with the exception of the extratidal flat located at MF05, MF06 and MF07.

PASS were noted within each profile (with the exception of MF05, MF06, MF07 and MF12) tested on the mudflats and sub-tidal areas with potential acidity ranging from 0.02%S to 2.94%S. Some locations were reported to have acid neutralising capacity sufficient enough to buffer net acidity to below QASSIT guideline levels. However, where coarse shell fragments were noted (i.e. within surface layers of 'W' location borelogs), acid neutralising capacity may not be readily available (refer Section 4.3.3). When an ASS management plan is developed, a review of treatment effectiveness from similar developments (i.e. Fishermans' Landing dredge material disposal and reclamation) should be considered to validate treatment strategies and maximise treatment efficiencies.

Based on the laboratory data alone and the proposed disturbance volume most soils located within mudflats and the east and west sides of the sub-tidal area will require an extra high level of treatment. As stipulated within the QASSIT guidelines, detailed soil management, monitoring and bunding plan will be required prior to the approval of construction. The ASS Management Plan (ASSMP) will need to be developed in consultation and co-ordination with design engineers and DERM in order to achieve a balance between best practice ASS objectives and project engineering design, construction, logistics and cost.

The ASSMP will need to consider the pipeline design and construction in combination with this investigation and existing data from other reports. This plan will also need to address the potential for the generation of subsurface acidic conditions through dewatering and aim to minimise the potential for the development of an oxidising environment in the subsurface away from the excavated areas and hence reduce the potential for the generation of acidic ground conditions. This plan should also incorporate storage, treatment and disposal of groundwaters and surface water (including tidal flows) where they are likely to affect earthworks operations.

6. Potential impacts

The disturbance of Acid Sulfate Soils (ASS) in the Narrows area has been identified as potential impact.

The proposed development poses a risk to the environment through disturbance of already acidic soil (AASS) and PASS causing oxidisation of sulfides and therefore the generation of sulfuric acid. This disturbance, through the fluctuation of tides in the study area, rainfall and groundwater movement, may lead to the migration of acidic fines to the receiving waterways of the Great Barrier Reef World Heritage Area. The potential impact of this acidic sediment to the environment may be the deoxygenation of waterways, release of heavy metals, such as aluminium and fish kills. Where these impacts have the potential to occur or where environmental monitoring detects breaches in development conditions imposed by regulatory bodies, there is the potential for lengthy delays to construction.

As described in Section 1.2, a fundamental understanding of the proposed works is required in order to describe the potential impacts of the development to the environment and the management strategies necessary to mitigate this impact. At this stage, precise design and construction methodologies for the gas pipeline crossing of the Narrows have not been developed. However, two potential broad scenarios are as follows:

1. A stand alone option in which Australia Pacific LNG would construct its gas pipeline in isolation from other proponents. This option will involve trenching across the mudflats portion and dredging across the sub-tidal portion.
2. A co-location option in which all four proponents gas pipelines will be constructed in one joint construction exercise as described in GHD (2010). This option will involve a single trench across the sub-tidal area adjoining two trenches (both with two gas pipelines) across the mudflats.

Without considering detailed engineering aspects of each scenario, the following potential outcomes may contribute to the potential migration of acidic fines to the receiving waterways of the Great Barrier Reef World Heritage Area leading to deoxygenation of waterways, release of heavy metals, such as aluminium and fish kills.

- Mishandling of soils through difficult transport and excavation logistics allowing excessive oxidisation of PASS and potential release of acidic fines into receiving waters
- Inadequate treatment then reuse, leaving a legacy of acidity within soil which may then be released into receiving waters
- Inadequate monitoring leading to the non-detection of low pH surface water and groundwater and its release into receiving waters
- Inadequate water management leading to tidal / groundwater flushing of acidic sediments into receiving waters
- Lack of emergency management leading to the inability to mitigate loss of acidic sediment, reduced pH and oxygen in receiving waters
- Excessive disturbance leading to inadequate treatment of AASS and PASS

- Disturbance of highly acidic soil located within the intertidal (mangrove) flats which require an extra high level of treatment and therefore increased risk of mismanagement
- Numerous occurrences of large volume ASS disturbance leading to increased likelihood of soil mismanagement
- The volume of disturbed ASS requiring treatment will be significant. Drying, treatment and validation timeframes may restrict construction progress where spoil reuse is required and may also increase the risk of non treated ASS remaining exposed. Where very high lime treatment rates are required, i.e. >100kg of lime / t of soil, such treatment may not be practical and other handling options would need to be addressed

The potential impacts identified above and practical solutions, incorporating the QASSIT recommended management strategies, will need to be addressed within the ASSMP to be prepared in liason with project design engineers and DERM representatives.

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