4 GEOLOGY AND SOILS

This chapter provides an overview of the geology and soil characteristics for the LNG Component, specifically the proposed LNG Facility on Curtis Island, and outlines expected impacts as a result of this proposed development.

4.1 DESCRIPTION OF PROJECT ENVIRONMENTAL OBJECTIVES

The Project environmental objective for geology and soils is: to protect soils from contamination and erosion arising from Project activities.

4.1.1 Methodology

An assessment of geology and soils associated with Project activities in the Gladstone region was undertaken[1]. This assessment used available data and published information (including aerial photographs, geological reports, topographic maps and database searches) supplemented by field investigations in October and November 2008.

Fieldwork involved detailed soil sampling and chemical characterisation of soils to assess the erosion potential of soils and landscape as a result of the proposed construction works. Specific investigations were also undertaken to identify and characterise acid sulfate soils (ASS) in the broader area of the LNG Facility.

A detailed discussion of the methodology and assessment of the potential environmental impacts and defined environmental values associated with the proposed development of the site is provided below. The complete *Geology and Soils Assessment Report* is included as *Appendix 5.1.* Additional data has been sourced from preliminary geotechnical investigations which are ongoing on the site to inform detailed design.

The assessment was undertaken with reference to the following guideline documents:

- *State Planning Policy (SPP) 1/92: Development and the Conservation of Agricultural Land (and associated Guidelines)*
- *SPP 2/02: Planning and Managing Development Involving Acid Sulfate Soils*
- *SPP 2/07: Protection of Extractive Resources*
- *SPP 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide*

1 Environmental Resources Management Australia (2009). *Queensland Curtis LNG Project: LNG Facility and Associated Infrastructure – Geology, Geomorphology, Topography and Soils Report*

- *Australian Soil and Land Survey Field Handbook* (McDonald et al, 1990) & *Australian Soil Classification* (Isbell, 1996)
- *Planning Guidelines: the Identification of Good Quality Agricultural Land,* Department of Employment, Economic Development and Innovation – DEEDI (formerly Department of Primary Industries), Department of Local Government, Planning, Sport and Recreation – DLGPSR (formerly Department of Housing, Local Government and Planning), 1993
- *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998 (Revision 4.0)*
- *Draft Guidelines for the Assessment and Management of Contaminated Land in Queensland* (Department of Environment and Resource Management – DERM (formerly Queensland Environmental Protection Agency), 1998
- *Queensland State Coastal Management Plan (SCMP) and Regional Coastal Management Plans (RCMP).*

The geology and soils assessment encompassed:

- the onshore component of the LNG Facility on Curtis Island
- the proposed road and pipeline routes on Curtis Island
- the pipeline route and bridge approach, east of Calliope River–Targinie Road.

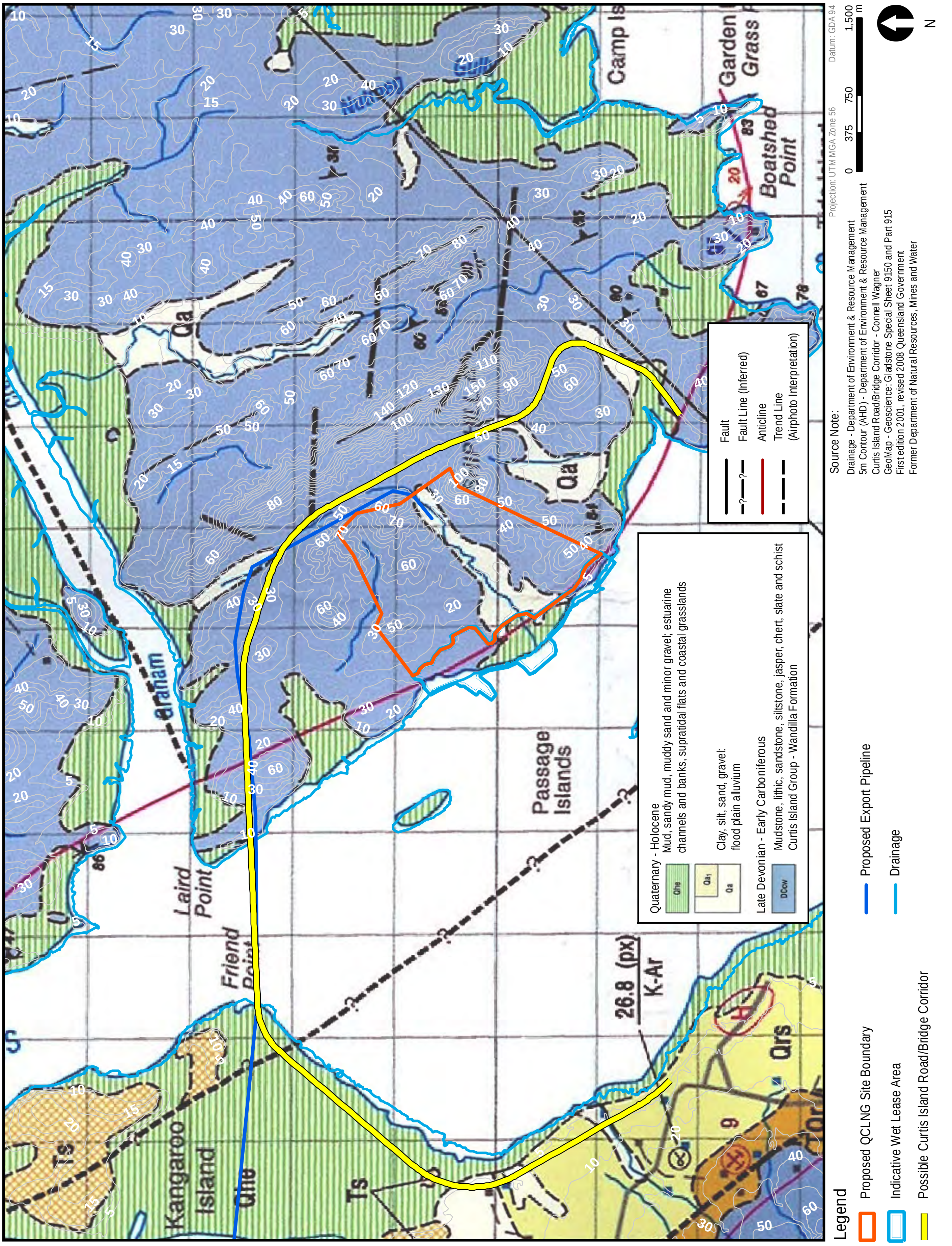
4.2 DESCRIPTION OF EXISTING ENVIRONMENT

4.2.1 Regional Geology

4.2.1.1 Desktop Assessment

The following description of the regional geology is based on Donchak and Holmes[2] (1991). A regional geological map is provided in *Figure 5.4.1*.

2 Donchak and Holmes (1991) *Gladstone Special Sheet 9150, 1:100,000*



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Project: Queensland Curtis LNG Project

Client: QGC - A BG Group business

Title: Geological Map of QCLNG Site Area

Drawn: JB | Volume 5 | Figure 5.4.1

Approved: GB | File No: 0086165b_EIS_GS_GIS001_F5.4.1

Date: 24.02.09 | Revision 1

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The main geological unit in the eastern portion of the region is the Devonian-Carboniferous Curtis Island Group, which consists of conformable sequence of three formations – the Doonside, Wandilla and Shoalwater. The Curtis Island Group has undergone a regional metamorphic event of upper greenschist to lower amphibolite grade, with the grade decreasing from east to west. The regional structural trend is toward the north-west at 330^0.

The Narrows Graben, a block faulted basin, was formed during a period of crustal extension which occurred throughout eastern Queensland during the Late Cretaceous period. The tectonic activity reactivated north-west trending basement faulting, resulting in relatively rapid subsidence in the region of The Narrows, producing The Narrows Graben, a block faulted continental basin approximately 40 km long and 5 km wide. The southern end of The Narrows Graben forms The Narrows Passage between the mainland and Curtis Island.

The main geological unit in the Project area is the Wandilla Formation, which forms a broad, north-west trending belt approximately 10 km wide. This unit makes up the majority of Curtis Island and extends to the south through Gladstone.

The thickness of the unit is uncertain due to internal folding and faulting. The unit consists mainly of mudstones and arenite, with subordinate chert and minor limestone. The mudstone is characteristically dark grey and is commonly indurated. Lenticular and discontinuous cream sandy laminae are common, with locally developed phyllitic, micaceous sheen developed on cleavage surfaces.

Thin quartz veinlets and occasional thick veins penetrate the rocks parallel to the major foliation. Interbedded with the mudstones are thick, massive beds of weakly foliated grey to greenish grey arenites, with minor greywackes and quartz arenites.

Holocene sediments comprising tidal flats and surficial alluvial material occur on the western margin of the site on Curtis Island and on the eastern shore at Friend Point.

4.2.1.2 Field Observations

Field surveys indicated an extent of outcrop across the site of less than 5 per cent, with outcrops of bedrock generally restricted to incised creeks. Colluvium deposits were observed across the site, comprising superficial deposits of angular to subangular clasts, ranging in size from 10 mm to 1 metre.

The dominant rock type identified in the site area consisted of fine grained to microcrystalline massive to blocky dark grey to light grey indurated mudstone and arenite, considered attributable to the Wandilla Formation. Minor cream to pale brown siltstone outcrops within the Project area exhibit foliation and jointing.

The siltstone exhibited a dominant jointing direction of 330^0, reflecting the regional trend. Quartz veinlets (2 mm to 5 mm wide) were observed in surface outcrops and colluvium as a result of the jointing and folding developed during the regional metamorphic event.

An exposed outcrop and soil profile in the creek bed at grid reference (GR) 0317168E 7370626N exhibited evidence of prolonged weathering, with the development of ferruginous soils and the formation of yellow brown to orange brown laterite. The underlying alluvial material also exhibited extensive cementation by ferruginous material.

The soil profile shown was observed in a single location and may represent an older soil profile which has undergone extensive weathering, resulting in the formation of a duplex soil exhibiting extensive ferruginous weathering and development of an underlying lateritic concretion/cemented matrix.

4.2.2 *Seismicity*

Regional seismicity of the Gladstone area has been reported by the Queensland University Advanced Centre for Earthquake Studies (QUACKES)[3]. The Gladstone area is considered the sixth most seismically active area in Australia, and lies on the northern edge of a seismic belt that stretches between Brisbane and Gladstone.

The Queensland catalogue contains a total of 409 earthquakes in the Gladstone map region. Major recorded earthquakes include the 1918 quake, possibly the largest earthquake to strike in or adjacent to eastern Australia, which occurred about 135 km offshore Gladstone (Richter local magnitude (ML)) scale estimate of ML=6.3 based on felt area and ML=6.0 based on an instrumental recording). The quake was felt from Mackay in the north to Grafton, New South Wales in the south and Charleville in the west.

Other noteworthy earthquakes near Gladstone include the 1953 Many Peaks earthquake, the Heron Island 1978 earthquake, and the 1998 offshore Rockhampton earthquake. Other earthquakes felt in Gladstone include the 1883 ML=5.9 Gayndah earthquake, the 1910 ML=5.2 Mundubbera earthquake, and the 1935 ML=6.1 Gayndah earthquake.

The western margin of Curtis Island falls within or near the boundary of The Narrows Graben, a prominent structural feature in the area. The available data indicate that these faults are not known to be active.

Data from the Rockhampton 1:250,000 geological sheet[4] SF 56-13 (1974) indicated that possible east-west faulting exists to the immediate north of the site through Graham Creek and south-east north-west through The Narrows.

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3 University of Queensland (2009) *Earthquake Maps of Queensland and Australia*.

4 Kirkegaard,A G,(1974). *Geology of the Rockhampton and Port Clinton area1:250,000 geological sheet SF 56-13*

4.2.2.1 *Seismic Hazard Assessment*

In addition to published seismicity data, a probabilistic seismic hazard assessment for the LNG Facility site has been undertaken by the Project[5]. This consisted of:

- evaluation of regional geology, tectonics and seismicity
- development of a seismic source model consisting of regional seismic sources and their earthquake recurrence rates
- probabilistic seismic hazard analysis (PSHA)
- development of rock or stiff soil response spectra for the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE) for the LNG Facility.

4.2.2.2 *Regional Seismicity*

The Global Seismic Hazard Assessment Program (GSHAP) has compiled a seismic hazard map of peak ground acceleration (PGA) for the region for a 10 per cent in 50 years probability of exceedence (i.e. 475-year return period) for rock/firm soil site conditions (GSHAP, 1999). The 475-year PGA ground motion from the GSHAP is approximately 0.107 g for the area around the Curtis Island site.

Earthquake loading code maps have been developed by Standards Australia with the PGA hazard map with 10 per cent probability of exceedence in 50 years (equivalent to a return period of 475 years)[6] provided in *Figure 5.4.2.* Based on this map the 475-year PGA near the Project site is around 0.09 g.

A seismicity catalogue was referenced for the seismic hazard assessment, with the combined catalogue recording 35,490 seismic events ranging from magnitude -9 (to represent felt event with no magnitude reported) to 8.1, covering an area defined approximately by latitudes 10° to 45°S, longitude 110° to 155°E[7]. A summary of catalogue data for Australia is provided in *Figure 5.4.3*.

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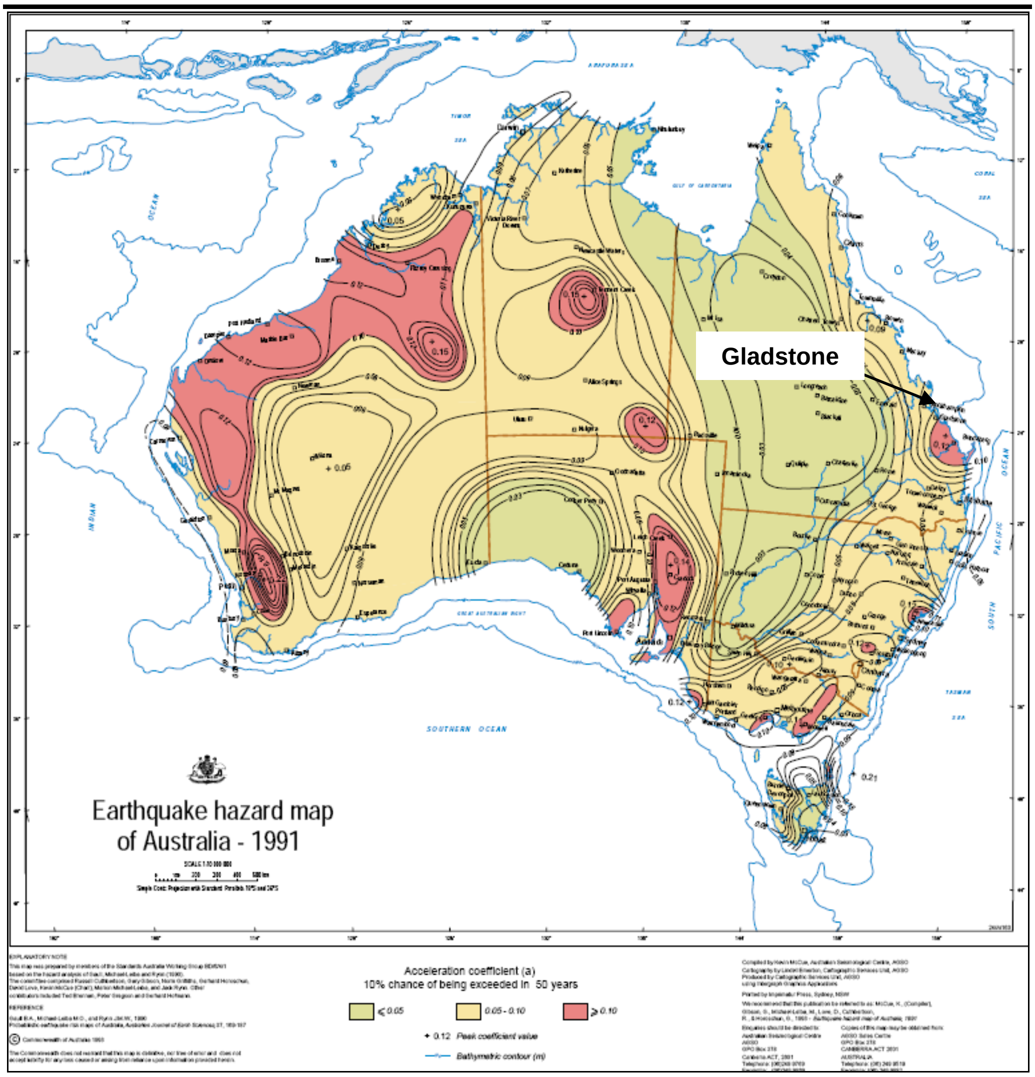
5 Bechtel Oil, Gas and Chemicals, Inc. (2008) *BG Queensland Curtis LNG Project: Probabilistic Seismic Hazard Assessment of BG Queensland Curtis LNG Site, Australia. Stage 1 Report.*

6 McCue, K., (Compiler), Gibson, G., Michael-Leiba, M., Love, D., Cuthbertson, R., & Horoschun, G (1993) *Earthquake Hazard Map of Australia – 1991*

7 Leonard, M. (2008a). *One hundred years of earthquake recording in Australia* as described in Bechtel Oil, Gas and Chemicals, Inc. (2008)

Figure 5.4.2 Earthquake Hazard Map of Australia



Probabilistic Seismic Hazard Assessment (PSHA)

The characterisation of a seismic source model requires several elements, including its geographical definition, the seismic activity rate, maximum magnitude and depth of the seismicity within the source zone. Based on assessment of seismic sources, recurrence parameters, maximum and minimum values and depth of seismicity, a magnitude–frequency relationship for Gladstone was derived and is presented in *Figure 5.4.4.*

The PGA and spectral accelerations for return periods of 475 and 2,475 years using ground-motion values for soft rock/stiff soil site conditions have been derived to determine the operating basis earthquake (OBE) and safe shutdown earthquake (SSE) for the LNG Facility detail design, as defined in the US National Fire Protection Agency (NFPA) 59A *Standard for the production, Storage, and Handling of Liquefied Natural Gas (LNG)*, 2006 edition.

Figure 5.4.3 Seismicity of Australia for Magnitude 2 and Greater

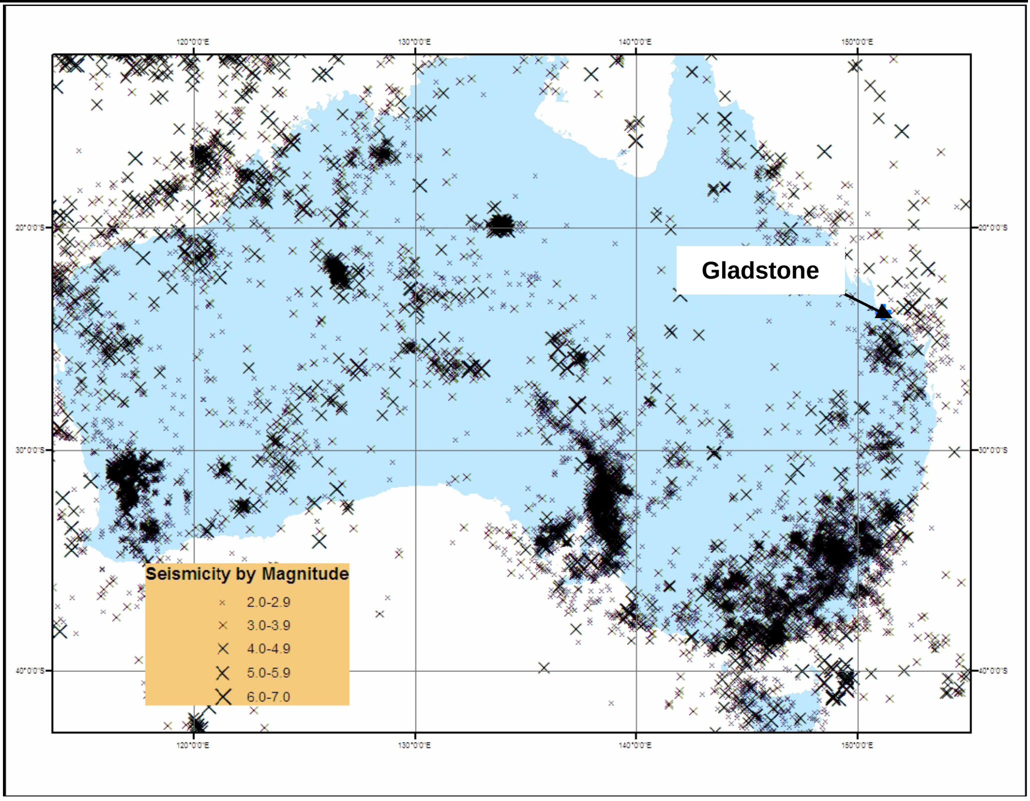
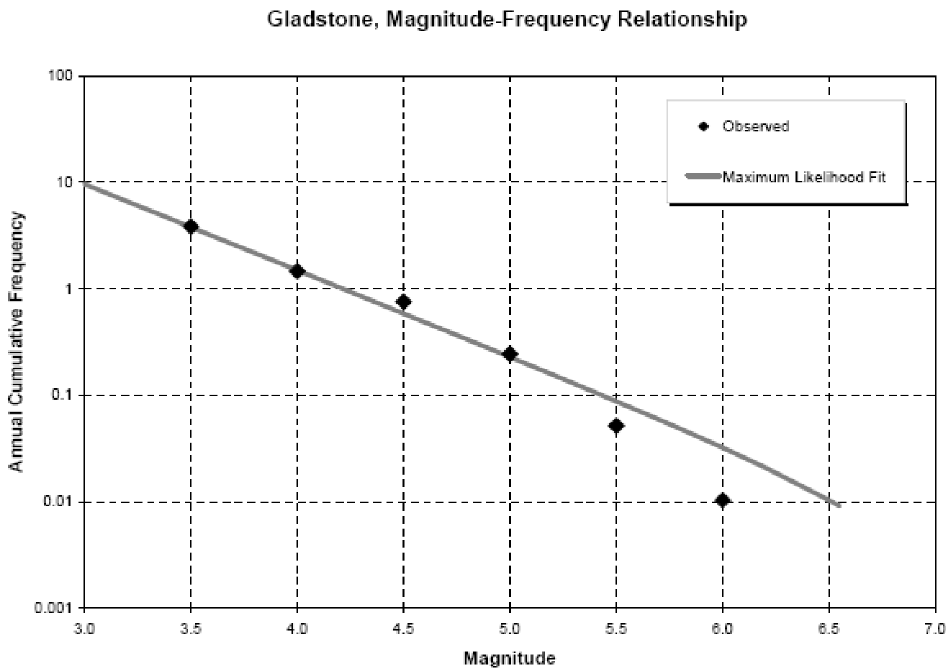


Figure 5.4.4 Gladstone, Magnitude – Frequency Relationship[8]



8 From Figure 12, *BG Queensland Curtis LNG Project: Probabilistic Seismic Hazard Assessment of BG Queensland Curtis LNG Site, Australia. Stage 1 Report.*

4.2.3 Soils

Soil sampling and analysis was undertaken as part of three individual investigations: contaminated land assessment; the assessment of the erodibility of soils across the LNG Facility site and proposed roadway and pipeline routes; and ASS. *Volume 5, Chapter 6* provides a discussion relating to the contaminated land impact assessment.

Soils were assessed using the *Australian Soil and Land Survey Field Handbook,* Second Edition[9]. There are a number of factors which influence the formation and soil development, including climate, geology, landform, land use and vegetation. Soil sampling locations are shown in Figure 5.4.5. Full sampling and analytical data is provided in the *Geology and Soils Assessment Report,* February 2009, provided as *Appendix 5.1.*

The density of the soil sampling undertaken on the site was based on the requirements specified in *Planning Guidelines: The Identification of Good Quality Agricultural Land (1993)* and detailed in *Table 5.4.1*.

Table 5.4.1 Recommended Density of Ground Observations for Detailed Mapping

Total Area of Site	Map Scale	Density (ha per observation)[1]
Less than 10 ha	1:2,500	0.5–1.0 ha
10 -100 ha	1:5,000	1.0–4.0 ha
More than 100 ha	1:10,000	6.25–25 ha

Notes: 1. Lower recommended densities are acceptable only in areas of uniform soil types.

The requirements outlined in the guidelines recommend sampling of soil profiles to a depth of 1.2 m, with samples collected from 0–0.1 m, 0.2–0.3 m, 0.5–0.6 m, 0.8–0.9 m and 1.1–1.2 m.

A total of 45 locations were sampled, with 59 samples collected for analysis. Sampling was conducted across the site of the proposed LNG Facility and along the proposed pipeline and access road routes on Curtis Island.

Samples were collected from depths between 0.05 m to 0.6 m, with depth of sampling restricted by ground conditions which limited the depth of penetration of the hand auger. As a result, most samples collected for analysis were obtained from depths of 0.15 to 0.2 m.

Samples were sent to a National Association of Testing Authorities (NATA) certified laboratory for determination of pH, salinity and cation exchange capacity (CEC) for sodium, calcium, magnesium, potassium and exchangeable sodium percentage (ESP). ESP was determined for the soils to

9 McDonald RC, Isbell RF, Speight JG, Walker J and Hopkins MS. (1998) *Australian Soil and Land Survey Field Handbook.*

ascertain the dispersivity of soils, which in turn is related to the erodibility of the soils.

4.2.3.1 *Baseline Description*

The soils across the LNG Facility site were typically classified within the Australian Soil Classification[10] as grey sodosols, and brown and red chromosols. Moving inland there is a change to bleached silty surface, and brown and grey sodic duplex soils on the lower colluvial slopes.

Sampling and analysis of soils at elevations less than 5 m Australian Height Datum (AHD) is described in *Section 4.2.8*. These soils have been classified within the Australian Soil Classification as hydrosols, sulfidic hydrosols and histic-sulfidic hydrosols (potential acid sulfate soils). Detailed information on the various properties of the soils on Curtis Island and adjacent mainland is available from Australian Soil Resource Information System (ASRIS)[11].

Surficial soils across the LNG Facility site on Curtis Island consist predominantly of hard, dry, pale-grey to light-brown clay and silts. These soils are relatively thin (0.5 m to approximately 1.5 m), although depth of the soil profile varies across the site. In areas below approximately +5 m AHD, gravelly clays/clayey gravels overly mudstone and lay typically 10 m to 15 m below surface. In tidally inundated areas the surficial soils are soft and potentially compressible. In areas with elevations between +5 m and +10 m AHD the subsurface conditions are generally very stiff to hard gravelly clays overlying weathered mudstones at between 5 m and 10 m below ground surface. Above +10 m AHD soils are underlain by weathered mudstone at depths typically less than 2 m to 3 m below surface.

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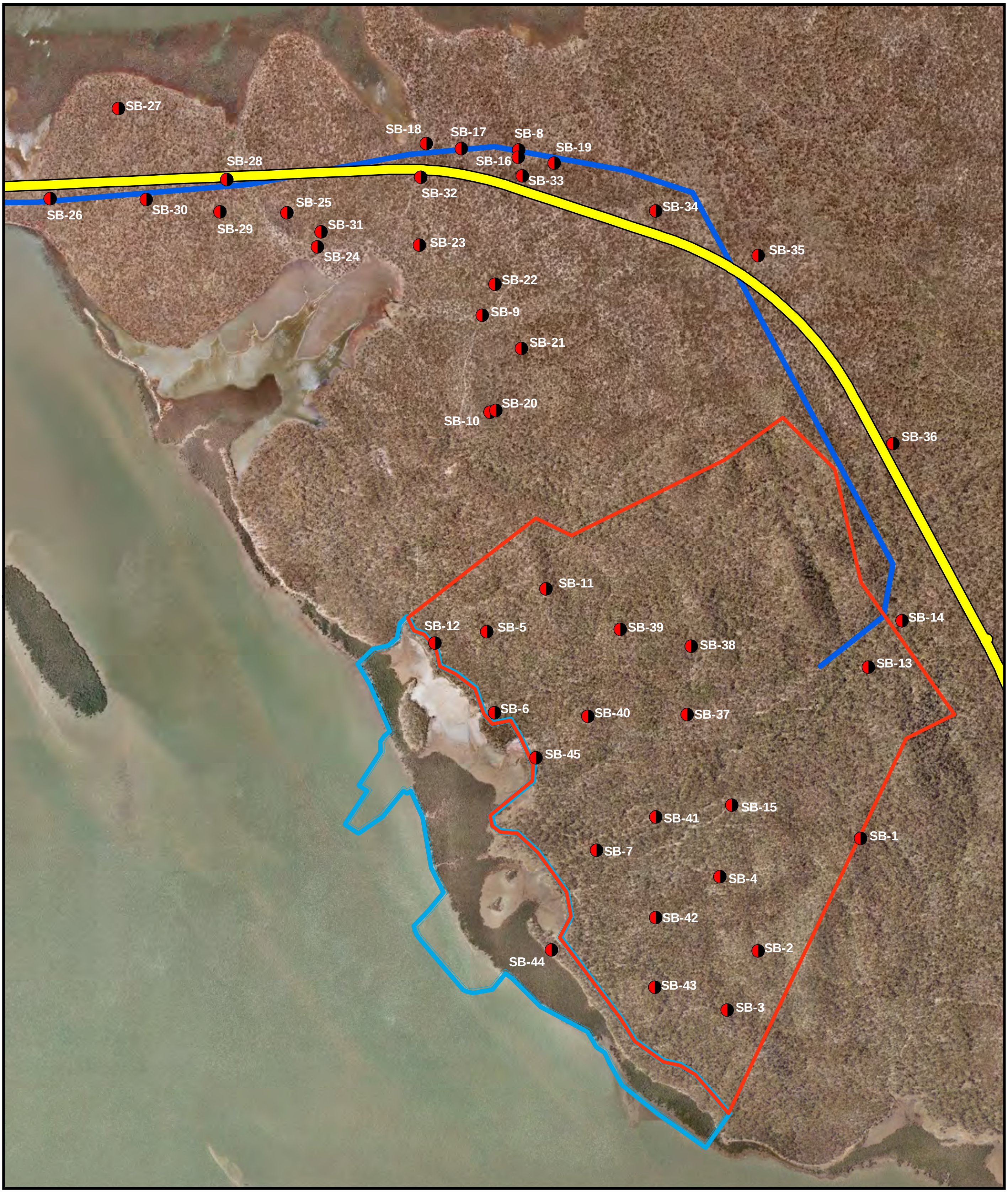
10 Isbell RF. (1996) *The Australian Soil Classification*,

11 CSIRO (2009) Australian Soil Resource Information System (ASRIS).



Legend

- Soil Bore
- Proposed QCLNG Site Boundary
- Indicative Wet Lease Area
- Proposed Export Pipeline
- Possible Curtis Island Road/ Bridge Corridor

Source Note:
Aerial Photo - Department of Infrastructure and Planning for QCLNG Project
Curtis Island Road/Bridge Corridor - Connell Wagner

Projection: UTM MGA Zone 56 Datum: GDA 94

0 200 400 800 m

N

QUEENSLAND CURTIS LNG A BG Group business	Project: Queensland Curtis LNG Project	Title: Soil Bore Location Plan - Curtis Island
	Client: QGC - A BG Group business	
ERM Environmental Resources Management Australia Pty Ltd	Drawn: JF; **Volume 5** **Figure 5.4.5**	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
	Approved: GO; File No: 0086165b_EIS_GS_GIS004_F5.4.5	
	Date: 22.12.08; Revision: 1	

4.2.3.2 *Field Observations*

The development of soil profiles encountered during sampling across the site was generally poor, with little organic matter observed in the soil samples. Soils are predominantly hard, dry and powdery, and form hard surfaces up to 10 cm in depth. The development of O-horizon was restricted to locations with extensive leaf litter, with the maximum observed thickness of 5 mm. This horizon was absent from the majority of sample locations.

The texture of the soils is generally fine, with clay and fine silt fractions dominant. Fine sand, where present, is subordinate (less than 2 per cent). Gravel fragments were widespread and constituted up to 25 per cent of some soil samples. Coarse fragments generally ranged in size from 2 mm to 30 mm and ranged from angular to sub-rounded in shape, with sub-angular fragments dominant.

The tidal flats along the western side of the site are underlain by hard Pleistocene clays at depths between 0.5 m and 2.5 m, with the thickness of the soft, intertidal/mangrove silts and muds decreasing towards the landward side of the site.

The depth of the tidal sediments at Friend Point was not able to be determined during the fieldwork as sampling was only conducted using a hand auger to a maximum depth of 3 m. Field penetrometer testing indicated that the substrate became harder and stiffer at depths between 5 m and 7.5 m below ground level.

The tidal flats from Curtis Island and Friend Point were generally oxidised in the upper 0.3 m to 0.5 m, grading into dark-grey silt and clay to depth. The sediments generally contained layers of organic-rich material 0.1 m to 0.2 m thick. The sediments from Curtis Island contained a layer of medium to coarse gravel 5 cm to 10 cm thick immediately above the Pleistocene clays which were observed to underlie the entire tidal flat area.

4.2.4 ***Stratigraphy***

An assessment of the stratigraphy across the low-lying areas (less than 5 m AHD) on the LNG Facility site on Curtis Island, and across areas of associated infrastructure on Friend Point was undertaken as part of the ASS investigation[12]. The full Acid Sulfate Soil and Geomorphological Modelling Report is provided in *Appendix 5.2*. A summary of outcomes is provided below.

12 Graham TL and Larsen RM (March 2009) Acid Sulfate Soil and Geomorphological Modelling Report, Proposed QCLNG Facility, Gladstone Queensland.

4.2.4.1 *Curtis Island Tidal Flats*

Pre-Holocene and Holocene-aged sediments were identified in the investigation. The interface of pre-Holocene/Holocene-aged sediments within this embayment is generally characterised by a seaward declining continuation of the residual landscape from the back of the tidal flat to a depth ranging to 2.75 m+ beneath the mangrove fringe.

Pre-Holocene substrates were identified as comprising of greenish grey to brown clay, being stiff to very stiff, with moderately high plastic and gravelly in places. A shallow zone of discoloration immediately below the surface was identified.

Holocene facies encountered include transgressive, sandy, gravelly lag; stills and near-shore clayey silt; progradational mangrove ridge; progradational mangrove, gravelly, sandy, clayey silt; supratidal surface silty, clayey layer; and colluvial fan.

A stratigraphic cross-section of local geology below 9 m AHD is presented in *Figure 5.4.6* which shows the complex suite of facies with a diverse physical character. *Figure 5.4.7* shows a shallower, more northern embayment which has a less complex sequence. Refer to *Figure 5.4.12* for locations of boreholes referred to in *Figure 5.4.6 and Figure 5.4.7.*

4.2.4.2 *Friend Point*

Pre-Holocene substrate is characterised only by approximate depth as it was not encountered during the investigation.

Holocene facies encountered include estuarine central-basin silt clay; mangrove clayey silt and upper tidal/supratidal clayey silt; and silt clay. A stratigraphic cross-section of local geology on Friend Point is presented on *Figure 5.4.8.* Refer to *Figure 5. 4.13* for locations of boreholes referred to in *Figure 5.4.8.*

4.2.4.3 *Soil Analytical Results*

The following parameters were determined for soil samples collected from Curtis Island:

- moisture content (percentage of moisture)
- pH (1:5 H_2O)
- electrical conductivity (1:5 H_2O)
- cation exchange capacity (CEC)
- exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+)
- exchangeable sodium percentage (ESP).

The full laboratory analytical results are presented in *Appendix 5.1.*

Moisture Content

The moisture content of the soils was generally low, ranging between 1 per cent and 6 per cent. Samples collected following overnight rainfall of 5 mm exhibited somewhat higher moisture contents of 8 per cent and 16 per cent.

Soil pH (1:5 H_2O)

The pH of the soils was relatively constant, ranging between pH 5.1 and pH 6.6. The only exceptions were samples SB-13 (pH 8.3) and SB-14 (pH 8.0). Soils with pH less than 5.5 are generally classified as acidic. Application of this criteria indicated that 19 per cent of the soil samples would be classified as acidic.

Exchangeable Cations (Meqv/100 g)

Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) analysis was conducted to determine the potential erodibility of the soils. The concentrations of exchangeable cations were reported in mg/kg, with the CEC calculated according to the following equation:

1 m_{eqv} = mg* valence/molecular mass

Sodicity of Soils

Sodicity is a measure of the proportion of sodium ions present in a soil. It is measured as the exchangeable sodium percentage:

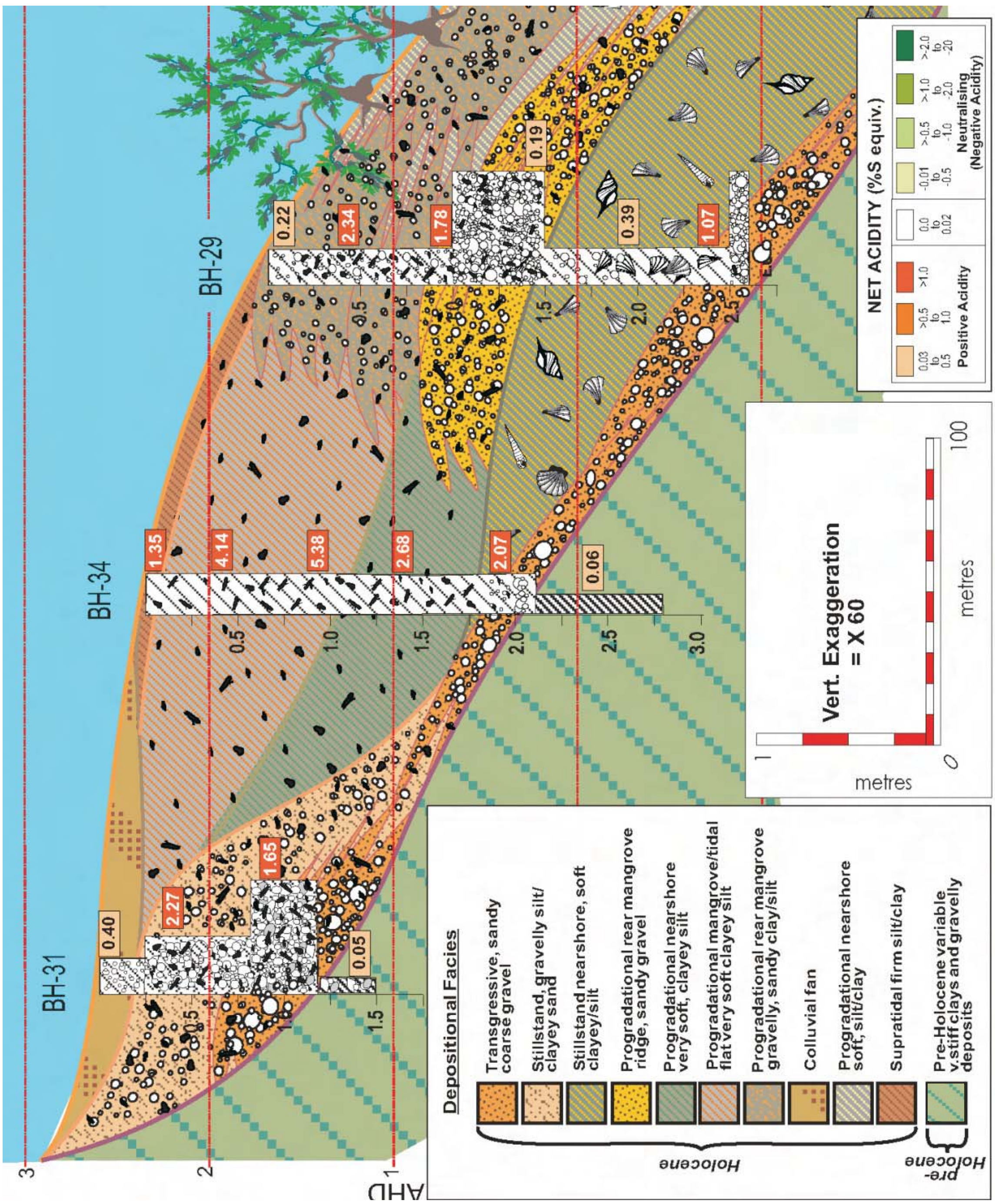
$$ESP = \text{Exchangeable Na/CEC}$$

General ratings for sodicity are as follows:

- non-sodic ESP less than 6 per cent
- sodic ESP 6 to 14 per cent
- strongly sodic ESP greater than 14 to 25 per cent
- very strongly sodic ESP greater than 25 per cent.

An ESP of 6 (per cent) is widely used in Australia as a critical limit for the adverse effects of sodicity (Northcote and Skene, 1972). ESP is conventionally defined as exchangeable sodium expressed as a percentage of the CEC - both usually determined in Australia at pH 7 or 8.5.

The influence of soil properties such as organic matter content, clay mineralogy, cation composition, sesquioxide content, and particularly electrolyte concentration will affect ESP on dispersion behaviour of the soils.



Source:
Figure adapted from Geocoastal Australia Report prepared for BG, Annex B - Acid Sulfate Geomorphological Modeling Report, March 2009.

QUEENSLAND CURTIS LNG A BG Group business	Project: Queensland Curtis LNG Project		Title: **Curtis Island Geological Cross-Section BH#29-BH31**
	Client: QGC - A BG Group business		
ERM Environmental Resources Management Australia Pty Ltd	Drawn JB	Volume 5 Figure 5.4.6	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
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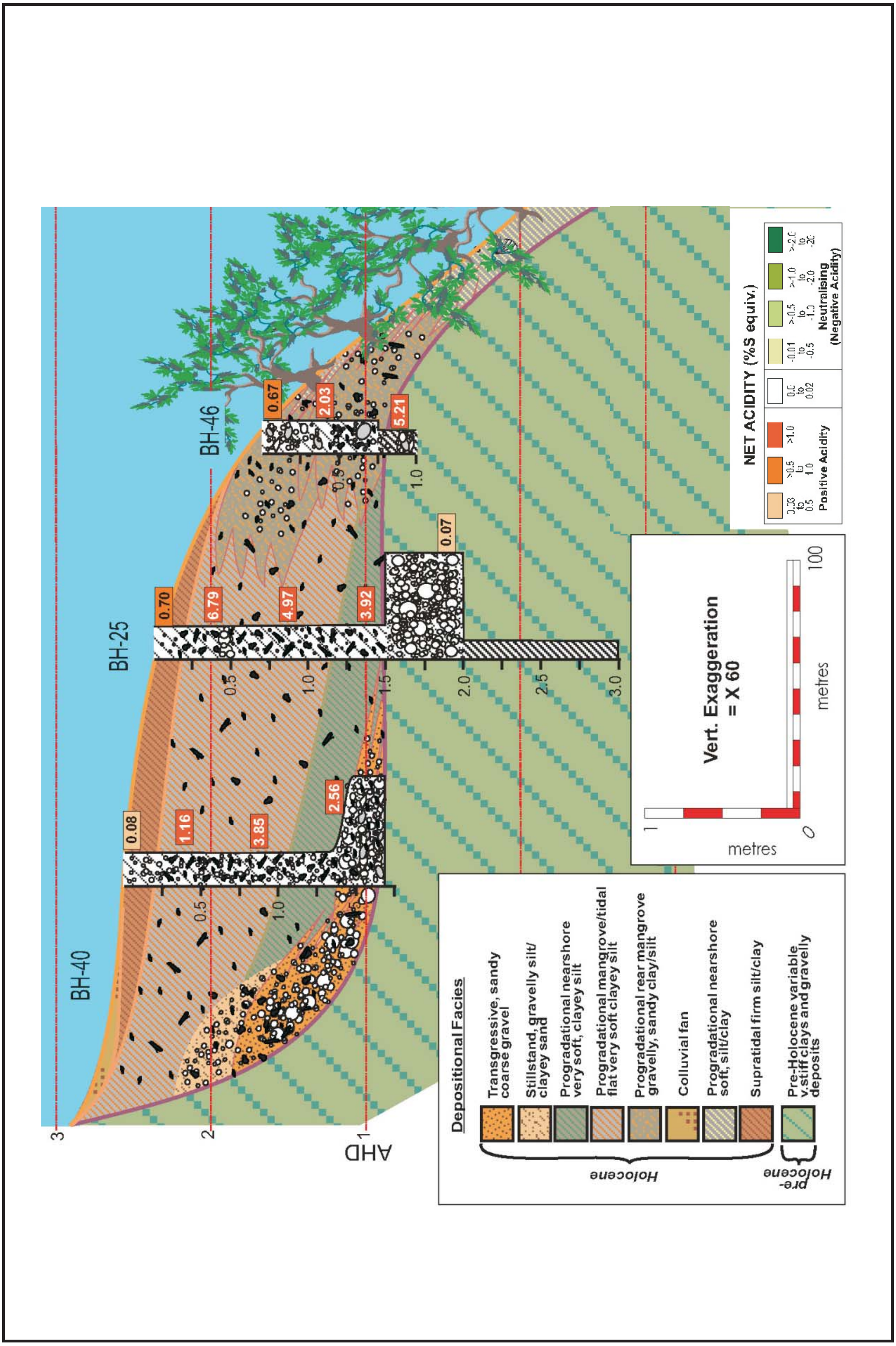

Source:
Figure adapted from Geocoastal Australia Report prepared for BG, Annex B - Acid Sulfate Geomorphological Modeling Report, March 2009.

Note:
This Cross Section is interpretive and generalised, and therefore may not be locally accurate.

QUEENSLAND CURTIS LNG A BG Group business	Project: Queensland Curtis LNG Project Client: QGC - A BG Group business	Title: **Curtis Island Geological Cross-Section BH#40-BH46**
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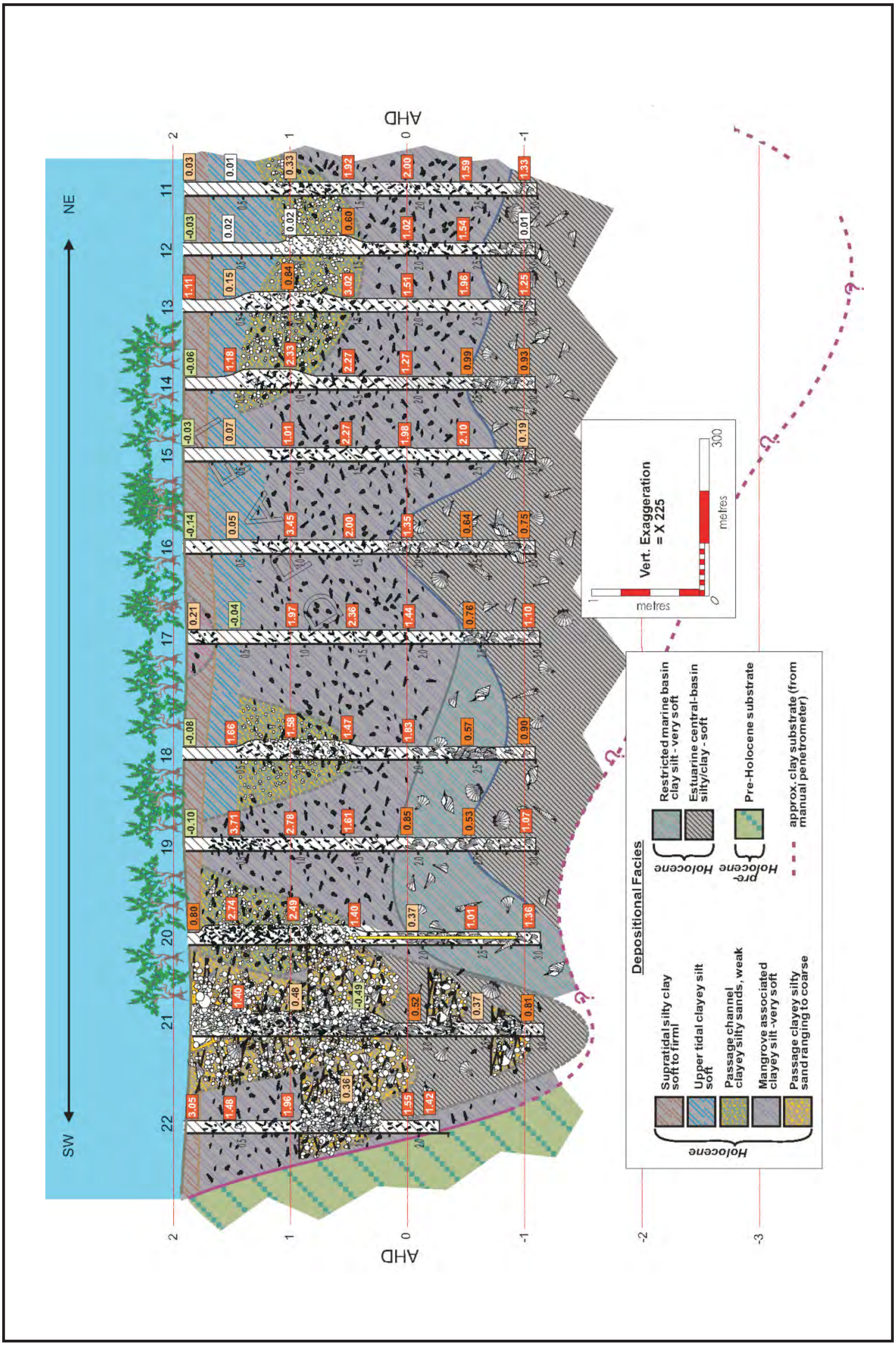

Source:
Figure adapted from Geocoastal Australia Report prepared for BG, Annex B - Acid Sulfate Geomorphological Modeling Report, March 2009.

Note:
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	Date 01/006/09	Revision 0		

The exchangeable cation concentrations are shown in *Table 5.4.2*. The maximum exchangeable cation concentration of 21.5 m_{eqv}/100 g was reported for calcium carbonate (Ca) in sample SB-30 (0 m–0.05 m). The maximum exchangeable magnesium (Mg), potassium (K) and sodium (Na) were reported for samples SB-14 (0.2 m–0.4 m), SB-28 (0 m–0.1 m) and SB-24 (0.2 m–0.3 m), respectively.

Table 5.4.2 Exchangeable Cations (meqv/100g)

	Minimum (m_{eqv}/100g)	Maximum (m_{eqv}/100g)	Geometric Mean(m_{eqv}/100g)
Calcium	0.07	21.8	1.93
Magnesium	0.32	18.1	2.69
Potassium	0.07	2.6	0.29
Sodium	0.09	2.4	0.29

The ESP of soils from Curtis Island ranged from 0.43 per cent to 12 per cent (geological mean = 1.47 per cent, n = 59), with ESP values of greater than 6 per cent reported from a total of four samples:

- SB3 (0.4 m–0.5 m): 12 per cent
- SB12 (0 m–0.1 m): 6.5 per cent
- SB12 (0.1 m–0.2 m): 9.5 per cent
- SB24 (0.2 m–0.3 m): 7.6 per cent.

The total areal extent of the sodic soils has not been fully delineated, but the presence of sodic soils, particularly in subsurface samples obtained from depths of 0.2 m to 0.5 m, does indicate that the potential for elevated erosion does exist and that further sampling on a finer scale may be required to fully address the extent of the sodic soils on the site.

Phillipie's Landing to Targinie Road

Soil characterisation and properties for the mainland section of the proposed pipeline route and proposed approach to the Curtis Island Bridge were derived from Australian Soil Resource Information System (ASRIS). The information on the soil properties and classification are presented in *Table 5.4.3.*

Table 5.4.3 Soil Characteristics and Properties – Phillipie's Landing to Targinie Road

Property	Soil Characteristics
Clay/silt/sand	20-40%/20-40%/20-40%
Topsoil thickness (m)	0.25 m-0.5 m
Solum Thickness (m)	0.5 m-1.0 m
Texture	Loam/sandy clay (<10%) (Topsoil), medium clays (> 45% clay – Layer 3)

Property	Soil Characteristics
Drainage	Imperfectly drained
pH	6-6.5 (topsoil – Layer 1), 4.8-5.5 (Layer 3)
CEC	15-20 cmol/kg (topsoil), 20-30cmol/kg (Layer 3)
Sodicity	< 5% (Topsoil), 5-10% (Layer 3)
Electrical Conductivity	Topsoil – < 0.05 dS/m, Layer 3 – 0.1-0.15 dS/m
ASS potential	Extremely low probability of ASS

4.2.5 *Engineering Geology*

In addition to the soils assessment described above, geotechnical investigations have been undertaken (and are ongoing) across the LNG Facility site to assess subsurface conditions to provide data for detailed LNG Facility design. Geotechnical investigations have included geotechnical boreholes as well as test pitting. The location of geotechnical sections are shown in *Figure 5.4.9.*

While data from these investigations is preliminary, the following observations can be made:

- The weathering profile across the site is highly variable, with depth to rock (very low-strength rock, as determined where 30 standard penetration test (SPT) blows penetrated between 100 mm and 150 mm, and weathered rock was encountered in split tube samplers) ranging from less than 2 m in creek outcrop and 3 m in borehole BH16 to 16 m below ground surface in BH 36[13].
- Rock suites encountered were predominantly mudstones of the Wandilla Formation, with minor bands of chert, greywacke and quartzite and some sandstone interbedded with the mudstone[14].
- Preliminary laboratory compaction testing on samples collected from test pits indicates that[15]:
  - weathered rock material in cut areas should be excavatable using heavy-duty plant, with the assistance of ripping
  - the weathered rock materials (and overlaying clayey strata where present) excavated to achieve the proposed platform levels should be suitable for placement as general fill or select fill materials on the lower part of the site where filling is required.

Sections showing geology encountered in geotechnical boreholes across the site are provided in *Figure 5.4.9, Figure 5.4.10 and Figure 5.4.11*.

13 Golder Associates (2008) *Queensland Curtis LNG Project – Preliminary Geological Observations*

14 Golder Associates (2008) *Queensland Curtis LNG Project – Preliminary Geological Observations*

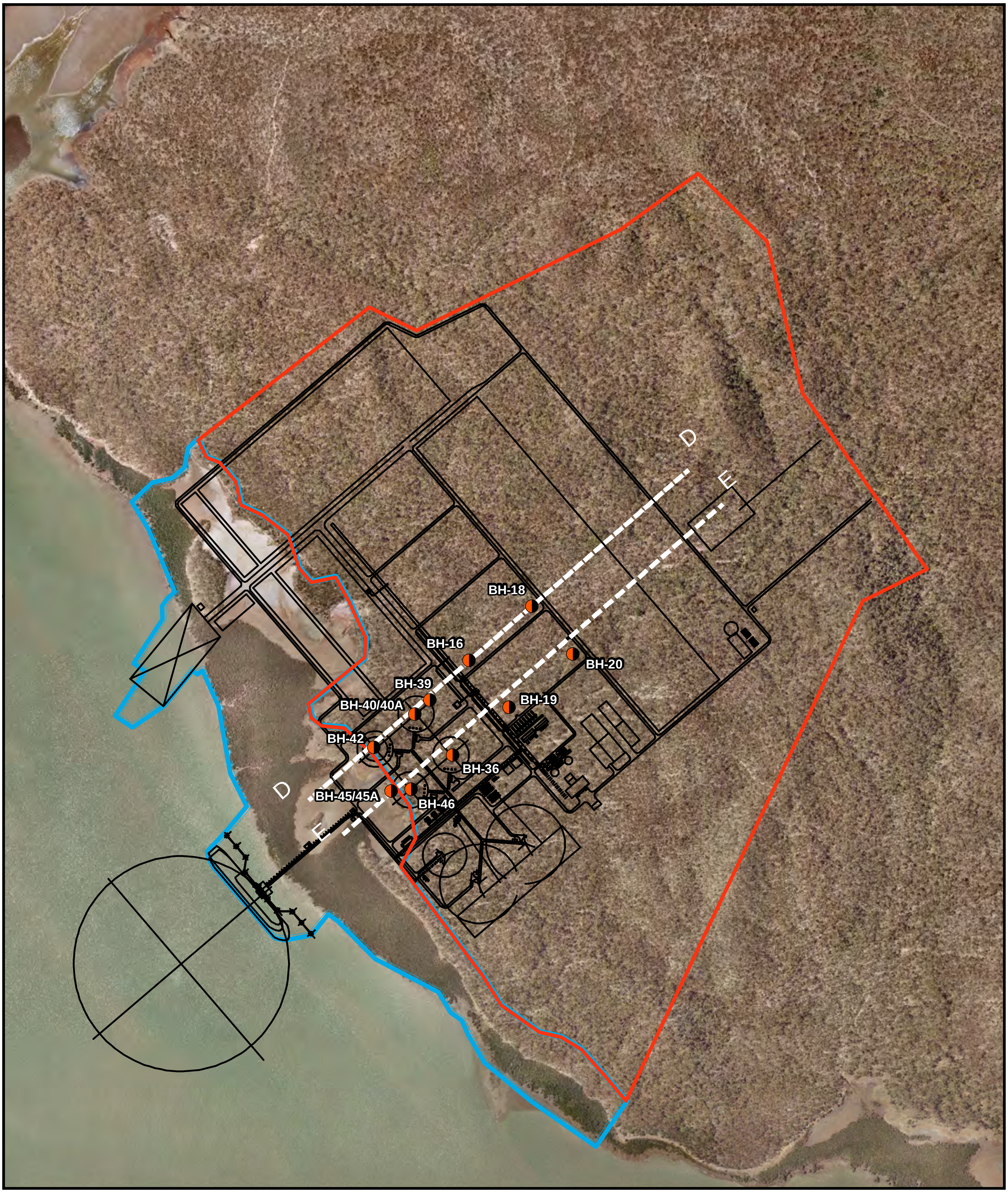
15 Golder Associates (2009) *Queensland Curtis LNG Project – Preliminary Results – Laboratory Compaction Tests.*

4.2.6 Soil Erosion and Stability

The erosion potential of the soils is considered to be low or the LNG Facility site as it currently exists due to the shallow depth of the soil profiles, the presence of extensive colluvium cover, vegetation coverage and the relatively gentle topography of the site.

The erosion potential is dependent upon climatic conditions and would be increased during periods of heavy rainfall, particularly along watercourses which are present on the site.

However, ESP data from a limited number of samples indicates that caution should be exercised when excavating soils from these sites (SB-3, SB-12, SB-24), as there is potential for increased erosion of these soils, particularly during higher rainfall events.



Legend

- Proposed QCLNG Site Boundary
- Indicative Wet Lease Area
- QCLNG Footprint Plant Layout
- D-D & E-E Section Location
- Borehole Location

Source Note:
Aerial Photo - Department of Infrastructure and Planning for QCLNG Project
Geotechnical Sections - Golder Associates, Queensland Curtis LNG Project, Geotechnical Investigation - Preliminary Geological Investigations
Unpublished report for BG International

Projection: UTM MGA Zone 56 Datum: GDA 94

QUEENSLAND CURTIS LNG
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Project	Queensland Curtis LNG Project	Title	Geotechnical Section Locations
Client	QGC - A BG Group business		
Drawn KP	Volume 5	Figure 5.4.9	
Approved RS	File No: 0086165b_EIS_GS_GIS022_F5.4.9		
Date 17.07.09	Revision 1		

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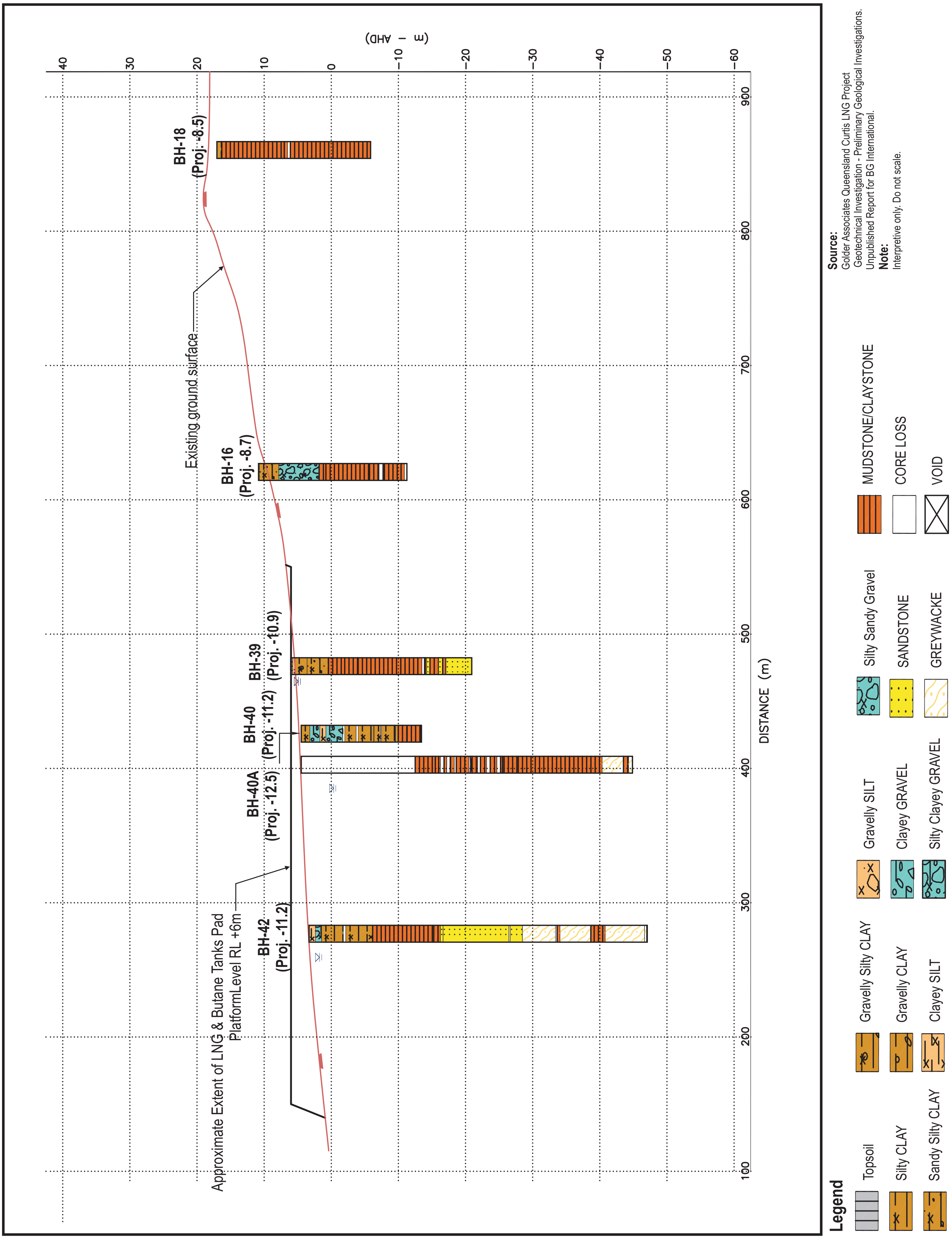
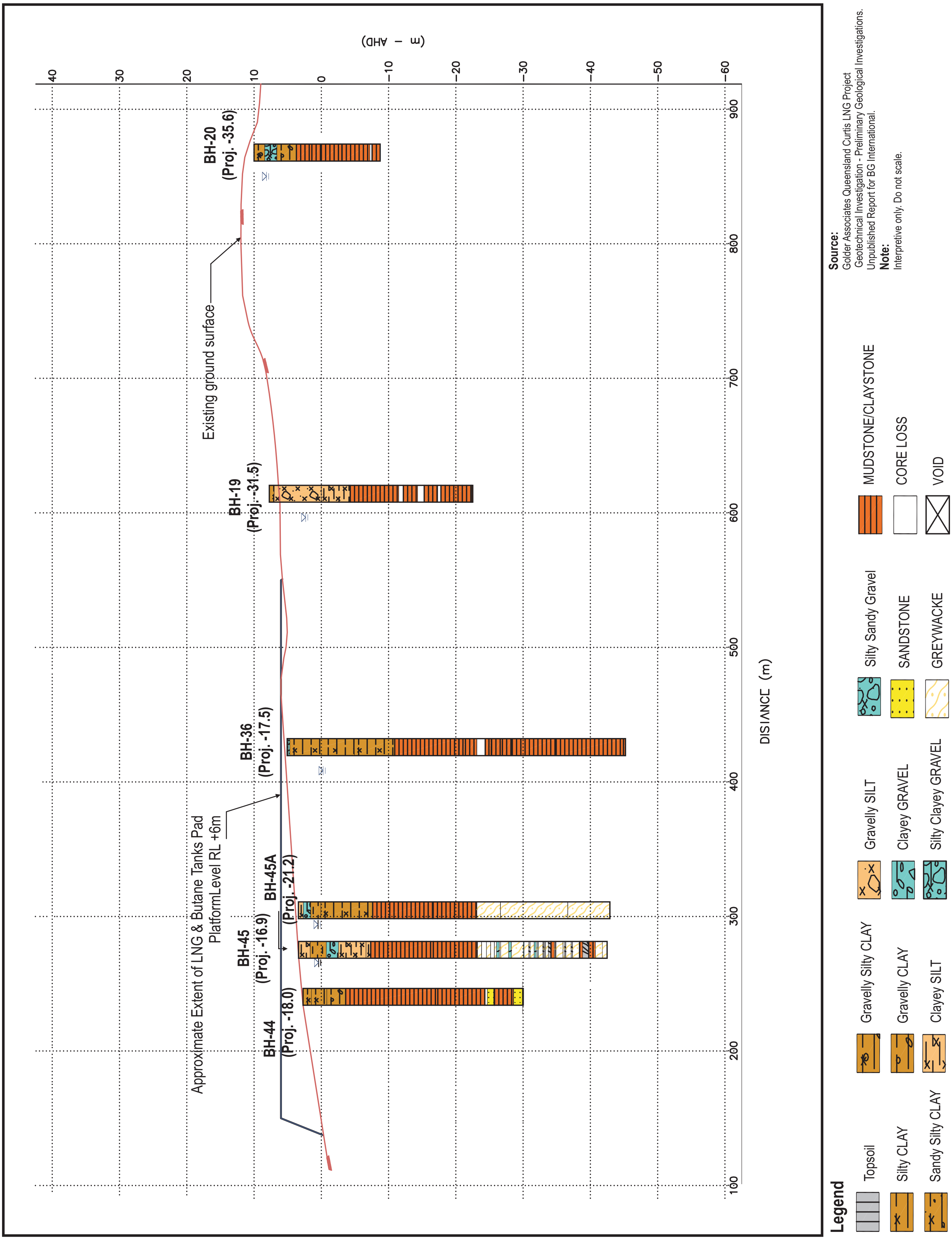


QUEENSLAND CURTIS LNG A BG Group business	Project: **Queensland Curtis LNG Project**		Title: **Geotechnical Borehole Geology Section D-D'**
	Client: **QGC - A BG Group business**		
ERM Environmental Resources Management Australia Pty Ltd	Drawn: JB	**Volume 5** **Figure 5.4.10**	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
	Approved: RS	File No: 0086165b_EIS_GS_CDR004_F5.4.10	
	Date: 16/06/09	Revision: 0	



QUEENSLAND CURTIS LNG A BG Group business	Project	Queensland Curtis LNG Project	Title	Geotechnical Borehole Geology Section E-E'
	Client	QGC - A BG Group business		
ERM Environmental Resources Management Australia Pty Ltd	Drawn JB	Volume 5 Figure 5.4.11	Disclaimer:	
	Approved RS	File No: 0086165b_EIS_GS_CDR005_F5.4.11	Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only.	
	Date 16/06/09	Revision 0	ERM does not warrant the accuracy of any such Maps and Figures.	

4.2.7 Good Quality Agricultural Land (GQAL)

The criteria used for the assessment of Good Quality Agricultural Land were derived from the *Planning Guidelines: The Identification of Good Quality Agricultural Land (1993)* as detailed in *Table 5.4.4* below.

Table 5.4.4 Description of Land Classes (Source: DHLGP (now DLGPSR), 1993)

Class	Description
Class A	**Crop land** – Land that is usable for current and potential crops with limitations to production which range from none to moderate levels. There are 3 sub-classes of crop land: **A** – land suitable for plantation, tree and vine crops **A1** – crop land suitable for rain-fed cropping **A2** – crop land suitable for horticulture.
Class B	**Limited crop land** – Land that is marginal for current and potential crops due to severe limitations; and suitable for pastures. Engineering and/or agronomic improvements may be required before the land is considered suitable for cropping. Land marginal for particular crops of local significance is considered GQAL.
Class C	**Pasture land** – Land that is suitable only for improved or native pastures due to limitations which preclude continuous cultivation for crop production. Some areas may tolerate a short period of ground disturbance for pasture establishment. In areas where pastoral industries are the primary industry, land suitable for improved or high-quality native pastures may be considered GQAL. There are three sub-classes of pasture land: **C1** – land suitable for sown pastures with moderate limitations **C2** – land suitable for sown pastures with severe limitations **C3** – land suitable for light grazing of native pastures in inaccessible areas. Of these, only C1 is considered GQAL.
Class D	**Non-agricultural land** – Land not suitable for agricultural uses due to extreme limitations. This may be undisturbed land with significant habitat, conservation or catchment values or land that may be unsuitable because of very steep slopes, shallow soils, rock outcrop or poor drainage.

The GQAL assessment was determined from the results from field and laboratory assessment and with reference to *Table 5.4.4*. Using this data, the land suitability is Class C3 – Pasture land – land suitable for light grazing of native pastures in inaccessible areas.

4.2.8 Acid Sulfate Soils (ASS)

Acid sulfate soils (ASS) occur predominantly in coastal lowlands with elevations below 5 m AHD. Acid sulfate soils contain iron sulfides, predominantly in the form of pyrite (FeS_2), which is produced through the interaction of iron-rich sediments and sulfate from seawater.

The formation of pyrite generally occurs under anaerobic conditions commonly found in low-energy estuarine environments. Undisturbed, these soils are present in the anaerobic subsurface environment as potential acid sulfate soils (PASS).

Actual acid sulfate soils (AASS) are the oxidised form of PASS which may occur as a result of natural or anthropogenic disturbance or through fluctuations or changes in the groundwater levels and/or exposure to oxygen.

The site description criteria used to determine the likely presence of ASS includes:

- land at elevations less than 5 m AHD
- sediments of recent geological (Holocene) age
- marine or estuarine sediments
- coastal alluvial plains.

4.2.8.1 Acid Sulfate Soils Investigation

The ASS investigation on Curtis Island and Friend Point[16] was conducted to:

- identify within the LNG Facility site less than 5 m AHD sediments and soils possibly containing AASS or PASS
- characterise the sediments/soil through sampling, field and laboratory analysis to enable quantification of the AASS and/or PASS.

The approach used during the investigation was that recommended by the Queensland Acid Sulfate Soils Investigation Team (QASSIT) and detailed in the *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland*. A summary of outcomes is provided below, with the full assessment report included as *Appendix 5.2*

Sample Locations, Sample Collection and Laboratory Analysis

Samples of ASS were collected by a vibracoring system mounted on an all-terrain vehicle (ATV). Samples in locations not accessible by ATV were collected by hand auger. Quality assurance/quality control procedures are documented in *Appendix 5.2.*

Field pH before and after oxidation was measured in small samples of soil/sediment taken every 0.25 m down the borehole.

Soil samples were analysed by a NATA accredited laboratory and analysed using Suspended Peroxide Oxidation Combined Acidity and Sulfate (SPOCAS) methodology suite Acid Base Accounting as per the *Acid Sulfate*

16 Graham TL and Larsen RM (2009) *Acid Sulfate Soil and Geomorphological Modelling Report, Proposed QCLNG Facility, Gladstone Queensland.*

Soils Laboratory Methods Guidelines. Further detail on laboratory analysis is provided in *Appendix 5.2* along with certified laboratory data sheets.

A total of 50 sites were sampled across Curtis Island and Friend Point, with sampling locations shown on *Figure 5.4.12* and. *Figure 5. 4.13*

4.2.8.2 Summary of Findings

Sampling at Friend Point was conducted based on an assumed excavation depth for the Pipeline of 2 m, while the sampling on the LNG Facility site on Curtis Island was conducted to determine the depth to the underlying Pleistocene basement.

Analytical results of the percentage of sulfur (SPOS) encountered on Curtis Island are presented in *Figure 5.4.14., Figure 5.4.15*, and *Figure 5.4.16.*

Analytical results of the percentage sulphur (SPOS) encountered across Friend Point are presented in *Figure 5.4.17, Figure 5.4.18,* and *Figure 5.4.19.*

Analytical Results – Curtis Island

Laboratory data for Curtis Island is summarised in *Table 5.4.5*

Table 5.4.5 Summary of Laboratory Data for ASS cores from Curtis Island[17]

Analyte	Unit	LOR[1]	Max	Min	Mean	N
Titratable actual acidity	% pyrite S	0.02	0.16	<0.02	0.031	94
Net acid soluble sulfur	% pyrite S	0.02	0.12	<0.02	0.028	25
Potential oxidisable sulfur	% S	0.02	7.20	<0.02	2.20	94
Excess acid neutralising capacity	% pyrite S	0.02	0.76	<0.02	0.10	27
Net acidity	% S	0.02	7.21	-0.08	2.18	94

1 Limit of Reporting:

17 Graham TL and Larsen RM (2009) *Acid Sulfate Soil and Geomorphological Modelling Report, Proposed QCLNG Facility, Gladstone Queensland.*

Legend

- Proposed QCLNG Site Boundary
- Indicative Wet Lease Area
- QCLNG Footprint Plant Layout
- Borehole Locations

Source Note:
Aerial Photo - Department of Infrastructure and Planning for QCLNG Project
Curtis Island Road/Bridge Corridor - Connell Wagner
5m Contours (AHD) - Department of Environment & Resource Management

Note:
Bore Holes BH35, BH36 and BH37 were not analysed in this study

Projection: UTM MGA Zone 56 Datum: GDA 94

0 25 50 100 150 200 m

N

QUEENSLAND CURTIS LNG A BG Group business	Project: **Queensland Curtis LNG Project**	Title: **Acid Sulfate Soil Sampling Locations Curtis Island**
	Client: **QGC - A BG Group business**	
ERM Environmental Resources Management Australia Pty Ltd	Drawn JB / Approved GB / Date 10.03.09	**Volume 5** **Figure 5.4.12** / File No: 0086165b_EIS_GS_GIS005_F5.4.12 / Revision 1

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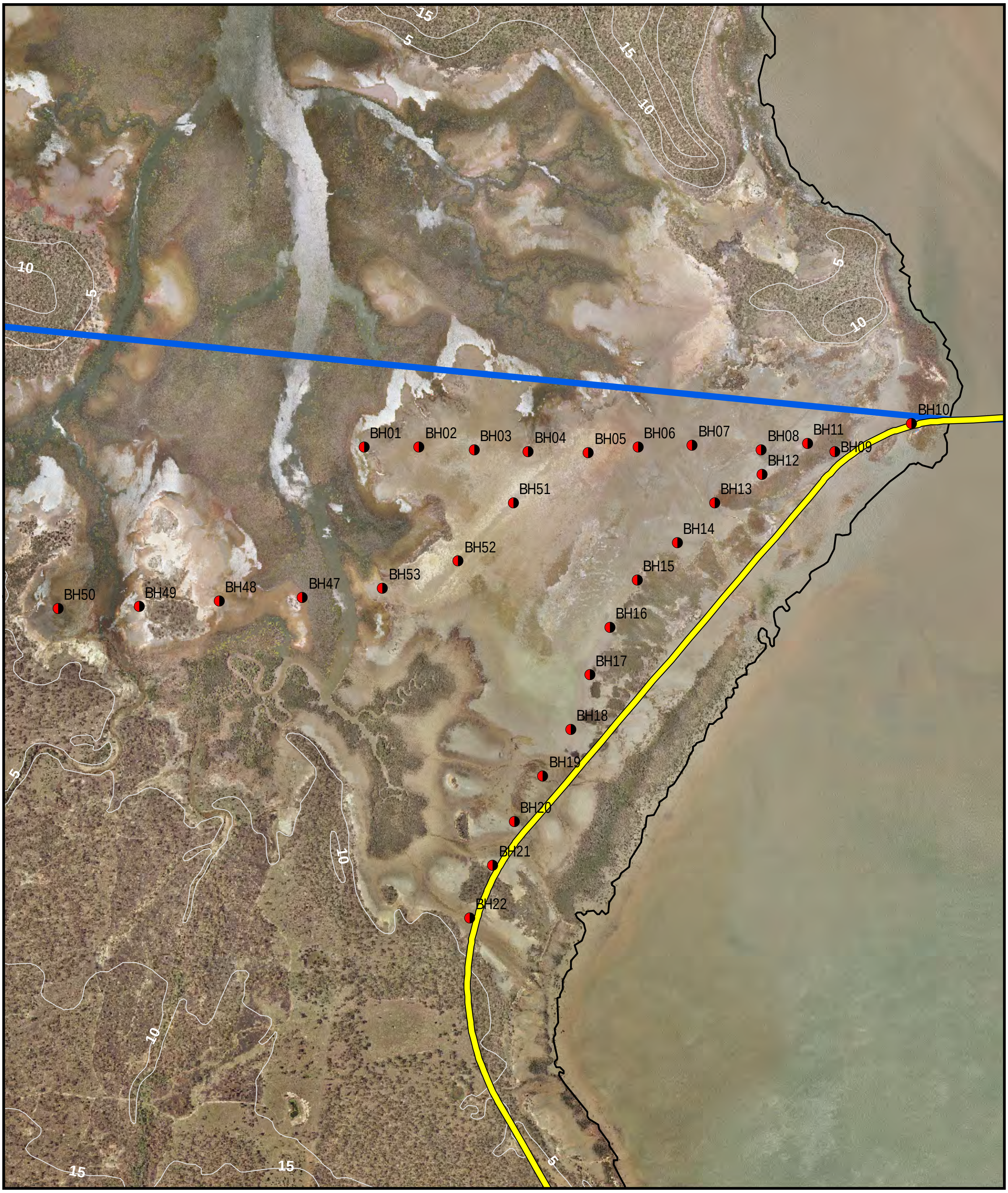

Legend

- Monitoring Locations
- Possible Curtis Island Road/Bridge Corridor
- Proposed Export Pipeline

Source Note:
Aerial Photo - Department of Infrastructure and Planning for QCLNG Project
Curtis Island Road/Bridge Corridor - Connell Wagner
5m Contours (AHD) - Department of Environment & Resource Management

Projection: UTM MGA Zone 56 Datum: GDA 94

0 125 250 500 m

N

QUEENSLAND CURTIS LNG A BG Group business	Project: Queensland Curtis LNG Project		Title: Acid Sulfate Soil Sampling Locations Friend Point
	Client: QGC - A BG Group business		
ERM Environmental Resources Management Australia Pty Ltd	Drawn: JB	**Volume 5** **Figure 5.4.13**	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
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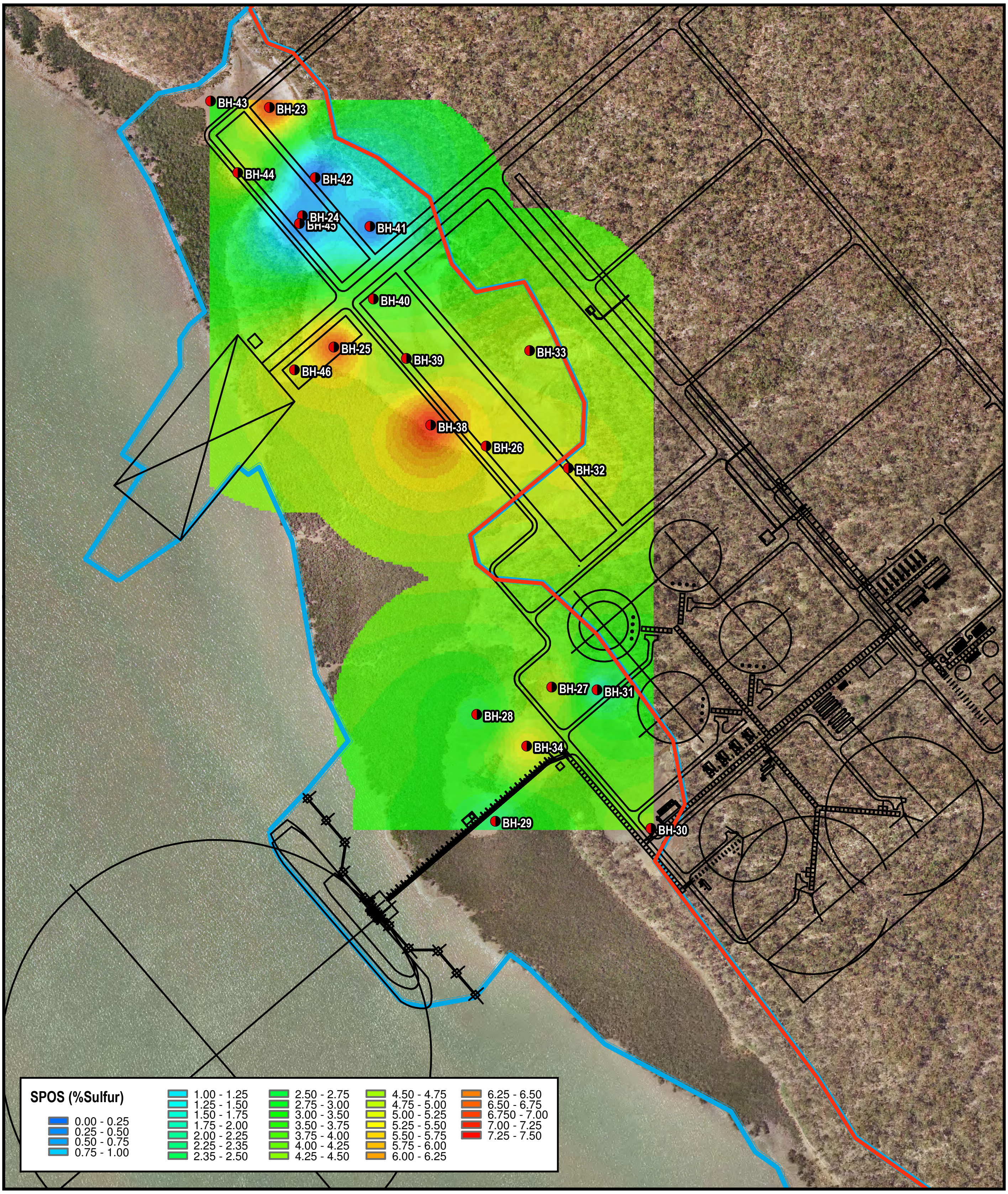
	Date: 10.03.09	Revision 1	



Legend

Proposed QCLNG Site Boundary

Indicative Wet Lease Area

QCLNG Footprint Plant Layout

Borehole Locations

Source:

Aerial Photo - Department of Infrastructure and Planning for QCLNG Project

Projection: UTM MGA Zone 56

Datum: GDA 94

0 50 100 200 m

N

QUEENSLAND CURTIS LNG
A BG Group business

Project	Queensland Curtis LNG Project	Title **SPOS (% Sulfur) 0-1m depth range Curtis Island**
Client	QGC - A BG Group business	

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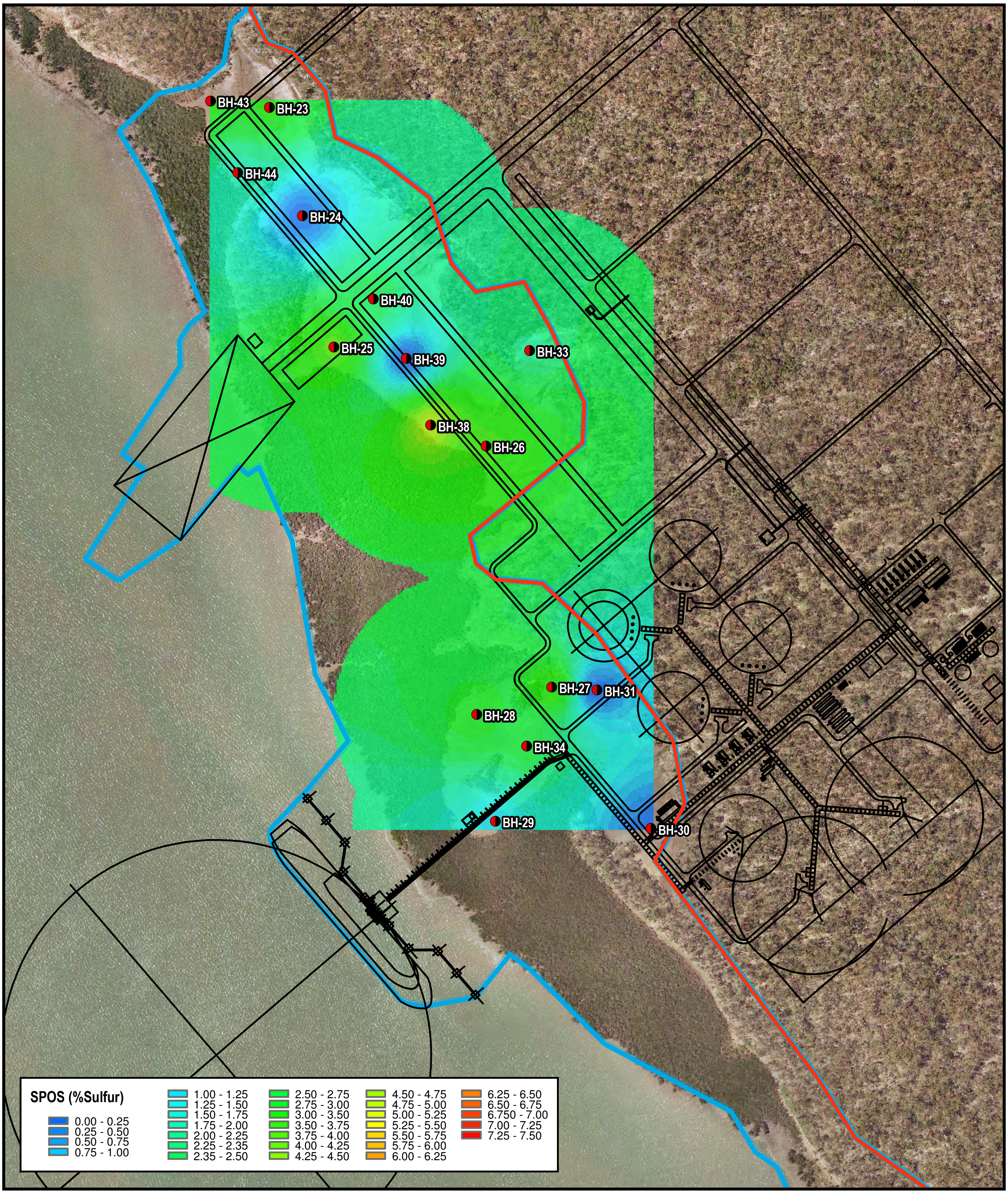
Drawn	JF	**Volume 5**	**Figure 5.4.14**
Approved	GO	File No: 0086165s_EIS_GS_GIS007_F5.4.14	
Date	15/07/09	Revision 2	



Legend

Proposed QCLNG Site Boundary

Borehole Locations

Indicative Wet Lease Area

QCLNG Footprint Plant Layout

Source:

Aerial Photo - Department of Infrastructure and Planning for QCLNG Project

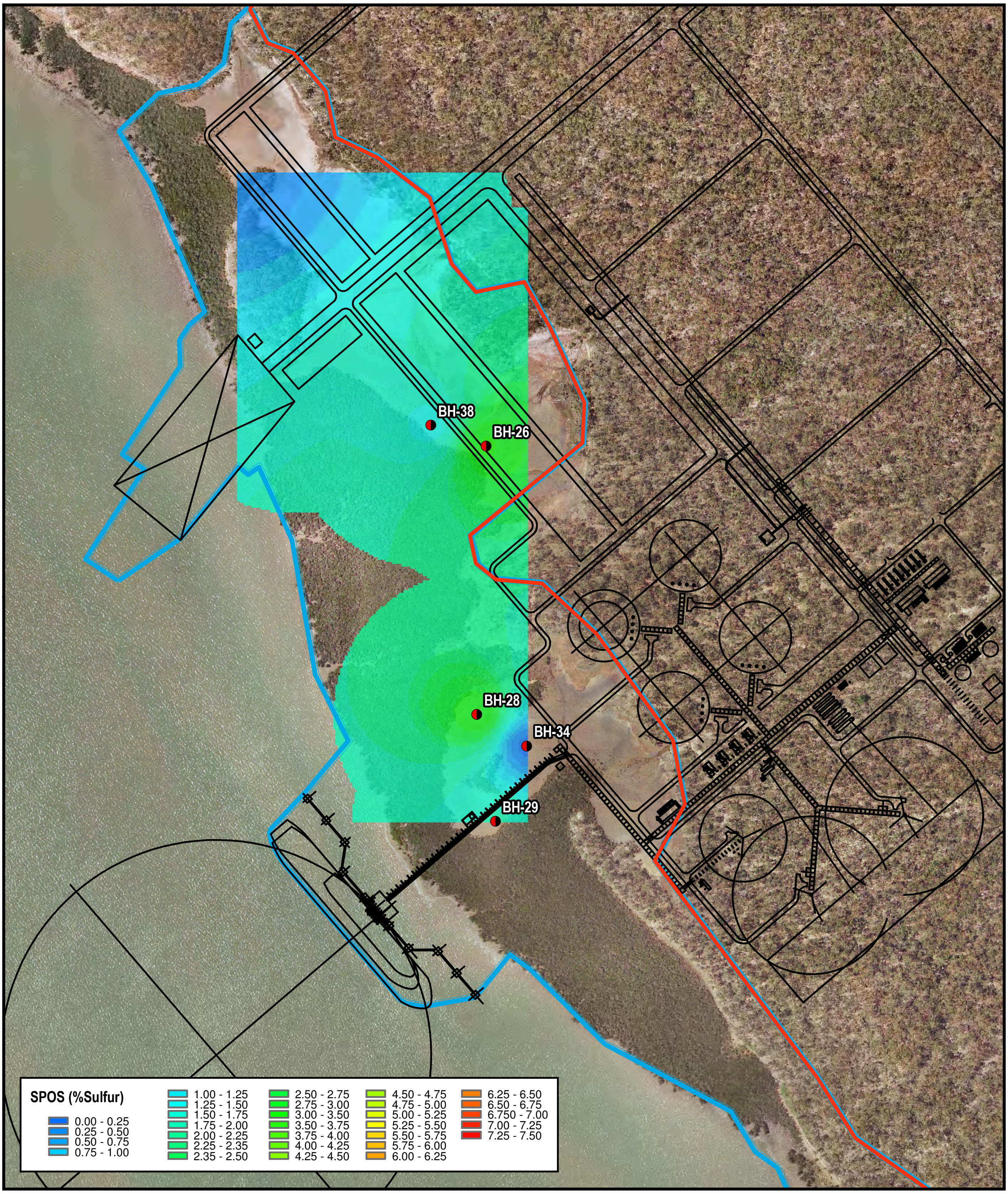
Projection: UTM MGA Zone 56

Datum: GDA 94

0 50 100 200 m

N

QUEENSLAND CURTIS LNG A BG Group business	Project **Queensland Curtis LNG Project** Client **QGC - A BG Group business**	Title **SPOS (% Sulfur) 1-2m depth range Curtis Island**
ERM Environmental Resources Management Australia Pty Ltd	Drawn JF | **Volume 5** **Figure 5.4.15** Approved GO | File No: 0086165s_EIS_GS_GIS008_F5.4.15 Date 15/07/09 | Revision 2	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.



Legend

- Proposed QCLNG Site Boundary
- Indicative Wet Lease Area
- QCLNG Footprint Plant Layout
- Borehole Locations

Source:
Aerial Photo - Department of Infrastructure and Planning for QCLNG Project

Projection: UTM MGA Zone 56 Datum: GDA 94

0 50 100 200 m

N

QUEENSLAND CURTIS LNG
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Project	Queensland Curtis LNG Project		Title **SPOS (% Sulfur) 2-3m depth range Curtis Island**
Client	QGC - A BG Group business		
Drawn JF	Volume 5	Figure 5.4.16	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
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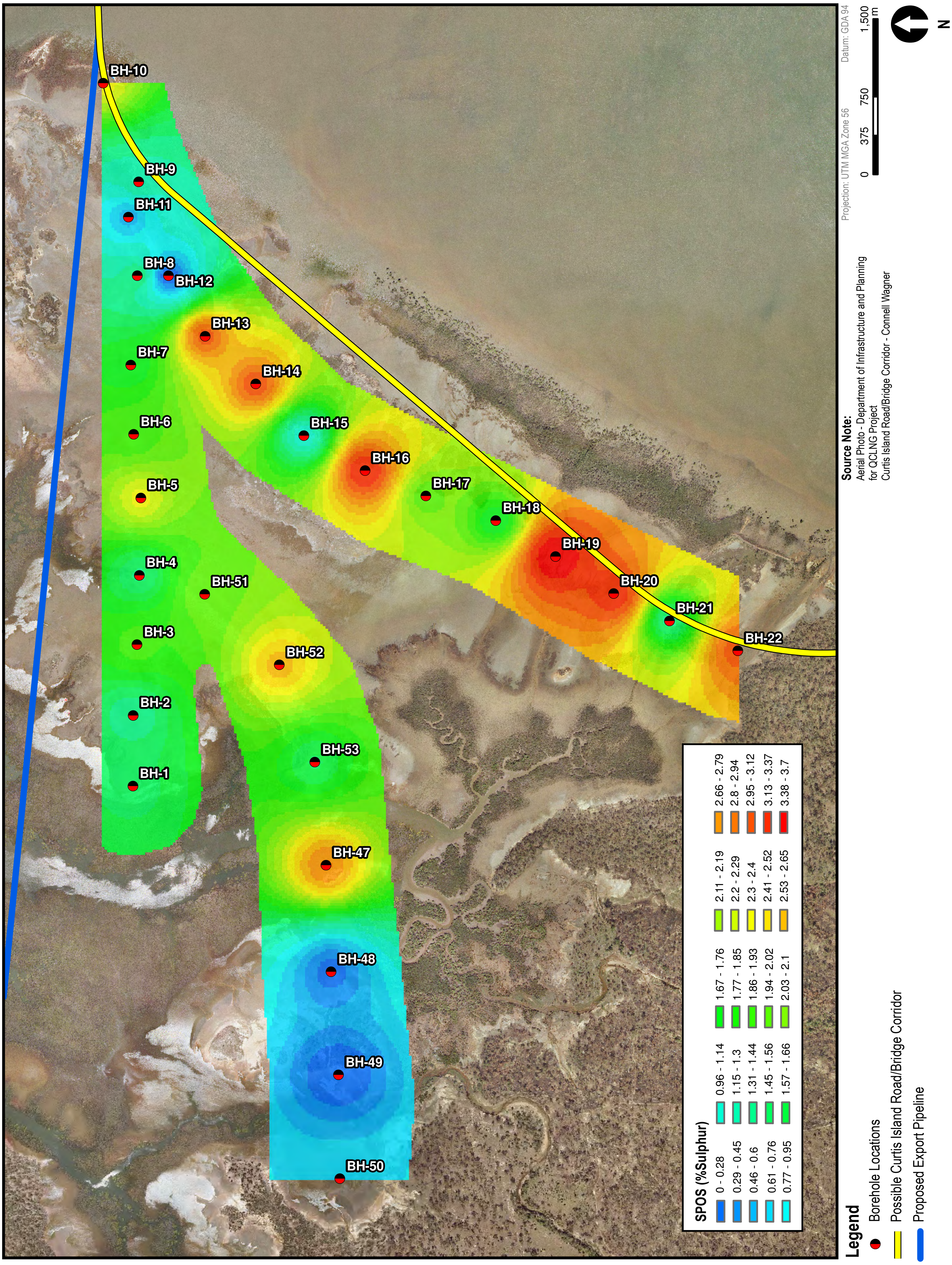
Date 16/07/09	Revision 2		



QUEENSLAND CURTIS LNG
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Project	Queensland Curtis LNG Project		
Client	QGC - A BG Group business		
Drawn	JF	Volume 5	Figure 5.4.17
Approved	GO	File No:	0086165b_EIS_GS_GIS018_F5.4.17
Date	16/07/09	Revision	2

Title **SPOS (% Sulfur) 0-1m depth range Friend Point**

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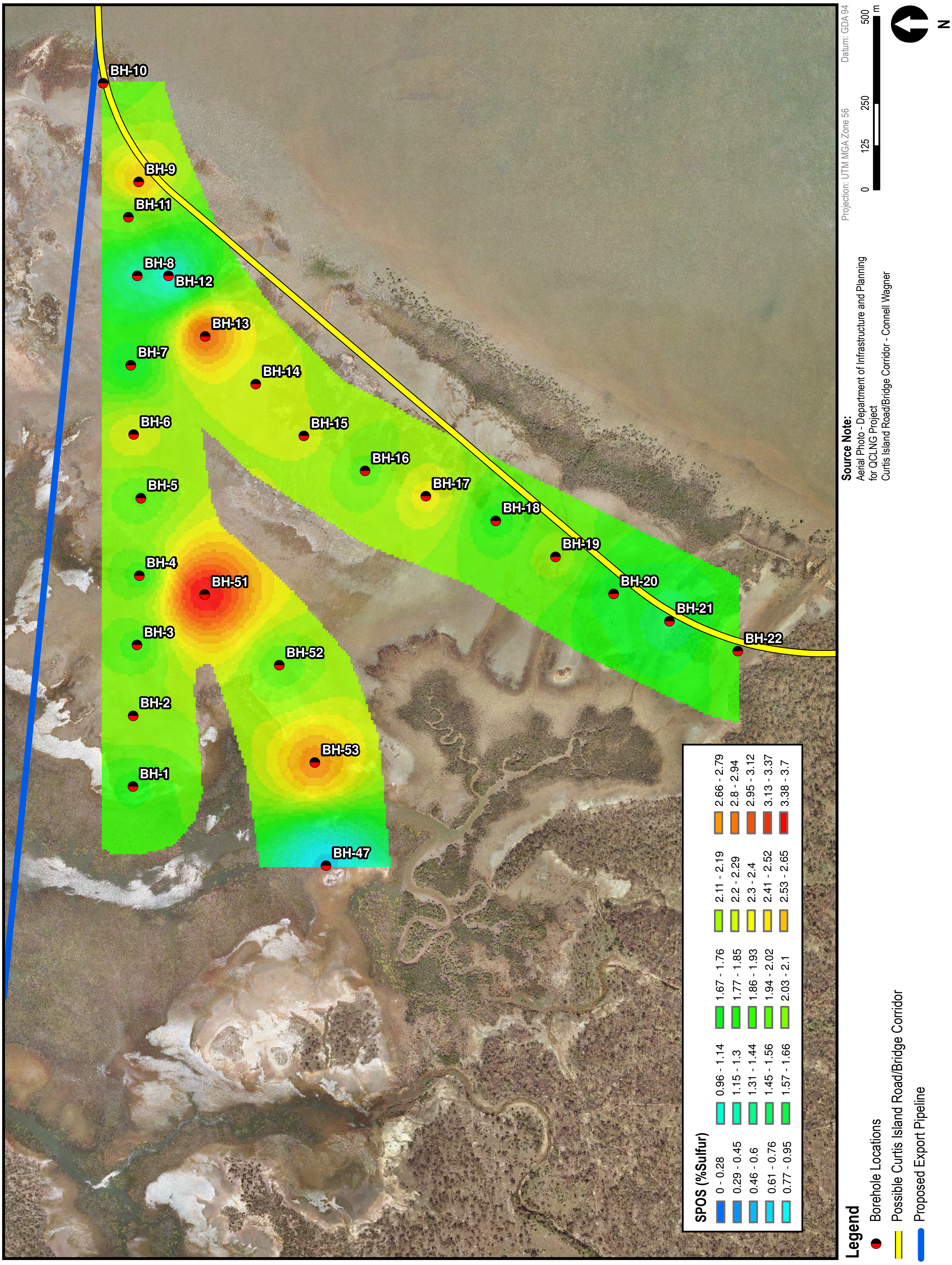
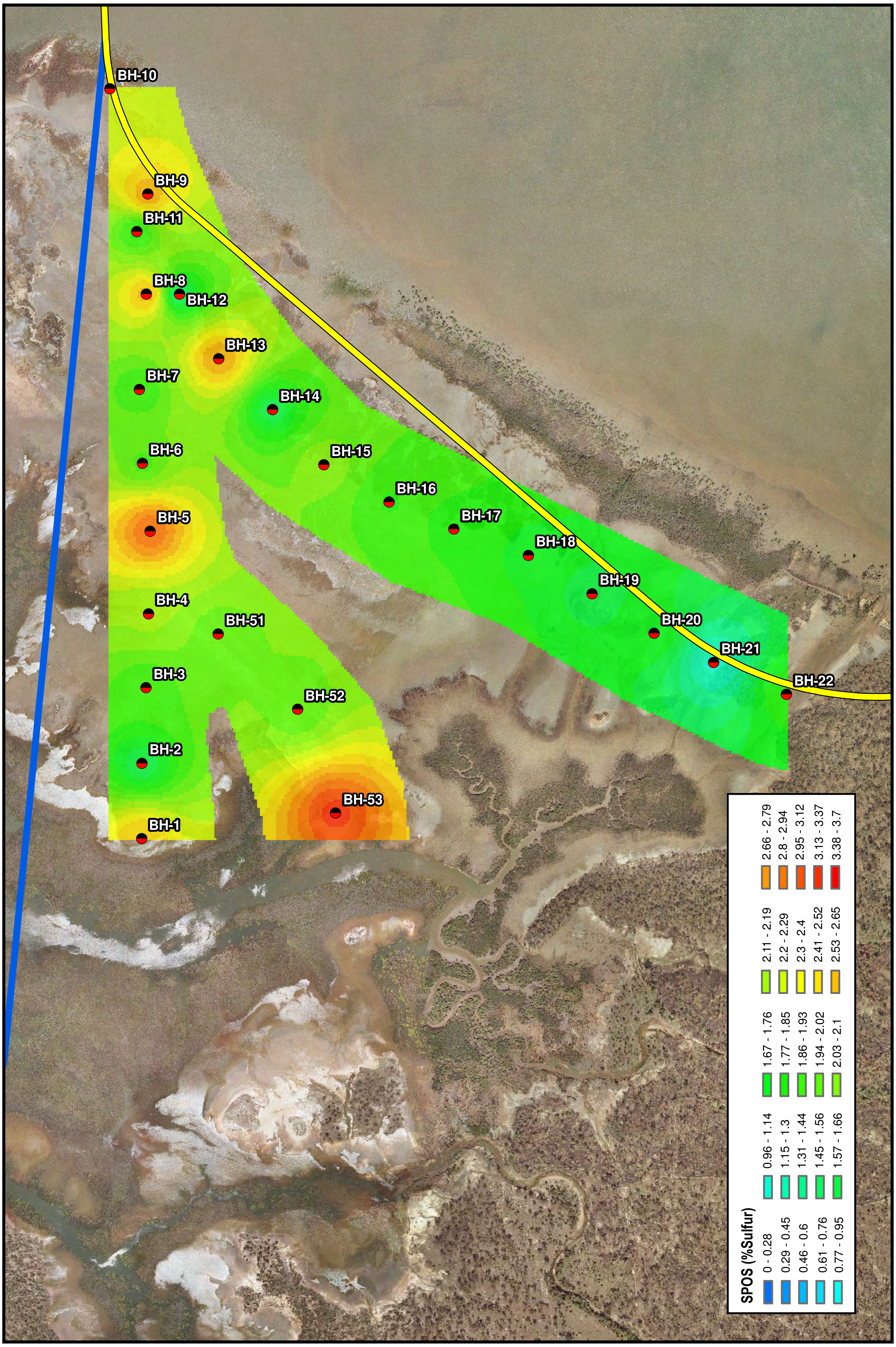


QUEENSLAND CURTIS LNG A BG Group business	Project **Queensland Curtis LNG Project** Client **QGC - A BG Group business**	Title **SPOS (% Sulfur) 1-2m depth range Friend Point**
ERM Environmental Resources Management Australia Pty Ltd	Drawn JF — **Volume 5** **Figure 5.4.18** Approved GO — File No: 0086165b_EIS_GS_GIS019_F5.4.18 Date 16/07/09 — Revision 2	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.



Projection: UTM MGA Zone 56 Datum: GDA 94

0 125 250 500 m

N

Source Note:
Aerial Photo - Department of Infrastructure and Planning for QCLNG Project
Curtis Island Road/Bridge Corridor - Connell Wagner

Legend
Borehole Locations
Possible Curtis Island Road/Bridge Corridor
Proposed Export Pipeline

QUEENSLAND CURTIS LNG A BG Group business	Project Queensland Curtis LNG Project Client QGC - A BG Group business		Title **SPOS (% Sulfur) 2-3m depth range Friend Point**
ERM Environmental Resources Management Australia Pty Ltd	Drawn JF Approved GO Date 16/07/09	**Volume 5** **Figure 5.4.19** File No: 0086165b_EIS_GS_GIS020_F5.4.19 Revision 2	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not to be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.

Analytical Results – Friend Point

Laboratory data for Friend Point is summarised below in. *Table 5.4.6*

Table 5.4.6 Summary of Laboratory Data for ASS cores from Friend Point

Analyte	Unit	LOR[1]	Max	Min	Mean	N
Titratable actual acidity	% pyrite S	0.02	0.08	<0.02	0.013	186
Net acid soluble sulfur	% pyrite S	0.02	0.06	<0.02	0.03	10
Potential oxidisable sulfur	% S	0.02	3.72	<0.02	1.36	186
Excess acid neutralising capacity + magnesium[2]	% pyrite S	0.02	1.90	0.02	0.2	121
Net acidity	% S	0.02	3.74	-0.49	1.08	186

1: Limit of Reporting
2: Sum of acid reacted calcium and magnesium values divided by the fineness factor (1.5).

4.3 POTENTIAL IMPACTS AND MITIGATION MEASURES

The following potential impacts have been identified as a result of the geology and soils investigation.

4.3.1 Construction and Operation

The construction phase of the Curtis Island LNG Facility will involve disturbing vegetation and excavation of soil and bedrock across the site. Preliminary estimates of the volume of material to be excavated are summarised in *Table 5.4.7*, although these values are subject to change due to optimisation of the LNG Facility layout based ongoing geotechnical investigation and detailed design.

Table 5.4.7 Indicative Volumes of Bulk Earthworks, LNG Facility Site - Curtis Island

	Volume (m^3)
Stripping/grubbing	774,000 m^3 (0.5 m over entire site)
Cut	3,154,000 m^3
Fill	2,890,000 m^3
Diversion ditch (cut)	500,000 m^3

Mitigation procedures to minimise the erosion of soils, runoff and associated environmental impacts, including the degradation of waterways, will be incorporated into a Soil Erosion and Sedimentation Management Plan to be finalised prior to commencement of construction. This plan will include a range of measures to minimise erosion and may incorporate:

- utilisation of stormwater drains and sediment control devices
- dust suppression measures (primarily water spray) to be used on an as needs basis on stockpile areas and roadways
- management of stormwater runoff to minimise erosion, including diverting flow over stable areas and away from disturbed areas and topsoil stockpiles, and maximising sheet flow
- stabilisation of the faces of engineered slopes on an as-needs basis
- mechanical compaction of graded areas to minimise the potential for erosion

A draft Soil Erosion and Sedimentation Management Plan is included in *Volume 11*.

4.3.2 Acid Sulfate Soil Impacts

The complete Holocene-aged sedimentary sequence tested in onshore locations revealed moderate to very high PASS[18]. Pre-Holocene substrate was consistently demonstrated to have no inherent PASS. However, a zone of approximately 0.5 m immediately below the Holocene/Pleistocene boundary in some boreholes revealed moderate PASS[19].

The distribution of AASS was widespread throughout the area sampled and continued to 2 m at a number of locations. This AASS was generally low level but widespread.

The potential exists for disturbance of ASS identified on Curtis Island and Friend Point during the construction phase of the LNG Facility and the associated infrastructure. Based on this, a draft EMP addressing ASS has been included in *Volume 11*. A full ASS Management Plan compliant with the *Queensland Acid Sulfate Soil Technical Manual Soil Management Guidelines* will be prepared and submitted for regulator approval following completion of detailed site layout, design works and ongoing geotechnical investigations; and prior to commencement of construction.

4.3.3 Decommissioning

Decommissioning of the LNG Facility will be undertaken as outlined in *Volume 2, Chapter 19*. Upon decommissioning, appropriate assessment will

18 Graham TL and Larsen RM (2009) Acid Sulfate Soil and Geomorphological Modelling Report, Proposed QCLNG Facility, Gladstone Queensland.

19 Graham TL and Larsen RM (2009) Acid Sulfate Soil and Geomorphological Modelling Report, Proposed QCLNG Facility, Gladstone Queensland.

be undertaken to assess soil contamination levels present and develop remediation strategies (as required).

4.4 CONCLUSION

The Gladstone area is considered the sixth most seismically active area in Australia. Therefore, a probabilistic seismic hazard assessment was undertaken to inform the design of the LNG Facility.

There is potential for erosion on Curtis Island. However, this is considered generally low due to the shallow depth of the soil profiles, limited presence of sodic soils, presence of extensive colluvium cover, vegetation coverage, and relatively gentle topography of the areas disturbed during construction. Additional erosion control measures are recommended for construction activities undertaken in sodic soils, along watercourses and during high rainfall events.

The potential for soil erosion and the presence of acid sulphate soils (ASS) was investigated at the LNG Facility site and along the road corridor. ASS was encountered in these areas and appropriate management measures will be required for ASS disturbed during construction.

An assessment of land suitability classified soils in the area of the LNG Facility as Class C3 (Pasture Land). Therefore, the LNG Facility and associated infrastructure will not impact on GQAL. A summary of the impacts outlined in this chapter is provided in *Table 5.4.8*.

Table 5.4.8 Summary of Impacts for Geology and Soils

Impact assessment criteria	**Assessment outcome**
Impact assessment	Negative for soil erosion and ASS Negligible for impacts on GQAL
Impact type	Secondary impact as soil erosion and ASS could impact on water quality thereby affecting sensitive receptors in the marine environment.
Impact duration	Short term (limited to construction phase)
Impact extent	Local
Impact likelihood	Medium

<u>Overall assessment of impact significance:</u> Moderate due to the widespread distribution of PASS in the LNG Facility site, and along the possible Curtis Island Bridge/Road corridor on the mainland and on the island, However, impacts will be localised and risks and impacts can be avoided or reduced through the implementation of an ASSMP.